Nebraska City Bridge
Nebraska City vicinity
Otoe County, Nebraska
(Fremont County, Iowa)

HAER No. NE-2

HAER
NEB,
66-NEBCI,
5-

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

MEASURED DRAWINGS

Historic American Engineering Record
National Park Service
Rocky Mountain Regional Office
Department of the Interior
P.O. Box 25287
Denver, Colorado

HISTORIC AMERICAN ENGINEERING RECORD

NEBRASKA CITY BRIDGE

Location:	Spanning the Missouri River on abandoned grade of Burlington Northern Railroad, immediately south of Nebraska State Highway 2 (Waubonsie) Bridge; Nebraska City vicinity; Otoe County, Nebraska and Fremont County, Iowa
USGS Quadrangle:	Nebraska City, Nebraska (7.5 minute series, 1966)
Construction Date:	October 1887 - July 1888
Engineer:	George S. Morison, Chief Engineer; E.L. Corthell, Assoc. Chief Engineer; B.L. Crosby, Resident Engineer
Contractor:	Union Bridge Company, superstructure fabrication; Baird Brothers, superstructure erection; T. Saulpaugh & Co., masonry piers; railroad crew, caisson foundations
Present Owner:	Burlington Northern Railroad
Present Use:	Abandoned
Significance:	With his long-span railroad bridges over the navigable Midwestern rivers, civil engineer George S. Morison (1842-1903) was instrumental in the development of the steel bridge industry in the 1880s and 1890s. The first to standardize bridge design for the Missouri River, he facilitated the American railroad expansion and was distinguished as one of the country's most prolific and influential bridge engineers. The Nebraska City Bridge is the oldest remaining of Morison's great river bridges and the oldest remaining major all-steel railroad truss in America.
Report by:	Clayton B. Fraser Principal, Fraserdesign Loveland Colorado October 1986

TABLE OF CONTENTS

Note: Due to an error in numbering, page numbers 163 through and including 167 have been omitted; this is a sequential error only and does not affect the continuity of the text. This document contains a total of 504 pages.

LIST OF APPENDICES

EDUCATION AND EARLY CAREER

At the age of twenty-four, George Morison appeared headed toward a distinguished career in the law. Educated at Exeter and Harvard, recently admitted to the New York Bar, and employed by a prestigious law firm in New York City, his future seemed assured. But he had been filled with self-doubt throughout law school, which only intensified as he began his legal practice. After only a month as a lawyer, he had begun to consider other alternatives. Finally, he turned to the one profession for which he had shown an aptitude throughout his early life: civil engineering, specifically bridge engineering. Once the decision was made, Morison's confidence was unshakable. In a dramatic move less than a year after becoming a lawyer, he abandoned the law to pursue, with no formal training, a career as an engineer. As he left the New York law office for the last time on August 10th, 1867, George Morison wrote hopefully in his journal:

> Last day at the office as in the law... so ends my legal life in which I have blundered along for these three years; may these years not prove wholly wasted. May I now in my new profession for which I have no doubt that I am much better fitted, work with a degree of interest and power which will make my life valuable both to myself and to others. [1]

George Shattuck Morison was born in New Bedford, Massachusetts, December 19, 1842. He was the son of John Hopkins Morison, a Unitarian minister, and Emily Rogers Morison, both from well-established New England families of Scotch-Irish and English extraction. When George was three, his father moved the family to Milton, near Boston, where he served as minister of the Unitarian Church, a position he held from 1846 until his death in 1896. George's early years were spent at Milton in a typical mid-19th Century New England milieu. The son of a prominent and well-published minister, his childhood was imbued with a strongly held sense of religious principles and ethics, which he would retain throughout his life.

His boyhood vacations, when not spent in Milton, were with his maternal grandmother in Salem or with his father's brothers, Baltimore teachers who summered in seasonal homes at Peterborough, New Hampshire. George relished his summer visits with relatives, and the two places for which he formed deep

attachments and often spoke of later in life were not his boyhood home at Milton, but Salem and Peterborough. When he would build his own house years later as an adult, it would be at Peterborough.[2]

One particularly notable characteristic that George Morison showed as a child was his need, or lack of, for the companionship of other children. It was a trait that would later color his adult life. As a boy, he was frequently absorbed in designing and building mechanical contrivances and could be most often found playing alone. Independent, solitary and introspective, he apparently did not have, nor tried to make, many friends.

An illustrative story about young George Morison involves the time his mother read to him about the burning at the stake of John Rogers, the martyr from whom he was thought to be descended. His nephew, George Abbot Morison, later described the boy's considered reaction:

> The child asked why John Rogers was burned, and was told because he would not tell a lie, upon which he said that he thought he would rather tell a lie than be burned at the stake. When his mother remonstrated, he went away by himself and after some time he returned and said he now would rather be burned at the stake than tell a lie. He had thoughtfully considered the matter and settled the question of absolute truth in his own mind once and for all.[3]

At the age of fourteen, the youth entered Phillips Exeter Academy, the venerable alma mater of his father and uncles. Widely recognized as one of the finest preparatory schools in the country, Exeter offered a curriculum which included a strong foundation in the classics. This provided a training in discipline, memory and attention to detail which George Morison came to regard as a particularly valuable educational asset and upon which he would draw often as an adult. His senior courses at Exeter consisted of three terms of Latin, the Aenid, the Georgics and Cicero; three terms of Greek, including sections of Aesop's Fables, the Odes of Anacreon, the Anabasis, and selections from Homer and Euripides; three terms of Geometry; one term of Ancient History and one of Rhetoric. An avid student, Morison enjoyed his two-year stay at Exeter. The considerable contributions he would later make to the Academy suggests the deep impression the school left upon him.

After graduating from Exeter in 1859 at sixteen, Morison immediately enrolled at Harvard College. There he followed a prescribed liberal arts curriculum which emphasized the Classics, with coursework in Latin, Greek, Mathematics, Elocution, History, Modern Languages and the Sciences. Morison was an able, but undistinguished student. Though gifted in mathematics, he apparently chose not to pursue this field to any great extent. He was a member of Phi Beta Kappa and several scientific and history societies, but his tenure at Harvard otherwise lacked distinction. "His classmates have said," his nephew later

wrote, "that although the capacity of his mind and the strength of his character were recognized they did not appreciate the fact that he was likely to become perhaps the most distinguished member of that class." Morison received a Bachelor of Arts degree in 1863 at the age of twenty, graduating ninth in a class of 121. After a year of employment in the South, he enrolled in Harvard Law School.[6] Again, he proved an excellent scholar and received the Bowdoin Prize for the best dissertation on "Mills Criticism of Sir William Hamilton", which was later published.[7]

Awarded a Bachelor of Laws degree in 1866, Morison was subsequently admitted to the New York Bar. That year he entered the prestigious New York law offices of Evarts, Southmayd and Choate - clearly an auspicious beginning to a promising legal career. Shortly thereafter, however, he began to experience serious doubts about his choice of a profession and was disillusioned to find the law, "a heterogeneous mass of precedents through which cases were more often determined upon former decisions than upon their abstract merits."[8] For Morison, the practice of law lacked the cool precision and certainty of mathematics, at which he had excelled in college. "He saw three opportunities open to him," according to his nephew: "to continue the practice of law, and perhaps become a successful lawyer, which did not attract him at all; he might study the theories behind the practice of law, and render signal service to his profession by formulating these theories either as a professor in a law school or elsewhere; or, finally, he might relinquish the profession and enter without previous training the comparatively new profession of civil engineering, which with the development of our Western country, offered a unique opportunity to an original and ambitious mind."[9]

Morison experienced his first doubts about the law in November 1866, only a month after beginning work in New York. He agonized over the enormity of his mistake, but with a sense of caution and deliberateness of purpose which would become his hallmarks, he resolved to continue his legal work until May 1st of the the following year before forming a final decision. Morison was twenty-four when his self-imposed deadline arrived. His decision in May 1867 was one that would alter his life dramatically: he would abandon his prospective law career and, equipped with only general mathematical training and a propensity for things mechanical, would pursue a far less certain career as a civil engineer. "He had a powerful intelligence," a colleague later wrote, "which would have distinguished him in any calling, and added to that he had in large measure those special gifts which make a man an engineer in spite of accidents of education. He had a contrivance: he had a quick and clear perception of cause and effect in material phenomena; he had the feeling for the laws and forces of Nature. So it was not extraordinary that he should have turned from the law to engineering when he was 25 years of age without what is commonly recognized as an engineering education."[10] In August, after less than a year of law practice, George Morison resigned from the firm, to which he would never return.

Friends in Boston recommended Morison to Detroit railroad entrepreneur James F. Joy. As the leader of the "Boston party", Joy was then promoting the extension of the Michigan Central and the Chicago, Burlington and Quincy rail systems into Missouri, Kansas and Nebraska. Undeterred by Morison's lack of professional credentials, Joy engaged the would-be engineer to work on the construction of the Kansas City Bridge over the Missouri River for the Kansas City and Cameron Railroad, a CB&Q subsidiary. This was an extremely important engineering project involving the erection of the first bridge across the Missouri River - "long known as so turbulent and unstable a stream, that it was considered by many of those best acquainted with its character, as almost incapable of being bridged."[11] The engineer in charge was Octave Chanute (1832-1910). A French immigrant, Chanute had served the previous four years as Chief Engineer of the Chicago and Alton Railroad.[12] Morison wrote in his personal journal on October 16, 1867, about his introduction to the bustling town and to Chanute:

> Reached Leavenworth, Kansas... Took train at once to Kansas City; put up at Pacific House, a wretched place. Went to Kansas City Bridge office and presented my letters to Mr. Chanute, the Chief Engineer; he said he thought this a very poor place to learn, but in the afternoon he told me I might stay here and receive $60 a month and in the mean while consider whether it would be best to continue.[13]

As he presented himself before Chanute two months before he turned twenty-five, George Morison's appearance was not unlike that of countless other young 19th century professionals. Slightly less than six feet tall and of average build which bordered on the overweight, he cut an unremarkable figure. His movements were slow and deliberate. Like the lawyer he had once been, he dressed conservatively. His hair was dark, with a single part on the left; his face in repose was gentle, like that of a benevolent uncle or, later in life, grandfather. A bushy moustache all but covered a full mouth, further framed by a pudgy chin, which later would acquire a double. In other details, however, one can glimpse traces of the inner intensity. When he stood, he hoisted his frame perfectly erect, adding to the impression of stature and presence. The most striking single feature about the man, though, were his eyes. Deeply set beneath high arching eyebrows, they formed a piercing glaze which flashed a sharp picture of the acute mind behind.

If George Morison's stature was unimposing, his demeanor was anything but. At last freed of the self-doubts that had plagued him in law school and as a lawyer, he had already begun to gain a self-confidence and to display many of the distinctive character traits which would mark him as an <u>eminence terrible</u> in the engineering profession. Strong-willed and unswervingly self-directed, he pursued all aspects of his life with the fierce determination and seemingly inexhaustible energy that sprang from steadfastly maintained convictions. He pondered his actions at length and viewed alternatives from every conceivable

angle. Yet, once decided, his convictions were unshakable. "Force was perhaps the most striking impression one received upon meeting him," his nephew later later wrote. "He spoke slowly, choosing his words carefully, and expressing himself so clearly as to leave no doubt as to his meaning. When George Morison entered a room one felt that power came with him, and that he dominated his surroundings."[14]

Intolerant of the perceived mental shortcomings of others, Morison held most lesser men openly in disdain. He demanded absolute precision and logic from those with whom he dealt and felt no compunction in pointing out others' errors publicly. "He had no patience with inaccuracy of thought or statement," George Abbot Morison stated. "Many people came to fear him for his ability to uncover shams or inaccuracies, and he never hesitated to express positively his impressions of things or individuals, sometimes to the embarrassment of the latter."[15] Understandably, this last trait tended not to endear him to his peers. As his father stated, "George is just, but he has never learned to temper his justice with mercy."[16] As a child, George Morison had not kept many friendships; this continued throughout his school career and into his adult life. He never married. But Morison did maintain several longstanding close friends - mostly other engineers - with whom he conversed or corresponded regularly. These he cherished with a characteristically intense loyalty, and to those few with whom he was congenial, Morison showed a side that was completely unlike his public or professional personna. Gentle, observant, and retentive, he could be a warm and witty conversationalist and could discourse on a variety of topics. Perhaps his most gentle side was directed toward his parents, as indicated by family friend, Dr. A.W. Jackson:

> One conspicuous grace I used to observe in him, the grace of filial piety. In the nobler meaning of the word this man of iron was a son. However severe his port toward others, in his voice there was a gentleness and in his manner there was a deference in the parental home. To be sure his were not ordinary parents, - a mother whose quiet dignity and fine intelligence might well oblige him to admire, a father whose cultivated mind and saintly spirit made reverence difficult to withhold. Still the freedom and familiarity of the home bring filial loyalty to a proof that is severe, and to that proof he was nobly equal.[17]

George Morison was eager to begin his career as a civil engineer. Although a more appropriate and challenging beginning can hardly be imagined than to work on the first bridge over the Missouri River, Chanute initially tried to discourage Morison from the project, perhaps because he understood that the aspiring young engineer's educational shortcomings would limit his usefulness to nontechnical functions. Undaunted, Morison signed on with the project. He wrote pensively in his journal of the radical new course he had undertaken, closing the book - literally - on the first part of his life:

> And now with the close of this year this volume is concluded. It bears witness to wider changes than were ever anticipated when it was begun, and in whatever form my diary may be continued this will remain the record of the four years of doubt, vacillation and search which have formed the introduction to my life. How I am to succeed remains to be seen; but I sincerely hope and pray that the blunder which has wasted so much of these four years is to be expiated and that I may yet lead a good and useful life.[18]

Morison undertook his training on the Kansas City Bridge seriously, prescribing for himself a disciplined work and study regimen. On Thanksgiving Day, 1867, he drafted a weekly schedule in his journal:

> To the end that my time may be spent with advantage, my mind improved, my professional standing bettered, and my life made a useful one, the following resolves are this day made:
>
> 1st. That my working hours (so far as they lie in my own choice) shall be from 8 A.M. to 5 P.M. while here in Kansas City, and that during these hours I will devote myself to the utmost to learn the practical work of an engineer.
> 2nd. That my evenings from 6:30 to 9:30 be devoted to study, not more than one evening in the week being ever excepted; my study to be systematic and thorough, and at least two-thirds of it to relate to my profession.
> 3rd. That my Sundays be spent as a season of rest, my usual vocations, so far as by avoidance and anything but opposition it is possible, be suspended, and the day devoted to mental and religious study, to writing to friends, and to solitary walks, with such other occupations as seem fitting to the day.[19]

Whatever reservations George Morison may have had regarding his radical career change soon disappeared, and he began to outline lofty plans and ideals for the future:

> It is my intention to remain in this city [Kansas City] through the winter; to spend the spring either here or in the field on a railroad; to go east in the summer, to spend one or two months in New England then to cross the Atlantic and devote a year to the study of French and German and the acquirement of scientific knowledge; it being my wish to make the profession of an engineer a truly liberal profession and through it to rise to science and philosophy, raising it with me, rather than to prostitute my life to mere money making, and to look upon professional advancement simply as the readiest means of acquiring wealth. Wealth is good as a means, but a deadly end, which dwarfs the mind and kills the soul. The spot which may become a home is already

> secured in a town dear to me from its natural beauty and its connection with my race, and should my profession leave me poor there at least I can live, supporting my life by such small income as I may have, and finding, among the beautiful hills of New England, opportunities for study and improvement which shall make up for the want of worldly success. I am ambitious, very ambitious to succeed, but money making is the smallest part of success, and I would rather fail in it than in more important things. [20]

Unlike the idealistic plans for the future that Morison penned in his journal alone in his hotel room at night, the daytime hours he spent on the construction site were marked by unrelieved drudgery. Chanute initiated the young apprentice to the rude reality of construction engineering by assigning him the tedious job of measuring the volume of rough stone for the masonry piers of the bridge. Morison felt demeaned by what he regarded as a menial assignment, calling it, "a simple and stupid task at which I suppose I must be kept for the present." He fretted, "it certainly does not furnish very good opportunities to learn engineering."[21] As construction progressed and Chanute recognized his natural ability, however, he quickly assumed ever greater responsibilities and eventually elevated to Assistant Engineer.

This first bridge on which Morison had so quickly advanced was no minor span. Chartered by Congress in July 1866, the bridge over the Missouri River at Kansas City would be the first structure of any type to span that problematical Midwestern river (See Figure 1 for location map of bridge.) The Congressional Act authorizing the bridge allowed for construction of either a fixed-span structure with sufficient clearance underneath to allow river traffic to pass unimpeded or for a low bridge with a moveable span over the main channel of the river. Section 2 of the charter stated:

> ...Any bridge built under the provisions of this Act, may, at the option of the company building the same, be built as a drawbridge, with a pivot or other form of draw, or with unbroken or continuous spans; <u>provided</u>, that if the said bridge shall be made with unbroken and continuous spans, it shall not be of less elevation, in any case, than 50 feet above extreme high-water mark, as understood at the point of location, to the bottom chord of the bridge; nor shall the spans of said bridge be less than 250 feet in length, and the piers of said bridge shall be parallel with the current of the river, and not less than 300 feet in length; <u>and provided also</u>, that if any bridge built under this Act, shall be constructed as a drawbridge, the same shall be constructed as a pivot drawbridge, with a draw over the main channel of the river at an accessible and navigable point, and with spans of not less than 160 feet in length in the clear on each side of the central or pivot pier of the draw, and the next adjoining spans to the draw shall not be less than

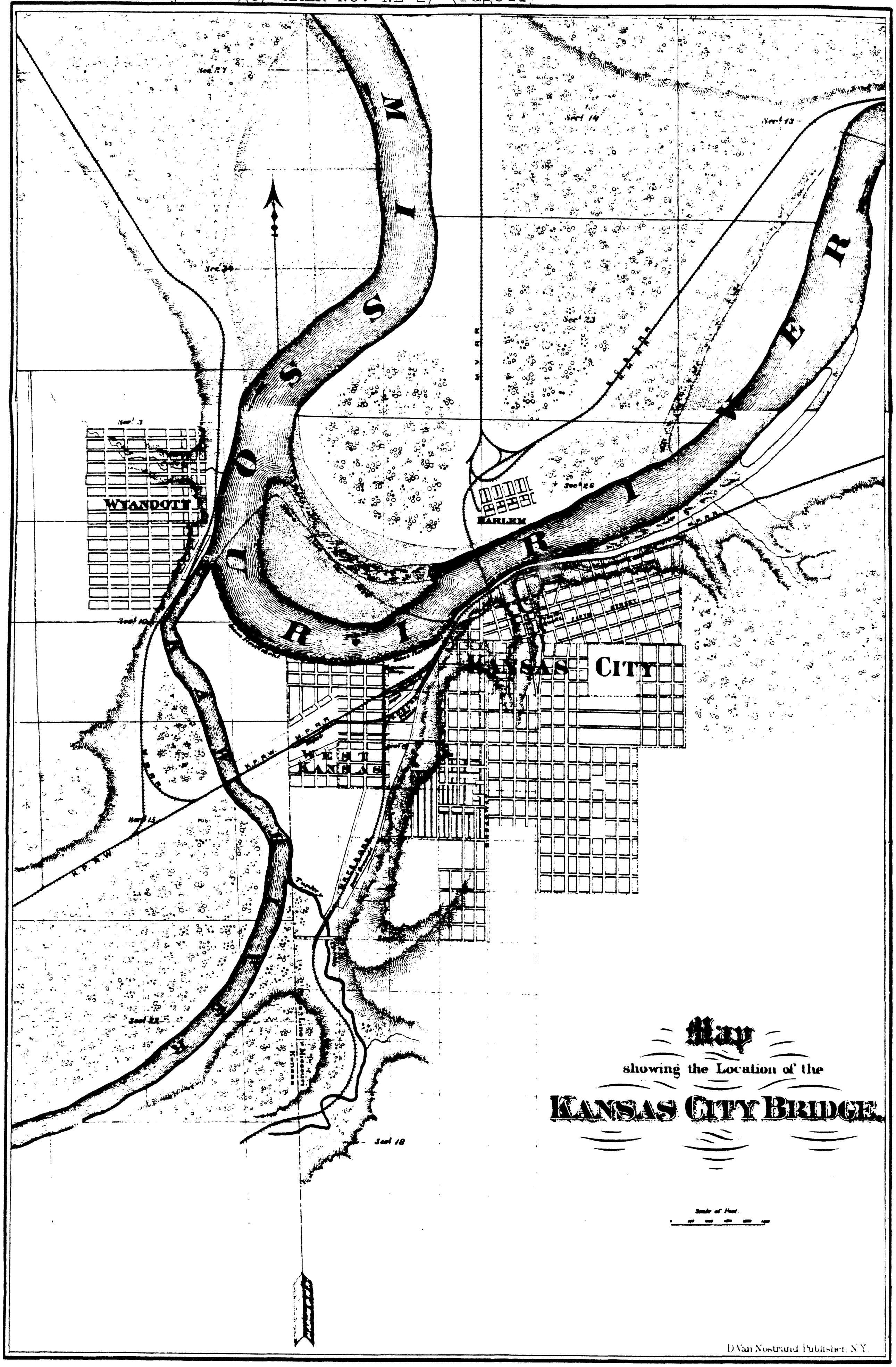

Map
showing the Location of the
KANSAS CITY BRIDGE
MISSOURI RIVER
WYANDOTT
HARLEM
KANSAS CITY
WEST KANSAS
D. Van Nostrand Publisher, N.Y.

Figure 1

> 250 feet; and said spans shall not be less than 30 feet above low-water mark, and not less than 10 above extreme high-water mark, measured to the bottom chord of the bridge, and the piers of said bridge shall be parallel with the current of the river; and provided also, that said draw shall be opened promptly, upon reasonable signal, for the passage of boats whose construction shall not be such as to admit of their passage under the permanent spans of said bridge, except when trains are passing over the same; but in no case shall unnecessary delay occur in opening the said draw, during or after passage of trains. [23]

The charter left little doubt that the sentiments of Congress lay with the riverboat interests. As the Kansas City Bridge was to be the first over the Missouri, the War Department used the minimum length and height requirements then in force for the Mississippi River. The problem was that river traffic and shore conditions on the two rivers were entirely different in character. "The requirement that the spans adjoining the draw should be 250 feet each," Morison later explained, "designed to accomodate the immense rafts which float down the comparatively tranquil channel of the Mississippi, become useless on the Missouri, whose turbulent torrent forbids the handling of any rafts, save those composed of a few cotton-wood logs, run down the shore a few miles to the nearest sawmill. Besides, as at almost every point where a bridge would be likely to be attempted, the channel of the Missouri lies close to one of its shores, the attempt to place spans of 250 feet on each side of the draw would result either in locating one leg of the draw beyond the main channel, or in building one of the 250 feet spans partly over dry land." [24]

Further, the length of the draw span prescribed in the charter was intended to meet the requirements of the big tows which plied the Mississippi. There were no tows then operating on the Missouri, however, due to the rapid current and abundance of snags along the channel. All previous attempts at towing barges on the Missouri had failed. Chanute argued that the 320-foot length required for the swing span was excessive due to the smaller craft and barges which ran the Missouri.

The relatively low riverbanks at Kansas City and the proximity of the bridge location to the connecting railroads prompted Chanute to design a low, swing-span structure. With a total length of 1400 feet, the Kansas City Bridge consisted of a series of medium-span fixed trusses on masonry piers with a single 363-foot pivot span over the navigable channel. The swing span (shown in Figure 2) was to be built of wrought and cast iron, the fixed trusses (shown in Figure 3), a combination of wood compression members and iron rods and eyebars for the tension members. Chanute had acquiesced to the length requirement for the swing span, but convinced the engineers in the War Department to waive the raft span requirement in response to the local river conditions. [25]

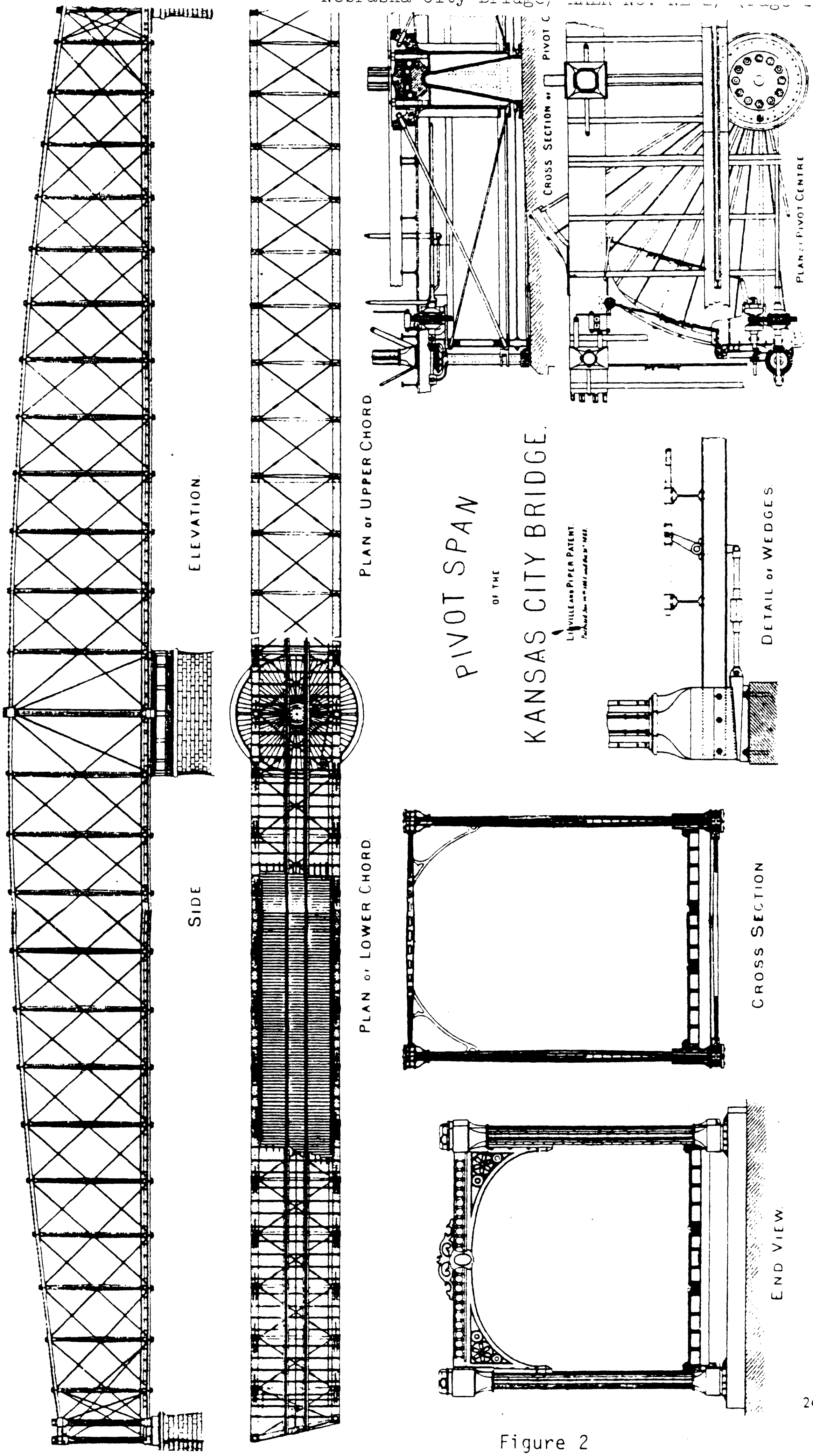
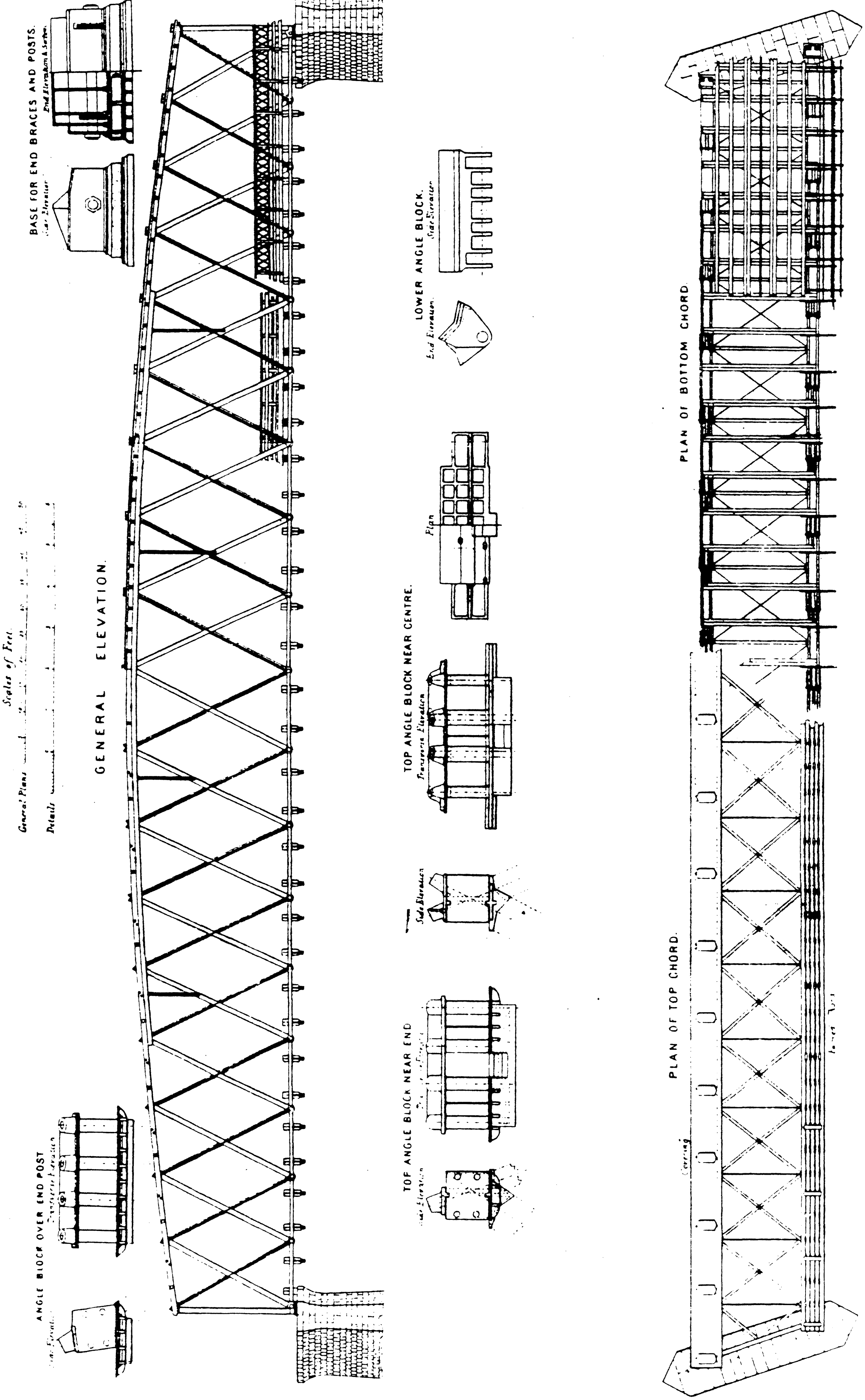

Side
Elevation.
Plan of Upper Chord
Plan of Lower Chord
Pivot Span
of the
Kansas City Bridge.
Linville and Piper Patent.
Cross Section of Pivot C
Plan of Pivot Centre
Detail of Wedges.
Cross Section
End View.

Figure 2



248 FT SPAN.
Scales of Feet.
General Plans
Details
GENERAL ELEVATION.
BASE FOR END BRACES AND POSTS.
ANGLE BLOCK OVER END POST
LOWER ANGLE BLOCK.
Side Elevation
End Elevation
Plan
TOP ANGLE BLOCK NEAR CENTRE.
Transverse Elevation
Side Elevation
TOP ANGLE BLOCK NEAR END
PLAN OF BOTTOM CHORD.
PLAN OF TOP CHORD.

Figure 3

Chanute himself had not designed the trusses. Rather, he issued general specifications which outlined the required span lengths, loading criteria, and the materials to be used - iron for the swing span and a combination of wood and iron for the other fixed spans. The individual bridge companies proposed the configuration of trusses which would form the bridge. Simultaneously, an engineer named Tomlinson drafted the plans for a fixed-span bridge supported high above the river on tall piers, to be used if none of the bridge companies' proposals appeared economically or structurally feasible. Chanute had sent these specifications to a number of prominent American bridge companies, and their response cut a cross section through current bridge engineering trends of the late 1860s. Of the nine proposals, two consisted of simply supported Howe trusses with wood upper and lower chords, three were adaptations of the Pratt truss, one entirely of iron, and the others featured Post, double- and single-intersection Warren, and Fink truss configurations, respectively. Chanute gave the construction contract for the superstructure to the Keystone Bridge Company of Pittsburg soon after George Morison arrived on the project. The iron for the bridge was to be paid by the pound, the timber by the foot. Chanute made minor modifications to the trusses that Keystone Bridge had designed, changing the depth and panel lengths of the fixed spans and substituting a 66-foot pony truss for one approach span. He described the truss configuration:

> The general design of the fixed spans is that of a double triangular truss or trellis girder, in which the top chord posts, and braces are of wood, and the other members of wrought-iron, cast iron being used in the details and connections. This combination, which has been used as yet only to a limited extent, is believed to overcome the most objectionable features of a wooden bridge, avoiding the wasteful connections which accompany the use of wood in tension, and disposing of the bulk of the perishable material in places where it can easily be protected... The trusses of the five fixed spans measure respectively 130, 198, 248, 198, and 176 feet, the difference between these distances and the lengths of spans being the allowance made for pedestals, wall-plates, and clearance room. The two shortest of these have straight parallel chords, the depth of the truss being 22 feet; the same depth is retained at the ends of the larger spans, but in them the upper chord is arched so as to increase the central depth to one-eighth of the length, the inclination of the braces being kept nearly constant by varying the lengths of the panels. The upper chord of the 130 foot span is formed of three pieces, packed in the usual manner; in the other spans the chord is of five parts, and supplemented at the centre by a sub-chord of two parts. The lower chords are of wrought iron upset links with pin connections, made under the Linville and Piper patent. The end posts and braces bear upon a cast-iron pedestal which rests on a wall-plate likewise of cast iron, carefully fitted to the masonry, and well bedded with mortar; at one end of each span a set of rollers is placed between the pedestal and the wall-plate.[28]

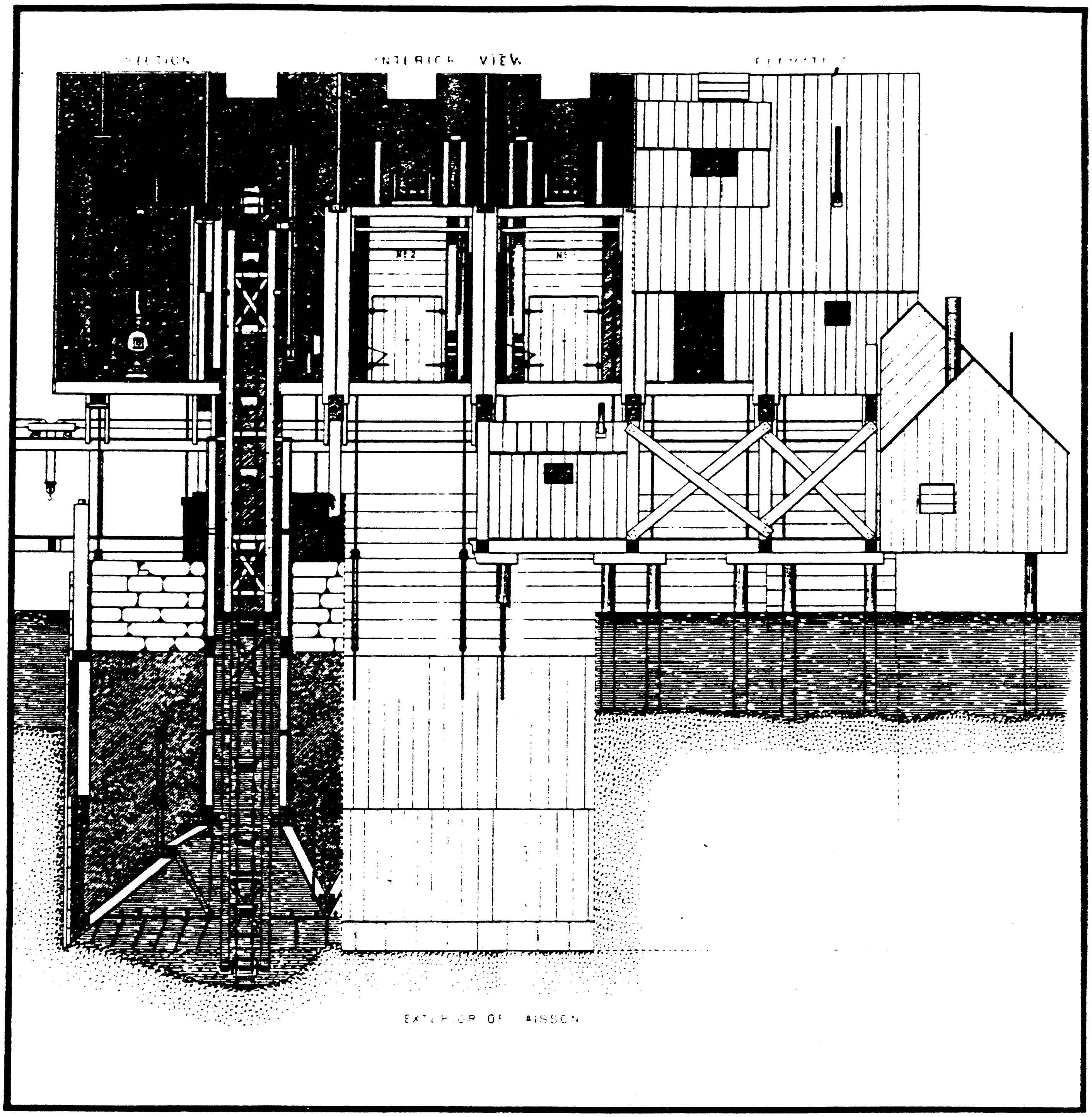


Figure 4

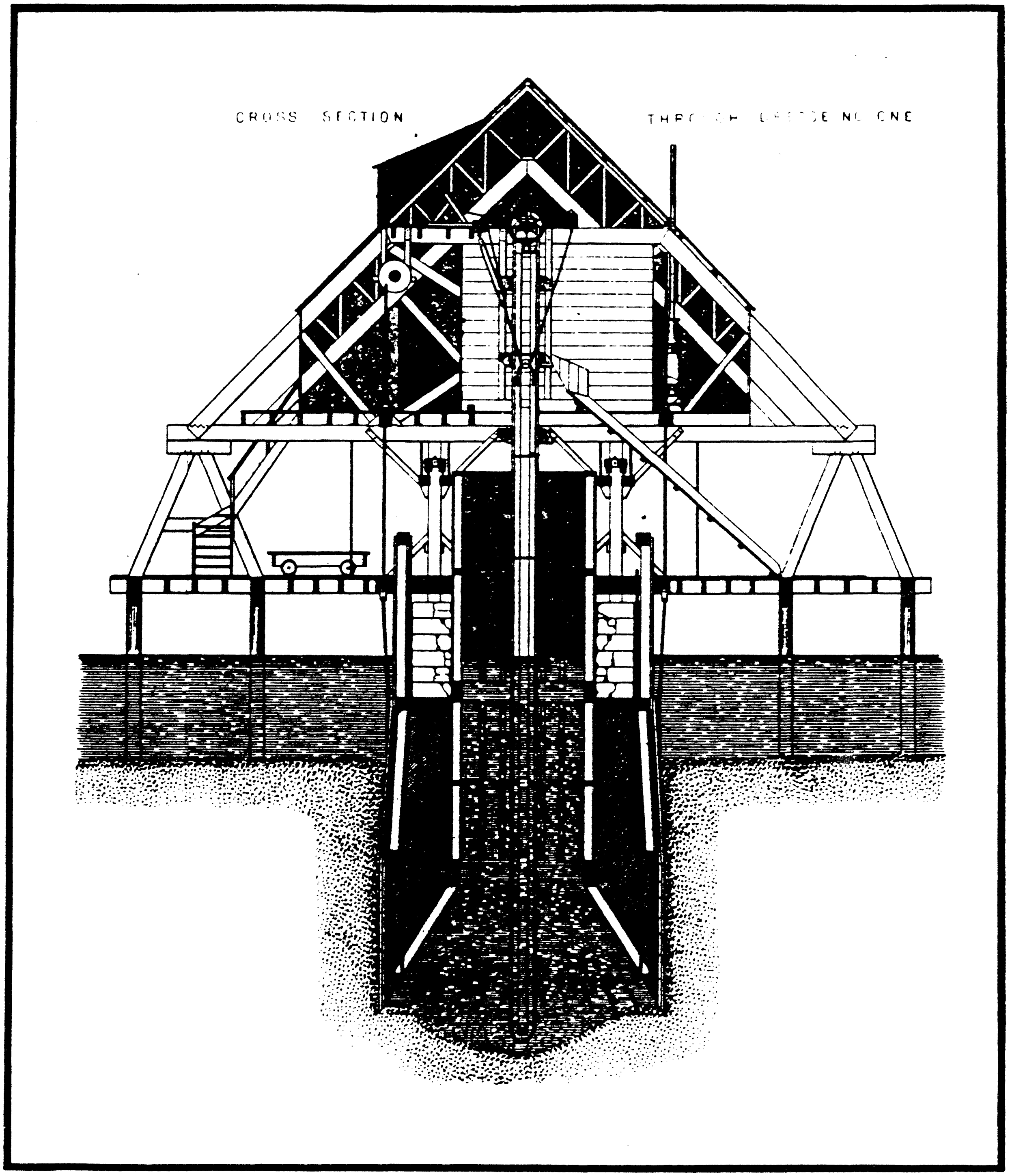


Figure 5

Although substantial, the superstructure represented no truly novel engineering design. The greatest difficulty in building the Kansas City Bridge lay in the foundations for the wood/iron spans. The construction of the foundations was unquestionably the most difficult part of the project. No other bridge had been erected over the Missouri River, and Chanute could only speculate about many of the characteristics of the river and its bed. Given the uncertainties of the project, the limited deep-water construction technology then available, and the fact that the isolated location away from Eastern mills and suppliers required that most of the equipment and machinery be fabricated on-site, he engineered the foundations for the great bridge through a process of elimination. Chanute described the substructural design of the Kansas City Bridge:

> The methods of founding which have been in most common use in the United States were not to be thought of, as the continual wash and scour of the river would have made piles and crib-work useless, while the great depth and rapid current must have rendered coffer-dams very hazardous and expensive. The use of iron columns, sunk by the pneumatic process, was considered; but the conviction was early and confidently formed that a cluster of separate columns resting upon the rock at a depth but little below the scour limit, as would have been the case in the most exposed foundations at this location, would fail to give the stability needed by the channel piers; while it was believed that the sand-bar piers, which are rarely exposed to a strong current, might be founded in a way less expensive, though amply secure. It was also feared that in the absence of pneumatic plant in America, and with the then high prices of iron work, the pneumatic process would prove in its entire execution an unreasonably expensive one.[29]

The system that Chanute finally chose consisted of solid masonry columns on timber/iron caissons carried to bedrock for the channel piers, with masonry on driven pile foundations for those piers not subject to the constant scour of the river. Despite their repetitive nature, each support required individual design drawings and construction techniques to account for the greatly different river conditions. Construction of the first pier began August 16th, 1867, just before Morison joined the project. Several work crews labored throughout the winter and into the next year, alternately building and sinking caissons, dredging, driving timber piles, hauling material and equipment, and quarrying and laying the stone for the large masonry piers. A particularly innovative excavation process was introduced for founding the draw pier which employed self-feeding machinery instead of man labor and thus eliminating the need for compressed air in the caisson (shown in Figures 4 and 5).[30]

The engineers were understandably concerned about the bridge's effect on steamboat traffic along the Missouri. They wanted to avoid repeating an incident in which the first bridge over the Mississippi was destroyed by fire less than two weeks after its opening when a steamboat crashed into a pier. "The chief

anxiety of all parties concerned in this work," Morison later wrote, "was so to locate and build the bridge that it should form the least possible obstruction to the navigation of the river, and prove as little objectionable as possible to the steamboat interests. It was felt that, whatever other mistakes might be made, the channel must be kept clear, and boats be enabled to pass and repass at all times, without danger or difficulty." As work progressed on the massive piers for the bridge, the steamboat captains learned to navigate the river at this point, and no serious accidents occured. Morison concluded: "This gratifying result must, in great part, be attributed to the care, reason, and justice of the men navigating this river, and has happily avoided the disputes and accidents which have attended the erection of the first bridges across some other of our large rivers." [31]

On September 14, 1868, masons laid the last stone for the bridge. The fixed and swing trusses were erected over falsework trusses supported by temporary timber cribs (shown in Figure 6). Workers first swung the draw span on June 15, 1869, the first locomotive crossed the bridge ten days later, and on Saturday, July 3rd, the Kansas City Bridge was opened with a citywide celebration.

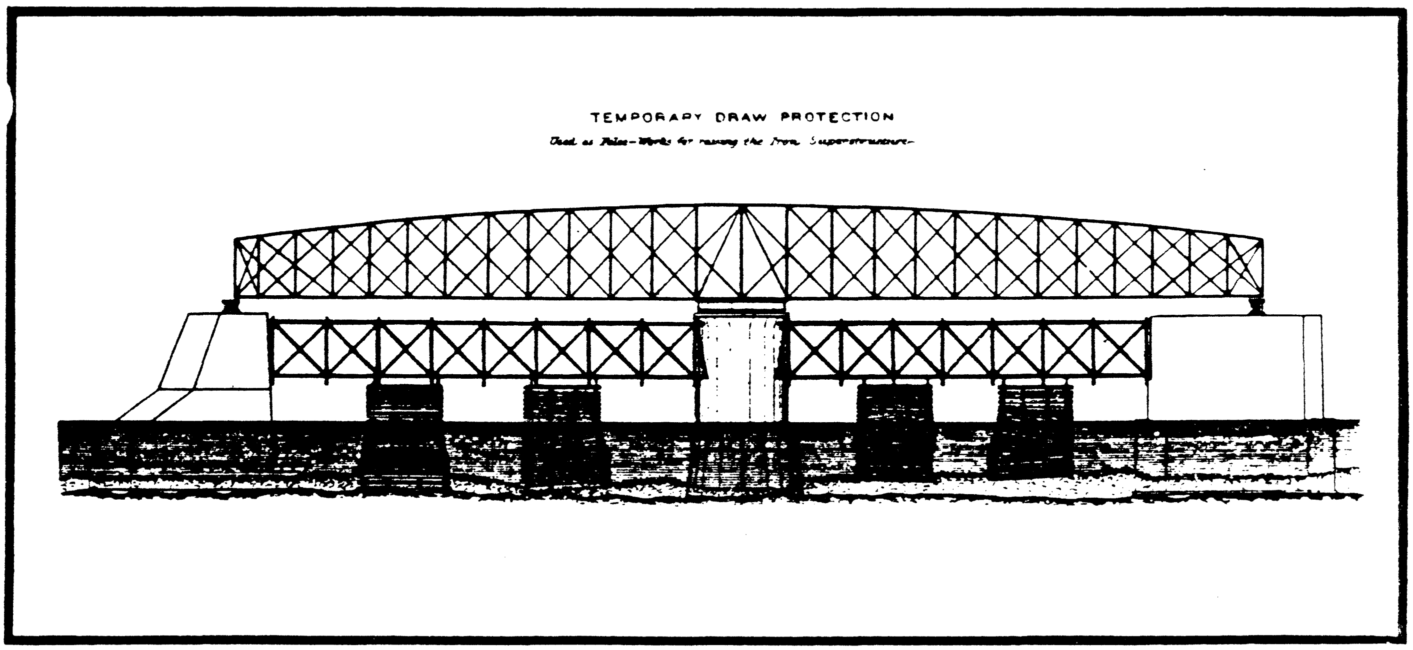


Figure 6 [32]

The cost of the bridge proper exceeded $886,000 - roughly double the cost-per-foot of comparable bridges built over the Mississippi River. This was attributed almost entirely to the deep and difficult nature of the foundations, which had had cost nearly $500,000. With the approach grading on both sides and riverbank rectification works, the total cost for the Kansas City Bridge was

slightly more than $1 million - a staggering sum for the time. Morison later described the problems which had plagued the project, summing up, in essence, bridgebuilding on the Missouri River:

> All the delays, difficulties and failures which took place were directly owing to the violence of the current, and its capacity for rapid scour. The precautions and watchfulness which these required, both by night and by day, were endless, and not always successful. The moods of the river were constantly changing, and its bottom and banks of most unstable regimen, thus causing no little anxiety and expense, while the absence of precedents in this kind of work, in this country, left the engineers to depend mostly upon their own resources.[33]

The impact that the bridge had on Kansas City was immediate and dramatic. During the two-and-a-half years that the monumental structure was under construction, the population of the river city had burgeoned from 13,000 to 30,000. Kansas City had almost instantaneously grown from little more than a way station along the Missouri Pacific Railroad into a major Missouri River port. At the completion of the bridge, no less than seven separate railroad lines extended into the city to capitalize on this first permanent crossing of the Missouri, and several others were projected.[34]

During his tenure on the bridge project, George Morison watched with interest the remarkable transformation of the town. Aside from his professional studies and work on the great bridge, he pursued a limited range of activities at Kansas City. It was not surprising, given his strong religious background, that he was a regular church-goer and was active in organizing and building the Unitarian Church. He was also beginning to write beyond his personal journals, though not yet on engineering topics. He authored several reviews of theological works for his father's publications, Unitarian and Christian Register. As a journalist, Morison wrote pointedly - often too acerbically for publication - and frequently corrected with his trenchant pen any inaccuracies in the works he was reviewing. This prompted his father to reply often, "to curb the somewhat ruthless criticism which the young engineer did not hesitate to apply to the occasional fallacious statement or reasoning of the most prominent Unitarian preachers and authors, at a period when the names of such men were household words."[35] George Morison was also a regular correspondent for the Salem Gazette, writing colorful articles on Western life under the *nom de plume* Rosman.[36]

Following the completion of the pioneer structure in June 1869, Chanute and Morison co-authored a descriptive publication through New York-based Van Nostrand publishers entitled, *The Kansas City Bridge*, which detailed the problems involved in the bridge's construction. This lengthy, illustrated monograph discussed every aspect of the project from background history to the methods used in founding each bridge pier. It was exemplary of the thorough and precise style shown in all of Morison's reports and papers. The book concluded

modestly: "It is hoped that this imperfect relation of the experience acquired upon this novel work may be of profit to others engaged in similar undertakings." [37]

Morison remained in Kansas City until June 1871 to work with Chanute on the survey, design, and construction of James Joy's railroad lines - commonly known as "Joy Roads". A large part of his time was spent supervising construction of the Leavenworth, Lawrence & Galveston Railroad from Lawrence, Kansas, through Garnett to the Indiana Territory. To overcome his lack of formal training in civil engineering, Morison undertook an intensive regimen of self-education that consisted of reading contemporary engineering reports and and journals, studying construction drawings, and observing other engineers' work in the field. In a determined effort to expand his professional knowledge whenever possible, he traveled almost continuously between the East Coast and the Rocky Mountains to observe the construction of railroad tracks and bridges across the country. This self-dedicated travel, with his duties for the LL&G and trips to Kansas, Nebraska, Wisconsin, Michigan, and other western states as a railroad construction consultant, combined to create a grueling schedule of travel and work. The consummate engineer would maintain this regimen with only occasional breaks throughout his career.

In the summer of 1871, Morison was called to Detroit to become Chief Engineer of Joy's Detroit, Eel River and Illinois Railroad. For a year and a half, he supervised construction of the rail line extending from Ypsilanti, Michigan, to Logansport, Indiana, occasionally consulting independently for Eastern banking interests on railroad construction and management. While this was a position of considerable responsibility and authority, the line was poorly managed, and he was anxious for a new assignment. [38]

An excellent opportunity materialized in April 1873, when Morison was hired as Resident Engineer of the Eastern Division of the Erie Railway headquartered in New York. There he renewed his association with Octave Chanute, who had become Chief Engineer of the line. Under Chanute, Morison quickly ascended to Principal Assistant Engineer. The Erie Railway was equipped primarily with wooden bridges designed for much lighter loads than those of the new locomotives proposed for the line, presenting the fledgling assistant engineer an ideal field laboratory to develop his talents in reconstructing and strengthening bridges. Morison was called on to design his first major railroad span - a replacement structure - in 1875. In the predawn twilight of Thursday, May 6th, the Portage Viaduct over the gorge of the Genesee River at Portageville, New York, caught fire. The conflagration completely destroyed the famous timber structure and heavily damaged the stone masonry piers and abutments at the bottom of the chasm. [39]

The original 850-foot wooden trestle had been engineered by Silas Seymour to serve the heavily trafficked Buffalo Branch of the Erie Railroad. Called the

boldest timber bridge ever erected, the spectacular viaduct carried the tracks 234 feet above the steep defile of the river on three-bent timber towers.[40] The single-track spans were 50-foot Howe deck trusses, 14 feet deep. "The magnitude of the structure," Morison stated, "and the fact that the railway had another line over which the Buffalo business could for a time be handled, made the erection of any temporary structure inexpedient, and it was at once decided to rebuild in iron."[41]

The heavy traffic volume over the Portageville crossing forced Morison to design the replacement bridge hurriedly. To use many of the existing stone foundations, he shaped the structure to conform substantially with the configuration of the original bridge. The 818-foot wrought iron viaduct that Morison delineated (shown in Figure 7) consisted of ten 50-foot spans, two 100-foot spans, and one 118-foot span, with a 50-foot span placed between each of the long spans. (Details of these and the towers are shown in Figures 8 and 9.) He used pin-connected Pratt deck trusses for the principal spans. These were supported on six towers, each consisting of two main pairs of wrought iron columns braced together to form two-post bents. Morison designed the supporting framework to carry a double-track superstructure to allow for the eventual addition of a second pair of rails.[42]

The railroad awarded the ironwork contract on Monday, May 10th, to the Watson Manufacturing Company of Paterson, New York. Morison, meanwhile, began drawing the replacement superstructure. Later that week, he directed stonemasons to build new abutments on either end and to repair the existing pier supports by by encasing them with beton coignet cement.[43] The rolling mills could not produce the pier components quickly enough, however, delaying the erection of the tall, web-like towers until June 13th. Once the material arrived on the site, construction continued steadily. Morison described the involved erection process for the 230-foot towers in a paper later presented to the American Society of Civil Engineers:

> The towers were raised with no other falsework than that actually used in handling the material of each successive section. Before beginning to raise a tower, a floor of long timbers reaching from pier to pier and loose boards, was laid at the site of the tower; on this floor was erected a frame-work 30 feet high, and composed of two bents, one on each side of the tower; each bent consisted simply of two posts 48 feet apart and a cap 55 feet long, braced with planks across the corners. These bents were kept in an upright position by long inclined braces reaching from near the top of each post to the floor. Sets of falls were attached by slings to the projecting ends of the caps, and with these falls the lower lengths of the columns were lifted by a hoisting engine and placed in position, the transverse and longitudinal struts were then put in place and the diagonal ties put on, the longitudinal ties being temporarily attached by a hook and eye plate to the same pin

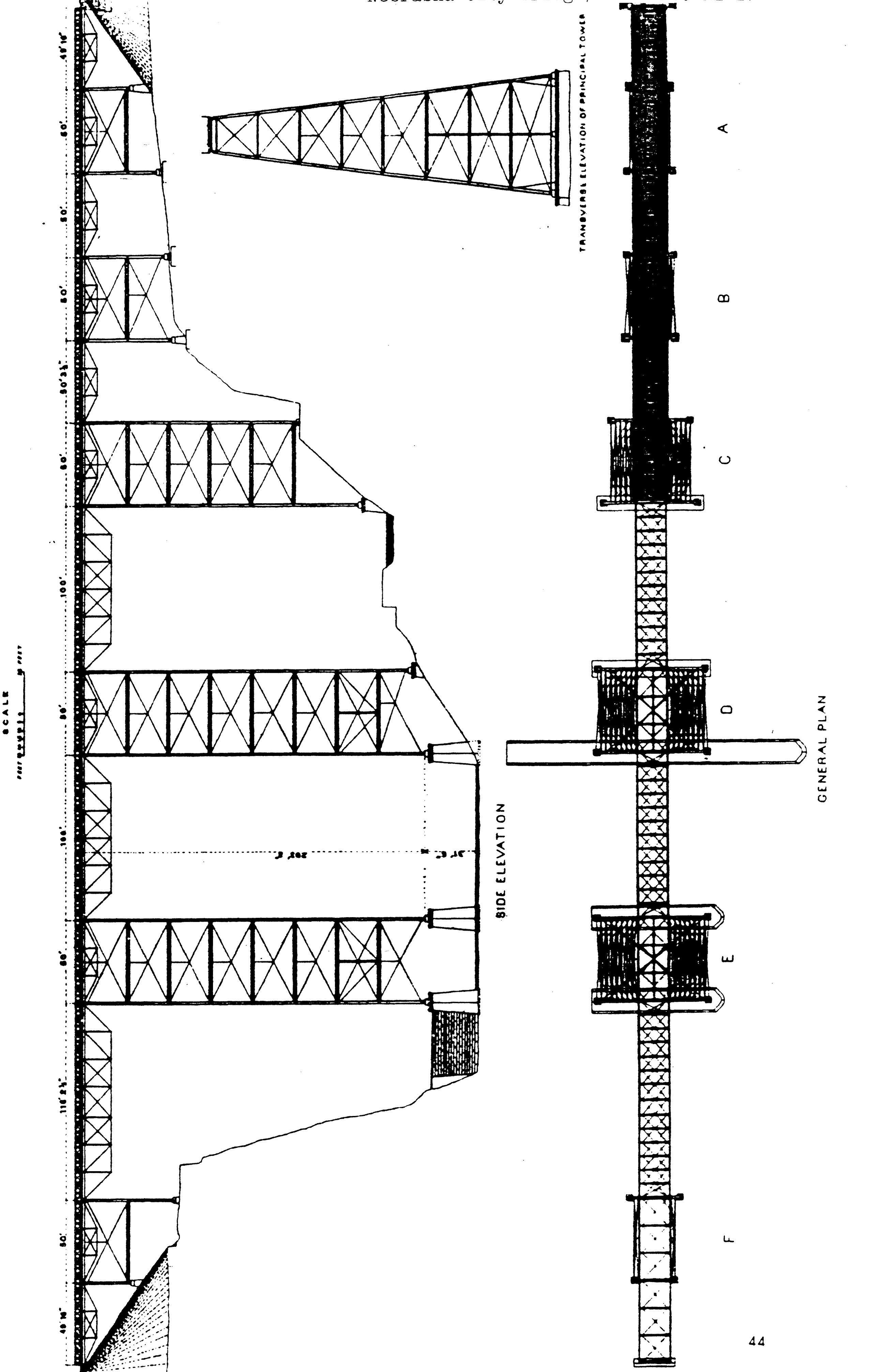

TRANSVERSE ELEVATION OF PRINCIPAL TOWER
SIDE ELEVATION
GENERAL PLAN
SCALE
A
B
C
D
E
F

Figure 7

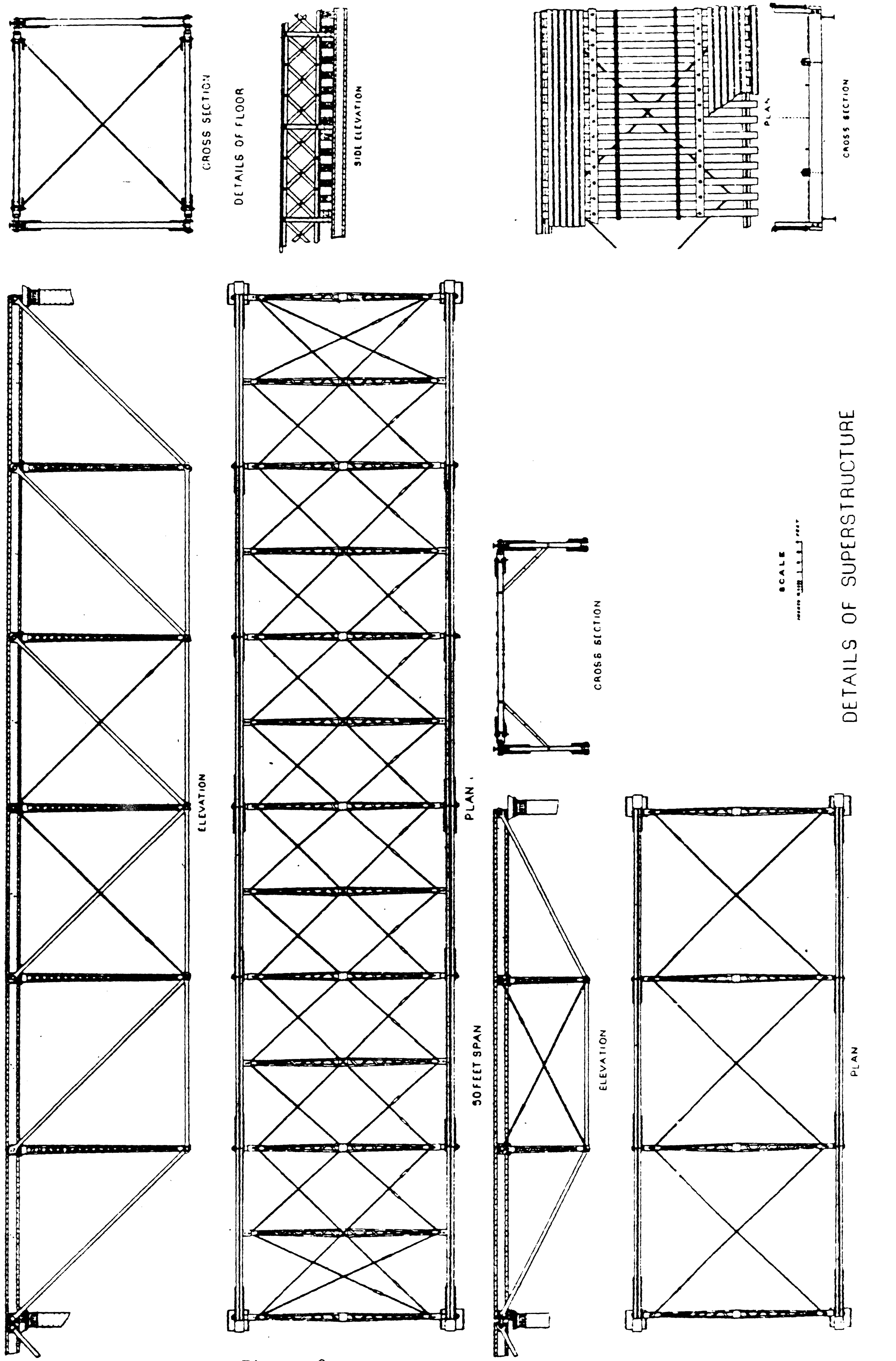

DETAILS OF SUPERSTRUCTURE
100 FEET SPAN
ELEVATION
PLAN
CROSS SECTION
DETAILS OF FLOOR
SIDE ELEVATION
PLAN
CROSS SECTION
CROSS SECTION
50 FEET SPAN
ELEVATION
PLAN
SCALE

Figure 8

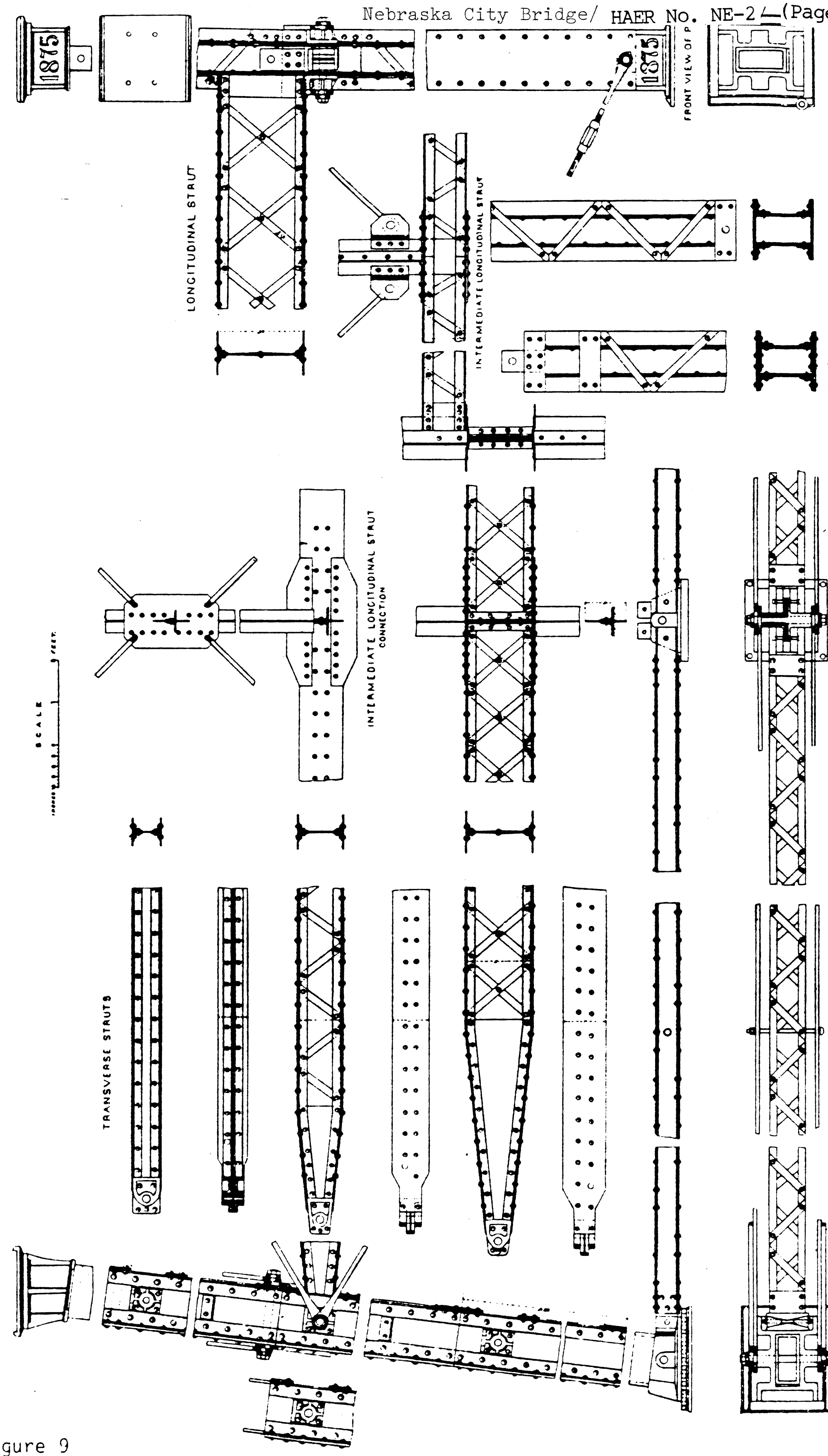

1875
1875
FRONT VIEW OF P
LONGITUDINAL STRUT
INTERMEDIATE LONGITUDINAL STRUT
SECTION AND REAR VIEW OF POST
INTERMEDIATE LONGITUDINAL STRUT CONNECTION
SCALE
DETAILS OF INTERMEDIATE POST
TRANSVERSE STRUTS
BOTTOM TRANSVERSE STRUT
SIDE VIEW OF POST

Figure 9

> with the transverse tie. A gin pole 55 feet high, was then lashed to each column and these gin poles were used to transfer the floor and frame to the top of the lower section of tower now completed. The same operation was then repeated with the second length of columns, which were placed over the tenon plates of the lower length, and secured by the pins; this done, the longitudinal ties were changed from their temporary connections to the permanent ones. When the second section of the tower was completed, the frame was used to raise the gin poles, which were lashed again to the columns and rested on the longitudinal struts. The floor and frame were then raised again, and the process repeated till the tower attained its full height.[47]

The last tower built in this manner weighed 277,000 pounds and required eleven days to construct. Once the towers were in place, the superstructure could be built. For the fifty-foot spans, the truss erectors laid simple timber beam falseworks. For the longer trusses, they built combination Pratt trusses below the permanent spans, upon which the iron trusses were built. The construction progressed smoothly and rapidly through June and July. The erection of the iron work set a particularly remarkable record: the first iron column was raised June 13th, all iron was in position by July 29th, the track was laid across the following day, and the bridge was formally tested and opened before a large crowd of spectators on July 31, 1875, only seventy-six days after the fire.[48]

In engineering and constructing his first major bridge, Morison received ample assistance. The superstructural spans and tower dimensions of the iron trestle had been dictated largely by the configuration of Seymour's original timber structure. Morison designed the trusses using typical components and detailing for standards of strength then maintained by the Erie Railroad. And J.H. Drake, superintendent of erection for the contractors, devised the erection system for the towers. When congratulated for his innovative engineering, Morison only slightly deflected the praise for himself, saying: "I ought to state that, although this was designed by myself and built under my direction, the particular arrangement of towers used was fixed, first, by the piers of the old wooden viaduct, and secondly, as suggested by others."[49]

Morison's viaduct was not a technologically innovative structure. Rather, it had "the same general character as other iron viaducts recently erected by American engineers, differing from these in size and detail rather than in any principle of construction." Civil engineer Charles MacDonald commented: "The general arrangement of piers and intermediate spans on the Portage viaduct appears to be judicious, in view of the fact that the masonry of the old bridge was assumed to be suitable for the new. The details at the joints of the posts are quite novel and possess some merit; scarcely sufficient, however, to warrant their general introduction."[50] Still, this structure has a recognized place in the evolution of the metal viaduct in America. Specifically, the

Portage Viaduct is credited as the first viaduct of note which had towers of two bents only for each span. In Bridges: The Spans of North America, David Plowden summarizes its significance in broader terms, stating: "since the completion of the Portage Viaduct, the design of metal viaducts has changed little, and it is for this reason that the bridge is often called the exemplar of this characteristically American form." [51]

While with the Erie Railroad, Morison continued his sideline business as a consultant to various banking houses, inspecting and reporting on railroad properties. His education as a lawyer and training as an engineer, combined with his analytical ability, fundamental honesty and forceful managerial style, equipped him to advise his investment clients on railroad construction, maintenance, operations, and financial management. "His clear mind quickly uncovered weak spots in financial structure or management," his nephew later wrote, "and on account of his incisive, forceful reports his services were in constant demand." [52] In November 1875, Morison left the Erie to take up consulting on a full-time basis. He engaged in this work for the next ten years from an office at 52 Wall Street in New York, principally managing railway properties for S.C. and G.C. Ward of New York, the American representatives of Baring Brothers & Company of London and Liverpool. As a representative of that firm, Morison served on the boards of directors of several railroads: the St. Louis, Iron Mountain & Southern (1876-1880), the Eastern Railroad of Massachusetts (1876-1886), the Maine Central (1877-1885) and the Ohio & Mississippi Railroad, (1884-1892).

Management consulting provided a steady and lucrative practice that gave George Morison the opportunity to travel across the country to study other engineering enterprises. But his first love was still bridgebuilding. In 1875, he joined with George S. Field and another civil engineer to form Morison, Field and Company, a bridge engineering and construction firm with headquarters in Buffalo, New York. While this too proved successful, Morison could divert only limited attention to the company from his thriving consulting practice. As he had definitively stated in his personal journal thirteen years before, Morison still preferred the professional side of bridge building to the profit-making side, exemplified by construction work. He resigned from Morison, Field and Company in 1880. Morison would eventually resume his professional association with George Field, however, with Field's firm later erecting several of the engineer's great river bridges.

By 1880, George Morison had established a solid, industry-wide reputation in railroad management. Bridge engineering remained a subsidiary component of his professional practice. Yet despite the enormous demands placed on his time by the Wards and others, Morison was determined to establish an independent engineering design practice. Increasingly, he chose to devote more energy to bridge design and less to railroad operations. Thirteen years after abandoning a law career in favor of structural engineering and ten years after beginning in

independent railroad consulting, Morison was thus displaying characteristic willfulness to control his own destiny. This determination would soon be rewarded by an important series of commissions for bridges over the Missouri River - landmark structures for what would prove to be a remarkable career.

ENDNOTES

1 Journal of George Shattuck Morison, 10 August 1867 (collection of John Morison, Peterborough, New Hampshire).

2 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir (Peterborough, New Hampshire: Peterborough Historical Society, 1940), page 3.

3 George A. Morison, George Shattuck Morison, page 2.

4 George A. Morison, George Shattuck Morison, page 2.

5 George A. Morison, George Shattuck Morison, page 3.

6 George A. Morison, George Shattuck Morison, page 3. Morison was appointed Superintendent of Plantations on St. Helena Island, South Carolina, and later worked for the United States Sanitary Commission in Virginia.

7 George A. Morison, George Shattuck Morison, page 3.

8 O. Chanute, H.W. Parkhurst, E.L. Corthell, A. Noble, R. Modjeski, and E. Gerber, "George Shattuck Morison: A Memoir," Journal of the Western Society of Engineers, Volume IX, No. 1 (February 1904), page 84.

9 George A. Morison, George Shattuck Morison, page 4.

10 E. Gerber and C.C. Schneider, "Memoir of George Shattuck Morison," Transactions of American Society of Civil Engineers, Volume LIV, 1905. page 521.

11 O. Chanute and George S. Morison, The Kansas City Bridge (New York, New York: D. Van Nostrand, 1870), page 9.

12 Onward Bates, Robert W. Hunt, Charles F. Loweth, and Charles L. Strobel, "Memoir of Octave Chanute," Transactions of American Society of Civil Engineers, Volume LIX, 1910, page 483.

13 Journal of George Shattuck Morison, 16 October 1867.

14 George A. Morison, *George Shattuck Morison, 1842-1903: A Memoir*, page 18.

15 George A. Morison, *George Shattuck Morison*, page 18.

16 Letter from George Abbot Morison to Samuel Elliot Morison , 3 December 1940. (Collection of John Morison, Peterborough, New Hampshire).

17 George A. Morison, *George Shattuck Morison*, page 23.

18 Journal of George Shattuck Morison, 31 December 1867.

19 Journal..., 27 November 1867.

20 Journal..., 27 November 1867.

21 Journal..., 18 October 1867.

22 Chanute and Morison, *The Kansas City Bridge*, Plate I.

23 Act of Congress, 25 July 1866, quoted in *The Kansas City Bridge*, page 11.

24 Chanute and Morison, *The Kansas City Bridge*, page 12.

25 Chanute and Morison, *The Kansas City Bridge*, page 13.

26 Chanute and Morison, *The Kansas City Bridge*, Plate XI.

27 Chanute and Morison, *The Kansas City Bridge*, Plate X.

28 Chanute and Morison, *The Kansas City Bridge*, pages 80-81.

29 Chanute and Morison, *The Kansas City Bridge*, pages 33-34.

30 Chanute and Morison, *The Kansas City Bridge*, pages 80-81.

31 Chanute and Morison, *The Kansas City Bridge*, page 17.

32 Chanute and Morison, *The Kansas City Bridge*, Plate VII.

33 Chanute and Morison, *The Kansas City Bridge*, page 120.

34 Chanute and Morison, *The Kansas City Bridge*, pages 15-16.

35 George A. Morison, *George Shattuck Morison, 1842-1903: A Memoir*, pages 19-20.

36 George A. Morison, George Shattuck Morison, page 20.

37 Chanute and Morison, The Kansas City Bridge, page 120.

38 George A. Morison, George Shattuck Morison, page 6.

39 George S. Morison, "The New Portage Bridge," Transactions of the American Society of Civil Engineers, Volume CXVI (November 1875), p. 1; O. Chanute et al. "George Shattuck Morison," page 84.

40 "The Principal Bridges of the World - A Comparison," The Engineer, 24 May 1918, pages 441-42.

41 George S. Morison, "The New Portage Bridge," page 2.

42 George S. Morison, "The New Portage Bridge," page 4.

43 Beton coignet was a manufactured concrete material comprised of sand, cement and stone aggregate used extensively in the late 19th Century for cast-in-place and pre-cast applications. Its most widespread use in America was for "artificial" building stones - early concrete blocks, manufactured by companies such as the New York and Long Island Coignet Stone Company. Pedro Guedes, Encyclopedia of Architectural Technology (New York: McGraw-Hill Book Company, 1979), page 255.

44 George S. Morison, "The New Portage Bridge," Plate 1.

45 George S. Morison, "The New Portage Bridge," page 3.

46 George S. Morison, "The New Portage Bridge," page 2.

47 George S. Morison, "The New Portage Bridge," page 5.

48 George S. Morison, "The New Portage Bridge," page 2.

49 George S. Morison, comments on "The American Railroad Viaduct - Its Origin and Evolution," by J.E. Greiner, Transactions of the American Society of Civil Engineers, Volume XXIV (October 1891), page 360.

50 Charles MacDonald, "On the New Portage Bridge," Transactions of the American Society of Civil Engineers, Volume CXXII (February 1876), p. 235.

51 David Plowden, Bridges: The Spans of North America, (New York: The Viking Press, 1974), page 71.

52 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir, page 6.

MISSOURI RIVER BRIDGES

> The Missouri River is essentially and preeminently a silt-bearing river, and that is what gives it all its peculiar features. In the eastern part of the country it is customary to think of a river as a running stream of comparatively clear water, but most of the principal rivers of the world are of a totally different character; they are not clear water at all, they are silt bearers. They are apparently muddy, but the mud is the silt which they are carrying down. A clear water river has, so to speak, but one function; its business is to drain the surrounding country and to carry away the water which is produced by rainfalls. A silt bearer performs a double duty; it not only carries away the drainage of the country through which it runs, but it also carries off a great deal of the country at the same time.[1]
>
> (George S. Morison, 1895)

> To look at it, some people would think it was just a plain river running along in its bed at the same speed; but it ain't. The river runs crooked through the valley; and just the same way the channel runs crooked through the river. The river changes whenever it feels like it in the valley; and just the same the channel changes whenever it feels like it in the river. The crookedness you see ain't half the crookedness there is.[2]
>
> (Charles P. Stewart, 1907)

These two descriptions - the first by George S. Morison and the second by story-teller Charles Stewart - though greatly different in sophistication, describe the two most significant characteristics of the Missouri River. Bounded over most of its length by steep bluffs or broad flood plains, floored by a deep bed of alluvial silt, subject to violent spring and summer flooding, choked by massive ice floes in the winter, and continuously redefining its main and subsidiary channels, the river had posed a formidable obstacle to westward overland traffic throughout much of the 19th Century. "The Missouri is a

notoriously fickle stream," engineer Thomas Doane concluded in his 1868 report, Bridging the Missouri River, "changing its bed many hundreds of feet transversely during a single freshet."[3]

Of the three great tributaries of the lower Mississippi - the Missouri, the Ohio and the upper Mississippi - the Missouri was the most difficult and the least known in the 1860s and 1870s. Its navigable length from Fort Benton in Montana Territory to its mouth at St. Louis extended some 3150 miles, as computed by the river pilots, and it drained a watershed of 518,000 square miles: an area more than one-third greater than the combined basins of the Ohio and upper Mississippi. The Ohio, in the eastern slope of the Mississippi basin, flowed through a settled country with relatively high riverbanks and a hard, stable bed. It was the most easily bridged. The upper Mississippi, which flows through the plains of the central valley, had a sandy and unstable bed, but fell at a shallow rate and had a predictable channel over most of its length. The Missouri, on the other hand, combined an unstable bed with a quick and unpredictable stream flow. "The Missouri," Morison stated, "drawing its source from the eastern face of the Rocky Mountains, and flowing with a rapid descent down the westerly slope of the great basin, unites within itself all elements of unstableness and irregularity, combining the impetuosity of a mountain torrent with the volume of a lowland river."[4]

Over most of its length, the Missouri coursed through an alluvial bottomland enclosed on both sides by bluffs. The distance between these bluffs ranged from one-and-a-half to fifteen miles, and they were highest and most rugged where they were closest together. Only slightly higher than the average high water level of the river, the bottoms were often inundated by flooding. For about five hundred miles from the river's mouth almost to the southern border of Nebraska, they were heavily timbered with cottonwood, sycamore, walnut, oak and elm. Beyond this, the timber was more scarce and the bottoms prone to prairie. The river wound between the bluffs with little apparent regularity with a width ranging from 900 to 4500 feet. At low water, the channel constricted to about 600-700 feet, leaving the remaining width a dry sand bar.

When the width of the bottomland was not more than two or three miles, the usual course of the river was to follow along the base of one of the bluffs for a short distance until deflected by an obstacle. Then it crossed the valley to the other bluff. The vein of strongest current was readily observable as it crossed the river diagonally in the straight reach between the serpentine turns. The current was always strongest on the outside of the turns. By this action, the river typically washed the lower bank as it crossed the bottomland, continually forming new sand bars which advanced down the valley. When the bottomland width exceeded two or three miles, the river was just as likely to return to the bluff it had just left before crossing the valley. In these locations, such as the length between Nebraska and Iowa, the Missouri tended to be very irregular.

During the warm weather months, the river held tremendous amounts of silt in solution as it flowed through the valley. This solid matter could only be carried when in rapid motion and was deposited wherever the river slowed. Thus, while the channel was cutting into a sand bar on one bank, it was depositing silt and creating another bar on the other. Spring and summer floods could change the nature of the stream flow entirely overnight within certain stretches, making navigation risky. To make matters worse, tree trunks which washed into the river tended to catch on the sand bars where they were partially buried. These created the snags for which the river was notorious.

The principal tributaries of the Missouri were the Yellowstone, the Platte, the Osage and the Kansas, or Kaw, Rivers. The latter two were prairie streams with irregular sources, the former had headwaters in the mountains. Each had its distinctive characteristics and effects upon the parent river. The Yellowstone typically was the cause of summer flooding along the upper Missouri. The Platte usually disgorged its floodwaters into the Missouri somewhat earlier in the spring. Freshets on the Kaw and Osage occured intermittently throughout the warm weather months, in response to local rainfalls. The great floods along the Missouri were produced by combinations of these prairie floods with water from mountain snowmelt. Although irregular, these massive floods tended to create tremendous damage and changes to the parent river. The 1844 flood, for instance, submerged the entire bottomland below the mouth of the Kaw entirely engulfing the site of Kansas City. Other, more localized floods occured regularly along the Missouri, typically in the early spring as the ice floes on the river broke up.

According to Morison, the best location for a bridge over the Missouri was just below one of the great bends, especially if the current there impinged upon a rocky shore. Under such conditions, the bedrock beneath the river was generally shallow on the bluff side, where the main channel flowed. The least promising location was on a long straight stretch, where the bedrock was usually found a great depth and the current veins were likely to be variable. This would make it necessary to sink excessively deep foundation, construct extensive shore protection to control the channel and erect an unnecessarily long bridge. The problem was, the best locations from the standpoint of bridge construction and maintenance were the worst locations for the steamboats which navigated the river. Ship pilots would rather confront the bridges on the long, straight stretches. But Morison's chief concern was the bridges over the river, not the steamboats which ran its length. He would locate his bridges to the best advantage of his railroad clients, over the objections of the steamboat interests.

The Missouri extended east-west from St. Louis across Missouri. Along this stretch the river did not represent a serious problem to most of the regional and transcontinental railroads, which were at the time extending their trunk lines east-west across the Midwest, parallel with the broad watercourse. At

Kansas City, however, the river swung north. From that point north to the Dakota Territory, the Missouri River formed a daunting barrier. As more and more railroads pushed westward in the sweeping national expansion following the Civil War, the problem of crossing the pernicious river became increasingly more critical.

The Missouri River, and not the wider Mississippi, presented the most formidable obstacle to travel between the Atlantic and Pacific coasts, according to Major General Grenville M. Dodge, Chief Engineer for the Union Pacific Railroad.[5] Faced with the prospect of building extremely expensive and technologically untried structures to span the river permanently, railroads such as the Union Pacific skirted the problem in the 1860s and 1870s by building makeshift crossings. These consisted typically of temporary tracks built on driven timber piles or laid directly on the frozen river in the winter. Ferries or moveable pontoon bridges operated the rest of the year. But the winter tracks broke up each year with the spring ice melt, and the pontoon bridges proved exceedingly vulnerable to destruction during spring and summer flooding. The transfer steamers or ferries had severe liabilities of their own. Time-consuming and dangerous, they were subject to interruption by downriver boat traffic and seasonal freezing and flooding. Moreover, the cumbersome transfer operations created tremendous bottlenecks during peak freighting seasons, snarling rail traffic for hours or days. These temporary crossings were at best inconvenient and at worst unacceptably dangerous. Without a feasible alternative, however, the railroads resorted to combinations of these operations to traverse the river above Kansas City. Almost every railroad bridge built over the Missouri into the 1890s had been preceded by one or more of these temporary crossings.

The problems associated with bridging the Missouri River had less to do with the overall lengths of the structures - far longer bridges had already been erected in the East and over the Mississippi and Ohio Rivers - or the sizes of their individual spans, than with the unpredictable conditions of the river itself. A prodigious silt bearer subject to violent shifts in channel, the Missouri River was without precedent in the eastern United States, where American bridgebuilding had been concentrated before the Civil War. Thus, the story of bridge engineering on the Missouri River was not the graceful metallic trusses spanning over it as much as the tremendous piers that supported them and the rectification works to control the channel. "I've spent a year putting the bridge over the river," an early engineer said. "I've spent my time ever since, keeping the river under the bridge."[6]

In the early 1860s structural engineers in America were experimenting with pneumatic caissons for deep-water bridge foundations and wrought iron for trussed superstructures. They were also beginning to understand mathematical statics and stress analysis calculations on trusses. These technological developments, fueled by the westward surge of the railroads in the aftermath of

the Civil War and the flourishing of the nation's iron industry, marked a watershed in American bridgebuilding. "Iron bridge building in America did not really begin till after the war," George Morison stated in 1890. "[Previously] the general practice even for the larger bridges was wood, and the great rivers of the continent were still unbridged; the wooden bridge across the Mississippi at Rock Island, finished in 1856, was the only exception."[7]

The late 1860s saw substantial bridges erected over the three great midwestern rivers: the Ohio, Mississippi and the Missouri. The first railroad bridge across the Ohio River was the Steubenville Bridge, completed in 1866. The Burlington Bridge, completed by the Chicago, Burlington and Quincy Railroad in 1868, was the first iron structure across the Mississippi. Before these were completed, other bridges were begun, and by 1867 wrought iron bridge building had been firmly established in America. Two years later, the Missouri was the only one of the three great rivers unspanned. Substructural and superstructural technology for large-river crossings had largely been developed by the engineering profession. It was only a matter of time before the first bridge over the Missouri would be designed.

Octave Chanute was the first engineer to succeed. With a young George Morison as an assistant, he bridged the Missouri at Kansas City with a multiple-span structure for the Kansas City and Cameron Railroad. Completed in June 1869, this remarkable combination truss consisted of a 363-foot iron double-intersected Pratt pivot span and five fixed iron/wood Post through trusses with lengths ranging from 132 to 250 feet.[8] The Kansas City Bridge proved that the unpredictable river could indeed be channeled and bridged. In the decade following its completion, a handful of others followed.

In 1870-71, the Army erected a fixed-span high bridge over the Missouri to provide access for Fort Leavenworth, Kansas. Made up of 320, 340, and 344-foot iron through trusses, the Leavenworth Bridge had an overall length of 1,004 feet: the shortest of the Missouri River structures built in the 1870s. Twenty-five miles upriver from Leavenworth, the city of Atchison contracted through an eastern investment group for an iron swing-span truss in 1874. The following year L.B. Boomer's Chicago-based American Bridge Company completed the structure. The Atchison Bridge consisted of a 360-foot pivot truss and three 258-foot fixed spans, for a total length of 1,134 feet. Fifteen miles further up the Missouri, another iron pivot bridge had been erected at Saint Joseph, Missouri, in 1873. This structure was made up of a 364-foot swing span and three 300-foot fixed spans and had an aggregate length of 1,264 feet: just short of the Kansas City Bridge.[9]

The most spectacular of the earliest Missouri River bridges was the multiple-span structure that the Union Pacific Railroad erected at its headquarters in Omaha, Nebraska. With a total length of over a half mile, the Omaha Bridge was

by far the longest of the early Missouri River structures.[10] Using Grenville Dodge's design, the American Bridge Company built the eleven 250-foot cast/wrought iron Post trusses that comprised the main superstructure in 1869-72.[11] A solid embankment formed the east approach for the bridge; a cottonwood trestle was erected over the broad floodplain on the west. The fixed-span through trusses were supported high above the water by one stone and eleven pairs of 8-foot cylindrical iron piers, all founded on bedrock. Morison himself called it "the most prominent example in America of the Post superstructure and pneumatic cylinder piers."[12]

The Union Pacific's bridge at Omaha was the longest and most impressive of the early Missouri River spans throughout most of the 1870s. But it was surpassed at the end of the decade by another bridge erected over the river by the Kansas City, St. Louis, and Chicago Railway (a subsidiary of the Chicago and Alton Railroad). Organized in 1877 to build a branch line from Mexico, Missouri, to Kansas City, the KCSL&C commissioned General William Sooy Smith in 1878 to design and supervise construction of its river bridge at Glasgow, Missouri. Sooy Smith, a graduate of Ohio University and West Point, had garnered considerable notoriety for his long-span bridge construction and deep-level pneumatic foundation work. The bridge that he designed for the KCSL&C consisted of five 314-foot Whipple through trusses on stone piers over the main river channel, 1,140 feet of deck truss spans, and 864 feet of wooden approach trestle. Work on the driven pile foundations was begun in March 1878, and a year later the great bridge was completed.[13] Though the Glasgow Bridge was significant as one of the earliest major spans over the Missouri, its principal distinction was as the first all-steel bridge built in America.

Sooy Smith's bridge was comprised of Bessemer process steel manufactured by the Edgar Thompson Steel Works and rolled by Hussey, Howe, and Company and Andrew Kloman into the various structural components. The engineer worked closely with Iowa steel innovator Abram Hay in formulating the alloy used for the bridge. They monitored the strength testing extensively, producing a material with a tensile strength of between 70,000 and 90,000 pounds and an elastic limit between 48,000 and 52,000 pounds. Sooy Smith limited the maximum tensile stress on the bridge components to a conservative 16,000 pounds per square inch. He concluded, "I had found [steel] 50% stronger than wrought iron, far more uniform in quality and nowise unsafe at low temperatures."[14] Sooy Smith's decision to use steel exclusively for a long-span bridge proved controversial among his contemporaries. Curiously, the bridge was all but dismissed by the profession after its completion, apparently regarded as a fluke rather than a daring example of engineering innovation. Sooy Smith was the first to use steel exclusively for a bridge, but it was George Morison's methodical materials testing and publication of the findings in the ealy 1880s that would later sway the industry toward the use of structural steel for bridge construction.

PLATTSMOUTH BRIDGE

In February 1879, as the Glasgow Bridge was nearing completion, Charles E. Perkins, General Manager of the Chicago, Burlington, and Quincy Railroad, contacted New York-based consulting engineer George Morison. Perkins was interested in erecting a permanent bridge to carry his railroad's main line over the Missouri River near Plattsmouth, Nebraska. The thirty-six year old Morison had had no formal engineering education and had worked on only one other railroad span over the Missouri River - and that almost ten years earlier as an apprentice. But as a consultant for James Joy and others in subsequent years, he had developed a solid reputation for carefully conceived engineering design and fiscally conservative railroad management. Perkins wanted the engineer to visit the site and make recommendations on the location for the behemoth structure. This initial contact between George Morison and the Burlington Railroad represented Morison's first major bridge commission as a consulting engineer and would lead to the construction of a significant span over that problemmatic river. But far more importantly, this first meeting marked the beginning of a professional relationship between the engineer and the railroad which would last throughout Morison's prolific career and would result in some of America's most spectacular and technologically significant spans.

For the CB&Q, the bridge at Plattsmouth would play an indispensable part in the railroad's expansion plans. Late in the 1870s, the Burlington was engaged in a bitter power struggle with the Union Pacific Railroad. As each company vied to penetrate ever more territory, the issue became more than potential expansion. At stake was corporate survival. In 1878 the Burlington could operate trains to Denver and the lucrative Rocky Mountain market by only three routes: the Kansas Pacific, the Santa Fe and the Union Pacific. As the Burlington management studied the acquisition of the Kansas Pacific, a faltering rail line which paralleled the UP main transcontinental trunk, Perkins' chief adversary, Jay Gould, bought it himself. The Burlington countered with a threat to build in Union Pacific territory, and Gould reacted with characteristic speed and aggression. In 1879 he bought the St. Joseph and Western, a small line which bisected the Burlington's profitable South Platte territory in Nebraska. That autumn he acquired control of the Wabash Railroad and in swift succession acquired the old Central Branch Union Pacific, the Kansas Central and the Missouri Pacific.[15]

These last moves were directed not only toward the Burlington, but to the Union Pacific as well. What followed was another shrewdly managed example of financial legerdemain for which Gould was notorious. For as he was acquiring the competing railroads across the midwest, Gould was secretly selling his own UP holdings. His new rail companies now surrounded the lines of both the UP

and the B&MR, creating a formidable new rival. In January 1880, he coerced the stunned Union Pacific management into absorbing all of his recent midwestern acquisitions for a share-for-share exchange of stock. Dismaying as this was to the directors of the Union Pacific, the consolidation spelled potential diaster for the Burlington Railroad. Gould and the Union Pacific had surrounded the Burlington lines west of the Missouri River. Worse yet, all but two - the Burlington and Missouri River and the Santa Fe - of the vital routes to Denver were controlled by UP interests. Charles Perkins had foreseen Gould's maneuverings and suggested that the Burlington follow a sweeping nationwide consolidation of its own to combat the ruthless rival:

> I have long been of the opinion that sooner or later the railroads of the country would group themselves into systems and that each system would be self-sustaining... Each line must have its own feeders. This law, like other natural laws, may work slowly, but it is the law nevertheless. Hence my judgement is so decided that the C.B.& Q. should take the B.& M. and the Atchison, and make up its mind to lose a large part (of course not all) of the U.P. and K.P. and other business west of the Missouri controlled by the Wabash or its owners. If we had the Santa Fe and the B.& M. today, would not the Rock Island people be open to argument and be glad to join us in forming a great system?[16]

Under any circumstance, Perkins declared, the first move would be the immediate consolidation of the CB&Q and the B&MR to insure Burlington access to Denver. The crossing over the Missouri River near the mouth of the Platte River at Plattsmouth, Nebraska, would form the crucial link between the two lines. For several years, the Burlington and Missouri had contracted with William Irving to ferry freight cars across the Missouri at Plattsmouth. But Irving's steamers were subject to the problems associated with all transfer operations on the river. Perkins and the railroad's directors were painfully aware of the dangers and limitations of the makeshift operation. In 1876, over 26,000 cars had to be loaded aboard the ferries at riverside and unloaded on the opposite shore, snarling interstate rail traffic.[17] As the traffic in later years increased, Burlington management recognized the need for a permanent overhead crossing to compete with the Union Pacific's bridge at Omaha, just fifteen miles upriver.

Perkins had studied the feasibility of a permanent bridge at Plattsmouth as early as 1877. That summer he hired consulting engineer J.E. Laylor of Burlington, Iowa, to prepare a preliminary survey of the site four thousand feet downriver from the small town's main street. The structure that Laylor delineated consisted of a series of wrought iron Post trusses - three 260-foot fixed through spans and a 370' swing span - similar in configuration to Octave Chanute's bridge at Kansas City. A single-track span with a 650-foot trestle approach on the east, the proposed bridge would exceed an estimated $580,000 in

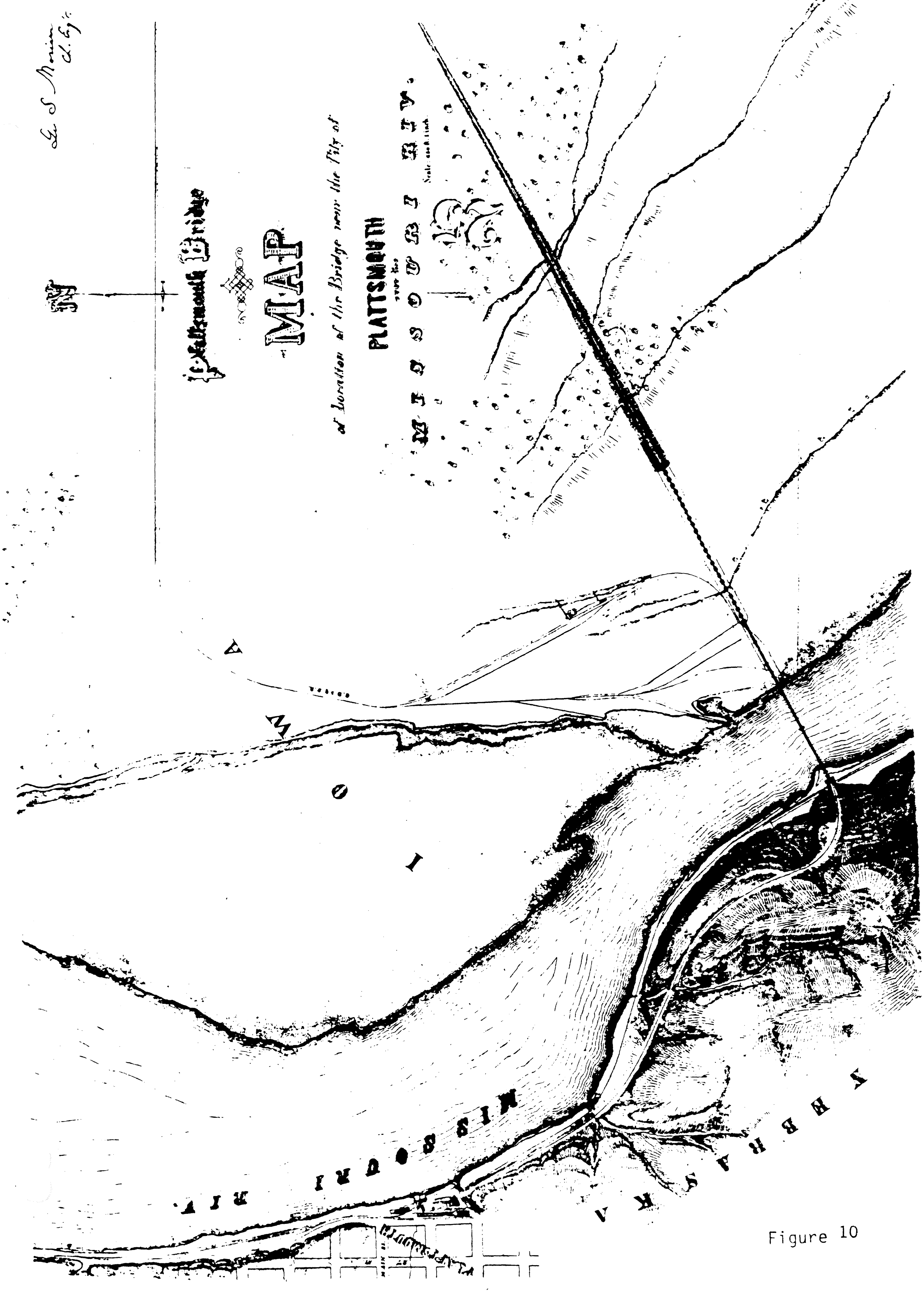
erection costs.[18] Thomas Choate, Chief Engineer for the Burlington and Missouri River Railroad in Nebraska, suggested an alternate, yet similar swing-span structure on a site located closer to town.[19] Naturally, ferryman Irving opposed construction of any bridge that would destroy his business. In September 1877 he reported the volume of traffic at Plattsmouth to Perkins, defending the shortcomings of his steamers and trying to dissuade the railroad official from building the permanent bridge:

> This is no measure of what we can do if we can keep the river open throughout the year. We could doubtless do better than this, but this is as much as we should in reasonable probability be called on to do, for our own business for some time to come; and would seem to show that we could put a half million to better use than by building a bridge. It should be remembered, however that we cannot rely on keeping our boats running from December 1 to March 15, a period during which we shall have about our heaviest call for transfer service. We recommend construction of a temporary winter bridge. The cost of doing this work, every year, must of course be given weight in considering the bridge project, but I should not, I think, by any means turn the scales in favor of it. If it was my railroad and I had the half million, I think I would spend it to better advantage.[20]

Irving was in luck. In 1877 Burlington management could not justify the cost of the bridge, and he continued his transfer operation. But after the competition with the Union Pacific intensified three years later, Perkins was able to convince the directors to fund the expensive structure. On February 12, 1879, he contacted George Morison at Burlington, Iowa, about the proposed bridge on behalf of the B&MR Railroad.

Morison traveled immediately to Plattsmouth to inspect the river and shore conditions. The location that he chose for the bridge (shown in Figure 10), however, coincided with neither Choate's nor Laylor's earlier surveys. "The objection to both of these locations," Morison reported back to Perkins, "was that they were in a portion of the river where the channel was variable and they could only have been maintained by the construction of entirely new works to confine the channel." He instead selected a bridge site a mile below Plattsmouth - just downriver from the jetty that had served as a landing for the transfer steamer. Under Morison's plan, the existing dike would serve as channel rectification to reduce the river's width at the bridge.[21]

Morison also ignored the superstructure designs of the two previous engineers. Rather than use a low bridge with a moveable span, he designed a fixed-span superstructure supported high above the river surface on massive solid masonry piers. Morison's bridge consisted of two Whipple through trusses - each 350 feet long - with three 200-foot deck trusses on the east approach.[22] In rejecting the two previous designs, he contravened conventional engineering



23

Figure 10

practice. Virtually all of the Mississippi River bridges of the time featured low, moveable spans. Most of the preceding Missouri River bridges - including Chanute's bridge at Kansas City - were also swing-span configurations. With the Plattsmouth Bridge, Morison first demonstrated his preference for high, fixed-span bridges - a professional proclivity that would persist throughout his career.

The issue of low versus high bridge design was critical to engineers building these first railroad spans over the navigable rivers of the Midwest. It was one that would reoccur on most of Morison's Missouri River bridges. Conventional engineering philosophy of the time held that a low bridge was more economically constructed than a high one. The additional expense of the engine and gears for the pivot mechanism and the higher operating costs for a moveable structure were more than offset by the savings in cost for the lower masonry piers and the shorter span lengths allowed by the War Department than for a high, fixed bridge. More important, though, was the simplification of the foundation design. Because of its minimal height above the high water mark, the piers for a low bridge could be founded on driven piles. A high bridge, on the other hand, required a far deeper and much more massive pneumatic caisson foundation to provide lateral stability for the extensive piers. The difference in cost and erection time between the two construction methods was substantial.

Morison had considered the question with characteristic thoroughness and had concluded, contrary to convention, that high was preferable to low. He based his argument on hard economics. High fixed bridges, he maintained, were in fact more economical to build and maintain than low, because of the extensive rectification work neeeded to provide a clear channel through the pivot of a moveable structure and because of the extensive cutting needed for a low bridge approach in the high riverbanks along most of the Missouri River. But as he espoused economics to his railroad clients, Morison, in fact, was philosophically predisposed toward high bridges. This colored his professional judgement and would lead to at least one instance in his career in which he would be accused of tampering with the cost estimates for a bridge to skew the figures to match his prejudice.

The crux of Morison's pragmatic philosophy held that the railroads, his primary clients, were being penalized financially by the steamship interests. Shipping along the Missouri River, he maintained, was a moribund industry, superceded in large part by the railroads. The boats which had once navigated the river could no longer operate at rates competitive with those of the rail companies. The railroads, therefore, should not be inconvenienced or penalized to accommodate the less important river traffic. "[Steamships] were the tools which made the original settlement of the [Mississippi] valley possible," he stated in a lecture to a group of St. Louis businessmen in 1889. "Still they are simply tools, not monuments, and they are worthy of preservation so long as they furnish the cheapest transportation, and no longer. If they cannot be so

improved as to accomplish this result there is no further use for them."[24] He compared the two interests graphically:

> The Missouri River above Kansas City is now crossed by ten railroad bridges representing an investment of perhaps eight million dollars in hard cash; two of these bridges have draws, and eight are high enough for steamers to pass under them, the height required being fixed by law at fifty feet. The additional cost of the last twenty-five feet of height on the bridges named has been perhaps one-quarter the whole cost, the principal increase being in the approaches. This is twenty times the value of all boats now on the river, and the saving in interest in a single year would equal the whole value of the fleet. This annual charge is borne by the traffic which crosses these bridges.[25]

Morison objected to "the extreme of despotism" that forced the railroads to adapt their bridges to the requirements of the shipping companies. He concluded with typical terseness, "If advances cannot be made in the river-boat, its usefulness as a carrier is gone; if the character of the river is such that the boats cannot be improved, then the rivers must cease to be routes of transportation, and become simply water-works and drains."[26] Short of this, the railroads should not be impeded, even occasionally, by shipping traffic passing through an opened pivot span of a moveable bridge. If the boats must be accommodated, he felt, the railroads should pass completely over them without the possibility of interruption.

The Plattsmouth Bridge allowed George Morison an opportunity to apply this singular philosophy. More importantly from a personal standpoint, with this first bridge as a consulting engineer he was finally able to pursue his idealized vision of the practice of engineering. George Morison had at last found his niche. Solitary and brilliant, completely dedicated to his career at the virtual exclusion of a private life, fiercely protective of his professional freedom, and aggressively defensive when faced with questions about his engineering judgement, he was ideally suited to the role of a consultant in private practice.

In his preliminary design for Plattsmouth, Morison demonstrated a faculty for independent engineering based upon meticulously logical reasoning - a distinctive trait that would become his hallmark. "Nature endowed him with a strong intellect and a strong will and he made the most of them," a group of his associates would later write of him. "The whole grand success may be summed up in the word 'work.' He had no influential friends to help him, whom he did not make himself by his indomitable energy and proven ability. He studied his work carefully and thoroughly, and the minutest detail was not too small to be worked out with the greatest consideration before it was executed. One of the rules was, that if he had five minutes in which to do a thing, he would take three if necessary to think it out, and do it in the other two."[27]

Morison's nephew, George Abbot Morison, wrote: "He was a man who made decisions slowly, but when once made, such decisions were inflexible. A person is rarely seen who so impressed one with his strength and force of character; but he was not willful; he was not unreasonable; he could be persuaded if it could be shown that his point of view was not correct."[28]

But there was a negative side to a dominatingly strong will. George Morison would soon become known among the engineering profession as a gifted, but difficult bridge designer. "The very abundance of his powers made him somewhat arrogant and intolerant of the opinions of less gifted men," a biographer later wrote. "He usually arrived at any conclusion only after an exhaustive study of all the facts, and once his decision was made, he was inclined to enforce it with a tenacity and ruthlessness that bore down all opposition but, even when he was right, did not endear him to those holding different opinions."[29] Nevertheless, his engineering judgments were virtually always accepted as correct, at times because of the sheer force of his character.

Morison's design for the Burlington's bridge at Plattsmouth differed completely from those of two preceding engineers. The Missouri River itself dictated his design, the engineer argued convincingly. In a report to Perkins, he elaborated:

> It was evident, that though the situation was one in which a bridge could be built at a very reasonable cost, the location was very unfavorable to the maintenance of a low bridge with a draw, as this would have involved an entire change in the character of the river; it would have been necessary, not only to fix the position of the channel which had already been done by the dike, but to secure a constant direction of current through narrow openings. The approach on the east side would have been expensive, but on the west side it would have been necessary either to curve around abruptly with a curve of a radius less than 300 feet, or to have made a tunnel of considerable length which would have had to be on quite a sharp curve, but with a roof of the clay or loess which forms the upper part of the bluffs along this portion of the Missouri. The difficulties of the approach could have been overcome by a reasonable expenditure, but the difficulty in controlling the channel was very much greater, and although it could undoubtedly have been accomplished in time, the works would necessarily have been of so tentative a character that it would have been unwise to construct the bridge until their effect was fully established.[30]

When Morison visited Plattsmouth in February, the Missouri River was frozen, making access for subsoil testing relatively simple. Morison arranged for the engineer of the Burlington and Missouri Railroad in Nebraska to make immediate soil borings at the tentative pier points to determine the substructural conditions before the breakup of the winter ice pack. With only makeshift

testing equipment, he completed the borings that month but incorrectly assessed the level of bearing stone. Mechanical engineer George W. Tennent was later hired to make additional borings during high water in April and May. With a more accurate appraisal of the level of stone beneath the river, Morison then reaffirmed the tentative bridge location chosen in February as the final location. [31]

Because the bridge was to be built over a navigable watercourse, Morison assumed that approval by the Secretary of War was needed. In May 1879, he presented a preliminary site plan and general elevation of the bridge to General H.G. Wright, Chief Engineer of the United States Army, in Washington. Ironically, the Burlington and Missouri River Railroad in Nebraska had acquired the right to bridge the Missouri River under the original charter of the Union Pacific Railroad. Citing the terms of the charter, Wright ruled that no further review of the bridge was necessary from the War Department. Assured of federal approval, the B&MR directors in Boston hurried in June to authorize the bridge project. A week later, while Jay Gould was beginning his run on the midwestern railroads, Perkins commissioned George Morison to begin the construction drawings for the Plattsmouth Bridge based upon his preliminary design. [32]

The Missouri River had begun its seasonal recession by then, and the optimum construction season - from mid-August to mid-November - was fast approaching. Morison quickly assembled a group of assistants to help with the design and construction of the great bridge. "While Mr. Morison always studied out and knew every detail of his work himself," Chanute later wrote, "he was careful to surround himself with a competent, faithful and conscientious staff."[33] The first assistant engineer that Morison hired for the bridge was Charles Conrad Schneider (1843-1916). Schneider, a graduate of the Royal School of Technology in Chemnitz, had emigrated to the United States in 1864. He had first worked as a mechanical engineer for the Rogers Locomotive Works in Paterson, New Jersey, and in 1871 became an assistant engineer for the Michigan Bridge and Construction Company. Two years later, he joined George Morison working under Chanute for the Erie Railroad and later worked for the Delaware Bridge Company before opening his own bridge engineering office in New York City on 1878.[34] Morison appointed Schneider the Assistant Engineer of the Superstructure, a position which, given his extensive bridge experience, undoubtedly involved a substantial amount of engineering design on the long- span trusses. Morison also hired Gorham P. Low as his First Assistant Engineer and Benjamin L. Crosby as Assistant Engineer. The Chief Engineer's stringent qualifications were difficult to meet and even harder to endure. "An indefatigable seeker after truth and the best obtainable himself," Chanute continued, "he expected his staff to be no less energetic, accurate and conscientious in their work than he and an indolent or slovenly worker did not remain long in his service."[35] After less than four months, Low was the first to leave; Morison soon replaced him with H.W. Parkhurst.[36]

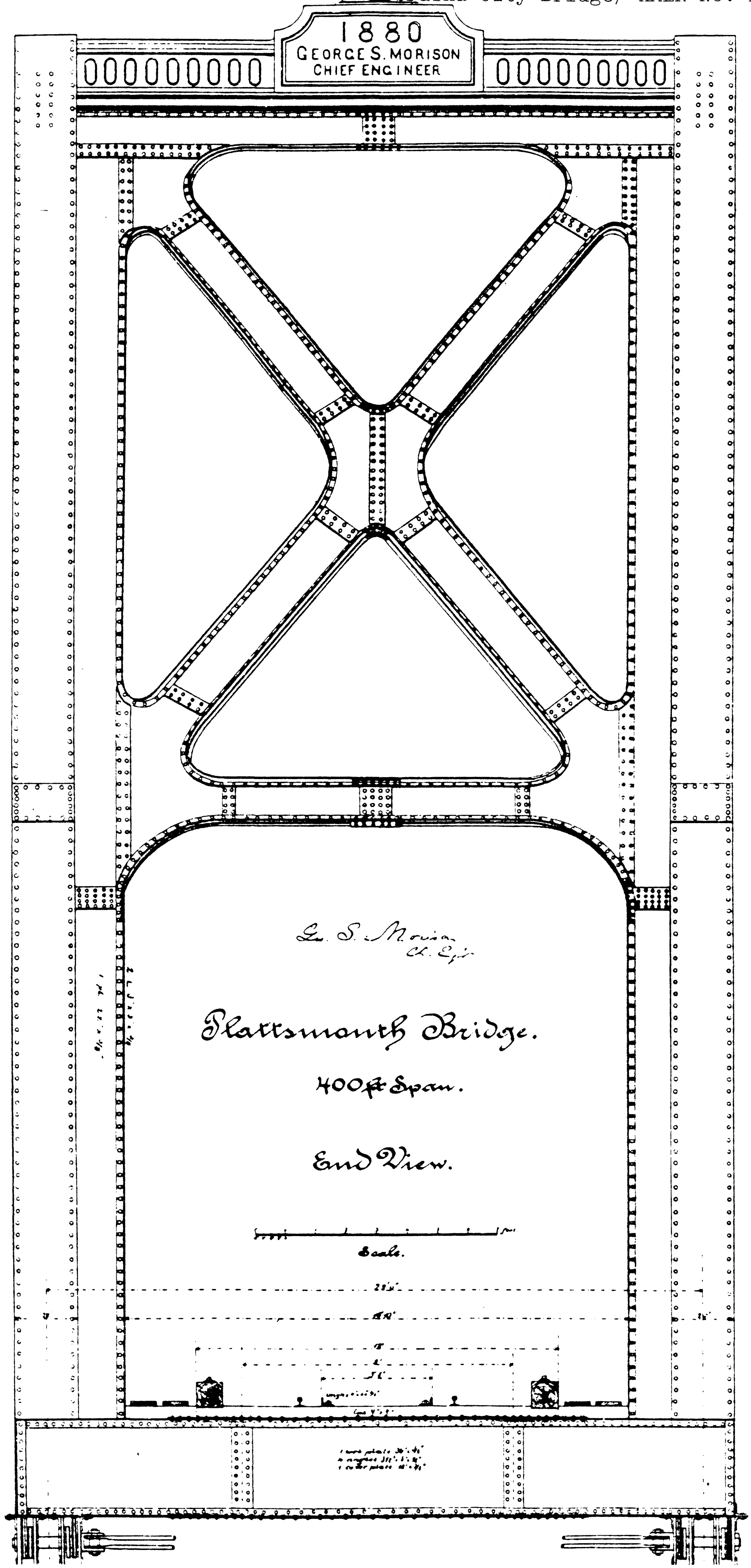

1880
GEORGE S. MORISON
CHIEF ENGINEER
Geo. S. Morison
Ch. Eng.
Plattsmouth Bridge.
400 ft Span.
End View.
Scale.

Figure 11

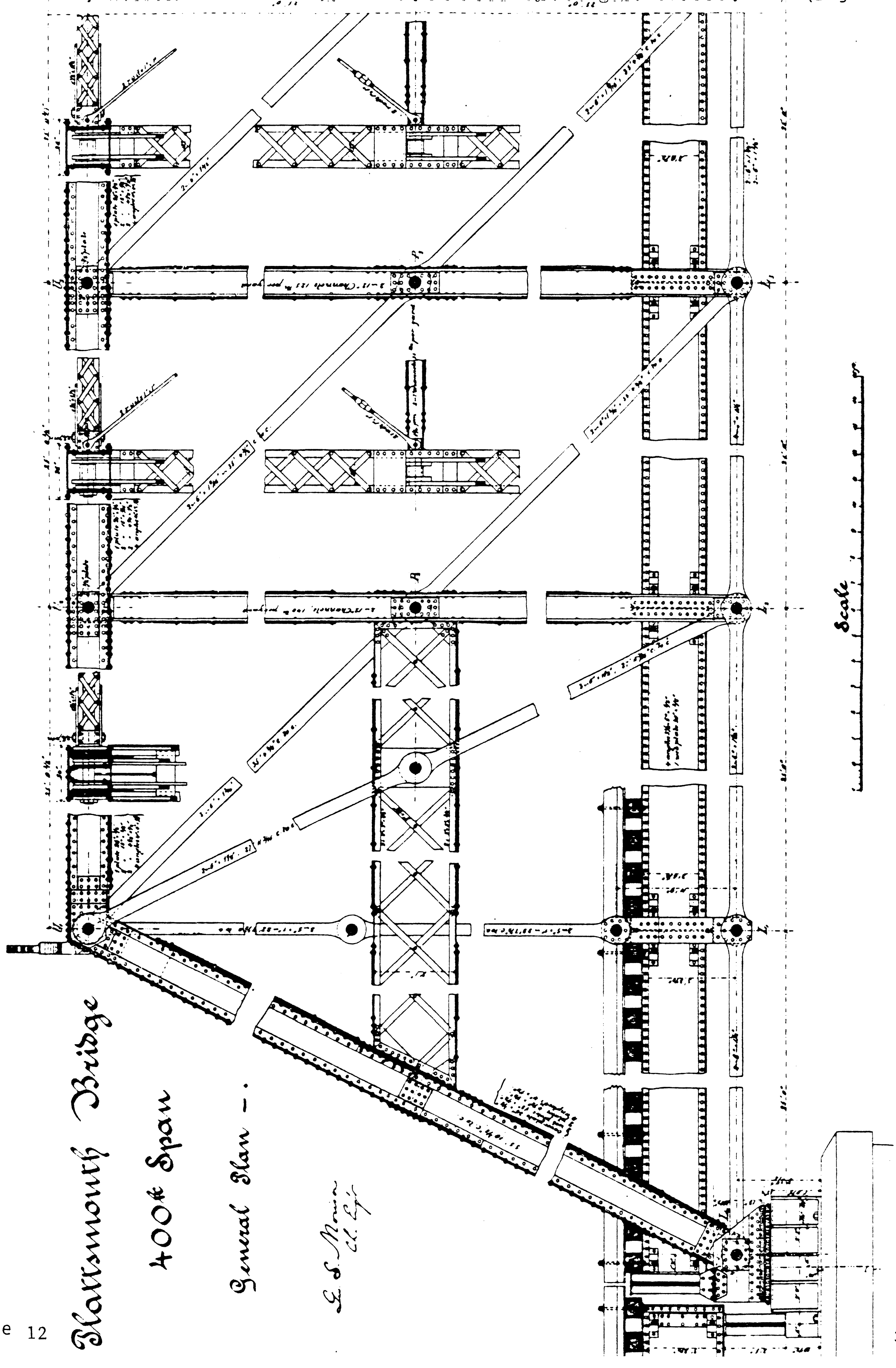


Figure 12

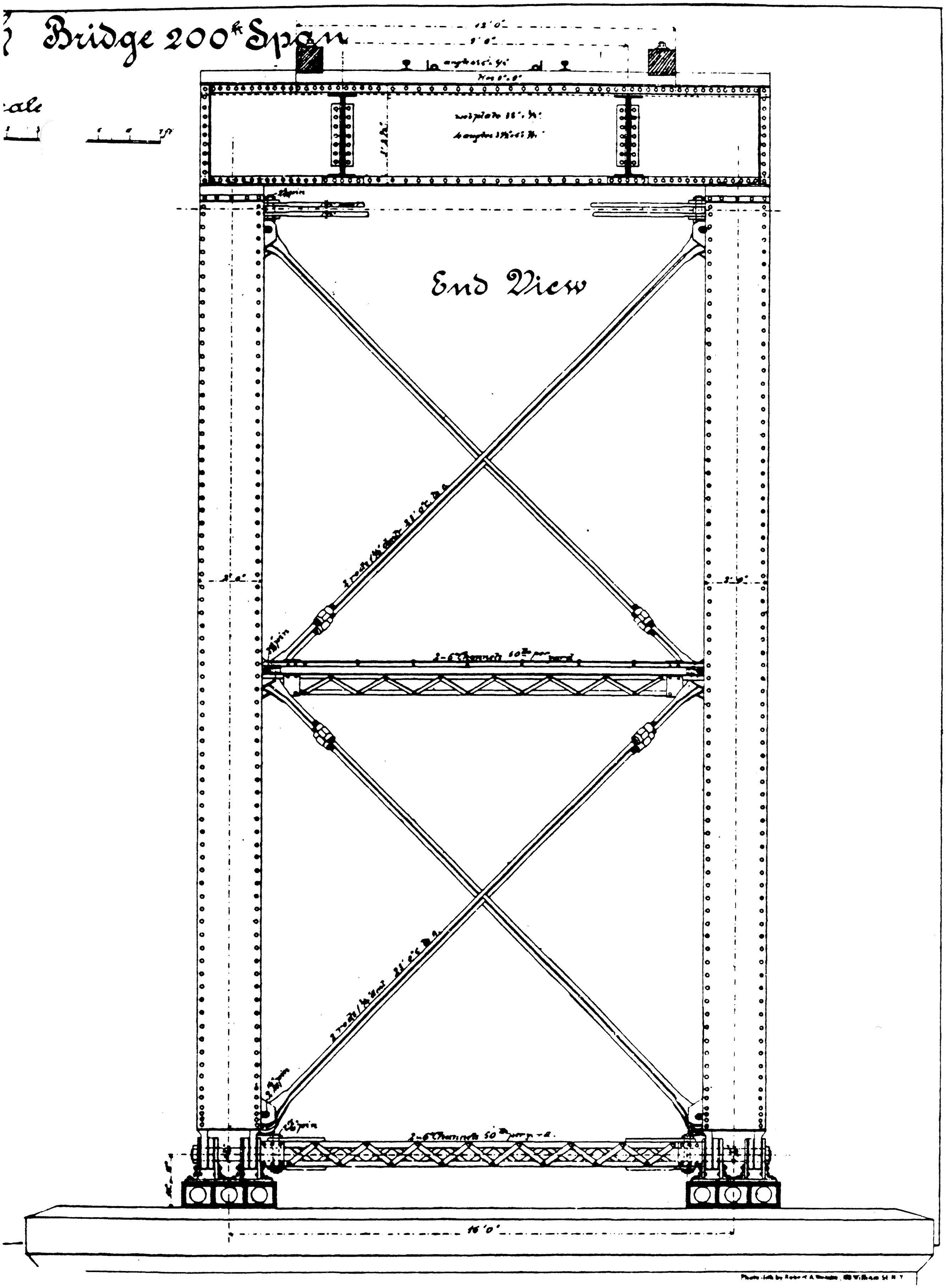


Figure 13

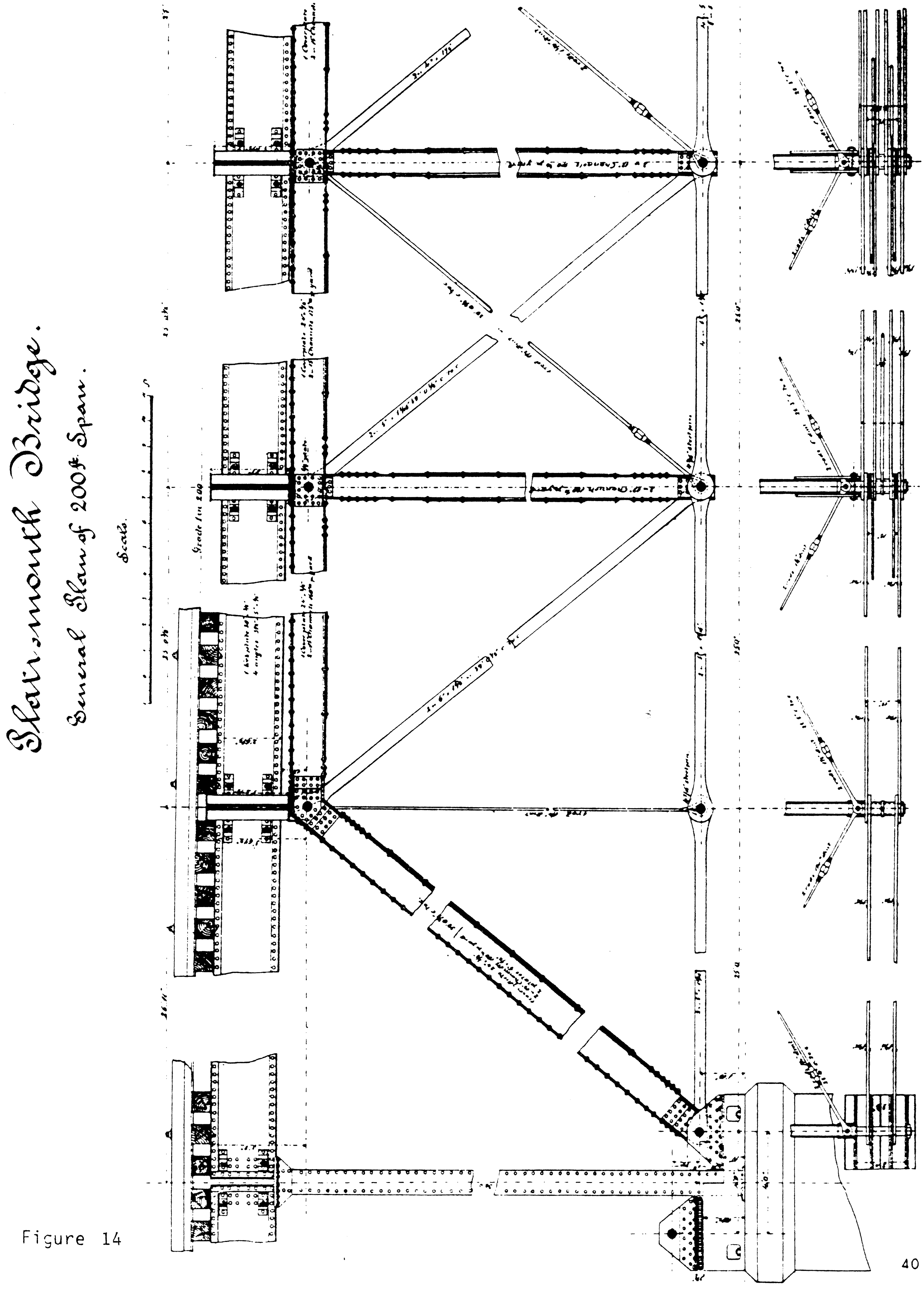


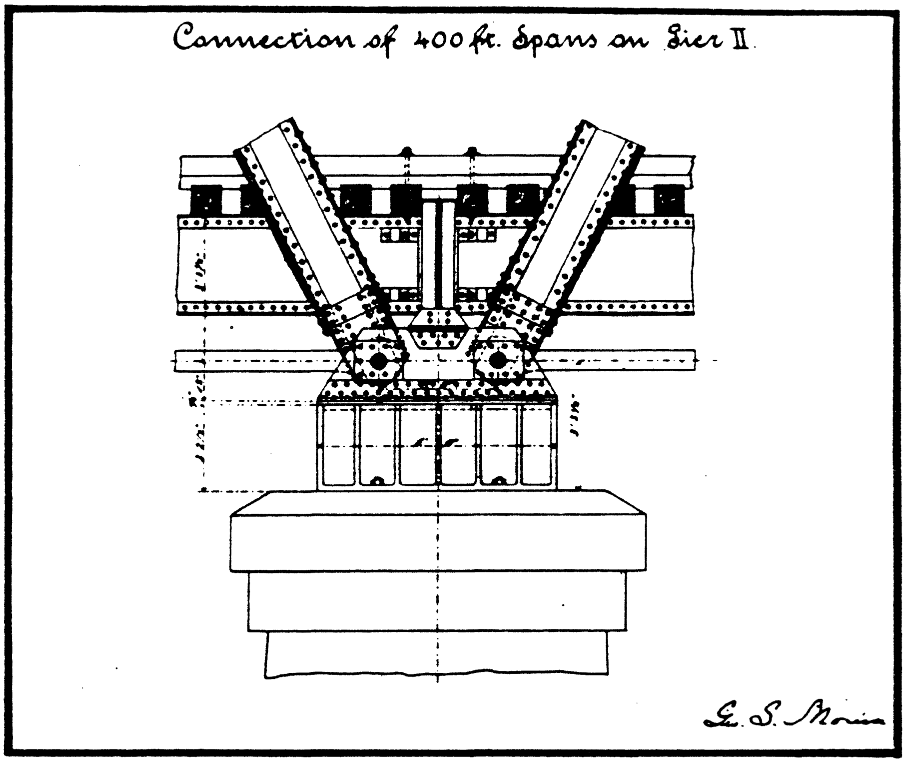
Figure 14

To span the Missouri, Morison and Schneider engineered a simply supported, trussed superstructure. Designed to carry a moving load of 2,000 pounds per lineal foot, it consisted of two Whipple through trusses over the navigable channel of the river and three Pratt deck trusses over the floodplain on the east. "This general arrangement," Morison later wrote, "was in brief that of a main bridge over the main river which would be able to withstand the violent scouring action which occurs in the channel of the Missouri, with an additional length of structure of such character as would be safe against any overflow outside of the channel, and which would pass floating driftwood without obstruction, beyond which a further opening would be placed though not relied upon to pass any considerable amount of water."[41] Morison had originally designed the channel spans with 350-foot lengths, but extended their length to 400 feet each to reduce the number of piers exposed to the main channel. The single-track Whipples (shown in Figures 11 and 12) each spanned 400 feet and were divided into sixteen pin-connected panels of twenty-five feet each; the eight-panel deck trusses (shown in Figures 13 and 14) spanned 200 feet each.

Given George Morison's conservative bent, the truss type that he and Schneider chose for the channel spans at Plattsmouth was hardly surprising. Virtually all early long-span railroad trusses in America used the Whipple - also called the Whipple-Murphy, Linville, and Double-intersection Pratt - truss design, patented by Squire Whipple in 1847. Essentially a deep-profile Pratt configuration with verticals in compression and long, two-panel diagonals in tension, it had been used by Jacob H. Linville on his 320-foot span over the Ohio River at Steubenville, considered the first long-span truss in America.[42] All succeeding bridges over the Ohio until 1888, except those designed by noted bridge engineer Albert Fink, were Whipple trusses. Similarly, most of the early bridges over the Mississippi and Missouri Rivers featured Whipple-type channel trusses. The most notable exceptions were the Post-truss Omaha Bridge, and the Fink- truss St. Charles Bridge, designed by C. Shaler Smith and reputed to be the longest iron bridge in America when it was completed in 1871. The simply supported Whipple trusses that Morison engineered for the Burlington Railroad featured a standard, unadventuresome design and were notable only for their long - though not record - spans.

Fifty feet tall and almost twenty-two feet wide, Morison's through spans at Plattsmouth did feature meticulously crafted pin-connected detailing. The top chord and inclined end posts were heavy composite members consisting of two side plates, four angles a cover plate, two balance plates, and lacing; on the center panels a filling plate was added on each side between the angles. The bottom chords were comprised of steel eyebars used in multiples of varying numbers corresponding to the tensile strains at individual panel points. The vertical posts each consisted of two laced channels. The verticals in the nine center panel points were single pieces; the heavier columns at the outer panels of the trusses were rolled as two pieces and spliced at the center. The main and counter ties - 70-foot long rectangular bars - were to be manufactured in

two pieces threaded at the center into an adjusting turnbuckle. These diagonal members were pinned at the panel points and through the center of the verticals which they intersected to sustain the tie against deflection and hold the column against flexure at the center. The main connecting pins were all five inches in diameter.[43]



[44]

Figure 15

The trusses were braced with composite struts and adjustable steel rods at all main connections. The lateral and intermediate struts were made of two channels laced on both sides and, like the main members, were all joined with turned pins. The end posts were stiffened with a laced-channel strut which connected horizontally with the stiff center of the first vertical column. The vertical posts were connected transversely at their centers by struts which were attached to the central pins by smaller pins which passed through the ends of the struts and through the main pins. The upper laterals were similarly attached. To each of these struts was pinned a set of transverse diagonal rods rods reaching to the top chord lateral system. "Each pair of vertical posts," Morison said, "is thus united into a stiff bent with a perfect system of bracing from the center up, and a stiff base made by the floor beam connection."[45] Deep plate floor beams were riveted with triangular gusset plates to the verticals above the bottom chords, increasing the vertical stiffness of the structure and decreasing its apparent height to 45 feet. The paired bottom laterals were connected at the lower chord panel points with steel pins that passed through steel jaw nuts on the main pins. These jaw nuts bore against brackets riveted on the underside of the floor beams, which acted as lateral

struts. The lateral bracing for each of the 50-foot high portals consisted of a single huge cruciform brace, extensions of which were run down the length of the end posts to the floor system.[46]

Each of the 850,000-pound trusses was carried on four massive cast iron bearing shoes (shown in Figure 15). The center connection between the two spans was fixed, with a single bolster under each corner resting on a large cast pedestal or shoe. The shoe was bedded on rust cement and secured to the masonry pier with four six-foot long anchor bolts. Expansion of the long spans was carried by massive multiple-cylinder roller bearings beneath the the outside end posts. The 3-inch diameter rollers were sandwiched between two heavy steel plates and set in frames which could be taken apart from the outside for cleaning. Rubber gaskets were positioned on the sides of the frames to keep dirt and debris from the space between the rollers.[47]

Although Morison's design for the 400-foot channel spans at Plattsmouth followed more-or-less standard engineering practice, his specification for their metallic composition was innovative in its extensive dependance on steel. The production of steel and its structural capacities were widely discussed by engineers at the time, including Morison, and after researching the properties of steel versus wrought iron, he favored steel as the primary superstructural material for bridges. Like many of his contemporaries, Morison undoubtedly read the article by noted civil engineer Theodore Cooper titled "The Use of Steel for Bridges" in the Transactions of the American Society of Civil Engineers, published in August 1879. In the text, Cooper outlined the physical properties of steel, discussed the material's applicability to bridge engineering, and concluded:

> As the first successful iron bridge builders were those who were able to throw aside the traditions and processes to the capabilities of the metal, iron - so must the successful builders in steel be those who can accept the fact that the new metal, structural steel, requires a like sacrifice of old traditions and practices, a development of new plant and process, and the education of a new class of metal workers.[48]

In the printed discussion that followed the article, Octave Chanute stated: "The general attitude of engineers on the subject of bridge steel may be stated as one of expectancy. It is only of late years that it has been produced cheaply enough to warrant us in thinking of employing it at all; and while most of us believe it to be the material of the future, we are all still inclined to put the burden of proof upon the steel makers, and to require them to furnish evidence of its adaptability and economy before we will agree to use it... For long spans, say those over 350 feet, where the dead weight of the bridge is greater than the moving load, it is probable that steel is already cheaper than iron for the main members, because it saves its own weight, to the extent of the greater strains, which it will be found safe to impose upon it." Chanute continued prophetically: "Such great spans, however, are rare, and it should

be the endeavoer of those who may be interested in bringing steel into use, so to develop its capacities, establish in safety, ensure its uniformity of production and cheapen its cost, as to enable us to make new specifications which will insure its substitution for iron in spans of, say 100 to 200 feet, such as are in daily demand."[49]

It is not known whether Morison consulted with his former teacher or with the influential Cooper while designing the Plattsmouth Bridge or whether he made the decision to use steel independently. He probably discussed the merits of the new material with General Sooy Smith, who came to Plattsmouth immediately after completing the first all-steel bridge at Glasgow, Missouri. Regardless, Morison determined at the outset that the Plattsmouth Bridge would contain a significant amount of the new material. He specified rolled steel for the top chords and end posts, bolsters, rollers pins, jaw nuts and all tension members except the vertical suspenders in the end panels. But unlike Sooy Smith, Morison - the resolute pragmatist - could not justify its greater expense for exclusive use on his bridge and relied on iron for the less critically strained components. All other components, except the cast-iron pin plates on the top lateral struts, a few washers, and the ornamental iron work on the portals, were wrought iron. By weight, steel comprised 58% of the superstructural weight of the two through trusses - a marked departure from prevailing all-iron truss engineering. The approach viaducts and the shorter span deck trusses carried lighter stresses than the channel spans. For these Morison specified far less steel to cut the cost of the bridge, making them essentially wrought iron structures. The metallic composition of the superstructure is given in the following table:

	Steel	Iron
East viaduct	-	799,557 pounds
Three 200-foot deck spans	10,290 pounds	800,871 pounds
Two 400-foot through spans - trusses	983,703 pounds	385,706 pounds
Two 400-foot through spans - floors	-	317,000 pounds
West viaduct	-	61,529 pounds
Total	993,993 pounds	2,364,663 pounds [50]

In addition to the trussed spans, Morison's design for the Plattsmouth Bridge delineated a 1,440-foot long iron viaduct for the east approach to the bridge and a shorter, curved viaduct on the west. Engineered to carry a moving load of 100,000 pounds, the long structures featured three-foot deep iron plate girders with 30-foot spans mounted on a series of two-column bents (shown in Figure 16). Morison's minutely detailed description of the configuration of the approach structure indicates the characteristic thoroughness of his design:

The bents of the viaducts are composed of two wrought iron posts, spaced

> 9 feet apart at the top and built with the usual batter of 1 in 8. Each post consists of two 9 inch channels and a plate 12 by 1-1/4 inches, with lacing on the under side, the cross section of the post being 13.56 square inches. Transversely the posts are connected at the top and at a point 18 feet below by lateral struts, and are braced with two 1 inch round rods above the middle strut and one 1-1/4 inch round rod below. The bents are connected in pairs by longitudinal struts attached at the centers of the posts; a pin is placed in the middle of each of these struts, on which couple four diagonal rods leading to the top and bottom of each of the adjoining posts, and screwing up against wrought iron skew backs on the outside of the posts. The stringers on the pair of bents connected in this way are bolted rigidly to the top of the posts; the stringers in the intermediate spaces are also bolted, but the bolts pass through oblong holes, leaving space for expansion; the several stringers are also connected with each other by side splice plates riveted to the stationary and bolted to the movable stringers, the bolts passing through oblong holes.[51]

Morison and Schneider completed the contract drawings for the superstructure in August. The late start precipitated a rush to secure suitable suppliers and contractors for the bridge substructure and piers. With no time to assemble suitable pneumatic equipment, he hired General William Sooy Smith on the first of August to sink the caissons for the deeper foundations, using the equipment that Smith had developed for the just-completed Glasgow Bridge. Later that month, Morison solicited proposals from the leading bridge manufacturers to fabricate and erect the bridge on a per-pound basis. Because of the unsettled nature of the iron market in 1879, only four companies were willing to commit to fixed bids: the Keystone Bridge Company of Pittsburgh; the Detroit Bridge and Iron Works of Detroit; the Edgemoor Iron Company of Wilmington, Delaware; and Kellogg and Maurice of Athens, Georgia. Morison awarded the construction contract for the approach viaduct and the deck trusses to Kellogg and Maurice. For fabrication of the mammoth through trusses he selected the Keystone Bridge Company. Reynolds, Saulpaugh and Company of Chicago were contracted to build the masonry piers; N.S. Young of Burlington, Iowa, was hired to do the earthwork for the approaches. Morison later complained: "It was necessary to collect a staff of untried men, who were not wholly satisfactory, and to make many arrangements which would have been wholly undesirable if the work had been begun earlier in the season."[52]

Actual construction of the Plattsmouth Bridge began on August 17, 1879, as workers started excavating the pit for the westernmost pier on the bank of the river. Morison had laid out the foundation for the Pier I, 40 feet long and 18 feet wide, ten days earlier on a narrow piece of land at the foot of the bluff. Because of its dry location above high water and the assumed high level of bedrock, Morison directed the excavation as an open pit with coffer dam sides. However, as the men dug through the alluvial sand, they discovered that what

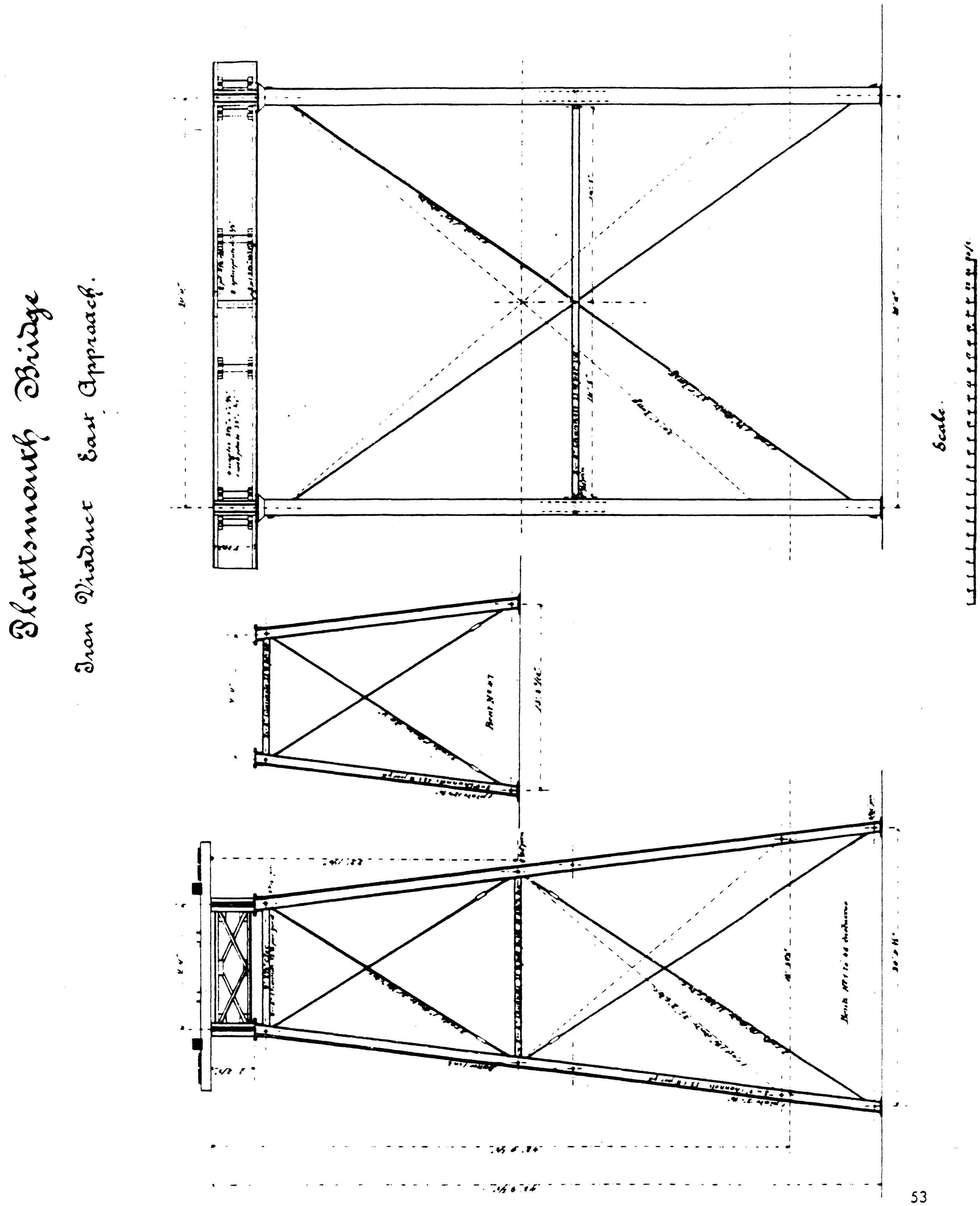


Figure 16

had been thought to be the bedrock was actually a boulder field buried in a mass of hard blue shale, or soapstone. The boulders were so large and packed so tightly that the engineer resorted to blasting to cut through the layer of rocks. After dynamiting through the stratum of boulders, the size of the pit was increased to 21 x 49 feet, new whaling timbers placed on the walls, an Andrews centrifugal pump set up to discharge water from the hole, and the excavation continued through the solid shale. In late October, the diggers finally struck bedrock thirty-two feet below the surface of the river. Morison directed them to drill 190 holes in the stone and place three-foot iron dowels to key the foundation to the stone. A concrete pad was poured, and on November 10th masons began laying the stone for the pier. [54]

Construction for the foundation for Pier I proceeded without great difficulty. But Piers II and III were situated well within the channel of the Missouri River and could not be excavated with an open pit. For these, George Morison intended to use pneumatic caissons - the most difficult and costly aspect of deep-water bridgebuilding. French for "chest," a caisson was, simply stated, an extraordinarily massive box made of timber and iron, with a cribbed timber roof and solid timber sides framing a floorless chamber. Floated to the pier position like a cumbersome barge and filled with ballast to sink it to the river bottom, the caisson acted both as the permanent foundation for the pier and as a temporary work chamber for men to excavate through the riverbed to the underlying stone. Once the ponderous structure was seated on the bottom of the river, the chamber would be pressurized pneumatically like a giant diving bell to keep out the water, help support the roof and walls from the pressure of the water and silt, and provide oxygen for the men working in the hole. As masons laid tons of stone on the roof of the caisson to build up the pier and add mass to keep the whole assemblage upright under the river, the workers in the chamber below would lower the box slowly, first below the surface of the river and then further below the riverbed itself until it hit bedrock. The diggers were assisted by the shape and the mass of the caisson itself. The bottoms of the chamber walls were tapered to sharp edges, called cutting edges. Sheathed with thick plates of wrought iron and pressed downward by thousands of tons of masonry ballast, the cutting edges sliced or crushed deeper into the silt as the men dug in the center of the chamber. When the excavation was stopped, the work chamber would be filled solid with concrete and the foundation would be complete.

General Sooy Smith began building the caisson for Pier III (shown in Figure 17) on the east shore as Morison was laying out the foundation for Pier I in August. Measuring 50 feet long, 20 feet wide and 15-1/2 feet high, the big box was built of white pine with solid sides of 12-inch timbers. Halfway up, a single course of 12"x12" timbers divided the work chamber from the crib work above. The walls of the chamber were inclined inward from the bottom; they, like the cribbing above, were built using 12"x12" timbers drift bolted to each other. Sooy Smith's men extended forty iron rods through the intersection of

the crib timbers to bind the whole assemblage together. They sheathed the outside of the caisson with two layers of 3-inch plank and the walls and roof of the chamber with plank, joined and caulked to make it airtight. Carpenters shaved the outside corners to an 18-inch radius and covered it with 1/4-inch boiler plate iron sheets. They trimmed the lower timbers and planks to form the chisel-like cutting edge, covering it with 5/16-inch iron sheets bent around the edge. Sooy Smith attempted to launch the huge structure on September 6th but hung up on a sand bar and could not get it afloat until the next day.[55]

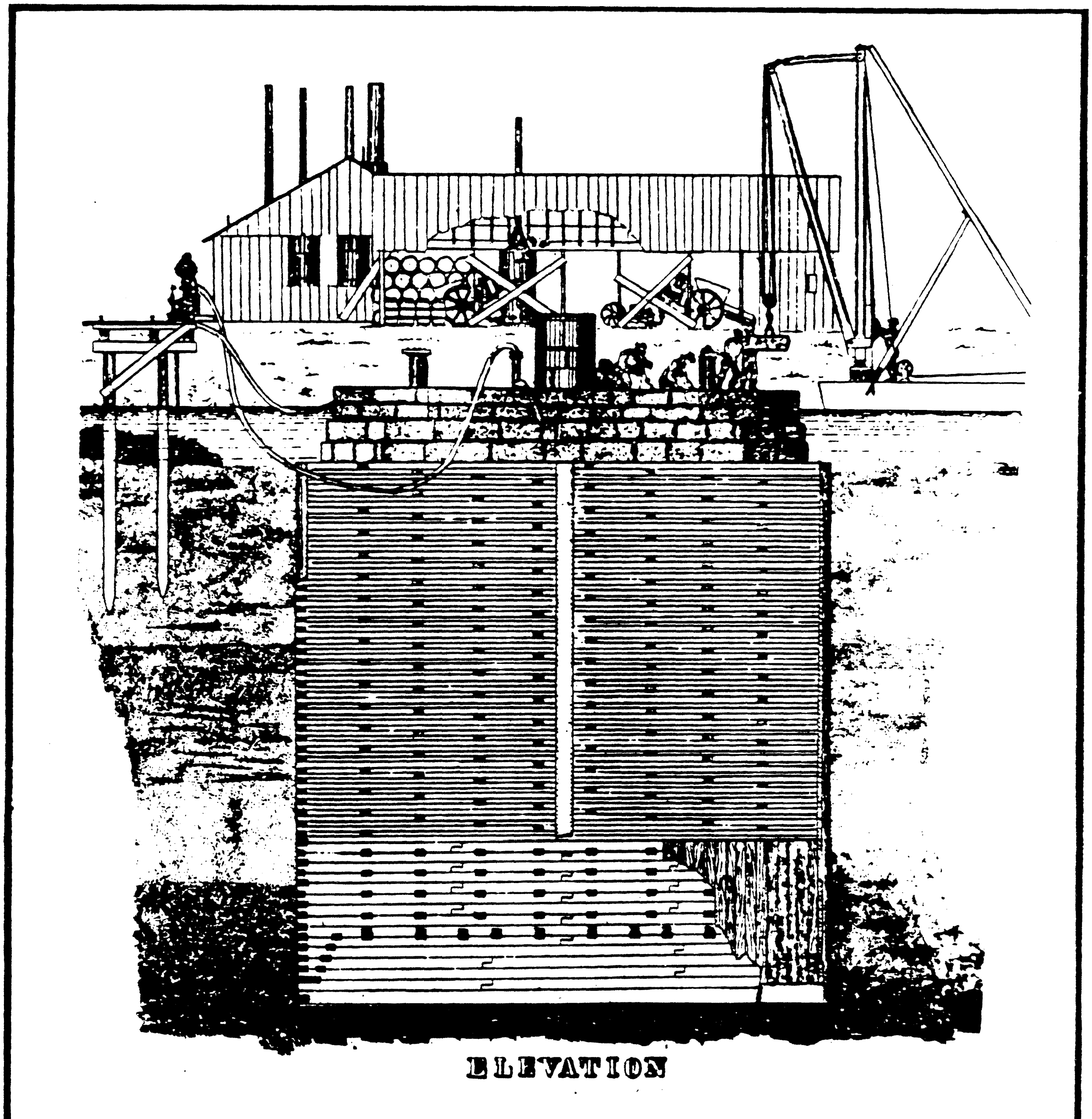
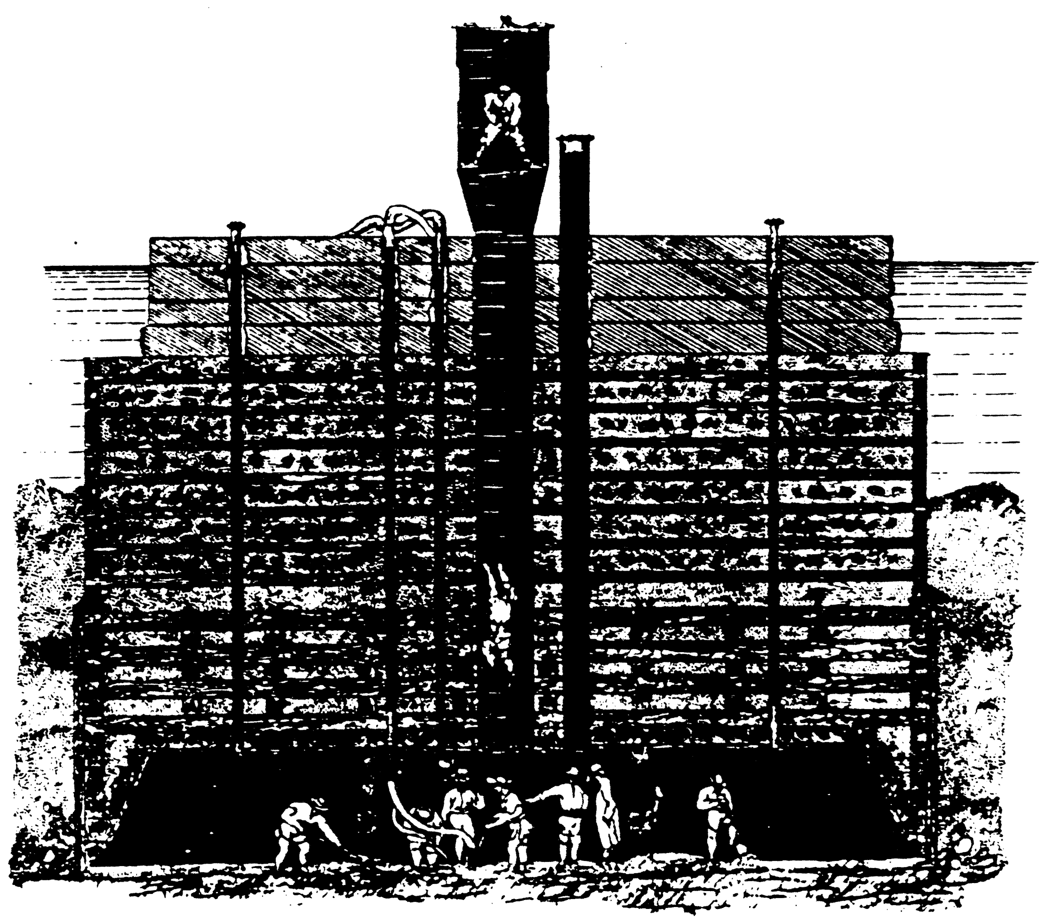


Figure 17

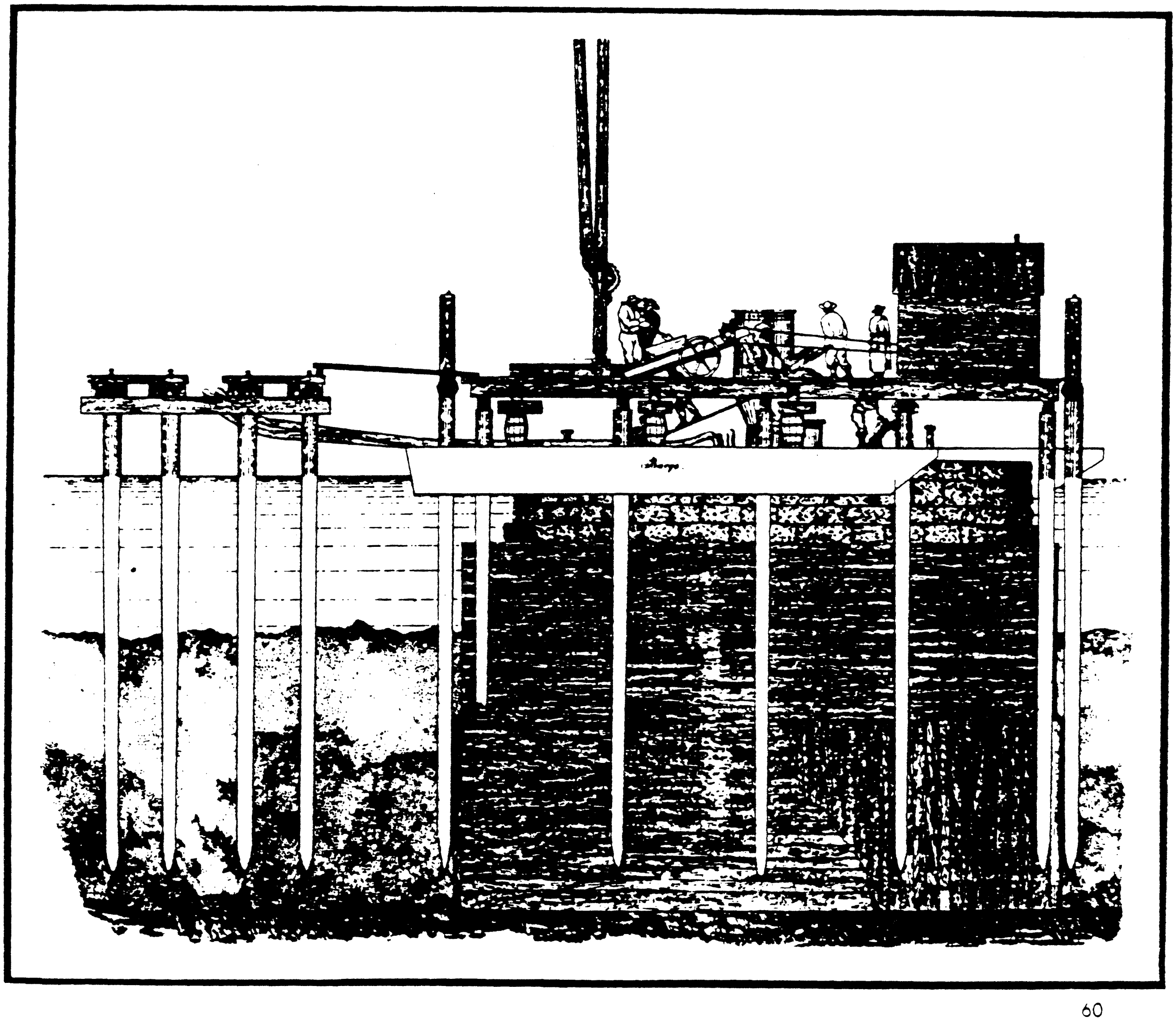
The caisson was positioned at the river bottom, and later that week, although the air lock had not yet been installed, the pressure men began pumping air into the work chamber. The pneumatic machinery was set up on the east shore, about one hundred feet from the caisson. The pumping machinery consisted of a Burleigh air compressor and a double compressor developed by Smith at Glasgow, both powered by four boilers. Men on the river surface added courses of cribbing to the top of the caisson and filled them with concrete, while others in the chamber sifted slowly through the course sand beneath the river using a sand pump that James Eads had invented for use on his namesake bridge in Saint Louis. In October, the diggers reached bedrock fifty-four feet below the surface of the river. They cleaned the floor of the chamber, drove spikes into the walls as dowels, and filled the area with concrete. The foundation work on Pier III, from the initial framing of the caisson to completion of the filling had taken seventy-nine days.[57]



LONGITUDINAL SECTION

Figure 18

Carpenters began building the caisson for Pier II (shown in Figures 18, 19 and 21) on August 29th. Launched, sunk, and pressurized in October, it proceeded simultaneously without interruption until the cutting edges reached bedrock on November 14th almost twenty feet higher than that under the other caisson. The men stuffed bags of cement around the bottom edges and filled the chamber with concrete, completing the foundation. Smith sunk the caisson for Pier IV (shown in Figure 21) in a similar fashion later in the year. On November 25th, the pressure was put on; on December 6th the crib work was completed and the masonry was begun; on December 14th the cutting edge struck a thin layer of soapstone overlaying the bedrock; and on the 20th of December the filling of the chamber was completed. Morison used driven sycamore piles for the foundation of Pier V, the last masonry pillar. Work on it was completed December 16th.[59]



60

Figure 19

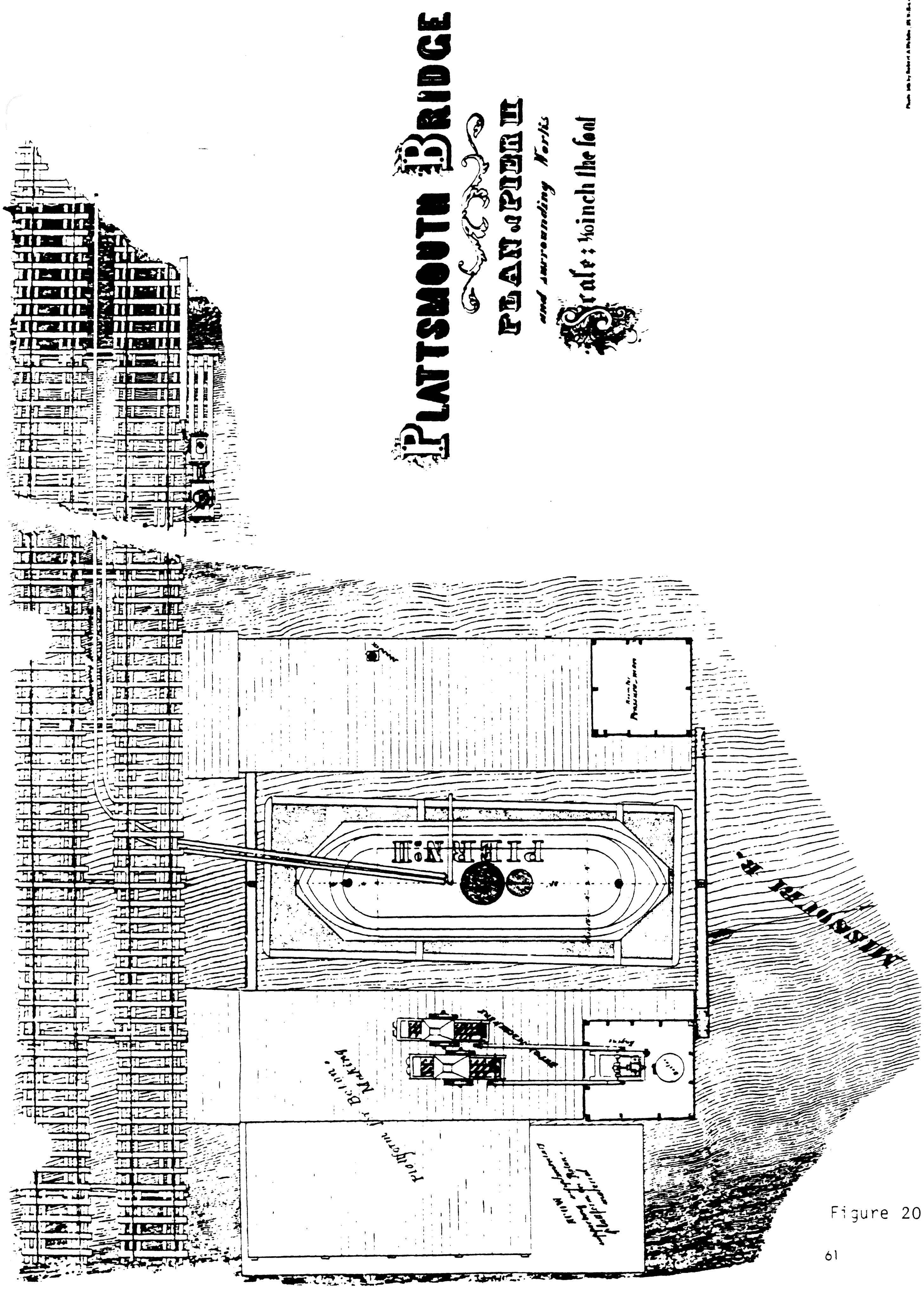

PLATTSMOUTH BRIDGE
PLAN of PIER II
and surrounding Works
PIER No II

Figure 20

Stone masonry had been the material of choice for the piers from the beginning, but no suitable quarries could be located anywhere in Nebraska. W.H.B. Stout operated a quarry on the bank of the Missouri twenty-five miles away. His output could not equal the demand for face grade stone on the immense piers, however, and Morison modified their design to use alternative materials. (The masonry specifications are reprinted in the Appendix.) Concrete was substituted for stone in all subaqueous work; artificial stone blocks made of imported Beton Coignet cement were substituted for stone on the copings. Masons laid the lower courses of stone over the pneumatic caissons as the men under cribbed structures burrowed through the alluvial silt. By early spring, 1880, they had completed the piers.

While work was underway laying foundations under the river, another early aspect of the project was the excavation of a major cut in the side of the

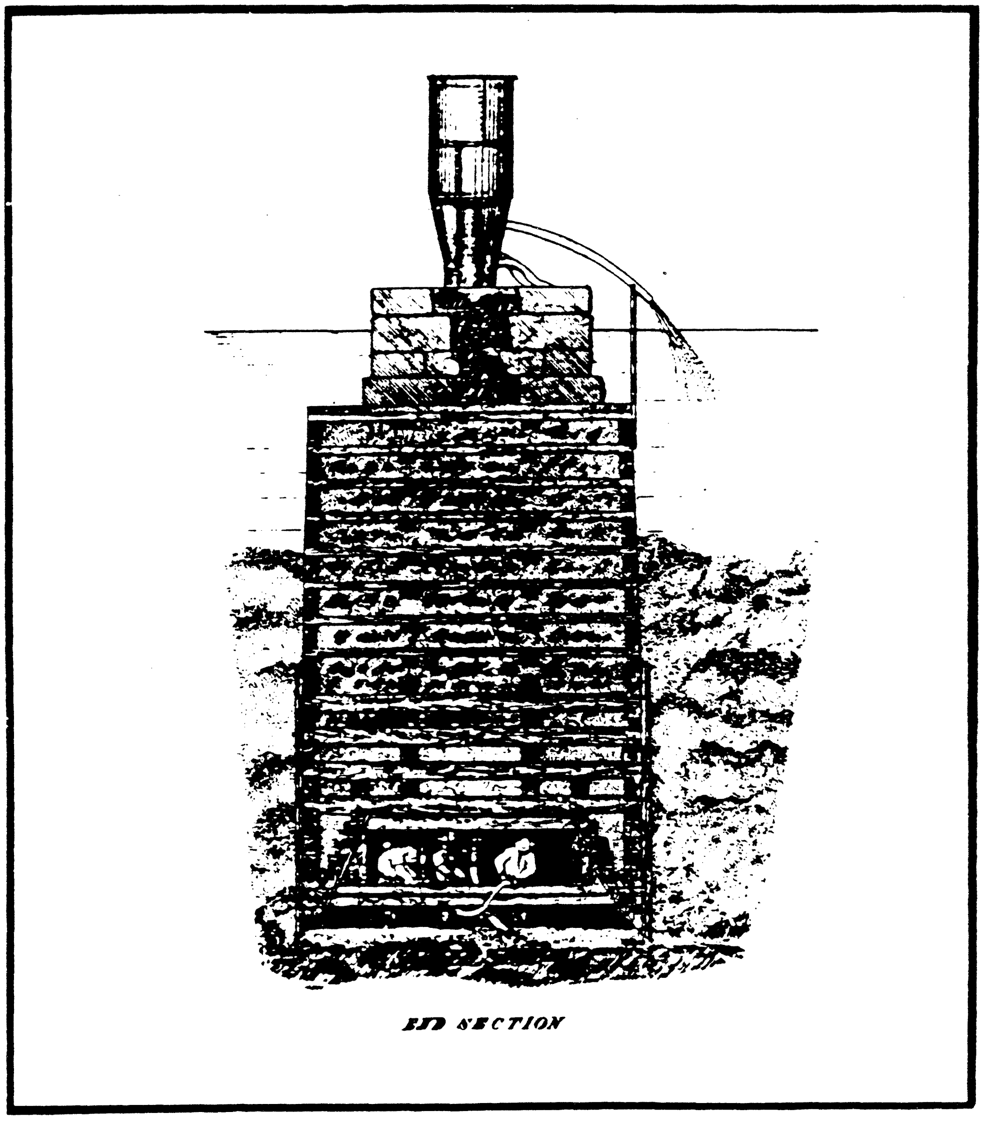


Figure 21

bluff for the west approach to the bridge. Curved, almost a half-mile long, and over eighty feet deep in some locations, this earthwork proved an expensive and time-consuming undertaking, which Morison termed "one of the most difficult features of the bridge."[63] It also proved to be the most dangerous.

Laborers for N.S. Young, the earthwork contractor, began excavation for the cut in November. By the first week of December, work was well under way. December 10th brought bitter cold. Morison had visited the bridge the day before in the mist and sleet and had left that morning, after telling Young to increase the slope of the walls in the cut. The next day was colder yet; a group of workers was loading a wagon with frozen clods of earth at the base of the cut when one of the walls collapsed, completely burying nine men, the team, and the wagon. The horses were killed instantly. Two of the men were drug dead from the pit. One other was uncovered unconscious and died later that night. A fourth man died the next day. Three others suffered lacerations and broken bones.[64] Morison returned immediately to the bridge to assay the damage, but there was little that he could do. The death and injury of seven men at Plattsmouth was to be the worst construction-related accident on any of George Morison's bridges.

In his subsequent report to the railroad, published over two years later, the overbearing engineer seemed less concerned about the individual tragedy of the workers than by the fact that they had disobeyed his orders. He laid the blame for their deaths squarely on the crew foreman and the unfortunate men themselves:

> On the 12th day of December, a force of men, directly contrary to orders, was put at work under the face of the vertical bank on the west side of the cut, and while working there, a large piece of material was thrown down on them by the frost. This unfortunate accident resulted in the death of four men; it was the only accident in the whole construction of this bridge in which any man was seriously injured; it occurred at a place where the cut was 50 feet wide, and the face from which the piece of frozen earth fell was not over 20 feet high, so that there was no occasion for working men at the place where these were engaged.[65]

In truth, Morison had apparently erred in the engineering, and his assistant H.W. Parkhurst had been less than firm with the earthwork contractor in rectifying the problem. Both engineers shared the blame for the men's deaths. To save time and money, Morison had designed the cut with vertical walls. He was depending entirely on internal friction to hold the earthen walls together - a dangerous practice which he justified, "as has often been done at other points on the Missouri."[66] But the earth could not hold for such a great height. Under stress caused by frost heaving and ground pressure, the walls began to crumble.

When the first serious mudslide occurred on November 23rd, Morison was away from the site, and Parkhurst tried in vain to reach him by telegraph. Parkhurst requested that the contractor hire a watchman to monitor the cut, but Young talked him out of it. When finally reached, Morison changed the design and ordered Young to slope the walls of the cut, but the contractor soon discontinued the sloped grading and continued the excavation work with vertical walls. Five days before the accident Parkhurst thought the conditions looked dangerous and ordered Young to resume the sloping work. The day before, Morison visited the site briefly, and he also reiterated the need to slope the excavation. Neither the engineer nor his assistant, however, were willing to force Young's compliance with the modified design - indirectly contributing to the fatal accident.[67]

Although demanding at the start of the project, Morison became virtually autocratic after the collapse of the west approach. When A.E. Touzalin, General Manager of the Burlington and Missouri River Railroad in Nebraska, rushed to the site to investigate the accident, Morison and Parkhurst ignored him. Finally tiring of Touzalin's numerous comments and suggestions, Morison reminded the railroad official of his "sole and exclusive control of the bridge and sole and exclusive control of all contracts and contractors." He dismissed Touzalin by telling the man to "refrain from making [suggestions] as useless and uncalled for."[68]

As the men were building the monumental stone piers and excavating the approach cut in 1880 and 1881, George Morison monitored production of the steel for the superstructure. He had contracted separately in September 1879 with the Keystone Bridge Company to fabricate and erect the two through spans and with Hussey, Howe and Company to manufacture the steel. Morison hoped that by signing an individual agreement with the Pittsburgh steel mill he could economize on the project and could control the critical inspection and testing of the material at the mill. He was able to inspect and supervise the steel manufacture thoroughly, but his extensive testing and repeated rejections of material created serious delays, for which Keystone claimed additional monetary damages.[69]

The contract with Hussey, Howe and Company stipulated that the mill would deliver 490 tons of steel to Keystone at a rate of 60 tons per week by the end of the year. Morison's specifications were exacting, as he described in a report to Perkins:

> [The contract] required that the steel should be manufactured in a Siemens Martin furnace, by what is known as the open hearth process; that it should contain 35/100 of one per cent. of carbon; the amount of carbon in no melt to differ more than 4/100 of one per cent. from this amount; that a sample bar when tested in a lever machine not to show a permanent set under a less strain than 50,000 pounds per square inch,

> and not to break under a less strain than 80,000 pounds per square inch; to show a uniform stretch of 12 per cent. and a reduction of area of at least 20 per cent. at the fracture; that the sample bar should bend 180 degrees around a circle of the same diameter as the bar without showing a crack or fracture; that tests should show the modulus of elasticity to be reasonably uniform; if the sample bar failed to come up to any of these requirements, the whole melt was to be rejected.[70]

Hussey and Howe poured about two thirds of the material from a rented open hearth furnace at Glenwood, Pennsylvania, a Pittsburgh suburb on the north bank of the Monongahela River. The remainder was produced by Schoenberger and Company in their furnace adjoining the Hussey and Howe mill in Pittsburgh. The capacity of the Glenwood furnace was five tons per melt, the Schoenberger furnace, seven tons. Morison tested almost two hundred melts, rejecting thirty-one outright. In addition, a considerable number of individual ingots and rolled sections were later rejected for structural defects. He described the manufacture of the various components:

> The steel was cast into ingots in the usual manner, the size being proportioned to the dimension of the finished material. Those intended for angle irons and narrow plates were rolled in Mr. Kloman's mill in Allegheny. The plates were rolled in the universal mill and the angle irons were rolled first in the universal mill in the shape of a flat plate with a fillet on the corner of one side, and then bent to the proper form by two passes through a train of grooved rolls. The ingot intended for the broad plates (18 and 26 inches) were rolled down into plates between flat rolls at the works of Messrs. Hussey, Howe & Co. without blooming; this arrangement was not a satisfactory one, as there was a large waste in shearing the plates to shape, and no less than forty per cent. of the plates rolled in this manner had to be rejected, as not being of full size or showing various surface defects; a much better practice would have been to make flat ingots of about the width of the finished plate and do the whole work in a universal mill.
>
> The ingots intended for the eye bars were bloomed to a proper size; these blooms were reheated and rolled in the Kloman universal mill, which is arranged to reverse while the metal is till between the rolls. A bar finished in this way passes the vertical rolls, but does not pass the horizontal rolls before the motion is reversed; when the blank leaves the rolls it is of uniform width throughout, but the ends are several times the thickness of the rest of the bar, the extra amount of material required for the head being thus left at the ends without either welding or upsetting. After rolling, the enlarged ends of the blank were reheated and worked into the shape of the finished eye, under a steam hammer. The whole bar was subsequently annealed by passing it slowly through a small furnace with an opening on each side; this method

> of annealing is not wholly satisfactory, but the experiments made on finished bars showed that if the material was injured by the work done on the heads this injury had been entirely removed by annealing.
>
> The steel counter rods were manufactured in the same way, the enlargement at one end being forged into a round for a screw thread in-stead of into a flat eye. The laterals, which are of square section with large eyes at one end and a screw at the other, were rolled in the universal mill, but between grooved rolls; the mill was reversed while the metal was still between the rolls at one end, but the metal was run completely out the other end of the pass. In this way a square bar was made with one enlarged end, afterward forged into a flat head for an eye, while the other end was a plain square; the square end was reheated, upset and hammered into a round on which a screw was cut. The tests made of these rods showed that this method of manufacture gave very excellent results.[71]

The engineer subjected steel samples and full-scale eyebars to an extensive battery of tests at the Keystone Bridge Company mill in Pittsburgh and the United States Arsenol at Watertown. The tests reinforced his opinion of the strength and reliability of the new material. Steel had a far stronger tensile strength than wrought iron, steel pins proved far stiffer than iron, and under controlled conditions, steel could be produced with far greater consistency than iron. "It appeared from these tests," Morison wrote, "that a number of steel bars could be trusted to pull together with a degree of uniformity seldom obtainable in iron bars."[72]

Despite his confidence in steel, its properties were still not completely understood. Morison therefore limited the stress on most of the steel members to well below their ultimate strength "as a matter of extreme prudence" (shown in Figure 22). Because the effect of impact on steel was not clearly known, he oversized the members at the span ends which were liable to receive their strain suddenly. The bottom chord eyebars in the end panels were strained to only 12,690 pounds per square inch, though a strain of 15,000 pounds was allowed in the center panels where the load would be applied more gradually, and the elastic limit of some of the steel bars had tested to 40,000 pounds per square inch on the Watertown machine. Similarly, he substituted iron eyebars for steel for the end panel suspenders, originally specified as steel.[73]

Although the Watertown testing lab had the facilities for pulling eyebars to their tensile limits, no machines had yet been developed to test the ultimate compressive strength of long steel compression members. For this reason Morison limited steel to short compression members only and used iron for the main panel verticals. He did this in part because the double-intersected Pratt truss used for the bridge reduced the strain on the long compression members to within the limits of ordinary iron sections, and partly because he considered soft steel no stronger in compression than iron in long columns, thus making

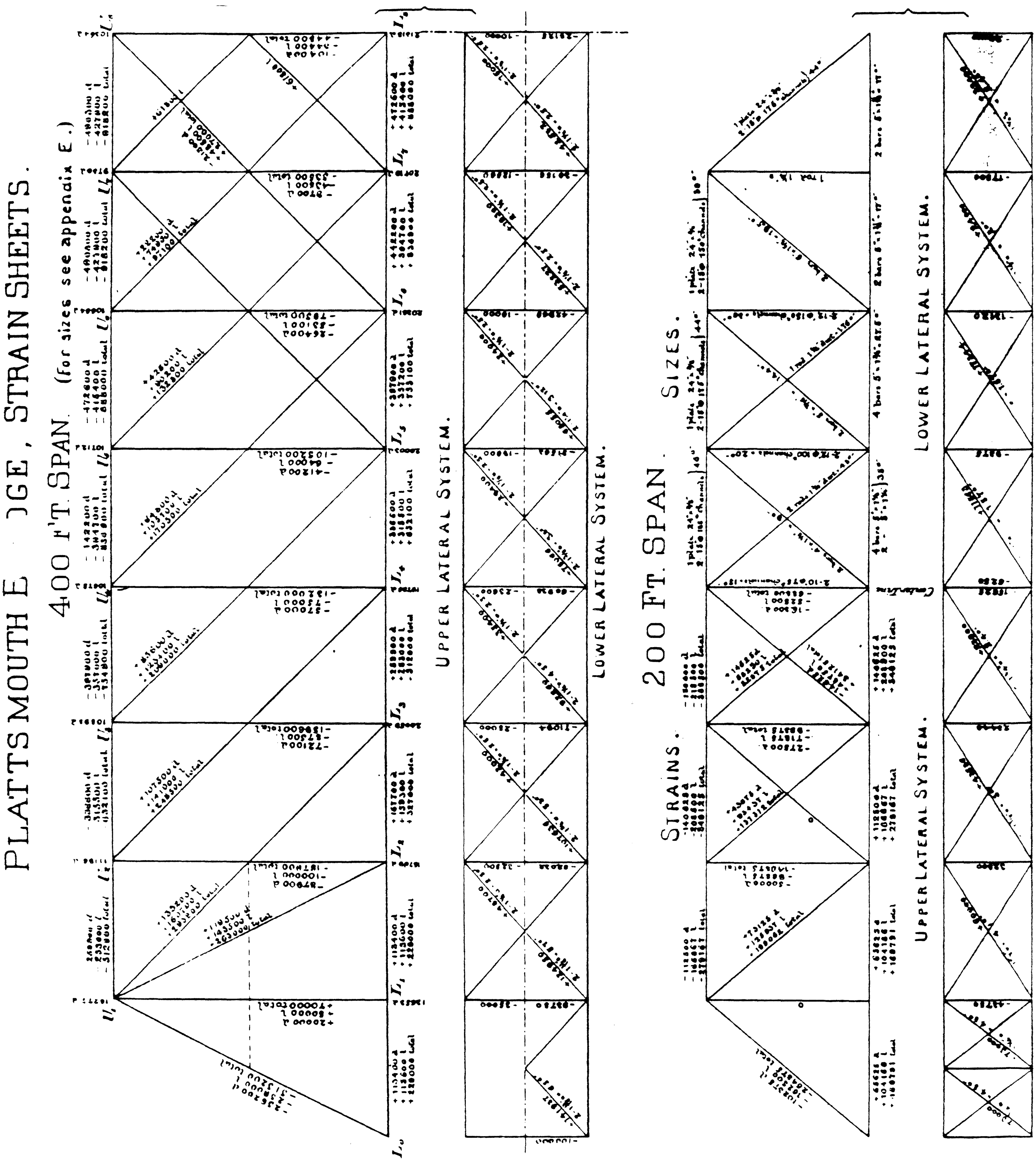

STRAIN SHEETS.
400 FT. SPAN. (For sizes see appendix E.)
UPPER LATERAL SYSTEM.
LOWER LATERAL SYSTEM.
200 FT. SPAN.
STRAINS.
SIZES.
LOWER LATERAL SYSTEM.
UPPER LATERAL SYSTEM.

Figure 22

its greater cost impractical. Hussey and Howe manufactured the steel compression members with much more care than they did the iron pieces, straightening the steel plates with wooden mallets. Keystone millworkers punched holes to assemble the built-up members with a 3/4-inch diameter, reamed them to a full inch after assembly, and them riveted them by machine immediately. The rivets were slightly oversized and could not enter the holes hot without driving.[75]

While Morison was testing and rejecting steel for the big through spans, iron for the deck trusses and approach viaducts was delivered to the site. Erectors for Kellogg and Maurice began assembling the supports and superstructures of the viaducts in February. The men erected the viaduct bents using a steam derrick which rolled on a track mounted on the stringers. They assembled the bents on the ground, raised them into position with the derrick, and then held them in place with plank stays while the girders were lifted and placed by the same derrick. The process proceeded smoothly in February until Perkins' lieutenant Albert Touzalin tried to intervene with a design modification.

Morison and Touzalin had first quarreled after the fatal accident in the west approach cut. Since then the two men had nurtured a cool professional dislike for each other, which had heated up whenever the railroad official tried to exercise any control over Morison's project. As the ironworkers erected the approach trestle in February, Morison and Touzalin clashed again. Touzalin felt that an additional stringer should be added to the trestle to strengthen the structure - a rare questioning of Morison's professional judgement which the bellicose engineer would not tolerate. "Like other powerful personalities, he was a person of prejudices." Morison's nephew-biographer later wrote. "He was very slow in forming opinions of persons or things, but when once formed his opinions were almost unchangeable. Many people with whom he disagreed he referred to ever after with contemptuous nicknames."[76] Morison never recorded his name for Touzalin.

In early February the two refused to communicate directly, relying on Morison's assistant Parkhurst as an intermediary. Finally, on February 9th, Morison and Touzalin exchanged words in a flurry of telegrams. Touzalin opened with an ultimatum:

> Even with the additions to the original plan, my belief is that the trestle needs both long bracing as well as additional stringers... Having the material on hand, and believing that ordinary business prudence demands the addition, I shall be obliged to make it, if you do not.

Morison refused to acknowledge Touzalin's authority on the bridge project, coolly referring the issue to Touzalin's boss:

> If Mr. Perkins desires additional stringers I shall put them on. I shall await instructions from him.

Touzalin countered with another threat:

> Your course does not seem to me a prudent or reasonable one and leaves me no alternative except to complete the work in such manner as I consider safe for the operation of the trains.

Morison cut the telegraphic conversation short by concluding:

> There will be no additional stringers put on the west approach trestle. The trestle has been inspected and approved as it stands.[77]

As Morison had promised, nothing further was done to strengthen the trestle. By early April, the long approach structure had been completed, and ironworkers for Kellogg and Maurice began erection of the easternmost deck truss. The men built all three 200-foot deck spans on pile falseworks, lifting the heavy metal components with the steam derrick that had been used to build the trestle. They completed the last approach span in mid-May.

Work on the 400-foot through trusses was begun in February, 1880. "As the two long spans extended across the whole channel of the Missouri," Morison wrote, "the difficulties in the erection of the superstructure were concentrated there." Part of the difficulty stemmed from the unusual construction technique that Morison had devised. To build the permanent Whipple trusses, workers first built temporary Howe trusses beneath the main bridge. Three per span, these timber structures rested on pile bent foundations driven to bedrock and were built using standard pile falsework. The top chords of the Howe staging trusses were positioned just beneath the level of the floor beams of the Whipples to serve as bottom chord falseworks for the long-span permanent bridge. Fifty-foot high, two-story bents were then attached to the staging trusses to serve as upper chord falseworks - two per panel. Tracks were laid on the cross sills of these bents upon which erection travelers rolled. The travelers were wheeled timber carts with adjustable cantilevered arms - "crabs", Morison called them - which could be used to haul material into place over the bridge. Components would be carried on the falsework at the level of the permanent track on small push cars, and then lifted and placed by workers operating the travelers.[78]

The pile driving crew aboard one of the transfer steamers began placing piles for the bent of the first staging truss in late March when ice was still running in the river. After a delay when the boat accidentally knocked several of the piles over, they finished the first temporary pier on April 2nd. Three days later the river rose suddenly, washing all the log piles away. The water level fell as rapidly as it had risen, and the workers soon drove new piles. They completed the structure two weeks later and the second staging truss support on the first of May; by the 20th, the men had built the three Howe falsework trusses.

Ironworkers under the supervision of Keystone erection foreman William Baird placed the first piece of iron for the east channel span on May 20th; eight days later they finished coupling and securing the huge truss. The staging blocks between the trusses were removed, the upper falseworks dismantled, the Howe trusses strapped to the lower chords of the completed Whipple, and the temporary piles were dynamited, letting the staging trusses hang from the main truss. The men disassembled two of the staging trusses and lowered the third onto staging erected on four barges. These were then swung around beneath the other main span, and the construction process began again on the other long-span metal truss. Baird's crew completed the second through span on August 16th. The bridge was then ready for traffic.[79]

On Monday, August 30th, 1880, the first train - a special from Omaha - crossed the bridge. In formal testing that morning, eight locomotives, each weighing 55 tons, rolled successively over both of the long spans. The inspecting engineers praised the completed structure and Morison's engineering. "I was impressed with the accuracy of the workmanship, and the symmetry and beauty of the structure as a whole," Charles MacDonald concluded. "I take pleasure in offering my congratulations upon the successful completion of this fine work."[80] Opened for traffic without fanfare, the Plattsmouth Bridge nevertheless formed a strategic link in the contest between the rival rail companies. Its completion touched off another round of maneuvering that would be marked by dramatic expansion and acquisition by both the Burlington and the Union Pacific and would assure George Morison a steady stream of lucrative Missouri River bridge commissions throughout the decade.[81]

BISMARCK BRIDGE

The Plattsmouth Bridge reflected the intense competition between two opposing western railroads. The next railroad company to retain George Morison for a major Missouri River span was also embroiled in conflict - this time from within. While the superstructure was still under construction for the Nebraska bridge in March 1880, Frederick Billings, President of the Northern Pacific Railroad, contacted Morison about a permanent railroad span over the Missouri River at Bismarck, in the Dakota Territory. The bridge would possess tremendous symbolic value in addition to a purely pragmatic function. The chain of events that had led the Northern Pacific to that point in 1880 had been tumultuous - marked by a tenuous beginning, scandalous collapse, eventual rebirth, and a bitter takeover battle. The Bismarck Bridge would play a pivotal role in one of America's most dramatic railroad development stories.

Chartered by Congress in 1864 as the northern transcontinental route from the Great Lakes to the Pacific Northwest, the Northern Pacific Railroad had undergone a chronically undercapitalized beginning. When nothing had been done beyond preliminary surveying in 1869, the NP directors solicited help from Philadelphia financier Jay Cooke. Cooke first commissioned a secret survey of the projected Northern Pacific route, purchased a large chunk of Minnesota for land speculation, and then contracted to market the railroad stock for an stock for an exorbidant fee. Cooke advanced the railroad $500,000 to purchase the rolling stock, rails, and material needed to begin construction. Later that year track laying began from the railroad's eastern terminus at Duluth, Minnesota. Gangs of graders, gaugers, track layers, spikers, and bolters extended the single trunk line across the prairie land of western Minnesota and onto the rolling plains of eastern Dakota. The railroad easily bridged the Mississippi River gorge west of Brainerd, Minnesota, and the James River in Dakota. In June 1873, the tracks reached the Missouri River - the inevitable barrier - just above Fort Abraham Lincoln. Here the construction crews stopped, and an end-of-the-line settlement known simply as The Crossing sprang up on the east bank. With no more money for wages, rails or materials, the Northern Pacific had ground to a halt.[82]

The Missouri River may have blocked the railroad's progress for a time, but it would be another obstacle - the imminent prospect of bankruptcy - that would ultimately stop the Northern Pacific. Under the shadow of the 1873 Credit Mobelier scandal, most of America's railroads had fallen under suspicion by investors. This was especially true of the stumbling Northern Pacific. Neither Cooke nor the NP Directors were in any condition to support a faltering railroad. Cooke tried various financing schemes, but to no avail. He even renamed the town at track's end Bismarck in a desperate bid to attract the investment

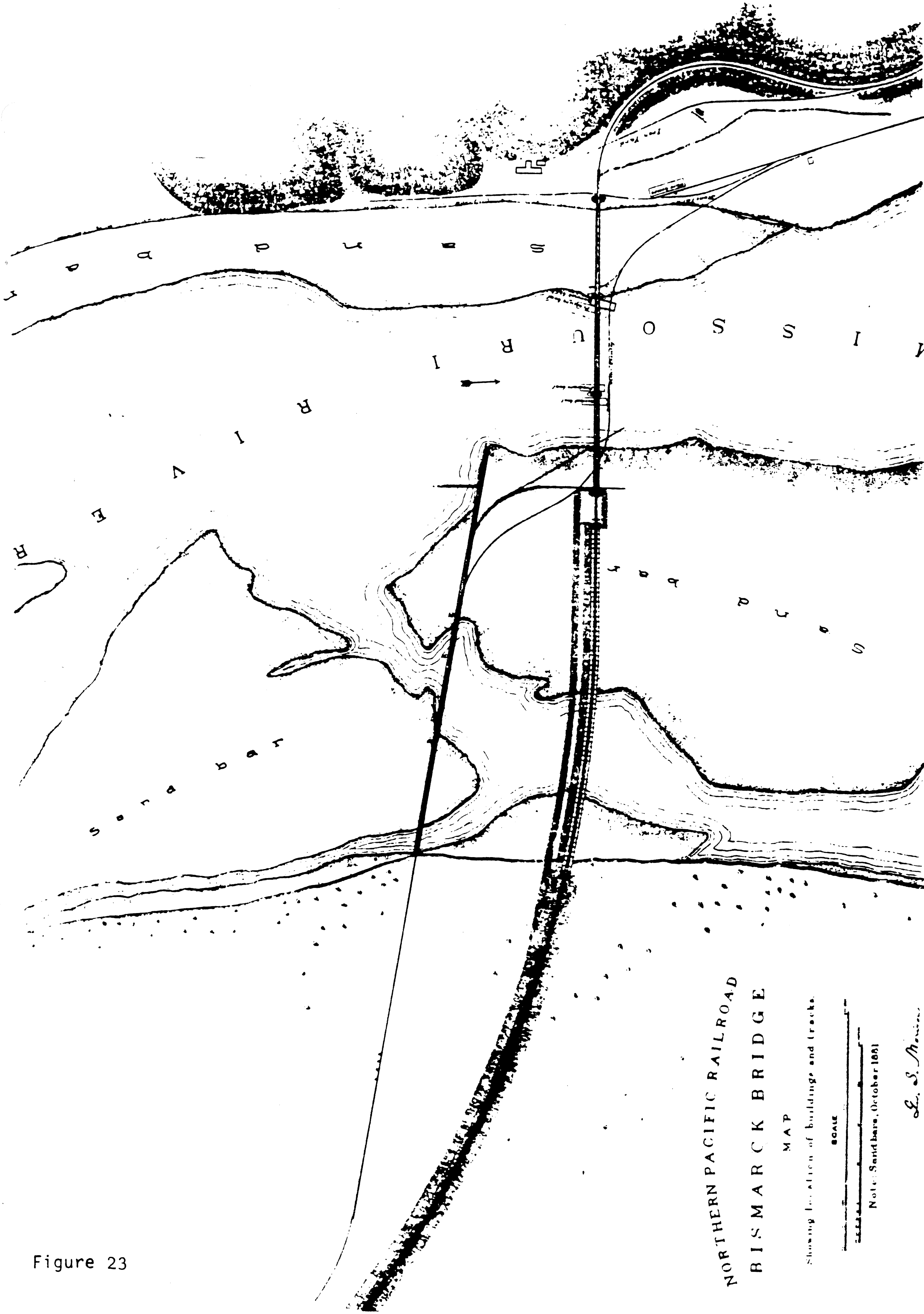

MISSOURI RIVER
sand bar
sand bar
sand bar
NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
MAP
SCALE
Note: Sandbars, October 1881

Figure 23

of German Chancellor Otto von Bismarck. But the Northern Pacific was failing and taking Cooke's banking empire with it. Chancellor Bismarck never did visit, and other investors shunned the troubled railroad. On September 18, 1873, while General George Custer was marching his cavalry back to winter quarters at Fort Lincoln from the Yellowstone Expedition and Jay Cooke was entertaining President Ulysses Grant at his fifty-room mansion, the financier's banks in New York and Philadelphia closed their doors. This effectively plunged the nation into a prolonged financial panic. For two years the Northern Pacific tried to attract other funding, but the search was futile in a depression-ridden land, and in 1875 the railroad declared bankruptcy.[83]

By the end of the decade, the financial climate in America had improved sufficiently for investors to resurrect the Northern Pacific with a new infusion of capital. Tracklaying crews began extending the iron rails westward through Dakota from the town of Mandan, across the river from Bismarck, in 1879. The railroad's directors immediately began to consider construction of a permanent bridge over the Missouri River to join the two sections of track. In March 1880, NP President Billings contacted consulting engineer George Morison to prepare a preliminary design for the bridge.[84]

Morison visited Bismarck the next month to inspect the site of the proposed bridge. He selected three tentative locations in the vicinity and ordered soil borings and surveys for each. In July, six weeks before final load testing of the bridge at Plattsmouth, the engineer returned to Dakota with the survey findings. With Billings, he then determined a final crossing site (shown in Figure 24). The east side of the river there was bounded by a substantial clay bank - the edge of the bluff on which Bismarck stood. The west bank was the wide floodplain of the Missouri, below the mouth of the Heart River. Across the river from Bismarck Mandan was situated, just beyond the normal floodplain of the Missouri in the valley of the Heart. Morison aligned the crossing almost directly between the two towns to minimize additional approach trackage and take advantage of favorable substructural conditions.[85]

To the townspeople of Bismarck his arrival was welcome news, for the proposed bridge over the Missouri represented the long-awaited revival of the troubled railroad. To an affluent man as religious and staidly conservative as George Morison, however, the rough-hewn frontier town of Bismarck must have been appalling. Servicing the track's end of a railroad, a steamboat port, and a nearby army post, the settlement's unsavory residents and clientele formed a world far removed from New England and New York society with whom Morison had grown accustomed. "Bismarck was started by the opening of a whiskey shop," another visitor, Canadian D. McEachran, wrote in his 1881 diary, "and though it now contains a population of over 2,000, the example set by the pioneer has been faithfully followed, since at least three-fourths of the buildings are grog shops, gambling houses or places of amusement." McEachran described his brief encounter with the Bismarck social scene:

> Having three days to wait for our steamer we took advantage of a high Government functionary's offer to show us the "city by gaslight." Our first visit was to a "keno" house where we stayed but a short time for the disgusting sight of gambling in its worst form, and the foul air and still fouler language drove us away. We next visited a faro bank where similar scenes presented themselves. We could not help remarking on the general expression of abandonment depicted in the faces and nervous expressions of the frequenters of those dens. Our next place of visit was to the "opera house," a wooden structure, the entrance of which is a barroom. At the counter tickets had to be procurred, the charge for entrance to the ground floor being twenty five cents, to the boxes fifty cents. We looked into the pit. Here we saw a sawdust covered floor, rough, unplaned board seats and forty or fifty frontiersmen, all with large, wide brimmed hats and nearly all smoking or chewing tobacco... About half a dozen women acted as waiters and their dress and manners indicated the life of immorality which they lead. The scenery on stage was of the most primitive nature and the acting was execrable. While we were looking on, a large woman with a voice like a cow horn attempted a vulgar ditty, "Champagne and Oysters".[86]

The Missouri River had been the principal thoroughfare through the region years before the arrival of the first railroad, and by 1880 steamboat freighting was solidly entrenched in the economic and military character of Bismarck and beyond, to Fort Benton in Montana Territory. The Northern Pacific bridge could not, therefore, impede river traffic. To provide a passable channel for the shallow-drafted mountain boats, Morison considered the conventional configurations: a low bridge with a moveable span or a fixed-span structure supported well above the shipping lane on high piers. He quickly rejected the concept of the low bridge, arguing that the extensive cutting on the east bank that would be necessary, the ferocity of spring flooding, and the problems of maintaining a navigable channel alongside the swing span during the ice-choked late autumn months made it impractical. The Bismarck Bridge, like the one at Plattsmouth, would feature a high configuration.

The most formidable engineering problem that Morison faced was not the height of the bridge but the exceptional width of the Missouri at Bismarck. At that point the channel was about 3,000 feet wide at ordinary high water - three times the width at Fort Abraham Lincoln, five miles downriver. Additionally, the broad plain on the west bank was necessary as a release for spring flooding and could not be filled for an approach without endangering Mandan - "that unfortunately situated town," as Morison called it. As a solution, the engineer proposed an extensive trestle approach from the west. To control the river width at the crossing, he detailed the construction of a major revetment project upstream, consisting of an earthen dike on the west shore which would constrict the water to a 1,000-foot channel at normal levels (shown in Figures 25 and 24).[87]

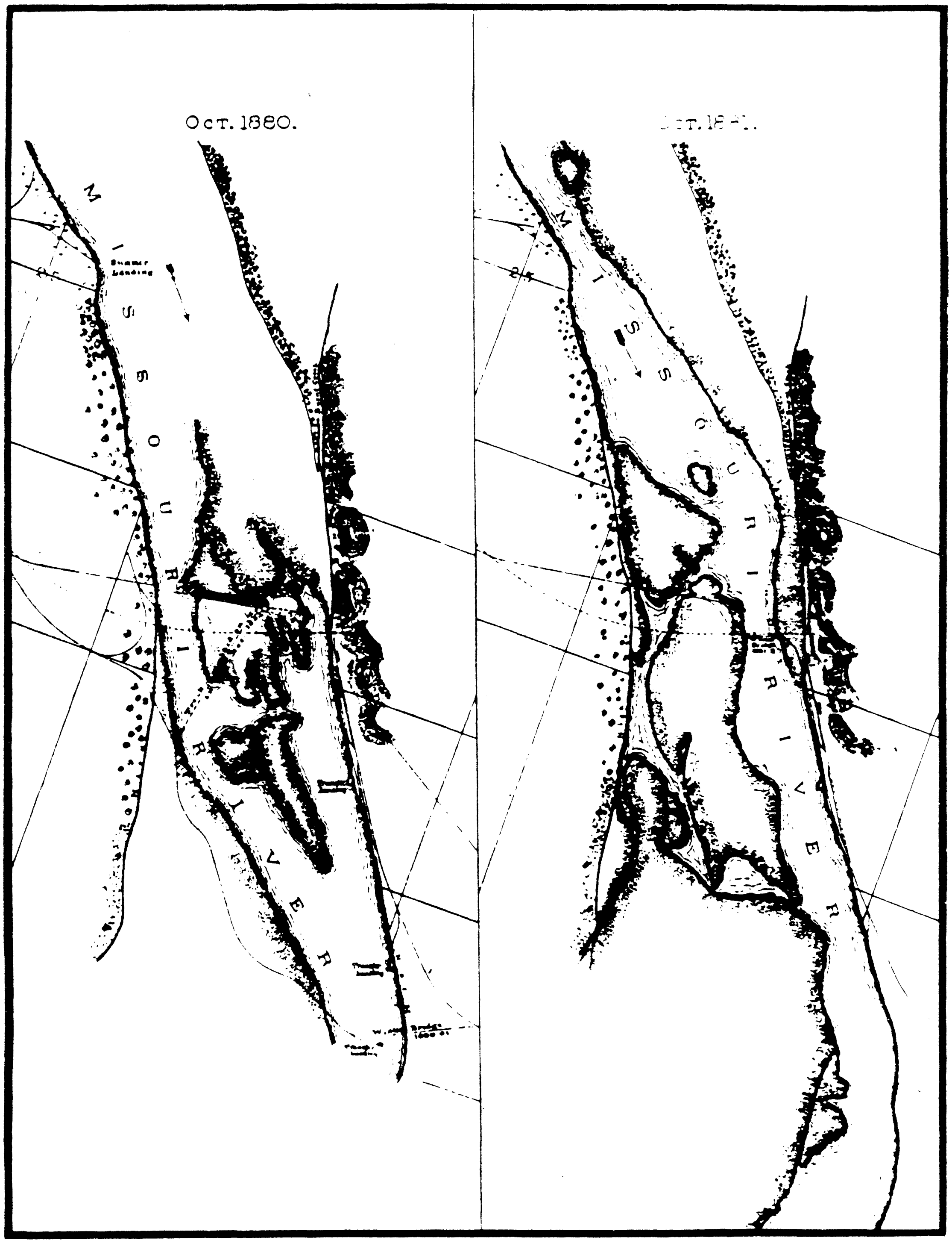


Figure 24

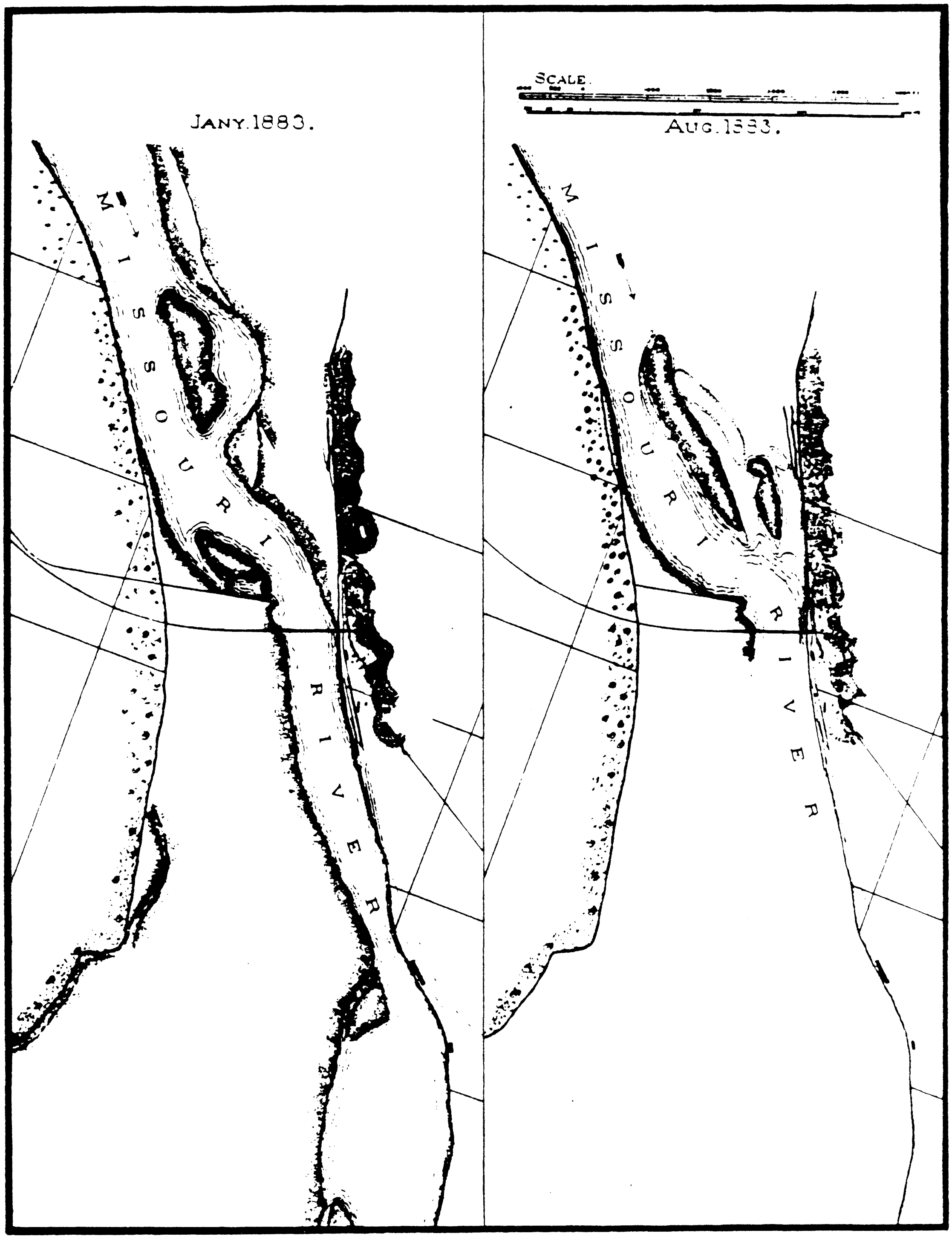


Figure 25

Although six major bridges spanned the Missouri River by 1880, none had been built over the river's upper reaches in Dakota Territory. The Bismarck Bridge would be the first. Most of the transcontinental and transregional railroad activity in America was then occurring south, through the central Midwestern states. Moreover, the problemmatical nature of the river in the north formed an obstacle to bridge construction. Although generally narrower than the channel downstream, the Missouri in Dakota and Montana was subject to extremely destructive surges of water and ice during the freezing and thawing of the winter ice flows, which would require costly construction to protect bridge piers. Morison succinctly described the problems of bridgebuilding on the upper Missouri in a report to Billings:

> The peculiarities of this portion of the Missouri valley are of two kinds: the first is due to the entire absence of any proper rock in the formation of this country, and the second is due to the ice, which is always very heavy in the long winters of this high latitude, and causes violent floods when it breaks up in the spring. The absence of rock is of comparatively small consequence, as the underlying formation is very hard clay of indefinite thickness, which seems entirely proof against the action of the water, and is capable of sustaining great weights. The action of the ice, however, is very important... The River is liable to open from above instead of below, causing a succession of ice gorges, accompanied by a series of violent local floods. Except for the violence of the ice flood, bridging the Missouri at Bismarck would be a comparatively simple matter. Fully one-half of the cost of a bridge here is due to conditions which seldom act as much as two days in a year.[90]

In his report to the NP in July, Morison presented two alternative fixed-bridge designs. One featured two spans of 500 feet each, the other, three 400-foot spans. The former plan would be more economical because of the deletion of one of the expensive piers; the later would be more technologically conservative. Billings opted for the latter. The engineer recommended that the bridge be built fifty feet above the established high water point for the shipping season - standard clearance height for the navigable rivers of the Midwest.

The Northern Pacific Board of Directors received Morison's report in July and then delayed making a decision to continue with the bridge's erection for six months, effectively missing the 1880 construction season. The delay stemmed from another round of financial controversy, this time involving a takeover threat from a powerful outside investor. German correspondent-turned-entrepreneur Henry Villard had recently acquired control of the Portland-based Oregon Steam Navigation Company, the dominant shipping enterprise on the Columbia River. He had reorganized the firm into the Oregon Railway and Navigation Company and extended a rail line along the south bank of the Columbia. This new trackage would not only control rail traffic along the river to the Inland Empire, it would form the link between Portland and a rail link from the east.[91]

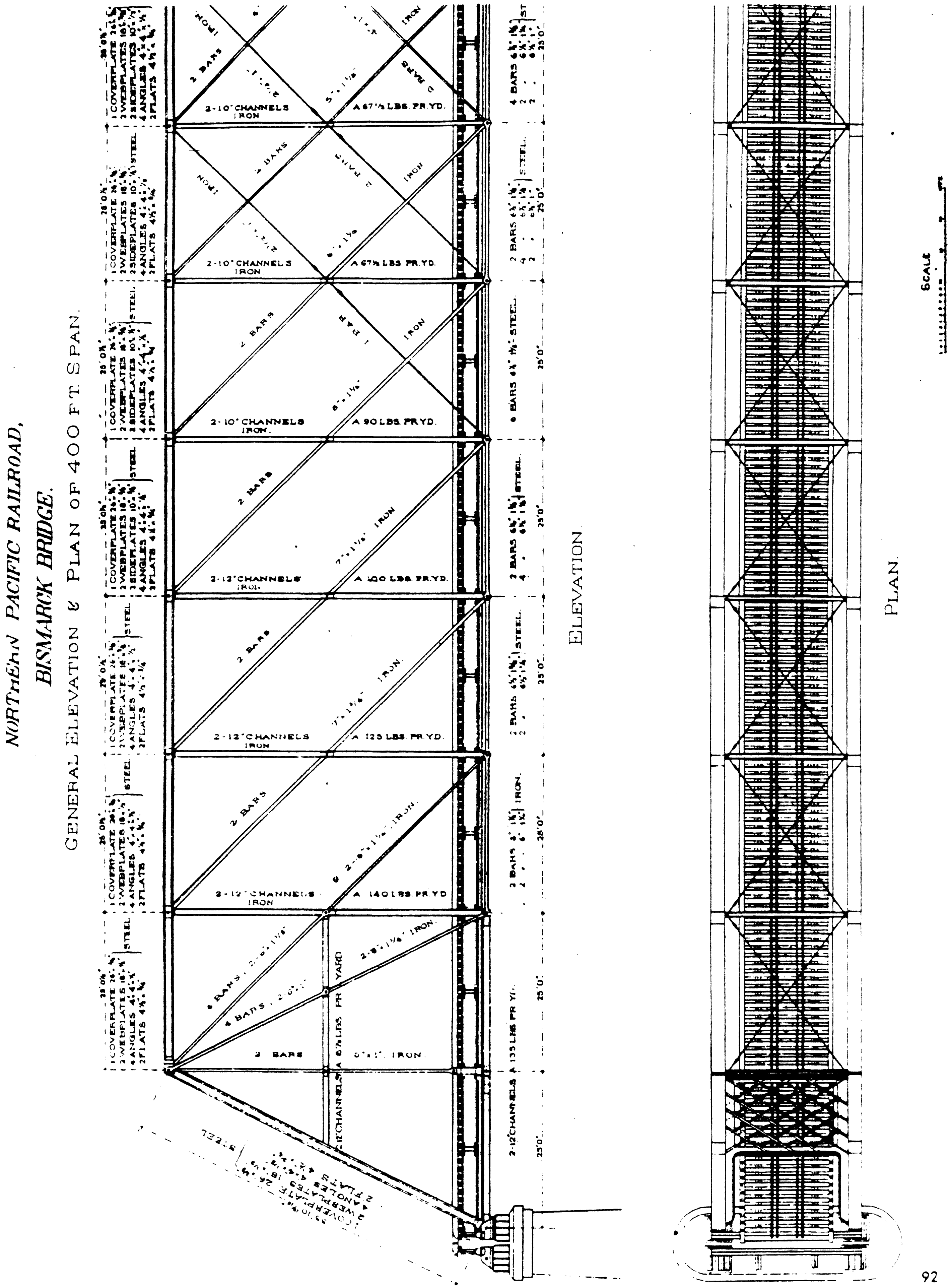

NORTHERN PACIFIC RAILROAD,
BISMARCK BRIDGE.
GENERAL ELEVATION & PLAN OF 400 FT. SPAN.
ELEVATION
PLAN
SCALE

Figure 26

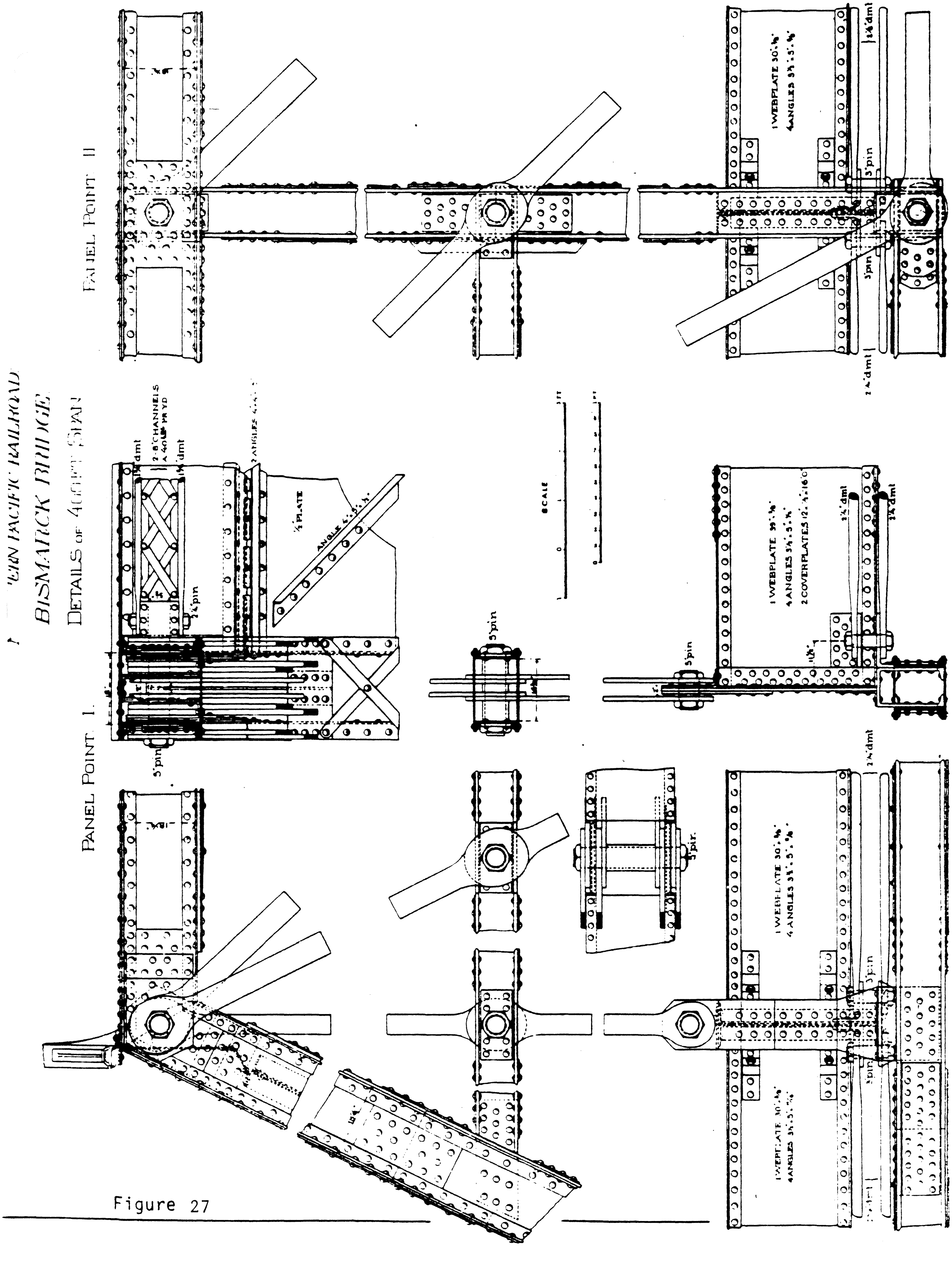

BISMARCK BRIDGE
DETAILS OF 400 FT SPAN
PANEL POINT II
PANEL POINT I
SCALE

Figure 27

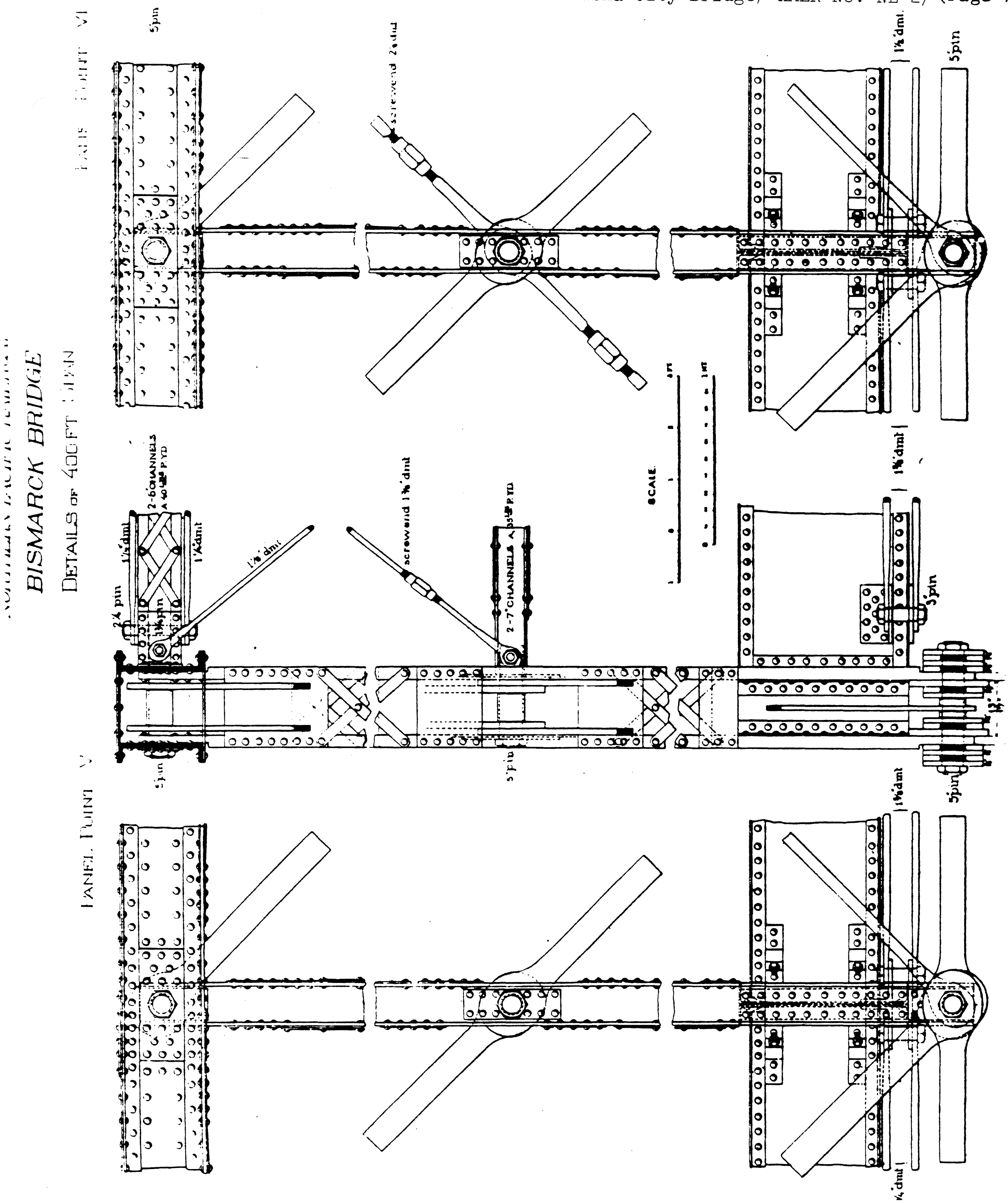

BISMARCK BRIDGE
DETAILS OF 400 FT SPAN
PANEL POINT V
SCALE
5 pin
2 ¼ pin
screwend 1⅜ dmt
2-7" CHANNELS
2-6" CHANNELS

Figure 28

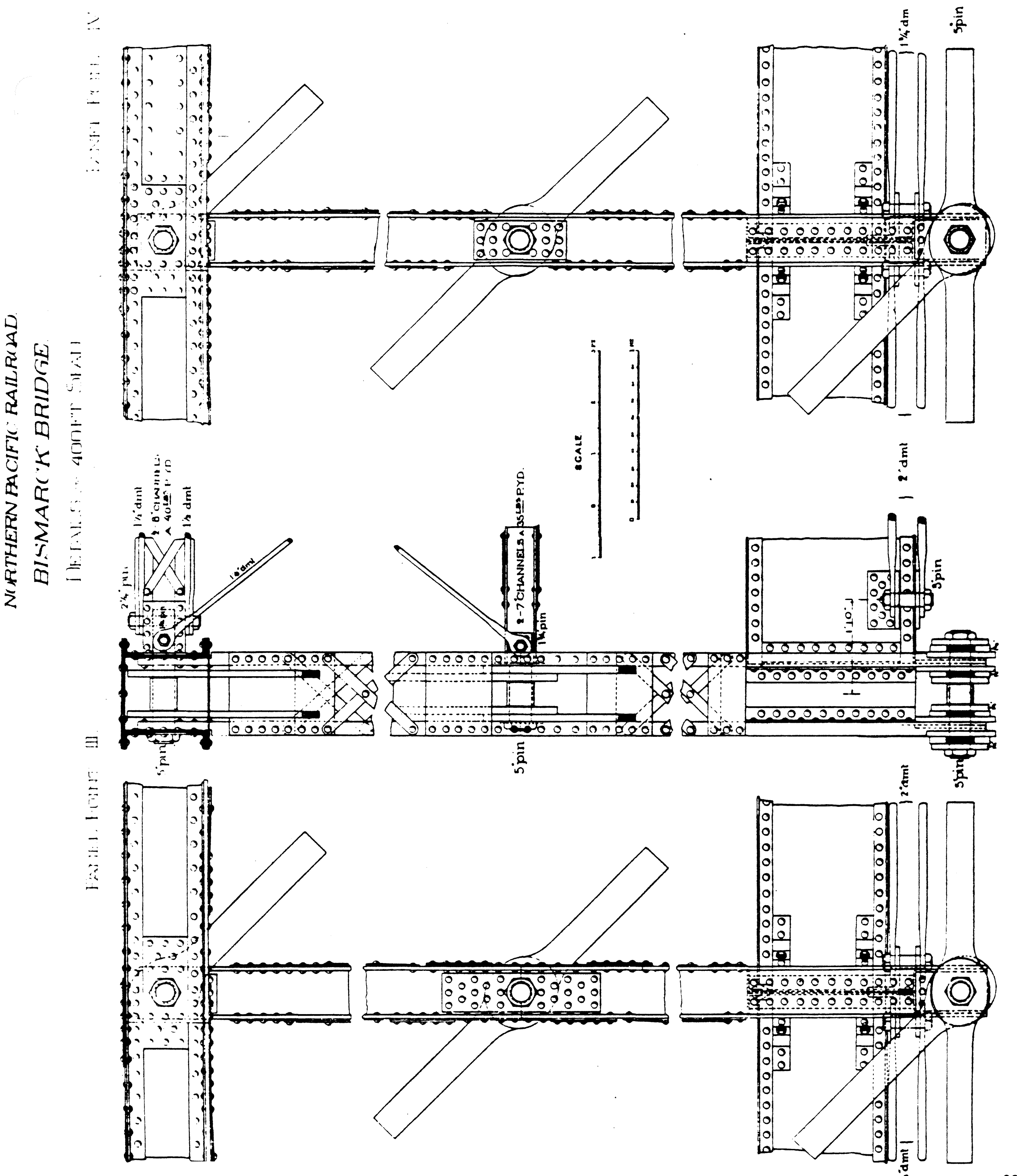

NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
2-7" CHANNELS A 35 LBS P.YD.
SCALE
5" pin
1¼" pin
2" dmt

Figure 29

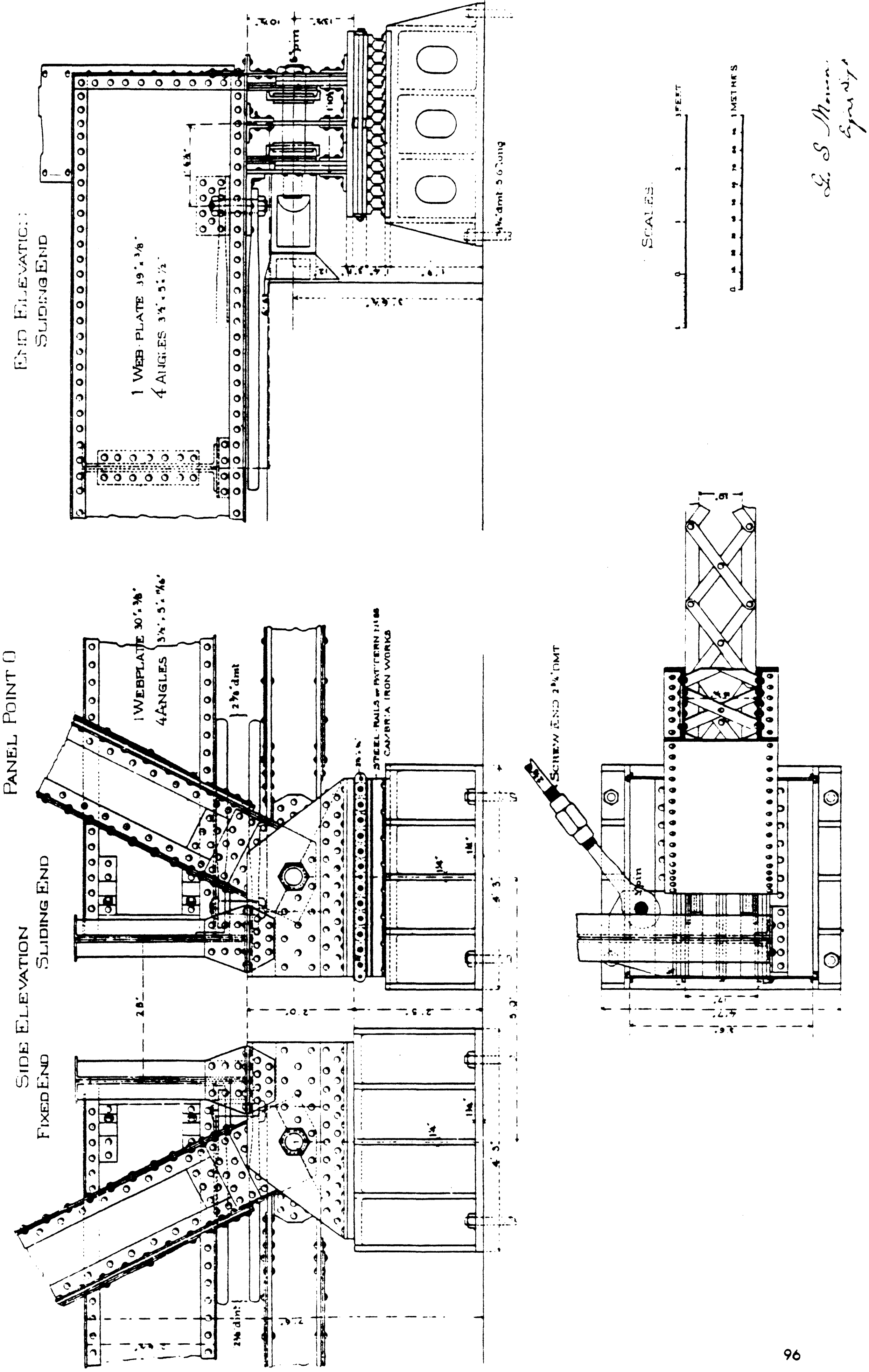

NORTHERN PACIFIC RAILROAD.
BISMARCK BRIDGE.
DETAILS OF 400 FT SPAN.
PANEL POINT 0
SIDE ELEVATION
SLIDING END
SIDE ELEVATION
FIXED END
END ELEVATION
SLIDING END
1 WEBPLATE
4 ANGLES
STEEL RAILS
CAMBRIA IRON WORKS
SCREW END
SCALES
FEET
METRES

Figure 30

Unfortunately for Villard, the only transcontinental railroad building toward the region was the Northern Pacific, and the NP directors planned to route the tracks, not to Portland, but along the north side of the Columbia to Tacoma, Washington. To protect his Portland interests, Villard initially tried to persuade the Northern Pacific to alter the route of the railroad to Oregon instead of Washington. But when the NP refused, he resolved to take over the railroad and reroute the tracks himself. Amply funded with a "blind pool" of nearly $20 million in cash, Villard gained control of the Northern Pacific by spring of 1881.[97]

While the Northern Pacific management grappled with Henry Villard in late 1880, Billings instructed George Morison to proceed immediately with the drawings and bidding for the bridge at Bismarck and, typically, to see that the monumental structure was erected as quickly as possible. The engineer immediately began drafting construction documents for the superstructure in his New York office. They were completed early that year. His truss design for the Northern Pacific's bridge in Dakota bore a striking resemblance to the one he had engineered a year-and-a-half earlier for the Burlington Railroad at Plattsmouth. Engineered to withstand a moving live load of 2,000 pounds per linear foot, the three 400-foot long through spans carried a single railroad track (shown in Figures 26 -31). The simply supported, 50-foot deep channel spans were divided into sixteen double-intersected panels spaced 22 feet between centers. Immense in scale, they differed from their predecessor only in detail. The end posts, top and bottom chords, verticals, diagonals and struts were all identical to those at Plattsmouth, as was the system of pinned member connections and riveted plate floor beams. The most apparent difference lay in the substitution of latticed portal bracing for the single huge X-brace that Morison had used at Plattsmouth.[98]

Morison's exhaustive testing of the steel for the Plattsmouth Bridge had convinced him of the strength and uniformity that could be achieved with the new, lighter metal. But his difficulty in finding sufficient quantities of acceptable material for the bridge demonstrated that structural steel manufacture still remained a hit-or-miss venture in 1880. The conservative engineer therefore specified steel to a substantially lesser extent for the main through trusses on the Bismarck Bridge than he had for Plattsmouth. The top chords, end posts, rollers, bolsters, bearing plates, pins, and eyebars were to be steel; all other parts except the wall plates on the masonry, washers, and the ornamental work were designed for wrought iron. "In proportioning the 400- feet spans, it was considered important to use steel in all positions where reduction of dead weight would materially reduce the strains in the structure," Morison later stated, "but it was known that the difficulties in procuring a satisfactory steel were such that it was unwise to to attempt to use any more of this material than necessary... The difficulties which were experienced in the manufacture of steel-work showed that these limitations had been wisely made."[99]

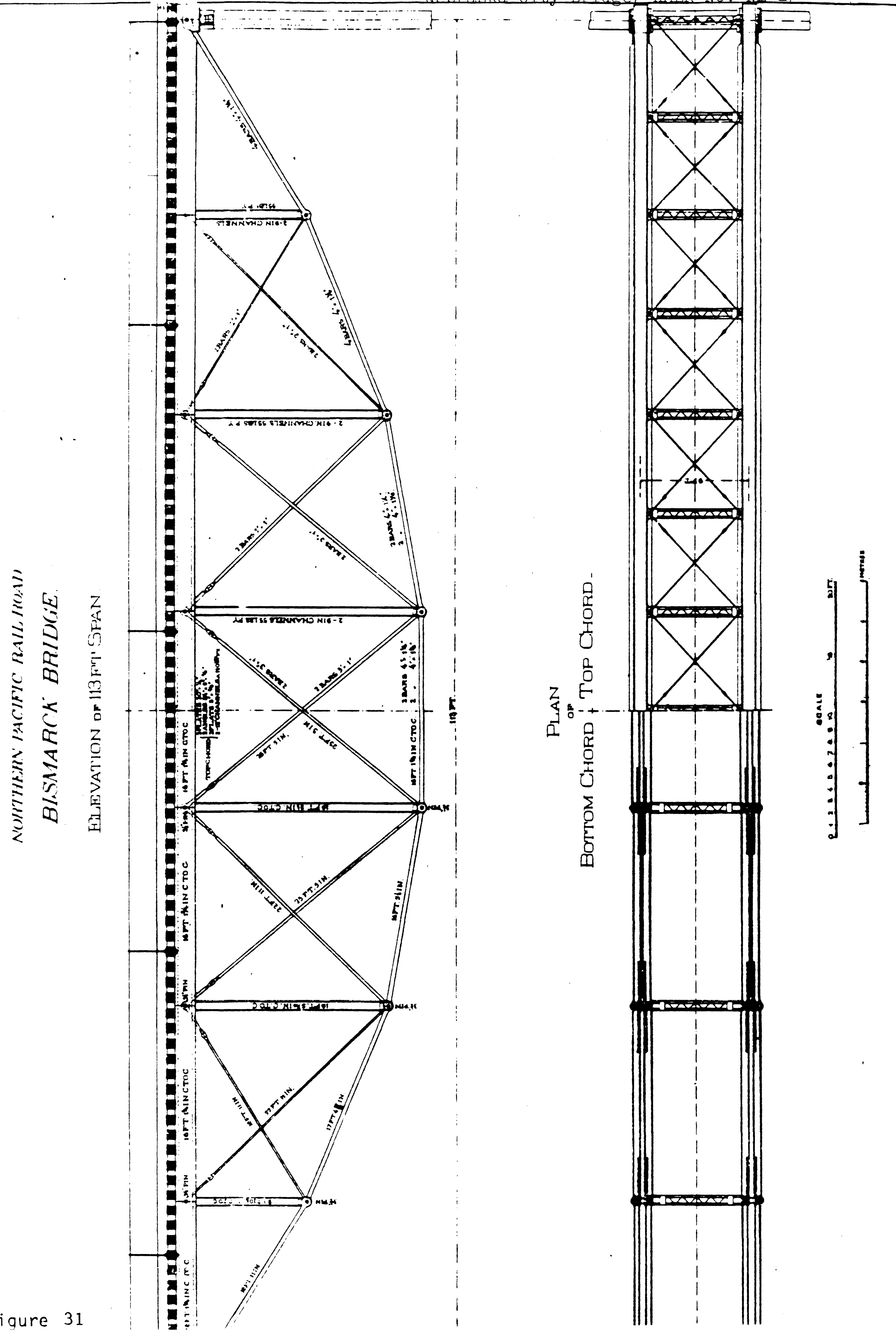

NORTHERN PACIFIC RAIL ROAD
BISMARCK BRIDGE
ELEVATION OF 113 FT SPAN
PLAN OF BOTTOM CHORD TOP CHORD
SCALE

Figure 31

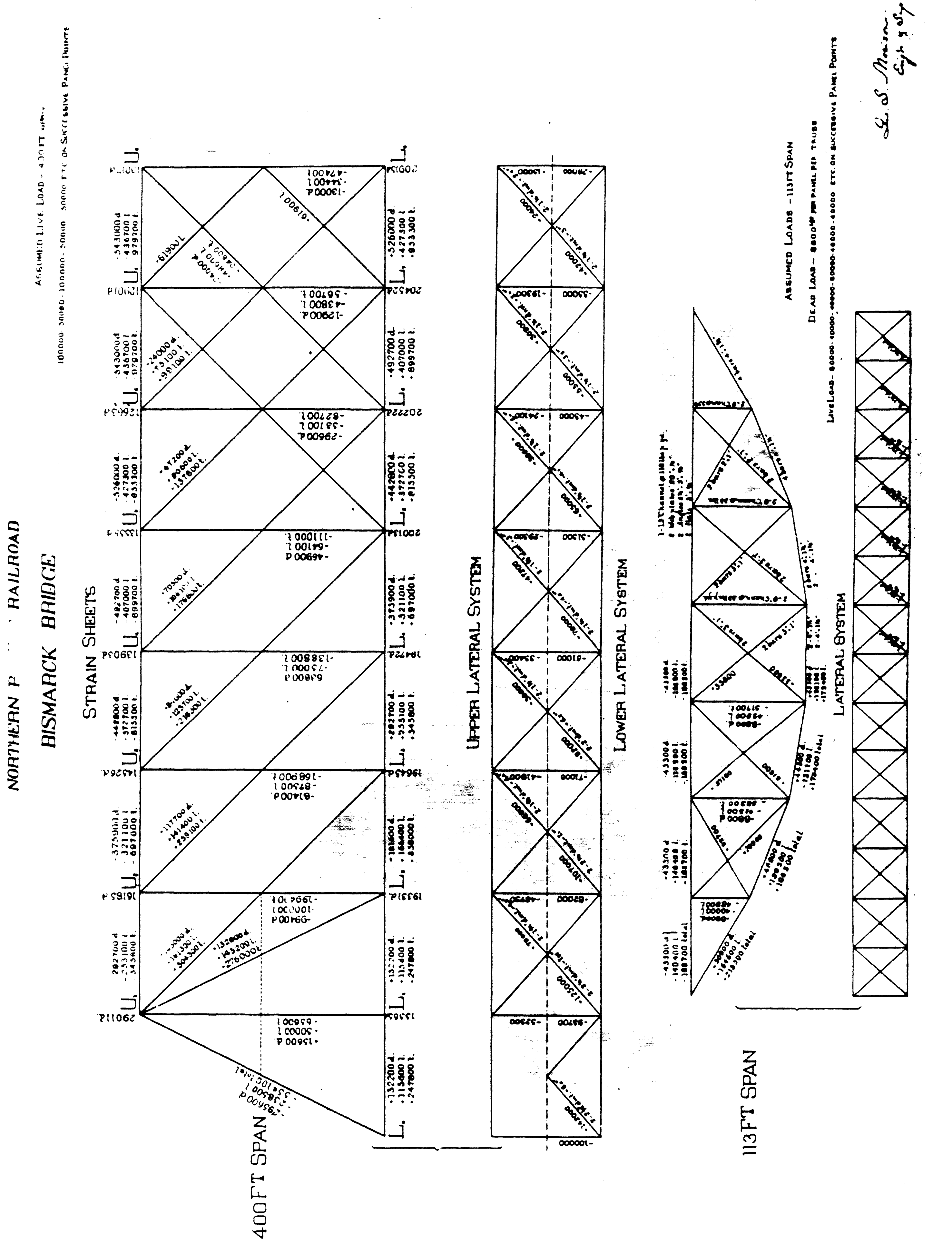

NORTHERN P RAILROAD
BISMARCK BRIDGE
STRAIN SHEETS
UPPER LATERAL SYSTEM
LOWER LATERAL SYSTEM
LATERAL SYSTEM
400FT SPAN
113FT SPAN
ASSUMED LOADS - 113FT SPAN

Figure 32

Morison dropped the amount of structural steel on Bismarck almost a quarter from Plattsmouth to about a third of the superstructural weight - or a little over a million pounds of the three million pound total weight of the immense Whipple trusses. Cast iron comprised only some 77,000 pounds - 3% of the total weight. The remainder of the trusses was made up of wrought iron. The metallic composition of the through spans is given in the following table:

	Total three spans	Average per span	Percentage
Steel	1,046,390 pounds	348,797 pounds	35.7%
Wrought iron in trusses	1,335,755 pounds	445,251 pounds	45.6%
Wrought iron in floor	466,591 pounds	148,863 pounds	15.9%
Cast iron	77,331 pounds	25,777 pounds	2.8%
Total	2,926,067 pounds	968,688 pounds	[101]

Morison used steel even more sparingly for the two approach spans (shown in Figure 32). The engineer chose pin-connected Pratt deck trusses with polygonal bottom chords, which he called "inverted bowstring" trusses. Each approach featured one of these 113-foot, seven-panel spans. Morison shaped the peculiar trusses to conform with the slope of the embankment, but the frequent adjustments necessary on the diagonal tension members created a continuous maintenance problem. Calling the approach trusses "not a form of structure which would generally be preferred," he would not use the design for any subsequent bridges. Of the 98,000-pound weight of each deck truss superstructure, steel comprised only about 3,000 pounds, or just 3% of the weight - half that of the cast iron and a fraction of the wrought iron.[102]

Compression testing of full-scale, long steel members was still not possible, and without specific test results, George Morison remained skeptical about the capacity of steel in the trusses to resist deflection under axial compressive loading. Additionally, he was still wary of sudden tensile loads applied to steel members in the outer panels. The "extreme prudence" that he had demonstrated at Plattsmouth, he continued for the steel components of the Bismarck Bridge. Morison justified his caution in a report to the railroad:

> The experience with the Plattsmouth Bridge had shown that a steel could be obtained, with comparatively little difficulty, which was admirably fitted to resist compression in members of moderate length, but we are still without accurate data to determine the strength of steel compression members of such length that their yielding is a matter of flexure rather than of compression. As regarded tension members, the fact was established that steel eye-bars could be made which would show a very uniform modulus of elasticity, within safe working limits, and an elastic limit fully one half higher per square inch than could be developed in iron eye-bars of the same working strength, but it had not

> yet been found practicable to get steel eye-bars of a uniform ultimate strength, or which would develop anything like a uniform elongation before fracture. Under these circumstances, it was thought best to limit the use of steel in compression to the end posts and top chords, where the length does not exceed sixteen times the least transverse dimension, and to limit the use of steel in tension to the ten central panels of the bottom chord, where there are never less than four bars side by side, where the strains are applied slowly, and where a high eleastic limit and a uniform modulus of elasticity are needed, the ultimate strength of the material being of comparatively little importance.[103]

In January 1881, Morison solicited competitive proposals from six of the country's most prominent bridge fabricators for the massive superstructure. Within two weeks, he received replies from four of them: the Delaware Bridge Company, Keystone Bridge Company, Kellogg and Maurice, and the Detroit Bridge and Iron Works. There was very little difference in the per-pound material prices quoted by the bidders, but Detroit Bridge was substantially lower than the others on erection price and was therefore awarded the contract. Bids for the substructural work were let at the same time. The contract for that was awarded to Saulpaugh and Company of Chicago. Bellows, Fogarty and Company of Mandan were contracted for the earthwork on the approaches; Bismarck contractor Charles Thompson would lay the riprap stone to consolidate the riverbank; and the Winston Brothers of Minneapolis would erect the iron trestle on the west approach.[104]

Construction of the Bismarck Bridge began hurriedly for Morison. In late autumn of 1880, Northern Pacific President Billings had authorized the construction of the protective upriver levee that Morison had outlined in his preliminary design. A railroad crew began building the dike's foundation mattress, a 140-foot wide base structure composed of woven and wired willow brush. By the time Morison and First Assistant Engineer H.W. Parkhurst arrived at Bismarck in January to begin construction supervision, work was well under way. But the men had failed to tie the dike with the western shore, allowing the river to cut an alternate channel. As the outspoken Chief Engineer later indicated, he was less than happy with the progress: "The situation was very unsatisfactory. The foundation mattress for a dike, which was to hold the river on the east side, had been constructed, but the entire river was running on the west side of the foundation; there was no water running where the bridge was to stand; moreover, the ice was likely to break up in a little over two months, and unless a vigorous effort was made, it would tear to pieces all the work that had been done."[105]

Morison immediately mobilized the crew to reinforce the weakened structure. Laborers had already gathered logs to cover the dike, and under his direction they built a three-foot high crib the entire length of the levee, filled it with boulders, earth, and anything that could be used for ballast, ramped the

upriver side, and covered it with earth to protect it from the ice breakup. Morison's dike was colossal: 1,750 cords of brush for the foundation mattress, 20,100 cubic yards of earth, and over 65 million pounds of 50- to 500-pound granite boulders collected from the rolling prairie west of the river. The men worked throughout the bitter Dakota winter on the frozen river until the rising floodwater drove them from the dike in March. The structure was soon covered entirely by the flood.

The winter ice breakup on the upper Missouri in March 1881 was the most violent on record. The weather had been bone-chillingly cold for months, and a thick ice crust had formed over the river. This was followed by an early spring on the Yellowstone and the upper tributaries of the Missouri, which precipitated severe flooding in Dakota. A great ice gorge - the rapid buildup of an immense floe that blocked the water in the channel behind - formed between Bismarck and Fort Lincoln, raising the river level four feet above Mandan and inundating the vast floodplain along the west bank. When the gorge at Bismarck broke on March 30th, a flood of icy water washed downstream to the next gorge at Fort Lincoln, which held for five days before it too collapsed. The succession of gorges and floods continued down the Missouri past Yankton. The rupture of the last ice dam released an unprecedented wave that roared past the mouths of the Kaw and the Platte and into Kansas City. The washout there was disastrous - exceeded only by the great flood of 1844.

The flood at Bismarck crested entirely over the dike, passing the broken ice with scarcely little structural damage. But when water receded after the breakup and the rectification work re-emerged, Morison was dismayed. The dike had held, but the river still resisted his attempts to wrest control of it. He described the scene:

> Although little harm has been done by the break-up, the situation was as perplexing as ever; the main channel was still between the dike and the west shore. The water gradually cut away about 200 feet at the west end of the mattress, where the crib had not been thoroughly filled with stone, but the opening between the dike and the west shore did not pass the whole discharge of the river, and the inclination of the dike seemed to have the desired effect, in causing the flow of water on the east side gradually to increase, at the expense of the discharge through the western opening... The river was now working in the way that we desired, but the open channel on the west side was a source of very grave apprehension.[106]

In May Morison ordered a temporary pile bridge built across the west channel in an unpromising attempt to block the flow of water. The June flood completely destroyed the log structure. As the river began its summer recession in July, the men resumed work rebuilding the pile bridge. A violent hailstorm in August wrecked the pile driver barge, halting work once again while it was raised and

repaired. Finally, at the end of the month the 900-foot bridge was completed. Tracks were laid along its length and a landing was built at its end for use by the transfer boats. By this time the river was closing the west channel itself by depositing silt around the bridge piles, and Morison decided to let the natural filling action proceed unaided. Despite this, the river continued to create problems throughout the bridge construction, commanding the engineer's continuous attention.

Construction on the bridge substructure was begun on May 12, 1881, with foundation work on the east abutment. Ground was broken the following day for the first pier on the eastern bank With a derrick set up alongside to hoist the dirt, workers excavated an open pit, 24x50 feet, twenty feet below the surface of the river before encountering the hard clay that formed the bed. By September 6th they had dug the first section of the pit to its final depth, and the men began pouring the concrete footing for the pier. They completed the three twelve-foot concrete shafts two weeks later. Over these a four-foot thick concrete pad was poured that filled the entire pit, and on top of this two layers of 12x12 timbers were then laid and covered with additional concrete. Masons laid the first stone for the Bismarck Bridge on October 4th, 1881.[107]

The problems of a remote construction site that Morison had faced the year before at Plattsmouth were far worse at Bismarck. Virtually all of the materials and equipment had to be shipped in by rail to the bridge site. When a sufficient quantity of suitable stone for the piers could not be located in Dakota Territory, structural grade granite had to be transported some four hundred miles from the Rock Island Quarry, near Sauk Rapids, Minnesota. The labor force, which also had to be imported from Minnesota, proved expensive and unreliable. Morison had foreseen the problem: "As Bismarck was situated in an unsettled country, being at the time 150 miles beyond any settled agricultural country, and more than 400 miles from the nearest labor market, it was thought important to keep control of the labor on the work in as few hands as possible, and so to place the whole substructure, including foundations, in the hands of a single contractor." Despite this, logistical problems commanded an inordinate amount of his time and energy. "The desired result," Morison continued, "was only partially obtained."[108]

George Morison was nothing if not intolerant of what he regarded as the shortcomings of others. "He was a hard task-master," his nephew said, "requiring only the best from his employees. Those who rendered inferior service did not long remain with him."[109] Morison could hardly conceal his disgust for the workers at Bismarck when he later wrote: "The labor in this country was of an inferior character, and very difficult to control, the men generally being indifferent as to whether they worked or not, and entirely ready to be discharged. It frequently happened that gangs of men sent out from St. Paul to work on the bridge disappeared almost as soon as they arrived."[110]

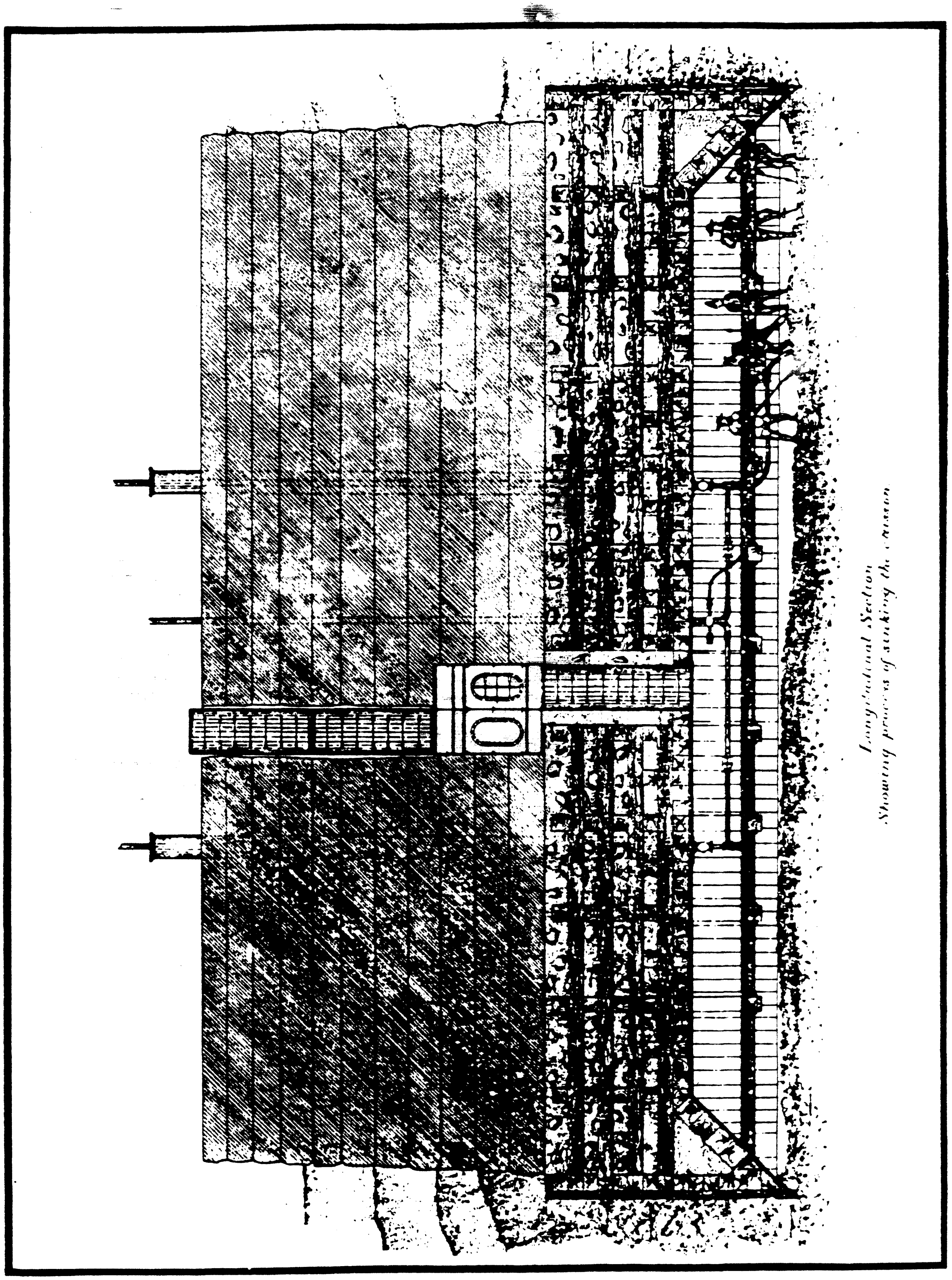


Figure 33

The motives of the disappearing laborers could be understood, if not excused. Working conditions in Dakota, especially during the bitter cold winter months, proved unbearably harsh. The desertion rate at nearby Ft. Lincoln was similarly high. Five hundred men of Custer's Seventh Cavalry took "the Grand Bounce" in one twelve month period in the mid-1870s, and soldiers that discharged themselves as soon as they could escape in the spring became known as snowbirds. Historian Evan Connell dramatically described life in Dakota: "The West was not dull, it was stupendously dull, and when not dull it was murderous. A man could get killed without realizing it. There were unbelievable flash floods, weird snakes, and God Himself did not know what else, along with Indians descending as swiftly as the funnel of a tornado."[112] The bridge project was slowed or stopped several times in 1881 due to bad weather, unfavorable river conditions, or labor problems. Despite these delays, pier construction continued throughout the year.

To withstand the tremendous downriver force of the ice floes on the upper Missouri, Morison had designed immense masonry piers for the Northern Pacific bridge. Far more massive than even the huge stone-and-concrete pillars for the Plattsmouth Bridge, the two channel piers for the Bismarck Bridge featured battered upriver edges sheathed with heavy wrought iron plates to break the ice. They would be situated within the channel of the river, making open excavations impossible. For these Morison had engineered foundations of pneumatic caissons: at the time the most difficult and dangerous aspect of large-scale bridge construction.

Although George and Thomas Saulpaugh were experienced in masonry and coffer dam excavation, they had never sunk pneumatic foundations and subcontracted the work to the more expert contractors, Rust and Coolidge of Chicago. Their equipment was shipped to the site by the Northern Pacific. A wooden barge was constructed to house the two Clayton air compressors and steam cylinders, the Cameron pump, two Eads sand pumps (invented by Captain James Eads for use on his bridge in St. Louis), and the two 60-horse boilers to power all of the machinery. A double-chamber wrought iron air lock and shaft were fabricated from Morison's design to provide passage and equalize air pressure for the caisson excavation below the riverbed.[113]

Laborers began building the first caisson on the east bank of the river on June 16th. They built the cribbed timber structure broadside to the flooded river, fitting it with a false bottom for floatation. Designed as the base for the huge masonry pier, the 26 x 74 foot caisson was massive: 133 thousand board feet of timber, 58,000 pounds of wrought iron bolts and rods, and 10,000 pounds of cast iron washers. The wrought iron cutting edge alone weighed almost 13,000 pounds. By the end of July the ponderous timber/iron assemblage was ready for launching into the river. After several mishaps, a Northern Pacific transfer steamer towed the caisson to its position at Pier II and attached it with the equipment barge to a pile mooring. There the men lowered it to the riverbed,

pressurized the work chamber, removed the false bottom, and began filling the timber crib with concrete. When a fire broke out five days later, the air pressure was relieved and the structure was allowed to fill with water for three days. The fire was soon extinguished without any real damage, the pressure resumed, and excavation begun.[114]

On the first day of September the masons began laying the first course of Minnesota granite over the timber cribbing. The first dimensional stone they laid had been quarried near Watab station and consisted of both grey and red granite. Morison thought the red stone "very handsome," but was forced to discontinue its use when the quarry fell short of the amount needed for the bridge. In June, 1888, a second quarry below Sauk Rapids was opened to supply the remainder of the stone. The stonemasons continued laying the foundation stone over the sunken caisson throughout the autumn as workers in the pressurized chamber below excavated through the river bottom, lowering the entire structure by inches a day. On November 9th, excavation was completed. The working chamber was then filled with concrete and the foundation complete. The contractors used the same procedure to build, position, sink, and excavate the caisson for Pier III, and by mid-January they had completed filling the working chamber with concrete. (See Figures 33-35 for pier profiles.)

The last massive pier was positioned near the west shore behind the dike that had been built the year before. Protected from the main thrust of the river, Morison determined that its foundation could be constructed more economically using piles. In September an open pit was excavated from which the timber piles were driven through the sand using a steam pile driver provided by the railroad. When the first boiler proved inadequate to drive the machine, a Northern Pacific locomotive was parked alongside the pit to provide steam. Workers drove the piles, cut the log tops to a uniform height, and built a cribbed timber grillage into which they poured concrete. The stonemasons began work on the four piers in mid-January. By June 1882, the last stone was set. The Saulpaughs had completed the substructure, over sixty million pounds of stone and concrete, and the Bismarck Bridge was ready for a superstructure.

Unfortunately, Detroit Bridge and Iron was not. Although the bridge company included a print of the Bismarck Bridge in its advertising (shown in Figure 37), it proved woefully inadequate on the superstructural fabrication. The bridge company had subcontracted with Andrew Kloman of Pittsburgh to supply the steel. Kloman himself had died a few months earlier, and his two sons in turn contracted with the Pittsburgh Bessemer Steel Company, a new firm whose works had been designed by Kloman, for the actual production. Morison approved the sub-subcontract early in 1881, but later grew to regret his decision. "The manufacture of the steel proved a source of very great trouble and delay," he wrote, "the difficulties being due in part to the inexperience of the manufacturers, and in part to other circumstances which were wholly inexcusable."[115] When the first sample Bessemer steel bars failed to meet Morison's

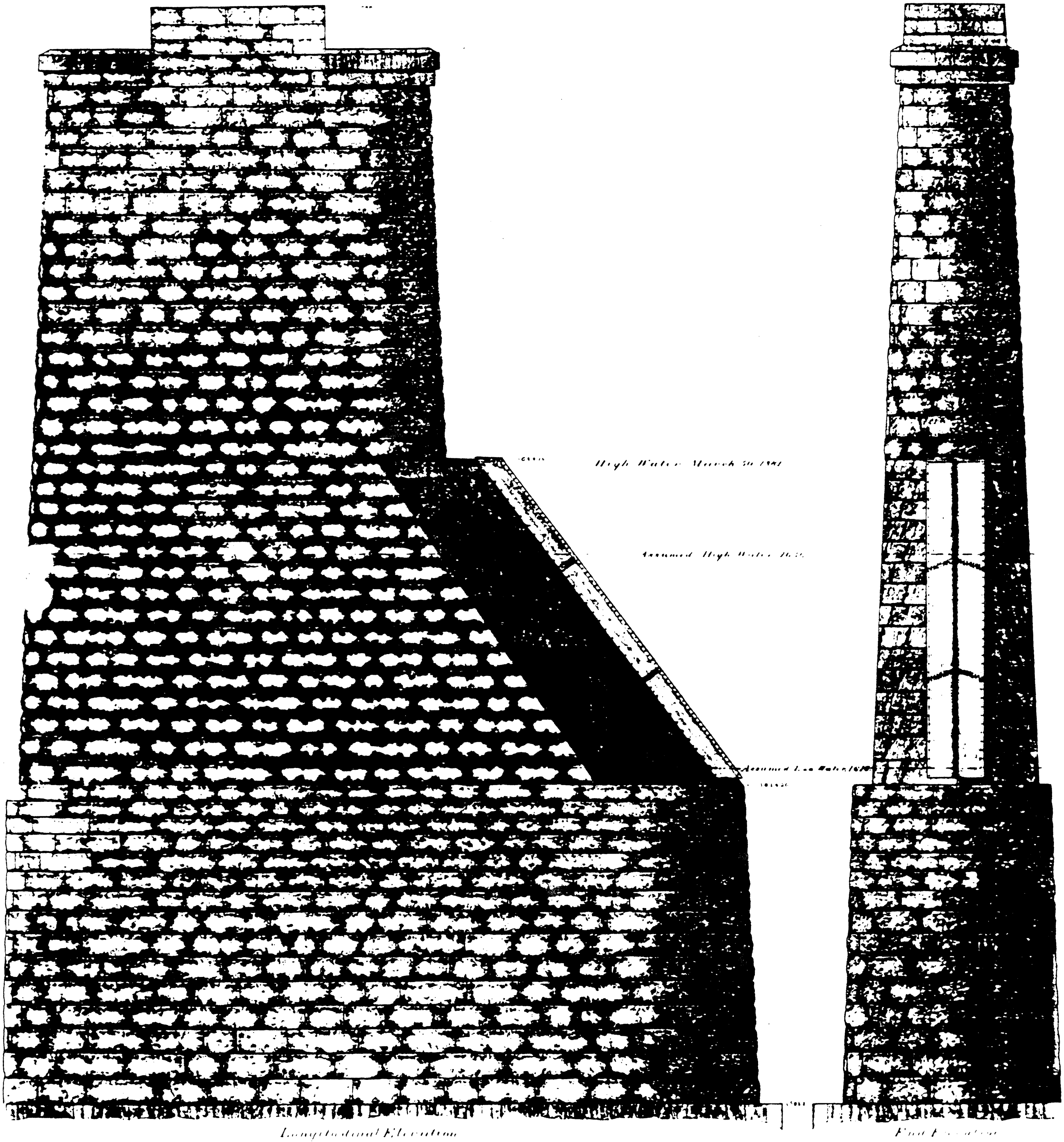
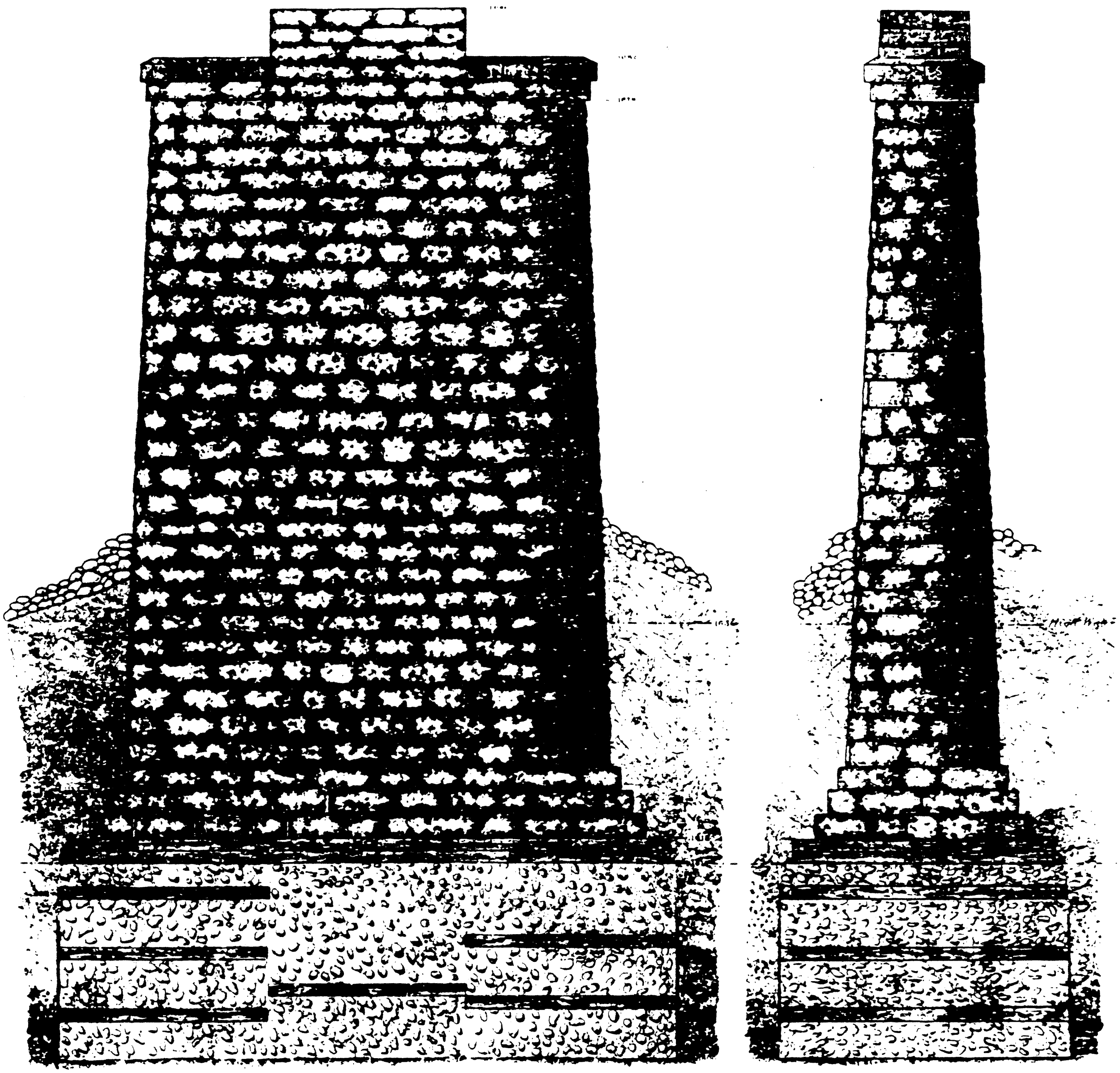


Figure 33



Longitudinal Elevation

End Elevation

117

Figure 34

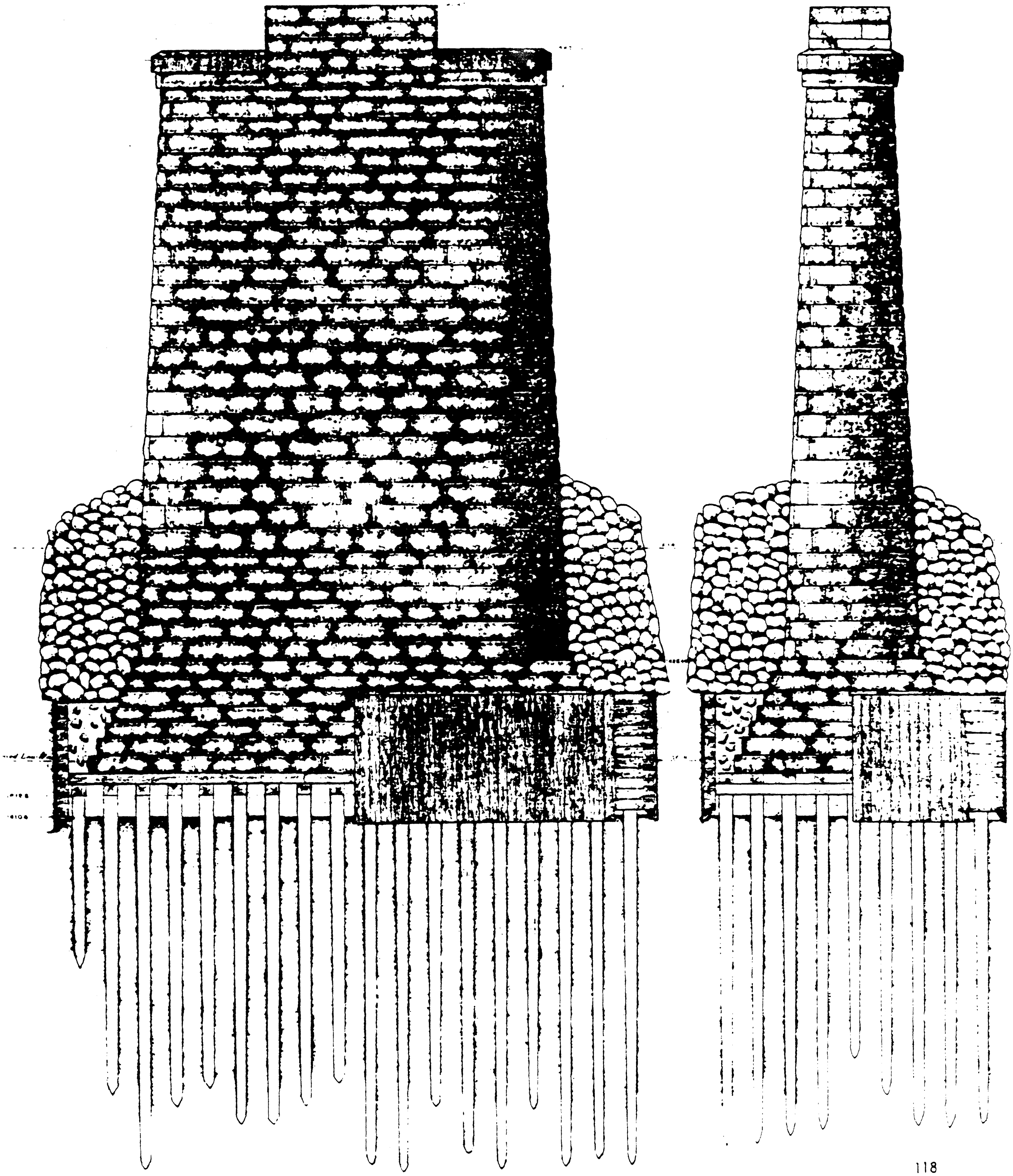


Figure 35

specifications in April 1881, he rejected the entire 9-ton melt, and a set of samples from a second pour was submitted. This also was very irregular in character and proved no better than the first.

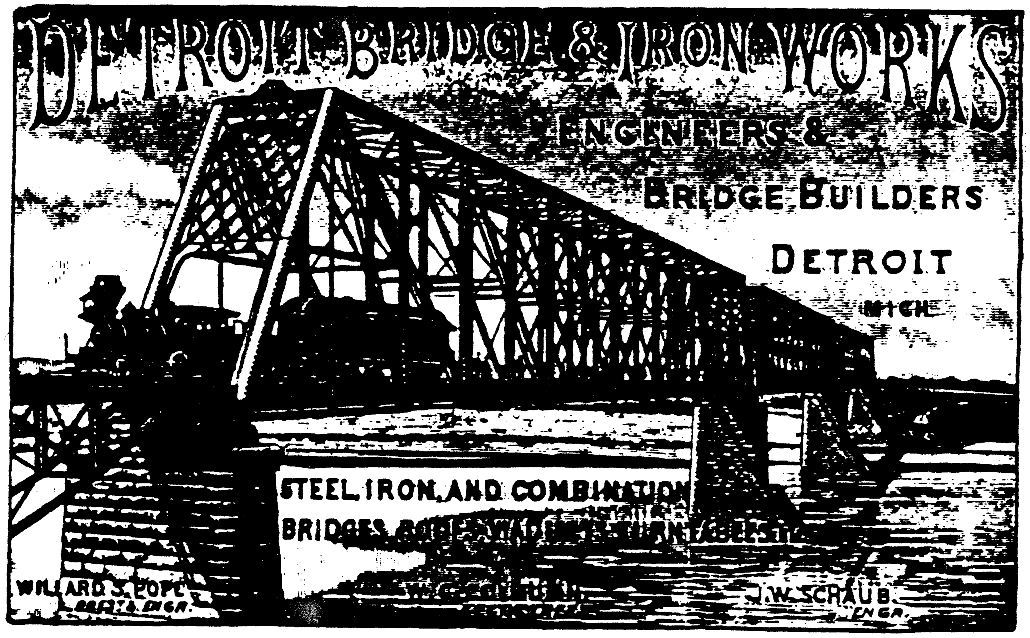


Figure 36 [119]

Between April and November, 1881, Pittsburgh Bessemer produced 235 melts of steel for the Bismarck Bridge. Of these, Morison rejected all but thirty-seven - an 85% failure rate - because the test samples displayed alarming irregularities in elastic limits and ultimate strength. He accepted a few of the melts for fabrication into compression members, but he rejected virtually all of the tension steel in the ingots, which were honeycombed with blow-holes. The total amount of Pittsburgh Bessemer steel approved for the bridge was fifty-eight tons - less than 3% of the material produced by the mill.[120]

The directors of the steel company tried to excuse the repeated failures by saying that their chief chemist had been involved in an accident and had been incapacitated during all of the Bismarck pours. Their inept excuse-making amused Morison at first, but ultimately he was unimpressed by their performance and treated the company with the same disdain he had directed toward the bridge laborers. "To make a uniform product of Bessemer steel, suitable for bridge purposes, requires no ordinary skill," he said, "but it was evident that the company made little or no effort to furnish the material according to the specifications, finding that they could make more profit by making steel rails."[121] Pittsburgh Bessemer Steel was dismissed. The Bismarck Bridge would be built using open hearth steel from another mill.

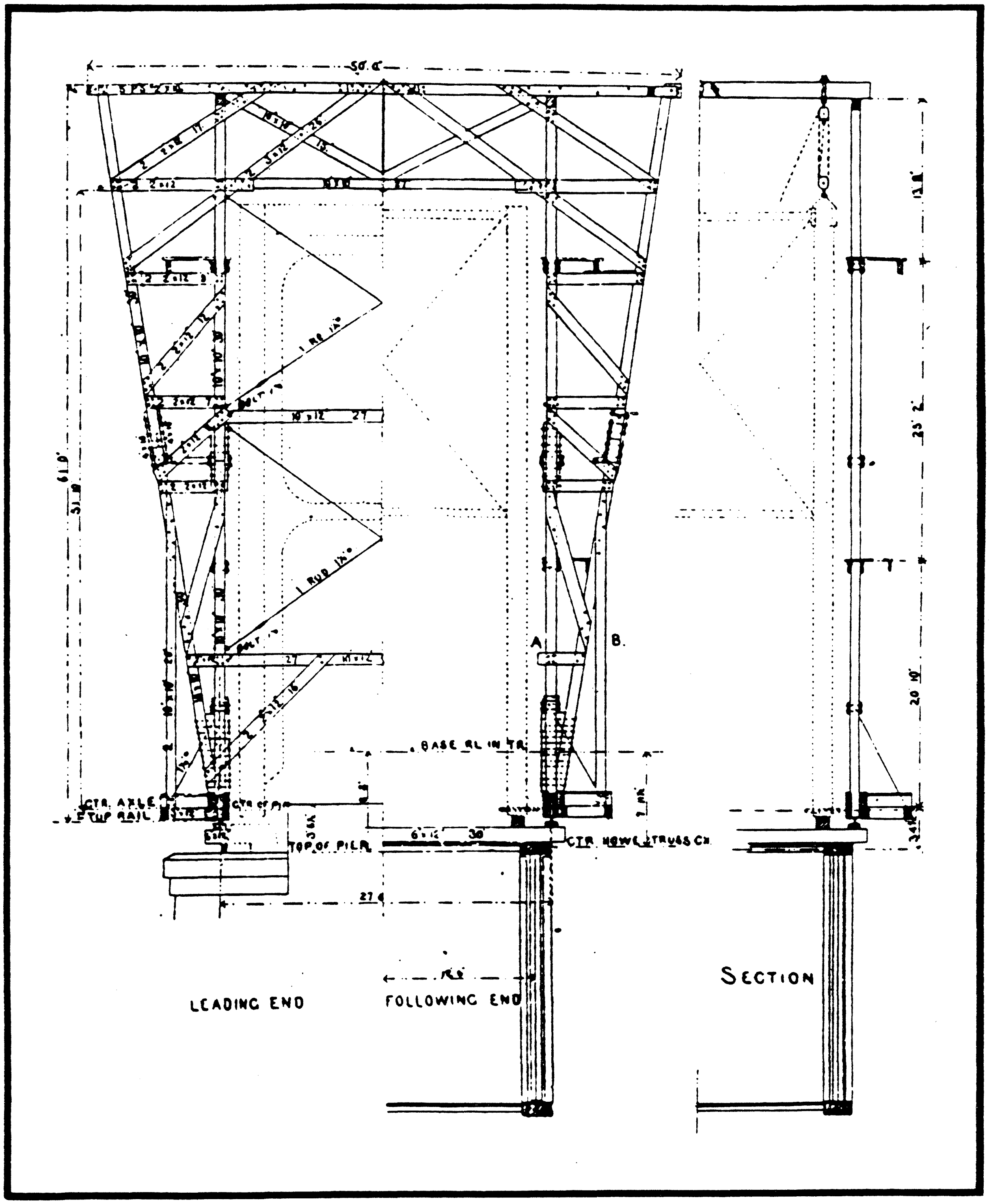

50.0
A
B.
BASE RL IN TR.
CTR. AXLE
TOP RAIL
TOP OF PIER
CTR. HOWE TRUSS CH.
LEADING END
FOLLOWING END
SECTION

Figure 37

All the established open hearth mills were previously committed, so Morison ordered the steel from Spang Steel & Iron Company, a new firm on the west bank of the Allegheny River near Pittsburgh. As he had for the Plattsmouth Bridge, the engineer subjected the steel to extensive testing and experimentation to determine its limits of strength. Because the class of steel furnished for the tension members was much lower than that which had previously been used for bridges, he ordered that the eyebars be strengthened by annealing. This was done by placing the bars side-by-side on small brick piers, building a wood fire under them, covering them with sawdust, heating them to a uniform temperature, and finally allowing them to cool slowly. Full-scale eye-bars were tested at the Watertown Arsenol, where Morison experimented with annealed, unannealed, and partially annealed material. Despite the vastly improved performance of Spang over the Bessemer mill, the meticulous engineer rejected a disproportionately high percentage of the steel produced: 23% of the compression steel and 61% of the tension steel outright. And of the material that passed this initial scrutiny, Morison ultimately accepted only an average of 4.4 tones per 9-ton melt of tension steel and only 1.9 tones per melt of compression material. The last shipment of steel was made in June 1882 - eighteen months after the initial contract and almost a year late.[123]

With the arrival of the metal components on site, Detroit Bridge could finally begin erection of the immense superstructure. Company ironworkers erected the east approach span for the bridge in April and May. At the same time, carpenters built a timber traveler, 61 feet tall by 30 feet long, to assist the construction of the main through trusses. The rolling derrick (shown in Figure 38) served as a work platform for the truss erection and lifted iron and steel bridge components into position using a pair of hoisting engines mounted on a railroad flatcar. The traveler was longer than each of the bridge panels so that four vertical posts of the truss could be erected and the top chords coupled without moving the platform. Moveable bracing of cross timbers and iron diagonal rods was attached to each end of the assembly structure. Workers could remove part of the bracing during construction of a bridge panel, and to roll the traveler around assembled parts of the trusses, the men removed the bracing entirely.

Morison specified the same trussed falsework as he had on the Plattsmouth Bridge for the two easterly through spans at Bismarck. For the third long span, situated over a sand bar, he used a single timber Howe truss in tandem with a driven pile trestle. Laborers first erected three timber Howe trusses on pile bents beneath the first long-span Whipple truss. With the staging trusses in place, the erection crew positioned the lower chord bars on July 26th, beginning the work on the main superstructure. Two days later, the ironworkers had coupled the lower chord and had laid a temporary track for the traveler. They rolled the assembly structure to the center panel point of the truss and erected the two center posts.

Over the next week, the men assembled the immense iron span, working from the center to the east end and then back to the west end. By August 12th, all the chords, columns, and diagonals were coupled and the first span was ready to be swung from the staging trusses. Four screw jacks had been positioned under each of the Whipple truss panel points during erection, and on whistled signals, 104 workers cranked them all in unison to lower the bridge. The carefully choreographed process took about thirty minutes to complete. Morison had designed the iron truss so that no field riveting was necessary before the structure was swung from the falsework. After the release, all the connections and the top lateral system were completed. Work progressed rapidly through the summer and fall on the other spans using the same erection system. Eight weeks later, on October 7th, the superstructure was complete.

The first test train - twenty-five empty stock cars pulled by a single locomotive - crossed the Bismarck Bridge on October 8th, 1882. A week later, the bridge was formally tested before a group of six independent engineers. The test load consisted of eight Mogul locomotives with a combined weight of a little more than five hundred tons. The bridge deflected well within the design limits, and the engineers proclaimed it eminently satisfactory. Morison instructed the contractors to remove the falseworks. In January, the heavy iron ice breakers were mounted on the raking upriver faces of the piers, and in the spring of 1883 the superstructure was painted with two heavy coats of Cleveland Iron Clad Paint. Almost ten years late and costing almost $1.1 million, the Northern Pacific had finally bridged the Missouri River at Bismarck.

BLAIR CROSSING BRIDGE

The bridges at Plattsmouth and Bismarck represented important structural accomplishments, notable among engineering professionals and the railway companies. With them to his credit, George Morison was soon approached by a third railroad. Pneumatic work was well underway at Bismarck in November 1881 when the engineer met with the directors of the Sioux City and Pacific Railroad, a regional carrier originally chartered in 1864 to link Sioux City with the Union Pacific transcontinental line. The railroad officials met Morison at the site of the existing SC&P ferry over the Missouri River near Blair, Nebraska. Situated some fifteen miles above Omaha, this crossing between Nebraska and Iowa was operated by the Missouri Valley and Blair Railway and Bridge Company, a 3.4 mile-long subsidiary of the SC&P, as a temporary staging point to load trains aboard transfer boats for passage across the river. But like all railroad transfer operations along the Missouri, the Blair crossing had severe limitations. MV&B President Marvin Hughitt intended to replace the steamer boats with a permanent span over the river.[124]

Although the Blair site was somewhat remote, it was seated in the lap of civilization compared to Bismarck. Scheduled to be the eleventh major span over the Missouri River, this Nebraska bridge was one of several structures erected in the stretch around Omaha and Kansas City. Blair Crossing, as the name implies, was little more than a rural river crossing - situated almost twenty river miles north of Omaha, the nearest major settlement. In this, the site differed from the that of the Dakota bridge and virtually all of its Missouri River predecessors which were located at railroad junctions in the river towns. The Blair site differed from the others in a more critical topographical aspect: the river there was not bounded by a bluff on either side for miles above or below. The Missouri River at Blair was therefore subject to dramatic changes of course (shown in Figure 39), even more than usual for the restless watercourse. The most recent of these had occurred just earlier in 1881. "The fact that the Missouri runs for so great a distance here without striking the bluff makes its regimen unusually irregular," Morison wrote, "there being no positive fixed points to exercise a corrective influence... While control of the river might be unusually difficult, the construction and maintenance of the bridge itself would be a comparatively simple thing."[125]

Morison's system of design was by then becoming routine. On November 18th he met with SC&P Chief Engineer J.E. Ainsworth on the site. The two men commandeered one of the MV&B transfer steamers and made a quick reconnaissance of the Missouri River above the loading wharf. At that time Morison selected two tentative bridge locations, ordering borings and surveys at each. In January 1882, he returned to the site for a second inspection. The following month, the engineer submitted a report to SC&P president Horace Williams, recommending

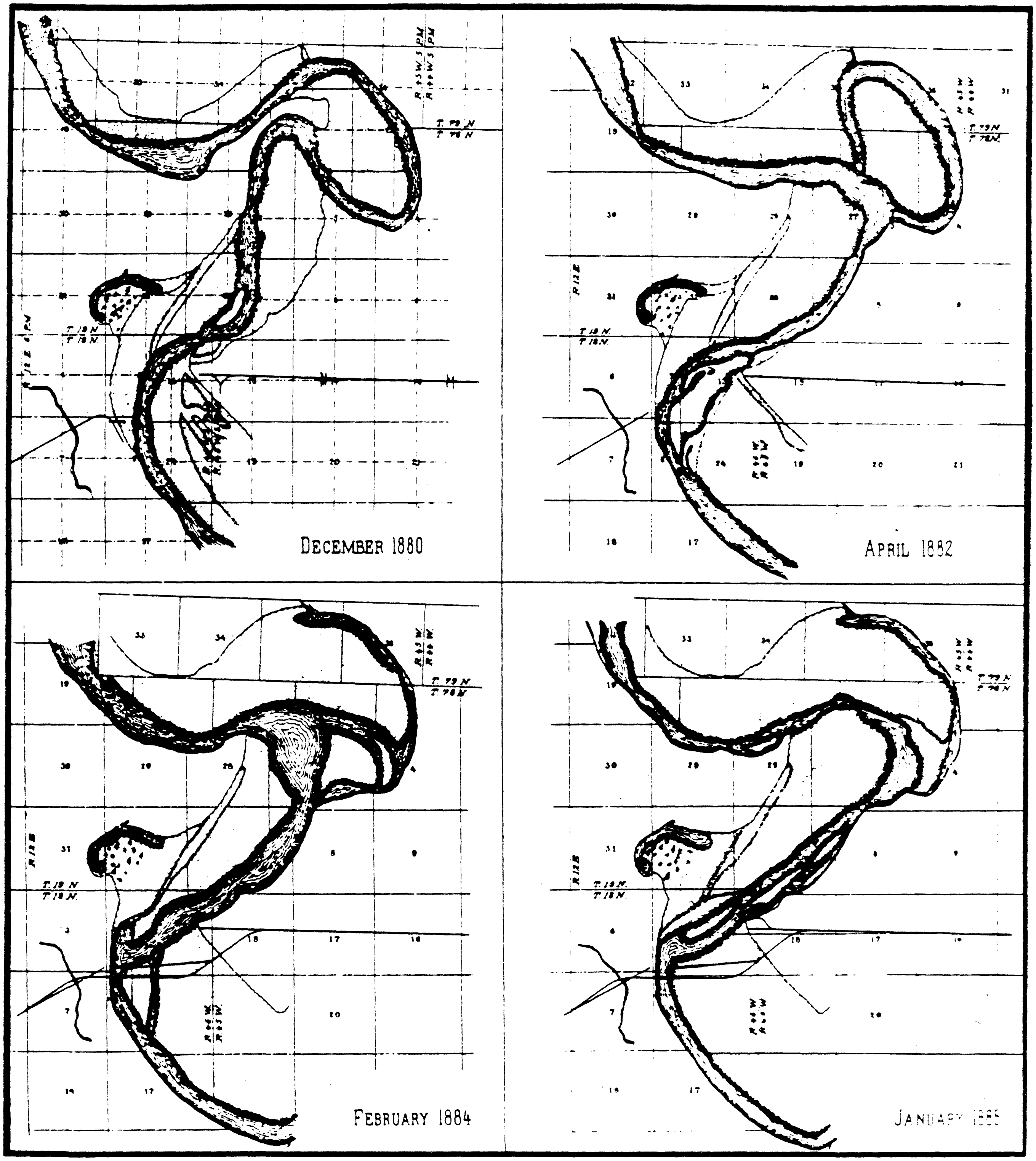


Figure 38

construction of a high, fixed-span bridge with extensive shore protection on both sides of the river.[127]

Without formal engineering training, George Morison had educated himself by studying structures designed by other engineers. He maintained a collection of others' bridge drawings and specifications and routinely visited other bridges over the Missouri River. He typically approached his own bridge design by comparing his projects with those of others and by observing the specific characteristics of the river at each bridge site. Morison arrived at the design and overall dimensions of the bridge at Blair Crossing in this manner. Drawing upon his extensive knowledge of the vagaries of the Missouri River and bridge specifications at other points, he concluded:

> The plan adopted for the bridge provided for a bridge across the river 1,000 feet long, and of a height that would give clear head-room of 50 feet between the lower chord and high water. High water was determined, not from any particular flood, but by a careful comparison with other bridges which are intended to give the same head-room: the heights of a long series of flood waves at the Blair Crossing were compared with the heights of corresponding flood waves at Plattsmouth, and the clear height above these flood waves was made as nearly as possible the same as the clear height above the corresponding flood waves at the Plattsmouth bridge. That the width of 1,000 feet is enough to pass the Missouri is shown by the fact that, at a number of points below this bridge, where the channel has been constant for a long series of years, the river has itself reduced its width to less than a thousand feet, by raising the bottom land to the high-water level. All of these narrow points occur at places where the river runs along a bluff, and generally where the bed-rock is not as deep as at the Blair Crossing bridge. The high-water width, selected by the Government engineers as that most consistent with stability on this section of the river, is but a trifle more than 800 feet.[128]

Because of the poor topography and subsoil conditions at the Blair site, the engineer investigated an alternate crossing for the railroad at the nearest bluff site upriver: Decatur, Nebraska, some fifty miles away. But the river bottom at the Decatur crossing proved even worse than Blair, and in April 1882 Morison made a second report to Williams recommending the bridge be located 500 feet north of the original location (shown in Figure 39). When the enormously expensive rectification work along the low riverbank and foundation work for the structure began later that year, however, he soon "regretted that the original location was not adhered to," as he later reported candidly to the directors of the railroad.[129]

On June 27th, 1882, Congress authorized construction of the Blair Crossing

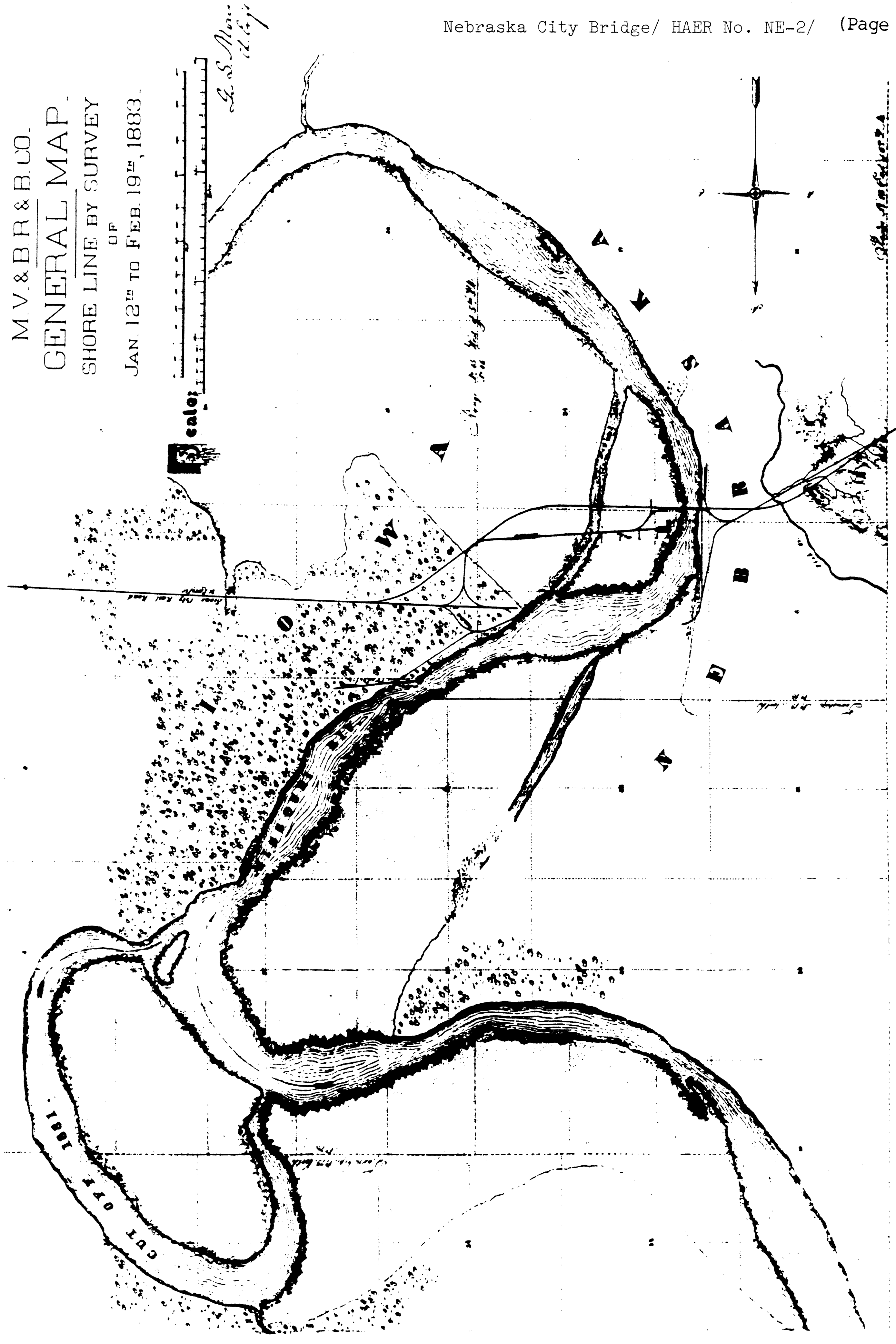

M.V. & B R R & B CO.
GENERAL MAP
SHORE LINE BY SURVEY
OF
JAN. 12TH TO FEB. 19TH, 1883.
Scale:
IOWA
NEBRASKA
CUT OFF 1881

Figure 39

Bridge, and within the week George Morison presented drawings of the proposed structure to the Secretary of War in Washington. A month later, General Wright, Chief of Engineers of the U.S. Army, approved the engineer's design. Morison had by then begun to marshal employees and contractors to erect the monumental structure. Among the key people he gathered around himself were some familiar faces. H.W. Parkhurst and C.C. Schneider, veterans of both the Plattsmouth and Bismarck projects, were once again retained as First Assistant Engineer and Assistant Engineer of the Superstructure, respectively. S.W.Y. Schiminsky had drafted the construction drawings for the Bismarck Bridge and would draw the Blair Crossing Bridge as well. The contractors also had worked with Morison on either or both of the earlier projects. After competitive bidding, Morison awarded the contract for the stonework to Saulpaugh and Company, masonry contractors for both other bridges, and selected the Keystone Bridge Company, fabricator for the Plattsmouth Bridge, to fabricate the superstructure. The Baird brothers would once again erect the immense through spans over the river channel.[131]

The engineer adopted a familiar design for the superstructure as well. Like the Plattsmouth and the Bismarck bridges, the three main spans of the Blair Crossing Bridge (shown in Figures 41-44) were pin-connected Whipple through trusses with a single-track width. The only discernible difference was the length of the channel spans: each simply supported structure extended 330 feet and was subdivided into fifteen double-intersected panels of 22 feet each. The total length of the channel spans, from pin to pin, was 999 feet - just a foot short of Morison's original plan. Reflective of the heavier locomotives used by the railroads, the Blair Crossing Bridge was engineered to carry a moving live load of 3,000 pounds per linear foot - 50% stronger than either of its predecessors - and was correspondingly heavier than the two others (shown in Figure 45).

A less noticeable difference between this bridge and the one at Bismarck lay in its steel content. After decreasing the amount of steel substantially between his first and second structures, Morison increased the percentage on the third. The top chords, end posts, bolsters, rollers, bearing plates, pins, and eyebars in the central nine panels of the bottom chord were designed for steel, with the remainder of the bridge made up of wrought iron. Of the 2.4 million pound aggregate weight of the three through trusses at Blair, 884,548 pounds, or 37%, were rolled steel. The remainder of the superstructural weight was made up of wrought (60%) and cast (3%) iron. The approach spans on both ends were Pratt deck trusses: a 110-foot, 5-panel span on the east end (shown in Figure 46) and a 176-foot, unsymmetrical 8-panel span on the west (shown in Figure 47). Like Plattsmouth and Bismarck, their steel content was substantially lower than that of the main trusses: only three percent of the total weight. The metallic composition of the Blair Bridge is given in the table on the following page:

Through Trusses:

	Total three spans	Average per span	Percentage
Steel	884,548 pounds	294,849 pounds	37%
Wrought iron in trusses	1,012,343 pounds	337,744 pounds	42%
Wrought iron in floor	434,805 pounds	144,935 pounds	18%
Cast iron	57,322 pounds	19,107 pounds	3%
Total	2,389,018 pounds	796,635 pounds	

Deck Trusses:

	110' span	176' span
Steel	4,979 pounds	6,753 pounds
Wrought iron	110,503 pounds	238,550 pounds
Cast iron	8,955 pounds	4,325 pounds
Total	124,437 pounds	249,628 pounds [132]

The engineering completed and the contractors on the job site, work could begin on the channel rectification. As Morison had predicted, construction of the bridge itself would prove far easier than the work needed to control the river at its base. The volatile nature of the Missouri River required that channel and shore protection works be built for virtually all structures built on or over it. To insure steamboat access to remote posts in Dakota and Montana, the Army Corps of Engineers had begun river improvements in the 1870s. After first surveying its length, Corps engineers modified difficult stretches by removing snags and obstructions, altering the river course with blasting and filling, and building "training structures" - dikes and jetties angled into the river to divert the current away from shoreline and form a passable channel. But the Corps' efforts were directed almost exclusively to maintaining navigation on the river. Rectification for an individual bridge was the responsibility of the railroad.

Because of its unusual nature, the Blair site would prove more problemmatical than that of other bridges along the Missouri. The rectification to control the river there involved three separate areas: a dike on the east shore and upriver riverbank consolidation on both east and west shores. Morison designed the east shore protection to fix a point on the riverbank beyond which the channel would shoot directly to the upper end of the west shore protection. The dike was intended to close any high water secondary channels in the river. He designed the west protection to hold the west bank and convert the friable bottom land into the equivalent of a permanent bluff shore.[133]

Workers began building the east shore protection in the summer of 1882. Using the existing piles of the transfer boat landing as an anchor point, they dumped wired bundles of brush and stone onto the riverbank and covered them with heavy

M.V.& B.R.& B.CO.

GENERAL ELEVATION & PLAN OF 330 FT SPAN

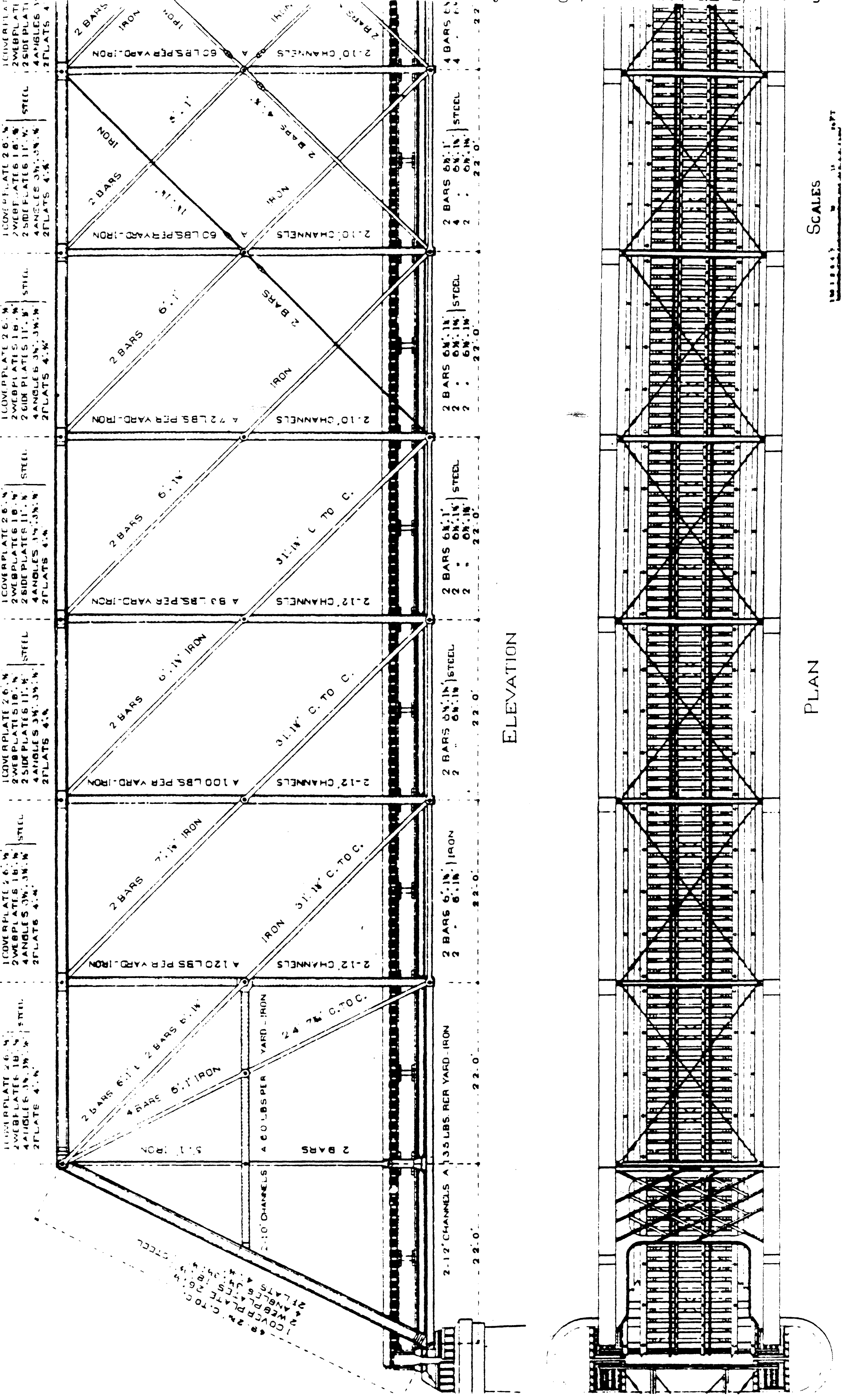


Figure 40

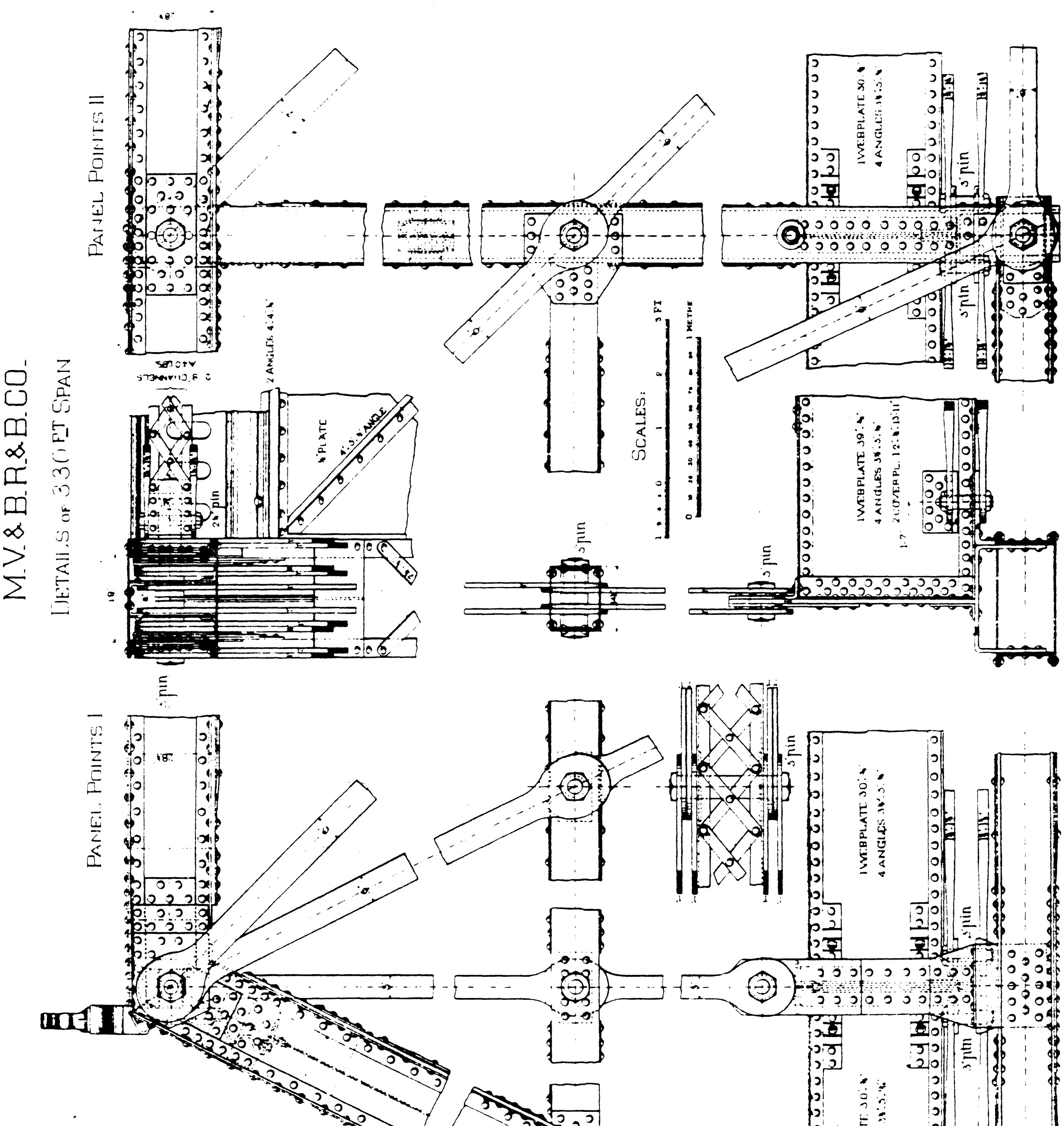

M.V.& B.R.& B.CO.
DETAILS OF 330 FT SPAN
PANEL POINTS II
PANEL POINTS I
SCALES:

Figure 41

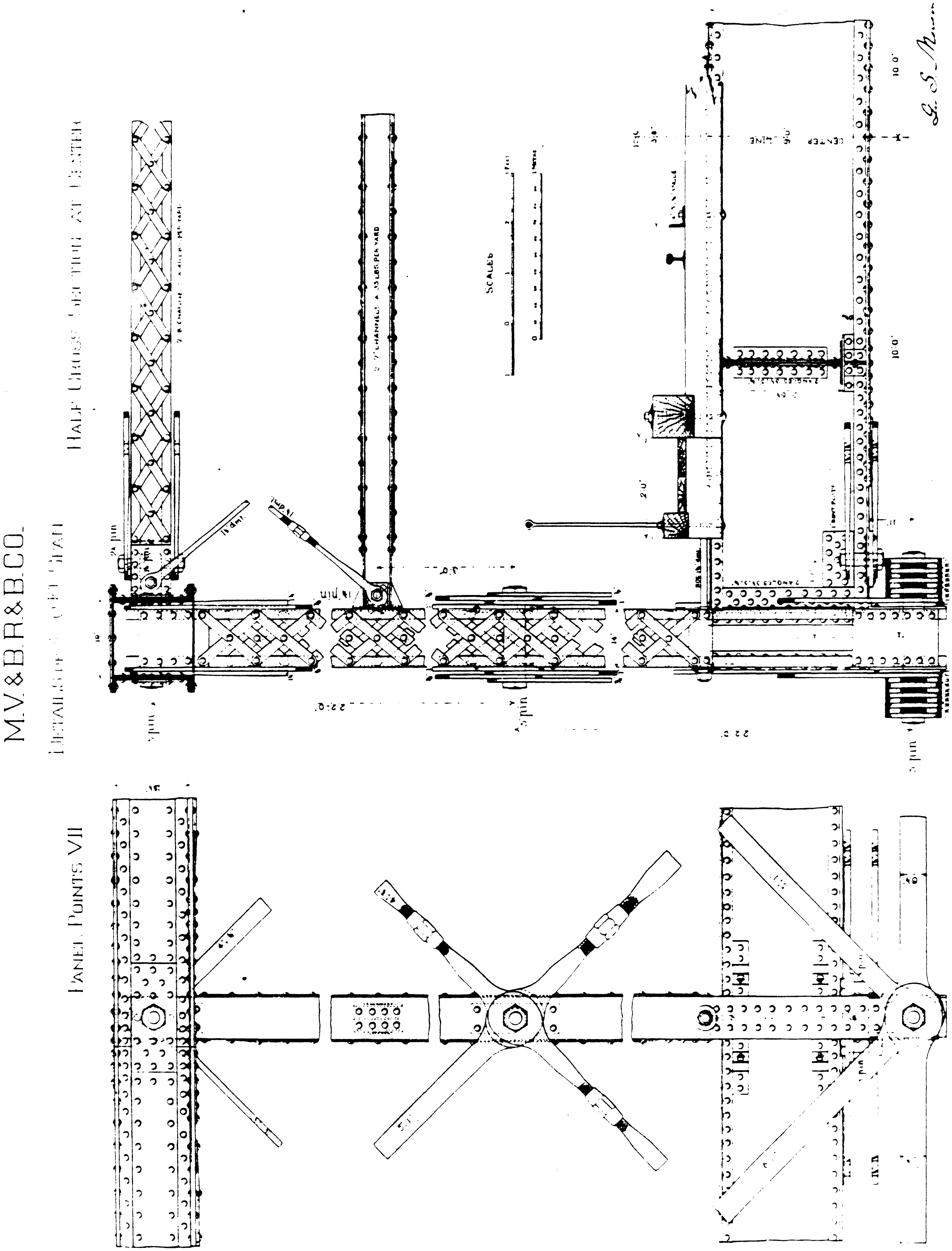


Figure 42

HAER, NEB, 66-NEBCI, 5-

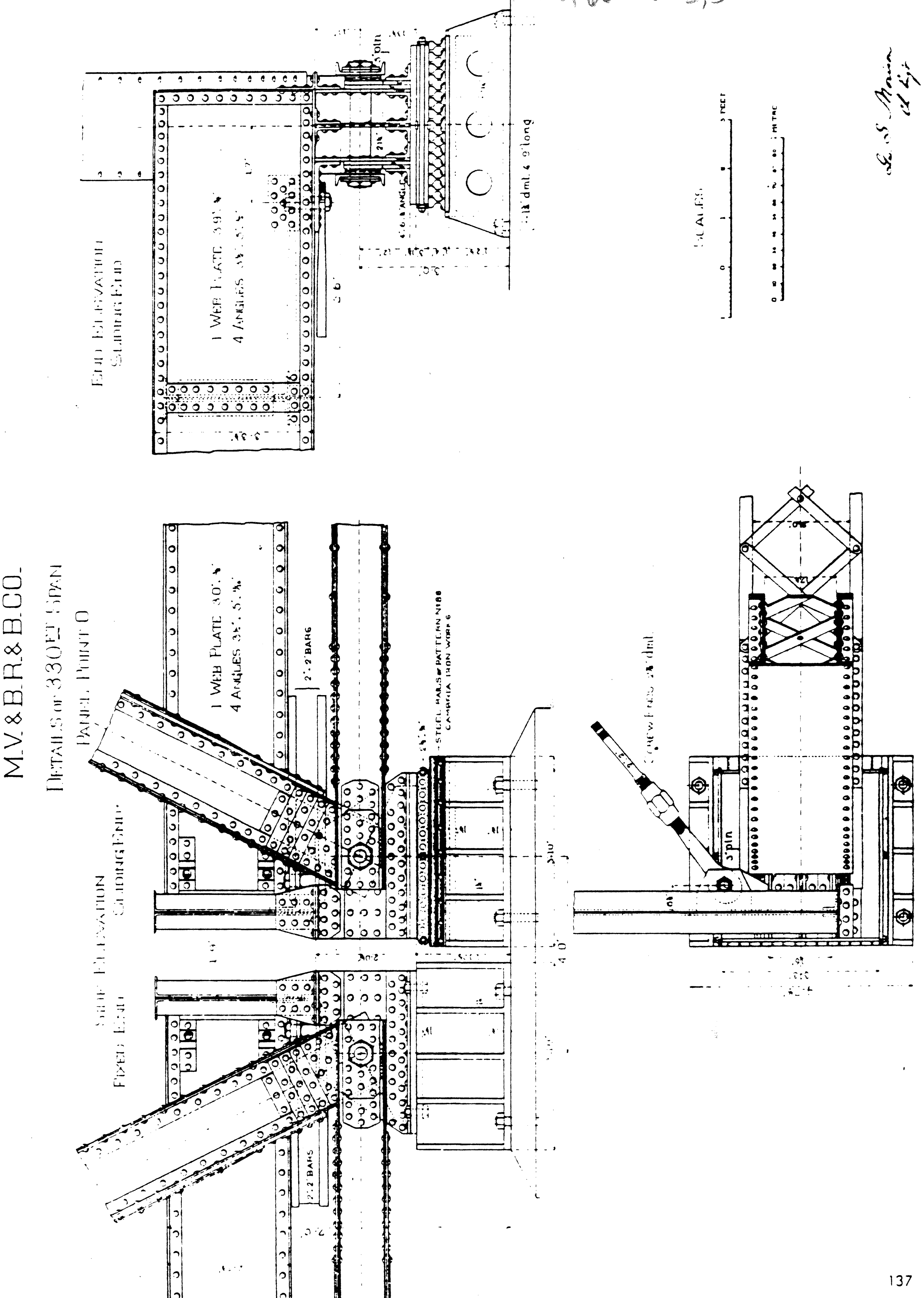


Figure 43

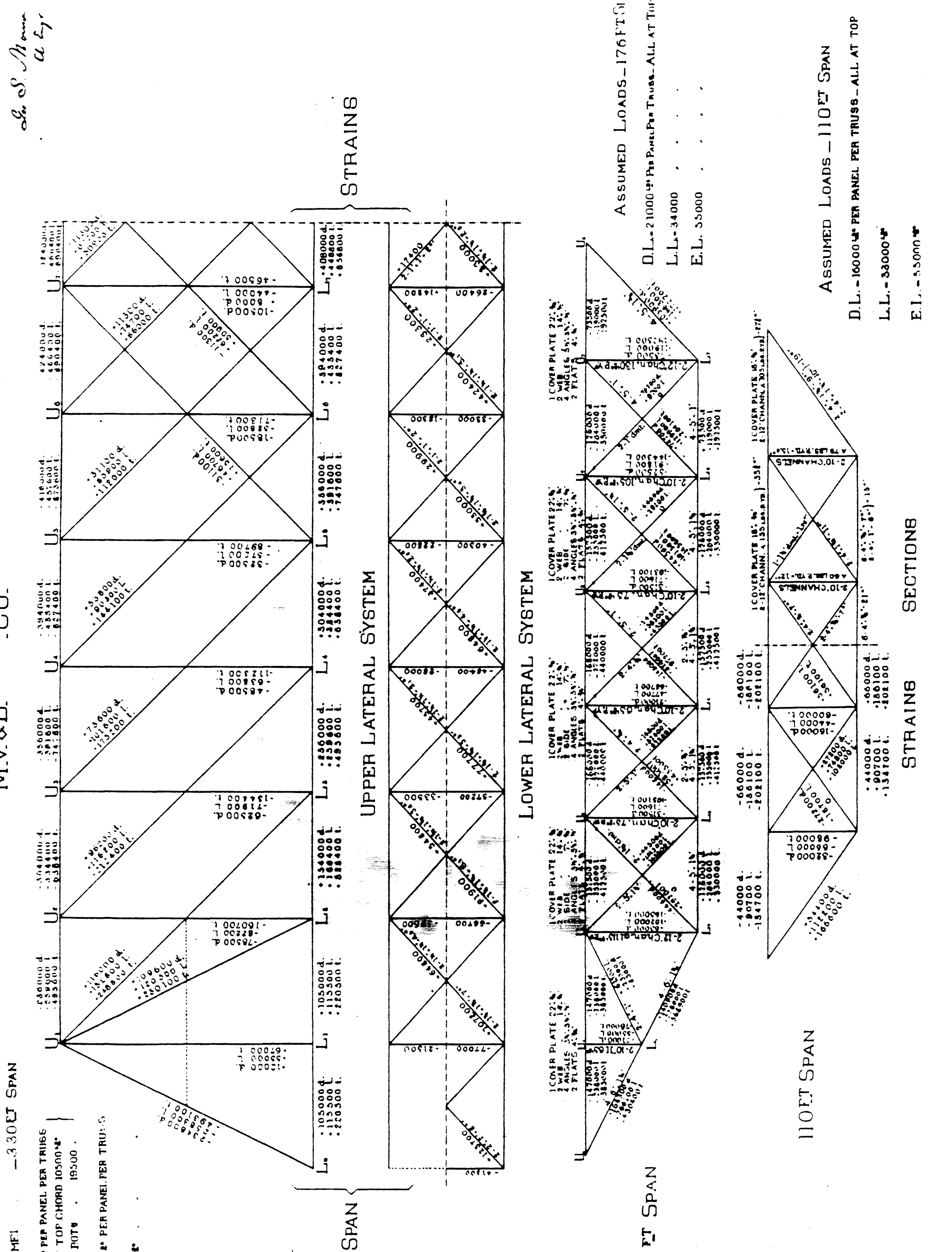

M.V.&B. CO.
STRAINS
UPPER LATERAL SYSTEM
LOWER LATERAL SYSTEM
330 FT SPAN
ASSUMED LOADS _ 176 FT SPAN
D.L. - 21000 # PER PANEL PER TRUSS _ ALL AT TOP
L.L. - 34000
E.L. 55000
176 FT SPAN
ASSUMED LOADS _ 110 FT SPAN
D.L. - 16000 # PER PANEL PER TRUSS _ ALL AT TOP
L.L. - 33000 #
E.L. - 55000 #
STRAINS
SECTIONS
110 FT SPAN

Figure 44

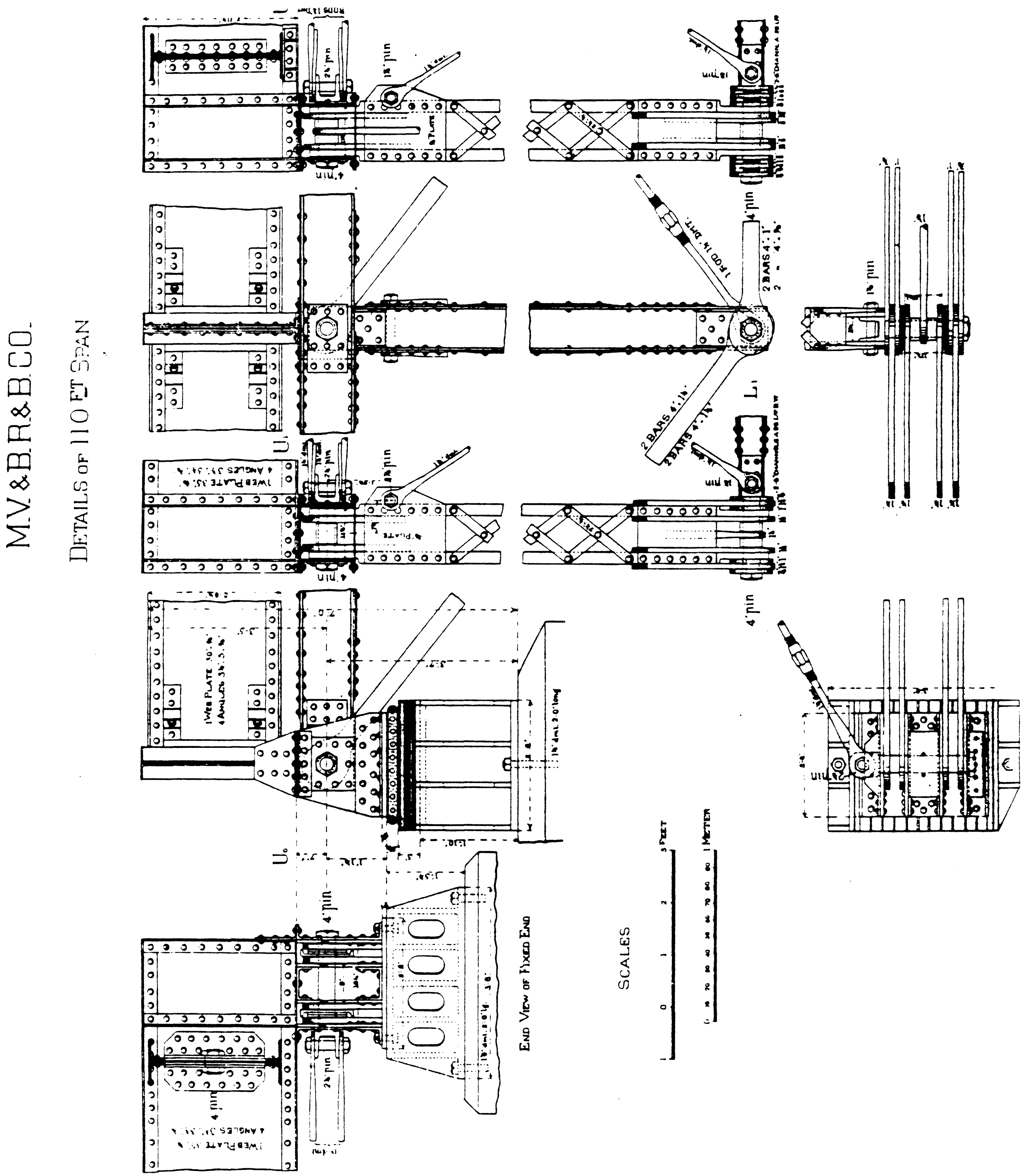


Figure 45

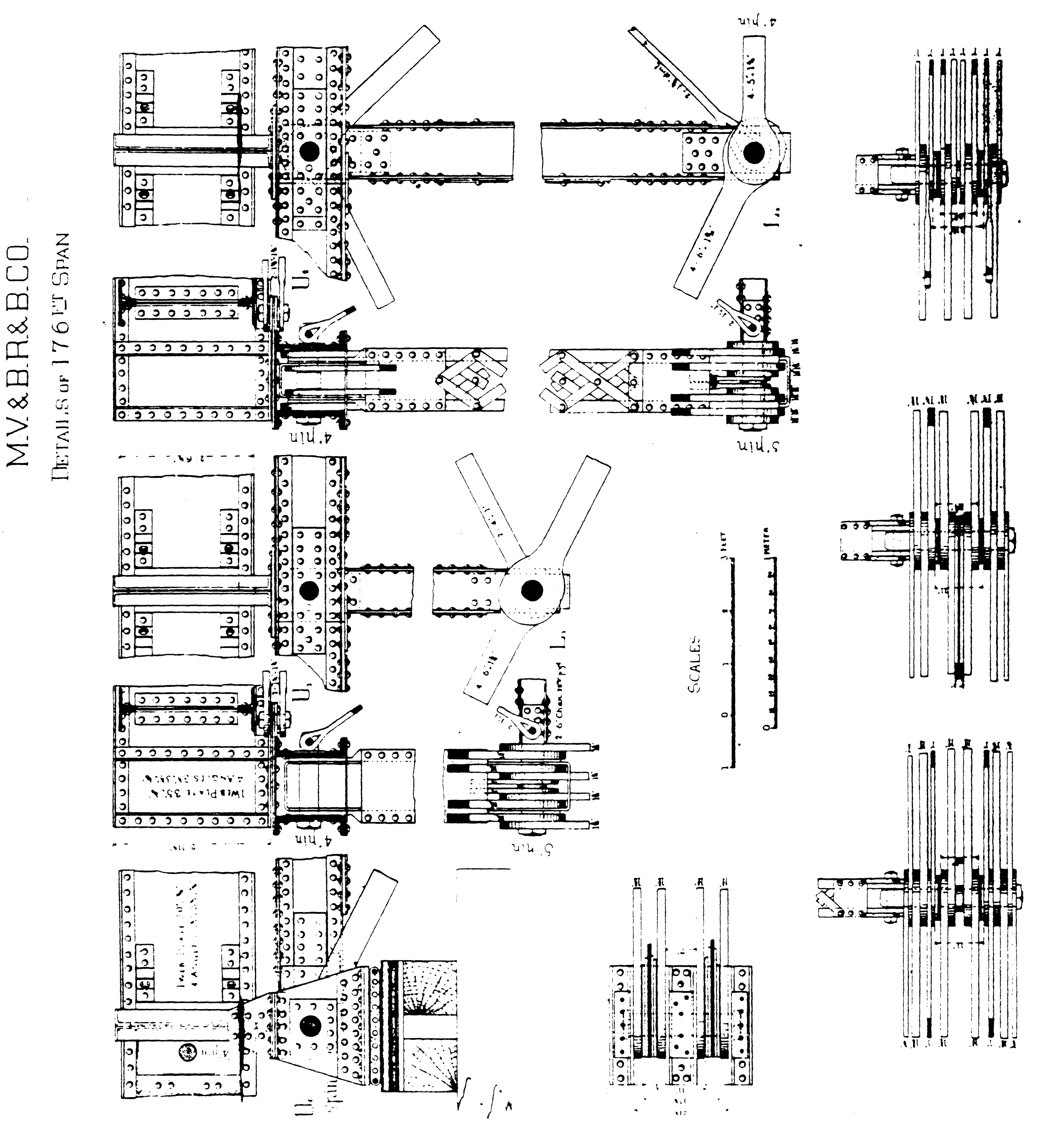


Figure 46

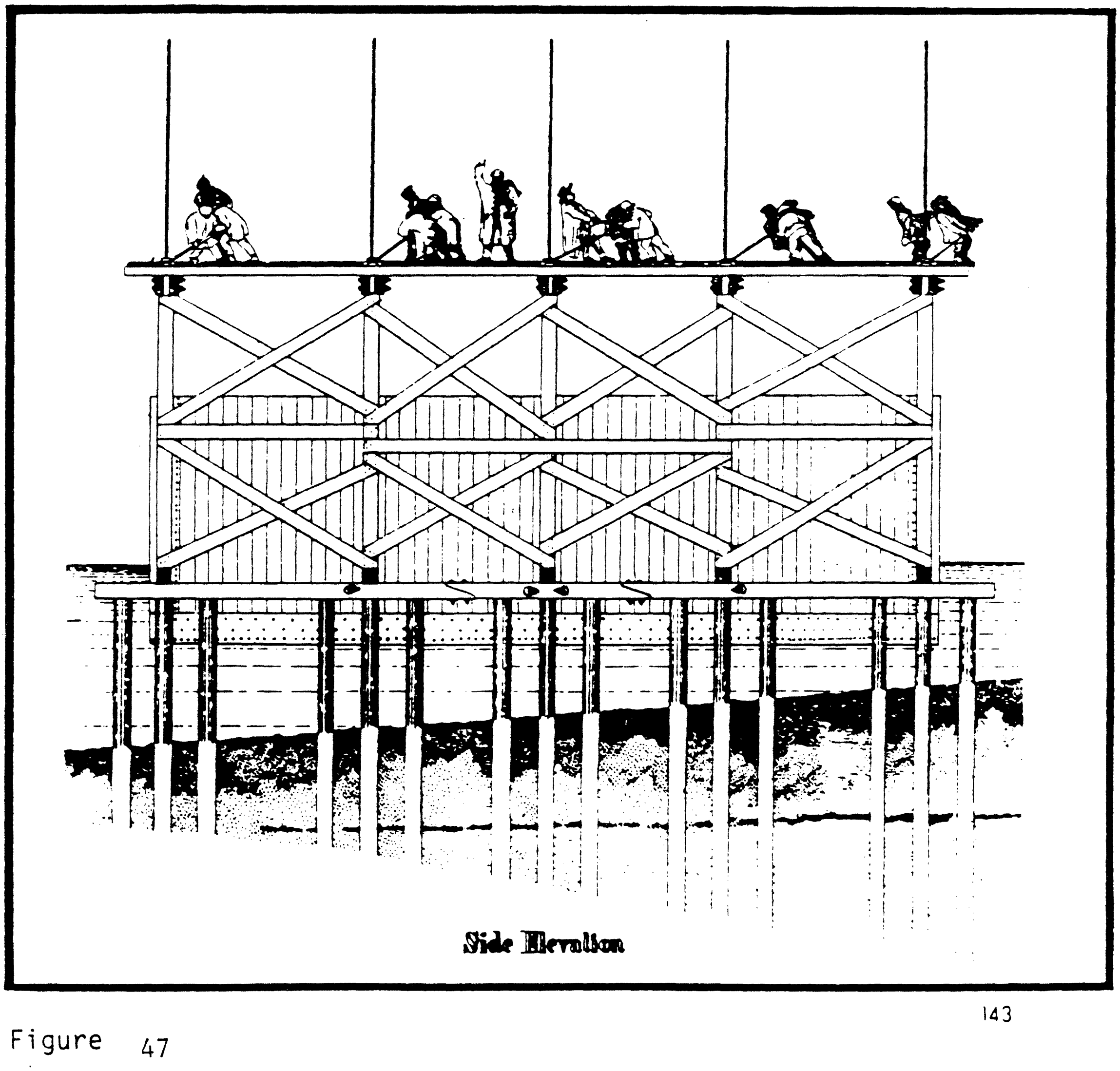
stone riprap. The western shore protection was built in the same manner, with the stone bundles stacked into a ten-foot-deep trench dug along the shoreline for additional scour resistance. Morison situated the dike six hundred feet above the bridge line, extending from the west bank; its westerly portion was made up of a woven willow mattress loaded with stone. To form the mattresses, workers first laid strands of brush five feet apart and interlaced them with twisted wires. They then drove wooden stakes at regular intervals along the strands, to which they twisted more wire. More brush was laid over the strands at alternating right angles, more stakes driven, and more wire attached. The men finally covered the mattress with sand to increase the weight and protect it from fire and covered the dike with riprap stone.

The cost of the extensive rectification work for the Blair Crossing Bridge proved to be inordinately high: over $400,000. This was due primarily to the sheer bulk of work necessary to control the river at the base of the bridge. The east shore protection required some 6,000 cords of brush and over 36,000 tons of stone; the dike, 9,300 cords of brush and almost 48,000 tons of stone. To make matters worse, no suitable stone for the riprap could be found locally, and the railroad was forced to import it from quarries along the Platte near Louisville, Nebraska, along the Missouri at Sioux City, and from the Le Grand quarries in eastern Iowa. Finally, the construction method that Morison used increased the cost considerably. "It was felt that it must be done in the most thorough manner," he reported to the railroad, "and that mattress protection, such as may be used safely where the only object is to regulate the course of the river, but which is liable to injury and temporary destruction, was not sufficiently permanent in its character to trust to hold the bank of a river where the preservation of a bridge depended on holding this bank in exactly the right place." Morison concluded, "The experience acquired on this work was very valuable, and undoubtedly it could be done again for a somewhat less sum."[141]

George Morison was characteristically brief in describing aspects of the bridge itself and did not discuss the workers at all in a final report to the railroad company. But he wrote at great length about the rectification works and - his favorite topic of discussion - the Missouri River:

> These works have accomplished their purposes with entire satisfaction, though at greater expense than was originally estimated, except in one respect. During the high-water season the channel of the river runs in an approximately direct course from the upper East Protection work to the head of the West Protection; but during the low-water season the channel becomes so narrow that a much more crooked course is possible than with the greater width of the high-water river. The result is that a series of bends is formed between the upper protection and the end of the dike, which have cut into the bar above the dike, and at times put the main channel of the river immediately along the western part of the dike. This difference in the course of the Missouri at high and low

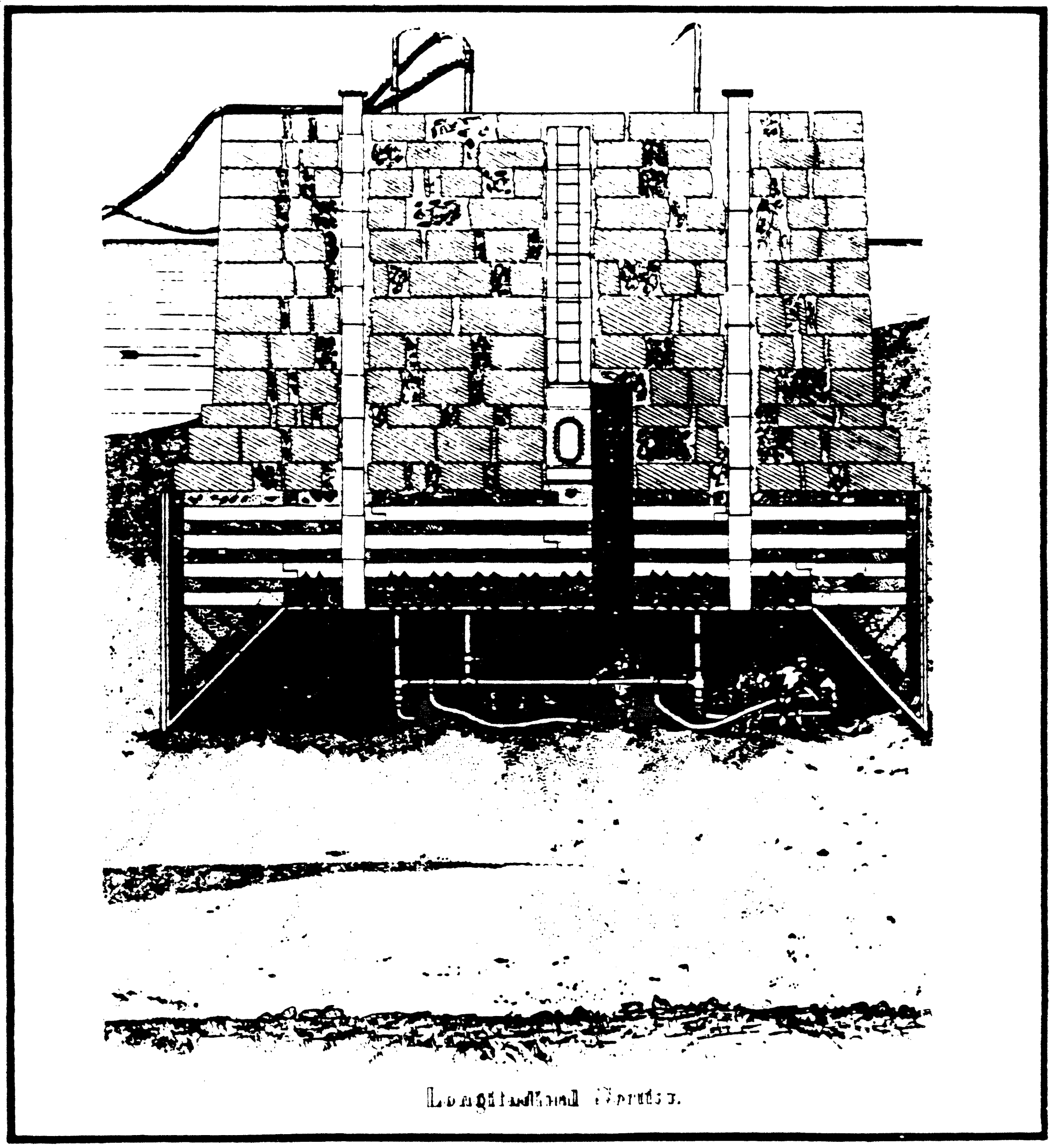
water is a striking fact, which must not be overlooked in a study of the river. The low-water width is often less than one third the high-water width, and the curves which the channel can easily take have a correspondingly less radius at low water than at high water. During the high-water season a channel and a series of shoals are formed which correspond to the dimensions of the river at that time. When the river falls the sandbars are left dry, but the channel begins to form a series a small bends corresponding to its reduced width. As during high water the river has eroded the bottom land on the outside of the larger bends, so during low water it erodes the sand-bars on the outside of the small bends which the low-water channel has formed. With the next flood these distinctive marks of the low river are obliterated, but a similar action occurs again with the next low-water season. As the Missouri at low water is a comparatively small river and the channel not very deep, the peculiar action of the low-water channel can be guarded against, and, if watched, is not a source of special danger; but it must not be overlooked in any plan which contemplates securing a direct channel.[142]



143

Figure 47

Construction on the first immense pier was begun in mid-October 1882. Morison had again specified masonry piers with pneumatic caisson foundations (shown in Figures 48 and 49), built on-site, floated, and sunk at the pier locations. For the first time, though, the engineer took direct control over the pneumatic work, using railroad day labor rather than contracting it out - a more economical system that he would use on all subsequent major bridge projects. In December, the railroad built a winter bridge across the frozen river to move the material and equipment. As the stonemasons labored throughout the winter and spring building the Minnesota blue granite piers, and workers dug in the pressurized chambers beneath the massive caissons, work plodded at mind-numbing pace. In March, the temporary bridge broke up with the ice pack. In May, the piers were completed.



144

Figure 48

The following month, the Baird Brothers' steelworkers erected the eastern deck truss. Steel blooms for the three long-span main trusses had been manufactured by the Cambria Iron Company in Pittsburgh; the steel was rolled at the Union Iron Mills of Carnegie Brothers and Company, also in Pittsburgh. Keystone Bridge had fabricated and assembled the iron and steel components for the superstructure earlier that year and had transported the material to Nebraska by rail. On August 5th, carpenters began construction of the falsework under the easternmost through span. The ironworkers began erection of the truss on the 16th of August and were finished a week later; the center span was coupled on September 9th. Erection of the last through truss was delayed several weeks after workers accidentally destroyed the wood-frame traveler and another had to be constructed. On October 22nd, 1883, Morison's third major Missouri River structure was completed.

Five days later the bridge was formally tested under six steam engines provided by the Sioux City and Pacific Railroad while an independent committee of engineers watched from the riverbank. The committee declined to analyze Morison's stress calculations, relying on the engineer's reputation for thoroughness and precision. Their report, not usually the format for extravagant praise, read like a testimonial to Morison:

> We are fully warranted in bearing testimony to the general excellence of the design; and in expressing the opinion from our knowledge of the methods employed by the Chief Engineer, Mr. George S. Morison, in the management of the work, that the Blair Crossing Bridge has been thoroughly well designed and in execution it is the equal, if not the superior, of any bridge of similar character in the country.[145]

OMAHA BRIDGE

Over ten years had elapsed since completion of the first railroad bridge over the Missouri River at Kansas City. In that time, rail traffic to the west had increased severalfold, and the great river was spanned in ten other locations. As traffic burgeoned and the trains became increasingly heavier, it was only a matter of time before one of these earliest structures would be replaced. In 1885, two years after the completion of the Blair Crossing Bridge, consulting engineer George Morison was hired by the Union Pacific Railroad to replace its existing iron bridge at Omaha, Nebraska - the third permanent bridge erected over the Missouri River.

As early as 1865, directors of the Union Pacific had seen the need for a bridge at Omaha. The Nebraska town was the eastern terminus of the first transcontinental rail line, completed in 1869. As such it was the primary link between the Union Pacific trunk line to the West and the railroads of the eastern United States. A bridge over the Missouri there was pivotal, but no permanent railroad bridge had yet been built over the muddy Missouri, and spanning the river was thought by many to be technologically and economically infeasible. As the only alternative then available to railroads which crossed the Missouri, the Union Pacific operated a series of transfer boats at the Omaha crossing to ferry passengers and freight across the watercourse. Cumbersome and inefficient, this operation snarled transcontinental traffic until the completion of a temporary timber bridge at the end of 1870. Within two years, a permanent multi-span iron Post truss, designed by Union Pacific Chief Engineer General Grenville Dodge, had replaced the temporary structure.

Construction of Dodge's Omaha Bridge had taken 1162 days - far longer than any other preceding or subsequent bridge over the Missouri River. Time-consuming and difficult, the structure cost the Union Pacific a staggering $2.9 million. To transform the tremendous deficit into a profit, the Union Pacific directors charged tolls for the bridge's use by other railroads. They justified their controversial policy by arguing that the bridge was actually a separate piece of trackage from the UPRR main line, not covered by the stipulations of the original Congressional charter. With no other Missouri River bridges north of Leavenworth, the Union Pacific commanded a virtual monopoly on east-west rail traffic through mid-America. The railroad charged an exorbitant 50 cents each for passengers crossing its bridge and $10 for each carload of freight and forced bridge users to transfer to dummy trains for the short passage over the river. While toll receipts averaged about $15,000 per month, UPRR directors blithely sidestepped complaints from Congressmen and competing rail lines forced to pay the tolls.[146]

The brouhaha over operation of the Omaha Bridge boiled throughout the early 1870s, reaching the Supreme Court in 1876. There the UP management lost, but in keeping with the railroad's most favored status, they successfully lobbied Congress to allow them to retain the tolls. Business continued as before over the iron truss. By the early 1880s, however, the need for a new bridge was becoming increasingly evident. Settlement in the West and Midwest was booming, and to compete with the rival Burlington Railroad the UPRR management pursued an aggressive policy of branch-line building, pushing out iron feelers into the rich farm and ranch lands of Nebraska, Kansas, and Colorado. By 1883, the Union Pacific owned some twenty branches of varying lengths and controlled five others. This effectively doubled the company's aggregate length of trackage to a total of 3600 miles in just three years.[147]

The number of ever-heavier trains pounding over the bridge increased correspondingly. The single-track structure constricted traffic over the river, creating a bottleneck at the railroad's primary transfer point. Additionally, the combination Post truss configuration was by then considered structurally archaic. Engineers had increased bridge design loads on subsequent bridges to accommodate heavier locomotives and had serious doubts on the structural safety of cast iron for bridge construction. The most notable of these technologically improved new structures were George Morison's Blair Crossing Bridge, twenty miles north of Omaha, and his Plattsmouth Bridge, fifteen miles south - bridges erected by rival railroads as direct competition with the Omaha crossing.

Finally, the ever-changing Missouri River had shifted course under the bridge, relocating the main channel from the east edge of the floodplain to the west side, along the bluff (shown in Figure 49). A new bridge at Omaha could therefore be erected that would be substantially shorter than the 1872 structure. "Had the construction of the bridge been deferred ten years," Morison commented ironically, "the channel would have skirted the bluff on which Omaha is built, the entire bottom-land now occupied by railroad yards and other interests in front of the city would probably have been washed away, and the situation would have become an exceptionally favorable one for the construction of the bridge."[148]

By 1885, Union Pacific President Charles Adams was sufficiently concerned about the carrying capacity of the Omaha Bridge to retain noted consulting engineer George Morison to inspect the existing structure and make recommendations for its disposition. Morison left immediately for Omaha and soon reported back to Adams that the existing bridge would be serviceable only with major structural modifications. A better solution, the engineer continued, would be to replace the obsolete superstructure entirely. As an alternative to repair of the existing bridge, Morison presented a plan for the reconstruction of the entire structure as a double-track railroad bridge with additional vehicular roadways.

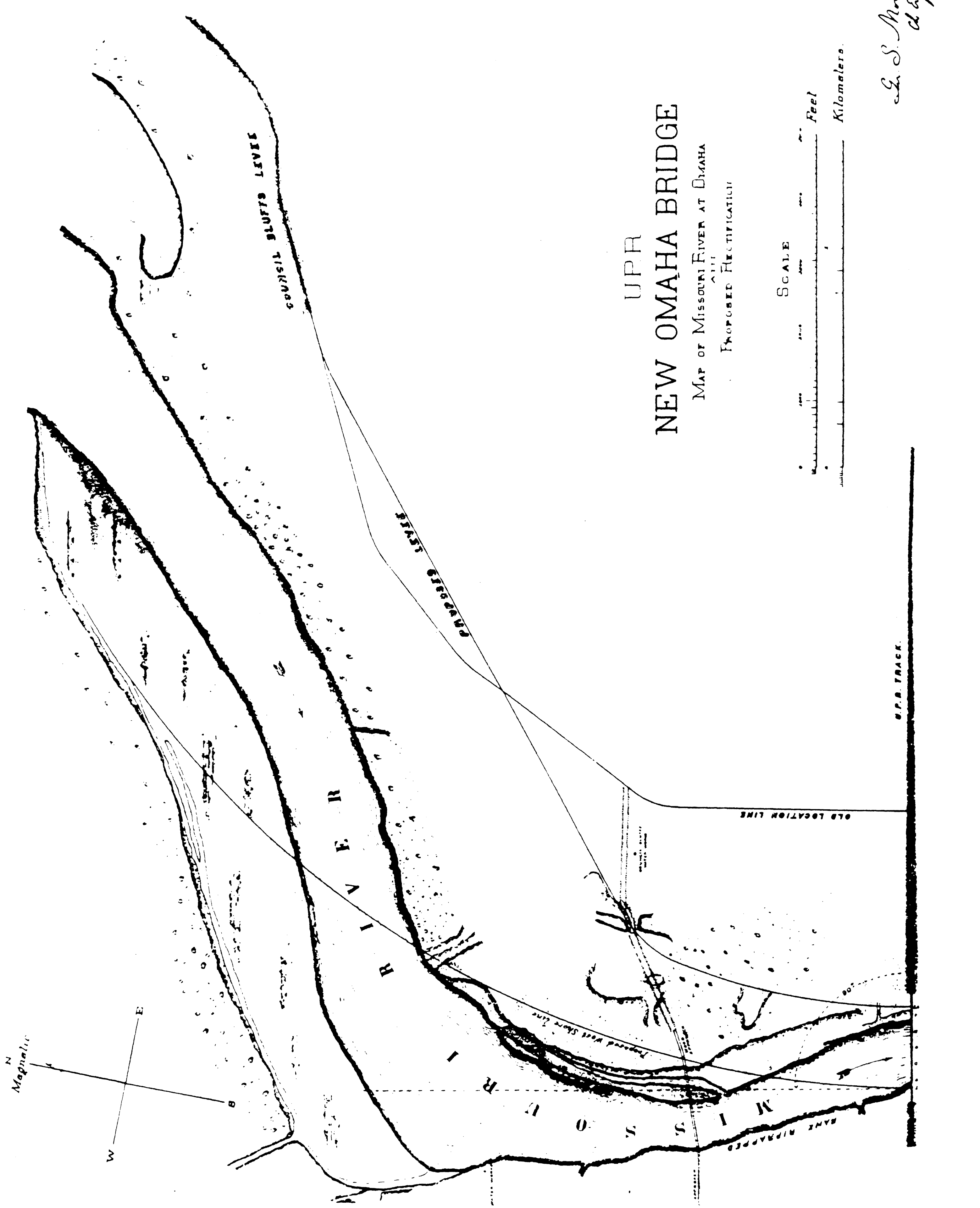

UPR
NEW OMAHA BRIDGE
Map of Missouri River at Omaha
Proposed Rectification
Scale
Feet
Kilometers
Council Bluffs Levee
Proposed Levee
Old Location Line
U.P.R. Track
Proposed West Shore Line
Bank Riprapped
MISSOURI RIVER
Magnetic
N
E
W

Figure 49

In September 1885, the Executive Committee of the Union Pacific accepted his reconstruction proposal. Just thirteen years after completion of the first extraordinarily expensive bridge at Omaha, the railroad commissioned Morison to design and supervise the erection of a replacement structure (shown in Figure 50).[150]

Almost two years had passed since Morison had worked on a major bridge construction project. He was anxious to return to the Missouri River and wasted no time in gathering a group of assistants and contractors for the project (listed in Appendix G). Intolerant of incompetence, Morison quickly weeded out incapable employees, but to those who could perform to his exacting standards he was unfailingly loyal. They in turn remained with him; many of the principals on this project had worked for him on his previous bridges. The day after the Union Pacific told Morison to proceed, he dispatched H.W. Parkhurst to Omaha to supervise the foundation and rectification work. In October, he hired Lewis Blickensderfer and Ralph Modjeski as assistant engineers, and early in 1886 he engaged Alfred Noble as chief inspector of the superstructure. Morison's principal design assistant, however, was absent from the project. Superstructural engineer C.C. Schneider had worked with Morison on his first three Missouri River spans while maintaining his own consulting practice in New York. In 1885, he was involved in the engineering for a major structure over the Niagra Gorge for the Canadian Southern Railroad - the first of several long-span cantilevered trusses for which he would become famous - and was unable to assist with the design of the replacement structure.[151] Construction of the new Omaha Bridge began on September 22, 1885, remarkably just four days after the engineer had been hired for the project.

Among Morison's group at Omaha, Ralph Modjeski was one of the few new men. Born Rudolphe Modrzejewska in Cracow, Poland, in 1861, he had decided to become an engineer early in life. He first came to America with his parents to visit the 1876 Centennial Exposition in Philadelphia. He remained with his mother in San Francisco, shortened his name to Ralph Modjeski, and began school. After naturalization as an American citizen in 1883, he returned to Europe - this time to study engineering at L'Ecole des Points et Chaussees in Paris. In 1885 Modjeski graduated with a degree in Civil Engineering at the head of his class and immediately returned to America. He had stepped off the boat just weeks before seeking out George Morison on the Omaha Bridge.[152]

In some ways, Ralph Modjeski reminded George Morison of his own start in civil engineering. Like Morison, the young Pole was beginning his professional career at the age of twenty-four. And like Morison, Modjeski had sought out a challenging bridgebuilding project on a major American river to begin his practical education. Most importantly, the two men shared a consummate interest in structural engineering and were totally committed to its practice. Although Morison had never acquired the formal engineering education from

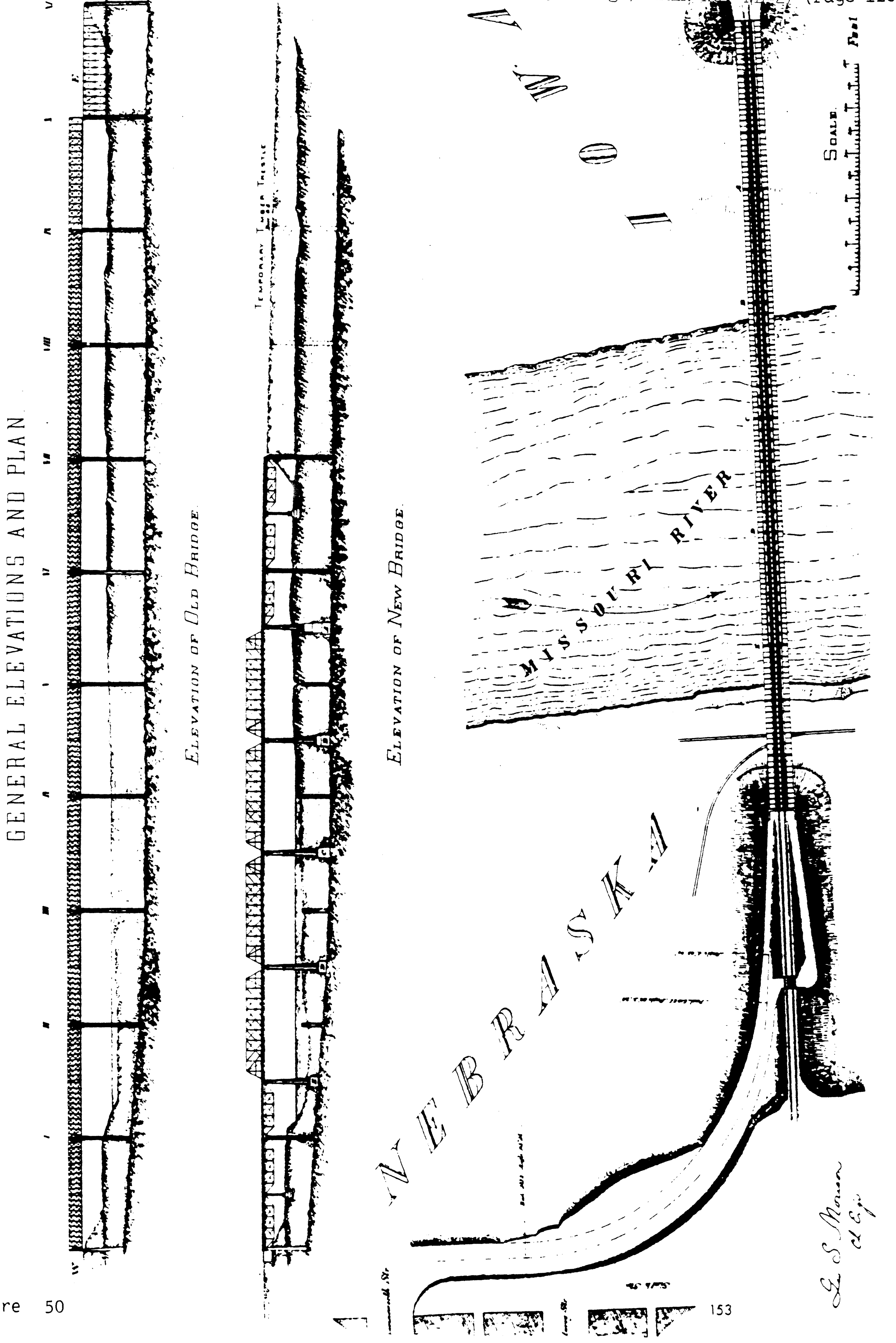

NEW OMAHA BRIDGE
GENERAL ELEVATIONS AND PLAN
Elevation of Old Bridge
Temporary Timber Trestle
Elevation of New Bridge
IOWA
Scale
Feet
MISSOURI RIVER
NEBRASKA

Figure 50

Modjeski had recently graduated, the forty-two year old Chief Engineer did not discriminate against the younger man. In many ways the relationship that the two formed on the Omaha Bridge was like that between Morison and Octave Chanute at Kansas City sixteen years earlier, when Morison was beginning his own career as an engineer. Modjeski worked as Morison's assistant at the site, doing the odd jobs associated with project supervision; in return the elder engineer educated the young apprentice on the practical aspects of American bridge engineering and construction. Modjeski would stay with Morison through this project and several subsequent bridges over a seven-year period as first assistant engineer, shop inspector, and chief draftsman.

One aspect of George Morison's character that first impressed Modjeski was not his hallmark thoroughness or professionalism, but his punctilious sense of economy. Modjeski later recounted an incident involving Morison that occurred during construction at Omaha. The caissons were built of Oregon fir, and the workmen were allowed to take home the scrap ends of the 12-inch timbers to use as firewood. To carry the wood, they would nail the blocks to a piece of scantling, which they balanced on their shoulders. Morison stopped the men as they were going home one day and demanded, "You must not use nails, they are wasted. Next time use screws and bring them back to use over again."[154]

Modjeski joined Morison at Omaha three days after the chief engineer had given the construction contract for the masonry piers to Saulpaugh and Company in October 1885. In December, Morison sent drawings and specifications to nine prominent American bridge firms with an invitation to bid for the fabrication and erection of the superstructure. Low bidder among the eight that responded, the Union Bridge Company of New York won the contract. The fledgling company had been formed the year before when Pennsylvania-based Kellogg and Maurice merged with the Central Bridge Company of Buffalo, New York.[155] Kellogg and Maurice had worked with Morison as approach span contractors for the Plattsmouth Bridge five years before.

Morison described the design of the replacement structure in a later report to Charles Adams: "The new Omaha Bridge was designed to accommodate both railroad and highway traffic. It is a double-track railroad bridge; the two tracks being placed 12 feet between centers, and the clearance between trusses being 26 feet. The highways are carried on cantilever arms projecting outside the truss." He used only a few parts of the original bridge: three of the iron cylinder piers and virtually none of the superstructural material. "The new bridge is really a reconstruction of the old bridge, though very little of it remains," Morison wrote. "The same approaches are used, and the location is entirely unchanged, while the dimensions of the old structure fixed the dimensions of the new structure."[156]

His design for the bridge - four through and six deck trusses - predictably

resembled his three earlier Missouri River structures. The througn spans were eleven-panel Whipples: 246 feet long, 40 feet deep, and almost 54 feet wide (shown in Figures 52-55); the deck trusses, 120-foot, five-panel Pratts (shown in Figures 56-58). Other than the markedly shorter length of the channel spans, the principal difference between the appearance of the Omaha Bridge and its successors by Morison was its double-track configuration and the pedestrian/vehicular roadways that cantilevered beyond the truss webs on the sides. The trusses were not proportioned for particular locomotives then in use, but were calculated for a moving load of 8,000 pounds per linear foot and an additional dead load of 5,000 pounds per foot (shown in Figure 59) - far heavier than the spans they replaced.

The engineer increased his reliance on steel for the main river spans with each major bridge. But with characteristic conservatism and close observation of steel prices, Morison approached this slowly and methodically. He continued his snail's pace with the Omaha Bridge. The top chords, end posts, eyebars, and the heavier portions of the main ties, bolsters, rollers, bearing plates, and pins were all made of steel, comprising almost 40% of the superstructural metal weight. All other components were wrought iron, except the heavy wall plates, the washers, and the ornamental work, which were cast. Like his preceding bridges, the short deck spans were made up almost entirely of wrought iron. The superstructural composition is given in the following chart:

Through spans:

	Total four spans	Average per span	Percentage
Steel	1,540,126 pounds	385,031 pounds	40%
Wrought iron in trusses	961,494 pounds	240,374 pounds	25%
Wrought iron in railway floor	955,114 pounds	238,779 pounds	24%
Wrought iron in highway floor	329,596 pounds	82,399 pounds	8%
Cast iron	108,160 pounds	27,040 pounds	3%
Total	3,894,490 pounds	973,623 pounds	

Deck spans:

	Total six spans	Average per span	Percentage
Steel	30,226 pounds	5,038 pounds	2%
Wrought iron in trusses	972,426 pounds	162,071 pounds	47%
Wrought iron in railway floor	624,195 pounds	104,032 pounds	30%
Wrought iron in highway floor	329,596 pounds	54,932 pounds	16%
Cast iron	108,160 pounds	18,026 pounds	5%
Total	2,064,603 pounds	344,099 pounds [157]	

Morison and Parkhurst had worked together on three preceding bridges over the

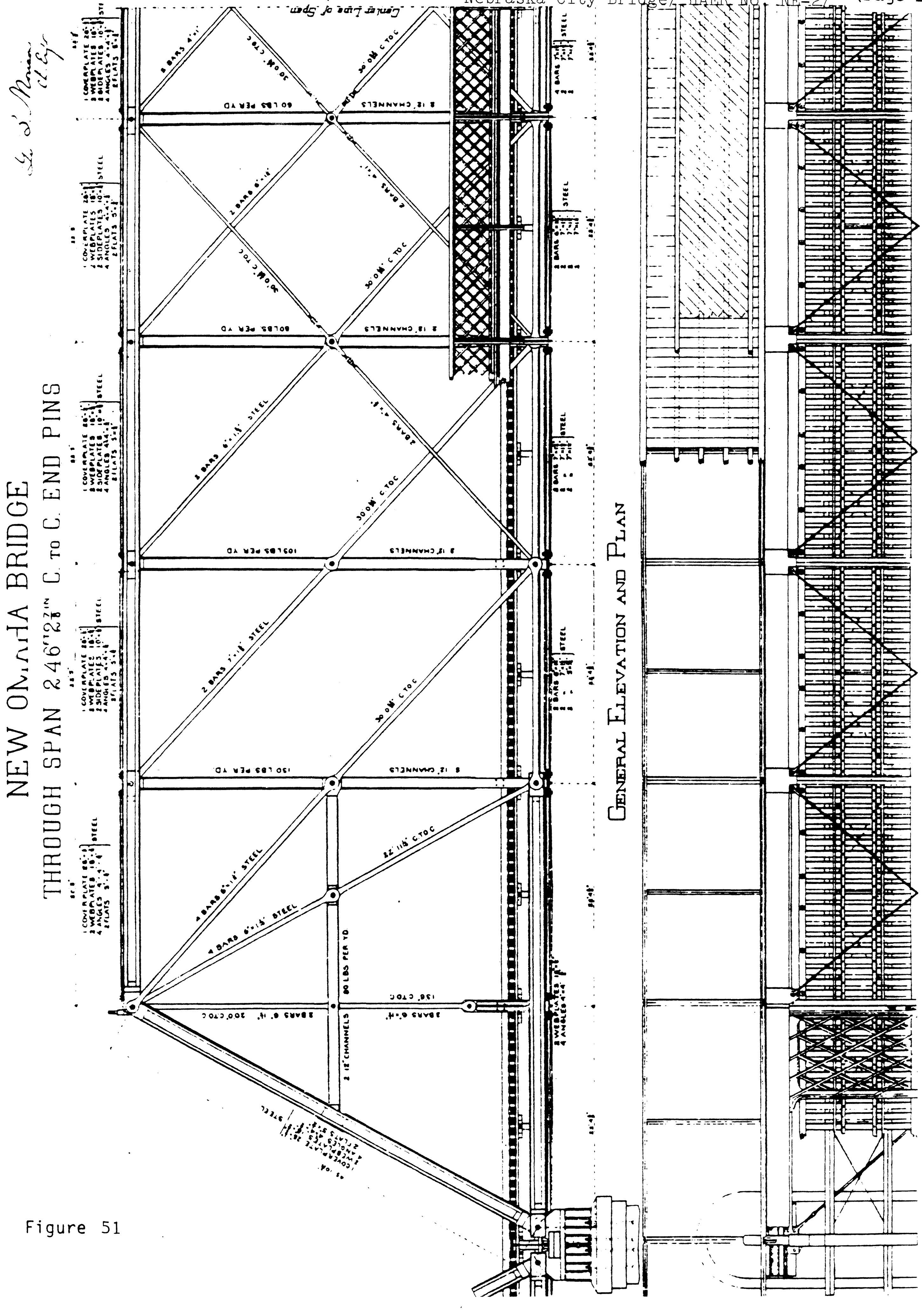
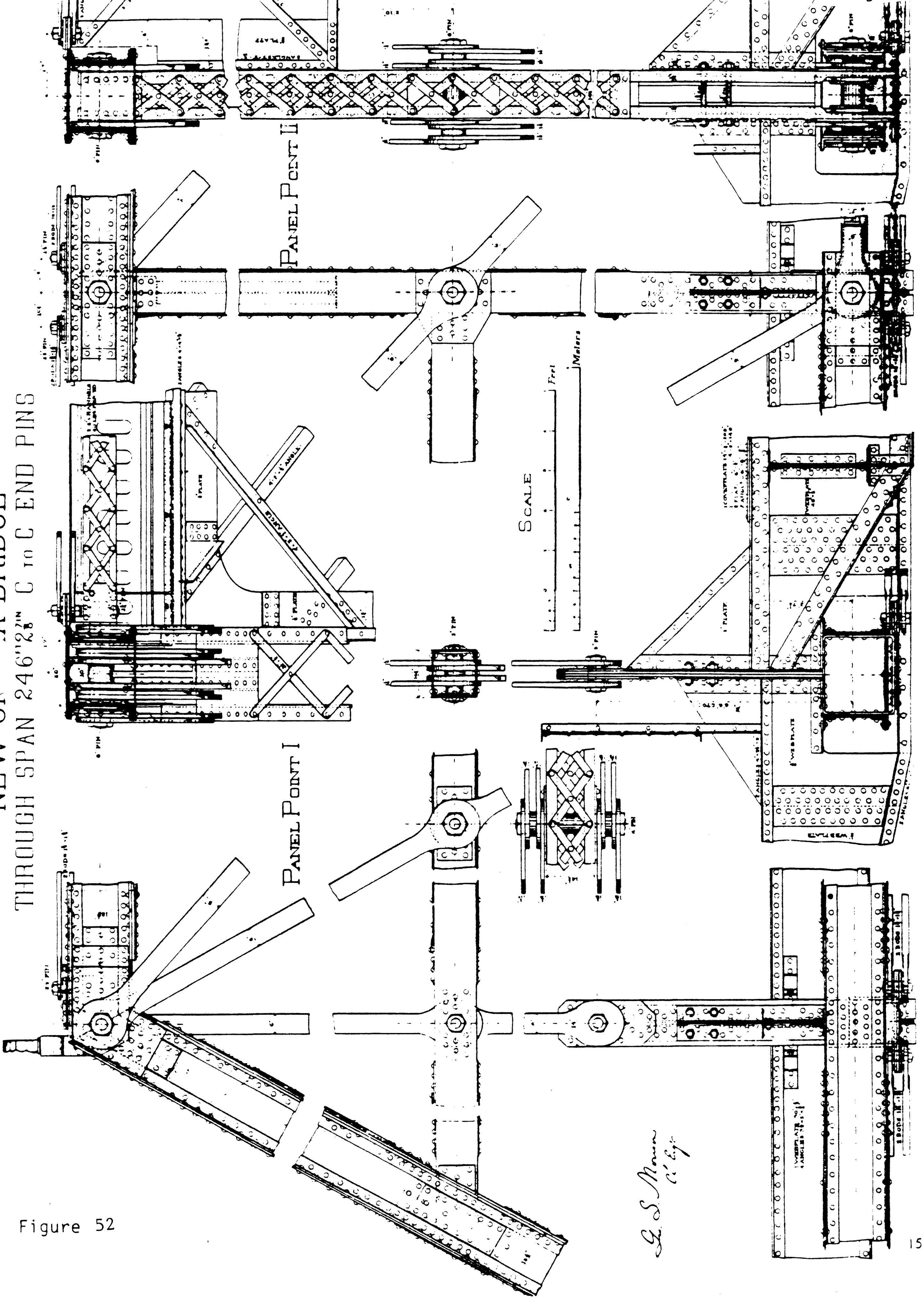

NEW OMAHA BRIDGE
THROUGH SPAN 246'2⅞" C. TO C. END PINS
GENERAL ELEVATION AND PLAN

Figure 51



NEW ON A BRIDGE
THROUGH SPAN 246'2 7/8" C to C END PINS
PANEL POINT II
PANEL POINT I
SCALE
Feet
Meters

Figure 52

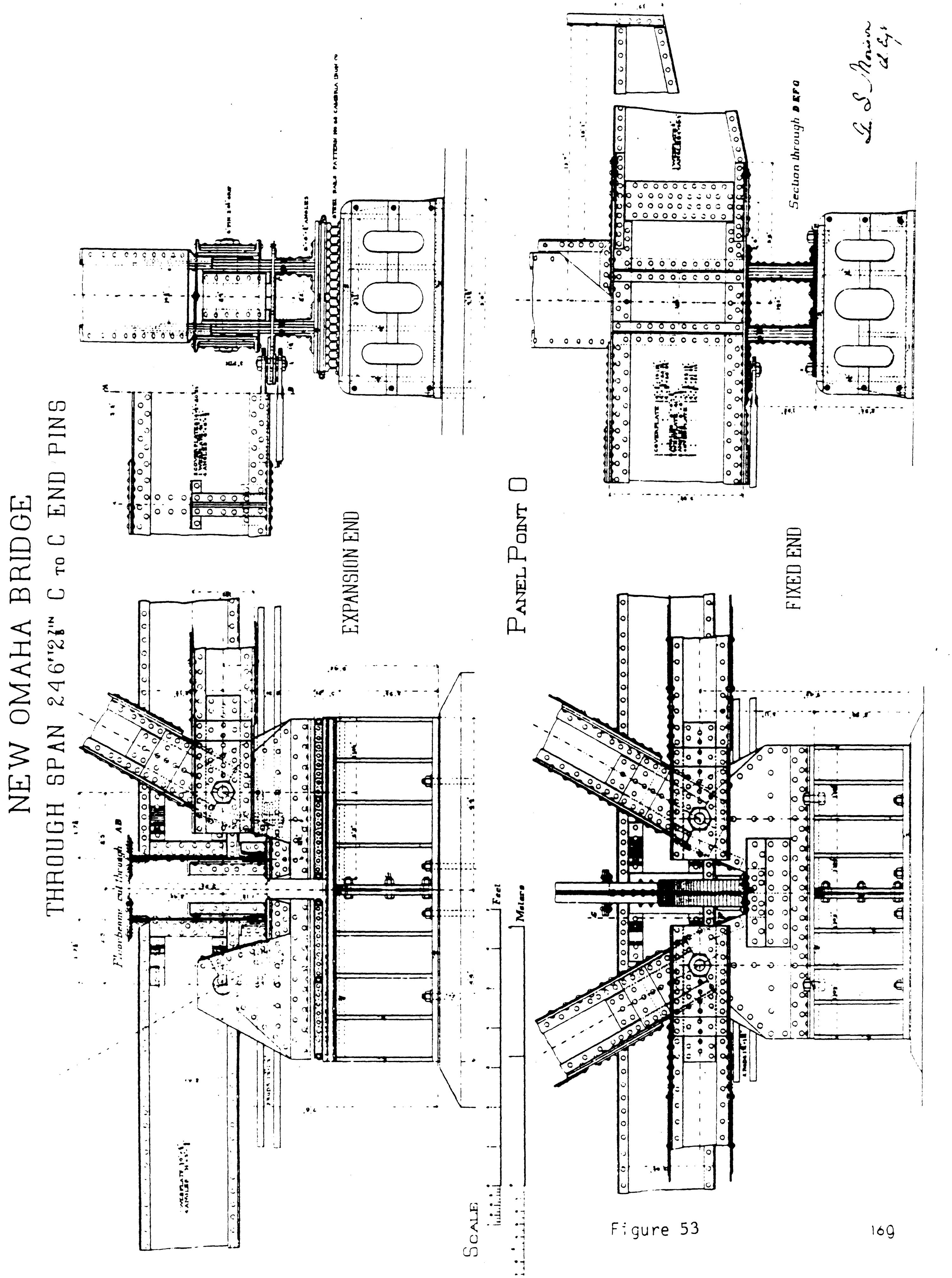

NEW OMAHA BRIDGE
THROUGH SPAN 246'2 7/8" C to C END PINS
PANEL POINT 0
EXPANSION END
FIXED END
Section through DEFG
Floorbeam cut through AB
SCALE
Feet
Meters

Figure 53

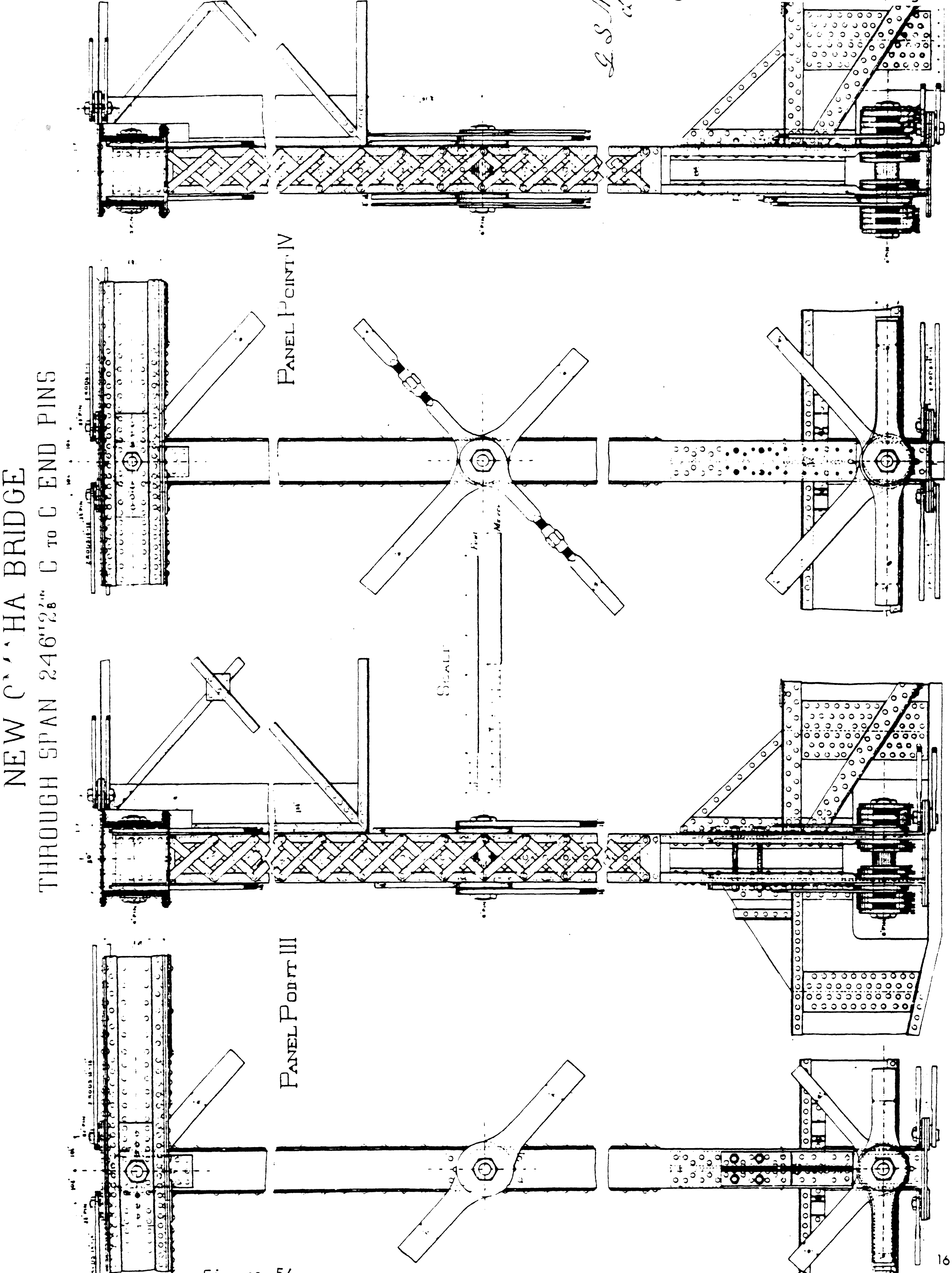

NEW O...HA BRIDGE
THROUGH SPAN 246'2 3/8" C TO C END PINS
PANEL POINT IV
PANEL POINT III
SCALE

Figure 54

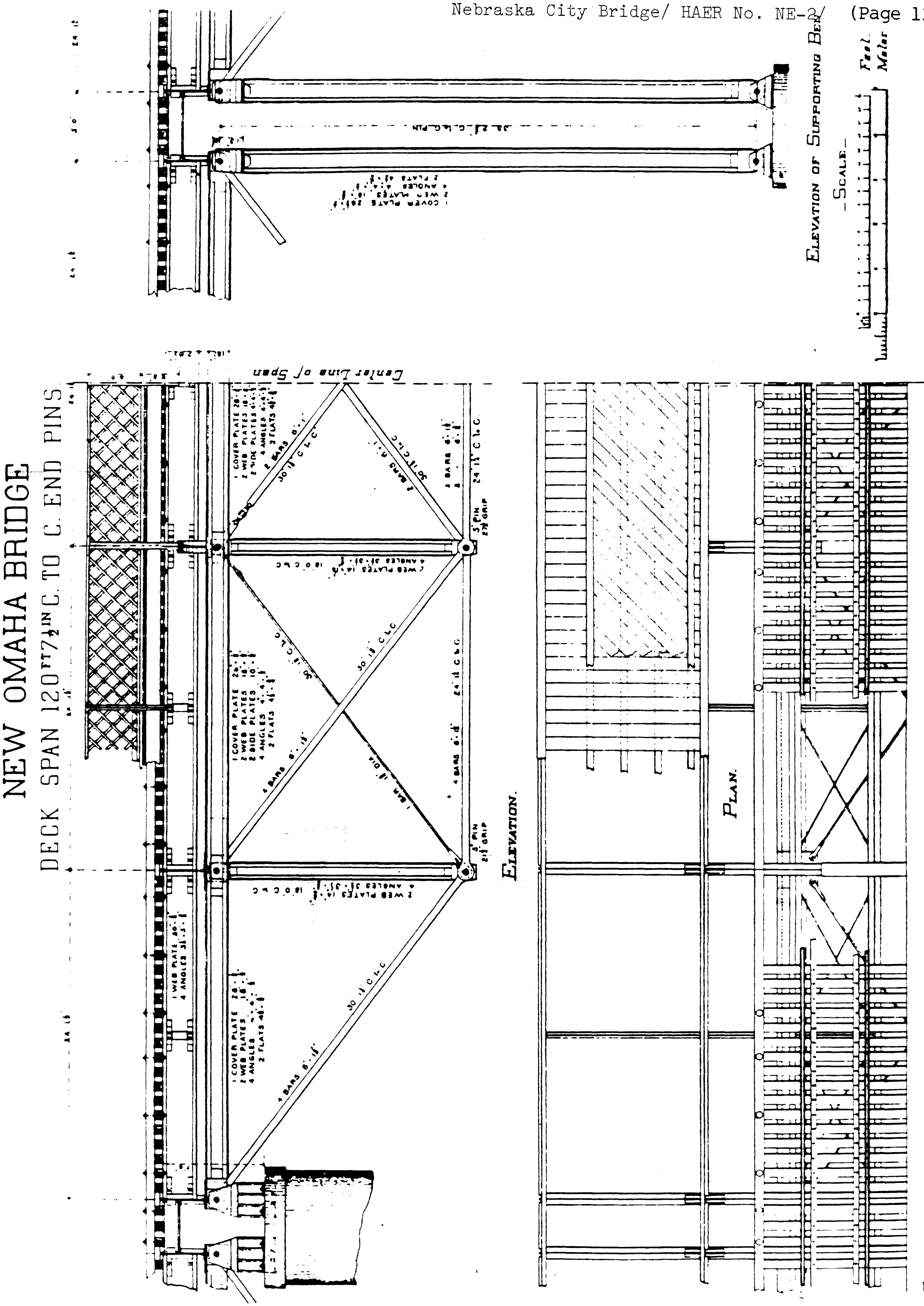

NEW OMAHA BRIDGE
DECK SPAN 120 FT 7½ IN C. TO C. END PINS
Center Line of Span
ELEVATION.
PLAN.
ELEVATION OF SUPPORTING BE
SCALE
Feet
Meter

Figure 55

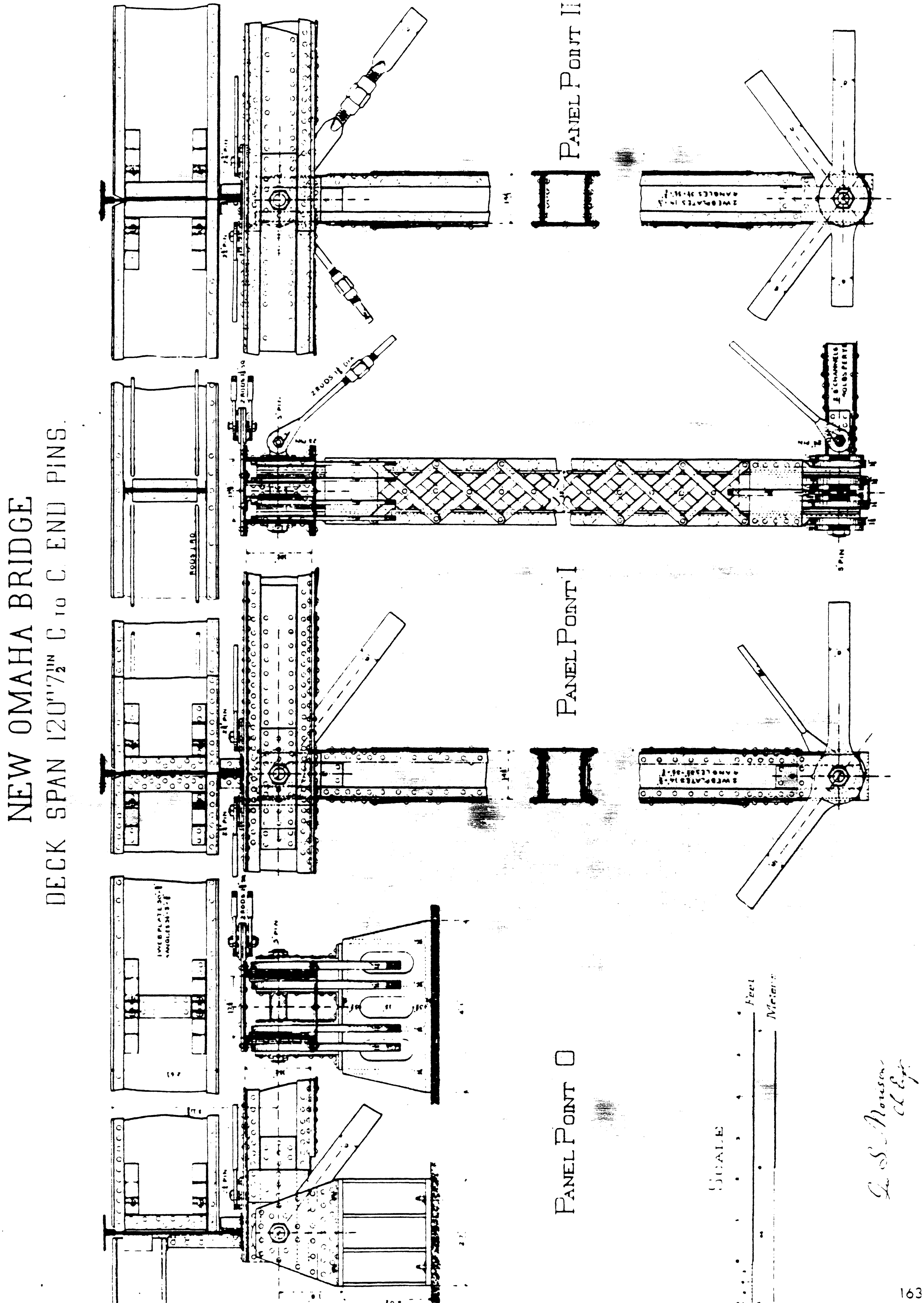

UPR
NEW OMAHA BRIDGE
DECK SPAN 120'7½" C to C END PINS.
PANEL POINT II
PANEL POINT I
PANEL POINT O
SCALE
Feet
Meters
163

Figure 56

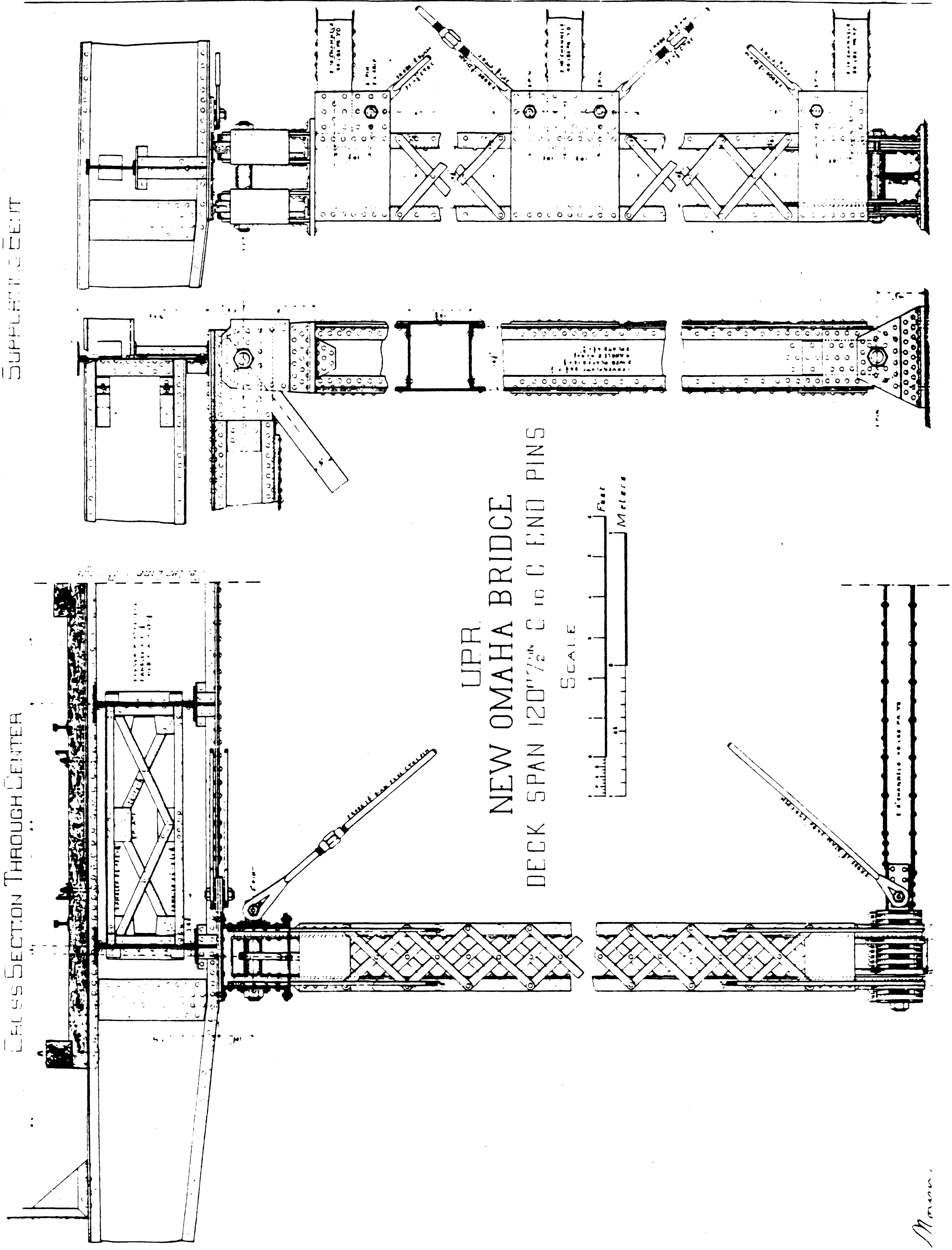

UPR
NEW OMAHA BRIDGE
DECK SPAN 120' 7 1/2" C TO C END PINS
SCALE
Feet
Meters
CROSS SECTION THROUGH CENTER

Figure 57

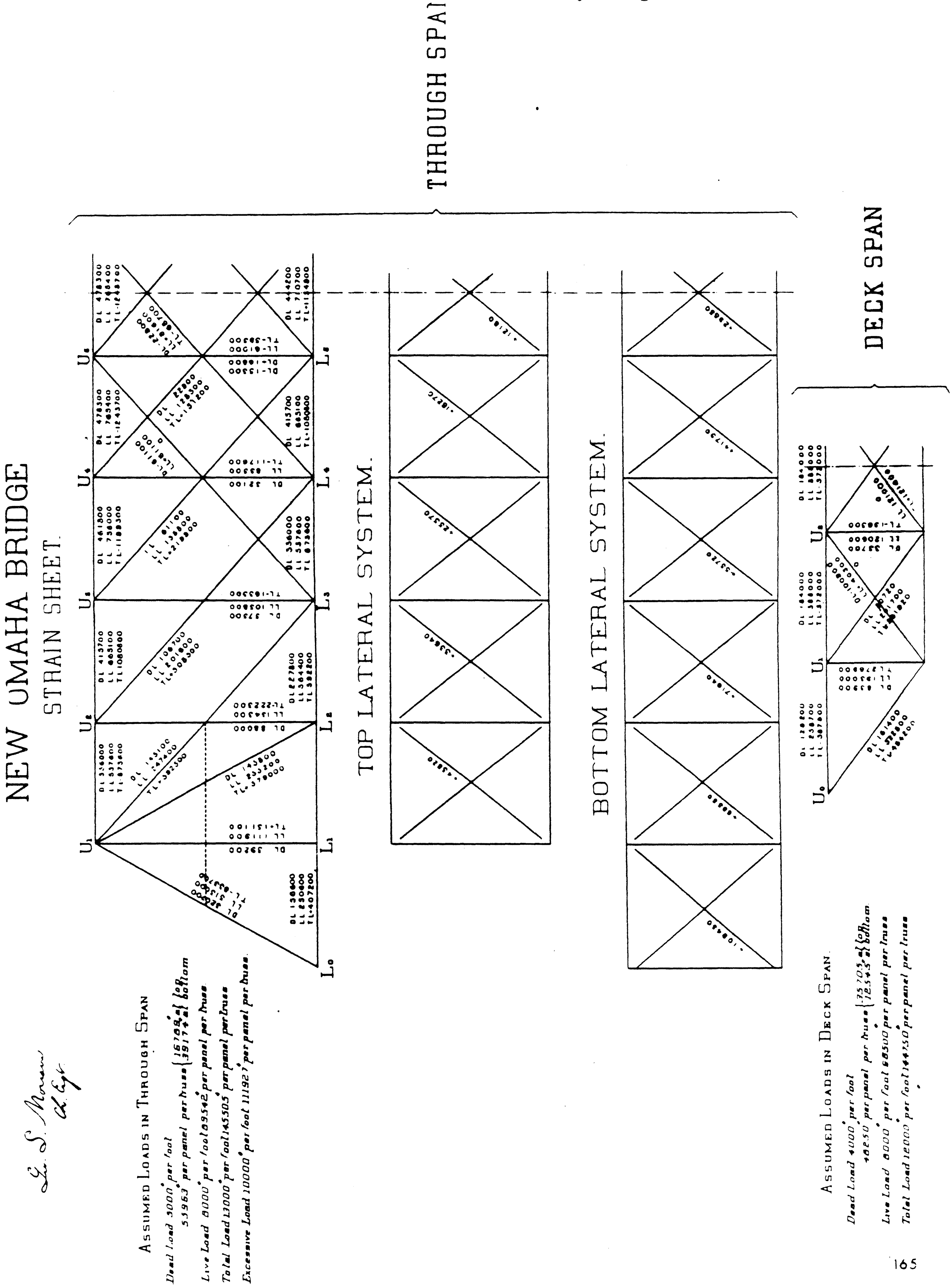

NEW UMAHA BRIDGE
STRAIN SHEET.
THROUGH SPAN
DECK SPAN
TOP LATERAL SYSTEM.
BOTTOM LATERAL SYSTEM.
Assumed Loads in Through Span
Dead Load 3000 per foot
55963 per panel per truss
Live Load 8000 per foot 89542 per panel per truss
Total Load 13000 per foot 145505 per panel per truss
Excessive Load 10000 per foot 111927 per panel per truss
Assumed Loads in Deck Span
Dead Load 4000 per foot
Live Load 8000 per foot 68500 per panel per truss
Total Load 12000 per foot 104750 per panel per truss
165

Figure 58

Missouri River, and other than the carefully staged demolition of the existing structure the construction of the Omaha Bridge presented them with no great difficulties. Preparatory work for the foundations began in September. When the first casualty among the men occurred soon after, it was not one of the laborers, but Parkhurst himself. He was incapacitated in an accident near his temporary house in Omaha, and Morison hired George A. Lederle as his replacement in December.[166] The chief engineer had designed five pneumatically founded piers (shown in Figure 60) of limestone quarried from Mankato and granite from St. Cloud, Minnesota. As one railroad crew set up the pneumatic machinery on the east bank of the river for the first pier, another built a temporary bridge fifty feet north of the bridge line to assist in moving the equipment and materials. Carpenters began framing the Oregon fir caisson (shown in Figure 61) for the first pier on October 29, 1885. By December 15th, the heavy iron cutting edges had been built and it was positioned and pressurized. Saulpaugh's crew laid the first course of stone over it on January 11th.

Work in the pneumatic caissons far below the river was undoubtedly the most dangerous aspect of bridge construction. Digging in the cramped quarters beneath the caisson sometimes a hundred feet beneath the surface of the river with thousands of tons of stone and concrete bearing down on the roof of the timber structure must have been a daunting prospect for the laborers. Access through the air lock of the pressurized chamber was difficult. Temperatures sometimes climbed over one hundred degrees. With candles lighting the dusty chamber, the danger of fire was ever-present. The men frequently used small charges of dynamite to blast boulders that the cutting edges could not penetrate or crush, compounding the risk. But the most terrifying aspect of work in the hole was a crippling - and often fatal - affliction commonly known as "caisson fever." The initial symptoms were soreness in the muscles and joints, particularly in the arms and legs. As the air compression increased with the sinking of the caissons, the severity of the problems intensified. The muscular pain became deep and relentless, resulting in temporary paralysis at times, and some of the men doubled over with excruciating stomach cramps. Often the cramps and pains persisted beyond the initial exposure, and the permanently stooped posture among the caisson workers caused by paralysis and cramps had become known as the "Grecian Bend." This was indeed gallows humor, for in some extreme cases caisson fever resulted in agonizing death.

Now diagnosed as the bends, caisson fever resulted from the effect of too rapid decompression on the circulation system when the men ascended too quickly from the compressed air of the caisson chamber to the normal surface atmosphere. The leg pains, stomach cramps, and painful joints resulted from the liberation of nitrogen bubbles from solution in the blood stream and in the body's tissues. Well understood now, it can be prevented by slow and gradual decompression, but in the late 19th century it was a baffling condition which afflicted some men

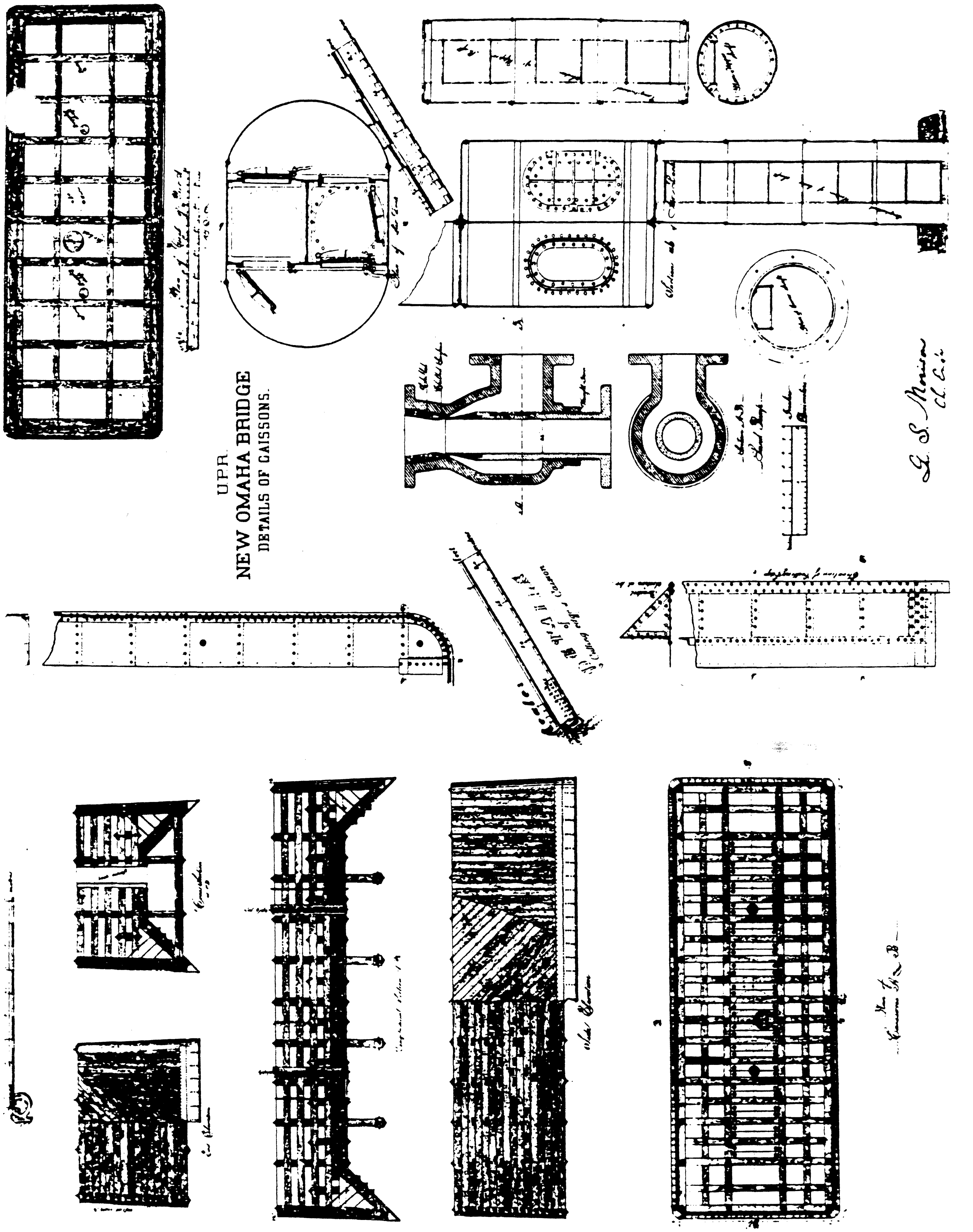


Figure 59

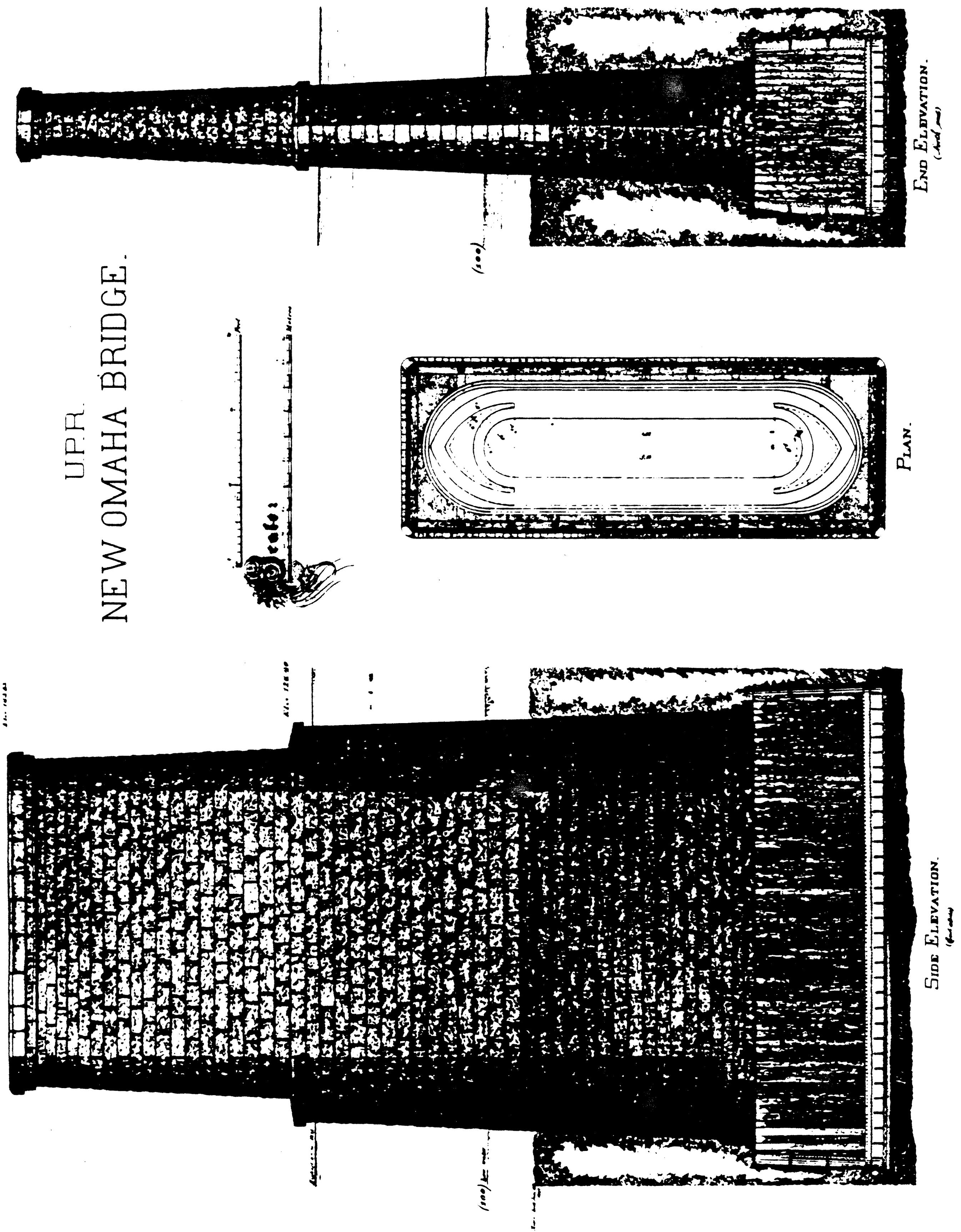

U.P.R.
NEW OMAHA BRIDGE.
PIER 'E'.
END ELEVATION.
PLAN.
SIDE ELEVATION.
Scales

Figure 60

severely while others felt nothing at all. In August 1872, French Professor Paul Bert published a paper which for the first time linked the bends with the decompressive release of nitrogen in the body. And after more empirical experimentation with limited work periods and gradual decompression on subsequent bridge projects, the incidence of caisson fever gradually decreased over the next two decades.[169]

Although the theoretical cause of caisson fever was understood by 1886, safety precautions for decompression still often lagged sadly. As the excavations for the tremendous piers of the Omaha Bridge reached their deepest levels, several of the men were overcome. Then on March 11, 1886, two men died after working in the caisson for Pier B, sixty-five feet below the surface of the river. The record of the deaths comes from an outside source; George Morison failed to mention any caisson fever problems in his subsequent report to the railroad. As a consequence of his editing, the number of other men were afflicted by the bends on his other bridge projects remains unknown.[170]

Despite the casualties, construction on the three easternmost piers continued ploddingly throughout the spring and summer. After completion of Pier C - the middle pier - in June, Morison halted the work for the flood season. With characteristic conciseness, he described the resumption of work three months later on the fourth great pier:

> The construction of the staging for Pier D was begun September 14, 1886, the framing of the caisson September 15, the erection of the caisson September 23, and the lowering with screws October 27. Air pressure was put on November 3, and on November 4 the caisson rested on the bed of the river. The laying of masonry began November 4, and the caisson reached bed-rock at elevation 40.80 on December 3. The concrete filling of the working chamber was begun December 4, and finished December 7. The masonry for this pier was completed March 8, 1887.[171]

Workers laid the last stone for the fifth pier on April 7, 1887, completing the masonry work. The aggregate weight of the five immense piers and the west abutment totaled over 16.5 million pounds of stone and 7 million pounds of concrete. Their total cost: $427,000.

Steel for the superstructure came from three Pennsylvania mills: the Pittsburgh Steel Casting Company, Carnegie Brothers, and the Pennsylvania Steel Company. Morison had tried to get steel made by the experimental Clapp-Griffiths process, but was dissatisfied with the uneven outcome and soon resorted to open- hearth material. The bridge components were all manufactured by the Union Bridge Company in their Buffalo, New York, shops and shipped by rail to the site. Union Bridge had subcontracted the truss building to Baird Brothers,

veteran erectors that had worked on three of George Morison's previous bridge projects.[172]

The heavy rail traffic over the Missouri River at Omaha could not be interrupted, and the necessity of maintaining rail traffic during removal of the old bridge superstructure and erection of the replacement spans prompted Morison to modify his normal construction sequence for the bridge. In May 1886, ironworkers for the Union Pacific began assembling the replacement deck spans beneath the outermost existing through trusses. The original iron cylinder piers were shortened slightly, with their cast iron caps replaced, to carry the deck trusses. These new spans were then used as temporary support for disassembly of the existing through spans above. Erection of the through trusses was more problemmatical. Although the replacement Whipple channel spans were longer than the existing Post trusses and the pier spacing was therefore different, Morison had designed the new masonry piers slightly lower than the existing iron supports, allowing a span-by-span replacement. He fabricated iron harnesses to be placed on the tops of the iron piers, which the men used as staging supports for the new truss erection. Morison described the replacement process for the long-span through trusses:

> Four lines of combination trusses were then erected, supported on the masonry piers and on the harnesses, the bottom chord bars of the old bridge being used in these combination trusses; the two inside trusses carried the traffic during erection and the two outside trusses the new work. This arrangement of four trusses was adopted as an extra precaution in case of an accident, it being thought that if one truss was destroyed by an accident the other three would remain in position. Fortunately no such accident occurred.[173]

The railroad crew dismantled the old iron Post trusses of the original bridge using a timber traveler, without upper falsework; the new trusses were erected in the same manner. The existing spans were removed and replaced one-by-one to avoid interrupting rail traffic on the bridge. The first through truss was begun on October 2, 1886, and completed a week later. On April 24, 1887, riveters completed the last of the steelwork, and the trusses were ready for the railroad construction crew to lay the floor and tracks. The railroad floor system consisted of 8x8-inch ties, which rested on iron stingers, spaced with 6-foot centers. The highway floor was also built of timber, the wooden stringers being supported by short cantilevered floor beams midway between the panel points. These were strengthened by the light lattice truss which doubled as the outside railing. The wearing surface of the cantilevered highway consisted of 2-inch oak planks laid diagonally; the pedestrian walkway was separated from the carriage-way by a gas-pipe railing. After completion of the new superstructure, the tops of all but three of the original paired iron foundation cylinders were cut to the level of the riverbed. The bridge had been

completed before the second set of connecting tracks were ready on either approach; it was not used as a double-track structure until October 1, 1887. Total cost of superstructure: $290,000. Morison later claimed that "the running of trains was never interrupted for more than two hours at any one time during the entire erection" - an incredible engineering and administrative accomplishment.[174]

A month after the second track was opened, Morison's Resident Engineer Edwin Duryea drove the first carriage across one of the cantilevered pedestrian decks (shown in Figure 62) to demonstrate its safety. But the prospect of horses crossing fifty feet over the river and precariously close to the steam-belching locomotives seriously concerned Union Pacific officials. Morison remained confident. An inveterate horse-hater, he preferred the logic and precision of mechanical devices to the uncertainty of livestock. Despite the fact that he had been raised in rural New England and that the horse was still a principal means of transportation, riding skills eluded him, and the irascible engineer could barely abide horses and their riders. "He was brought up with animals but he never seemed to understand them," his nephew, George Abbot Morison, later wrote. "Although he rode horseback regularly in New York for some years, in fact, except for walking, it was his only exercise, he was never able to control horses properly, and he had occasional accidents." Morison justified his equestrian ineptitude by belittling those that had mastered riding. "There is a certain kind of man that likes animals and handles them well, particularly horses," he once told his nephew. "Such men are usually the type who are popular with others, and are known as 'good fellows'." The elder Morison then hesitated before continuing, "but such men are usually fellows of very lax morals."[175] Given such a strongly held view, George Morison's unsympathetic response to UPRR vice president Thomas Potter about the possible danger to riders on the bridge was hardly surprising:

> While the position of these roadways is undoubtedly such that horses unaccustomed to the situation would be frightened by trains, the position of the roadways between two strong fences is such that the frightened horses could do no harm, and after they had been used a short time, the number of horses that would be frightened would be comparatively small. I do not think the danger of driving on these roadways is as great as the danger of driving in one of the New York streets in which an elevated railroad is built... It may be expedient to build such a fence; but I should prefer to use the bridge first without it, simply making a regulation that no whistle should be blown, and no steam allowed to escape, while trains are on the bridge... My judgement would be to fix the tolls at about one half the tolls charged on the ferry trains, and that a notice be put up at each toll-house stating that at certain times the bridge would be kept clear of trains, and that persons whose horses were unaccustomed

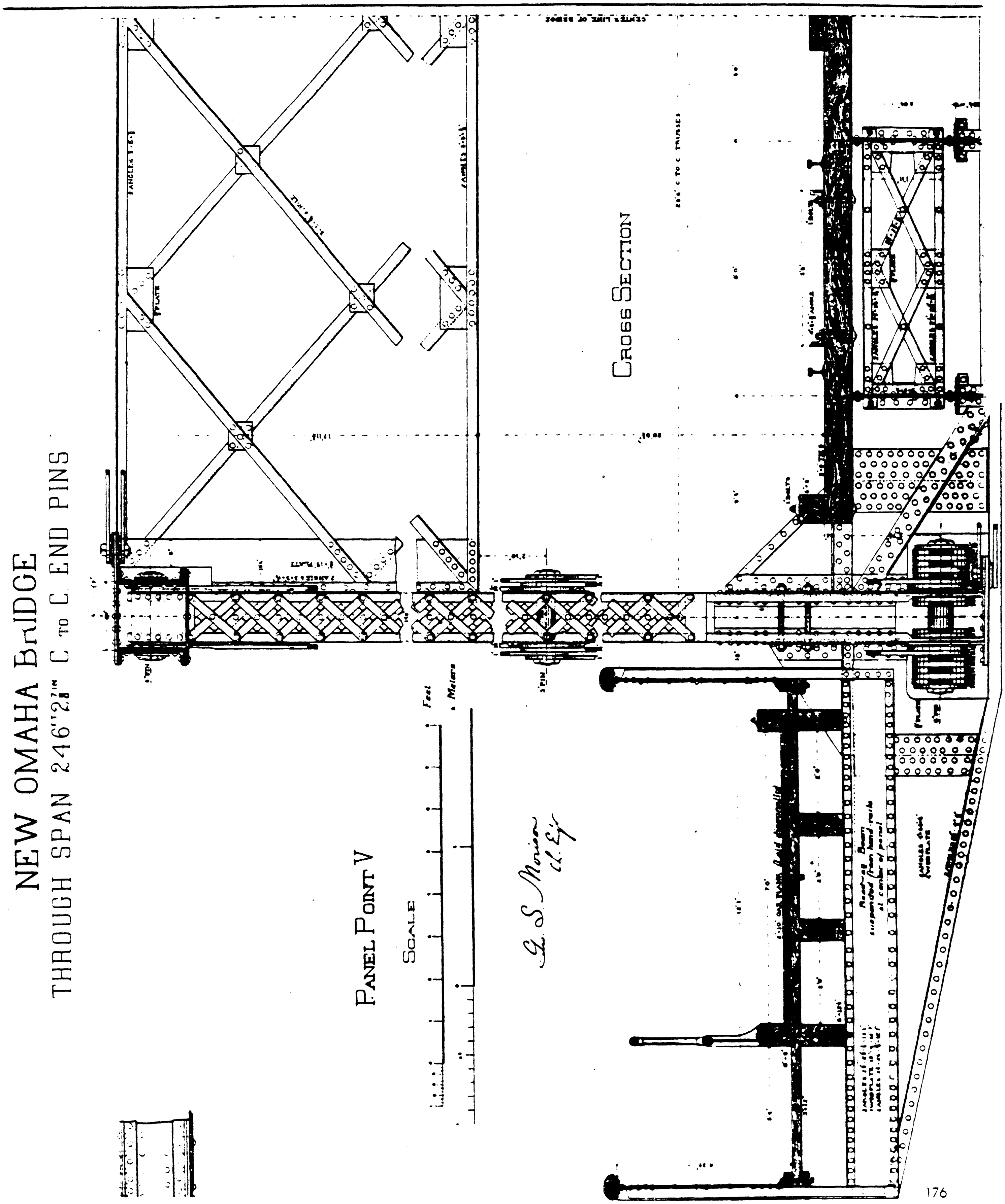

NEW OMAHA BRIDGE
THROUGH SPAN 246'2 7/8" C TO C END PINS
CROSS SECTION
PANEL POINT V
SCALE
Feet
Meters
176

Figure 61

> to locomotives had better cross at those hours; with such notice any responsibility for accidents from frightened horses would be thrown upon the riders.[177]

Morison disliked architects perhaps as much as he did horses and normally eschewed any nonstructural ornamentation on his bridges. This, he felt, added unnecessary expense and added nothing to the engineering of the structure. But he suffered Charles Adams' dramatic gesture when the Union Pacific President commissioned decorative figures for both portals of the bridge. For the east, Captain Edward Kemeys of Perth Amboy, New Jersey, sculpted a bronze buffalo head, cast by Etienne Favy of New York. Morison thought the colossal figure represented "the wildness of the plains which the travelers are approaching." On the west end a large bronze bas relief featured a plow, anchor, and a steam hammer - symbols of "the agriculture, commerce and manufactures of the East."[178] On November 10th, Morison relinquished control of the Omaha Bridge to the Union Pacific. Costing less than a third of the original structure, the bridge marked the first of several bridge replacements on the Missouri River as more sophisticated engineering rendered the earliest spans obsolete.

RULO BRIDGE

While construction was underway on the Omaha Bridge, George Morison received four more major bridge commissions in quick succession. One involved the design and construction of a multiple-span truss at Cairo, Illinois - Morison's first engineering project on the Ohio River. The other three were for bridges in a more familiar setting: the Missouri River at Sioux City, Nebraska City, and Rulo, Nebraska. The initiation of this last bridge, however, had actually occurred in 1880, before completion of his first span over the Missouri at Plattsmouth.

The directors of the Chicago, Burlington and Quincy Railroad were at that time considering erection of a third bridge over the Missouri about midway between the existing Burlington bridges at Plattsmouth and Kansas City, near the mouth of the Little Nemaha River. A bridge over the river at the small village of Aspinwall, two miles below the Little Nemaha, would form a direct link in the railroad leading westerly from Nemaha City to Beatrice and would forge a major crossing for the southern lines of the railroad's Nebraska system. Burlington Vice President Charles Perkins called George Morison off of the Plattsmouth project in the winter of 1880 to visit the Aspinwall site and make recommendations for the bridge. When the engineer's cost estimates proved to be extremely expensive, the Burlington management shelved the project.[179]

The need for the second major bridge over the Missouri River in Nebraska was not critical to the CB&Q in 1880, but events in the following years would soon necessitate its construction. The proposed bridge at Aspinwall represented an extension of the intense competition between the Burlington and the Union Pacific Railroads that had prompted erection of the Plattsmouth Bridge. During the 1870s and 1880s, both rail lines sought to increase their influence in the West and Midwest through extension of existing lines and consolidation of smaller railroads. Among these smaller regional lines, the Hannibal and St. Joseph Railroad was one of the more promising. With tracks extending from Hannibal on the Mississippi River, across northern Missouri to St. Joseph on the Missouri River and with a southwestern branch to Kansas City, the rail forged a strategic regional link. Both Charles Perkins, elected President of the CB&Q in September 1881, and his nemesis Jay Gould coveted the H&SJ in 1882. When its principal stockholder tendered an offer to sell, Gould once again outmaneuvered Perkins and quickly acquired control of the rail company.[180] The CB&Q president bought Gould out in April 1883, and the H&SJ became a permanent component in the Burlington system. The purchase was "the best solution of the Southwestern Question," Perkins argued, "and it places us in a strong position at Kansas City, the great and growing commercial center of the region."[181]

Perkins was correct. With integral connections to other Burlington lines, rail

traffic on the Hannibal and St. Joseph soon increased substantially. From 1883 to 1886, freight carried over the railroad increased 25% and gross annual revenues averaged $2.5 million. In 1887, the gross topped $3 million, and net earnings for the 295-mile track exceeded $4,600 per mile.[182]

The Hannibal and St. Joseph, though nearly as old as the Burlington, had never erected its own bridge over the Missouri, instead relying on the existing bridges at St. Joseph and Kansas City to link with other railroads west of the great river. Acquisition of this new line increased the need for a bridge over the Missouri in southern Nebraska. The best crossing site to incorporate the new rail line into the Burlington system was no longer Aspinwall, however, but the small river town of Rulo, Nebraska. A bridge there (shown in Figure 63) would connect the two Burlington rails from Denver and Lincoln with the Council Bluffs line on the other side of the river - an important link in the growing Burlington network. The railroad directors wanted to try again, and Perkins sent Morison back to the river in September 1883 to re-evaluate the prospects. Morison's report the following January was again discouraging:

> The borings showed a state of affairs quite unlike that usually found in the Missouri River, there being no rock within any reasonable depth, but a stiff bed of blue clay, of an average thickness of about 15 feet was found under the alluvial sand, this clay resting on a bed of course sand and gravel of varying thickness, which itself rested on a bed of clay, the surface of which was nearly level and which from its stratified character was found to be more truly a shale than a clay. These borings showed that though the bridge when built would be of a satisfactory character, the cost of the foundations would be exceptionally large.[183]

Morison recommended that a dike be constructed upriver from the bridge site to constrict the channel to a manageable 1100-foot width. For the bridge, he delineated two configurations of high, fixed trusses: one consisting of three 375-foot spans, the other two spans of 500 feet. Because of the poor substructural conditions under the river at Rulo, both would involve unusually deep and costly foundations. The engineer estimated the total construction cost, including six miles of approach track to the high bridge, at $1.2 million. Typically, he rationalized his selection of high configurations by stating that the price of a low bridge with a swing span would be approximately the same. Although the cost of the piers would be substantially less for a low structure, he maintained, "the expense of maintenance and control of the channel, would be considerably greater for a low than a high bridge."[184] When Perkins recoiled at the prohibitive expense of the structure, Morison recanted somewhat, saying, "I feel quite confident that a bridge and approaches can be built here at an immediate cost which will not exceed $1,000,000 - though there may be a quantity of filling to be done some years later."[185]

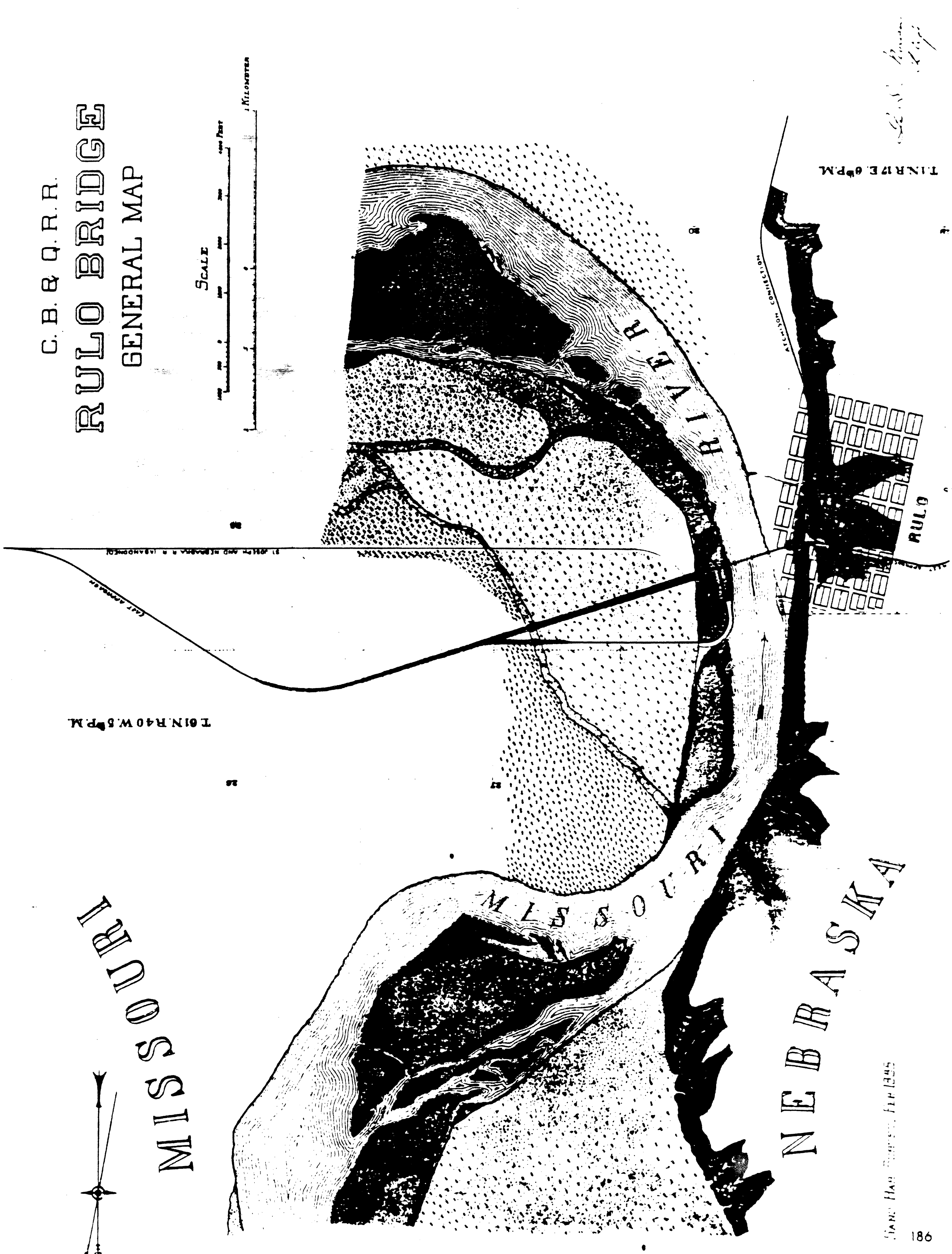

C. B. & Q. R. R.
RULO BRIDGE
GENERAL MAP
SCALE
MISSOURI RIVER
MISSOURI
NEBRASKA
RULO
186

Figure 62

By comparison, the total cost of the Plattsmouth Bridge, completed in 1880, had been a little over $600,000.[187] The expense for the recently completed trussed structure at Blair had been $433,000. With an additional $700,000 for tracks, approaches, protection work, real estate, and fees, the aggregate cost for the bridge exceeded $1.1 million, including Morison's $27,000 fee for engineering and construction supervision.[188] The Bismarck Bridge, unusual in its construction delays and extreme working conditions, had also cost nearly $1.1 million. (The engineering fee for this bridge had been $36,000.)[189] George Morison's bridges tended to be more expensive than those by other engineers, because the contractors familiar with his unyielding nature generally boosted their bids to allow for his exacting standards. But Morison was the only bridge designer then erecting railroad structures over the Missouri. Comparable construction figures could be derived only from his previous projects. Among American civil engineers of the time, his assessment of construction cost to span that problemmatic river was considered the most knowledgeable. Still, his extraordinarily high cost estimates for the Rulo Bridge prompted Burlington officials to question its location and design. Three days after receiving Morison's estimates, Perkins wrote to CB&Q First Vice President T.J. Potter:

> You will observe that the structure is necessarily an expensive one; and before going further and finally deciding to locate there, I desire to raise the question... whether there is any other point on the river worth trying... If, as I believe, the Rulo location is geographically the correct one, then I suppose the bridge should be located there, even at a cost of $500,000 or $600,000 more than it might cost to build at another point, even if only three or four miles away; but it is worth while to have the matter thoroughly investigated before we decide to go on.[190]

Perkins sent Morison back into the field once again - this time to explore alternative bridge locations along the Missouri. In the spring and summer of 1884, the engineer made borings at two other crossing sites: White Cloud, ten miles downriver from Rulo, and Arago, ten miles above. The former site proved promising, but at Arago bedrock lay an incredible 123 feet below the river bottom. Neither location could match Rulo's convenience as a connection between the H&SJ and the Atchison and Nebraska Railroad, which followed the valley of the Great Nemaha to the Missouri River. And approaches to both would be difficult. Rulo was therefore chosen as the site for the bridge. The Atchison and Nebraska Railway Company was another of the Burlington's myriad subsidiary lines, acquired by James Joy for the Burlington and Missouri River Railroad in 1870-71. When the Burlington directors sought Congressional authorization for construction of the bridge at Rulo in spring 1884, they did so under the name of the A&N. The approval was granted by Congress in June 1884.[191]

Typical of Congressional authorizations for bridges over navigable rivers, the

Act for the Rulo bridge specified only minimum span lengths and heights and gave the railroad the option to erect either a high, fixed bridge or a low one with a moveable span. Morison and his staff proceeded with the drawings for a high bridge in his New York office, as Burlington officials began thinking of ways to cut costs. When the discussion turned to the question of high versus low in the summer of 1884, the principals soon divided into factions, each vying ardently for CB&Q President Perkins' approval. Burlington Vice President Potter and railroad officials T.E. Calvert and J.S. Cameron argued for a low bridge. On the other hand, George Morison, Burlington Chief Engineer R.J. McClure, and H&SJ General Manager J.F. Bernard advocated the high bridge design. Calvert fired the first volley in August:

> The man who has to live with a bridge of this kind and be responsible for its operation will always favor a low bridge where its construction is practicable. At Rulo I think a low bridge is not only practicable, but has many advantages over a high bridge, though I would not care to decide against a high bridge at that point before seeing the estimates of cost of the two bridges, and Mr. Morison's maps and profiles of line... Morison may be able to get a cheaper high line than I had anticipated, but with additional line to be built, and heavy expensive work, I doubt if he will get a high line which it will pay us to build. As to holding channel for draw, I think there will be no additional expense for if it is held at all it can be held for draw.[192]

The controversy raged through the autumn and into the next year. Perkins and Potter sent typed letters and telegrams from the Burlington's Chicago office and George Morison dashed off hand-written messages from his home office in New York, field offices in Dakota, Nebraska, and Oregon, and in between aboard trains. Railroad engineering, Morison maintained, was governed almost exclusively by economy, and the high truss design would be the most economical to build and operate. "In my own mind, the advantages of a high bridge at Rulo over a low bridge are very great," he restated in March 1885. "It seems to me that to construct a low bridge there would be to commit a very serious mistake from both a commercial and engineering aspect."[193] To this Potter countered:

> Morison and McClure will say that, with a low bridge, we are likely to have the channel to change. I venture to stake my reputation as a railroad man, that it will cost as much money to keep the channel inside of a high bridge as to keep it within a draw span. There is something about low bridges that commends it to the public and to our employees, as being more safe, and as though we were doing business on a good foundation, and not flying through the air and taking chances no good Railroad Company should take.[194]

Perkins himself favored the low bridge configuration, saying, "Personally I

prefer to ride over low bridges rather than high ones, and I have no doubt many people have the same feeling."[195] But he trusted George Morison's judgement and was waiting, he said, to see the bottom line figures for both designs before deciding. "The cost, however, may well cause us to stop and carefully re-examine the question," Potter wrote in a memo to the Burlington president, "Comparatively it represents 100 miles of road in Nebraska, or 100 miles of double track in Illinois and Iowa; or a 160 mile division of Iowa grades reduced from 70 to 40 feet. If we were to-day to choose which of the above four improvements we would have for 1884, I hardly think it would be the bridge at such cost."[196] He cautioned Perkins to wait:

> My judgement would not be to hurry the construction of the Rulo bridge, but let matters drift another year and see what other people are going to do with reference to invading northern Kansas and southern Nebraska from the east. We can put in a temporary bridge there that will last four months and run the boat the other eight months without any great expense and as there are no passenger trains running there, the delay will not be serious.[197]

When Morison prepared comparative cost estimates for the two configurations, Potter accused him of tinkering with the figures to skew them in favor of a high bridge. The railroad vice president wanted to call in General William Sooy Smith for a second opinion. Realizing that another strong personality would only exacerbate an already explosive situation, Perkins refused. "I doubt the expediency of employing General Sooy Smith to revise Mr. Morison's estimates," he replied to Potter, "because he and Mr. Morison do not like each other, and I am afraid it would cause ill feeling to do so."[198]

While Morison and Potter battled through 1884 and early 1885, Burlington trains in the region were crossing the Missouri River over the existing bridge at St. Joseph - a satisfactory short-term situation. This lack of urgency might help to explain why the otherwise decisive Burlington president delayed for over a year making a decision about the bridge at Rulo. In late spring of 1885, however, Perkins finally made up his mind. Against Potter's protests and his own personal preference, he sided with the Morison group, approving the high bridge design. The decision wounded Potter's pride, as a May 1886 letter to Perkins indicates: "I am sorry to see you have decided to build a high bridge. I am satisfied in my own mind that it is a mistake. While I am not up in figures as Morison, McClure and others are, I think my knowledge of the Missouri River in all its bearings, is worth something."[199] To Perkins' chagrin, Potter quit the Burlington the next year to become vice president for the rival Union Pacific.

The affirmation of his engineering judgement must have buoyed George Morison, but the bellicose engineer was barely able to conceal his irritation as he

sniped at Potter and the others one last time in a later report to Perkins:

> It was to me evident from the beginning that the only proper structure was a high bridge without a draw, the western approach to which would run nearly due west connecting with the Atchison & Nebraska Railroad in the Nemaha valley... There was, on the other hand, a decided demand by some of the operating officials of the company for a low bridge, the west approach to connect with the old track of the Atchison & Nebraska R.R. in front of the town of Rulo, which ran south along the Missouri bottom till it reached the Nemaha valley. The merits of a high bridge scheme was its simplicity, a less cost of maintenance of the bridge and the fact that it shortened the through distance two miles. The only advantage of the low bridge scheme was that it avoided the deep cut west of Rulo, and a careful estimate showed that a low bridge would be the more expensive of the two. The difference of opinion prevented an early determination of the plan of bridge and did much to render the cost of real estate on the west side of the river unreasonably large.[200]

The argument about the bridge height finally settled, Morison could complete the construction documents in New York and let the project out to bid. For the substructure in the river channel he turned predictably to his standard configuration - massive, solid masonry piers founded on pneumatic caissons (shown in Figures 64 and 63). And for the superstructure, he once again engineered Whipple through trusses for the three channel spans, with six Pratt deck trusses for the approaches. As he had outlined in his 1881 preliminary design, the through trusses (shown in Figures 65-69) extended 375 feet, and were divided into fifteen panels of twenty-five feet each; the five-panel deck trusses (shown in Figures 70-72) spanned 125 feet each. Morison was by then using standard drawings and specifications for his bridge superstructures, developed on previous projects with C.C. Schneider, and other than the overall length, the channel spans of the Rulo Bridge were virtually identical to his single-track bridges at Bismarck and Blair. The deck trusses were identical with those of the Omaha Bridge, differing only in the substitution of four-bent towers for the masonry piers.

But a more subtle difference lay in the metallic composition of the bridge at Rulo. As more steel mills opened and production increased, the quality and consistency of structural-grade steel was improving and its price and availability were inching toward parity with wrought iron. Again George Morison increased the percentage of steel by degree for the superstructures of the channel spans. This bridge marked a milestone of sorts for the engineer: the Whipples at Rulo were his first long-span trusses since Plattsmouth to contain more steel than iron. Only slightly more - 52% steel versus 48% cast/wrought iron - but the Rulo Bridge represented Morison's commitment toward steel and foretold his, and

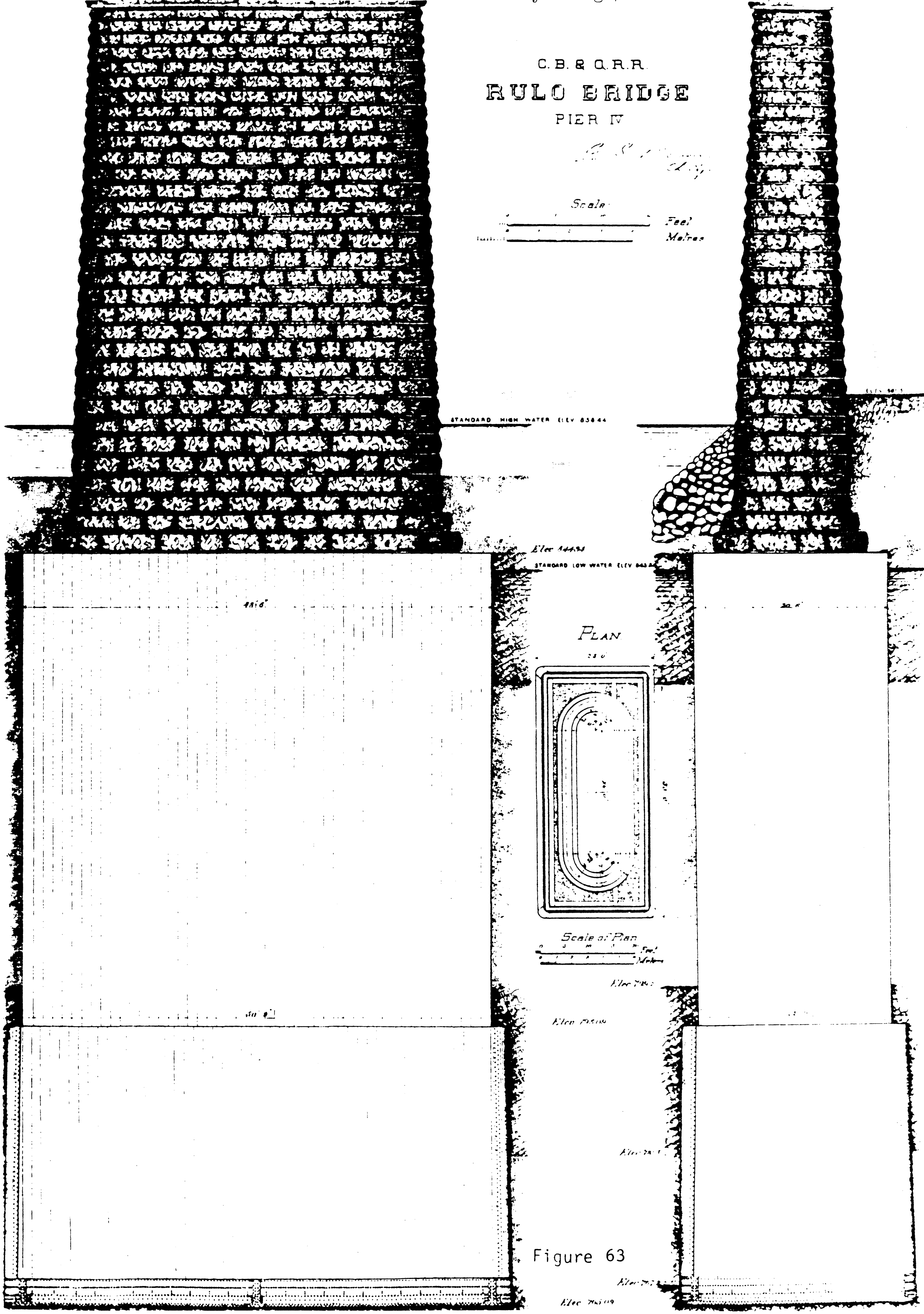
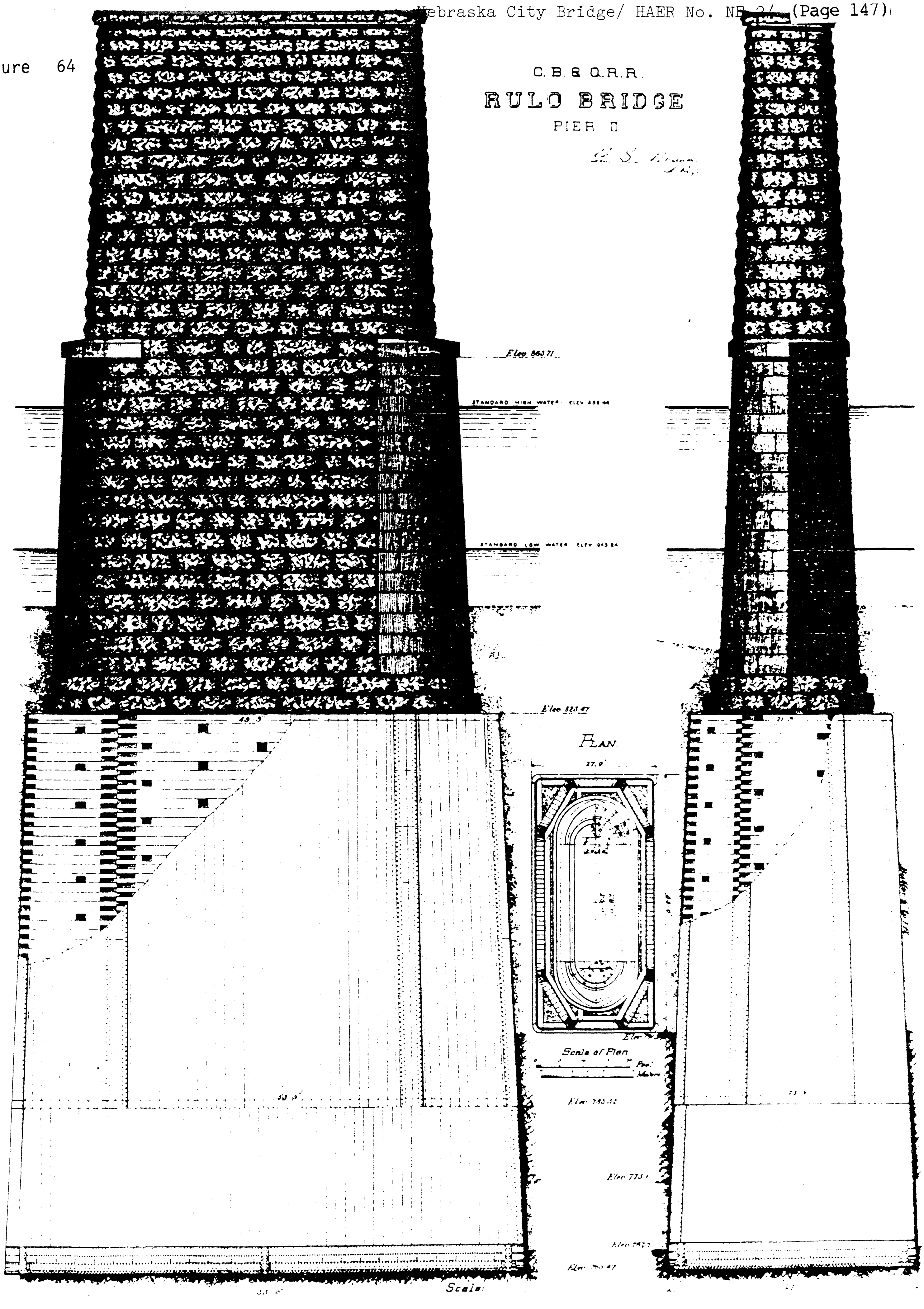

C.B.&Q.R.R.
RULO BRIDGE
PIER IV
Scale
Feet
Metres
STANDARD HIGH WATER
STANDARD LOW WATER
PLAN
Scale of Plan

Figure 63

Figure 64



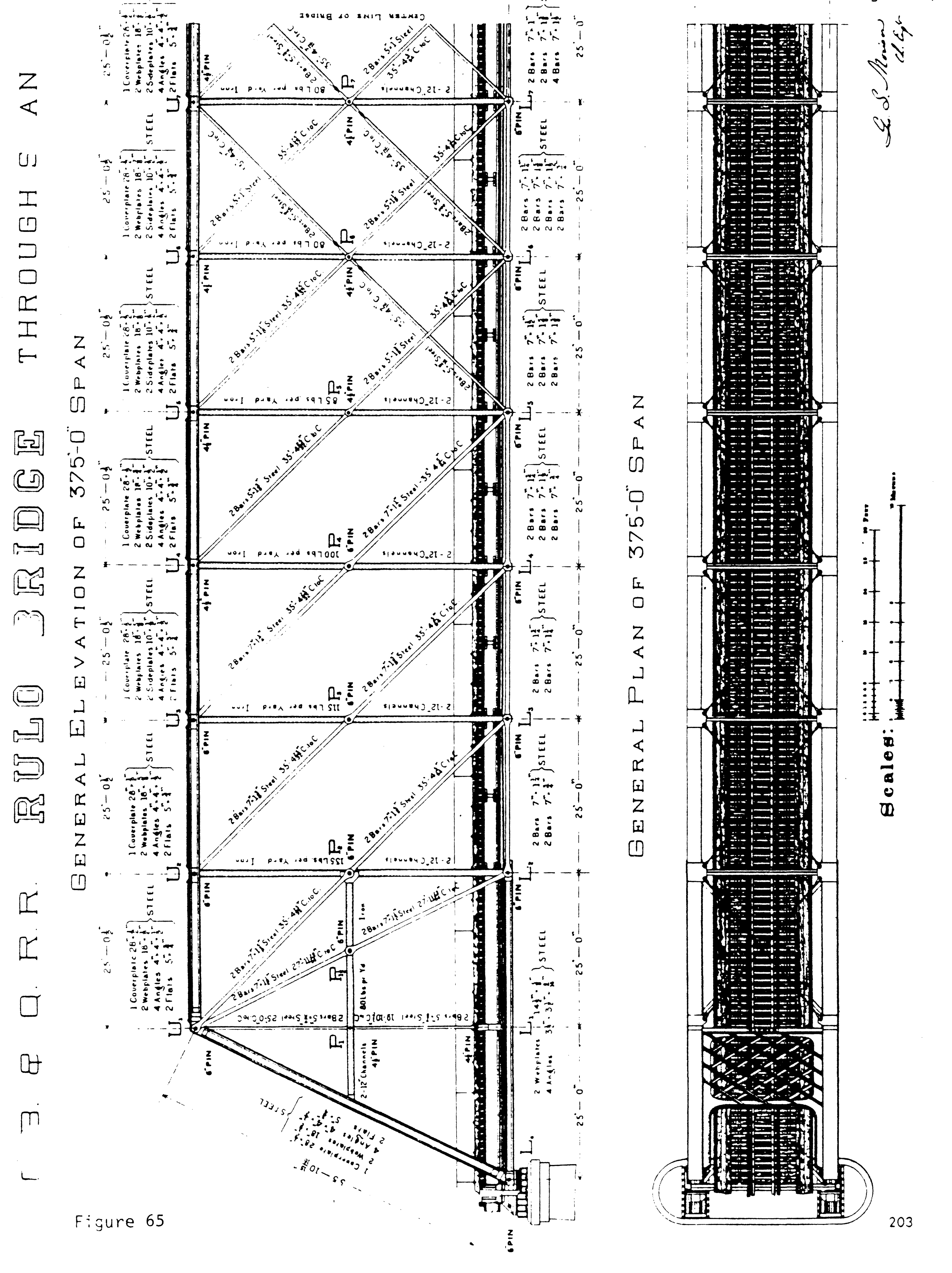

B. & Q. R.R. RULO BRIDGE THROUGH SPAN
GENERAL ELEVATION OF 375'-0" SPAN
GENERAL PLAN OF 375'-0" SPAN
CENTER LINE OF BRIDGE
Scales:

Figure 65

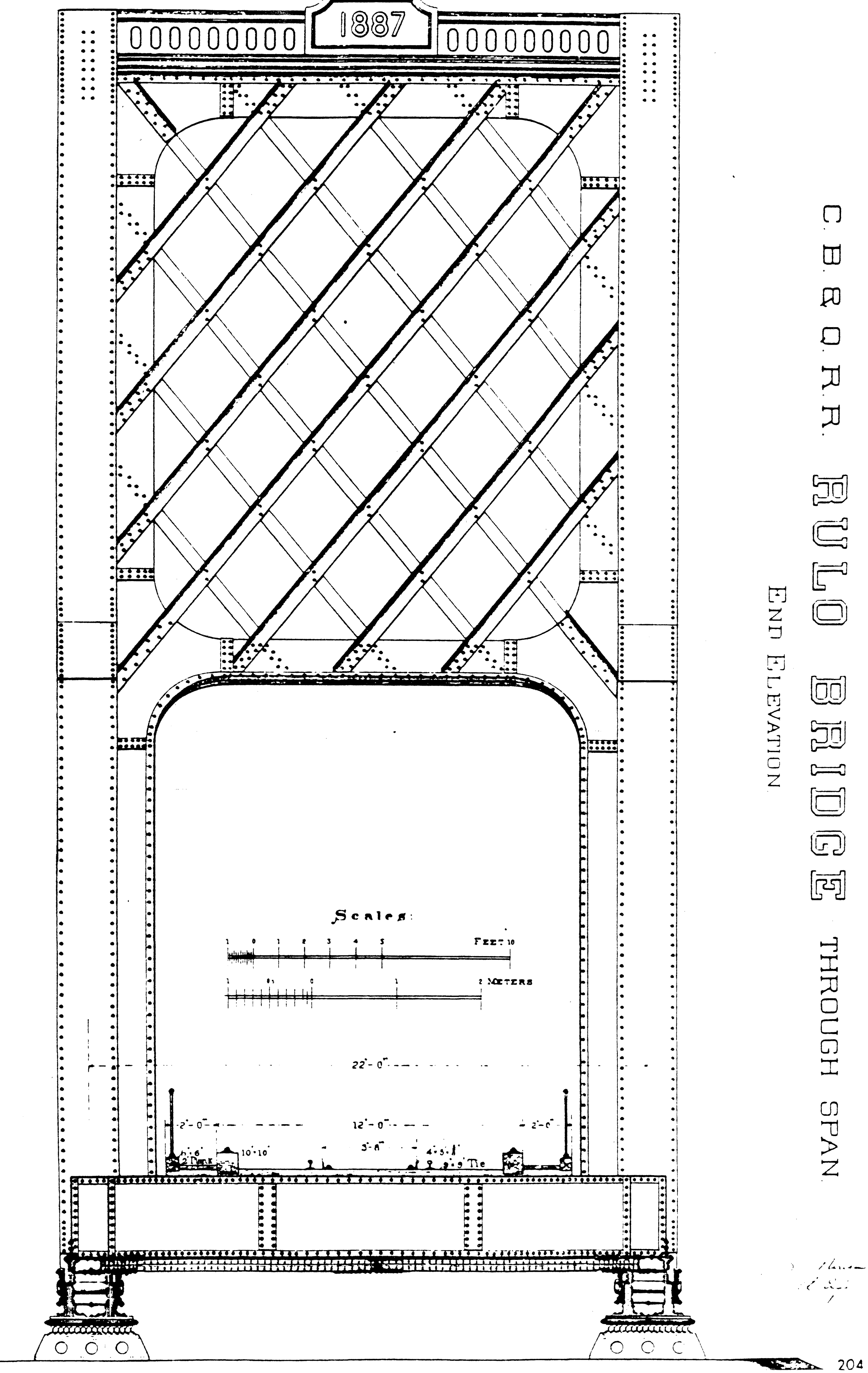

1887
C.B.&Q.R.R.
RULO BRIDGE
THROUGH SPAN
END ELEVATION
Scales:
FEET
METERS
22'-0"
12'-0"
2'-0"
5'-8"

Figure 66

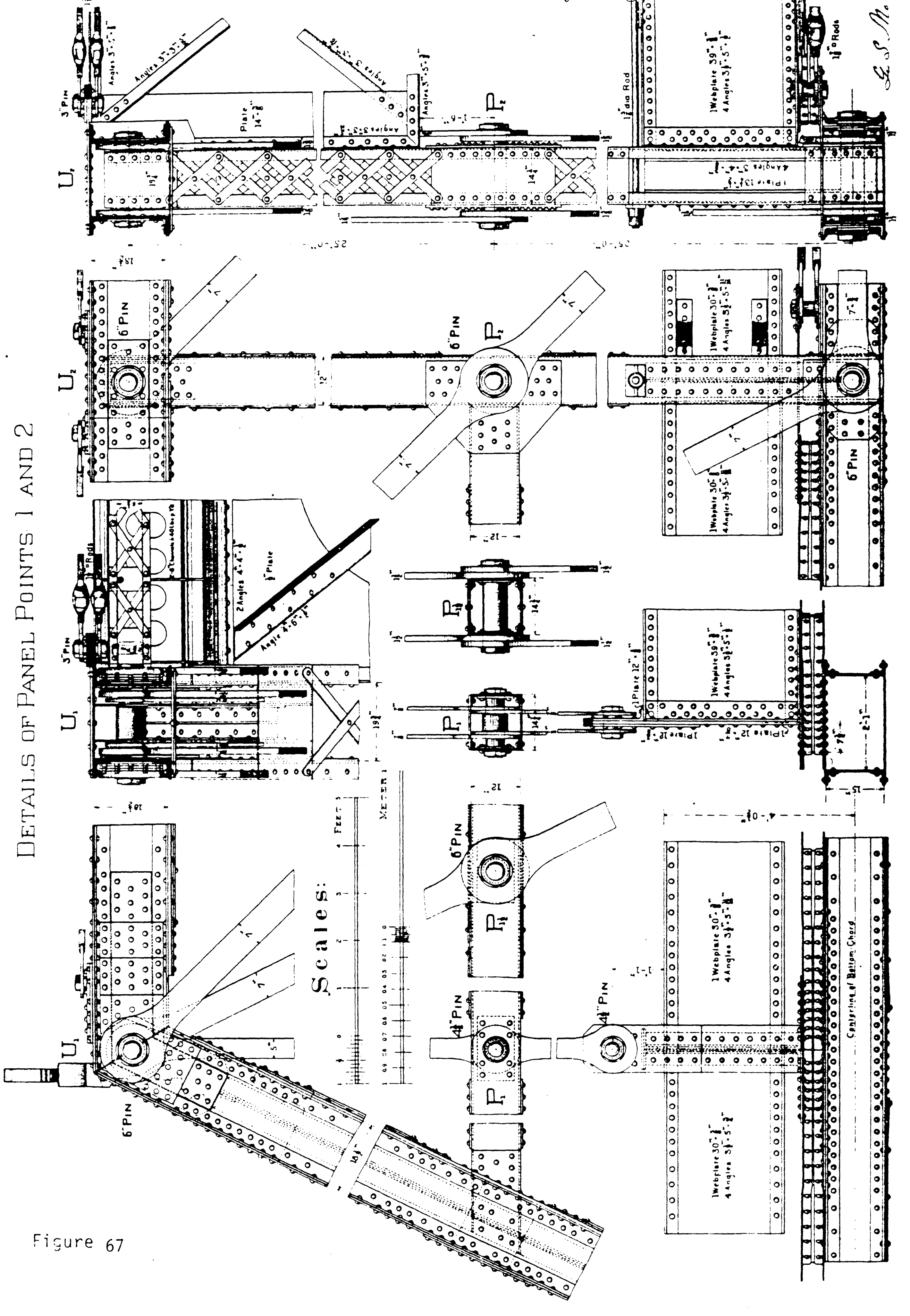

THROUGH SPAN
DETAILS OF PANEL POINTS 1 AND 2
Scales:
6" PIN
4½" PIN
Centerline of Bottom Chord

Figure 67

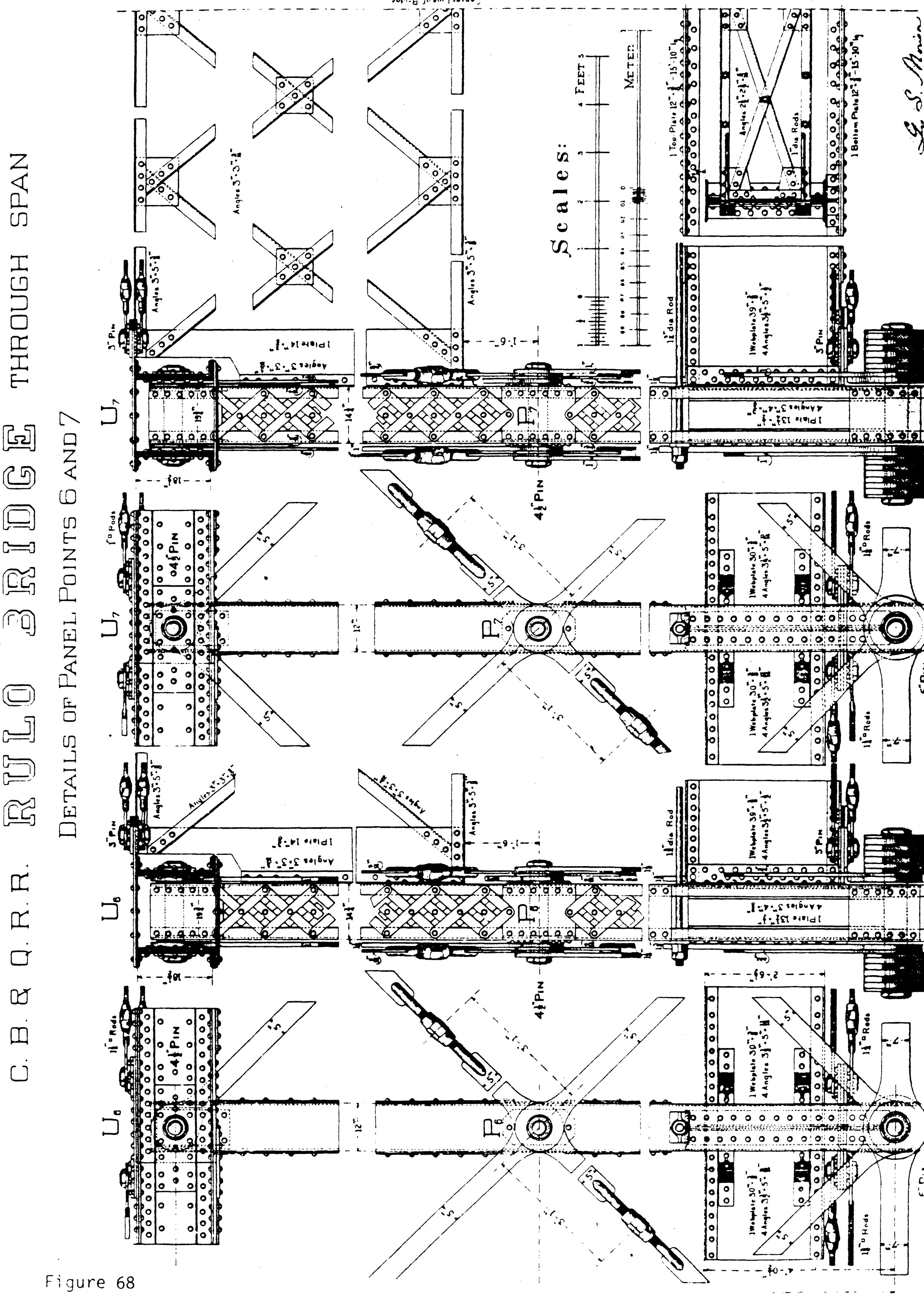

C. B. & Q. R. R. RULO BRIDGE THROUGH SPAN
Details of Panel Points 6 and 7
Scales:
Feet
Meter

Figure 68

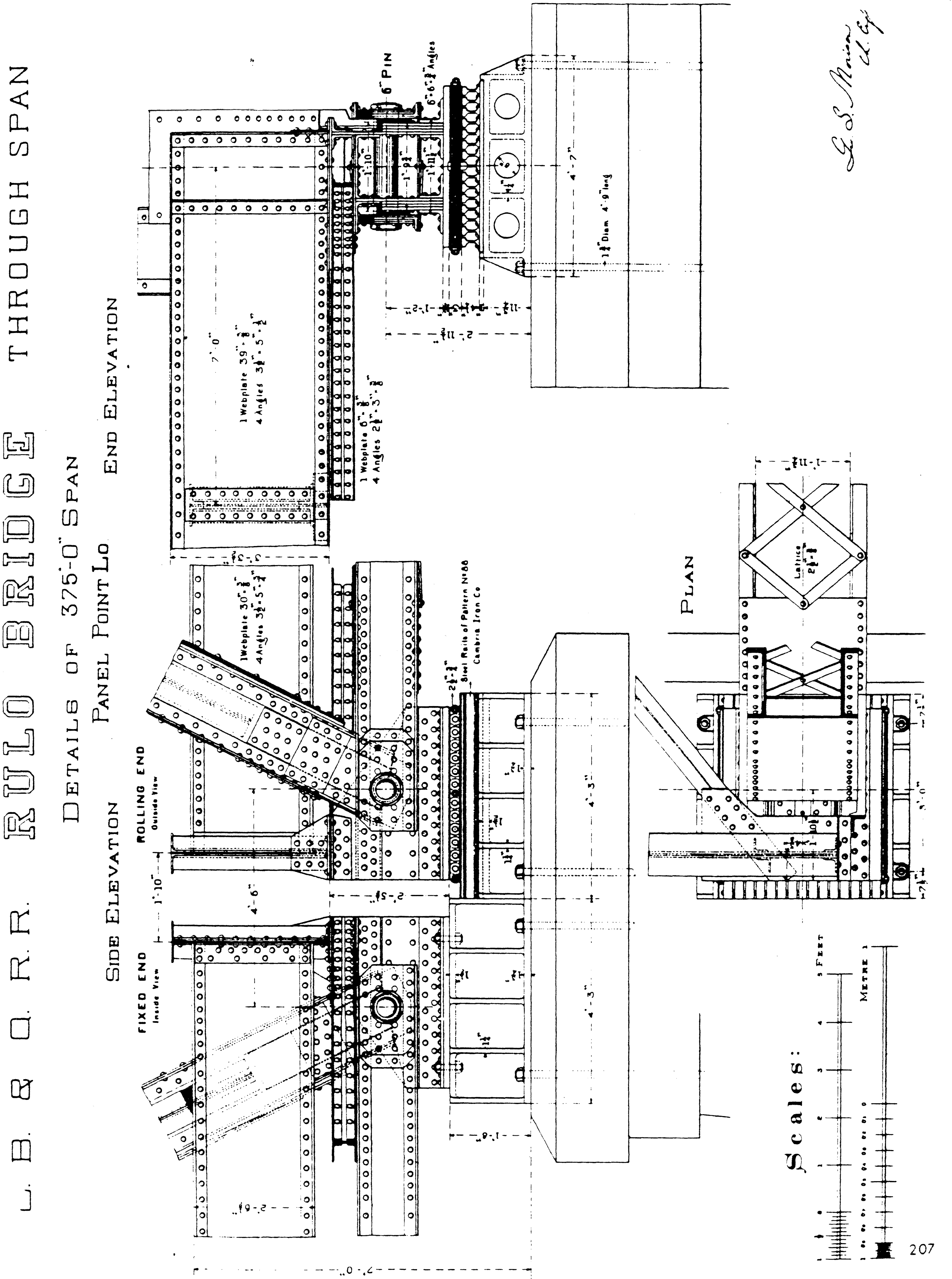

L. B. & O. R.R. RULO BRIDGE THROUGH SPAN
DETAILS OF 375'-0" SPAN
PANEL POINT L0
SIDE ELEVATION
END ELEVATION
PLAN
FIXED END
Inside View
ROLLING END
Outside View
6" PIN
1 Webplate 39"·⅜"
4 Angles 3½"·5"·½"
1 Webplate 30"·⅜"
4 Angles 3½"·5"·½"
Steel Rails of Pattern No 86
Cambria Iron Co
Lattice
Scales:
Feet
Metre
207

Figure 69

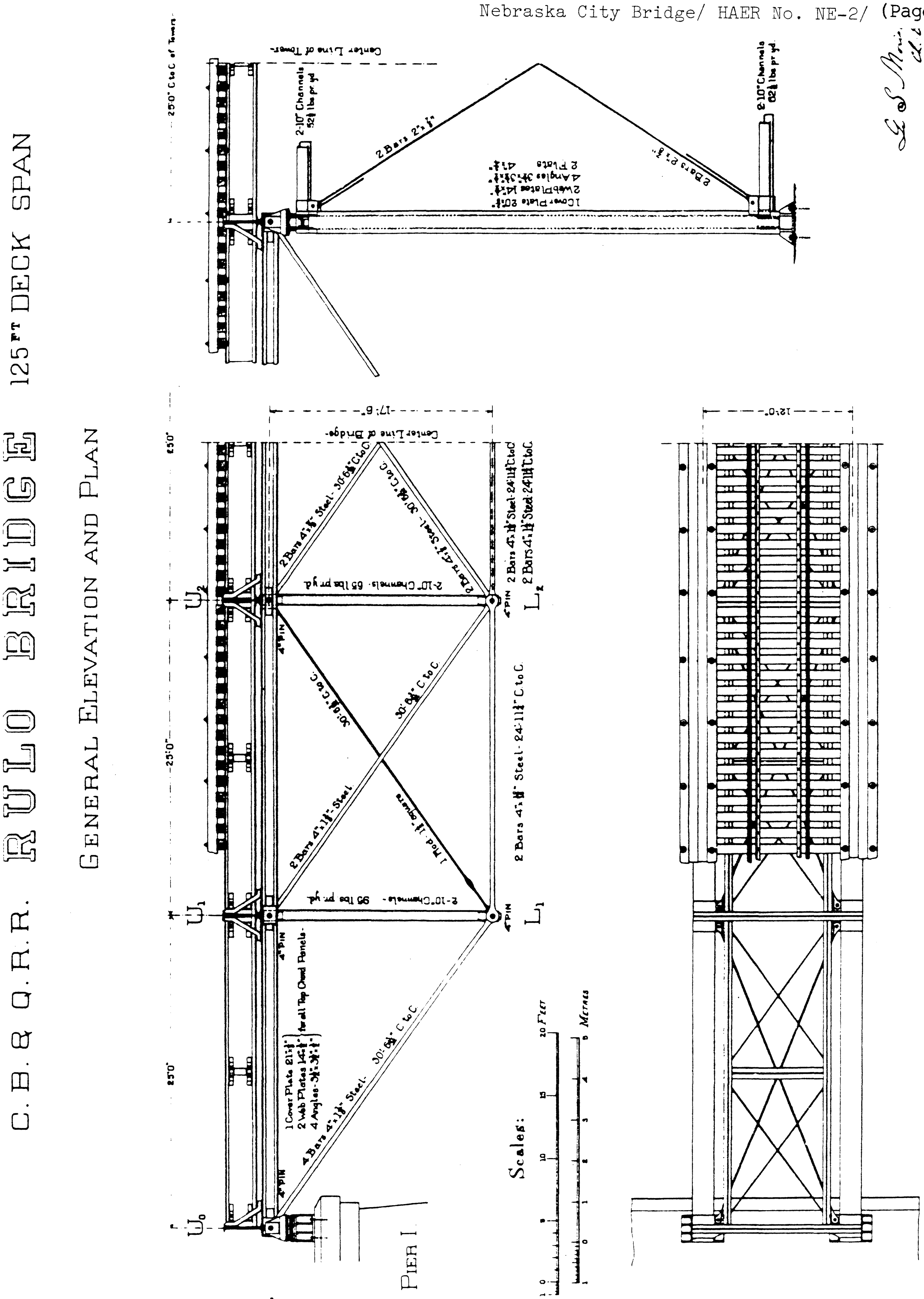

C.B.&Q.R.R. RULO BRIDGE
125 FT DECK SPAN
General Elevation and Plan
Pier I
Scales:
Feet
Metres
Center Line of Tower
Center Line of Bridge
2 Bars 4"x 1⅞" Steel - 24'-11⅜" C to C
2-10" Channels - 65 lbs pr yd.
2-10" Channels - 95 lbs pr yd.
1 Rod 1⅜" square
4" PIN
U0
U1
U2
L1
L2

Figure 70

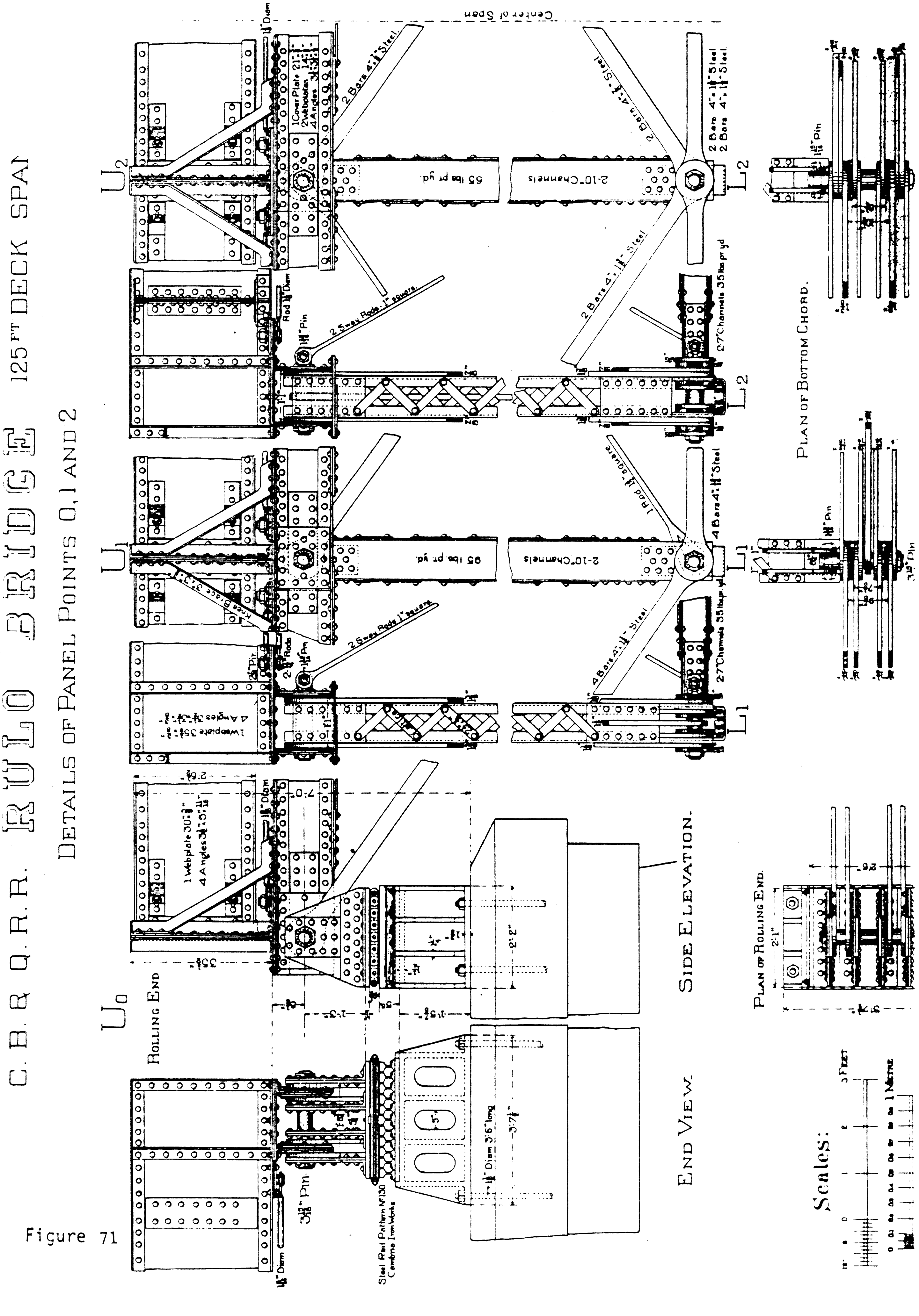

C.B.&Q.R.R. RULO BRIDGE 125 FT DECK SPAN
DETAILS OF PANEL POINTS 0, 1 AND 2
SIDE ELEVATION
END VIEW
ROLLING END
PLAN OF BOTTOM CHORD
PLAN OF ROLLING END
Scales:
Center of Span
2-10" Channels
95 lbs. pr. yd.
2 Sway Rods 1" square
Knee Brace
Steel Rail Pattern No 130 Cambria Iron Works

Figure 71

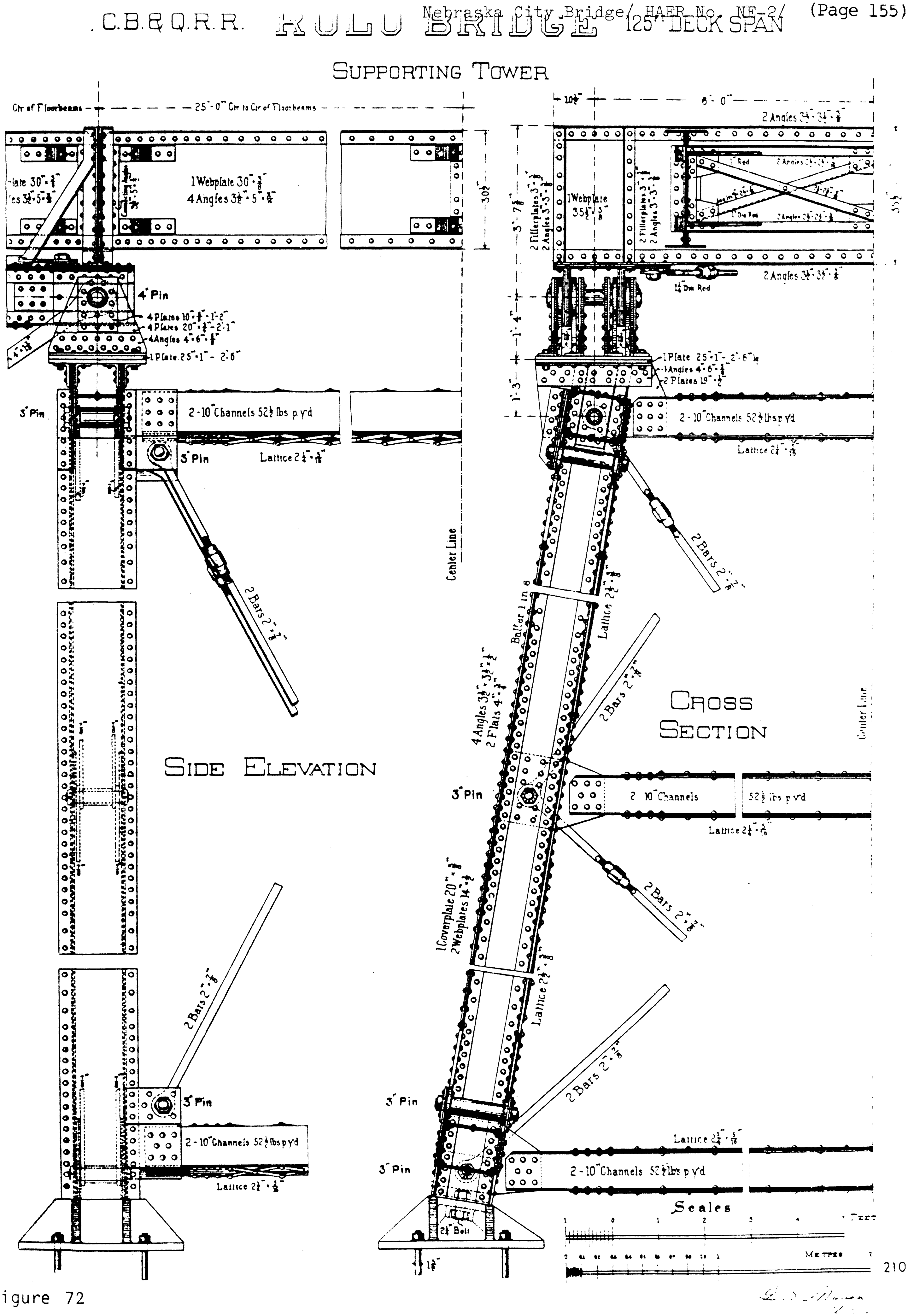

C.B.&Q.R.R. RULO BRIDGE 125' DECK SPAN
SUPPORTING TOWER
SIDE ELEVATION
CROSS SECTION
Ctr of Floorbeams
25'-0" Ctr to Ctr of Floorbeams
1 Webplate 30" · 3/8"
4 Angles 3½" · 5" · 7/16"
30½"
4" Pin
4 Plates 10" · ½" - 1'-2"
4 Plates 20" · ½" - 2'-1"
4 Angles 4" · 6" · ½"
1 Plate 25" · 1" - 2'-6"
3" Pin
2 - 10" Channels 52½ lbs p yd
Lattice 2½" · 5/16"
2 Bars 2" · 7/8"
Center Line
2 Angles 3½" · 3½" · 3/8"
6'-0"
1 Webplate 35½" · 3/8"
2 Fillerplates
2 Angles
1" Rod
2 Angles 3½" · 3½" · 3/8"
1¼" Dia Rod
3'-7⅞"
1'-4"
1'-3"
1 Plate 25" · 1" - 2'-6"
4 Angles 4" · 6" · ½"
2 Plates 19" · ½"
Batter Line
4 Angles 3½" · 3½" · ½"
2 Flats 4" · ½"
1 Coverplate 20" · 3/8"
2 Webplates 14" · ½"
2½" Bolt
Scales
Feet
Metres

Figure 72

soon thereafter the industry's, complete transfer to the stronger, lighter material.

Morison submitted the final plans to Secretary of War William C. Endicott for approval in July 1886, running immediately into another bureaucratic obstacle. Three years earlier, a bill had been introduced in Congress to standardize the design requirements for bridges over the Missouri River. Although it had not passed, General Wright of the War Department recommended that the Rulo Bridge be forced to comply with the bill's provisions. The bridge exceeded the 300-foot minimum span length requirement for a high fixed structure, but Wright's height requirement exceeded that of the the 1884 Congressional Act authorizing the bridge at Rulo. Morison was enraged. "The provision requiring the bridge to be 80' above low water, if a high bridge, is an unreasonable and a very objectionable one," he protested to the Secretary. "It has never been required before, and the bridges already built on the Missouri are generally from 65' to 70' above low water."[211] He forced the department to drop the eighty-foot requirement and to approve his design in February 1887.

Work on the bridge was by then well under way. While Morison and Potter bickered telegraphically over its design throughout 1884 and 1885, the engineer convinced Perkins to authorize construction of the upriver rectification works (shown in Figure 74) and the foundation for the easternmost pier to better determine the substructu- ral conditions. A railroad crew began construction of the curved east shore dike in December 1884. The foundation for the dike consisted of a woven willow mattress 125 feet wide. On this the men built an embankment of brush and rock, on which they laid a track. The dike was later extended 700 feet downstream to the easternmost pier of the bridge by driving a series of piles through a 50-foot wide woven mattress and wiring a second mattress to the piles. The effect of this permeable screen was to allow the river to flow through, preventing the formation of an eddy at the lower end of the dike. Construction of the east shore dike and the riprap west bank protection was completed in May 1885.

Work on the pier foundation began in December 1885, and by the following April it too was completed. During most of 1886 and 1887, Morison's firm was simultaneously engaged in designing and/or supervising construction of four Missouri River bridges bridges between Sioux City and Rulo in addition to the behemoth structure at Cairo. As a result, his usual group of assistants was occupied on other bridge projects, and he was forced to work with an untested crew at Rulo (listed in Appendix H). Benjamin L. Crosby was hired as the resident engineer; Edwin Duryea, a veteran from the Omaha Bridge, Mark A. Waldo, and W.S. MacDonald were hired as assistant engineers. In July 1886, Morison awarded the masonry contract to his former bridgebuilding partner, George S. Field, who then transferred it within the week to the contracting firm of Drake and Stratton. He awarded the contract for the fabrication and erection of the

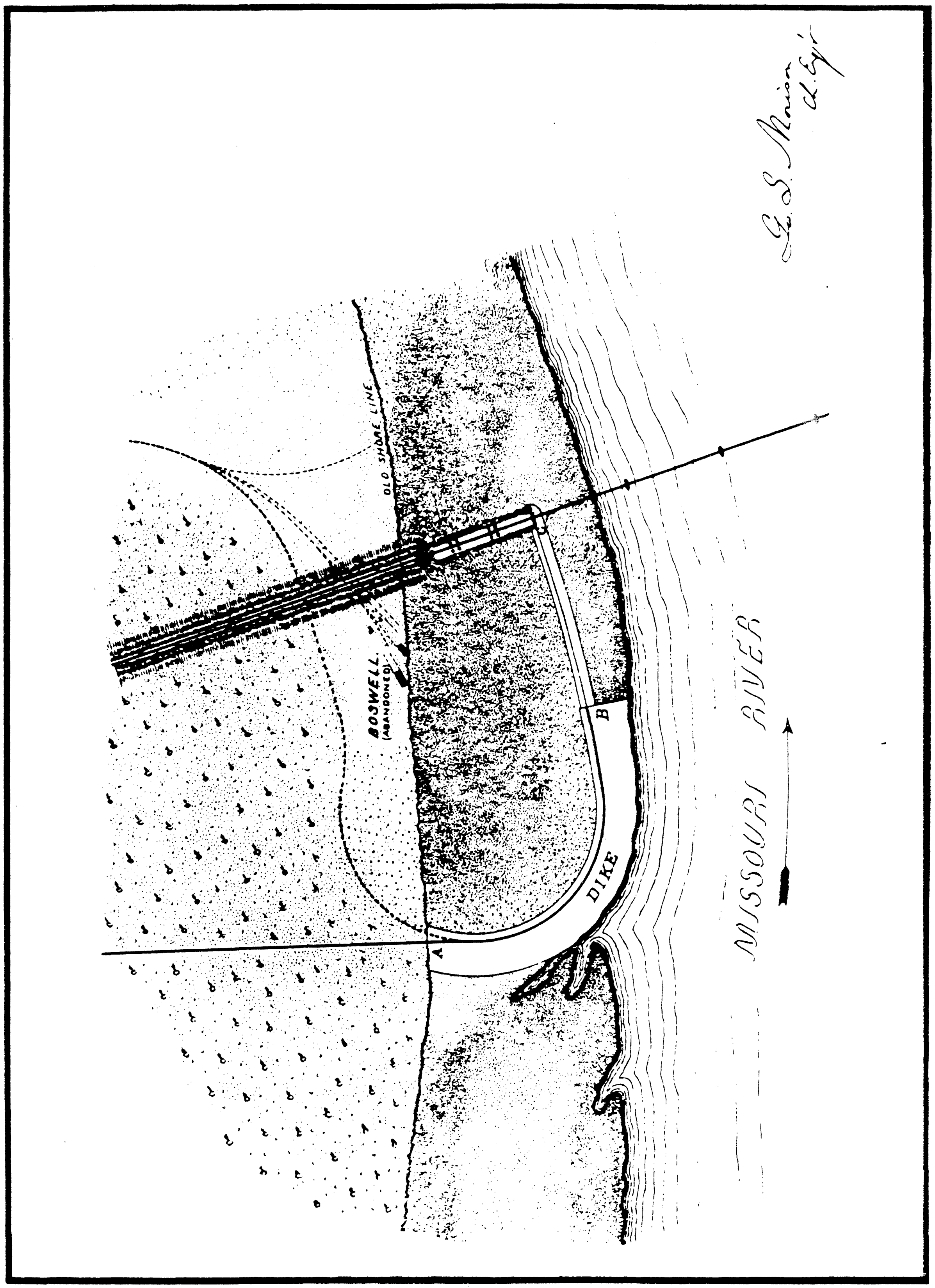


Figure 73

superstructure to the Edgemoor Iron Company. Typical of all of Morison's bridges since Blair, railroad crews were to build the pneumatic foundations, directly under the supervision of his resident engineer.

Like Ralph Modjeski on the Omaha Bridge, Mark Waldo was beginning his engineering career under the tutelage of George Morison as an assistant on one of the largest bridge projects in America. And as he had with Modjeski, the formidable Chief Engineer made an powerful impression on his young apprentice which would last throughout their lifelong friendship. Waldo years later would write fondly of Morison:

> As I saw that tower of professional strength - that bulwark of sturdy rectitude which swayed not one inch to favor anything or anybody which had not the nearest attainable truth as its basis - I grew to love it - shaggy coat and all... Like Jowett of Baliol he hated incompetency and the men who half knew things. He was the terror of contractors who wanted to shirk, or not come up to the engineering specifications he drew. When bids were invited, the estimates were always higher, if it was known that Morison was to approve the work finally. The General Manager of a great Steel Company said to me: "Morison is a great engineer, but he has made us a hell of a lot of trouble." Nothing passed that great engineering judge but what was right... In all our association together there was never a cloud. He had two themes which he was fond of trotting out with me: one was his opinion of a certain College President, and the other was his often expressed thought that my musical study interfered with my attainments as an engineer! Both of these ideas I had often enough to stand by my guns to defend. Judge of my surprise when I told him one Monday that the Saturday previous I had gone to Bethlehem to hear the consecrated performance of the great B Minor Mass of Bach, by the Moravian Brotherhood, to have him say, "I wish I had gone myself. That is music I should like to have heard." [213]

By 1886, Morison had changed the substructural design for the Rulo Bridge to reduce its enormous expense. Test excavations under the first caisson had revealed that the upper clay layer could support the piers. This would eliminate the need to penetrate through the underlying gravel bed into the bottom clay bed and would result in a substantial saving. To cut costs further, the engineer deleted several solid stone pillars under the approach spans, substituting iron towers for masonry. As built, the main bridge supports consisted of four immense granite piers beneath the three channel spans and sixteen steel-cased cylindrical concrete piers which supported the towers. All of the masonry piers were supported on pneumatic foundations. To equip the caissons, the Burlington railroad purchased the pneumatic machinery used on the Blair Crossing bridge from the Missouri Valley and Blair Railway and Bridge Company.

From the Sioux City and Pacific Railroad the CB&Q bought the steamer John Bertram, which had functioned as a car transfer boat at Blair. Workers fitted the boat with the equipment, forming what Morison called, "an admirable tool."[214]

The first caisson had already been positioned when the laborers began full-scale construction on the others in July 1886. The pilot positioned the John Bertram over the westernmost pier, and the men began lowering the massive timber/iron caisson to the riverbed with large screws. When the cutting edges of the caisson hit the upper clay level in September, the material proved structurally unsuitable, and Morison ordered the excavation continued into the lower clay layer. On October 19, as the caisson was reaching its lowest depth, trouble developed when a leak was discovered in the well leading to the air lock. To Morison the leak was an irritation because the problem was "clearly due to bad workmanship," but to the nervous laborers working well below the surface of the water, the spreading cracks were cause for alarm. After two days of increasing water leakage, the engineer finally halted work in the caisson and ordered the well lined with oak. Work resumed three days later.

On November 5th, the excavation was completed and the work chamber filled with concrete. Construction on the next pier began after piledrivers built a pile breakwater above the pier location in September. By November, the caisson was built and positioned on a sand bar created by stacking brush behind the breakwater. Winter was by then fast approaching, ice beginning to form on the surface of the river, on the structures, and on the equipment. A gang of thirty men was stranded on the caisson overnight later in the month when ice floes immobilized the John Bertram. As the men on the river surface struggled in the bitter cold to keep the machinery operating, others in the pressurized chamber below dug through the silt riverbed - about six inches per day - throughout the rest of the year. The river ice pack formed and collapsed several times during the winter, disrupting the work. By January, the caisson crew had reached the first clay level. By the end of April they had sunk iron cutting edges into the lower clay, and soon thereafter the foundation was completed. After the final ice breakup in early March, the substructural and masonry work could continue uninterrupted throughout the spring, and in June all of the foundation work was completed. Masons laid the last of the St. Cloud granite on the piers two months later.[215]

The Rulo Bridge was now ready for the superstructure. The steel was produced in 161 open-hearth melts from four Pennsylvania mills. The Cambria Iron and Steel Company rolled half of the material, with the rest produced by Carnegie, Phipps & Company, Limited; the Pennsylvania Steel Company; and the Pittsburgh Steel Casting Company. Edgemoor Bridge cut and assembled the rolled sections at its works near Wilmington, Delaware. As he had on the preceding bridges, Morison rejected a fairly high percentage of the steel as not meeting his printed specifications. On the Rulo Bridge, however, breakage of the full-

length eyebars during testing was traced not to deficiencies in the steel but in the testing machine itself. The bars were eventually accepted.[216]

The trusses were erected on pile falsework, using a large timber traveler built at the site. Workers began erection of the west approach spans in April 1887, and five weeks later they swung the first steel for the first of the channel spans. The first and third through trusses each took six days to build. The middle million-pound span was put up in only four days. On September 14, 1887, all of the superstructural steel was in place, ready for the railroad's crews to install the timber floor and paint the immense structure. The piers and foundations for the Rulo Bridge had cost $365,000; the superstructure almost $200,000; protection works, approaches, and service tracks over $400,000; and George Morison's fee almost $50,000. The aggregate cost of the structure was $1.02 million - slightly more than Morison's revised estimate. The first train crossed over on the afternoon of October 2nd, and the great bridge was opened for traffic.[217]

SIOUX CITY BRIDGE

Conservatism lay at the core of George Morison and his approach to engineering. It had taken the cautious engineer five of the greatest bridge commissions in the country over the previous seven years to increase his dependence on steel to an equal basis with wrought iron for the main spans of his structures. What he did on his next two represented for him the culmination of the evolutionary process. The bridges over the Missouri River that he designed and supervised simultaneously at Sioux City and Nebraska City, Nebraska were similar in configuration. Both were single track railroad bridges, consisting of fixed long-span Whipple trusses supported high above the river on behemoth masonry piers. In this respect the two resembled all of Morison's previous trusses over the Missouri. Yet the Nebraska City and Sioux City bridges differed from Morison's earlier structures - and from all other bridges in America except one - in their complete dependence on steel for the channel spans. William, Sooy Smith had built a multiple span Whipple truss entirely of steel at Glasgow, Missouri, ten years earlier. But, like Morison, the engineering profession had been skeptical of the durability, consistency and economy of the new material. At Sioux City and Nebraska City Morison made the first complete break from wrought iron.

The Sioux City Bridge was the earlier of the two started. The need for a bridge

over the river there had been established over twenty years before. To placate economic interests along the Missouri River, Congress in 1862 had designated feeder branches from five river towns in its enabling legislation for the Union Pacific Railroad. These towns - Kansas City, Leavenworth, St. Joseph, Sioux City, and Omaha - would join with the single transcontinental trunk line near Ft. Kearny, Nebraska.[218] When the first train reached Sioux City on March 7, 1868, boosterish newspapers proclaimed the frontier settlement the "new gateway to the west," because of its combined rail and steamboat links. The population of the rough-hewn town (1,030 just before the railroad's entry) burgeoned as steamers plying the Missouri began to bypass nearby Yankton, Dakota, to debark at the new rail nexus. Yankton merchants built their own rail connection with the Sioux City line in 1873, and almost simultaneously the Northern Pacific reached Bismarck, upriver from both the other towns. The intense competition among the three settlements tended to siphon the riverboat business from the Sioux City port, and by 1876 of the five Congressionally designated towns, only Sioux City had not erected a railroad bridge over the Missouri River.

In August that year, the Sioux City Bridge Company petitioned Congress successfully for authorization to erect a permanent railroad bridge over the river. By the end of 1884, however, the Boston-based company was no closer to building a bridge since receiving the charter. The following January, company directors finally acted by asking George Morison to inspect the site and make preliminary recommendations on a bridge location and design. City engineer L.F. Wakefield surveyed a seven-mile stretch of the river - four above the city and three below - taking soundings and borings at various points to ascertain the water depth and the level of bedrock beneath the riverbed. From this report, Morison described the character of the river at Sioux City to the bridge company:

> About a mile and a half from the bridge and immediately in front of Sioux City the channel is of very variable character, shifting from side to side of the river; the current, wherever it may be above, strikes the east bank before reaching the bridge. The portion of Sioux City next to the river is built on bottom land and when the channel has been next to this shore it has cut badly into this bottom land. A little above the mouth of the Floyd River there is a considerable deposit of gumbo in this bottom land which has cut away very slowly, leaving a projecting point which has caused a temporary local disturbance.[219]

The engineer recommended two locations for the bridge: at the foot of Kansas Street in the heart of town and at Sawyer's Bluff just below Sioux City. The directors of the bridge company had set a $1.2 million limit on the erection cost of the bridge. Morison assured them that the structure could be built within the budget.[220]

The improvement in the business climate at Sioux City between 1876 and 1885 was

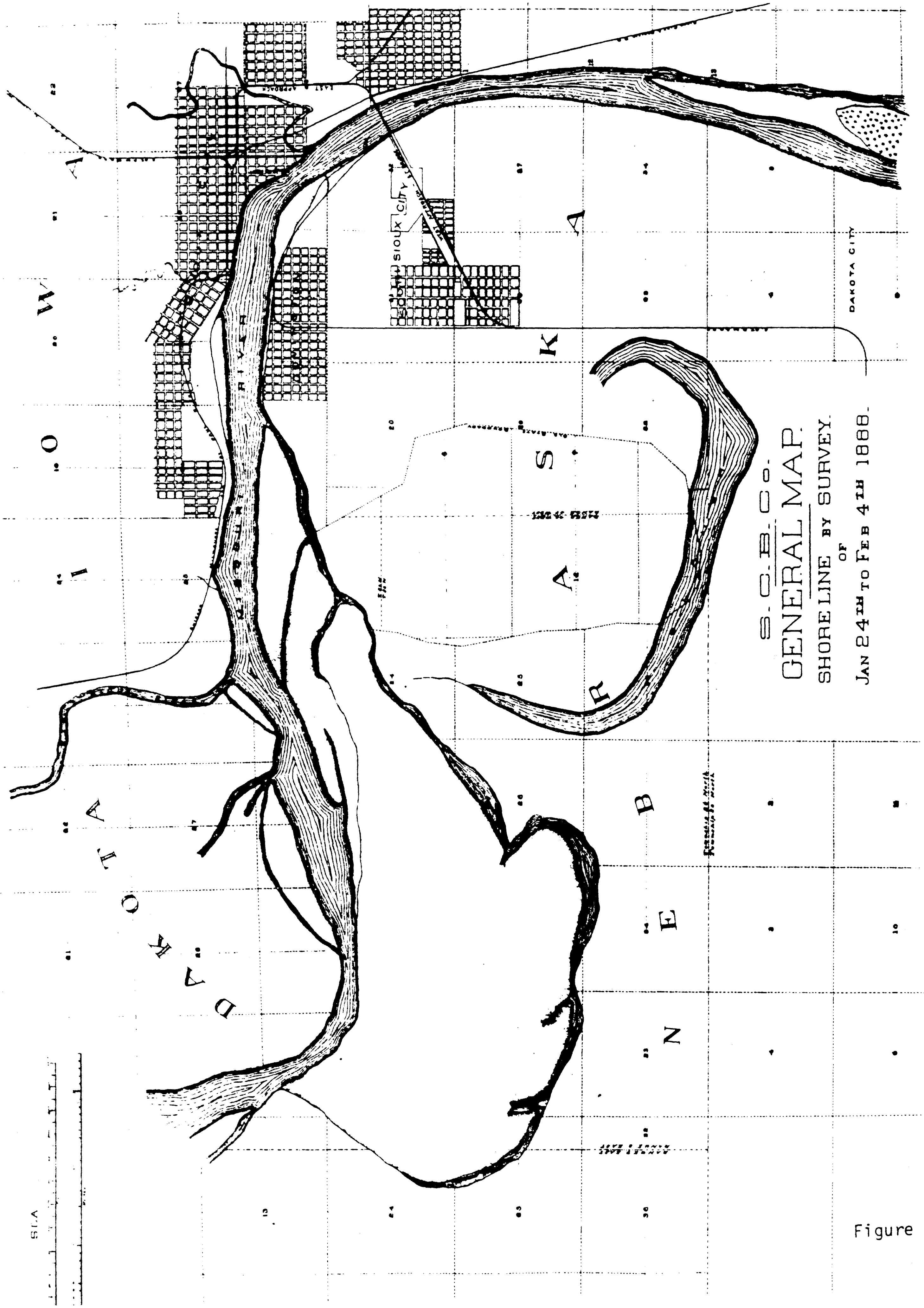

S. C. B. Co.
GENERAL MAP
SHORE LINE BY SURVEY
OF
JAN 24TH TO FEB 4TH 1888
IOWA
DAKOTA
NEBRASKA
SIOUX CITY
DAKOTA CITY

Figure 74

largely attributable to changes in the complexion of the Union Pacific Railroad. The dramatic branch-line expansion undertaken by the UPRR in the early 1880s had nearly doubled the company's total length. Most of this construction activity had centered in the region south of the Platte River, between the westwardly parallel trunk lines of the Union Pacific from Omaha and the Kansas Pacific from Kansas City. In 1884, however, the UPRR was also contemplating rail service to northeastern Nebraska by extending its existing Omaha, Niobrara and Black Hills branch line.[222] The ON&BH - an unfinished feeder to the Black Hills gold region - had been truncated at Norfolk, Nebraska, in 1879. Its logical extension would carry it to Sioux City at the corner of Nebraska, Iowa, and Dakota to cross the Missouri River. Entry of his major rail line would vitalize rail traffic in the river town. In early 1885, the directors of the bridge company were acting on the hope that the proposed Sioux City branch would materialize and provide adequate tolls from rail traffic to support the enormous investment in construction. Prospects for the bridge, however, were beginning to dim by April, as indicated by a note in Engineering News:

> It is reported that the building of a bridge across the Missouri River at Sioux City is still a question. The Boston capitalists believe that the cost of building a bridge, with levee repairs, is in accordance with what the estimated income from the bridge would justify. It is believed that the Omaha Road wants exclusive use of the bridge when completed, which the bridge company will not willingly accede to. The bill for reviving the franchise of the Sioux City branch of the Union Pacific is not dead yet, and if passed by the Senate, will result in a line from the Missouri west to a connection with the Union Pacific in Wyoming. The Omaha will, by insisting on an exclusive use of the bridge, retard the building of such a line, which would be a most important feeder to the Omaha if built.[223]

The Union Pacific's extension was not immediately forthcoming, and the bridge company delayed for two more years before resuming the project. In early 1887, the directors asked Morison to revisit the site, this time to begin the engineering for the bridge. When right-of-way could not be secured for the location in town, the bridge company chose the engineer's alternate site at the base of Sawyer's Bluff (shown in Figure 75). Morison's draftsmen in New York prepared the contract documents for the bridge, and he brought the drawings to Washington in mid-April 1887 for approval by Secretary of War Endicott. Endicott approved them two months later.[224]

In May, two things happened that would facilitate construction of the bridge: Sioux City extended its corporate limits and the bridge company transferred its Congressional charter. The first occurred on May 9, when the city limits were extended south to include Sawyer's Bluff and the east approach of the proposed

bridge. Although this move would not affect the configuration of the railroad structure itself, the special levy voted by city council helped to fund the bridge's construction. The second event transpired two days later, when the directors of the Sioux City Bridge Company transferred their interests in the bridge to the Chicago and North Western and the Chicago, St. Paul and Omaha Railway Companies. The bridge company was reorganized a month later with a new board of directors. Replacement president Marvin Hughitt, who as president of the Sioux City and Pacific Railroad had retained George Morison to engineer the Blair Crossing Bridge, instructed Morison to proceed at once with construction of the bridge.[225]

Again, Morison's plan for the Sioux City Bridge differed little in appearance from its predecessors. His single-track superstructure consisted of three pin-connected Whipple through trusses, (shown in Figures 76-79) each four hundred feet long and subdivided into 15 panels of 27 feet each. For the east approach he designed a plate girder (shown in Figure 80) to span from the bluff to the first pier. A short deck truss was to be placed on the west, adjoining the long approach trestle. The all-steel makeup of the trusses may have been a significant structural bellwether for the engineering profession, but its importance could hardly be judged by Morison's characteristically brief description in his report to the bridge company. "Except the web plates of the plate girder, the entire superstructure is of steel," was the extent of his discussion of steel composition of the Sioux City Bridge.[226] The steel trusses were to be supported by immense masonry columns resting on pneumatic caissons (shown in Figures 81 and 82). Although the piers resembled those of his preceding bridges, beneath the riverbed they presented a novel engineering condition, as described by the engineer:

> In one respect the Sioux City Bridge differs materially from the other bridges which have been built on the Missouri River. The piers are not founded on rock, nor is there any available rock to be found in this location. The bluffs east of the river rest on a prealluvial gravel which extends under the river, and the piers are founded in this gravel to a depth of fifty feet below the alluvial deposit... The piers are not founded in the alluvial deposit of the Missouri River, but are on an entirely different class of material, which is permanent in character and is the same material that forms the foundations of the bluffs. I say this specifically for the reason that the statement has been made that these piers are founded in the alluvium of the Missouri River, which is entirely incorrect.[227]

The three 400-foot spans created a passable channel for the river of more than 900 feet. "The width thus provided," Morison reported, "is greater than experience has shown to be necessary at any point on the river above Kansas City,

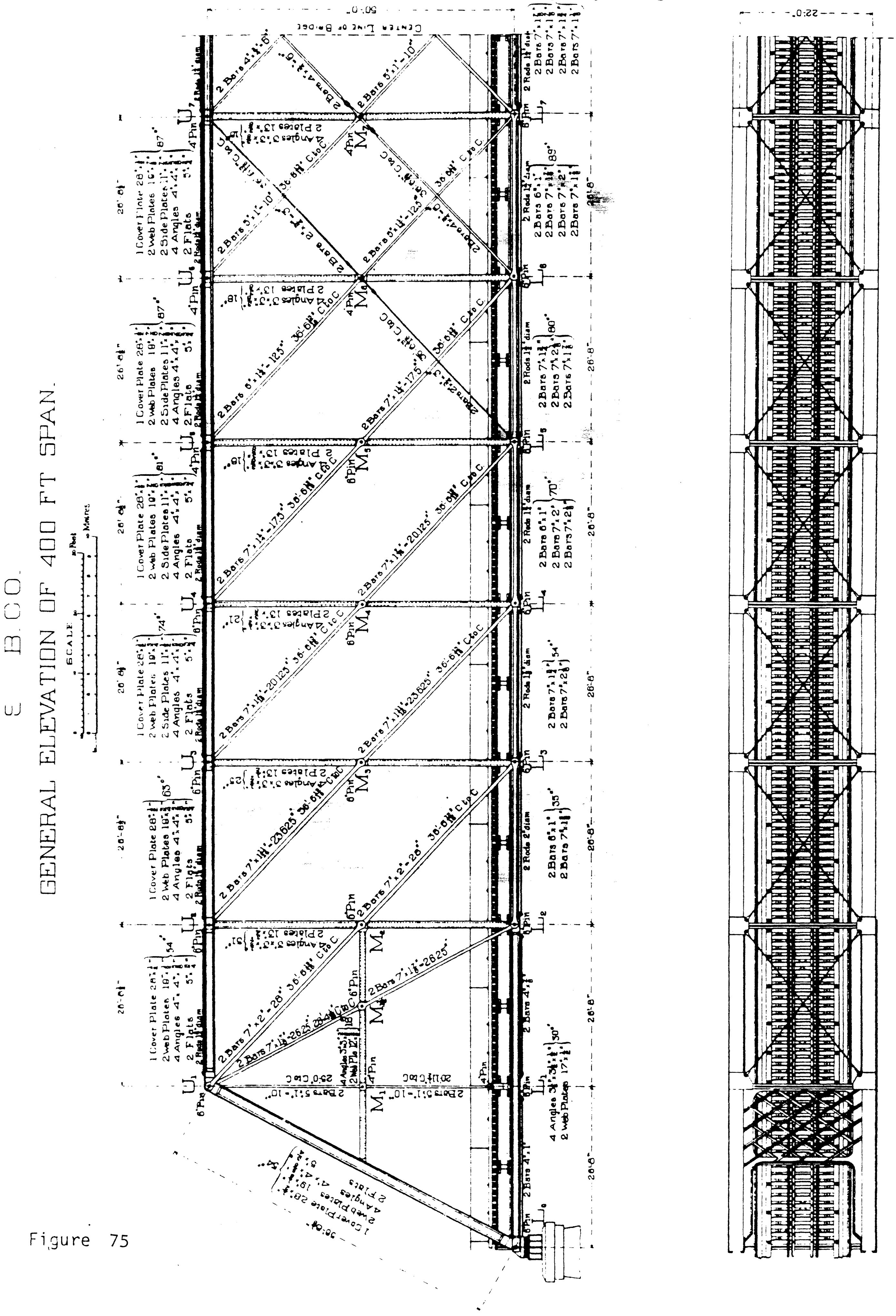


Figure 75

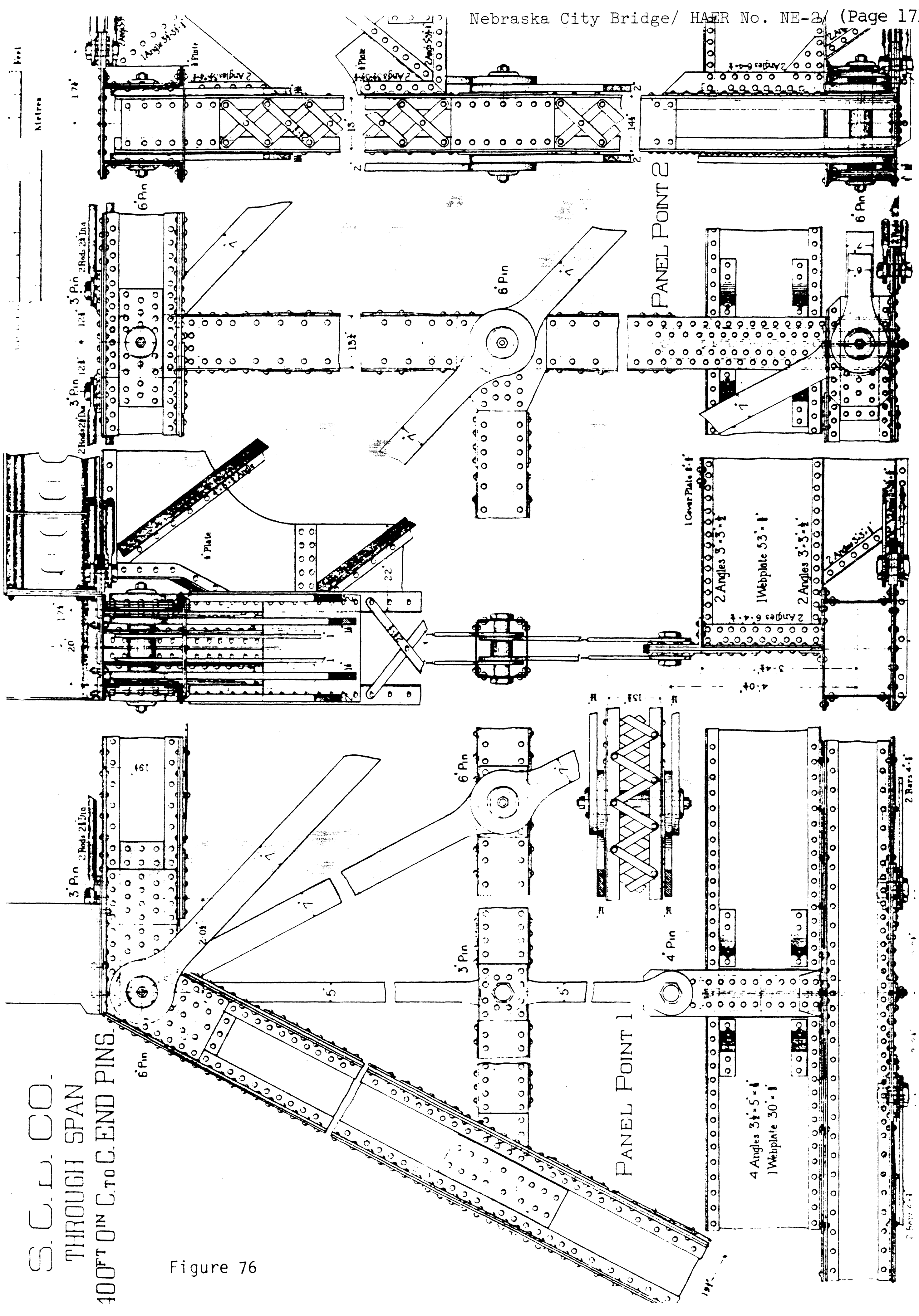

THROUGH SPAN
100FT 0IN C. TO C. END PINS
PANEL POINT 1
PANEL POINT 2

Figure 76

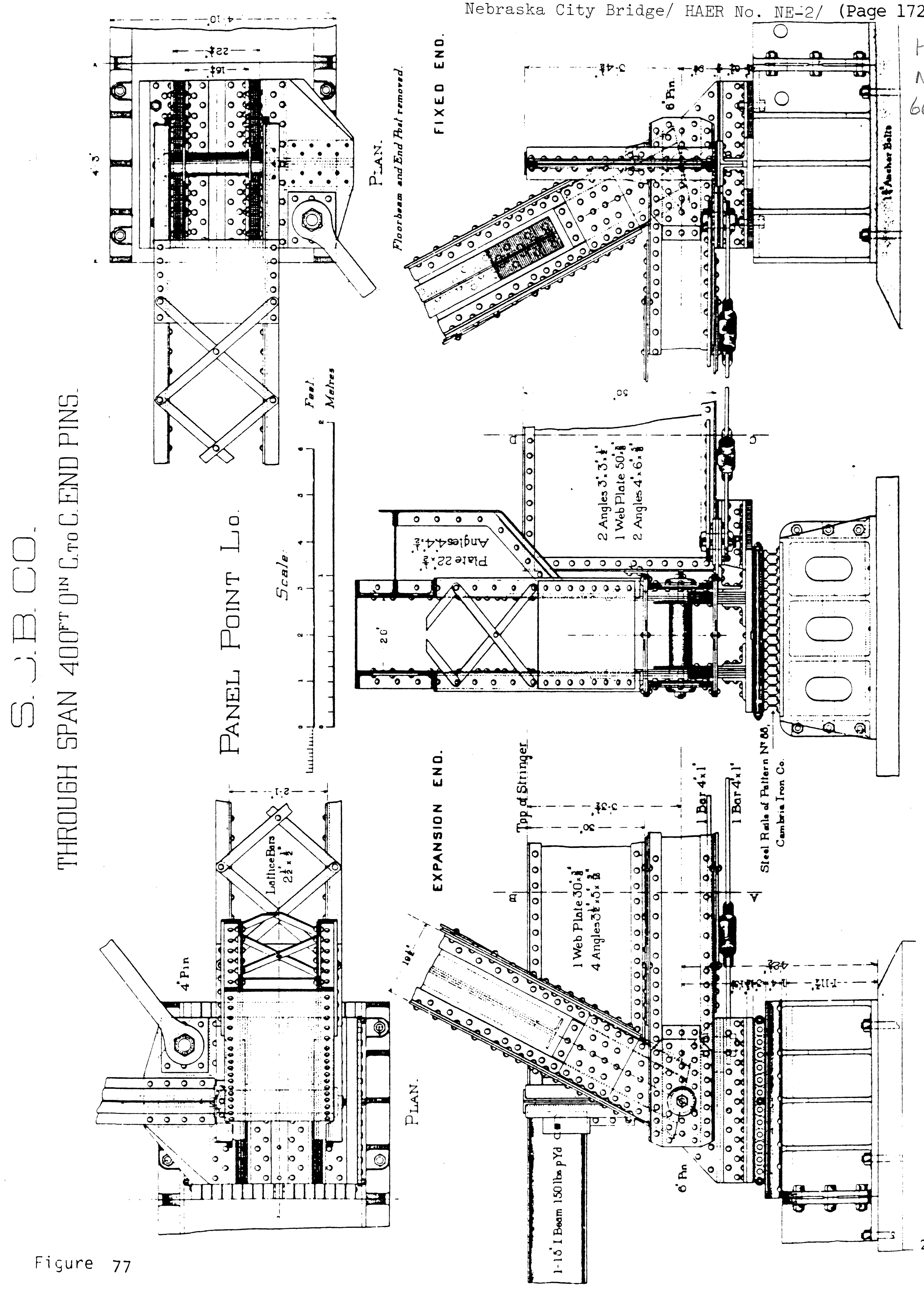

S. J. B. CO.
THROUGH SPAN 400FT 0IN C. TO C. END PINS.
PANEL POINT L0
Scale
Feet
Metres
FIXED END.
EXPANSION END.
PLAN.
Floorbeam and End Post removed.
6" Pin
4" Pin
Lattice Bars 2½" x ½"
2 Angles 3"x3"x½"
1 Web Plate 50"x⅜"
2 Angles 4"x6"x⅜"
Plate 22"x½"
Angles 4x4x½
20'
1 Web Plate 30"x⅜"
4 Angles 3½"x5"x⅜"
Top of Stringer
1 Bar 4"x1"
1 Bar 4"x1"
Steel Rails of Pattern No 88
Cambria Iron Co.
1-15" I Beam 150 lbs p Yd
1¼" Anchor Bolts
PLAN.

Figure 77

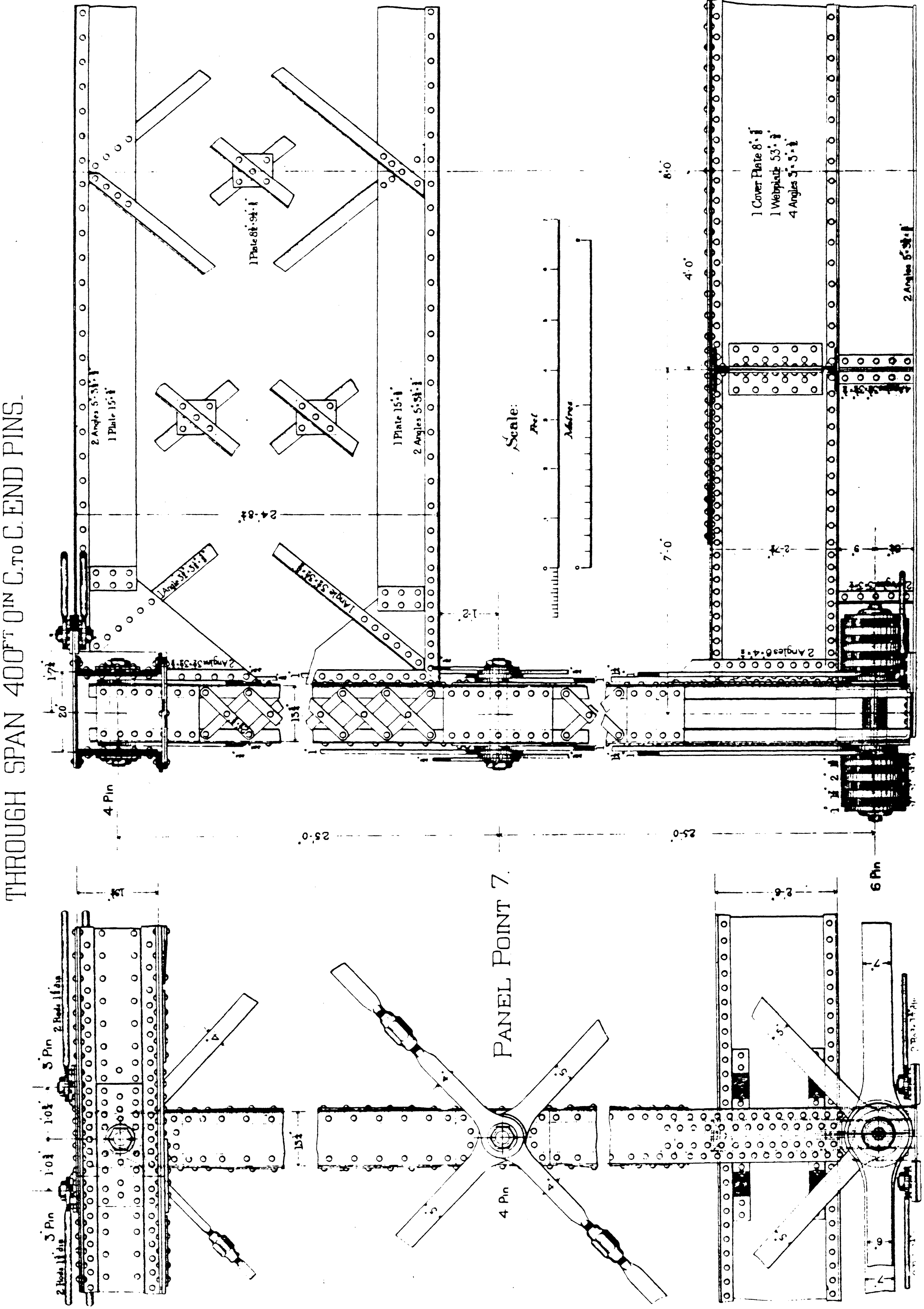

THROUGH SPAN 400FT 0IN C. TO C. END PINS.
PANEL POINT 7.
Scale:
1 Cover Plate 8·⅜
1 Webplate 53·⅜
4 Angles 5·5·⅜
1 Plate 15·⅜
2 Angles 5·3½·⅜
4 Pin
6 Pin
3 Pin
25·0
25·0

Figure 78

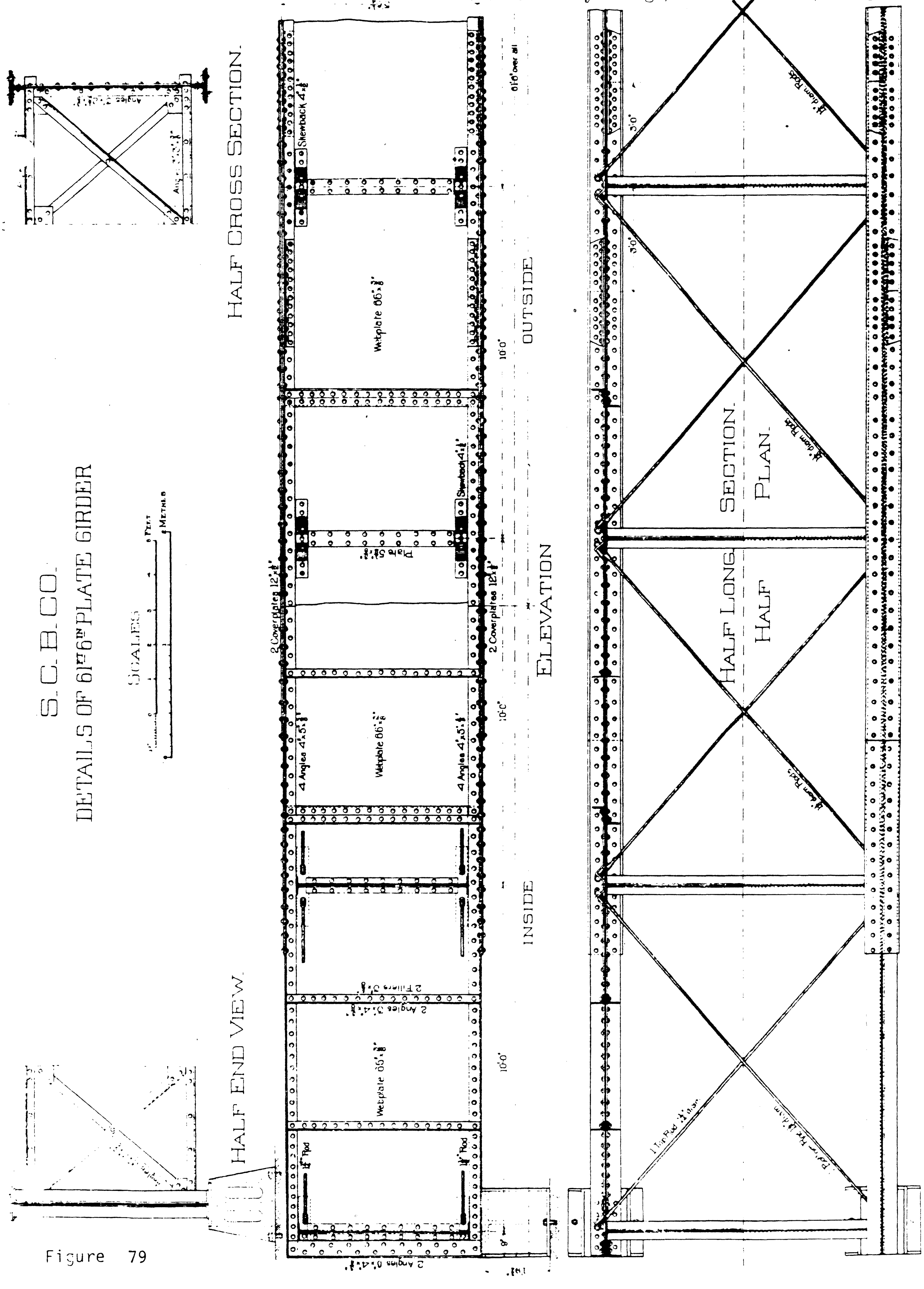

S. C. B. CO.
DETAILS OF 61FT 6IN PLATE GIRDER
SCALES
HALF CROSS SECTION
HALF END VIEW
ELEVATION
OUTSIDE
INSIDE
HALF LONG SECTION
HALF PLAN
Webplate 86"x3/8"
4 Angles 4"x5"x3/8"
2 Coverplates 12"x3/8"
10'0"

Figure 79

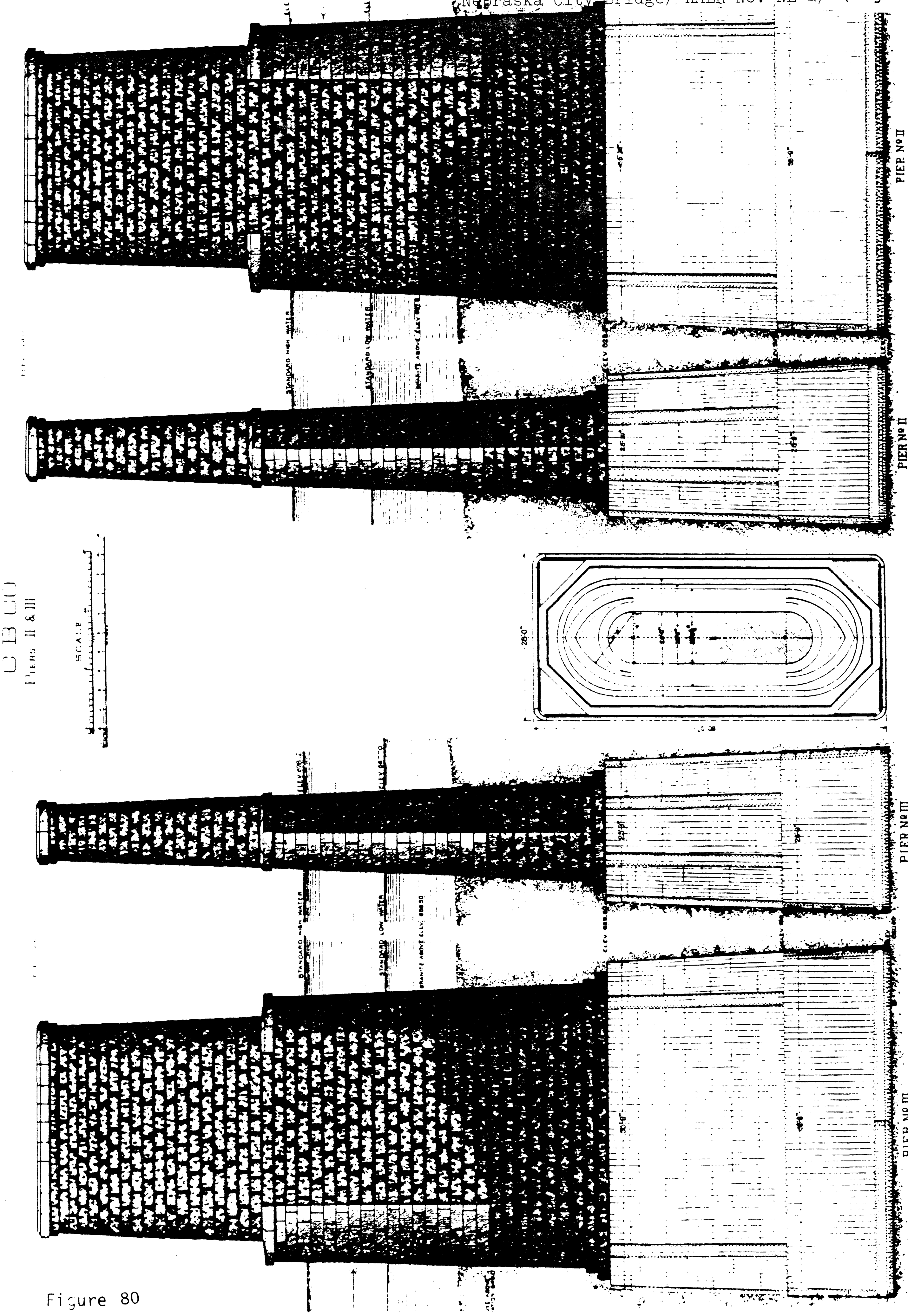

C B CO
Piers II & III
SCALE
PIER No II
SIDE ELEVATION
STANDARD HIGH WATER
STANDARD LOW WATER
PIER No II
END ELEVATION
PLAN UNDER COPING
PIER No III
END ELEVATION
STANDARD HIGH WATER
STANDARD LOW WATER
PIER No III
SIDE ELEVATION

Figure 80

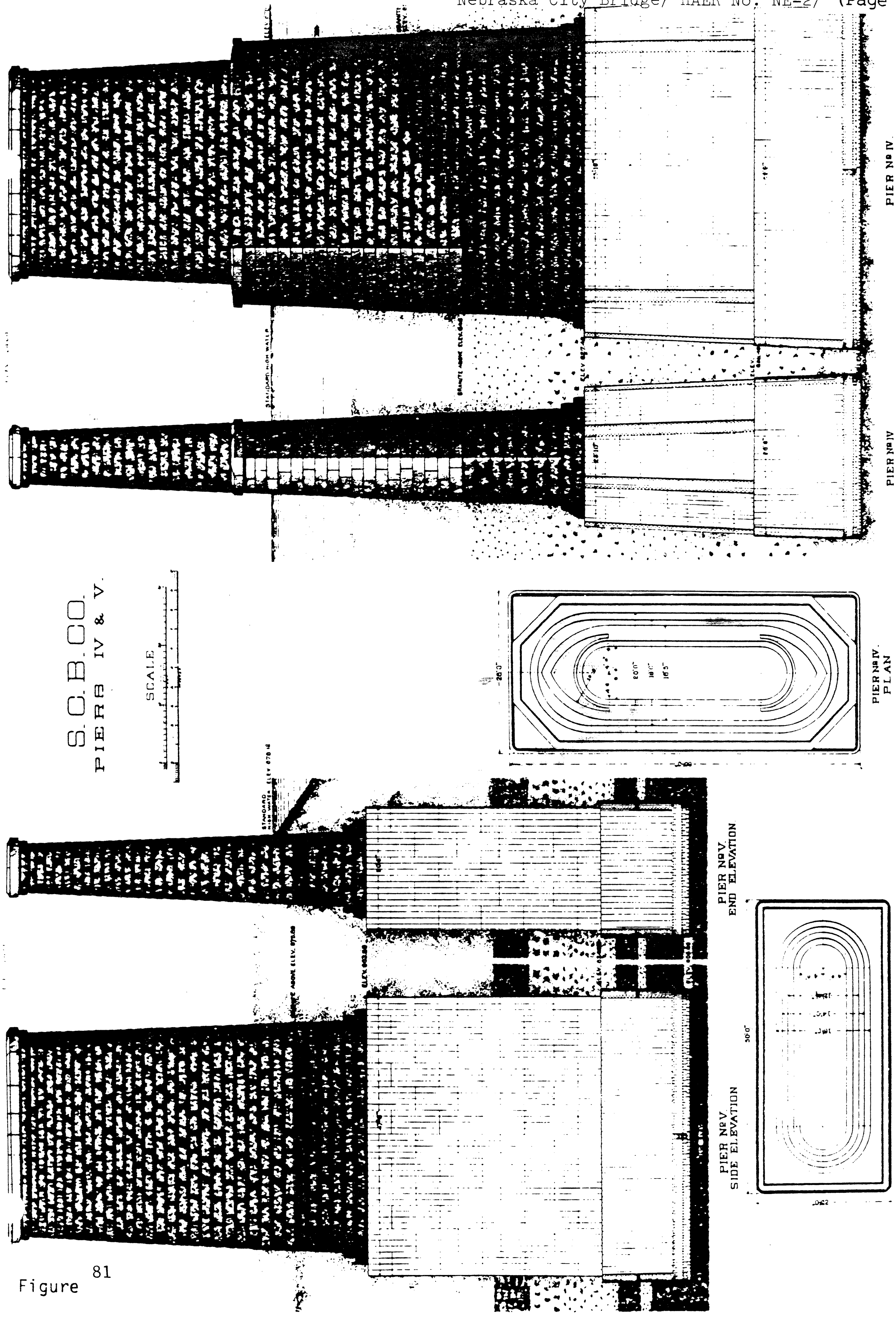

S.C.B.CO.
PIERS IV & V.
SCALE
PIER No IV. PLAN
PIER No V. END ELEVATION
PIER No V. SIDE ELEVATION

Figure 81

where the channel has remained fixed for a long series of years." But during the summer of 1887, the main channel shifted course dramatically. "The result," Morison wrote, "was that in the winter of 1888 the channel was on the west side of the river instead of in its accustomed place on the east side and the greater part of the bridge was left over dry land."[235] Rather than try to rechannel the river with extensive rectification works, Morison substituted a fourth long- span through truss for the west deck truss approach span.

After assembling a cast of engineers and contractors (listed in Appendix I), which by now had become familiar, Morison initiated construction of the monumental structure in the summer of 1887. A temporary service bridge was first built in mid-August to provide access to the pier locations. Workers for the railroad began driving the piles for staging the caisson of the first channel pier at the end of the month. By September 9th, all of the piles had been driven and capped, and the men began erection of the first caisson in October. They continued work on the foundations throughout the winter as masons for Saulpaugh and Company laid the stone for the piers. Limestone was quarried and shipped from Mankato, Minnesota; the face granite came from Morton, Minnesota. Steel for the superstructure of the easternmost span was imported from mills in Scotland and for all the other spans was made in America. "The imported steel seemed to be a little more uniform in quality than the American," Morison wrote, "but was less uniform in finish and sections. The weight of the Scotch steel span is slightly in excess of that of the others."[236] The steel members were fabricated by the Union Bridge Company. By the time the masons had completed the stonework for the last pier at the end of October, 1888, the Baird Brothers' steel crew had already swung all but one of the through trusses; by November 18, the superstructure was complete.

The first train crossed the bridge on November 26, 1888. On December 5, it was formally tested. George Morison and the others celebrated the approval of the Sioux City Bridge that night at a banquet at his temporary home in town - the Hotel Booge.[237]

NEBRASKA CITY BRIDGE

During 1887 and 1888, George Morison divided his time between two Missouri River railroad bridges under simultaneous construction: the Sioux City Bridge and another major span at the established river town of Nebraska City, Nebraska, some 160 miles downriver. The Missouri River near Nebraska City had been relatively narrow and stable for decades, following the bluffs on the Nebraska side for miles upstream. For this reason the town had long been considered by engineers to be one of the best crossing sites over the Missouri between Omaha and Kansas City. Fifteen years would elapse, however, from the initial approval from Congress until Morison would be retained by the Chicago, Burlington and Quincy Railroad to erect a bridge there.

Incorporated in 1855 at the site of old Fort Kearny, Nebraska City had been from the start a major mid-American transportation center. During the late 1850s and early 1860s, the fledgling town prospered as the eastern terminus of the great Platte Valley freighting business of Russell, Majors, and Waddell, and overshadowed Omaha, fifty miles upriver, in regional importance. After the freighting firm - premier outfitters for the Pike's Peak and Virginia City gold rushes - collapsed in 1862 under the weight of their ill-fated overland stage to the west coast, the river town continued to function as a major docking point for freighting along the Missouri. In April 1870, the Midland Pacific Railroad Company laid the first rail line from Nebraska City westward. The town received its first train service a year later when the MP tracks reached Lincoln, Nebraska.

In June 1872, the Nebraska City Bridge Company secured a Congressional charter to erect a bridge over the Missouri River at the new railroad town.[238] General W.W. Wright, Chief Engineer for the Atchison and Leavenworth bridges, designed an iron truss for the combination railroad and wagon structure and secured approval from the Secretary of War later that year. The bridge company then issued $100,000 in 10% bonds, far short of the total needed to erect a permanent structure, in the hope that a railroad would fund the rest. Failing to attract other investors or to act on the construction for over a year, company directors dramatically burned $90,000 of the bonds in the presence of the Nebraska City Mayor, Council, and Trustees and used the remaining $10,000 to defray the costs already incurred. The Midland Pacific on the west shore and the Kansas City, Saint Joseph, and Council Bluffs Railroad on the east lacked the necessary capital to erect the immense structure themselves and instead resorted to ferrying trains across the river on transfer steamers - a less-than-ideal situation which continued throughout the 1870s and into the 1880s.[239]

While ferries carried railroad passengers and freight across the channel for

years, the river etched a wider channel around a center island at Nebraska City, making bridge construction an increasingly more expensive proposition. Meanwhile, the Midland Pacific extended tracks along the west bank of the river south to Nemaha and in the process reorganized as the Nebraska Railway. In 1876, the Chicago, Burlington and Quincy Railroad leased the track to consolidate its holding on southeastern Nebraska. The move made Nebraska City a nexus in the regional Burlington network on the eve of an unprecedented surge of expansion by the railroad. Betwen 1881 and 1888, the CB&Q with Charles Perkins as president almost doubled its trackage to an aggregate five thousand miles. More than half of this increase involved the Nebraska lines and subsidiaries, and by the late 1880s the railroad felt increasing pressure to bridge the Missouri River in southern Nebraska at some location between Plattsmouth and Rulo.[240]

With all of the Burlington's capital improvement funds committed to tracklaying and repair, however, Perkins was reluctant to build another million-dollar bridge over the Missouri River into Nebraska. Throughout the early 1880s, the railroad continued to ferry trains across the river at Nebraska City or route them over the bridges at Rulo or Plattsmouth. In 1886, the Missouri reversed its course dramatically near the town, creating a narrow new channel alongside the western bluff and making economical erection of a bridge there a tantalizing possibility. George Morison described the fortituitous situation:

> In 1886 a sudden and important change took place, changing the relative size of the channels east and west of the island, the main river passing down the west side of the island, and leaving only a secondary channel almost dry at low water east of the island. This change of a single season restored the condition of the river to what it had been thirty years before, with the exception, however, that the island was east instead of west of the main channel. The very favorable conditions for bridging the river were restored, but it was evident that unless some artificial means were taken to prevent it, the river would again go through the same manoeuvres [sic] as before and would cut away the island and sand bar west of where the channel had recently been and resume its late position; and furthermore, that as the material recently deposited was sand and silt, the change would take place rapidly. If anything was to be done with the river it must be done at once.[241]

In October 1886, Perkins instructed Morison to inspect the river at Nebraska City and make recommendations for the bridge location and configuration. Morison in turn hired Addison Connor to survey the riverbank and take water depth soundings and subsoil borings. When he received the survey results, the engineer reported to Perkins that, whether or not the bridge was built, a dike

across the eastern channel would be needed to divert all of the water into the deeper western channel. The proposed brush-and-stone structure would constrict the river to a 1,000-foot width, allowing for a relatively short bridge over the main channel (shown in Figure 83). Against the recommendations of local river watchers, Morison positioned the dike 1,500 feet above the bridge site - behind, not at the head of, the existing island. "As the location of the bridge was determined in a considerable degree by the form of the bluffs on the west side of the river," Morison reported, "the position of the dike was determined by the location of the bridge, rather than the location of the bridge by the position of the dike," which had been the case at Plattsmouth and Blair Crossing. "It was evident that even if no bridge was to be built the dike would become necessary if a transfer was to be maintained at this point." [243]

The Chicago, Burlington and Quincy Railroad bought the Congressional charter from the Nebraska City Bridge Company for less than $6,000 and assigned it to the Nebraska Railroad, which by then had become a proprietary company. Once again, Morison prepared plans for a high truss, submitting them to the Secretary of War Endicott in Washington in April 1887. Endicott approved the design with the stipulation that the bridge be raised an additional two feet beyond the standard fifty foot clearance over the projected high water level. On June 27th, the contract between the War Department and the Nebraska Railway Company was executed. [244]

By then well acquainted with Morison's engineering style and proclivities, Perkins was not surprised with the design of the great bridge. Like all of his others, Morison designed the Nebraska City Bridge as a series of fixed Whipple through trusses supported high above the surface of the water on massive masonry piers. The short overall length reduced this series from the standard three (Bismarck, Blair, Rulo) or four (Sioux City) long channel spans to only two 400-foot spans. The westernmost truss abutted the high bluff on the west bank, and the short approach track to the bridge on the Nebraska side joined with the Nebraska Railroad main line near the town. The longer east approach extended a little more than a mile from the Kansas City, St. Joseph and Council Bluffs Railroad to a new junction point named Morison on the Iowa side and from there up a lengthy graded ramp and timber trestle to the east portal of the bridge. The total length of the trusses was 1,132 feet - Morison's shortest Missouri River structure. [245]

Each of the 400-foot channel trusses (shown in Figures 84-89) extended 50 feet in height and was subdivided into fifteen panels of slightly less than 27 feet between centers. Like all of his bridges since Rulo, Morison proportioned the trusses to carry a moving live load of 3,000 pounds per linear foot (shown in Figure 90). The top lateral system was designed to withstand a horizontal wind pressure of 300 pounds per linear foot and the bottom lateral system 500 pounds. The compressive strain on the top chord was limited to 14,000 pounds

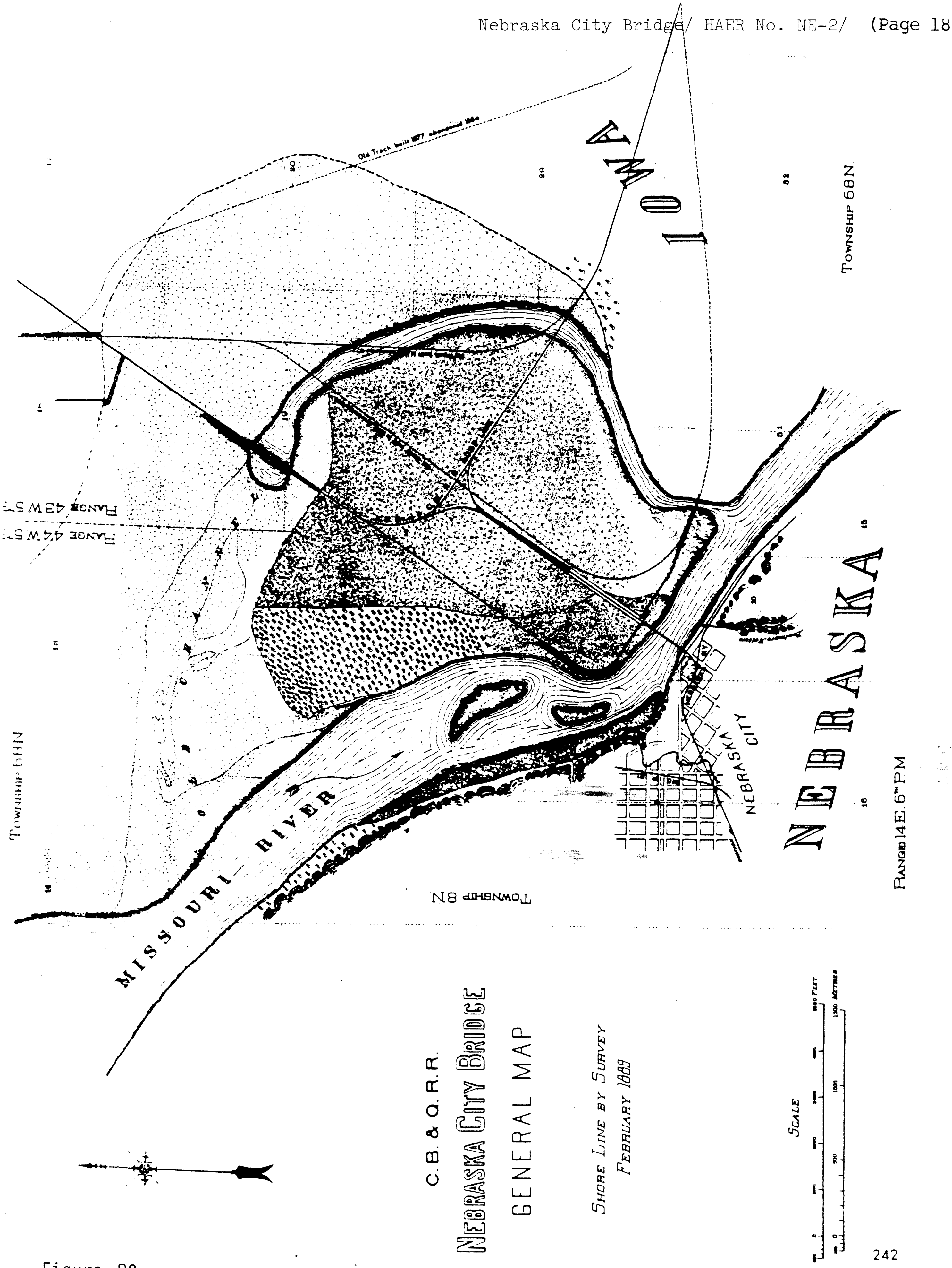

C.B.&Q.R.R.
Nebraska City Bridge
General Map
Shore Line by Survey
February 1889
Scale
IOWA
NEBRASKA
MISSOURI RIVER
NEBRASKA CITY
Township 68N
Township 68N
Township 8N
Range 14 E. 6th PM
Range 43 W 5th
Range 44 W 5th

Figure 82

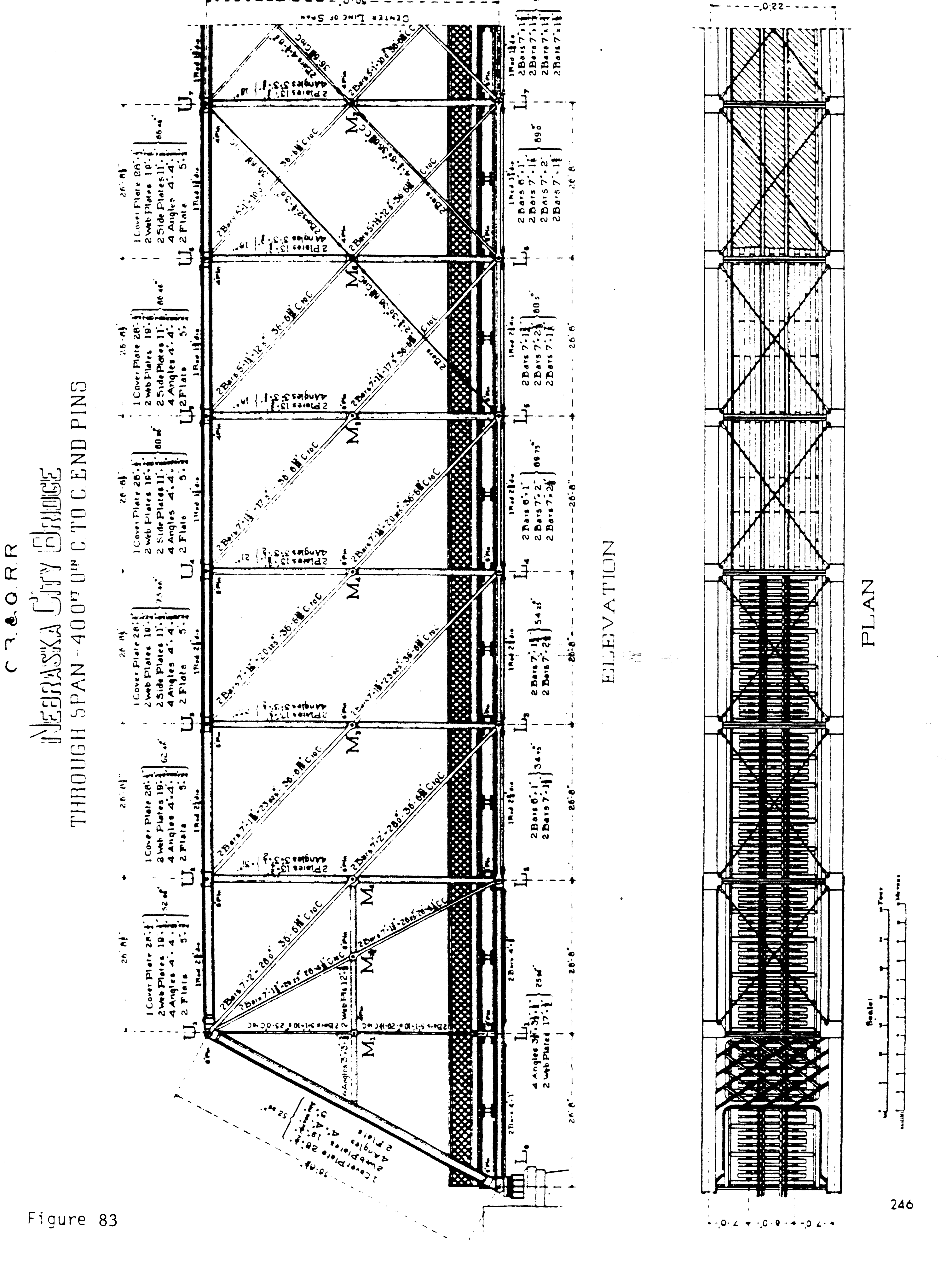

C. B. & Q. R.R.
Nebraska City Bridge
Through Span - 400 FT 0 IN C TO C END PINS
ELEVATION
PLAN

Figure 83

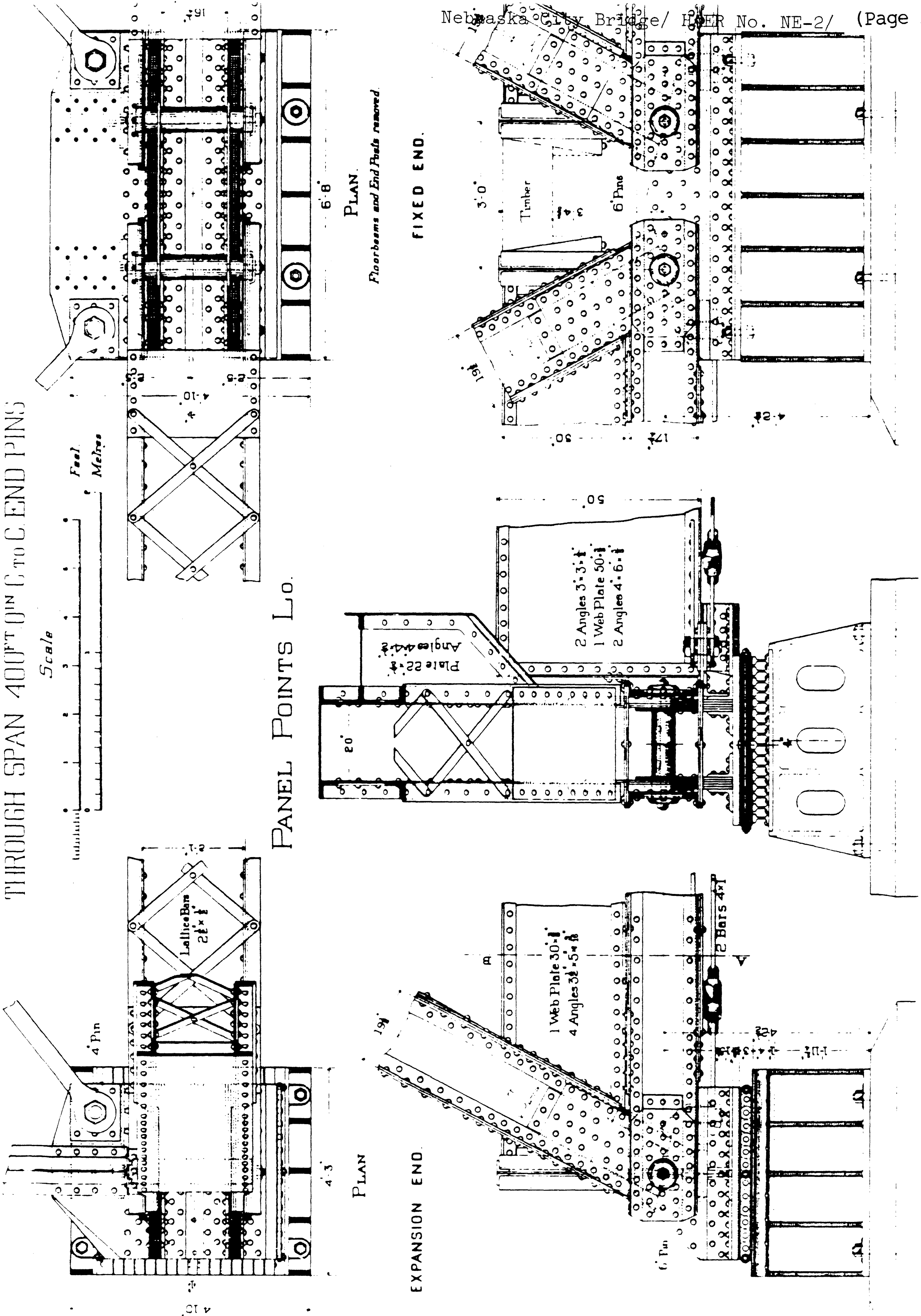

C.B.&Q.R.R.
Nebraska City Bridge
Through Span 400 FT 0 IN C to C End Pins
Scale
Feet
Metres
Panel Points L0
Plan
Floorbeams and End Posts removed
Fixed End
Expansion End
Timber
6" Pins
4" Pin
Lattice Bars
2 Angles 3·3·½
1 Web Plate 50·½
2 Angles 4·6·½
Plate 22·½
Angles 4·4·½
1 Web Plate 30·½
2 Bars 4×1

Figure 84

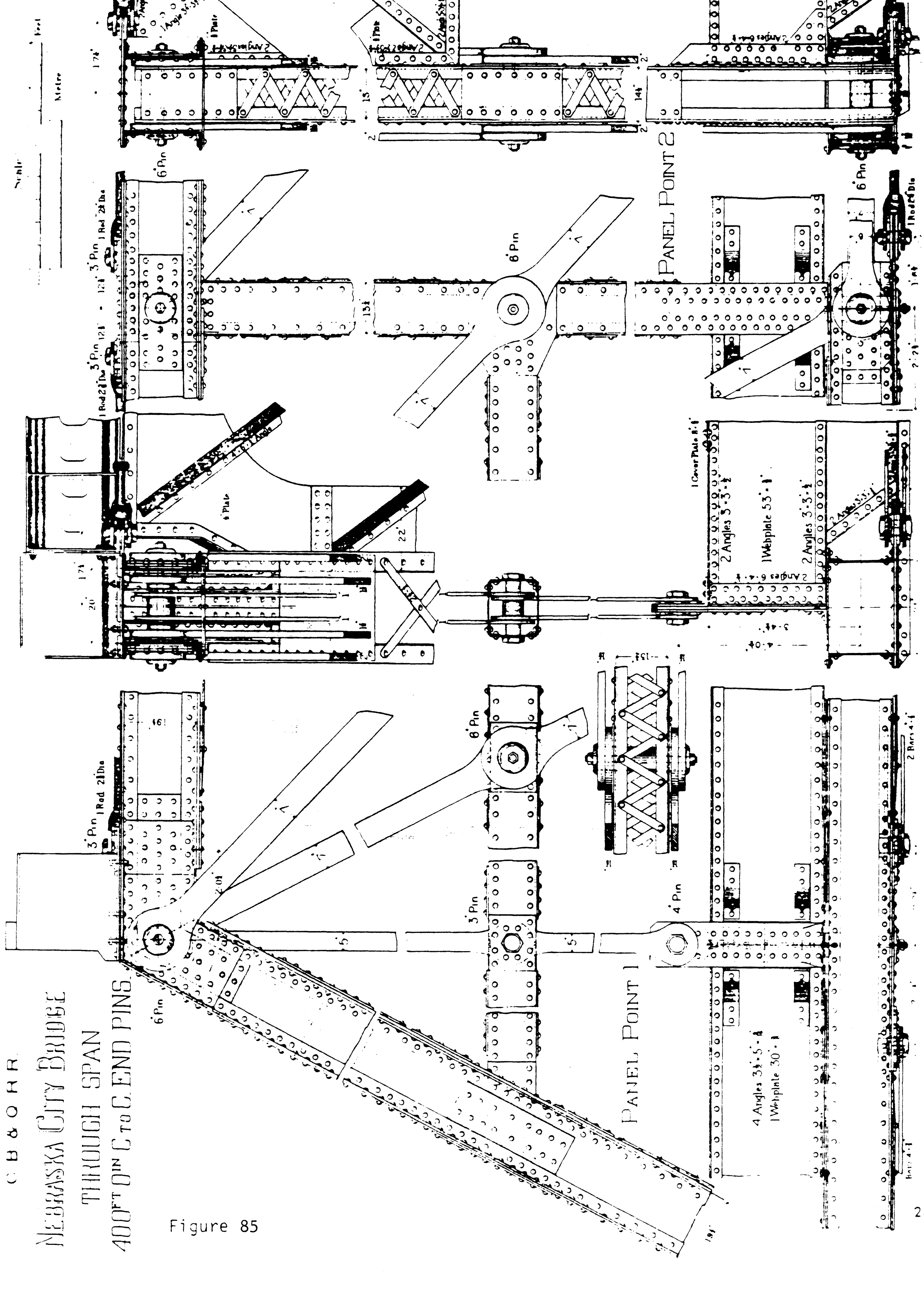

C B & Q R R
Nebraska City Bridge
Through Span
400 FT 0 IN C to C End Pins
Panel Point 1
Panel Point 2
Scale
Metre
Feet
6" Pin
8" Pin
3" Pin
4" Pin
1 Webplate 53"
2 Angles 3 1/2 · 3 · 1/2
4 Angles 3 1/2 · 5 · 1/2
1 Webplate 30"
1 Cover Plate
2 Bars

Figure 85

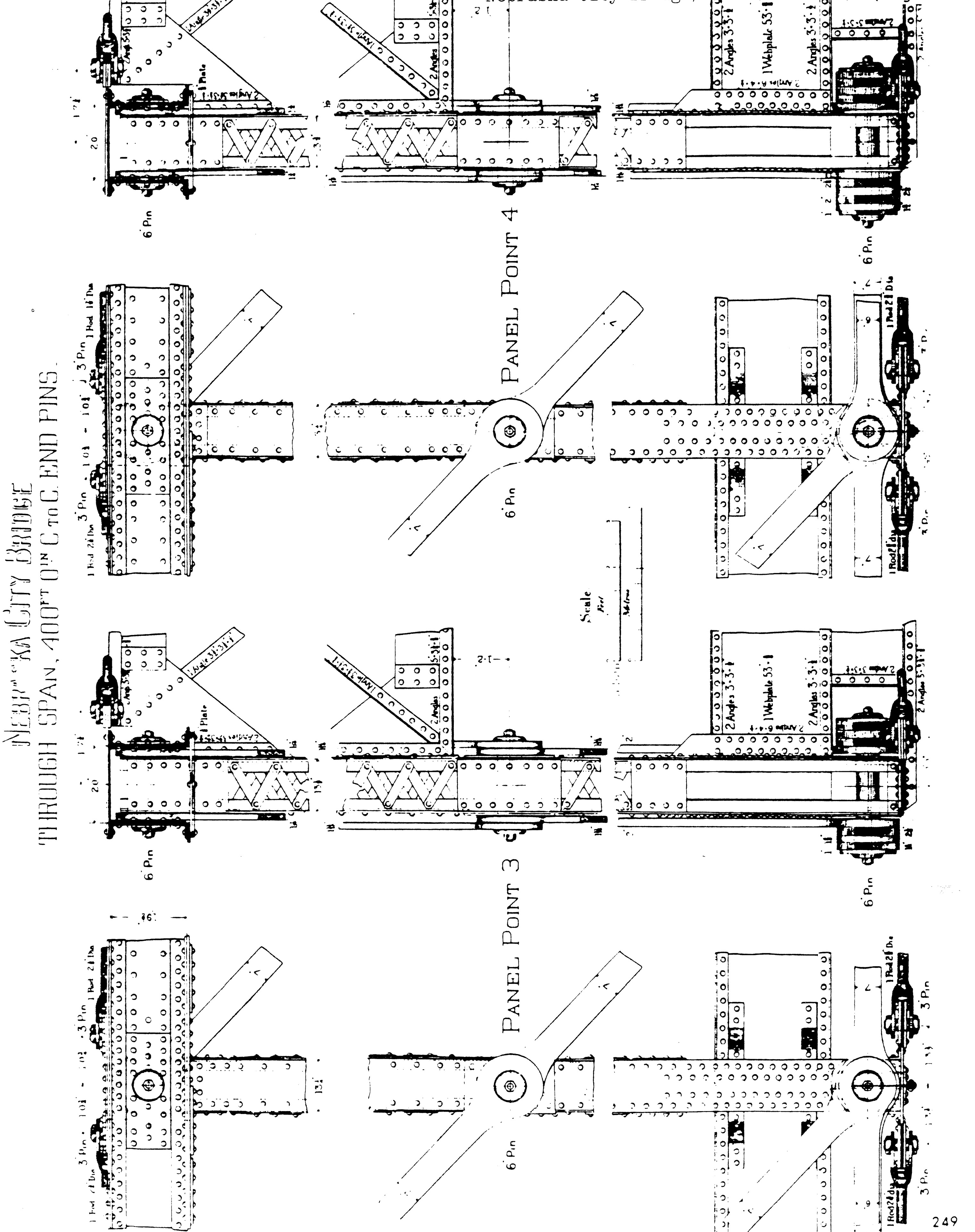

NEBRASKA CITY BRIDGE
THROUGH SPAN, 400FT 0IN C TO C END PINS.
PANEL POINT 4
PANEL POINT 3
6" Pin
3" Pin
Scale

Figure 86

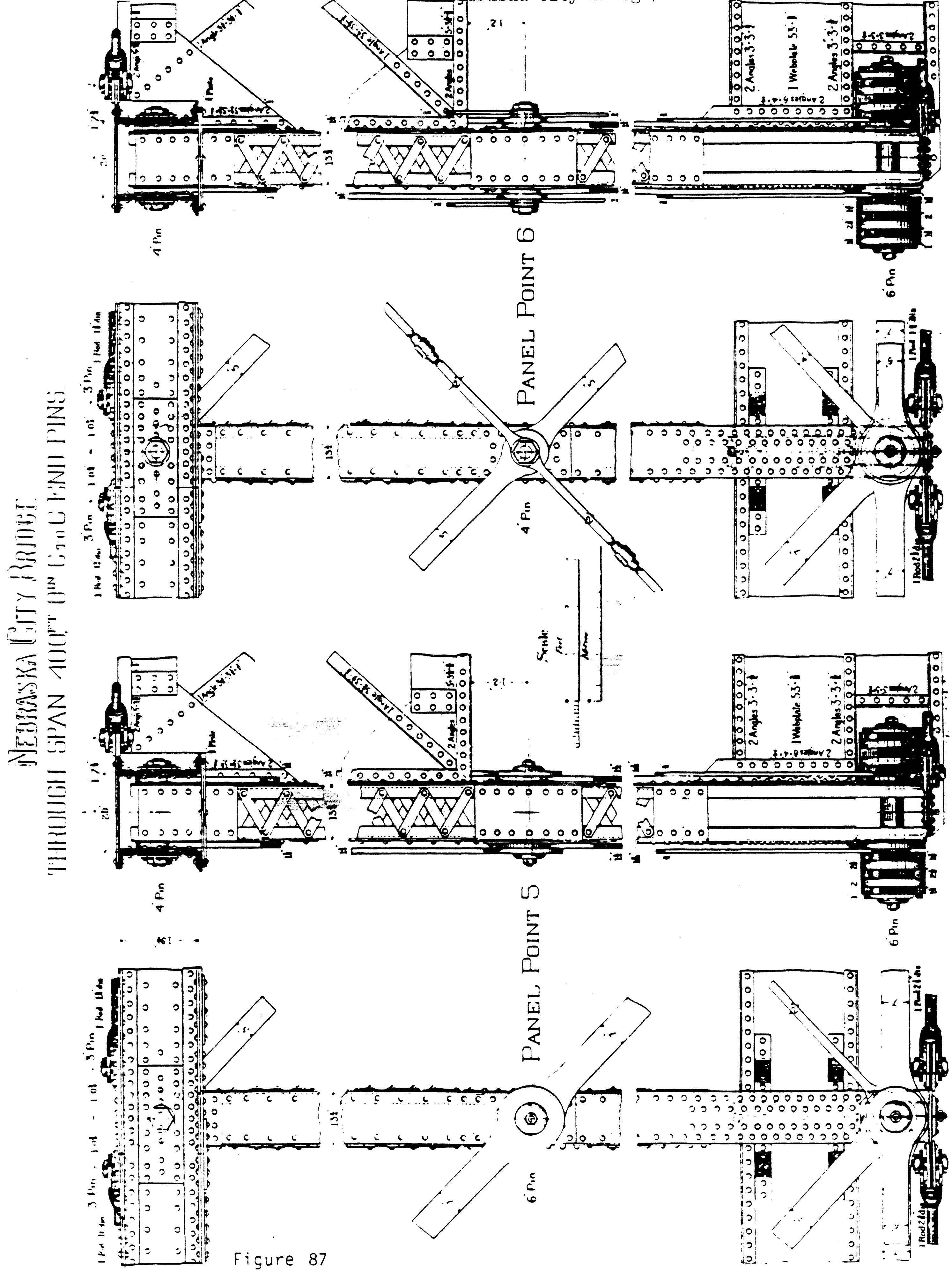

NEBRASKA CITY BRIDGE
THROUGH SPAN 400FT 0IN C TO C END PINS
PANEL POINT 6
PANEL POINT 5
Scale
4 Pin
6 Pin

Figure 87

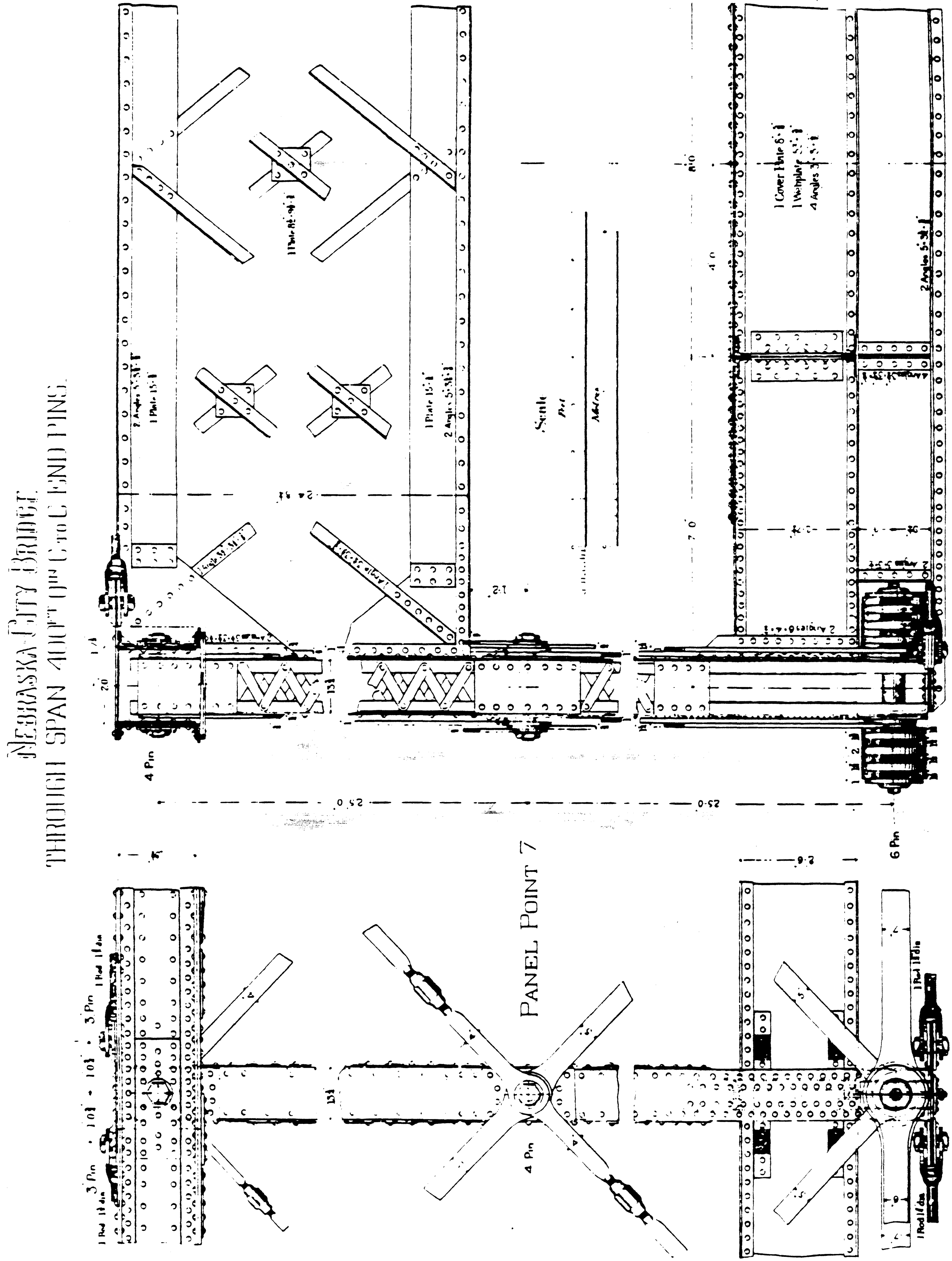

NEBRASKA CITY BRIDGE
THROUGH SPAN 400 FT C to C END PINS
PANEL POINT 7
Scale
4 Pin
6 Pin
3 Pin
25.0
1 Cover Plate
2 Angles
1 Plate
1 Rod

Figure 88

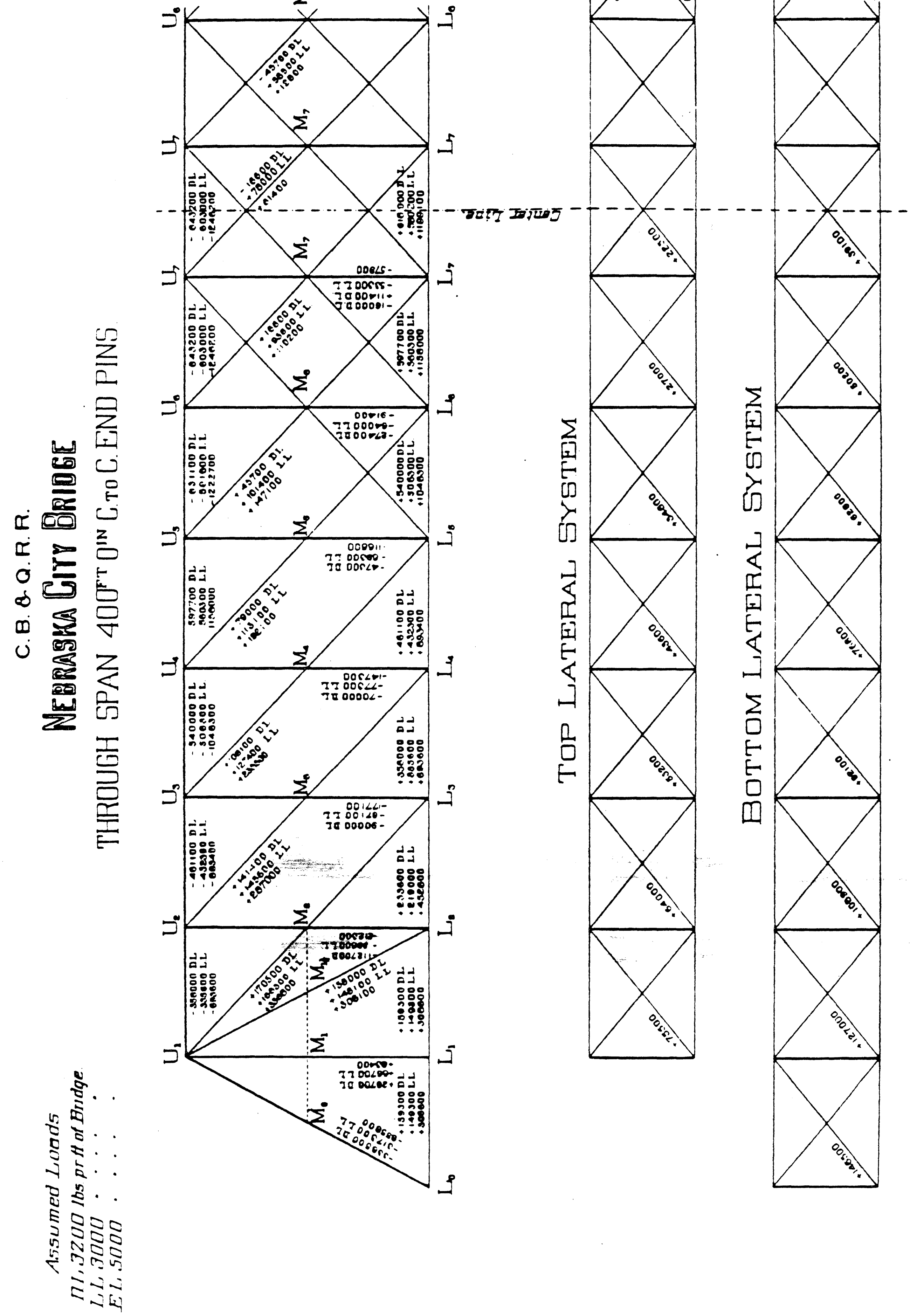

C. B. & Q. R. R.
Nebraska City Bridge
Through Span 400 FT 0 IN C. to C. End Pins
Top Lateral System
Bottom Lateral System
Center Line
Assumed Loads
D.L. 3200 lbs pr ft of Bridge
L.L. 3000
E.L. 5000

Figure 89

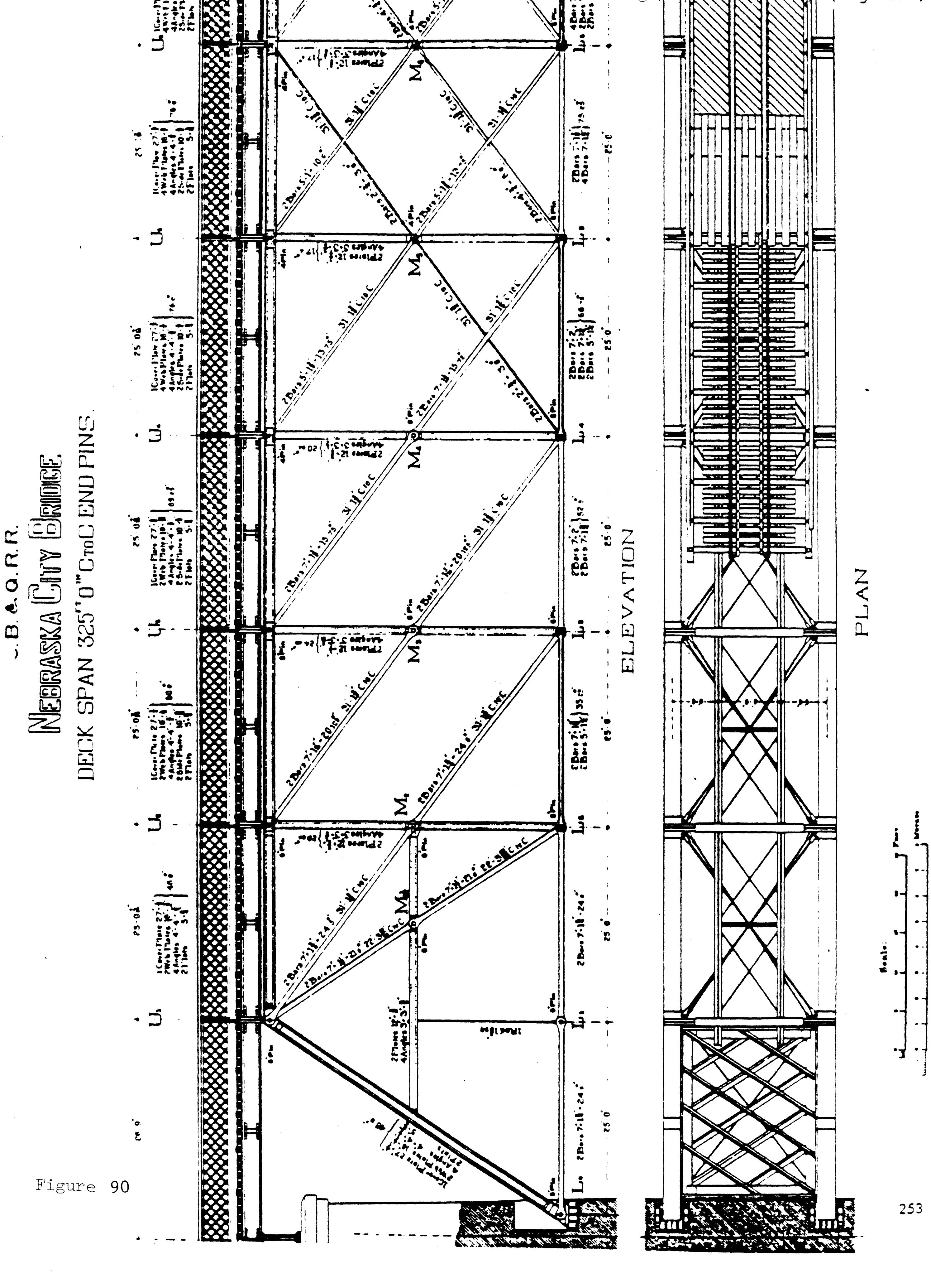

B. & Q. R.R.
NEBRASKA CITY BRIDGE
DECK SPAN 325' 0" C TO C END PINS.
ELEVATION
PLAN
Scale:

Figure 90

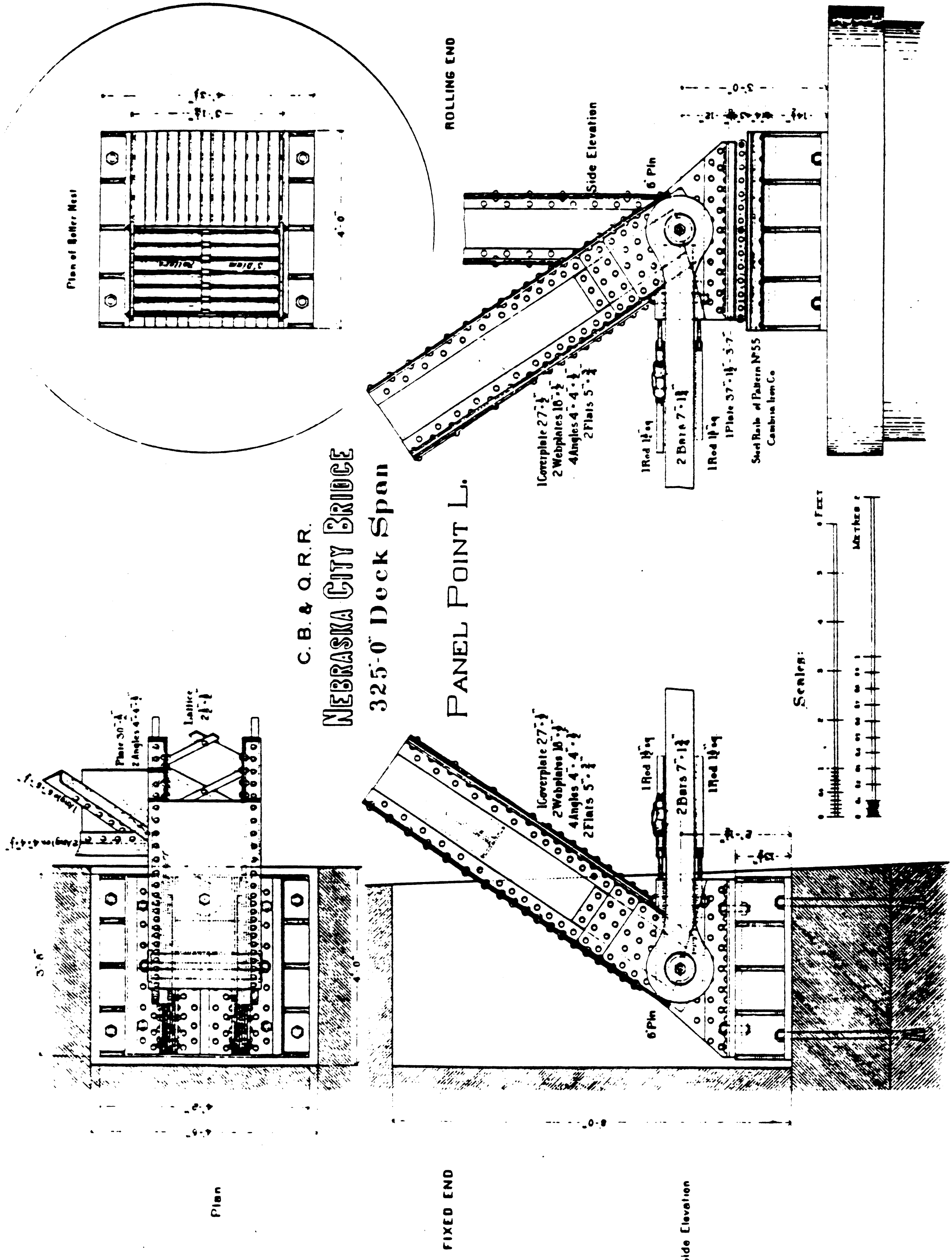

C. B. & Q. R.R.
Nebraska City Bridge
325'-0" Deck Span
Panel Point L.
Rolling End
Plan of Roller Nest
Side Elevation
6" Pin
Fixed End
Plan
Side Elevation
6" Pin
Scales:

Figure 91

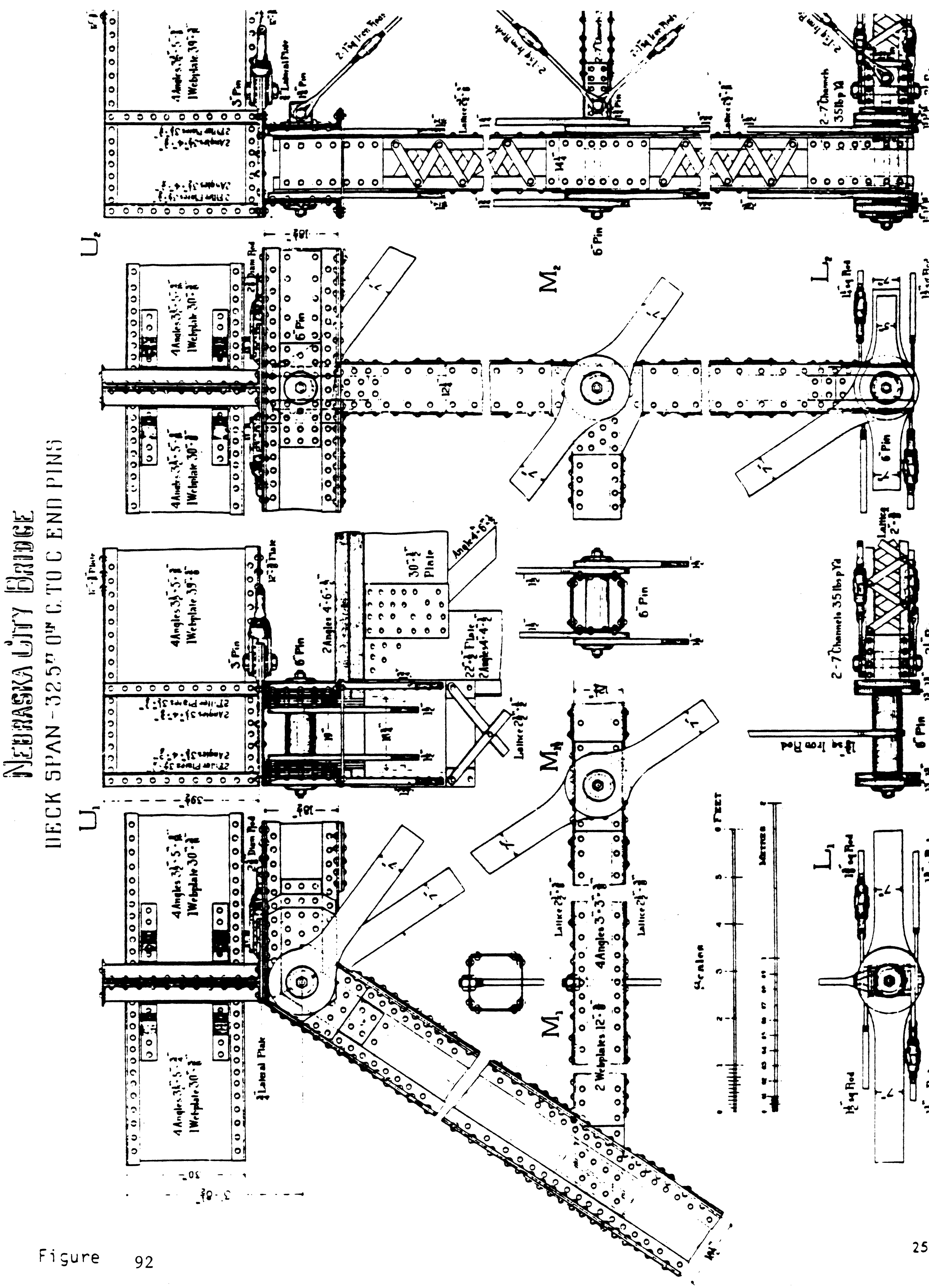

Nebraska City Bridge
Deck Span - 325' 0" C. to C. End Pins
U1
U2
M1
M2
L1
L2
6" Pin
Scales
Feet
Metres

Figure 92

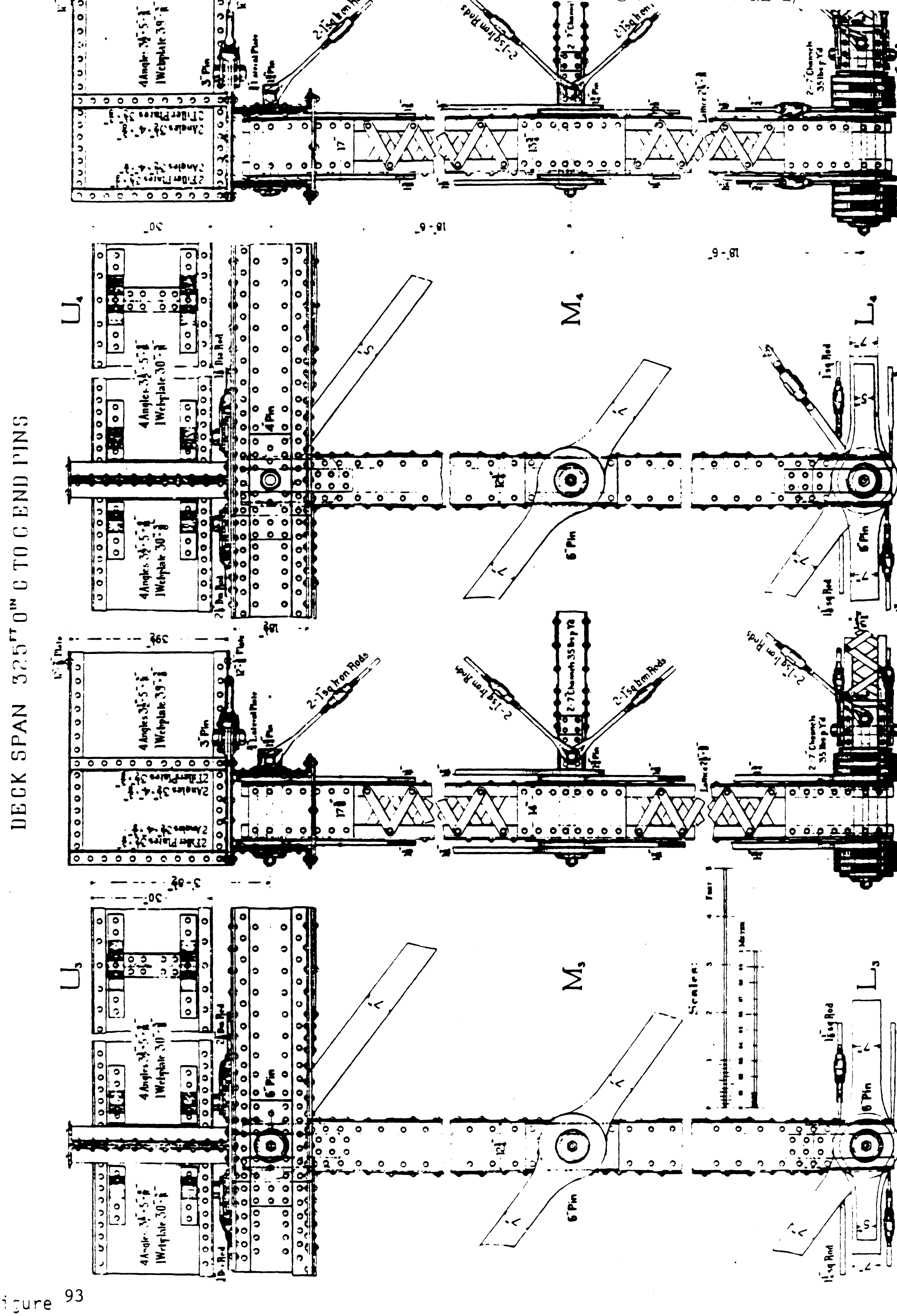

NEBRASKA CITY BRIDGE
DECK SPAN 325 FT 0 IN C TO C END PINS
U4
M4
L4
U3
M3
L3
Scales:

Figure 93

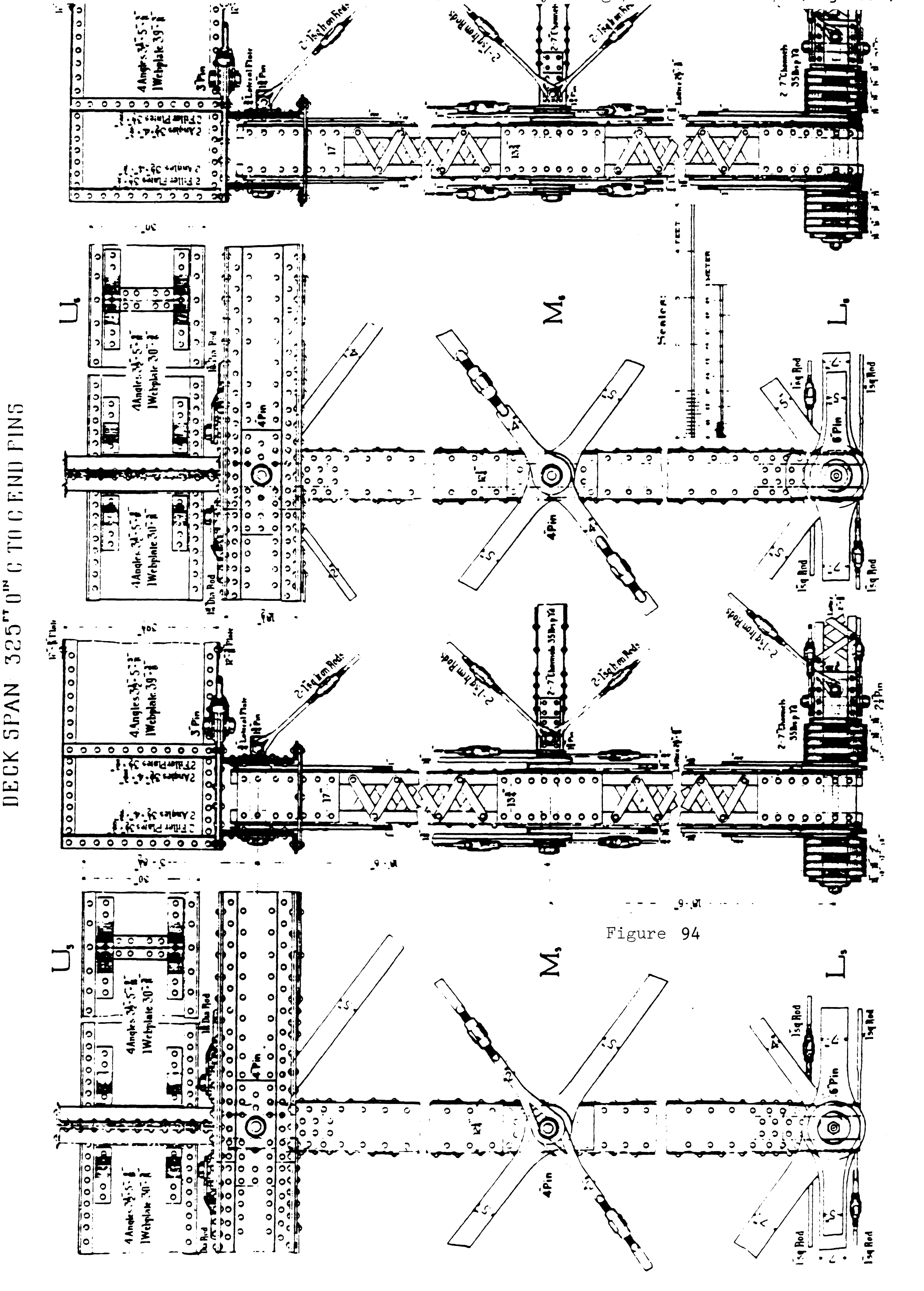

NEBRASKA CITY BRIDGE
DECK SPAN 325 FT 0 IN C TO C END PINS
U6
M6
L6
U5
M5
L5
Scales:
4 Angles 3½·5·⅜
1 Webplate 30·⅜
4 Pin
6 Pin
1 sq Rod
2-1 sq Iron Rods

Figure 94

per square inch of balanced section; the tensile strain on the bottom chord was limited to 13,000 pounds, and that in the web members slightly less, despite a minimum specified tensile strength of 40,000 pounds per square inch for the steel. Although the individual through spans of the Nebraska City Bridge followed Morison's standard design, the bridge's overall profile differed from its predecessors in one significant aspect. For the relatively narrow floodplain at Nebraska City, Morison eschewed his usual series of short-span deck trusses for the approaches in favor of a single long-span deck truss (shown in Figures 91-95). The 37-foot deep, double-intersected Pratt deck truss on the Iowa side spanned 325 feet and was subdivided into thirteen panels of 25 feet each. This would mark the only bridge that the engineer deviated from his short-span approach configuration.

Like the Sioux City Bridge then under construction, the bridge at Nebraska City carried a single railroad track. And like the bridge at Omaha, this bridge was designed to carry both rail and vehicular traffic on the same level. Unlike the Union Pacific bridge at Omaha, though, planking was to be laid over the railroad floor, and horses and pedestrians would be allowed to travel, not on a deck cantilevered outside the web, but within the trusses themselves. According to Morison, the bridge would be closed to one type of traffic while the other crossed. On the west side of the bridge the highway traffic was routed north on a graded approach; on the east it turned south on a trestle with a five percent grade. Morison engineered the superstructure of this bridge almost entirely of steel. Only the nuts and swivels were to be made of wrought iron and the heavy wall pedestal plates and ornamental name and date portal plates to be cast iron. The metallic composition of the bridge is given in the following table:

Through spans:		Total two spans	Average per span	Percentage
Steel		2,167,680 pounds	1,083,840 pounds	97.5%
Wrought iron		11,370 pounds	5,865 pounds	.5%
Cast iron		42,550 pounds	21,275 pounds	2.0%
	Total	2,221,600 pounds	1,110,800 pounds	

Deck span:		Total one span	Percentage
Steel		740,346 pounds	98.0%
Wrought iron		1,936 pounds	.2%
Cast iron		13,206 pounds	1.8%
	Total	755,488 pounds	

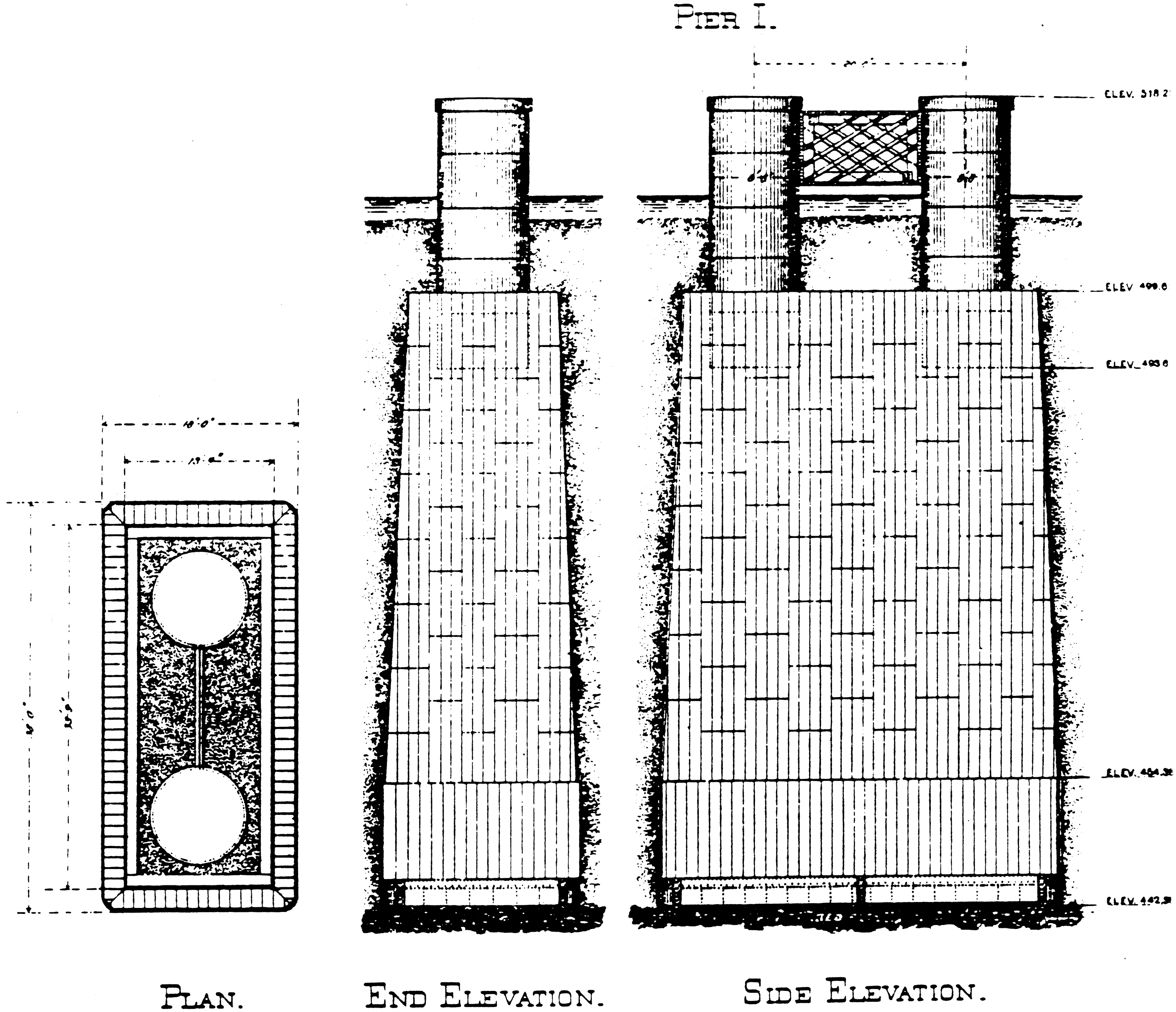
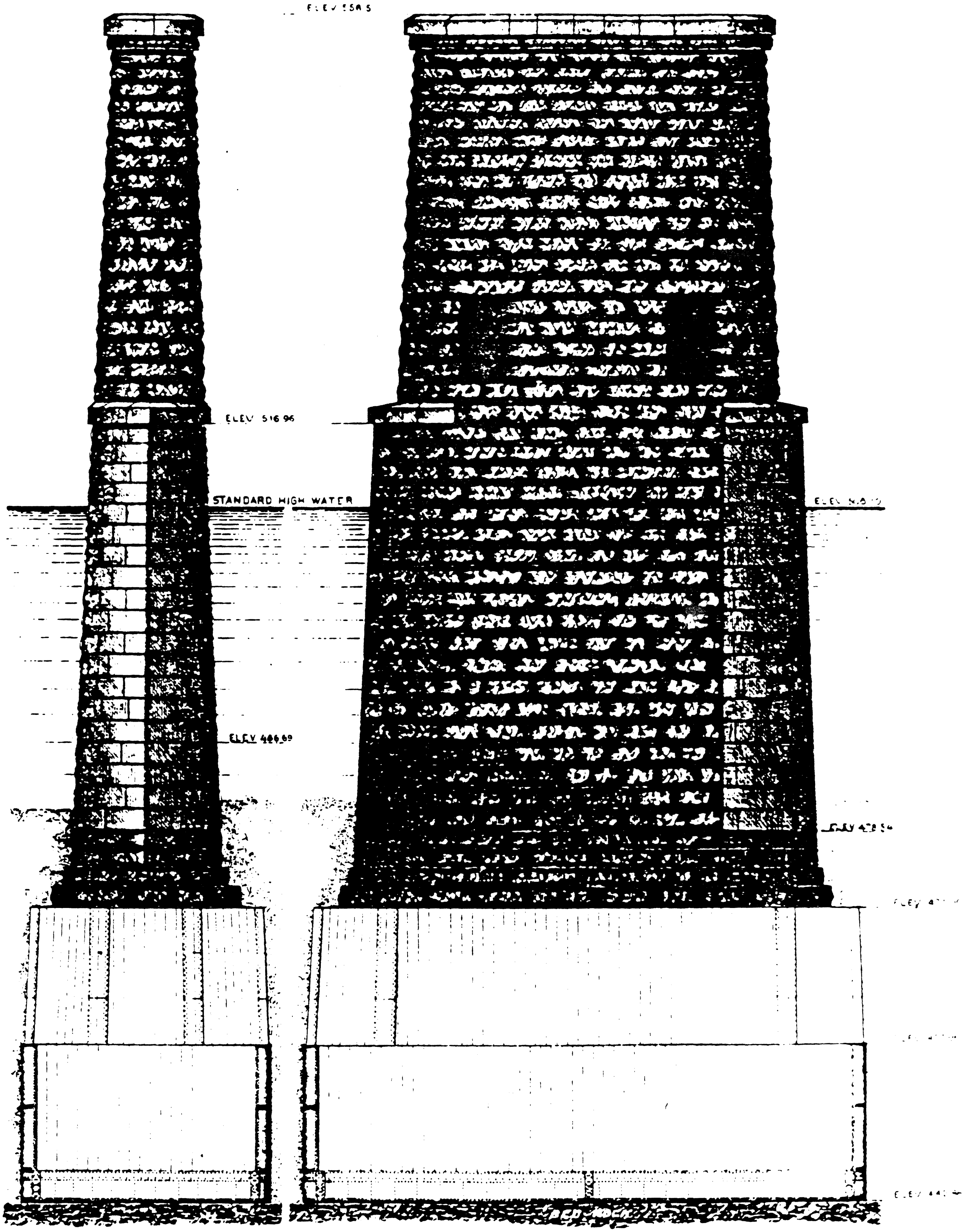

PIER I.
ELEV. 518.2
ELEV. 499.6
ELEV. 493.6
PLAN.
END ELEVATION.
SIDE ELEVATION.

Figure 95

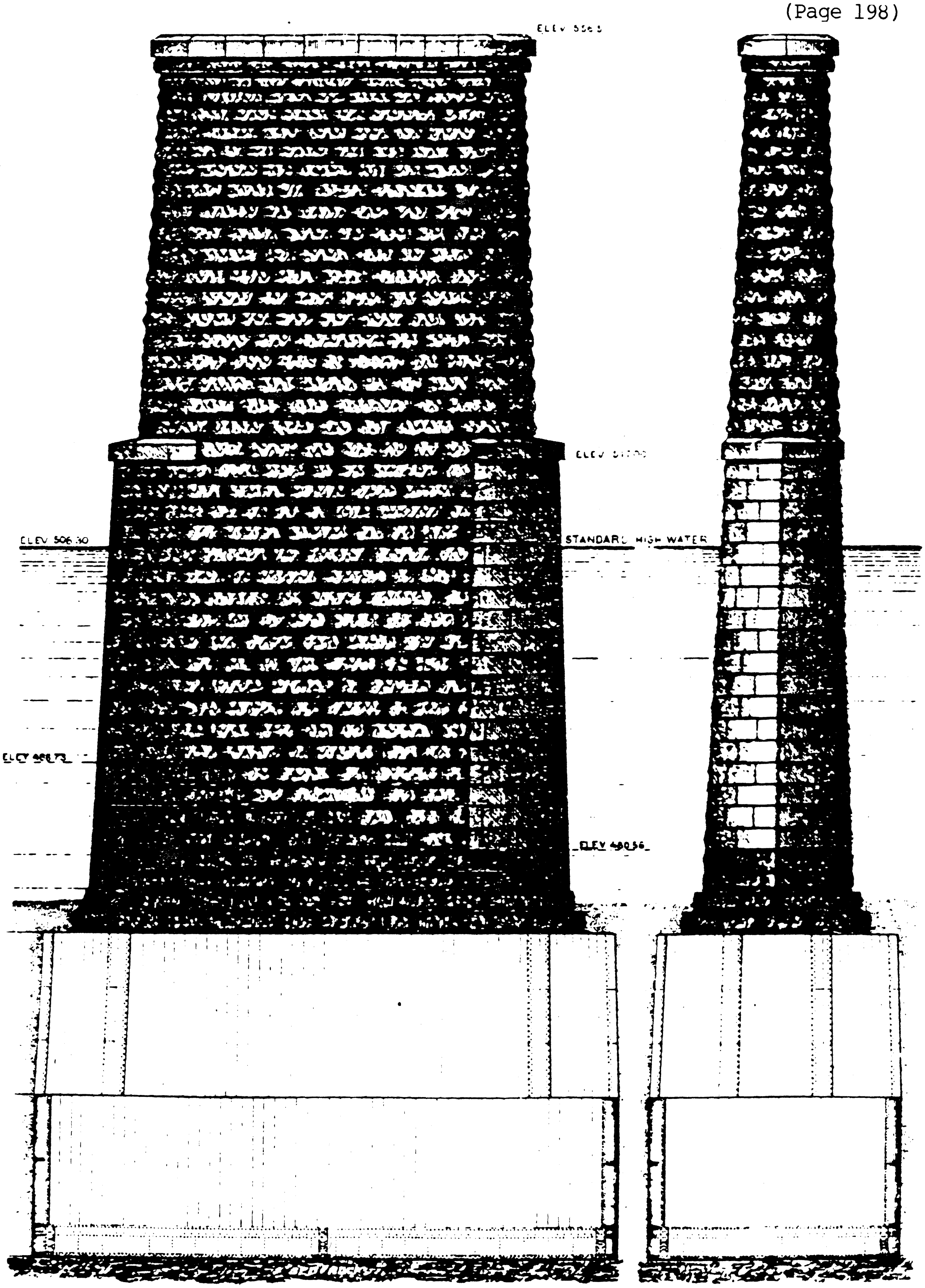
Pier II.



End Elevation. Side Elevation.

Feet Figure 96

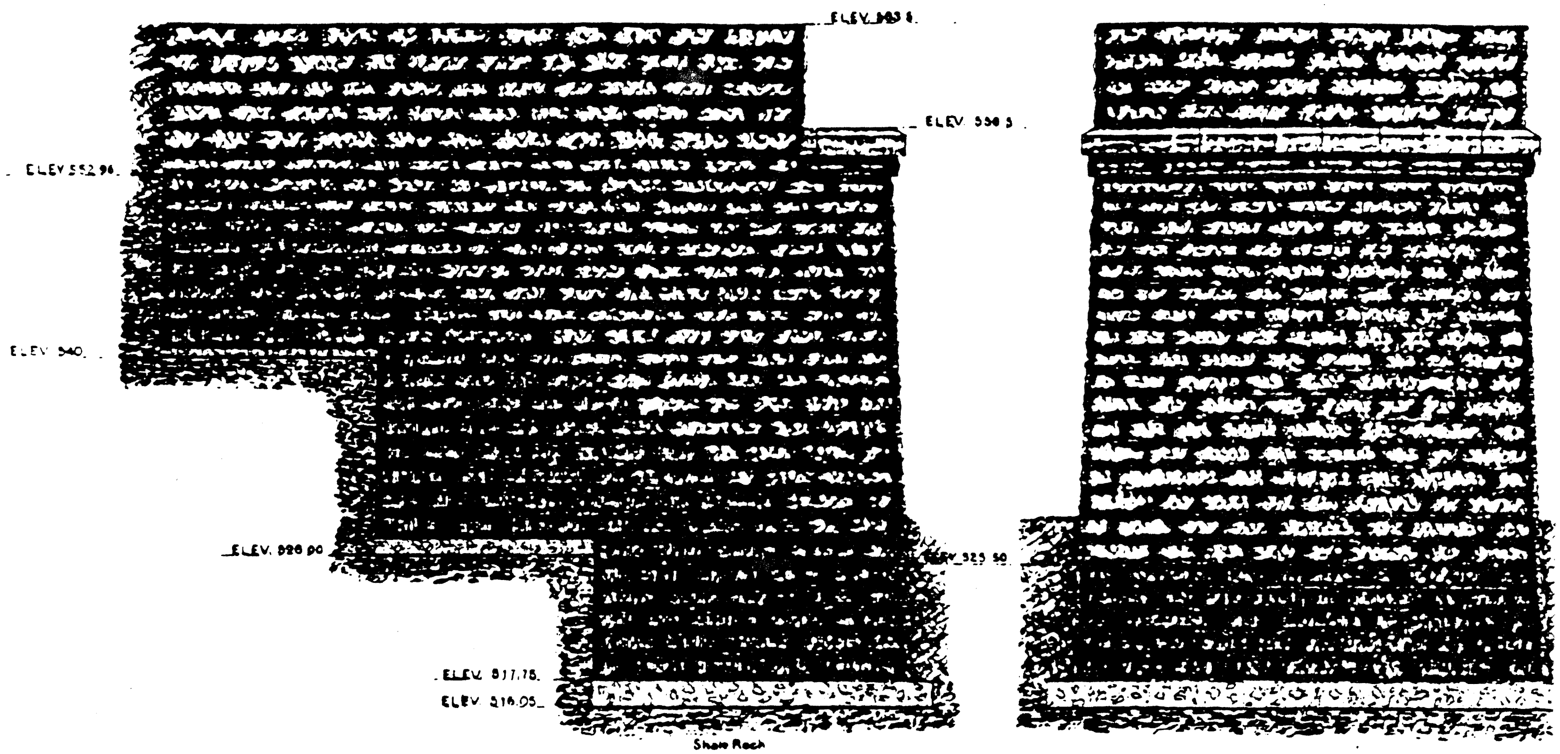
Pier III.



Side Elevation. End Elevation.

Figure 97

Abutment or Pier IV.



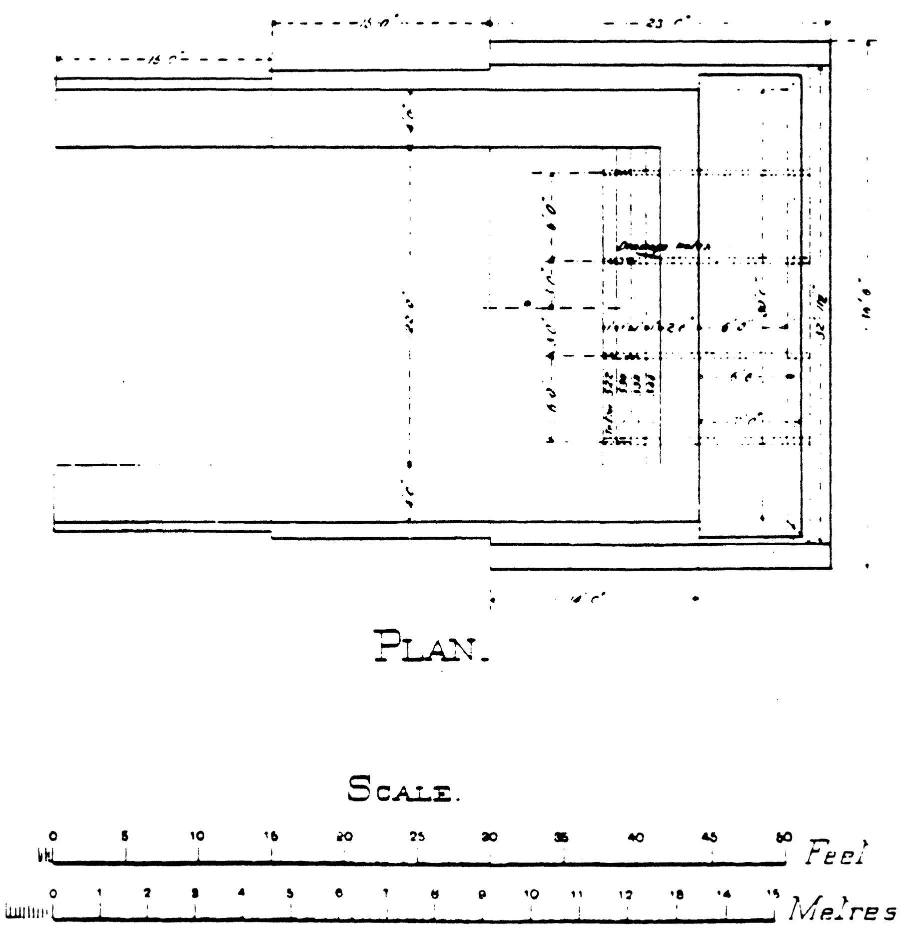


Figure 98

The specifications for the superstructural steel (given in Appendix L) reflected Morison's experience on his preceding bridges. He would accept either Bessemer or open-hearth steel for the Nebraska City Bridge, but under no circumstances would he approve material made by the Clapp-Griffiths process, which he had tried unsuccessfully to obtain for the Omaha Bridge two years earlier. To avoid the steel supply problem that had created the costly delay on the Bismarck Bridge five years earlier, Morison would accept no material produced by a mill which had been in operation for less than a year. Again, he would subject the steel to what had become his standard battery of sample and full-scale testing.[263]

Immediately after formal approval was given by the War Department in June 1887, Perkins instructed Morison to proceed with the construction of the Nebraska City Bridge. The Chief Engineer began the project as he had all the preceding bridges by marshaling a group of experienced assistants and contractors. Several familiar faces were among Morison's staff for Nebraska City. Morison's partner, E.L. Corthell, was the Associate Chief Engineer; Benjamin Crosby (Plattsmouth, Bismarck, Rulo) was hired as the Resident Engineer in charge of the actual construction. Morison hired several Assistant Engineers for Nebraska City: Edwin Duryea (Omaha, Rulo), M.A. Waldo (Omaha, Rulo), W.S. MacDonald (Blair Crossing, Omaha, Rulo), A.J. Himes (Rulo), L.V. Rice, and Addison Connor. H.W. Parkhurst (Plattsmouth, Bismarck, Blair Crossing, Sioux City) was sent to Minnesota to inspect the stone quarries, and Paul Willis (Rulo, Sioux City), R.W. Hildreth (Omaha, Sioux City), Ralph Modjeski (Omaha, Sioux City), and W.A. Nettleton were sent to the eastern steel mills to inspect the truss fabrication. The contractors were all well acquainted with the irascible Chief Engineer from previous bridge projects. Tom Saulpaugh, Morison's favorite stonemason, would build the masonry piers. The Union Bridge Company, managed by Morison's former bridgebuilding partner, George Field, was awarded the contract for the steel fabrication. And the Baird Brothers, veterans of all but one of Morison's Missouri River bridges, would oversee the superstructural erection. (The full list of engineers and contractors is given in Appendix M)

Resident Engineer Crosby was the first assistant to move to Nebraska City. As Morison's staff was drafting the construction drawings for the bridge at his Chicago office in February 1887, Burlington President Perkins ordered work begun on the protective dike on the east bank of the river. Laborers built the woven willow foundation mattress on the riverbank under Morison's design and Crosby's supervision, wiring the assemblage in place to driven log piles and covering it with tons of riprap stone. Though substantial, the 125-foot wide dike and associated east shore protection involved far less labor and materials than did the rectification works at either the Plattsmouth or Blair bridges. The shore construction completed that spring consumed some 4200 cords of willow brush, 7400 pounds of iron wire, and 37 million pounds of rock at a cost of $54,000.[264]

Actual construction on the bridge began on August 13, 1887. The John Bertram had steamed up the Missouri from Rulo with the pneumatic equipment to sink the caissons three weeks earlier, and the first caisson material had been shipped to the site by train on August 7th. The substructural work at Nebraska City began on Pier I (shown in Figure 96), the easternmost support under the east end of the long deck truss. In September, a work crew hired by the railroad began digging an open pit in the sand bar on the east bank of the river at the pier's position. In it the carpenters built the caisson for the pneumatic excavation. Like all of Morison's caissons, the 38x18x12-foot structure featured solid timber walls with radiused corners, a cribbed timber roof, and an iron sheathed work chamber with a heavy wrought iron cutting edge at the bottom. By the time the caisson construction was completed and the air pressure pumps were started on the morning of December 9th, the massive structure consisted of 186,000 pounds of timber, 32,000 pounds of iron, and over 300,000 pounds of Michigan concrete for a total weight exceeding 500,000 pounds.

As laborers excavated for Pier I during the warm days of October, other crews began the simultaneous construction on Piers II and III (shown in Figure 97) and on the stone abutment at the foot of the bluff on the west shore (shown in Figure 98). Piledrivers drove the first staging piles for the caisson at Pier III on October 3rd and then moved to Pier II two weeks later. Ironworkers riveted the cutting edge for Pier III on the east bank in preparation for the timber walls, and on the west bank Saulpaugh's stonemasons began laying stone for the abutment.

To the townspeople of Nebraska City, this full-scale construction signaled the fulfillment of their long-held hopes for a bridge over the Missouri. The boosterish Nebraska City News inevitably began reading more far-reaching implications in the Burlington's decision to erect the bridge. On October 7th, the paper quoted an unidentified "well posted railroad man" as saying: "It is foolish to suppose that the C.B.& Q. is building the bridge at this point simply to accommodate the road from here to Grand Island or to transfer what few passengers come on the Red Oak Branch. I know that the management are figuring on a change that will be of the utmost importance to Nebraska City. It is the building of a road from this city to Sterling and then to DeWitt, there to make connection with their own line... Of course, I cannot say definitely that they will build that branch, but I know that President Perkins and others are figuring on the cost and the benefits. Nebraska City should urge the building of that line."[265] Additionally, the News began booming for other railroads attracted by the bridged crossing over the Missouri, among them the Missouri Pacific and the Rock Island lines. After years of uncertainty, the paper could at last afford to be smug, stating:

> Eighteen months ago, when the C.B.& Q. first sent its engineers to

> this point to watch the course of the river, certain persons indulged in a great deal of criticisms at their expense, the favorite expression being that they were "sent here to watch chips float down the river." They watched and watched closely, and the result was the locating of the bridge in its present position. Those who were so flippant then now acknowledge their mistake.[266]

To celebrate the bridge - and the first testing of the city water works - the townspeople held a cornerstone-laying ceremony on November 3rd. The festivities began in the morning with a jubilant procession through the small town, as reported by the News:

> Never before has Nebraska City covered herself with glory as she did today in the shape of the procession that took place this morning. It was over four miles in length and took one hour and twenty minutes to pass a given point. Every one seemed to take an interest and did all they could to make it a grand success in every particular.[267]

The parade marched down to the bridge site, where local Masons, Odd Fellows, Knight Templars, Knights of Pythias, militia companies, the Otoe Hook and Ladder Company, and assorted officials and guests crowded the levy and spectators lined the bluffs. Morison had ordered a cornerstone for the occasion, but when it failed to arrive another was substituted. In it a tin box was placed containing a copy of the anniversary issue of the News and other newspapers, histories of the Masons and Odd Fellows, a copy of the 1872 bridge charter, railroad timetables, a list of bridge officials, and a few other documents. The stone was ceremoniously laid in a lower course of the west abutment, Representative J. Sterling Morton gave a long-winded and sometimes bewildering speech on "the inestimable value of motion," and the crowd, satisfied by the ceremony, dispersed.[268]

Construction on the foundations continued under Crosby's supervision throughout the long winter. When Burlington engine crews went on strike early in 1888, the workers resorted to hauling materials by pushing the rail cars themselves. The west abutment, scene of the cornerstone ceremony, was the first support completed. Flanked by stepped masonry wingwalls, it was finished on December 26, 1888. A month later stonemasons laid the last stone for Pier III. Typical of piers for all of Morison's previous bridges, it was a 133-foot tall massive stone monolith seated on the timber cribbing over the caisson with a stepped stone cap and a distinctive stone corbel at the high water level. Pier I was completed on January 30, 1888. Its shaft consisted of two 8-1/2-foot round, 18-foot tall, wrought iron cylinders salvaged from the piers of the original Union Pacific bridge at Omaha. These were secured to the concrete-filled timber crib on top of the caisson, topped with heavy cast-iron caps, and joined by a wrought iron lattice frame.

As Pier II - the last support - was reaching its farthest depth in February, a number of the "sand hogs," as the diggers were called, were overcome with the bends. The News indicated the still poorly understood nature of the affliction in its description of the men's symptoms and treatment:

> The attack is something peculiar and comes on to a well man as soon as one who is not feeling in the best of health. It consists of violent pains, in the stomach, principally, and the suffering is intense. The victim who is attacked is hoisted at once to the surface where he is placed in a hot room, stripped of his clothing and rubbed down with course towels, after being given a strong cup of coffee. If that does not relieve him, then whiskey is freely administered, after which the patient is placed in a warm bed, from which he usually arises feeling all right, having fully recovered from the effects of the attack.[269]

The caisson inched further downward and the air pressure was increased. More men were affected by the illness until the afflicted workers outnumbered the healthy ones. The final depths, however, were some ten to twenty feet shallower than those for the Omaha Bridge, and no bends-related deaths were reported at Nebraska City.

The excavation for Pier II was finished and the caisson chamber filled with concrete later that month, completing the last foundation for the bridge. On May 2nd, masons laid the last sill stones on the top of the column. The three pneumatic piers for the Nebraska City Bridge were typically immense: comprised of 668,000 pounds of timber, 238,000 pounds of iron, almost 9 million pounds of Michigan and Portland concrete, and over 11 million pounds of limestone from Mankato and granite from Morton, Minnesota, for an aggregate weight of over 22 million pounds. The total substructural cost was modest by Missouri River standards: only slightly more than $179,000.[270]

The Baird Brothers' steelworkers had already begun work on the superstructure before the last pier was completed. In January 1888, men on the work barge began driving the log piles for the falsework under the west through truss. By the first week of February, the men had completed the falseworks. Two weeks later they rushed to begin laying the bottom chords of the first truss. The Bairds' crew had accrued extensive experience in building long-span Whipple trusses on Morison's previous bridges and erected the first channel span at Nebraska City in a record four days. Morison wanted to build the second span before the ice pack broke up in March, but the river began its annual clearing early in 1888. As the News reported on March 2nd, the breakup was an anxious time for the bridge workers:

> For the past three days the river has been watched very closely by

> both those directly interested and those who hoped that when the ice did move it would go out gradually and in a manner so as to do no damage to anything. Yesterday morning the ice began moving below the lower pile bridge and it was thought that the workmen would be unable to get the timbers off the pile bridge before the ice would go out. A large force of men were at work all day, and when last night came they were still laboring and some of them worked late into the night. The steamboat men have been the most anxious and they have not been absent from their boats more than an hour for the past two days... About midnight last night the ice in the river began to move near the head of the island and for a time it forced its way down the main channel until it got near the water works where it blocked, and in a short time the open space was filled with a solid mass of ice, which became so heavy at the head of the island that it stopped the current coming down the main channel.[271]

The island forced the ice-gorged river over the dike into the eastern channel, washing out the pile bridge and much of the rectification works. As a CB&Q work crew struggled to pitch sand bags onto the breached dike, at least one local riverman recommended that the ice be dynamited to clear the channel and criticized Morison's engineering on the dike's location, saying: "If the confounded fools had only built that proposed dike at the head of the island, as suggested by Capt. Butts, they would have avoided all this trouble and a great deal of expense. They will have to build it yet before they make things safe." Despite the local criticism, Morison remained intractable, refusing to change the dike configuration.

The men repaired the dike, and repaired it again after another washout a month later. The barge crew began driving the falsework piles for the second through truss soon after the river level fell behind the ice breakup. On May 22nd, the steelworkers laid out the bottom chords of the long-span truss over the completed staging bents and used a timber traveler like the one used at Bismarck to erect the truss in a remarkable three days. They built the deck span in four days in early June as the railroad work crew was assembling the long approach trestle and again repairing the faulty dike. The News described the approach structure as it was nearing completion on June 22nd:

> The last bent of the trestlework at the east end of the bridge was put up yesterday afternoon. This is known as the permanent trestle and consists of ninety nine bents. At the east end of this is the cottonwood trestle, of which there are forty nine bents, and the last of these is expected to be up this evening. This section of the work will be filled in with earth as soon as the work train can cross over the permanent section and will be left as it is for an indefinite time. The entire length of the trestle is 2,980 feet, the highest be-

ing fifty seven feet and the lowest, which is the east end of the cottonwood section, twenty three feet.[272]

Engineers Crosby and Waldo staged the ceremonial first crossing of the bridge with local dignitaries on the rainy morning of July 27, 1888. "As soon as the train landed on this side a loud hurrah was given," the News announced, "the engineer aiding in the noise by vigorously blowing the whistle... 'Mid waving of handkerchiefs, cheering and the discharging of a cannon fire cracker, the trip was ended - but a great and grand feat accomplished, the first train that ever entered Nebraska City over the Missouri on a bridge."[273] The tracks were soon completed on both approaches, and by the end of the month the bridge was opened to regular traffic. By acting quickly, Charles Perkins had taken advantage of ideal river conditions, and resultingly the Nebraska City Bridge was at its completion the least expensive fixed-span bridge over the Missouri River. The total cost was less than $600,000, broken down as follows:

Substructure........................	$179,440
Superstructure......................	183,305
Approaches..........................	97,200
Dike................................	54,180
Tools, Service tracks, etc..........	28,191
Land damages and charter............	7,438
Engineering fees....................	33,033
Total cost....	$582,790 [274]

The townspeople had wanted to celebrate the bridge's inauguration at the end of July, but George Morison convinced them to postpone the occasion until a time when the weather would be more pleasant. The ebullient town fathers could not wait until autumn, however, and held the grand opening on August 30th. Like the cornerstone celebration held almost a year earlier, the people of Nebraska City staged a glorious celebration, marked by excursion trains, parades and speeches, flag waving and marching bands, picnics and fireworks.[275] Morison himself did not attend, sending Resident Engineer Crosby in his stead.

The completion of the Nebraska City Bridge marked the seventh major railroad span that George Morison had engineered over the Missouri River in a nine-year period. Like the others, it involved a tremendous commitment of money and man-power. At times urgent, dramatic, and possibly heroic, but more often mind-numbingly dull on a day-to-day basis, erection of these Veblenian scaled bridges came to resemble more military campaigns than construction projects. George Morison clearly relished his role as field marshal, assembling the men and materiel and orchestrating the contest to wrest control over the pernicious river. He had begun his engineering career on the Missouri and established a

nationally known reputation for his bridges over it. Morison felt challenged by the river and had a great affinity for it - far more than for any other watercourse.

The series of railroad bridges over the Missouri River that Morison designed and supervised between Plattsmouth and Nebraska City represented a singular accomplishment in bridge engineering. In the nine years between 1879 and 1888 in which they were erected, Morison held almost a monopoly on bridging the most problemmatical river in the country, at a time when railroad expansion through the Midwest was at its peak. By 1889, twelve railroad bridges spanned the great river above Kansas City.[276] Of those erected after 1879, Morison had engineered all but two. Steadfastly true to his conviction, he had designed all seven of his 1880s Missouri River structures as high, fixed-span bridges, rather than to copy the moveable-span predecessors. As a result, his monumental bridges created the standard for railroad and vehicular crossings over the Missouri River. Other engineers would design fixed- and moveable-span railroad structures over the Missouri in the 1890s. Morison himself would later engineer three more Missouri River structures, including the replacement for the bridge at Atchison. But these seven bridges as a group signaled not only the vitality of the railroad industry during the period, but indicated a coming-of-age for bridge technology in America. Although the last in the series at Nebraska City may have resembled the first at Plattsmouth visually, its all-steel composition marked the most significant watershed in American bridgebuilding - the transition from wrought iron to steel.

ENDNOTES

1 George S. Morison, "The Missouri River," (Columbia College) School of Mines Quarterly, Vol. XVII, No. 1. (Reprinted from a lecture given by George Morison to the Department of Civil Engineering on 27 March 1895.)

2 Charles D. Stewart, "A Race on the Missouri," The Century Magazine, Volume LXXIII, No. 4 (February 1907), page 588.

3 Thomas Doane, Report on Bridging the Missouri River (Boston: Press of T.R. Marvin and Son, 1868).

4 Octave Chanute and George S. Morison, The Kansas City Bridge (New York: D. van Nostrand, 1870), page 19.

5 Robert G. Athearn, Union Pacific Country (New York: Rand McNally & Company, 1971), pages 335-36.

6 Stanley Vestal, The Missouri (New York: Farrar & Rinehart, Inc., 1940), page 14.

7 George S. Morison, "Bridges Regarded as Commercial Tools," New York: Evening Post Job Print, 1 February 1890. Privately published pamphlet reproducing paper read by George Morison to St. Louis Commercial Club in March 1889. page 6.

8 Chanute and Morison, The Kansas City Bridge, page 2.

9 George S. Morison, The Plattsmouth Bridge (New York: S.B. Leverich, 1882). page 3.

10 George S. Morison, The Plattsmouth Bridge, page 3.

11 Grenville M. Dodge, How We Built the Union Pacific Railway (Council Bluffs, Iowa: Monarch Printing Company, ca. 1911; reprinted in 1965 by Sage Books, Denver Colorado). pages 34-36; Robert Athearn, Union Pacific Country, pages 335-336; George S. Morison, The New Omaha Bridge, page 3.

12 George S. Morison, The Plattsmouth Bridge, page 3.

13 H.B. Voorhees, "The First Steel Bridge Recalled," Railway Age, 17 February 1945, pages 343-44.

14 "Early Steel Bridges in America," Engineering News, 8 February 1894, page 120.

15 Richard C. Overton, Burlington Route (New York: Alfred A. Knopf, 1965), page 168.

16 Richard C. Overton, Burlington Route, page 169.

17 Letter: William Irving to Charles E. Perkins, 19 September 1877, Newberry Library, Burlington Northern Collection, (63 1870 8.5).

18 Letter: J.E. Laylor to Charles E. Perkins, 1 September 1877, Newberry Library, Burlington Northern Collection, (63 1870 8.5); George Morison, The Plattsmouth Bridge, page 2.

19 George Morison, The Plattsmouth Bridge, page 2.

20 Letter: William Irving to Charles E. Perkins, 19 September 1877, Newberry Library, Burlington Northern Collection, (63 1870 8.5).

21 George Morison, The Plattsmouth Bridge, page 2.

22 George Morison, The Plattsmouth Bridge, page 1.

23 George Morison, The Plattsmouth Bridge, Plate 1.

24 George S. Morison, Bridges Regarded as Commercial Tools, paper read before the St. Louis Commercial Club, 16 March 1889, page 14.

25 George Morison, Bridges Regarded as Commercial Tools, page 15.

26 George Morison, Bridges Regarded as Commercial Tools, page 14.

27 Chanute, Parkhurst, Corthell, Noble, Modjeski and Gerber, "George Shattuck Morison: A Memoir," Journal of the Western Society of Engineers, Volume IX, No. 1, page 88.

28 George Abbot Morison, George Shattuck Morison, 1842-1903: A Memoir, (Peterborough, New Hampshire: Peterborough Historical Society, 1940), page 23.

29 "George Shattuck Morison," The Engineering Record, 11 July 1903, page 51.

30 George Morison, The Plattsmouth Bridge, page 2.

31 George Morison, The Plattsmouth Bridge, page 1.

32 George Morison, The Plattsmouth Bridge, page 1.

33 Chanute, Parkhurst, Corthell, Noble, Modjeski and Gerber, "George Shattuck Morison, 1842-1903: A Memoir," page 88.

34 Paul L. Wolfel, Richard Khuen and O.E. Hovey, "Memoir of Charles Conrad Schneider," Transactions of the American Society of Civil Engineers (1916), pages 1666-67.

35 Chanute et al., "George Shattuck Morison, 1842-1903: A Memoir," page 88.

36 George Morison, The Plattsmouth Bridge, page 23.

37 George Morison, The Plattsmouth Bridge, Plate 21.

38 George Morison, The Plattsmouth Bridge, Plate 18

39 George Morison, The Plattsmouth Bridge, Plate 17

40 George Morison, The Plattsmouth Bridge, Plate 16

41 George Morison, The Plattsmouth Bridge, page 3.

42 George Morison, The Plattsmouth Bridge, page 12.

43 George Morison, The Plattsmouth Bridge, pages 10-13.

44 George Morison, The Plattsmouth Bridge, Plate 23.

45 George Morison, The Plattsmouth Bridge, page 12.

46 George Morison, The Plattsmouth Bridge, page 12.

47 George Morison, The Plattsmouth Bridge, page 13.

48 Theodore Cooper, "The Use of Steel for Bridges," Transactions of the American Society of Civil Engineers, Volume IX (1879), page 345.

49 Octave Chanute, "Comments on 'The Use of Steel for Bridges,'" page 367.

50 George Morison, The Plattsmouth Bridge, pages 13-14.

51 George Morison, The Plattsmouth Bridge, page 11.

52 George Morison, The Plattsmouth Bridge, page 1.

53 George Morison, The Plattsmouth Bridge, Plate 14.

54 George Morison, The Plattsmouth Bridge, page 4.

55 George Morison, The Plattsmouth Bridge, pages 4-5.

56 George Morison, The Plattsmouth Bridge, Plate 7.

57 George Morison, The Plattsmouth Bridge, pages 5-6.

58 George Morison, The Plattsmouth Bridge, Plate 7.

59 George Morison, The Plattsmouth Bridge, pages 5-6.

60 George Morison, The Plattsmouth Bridge, Plate 5.

61 George Morison, The Plattsmouth Bridge, Plate 4.

62 George Morison, The Plattsmouth Bridge, Plate 5.

63 George Morison, The Plattsmouth Bridge, page 18.

64 Report: H.W. Parkhurst to George Morison, 20 December 1879, Newberry Library, Burlington Northern Collection, (8 P4.2 CB&Q).

65 George Morison, The Plattsmouth Bridge, page 19.

66 George Morison, The Plattsmouth Bridge, page 19.

67 George Morison had been given explicit control of the engineering and construction of the bridge by Perkins at the beginning of the project. In a handwritten "Rules for the Division of Authority" from the CB&Q Railroad, he was named final judge of all engineering questions, with no appeal except through the vice president of the railroad, Charles Perkins. Newberry Library, Burlington Northern Collection (8 P4.2).

68 Letter from A.E. Touzalin to George Morison, 13 December 1879, Newberry Library, Burlington Northern Collection (8 P4.2).

69 George Morison, The Plattsmouth Bridge, page 14.

70 George Morison, The Plattsmouth Bridge, page 14.

71 George Morison, The Plattsmouth Bridge, pages 14-15.

72 George Morison, The Plattsmouth Bridge, page 17.

73 George Morison, The Plattsmouth Bridge, pages 14-15.

74 George Morison, The Plattsmouth Bridge, Plate 24.

75 George Morison, The Plattsmouth Bridge, pages 15-16.

76 George A. Morison, George Shattuck Morison, pages 18-19.

77 Telegraphic correspondence between George Morison and A.E. Touzalin, 6-9 February 1880, Newberry Library, Burlington Northern Collection (8 P4.2).

78 George Morison, The Plattsmouth Bridge, page 13.

79 George Morison, The Plattsmouth Bridge, page 15.

80 Letter to George Morison from Charles MacDonald, 20 October 1880, reprinted in The Plattsmouth Bridge, page 36.

81 Richard Overton, Burlington Route, page 168.

82 Litton Shields, "Remininiscences of a Railroad Builder," pages 47-48, reprinted in Hear That Lonesome Whistle Blow by Dee Brown (New York: Holt, Rinehart, Winston, 1977).

83 George Morison, The Bismarck Bridge, Plate 3.

83 Dee Brown, Hear That Lonesome Whistle Blow, pages 210-11. Ray Allen Billington, Westward Expansion (New York: The Macmillan Company, 1967), page 651.

84 George Morison, The Bismarck Bridge (n.p., 1884), page 1.

85 George Morison, The Bismarck Bridge, page 1.

86 Paul O'Neil, The Rivermen (New York: Time/Life Books, 1975), page 189.

87 George Morison, The Bismarck Bridge, page 4.

88 George Morison, The Bismarck Bridge, Plate 2.

89 George Morison, The Bismarck Bridge, Plate 3.

90 George Morison, The Bismarck Bridge, page 2.

91 Billington, Westward Expansion, page 652.

92 George Morison, The Bismarck Bridge, Plate 19.

93 George Morison, The Bismarck Bridge, Plate 21.

94 George Morison, The Bismarck Bridge, Plate 23.

95 George Morison, The Bismarck Bridge, Plate 22.

96 George Morison, The Bismarck Bridge, Plate 20.

97 Billington, Westward Expansion, page 652.

98 George Morison, The Bismarck Bridge, pages 12-13.

99 George Morison, The Bismarck Bridge , page 15.

100 George Morison, The Bismarck Bridge, Plate 17.

101 George Morison, The Bismarck Bridge, page 14.

102 George Morison, The Bismarck Bridge, page 13.

103 George Morison, The Bismarck Bridge, page 14.

104 George Morison, The Bismarck Bridge, page 1.

105 George Morison, The Bismarck Bridge, page 4.

106 George Morison, The Bismarck Bridge, page 5.

107 George Morison, The Bismarck Bridge, page 6.

108 George Morison, The Bismarck Bridge, page 2.

109 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir, page 19.

110 George Morison, The Bismarck Bridge, page 19.

111 George Morison, The Bismarck Bridge, Plate 10.

112 Evan S. Connell, Son of the Morning Star, page 159.

113 George Morison, The Bismarck Bridge, page 8.

114 George Morison, The Bismarck Bridge, page 9.

115 George Morison, The Bismarck Bridge, page 15.

116 George Morison, The Bismarck Bridge, Plate 7.

117 George Morison, The Bismarck Bridge, Plate 5.

118 George Morison, The Bismarck Bridge, Plate 8.

119 Victor C. Darnell, Directory of American Bridge Building Companies, 1840-1900, (Washington, D.C.: Society for Industrial Archeology, 1984), page 27.

120 George Morison, The Bismarck Bridge, page 15.

121 George Morison, The Bismarck Bridge, page 15.

122 "Traveller for Erecting 400 Foot Span Bismarck Bridge," The Engineering and Building Record, page 276.

123 George Morison, The Bismarck Bridge, page 16.

124 George Morison, The B.C. Bridge, (n.p., 1886), page 1.

125 George Morison, The B.C. Bridge, page 1.

126 George Morison, The B.C. Bridge, Plate 1.

127 George Morison, The B.C. Bridge, page 1; "The Blair Crossing Bridge," Engineering, 2 September 1887.

128 George Morison, The B.C. Bridge, page 2.

129 George Morison, The B.C. Bridge, page 1.

130 George Morison, The B.C. Bridge, Plate 2.

131 George Morison, The B.C. Bridge, page 9.

132 George Morison, The B.C. Bridge, page 6.

133 "The Blair Crossing Bridge," 2 September 1887.

134 George Morison, The B.C. Bridge, Plate 11.

135 George Morison, The B.C. Bridge, Plate 13.

136 George Morison, The B.C. Bridge, Plate 16.

137 George Morison, The B.C. Bridge, Plate 12.

138 George Morison, The B.C. Bridge, Plate 19.

139 George Morison, The B.C. Bridge, Plate 18.

140 George Morison, The B.C. Bridge, Plate 17.

141 George Morison, The B.C. Bridge, page 4.

142 George Morison, The B.C. Bridge, page 2.

143 George Morison, The B.C. Bridge, Plate 7.

144 George Morison, The B.C. Bridge, Plate 6.

145 Report of the Testing Committee for the Blair Crossing Bridge to George Morison, 27 October 1883, reprinted in The B.C. Bridge, page 25.

146 Robert Athearn, Union Pacific Country, page 336.

147 Robert Athearn, Union Pacific Country, page 235. George Crofutt, New Overland Tourist (Omaha: 1880), page 21.

148 George Morison, The New Omaha Bridge, page 3.

149 George Morison, The New Omaha Bridge, Plate 26.

150 George Morison, The New Omaha Bridge, page 3.

151 Wolfel et al., "Memoir of Charles Conrad Schneider," page 1667.

152 "Ralph Modjeski," unpublished biography by Modjeski, Masters and Assoc., (n.a., n.d.), Modjeski and Masters, Harrisburg, Pennsylvania.

153 George Morison, The New Omaha Bridge, Plate 1.

154 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir, page 19.

155 Victor C. Darnell, Directory of American Bridge-Building Companies, 1840-1900 (Washington, D.C.: Society for Industrial Archeology, 1984), page 37.

156 George Morison, The New Omaha Bridge, page 4.

157 George Morison, The New Omaha Bridge, page 10.

158 George Morison, The New Omaha Bridge, Plate 15.

159 George Morison, The New Omaha Bridge, Plate 17.

160 George Morison, The New Omaha Bridge, Plate 16.

161 George Morison, The New Omaha Bridge, Plate 18.

162 George Morison, The New Omaha Bridge, Plate 20.

163 George Morison, The New Omaha Bridge, Plate 21.

164 George Morison, The New Omaha Bridge, Plate 22.

165 George Morison, The New Omaha Bridge, Plate 23.

166 George Morison, The New Omaha Bridge, page 3.

167 George Morison, The New Omaha Bridge, Plate 7.

168 George Morison, The New Omaha Bridge, Plate 6.

169 David McCullough, The Great Bridge: The Epic Story of the Building of the Brooklyn Bridge (New York: Avon Books, 1972), page 311.

170 "The U.P.R.R. Bridge," Engineering News and American Contracting Journal, 20 March 1886, page 190.

171 George Morison, The New Omaha Bridge, page 5.

172 George Morison, The New Omaha Bridge, page 3.

173 George Morison, The New Omaha Bridge, page 10.

174 George Morison, The New Omaha Bridge, page 10.

175 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir, page 19.

176 George Morison, The New Omaha Bridge, Plate 19.

177 Letter from George Morison to T.J. Potter, Vice President of the Union Pacific Railroad, 3 November 1887, reprinted in The New Omaha Bridge.

178 George Morison, The New Omaha Bridge, page 10.

179 George Morison, The Rulo Bridge (n.p., 1890), page 1.

180 Richard Overton, Burlington Route, page 92.

181 Richard Overton, Burlington Route, pages 187-88.

182 Richard Overton, Burlington Route, page 188.

183 George Morison, The Rulo Bridge, page 3.

184 Letter from George Morison to Charles Perkins, 15 January 1884, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

185 Letter from George Morison to Charles Perkins, 19 January 1884, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

186 George Morison, The Rulo Bridge, Plate 1.

187 George Morison, The Plattsmouth Bridge, page 20.

188 George Morison, The B.C. Bridge, page 8.

189 George Morison, The Bismarck Bridge, page 19.

190 Letter from Charles Perkins to T.J. Potter, 18 January 1884, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

191 Act of June 18, 1884, Authorizing Construction of Rulo Bridge, reprinted in The Rulo Bridge, page 14.

192 Letter from T.E. Calvert to G.W. Holdrege, 3 August 1884, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

193 Letter from George Morison to Charles Perkins, 10 March 1885, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

194 Letter from T.J. Potter to Charles Perkins, 16 March 1885, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

195 Letter from Charles Perkins to T.J. Potter, 13 April 1885, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

196 Letter from T.J. Potter to Charles Perkins, 21 January 1885, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

197 Letter from T.J. Potter to Charles Perkins, 20 October 1885, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

198 Letter from Charles Perkins to T.J. Potter, 18 August 1885, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

199 Letter from T.J. Potter to Charles Perkins, 13 May 1886, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

200 George Morison, The Rulo Bridge, page 3,

201 George Morison, The Rulo Bridge, Plate 6.

202 George Morison, The Rulo Bridge, Plate 5.

203 George Morison, The Rulo Bridge, Plate 13.

204 George Morison, The Rulo Bridge, Plate 18.

205 George Morison, The Rulo Bridge, Plate 15.

206 George Morison, The Rulo Bridge, Plate 17.

207 George Morison, The Rulo Bridge, Plate 14.

208 George Morison, The Rulo Bridge, Plate 19.

209 George Morison, The Rulo Bridge, Plate 20.

210 George Morison, The Rulo Bridge, Plate 21.

211 Letter from George Morison to J.S. Cameron, 19 January 1887, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

212 George Morison, The Rulo Bridge, Plate 23.

213 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir, pages 21-22.

214 George Morison, The Rulo Bridge, page 4.

215 George Morison, The Rulo Bridge, page 7.

216 George Morison, The Rulo Bridge, page 10.

217 George Morison, The Rulo Bridge, page 3.

218 Robert Athearn, Union Pacific Country, page 28.

219 George Morison, The Sioux City Bridge (n.p., 1891), page 4.

220 "Sioux City Bridge Scheme," Engineering News and Contracting Journal, 24 January 1885, age 62.

221 George Morison, The Sioux City Bridge, Plate 1.

222 Robert Athearn, Union Pacific Country, page 234.

223 "The Sioux City Bridge," Engineering News and Contracting Journal, 18 April 1885, page 255.

224 George Morison, The Sioux City Bridge, page 3.

225 George Morison, The Sioux City Bridge, page 3.

226 George Morison, The Sioux City Bridge, page 6.

227 George Morison, The Sioux City Bridge, page 4.

228 George Morison, The Sioux City Bridge, Plate 10.

229 George Morison, The Sioux City Bridge, Plate 12.

230 George Morison, The Sioux City Bridge, Plate 11.

231 George Morison, The Sioux City Bridge, Plate 15.

232 George Morison, The Sioux City Bridge, Plate 17.

233 George Morison, The Sioux City Bridge, Plate 6.

234 George Morison, The Sioux City Bridge, Plate 7.

235 George Morison, The Sioux City Bridge, page 4.

236 George Morison, The Sioux City Bridge, page 6.

237 George Morison, The Sioux City Bridge, page 6.

238 Act of Congress Authorizing Construction of Nebraska City Bridge, 4 June, 1872, reprinted in The Nebraska City Bridge (Chicago: Knight, Leonard & Co., 1892), page 14. (See Appendix A for text of charter).

239 George Morison, The Nebraska City Bridge, page 3.

240 Richard Overton, Burlington Route, page 197. George Morison, The Nebraska City Bridge, page 3.

241 George Morison, The Nebraska City Bridge, page 3.

242 George Morison, The Nebraska City Bridge, Plate 1.

243 George Morison, The Nebraska City Bridge, page 4.

244 George Morison, The Nebraska City Bridge, page 15. (See Appendix A for text of contract.)

245 George Morison, The Nebraska City Bridge, page 4.

246 George Morison, The Nebraska City Bridge, Plate 7.

247 George Morison, The Nebraska City Bridge, Plate 8.

248 George Morison, The Nebraska City Bridge, Plate 9.

249 George Morison, The Nebraska City Bridge, Plate 10.

250 George Morison, The Nebraska City Bridge, Plate 11.

251 George Morison, The Nebraska City Bridge, Plate 12.

252 George Morison, The Nebraska City Bridge, Plate 13.

253 George Morison, The Nebraska City Bridge, Plate 14.

254 George Morison, The Nebraska City Bridge, Plate 15.

255 George Morison, The Nebraska City Bridge, Plate 16.

256 George Morison, The Nebraska City Bridge, Plate 17.

257 George Morison, The Nebraska City Bridge, Plate 18.

258 George Morison, The Nebraska City Bridge, page 9.

259 George Morison, The Nebraska City Bridge, Plate 3.

260 George Morison, The Nebraska City Bridge, Plate 4.

261 George Morison, The Nebraska City Bridge, Plate 4.

262 George Morison, The Nebraska City Bridge, Plate 3.

263 George Morison, The Nebraska City Bridge, page 9.

264 "The Nebraska City Bridge," Engineering, 11 January 1895, page 43.

265 "Railroad Notes," Nebraska City News, 7 October 1887.

266 "The Bridge," Nebraska City News, 4 November 1887.

267 "Let Us Celebrate," Nebraska City News, 4 November 1887.

268 "Laying the Stone," Nebraska City News, 4 November 1887.

269 "The Bends'," Nebraska City News, 17 February 1888.

270 George Morison, The Nebraska City Bridge, page 6.

271 "The Mighty Muddy," Nebraska City News, 2 March 1888.

272 "The Mighty Muddy."

273 Nebraska City News, 22 June 1888.

274 George Morison, The Nebraska City Bridge, page 11.

275 "The New Era," Nebraska City News, 30 August 1888.

276 "The Sibley Bridge," Engineering News, 18 February 1888. The article compared the construction lengths of most Missouri River bridges to date as follows: (Morison's bridges are preceded by asterisks).

Location	First work done	First engine crossed	Number of days
Kansas City	27 Feb 1867	25 Jun 1869	847
St. Charles	1 Aug 1868	29 May 1871	1032
Omaha	3 Feb 1869	15 Apr 1872	1162
St. Joseph	23 Sep 1871	20 May 1873	605
Booneville	1 Oct 1872	15 Mar 1874	502
*Plattsmouth	14 Jul 1879	28 Dec 1880	532
*Bismarck	8 Jan 1881	21 Oct 1882	620
*Blair	12 Jun 1882	10 Nov 1883	516
*Omaha (new)	1 Sep 1885	1 Oct 1887	760
*Rulo	3 Dec 1885	2 Oct 1887	668
Randolph	1 Oct 1886	15 Oct 1887	379
Sibley	8 Apr 1887	25 Jan 1888	293
*Sioux City	5 Aug 1887	26 Nov 1888	253
*Nebraska City	13 Aug 1887	27 Jul 1888	348

OTHER RIVERS, OTHER BRIDGES

George Morison acquired a national reputation as a bridge engineer in the early 1880s with his series of long-span structures over the Missouri River. Although technologically conservative, these bridges quickly became hallmarks in American bridge engineering. It is not surprising, then, that other railroad companies soon approached him about permanent crossings in other parts of the country. As contractors worked to complete the Rulo, Sioux City and Nebraska City Bridges, Morison became involved with the construction of three other major railroad structures: over the Ohio River at Cairo, Illinois, over the Willamette River at Portland, Oregon, and over the Columbia River in Washington Territory. The first undertaken and by far the most important of these was the Cairo Bridge.

CAIRO BRIDGE

George Morison's railroad clients in the 1880s - the Union Pacific, the Northern Pacific and the Chicago, Burlington and Quincy - were all striving to extend their steel lines westward across America. For each of them the north-south Missouri River formed the most troublesome barrier. But not all American rail construction during this period followed an east-west orientation.

Even before the Civil War, railroads had sought to displace river and canal boats in the Ohio and Mississippi River valleys as prime freight carriers. As one of the most successful of these, the Illinois Central (IC) was a regional carrier which served a heavily populated industrial and agricultural area. Incorporated in 1851, the IC trunk line extended from Galena, near the northwest corner of Illinois, across the center of the state to Cairo at the state's southern tip. A branch line connected the trunk with Chicago. The Illinois Central was the longest single railroad operating in America at the time of its completion in 1856, with an aggregate length of 700 miles.[1] At its southern terminus at Cairo, the railroad sought to join with another line form an important link from the Great Lakes to the Gulf of Mexico. For this

primarily north-south line, another river - the westward flowing Ohio - proved to be a daunting obstacle.

Named Ohio - "great river" - by the Seneca Indians, this broad watercourse served as the throughway to the West in the years between the Revolutionary and the Civil Wars.[2] Located farther east than either the Mississippi or the Missouri, the Ohio was the first of the great midwestern rivers to impede the railroads' post-war western expansion. The river's extreme width - greater than American engineers had faced with any of the eastern rivers - necessitated the construction of longer spans than had been previously attempted in this country. Immediately after the end of the Civil War, railroads began extending their tracks across bridges over the river. The first of these was the bridge at Steubenville, Ohio, built by the Pennsylvania Railroad. Chartered by Congress in 1862 and completed in 1865, the 320-foot-span Steubenville Bridge was designed by Jacob H. Linville, one of the most influential bridge engineers of the time, and is generally considered as the country's first long-span truss.[3]

The Illinois Central was thinking not so much about bridge construction as interstate commerce when it chose a site to cross the Ohio during its formative development in the early 1850s. At that time, no connecting links existed to carry rail service further south beyond the end of the IC tracks in Illinois. The railroad directors strategically positioned the southern terminus of their road as close as possible to the confluence of the Mississippi and Ohio Rivers at the riverport town of Cairo, 180 miles below St. Louis. Here the railroad could take advantage of the existing steamship traffic to the southern cities along the Mississippi.

On January 1, 1859, IC Master of Transportation James C. Clarke, who later as president of the railroad would authorize construction of the bridge, outlined the goal of the railroad, stating: "The Company's natural connections are with those roads leading to Mobile and New Orleans, and the early completion. probably not later than August next, of a through connection with those cities cannot fail to confer upon us substantial benefits. The value of a great through traffic north and south by rail is yet unknown but it is reasonable to suppose that passengers, and the more costly freights, will seek the most direct and least expensive route, to the exclusion of that by the river, which is circuitous and uncertain. As this is the last time I shall submit a report upon the Operating Department of this road, I desire to record my opinion that the north and south traffic of the Mississippi Valley by rail will, ere long, give such results as will surprise the shareholders, and cause them to regret the sacrifice they have submitted to in disposing of their stock at a time of temporary distrust and depression."[4] Clarke's views were widely held. Senator Stephen A. Douglas supported the so-called Lakes-to-Gulf rail route. Illinois Central President William H. Osborne predicted that his line, linked

with the Mobile and Ohio Railroad, would provide "a great avenue of commerce to all the major cities of the Gulf of Mexico."[5]

Two years later, the railroad attained this goal, as the Mobile and Ohio extended rails to its northern terminus at Columbus, Kentucky - twenty miles downriver from Cairo. Connection between the two lines was to be made by transfer steamer on the river. Unfortunately for the IC, this long-awaited linkage occurred in April 1861, just days after the firing on Fort Sumter. The onset of the Civil War thus postponed any further activity between the lines.

The war left the southern railroads in shambles but clearly demonstrated the need for an adequate overland transportation link between the Great Lakes and the Gulf of Mexico. In the Reconstruction years immediately after the war, a trickle of traffic reached the IC line from the south. This small amount was attributable in large part to the lack of production - and therefore commerce - by the south's crippled industrial complex. But the Illinois Central management also blamed the poor linkage between their line and the Mobile and Ohio and reasoned that an improvement here would reflect in their business volume. IC President John Douglas tried to persuade the M&O in 1870 to extend its line to a point immediately across from Cairo, thus eliminating the long steamer transfer. Douglas even offered to advance much of the money for the extension, but the M&O was still too weakened to undertake any sort of capital improvement. When their negotiations broke off, the Illinois Central began looking for an alternative route through the south.[6]

In 1872, the Illinois Central negotiated with the Southern Railroad Association to extend the Mississippi Central (later reorganized as the Chicago, St. Louis and New Orleans (CSL&NO)) to a point in Ballard County, Kentucky, opposite the river at Cairo. The two railroads felt no pressing need to connect their lines directly with a bridge over the Ohio, because they used incompatible rail widths, the IC using the English standard gauge and the CSL&NO a five-foot gauge. This would necessitate transfer of freight cars anyway. To ship the trains across the river, the Illinois Central commissioned a steam transfer ferry, the H.S. McComb, in 1873. Capable of carrying six passenger cars or twelve freight cars, the H.S. McComb carried its first train across the Ohio on Christmas Eve that year. The railroad exchanged the trucks of all the cars to compensate for the gauge differential. Two years later, a slightly smaller second steamer, the 10-car W.H. Osborne was added. Together the two formed the weak link in the north-south chain.[7] Meanwhile, during the 1870s other railroads bridged the Ohio at Steubenville, Cincinnati and Bellaire, Ohio; Parkersburg, West Virginia; and Louisville, Kentucky, creating more efficient competition for the IC. In a bold stroke by the City of Cincinnati, the Cincinnati Southern Railroad forged a direct connection over its bridge with the southern railroad network. By the end of the decade, the IC could see its traffic beginning to shift to these rival rail lines. Clearly, the Illinois

Central would have to bridge the river itself in order to remain competitive.

The extensive construction activity over the Ohio in the 1870s and 1880s not only reflected railroad expansion across the country but also fueled the growing conflict between the railroads and steamboat interests. Through trunk lines which crossed the river and numerous secondary and branch lines which paralleled it and entered the port towns, the railroads had gradually encroached on the steamboats' field. An 1887 survey of major towns along the Ohio River between Pittsburgh and Cairo revealed that, of the thirty towns listed, only three did not have rail service. And one of these three - Canneltown - was scheduled to receive a branch line within the year.[8] One by one, as the small river towns each acquired rail connections, the once-great steamboat lines watched their commerce dwindle. In the four years between 1882 and 1886, the tonnage of the Ohio and Mississippi River steamboats which docked at Cairo decreased by almost 500,000 tons, while rail traffic at this point increased over 200,000 tons.[9]

The steamboatmen attacked the railroads in one of the only arenas available to them: the regulation of bridge construction over the river. Although they did present hazards to river navigation, the piers of railroad bridges did not present the deadly menace that the river interests maintained in their frequent and bitter complaints. The battle was first joined in 1849, with the construction of Charles Ellet's suspension bridge over the Ohio at Wheeling. The Wheeling Bridge carried vehicular and not rail traffic and as such did not represent a direct conflict between the rail and river interests, but the litigation and controversy which surrounded this pioneer structure formed a pivotal precedent for Congressional regulation of later interstate railroad bridges.

The Wheeling Bridge had been built under enabling legislation from Virginia. Its deck was so low, however, that the stacks of some of the taller steamers could not clear beneath the bridge at high water. The State of Pennsylvania, which stood to lose a substantial amount of commerce if the bridge were converted to railroad use as proposed, filed a thinly veiled suit against the bridge company, contending that the structure blocked interstate commerce. In December 1851, the Supreme Court ruled that the Wheeling Bridge was an unlawful obstruction to river traffic and must be elevated to a minimum height of 111 feet over the river or "abated." But Congress immediately passed an act, which President Fillmore signed on August 31, 1852, authorizing the bridge and setting aside the high court's decision. Congress stated that the bridge was indeed lawful, established it as a post road beyond the jurisdiction of the court and ordered the steamboat companies to make adjustments to their boats to allow them to pass. When the river interests pushed to have this Congressional action declared unconstitutional, the Supreme Court ruled that Congress had full power under its right to regulate interstate commerce to determine what

constituted an obstruction. From this was born Congress' authority to review designs and grant charters for the bridges over the great Midwestern rivers.[10]

On the Ohio River, the issue was moot until after the Civil War, because there were no other bridges built. This all changed after the war, however. As each new bridge was proposed, the steamboatmen howled in protest. The Steubenville Bridge drew numerous protests from the river pilots. As it turned out, these objections really did have merit. The bridge's pier placement was both difficult and dangerous for steamboats with tows to pass, subjecting them to delays and additional expenses. In response to the increased activity and attendant protests, Congress in 1872 passed the Ohio River Bridges Act (included as Appendix N), the only such river-wide bridge provision enacted for a Midwestern river. The bill required railroads and bridge companies to submit extensive plans, maps and topographical profiles to the Secretary of War for review and approval before construction, but eliminated the need to apply individually to Congress for bridge charters. The law specified 40-45-foot minimum high-water clearance heights and 350-foot channel span lengths to avoid impeding navigation along the river. Unlike the War Department policy for the Mississippi and Missouri rivers, however, the Ohio River bill not only stipulated high-clearance bridges, but required pivot spans as well to permit the passage of tall-stacked steamboats.[11]

This, of course, placed a tremendous financial burden upon the bridge companies, and they soon began to lobby Congress to allow low, swing-span structures like those permitted over the Mississippi. The steamboat companies - and the port towns which depended heavily upon their commerce - objected vociferously. One of the more vocal opponents to low bridges was the Cincinnati Chamber of Commerce. Although essentially agreeing with George Morison in its stated preference for high bridges, the Chamber in an 1876 pamphlet couched its argument in exactly opposite terms:

> Travel and trade on the river as well as across the river must be taken into consideration. No friend of commerce of the great Mississippi Valley will contend that its streams should not in any instance be bridges, but every friend of that commerce will contend that the bridges shall be built so as not to injure the navigation of the streams they span. In this advanced day of engineering science and skill, the problem of bridging rivers without injury to their navigation is easily solved. The only question in the problem is one of cost, and the point to be determined is whether or not the navigation shall be interrupted and the public welfare injured to save a few dollars to a bridge company.[12]

The steamboat interests prevailed; Congress retained the requirement of a high pivot until 1883.

It was in the midst of this controversy that the Illinois Central considered erecting its bridge over the Ohio River. The first impetus for the bridge came, not from within the company, but from an outside interest. Judge Lawrence S. Trimble, of Paducah, Kentucky, president of the New Orleans & Ohio Railroad, proposed a river link for the IC in the mid-1870s. Trimble hoped that by spanning the Ohio at Paducah and extending his railroad northward to meet with the Illinois Central, he could gain an advantage for his town over Cairo and thus force rail traffic over his road. Trimble's plan quickly dissolved, however, under a lukewarm reception from IC management.[13] The railroad itself first seriously considered erecting a permanent bridge over the Ohio River at Cairo several years later in 1879, when IC President W.K. Ackerman ordered preliminary soundings, surveys and estimates made. Officials of the IC and the CSL&NO spent the next few years observing the river and negotiating intermittently about the bridge and rail gauges.[14] Meanwhile, as the railroads assumed an expanding role in interstate traffic - at the expense of the steamboat lines - rail traffic at Cairo increased. In 1884 alone, the Illinois Central transferred almost 62,000 freight cars and some 8,000 passenger cars across the river at Cairo.

In a jurisdictional quirk, the border between Kentucky and Illinois was not the middle of the Ohio River, but the low water line on the Illinois shore. Thus at low water, a bridge at Cairo would lie entirely within the boundaries of the Commonwealth of Kentucky and under that state's authority. For this reason, Judge James Fentress, general solicitor for the CSL&NO, persuaded IC president James Clarke that it would be advisable to have his subordinate but southern-based railroad build the bridge and secure the charter from the Kentucky legislature. On March 17, 1886, the Commonwealth of Kentucky authorized either or both railroads to bridge the Ohio River at Cairo. The Trimble faction was still agitating to force the Illinois Central to build the bridge in Paducah, however, and to appease this group the Kentucky legislature provided for a bridge "at Cairo or any point within five miles above the upper corporate limits of Cairo or Paducah."[15] For a brief period, the railroad even considered tunneling beneath the river to avoid the inevitable opposition to a bridge from the steamboat interests. This was quickly rejected as economically impractical.[16]

E.T. Jeffrey, general manager of the Illinois Central, was named general manager of the CSL&NO to supervise the bridge construction. On Christmas Eve, he addressed a letter to George Morison regarding its engineering.[17]

Like Charles Perkins of the Chicago, Burlington and Quincy Railroad, Edward Jeffery was a dynamic and ambitious manager who had risen through the ranks of his railroad. Born in England in 1843, he came to America with his widowed mother and hired on with the Illinois Central as an office boy in 1856 at the age of thirteen. He later became a draftsman, mechanical engineer, general

superintendent and finally general manager by the time he was forty-two. Jeffery cemented his relationship with IC president Clarke in 1877 by eloping with the man's daughter, Virginia, in 1877. Jeffery had managed the Illinois Central for less than a year before contacting Morison about the Cairo Bridge.[18]

Jeffery asked Morison and E.L. Corthell to review a design for the bridge prepared by another engineer. Morison agreed, saying "the work was one which I should be glad to take part in, Mr. Corthell a gentleman I should be happy to be associated with, and I would be happy to do the work."[19] Morison and Corthell reviewed the design and issued a joint report in February 1887. In this, they made some general comments about substructural and superstructural engineering but requested a site inspection with Jeffery before making any final recommendations for the design of the bridge. On March 11, Morison, Corthell, Jeffery and George Field of the Union Bridge Company met at Cairo and began a three-day inspection of the proposed site. The Ohio was then in its spring flood, which allowed the engineers to observe the river at extreme high water. Morison and Corthell, with Field's help for the cost estimates, issued a second report on March 23, in which they delineated in detail their design for the bridge. In this, Morison described the principal differences between the Ohio and the Mississippi:

> Although the two rivers are in the same alluvial delta, their physical characteristics differ very materially. The bed of the Ohio River is strengthened by the heavy sands which are characteristic of that river, and which overlie the lower deposits, leaving the regimen of the river about as stable here as it is within the limits of its own proper valley. On the other hand, the upper deposits of the Mississippi are the light alluvial silts and sands which are characteristic of that river and the Missouri, and the same instability which characterizes the Mississippi everywhere below the mouth of the Missouri is to be found here. The two rivers are of about equal size, but the problem of bridging the Ohio River was a much more simple one than the bridging of the Mississippi would have been. Foundations which are perfectly safe in the Ohio would have been of doubtful character in the Mississippi. On the other hand, the Ohio River is liable to more violent floods than the Mississippi, and the floods which generally cause the most trouble in the Lower Mississippi come from the Ohio and its tributaries.[20]

No other watercourse of comparable length in the country flowed with such a smooth, uniform and placid course as the Ohio. Beginning at its headwaters at the confluence of the Allegheny and Monongahela in Pittsburgh, the banks along most of the river's length were generally steep and high - as much as 300 feet in some locations - and covered with endless dense forests. The Ohio River at its mouth, on the other hand, was wide, deep and prone to flooding and commanded a broad, low floodplain. Completely surrounded by a series of

earthen dikes, the city of Cairo resembled the towns along the lower Mississippi - particularly New Orleans - more than the other towns which lined the Ohio upriver. The Ohio Levee protected the city for some two miles on the east; the three-mile-long Mississippi Levee flanked the city on the west and southwest; on the northwest was the Cross Levee; and on the north the embankment of the Illinois Central formed another dike.[21]

The bridge was to be built over the Ohio River, but its location close to the confluence with the Mississippi significantly affected the substructural conditions. "In point of fact," Morison stated, "both banks of the river are entirely alluvial for about ten miles above Cairo. During the lower half of this distance, the river has a curve to the east, the general course being one favorable to stability; but the want of any fixed material in either bank or bottom makes this a relative, rather than an absolute, stability."[22]

Borings made almost 200 feet beneath the river at the bridge site revealed nothing but sand and gravel. In their report to Jeffrey, Morison and Corthell recommended that hybrid piers be designed, constructed with pneumatic caissons but providing the stability of piles in the absence of bedrock. "Below the masonry [pier]," they stated to Jeffery, "we should propose to make the foundation of timber crib-work filled with concrete, the amount of timber-work and concrete to be in such proportions that the specific gravity of the whole should average the same as that of the sand which it displaces; so that the additional weight put on the foundation, this additional weight really measuring the fatigue of the foundation, should be simply the weight of the masonry and the superstructure above the bed of the river. The pier would then be sustained, first by the friction of the sand against the sides of the timber-work, and second, by the bearing on the sand at the base of this timber-work, and the design should be so made as to make this friction and bearing as great as possible."[23]

The foundations would prove difficult and costly to build, but Morison and Corthell were more concerned about the extreme width of the Ohio River at its mouth. Here the river's width extended nearly 4,000 feet. Two miles upriver, the channel narrowed to three thousand feet, raising the issue of whether the channel under the bridge could be constricted by means of shore rectification works as had been done at the Blair Crossing site. Morison and Corthell considered this possibility at length, but eventually dismissed it. In their report to Jeffrey, they stated, "This could undoubtedly be done, and we believe it could be done successfully, but any such action would throw upon your Company the burden of proving that any injuries to local interests caused subsequently by the river were not due to the reduction in its width at this point; and while this might be proved to the complete satisfaction of a board of river engineers, it could not be proved to the satisfaction of a jury. We think that any such scheme, though good engineering, would be, commercially

speaking, very imprudent."[24] Their concern was real. The riverport town of Cairo straddled the confluence of the Ohio and Mississippi, and like the surrounding countryside, it sat some ten to twenty feet below the high water level of the two watercourses. Only the levees which completely surrounded Cairo protected the town from inundation.

Their reluctance to reduce the extreme width of the channel and flood plain forced Morison and Corthell to engineer an extraordinarily long structure, larger than any other bridge then standing in America. In fact, with fifty-two trussed steel spans and a length of 10,560 feet, the Cairo Bridge was to be the longest metal bridge in the world.[25] The total length of the bridge, including timber trestles, would extend 20,461 feet, or 3.875 miles. The channel portion of the bridge consisted of nine pin-connected, Whipple through spans, two of which were 518.5 feet long and the other seven 400 feet long, and three Pratt 249-foot deck spans. Morison had proposed extremely long-span trusses for previous bridges but had been overruled by his traditionally conservative railroad clients. At Cairo, he was finally able to use trusses that exceeded 500 feet in span. In so doing, Morison had stretched the Whipple truss configuration to its structural limit. With spans in excess of 500 feet, the extreme length of the Whipple's double-panel diagonals seriously decreased its rigidity under load. With a span length some 18 inches longer than Linville's 1877 Cincinnati Bridge over the Ohio, the two long channel spans of the Cairo bridge were the longest pin-connected Whipple trusses ever built.

In designing the bridge at Cairo, George Morison once again encountered the thorny issue of fixed versus moveable spans, with a variation. The 1872 Ohio River Bridges Bill had specified a minimum high-water clearance height of 45 feet for bridges below the mouth of the Big Sandy. Additionally, under this bill every bridge over the Ohio was required to have a pivot span to allow passage of the taller steamboats. In 1883, Congress amended its original legislation to allow the omission of the pivot span for bridges which provided a 53-foot high-water clearance.[26] (This amendment is given in Appendix N.) In reviewing Morison and Corthell's plans for the fixed-span Cairo Bridge, the U.S. Board of Engineers invoked this provision, making it a part of the contract with the railroad (given in Appendix O). The irony was poignant. Not only was the Cairo Bridge intended to allow the railroads to compete efficiently with the steamboat companies, but it was competing for air space over the river as well.

For Morison, an outspoken advocate for the railroads, the issue of transportation rights was clear-cut. As the more efficient carriers, the relatively new railroads, not the long-established steamboat lines, deserved favorable treatment in such disputes. "The true problem," he maintained, "is to secure for all classes of business the greatest advantages in the way of transportation, and to accomplish this the modifications of transportation methods must always

be studied." He continued, prophetically:

> The development of railroads has given land transportation an importance which was formerly unknown. Any such increase of the importance of land transportation must necessarily, from mathematical rules alone, have been accompanied by a relative decrease in the importance of river transportation. This decrease, however, though relative, is not absolute, though on many of the shallower streams navigation has virtually disappeared. There is a natural feeling that the disappearance of this water transportation is an injury to the community and that railroads have burdened the country by superceding the river lines. This, however, is very far from the fact; railroads have broken up river lines only because railroads could furnish better and cheaper transportation than river boats could furnish. The boats have ceased to run because they cannot do the work at the rates which are profitable to the railroads. To restore the old system of transportation on the deserted routes at the prices under which it was once and would again be possible, would be commercial ruin to the communities served.[27]

Morison was incensed by the War Department's decision. Most of the steamboat companies had already stated a willingness to accept a 45-foot-high fixed bridge. In 1886, only ten boats then plying the river could not pass beneath such a structure, and unless they left the Ohio to run on the Mississippi, the bridge at Cairo did not present an obstacle. Although many of the other boats actually exceeded this height, they featured hinged, "Telegraph plan", smokestacks, which could be jackknifed to pass under bridges. These were named for the 80-foot tall steamer, Telegraph, which in 1849 was the first to employ such hinged stacks to pass beneath the Wheeling Bridge.[28] Further, the river remained at extreme high water less than two weeks per year.[29] Complaining bitterly, Morison estimated that the additional eight feet would add $500,000 to the cost of the bridge, amounting to $50,000 for each of the ten tall boats.[30] This exceeded their actual worth. But his distaste for pivot spans, which would periodically impede rail traffic, overruled his objection to the increased construction cost. To comply with the charter, he and Corthell grudgingly designed the fixed trusses over the navigable lanes with their lower chords 53 feet above high water. (The contract with the War Department is given in Appendix O.)

With its series of long Whipple through trusses and deck truss approach spans held high above the river by massive masonry piers, the Cairo Bridge resembled a larger version of Morison's previous major trusses. Each of the 518-foot-long channel trusses was subdivided into seventeen 30-foot panels, with a width of 28 feet and a web height of over 63 feet.[31] Morison and Corthell used essentially the same detailing for the trusses of the Cairo Bridge as Morison had for his Missouri River structures. The only appreciable differences lay in

the greater lengths of the two channel spans and the increased number of trusses to be used at Cairo. The engineers proportioned the single-track structure to carry an industry-standard live load of 3,000 pounds per lineal foot, but in calculating the effects of a moving load they increased this to 5,000 pounds per foot. The two engineers designed the top lateral system of the through trusses to withstand a wind pressure of 300 pounds per lineal foot, and the bottom lateral system 500 pounds per foot. Morison and Corthell limited the compressive strain on the top chords to 14,000 pounds per square inch, the tensile strain on the bottom chord to 13,000 pounds per square inch.[32]

The approach viaduct on the Kentucky side consisted of twenty-one deck spans of 150 feet each and one span of 106 feet. The Illinois approach consisted of seventeen 150-foot spans and one 106-foot span.[33] The approach trusses on both sides rested on cylinder piers filled with concrete and supported by piles driven within the limits of the cylinders. Virtually the entire superstructure, except for the cast iron pedestals and other minor details, was made of steel, as indicated by the following table:

	steel	wrought iron	cast iron
(2) 518' through spans	4.048,674 pounds	6,255 pounds	74,540 pounds
(average)	2,024,337 pounds	3,127 pounds	37,270 pounds
(7) 400' through spans	7,720,275 pounds	28,278 pounds	192,994 pounds
(average)	1,102,896 pounds	4,040 pounds	27,571 pounds
(3) 249' deck spans	1,377,316 pounds	7,834 pounds	22,615 pounds
(average)	459,105 pounds	2,611 pounds	7,538 pounds [34]

The Cairo Bridge was far more massive than any previous structure that Morison had engineered. By comparison, the steel-and-iron superstructure for the Plattsmouth Bridge weighed 3.3 million pounds, and the all-steel Nebraska City Bridge weighed almost 3 million.[35] The steel for the twelve river spans of the Cairo Bridge totaled almost 13.5 million pounds. The steel for the approach spans weighed an additional 7.8 million pounds. The entire bridge proper, including superstructure and substructure but not the approaches, would weigh a colossal 194.6 million pounds.[36] Morison and Corthell estimated that the Cairo Bridge would cost $2.4 million to build, making it one of the most expensive bridges in America. "While this seems a very large sum for a single-track bridge," they justified to Jeffery, "it must be remembered that the bridge is one of very unusual dimensions. It is twice as long as the bridges on the Upper Mississippi. The foundations are of an unusual depth, and the distance from the bottom chord of the bridge to the bottom of the foundation is more than 180 feet. If the size of the structure be compared with other Western bridges, it will be found to be a very economical bridge."[37]

The substructure for the channel spans consisted of ten massive masonry piers

founded on pneumatic caissons. The deepest of these were to be extended 75 feet below the low water level, making the total height of the structure, from the bottom of the deepest foundation to the top of the highest piece of iron, almost 250 feet. With one of Morison's assistants, F.H. Joyner, overseeing the work, quarries at Bedford, Indiana, cut, fitted and numbered the stones before shipping them by train to the bridge site. Morison specified granite only for the upstream nosing stones from the starling copings to the low water marks of the piers, with coursed limestone blocks for the remainder. The smaller piers for the spans away from the main channel of the river, where lateral pressure from the water would not be a problem, rested on driven timber piles. Morison designed the caissons to be similar with those he had used earlier on the Missouri River. Up to 70 feet long, 30 feet wide and 16 feet high, these heavy timber boxes were constructed of pine timbers with oak sills and iron cutting edges. They were planked with one layer of pine boards laid diagonally and a layer of oak laid vertically, and their corners were rounded and sheathed with three-eights-inch iron sheets. Thirty-seven foot tall timber cribs surmounted the caissons themselves, into which workers poured cement as ballast to sink the caisson.[38]

The contract with the War Department stipulated that work on the bridge be undertaken before March 29, 1887, and pile driving had already begun on the Kentucky approach to the bridge when Morison's draftsmen began preparing the construction drawings. Time was therefore short when Morison and Corthell agreed to act as chief engineer and associate chief engineer, respectively, for the project. In giving his estimate for the construction costs, Morison recommended that the railroad hire the Union Bridge Company to fabricate and build the bridge, saying, "We believe that the Union Bridge Company is better able to carry out the entire work of the bridge proper, both sub-structure and superstructure, than any other concern in America, and that the interests of your company will be furthered by closing a contract with them on the basis of this estimate."[39] The railroad company followed his recommendation and in May negotiated a contract with the Union Bridge Company to fabricate the superstructure.[40] (This contract is given in Appendix P.)

As his draftsmen penned the drawings for the bridge in 1887, Morison made two major changes in his practice: he moved his office and took on a partner. Throughout the 1870s and 1880s, Morison had operated his consulting business from New York, maintaining an office at 35 Wall Street and a residence at 133 East 21st Street in Gramercy Park. With virtually all of his major bridge commissions in the Midwest, however, this Eastern base became increasingly impractical. That spring, Morison moved from New York to Chicago. He rented his house at Gramercy Park and in Chicago constructed an apartment house at 49 Delaware Place. He occupied one apartment of this himself, and another he used for drafting rooms, maintaining a primary business office downtown. Morison retained his Wall Street suite in New York as a branch office, while in

Chicago, he maintained a suite in the Temple, and later the Rookery and the Monadnock Building. Where Morison resided mattered little in practical terms, though, because he was rarely home. Until he was fifty-five years old, he could hardly be said to have had a permanent home. Seemingly always on the road, Morison spent his solitary life in hotels, clubs and sleeping cars, treating waiters and servants rudely. Even in New York, his Gramercy Park house was little more than a place to sleep, and he ate most of his meals at the Union, University or Engineers' Clubs. He occupied his Chicago apartment similarly.[41]

George Morison could probably have not chosen a more suitable partner than Elmer Lawrence Corthell (1840-1916). Born in South Abington, Massachusetts, Corthell attended Exeter as Morison's classmate and later entered Brown University in 1859. He volunteered for the First Rhode Island Artillery in the Civil War, rising to the rank of Captain by the war's end. He then returned to Brown and graduated in 1867. Like Morison, Corthell had spent an educational career studying a field unrelated to engineering. From boyhood, Corthell had intended to become a Baptist minister, and he directed his studies toward this goal. But after leaving Brown, he was advised by his doctor to pursue a more active career to remedy his poor health. Corthell chose civil engineering and, like Morison, apprenticed with a prominent engineer to gain a practical education.

During the 1870s, Corthell worked in a variety of positions around the South, East and Midwest, acting as chief engineer for the bridge over the Mississippi river at Louisiana, Missouri - at that time the longest pivot span in the world. From 1884 to 1887, he worked with James Eads on a proposed ship railway across the Isthmus of Tehuantepec in Mexico.[42] Corthell was traveling across the United States on a promotional tour for the railroad when IC President Jeffery contacted him to evaluate the prospects for the Cairo Bridge with Morison. After working together on the preliminary proposal for the Cairo Bridge, the two engineers formed a formal partnership in April 1887. Despite the two men's mutual friendship and respect, their partnership was intended only as a temporary measure: by prior agreement, the partnership would end May 1, 1889.

Clearly, Morison teamed with Corthell for assistance with the several bridge and civil engineering projects then underway. One reason that Morison sought help from a partner, however, was strictly personal: he wanted to take an extended leave of absence from his booming consulting practice. Leaving several bridges on the drawing board or under construction, Morison sailed from New York harbor with his sister in November 1887 for a six-month, worldwide voyage. The two visited, among other places, Europe, India, Egypt, China and Japan. In his travels, one country left its greatest mark upon him. "The few weeks we spent in India were full of disappointment at the time," he wrote,

"for the sad, unnamed people, who never smile, were not what we had hoped to find. But since our return, there is no part of the journey to which my thoughts return as they do to India, nor is there any Eastern country which I wish to visit again."[43] This long journey represented the only true vacation that George Morison would ever allow himself during his adult life. Even on vacation, Morison observed bridges and their applications, including one in Cairo, Egypt, namesake for the Ohio town:

> At the city of Cairo a bridge spans a river which has been navigated as many centuries as the Mississippi has years; it is a modern structure, guarded at each end by clumsy cast-iron lions; it is a low bridge with a draw; it is the outlet from the great Mohammeden city to the grandest monuments of ancient Egypt; it is open at all hours, except the two hours after noon, for the passage of men, camels and carriages; for the two hours after noon, and these two hours only, the draw is opened to allow the fleet of Nile boats to go through. The bridge is a free bridge for every class of traffic, but every boat that passes through the draw and every skiff that rows under the fixed spans is charged a toll; the entire revenue is collected from the only class of traffic which was injured by its construction. This seems the extreme of Oriental despotism.[44]

Upon his return into San Francisco from Japan, Morison and his sister were detained aboard ship with the rest of the passengers and crew for two weeks by the city's quarantine board. Predictably, Morison was outraged. Calling the City of San Francisco "a spoiled child who grows up to be a bad boy," he was galled by his powerlessness to escape from the control of petty officials like those he had dismissed or bullied all of his professional life. "Few facts are better established," he fumed, "than that men, as a rule, are not fit to be intrusted with irresponsible power. The number who will steal when certain that they will not be detected, is enormous; but the number who will use power to injure others when such injury involves no punishment, is far greater." To vent his vindictiveness once released from the ship, Morison devoted himself to researching the legislation and history behind the quarantine, even tracing the lives of the individual board members. He published his findings a year later, paying for the printing out-of-pocket, in an indignant broadside titled The So-Called Quarantine at San Francisco.[45]

Before Morison left for Europe, he assembled a typical entourage of contractors and assistant engineers. Union Bridge, already under contract with the IC, in turn subcontracted with Anderson and Barr for the foundations, Louis M. Loss for the masonry and the Baird Brothers for the truss erection.[46] On June 12, Morison sent Addison Connor to the site as an assistant engineer to establish a base line for the structure and begin surveys. On July 9, Morison's long-time associate Alfred Noble arrived at Cairo to begin serving as resident engineer in charge of the construction. George Lederle, Edwin Duryea, E.H.

Connor and Elijah Butts, other Morison assistants who had served with the chief engineer on previous bridges, also signed on as assistant engineers. Ralph Modjeski and R.W. Hildreth, veterans of the Omaha and Sioux City projects, were hired as inspectors of the superstructure. (See Appendix Q for a list of engineers and contractors on the project.)[47]

On July 1, 1887, the carpenters began framing for the first caisson, Pier XI, thus beginning full-scale construction of the bridge proper. The iron workers set the 67-ton cutting edge for the pier on the launching ways on the Illinois shore ten days later, and on July 21 the men began building the heavy timber structure. In mid-August, they launched the completed caisson into the river, manuevered it into position over the pier location, pressurized it and sank it to the river bottom. As the pumping crew operated the pneumatic equipment from a barge over the caisson, sand hogs in the pressurized chamber began excavating through the alluvial bed of the river. On October 6, the men completed the timber crib on the caisson roof and the masons began laying the massive granite and limestone blocks five days later.[48]

The men beneath the caisson labored steadily throughout the fall of 1887, digging through the sand and blowing it out of the chamber using a Monson pump. Slowly, they lowered the ponderous structure through the layers of riverbed at an average of four inches per day. The men were forced to interrupt their digging often to cut up the huge sunken logs which paved the river bottom. On November 10, as the caisson floor reached nearly 75 feet below the surface of the river and the air pressure inside the chamber approached an excrutiating 35 pounds per square inch, the workers stopped at Morison's predetermined terminal depth. They depressurized and sealed the work chamber with concrete, as the masons continued laying the stone for the pier above. The men followed this standard procedure for the construction of the subsequent channel piers on the Cairo Bridge, with variations only in the amount of time necessary to perform the sequential steps.

With the extreme caisson depths, caisson fever posed a constant threat to the men working deep below the river. Morison's assistant Edward Connor described the process used to ward off the affliction: "In sealing the first caisson, at a depth of 77', several of the men were temporarily paralyzed, and two lost their lives. Afterward a different method of working was employed with better success. One room on the pressure boat was fitted up for the men, with a stove and coffee pot, so that every one could have a cup of hot coffee on coming out of the caisson. A hot bath was also provided. While sealing one caisson a man carried in hot coffee a few minutes before the gang came out. No serious illness occurred while this was continued."[49] To help alleviate the problem, the engineers devised a way to cool the air pumped into the work chamber. They did this by passing the compressed air through a number of 1-inch pipes coiled in a box into which water was pumped from the river and overflowed constantly

through a pipe near the top of the cooler. By employing this early form of air conditioning, the temperature of the pressurized air pumped into the work chamber was lowered from 125° to 95°.[50] Despite these precautions, five men died of the bends beneath the caissons at Cairo.

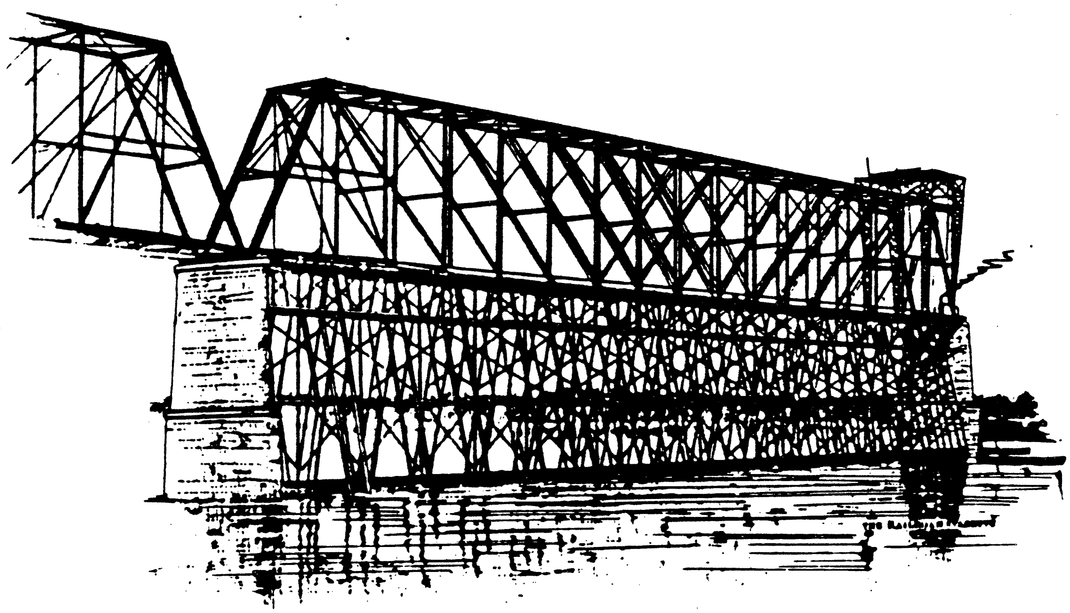
The crews above and below the river labored without stop throughout 1887 and 1888, framing, launching, sinking, digging, sealing and laying the massive bridge supports one by one in syncopated drudgery. With several caissons underway simultaneously, the railroad later added a second pneumatic outfit, loaded aboard the old steamer Kate Elliott. Finally, on February 19, 1889, the masons set the last stone on the coping of Pier VIII, completing the piers for the Cairo Bridge.[51]

Typical of all of Morison's large scale trusses, the piers for Cairo were huge. Pier VII contained over 7600 tons of timber, iron, concrete and stone; Pier IV, 9400 tons. Pier IX was the most massive of all, weighing almost 22 million pounds. Measures of the materials used in the piers and caissons are given in the following table:

Pier	Piles (lin.ft.)	Timber (m.bd.ft.)	Iron/Steel (pounds)	Concrete (cu.yds.)	Masonry (cu.yds.)
I	2,422	-	-	91.6	327.7
II		264.640	120,721	2,052.7	2,579.7
III		264,640	120,022	2,056.2	2,682.2
IV		264,640	124,644	2,059.8	2,871.7
V		264,640	129,822	2,029.2	2,875.2
VI		264,640	121,518	2,055.6	2,884.6
VII		264,640	126,570	2,052.1	2,884.3
VIII		264,640	127,884	2,070.8	2,891.6
IX		330,990	140,611	2,864.6	3,796.6
X		330,990	136,031	2,875.9	3,819.9
XI		330,990	134,260	2,845.3	3,801.5
XII	2,065	-	-	91.6	447.1
XIII	2,208	-	-	91.6	403.5
Total	6,695	2,845,450	1,282,083	23,237.0	32,265.6[52]

As the stonemasons worked on the piers in 1888, the steelworkers for the Baird Brothers began erecting the superstructure. The men began laying the first steel span for Cairo in July 1888, taking six days to complete it. The men then disassembled the pile falseworks and redrove them for erection of the second span.[53] The Union Bridge Company fabricating plant shipped trainload after trainload of prefabricated truss components from Pennsylvania, and the

men at Cairo erected the successive spans using a traditional timber traveler and pile falsework (shown in Figure 99).



November 3, 2:50 p. m.
ERECTING A LONG SPAN OF THE CAIRO BRIDGE.

Figure 99

Typically, one twelve-man crew sorted and handled the material in the yard at one end of the bridge, bringing it to the derrick which swung the steel members to a 10-ton push-cart. A second twelve-man crew rolled the material to the large timber traveler for erection. A twenty-five-man erection gang assembled each channel span, with eight men on the top scaffold of the traveler, four men on the middle scaffold, eight men at the foot of the traveler, two at the ropes, two at the engine and one engineer supervising the work. With about 90 men carrying out their carefully delineated tasks, the erection proceeded swiftly and without serious incident.[54] Unlike the laborious construction of the foundations, which had taken years to complete, progress on the superstructure was measured by the hour. The Baird crew - well practiced at fast-paced truss erection on Morison's Missouri River structures - assembled each of the two-million-pound channel spans in four days, the fastest erection

pace ever undertaken on a bridge of this magnitude.[55] At the end of August 1889, the steelworkers coupled the last through span.

Shortly after 9:00 on the morning of October 29, 1889, the first train crossed the bridge from Illinois to Kentucky. Indicative of the structure's importance to the city and the region, spectators flocked to Cairo aboard chartered trains from all over the region, crowding the hotels and restaurants and jostling on the riverbank for a good view of the crossing. The test train consisted of nine 2-6-0 Mogul locomotives, which, at 75 tons each, were the heaviest IC engines in service. Engineer Gordon Weldon throttled the forward locomotive, accompanied by IC President Stuyvesant Fish and Vice President E.H. Harriman. In the engine behind, with M. Eagan at the throttle, stood IC General Manager C.A. Beck and General Superintendent A.W. Sullivan. Other railroad dignitaries and engineers, including George Morison, crowded aboard the cabs and foot boards of the remaining locomotives. Conspicuously absent from the celebration, however, was Edward Jeffery, the railroad official most responsible for the construction of the bridge. Jeffery's father-in-law James Clarke had by then given away to Fish and the young general manager had quit the railroad in a rage only weeks earlier, following a violent argument with Harriman.[56]

A vast throng of onlookers watched breathlessly from both riverbanks and aboard steamboats as the 675-ton train inched forward across the long steel spans. When the last engine passed the easternmost truss, pandemonium broke out among the crowd in a cacophany of cheers, engine blasts and whistles from the steamboats and factories in the city. The test train then steamed into East Cairo, turned around, picked up a tenth Mogul engine and roared back over the bridge at full speed, followed by a second train filled with newspapermen. As soon as the two trains cleared the track in Cairo, a southbound freight - New Orleans-bound train No. 3 - inaugurated regular service over the bridge.[57] The _Memphis Appeal_ reflected the feelings of those in attendance:

> No adequate estimate of the strength of the Illinois Central can be made without taking into consideration that tremendous triumph of modern engineering science - the bridge at Cairo - which in a gigantic letter "S," four miles in length, spans the Ohio River at its broadest point. It is indeed one of the wonders of the world - a work that fills the beholder with amazement - so extraordinary is the demonstration of men's ability to overcome natural obstacles... The bridge has yet to play its full part in the development of the Illinois Central System.[58]

Although trains now rolled over the bridge regularly, a considerable amount of finishing work remained, involving work on the floor, painting and other details of construction. Work on the bridge continued under Morison's indirect supervision until March 1, 1890, at which time the engineer turned the monumental structure over to the railroad. The cost of the bridge totalled

almost $3 million, slightly more than $200,000 over Morison's and Corthell's original estimate. This is itemized in the following table:

Substructure	$1,189,743.73
Superstructure	765,616.14
Kentucky approach.	338,267.40
Illinois approach.	290,190.51
Protection works	8,622.87
Service tracks	565.90
Right of way and franchises.	12,277.63
Engineering.	67,620.65
Legal and supervisory.	947.24
Miscellaneous.	1,605.85
Total. . . .	$2,675,457.92[59]

The completion of the Cairo Bridge marked the end to what had been one of the largest and most expensive bridge construction projects undertaken in the United States. Although comprised of technologically standard elements - long-span, simply supported through trusses on masonry piers with pneumatic caissons - the structure as a whole formed a milestone in bridge construction. Edward Jeffery himself called the bridge one of the greatest engineering feats of the age.[60] Its total length of 10,560 feet distinguished the Cairo Bridge as the longest metallic structure in the world at the time of its completion, extending some 33 feet further than the Tay Bridge in Scotland. And the 518-foot channel span represented the ultimate extension of the Whipple truss. As the bridge at Cairo neared completion, other railroads contemplated the erection of major trusses over the Ohio. No less than seven other bridges had then been proposed across the river, prompting the Louisville Courier Journal to comment wryly: "If all the railroad bridges across the Ohio river that are now contemplated are built, and it seems that a larger portion of them will be, the boats will have little or nothing to do between Louisville and Henderson but to dodge piers."[61]

The historical significance of the Cairo Bridge could hardly be underestimated. Like the driving of the Golden Spike at the juncture of the Union Pacific and Central Pacific Railroads, the bridge at Cairo represented the completion of a major transcontinental line. Morison's immense structure comprised the final and most problemmatic component in a pivotally important north-south route across the heart of America. For the first time a direct rail link existed between the Great Lakes and the Gulf of Mexico. As the average freight rate over the Illinois Central dropped below a penny per ton-mile by 1890, the railroad increased its traffic dramatically throughout the 1890s and soon eclipsed the steamboats along the Mississippi in importance. The newly opened bridge at Cairo thus provided assurance to shareholders of the Illinois Central that the railroad would continue to function in an expanding role, carrying interstate commerce through the industrialized heart of the country.

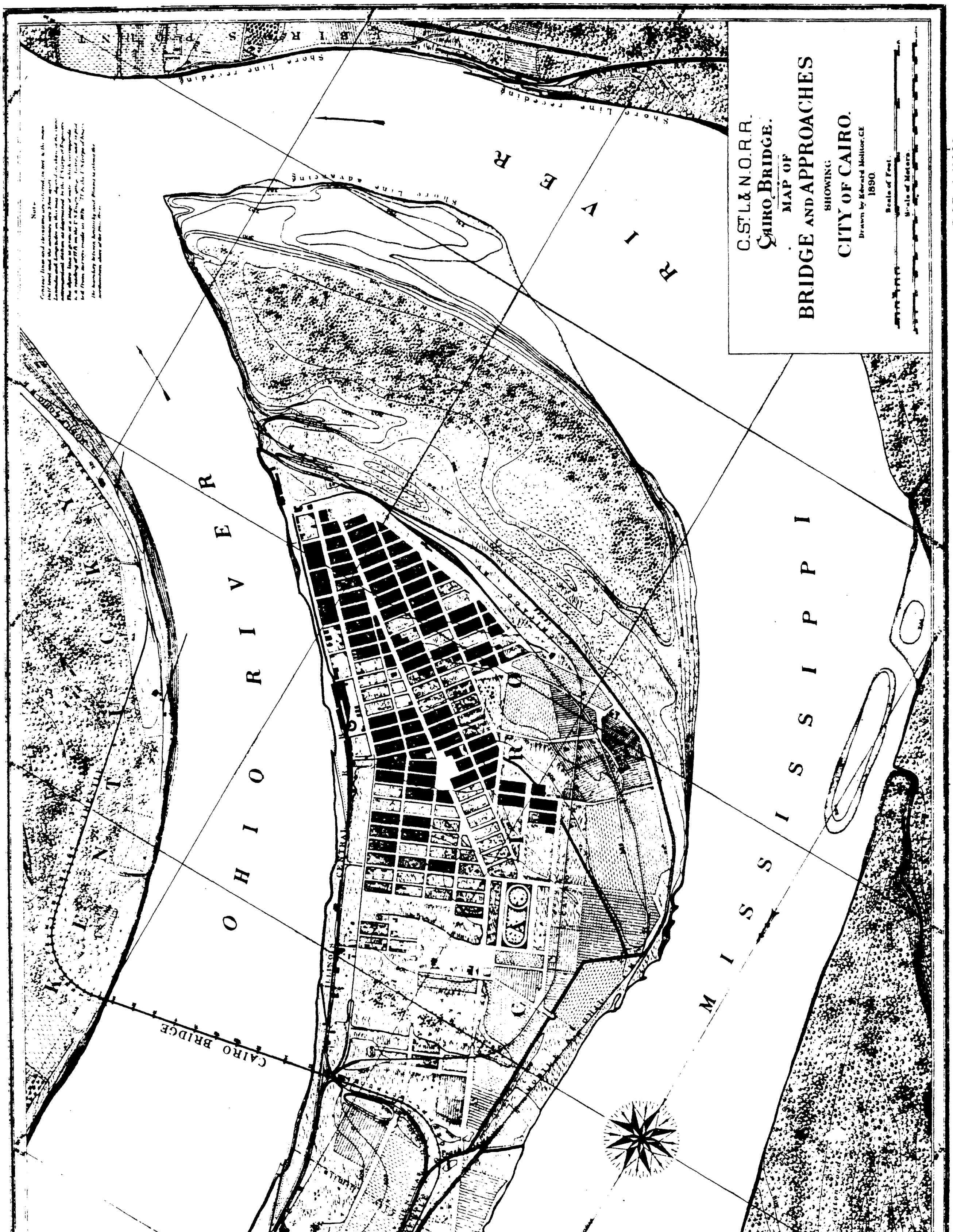


PLATE No 2
C.ST.L.& N.O.R.R.
CAIRO BRIDGE.
MAP OF
BRIDGE AND APPROACHES
SHOWING
CITY OF CAIRO.
1890.
SCALE - 1:10000
OHIO RIVER
MISSISSIPPI
RIVER
CAIRO BRIDGE
KENTUCKY
CAIRO

Figure 100

Plate 5

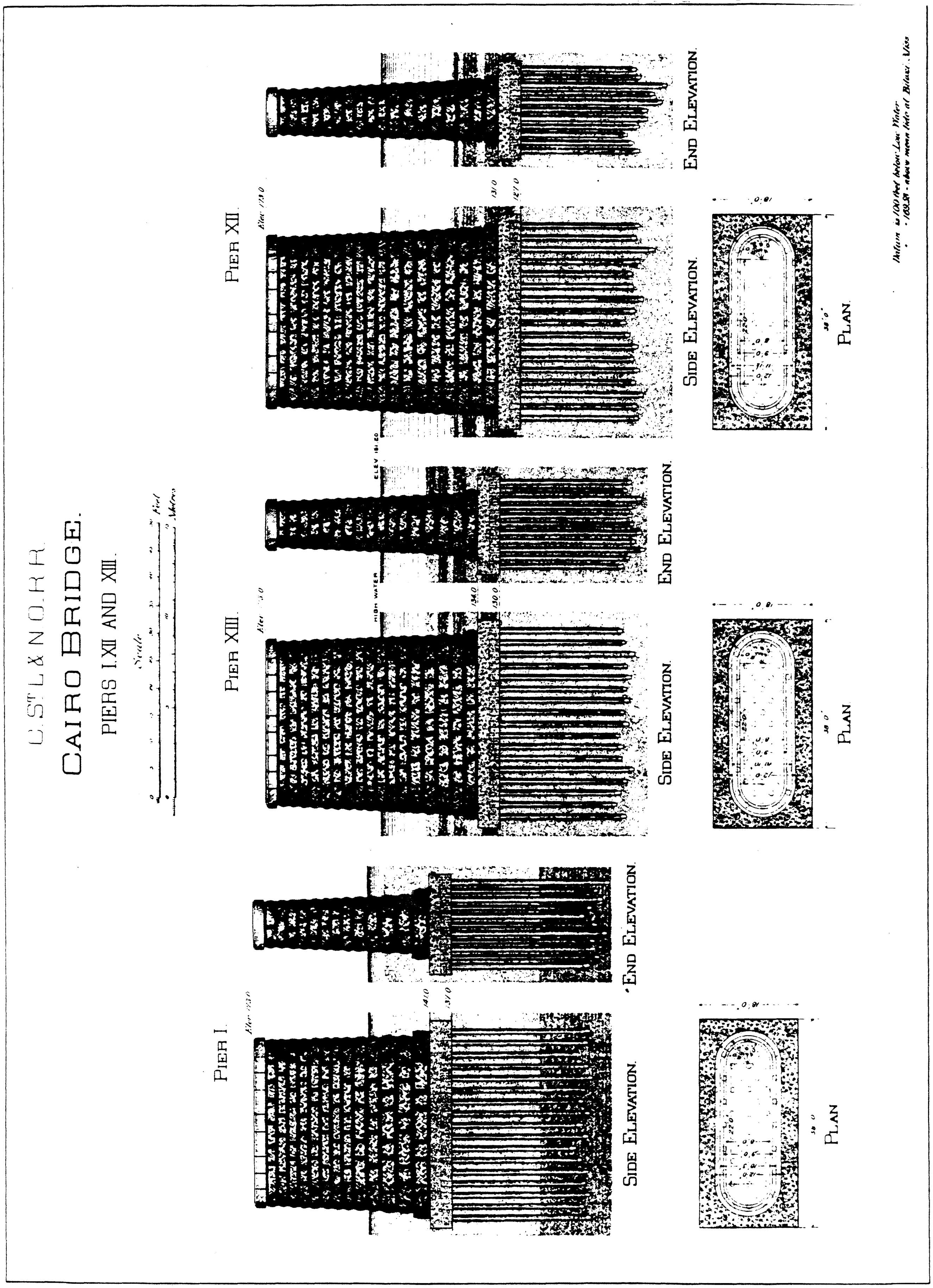


Figure 101

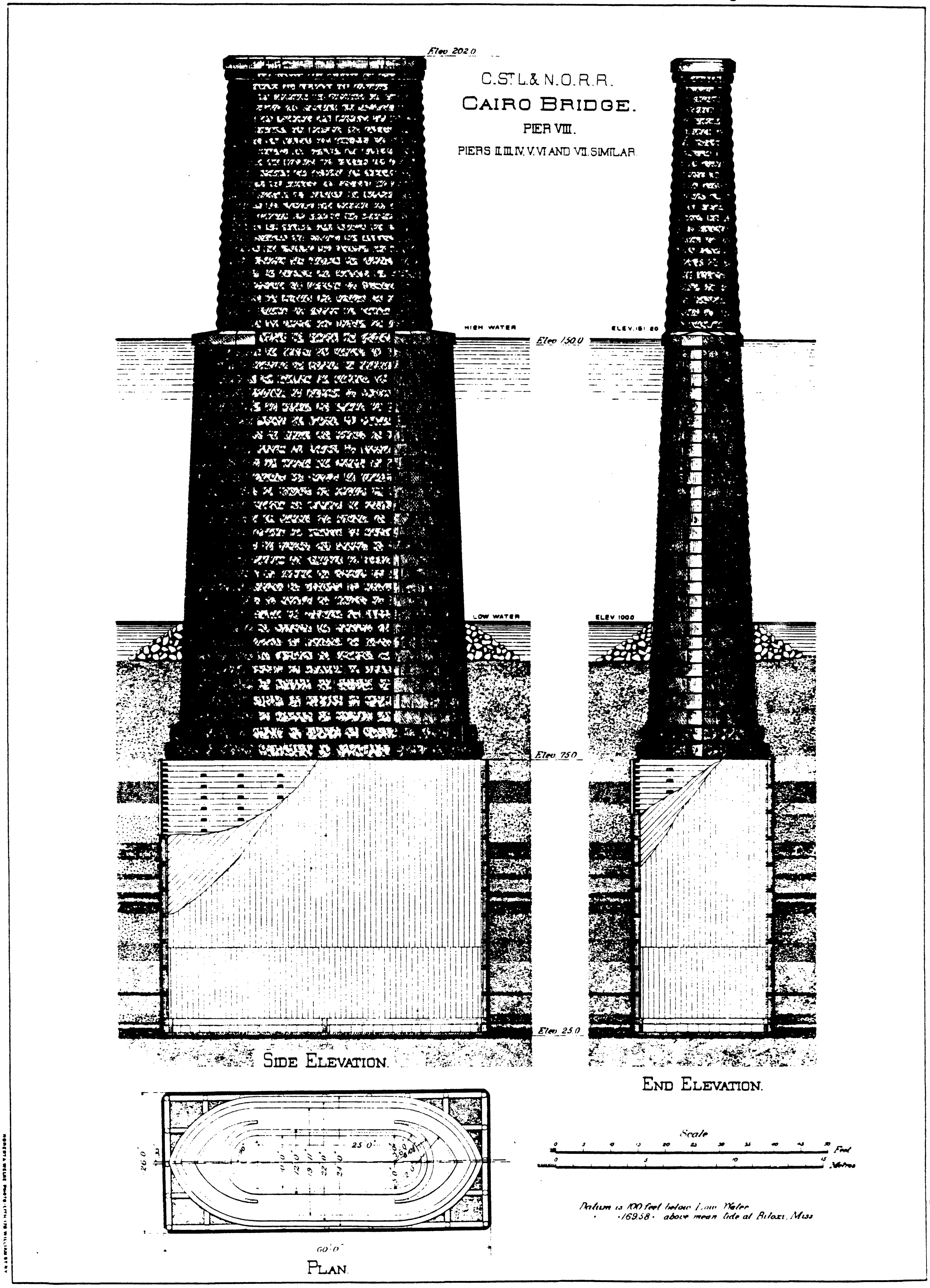

Elev 202.0
C.St L.& N.O.R.R.
Cairo Bridge.
Pier VIII.
Piers II.III.IV.V.VI and VII. Similar.
High Water
Elev. 150.0
Low Water
Elev. 100.0
Elev. 75.0
Elev. 25.0
Side Elevation.
End Elevation.
Scale
Feet
Metres
Datum is 100 feet below Low Water
16958 above mean tide at Biloxi, Miss.
25'0"
60'0"
26'0"
Plan.
Plate 6

Figure 102

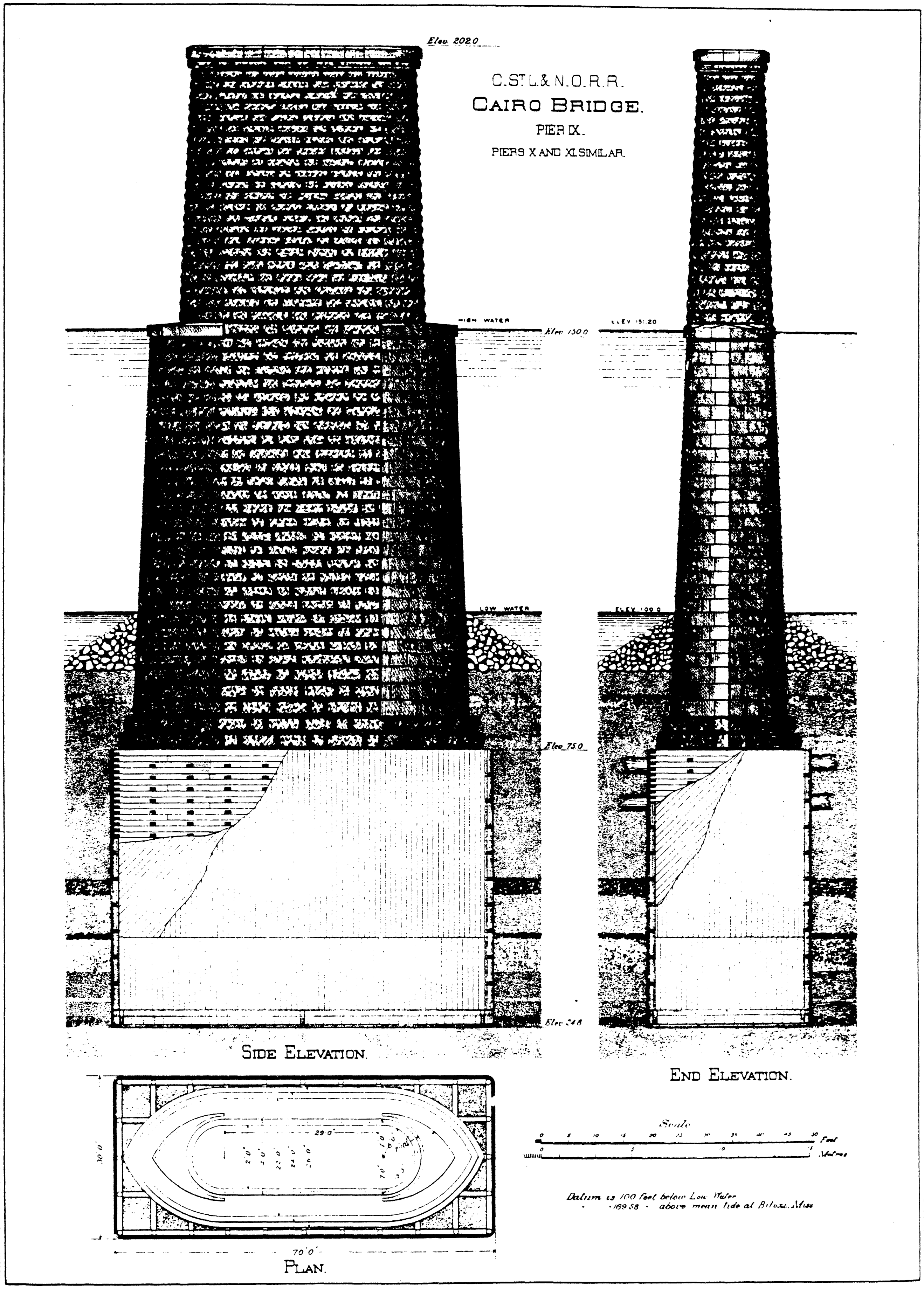

C. St. L. & N. O. R. R.
CAIRO BRIDGE.
PIER IX.
PIERS X AND XI SIMILAR.
Elev. 202.0
HIGH WATER
Elev. 150.0
ELEV. 151.20
LOW WATER
ELEV. 100.0
Elev. 75.0
Elev. 24.8
SIDE ELEVATION.
END ELEVATION.
29.0
30.0
70.0
PLAN.
Scale
Feet
Metres
Datum is 100 feet below Low Water
169.58 above mean tide at Biloxi, Miss.
Plate

Figure 103

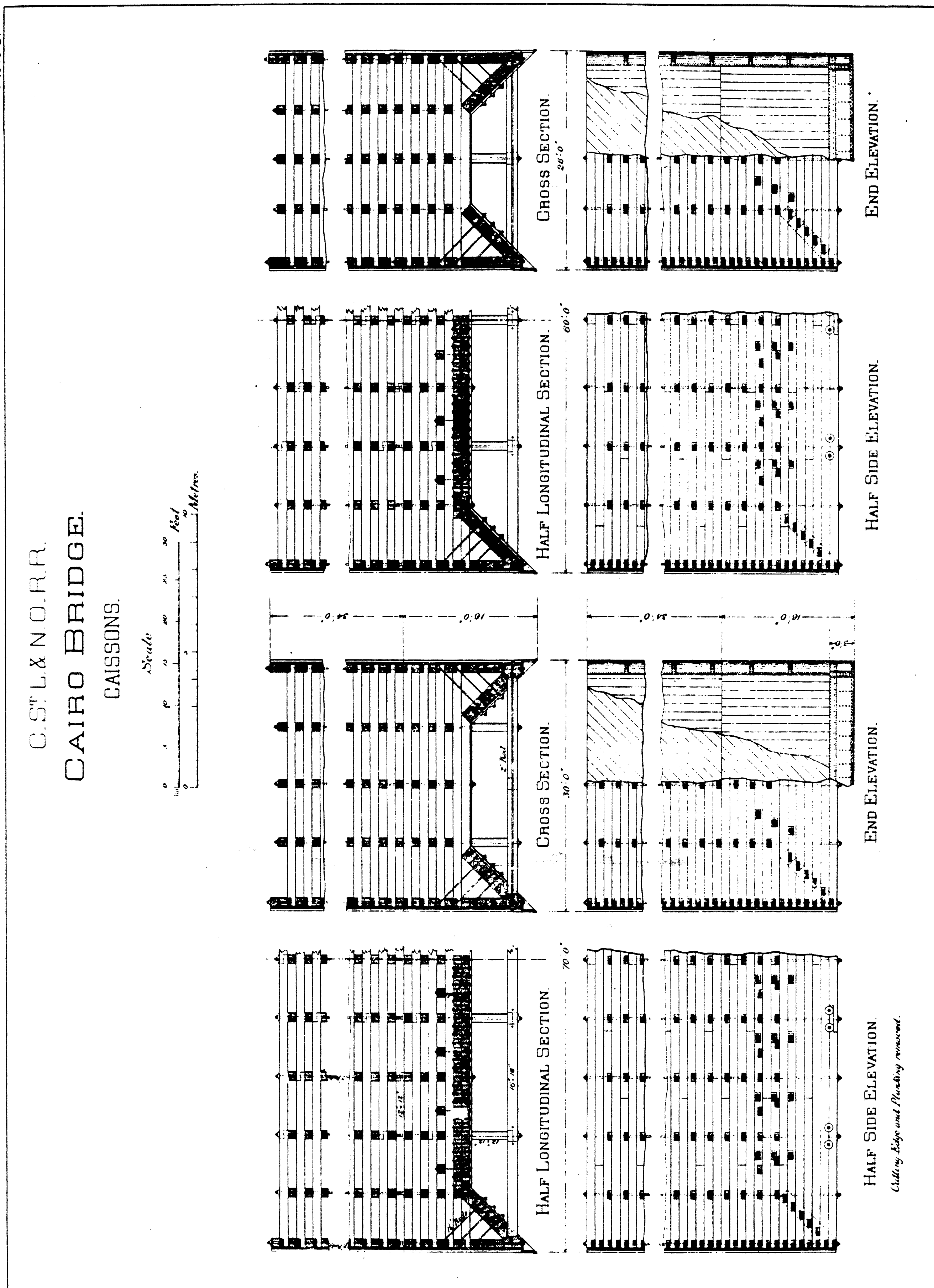


Plate 8.
C. ST L. & N. O. R.R.
CAIRO BRIDGE.
CAISSONS.
Scale
Feet
Metres
Cross Section.
26'0"
End Elevation.
Half Longitudinal Section.
60'0"
Half Side Elevation.
Cross Section.
30'0"
End Elevation.
Half Longitudinal Section.
70'0"
Half Side Elevation.
Cutting Edge and Planking removed.

Figure 104

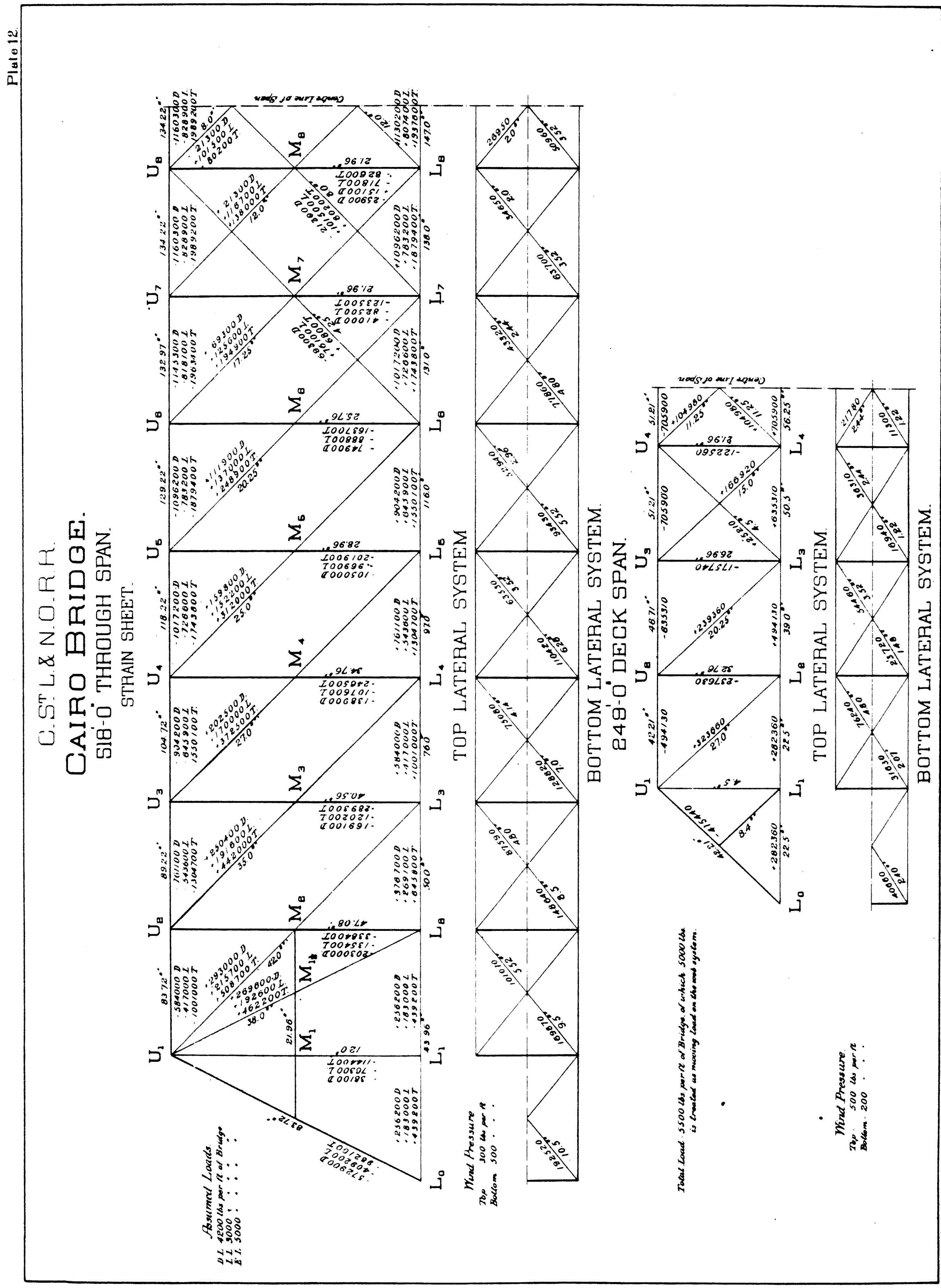


Plate 12.
C. ST. L. & N. O. R. R.
CAIRO BRIDGE.
518'-0" THROUGH SPAN.
STRAIN SHEET.
TOP LATERAL SYSTEM
BOTTOM LATERAL SYSTEM.
249'-0" DECK SPAN.
TOP LATERAL SYSTEM.
BOTTOM LATERAL SYSTEM.

Figure 105

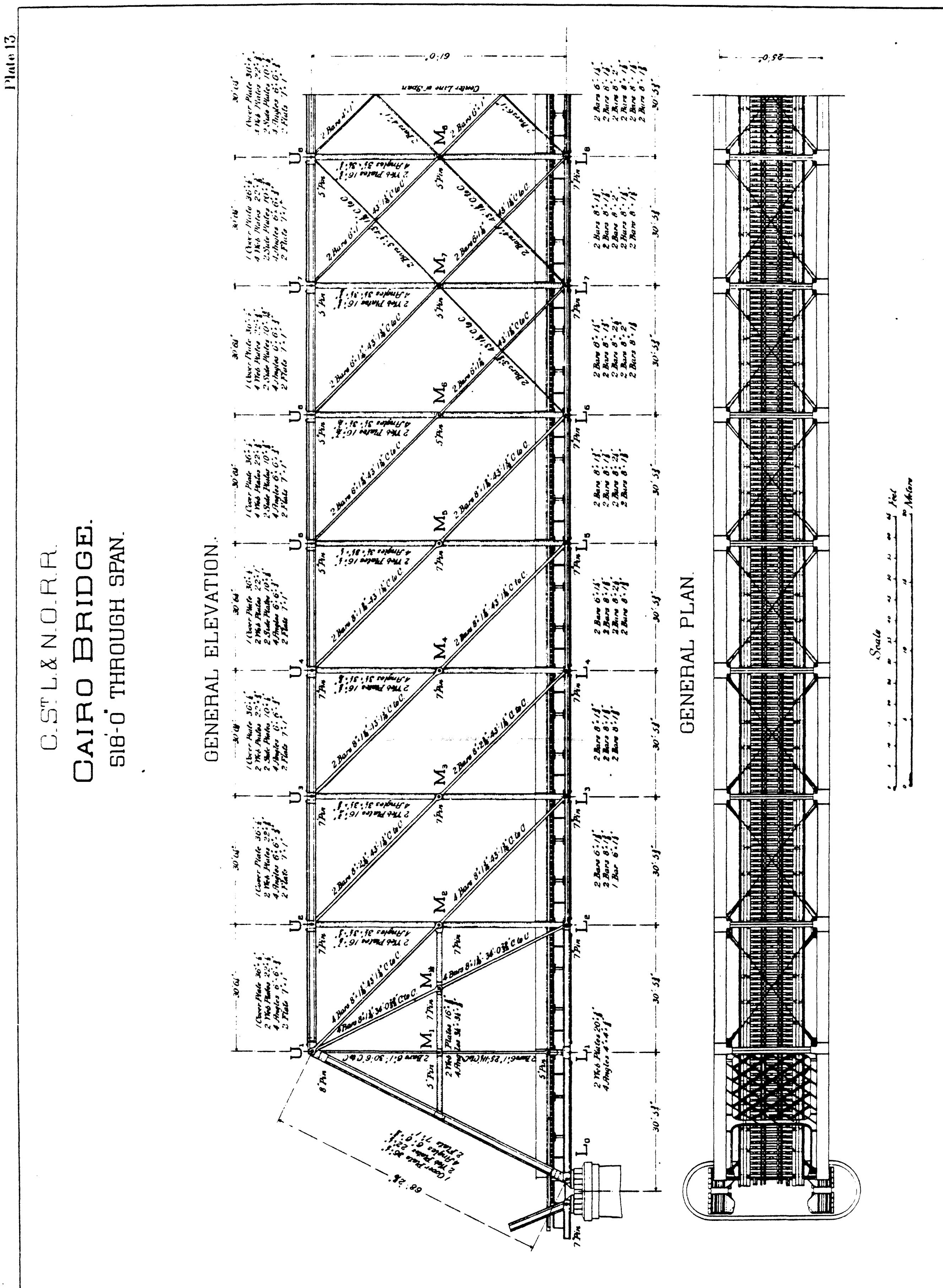


Plate 13
C.ST.L.& N.O.R.R.
CAIRO BRIDGE.
518-0' THROUGH SPAN.
GENERAL ELEVATION.
GENERAL PLAN.
Scale

Figure 106

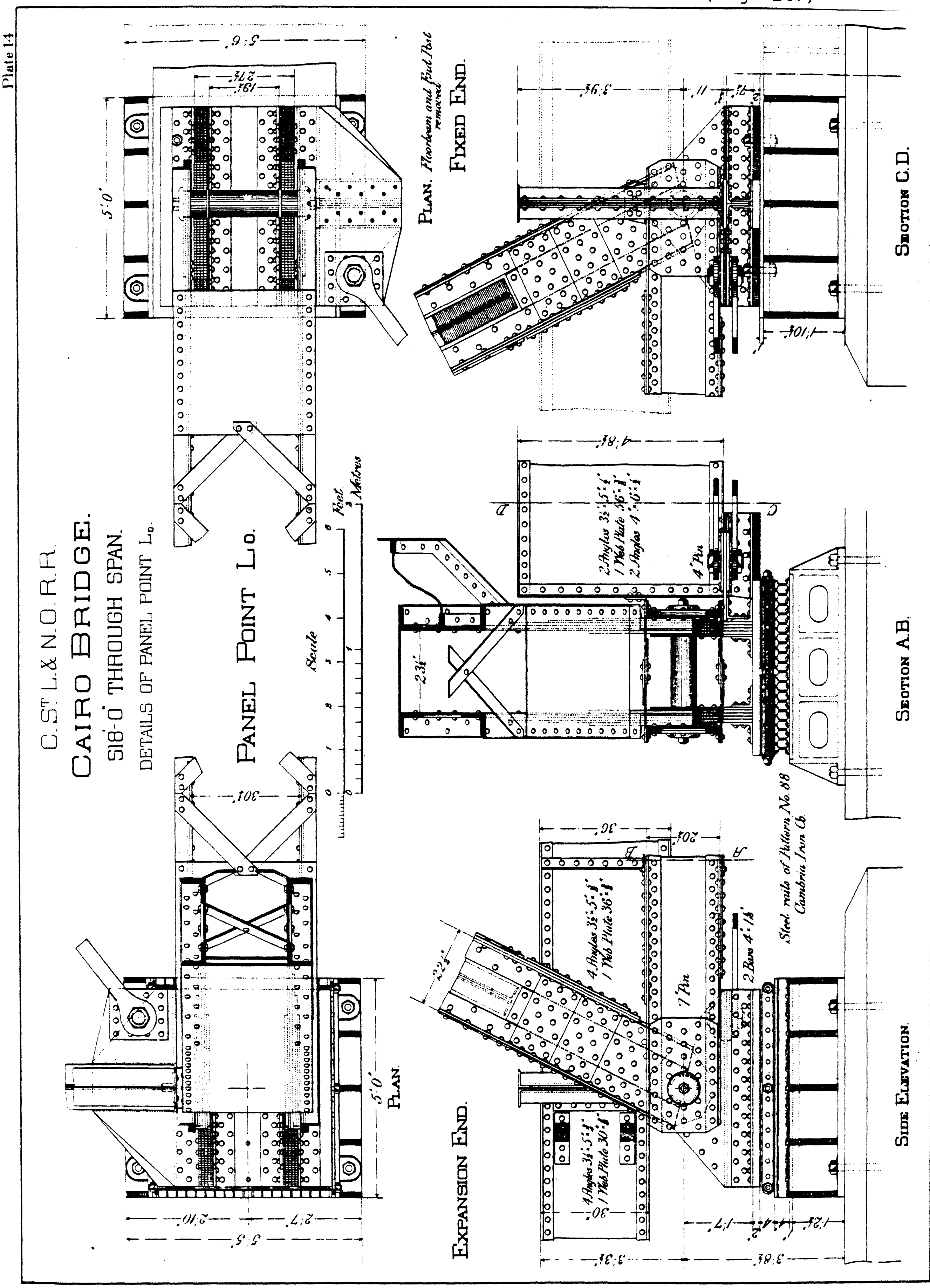


Plate 14
C. St. L. & N. O. R.R.
CAIRO BRIDGE.
518-0" THROUGH SPAN.
DETAILS OF PANEL POINT L0.
PANEL POINT L0.
Scale
Feet.
3 Metres
PLAN.
PLAN. Floorbeam and End Post removed.
FIXED END.
EXPANSION END.
SIDE ELEVATION.
SECTION A.B.
SECTION C.D.
Steel rails of Pattern No. 88 Cambria Iron Co.
7" Pin
4" Pin
2 Bars 4"·1⅛"

Figure 107

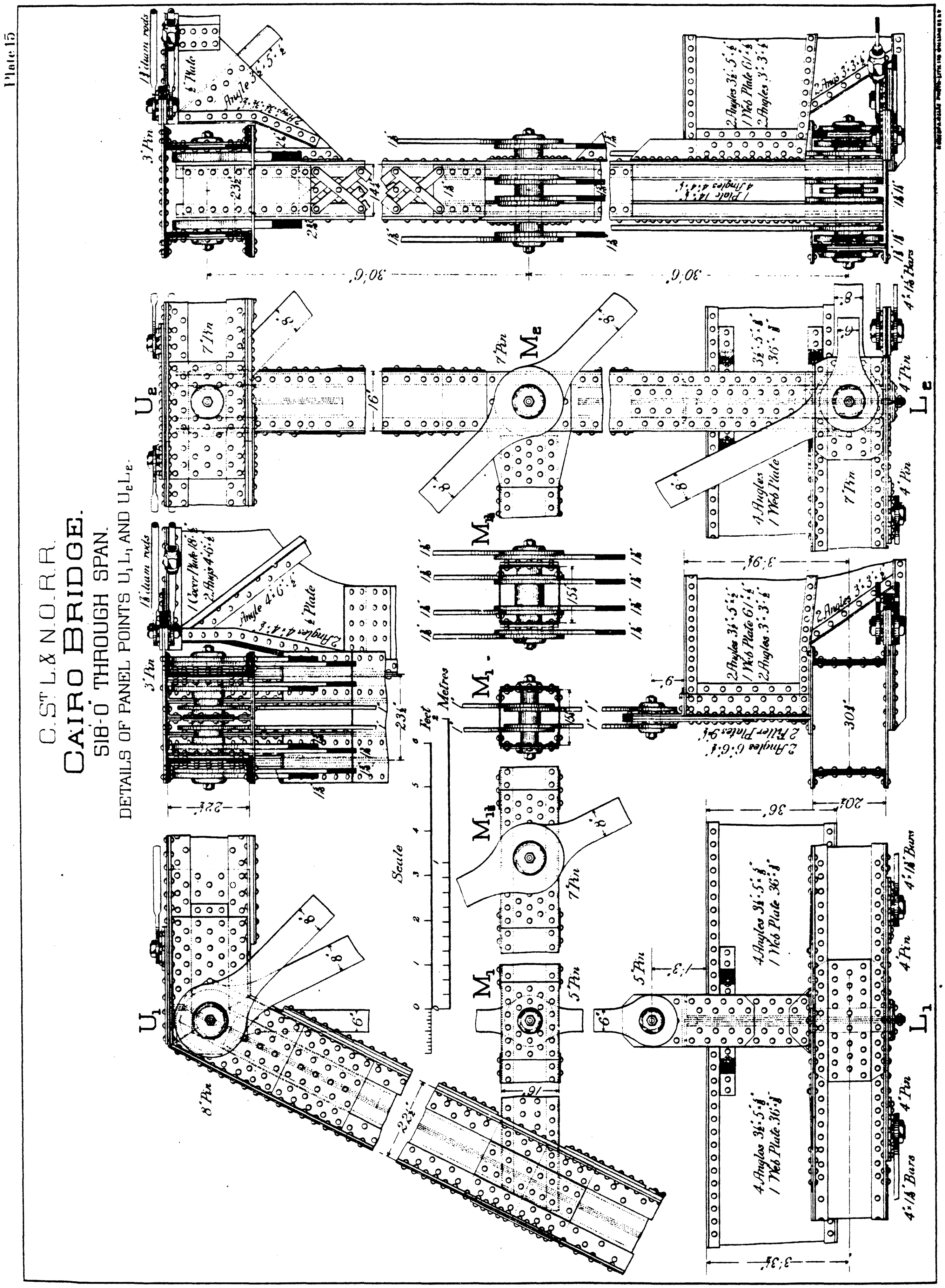


Plate 15
C.ST.L.& N.O.R.R.
CAIRO BRIDGE.
518'-0" THROUGH SPAN.
DETAILS OF PANEL POINTS U1 L1 AND U2 L2.
Scale
Feet
Metres

Figure 108

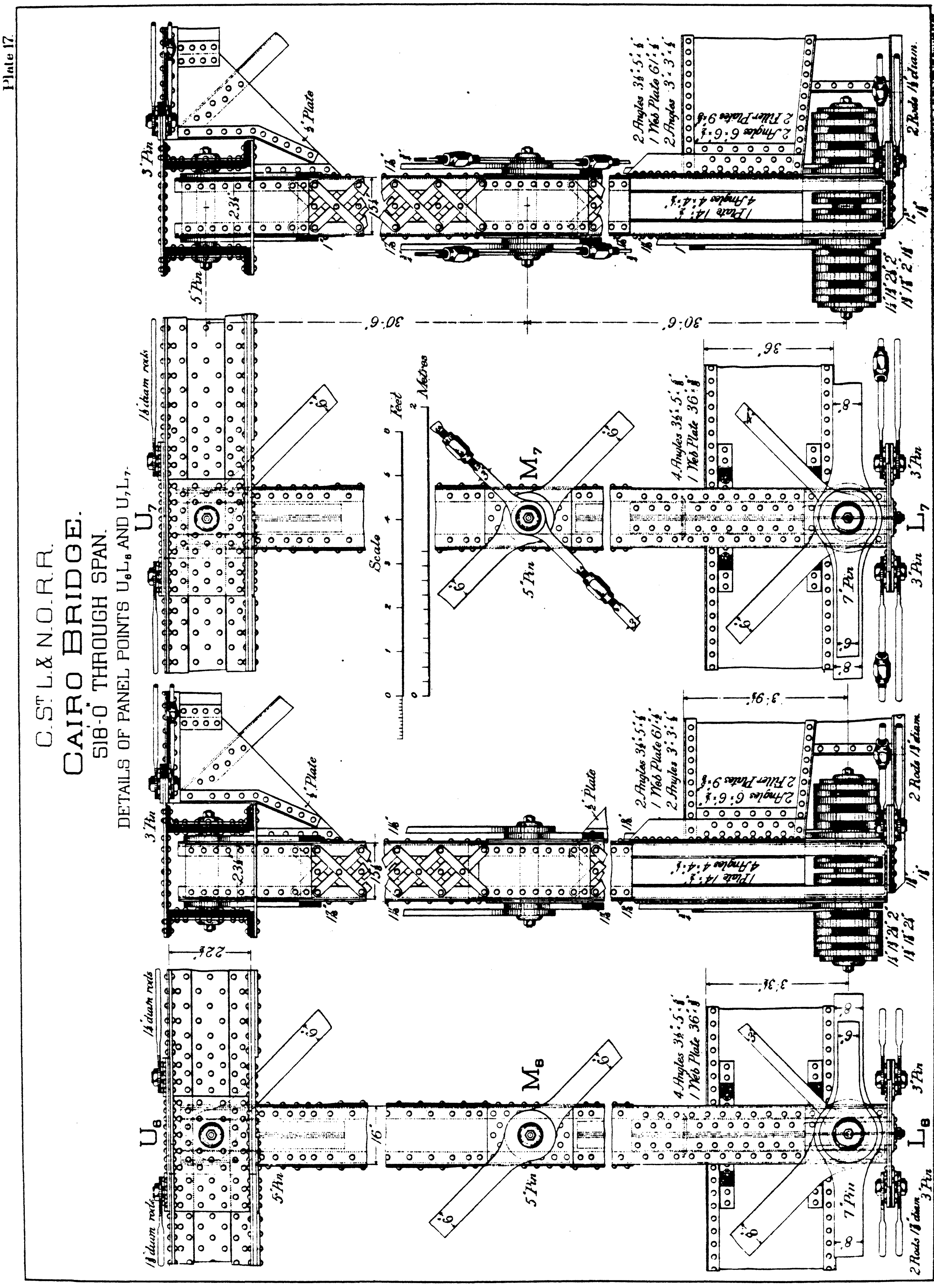


Plate 17.
C. ST. L. & N. O. R.R.
CAIRO BRIDGE.
518'-0" THROUGH SPAN.
DETAILS OF PANEL POINTS U8L8 AND U7L7.
U7
M7
L7
U8
M8
L8
Scale
Feet
Metres

Figure 109

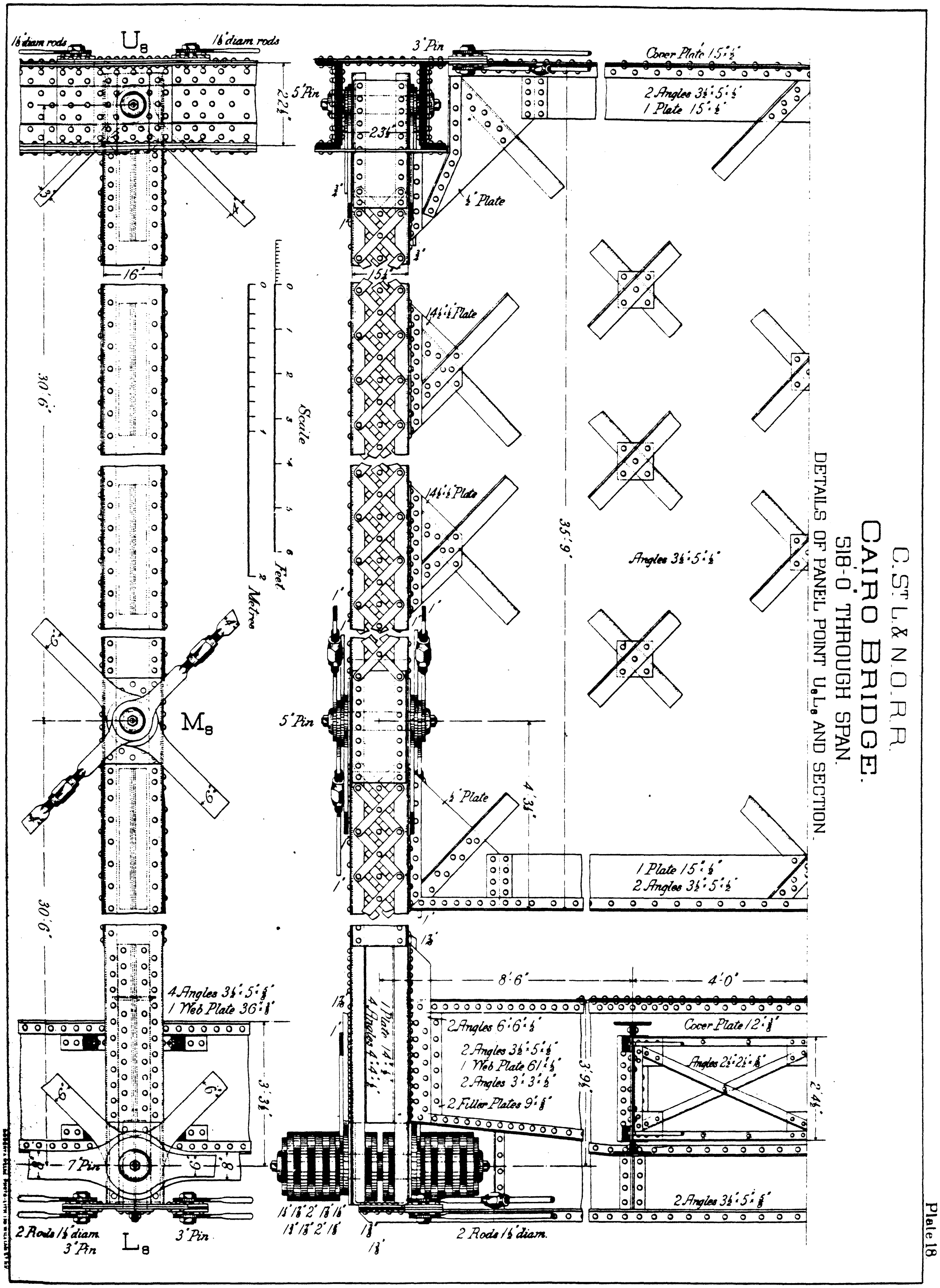

C. ST L. & N.O.R.R.
CAIRO BRIDGE.
518-0 THROUGH SPAN.
DETAILS OF PANEL POINT U8L8 AND SECTION.
Plate 18
U8
M8
L8
1½ diam rods
1½ diam rods
3" Pin
5" Pin
5" Pin
7" Pin
3" Pin
Cover Plate 15"·½"
2 Angles 3½"·5"·½"
1 Plate 15"·½"
½" Plate
14½"·½" Plate
14½"·½" Plate
½" Plate
Angles 3½"·5"·½"
1 Plate 15"·½"
2 Angles 3½"·5"·½"
Scale
Feet
Metres
30'6"
30'6"
35'9"
4'3½"
8'6"
4'0"
4 Angles 3½"·5"·⅝"
1 Web Plate 36"·⅜"
1 Plate 14"·½"
4 Angles 4"·4"·½"
2 Angles 6"·6"·½"
2 Angles 3½"·5"·½"
1 Web Plate 61"·⅜"
2 Angles 3"·3"·½"
2 Filler Plates 9"·⅝"
Cover Plate 12"·⅜"
Angles 2½"·2½"·⅜"
2 Angles 3½"·5"·⅝"
2 Rods 1½ diam
3" Pin
3" Pin
2 Rods 1½ diam.

Figure 110

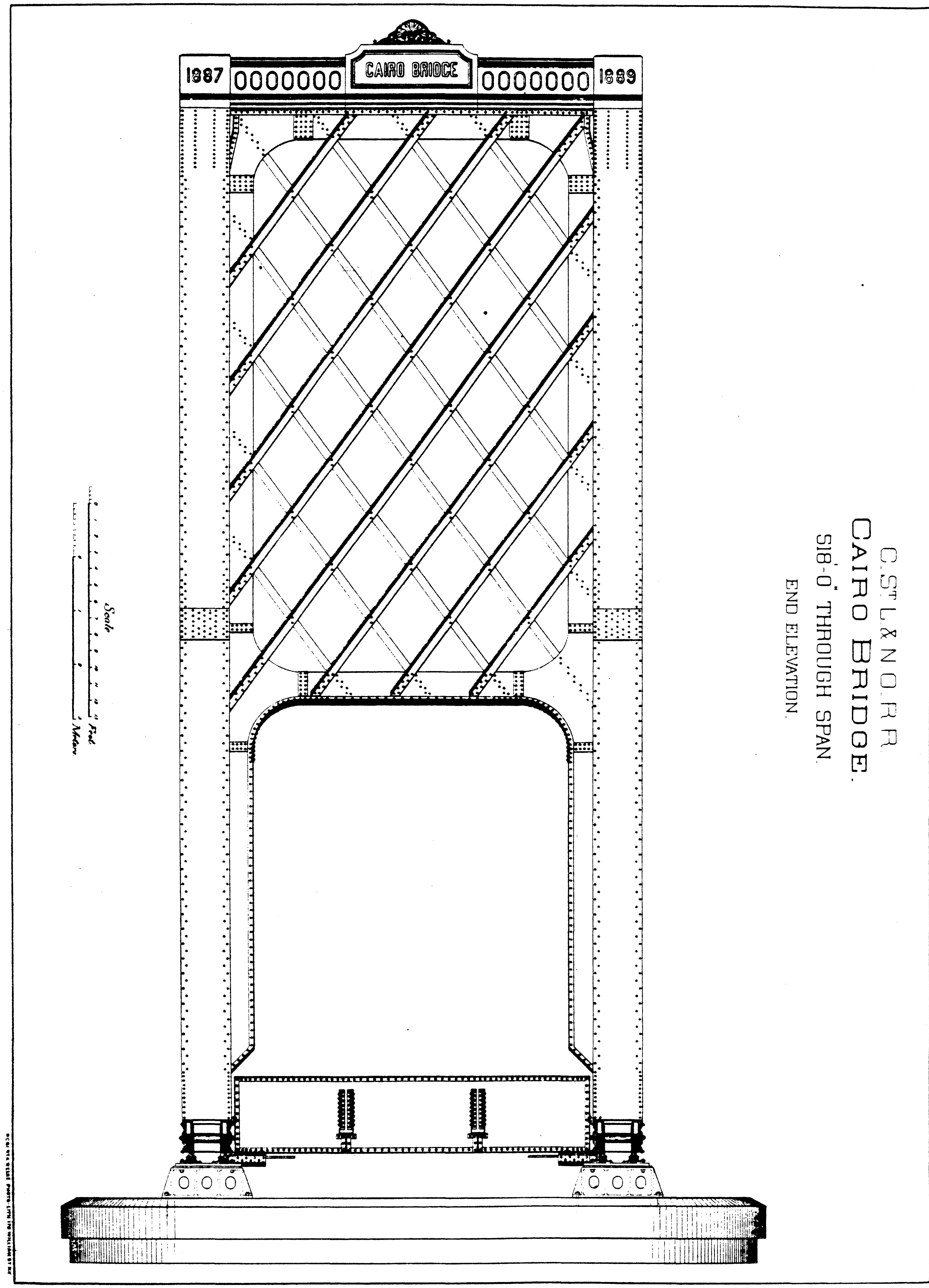

1887
CAIRO BRIDGE
1889
C.ST.L.&N.O.R.R.
CAIRO BRIDGE.
518'-0" THROUGH SPAN.
END ELEVATION.
Scale
Feet
Metres
Plate 19

Figure 111

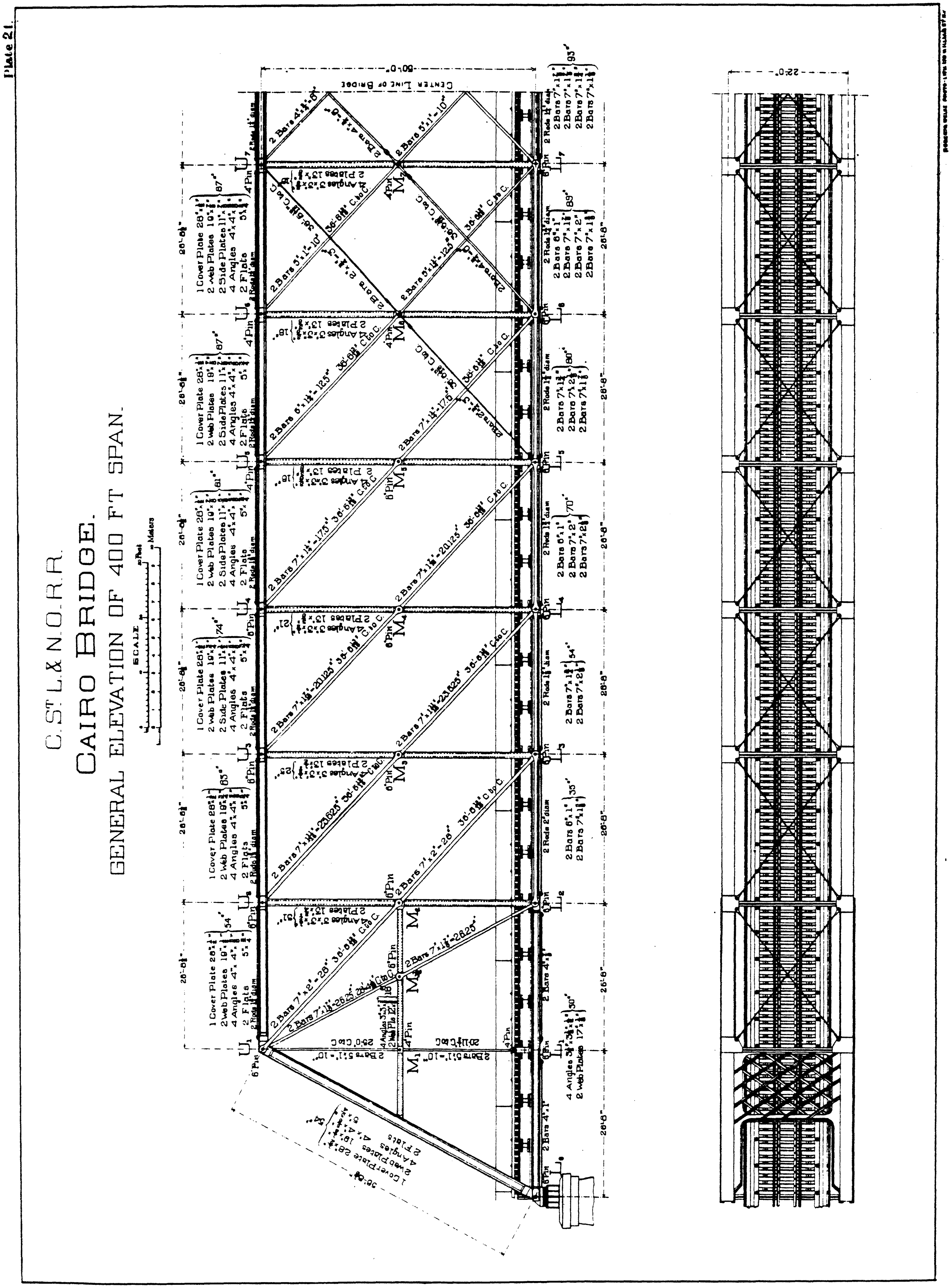


Plate 21.
C. ST. L. & N. O. R.R.
CAIRO BRIDGE.
GENERAL ELEVATION OF 400 FT SPAN.
SCALE
CENTER LINE OF BRIDGE

Figure 112

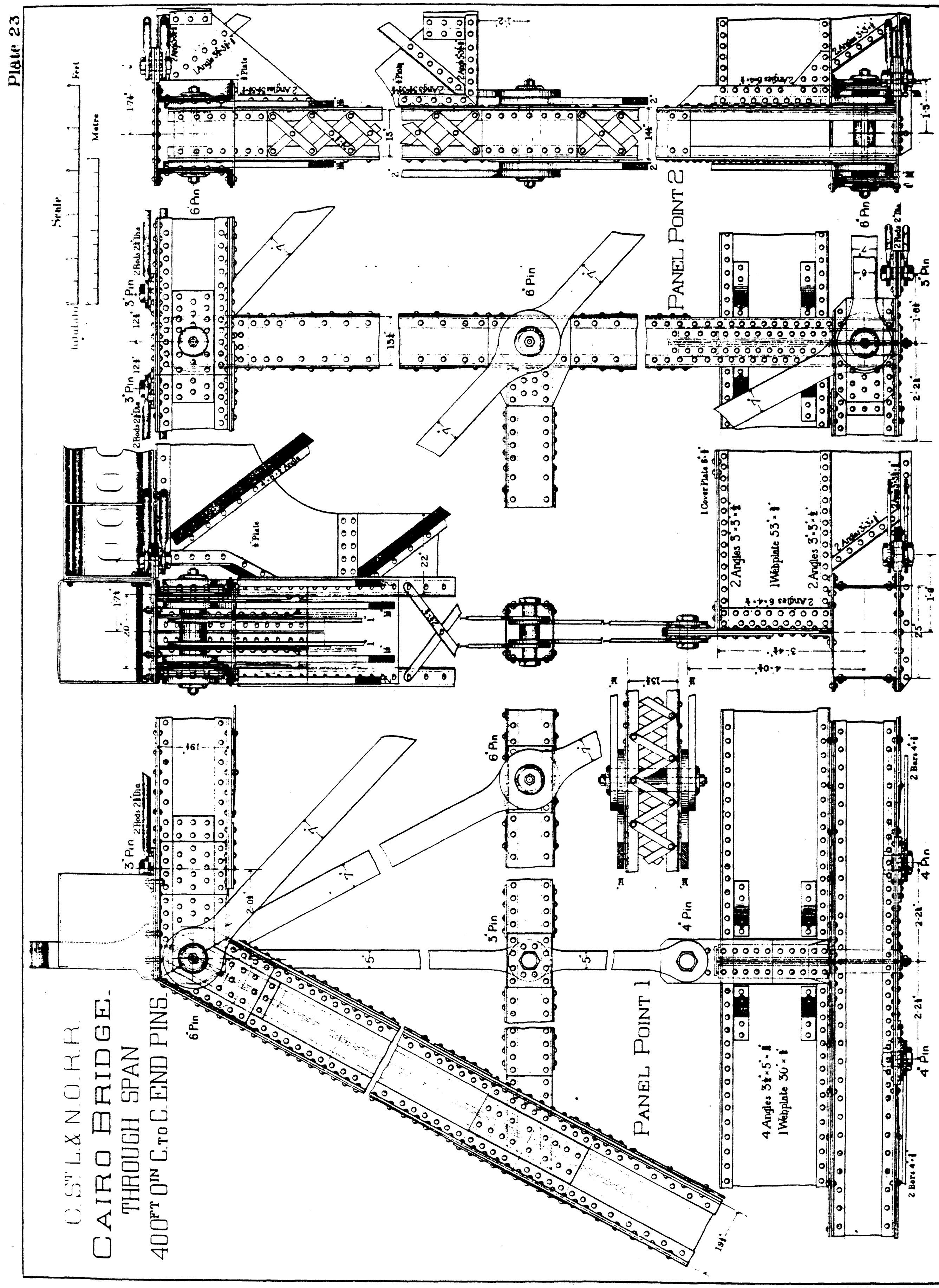


Plate 23
C.ST.L.& N.O.R.R.
CAIRO BRIDGE.
THROUGH SPAN
400FT 0IN C. TO C. END PINS.
PANEL POINT 1
PANEL POINT 2
Scale
Feet
Metre

Figure 113

Plate 22

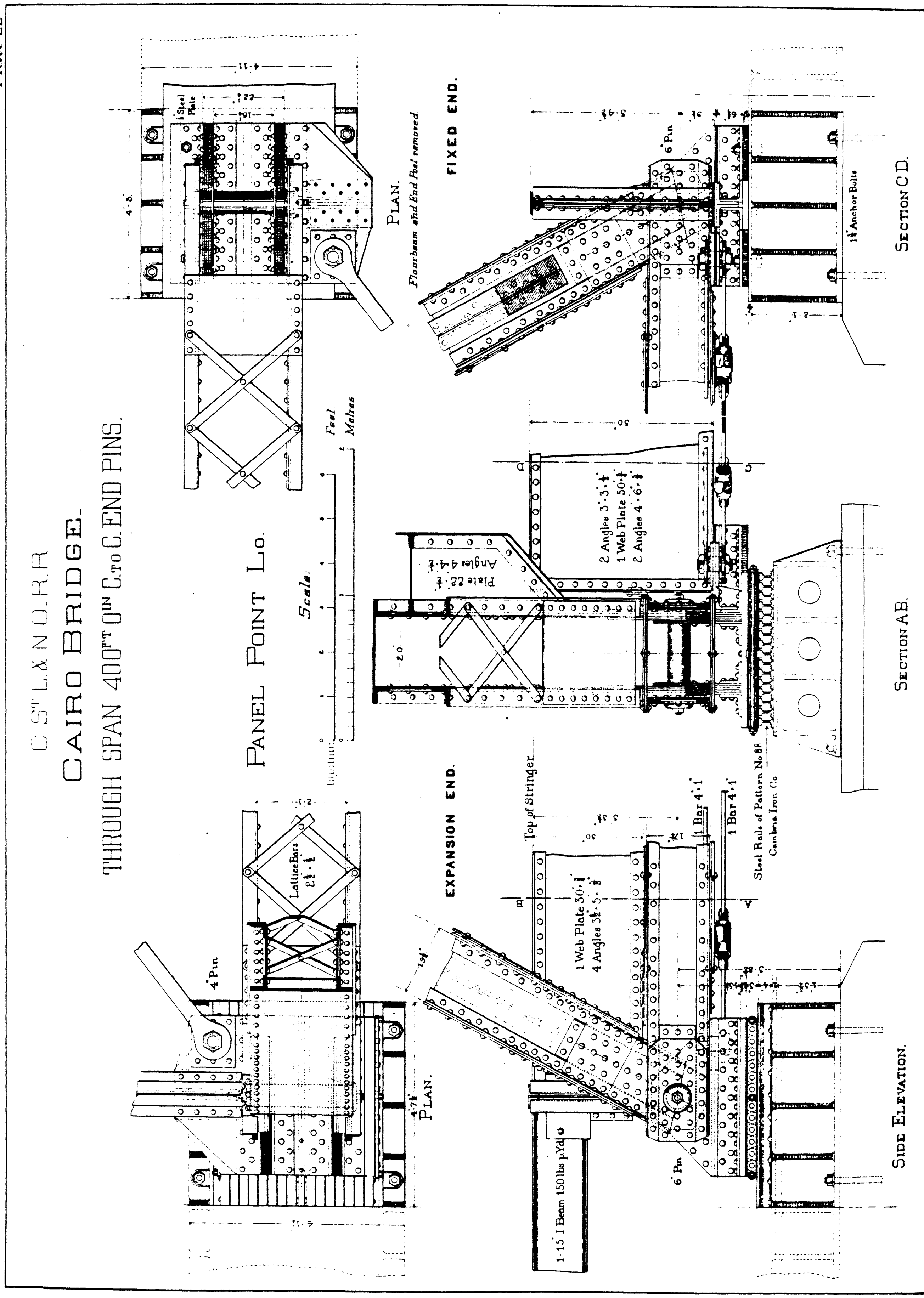


Figure 114

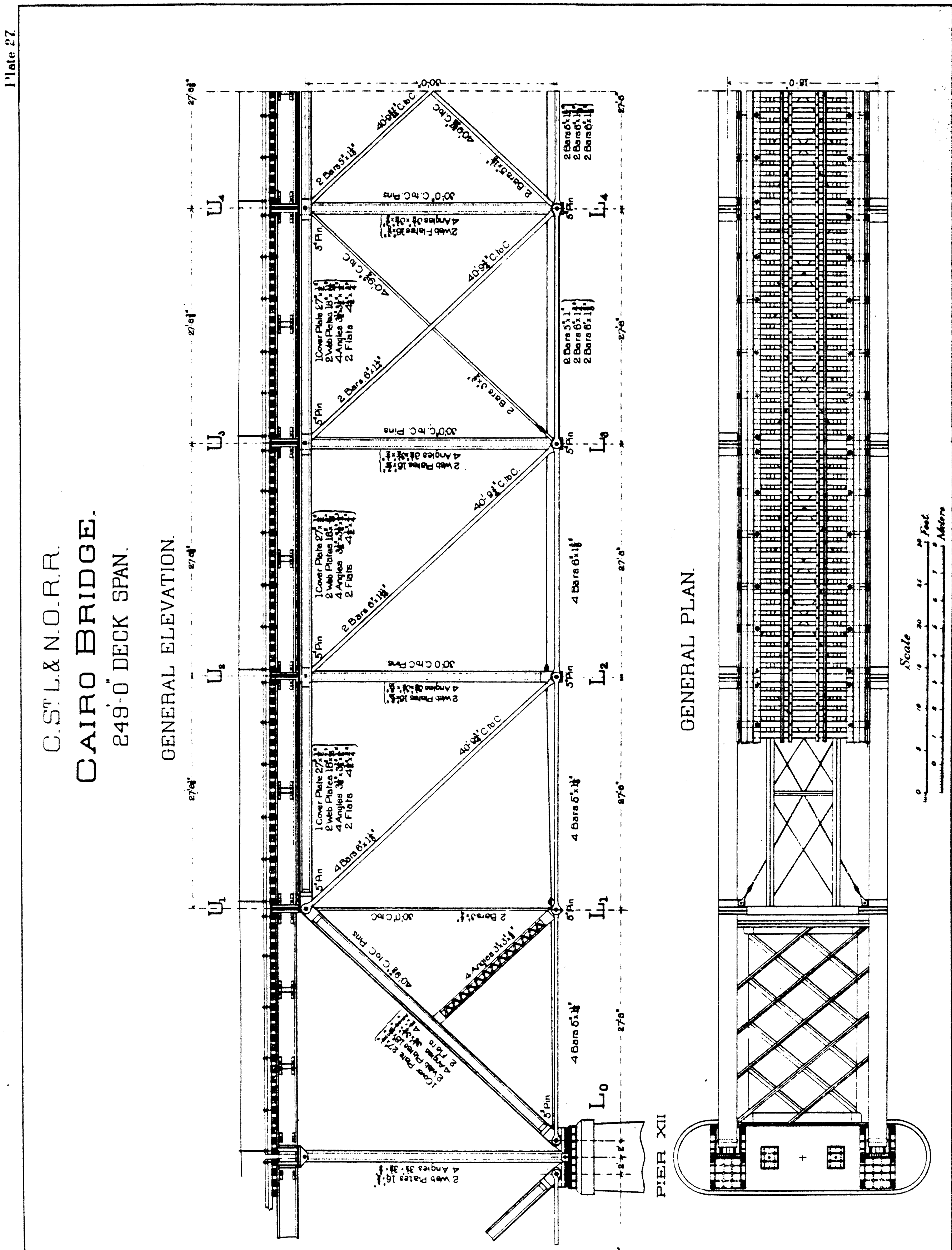


Plate 27
C. St L. & N.O.R.R.
Cairo Bridge.
249'-0" Deck Span.
General Elevation.
General Plan.
Pier XII
Scale

Figure 115

Plate 28

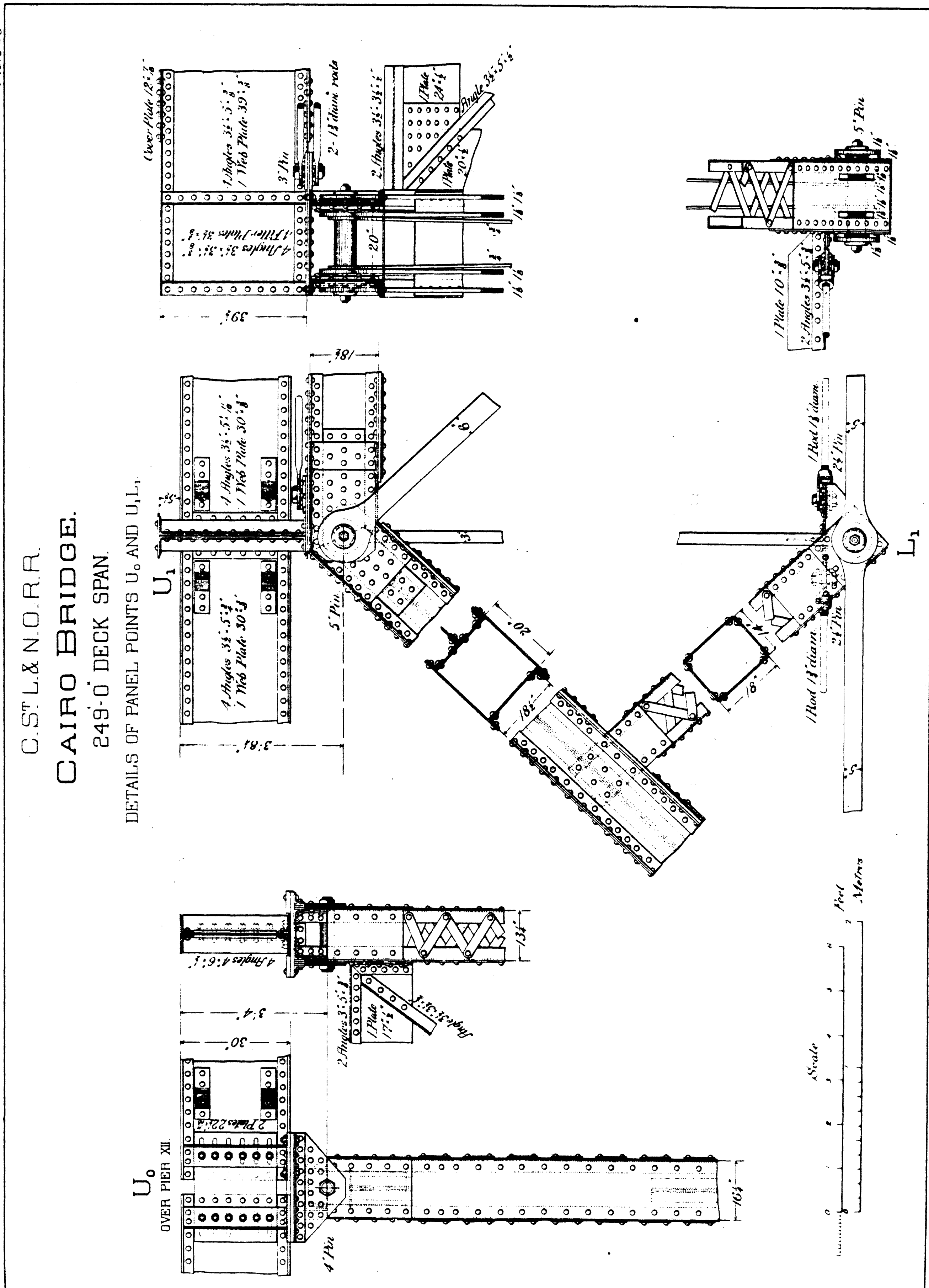


Figure 116

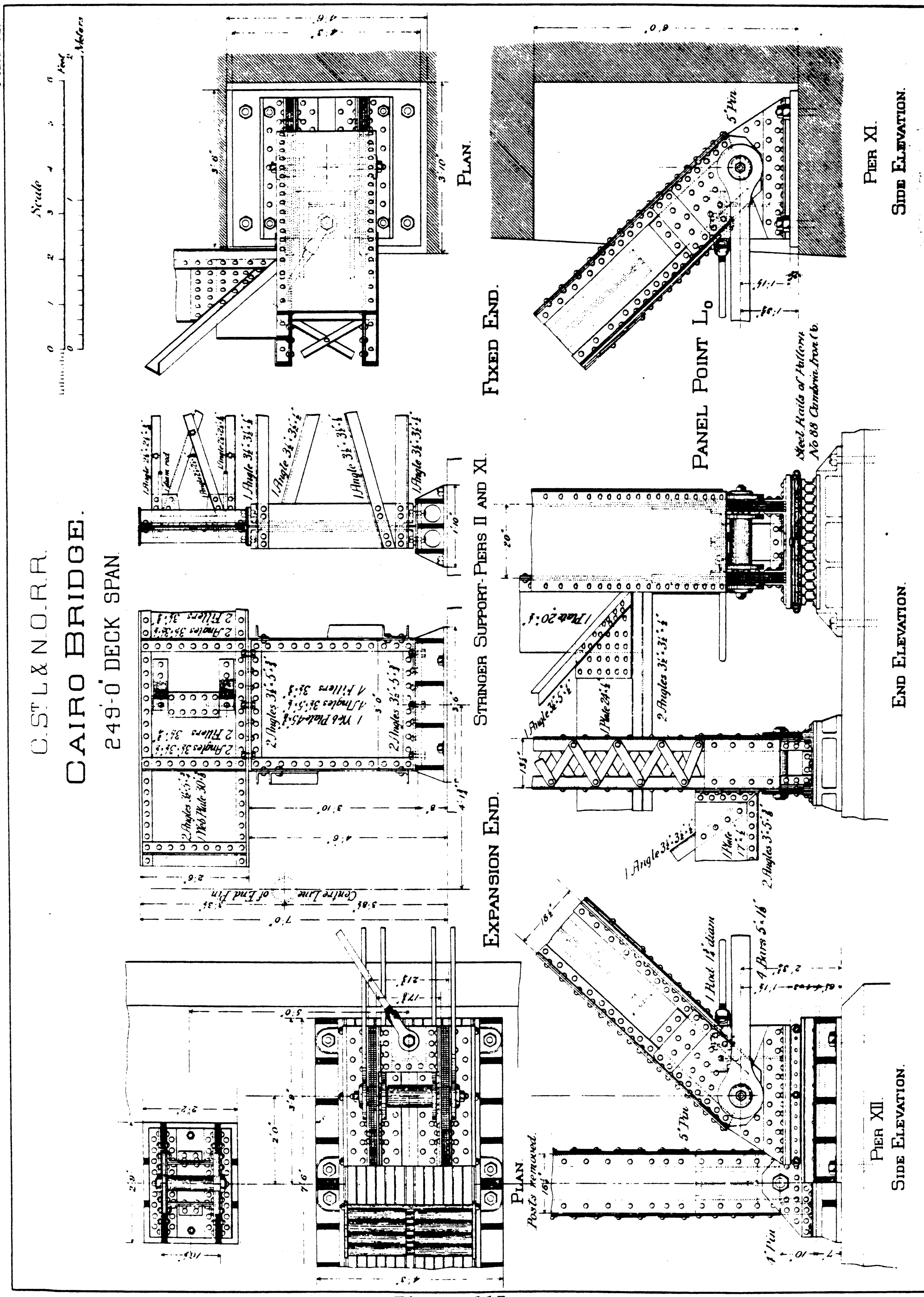


Plate 28.
C.St.L.&N.O.R.R.
CAIRO BRIDGE.
249'-0" DECK SPAN
Scale
Plan.
Fixed End.
Panel Point L_0
Pier XI.
Side Elevation.
Stringer Support-Piers II and XI.
End Elevation.
Expansion End.
Plan.
Posts removed.
Pier XII
Side Elevation.
Centre Line of End Pin
Steel Rails of Pattern No 88 Cambria Iron Co.

Figure 117

Plate 30

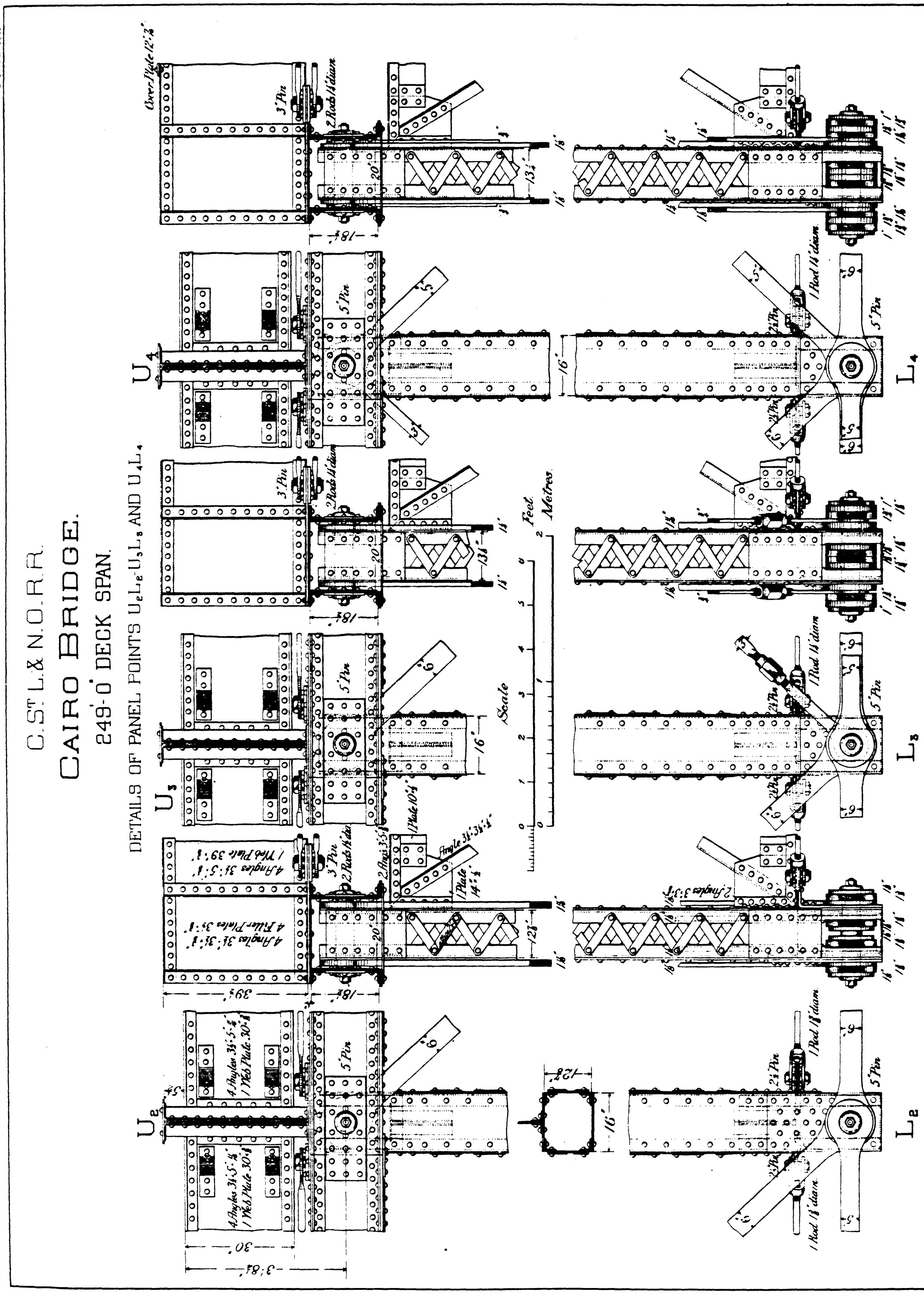


Figure 118

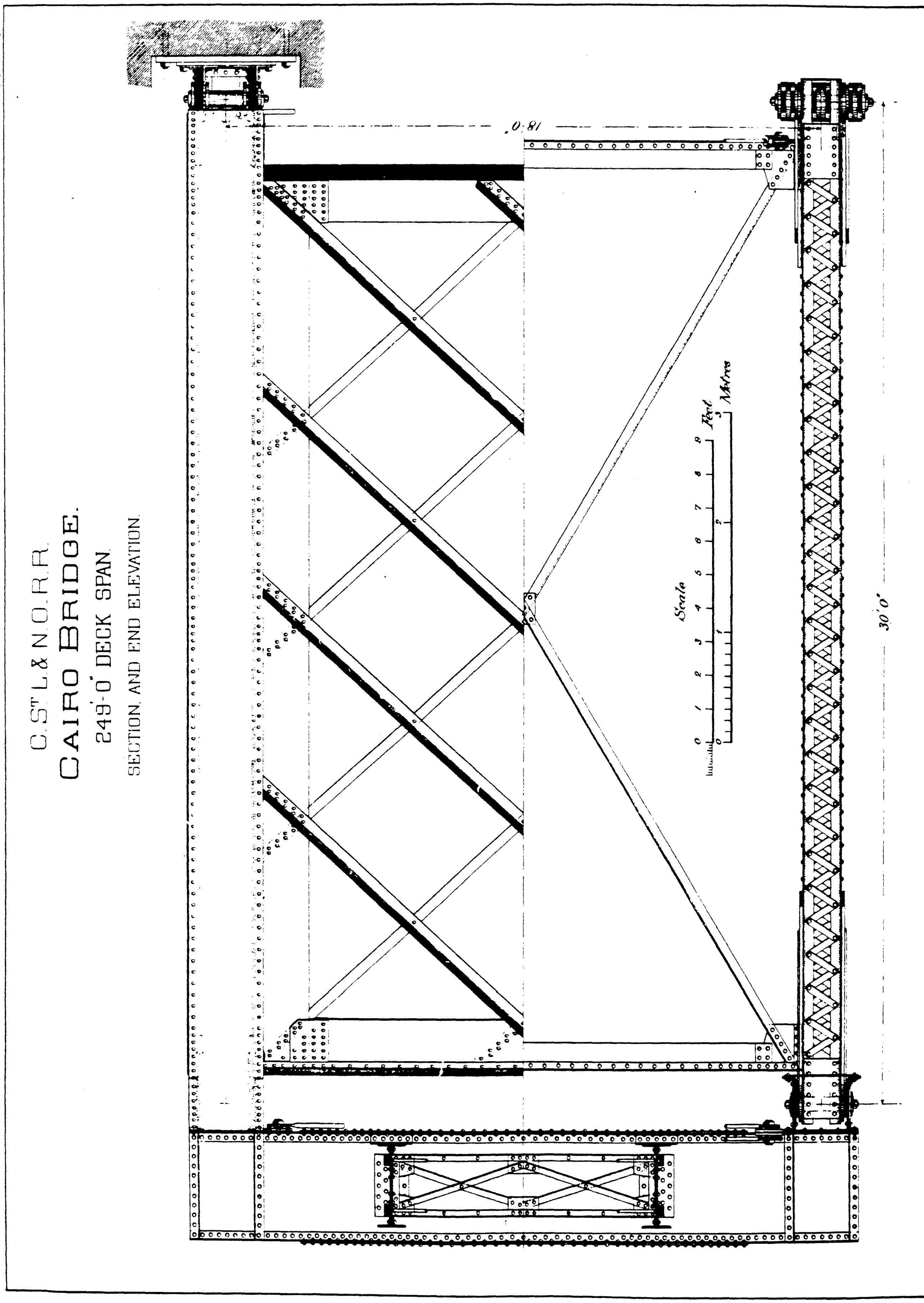


Plate 31
C. S^T L. & N. O. R.R.
CAIRO BRIDGE.
249'-0" DECK SPAN.
SECTION. AND END ELEVATION.
Scale
Feet
Metres
30'0"
0.81

Figure 119

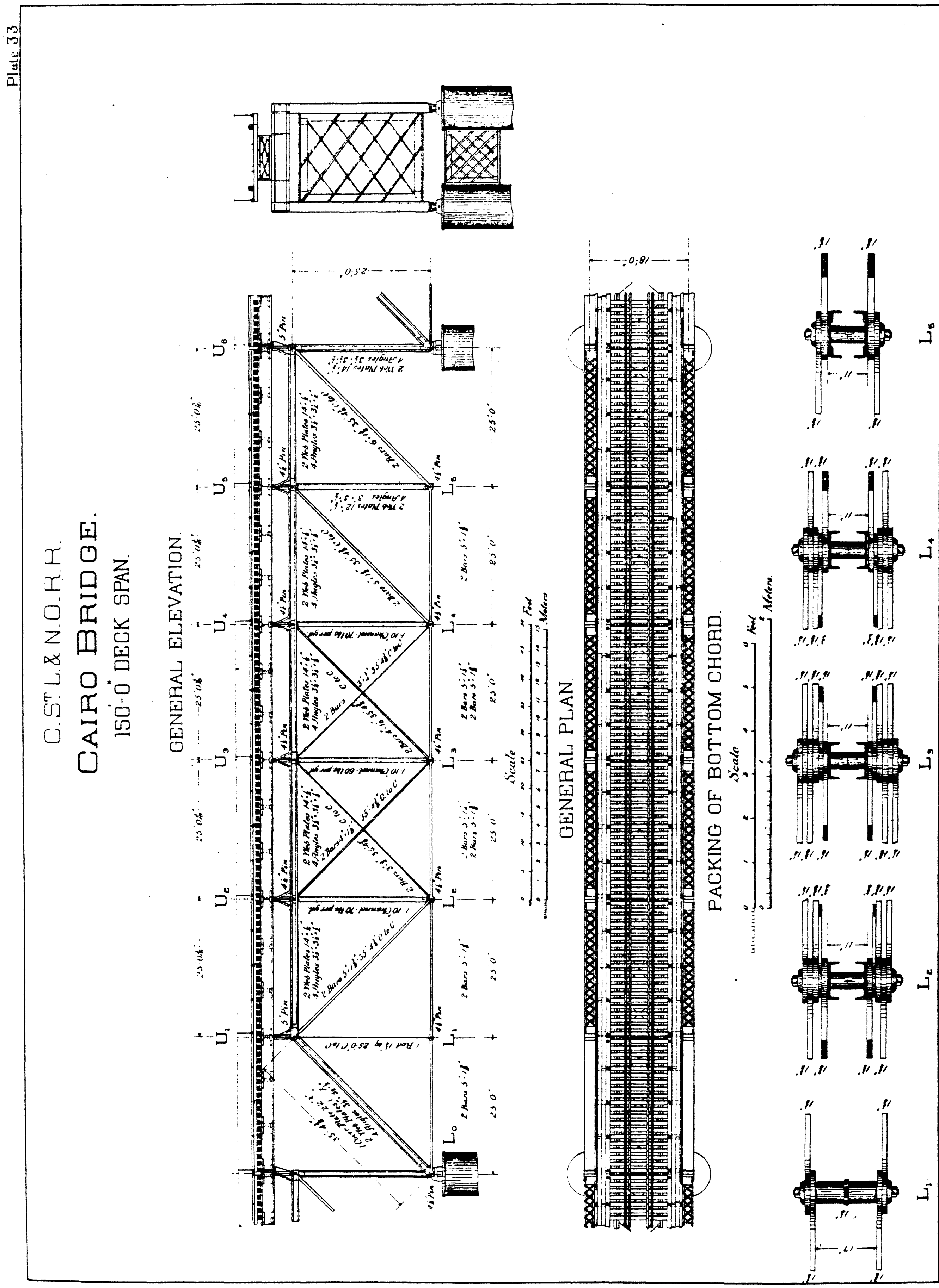


Plate 33
C.ST.L.& N.O.R.R.
CAIRO BRIDGE.
150'-0" DECK SPAN.
GENERAL ELEVATION.
GENERAL PLAN.
PACKING OF BOTTOM CHORD.
Scale
Feet
Meters

Figure 120

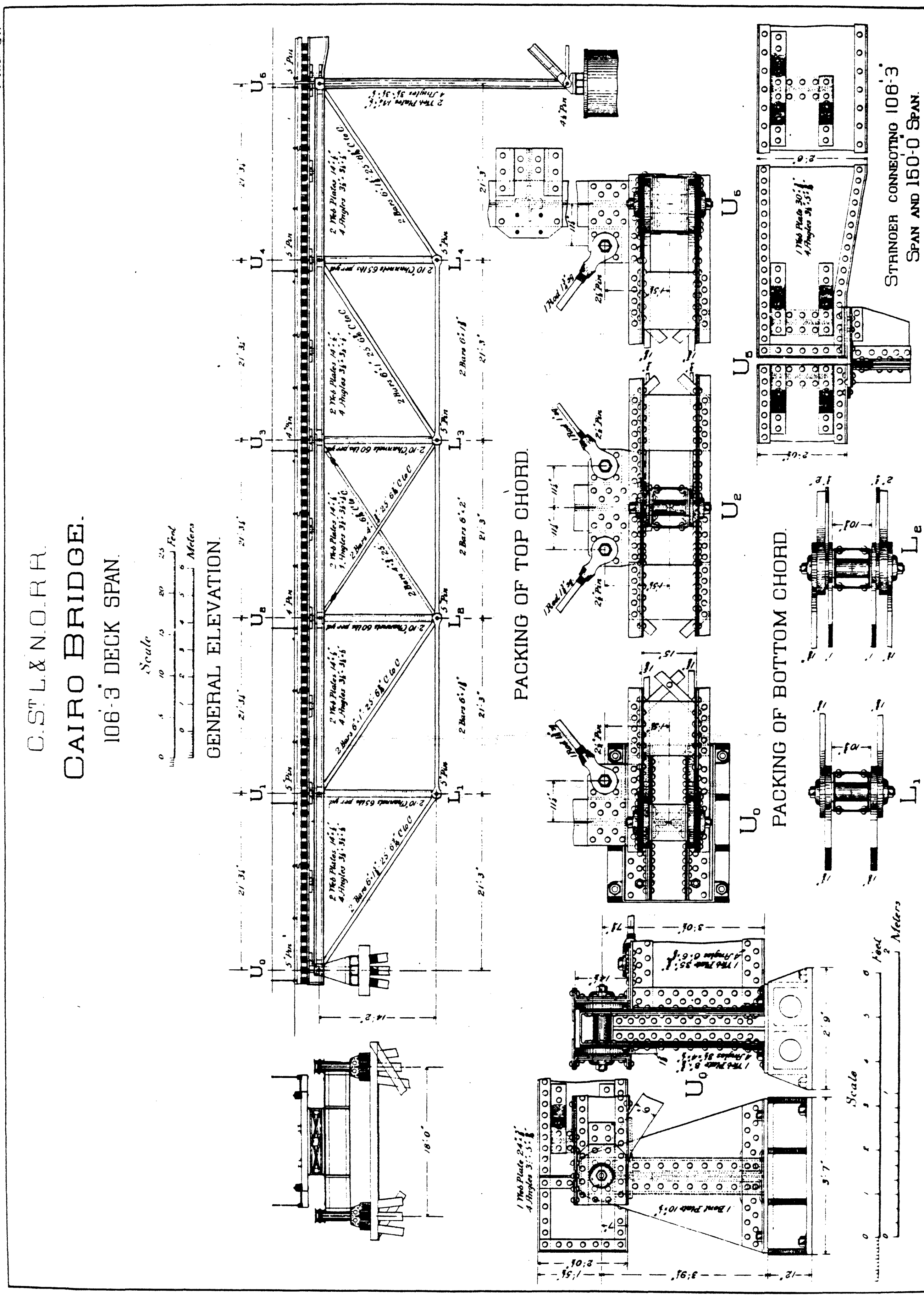


Plate 37.
C.ST.L.& N.O.R.R.
CAIRO BRIDGE.
106'-3" DECK SPAN.
GENERAL ELEVATION.
PACKING OF TOP CHORD.
PACKING OF BOTTOM CHORD.
STRINGER CONNECTING 106'-3" SPAN AND 150'-0" SPAN.

Figure 121

PACIFIC NORTHWEST BRIDGES

As construction progressed on the immense Cairo Bridge in 1888, George Morison undertook two important bridge commissions far afield in the Pacific Northwest. That year, the Oregon Railway and Navigation Company contracted with the engineer to design spans over the Willamette River at Portland, Oregon, and over the Snake River at a rural crossing in Washington Territory. Morison had dealt vicariously with the Portland-based company on an earlier bridge project, for it was Henry Villard and the OR&N who were vying to take over control of the Northern Pacific Railroad as Morison engineered the Bismarck Bridge eight years earlier. But several events had taken place since the completion of that early structure which would significantly change the complexion of commerce in the Pacific Northwest.

After acquiring the Northern Pacific in 1881, Villard at once organized the Oregon and Transcontinental, a holding company with interest in both the NP and the OR&N. He rationalized this as a move "to supply the Northern Pacific with needed branch lines which the latter company, owing to the limitations of its Congressional Charter, could not build itself," but a member of Villard's staff later revealed that the consolidation was intended to "anticipate and forestall all future rival corporations, by covering every choice or available location while laws and circumstances are so favorable."[62] Typical of Villard, the move was both daring and shrewd. But Villard's strength lay in financial maneuvers; he knew little about, nor paid much attention to, the costs involved in day-to-day construction and operation of a railroad. The unexpectedly high cost of completing the Northern Pacific had left his holding company near bankruptcy, and by 1883 Villard faced serious financial difficulty. In exchange for an infusion of capital from a syndicate of bankers, Villard relinquished executive control of his two railroads to William J. Endicott (NP) and T. Jefferson Coolidge (OR&N).

The two bankers soon discovered a disasterous state of confusion in the operation of Villard's railroads, and Coolidge, who had once managed the Atchison, Topeka and Santa Fe, quit in disgust after only six months. "The confusion in everything is so great," he complained, "that $1400 tons of steel rails which had been shipped by us, via Northern Pacific Railroad had been lost without anybody knowing anything about them, and after several months search they were found laid in the track of the Northern Pacific."[63] One of the priorities of new management was to make much-needed physical improvements to the line, including bridge construction. They contacted George Morison late in 1883 to consult on this. After an extended stay in the region in late winter

1884, Morison made his recommendations, but the railroad did not undertake any construction on either the Willamette or Riparia bridges.[64] Then in April 1885, Coolidge's successor, Elijah Smith, and the Union Pacific bought 40,000 shares of Oregon and Transcontinental stock. With controlling interest in both the O&T and the OR&N, UP representatives assumed seats on the boards of directors of both companies. "The significance of this you will see at once," said UP President Charles Adams, "The whole thing changes front. Instead of being in an alliance with the Northern Pacific, [the Oregon Railway] passes into alliance with the Union Pacific... I regard it myself as one of the most significant developments that have taken place since I have been in control."[65]

The Union Pacific would later acquire the Oregon Railway outright after lengthy negotiation, but for the present was content to settle a 99-year lease between the OR&N and another of its holdings, the Oregon Short Line, in April 1887. But Henry Villard, now a director of the Northern Pacific, would not concede defeat. Over the next eighteen months the Northern Pacific and Union Pacific engaged in round after round of of acrimonious maueverings to gain control of the Oregon Railway and the lucrative Portland market. Late in 1888, the Union Pacific sensed victory after going back into the market and purchasing still more shares of O&T stock, and Adams offered a concessionary offer to the Northern Pacific. The NP directorate spurned this, and on May 17, 1889, the two now-bitter rivals engaged in battle in the stock market described as the most exciting in Wall Street history to gain final control of the O&T. Villard won that round. After several more moves, countermoves and, finally, concessions, the Union Pacific wrested control of the Oregon Railway from Villard and the Northern Pacific in July.[66]

Thus, although the contenders were different, things had not changed much over the preceding eight years for the Oregon Railway, as far as George Morison was concerned. The company that Villard had built was locked in another desperate takeover struggle when the engineer was called upon to design the two final links in the Oregon Railway's main line: the bridges over the Willamette near the rail yards in Portland and over the Snake at Riparia. The company had operated rail car transfer ferries at both points for years. The relatively mild nature of the crossings did little to encourage construction of permanent bridges. By 1888, however, the OR&N was prepared to erect spans over the two rivers and had received Congressional charters for both.[67] The structures that George Morison designed for the railroad company would be the first steel bridges built in the Pacific Northwest.

WILLAMETTE BRIDGE

Portland was situated some eight miles above the confluence of the Columbia river and the Willamette, its tributary. Located so close to its parent river, the level and character of the Willamette here were thus determined by the Columbia. The Willamette ranged twenty-eight feet between low and high water at Portland, with the highest water typically occurring in June as the Columbia flooded. Winter or early spring floods frequently raised the water level in the Willamette, sometimes as much as twenty feet, but typically much less. In extreme high water, however, the river at Portland carried no current at all or even a slight upstream current due to the backwater effect from the larger Columbia.

The location for the Willamette Bridge had been predetermined by the railroad as the site of its earlier transfer operation. Immediately north of the location were the grounds of the Northern Pacific Terminal Railroad and the proposed site for the Portland station. The channel at this point (shown in Figure 122) had already been constricted to a 580-foot width by wharves on both

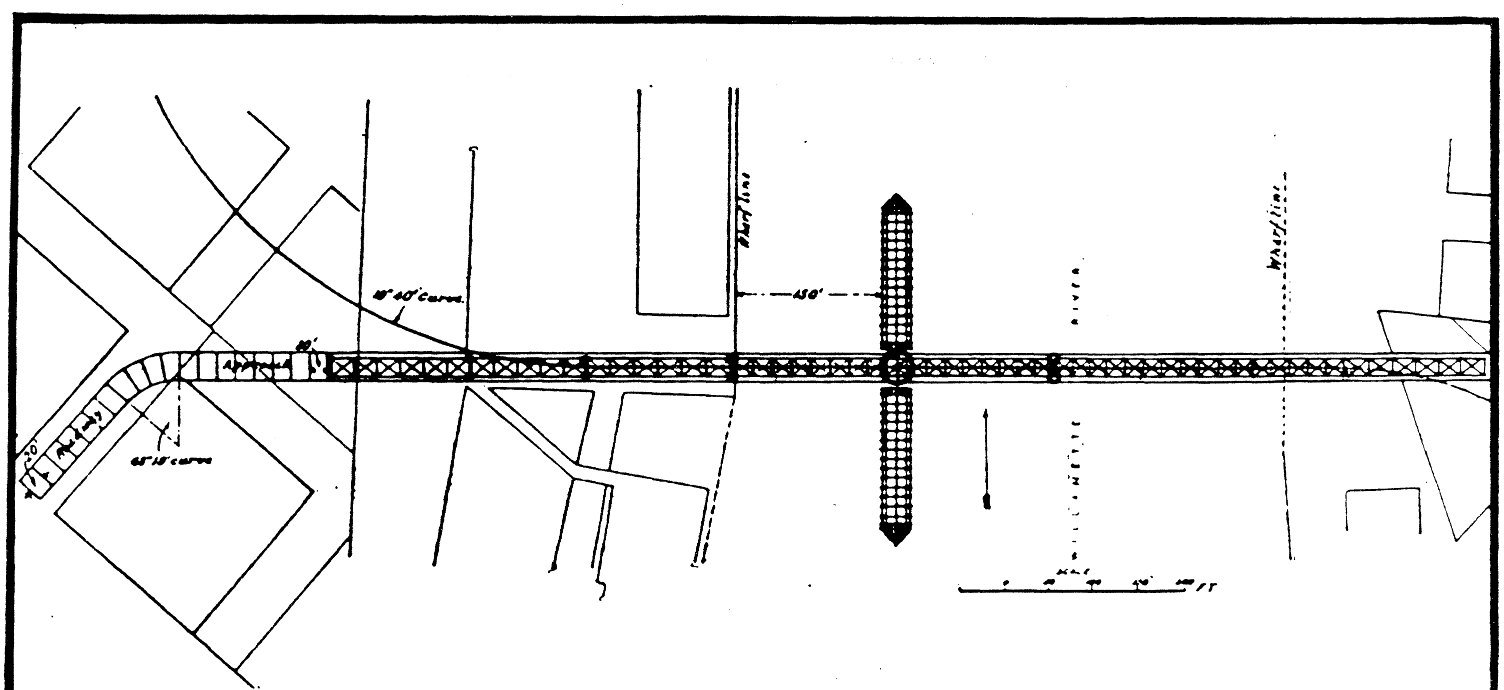


Figure 122

sides. This resulted in a site with a relatively narrow channel and stable riverbed, but with an unusually great water depth.

The design constraints that Morison faced were severe. First, the Willamette was a navigable watercourse through Portland and was used frequently by the steamships of the Oregon Railway and Navigation Company. No bridge could therefore impede river traffic. At Portland, as at Riparia, Morison did not have the benefit of a riverside bluff from which to launch a high truss. Moreover, the established street grades immediately adjacent to the bridge site stood only inches above the high water level. The Willamette Bridge would have to accomodate both railroad and vehicular traffic. With street and railroad links already established at both approaches of the bridge, a high, fixed-span bridge was impossible. "In order to utilize the [railroad] grounds," Morison stated, "it was necessary to cross the street at grade, and this involved putting the bridge as near as possible to high water."[69] Given these restraints, it is unsurprising that the bridge that Morison designed for Portland was completely unlike any of his Missouri River spans of the 1880s. In fact, the Willamette Bridge was unlike any other structure he would ever design.

The most striking feature of the Willamette Bridge was its double-deck configuration. The bridge carried a single railroad track on its bottom chord and a highway midway on the web. To accommodate the two levels of traffic with a pivot, Morison engineered double-intersected through trusses for both the fixed and moveable spans. The draw span was was 40 feet tall and 340 feet long, subdivided into seventeen panels of 20 feet each. The main fixed span on one end of the draw was also 40 feet tall and 320 feet long. On either end of the channel trusses, the highway was carried over the railroad grade by single-intersection through trusses, half the depth of the double-deck spans. Unlike Morison's other bridges, the channel spans of the Willamette featured upright end posts and unusual pin connected details (shown in Figure 3). The substructure consisted of a massive masonry pier beneath the pivot of the draw span, founded on driven timber piles. The one anchor pier for the draw in the main channel consisted of two 14-foot iron cylinders filled with concrete and supported by piles (19 per cylinder).[70]

Morison engineered the turntable drum using a standard cylindrical configuration. The bottom chords of the pivot span were attached to the five-foot tall, 28-foot diameter plate girder drum (shown in Figure 4). This in turn rested on 50 conical, cast steel wheels, which radiated on spokes from a central hub within the drum. To rotate the draw span, power from a bridge-mounted steam engine drove a vertical shaft, at the end of which a pinion gear was attached. This engaged with a geared, circular rack, which in turn was bolted to the masonry pier.

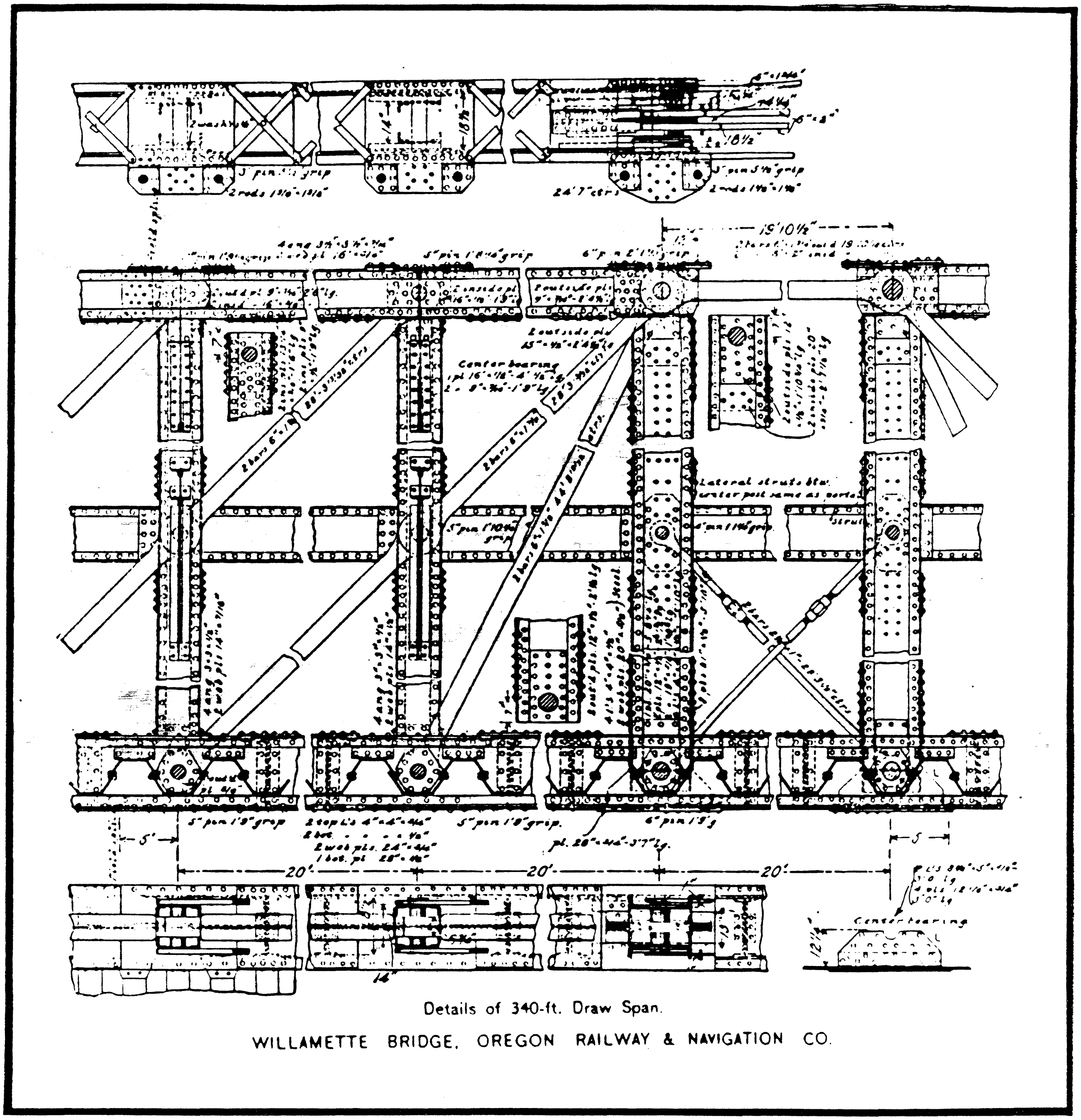
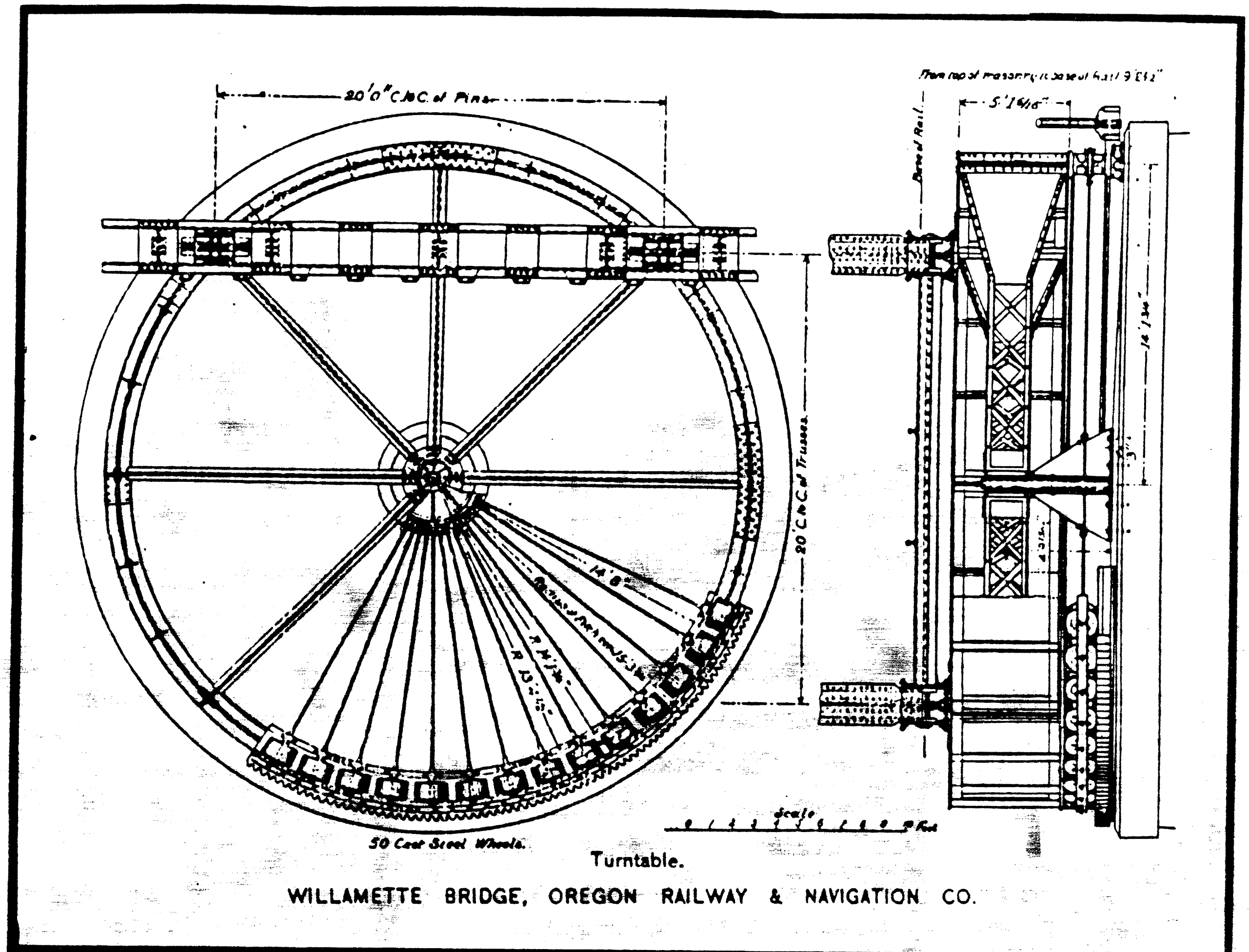


Figure 123

Vertical clearance under the bridge was at a premium. "The character of the river is such," Morison stated, "that it was considered entirely judicious to use the small head room indicated, and even allow the turn-table of the draw to



Turntable.
WILLAMETTE BRIDGE, OREGON RAILWAY & NAVIGATION CO.

72

Figure 124

be submerged."[73] To further reduce the depth from the base of the rail to the bottom of the lower chord, Morison delineated an innovative floor system for the railroad level. Instead of the traditional arrangement of floor beams and stringers, Morison designed the bridge with a structural steel deck which spanned between the rigid bottom chords on each side. This deck was made up of obtuse channels riveted to form deep corrugations. The ties for the tracks were placed within the corrugations to further reduce the depth. The deck plate and the stiff lower chords therefore acted as a horizontal deck girder, which not only supported the rolling weight of the locomotives, but resisted the lateral impact from material floating on the river in flood stage. As an additional precautionary step, Morison fixed the bearing points for the fixed channel truss rigidly to the abutment. Expansion and contraction, much less at

Portland than at Midwestern locations, was to be taken up entirely by the spring of the piers.

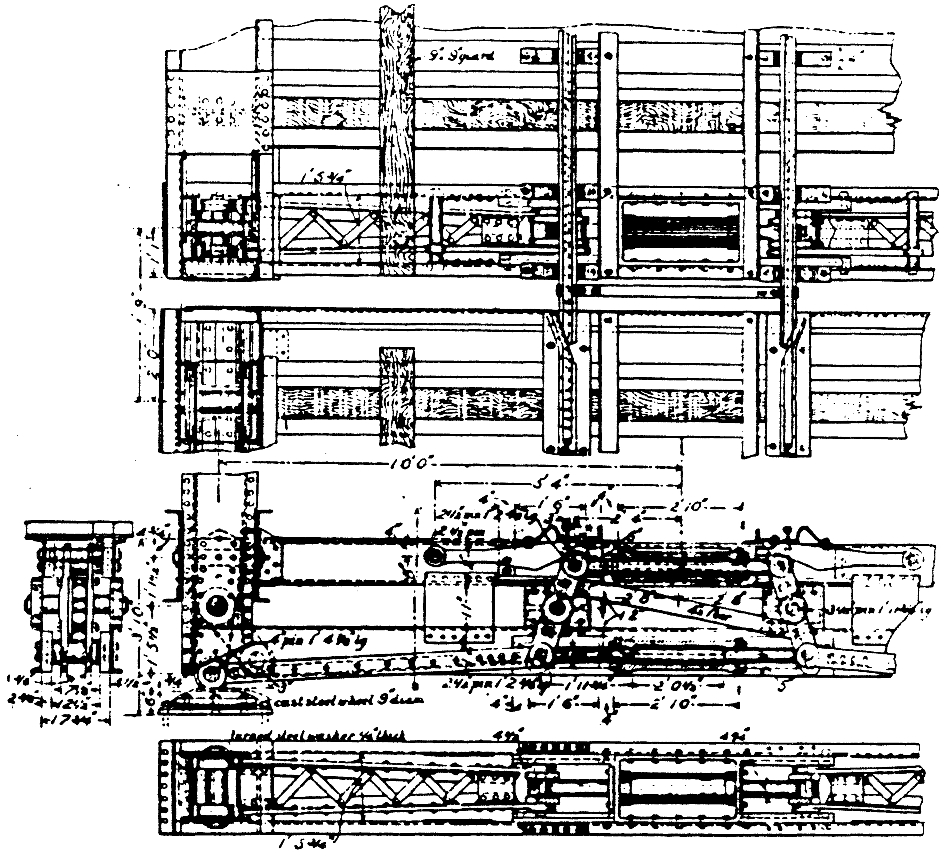
Steamship traffic along the Willamette was heavy, with as many as four major boats passing the bridge site per hour. One of the constraints placed on Morison's design, therefore, was that the bridge be capable of swinging quickly to avoid interrupting shipping traffic. He geared the swing mechanism of the 1.2 million pound pivot span to release and turn in less than one minute. This speed was due in part to his novel latching mechanism for the draw span, as described in The Railroad Gazette:

> The draw is turned by steam, the machinery for this purpose having been built and erected by the Vulcan Iron Works of Chicago. The turntable is of the usual rim-bearing pattern, the tread being of rolled steel and the wheels of cast steel. The ends of the draw are lifted, after closing, by cams similar to those used on many other bridges, but worked by hydraulic pressure instead of the customary toggle joint and screw. There are two horizontal presses, one of which is used to lift the ends and the other to release them. They are worked by a Worthington pump, placed at the centre. The diameter of hydraulic piston is 4-1/4 in. and stroke 12 in. The water pressure is 1,000 lbs. per square inch.[74]

Morison used a hydraulic lift mechanism (shown in Figure 5) to allow quick action on the bridge. "The time to lift and release the ends of the draw is inappreciable," the magazine concluded.

As he had for his other bridges of the late 1880s, Morison specified all the principal components of the draw and fixed trusses to be steel. "All parts, except nuts, swivels, clevises, wall pedestal plates, and ornamental work, will be of steel," he stated. "The nuts, swivels, and clevises may be of wrought iron; the pedestal plates and ornamental work will be of cast iron."[75] The channels for the corrugated railroad decking was imported from England, because the pattern was not yet manufactured in America. The roadway approach spans were to be wrought iron. To fabricate the trusses, Morison, as usual, contracted with the Union Bridge Company. The Lassig Bridge Works of Chicago would build the iron approaches.

Although configured differently from Morison's other bridges, the Willamette Bridge was built using his standard construction sequence. Before construction began, the OR&N had secured a Congressional charter for the bridge. At the beginning of the project, Morison sent assistant George A. Lederle to Portland to serve as resident engineer in charge of the construction. Lederle had worked as an assistant engineer/draftsman on the Bismarck Bridge six years earlier. With the shore rectification works already in place, work on the Willamette Bridge commenced in mid-1888 as the Portland-based firm of Hoffman



Hydraulic Device for Lifting End of Draw

76

Figure 125

and Bates drove the foundation piles for the piers. Praised as a "length and straightness never seen in the eastern parts of the country," these timber piles were placed relatively inexpensively using barge platforms towed to the site. Carpenters erected a grillage - a heavy timber platform on which the masonry pier was constructed - over the piles for the pivot span pier.

Under Lederle's direction, a railroad work crew laid the massive masonry pier over the grillage and built the steel anchor piers at each end of the pivot. Early in 1839, the Union Bridge Company shipped the superstructural steel for the trusses and the Lassig bridge works completed the approach components. By April 1889, the railroad crew had completed erection of the superstructure, and the bridge was swung for the first time. Regular rail and wagon traffic soon followed.

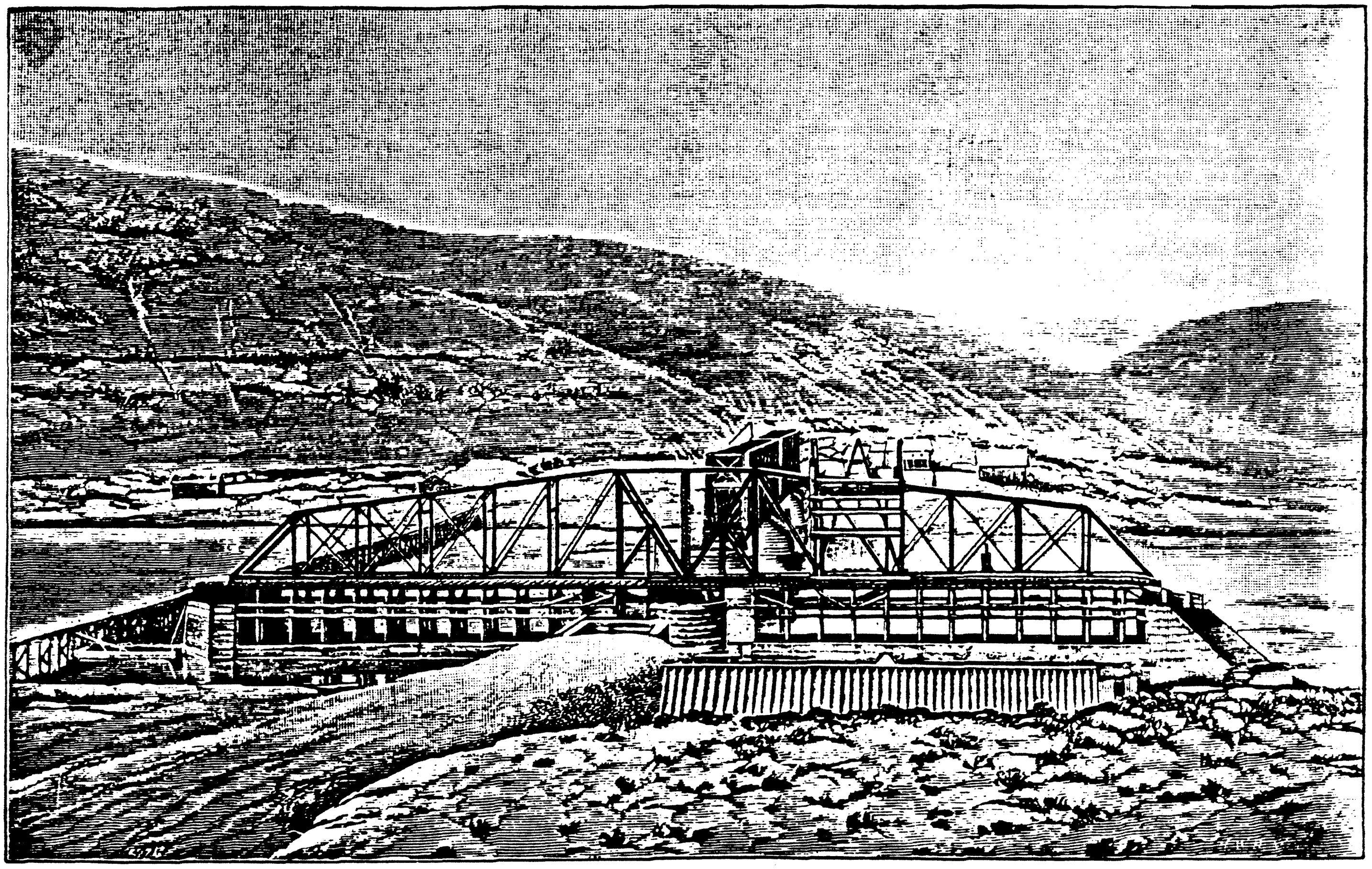
RIPARIA BRIDGE

The proposed Riparia Bridge presented a more conventional situation, and Morison's design reflected this. Like Willamette, Riparia was a swing-span structure, but the similarity ended there. Riparia was located at a rural crossing of the Snake River in Washington Territory, where the Oregon Railway trunk line dipped southwestward from its juncture with the Northern Pacific. The crossing of the Snake here was chosen to allow the railroad to parallel the south bank of the Columbia River on its route to Portland, some 300 miles west. This eliminated the need to cross the wider and more heavily trafficked parent river. Situated about 75 miles above its confluence with the Columbia, near the present town of Dodge, the Riparia crossing featured low riverbanks and did not present the severe space restraints that the Portland bridge had. Morison could therefore use a more traditional pivot-span design.

For Riparia, Morison delineated three single-track spans: two simply supported fixed trusses and a pivot span on one end over the navigable channel (shown in Figure 6). The fixed trusses were pin-connected Whipple throughs, 325 feet long and subdivided into thirteen 25-foot panels. Forty feet deep, eighteen feet wide and weighing approximately 700,000 pounds each, these trusses were virtually identical in detailing to those which Morison had erected over the Missouri River. As he had on his last two Missouri River bridges, the Cairo and the Willamette bridges, Morison specified steel - either open hearth or Bessemer - for the superstructure of the Riparia Bridge. The 325-foot draw span featured sloped upper chords and standard detailing. The center two panels, about which the bridge rotated, were suspended by heavy diagonal members which connected at the bottom chord to a built up center column. For the pivot span and the draw mechanism, Morison used standard configuration and detailing. "The only original feature of this bridge," Engineering Magazine stated, "is the turntable of the draw span." The magazine continued:

> The entire weight of the draw is carried on two cross-girders which connected together. The girders are carried on the plunger of a central hydraulic press. When the bridge is closed the weight of the trusses is carried directly to the masonry by side bearings, on which the crossing is raised by the hydraulic press until the side bearings are entirely clear, and then the bridge turns easily on the fluid centre. In turning the draw is guided and kept level by eight wheels with heavy spring bearings, the springs being strong enough to prevent any rocking of the draw when turning, and not so stiff but what they are compressed when the bridge is lowered on the side bearings.[77]

Morison engineered heavy masonry piers for Riparia. The three channel piers



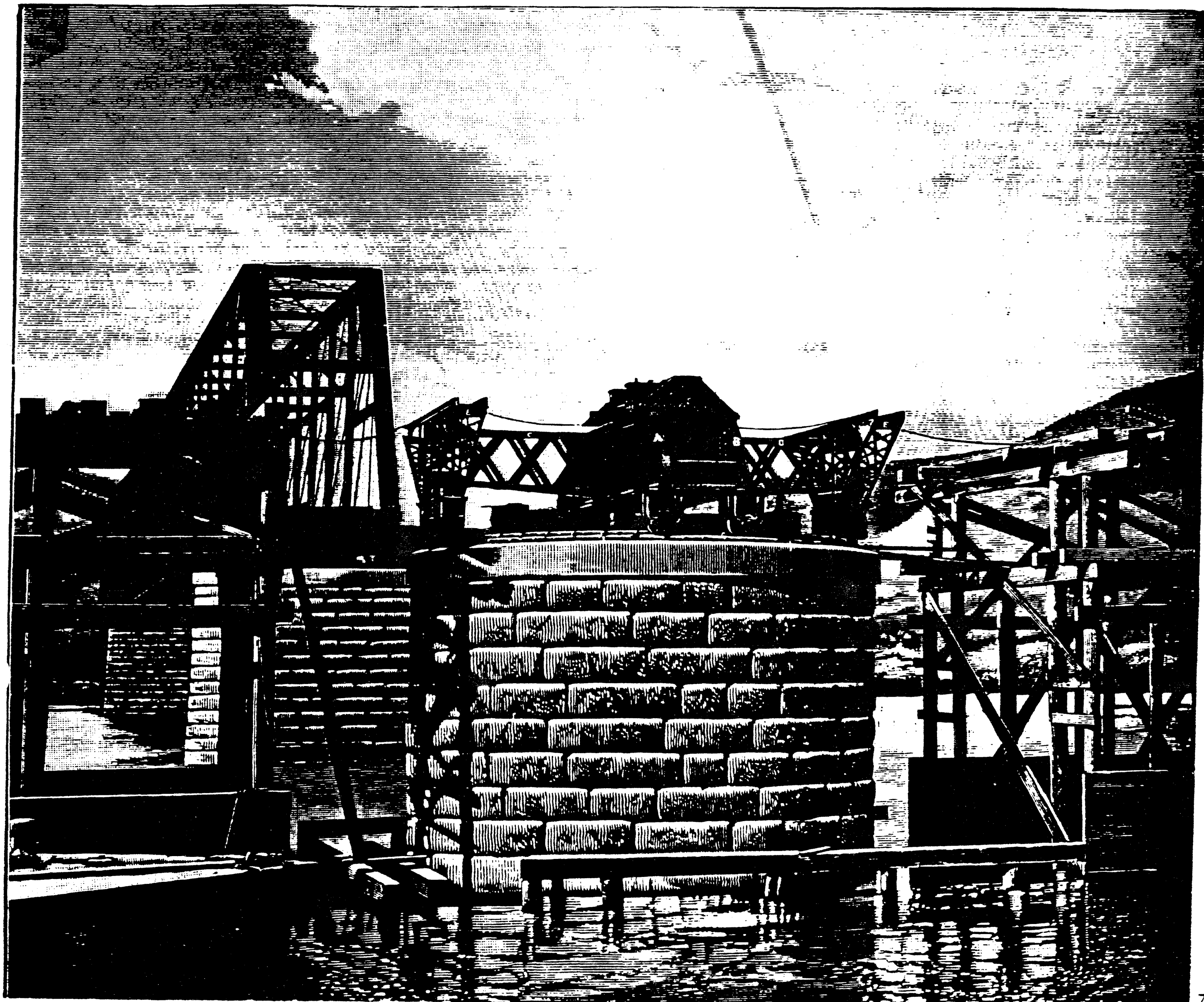
78

Figure 126

were founded on pneumatic caissons and the two abutments on driven piles. The piers were built of basaltic stone, cut at the quarries and laid in a coursed ashlar pattern with dressed stone copings. The pivot pier, which carried the circular turntable and machinery, was a massive cylinder with vertical walls (shown in Figure 7). The fixed-span piers were simply shorter versions of his fixed-span piers used on previous bridges.

Construction of the Riparia Bridge commenced simultaneously with the Willamette Bridge in 1888. As specified, the steel for the fixed spans was shipped to the site by December 1888 and the draw span material a month later. The bridge was opened later in 1889.

The Riparia and Willamette Bridges represented Morison's first swing-span structures. As he faced similar conditions on another great American river, the engineer would design bridges which combined the length of the Cairo Bridge



79

Figure 127

with moveable trusses similar to those he had executed in the Pacific Northwest. Though not as technologically challenging as his Missouri River bridges, Morison's next spans would become among his best known, because they were located in the populated heart of the nation on America's most famous watercourse - the Mississippi River.

ENDNOTES

1 Richard C. Overton, Burlington Route (New York: Alfred A. Knopf, 1965), page 12; Stewart H. Holbrook, The Story of American Railroads (New York: Crown Publishers, 1947), pages 103-04.

2 Robert West Howard, "The Ohio River: Throughway 'For the West'," Water Trails West (New York: Doubleday & Company, Inc., 1978), page 44.

3 David Plowden, Bridges: The Spans of North America (New York: The Viking Press, 1974), page 69; Theodore Cooper, "American Railroad Bridges," Transactions of the American Society of Civil Engineers, July 1889, page 17. As George Morison was known as the pre-eminent bridge designer for the Missouri River in the 1880s, Jacob Linville was by far the most prolific engineer on the Ohio River in the 1860s and 70s. Linville designed the 320-foot-span Steubenville Bridge in 1863 and in 1870 built 340-foot-span bridges over the Ohio at Parkersburg and Bellaire. In 1872, Linville built the Newport and Cincinnati Bridge, with a channel span of 420 feet. In 1876 he designed another bridge over the Ohio for the Cincinnati Southern Railroad to connect the coal fields of Kentucky with the industrial region of the Great Lakes. Completed the following year with a channel span of 517 feet, it was the longest truss built to date. It was also the first major American bridge for which competitive bidding among bridge companies was solicited based upon specifications drawn by an engineer acting solely in behalf of the railroad. The Steubenville Bridge was the first major railroad truss in this country proportioned to carry a moving load of 3,000 pounds per lineal foot, superceding the previous industry standard of one ton per foot

4 Stuyvesant Fish, President, "Report to the Board of Directors of the Chicago, St. Louis and New Orleans Railroad Company," 24 February 1892, Newberry Library, Illinois Central Collection.

5 John F. Stover, History of the Illinois Central Railroad (New York: Macmillan Publishing Company, Inc., 1975), page 144.

6 John F. Stover, History of the Illinois Central Railroad, page 158.

7 Carlton J. Corliss, Main Line of Mid-America (New York: Creative Age Press, 1950), pages 205-06. John F. Stover, History of the Illinois Central Railroad, page 159.

8 Louis C. Hunter, Steamboats on the Western Rivers: An Economic and Technological History (New York: Octagon Books, 1969), page 587.

9 S.F. Balcom, Assistant Engineer, Illinois Central Railroad, "The Ohio River Bridge at Cairo," paper presented to Illinois Society of Civil Engineers and Surveyors, excerpted in Railroad Gazette, 1 June 1888.

10 Lewis H. Haney, A Congressional History of Railways in the United States: 1850 to 1887 (1908-10; reprint edition, New York: Augustus Kelley, Publisher, 1968), pages 231-32; David Plowden, Bridges: The Spans of North America, pages 75-78.

11 "An Act to Authorize the Construction of Bridges Across the Ohio River, and to Prescribe the Dimensions of the Same," 17 December 1872; "A General Bridge Bill for Western Rivers," Engineering News, 11 February 1888. Under the Ohio River Bridges Act, a railroad or bridge company had only to notify the Secretary of War of the its intentions to bridge the Ohio and present the required documentation for the bridge's design. The Secretary then appointed a board to review the proposal, and upon the board's approval entered into a contract with the proposing group. On the other hand, bridge charters for the other navigable Midwestern Rivers, including the Mississippi and Missouri, were granted individually by Congress. The design guidelines were enforced on a policy level by the War Department, which, as on the Ohio, held the power of review over the proposing companies. This cumbersome procedure necessitated considerable time and expense to shepherd a special bill through the Congressional process. The difficulty in securing charters predictably led to abuses, and a sort of black market for bridge charters eventually developed. The asking price for one Mississippi River bridge charter in 1888 was said to be around $250,000.

12 Cincinnati Chamber of Commerce, Bridging the Ohio River: A Presentation by a Committee of the Cincinnati Chamber of Commerce in Opposition to the Modification by Congress of the Act of Dec. 17th, 1872, Prescribing the Dimensions of Bridges over the Ohio River (Cincinnati: Times Steam Printing, 1876).

13 Carlton J. Corliss, Main Line of Mid-America, pages 229-231.

14 Stuyvesant Fish, "Report to the Board of Directors..."; John F. Stover, History of the Illinois Central Railroad, page 202. In a herculean effort, the southern railroad changed its entire 550-mile length between Cairo and New Orleans to standard gauge in less than a day in July 1881, using some 3,000 men deployed along the tracks.

15 "An Act Authorizing the Chicago, St. Louis and New Orleans Railroad Company and the Illinois Central Railroad Company, or Either of Them Separately, to Build and Maintain a Railroad Bridge across the Ohio River," Commonwealth of Kentucky, 30 March 1886, reprinted in The Cairo Bridge, George S. Morison, (Chicago: Knight, Leonard and Co., 1892), page 20.

16 Carlton J. Corliss, Main Line of Mid-America, pages 229-231.

17 Stuyvesant Fish, "Report to the Board of Directors..."; George S. Morison, The Cairo Bridge, page 9.

18 O.S. Nock, Railways of the USA (New York: Hastings House, 1979), page 93; John F. Stover, History of the Illinois Central Railroad, page 204.

19 George S. Morison, The Cairo Bridge, page 9.

20 George S. Morison, The Cairo Bridge, page 10.

21 S.F. Balcom, "The Ohio River Bridge at Cairo."

22 George S. Morison, The Cairo Bridge, page 10.

23 George S. Morison and E.L. Corthell, "Report to E.T. Jeffery," 3 March 1887, reprinted in The Cairo Bridge.

24 George S. Morison and E.L. Corthell, "Report to E.T. Jeffery."

25 George S. Morison, The Cairo Bridge, page 10; Modjeski and Masters, Engineers, Final Report on the Reconstruction, Illinois Central Railroad, Cairo Bridge Over the Ohio River, 1 June 1953, page 15, Modjeski and Masters, Harrisburg, Pennsylvania.

26 "Act of Congress Authorizing Construction of Bridges over the Ohio River," 17 December 1872, reprinted in The Cairo Bridge.

27 George S. Morison, "Bridges Regarded as Commercial Tools," New York: Evening Post Job Print, 1 February 1890. Privately published pamphlet reproducing paper read by George Morison to St. Louis Commercial Club in March 1889, page 2.

28 Walter Havighurst, Voices on the River: The Story of the Mississippi Waterways (New York: The Macmillan Company, 1964), page 99; George S. Morison, "Argument for Amendment of Charter of the Memphis Bridge," 4 January 1890.

29 George S. Morison, "Bridges Regarded as Commercial Tools," page 2.

30 S.F. Balcom, "The Ohio River Bridge at Cairo."

31 "Fast Erecting on the Cairo Bridge," Railroad Gazette, 11 January 1889, pages 18-19.

32 George S. Morison, The Cairo Bridge, page 13.

33 "The Cairo Bridge," Railroad and Engineering Journal, December 1889, page 557.

34 George S. Morison, The Cairo Bridge, page 13.

35 George S. Morison, The Plattsmouth Bridge (New York: S.B. Leverich, 1882), page 10; George S. Morison, The Nebraska City Bridge (Chicago: Knight, Leonard & Co., 1892), page 14.

36 George S. Morison, The Cairo Bridge, pages 12-13; E.L. Corthell, "Address on Retiring from Presidency of the Western Society of Engineers," paper read before the Western Society of Engineers, 8 January 1890.

37 George S. Morison and E.L. Corthell, "Report to E.T. Jeffery."

38 George S. Morison, The Cairo Bridge, pages 10-11.

39 George S. Morison and E.L. Corthell, "Report to E.T. Jeffery."

40 "Contract for Bridge Across the Ohio River, at Cairo, Ills." Contract between the Union Bridge Company and the Chicago, St. Louis and New Orleans Railroad Company, 4 May 1887, reprinted in The Cairo Bridge.

41 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir (Peterborough, New Hampshire: Peterborough Historical Society, 1940), pages 9, 16-17.

42 John F. Wallace, J.A. Ocker and W.J. Karner, "Elmer Lawrence Corthell," Transactions of the American Society of Civil Engineers, 1917.

43 Letter: George Morison to John H. Morison, 28 December 1890, reprinted in George Shattuck Morison, 1842-1903: A Memoir.

44 George S. Morison, "Bridges Regarded as Commercial Tools," page 13.

45 George S. Morison, The So-Called Quarantine at San Francisco, New York: Evening Post Job Print, 1 May 1889. Privately published pamphlet.

46 Despite the collective name of the firm, William Baird, who as superintendent of superstructure for the Keystone Bridge Company had built the Plattsmouth Bridge nine years earlier, was again working alone. A few years earlier, two of his brothers were erecting a bridge at Covington, Kentucky, when a large traveler collapsed, shattering the bridge and killing several men, including the Bairds. William Baird retained the "Brothers" in the name of his firm. Alton (Illinois) Daily Telegraph, 14 September 1893.

47 George S. Morison, The Cairo Bridge, page 17.

48 George S. Morison, The Cairo Bridge, page 11.

49 Edward H. Connor, "The Substructure of the Cairo Bridge," paper presented to the Engineers' Club of St. Louis, 19 February 1890, reprinted in the Journal of American Engineering Societies, June 1890, pages 296-297.

50 George S. Morison, The Cairo Bridge, pages 11-12.

51 George S. Morison, The Cairo Bridge, page 12.

52 George S. Morison, The Cairo Bridge, page 13.

53 "Fast Erecting on the Cairo Bridge," Railroad Gazette, pages 18-19.

54 "Fast Erecting on the Cairo Bridge," Railroad Gazette, pages 18-19.

55 George S. Morison, The Cairo Bridge, page 13.

56 George S. Morison, The Cairo Bridge, page 9; O.S. Nock, Railways of the USA, pages 93-94.

57 Carlton J. Corliss, Main Line of Mid-America, pages 226-228.

58 Reprinted in Carlton J. Corliss, Main Line of Mid-America, page 226.

59 George S. Morison, The Cairo Bridge, pages 14-16.

60 "A Proposed Great Bridge," Engineering News and American Contract Journal, 13 March 1886.

61 Louisville Courier Journal, as quoted in Engineering News, 15 September 1888.

62 Letter: Henry Villard to J.H. Halstead, 2 March 1882, reprinted in Union Pacific Country, Robert G. Athearn, (New York: Rand McNally & Company, 1971), pages 326-28.

63 Letter: T. Jefferson Coolidge to Executive Committee of the OR&N, 10 July 1884, reprinted in Union Pacific Country.

64 Letter: George Morison to J.S. Cameron, 19 January 1884, Newberry Library, Burlington Northern Collection (8R8.1 - 2).

65 Letter: Charles Adams to Gardiner Lane, 11 June 1886, reprinted in Union Pacific Country.

66 Robert G. Athearn, Union Pacific Country, pages 326-28.

67 Despite the fact that the Willamette Bridge lay entirely within the state of Oregon and did not, strictly speaking, constitute interstate travel, Congress excercised its power to regulate its construction because the bridge was situated over a navigable watercourse and therefore indirectly

effected the interstate commerce which traveled along the river. Additionally, Congress authorized the construction of bridges within states, empowering the railroads to take the land needed for piers by eminent domain. In chartering the Pacific railways, Congress empowered the various companies to construct bridges as necessary. Congress' authority to do so had been recently affirmed by the courts in Hatch vs. Willamette Bridge Company, involving another Oregon bridge. Lewis H. Haney, A Congressional History of Railways in the United States: 1850 to 1887, page 236.

68 "The Willamette Bridge," Railroad Gazette, 19 April 1889, page 260.

69 "The Willamette Bridge," page 261.

70 "The Willamette Bridge," page 261.

71 "The Willamette Bridge," page 261.

72 "The Willamette Bridge," page 261.

73 "The Willamette Bridge," page 261.

74 "The Willamette Bridge," page 261.

75 "The Willamette Bridge," page 261.

76 "The Willamette Bridge," page 261.

77 "The Riparia Bridge," Engineering Magazine, 6 November 1891, page 533.

78 "The Riparia Bridge," page 533.

79 "The Riparia Bridge," page 533.

MISSISSIPPI RIVER BRIDGES

No other river in America has touched Americans' collective psyche quite like the Mississippi. Extending from the backwoods of northern Minnesota through the middle of the nation to the Gulf of Mexico, the Mississippi effectively drains the country's center. Throughout most of the 19th Century, it served as the dividing line between East and West, between civilization and the vast prairieland that lay beyond. Functioning as an immense winding throughway, the river joined North and South, and the commerce which steamed over it nurtured dozens of major cities along its course. The Mississippi formed the real and symbolic heart of the Republic.[1]

As it meandered southward, the Mississippi formed an unavoidable obstacle to regional and transcontinental rail traffic. Fortunately for the railroads, its stable, sandy subsoil conditions, especially north of St. Louis, were far more favorable than that of the Missouri River for sinking bridge foundations. For this reason, and the fact that the Mississippi was closer to the eastern United States, this river was first bridged more than thirteen years earlier than the Missouri.

Over the first half of the 19th century, the great river had been the exclusive province of the steamboats which hauled freight and passengers over its length. Predictably, when the railroads began bridging the Mississippi at mid-century, the river interests reacted jealously to the challenge of their domain. They mounted a concerted opposition in Congress, in the courts and even at the bridge sites themselves to prevent the rival railroads from crossing the river. The first bridge over the Mississippi was for decades also the closest to its headwaters. In 1855, a suspension bridge was completed at Hennepin Avenue in Minneapolis, Minnesota. It was a lightweight roadway structure, spanning 620 feet, with four main cables supported by wooden towers. (This bridge was replaced in 1877 by another, longer-span suspension bridge, which in turn was replaced by a series of steel arches.)[2]

Located at the far northern reaches of the river in Minnesota, this first structure did not present much of an obstacle to the steamship companies. Moreover, it carried vehicular and not rail traffic and thus did not present a direct threat to river commerce. The Hennepin Avenue Bridge was followed in 1856 by the first railroad bridge over the Mississippi, located at Rock Island, Illinois.[3] The first all-metal bridge over the Mississippi was the wrought/cast iron swing-span bridge at Burlington, Iowa, completed in 1868 by the Chicago, Burlington and Quincy Railroad. Other iron draw bridges soon followed,

including railroad bridges at Quincy, Illinois (1868), Dubuque, Iowa (1868) and Hastings, Minnesota (1871). All of these were built in the upper reaches of the river, above the mouth of the Missouri. In completing his St. Louis bridge in 1874, Colonel James Eads was the first to succeed in bridging the lower Mississippi.

George Morison designed his first bridge over the great river with E.L. Corthell in 1888. Called the Merchants' Bridge, it was funded as a double-track railroad crossing over the Mississippi by a collection of St. Louis railroad entrepreneurs and businessmen and chartered by Congress in 1887. Morison designed a high, fixed-span structure for St. Louis that generally resembled his bridges over the Missouri River. The Merchants' Bridge consisted of three 518-foot, pin-connected Pennsylvania trusses, with deck span approaches on both ends. The clearance beneath the bridge, as prescribed by law, was fifty feet over the high water mark. The immense all-steel trusses were supported by solid masonry piers, which were founded, like Morison's Missouri River bridges, by pneumatic caissons on bedrock. Completed in May 1890, the Merchants' Bridge was the first curved-chord truss erected over the Mississippi.[4]

By the time of completion of the Merchants Bridge in 1890, twenty-one railroad bridges spanned the Mississippi between St. Louis and St. Paul.[5] Of all those below the Twin Cities, all but the Merchants and Eads bridges were swing-span structures. Construction of each of these bridges had been accompanied by the vehement protests of the steamboat interests, but their complaints, by this time, went largely unheeded.[6] By the early 1890s, as more and more of the boat companies slipped into depression and bankruptcy, the railroads were reinvesting their increased profits in construction programs. This decade saw nine more railroad bridges erected over the river (two of which were replacement superstructures).[7] Of these, George Morison designed five. In addition to his long-span structure at St. Louis, he would, over the next five years, build railroad bridges at Winona, Minnesota, Burlington, Iowa, and Alton, Illinois. And it was on the Mississippi River that Morison would achieve his greatest bridge engineering accomplishment, "the first bridge across the Mississippi River proper," as he put it: the immense cantilevered span at Memphis, Tennessee.

WINONA BRIDGE

With its high truss configuration, the Merchants Bridge resembled Morison's Missouri River bridges more than it did contemporary spans over the Mississippi. High bridges were impractical at most locations along the Mississippi River, because the relatively low river banks would require extensive grading to raise the road to a level fifty feet above high water. Always pragmatic, Morison did not hesitate to design swing span bridges under such conditions, as he had demonstrated in the Pacific Northwest. His first opportunity to engineer a moveable span bridge over the Mississippi came in 1888, along the upper reaches of the river at Winona, Minnesota.

As had been the case with most of the bridges over the great Midwestern rivers, the idea for Winona Bridge had been conceived years before actual construction commenced. Congress first authorized the construction of a bridge here in 1866 as one of the first bridge charters granted for the Mississippi.[8] As early as 1882, Chicago, Burlington and Quincy president Charles Perkins suggested that his railroad extend its lines northward to St. Paul, Minnesota, which he called "the Kansas City of the North". The completion of the Northern Pacific in 1883 between St. Paul and the Pacific Northwest insured a lucrative rail traffic to this rapidly growing city. Perkins observed this as he took quiet reconnaissance trips that year over the St. Paul, Minneapolis and Manitoba, and Northern Pacific railroads. Back in Chicago, he reported to John Forbes that he was "a good deal impressed with the whole northern region, and with the importance of St. Paul as a growing commercial center to which the CB&Q ought to obtain access."[9] Perkins authorized surreptitious preliminary surveys that same year.

Later in 1883, Perkins could no longer keep his plans secret. In November, he ordered a full-scale survey for a line through Wisconsin to St. Paul. In March 1884, the State of Minnesota granted the railroad a charter for a railway between the Wisconsin state line and the capitol city. The railroad routed its new line on the eastern side of the river, from an extension of the Chicago and Iowa line through Wisconsin, as the shortest route between its terminus at Chicago and the proposed terminus at St. Paul. To build and operate the new line, Perkins established a subsidiary company, the Chicago, Burlington and Northern Railroad, with an initial capitalization of $18,000,000, equally divided between stocks and bonds. And to manage the new corporation, Perkins lured Albert Touzalin - George Morison's old adversary - back to the Burlington management from the Santa Fe Railroad.[10]

In the summer of 1885, construction began. Touzalin, who had repeatedly counseled caution and deliberation for the Rulo Bridge, pushed the construction of the new line at a breakneck pace. "Are you not perhaps trying to crowd your

construction too fast," Perkins counseled Touzalin in October, "to force conclusions which perhaps would be sooner reached if not forced? Of course time is important, but so is peace with your neighbors; sometimes you can make haste by going slow. Men don't like to be crowded, and of course you can't expect that the North-Western and the St. Paul people are going to welcome you with outstretched arms. They have power as well as you, and they also have more or less possession, and I should say the best general policy would be to let them take all reasonable time to talk and consult and negotiate even if it should delay you a month or two, but I don't believe it will. You can catch more Millers and Hughitts with molasses than with vinegar!"[11]

Despite Perkins' pleas to slow the construction, Touzalin progressed rapidly with the track-laying through Wisconsin. The Illinois Central soon reacted to the formidable competition by trying to impede track construction near Dubuque, Iowa, building a maze of unnecessary sidings on the constricted Portage Curve to block the Burlington's entry into this lucrative port city. This obstacle was removed eventually through a federal court order and a negotiated compromise between the two competing lines.[12] On April 9, 1886, the Chicago, Burlington and Northern Railroad ran its first regularly scheduled train from St. Paul to Prairie du Chien, Wisconsin, passing Winona on the Wisconsin side of the Mississippi River.[13]

Winona and southeastern Minnesota represented too fertile a territory for the railroad to bypass, however, and CB&N management immediately began implementing plans to enter the region. The railroad remodeled a building on the corner of Second and La Fayette streets in Winona as a station, acquired a right-of-way and built spur lines and switching yards.[14] During the first months, passengers and freight were ferried across the Mississippi River. William Osborne piloted the transfer steamer, the Little Hoddie [Hodie], from a landing near the station on the Minnesota side to another across the river in East Winona.[15] This second landing connected with the Wisconsin mainline by a spur track built from the mainline to the Wisconsin shoreline in September, 1886. Later that year, when ice on the river made navigation impossible, the Burlington put the boat into storage at Minneiska and built its first winter bridge. On December 16, the railroad shipped its first load of freight over the temporary structure.

The Burlington management was familiar with the shortcomings of this system, having functioned with ferries and winter bridges at several other points along the Mississippi and Missouri rivers at various times. Touzalin himself was acutely aware of the choice between operating a stopgap crossing and building permanent structure. The Winona operation would serve for the present, but the Little Hoddie could be considered at best a temporary and not very satisfactory solution. "Many persons would travel on the Burlington now," stated one local railroad official, "but the delay in crossing by the ferry boat, and the

annoyance of changing cars on the other side, results in most of the travel going to the Milwaukee road."[16] The solution was clear: if the Burlington was to continue service into Winona, it would have to erect a permanent bridge over the Mississippi.

One bridge already spanned the river at Winona. Built under the 1866 charter and opened to traffic in 1871, it was designed by Edward C. Carter for the Chicago and North Western Railroad. Crossing the river opposite the center of town to take advantage of a center island, the bridge originally consisted of a steam-driven, iron Post draw span with multiple Howe and queenpost fixed spans, but in 1886 the railroad replaced the fixed spans with riveted lattice trusses erected by the Lassig Bridge and Iron Company of Chicago. The trusses were supported by masonry piers with pile foundations.[17] Although the Burlington used the C&NW bridge for its passenger trains beginning in January 1887, the tolls exacted by the rival railroad were exorbitant, and the the CB&N soon considered an alternative crossing of the river.

Plans for a second railroad bridge at Winona began to take definite shape in spring of 1888. In that year, the Burlington allied itself with the Winona and Southwestern and the Green Bay and Western Railroads to undertake the costly construction project. The directors of the Winona and Southwestern (W&S) Railway applied for and received a Congressional charter to construct the bridge over the Mississippi at Winona. The following year, the rail company secured the requisite state charters from Minnesota and Wisconsin. Early in 1890, Chief Engineer D.M. Wheeler formulated the preliminary plans for the bridge. These were submitted to the War Department that spring.[18]

The original Congressional Act stipulated that construction must be undertaken on the bridge by August 13, 1890 or the charter would expire. With this deadline looming, the railroads moved rapidly once the Secretary of War approved the design. A new company - the Winona Bridge Railway Company - was incorporated in Minnesota on July 9, 1890. With an initial capitalization of $681,000 supplied by the three railroads, the corporation was formed to "maintain a railway which should cross the bridge, have its eastern terminus in Wisconsin at a connection with the Burlington road, and its western terminus in Winona."[19] Albert Touzalin, whose health had been failing under the stress of running the CB&N, would not live to see the construction of his last major bridge as a railroad administrator, however; in September 1899, he died.

The Winona Bridge Railway Company existed only to build and operate the bridge. The company's total trackage extended only 5,440 feet between the parent railroads' lines on either side of the river. Nevertheless, the company featured a novel provision in its articles of incorporation. In the past, railroads had been able to fix tolls for their bridges over the Mississippi, which other railroads using the bridges were forced to pay without appeal to the War

Department. This had spawned numerous complaints and disputes over which the government had no jurisdiction. The Winona Bridge, on the other hand, would be the first railroad structure over the Mississippi for which the Secretary of War had the authority to intervene and set reasonable tolls.

This provision reflected some broad trends in the country regarding interstate transportation. The 1866 Congressional act authorizing construction of bridges over the Mississippi River had required equal rate treatment of all railways that wished to cross the authorized bridges. Additionally, "no higher charge shall be made," the act stated, "for the transmission over the same of the mails, the troops, and the munitions of war of the United States, than the rate per mile paid for their transportation over the railroads or public highways leading to the said bridge." Congress was clearly looking after the interests of the government, but the formula made no provision for the government to set the rate. The 1866 charter served as a model for subsequent bridges over navigable rivers.[20]

In 1873, Congress considered regulating the rates charged by the Chicago, Rock Island and Pacific Railroad for its bridge over the Mississippi at Rock Island (the original Rock Island Bridge under new management), but made no resolution.[21] In the charter for a Missouri River bridge at Omaha, Congress ten years later "reserve[d] the right at any time to regulate by appropriate legislation the charges for freight and passengers over said bridge." This represented a considerable step beyond the provisions of the 1866 act, but tied rate regulation to the cumbersome legislative process. In so doing, the lawmakers hoped to stimulate competition for the Union Pacific, which had for years monopolized this crossing of the river. An investigating committee report stated that the great amount of traffic in Omaha - amounting to 1000 carloads per week - justified the move "for the accomodation of commerce, and the reduction of tolls incident to competition."[22] Although moving closer, Congress was still reluctant to control the rates charged by the railroads.

Meanwhile, in lodges across the country during the 1870s, the National Grange of the Patrons of Husbandry was organizing against what it perceived as the onerous monopolies of the railroads. The grangers succeeded in placing enough representatives in the legislatures of Minnesota, Wisconsin and nine other Western and Midwestern states to pass freight rate control bills. Though differing in detail, these revolutionary laws established control of the states over the rail carriers' ability to set rates. To the railroads' horrified surprise, the Supreme Court in 1876 upheld the constitutionality of the state granger laws.[23] In response, the railroads waged a ten-year campaign against the grange, which culminated in 1886 with a reversal by the Supreme Court in another case. The high court ruled that Congress alone had the right to regulate interstate commerce and suggested the formation of a federal agency to accomplish this. The following year, Congress created the Interstate Commerce

Commission. It was with the goal of further regulating interstate commerce that the lawmakers included the rate provision in its charter for the Winona Bridge.

The Winona and Southwestern Railroad immediately assigned the bridge charter to the new company. The rapid succession of events to follow suggests that one or more of the railroads had already negotiated a contract for the bridge construction with the Union Bridge Company of New York sometime earlier in the year. (The actual contract was not executed until August 8, one week after construction of the bridge had begun.) The railroad company contracted with Union to locate, design and build the Winona bridge.[24] Union management in turn, retained George Morison as the consulting engineer to design and prepare the construction drawings for the immense structure. In doing so, the bridge company continued its long-standing relationship with the noted bridge engineer. Morison had awarded construction contracts totaling millions of dollars to Union Bridge for his Missouri River bridges at Omaha, Sioux City and Nebraska City and for the Merchants and Cairo bridges. Moreover, the company's president was George S. Field, Morison's former partner in the bridge construction business. The two men were close friends and had maintained frequent contact throughout the previous years. Retaining Morison as the consulting engineer for the Winona project was a fitting turnabout for Field and the Union Bridge Company.

George Morison engineered a trussed structure which closely followed the preliminary design approved by the War Department. The relatively flat landscape at Winona dictated that the bridge would be a low structure with a moveable span to permit river navigation. The extensive approach grade that would be necessary and the position of the bridge close to the riverside town eliminated the possibility of a high bridge. Morison detailed a structure in the summer of 1890 which consisted of four fixed spans and one draw span on the Minnesota side of the river. The 1888 charter had specified that 200-foot wide minimum navigation channels be maintained on either side of the opened draw. Morison's 440-foot pivot truss, located over the main channel near the western shore of the river, provided exactly this. The impressively scaled pin-connected structure featured a single-intersection Pratt design and consisted of fourteen 30-foot panels, with diagonal counters in the outermost four panels only. A 20-foot wide, 50-foot high tower stood over the center pivot. The center tower was braced laterally by two horizontal girts, tied together by diagonal eyebars.[25]

Although Morison used a standard swing truss configuration (shown in Figure 1) similar to his Riparia Bridge and several previously completed bridges over the Mississippi River, the moveable span he designed for Winona was distinguished as one of the longest of its type in America. The Winona swing was exceeded in length by only one other Mississippi River swing span - the 446-foot structure

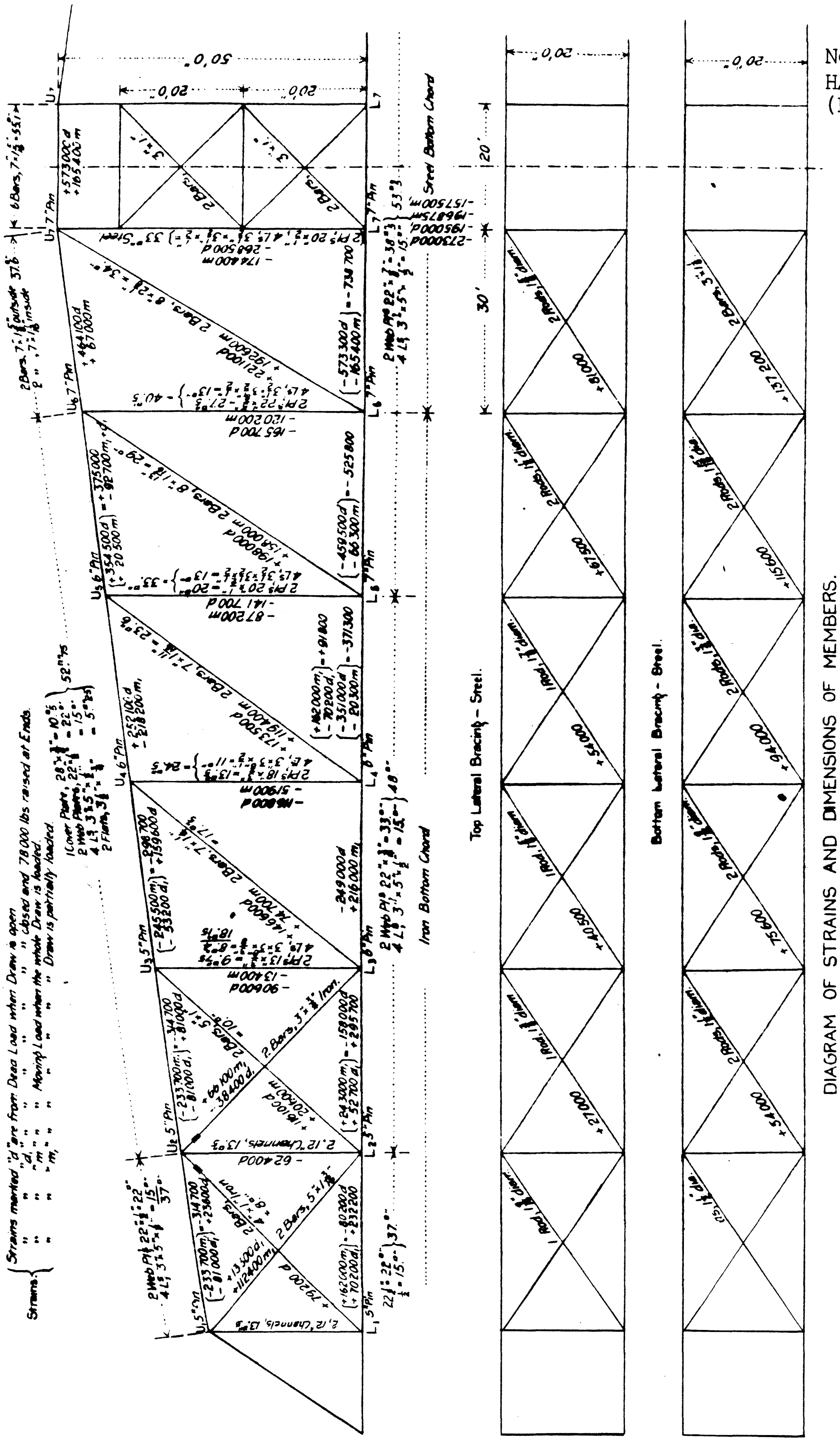


DIAGRAM OF STRAINS AND DIMENSIONS OF MEMBERS.
Top Lateral Bracing - Steel.
Bottom Lateral Bracing - Steel.
Iron Bottom Chord
Steel Bottom Chord

Figure 128

built by Corthell at Louisiana, Missouri, in 1873. And only two other swing spans elsewhere in the country were longer: the 500-foot Arthur Kill Bridge in New York and the 503-foot New London Bridge over the Thames River in Connecticut.[27]

West of the pivot span, Morison delineated a single 240-foot fixed Parker truss and east of the pivot were, west-to-east, one 360-foot Parker truss and two 240-foot Parker trusses. The three 240-foot spans each had a width of seventeen feet between the centers of the webs and were divided into eight 30-foot panels. The 360-foot span, termed the raft span, was twenty feet wide and was subdivided into twelve 30-foot panels. Typical for its time, the single-track bridge was designed to bear a moving load of 3000 pounds and a dead load of 2,600 pounds per lineal foot. Beyond the trusses on the east approach, the engineer designed a 1,120-foot, curved timber trestle over the broad flood plain on the Wisconsin shore.[28] The Winona Bridge was a low structure. But its relatively narrow, tall and long trusses, which featured sloping top chords and rested upon well-proportioned stone piers, belied the great superstructural weight and gave the bridge a sinnewy grace that had characterized Morison's earlier Missouri River high bridges.

Because of the structurally moderate spans and the comparatively high cost of steel, Morison reverted to wrought iron for both the fixed and swing trusses at Winona. He specified iron for the compression members of the trusses and steel for the the tension members. Morison used soft steel in place of iron in the upper chord of the 360-foot span, and he used medium steel in the center panel and a portion of the bottom chord of the swing span. Morison employed his standard metal specifications - the most exacting in the industry - for the bridge. All wrought iron was required to have an elastic limit of at least 24,000 pounds per square inch and an ultimate strength of 47,000 pounds. All steel was to be manufactured by the open hearth process, with a content averaging 5/100% and not exceeding 6/100% of phosphorous. Morison's assistants would test samples and full-scale scale members from the mill extensively to verify that they met the following specified strengths:

	medium steel	soft steel
Maximum ultimate strength	72,000 psi	63,000 psi
Minimum ultimate strength	64,000 psi	55,000 psi
Minimum elastic limit	37,000 psi	30,000 psi
Minimum elongation in 8 ins	22%	28%
Minimum reduction at fracture	44%	50%

[29]

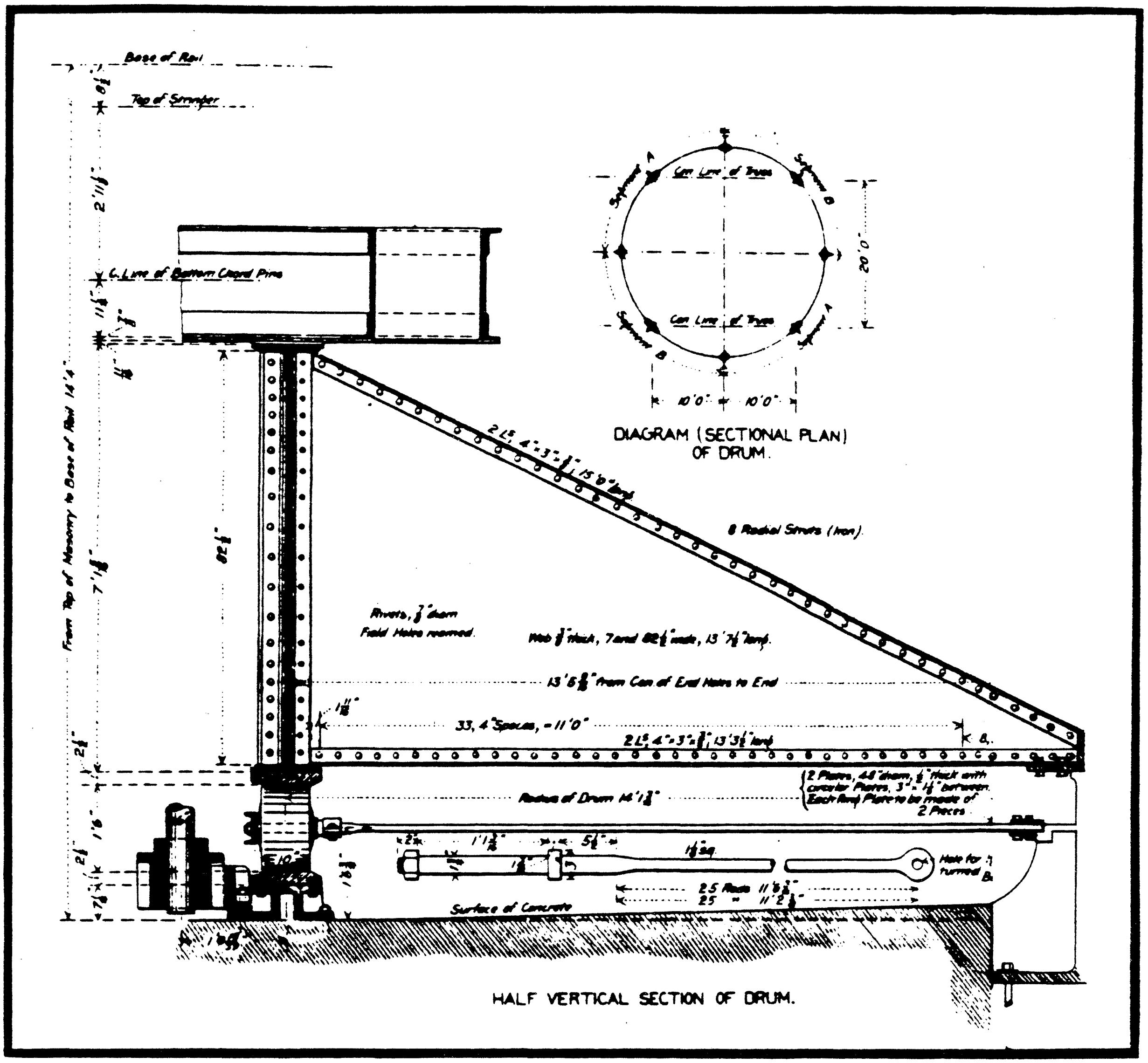
Typical of Morison's bridges, nine massive stone masonry piers supported the trusses for the Winona structure. These included, from west to east: two

small rectangular piers, 6 feet by 26 feet, under coping; the pivot pier, a 30-foot diameter cylinder with vertical sides; and six fixed-span piers, 22 feet long between the shoulders and 8 feet wide, with sides battered with a 1:24 slope and the upriver face battered to a 1:2 slope to form an ice breaker. The piers featured grouted stone exterior walls, with solid concrete cores. The massive granite stones were quarried and dressed near Winona by the Gilmore Valley Stone Company. Like virtually all of the previous bridges built over the upper Mississippi, the piers for Winona were founded on heavy timber piles driven into the riverbed. The fixed-span piers each had 65 piles and the larger, heavier pivot pier had 100.[30]

Morison also designed the swinging, lifting and locking mechanisms for the draw span. Although the swing-span superstructure for Winona resembled his Riparia Bridge, the turning mechanism more closely resembled the bridge at Portland. It was a well-conceived, if unadventurous, configuration, featuring a single large cylinder with the turning power applied from gears on the outside. Morison supported the three-million-pound pivot span for Winona on a plate girder steel drum, 28'- 3-1/2" in diameter and 7'- 1-5/16" high (shown in Figure). The drum rotated about a central hub, connected to the outer wall by triangular plate steel spokes and rolled on fifty 18" diameter cast steel wheels. The wheels tapered to conform with the curvature of the drum and rolled between wrought steel rails with a mean diameter of 14'-2". On the outside of the drum on one side was attached a 6-inch-diameter steel shaft, carrying a pinion which engaged with a geared rack bolted to the pier (shown in Figure). The rotation of this shaft drove the wheels around their cylindrical track, turning the bridge.[31]

A double-cylinder, twenty-horsepower steam engine, built by the Vulcan Iron Works of Chicago, supplied the power for the draw. The engine, with its attendant Vulcan boiler, sat in a frame structure cantilevered over the side of the truss at mid-span, just over the drum. The engine rotated the bridge at a rate of 1° per second, requiring three minutes to open or close the swing span. Shafts which ran from the center of the bridge to each end lifted the ends of the draw span. Vertical spur wheels, located at the ends of the shafts, transmitted the power by means of a second spur wheel attached to a shaft carrying a bevel gear (shown in Figure).[32]

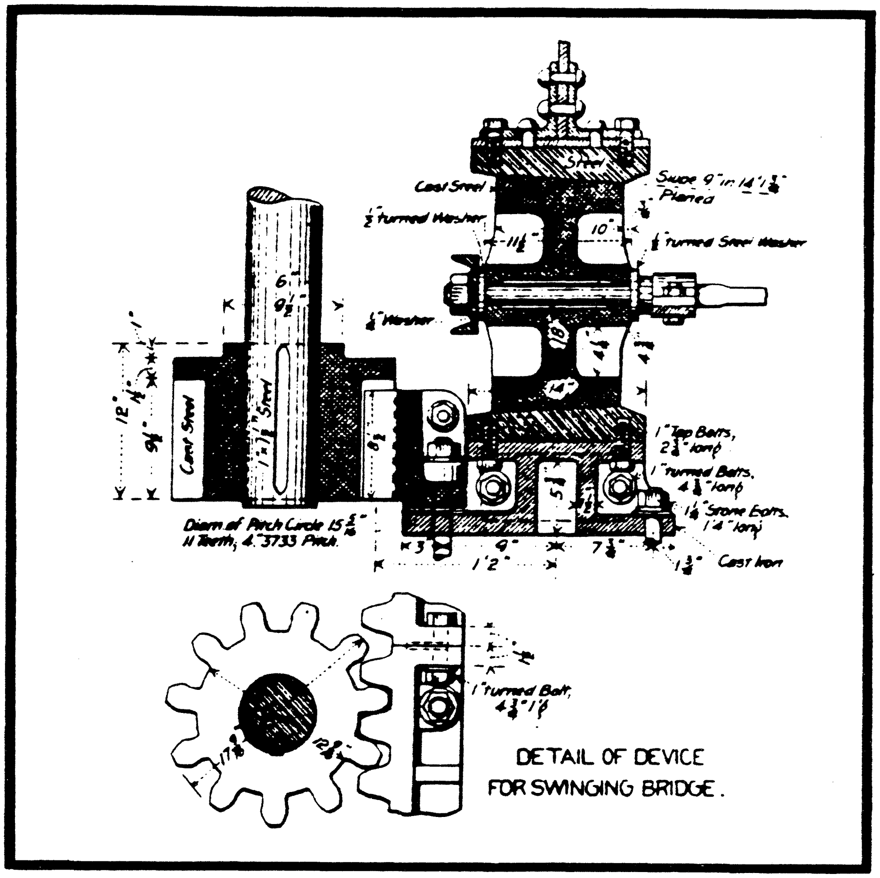
As he had on most of his previous major bridge projects, Morison hurried the engineering for the Winona Bridge to meet an almost impossible schedule. With the charter deadline approaching, construction began well before draftsmen in his office could complete the drawings. In July, the Union Bridge Company, with T.J. Long as superintendent, began on-site preparatory work for the construction project. The company first built a small headquarters shack, equipped with a typewriter and a telephone, at the west end of the bridge on the Minnesota side. Laborers constructed a blacksmith shop and five storage sheds nearby for tools and equipment.[33]



34

Figure 129

Construction on the bridge itself commenced on August 1, 1890. With D.M. Wheeler acting as supervisory engineer, work began with pile driving for the channel piers. Morison numbered the nine massive masonry piers with the easternmost Pier 1 on the Wisconsin side and the others in ascending order toward the Minnesota shore. Work began on Pier 4 first. Using oak piles supplied by three firms - Hersey and Bean of Stillwater, Minnesota, the Saint Paul Timber and Supply Company and John McLeod of Ellsworth, Wisconsin - the workers began sinking the heavy timber piles with a Jumbo pile driver seated on an anchored barge. They soon replaced this with a Nasmorth driver, a more powerful steam-driven machine with a comparatively shorter and heavier stroke.

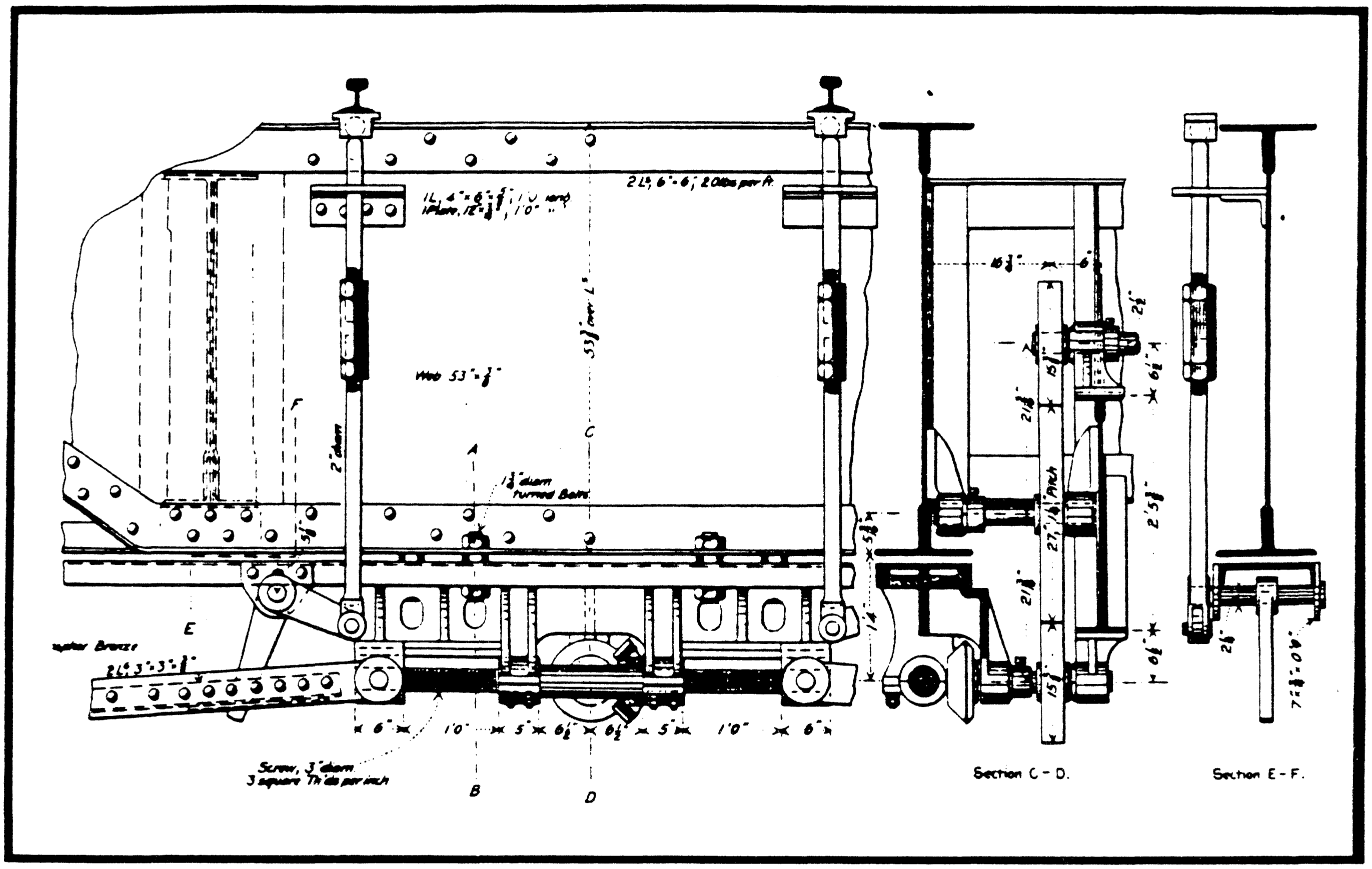


35

Figure 130

The Nasmorth combined the concussive force of a 5,000-pound steel hammer with a powerful water jet which washed sand from the base of the pile to aid the penetration. With it, the workers quickly drove a 75-foot pile in half an hour, averaging eighteen piles per day.[36]

Pile driving continued on Piers 4, 5 and 6 throughout August and September, as the bridge company built its work force up to fifty men. On September 12, the barge crew began driving piles for the pivot pier. By mid-October, Union Bridge was pressing to complete the underwater construction before the river froze. With a work force increased to seventy-eight men, the company had driven the piles for all but Pier 3 - located on a sand bar on the Wisconsin side. At this pier the men used a steam-powered centrifugal sand pump to excavate the sand to the level of the pile cap. Workers drove the timber piles to a depth of 75 feet: the deepest the pneumatic driver could manage. By October 15, the tops of the piles at Piers 4, 5 and 6 had been sawn to a uniform length ten feet below the low water level.[37]



38

Figure 131

On top of the piles, the men attached grillages, heavy timber structures which functioned as platforms for the broad-based stone piers. The grillages consisted of four to six layers of 12"x 12"x 16' pine timbers - half solid and half latticed - which were assembled on-shore, floated into position like caissons and bolted to the pile caps. With the grillages in place, stonemasons worked inside coffer dams beneath the water level, laying course after course of granite stones which had been pre-cut, pre-fitted and numbered at the quarries. When the work reached the surface of the river, the workers removed the coffer dams and the masons continued laying stone to the piers' coping heights. By October 15, Pier 5 was the farthest advanced, extending seven feet above the water line. The stone coursing for Pier 6 had just reached the water line and the grillage for Pier 4 was under construction on the Minnesota shore.[39]

The piles for Pier 7 - the pivot pier - had similarly been driven and sawed beneath the water line. While carpenters assembled the grillage for this pier, three piles were left unsawn to mark its location for steamboat captains. Two

barges attended the work on the piers. On the deck of one, a large timber derrick had been built to swing the stones and concrete into place. The other barge carried a steam engine which pumped water from the coffer-dammed work area. Meanwhile, on the Wisconsin side of the river, McDougall and Beacon of Mankato, Minnesota, began the extensive filling and grading for the bridge's east approach.[40] The Winona Weekly Republican described the frenetic activity at the bridge site: "On the Minnesota shore, the headquarters of the bridge company, a busy scene is presented. Three derricks are used in the handling of the stone, which is brought over the Winona and Southwestern railway, and the musical click of the stone cutter is heard from morning until night. The grillage is constructed at the end of an inclined railway leading from the water's edge to the Southwestern track. A blacksmith shop adds its quota to the bustling scene of activity. At night the lights on the bridge and about the yards present a pretty sight."[41]

Morison altered the design of the bridge during the pier construction, deleting Piers 1 and 2 on the Wisconsin side and Pier 9, with one of the 240' fixed trusses, on the Minnesota approach. This served to speed the construction somewhat, and by the first of December the stonemasons were approaching completion for most of the bridge supports. The Little Hoddie was then in winter storage, and the pile driving crew was using another steamer, the Van Gorder, as a working platform to position the supports for the winter bridge. Pier 4 lacked only a single course of stone for completion, Pier 5, six courses, Pier 6, two courses, and Pier 8, five courses. Pier 7 - the pivot pier - was five feet lower than the others because of the swing machinery; it was completed except for the coping.[42] The masons completed the last of the stonework on January 6, 1891. As the substructural work proceeded on-schedule, the Weekly Republican quoted a "gentleman well up on railroad manners" about the impending completion of the new structure, "The completion of the new railway bridge across the Mississippi River will mark a new era in railway affairs in Winona. There is little doubt now but that the bridge will be completed at the time specified in the contract, March 1, 1891. Its completion will give the Burlington road facilities for handling freight and passenger traffic from Winona that it has not heretofore enjoyed. It is my firm belief, founded too on something besides a mere guess, that the through passenger trains of the Burlington road will then run directly into Winona."[43]

Although the unnamed informant may have been justified in his enthusiasm for the bridge, his prediction of a timely completion of construction proved overly optimistic. In January, the barge crew began driving piles to support the protection works for the swing span. Pier 8, at the west end of the swing, was to be guarded by a 1600-foot timber shear boom. Pier 7 and the swing span itself would be protected from steamboat collision by a large timber crib extending 220' from either end of the pivot pier. This fender work was supported by driven piles, to which 4x12 planks were bolted from one foot below to nineteen

feet above the low water mark. Morison designed the upriver end of the protective crib with tapered edge sheathed with iron plates to serve as an ice breaker. By mid-January, the carpenters had completed the upriver half of the protective pier, and workers began pouring more than 1000 cubic yards of stone ballast into the cribbed structure.[44]

The pile drivers worked without interruption throughout the winter, setting hundreds of timber piles for the shear boom and draw rest, the truss falsework and the 1,140-foot approach trestle on the Wisconsin side. "The pile driver is kept constantly busy," the Daily Republican reported. "After the false work piles have been driven there will still remain to be driven the piles for the approach on this side for the shear boom, and for the lower end of the draw rest." By January 19, 126 piles had been driven for the falseworks under the fixed spans, with 49 more to drive. The pivot span would be erected in the open position over the protective pier, obviating the need for falsework in the channel.[45]

But when would the erection take place? The first load of truss components was due at the bridge by the first of the year. As January passed with no steel on-site, however, the townspeople of Winona began to watch the river nervously, for the breakup of the winter ice pack would wash away all of the falseworks. "Although none of the steel work has arrived from the works of the Union Bridge Co. at Athens, Pa.," the Daily Republican predicted on January 19, "it is expected very shortly, and every effort will be made to get it into position before the ice going out of the river in the Spring shall remove the piles lightly driven for the false work."[46] Three weeks later, the newspaper reported the grim news: "The tardy arrival of the steel from the works of the Union Bridge Co. is delaying matters considerably. It ought to have been here by the first of the year. The employees of the company now admit that it will be impossible to finish the bridge at the specified time, March 1. Indeed, the company will be fortunate if it can put in before the ice goes out of the river the three spans on the Wisconsin side for which the false work has already been put in."[47]

The problem with the steel was by now a familiar one for George Morison. In truth, as had happened on their earlier bridges for Morison, the Union Bridge Company was experiencing severe difficulties in obtaining steel and iron which could meet the engineer's stringent specifications. As the engineer's assistants tested and rejected one melt after another, the company edged uncomfortably toward the construction deadline. The first steel arrived on the site at the end of February. While the ice pack began to show signs of breaking, the greatly expanded Union Bridge crew worked feverishly to erect the eastern two fixed spans.

By April 1, 1891, the ironworkers had erected the two trusses, but the spans

still stood on the falsework.[48] The ice had broken only days before and the river was rising rapidly. By April 2, the water had risen six feet above the winter level. It rose another nine inches the following day. Ten days later the Silver Crescent arrived in Winona as the first steamer to navigate the river that year.[49] As predicted, the spring flood did wash the falseworks away, but the two completed spans held fast. By the first week of May the water level began to recede, and the pile drivers were able to reposition the falsework for the one remaining fixed span. The steel and iron for the 2,800,000-pound swing span was shipped to the site on ninety-five rail cars. Work continued throughout May and June on the swing span and the last fixed span without reported incident.[50] The last steel reached Winona on June 1. Later that month, the bridge was complete except for the 500-foot west approach trestle and a few other details.[51]

When the first train crossed the bridge at 8:30 in the morning of July 4, 1891, George Morison was aboard. He spent the day inspecting the bridge and pronounced it "satisfactory as far as completed." Three weeks later, Morison sent his assistant, Emil Gerber, to inspect the completed structure, ending his involvement with the construction project. Providing employment for an average of sixty men and costing almost $800,000, the second railroad bridge over the Mississippi at Winona was essentially complete.[52]

As the second railroad crossing, the Burlington's new bridge lacked the symbolic impact to Winona that the earlier C&NW structure had enjoyed. Although the new bridge would increase commerce tangibly by linking the river town to a major national rail network, the townspeople regarded its opening with somewhat less than characteristic enthusiasm. And as the bridge crew worked on the final details and painters coated the iron and steel superstructure with white paint, Winonans were already looking forward to the construction of their next bridge over the Mississippi. (This latter structure, a cantilevered, high wagon bridge, was completed in 1894.)[53] The Weekly Republican reported: "Winona is an ambitious city in the matter of bridges. Not content with one railroad bridge she has secured another, and is now planning for a high wagon bridge to bind her still closer to tributary territory in Wisconsin." The newspaper proclaimed Winona the City of Bridges, "having more than any other city on the Upper Mississippi below St. Paul and Minneapolis."[54] The town quickly turned to other matters. George Morison also turned his attention from the bridge at Winona to begin a series of other major bridge commissions over the Mississippi River in what would be the most prolific period in his career as a bridge engineer.

BURLINGTON BRIDGE

George Morison's next major bridge project on the Mississippi River involved, not the construction of a new structure like the Winona Bridge just completed, but the major renovation of an existing railroad crossing. One of the bridges chartered by Congress in 1866, the bridge at Burlington, Iowa, was built by the Chicago, Burlington and Quincy Railroad in 1867-68. It antedated the Dubuque and Quincy bridges by only a few months and, as such, was distinguished as the first all-metal bridge over the Mississippi.[55] The single-track structure was considered at its completion in 1868 to be "sufficient for all time."[56] By 1891, however, the Burlington management had decided to replace the entire superstructure of the bridge.

Although actual reconstruction would not begin until 1890, the project for George Morison had begun several years earlier. In 1885, as Morison worked on the construction drawings for the Rulo Bridge, Burlington president Charles Perkins retained him to inspect the existing swing-span bridges over the Mississippi River at Burlington and Quincy. Both were low bridges with pivot spans, built about the same time using designs which were virtually identical.

The bridge that George Morison inspected at Burlington (shown in Figure 5) remained in essentially original condition. Designed by engineer Max Hjortsberg and constructed by the Detroit Iron and Bridge Company, it consisted of six fixed Whipple trusses and the 360-foot pivot span, with 200-foot and 175-foot spans west of the draw.[57] Morison found cracks in the original limestone piers but judged them otherwise in good condition. He was more critical of the superstructure. Although the bridge had changed little over the preceding twenty years, bridge engineering during the period had advanced considerably, and Morison bluntly noted the archaic construction in his report to Burlington Vice President T.J. Potter in September:

> The details of this truss are old-fashioned and very different from those which would be adopted now. Those of the bottom chord connectors were very clumsy even for the time the bridge was built. The cast iron top chord is the feature which would now be most generally condemned and these chords are of light section for the work they have to do. The details of the draw are very much better than those of the fixed spans.[58]

The major flaw in the existing bridge, Morison reported, was its reliance upon cast iron for critical chords and connections. The upper chords and end posts of the fixed spans used cast iron Phoenix columns, and the joint box connections at the bases of the posts were similarly of cast iron. The bottom chords used open loop eyebars. "The design," Morison stated, "would compare

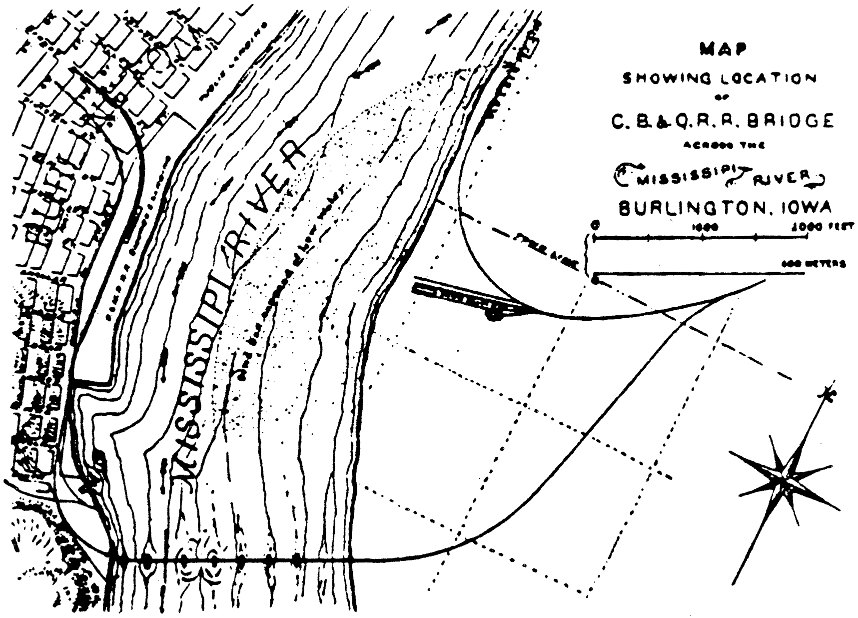


FIG. 1.—PLAN OF LOCATION.

59

Figure 132

favorably with that of other bridges built at the same time. Both chords of the draw were of wrought iron and the draw was carried on a wrought iron drum and a heavy central cross girder, both drum and girder being of the box girder pattern; the only adjustment about the drum was in the six vertical rods which by weight was thrown upon the center, and by tightening or loosening these rods the division of weight between the center and the live ring, could be varied. The weakest feature of the superstructure was the attachment of the floor beams which were suspended from the pins by comparatively light hangers, which were subsequently reinforced."[60] The upper and lower chords of the draw span used wrought iron. This truss was carried on a wrought iron drum. Despite his critical appraisal of the structure, Morison's conclusion was optimistic: "All in all, this draw is a remarkably good structure considering the time it was erected, and is evidently good for quite a number of years."[61]

Morison's recommendation convinced the CB&Q officials to delay any major action on the bridge for five years. By 1890, however, the situation at Burlington had changed considerably, due in large part to Charles Perkins' ambitious policy in the late 1880s of expansion and consolidation. Traffic over the southern Iowa trunk line had increased severalfold. The bridge at Burlington, which linked the company headquarters in Chicago with the western lines, created a serious bottleneck, and the old trusses were too narrow and too light to allow modification. As the Union Pacific had done seven years earlier at

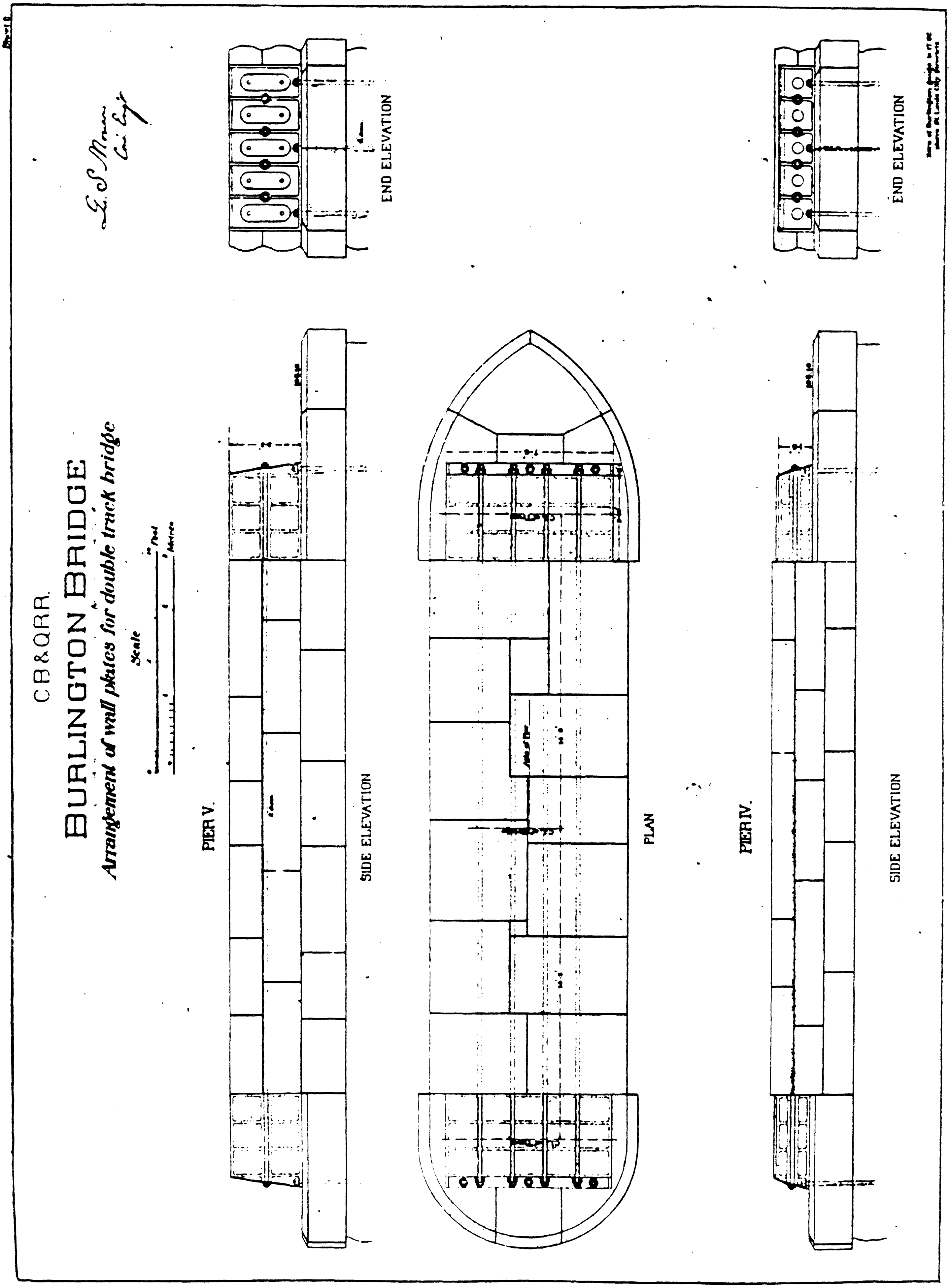

C.B.&Q.R.R.
BURLINGTON BRIDGE
Arrangement of wall plates for double track bridge
Scale
PIER V.
SIDE ELEVATION
END ELEVATION
PLAN
PIER IV.
SIDE ELEVATION
END ELEVATION

Figure 133

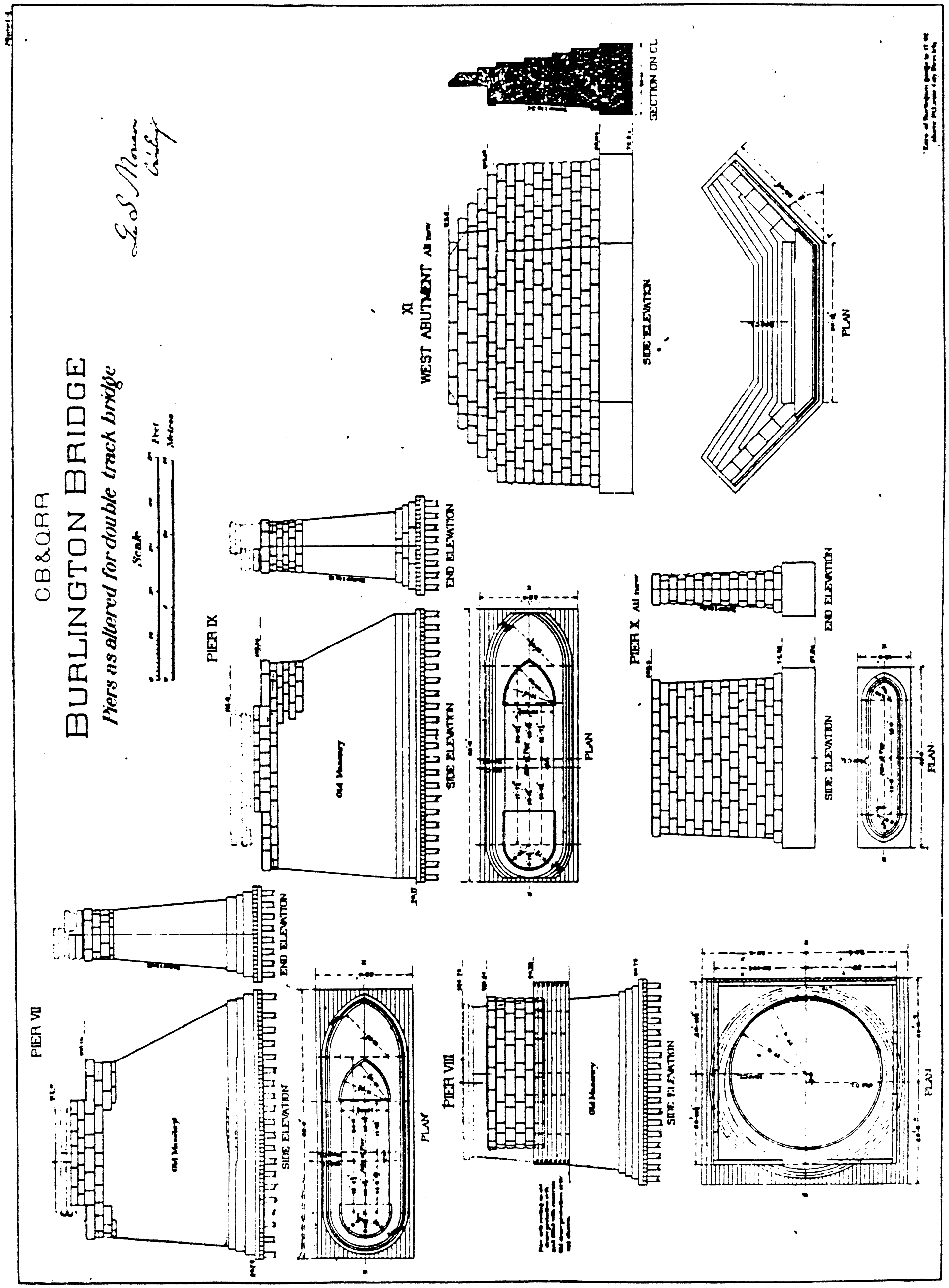

C.B.&Q.R.R.
BURLINGTON BRIDGE
Piers as altered for double track bridge
Scale
PIER VII
SIDE ELEVATION
END ELEVATION
PLAN
Old Masonry
PIER VIII
SIDE ELEVATION
PLAN
Old Masonry
PIER IX
SIDE ELEVATION
END ELEVATION
PLAN
Old Masonry
PIER X All new
SIDE ELEVATION
END ELEVATION
PLAN
XI
WEST ABUTMENT All new
SIDE ELEVATION
PLAN
SECTION ON C.L.

Figure 134

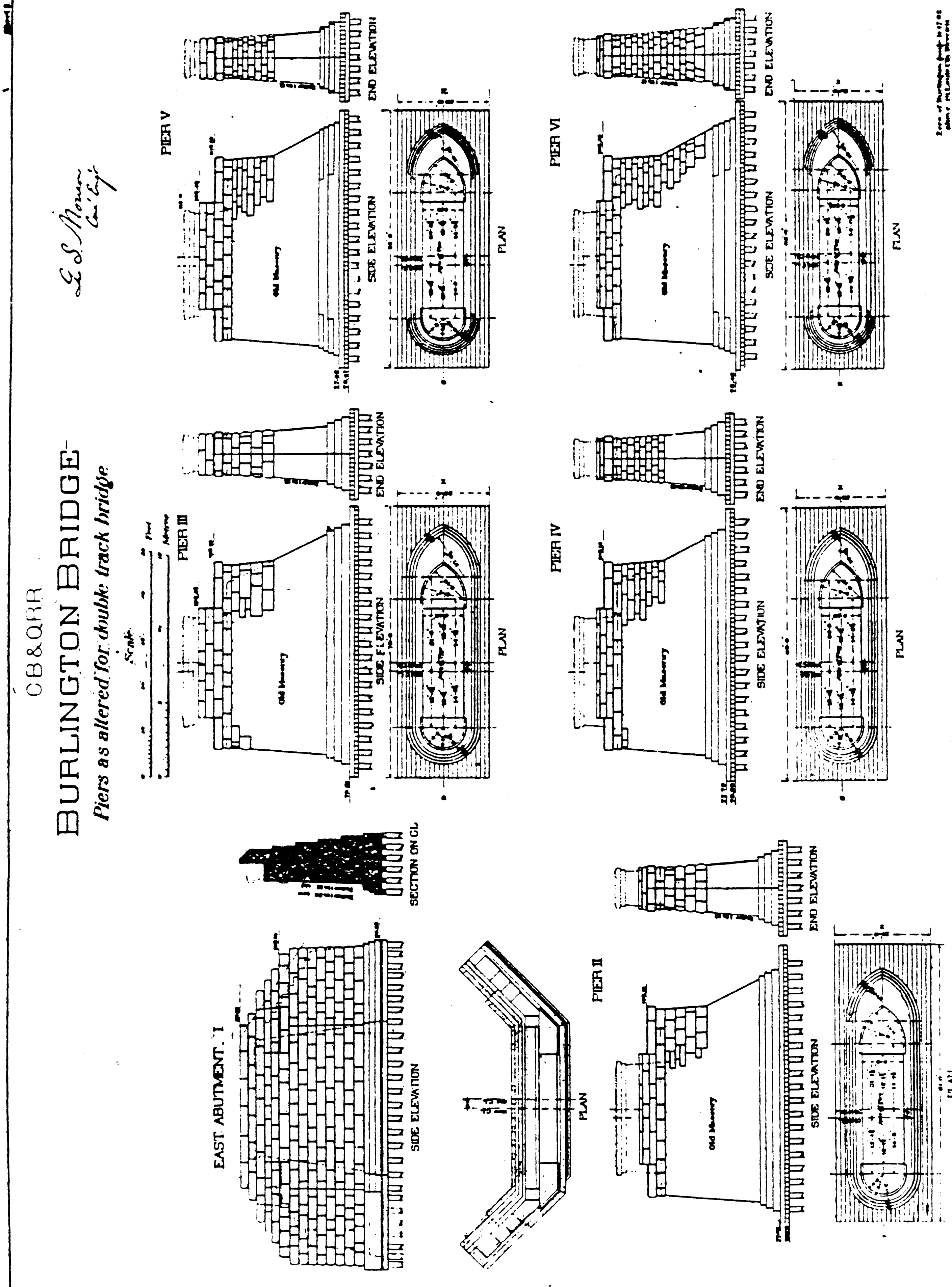

C B & Q R R
BURLINGTON BRIDGE
Piers as altered for double track bridge
Scale
PIER V
SIDE ELEVATION
END ELEVATION
PLAN
PIER VI
SIDE ELEVATION
END ELEVATION
PLAN
PIER III
SIDE ELEVATION
END ELEVATION
PLAN
PIER IV
SIDE ELEVATION
END ELEVATION
PLAN
EAST ABUTMENT I
SIDE ELEVATION
SECTION ON CL
PLAN
PIER II
SIDE ELEVATION
END ELEVATION
PLAN
Old Masonry

Figure 135

Omaha, the Burlington management decided to replace the superstructure entirely and modify the existing piers to accomodate two tracks. In 1890, after twenty-two years of service from the original structure, they retained George Morison to engineer and supervise construction of the replacement bridge.

Given the scale of Morison's other bridge projects, the replacement of the superstructure for the Burlington Bridge was unremarkable. Morison himself dismissed it, saying, "There are no features about the superstructure which call for special consideration."[62] In order to use the existing piers, Morison designed the span lengths of the replacement trusses to coincide with the original superstructure. His six fixed spans were Whipple through trusses, 246 feet long between the centers of the pins. Each truss was divided into nine 27'4" panels and was 28'6" wide. The draw span was 356'6" long, consisting of twelve single-intersection panels, each 27'4" long, and a central 28'6" tower. The weight of the superstructure is given in the following chart. (The coefficient is the weight per foot divided by length of span):

	total weight	weight per foot	coefficient
Six fixed spans	4,937,987 lbs.	3,339 lbs.	13.58
Draw span	1,420,272 lbs.	3,984 lbs.	11.17
Plate girders	306,383 lbs.	1,955 lbs.	27.93
Total	6,654,642 lbs.		

[63]

Morison proportioned the components of the trusses to carry a moving load of 6,000 pounds per lineal foot. "All parts," he stated, "which received a maximum strain from a load on a single track are proportioned on a basis of 4,000 pounds per lineal foot of track, increased to 8,000 pounds on a wheel base length of 20 feet. It will be observed that the weight taken per foot of track, when both tracks are loaded, is three-quarters the weight per track when only one track is loaded; this is the equivalent to using a larger factor of safety on a single than on a double track, which the Engineer [Morison] believes to be the correct practice."[64] In the drawings and specifications completed in his Chicago office in May 1890, he called for open-hearth steel to be used exclusively for the trusses and wrought iron for the plate girder west approach spans. The railroad contracted with the New Jersey Steel and Iron Company to fabricate the superstructure in its Trenton, New Jersey, shops. The actual truss erection would be conducted using railroad laborers under the direction of Morison's resident engineer.

In choosing pin-connected, double-intersected trusses for the fixed spans, Morison relied on what many then considered to be an obsolescent structural type. His fixed-span trusses followed the same general profile as had Hjortsberg's original Whipple spans. The difference was, in 1868 the Whipple represented the industry standard in medium-span railroad construction; by

1890, it had been superceded by the more economical Pratt variations for all but the longest span lengths. "Forms of trusses with more than a single system of triangulation," noted bridge engineer Theodore Cooper wrote in 1889, "have gradually been rejected, and have now disappeared from first-class bridge designing... The old forms like the Bollman, Fink, Lowthorp and Post trusses have disappeared from American practice. The double intersection Whipple or Linville is rapidly following them."[65]

Clearly, the 246-foot spans at Burlington were unambitious by any standard, and other engineers had often used single-intersection Pratt trusses under similar circumstances. Morison, in fact, chose Pratt trusses himself for the fixed spans of another Mississippi River bridge at Alton, Illinois, then also under construction. Further, he had shown no reluctance to replace an outdated structural configuration with a more contemporary design at Omaha five years earlier. Morison prided himself in his knowledge about current technological trends and maintained a deserved reputation among his peers for his carefully conceived engineering. Why he relied upon obsolescent and expensive Whipple trusses for Burlington is unclear, and he does not offer an explanation for this apparent incongruity. For whatever reason he chose this truss type, the Burlington Bridge was the last major structure on which George Morison would use what had once been his mainstay - the Whipple truss.

Morison engineered the turning mechanism for Burlington as a duplicate of the equipment he had used for Winona. He changed only the general dimensions of the turntable to carry the wider pivot truss and account for the differences in height between the two bridges. Under Morison's design, four girders which formed a 28-foot square bore the weight of the draw span. These were bolted at eight equidistant points to the 30'10" diameter turntable drum. This massive drum rested on 63 cast steel wheels, which radiated on spokes from a center hub and rolled between circular wrought steel tracks. Both the upper and lower treads were of forged steel turned accurately to a true cone, the lower tread resting on a flat cast iron circle which was bolted to the masonry. A quarter-scale model of the turntable, including the center tower of the bridge, was exhibited by the manufacturers at the World's Columbian Exposition.[66]

The reconstruction work began in July 1890. At that time, Morison appointed Elijah P. Butts as his resident engineer to supervise the construction at Burlington. Butts had worked for Morison since 1886 in a variety of capacities for several of the chief engineer's early bridges. These included the Omaha Bridge, where he functioned as an assistant engineer and inspector of the stone work at the quarries, the Rulo Bridge, and most recently the Cairo Bridge, as an assistant engineer.

Fortunately for the construction, the original piers had been built with an enlarged ledge just above the high water level, making their modification to

carry a wider truss relatively easy. The change involved nearly doubling the weight to be carried by each pier and concentrating this additional load at bearing points nearly twice as far apart as those of the original trusses. Fearing that the masonry might crack and fail under these conditions, Morison first proposed to put plate girders longitudinally on the top of each pier to distribute the increased weight over the length of the pier. After further consideration, he determined that it would be "simpler, cheaper and at least equally effective" to convert each pier into a girder by placing a steel tension member at the top. This would allow the masonry to act as the compression member at the bottom and function as a web.[67]

Morison called this aspect of the design (shown in Figure) "the only novel feature of the work." As construction began, Butts directed the stonemasons to infill both sides of the ledge, thus creating the additional pier width to carry the wider superstructure (shown in Figures and). Using this relatively simple and inexpensive process, the masons enlarged one pier after another throughout 1890 and 1891. The stones used in the reconstruction were substantially larger than the originals, and in some cases single courses of new stonework corresponded with double courses of the old material. "The alteration of these piers was conducted without any serious difficulty of any kind," Morison stated, "and the material removed from the old piers was, for the most part, left around the piers where it serves as additional riprap."[68] As the masons enlarged the piers, the railroad's steelworkers replaced the original iron fixed trusses, one at a time, to avoid lengthy delays of rail traffic over the bridge.

The pivot pier required additional work. Much larger and heavier than the fixed-span piers, is had been constructed with battered walls. The railroad had originally shrouded this pier with a 400-foot draw protection crib, which functioned as a fender for river traffic passing through the draw. The protection crib was originally carried above high water by driven piles. A railroad maintenance crew later cut these piles to the low water level and put a floating pier in place, "an arrangement which was not as good as the original one," according to Morison.[69] He ordered the protection pier reconstructed to match the original configuration.

The masonry pier itself required extensive alteration to prepare it for the new turntable. The turntable that Morison designed was 30'10" in diameter, measured on the centerline of the circular track, which required a 34-foot minimum diameter pier. The original pier was 34 feet in diameter, but had been built with a batter and was therefore unsuitable to carry the new equipment. Further, the centerline for Morison's new swing span differed from the original centerline by some two feet, requiring a virtual repositioning and large-scale reconstruction of the old pier. The men first cut the old pier to a height that a new plumb-walled pier could be built atop it with no more than a

three-inch projection of the new masonry over the old. Stonemasons then laid a new pier top using an outer wall of Bedford limestone with concrete fill. The work would have been a simple matter but for the fact that the original draw span had to be held in place for rail traffic while the pier was reconstructed. To accomplish this, two wells were sunk to the masonry under the center posts of the trusses and carried down to the level at which the new masonry was to be started. In each of these wells the men assembled and bolted a column formed of cast iron blocks, each two feet high, to. support the cross girder immediately under the trusses. They then cut out and removed the drum, leaving the truss supported entirely by the two columns.[70]

Morison scheduled this part of the construction for winter, when the river was frozen and there was no steamboat traffic with which to contend. The draw could thus be held aloft by the anchor piers in the closed position without impeding river traffic. After the perimeter stones were in place, one work crew positioned the drum of the new turntable while another placed falsework beneath both sides of the existing draw span. The old truss was then disassembled and the new one erected on top of the new turntable. Workers then removed the two temporary columns and filled the pier with concrete, completing the process.

The work continued without incident throughout the winter until January 11, 1892. That afternoon, as Resident Engineer Elijah Butts was standing on the protection pier, he was struck on the head by a large stone dropped as the men were dismantling the old pivot pier. The three-hundred-pound rock struck Butts on the right side of the head, crushing his skull. No one saw the incident, and Butts was found unconscious under the pier. "The bleeding, senseless form of the engineer was removed at once to the hospital where surgeons awaited his coming," the Burlington Daily Hawk-Eye reported.[71] Despite extensive surgery, he died that night. "He had shown rare efficiency in the conduct of the work," Morison eulogized, "and his death was greatly regretted by every one who knew him."[72] George Lederle, another Morison veteran, succeeded Butts as resident engineer and supervised the construction to its completion.

With Lederle in charge at the job site, the reconstruction of the Burlington Bridge continued throughout the spring and summer of 1893.[73] On October 20, the ironworkers had completed the superstructure and the bridge was returned to uninterrupted service. All but ignoring the bridge construction, the townspeople of Burlington held no ceremony to commemorate this event. The local newspaper had carried only brief articles chronicling the construction progress over the previous two years. In fact, as gauged by the newspaper coverage, the most attention that the bridge received from the town was the tragic death of Elijah Butts. The costs for the three-year project are given in the following table:

Abutments.	$ 16,588.27
Fixed span piers	24,321.65
Pivot span pier.	5,395.15
Total substructure cost.	46,305.07
Fixed span trusses	
Pivot span truss	77,898.00
Plate girders.	12,495,42
Painting	1,751.94
Floor and track.	16,341.69
Turning machinery on draw.	8,245.52
Telegraph fittings	1,275.63
Total superstructure costs	326,816.10
Tools and machinery.	8.031.56
Engineering salaries and expenses.	20,069.81
Total construction cost.	$401,222.54 [74]

Although it would be Morison's most modest bridge project on the Mississippi River, the reconstruction of the Burlington Bridge reflected the rapid technological improvements which were changing the complexion of the bridge industry during the last decades of the 19th Century. Engineers had steadily increased the design loads for their bridges to accomodate the larger and heavier locomotives produced by the train yards. The quality and availability of bridge materials had improved dramatically, and with more sophisticated stress analysis, engineers detailed trusses which were markedly more sophisticated. C.H. Hudson, resident engineer for the original Burlington Bridge, summarized the differences in bridge design which had taken place, saying, "It should be borne in mind that the science of bridge building has made great strides in the last quarter of a century, and that engineers of that day had to depend very largely on their own judgement and ingenuity. They had fewer precedents for their guidance than has the engineer of to-day, and much less engineering literature was then accessible than is now at the disposal of the engineer." [75]

As a long-time student of engineering, Morison also recognized the bridge's symbolic importance. He concluded a paper published in the Journal of the American Engineering Societies by saying, "It will be observed that this is a striking illustration of the advances which have been made in bridge construction. The old single track Burlington Bridge, including approaches, cost about $1,250,000; it has been converted into a double track structure with an entirely new superstructure for less than one-third of the original cost." [76] A year later, he restated, "If, at the time of rebuilding the Burlington Bridge, I had had to build an entirely new bridge at the same site, I think the cost of the piers, using precisely the same spans, would not have

been half the cost of the superstructure."[77] Engineer Henry Goldmark, in assessing the reconstruction of the bridge at an engineers' meeting in 1894, also commented on the improvement of superstructural engineering in general:

> The superstructures of many of these old bridges have been renewed because they were no longer able to do the work required of them. I understand very well that this work, owing to the increase in the weights of the engines and trains carried, is much greater than that to which they were originally subjected. But it is doubtful whether, even for the same loading, we could to-day pronounce the old superstructures safe and, in general, I think we shall find that from the days of these early bridges even to the present time, the substructures have stood the test of time far better than the bridges they carry, in the West at least. And this has been the case, although we have had to experiment with untried qualities of stone, and slowly learn the characteristics of our rivers, so different from those of eastern streams.[78]

ALTON BRIDGE

As he engineered the replacement superstructure for Burlington, George Morison undertook the commission for another major bridge over the upper Mississippi River, also for the Burlington Railroad. This latter structure was the railroad swing span at Alton, Illinois. Located over 200 miles downriver from Burlington, the Alton Bridge was Morison's fifth and last major bridge commission over the Mississippi River.

The city of Alton was the lowest settlement on what is known as the upper Mississippi River, above its confluence with the Missouri River. Approximately six miles above the mouth of the Missouri, Alton stood on the bluffs which bounded the river on the east. The river left the bluff about a half mile above the town, and near the lower limits of Alton there was low ground about a quarter mile wide between the low water bank and the foot of the bluff.

At high or normal water levels, the main channel of the river flowed at the base of the bluff on the Illinois side, near the business district of the port community. On the Missouri side opposite Alton lay a four-mile-wide bottomland which served as a floodplain for both the Mississippi and Missouri Rivers. The range between high and low waters at Alton was some 26 feet.[79]

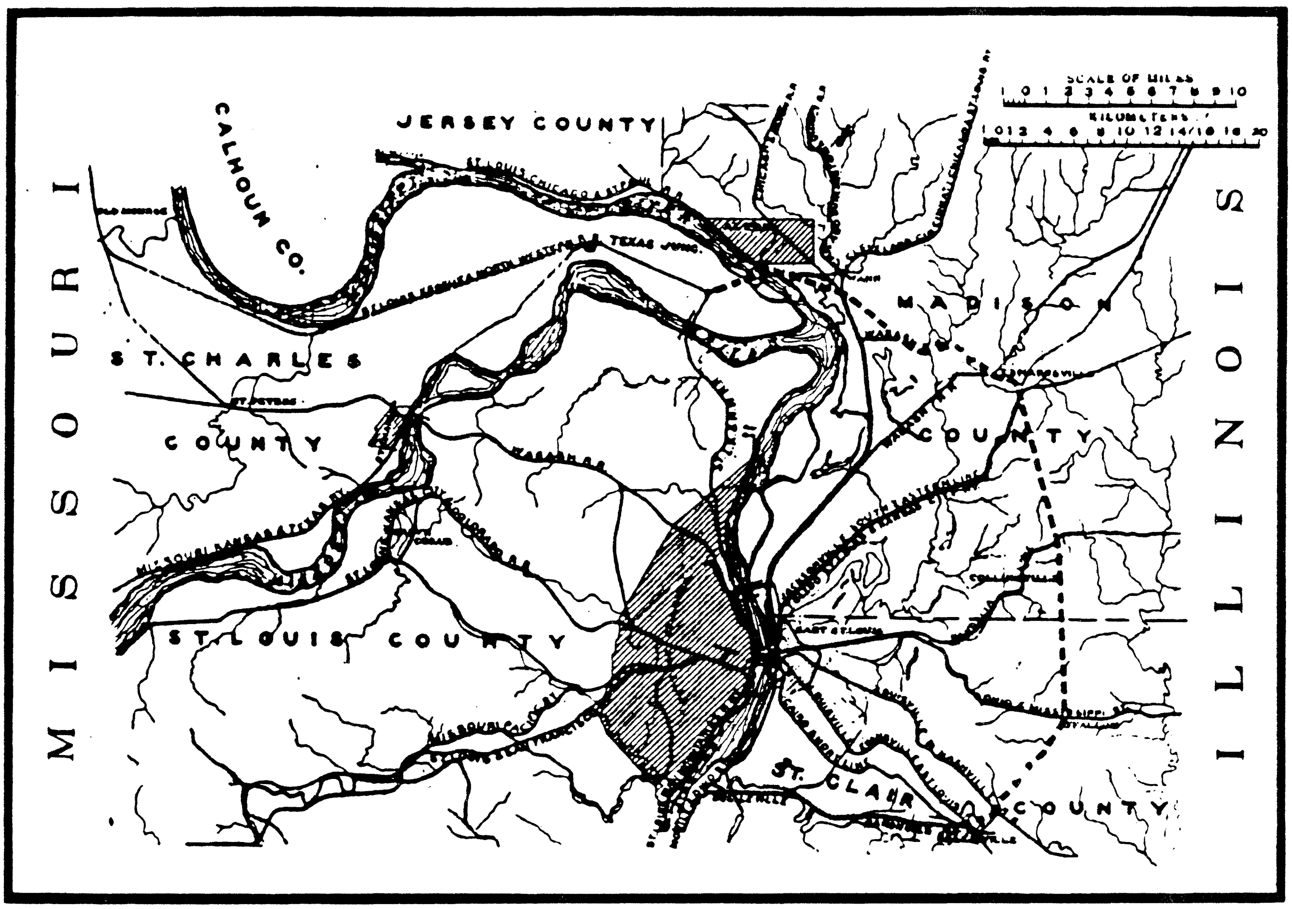
Located so close to St. Louis, Alton had always existed under the shadow of the great Missouri port town. When the Mississippi was first bridged in St. Louis with the Eads Bridge in 1874, the townspeople of Alton could only watch as their neighbor grew increasingly larger and more prosperous. They had considered bridging the great river more than three decades earlier, as had happened at virtually every aspiring town or city located along the river, Alton entertained a series of would-be bridgebuilders throughout the mid-19th Century. One of these was G.W. Long, a local engineer who proposed a bridge over the Mississippi at Hop Hollow near Alton in 1839. Long's structure featured a steeply sloped deck which lifted from a low approach on the Illinois side to a high span on the Missouri side. Presumably, steamboat traffic could pass beneath the high section of the bridge. If built, Long's bridge would have been the first anywhere over the Mississippi. With an impractical location and design, however, he never received the financial backing necessary to erect the structure and eventually abandoned his plan.[80] The citizens of Alton soon forgot Long's proposal, but every twenty years or so they rekindled the idea of a bridge.

Ironically, it was to provide access to St. Louis that a bridge at Alton would finally be built. In the late 1880s, President Charles Perkins and the directors of the Chicago, Burlington and Quincy Railroad were thinking not so much about the fortunes of the merchants in Alton as their own regional plans for expansion. In fact, for several years the railroad officials took great pains to keep their plans secret from the press and the townspeople.

The events that would lead to the construction of the Alton Bridge began in the summer of 1879. At that time the CB&Q began running trains into St. Louis through one of its proprietary lines, the St. Louis, Keokuk and North Western, a small network which extended from Mt. Pleasant, Iowa, to Keokuk, Hannibal and Dardenne. In 1881, the Burlington acquired the SLK&NW outright, although it would be several years until the smaller line would be consolidated as part of the Burlington system. The SLK&NW held trackage rights with the Wabash Railroad for a 40-mile stretch of rail into the city. But the arrangement was less than satisfactory for the Burlington, which had to pay the Wabash for use of its tracks and rail yards and for passage of its trains over the Missouri River on the St. Charles Bridge.[81]

Perkins reasoned that it would be more economical for the railroad to run its own tracks, under the name of the SLK&NW, to rail yards built by the Burlington

in St. Louis, crossing the Missouri River to the northwest over the railroad's own bridge (shown in Figure 9). This new section of track would then be linked with the Burlington trunk line east of the Mississippi by crossing the river with another Burlington-built bridge. All of these components would be new,



82

Figure 136

involving land acquisition and construction worth millions of dollars. As early as June 1887, the CB&Q began buying property quietly in the north part of St. Louis to build its own freight and passenger facility. Part of Perkins' plan became public when the railroad secured Congressional charters for bridges over the Missouri and Mississippi rivers north of St. Louis in 1888. (The Missouri River Bridge, called the Bellefontaine Bridge, was to be a part of the SLK&NW; the bridge over the Mississippi River at Alton was chartered by the St. Clair, Madison and Belt Railway (SCM&B), another CB&Q client company.) Burlington officials revealed the rest of their plan in the spring of 1889 when they began construction of a Union Station and freight house on Franklin Avenue in St. Louis. To design the whole system - tracks, bridges, railroad yards and stations - Perkins once again turned to his perennial consulting engineer, George Morison.[83]

The bridge over the Mississippi River at Alton comprised one of the larger components of the project. Although most of the town's business district stood on a bluff overlooking the river, the rail yards and crossing were to be located in an area close to the riverbank, opposite a low-banked bottom on the other side of the Mississippi. This topography, combined with the fact that the bridge was to be located immediately adjacent to the switching yard, forced Morison to delineate a low structure with a moveable span over the navigable channel. The engineer designed a bridge with seven fixed spans and a single swing span near the Illinois shore. The single-intersection web profile of the double-track draw span for Alton closely resembled the bridges Morison had designed for the Burlington Railroad at Winona and Burlington. Weighing 2,124,860 pounds, the pivot span constituted almost one third of the total weight of the entire bridge. With a span length of 460 feet, it was one of the longest swing bridges in the country and was exceeded in gross weight by only one other swing truss in America.[84]

For the turning machinery at Alton, Morison again employed what had by then become his standard turntable and gear configuration. The rotating truss rested on a large, cylindrical plate-steel drum, which was carried, like the Burlington Bridge, on 66 cast steel tapered wheels. Each of the wheels had a 10-inch wide face and a mean diameter of 18 inches. Like the other bridges, these rolled between wrought steel tracks with a mean radius of slightly more than 16'2". The Vulcan Iron Works of Chicago constructed the engine and vertical boiler, using the design of staff mechanical engineer James N. Warrington. The Union Bridge Company fabricated the end lifts using Morison's design. The engine and machinery, according to Morison, were designed "to be self-contained and symmetrical in design and to avoid as far as possible the use of bevel gearing."[85]

Other than the sheer size of the swing span, Morison's bridge was unremarkable. With a total length of over 2,060 feet, it extended slightly longer than the

Burlington Bridge, though was substantially shorter than several other bridges over the river. For the six fixed spans on the Missouri side, Morison designed 210-foot Pratt through trusses; he drew a 360-foot Parker truss for the raft span next to the pivot. The aggregate weight of the steel spans, exclusive of the turning machinery, would total almost eight million pounds. Typical of Morison bridges, these trusses were to be held aloft by massive limestone piers built atop piles and grillages.

The Alton Bridge, like all of Morison's large scale trusses, was a plainly utilitarian structure. George Morison designed his immense railroad bridges in direct response to the local topographical and hydrological conditions, with economy of construction and maintenance as his foremost consideration. "The object of a bridge is to carry traffic," he stated in a lecture before the St. Louis Commercial Club in 1889, "and the most perfect bridge is one which at a minimum cost will carry this traffic with a maximum efficiency and safety. A bridge is not a monument to commemorate an historical event, nor a temple of architectural magnificence; it is simply a tool, a part of a system of transportation, one of the machines by which transportation is manufactured... The cheapest thoroughly good tool is the best."[86]

As he often stated, the river conditions moulded the shape of his bridges, and it seemed that the more challenging conditions pushed Morison toward more innovative solutions. The Alton location did not pose any significant engineering problems. Morison's unambitious design for the bridge reflected this. Unlike the graceful Winona Bridge, with its long, slender spans, and the quaint Burlington Bridge, with its archaic truss configuration and weathered limestone piers, the Alton Bridge appeared only ponderous and heavy. Featuring a row of short, double-track Pratt trusses sitting on squat masonry supports, the Alton Bridge was singularly graceless among Morison's Mississippi River swing structures.

Morison had virtually completed the design for the bridge before the citizens of Alton knew of its planning. A pre-construction visit by CB&Q officials on February 10, 1892, provided one of the first indications to the town that the railroad planned to erect a bridge over the Mississippi. George Morison, Charles Perkins, several Burlington officials and Morison's assistant engineer W.S. MacDonald steamed to Alton aboard a special train to inspect the site and review Morison's design for the bridge. Despite constant questioning by the local press, Morison, Perkins and the others refused to divulge much about the proposed structure. "When railroad officials wish to be reticent they can be very much so," complained the reporter for the Alton Daily Telegraph. "In fact such matters have come to be proverbial. Little did any one in Alton dream that we should have a distinguished party of railroad officials here to-day."[87]

MacDonald had worked for Morison for almost ten years, having begun with the

chief engineer in December 1882 as office assistant on the Blair Crossing Bridge and later functioning as assistant engineer for the Rulo and Nebraska City Bridges. As Morison explained his plans for the bridge to the railroad officials, MacDonald held the drawings tightly under his arm, to the consternation of the curious local press. "[The drawings] were the object of many longing glances from the 'news-founders' but Mr. McDonald [sic] could not see the wisdom of allowing them to inspect the maps... There were perhaps twenty of these prints, which proves that the enterprise is a very large one."[88] Although Morison's and Perkins' visit was short and not very illuminating for the town, it sufficiently revived the local dream of a bridge for Alton.

The townspeople reinforced their suspicions two days later when CB&Q surveyors began work sighting lines for the east approach of the proposed bridge.[89] A week later, Louis Whitzell arrived at the site from Rulo to supervise the pile driving crew.[90] MacDonald, under Morison's directions, would act as resident engineer of the construction project. On February 25, Louis M. Loss, the masonry and substructure contractor, and his draftsman arrived onsite from Cairo. "There are no more secrets about the bridge," Loss announced self-importantly to an eager reporter for the Telegraph, "I am here to stay."[91] The town was ebullient, as indicated by the Daily Telegraph: "The news about the bridge ...has been heralded with delight all over the city. People have waited so long that they can scarcely believe their own senses in matters pertaining to the bridge. But it is a sure go and no mistake."[92] Loss and other contractors began renting houses and offices in February. MacDonald rented rooms over Kane's Grocery at the corner of Second and Langdon for his offices. As the entourage of railroad and steamer crews, contractors and engineers began to set up operations throughout Alton, the townspeople engaged in animated interest and speculation, with the realization that their long-awaited bridge was at last a reality.

Loss brought his construction barges, derricks and blacksmith boats to Alton from Cairo in the first week of March. He then purchased a small steamer named Penguin to steer the barges for the pile driving. As MacDonald's survey crew plotted the line of the bridge, Loss began driving the first of the hundreds of piles for the bridge substructure. By April 23, the Bedford quarries had shipped nineteen carloads of stone for the piers to the construction site. By mid-August, Loss had accumulated most of the stone in a sprawling stockpile beside the bridge site. Morison had stipulated in the contract that the pier construction would not begin until the river receded to a predetermined level.[93]

With his piles and cofferdams in place, Loss was anxious to begin the stonework and traveled to Chicago to lobby the Burlington management for permission to commence work immediately. Predictably, the railroad officials upheld Morison's edict. The stonemasons were forced to wait until September to begin laying the piers, after the water level had dropped. The Daily Telegraph described the process of positioning the pre-cut, pre-fitted stones for the piers: "[The] stones, weighing from two and a half to five tons, are handled

quite simply, and the work of laying them is done with the greatest of ease. The stone is first attached to a derrick, then lowered and washed off in the river and placed on the top of the pier. Not over a minute's time is consumed in raising the stone after attaching it to the derrick. After the stones are placed, they are carefully cemented, and much care is taken that the solution of cement does not leak out through the crevices... The work is being pushed with a vigor."[94]

Construction of the piers continued without incident throughout the latter part of 1892. At the end of September, grading contractors Brehney and Sons steamed their plows, wheel scrapers, graders and dozens of head of stock down the river from Keokuk, Iowa. After building cabins, barns and corrals on the Missouri bottomland, they began grading the lengthy western approach to the bridge.[95]

In November, railroad work crews under MacDonald's supervision began weaving willows for the foundation mattress of the shore rectification works. Morison had called for an extended dike along the riverside to control bank erosion and direct the river's channel through the swing span on the east end of the bridge. To provide for low-water navigation through the draw, he directed that the channel be deepened on the east end of the bridge. Men aboard the steamer City of Paducah dredged a canal along the eastern shore with sand pumps to deepen the river through the pivot-span channel. Sand pumped from the channel was thrown onto the willow mattress to form the dike.[96]

When problems developed in positioning one of the grillages in October, Morison visited the site to inspect the work. Once the grillage was successfully laid in place, however, he returned to his Chicago office and the substructural construction continued into the winter. In December, before the river closed, barges brought large quantities of timber and riprap down the river. "Alton's much talked of bridge is getting under way," the newspaper enthused, "and before many days things will be booming."[97]

By mid-summer the stonemasons had completed the piers and the bridge was ready for a superstructure. As it had on so many other Morison-designed bridges, the Union Bridge Company contracted to fabricate and erect the trusses for Alton. In July, the company shipped the first trainload of superstructural steel, constructed blacksmith shops on the Missouri shore and positioned derricks to move the material to the construction area. Resident engineer MacDonald was joined by long-time Morison assistant engineer Alfred Noble, who would supervise the steel erection. On August 2, the Daily Telegraph predicted optimistically, "Active operations with a force of iron workers will commence on the Alton bridge in a very short time. Altonians who have been waiting for the sound of a hammer will be greeted by it before August expires, and will have ocular assurances that a bridge will soon take form."[98]

Later that month, the steelworkers began placing the first material for the

fixed trusses over the pile falsework. They proceeded without incident, and by mid-October they had hung the third fixed span and began work on the fourth. The erection stalled in September, however, when the Union plant fell behind schedule for the truss fabrication. The company fell further behind when a train carrying some of the steel wrecked, damaging the components. By the end of the year, the piledrivers had placed the falsework for the raft span, but the long truss remained unfinished. And another, more serious, complication soon arose which would delay construction even further.

"The unruly river channel has caused the engineers of the Alton bridge an enormous amount of trouble," the Daily Telegraph reported on December 30, 1893. Morison had directed that a channel be dredged through the pivot span to create a navigable lane, but no amount of sand pumping by the City of Paducah could coax the river through the draw. "The draw span of the bridge is located at a point where a huge bar looms up as a barrier to navigation," the newspaper stated, "and all the skill of practical engineers has, as yet, failed to force a sufficient channel to insure navigation in the spring."[99] Steamers had passed between the piers for the raft span the previous fall, but with its completion imminent, the steamboat companies worried that the bridge might render the river unnavigable. They filed a formal request with the Board of Government Engineers to stop completion of the Alton Bridge until Morison could gain control of the river there.

Morison's design for the bridge frankly perplexed the steamboat companies which operated on the Mississippi near Alton. Although the main channel of the river flowed along the foot of the eastern bluffs at high or normal water levels, the channel shifted to the Missouri side at low water. Morison's placement of the draw on the Illinois side apparently placed the navigable lane through the bridge over dry land at low water, thus making the bridge impassible throughout late summer and fall.

The board convened in St. Louis on February 14, 1894, to hear the protests of the steamship interests. Before a room packed with hostile boat owners and pilots, Morison unrolled a set of blueprints and explained his plan for the bridge and channel. He outlined the history of the project and stated that the new channel through the draw then carried four feet of water. Continued dredging, he maintained confidently, would make the channel substantially deeper. Morison concluded by asking the board to allow the completion of the bridge with the assurance that a navigable channel would be maintained.

One after another, the boat captains presented their objections. One of the most vehement of these was Captain Sarr of the Alton Ferry Company, which would be financially crippled by the completion of the bridge. The Daily Telegraph reported Sarr's argument: "He said that the bridge company had placed the draw span on the wrong position; that the current was not there, and that not a

thing should be done until the bridge company remedied the evil. He suggested the extension of the Government dike because of the fact that it would obstruct ferrying above the bridge, and declared that whatever remedies were proposed, the bridge company should pay."[100] Despite the open hostility which pervaded the proceedings, Morison did have a few defenders among the river pilots. "I think that the channel is all right," said Captain Brolaski, "I recognize that the water does not flow entirely that way now, but I believe that it will. Since 1865 I have noticed that the channel of the river has changed a number of times."[101] After hearing arguments from both sides and deliberating on the suggestions, the board gave its approval to complete the bridge, with the understanding that the bridge company extend the dike and continue large-scale dredging through the draw. Morison was finally vindicated when he was able to channel the river successfully to the east shore through the draw.

Union finally delivered the steel for the two remaining trusses to Alton, and the steelworkers completed the pivot span early in March. On March 9, another incident marred the bridge construction. Night watchman Casper Wild stepped overboard into the river from a pile driver platform late that night. "He struggled bravely," the newspaper reported, "and his cries were heard by the other watchman, who also yelled for assistance."[102] Wild was swept under by the icy current and drowned.

One week later, the railroad swung draw for the the first time, as described by the Daily Telegraph:

> A few minutes before noon Saturday the sound of numerous steam whistles on the levee announced that the time set for the draw span had arrived. A crowd immediately gathered on the levee and viewed the big span with its traveling derrick, steam engine and crew of fifty men swing slowly on its substantial pivot pier. The draw gave perfect satisfaction as to the proper length for the connections with the other piers and the trestle.[103]

On April 5, 1894, the first passenger train crossed the bridge amid another celebration among the townspeople.[104] A month later, the town staged yet another fete for the bridge: a jubilant May Day celebration and formal dedication. Thousands of visitors, including the governors of Missouri and Illinois, arrived in Alton aboard chartered trains to inspect the monumental structure, socialize and present and hear speeches. Edith Brenholt, the mayor's daughter, smashed a bottle of champagne over the steel superstructure and christened the bridge grandiosely, saying, "I name this bridge the Alton bridge and dedicate it to the cause of commerce, and may the Giver of All Good, guide and protect and watch over it and all of us."[105] The Daily Telegraph, which had heralded the bridge for years, reflected:

> For nearly ten years the citizens of Alton have looked forward to this

> day. They have longed for it; many have worked for it most earnestly; some have been fearful that it would never come; some even now prophesy evil for our town; other some have, probably, too remote a view of the benefits to be derived from the opening of the bridge. But in this day of general rejoicing it is better that there should be no recrimination; infinitely better that, optimat [sic] and pessimist, alike should take a deep interest in making the bridge and the new era that it gives an onward impetus to of real and practical benefit to the city and surrounding community... The Telegraph tenders congratulations to all our citizens, wishing the large amount of genuine prosperity in the present and future. It has worked for many years for this event, and now that it is here it joins in with every other true friend of Alton and asks the question, "will you continue in the march to prosperity?"[106]

Among the railroad officials and local dignitaries, George Morison gave a brief speech on "Great Engineering Achievements of the Age," a somewhat perplexing title in view of his statement in the speech that the subject was "not worth expounding because there are no great engineering feats of the age." Morison told the crowd, "There is no preeminence in the leading engineers and the small engineering feats are executed in as wonderful a manner as the larger projects."[107] After the speechmaking concluded, the crowd dispersed, and at the end of the day the citywide celebration ended. The town was still abuzz from the festivities when one last accident occurred on the bridge two days later. While working on the draw span, David Hull, foreman of the bridge carpenters, died after being struck on the head by a falling timber.[108]

For George Morison, the Alton Bridge represented a milestone, although he had no way of knowing it at the time. This undistinguished swing-span truss was his last bridge commission over the Mississippi River. But while the Alton Bridge represented the culmination of Morison's career on what many consider to be the quintessential American watercourse, it falls under the shadow of another of his Mississippi River structures - the most challenging bridge of his career - the high span over the lower Mississippi at Memphis, Tennessee.

MEMPHIS BRIDGE

Morison's last major bridge over the Mississippi River was also his largest and most technologically ambitious structure. Begun twenty years after he started his engineering career at the Kansas City Bridge, the railroad bridge at Memphis, Tennessee, was an immense undertaking, which would ultimately become known as his most important bridge project.

Memphis had long been considered by engineers and railroad capitalists as a particularly attractive location for a bridge across the Mississippi. Situated on the line of expanding industrial traffic between Kansas City and the Southwest and the Atlantic and Gulf coasts, Memphis presented an ideal crossing site. By the mid-1880s, no less than ten rail lines entered the southern city: three from the west and the remainder from the east. These included the Kansas City, Fort Scott & Memphis; the Kansas City, Memphis & Birmingham; the St. Louis, Iron Mountain & Southern and the Little Rock & Memphis Railways, all important regional carriers. As had been the case at numerous other Mississippi and Missouri River crossings, rail traffic over these lines was often tangled at Memphis by a transfer steamer operation.[109]

In February 1885, Congress granted a charter to two corporations to build and maintain a bridge over the Mississippi River at Memphis. Granted to the Tennessee and Arkansas Bridge Company, incorporated in Arkansas, and the Tennessee Construction Company, incorporated in Tennessee, the charter specified a bridge with two 550-foot spans and the remainder of the spans to be no less than 300 feet in length. The stone bluff on the Tennessee side of the river dictated that the bridge be a high structure. The charter, therefore, called for the fixed spans to be at bluff level, 65 feet above the high water mark.[110]

A few months after the charter was granted, consulting engineer Simon Stevens visited George Morison in his New York office in behalf of the two bridge companies. At Stevens' request, Morison prepared preliminary plans and estimates for the proposed structure. Morison's design featured two long spans, supported by abutments at either side of the river and a center double pier. No surveys had been made of the river at the proposed crossing, and Morison prepared the plans from some old maps of the river. When actual surveys were made, however, the width of the river proved to be substantially greater than the maps had indicated, and he scrapped his first design.

Although his initial engineering proved worthless, Morison was intrigued by the possibility bridging the Mississippi at Memphis. No engineer had ever bridged what he termed the "real Mississippi." During the 1880s, the general wisdom in

the industry held that bridging the Mississippi as far south as Memphis was a practical impossibility.[111] Morison described this sentiment, saying:

> The construction of a bridge at Memphis has been a matter of professional interest among American engineers for many years. In 1867 the bridge across the Missouri River at Kansas City, the first bridge across that river and the bridge whose construction led to the building of the railroad of whose system the Memphis Bridge now forms a part, was begun. At this time a bridge at Memphis was talked of as one of the works in the future. Like other works which were considered far in the future, the difficulties of the problem were overestimated: the depth of the river was overstated and other conditions were considered much more difficult than they really were. At that time, however, the construction of a bridge at Memphis would have been a matter of great expense, and the changes which finally rendered the building of this bridge a comparatively simple affair represent the advances which bridge engineering has made in twenty years.[112]

In addition to the far greater amount of water which flowed through it, the river here was vastly different in character than in its more northerly reaches. The Mississippi and the Missouri rivers join near Alton, Illinois, and although roughly equal in flow, they differ significantly in character. There the Mississippi changes from a relatively clear, calm watercourse and takes on the characteristics of the muddy Missouri. "Like the Missouri, it is a great silt-bearer. Like the Ohio, it is subject to extreme floods," Morison stated. "As is always the case when magnitude is increased, the changes in channel and the local disturbances are much less rapid than on the Missouri, but they are of the same character, and on a much larger scale. The floods which are most active and dangerous come from the Ohio. The flood season in the Ohio is in winter and early spring; the flood season of the Mississippi and Missouri is in the spring and early summer; the flood season of the two rivers covers about one half of the year, extending from about the first of January into July. The whole working season which can be safely depended upon in the Lower Mississippi covers only about five months of the year."[113]

Morison was anxious to be the first engineer to bridge the lower Mississippi. Having analyzed railroad finances on many occasions as a consultant, however, he was concerned about the bridge companies' ability to undertake the project. The two companies which held the bridge charter were independent of any railroad. Their intention was to build the bridge and charge tolls to any train which crossed. Morison worried about their ability to undertake the extraordinarily expensive project independently, and shortly after he became involved with the project, he contacted George H. Nettleton, president of the Kansas City, Ft. Scott & Memphis System of railroads.

Morison knew Nettleton from earlier work with the railroad, beginning with his own apprenticeship on the Kansas City Bridge. On January 15, 1886, he met with Nettleton at the railroad's headquarters in Kansas City with the proposal that the railroad take an active interest in the construction of the bridge. "It is from this date that the connection of your system with the scheme really began," Morison later reported to the railroad. He left Kansas City that night and arrived at Memphis the following afternoon. "The river was full of ice and it was difficult to go about," he wrote, "but I made a short trip on the transfer-boat Charles Merriam and climbed up the bluff on the Memphis side of the river. On this day I selected the location for the bridge, this location being fixed by the top of a rude staircase on the Memphis side and by a log cabin in the bottom-land on the Arkansas side. I never had occasion to alter this location and the bridge was built upon it."[114]

After choosing the bridge site, Morison waited throughout most of 1886 for either the bridge company or the railroad to act. Late in the year, Nettleton asked him to investigate the site once more and prepare another set of cost estimates for the bridge's construction. On November 23, Morison and his long-time assistant, Edwin Duryea, traveled to Memphis. Morison looked the site over briefly and returned to New York. Duryea remained throughout the winter, making borings of the river bottom. The borings showed a favorable subsoil condition under the river at Morison's chosen location. Here the river was floored across its entire width by a thick layer of hard clay at a depth within the limits to which caissons could be sunk.

With a more definite picture of the river conditions at Memphis, Morison prepared two revised designs. The conservative version featured three equal, simply supported spans of about 660 feet each. The more daring design incorporated a 1,300-foot cantilevered span. The railroad used these designs in its application for another Congressional charter, and soon after Morison submitted his report, a bill was introduced in Congress to grant another charter for a bridge at Memphis. It did not pass. The railroad tried again the following year, and on April 24, 1888, Congress granted permission to erect the bridge, with the stipulation that it also carry highway traffic. The new charter (given in Appendix R) was more stringent than its predecessor, however, with regard to the dimensions of the bridge.[115] The Act fixed the minimum length of the channel span at 700 feet - 150 feet longer than the clear spans specified in the 1885 Act. A more serious difference to Morison lay in the fact that the new charter fixed the height of the bridge at 75 feet above high water, instead of the original 65 feet. Morison was quarantined aboard ship in San Francisco at the time, and his partner Elmer Corthell prepared the documents for the War Department.[116]

The 1888 charter required that three government engineers from the War Department visit the site to determine the bridge location and specify the lengths of the channel spans. The board, consisting of Colonel W.E. Merrill,

Major O.H. Ernst and Captain D.C. Kingman convened in Memphis in May 1888. Only recently freed from California, Morison presented the case for the railroad company, while a number of representatives of the steamboat companies voiced objections. Morison was prepared to accept the span lengths given in the charter but argued that the 75-foot height provision would add unnecessary expense to the construction of the bridge, would force the railroad to grade extensive approaches on both sides and would interfere with existing street levels in the city of Memphis. He recounted the original charter and referred to Senate Bill 275, the so-called General Bridge Law introduced in 1887 but never enacted.[117] With no bridges under which to pass, the boats which ran the lower Mississippi did not use hinged smokestacks. In quoting a report of the Board of Engineers commissioned for the bill, Morison argued in favor of the Telegraph-plan smokestacks used on the Ohio River, saying, "the Board recognized the fact that smoke stacks can be so easily lowered that it is unwise to insist on bridges being built so as to give the height necessary for boats to pass without lowering their smoke stacks."[118]

Morison even went so far as to send an agent down the Mississippi from St. Louis to New Orleans to examine and measure every boat then operating on the river. (His inventory of boats is given in Appendix U.) "The pilot houses of the western river boats as now built are surmounted by a wooden ornament of absolutely no use, several feet higher than the flat roof of the pilot house," he stated. "The smoke stacks are also ornamented on top, the ornamentation being often in the form of an open work resembling the feathered head dress of an Indian." Morison concluded his argument, saying, "There are only about six steamboats on the Mississippi River whose pilot houses including ornamentation are more than 60 feet high, and there is not a single boat on which the pilot house without ornamentation is 60 feet high, while there are only six boats in which the height of pilot houses without ornamentation is more than 55 feet."[119]

The board maintained the 75-foot height requirement, despite Morison's well-documented objections. Although the three engineers were unanimous in their recommendations to locate the channel span next to the Tennessee shore, they could not agree on the minimum length for the channel. The two younger officers recommended a 1,000-foot span length, while the senior board member considered 700 feet enough clearance. Secretary of War William Endicott resolved the matter by overruling the board entirely and specifying a 730-foot minimum length. Morison calculated that if the channel span could be increased to a 770-foot length, fenders would not have to be installed to protect the piers from collision by barges, because of the decreased likelihood of collision. With this new requirement, Morison designed the bridge and submitted a revised report to Nettleton in August 1888.[120]

In this final design, Morison followed Endicott's dictates. On August 2, he hand-carried the plans for the bridge to Endicott in Washington. The Secretary approved the plans in a contract with the bridge company, dated August 23,

1888. The charter had required that provisions would be made "for the passage of railway trains, and wagons and vehicles of all kinds, (and) for the transit of animals." At Endicott's insistence, Morison showed a deck for vehicular and pedestrian traffic on the same floor as the railway traffic. If this arrangement proved inadequate, the railway company agreed to operate ferry trains across the river for the benefit of the other bridge users.[121]

Morison's final design for the bridge at Memphis contained both familiar and novel elements. For the substructure, he engineered typically long masonry piers founded on heavy timber caissons. This bridge, unlike his others across the Missouri and Ohio Rivers, would not be founded upon bedrock, however, but on the hard clay that floored the river bottom. Morison realized that the foundations would have to be sunk through the riverbed sand and well into the alluvial clay to develop sufficient bearing capability. Duryea's tests had revealed that this clay was so compact that it would be impractical to dredge using traditional means. He therefore designed the foundations to meet four requirements: The weights of the piers were to be limited as much as possible to reduce their immense dead loads. The pier bases were to be large enough to distribute the bearing pressures over as great as areas as possible. The pier bases would be heavily protected against scouring at the river bottom. Finally, the foundations would be sunk using the plenum caisson process.

To reduce the pier weights, Morison specified an unusually high quality of masonry, reduced their overall dimensions and designed their bottom portions using hollow construction. Although usually considered imprudent in colder climates, this last feature would be acceptable under the relatively warm conditions at Memphis. The general rule he followed in determining the size of the foundations was to build the caissons so that their weight below the river bottom would not exceed that of the sand that they displaced and that, after deducting 400 pounds per square foot for friction along the caisson sides, the weight placed on top of the caissons would not exert more than two tons per square foot of downward pressure. Using this guideline, Morison determined that the caissons would measure 92 feet long and 47 feet wide. He configured them with vertical sides below the bottom of the river. To limit scour, he designed a unique system whereby woven willow mats would be built on the surface of the river and sunk with riprap ballast to carpet the river bottom around the pier bases.[122]

Morison designed a superstructure for the Memphis Bridge unlike any of his others. To achieve the requisite 770-foot clear channel width, he delineated a bridge with a 790-foot cantilevered main span next to the Tennessee shore and two 620-foot spans over the remainder of the channel. Two other bridges in the world - the Forth Bridge at Queensferry, Scotland, then under construction, and the Lansdowne Bridge over the Indus River at Sukkur, India - exceeded the span length of the Memphis Bridge, but they were completely unlike Morison's bridge in design and detailing and did not employ American-type pinned connections.

The bridge that Morison had designed for Memphis would feature the longest span length built to date in America. Still, Morison would have preferred to engineer the bridge with three equal, simply supported spans or with the long span placed in the center.[123] The Secretary of War's stipulations procluded such a solution, however, as the engineer stated in a report to Nettleton:

> The arrangement which would have been most satisfactory to the engineer would have been three equal spans of about 675 feet each. If, however, one span of extra length was required, it would have been preferable to place it at the centre, making this central span a cantilever structure, the cantilevers projecting from the ends of two heavy side spans. The arrangement required by the War Department, however, placed the long span next to the east shore, so that if this span was built as a cantilever span it was necessary to provide an independent anchorage on the Memphis bluff. This course was adopted.[124]

The result was an oddly asymmetrical structure, which would later be criticized for its starkly pragmatic configuration.[125] But even given the severe design constraints and the overwhelming need for economy, Morison managed to rationalize the shape of the bridge in technological terms. By projecting a 170-foot cantilever from Pier I on the Tennessee shore, the distance between the end of this cantilever and Pier IV on the Arkansas shore was divided by the two other piers into three equal 620-foot spans. Morison engineered the central span with continuous chords and 170-foot cantilevers at either end. This left two equal 450-foot spans to complete the bridge, one between two cantilevers and the other between a cantilever and Pier IV. The result was a bridge with a central span 620 feet long, three identical 170-foot cantilevers and two identical 450-foot spans, with an anchorage span between Pier I and the Tennessee abutment.[126]

To simplify fabrication and construction, Morison sought to configure the through trusses with equal panel lengths throughout. This required that the panel lengths be common divisors of the cantilevers, the suspended spans and the central span. No practical increment existed for 170 feet and 450 feet, but by shortening the length of the cantilevers to 169'-4 1/2" and increasing the length of the suspended span to 451'-8", he could use a common panel dimension of 56'-5 1/2". Thus Morison adjusted the shape of the bridge slightly to provide for uniformity, with each cantilever arm divided into three panels, each suspended span into eight and the central span divided into eleven panels, all of equal length. The anchorage span on the east end consisted of four panels and the channel span, fourteen, making a total of 40 equal panels over the river channel. As each truss panel was subdivided into two equal-length floor panels, there were therefore 80 panels in the floor system. The total length of the through superstructure is given in the table on the following page:

Anchorage span	225 ft. 10.0 in.
Channel span	790 ft. 5.0 in.
Central span	621 ft. 0.5 in.
West span	621 ft. 0.5 in.
Deck span	338 ft. 9.0 in.
Total length	2597 ft. 1.0 in. [127]

Morison proportioned the width of the single-track bridge based upon the length of the channel span and the need for economy in the breadth of the masonry piers. "In the matter of transverse stiffness," he stated, "the position of this span corresponds with the separate spans of a common bridge, whereas the longer span by its cantilever construction was held rigidly at the ends." To determine the width for the 620-foot central span at Memphis, Morison looked to the 518.5-foot channel spans of the Cairo Bridge, which were 25 feet wide. He established the width for this bridge empirically at 30 feet.[128]

Morison established the trusses' depth similarly, with economy of fabrication and erection as overriding considerations. The difficulties of erection made it important to keep the truss dimensions within limits of ordinary falsework. And to keep live load vibrations to a minimum, he restricted the depth to no more than 2-1/2 times the width of the bridge. "By fixing the depth of both the central and the suspended spans at one eighth of the span and making all three of the cantilevers alike," Morison reasoned, "the depth of the structure over each of the piers and for the whole length of the central span became 77 ft. 7-13/16 in., and the depth of the suspended spans, 56 ft. 5-1/4 in. These dimensions were adopted."[129] Because the depth of the cantilevers over the piers corresponded to the depth of the central span, the upper chords were not parallel with the lower. To maintain uniform floor panel lengths, Morison found it necessary to keep the points of intersection of the web members over the panel centers, which created irregular upper panel chord lengths. But with eyebar upper chords, this would not present serious fabrication difficulties.

For the truss design, Morison chose what he termed a double triangular or double Warren girder. He intended to erect the channel span without falsework, cantilevering from each end. In addition to the elimination of dangerous and expensive falsework, the cantilever construction made it possible to bear the weight of the spans on each side of each pier to a single large bearing shoe and transfer this weight directly to a single point at the center of the pier. This allowed the engineer to use somewhat lighter and thinner piers than would have been possible with simply supported trusses, which require individual bearing points. The increased cost of the superstructure design over three equal separate spans was thus balanced to a degree by the decreased substructural costs.[130]

The only truly continuous span on the Memphis Bridge was to be the central one, and Morison allowed for expansion and contraction at one end of this. All other expansion was taken up by pinned sliding joints at the ends of the cantilevers. With two such joints in the channel span and only one in the west span, he had a double chance to take up expansion in the chords and floor system of the channel span. For this reason, Morison fixed the west end of the central span and placed the east end on expansion rollers.

At the west end of the through channel truss, Morison engineered a long-span deck truss to reach over the flood plain on the Arkansas shore. Spanning 338'9", this truss used a Warren, or as Morison termed it a single triangular, configuration, which was subdivided into six panel points with the floor supported at the half panel points by columns. The length of the floor panels of the deck truss equaled that used for the through spans, and the actual weight of the truss, including the floor system, was 3600 pounds per lineal foot. On its west end the truss was supported conventionally with the lower chord bearing shoe resting atop a double-cylinder pier. On its east end, the truss corner points rested in two niches in the stone pier which also held the easternmost through span. This asymmetrical bearing condition prompted Morison to design the truss using a peculiarly asymmetrical web profile, with the end posts on the east end shortened and the lower chord at the end panel point angled upward somewhat.

West beyond the deck truss, Morison delineated an extensive iron viaduct with a total length of 2290 feet. His design for the viaduct featured a standard series of plate girders, supported by iron towers. The spans over the towers measured 29 ft. 6 in. and the spans between the towers were twice this length at 59 feet. Each pier rested on concrete foundations, with driven piles beneath.[131]

The total superstructural weight of the bridge proper, excluding the approach viaduct, exceeded 16 million tons - more than any previous Morison bridge, except the two-mile-long Cairo Bridge. Truss weights are given by span in the following table:

East approach	66,812	pounds
Anchorage span	1,606,727	
Cantilever Pier I	1,252,365	
East intermediate span	2,329,759	
Cantilever Pier II	1,284,674	
Central span	5,122,252	
Cantilever Pier III	1,260,452	
West intermediate span	2,327,845	
Deck span	1,072,951	
Total weight	16,323,837	pounds [132]

With such numbers, dead weight was a critical factor in the bridge design, particularly for the long continuous spans. To decrease the weight while maintaining sufficient structural strength, Morison specified that all the trusses were to be composed entirely of steel, produced either by the Bessemer of open-hearth process. "As the sections of the superstructure were necessarily unusually heavy, and the strains from the dead load were greatly in excess of those from moving load," he stated, "it was thought best to use a slightly higher steel than is now generally used for lighter structures, and to work this steel without punching, all holes being drilled."[133] The specified strengths for the steel are given in the following table:

	high-grade steel	medium steel	soft steel
Maximum ultimate strength	78,500 psi	72,500 psi	63,000 psi
Minimum ultimate strength	69,000 psi	64,000 psi	55,000 psi
Minimum elastic limit	40,000 psi	37,000 psi	30,000 psi
Minimum % of enlongation in 8"	18%	22%	28%
Minimum % of reduction at fracture	38%	44%	50% [134]

Additionally, a sample bar from each melt was to be bent 18 degrees without showing any cracks or flaws on the outside of the bend portion.

The problem of securing a sufficient quantity of steel to meet his stringent specifications - which by then had been adopted more-or-less as the industry standard - again plagued Morison as it had on virtually all of his previous major bridges.[135] The problem was only exacerbated on the Memphis Bridge, because of the extremely long spans and the cantilevered construction required an extraordinarily heavy superstructure. Morison called for strength testing on 3/4" round sample bars produced from the melts. But even after reducing the strength requirements, the engineer still could not coax an adequate performance from the Bessemer material. "So much difficulty was experienced in getting a satisfactory Bessemer steel," he said, "and the requirements for the preliminary test on the round bar were so much reduced as to amount to little, that all steel was required to be made by the open-hearth process."[136] This revision was incorporated in a new set of steel specifications, issued in May 1890.

Under these new specifications, the strength of the steel for the eyebars was reduced for the sake of expediency. The new requirements are given in the following table:

	eyebar steel
Maximum ultimate strength	75,000 psi
Minimum ultimate strength	66,000 psi
Minimum elastic limit	38,000 psi
Minimum % of enlongation	20%
Minimum % of reduction at fracture	40% [137]

While the railroad company was making the financial arrangements for the bridge construction, Morison convinced Nettleton to construct the foundation for Pier IV during the low-water season of 1888, "believing that the information to be obtained by sinking this pier might be of great assistance in preparing the plans for the other piers."[138] Nettleton agreed, and on October 7, actual construction of the bridge commenced as carpenters began framing the caisson for the pier. To supervise the construction of the great bridge, Morison appointed Alfred Noble as resident engineer. Noble arrived on the site on October 1. Meanwhile, the steamers John Bertram - veteran from the Rulo and Nebraska City Bridge projects - and the John F. Lincoln from the Sioux City Bridge were bought and piloted to Memphis. The two boats were used to hold compressors and equipment and to maneuver the nine coal barges used on the project.[139]

For the construction of this bridge, Morison again assembled an experienced group of assistants and contractors. Noble, who had been with Morison since the Omaha Bridge, would act as resident engineer, dividing his time for the first year equally between the Memphis and Cairo bridges. M.A. Waldo, Assistant Engineer; E.H. Connor and W.S. McDonald, the Inspectors of the Superstructure; Emil Gerber, Office Engineer; and Irving Dickinson, Draftsman, had all served with Morison on previous bridge projects. Ralph Modjeski, who like Alfred Nobel had first signed on in 1885 during construction of the Omaha Bridge, functioned first as Chief Draftsman and later as the Chief Inspector of the Superstructure. Memphis would mark his last bridge project with his mentor. Morison hired his contractors and fabricators one-by-one, but the assembled group was a familiar one. Lewis Loss, veteran of the Cairo and Alton bridges, would build the masonry piers. The Union Bridge Company - with the help of several subcontractors - would fabricate the superstructure, and the Baird Brothers, erectors on almost all of Morison's major bridges, would erect the trusses. One newcomer to the project was the Pennsylvania Steel Company, contracted in March 1891 to manufacture the west approach viaduct. (A complete list of engineers, employees and contractors is given in Appendix V.)[140]

The work on Pier IV continued throughout the fall and winter of 1888. The foundation was completed in February 1889. By this time, Morison had completed the design of the large caissons for Piers II and III. He pushed the work on these two channel piers during the low-water season of 1889-90, employing up to 160 men to work in three eight-hour shifts, with the thought of completing the bridge by 1891.[141] "But the season was too short, and the foundation of Pier II had to be abandoned before it was completed," he stated. "No harm was done, but two seasons instead of one were required for the foundation work."[142] To develop sufficient bearing capacity, Morison called for unusually great caisson depths on the channel piers. The deepest foundations - under Piers II and III - extended almost 131 feet below the high water level. With a maximum immersion depth of 108 feet during construction, these piers ranked second only to the Eads Bridge (109.7 feet) as the greatest depth to which the pneumatic process had ever been taken.[143]

At these extreme depths, caisson fever once more plagued the men working so far under the river. The air pressure in the poorly lit, poorly ventilated chambers reached up to 47 pounds per square inch, and to lessen the risk, the men worked three 45-minute shifts during each 24-hour period. Still, four of them died and many others were crippled from the bends.[144] The pier construction was further marred by tragedy, when early on the morning of February 10 a towboat pulling a load of grain barges rammed one of the partially completed, submerged piers. The boat was ripped to pieces, the barges scattered over the river and six crewmen died.[145] Because the accident did not damage the bridge or delay construction significantly, Morison noted it only briefly in a later report to the railroad.

On April 3, 1889, a contract was executed with Lewis M. Loss of Rochester, New York, to build the slender masonry piers. Loss completed the last of the stonework for Pier II on April 25, 1891, almost 2-1/2 years after beginning construction of the first caisson. "During the entire work very little trouble was experienced from bad weather or high water," Morison stated flatly, "and with the exception of a few unimportant delays work was carried on continuously from the beginning."[146] On January 24, 1890, Morison awarded the contract for the fabrication of the superstructure to the Union Bridge Company, and that May he contracted with the Baird brothers to erect the cantilevered truss.

The masonry piers for the bridge were typically massive and tall. The 75-foot requirement of the War Department meant that the Memphis Bridge was some 25 feet taller than Morison's Missouri River structures. Although the superstructural design allowed Morison to reduced their mass somewhat, the four huge channel piers for Memphis nevertheless consumed a prodigious amount of material. Pier II, which stretched 193 feet from caisson floor to starling course and was the heaviest support, weighed over 37 million pounds.[147] Materials used in the piers are given in the following table:

Pier	Timber (m.b.f.)	Iron (lbs.)	Concrete (cu.yds.)	Limestone (cu.yds.)	Granite (cu.yds.)
I	336,768	187,206	3,079	1,292	1,403
II	1,560,492	450,187	3,379	2,459	1,738
III	1,085,496	366,967	2,379	2,868	2,002
IV	266,472	145,147	2,065	1,157	1,604
Total	3,249,228	1,149,507	10,902	7,776	6,747 [148]

Throughout 1889 and 1890, work was pushed in the great northeastern bridge fabricating plants to produce the components for the superstructure. All the steel for the bridge was poured by Carnegie, Phipps and Company (later the Carnegie Steel Company). From there the uncut structural sections were shipped by rail to the fabricating plant for cutting, punching, riveting and assembly.

Morison had contracted exclusively with the Union Bridge Company for the steel fabrication of the Memphis Bridge. That the project was more than a single mill could handle soon became apparent, as Union fell behind on the fabrication schedule. This was exacerbated by Morison's repeated rejections of the Bessemer steel during the early months of production. Although Union actually produced the majority of the material at its Athens, Pennsylvania, shops, almost 36% of the steel was produced elsewhere. This was procurred either by subcontractors with Union or by orders which Morison made directly. The largest supplementary steel contract was placed with A.P. Roberts and Company. To speed production, Morison convinced Union to relinquish parts of its original contract to Roberts for the deck span and one of the intermediate spans, excluding eyebars. Additionally, several other shops ultimately became involved with the fabrication of the immense bridge. The weights and percentages of steel produced by the different mills are given in the following table (components produced are given in parentheses):

	pounds	percentage
Union Bridge Company (majority of bridge parts)	10,432,020	63.90%
A.P. Roberts & Company (deck span; intermediate through span)	3,113,250	19.07%
Elmira Bridge Works (web members of central and intermediate spans)	1,127,574	6.94%
Lassig Bridge & Iron Works (web members; four vertical posts and central span portals)	806,617	4.94%
Scaife Foundry & Machine Co. (large castings on the piers)	423,963	2.59%
Keystone Bridge Company (anchor rods for anchorage pier; eyebars; bearing plates for Pier II)	310,585	1.90%
Pittsburg Steel Casting Co. (steel castings for Piers II, III and IV)	61,935	0.37%
New Jersey Steel & Iron Co. (expansion rollers)	40,712	0.25%
Pittsburg Bridge Company (miscellaneous)	7,171	0.04%
Total	16,323,837 pounds	

[149]

All of the bridge except the suspended span between the cantilevers of the channel span was erected on falsework. The suspended span was projected from the ends of the cantilevers, connected at the center and then swung free. Because of the extreme height of the bridge above the river bottom, it was impossible to drive single-pile falseworks under the trusses. Instead, the Baird Brothers erected three-story timber bents under the panel points of the trusses. Each bent rested on each side, to carry the four lines of travelor tracks. The traveler itself was a timber structure almost 100 feet tall and long enough to span three floor panels of the bridge.[150]

Erection began on the east shore anchorage span at the end of March 1891. The Baird's crew laid the first lower chord sections for this truss on April 3, completing it three days later. At the same time, the pile driving crew was placing the falsework under the east cantilever arm, which was then completed on June 20. The driving of the falsework for the central span was begun in July, with the steelwork completed two months later. The west cantilever was completed in late November, the suspended span to Pier IV a month later.[151]

The Baird Brothers commenced the erection of the last suspended span - the only part of the Memphis Bridge built without falsework - on February 9, 1892. To aid with the construction, the men built another traveler. Simpler than the device used for the other spans, the traveler consisted of a platform which rested on the top chords of the truss. It carried two derricks guyed to a stiff timber frame, which had been placed at the end of the west cantilever. The material for this last span was floated by barge beneath the span opening and hoisted into place by the traveler's boom. The opening between the cantilever arms on both sides was carefully triangulated and measured with a steel wire. Computations were then made showing the change in length of the members of the central span, the anchorage span and the cantilever arms resulting from the building out of the half spans of the intermediate span.[152]

The weight of the suspended span was so great that Morison hesitated to use standard adjustable wedges at the connections between the cantilever arms and he suspended span. With the wedges, oblong holes each carrying two pins could be places at the sliding joints and by placing wedges between these pins the position oft he projecting span could be raised or lowered or the span could have been moved forward or backward to fit the suspended span properly. Instead, he decided to erect the west end without adjustment and the east end with a hydraulic adjustment, making the bottom chord connection between the two ends with eyebars, which, acting as a toggle joint, could take up variations in length.[153]

In calculating the final position of the half span, Morison assumed that the erecting outfit of travelor, engines, lines and scaffolds would remain on it until the span was swung. "This was an error," he later admitted, "the unusual weight of the span insured much difficulty in swinging, and it should have been assumed in the first place that all appliances not absolutely necessary in swinging the span would be removed as soon as the half spans were built out."[154] Morison's miscalculation meant that the half spans were some five inches above their intended height, which added to the already difficult task of swinging and connecting the suspended truss. To further complicate the erection, the removal of all the equipment reduced the strains in the trusses, causing the free end of the upper chord to move about an inch out of line. This was balanced, however, because the time to erect the span was greater than the engineer had accounted for, pushing the connection at the center later in the season when the temperatures were higher.

The crew completed the erection of the east half of the suspended span on April 8. The west half had already been completed, and it remained to join and adjust the two halves to complete the bridge. To supply the place of the end adjustments ordinarily provided for swinging the span, Morison decided to depend mainly on expansion by temperature to extend the upper chord and on toggle joints to shorten the lower chord, so that the adjustment pins could be withdrawn. For one full truss panel of the lower chord, he substituted two lengths of eyebars for the normal chord members. These he had connected to the adjacent chords with temporary pins and to each other by short coupling bars. A short vertical rod with a nut at the lower end and an eye at the upper end passed between each pair of coupling bars and through a washer, which bore on the lower edge of the coupling bars. This formed the toggle joint. After completion of the east end, the men removed the travelor and all other unneeded equipment from the span and erected a derrick on the end of each arm to handle the closing sections. With the arm ends higher than anticipated by the removal of the weight, the crew was forced to wait for cooler weather to couple the two suspended halves. On the morning of April 10, the temperature had cooled sufficiently to allow the connection, and the crew inserted the last pins with an opening of only 1/16" more than required.[155]

The cool weather aided the connection, but hindered the final swinging of the span. Workers removed the derricks and installed two pairs of heavy triple blocks rove with 2-inch manilla rope to hold the spans, "but the weather became cold when heat was wanted," Morison lamented. The men loaded the cantilever arms between Piers I and II with timber rails, locomotives and machinery to shorten the upper chords. A 97 temperature was necessary, however, to release the adjustment pins in the upper chord. Finally, after waiting several days in vain for the weather to improve, Noble began heating the upper chord with steam from the locomotives while adjusting the ropes and the toggle rods to apply a sufficiently heavy strain to the upper chord eyebars. As the temperature reached its high that afternoon, the immense truss remained in place but the masonry piers on either end began to push outward. "The motion of the piers worked against the shortening of the top chord by compression," Morison stated, "and this attempt to swing the span failed."[156]

During the next two days, the workers installed additional rods to the toggle joints, attached steam pipes to the adjustment points and installed more clamps and blocks to budge the truss into position. On the morning of April 22, they again began lifting the toggle joints to adjust the upper chords. With 24 toggle rods, it took several hours to turn their nuts, but the joint was finally raised almost four feet above the line of the lower chord. Late that afternoon, they connected the steam pipes to the locomotives, tightened the clamps, and within an hour the adjustment pins at the west end of the upper chords became loose enough to remove. The Baird crew loosened the adjustment wedges, releasing the upper chord at both ends, and the job of swinging the span was almost complete when approaching darkness halted the work. The

following day they completed the continuous superstructure for the Memphis Bridge. The railroad crew installed the floor system while the steelworkers completed the last of the field riveting.[157]

By May 12, 1892, the structure was ready for its formal testing and opening. Given the importance attached to the bridge by the city of Memphis, the opening ceremonies were fittingly grand. Called by the local newspaper "the event most auspicious to the people of Memphis in the history of this city since the first lone wanderer found resting place on the banks of the Mississippi in the long ago", the celebration had been planned well in advance and drew tens of thousands of spectators.[158]

The celebration opened at noon with the crossing of the first train, a string of 18 locomotives, each newly painted and polished and heavily decorated with flags, flowers and bunting. (The engine covered with birds and cranes won the prize for best ornamentation.) Engineer William Haggerty piloted the lead engine as the train crossed slowly from the Arkansas side into Memphis to test the flag-draped bridge under load. As the train labored over each span of the bridge under the inspection of observors placed on each pier, steam whistles throughout town and on the riverboats crowded around the bridge screamed, cannons boomed and the throng of 50,000 people lining the riverbank cheered wildly. Haggerty then turned the train around in Arkansas and roared back across the bridge into Arkansas at full steam. Then Tennessee Governor John P. Buchannon and his entourage met Arkansas Governor J.P. Eagle and his midway on the bridge, the two men shook hands and exchanged congratulations to themselves and to the railroad. The two governors were followed by a similar meeting on the bridge between George Nettleton and George Morison, who also exchanged pleasantries and adressed the crowd "to the great edification and delight of those who heard." according to the Memphis Appeal-Avalanche.[159] Morison briefly and rather dryly recounted the history of the railroad and the bridge project, concluding by turning the bridge over ceremoniously to Nettleton. Nettleton replied, saying:

> Mr. Morison, for a little more than four years your time and talents have been engaged in planning and building this noble structure which I now, as the president of the Kansas City & Memphis Railway and Bridge Company, receive from your hands. The work is a triumph of engineering skill and will rank high in the list of the great bridges of modern times. It is my duty - a pleasant and grateful duty - to congratulate you upon its successful completion. It will stand long after the generation which witnessed its erection has passed away, a monument to your genius in designing and skill and ability of your assistants, Mr. Alfred Noble, Mr. M.A. Waldo and Mr. Ralph Modjeski, who thoroughly understood your plans and, overcoming all difficulties, successfully executed them.[160]

Morison's meeting with Nettleton was followed by more speechmaking from assorted dignitaries at a nearby grandstand built for the occasion, and the festivities lasted throughout the night and into the next day. After the crowds had dispersed two days later, the Memphis Bridge attracted additional attention from the city as a man attempted suicide by jumping from it.[161]

Construction on the highway deck and the viaduct continued throughout 1892, and Morison finally turned the bridge officially over to the railroad almost a year later, on May 1, 1893. As predicted, the cost of the bridge was staggering: slightly less that $3 million. This is itemized in the following table:

Substructure		$968,987.55	
Superstructure		979,991.04	
(steel work:	739,532.77)		
(erection:	211,746.86)		
(painting:	8,692.60)		
(flooring:	20,018.81)		
Total bridge proper			$1,948,978.59
Approaches		289,751.38	
Permanent track		38,895.33	
Shore protection		93,683.44	
Tools, service tracks, etc.		43,533.59	
Engineering		128,523.12	
Real estate		218,369.94	
Sidings, switches, etc.		7,425.47	
Interest during construction		206,409.86	
General expense		23,573.33	
Total cost of project			$2,998,144.05 [162]

Completion of the Memphis Bridge marked the climax of George Morison's bridge engineering career. Considered by his peers as his greatest accomplishment, it marked the first time the Mississippi river had been crossed this far south. Although Morison would design other bridges, none could match this structure for technology and sheer size.


K C & M R & B Co
MEMPHIS BRIDGE
General Map.
TENNESSEE CHUTE
ARKANSAS CHUTE
MISSISSIPPI RIVER
MEMPHIS BRIDGE
HOPEFIELD LAKE

Figure 137

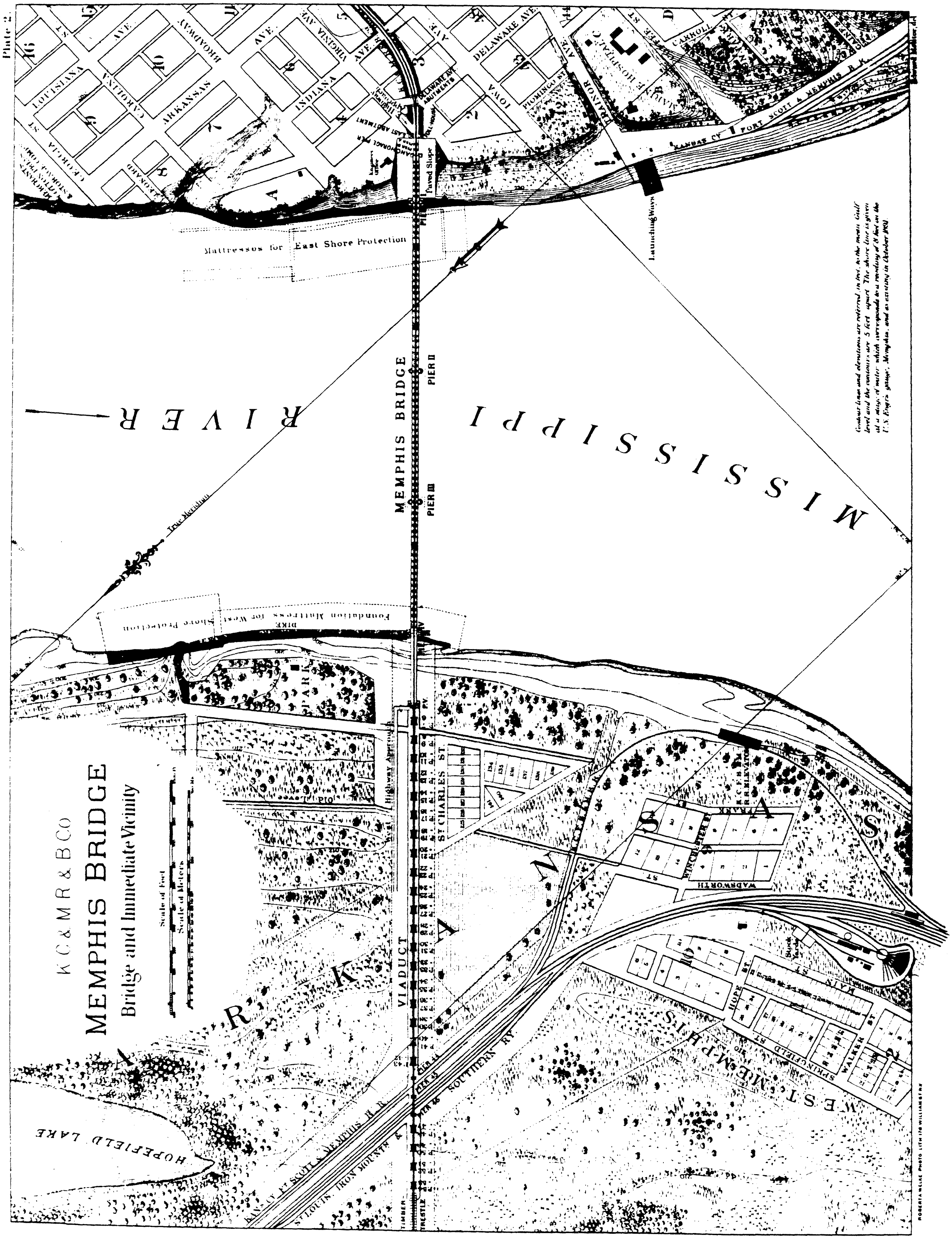

K C & M R & B Co
MEMPHIS BRIDGE
Bridge and Immediate Vicinity
MEMPHIS BRIDGE
PIER II
PIER III
MISSISSIPPI
RIVER
Mattresses for East Shore Protection
Foundation Mattress for West Shore Protection
VIADUCT
HOPEFIELD LAKE
WEST MEMPHIS

Figure 138

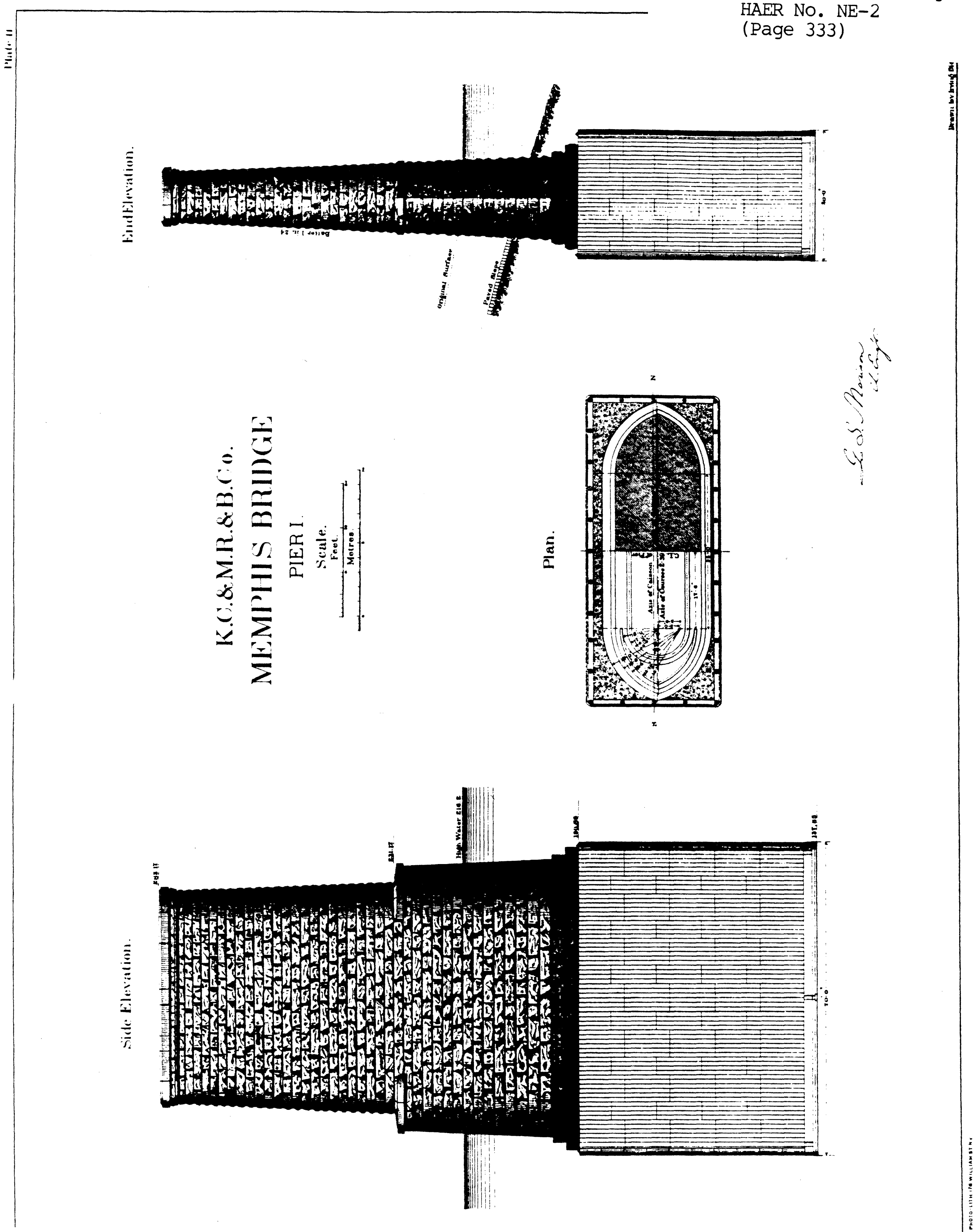


Plate II
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
PIER I.
Scale.
Feet.
Metres.
End Elevation.
Side Elevation.
Plan.
Original Surface
Paved Slope
High Water
Axis of Caisson
Axis of Courses

Figure 139

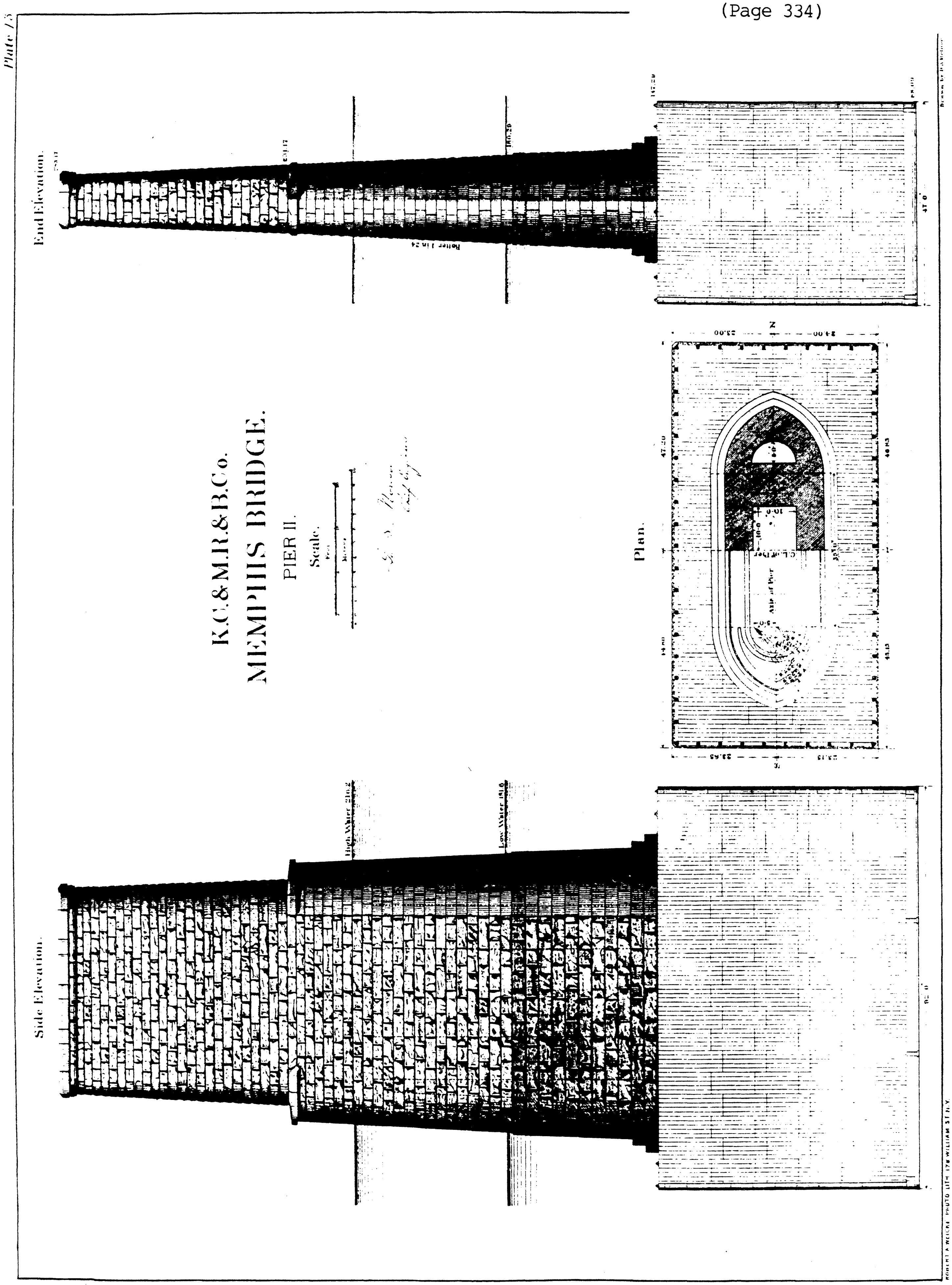

K.C.&M.R.&B.Co.
MEMPHIS BRIDGE.
PIER II.
Scale.
End Elevation.
Side Elevation.
Plan.
High Water 216.2
Low Water 181.6

Figure 140

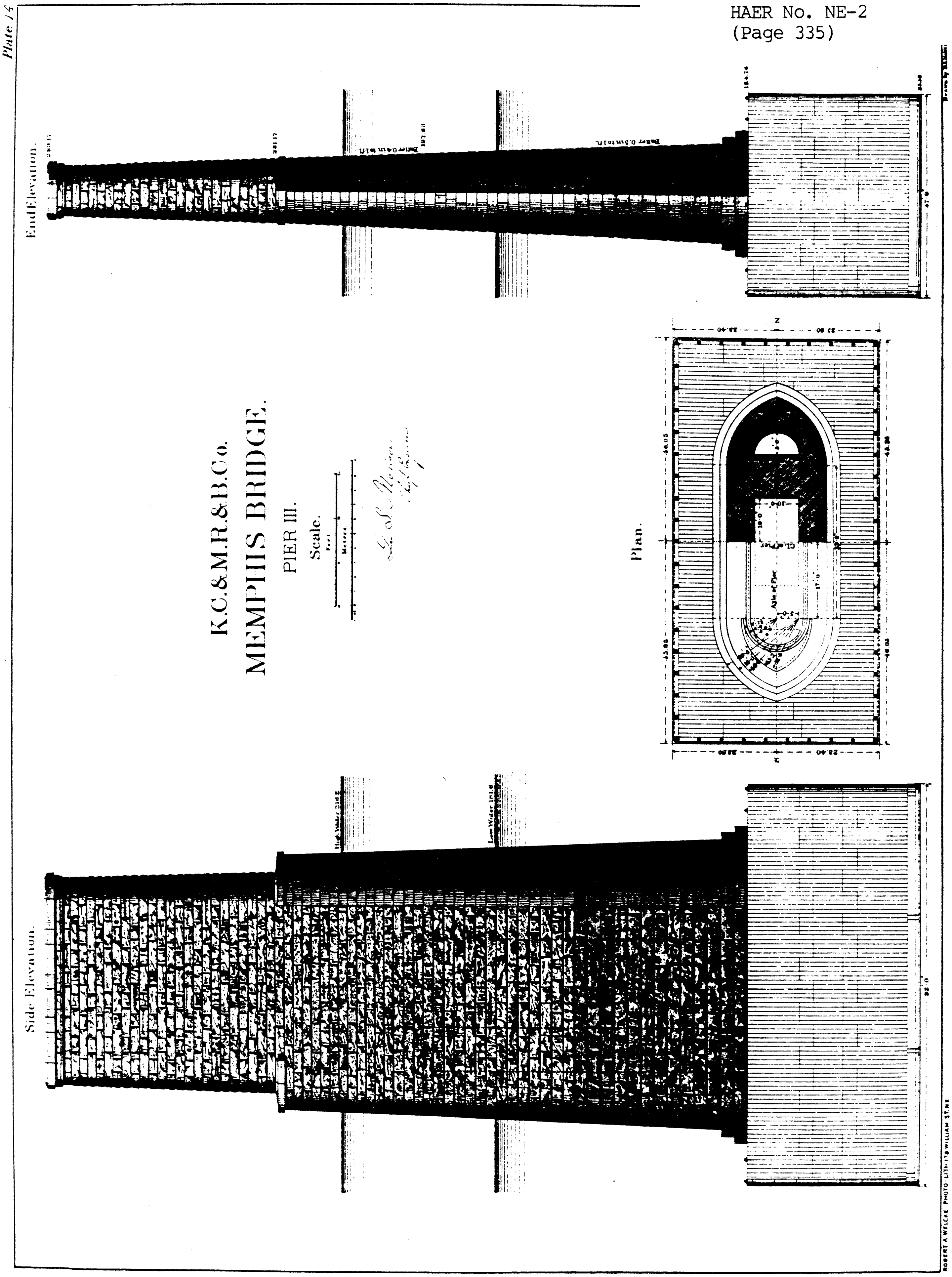

End Elevation.
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE.
PIER III.
Scale.
Plan.
Side Elevation.

Figure 141

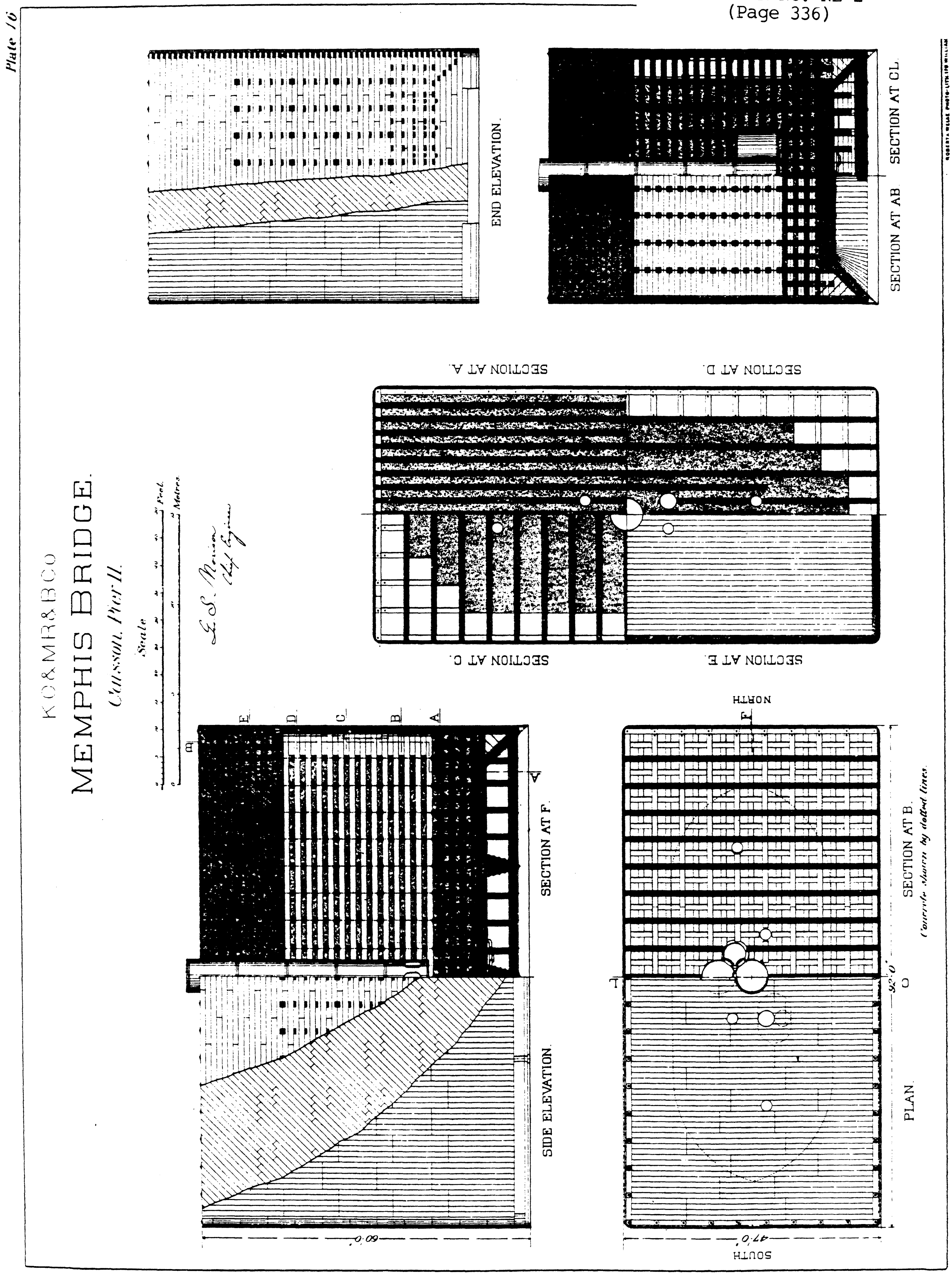


Plate 16
K C & M R & B Co
MEMPHIS BRIDGE.
Caisson, Pier II.
Scale
Feet
Metres
END ELEVATION.
SECTION AT CL.
SECTION AT AB
SECTION AT A.
SECTION AT D.
SECTION AT C.
SECTION AT E.
SECTION AT F.
SIDE ELEVATION.
NORTH
SOUTH
SECTION AT B.
Concrete shown by dotted lines.
PLAN.
60.0'
47.0'

Figure 142

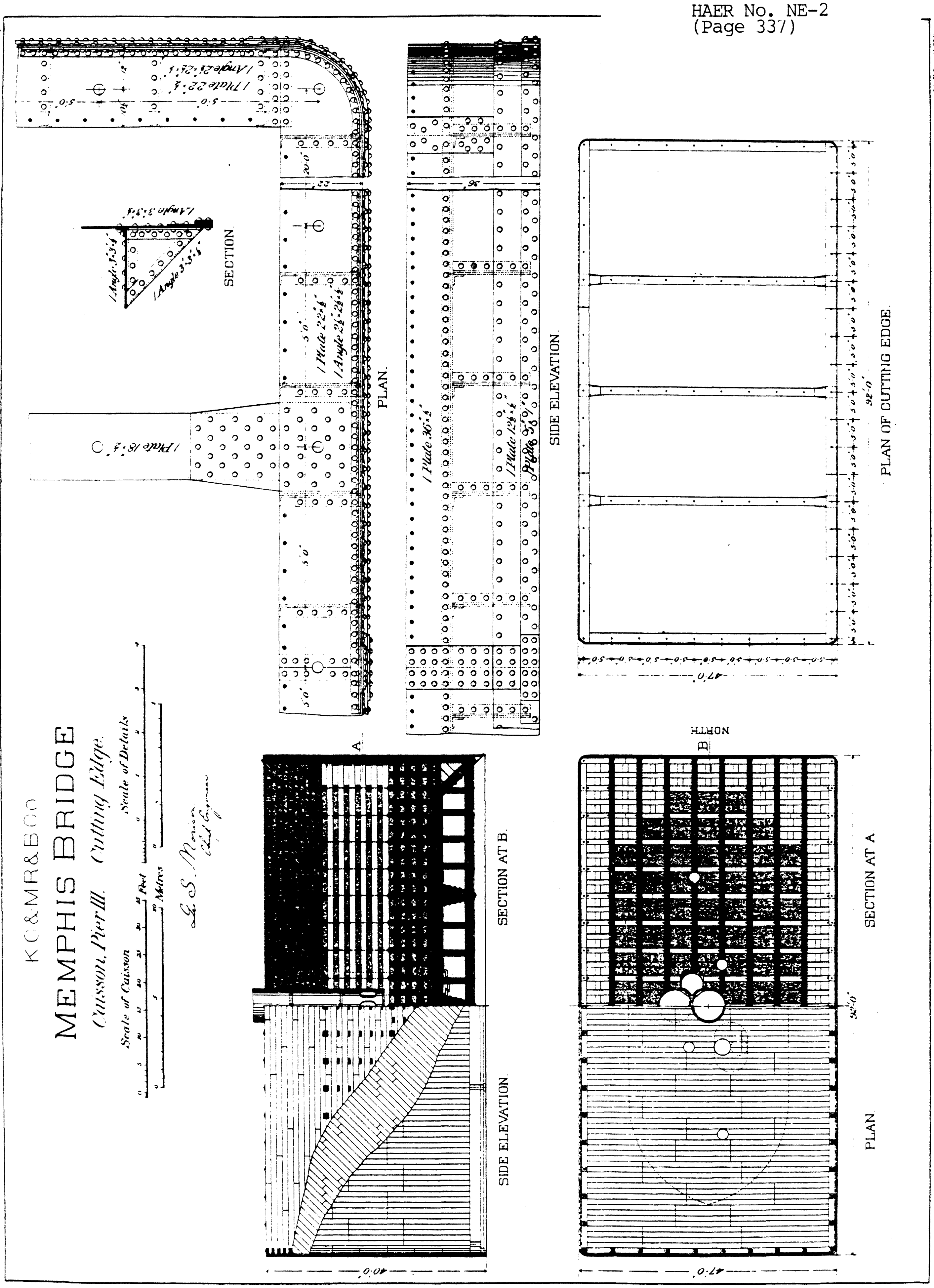

K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Caisson, Pier III. Cutting Edge.
Scale of Caisson
Scale of Details
Feet
Metres
PLAN
SECTION
SIDE ELEVATION
PLAN OF CUTTING EDGE
SECTION AT B
SECTION AT A
NORTH
PLAN
SIDE ELEVATION

Figure 143

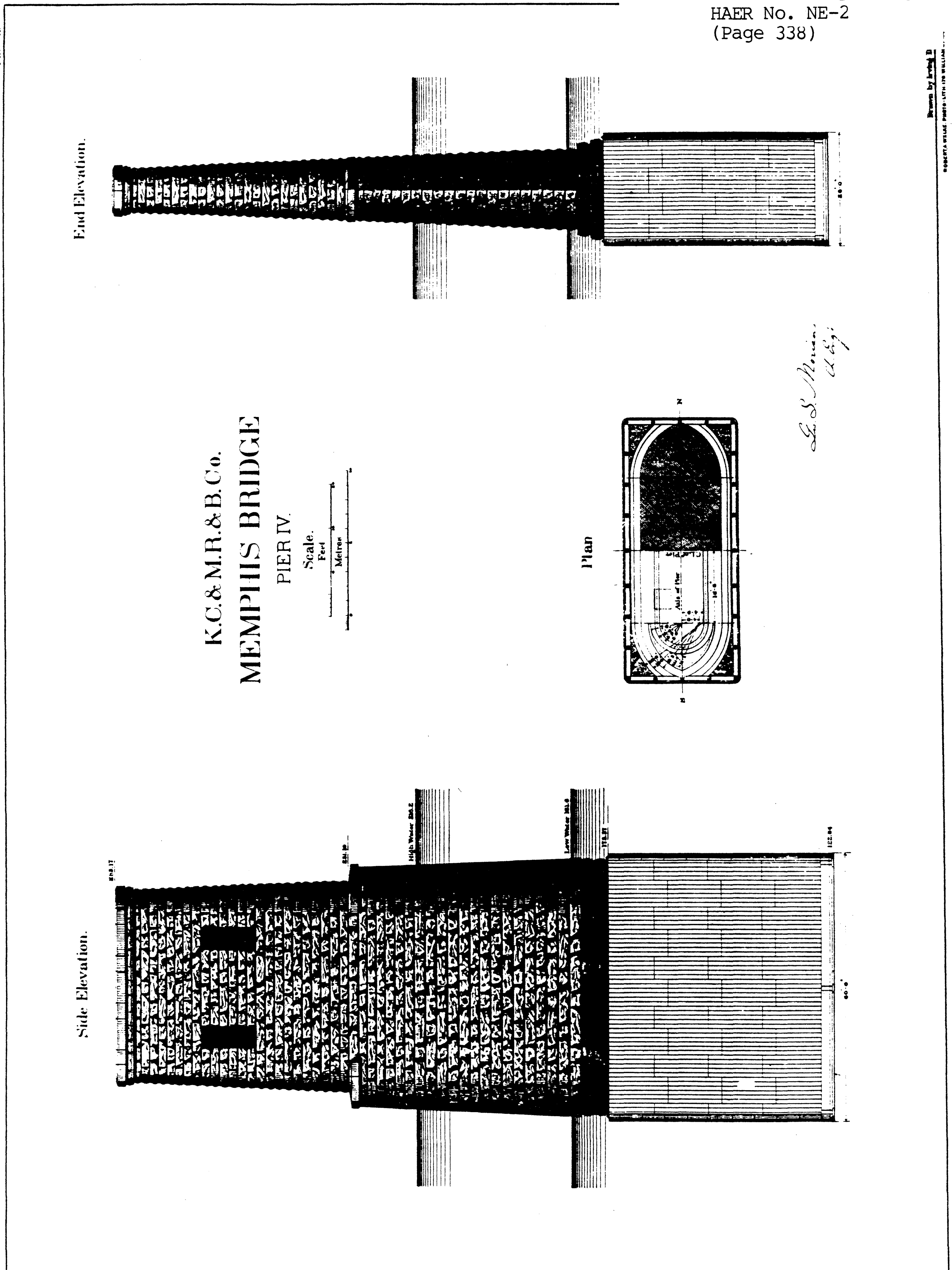

K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
PIER IV.
Scale.
Feet
Metres
End Elevation.
Side Elevation.
Plan

Figure 144

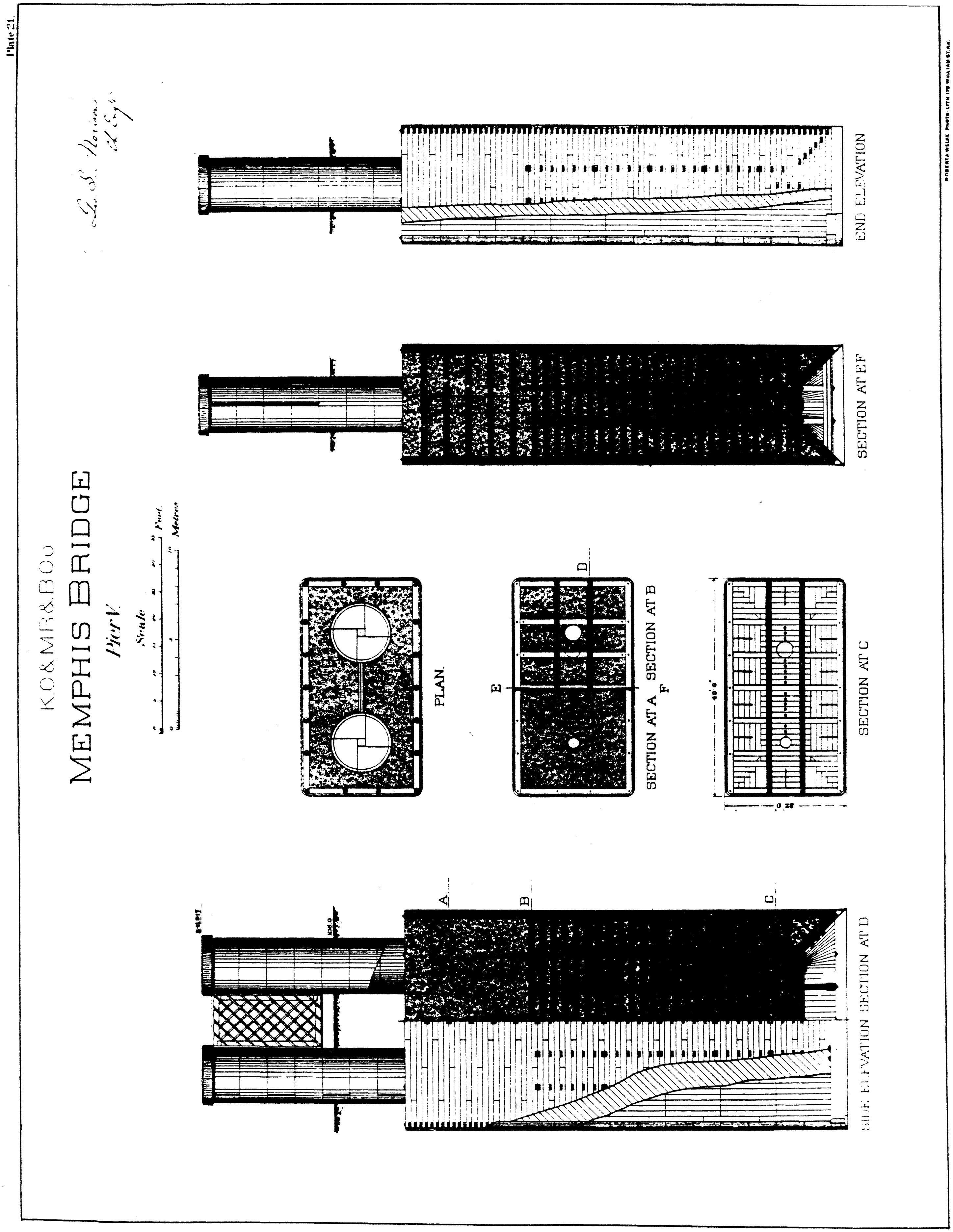


Plate 21.
K.C.&M.R.&B.Co
MEMPHIS BRIDGE
Pier V.
Scale
Feet
Metres
PLAN.
SECTION AT A
SECTION AT B
SECTION AT C
SECTION AT EF
END ELEVATION
SIDE ELEVATION SECTION AT D

Figure 145

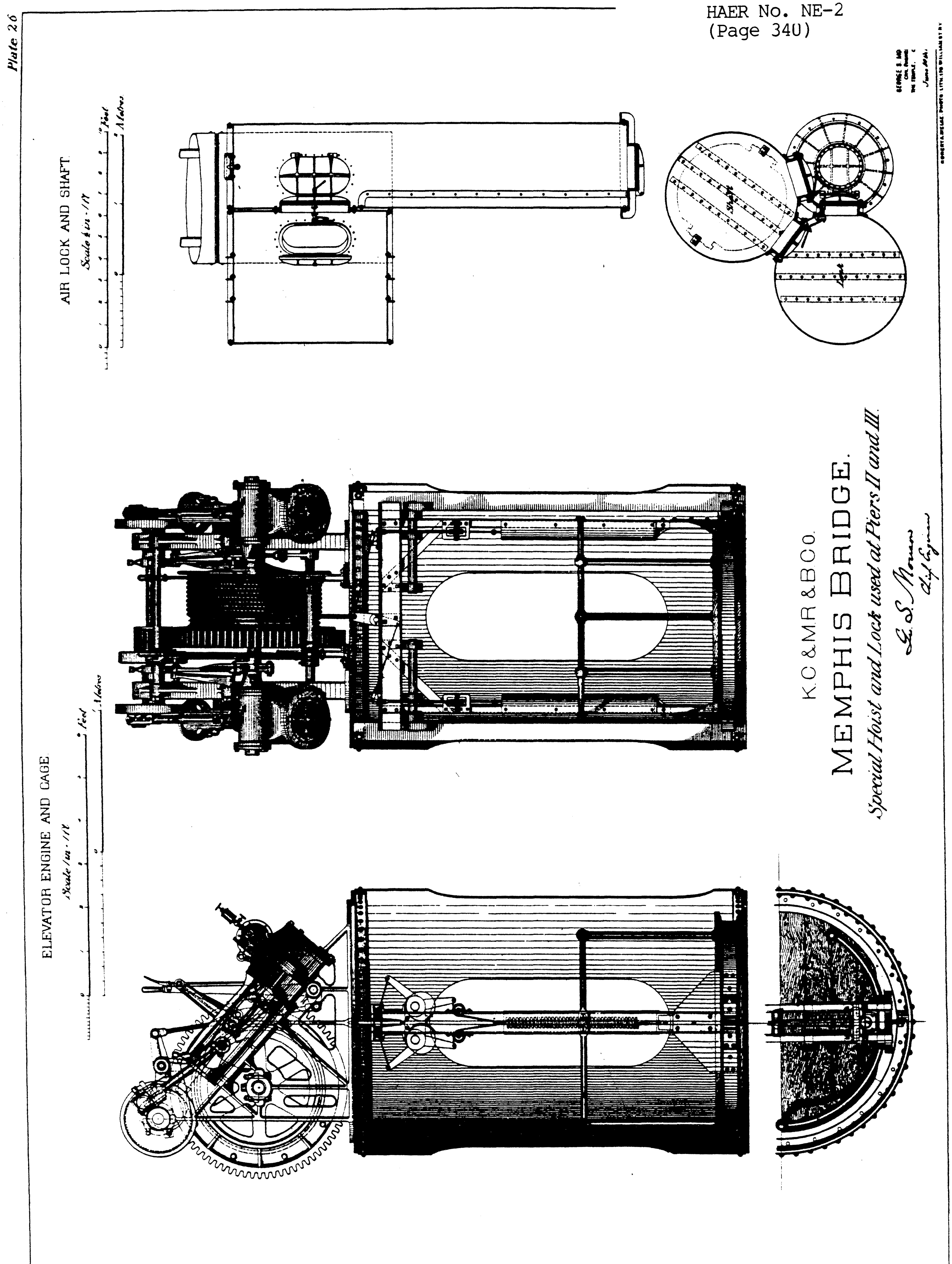


Plate 26
AIR LOCK AND SHAFT
ELEVATOR ENGINE AND CAGE
K.C. & M.R. & B. Co.
MEMPHIS BRIDGE.
Special Hoist and Lock used at Piers II and III.

Figure 146

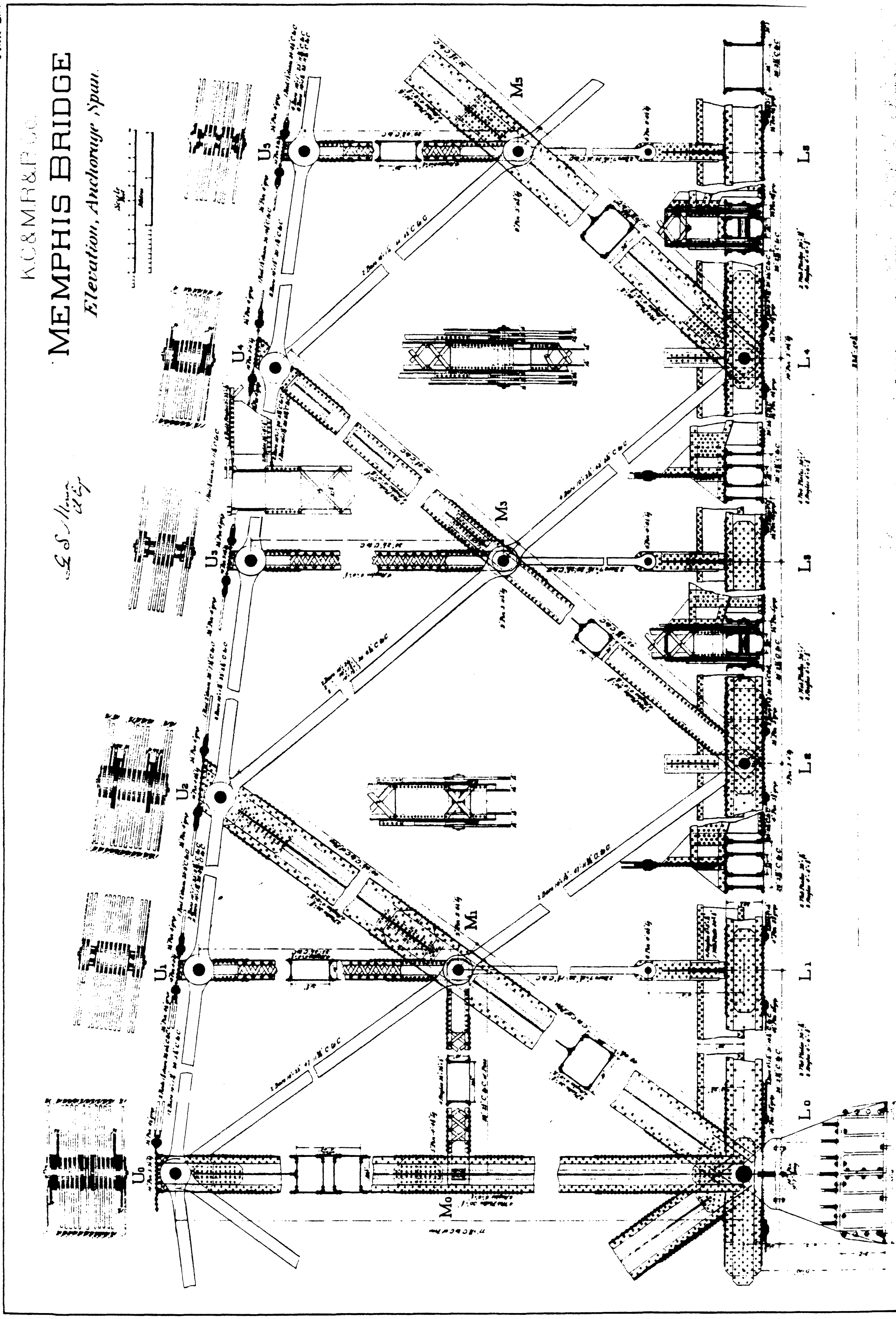


Plate 29.
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Elevation, Anchorage Span.
U0
U1
U2
U3
U4
U5
M0
M1
M3
M5
L0
L1
L2
L3
L4
L5

Figure 147

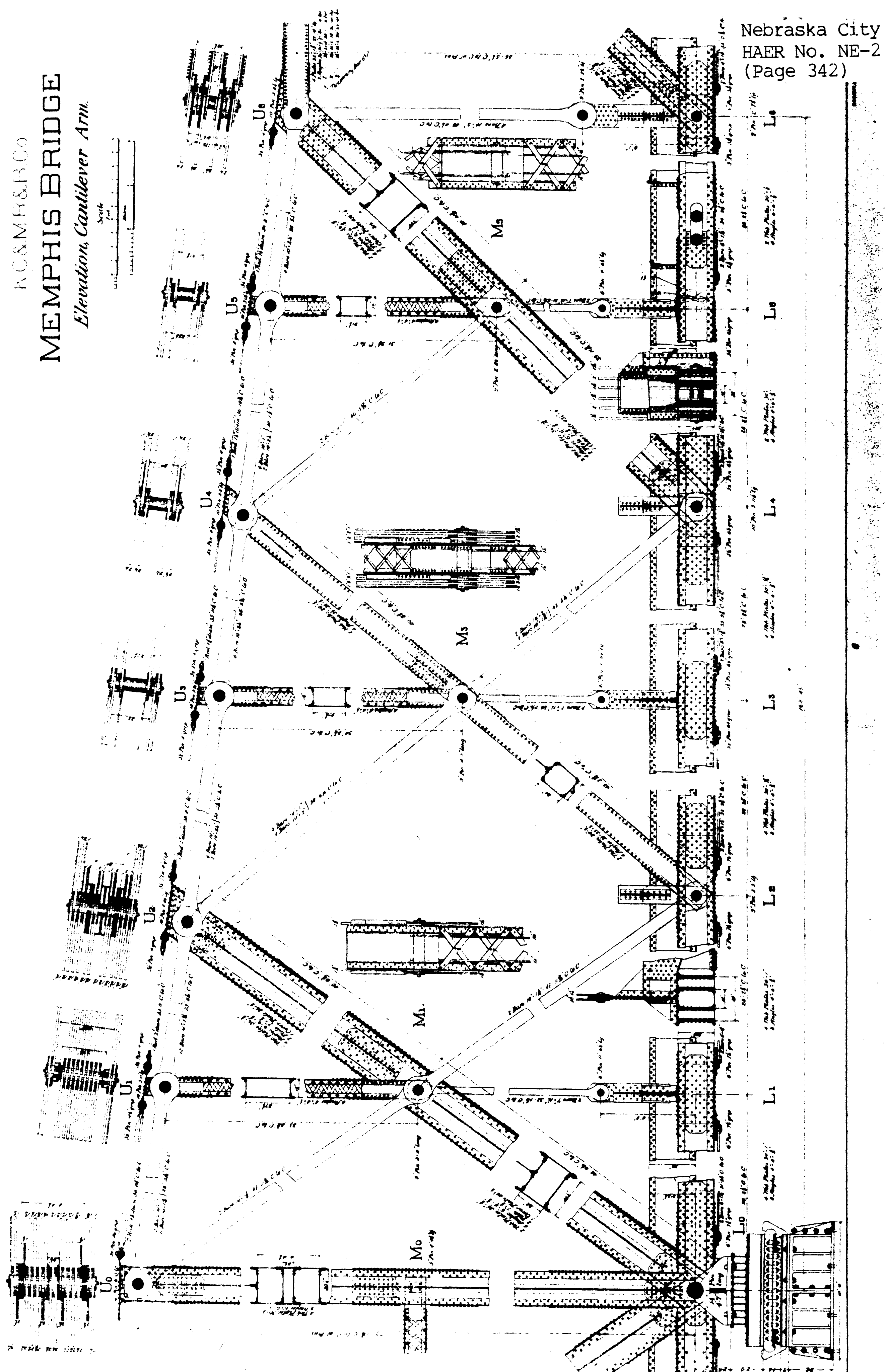


Figure 149

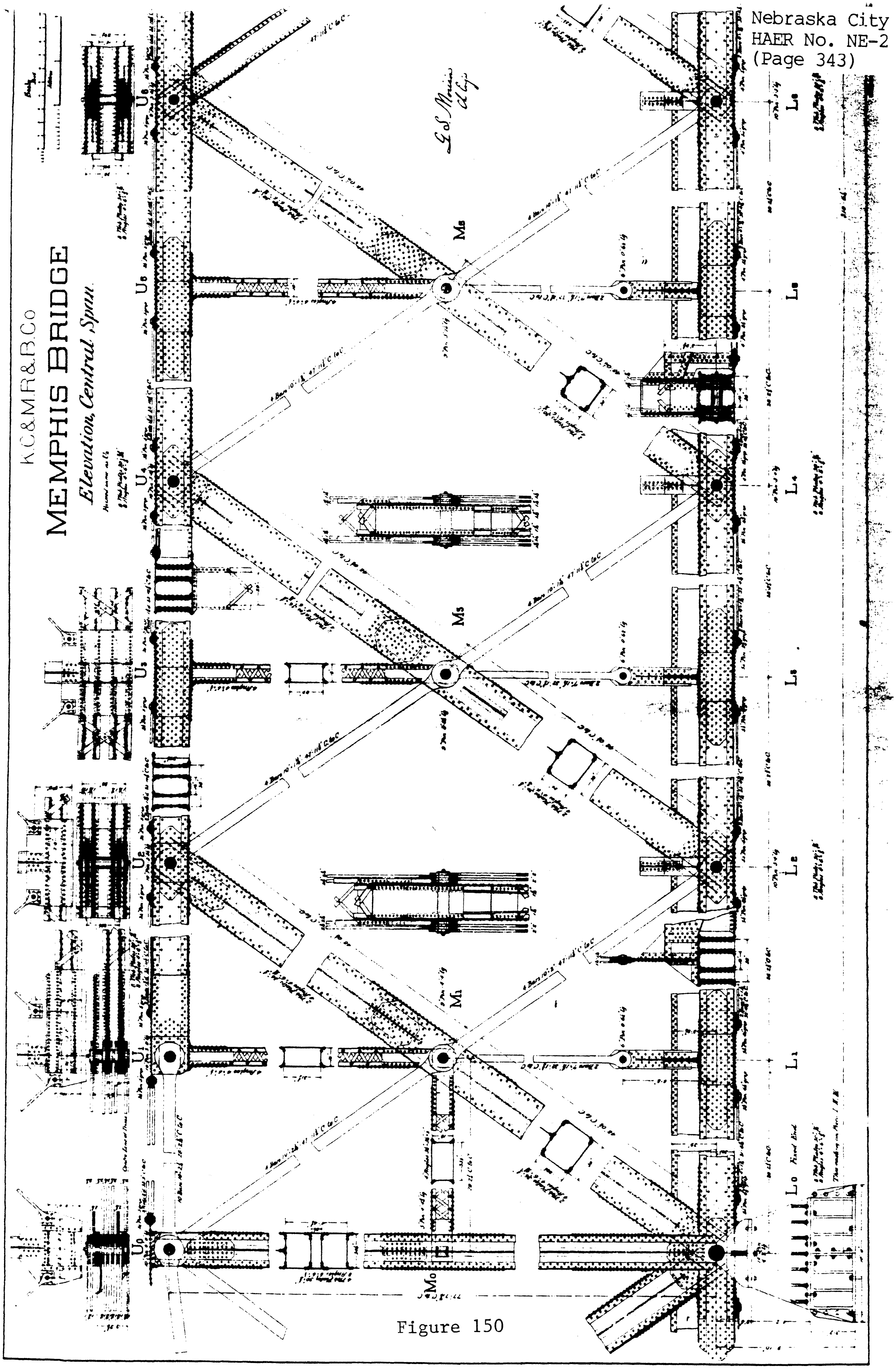


Figure 150

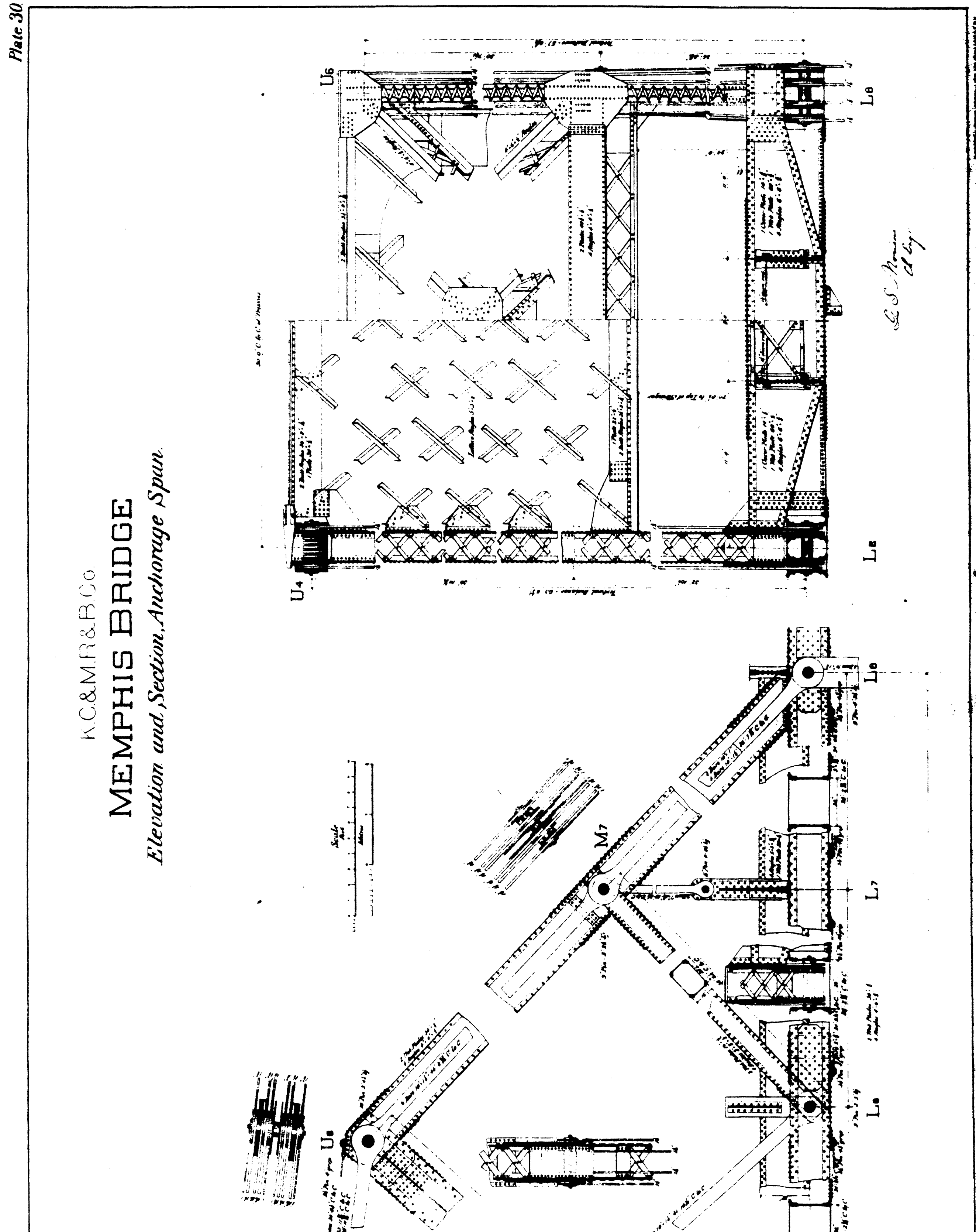


Plate 30
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Elevation and Section, Anchorage Span.
U6
L8
U4
L8
L8
M7
L7
L6
U6

Figure 148

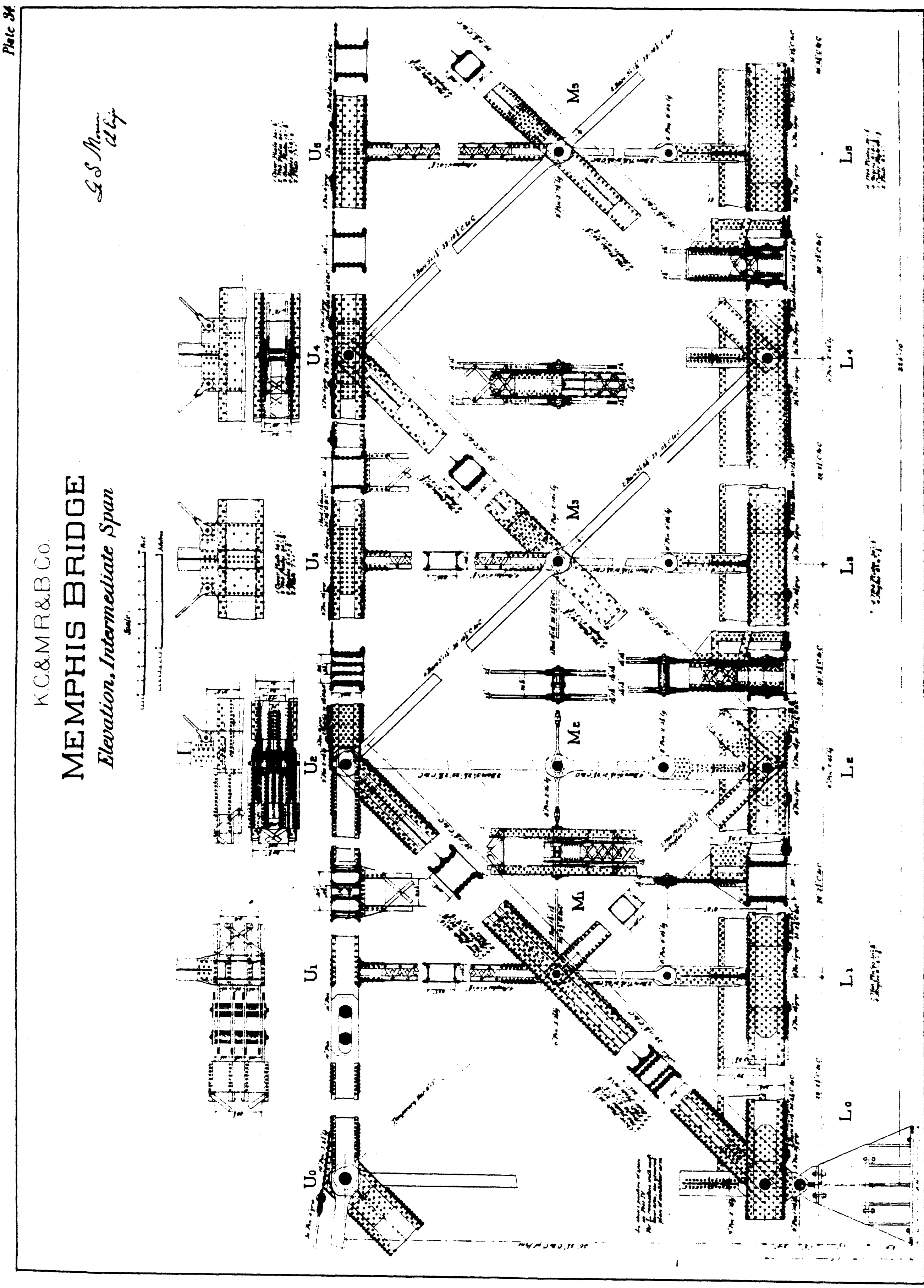


Plate 34
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Elevation, Intermediate Span
U0
U1
U2
U3
U4
U5
M1
M2
M3
L0
L1
L2
L3
L4
L5

Figure 151

Plate 35

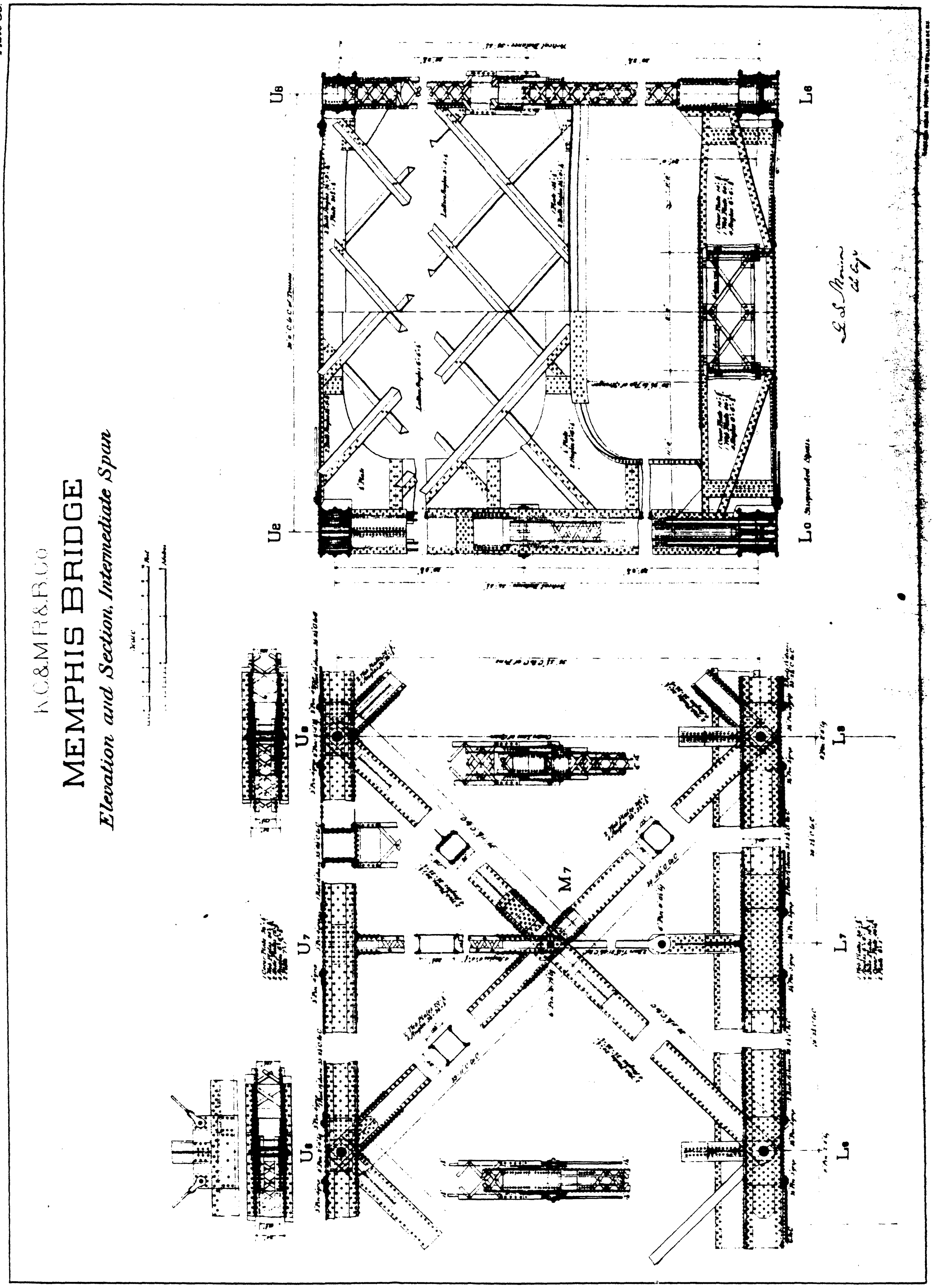


Figure 152

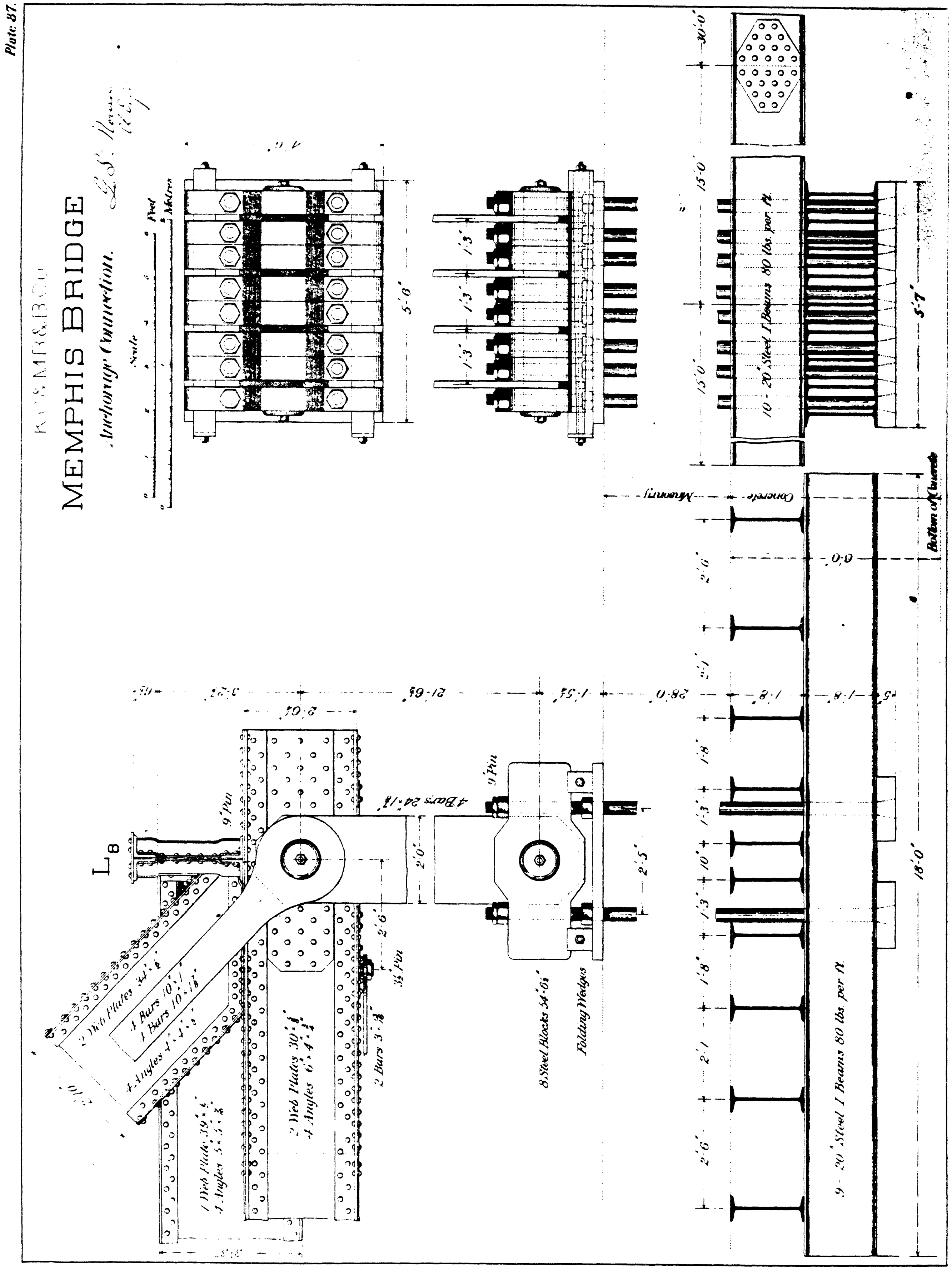


Plate 87.
MEMPHIS BRIDGE
Anchorage Connection.
Scale
Feet
Meters
L8
9" Pin
4 Bars 24"×1⅞"
2 Web Plates 34"×⅝"
4 Bars 10"×1"
4 Bars 10"×1⅛"
4 Angles 4"×4"×⅝"
2 Web Plates 30"×⅝"
4 Angles 6"×4"×⅝"
2 Bars 3"×⅞"
3½" Pin
1 Web Plate 39"×⅝"
4 Angles 5"×3"×⅝"
8 Steel Blocks 34"×6½"
Folding Wedges
10 - 20" Steel I Beams 80 lbs. per ft.
9 - 20" Steel I Beams 80 lbs. per ft.
Masonry
Concrete
Bottom of Concrete
5'-6"
5'-7"
18'-0"
15'-0"
30'-0"
2'-0"
2'-5"
2'-6"

Figure 153

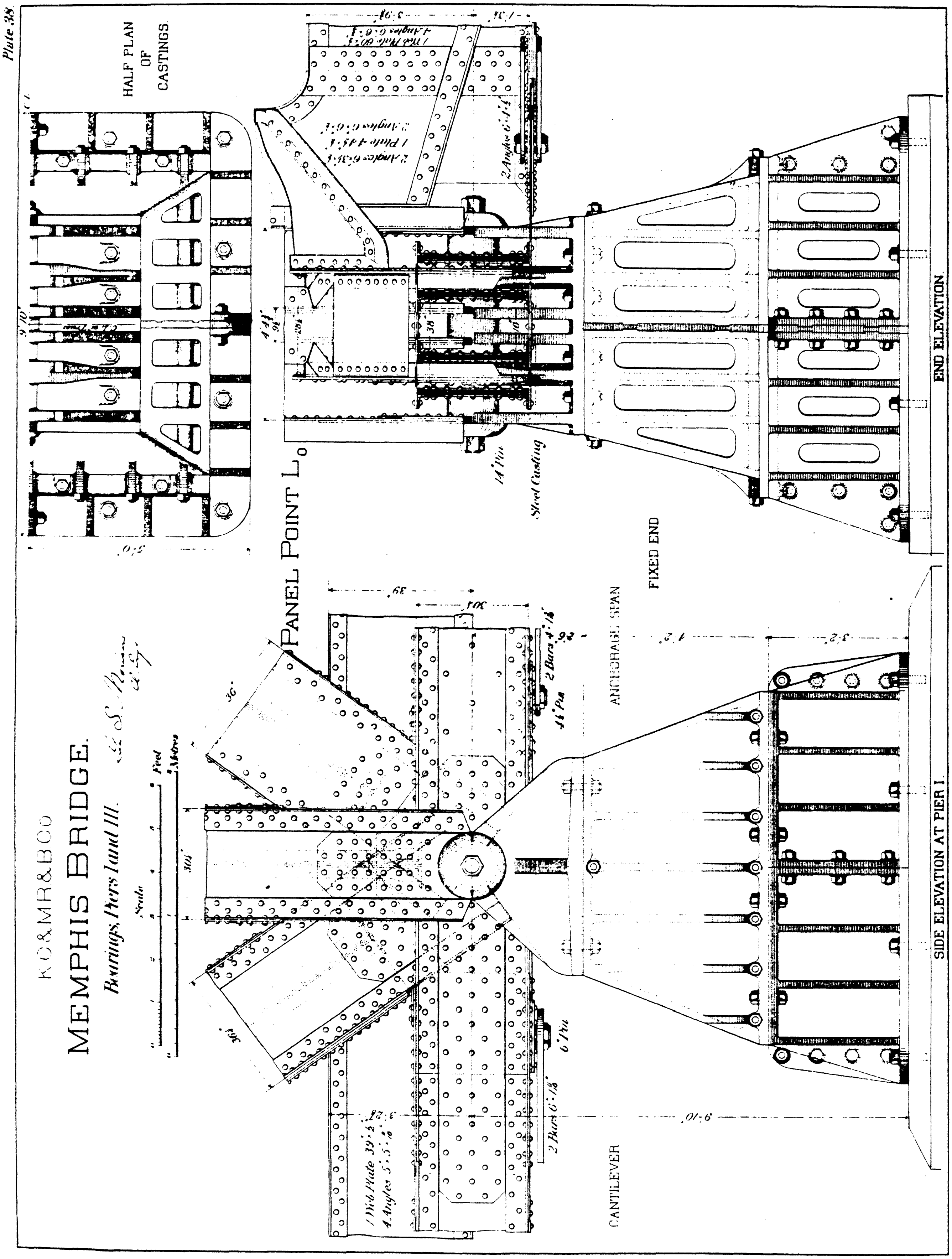


Plate 38
HALF PLAN OF CASTINGS
PANEL POINT L0
Steel Casting
FIXED END
END ELEVATION
ANCHORAGE SPAN
SIDE ELEVATION AT PIER I
CANTILEVER
MEMPHIS BRIDGE
Bearings, Piers I and III
Scale
Feet
Metres

Figure 154

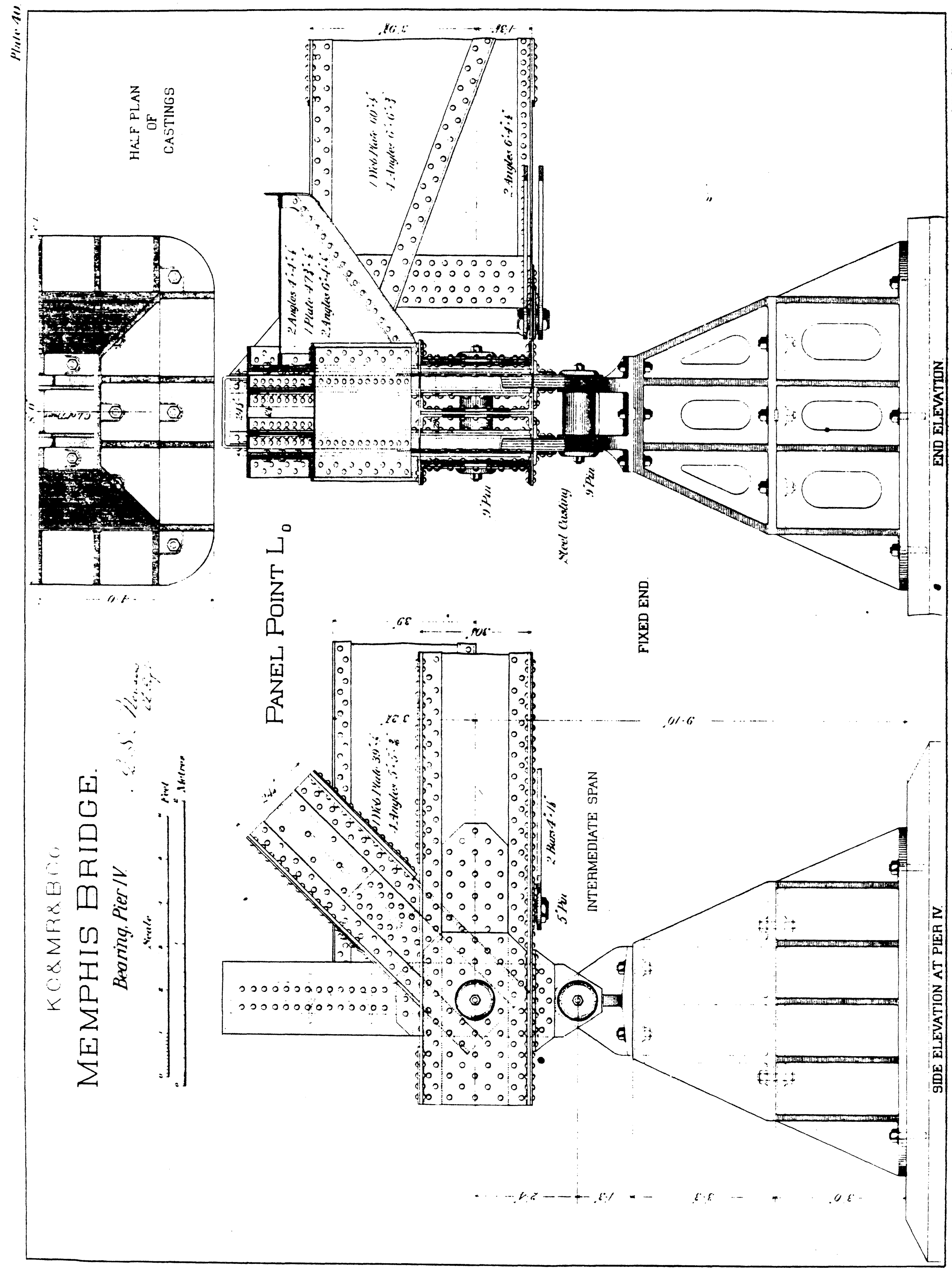


Plate 40
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE.
Bearing, Pier IV.
PANEL POINT L_0
HALF PLAN OF CASTINGS
FIXED END
INTERMEDIATE SPAN
END ELEVATION
SIDE ELEVATION AT PIER IV.
Steel Casting
9" Pin
5" Pin
2 Angles 4"·4"
1 Plate
2 Angles 6"·4"
1 Web Plate
4 Angles
2 Bars 4"·1"
Scale
Feet
Metres

Figure 155

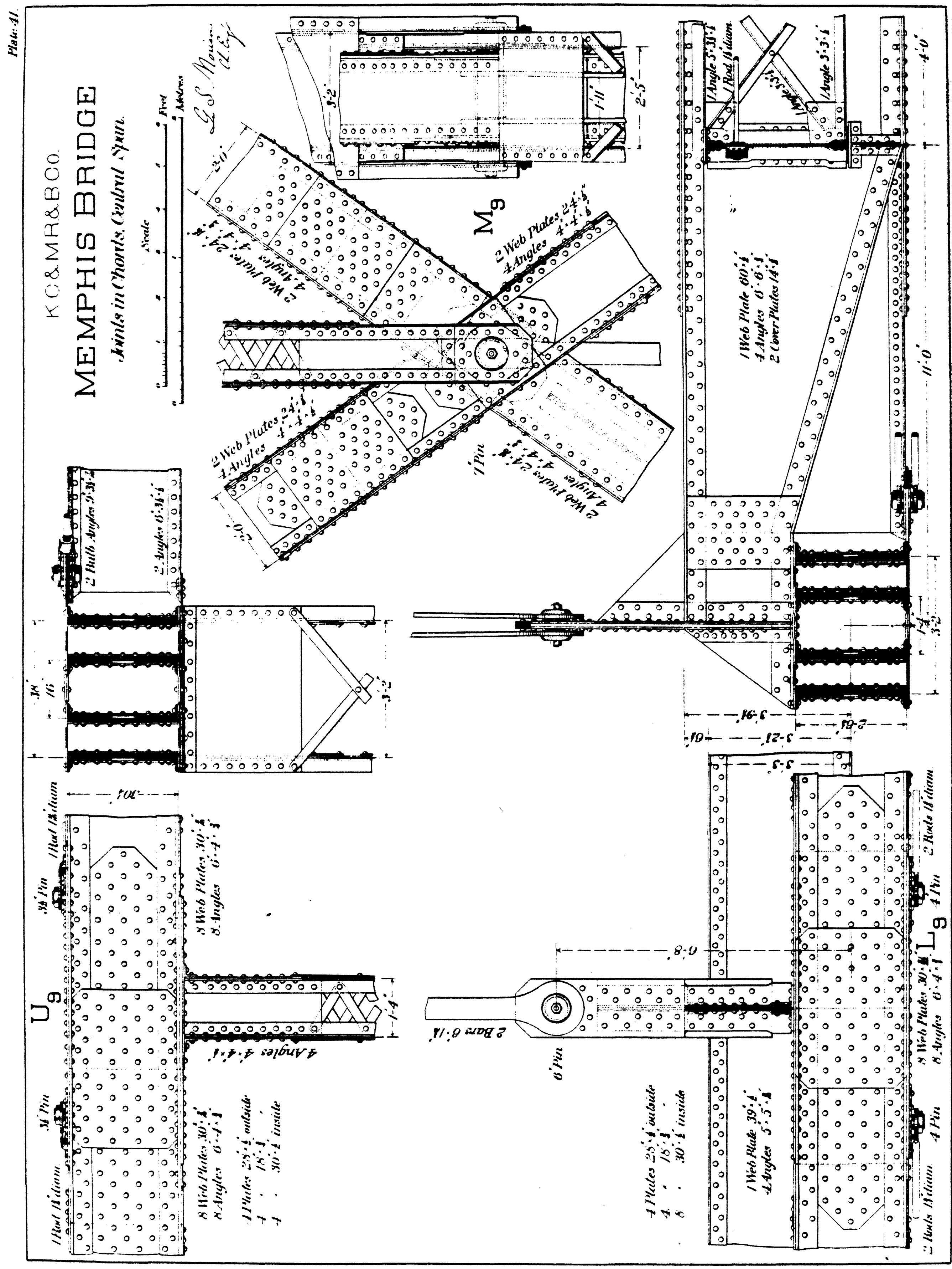


Plate 41.
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Joints in Chords, Central Span.
Scale
M9
U9
L9

Figure 156

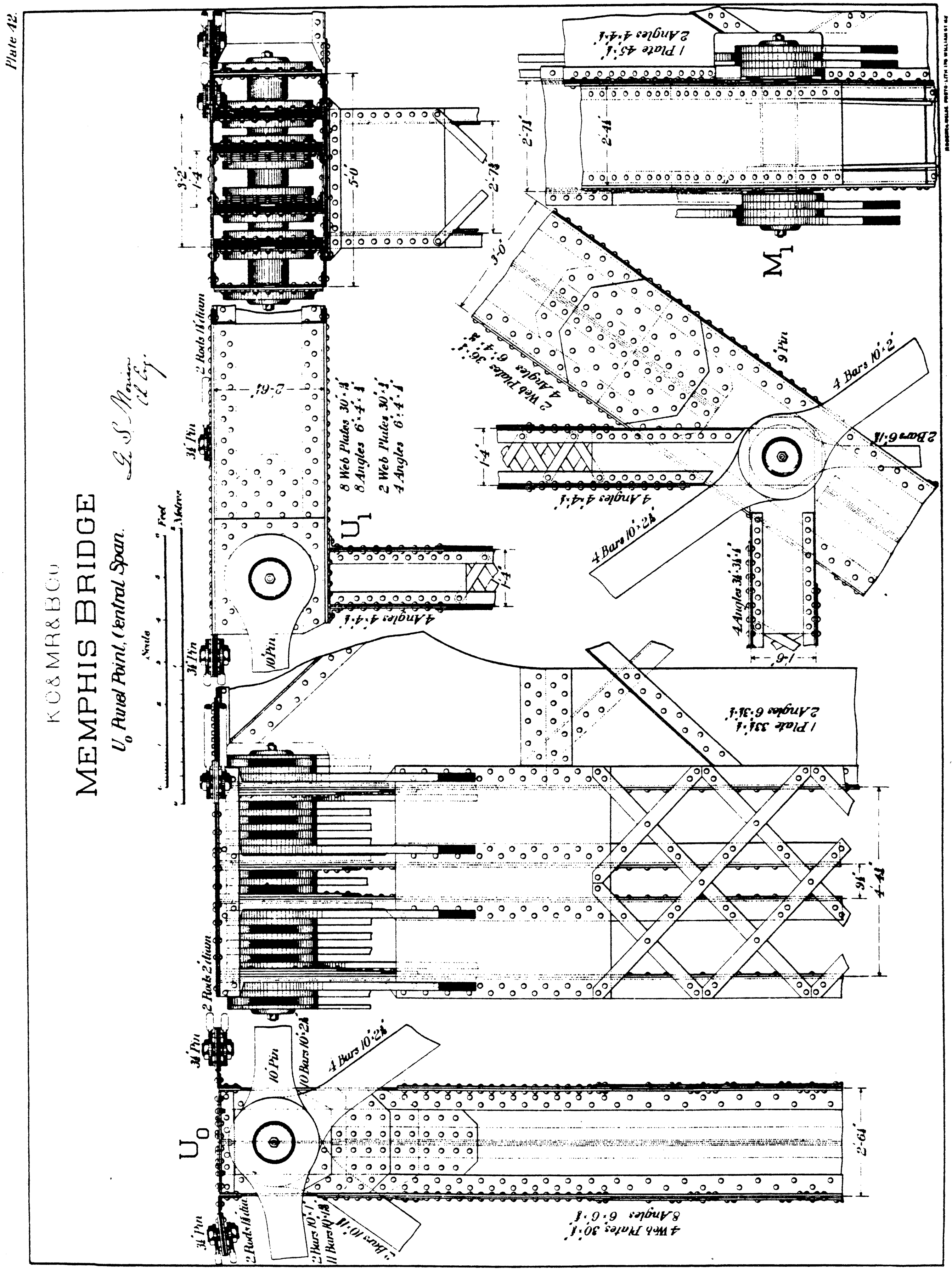


Plate 12
K C & M R & B Co
MEMPHIS BRIDGE
U_0 Panel Point, Central Span.
U_0
U_1
M_1

Figure 157

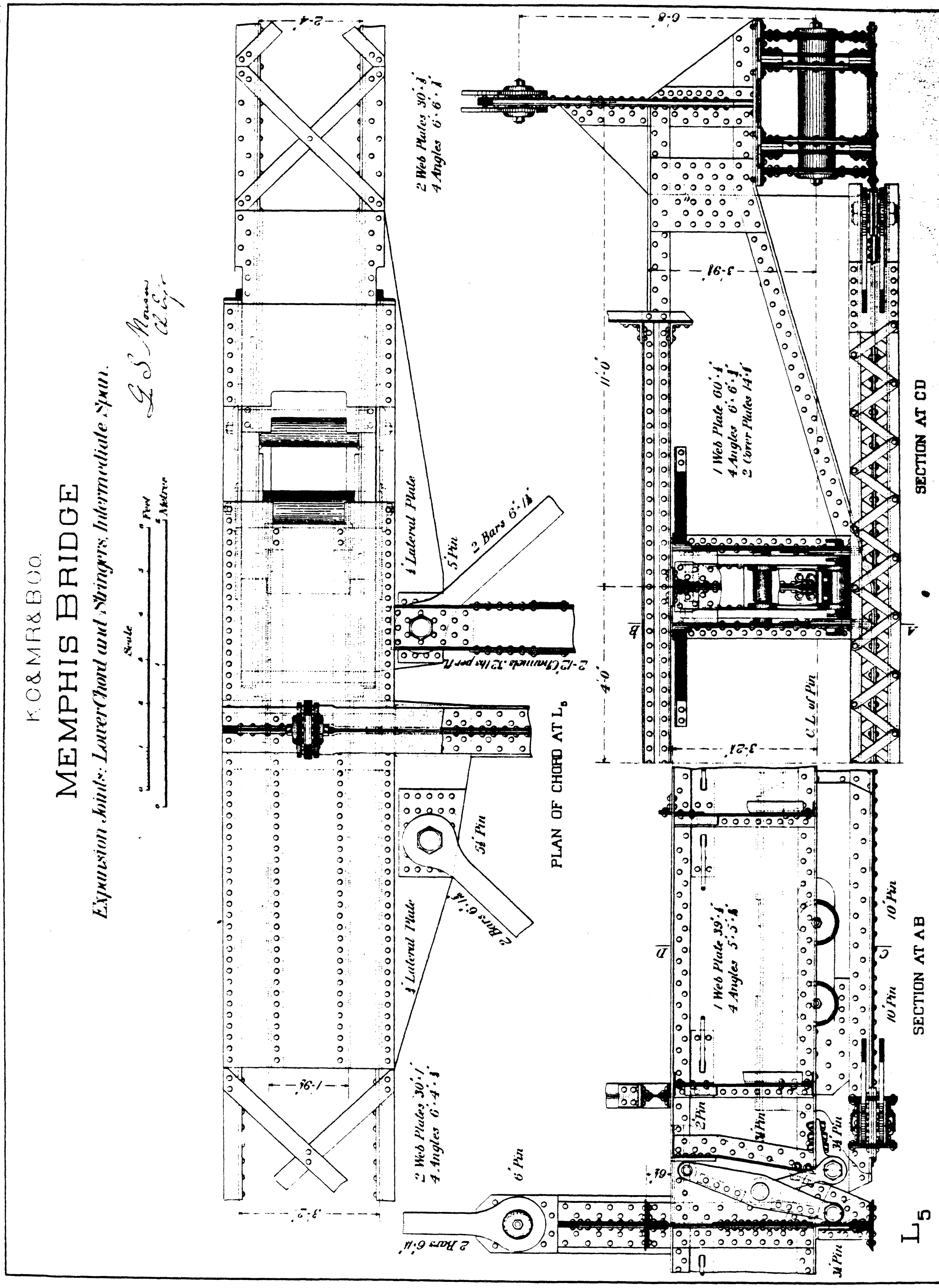


Plate 43.
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Expansion Joints: Lower Chord and Stringers, Intermediate Span.
Scale
Feet
Metre
PLAN OF CHORD AT L5
SECTION AT CD
SECTION AT AB
L5
2 Web Plates 30"×½"
4 Angles 6"×6"×½"
1 Web Plate 60"×½"
4 Angles 6"×6"×½"
2 Cover Plates 14"×½"
1 Web Plate 39"×½"
4 Angles 5"×3"×½"
2 Web Plates 30"×1"
4 Angles 6"×4"×½"
½" Lateral Plate
2 Bars 6"×1½"
2-12" Channels 32 lbs per ft
5" Pin
5½" Pin
6" Pin
10" Pin
C.L. of Pin
11'-0"
4'-0"

Figure 158

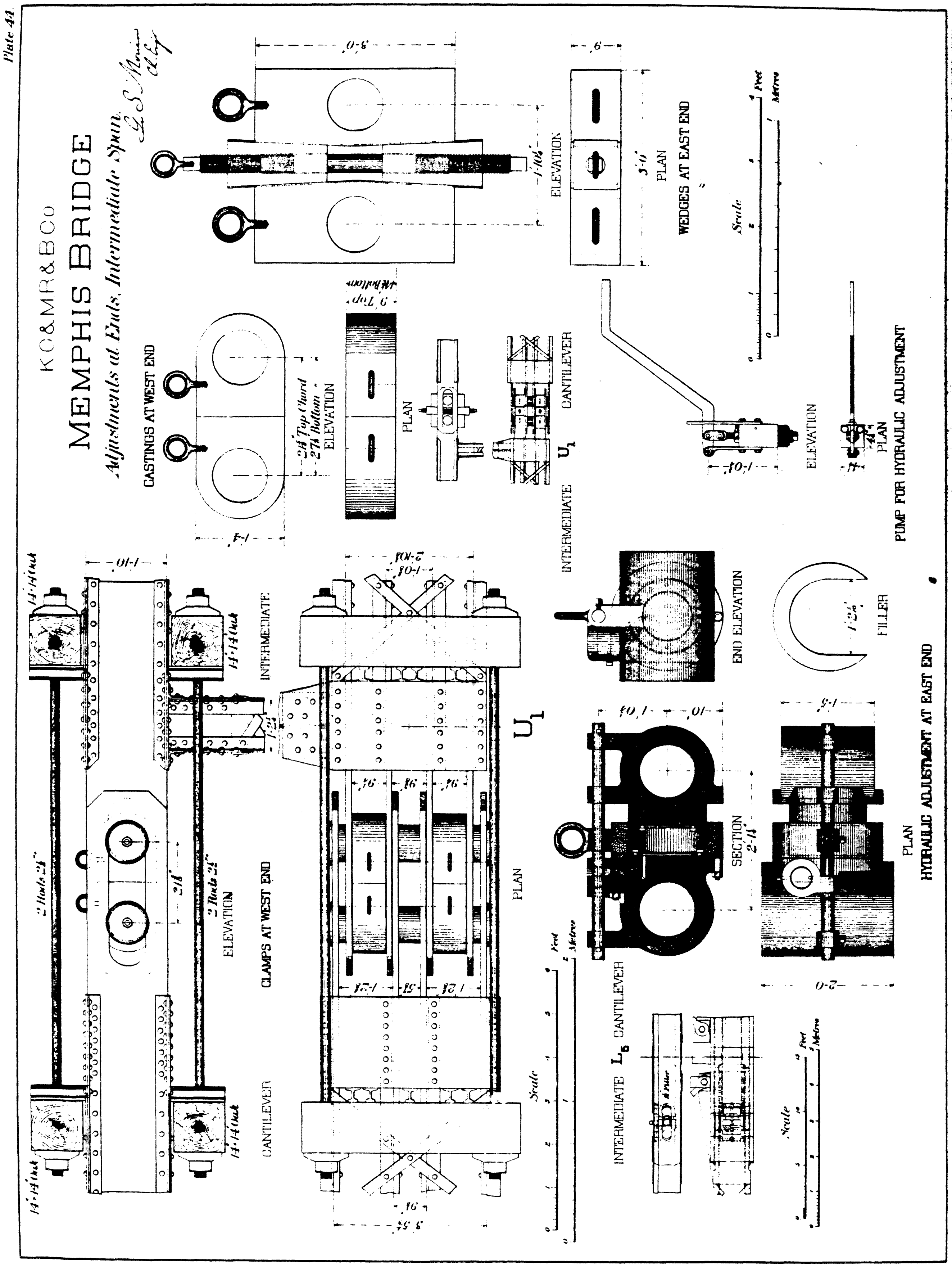


Plate 41.
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Adjustments at Ends, Intermediate Span.
CASTINGS AT WEST END
ELEVATION
PLAN
WEDGES AT EAST END
INTERMEDIATE
CANTILEVER
END ELEVATION
FILLER
SECTION
HYDRAULIC ADJUSTMENT AT EAST END
PUMP FOR HYDRAULIC ADJUSTMENT
CLAMPS AT WEST END
Scale
Feet
Metres

Figure 159

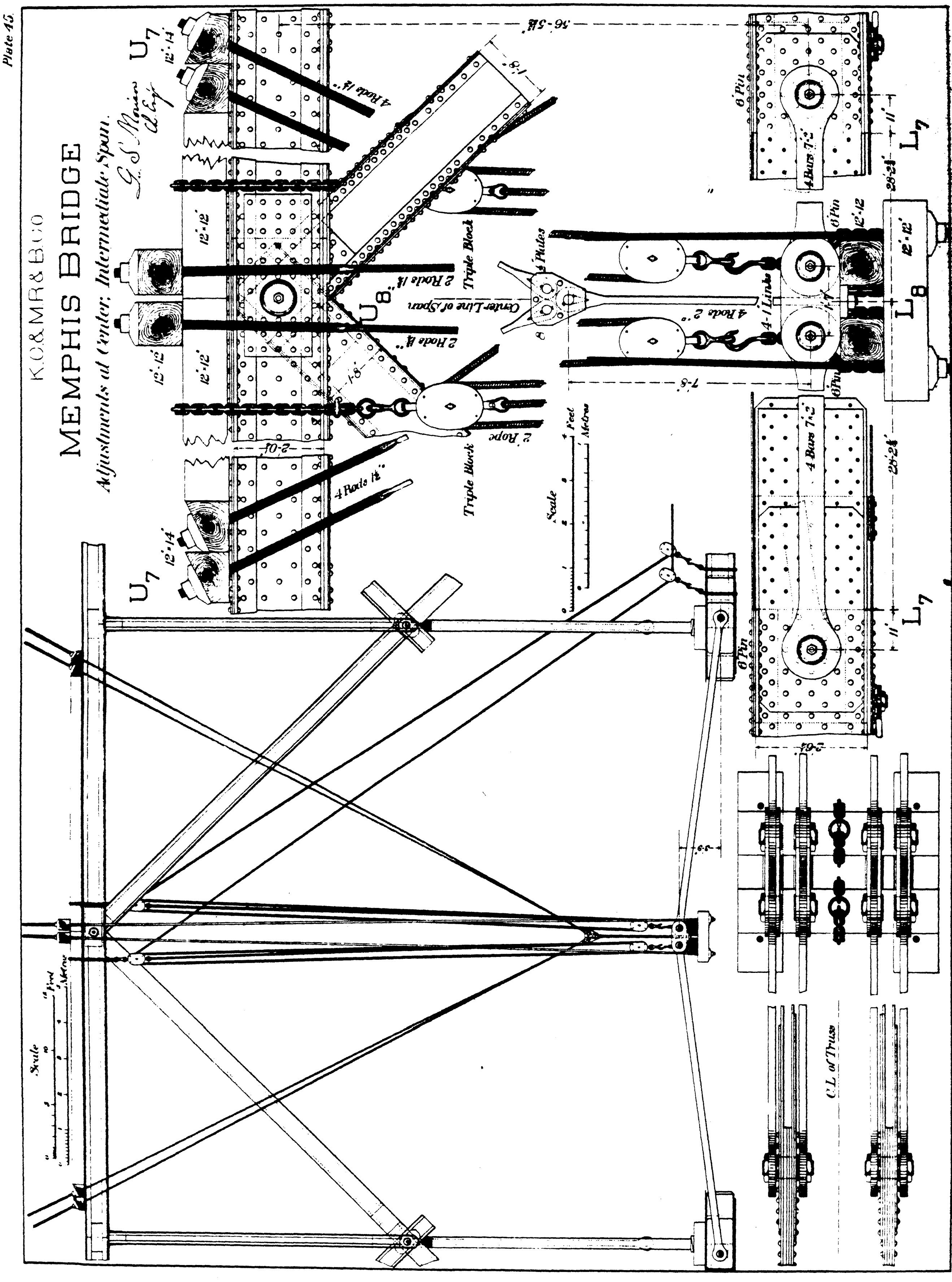


Plate 45
K.C.&M.R.&B.Co
MEMPHIS BRIDGE
Adjustments at Center, Intermediate Span.
Triple Block
Center Line of Span
4 Rods 1½"
2 Rods 1½"
4 Rods 2"
2" Rope
4-1 Links
4 Plates
4 Bars 7.2
8" Pin
U7
U8
L7
L8
Scale
Feet
Metres
C.L. of Truss

Figure 160

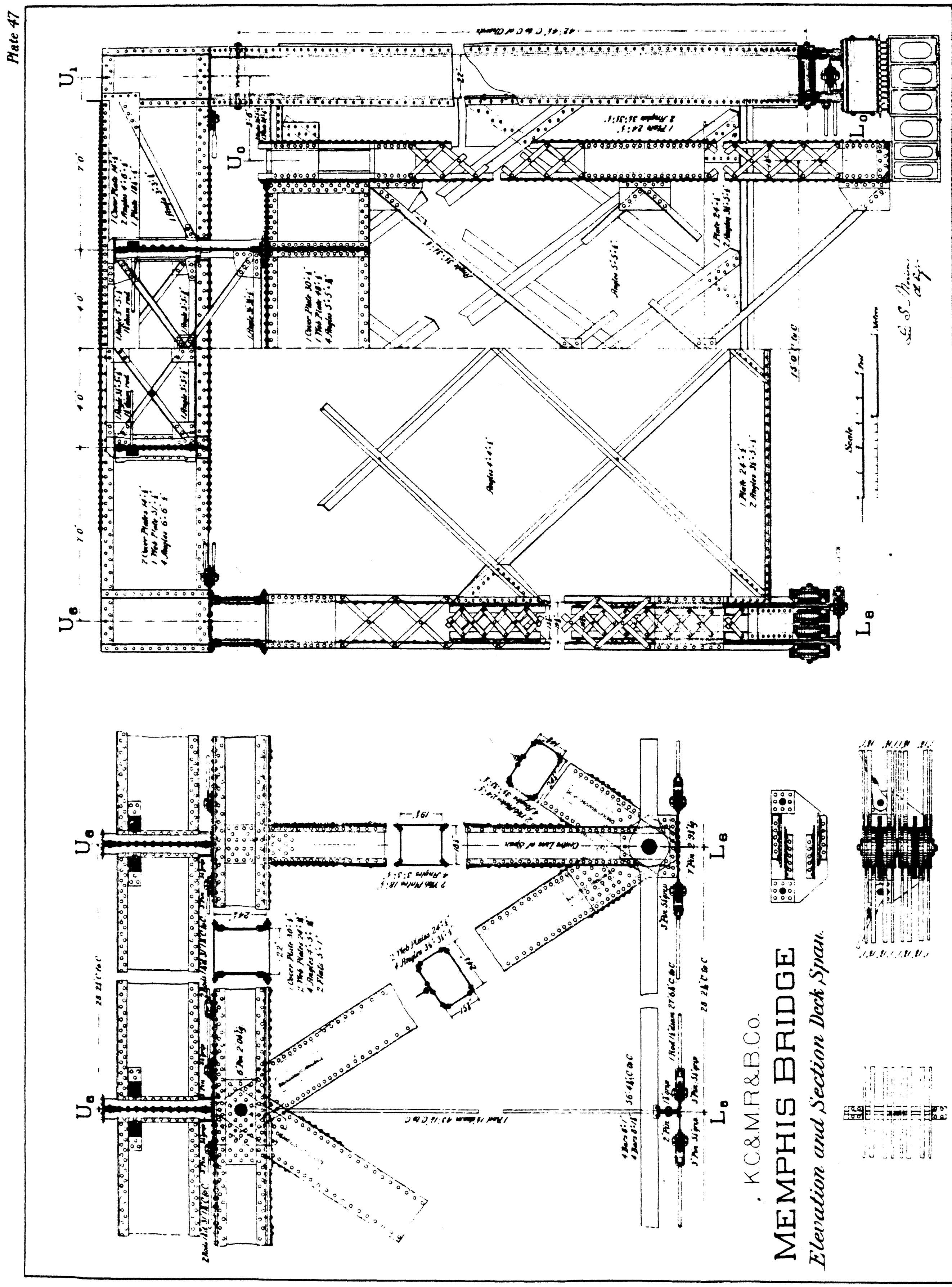


Plate 47
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Elevation and Section Deck Span.

Figure 161

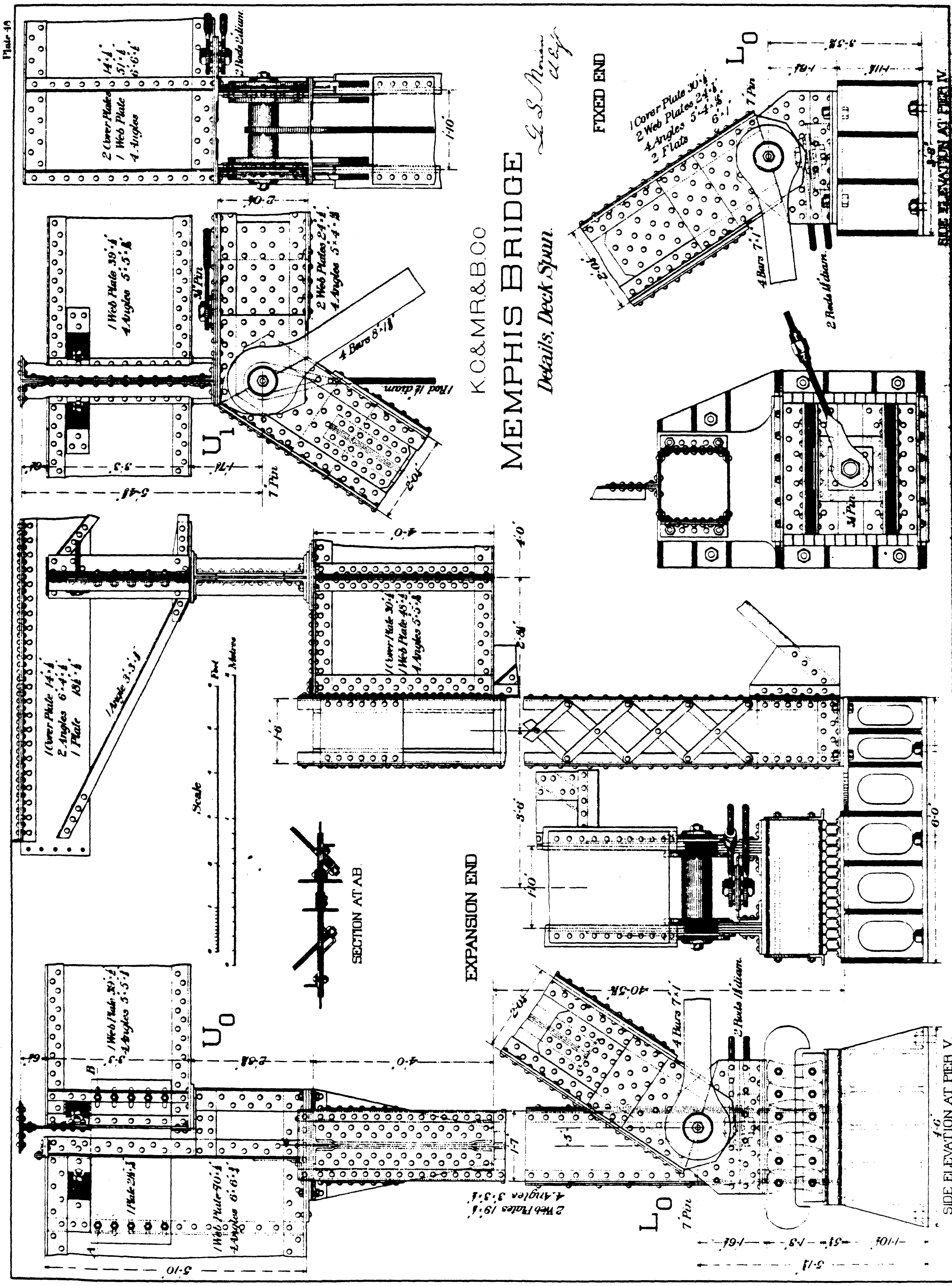

K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Details, Deck Span.
FIXED END
EXPANSION END
SECTION AT AB
Scale
SIDE ELEVATION AT PIER IV
SIDE ELEVATION AT PIER V

Figure 162

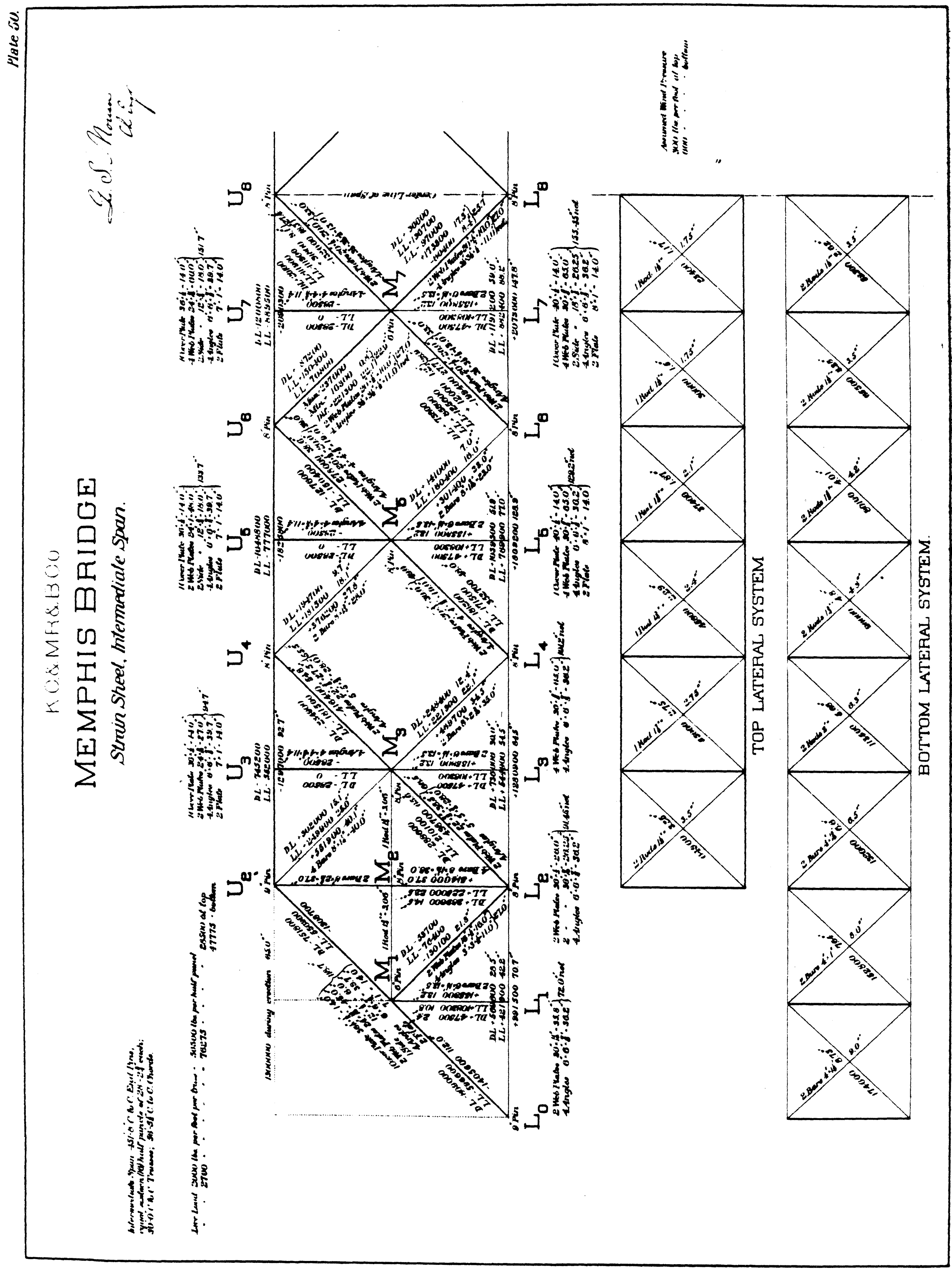


Plate 50.
K.C.&M.R.R.&B.Co.
MEMPHIS BRIDGE
Strain Sheet, Intermediate Span.
TOP LATERAL SYSTEM
BOTTOM LATERAL SYSTEM

Figure 163

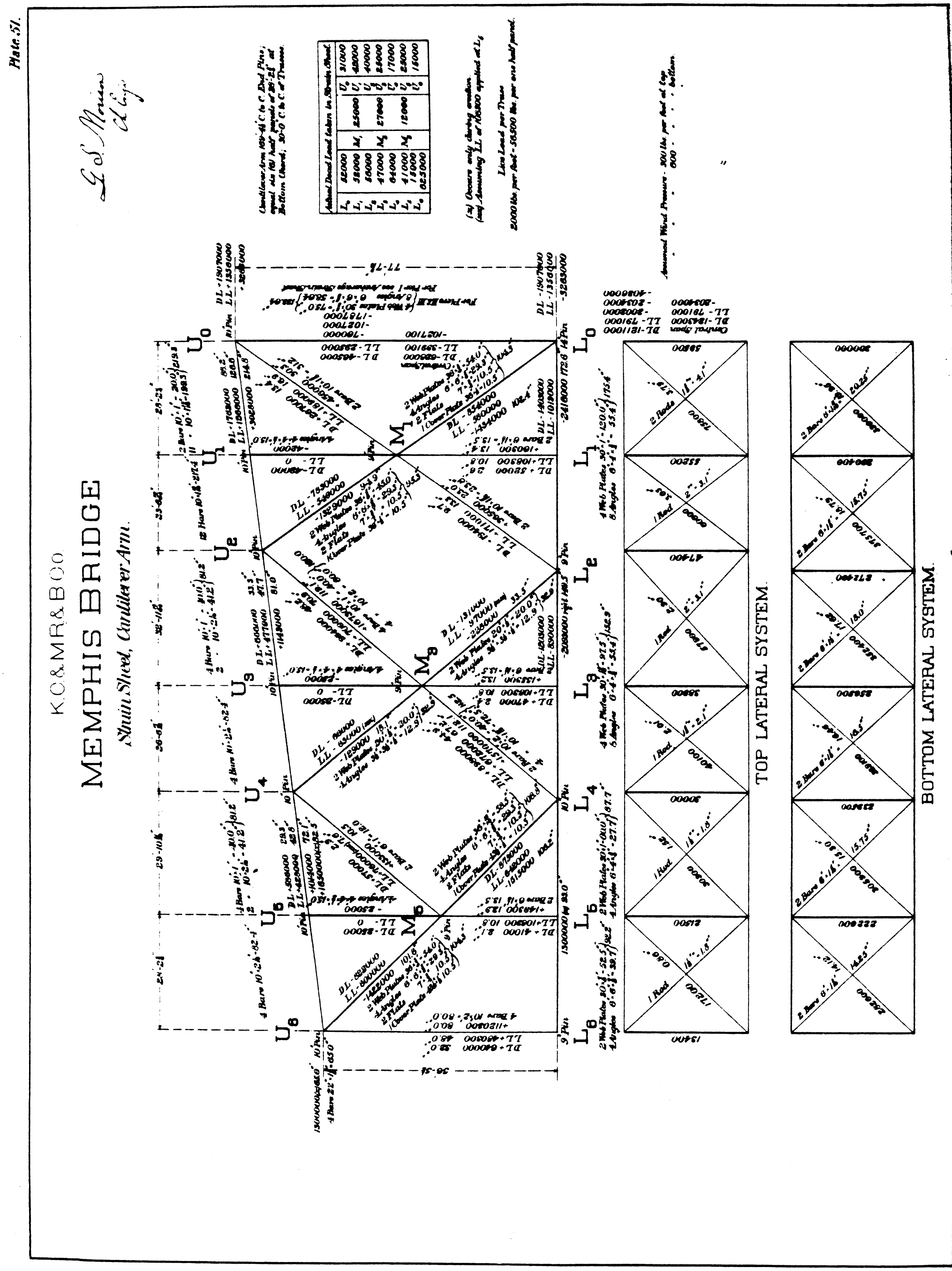


Plate 51.
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Strain Sheet, Cantilever Arm.
TOP LATERAL SYSTEM.
BOTTOM LATERAL SYSTEM.

Figure 164

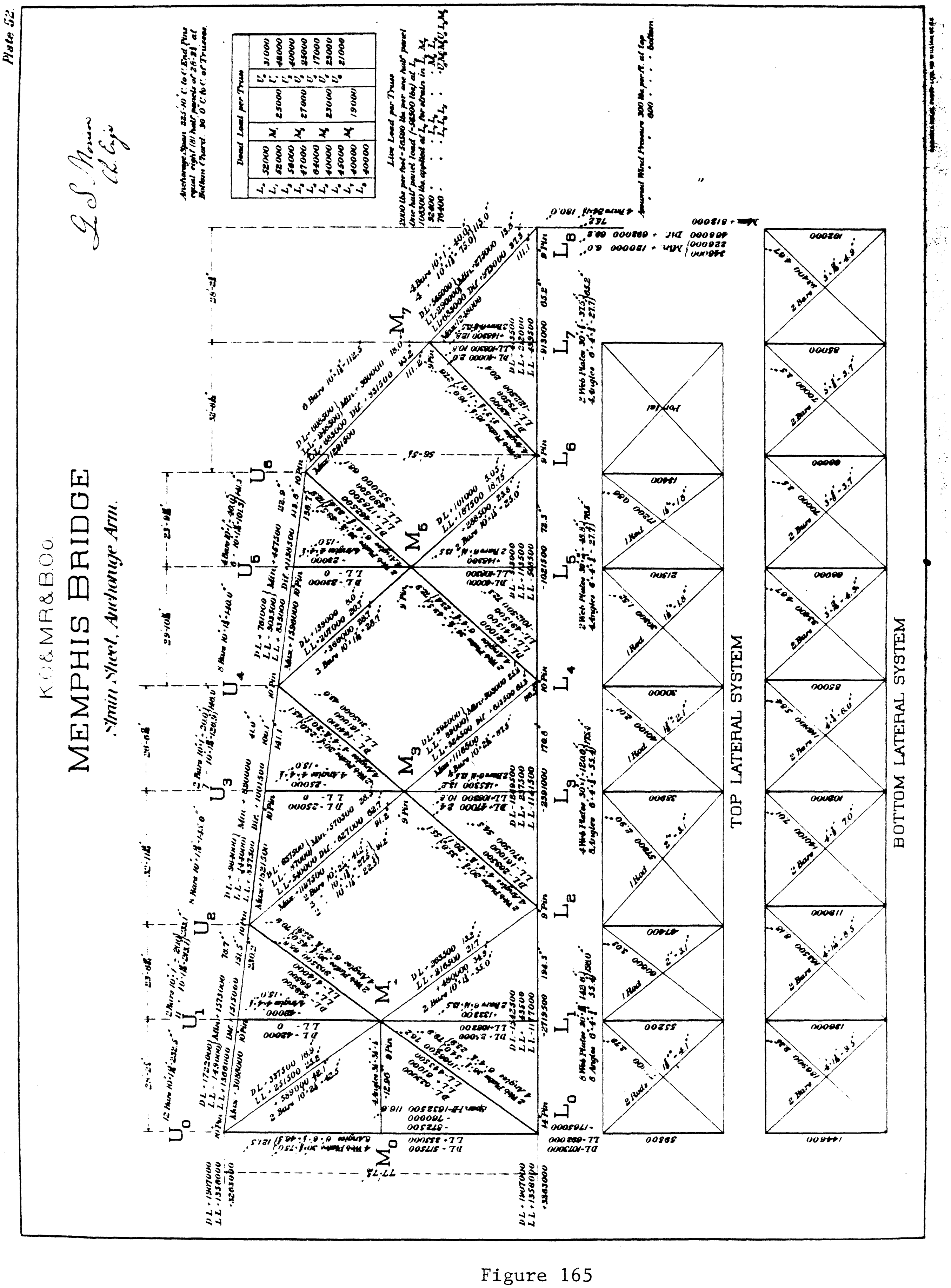


Plate 52
K C & M R & B Co.
MEMPHIS BRIDGE
Strain Sheet, Anchorage Arm.
TOP LATERAL SYSTEM
BOTTOM LATERAL SYSTEM

Figure 165

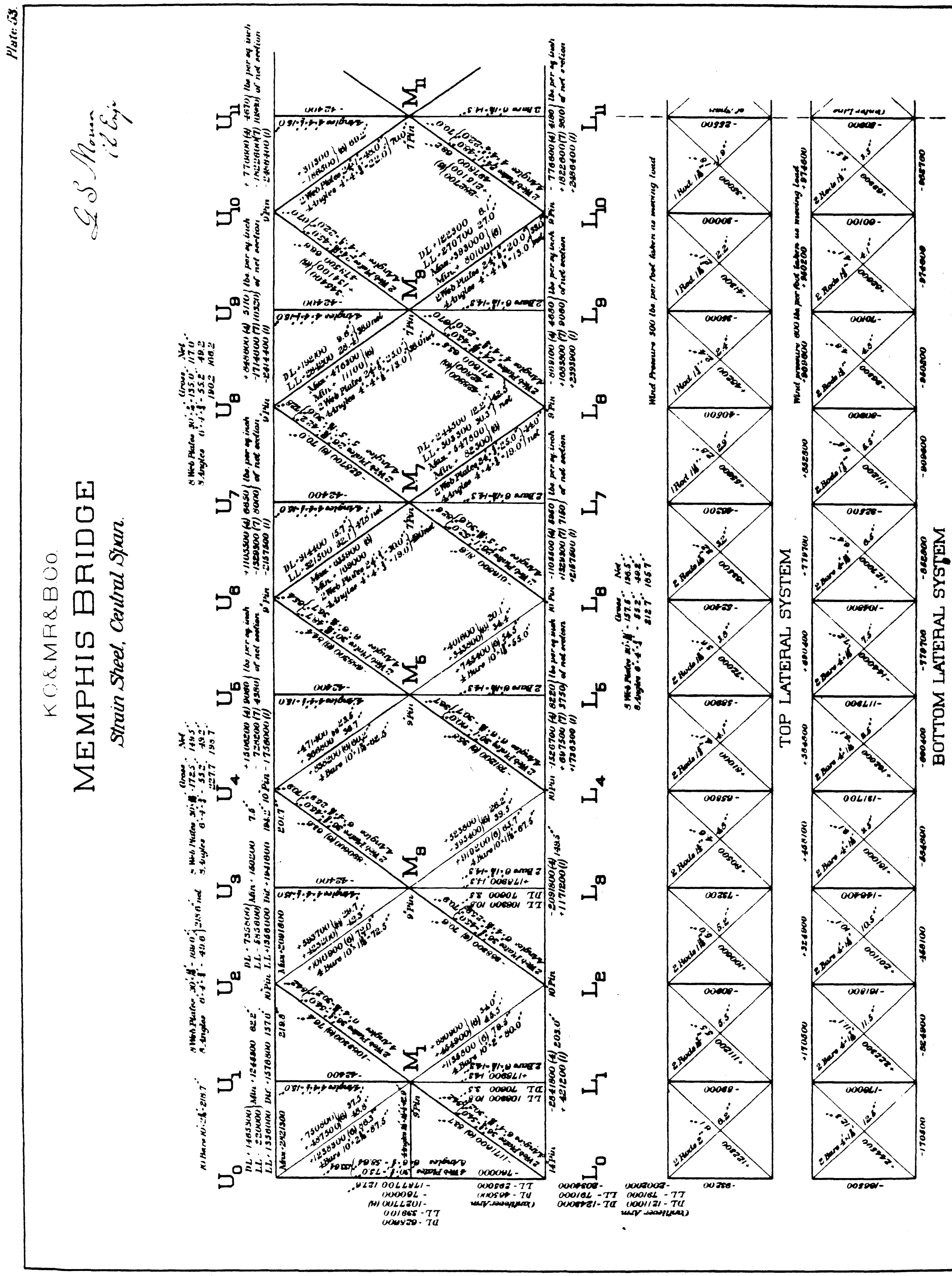


Plate 53.
K C & M R & B Co.
MEMPHIS BRIDGE
Strain Sheet, Central Span.
TOP LATERAL SYSTEM
BOTTOM LATERAL SYSTEM

Figure 166

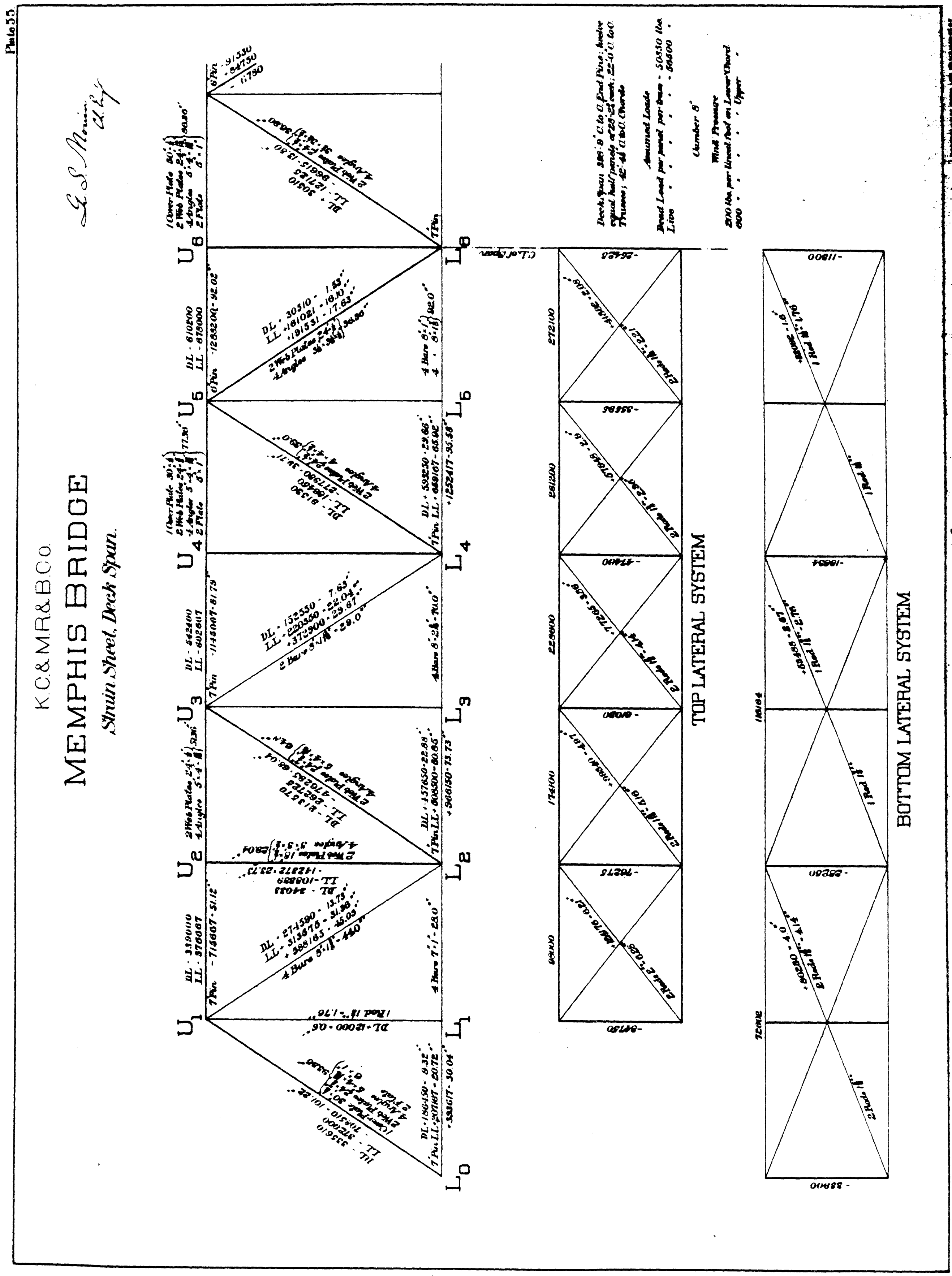


Plate 55
K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Strain Sheet, Deck Span.
TOP LATERAL SYSTEM
BOTTOM LATERAL SYSTEM

Figure 167

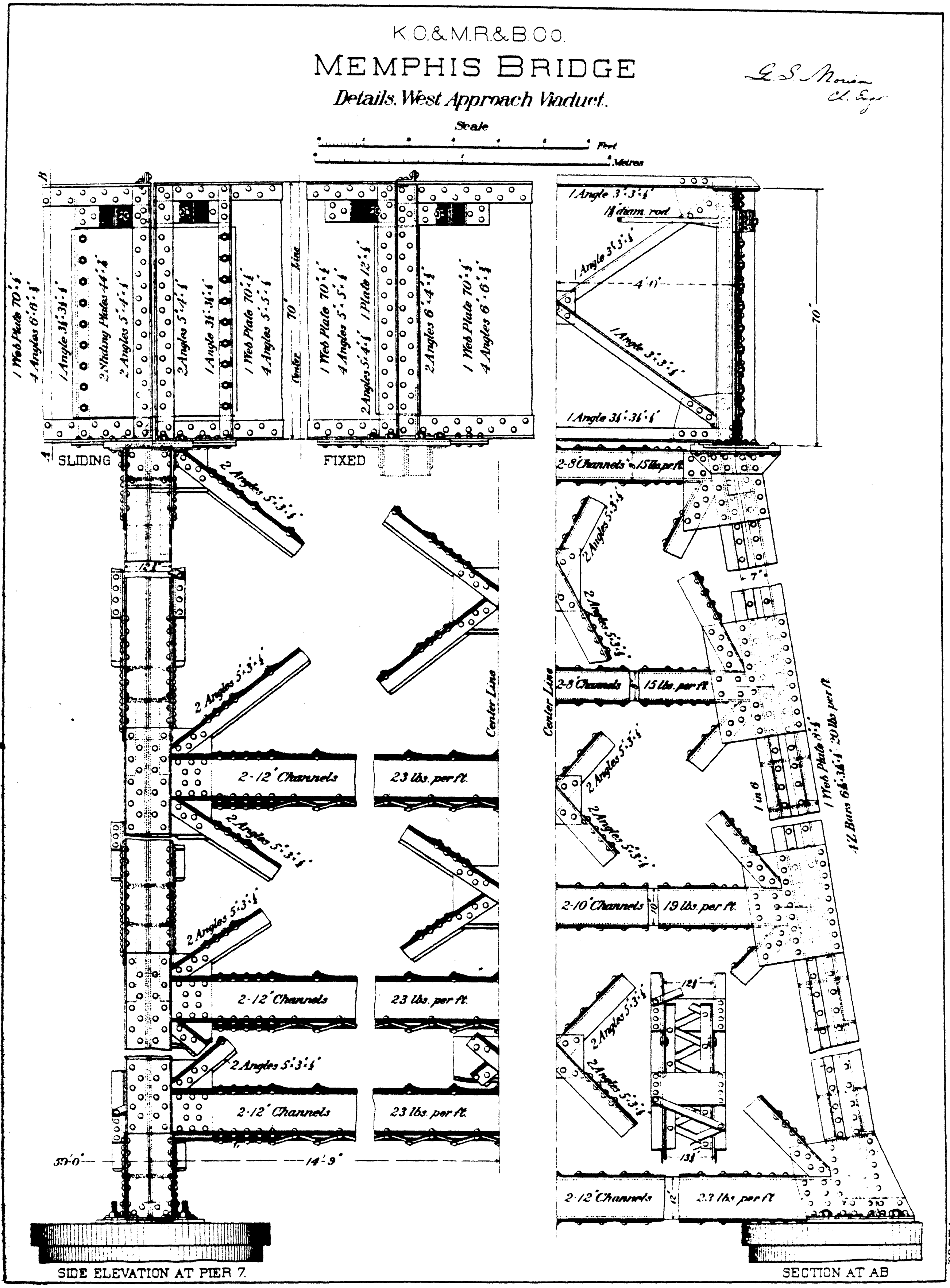

K.C.&M.R.&B.Co.
MEMPHIS BRIDGE
Details, West Approach Viaduct.
Scale
Feet
Metres
SLIDING
FIXED
Center Line
Center Line
2-12" Channels
23 lbs. per ft.
2-8" Channels
15 lbs. per ft.
2-10" Channels
19 lbs. per ft.
SIDE ELEVATION AT PIER 7.
SECTION AT AB

Figure 168

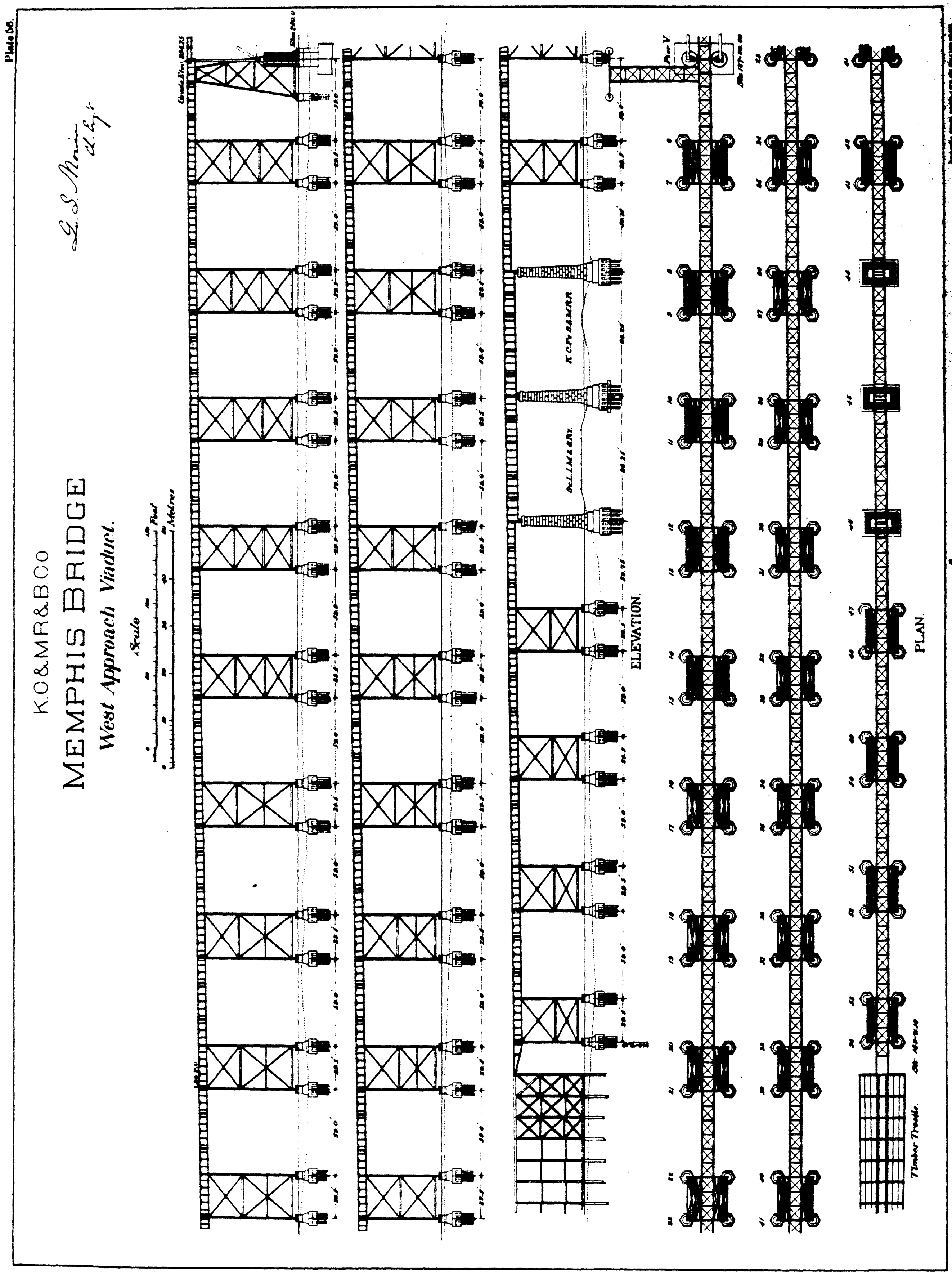

K.C.&M.R.&B.CO.
MEMPHIS BRIDGE
West Approach Viaduct.
Scale
ELEVATION.
PLAN.
Timber Trestle.

Figure 169

ENDNOTES

1 Of the three great Midwestern rivers - the Missouri, the Mississippi and the Ohio - the Mississippi was by far the largest, receiving much of its flow from the other two. The Ohio contributed 31% of volume to the lower Mississippi; the upper Mississippi, 19%; and the Missouri, 14%. Combined, these three watercourses contributed almost two-thirds of the flow through the lower Mississippi. The remainder poured in from a series of major and minor tributaries, including the St. Croix, Wisconsin, Iowa, Des Moines, Salt, White, Arkansas, Yazoo and the Red. In all, more than fifty navigable tributaries drain into the Mississippi along its twisting course through Mid-America, totaling more than 14,000 miles of navigable waterways which bordered or traversed twenty-seven states. (William J. Petersen, Steamboating on the Upper Mississippi (1937; reprint edition, Iowa City, Iowa: State Historical Society of Iowa, 1968), pages 22-27; Henry Lewis, The Valley of the Mississippi (St. Paul: Minnesota Historical Society, 1967), pages 59-63.)

From its source at diminutive Lake Itasca, the Mississippi first trickled through a series of deep-forest lakes in northern Minnesota and glided swiftly through a series of other lakes past Grand Rapids, Little Falls and St. Cloud. By the time it reached Minnesota's Twin Cities, 600 miles south, the Mississippi dropped only 900 feet. Below the Falls of St. Anthony, some 1100 miles below its source, the river was bounded by steep limestone bluffs and flowed through a relatively stable channel.

At the mouth of the Missouri River, just above St. Louis, the Mississippi changed character dramatically, resembling more the raucous tributary than its own calm upper reaches. The silt-clogged water which roiled down the Missouri entirely changed the character of the parent river. "They are rivers of very different character," George Morison stated in 1894, "the Mississippi being a quiet stream of comparatively stable character and the Missouri a silt-bearer of the first magnitude. The Missouri gives the character to the united river below the junction. It is a silt-bearer subject to floods, but not to as violent floods as those in the Ohio." (George S. Morison, The Memphis Bridge (New York: John Wiley and Sons, 1894), page 7.)

The Mississippi at this point changed from a placid, relatively clear stream with smooth shores and gentle sand bars to, as George Conclin observed in 1852, "a furious and boiling current, a turbid and dangerous mass of sweeping waters, jagged and dilapidated shores, and, wherever its waters have receded, deposits of mud. In its course, accidental circumstances shift the impetus of its current, and propel it upon the point of an island, bend, or sand bar. In these circumstances, it tears up the island, removes the sand bars, and sweeps away the tender alluvial soil of the bends, with all their trees, and deposits the spoils in another

place. At the season of high water, nothing more is familiar to the ears of the people on the river than a deep crash of a landslip, in which larger or smaller masses of the soil on the banks, with all the trees, are plunged into the stream. Such is its character, from the Missouri, to the [Gulf of Mexico] - a wild, furious, whirling river, never navigated, except with great danger." (George Conclin, New River Guide, or a Gazeteer of all the Towns on the Western Waters (Cincinnati, 1852), pages 67-71.) Between the Missouri and the mouth of the Ohio at Cairo, the Mississippi became deeper and more constricted, with a mean width of some three-quarters of a mile. It also gained velocity and a considerable amount of force with the increased amount of water.

The dividing line between the upper and lower Mississippi was generally believed to be the mouth of the Ohio, for it was this major tributary that almost doubled the flow of the Mississippi. For over 1000 miles below Cairo, the river meandered with a barely perceptible current through a level flood plain from 50 to 100 miles wide. With millions of years of accumulated silt lining its banks, the Mississippi throughout much of this length was actually higher than the surrounding countryside. Only elaborate series of high-banked earthen dikes protected many riverside towns from destruction by the river. Floods along the Mississippi were legendary. During low water, the lower Mississippi discharged about 70,000 cubic feet of water into the Gulf of Mexico; during flood stage, this increased more than thirty times to about 2.3 million cubic feet. In especially heavy flood years, the flow increased far more as the water-gorged river inundated its entire flood plain and overran the dikes, causing hundreds of millions of dollars of property damage.

2 F.B. Maltby, "The Mississippi River Bridges: Historical and Descriptive Sketch of the Bridges over the Mississippi River," Journal of the Western Society of Engineers, August 1903, pages 419-20.

3 As they had done with the Wheeling Bridge over the Ohio River, the steamboat companies fought the Rock Island Bridge as an intrusion into what had for decades been their private domain. In fact, the Wheeling dispute was still in the courts when surveyors began planning for the bridge at Rock Island. Its construction, and the ensuing battle between the railroad and the steamboat companies, would set the stage for bridge regulation and litigation for decades to follow.

The Chicago & Rock Island (C&RI) was the first railroad to reach the Mississippi River from the East, steaming the first locomotive to the banks of the river amid great celebration on Washington's birthday, 1854. The surveyors had chosen the port city of Rock Island as its western terminus, because they reasoned that a bridge over the Mississippi at this point would be economical to build to an existing center island and would present a minimal hazard to river navigation. Steamboat owners in St. Louis

immediately cried out that the proposed bridge at Rock Island was "unconstitutional, an obstruction to navigation, dangerous," and stated that it was "the duty of every western state, river city, and town to take immediate action to prevent the erection of such a structure." (Carl Sandburg, Abraham Lincoln, the Prairie Years (New York: Harcourt, Brace, 1926), page 37.)

As soon as the Railroad Bridge Company, a C&RI subsidiary, began laying the foundations for the piers, Southern sectionalists led by Jefferson Davis protested its construction in favor of a transcontinental road across the southern, slave-holding states. This latter opposition proved formidible, for as Secretary of War, Davis stood in a position to block the bridge and ordered the railroad company to halt construction. (Dee Brown, Hear That Lonesome Whistle Blow (New York: Holt, Rinehart and Winston, 1977), pages 6-8.)

Late in 1854, a St. Louis merchant secured a federal injunction against the bridge, charging the C&RI with trespassing, destruction of government property and obstruction of navigation along the river. But in court in July 1855, the Railroad Bridge Company prevailed. The judge ruled for the railroad, stating that, "railroads had become highways in something the same sense as rivers; neither could be suffered to become a permanent obstruction to the other, but each must yield something to the other according to the demands of the public convenience and necessities of commerce." Thus freed from legal entanglements, the railroad continued with its construction, completing the 1,535-foot wooden structure in April 1856. (Benedict K. Zobrist, "Steamboat Men versus Railroad Men," Missouri Historical Review, 1965, pages 159-72.)

Vindication in the courts and completion of construction, however, did not assure the bridge's continued existence, however, as the steamboat companies took it upon themselves to eliminate their obstacle. Only two weeks after the first train passed over the Rock Island Bridge, it was struck by a riverboat. The 431-ton Effie Afton, caught in the swirling waters around the base of the bridge, smashed against the central bridge pier. The impact overturned the galley stove and the boat's smokestacks, which ignited the wooden vessel. While the Effie Afton floundered in flames, it in turn ignited the wooden bridge. The fire destroyed the boat and one span of the bridge. The railroad men began to suspect a plot when steamboats up and down the river that day blew their horns triumphantly, and the skipper of the Hamburg unfurled a large banner which read: "MISSISSIPPI BRIDGE DESTROYED. LET ALL REJOICE." (Dee Brown, Hear That Lonesome Whistle Blow, pages 8-9; Walter Havighurst, Voices on the River: the Story of the Mississippi Waterways (New York: The Macmillan Company, 1964), page 121.)

In the ensuing lawsuit, a young lawyer from Springfield, Illinois, named Abraham Lincoln successfully represented the bridge company. Lincoln argued convincingly that travel between East and West over the railroads

was as important as travel between North and South over the river. He stated that, "rivers were to be crossed and that it was the manifest destiny of the people to move westward and surround themselves with everything connected with modern civilization." (Rock Island Magazine, February 1926, page 6.) Despite this defeat, the river interests continued their desperate struggle against the encroachment by the railroads. In 1858, they lobbied Congress unsuccessfully for a law forbidding bridges over navigable rivers. Later that year, the steamboatmen won a rare victory as an Iowa judge declared the Rock Island Bridge a "common and public nuisance" and ordered its Iowa portion demolished. The Supreme Court later overturned this decision, finally settling the issue of the railroads' right to bridge the Mississippi. Nevertheless, the steamboat interests would still use a variety of legal and illegal means to harass the railroads on subsequent bridges. (Dee Brown, Hear That Lonesome Whistle Blow, page 9; "At least one more attempt was made to destroy the Rock Island Bridge. On the night of June 5, 1859, a watchman making his rounds of inspection found in the middle of the bridge a collection of gunpowder, tar, oakum, and brimstone, heaped up and ready to be set on fire.")

4 "The Merchants' Bridge across the Mississippi River at St. Louis, Mo.," Engineering News, 21 December 1889, pages 578-79; "The St. Louis Merchants' Bridge, Engineering, 5 June 1891, pages 686-87.

5 These were, from north to south:

location	railroad	date	bridge type
Minneapolis MN	Minneapolis Union	1883	fixed stone arch
Minneapolis MN	Northern Pacific	1885	fixed deck truss
Minneapolis MN	C.M. & St. Paul	1880	fixed deck truss
St. Paul MN	C.M. & St. Paul et al.	1869	fixed truss
St. Paul MN	Chicago Great Western	1885	fixed truss
Hastings MN	C.M. & St. Paul	1871	pivot truss
Reed's Landing MN	C.M. & St. Paul	1882	moveable pontoon
Winona MN	Chicago & North Western	1871	pivot truss
La Crosse WS	C.M. & St. Paul	1876	pivot truss
Prairie Du Chien	C.M. & St. Paul	1874	pivot truss
Dubuque IA	Illinois Central	1868	pivot truss
Sabula IA	C.M. & St. Paul	1881	pivot truss
Clinton IA	Chicago & North Western	1865	pivot truss
Rock Island IL	Chicago & Rock Island	1856;1872	pivot truss
Keithsburg IL	Iowa Central	1886	pivot truss
Burlington IA	Chicago Burl. & Quincy	1868	pivot truss
Ft. Madison IA	independent	1888	pivot truss
Keokuk IA	independent	1871	pivot truss
Quincy IL	Chicago Burl. & Quincy	1868	pivot truss
Hannibal MO	independent	1871	pivot truss
Louisiana MO	C. & A.	1873	pivot truss
St. Louis (Eads)	independent	1874	fixed arch

6 Thwarted in Congress and in the courts in their efforts to stop the railroads and bridge companies, the river pilots engaged in a more clandestine tactic to rid themselves of these impediments. They rammed their boats into the bridge piers, causing varying amounts of injury and damage. Although it was never proved, the Effie Afton appeared to be the first of many deliberate wrecks on Mississippi River bridges. Major G.K. Warren of the Army Corps of Engineers reported to Congress during an 1866 debate that in the ten years since the burning of the Effie Afton an astonishing 64 steamboats had been damaged or destroyed on the piers of the Rock Island Bridge.

Montgomery Miegs described the collision of another famous boat, the War Eagle, with the Keokuk (Iowa) Bridge in 1881: "The War Eagle, a side-wheel boat and one of the largest class employed on the upper Mississippi River, came down over the rapids at a very high stage of water, being loaded down to about a 6-foot draft. The current was so rapid that the pilot was afraid of the east draw opening and attempted to pass through the opening next to the Iowa shore by stopping the boat and floating her through. Unfortunately the bow of the boat was caught in the eddy above the bridge along the Iowa shore, while the stern projected in to the strong current outside the lock. The result of these two forces was to turn the boat broadside to the bridge with her stern pointing towards the Illinois shore. The boat backed the wheel on the lower side and attempted to straighten her up, but before he could do so the bow struck one of the piers and she passed through the raft span broadside-to, pushing the span off its bearings and allowing it to drop into the river. The falling bridge razed the guards and wheel from the lower side of the boat and she floated over the submerged span and passed on through in a sinking condition. The pilot had the nerve to stay in the pilot house, and, assisted by the engineers, managed with one wheel to work the boat to shore some distance below the bridge on the Iowa shore, where she sank across the submerged railroad tracks." (F.B. Maltby, "The Mississippi River Bridges...," page 477.) The boat company later raised and repaired the War Eagle, and the boat served for many years after. In the litigation that inevitably followed, the courts once again affirmed the right of the railroads to span the river.

Most of these collisions, like the wreck of the War Eagle, were undoubtedly accidents, but several were merely thinly disguised attempts to destroy the bridges or force their removal in ensuing litigation. Virtually all of the bridges that had stood for any time were involved in steamboat incidents, many of which occurred under suspicious circumstances. In stating an obiter dictum for a bridge accident case, Supreme Court Justice David Davis all but indicted the steamboat companies in purposeful destruction, stating: "The officers of steamboats plying the Western rivers must be held to the full measure of responsibility in navigating streams where bridges are built across them. These bridges, supported by piers, of

necessity increase the dangers of navigation, and rivermen, instead of recognizing them as lawful structures built in the interests of commerce, seem to regard them as obstructions to it, and apparently act on the belief that frequent accidents will cause their removal. There is no foundation for this belief. Instead of the present bridges being abandoned, more will be constructed. The changed conditions of the country, produced by the building of railroads, has caused the great inland waters to be spanned by bridges. These bridges are, to a certain extent, impediments in the way of navigation, but railways are highways of commerce as well as rivers... It is the interest as well as the duty of all persons engaged in business on the water routes of transportation to conform to this necessity of commerce. If they do this and recognize railroad bridges as an accomplished fact in the country, there will be less loss of life and property, and fewer complaints of the difficulties of navigation at the places where these bridges are built." (Louis C. Hunter, Steamboats on the Western Rivers: An Economic and Technological History (New York: Octagon Books, 1969), pages 595-96.)

7 These were, from north to south (Morison's bridges indicated with an asterisk):

location	railroad	date	bridge type
Minneapolis MN	Great Northern	1891	fixed truss/girder
St. Paul MN	St. Paul Belt	1895	pivot truss
*Winona MN	Chicago Burl. & North.	1890	pivot truss
Rock Island IL	Davenport R.I. & N.E.	1899	pivot truss
*Burlington IA	Chicago Burl. & Quincy	1893	pivot truss (replace)
Quincy IL	Chicago Burl. & Quincy	1899	pivot truss (replace)
*Alton IL	Chicago Burl. & Quincy	1894	pivot truss
*St. Louis (Merch.)	St. Louis Terminal	1890	fixed truss
*Memphis	Kansas City & Memphis	1892	fixed truss

8 Citing the Wheeling Bridge precedent, Congress excercised its power to regulate bridge construction on the Mississippi by the granting of charters. In an "act to authorize the construction of certain bridges, and to establish them as post roads," Congress in 1866 first authorized the construction of bridges over the Mississippi by approving structures at Winona; Dubuque, Burlington and Keokuk, Iowa; Quincy , Illinois; Hannibal, Missouri; and St. Louis (the Eads Bridge). Ironically, as Congress considered the authorization of these bridges in 1866, the rail company which had built the original Mississippi River railroad bridge, the Chicago and Rock Island, went into foreclosure, the victim of continuous litigation with the steamboat companies since the bridge's opening in 1856. (Robert Edgar Riegel, The Story of the Western Railroads (New York: The Macmillan Company, 1926), pages 98-99.) The enabling legislation for these bridges

specified the minimum dimensions of any bridge erected over the Mississippi, stating: "If built as high bridges, they should be 50 feet above extreme high water, with spans not less than 250 feet in length, and one main or channel span not less than 300 feet in length; if built as draw bridges, they should have two draw openings of 160 feet in the clear, and the next adjoining spans should not be less than 250 feet and should be 10 feet above high water and 30 feet above low water." (F.B. Maltby, "The Mississippi River Bridges...," page 420.)

The purpose of this legislation, of course, was to preserve the freedom of navigation over the river by stipulating both location and manner of the bridge construction. "In the frequent acts declaring bridges post-routes the operation of the post office and post-roads clause is seen," stated congressional historian Lewis Haney in 1910, "and the importance of bridges in this connection contributed to their regulation. But, judging from the congressional debates and legislation, this regulation seems to have been based on a broad interpretation of neither of these constitutional provisions, but to have rested on the preservation of the commerce of waterways and the better promotion of the public trade and welfare in general." (Lewis H. Haney, A Congressional History of Railways in the United States: 1850 to 1887 (1908-10; reprint edition, New York: Augustus Kelley, Publisher, 1968), pages 238-39.)

Congress was keenly aware of the tremendous influence garnered by the steamship companies and in 1866 passed the River and Harbor Act. This legislation provided for "examining and reporting upon the subject of constructing railroad bridges across the Mississippi between St. Paul and St. Louis upon such plans of construction as will offer the least impediment to the navigation of the river." Major Warren prepared the survey and published his report, titled, "Bridging the Mississippi River between St. Paul and St. Louis," in the 1878 annual report of the Chief of Engineers, U.S.A. (F.B. Maltby, "The Mississippi River Bridges...," page 419.)

Unlike its 1872 general authorization of bridges over the Ohio River, Congress chose to review construction on the Mississippi on a bridge-by-bridge basis. With the River and Harbor Act for a general guideline, Congress ruled on subsequent structures using the cumbersome, expensive and time-consuming process of enacting individual legislation for each. Final approval of the bridge designs rested with the War Department.

9 Letter: Charles Perkins to John Forbes, 20 October 1883, Newberry Library, Burlington Northern Collection (8 C5.321).

10 Richard C. Overton, Burlington Route (New York: Alfred A. Knopf, 1965), page 192.

11 Letter: Charles Perkins to Albert Touzalin, 6 October 1885. Newberry Library, Burlington Northern Collection (8 C5.321).

12 Richard C. Overton, Burlington Route, pages 193-94.

13 R.E. Miles, *A History of Early Railroading in Winona County* (Winona, Minnesota: self-published, 1958), page 26.

14 R.E. Miles, *A History of Early Railroading in Winona County*, pages 26-27.

15 *Winona Weekly Republican*, 3 December 1890.

16 *Winona Weekly Republican*, 5 November 1890.

17 F.B. Maltby, "The Mississippi River Bridges...," pages 447-48.

18 *Winona Daily Republican*, 30 June 1890.

19 Record Book of the Winona Bridge Railway Company, Newberry Library, Burlington Northern Collection, (f8 W7.1).

20 Lewis H. Haney, *A Congressional History of Railways in the United States*, pages 234-35.

21 *Congressional Record*, 1873-74, page 346.

22 *Congressional Record*, 1883-84, page 4182.

23 It was the CB&N's parent company, the CB&Q, which provided the test case for the high court. The railroad intentionally broke an 1874 Iowa granger law to test its constitutionality; a lower court found against the railroad, as, eventually, did the Supreme Court. (Overton, *Burlington Route*, pages 113-14.)

24 Record Book of the Winona Bridge Railway Company, Newberry Library, Burlington Northern Collection, (f8 W7.1).

25 "The River Spanned," *Winona Weekly Republican*, 24 June 1891; "Swing Span of the Winona Bridge," *Engineering News*, 17 October 1891.

26 "Swing Span of the Winona Bridge," *Engineering News*, 17 October 1891.

27 "Long Span Bridges," *Railroad Gazette*, 2 May 1890, page 302; "The 520-Ft. Span, Interstate Bridge, Omaha, Neb.," *Engineering News*, 7 December 1893, page 448.

28 "The River Spanned," *Winona Daily Republican*, 20 June 1891; "Swing Span of the Winona Bridge," *Engineering News*, 17 October 1891.

29 "Swing Span of the Winona Bridge," *Engineering News*, 17 October 1891.

30 "The River Spanned," Winona Daily Republican, 20 June 1891; Winona Weekly Republican, 3 December 1890.

31 "Swing Span of the Winona Bridge," Engineering News, 17 October 1891.

32 "Swing Span of the Winona Bridge," Engineering News, 17 October 1891; Winona Weekly Republican, 3 December 1890.

33 Winona Daily Republican, 14 July 1890.

34 "Swing Span of the Winona Bridge," Engineering News, 17 October 1891.

35 "Swing Span of the Winona Bridge," Engineering News, 17 October 1891.

36 Winona Weekly Republican, 17 September 1890.

37 Winona Weekly Republican, 3 December 1890.

38 "Swing Span of the Winona Bridge," Engineering News, 17 October 1891.

39 Winona Weekly Republican, 15 October 1890; Winona Daily Republican, 12 September 1890.

40 Winona Weekly Republican, 15 October 1890.

41 Winona Daily Republican, 8 October 1890.

42 Winona Weekly Republican, 3 December 1890.

43 Winona Weekly Republican, 5 November 1890.

44 Winona Daily Republican, 19 January 1890.

45 Winona Daily Republican, 19 January 1890.

46 Winona Daily Republican, 19 January 1890.

47 Winona Daily Republican, 12 February 1891.

48 Winona Daily Republican, 2, 3, 13 April 1891.

49 Winona Weekly Republican, 1 April 1891.

50 Engineering News, 25 April 1891, page 389.

51 Engineering News, 27 June 1891, page 543.

52 Winona Daily Republican, 6 July 1891; Engineering News, 27 June 1891, page 543.

53 "The Winona Bridge," Engineering Record, 25 August 1894, pages 200-201.

54 Winona Weekly Republican, 24 June 1891; "The River Spanned," Winona Daily Republican, 20 June 1891.

55 F.B. Maltby, "The Mississippi River Bridges," page 473. Two other bridges - at Clinton, Iowa, and Rock Island, Illinois - predated the structure at Burlington, but both were composed partially of timber.

56 Burlington Daily Hawk-Eye, 19 November 1891.

57 C.H. Hudson, "The Original Construction of the Burlington Bridge in 1867-68," paper read before the Western Society of Engineers, 7 March 1894, page 257.

58 Letter: George Morison to T.J. Potter, 29 September 1885, Newberry Library, Burlington Northern Collection (33 1880 2.31).

59 George S. Morison, "Reconstruction of the Burlington Bridge," paper read before the Western Society of Engineers, 6 December 1893, page 600.

60 C.H. Hudson, "The Original Construction of the Burlington Bridge in 1867-68," page 258.

61 Letter: George Morison to T.J. Potter, 29 September 1885.

62 George S. Morison, "Reconstruction of the Burlington Bridge," page 604.

63 George S. Morison, "Reconstruction of the Burlington Bridge," page 605.

64 George S. Morison, "Reconstruction of the Burlington Bridge," page 605.

65 Theodore Cooper, "American Railroad Bridges," Transactions of the American Society of Civil Engineers, July 1889, page 42.

66 George S. Morison, "Reconstruction of the Burlington Bridge," page 605.

67 George S. Morison, "Reconstruction of the Burlington Bridge," page 601-02.

68 George S. Morison, "Reconstruction of the Burlington Bridge," page 603.

69 George S. Morison, "Reconstruction of the Burlington Bridge," page 602.

70 George S. Morison, "Reconstruction of the Burlington Bridge," page 603.

71 "Crushed by Rock," Burlington Daily Hawk-Eye, 12 January 1892.

72 George S. Morison, "Reconstruction of the Burlington Bridge," page 604.

73 Engineering News, 13 February 1892, page 162.

74 George S. Morison, "Reconstruction of the Burlington Bridge," page 605-06.

75 C.H. Hudson, "The Original Construction of the Burlington Bridge," page 257.

76 George S. Morison, "Reconstruction of the Burlington Bridge," page 606.

77 George S. Morison, "Comments on 'The Original Construction of the Burlington Bridge,'" page 271.

78 Henry Goldmark, "Comments on 'The Original Construction of the Burlington Bridge,'" page 271.

79 F.B. Maltby, "The Mississippi River Bridges," page 485.

80 "Bridges over River Fulfilled Dreams of Alton Pioneers," Alton Evening Telegraph, Centennial Edition, 15 January 1936.

81 Richard C. Overton, Burlington Route, pages 174, 231.

82 "On Certain New Work in and about St. Louis," Railroad Gazette, 15 December 1893.

83 Richard C. Overton, Burlington Route, pages 174-75; Benjamin Crosby, "St. Louis Extension of the St. Louis, Keokuk and North Western Railroad," Journal of the Association of Engineering Societies, 1 January 1895, pages 57-58.

84 "The Draw Span," Alton Daily Telegraph, 1 March 1894.

85 "Swing Span of the Alton Bridge," Engineering News, 14 June 1894.

86 George S. Morison, "Bridges Regarded as Commercial Tools," New York: Evening Post Job Print, 1 February 1890. Privately published pamphlet reproducing paper read by George Morison to St. Louis Commercial Club in March 1889, pages 2-3.

87 "The Bridge," Alton Daily Telegraph, 10 February 1892.

88 "The Bridge," Alton Daily Telegraph, 10 February 1892.

89 "Bridge Items," Alton Daily Telegraph, 13 February 1892.

90 "Work on the Bridge," Alton Daily Telegraph, 19 February 1892.

91 "The Bridge," Alton Daily Telegraph, 25 February 1892.

92 "Bridge Notes," Alton Daily Telegraph, 3 March 1892.

93 Alton Daily Telegraph, 20 & 29 February, 3 March, 23 April, 15 & 30 August, 20 September 1892.

94 "Bridge Notes," Alton Daily Telegraph, 29 September 1892.

95 "Pier No. 10," Alton Daily Telegraph, 20 September 1892.

96 "Bridge Work," Alton Daily Telegraph, 16 November 1892.

97 "A Matter of Importance to Alton," Alton Daily Telegraph, 15 February 1893.

98 "Bridge Work," Alton Daily Telegraph, 2 August 1893.

99 "Bridge Work Delayed," Alton Daily Telegraph, 30 December 1893.

100 "The Bridge," Alton Daily Telegraph, 15 February 1894.

101 "The Bridge," Alton Daily Telegraph, 15 February 1894.

102 "Drowned," Alton Daily Telegraph, 15 March 1894.

103 "A Success," Alton Daily Telegraph, 22 March 1894.

104 Engineering News, 12 April 1894; "The First Train," Alton Daily Telegraph, 5 April 1894.

105 "It Is Dedicated," Alton Daily Telegraph, 3 May 1894.

106 "It Is Dedicated," Alton Daily Telegraph, 3 May 1894.

107 "It Is Dedicated," Alton Daily Telegraph, 3 May 1894.

108 "Fatal Accident," Alton Daily Telegraph, 10 May 1894.

109 "Act of Congress Approved February 26, 1885," reprinted in The Memphis Bridge, George S. Morison, (New York: John Wiley & Sons, 1894), page 30.

110 "The Memphis Bridge," Engineering News, 12 May 1893, page 470.

111 Engineering News, 16 February 1889, page 144. As the Memphis Bridge was under construction, the magazine editorialized about this, stating: "A very few years ago a bridge across the lower Mississippi was deemed an engineering impossibility owing to the deep alluvial bottom and the requirements of river navigation that called for spans of dimensions then unheard of, if spans of any kind were to be permitted. But the advance in the art of founding bridge piers has been so rapid, and spans have been stretched to such a length, that old-time objections have been met, and engineers stand ready to bridge almost any space for which capital will provide the means. As to the Mississippi river at the present date - another bridge is under contract at St. Louis [Merchants' Bridge], one is started at Memphis another is chartered for Natchez, and now a company is organized for the construction of a bridge at New Orleans with every indication of being pushed to completion. For many years the broad Mississippi made a gap in all east and west railway communication, for a thousand miles and more of its course; but that day has passed, and in the next decade we may look for bridges wherever the traffic needs or the public may demand them."

112 George S. Morison, The Memphis Bridge, page 5.

113 George S. Morison, The Memphis Bridge, page 7.

114 George S. Morison, The Memphis Bridge, page 5.

115 "Act of Congress Approved April 24, 1888," reprinted in The Memphis Bridge, page 31.

116 George S. Morison, The Memphis Bridge, page 5; George S. Morison, The So-Called Quarantine at San Francisco, New York: Evening Post Job Print, 1889

117 George S. Morison, "Argument for Amendment of [Memphis Bridge] Charter," 4 January 1890. Unpublished report to War Department, reprinted in The Memphis Bridge, page 39.

118 George S. Morison, "Argument for Amendment of [Memphis Bridge] Charter."

119 George S. Morison, "Argument for Amendment of [Memphis Bridge] Charter."

120 George S. Morison, "Report of August 2, 1888." Unpublished report to George H. Nettleton, President, Kansas City & Memphis Railway and Bridge Company, reprinted in The Memphis Bridge, page 37.

121 Contract between Kansas City & Memphis Railway and Bridge Company and the War Department, 23 August 1888, reprinted in The Memphis Bridge, page 32.

122 George S. Morison, "Construction of the River Piers for the Memphis Bridge," Engineering News, 28 December 1893, page 509.

123 George S. Morison, The Memphis Bridge, page 7. Morison reported to Nettleton in his initial report: "Comparing the two structures when once completed, I think the Three Span Bridge would be the better one for the railroads. It would be a perfectly simple structure, the expense for maintaining which would be a minimum. It would involve no complicated details, and as it consists simply of straight trusses resting on masonry piers, would be subject to a minimum degree of disturbance should any slight settlement occur in the foundations. In brief, it would fulfill the universal requirement that the simplest structure is the best." (George S. Morison, "Report of February 15, 1887." Unpublished report to George H. Nettleton, President, Kansas City & Memphis Railway and Bridge Company.)

124 George S. Morison, The Memphis Bridge, page 17.

125 "The Principal Bridges of the World - A Comparison," The Engineer, 24 May 1918, page 441. "This structure is criticized as being both unsightly, uneconomical of material, its lay out of spans unfortunate, and its truss depth too small. The spans were however, laid out to meet the desires of the War Department. There is no symmetry about the design, and it is not happy to have one end of the structure formed into an anchor arm of the through type and the other end as a deck span below the level of all the other openings."

126 George S. Morison, The Memphis Bridge, page 17.

127 George S. Morison, "The Continuous Superstructure of the Memphis Bridge," Transactions of the American Society of Civil Engineers, September 1893, page 574; "Details of the Anchor Span and Cantilevers for the Memphis Bridge," Engineering News, 16 June 1892, page 611.

128 George S. Morison, The Memphis Bridge, page 17.

129 Engineering News, 19 May 1892, page 521.

130 George S. Morison, The Memphis Bridge, page 18.

131 George S. Morison, "The Continuous Superstructure of the Memphis Bridge," page 576.

132 George S. Morison, The Memphis Bridge, page 25.

133 George S. Morison, Specifications for Superstructure of the Memphis Bridge, 4 January 1890.

134 George S. Morison, The Memphis Bridge, page 21.

135 George S. Morison, The Memphis Bridge, page 21; "Recent Construction in Railway Bridges," The Engineering and Building Record, 23 August 1890, In a paper presented to the Engineers' Club of Cleveland, James O. Ritchie called the specifications for the Memphis Bridge "the most complete and systematic, and on account of the minuteness of their details they are not likely to be evaded."

136 George S. Morison, The Memphis Bridge, page 21.

137 George S. Morison, The Memphis Bridge, page 21.

138 George S. Morison, The Memphis Bridge, page 8.

139 George S. Morison, The Memphis Bridge, page 6.

140 George S. Morison, The Memphis Bridge, page 9.

141 George S. Morison, "Construction of the River Piers for the Memphis Bridge," page 510.

142 George S. Morison, The Memphis Bridge, page 10.

143 "The Memphis Bridge," Engineering News, 12 May 1892, page 470.

144 George S. Morison, "Construction of the River Piers for the Memphis Bridge," page 510.

145 "She Is Gone: A Towboat Wrecked on the Bridge," Memphis Appeal, 11 February 1890. The newspaper reported the wreck: "The disaster occurred just before the mill whistles blew for 7 o'clock. The Eads sighted Memphis about daylight. The morning was clear, and presently the sun rose and the placid bosom of the river glittered like a silver shield. Pilot Gus Hiner was at the wheel... The Eads was towing six freight barges, loaded with about 8,000 tons of grain, flour and packages, and a fuel barge. As she came into the current, opposite the elevator, the east wind wafted the smoke from the chimneys and stacks of the city over the river. The atmosphere under the bluffs was lighter than the smoke, and it settled down on the water like a fog. The pilot could see the banks when he passed the wharfboat, but could not distinguish objects on the water. The artificial fog became denser as the mills and factories in Fort Pickering added their quota of smoke, and the pilot on the Eads lost his bearings.

He thought he was opposite the Bohlen-House Icehouse, when only a few hundred yards above the bridge site...

The channel of the river at the bridge is between the Tennessee shore and Pier 2, and Hiner thought he had plenty of room. He had the boat headed toward this bank, and was perfectly easy in his mind when Capt. Davis entered. Just at that moment the smoke lifted and the break of the current over the submerged top of the pier was seen on the starboasrd side of the bow, perhaps 100 feet away. There was but one course to pursue. If the boat or her tow drifted against the hidden pier a wreck was inevitable. The pilot called to the engineer for the full stroke of the powerful engines, and swung the nose of the boat quartering across the stream. The remorseless and practically irresistible current swept the doomed boat and her tow nearer and nearer to the pier. The pilot and Captain held their breath and almost prayed to the engines which were making the vessel tremble in every timber, to drive her past the danger line. Even if she could get far enough for the blow to be a glancing one, or if the wheel alone suffered, they would be thankful...

The boat was drawing about six feet of water and struck the pier, which was submerged about two feet, amidships. The engines were smashed and the furnace knocked to pieces. The lower deck caught fire, and when Pilot Townsend got his wife out of the cabin a sheet of flame was poking out of the front of the boat. Those members of the crew who were nearest the tow clambered over into the barges; others who were cut off by fire siezed life floats and planks and sprang overboard; others rushed off for the life boat; others hurried to the hurricane deck and a few jumped into the fuel barge. The boat went to pieces immediately and the freight barges drifted down the river, leaving the water around the pier black with fragments of the wreck, floating baggage and human beings floating for life in the icy current.

Before the Eads had ceased grinding out her life against the rock pier, the tugs were steaming forth to the rescue, and skiffs, manned by strong and willing arms, were darting out from both banks. There were thirty-four people on board, and the fact that only six lives were lost speaks well for the rescuers. Only one body was found."

146 George S. Morison, "Construction of the River Piers for the Memphis Bridge," pages 509-10.

147 George S. Morison, "Construction of the River Piers for the Memphis Bridge," pages 510.

148 George S. Morison, The Memphis Bridge, page 16.

149 George S. Morison, The Memphis Bridge, page 16.

150 George S. Morison, The Memphis Bridge, page 22.

151 George S. Morison, The Memphis Bridge, pages 22-23.

152 George S. Morison, The Memphis Bridge, page 23.

153 George S. Morison, The Memphis Bridge, page 23.

154 George S. Morison, The Memphis Bridge, pages 22-24.

155 George S. Morison, The Memphis Bridge, page 24.

156 George S. Morison, The Memphis Bridge, page 24.

157 George S. Morison, The Memphis Bridge, page 24.

158 "Novel Pageantry: Yesterday's Great Parade," Memphis Appeal-Avalanche, 13 May 1892.

159 "A World's Wonder: The Great Bridge at Memphis," Memphis Appeal-Avalanche, 13 May 1892.

160 "They Built the Bridge," Memphis Appeal-Avalanche, 13 May 1892.

161 Memphis Appeal-Avalanche, 15 May 1892; Engineering News, 26 May 1892, page 545.

162 George S. Morison, The Memphis Bridge, pages 226-28.

LATE CAREER

While George Morison concentrated his bridgebuilding efforts on the Mississippi and Ohio Rivers in the late 1880s and early 1890s, conditions changed only slightly on the Missouri River. As had happened on the other major Western rivers, steamboat transportation had been dropping steadily since about 1885 and by 1890 had largely been eclipsed by rail transportation.[1] Congress still approved construction of bridges over the Missouri on a case-by-case basis, subject to general guidelines enforced by the War Department.[2] And three more railroad bridges were completed over the river.

In 1887, the Chicago, Milwaukee & St. Paul Railroad completed a high bridge over the river at Randolph Bluffs, Missouri, just downriver from Kansas City. Comprised of three 389-foot Whipple through trusses and a medium-span deck truss on the east approach, it closely resembled Morison's earlier structures. The following year, the Atchison, Topeka and Santa Fe Railroad erected a four-span bridge over the river at Sibley, Missouri, and the Omaha and Council Bluffs Railroad and Bridge Company put up a multi-span at Omaha.[3] All three bridges followed the standards that Morison had established earlier in the decade, featuring high, fixed trusses supported by pneumatically founded masonry piers. Morison himself would return to his favorite river in the early 1890s to erect two other major structures: one at Bellefontaine Bluffs on the outskirts of St. Louis, and a second on the other edge of Missouri, into Leavenworth, Kansas.

BELLEFONTAINE BRIDGE

Another major component of the St. Louis, Keokuk and North Western Railroad extension into St. Louis contemplated by the Burlington Railroad in the late 1880s was the bridge over the Missouri River at Bellefontaine Bluffs. Like the Alton Bridge four miles away, the Bellefontaine Bridge was designed by George Morison, and like the other bridge it was an all-steel structure. Unlike the Mississippi River bridge, however, the Bellefontaine Bridge was a high, fixed structure. In this Morison was only continuing his prediliction for high

trusses over the Missouri River. The Bellefontaine Bridge would be Morison's last high truss built over the Missouri.

As the Burlington officials were secretly purchasing land in St. Louis for their rail yards there, Morison was examining the countryside north of the city for a suitable line for the proposed railroad.[4] "An examination of the country north of St. Louis and of the Missouri River," Morison reported to Burlington president Charles Perkins, "convinced me very early that the extension ought to be built through the bottom land between the Mississippi and Missouri rivers, crossing he Missouri River so near the mouth that a low grade line could be built from the bridge to the city."[5] Early in 1889, he located a tentative site for the bridge near a point named Jamestown Landing, a little more than eight miles from the mouth of the river. The Landing was the point where several years before the wrecked steamer Jamestown had been landed and unloaded before sinking. Morison called for borings to determine the level of bedrock under the river. Although the borings showed the rock level to be much deeper than anticipated, bedrock could be reached using pneumatic caissons, and Morison continued with the design of the bridge at that location.

Morison presented the design for the bridge to the Secretary of War that fall; the Secretary approved the plan by formal contract on December 21, 1899. The design for the Bellefontaine Bridge resembled Morison's other Missouri River structures in significant ways. The superstructure consisted of four equal-length fixed trusses, held aloft fifty feet above the high water mark of the river by massive masonry piers built over caissons. The superstructure, however, indicated the changes in the bridge industry which had taken place since Morison built his first spans over the Missouri in the early 1880s.

Plattsmouth, Bismarck, Blair, Omaha, Rulo, Sioux City and Nebraska City were all almost identical bridges, featuring long-span, double-intersection superstructures. At Cairo, Morison had stretched the Whipple configuration to its ultimate practical length, and many considered it to be the quintessential example of its type. From Jacob Linville's Steubenville Bridge, completed in 1865, until the completion of Morison's major trusses of the late 1880s, the Whipple design had been considered the industry standard for long-span truss technology. It presented serious drawbacks, however, not the least of which was its need for frequent adjustment of the two-panel diagonals. By the early 1890s, this truss type was rapidly superceded by the more economical, more rigid single-intersection Pratt variations.

Although the span lengths for the Bellefontaine trusses were somewhat longer than his earlier bridges over the Missouri River, Morison abandoned the double-intersection configuration in favor of a single-intersection truss with lateral substruts. He delineated Baltimore through trusses with pin-connected detailing for this superstructure. Each span was 440 feet long and 55 feet

tall, subdivided into sixteen panels, 27'6" long. The truss width for the double-track structure was 30 feet between centers of the webs. "The trusses have single system webs and are made absolutely without adjustment," Morison reported to the railroad. "The top and bottom lateral systems are riveted."[6] He compensated for the reversal of strains at the centers of the trusses by constructing the inclined web members to resist compression as well as tension, in lieu of the usual adjustable counters.[7]

Morison proportioned the double-track sections of the bridge to carry a Class C load, with a rolling weight of 3,000 pounds per lineal foot. He used a Class A - 4,000 plf - load for the single-track sections. In proportioning the floor system, he doubled these loads on the basis of a 20-foot wheelbase for the trains, and reduced this double load at the rate of 1% for each additional foot over 20 feet. He sized the stringers for a moving load of 7,700 plf and the floor beams, which were double-track members, for a moving load of 5,775 plf.[8]

To allow for expansion, Morison designed expansion bearings which consisted of 12-inch segmental rollers upon which sat a rocker plate with two cylindrical surfaces at right angles to each other. This system had the advantage of taking up lateral movement as well as axial, caused by differential expansion and contraction. Morison patented this expansion system in October 1892 and adopted it for his subsequent major trusses.[9]

Morison specified open-hearth steel exclusively for the Bellefontaine Bridge. This material was rolled by several eastern mills: the Carbon Steel Company, Carnegie Steel Company, Midvale Steel Company, Pencoyd Iron Works, Pennsylvania Steel Company and the Standard Steel Casting Company. The Union and Keystone Bridge companies produced the eyebars, and the New Jersey Steel and Iron Works fabricated all of the bridge components. With each of the four spans weighing 2.8 million pounds, the total superstructural weight of the Bellefontaine Bridge exceeded 11.2 million pounds. The component weights of each of the trusses are given in the following table:

	Total weight	Weight per foot
Truss	1,899,262 pounds	4,316 pounds
Wind bracing	166,268 pounds	378 pounds
Floor	602,697 pounds	1,370 pounds
End supports	87,094 pounds	198 pounds
Fence and ladders	50,233 pounds	114 pounds [10]

With Benjamin L. Crosby as the resident engineer, construction of the bridge was to begin early in 1892. The railroad steamed the venerable John Bertram to the site in May 1892 preparatory to launching the first caisson. High water on the river forced the foundation crew to wait, however, as Morison described: "Eighteen hundred and ninety-two was a year of high water; the lower Missouri River as well as the Mississippi River at St. Louis were higher than at any


MISSISSIPPI RIVER
ST. CHARLES COUNTY
MISSOURI
MISSOURI RIVER
ST. LOUIS COUNTY
STL K&NWRR
BELLEFONTAINE BRIDGE
General Map.
Scale

Figure 170

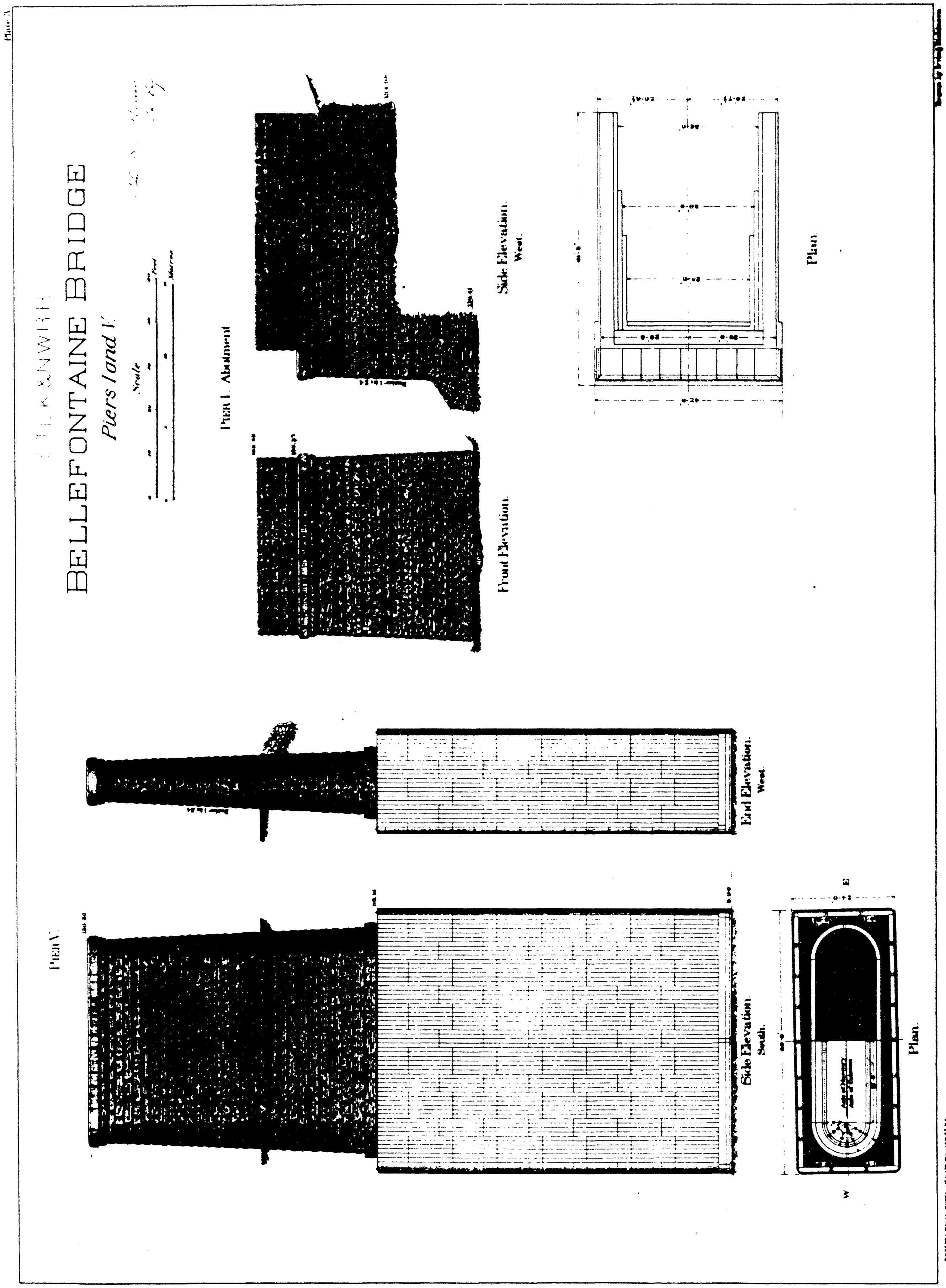

BELLEFONTAINE BRIDGE
Piers I and V.
Scale
Pier I. Abutment.
Side Elevation.
West.
Front Elevation.
Plan.
Pier V.
End Elevation.
West.
Side Elevation.
South.
Plan.

Figure 171

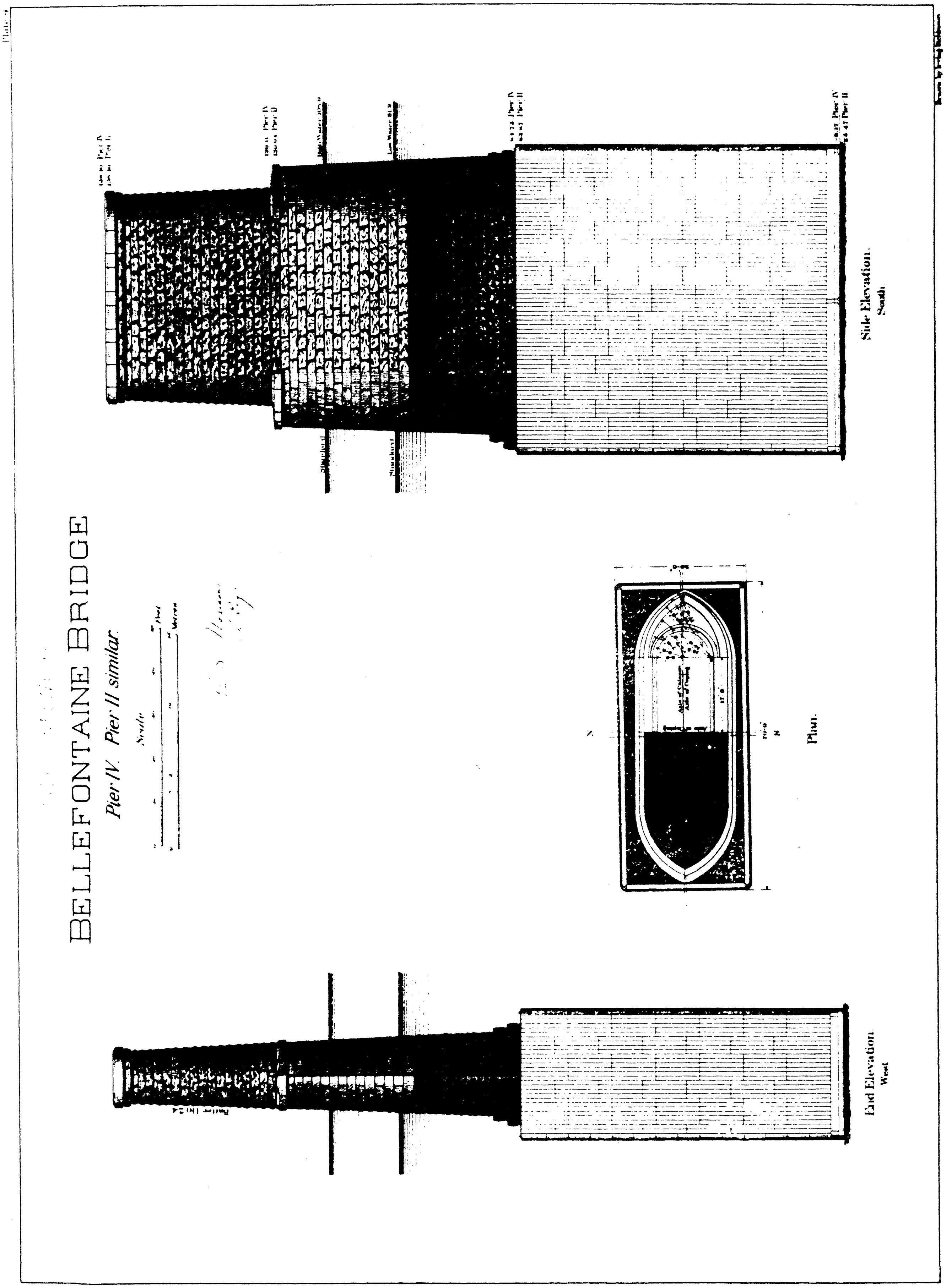

BELLEFONTAINE BRIDGE
Pier IV. Pier II similar.
Scale
Side Elevation.
South.
Plan.
End Elevation.
West

Figure 172

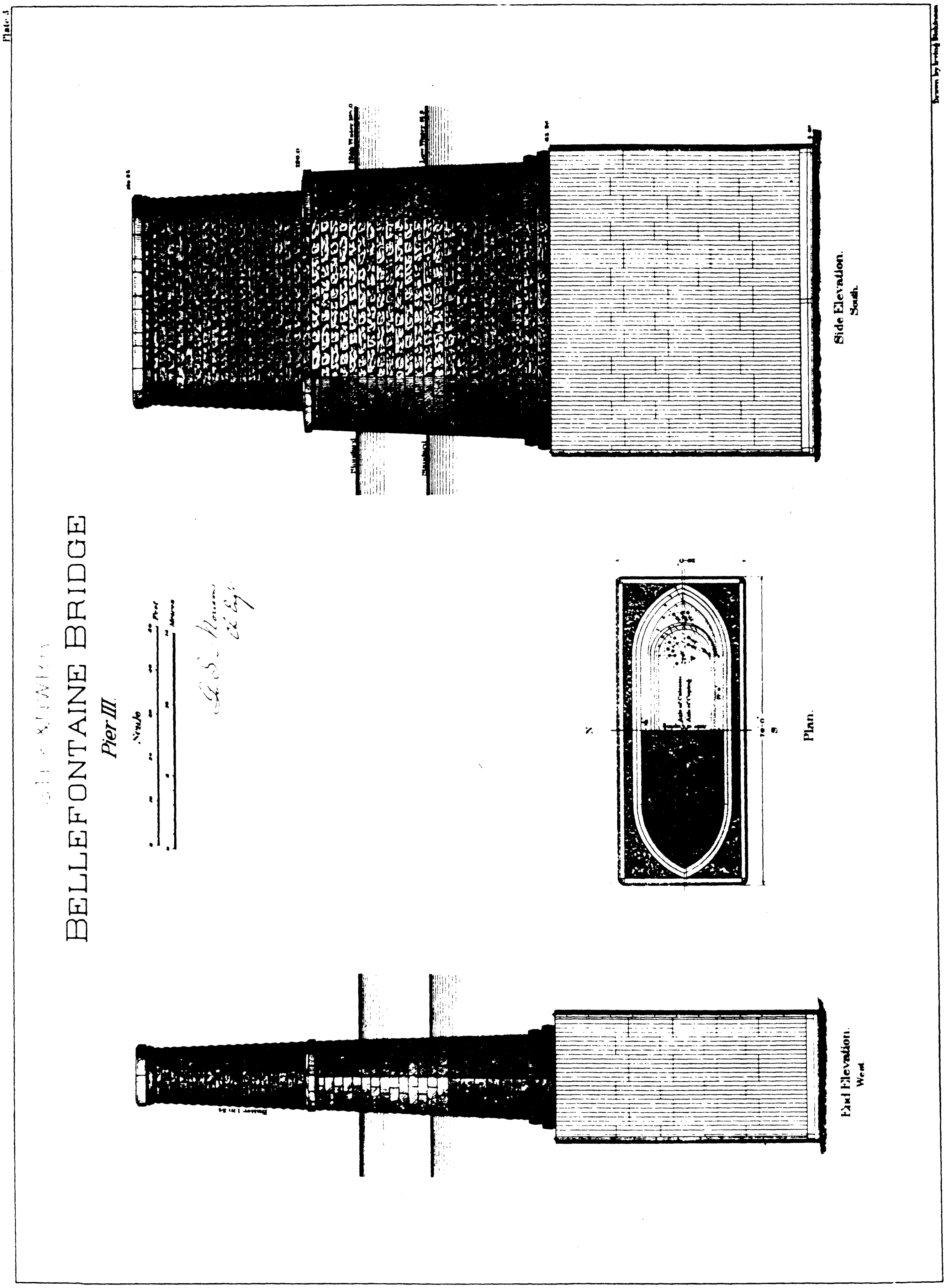

BELLEFONTAINE BRIDGE
Pier III.
Scale
Side Elevation.
South.
Plan.
End Elevation.
West.

Figure 173

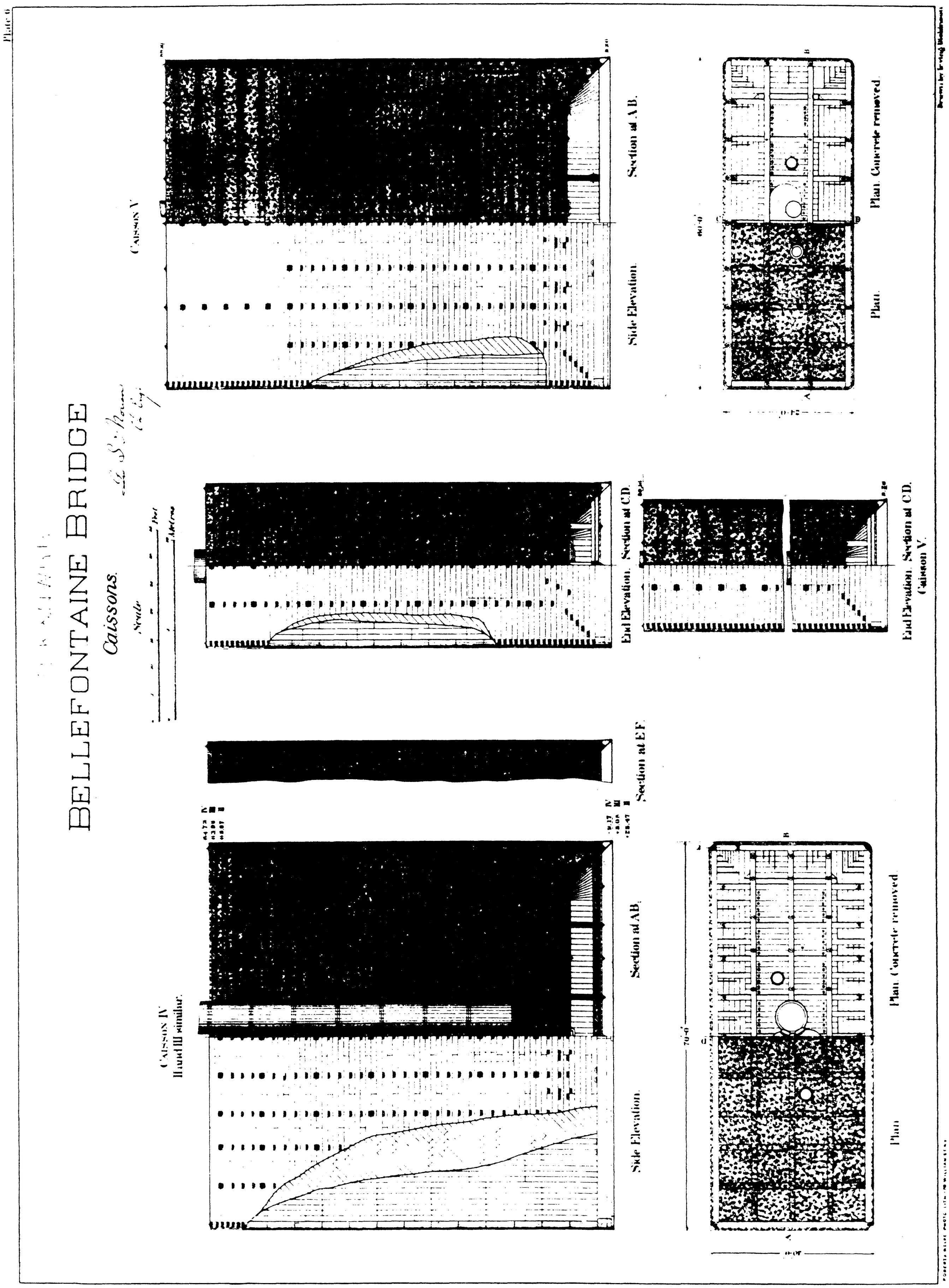

BELLEFONTAINE BRIDGE
Caissons.
Scale
Caisson V
Side Elevation.
Section at A.B.
Plan.
Plan. Concrete removed.
End Elevation. Section at C.D.
End Elevation. Section at C.D. Caisson V.
Section at E.F.
Caisson IV
II and III similar.

Figure 174

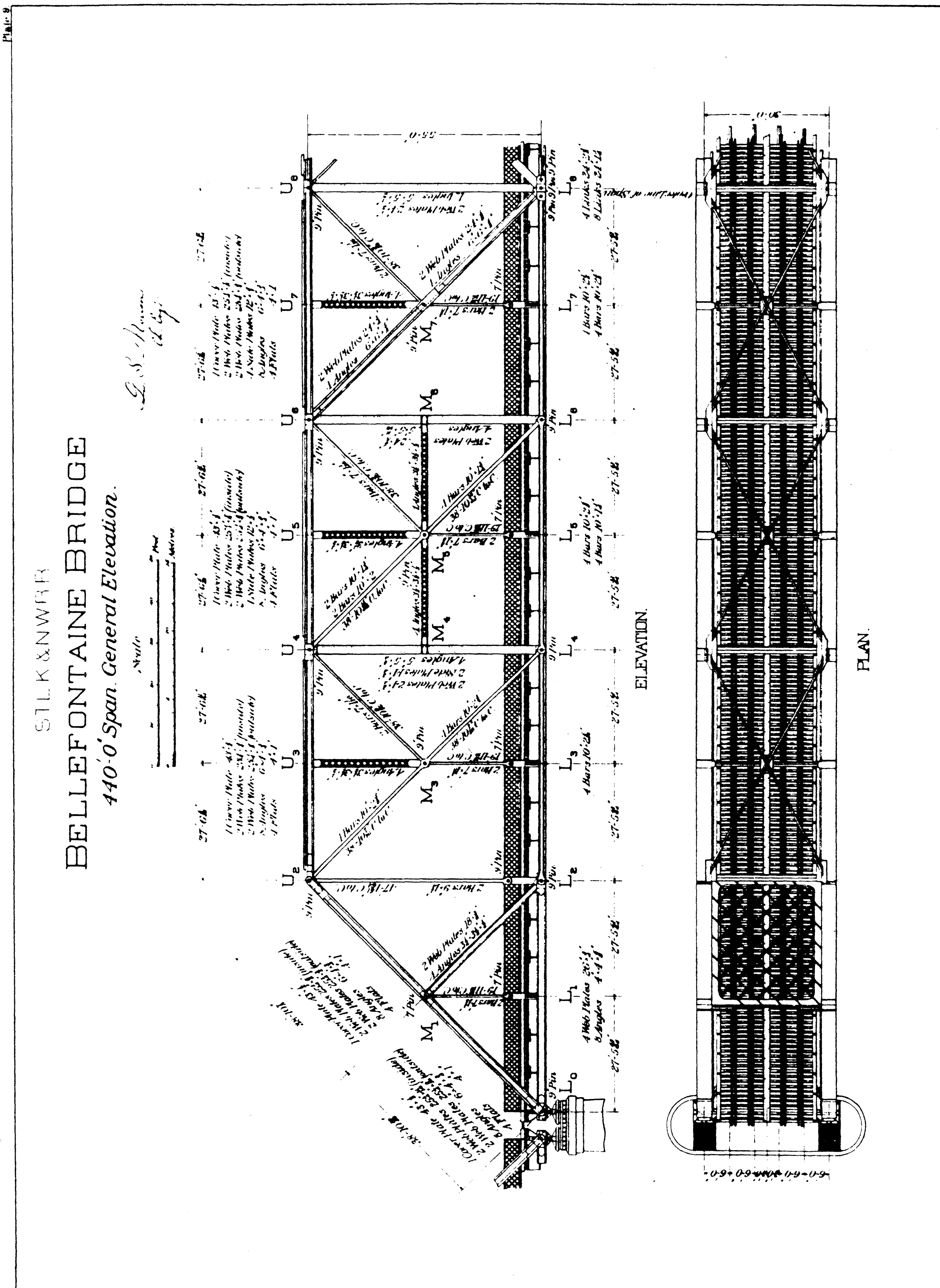

STL K & NW RR
BELLEFONTAINE BRIDGE
440'-0' Span General Elevation
ELEVATION
PLAN

Figure 175

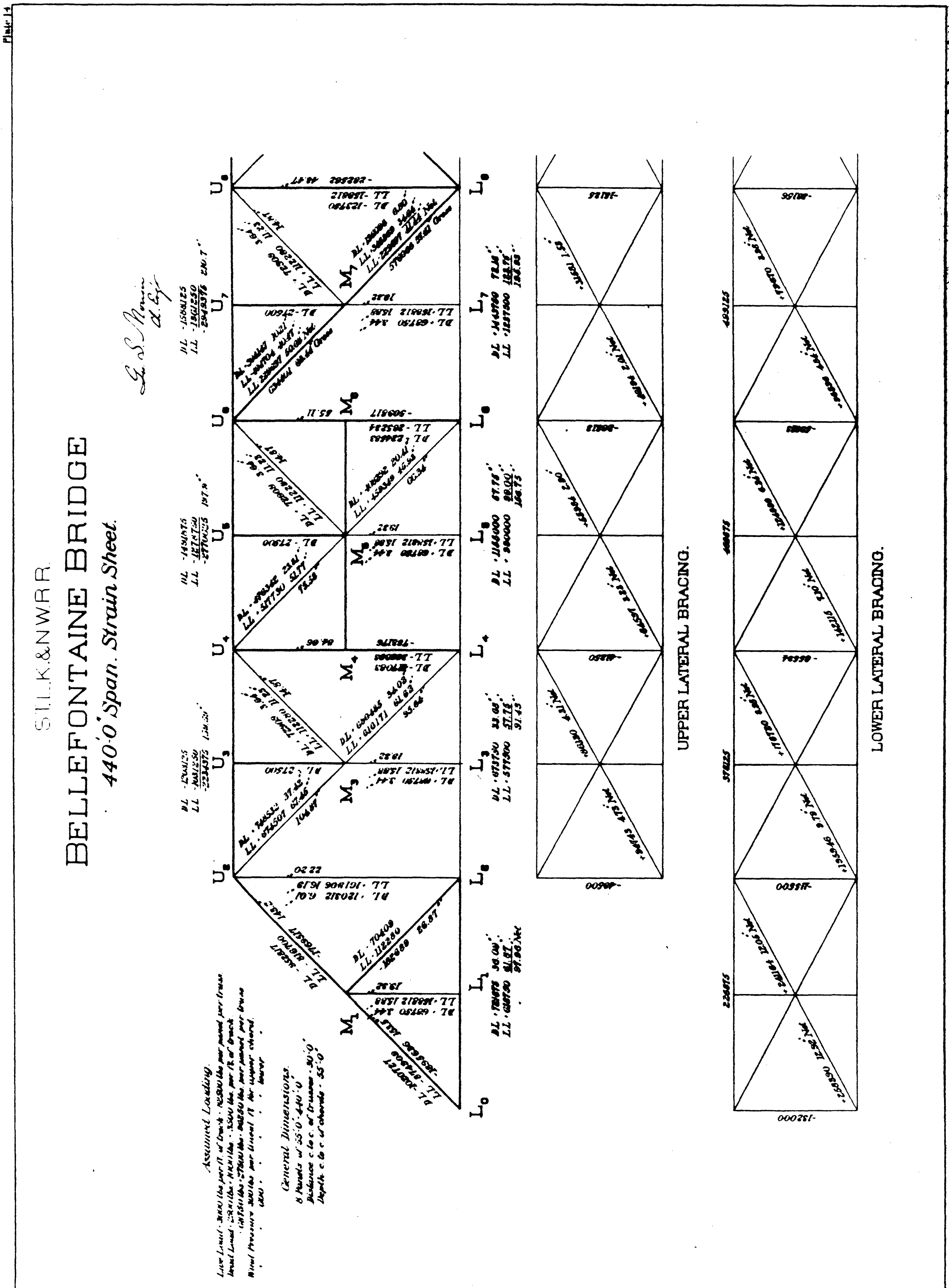

St.L.K.&N.W.R.R.
BELLEFONTAINE BRIDGE
440'0" Span. Strain Sheet.
UPPER LATERAL BRACING.
LOWER LATERAL BRACING.
Assumed Loading.
General Dimensions.

Figure 176

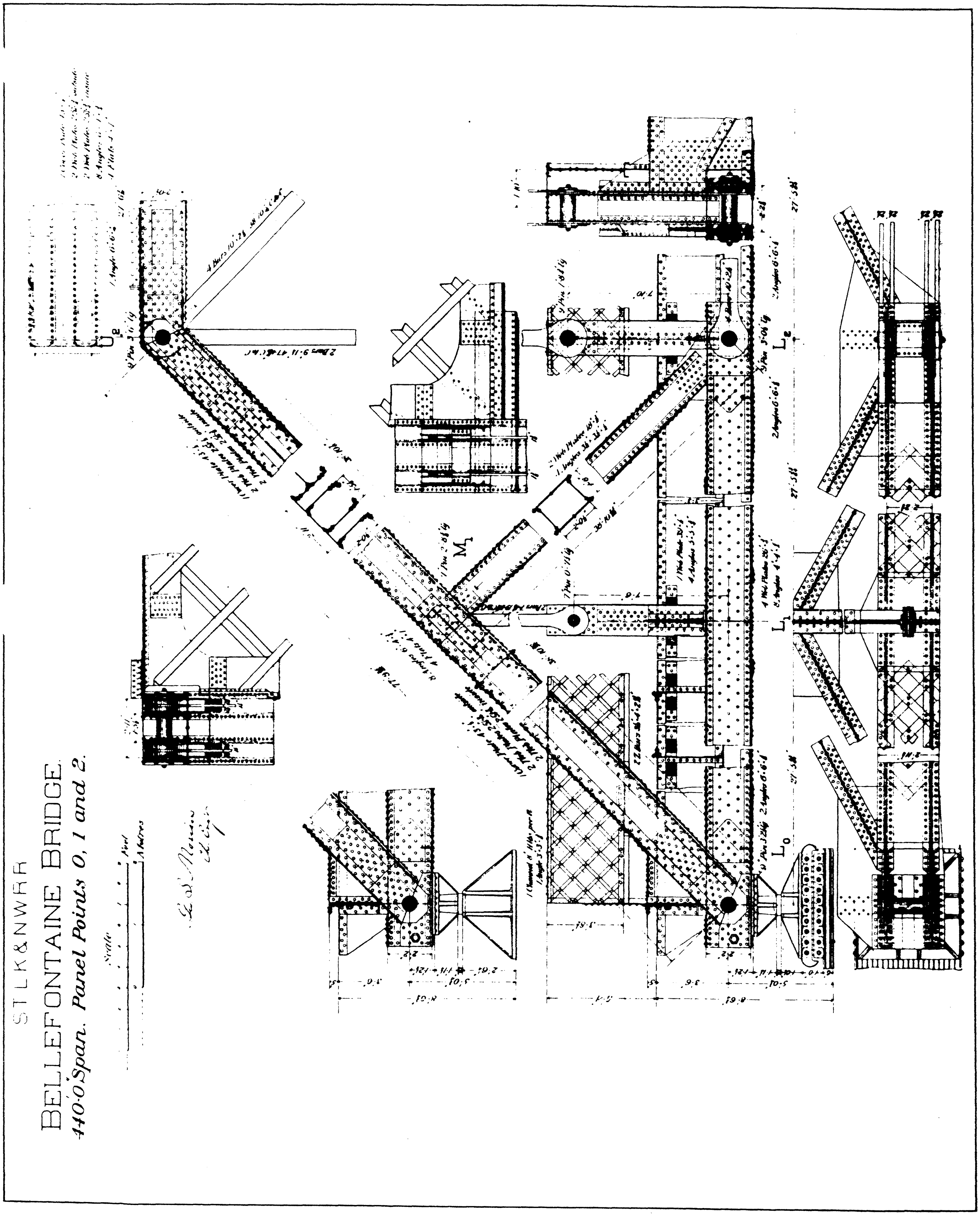

ST L K & N W R R
BELLEFONTAINE BRIDGE
440'0" Span. Panel Points 0, 1 and 2.

Figure 177

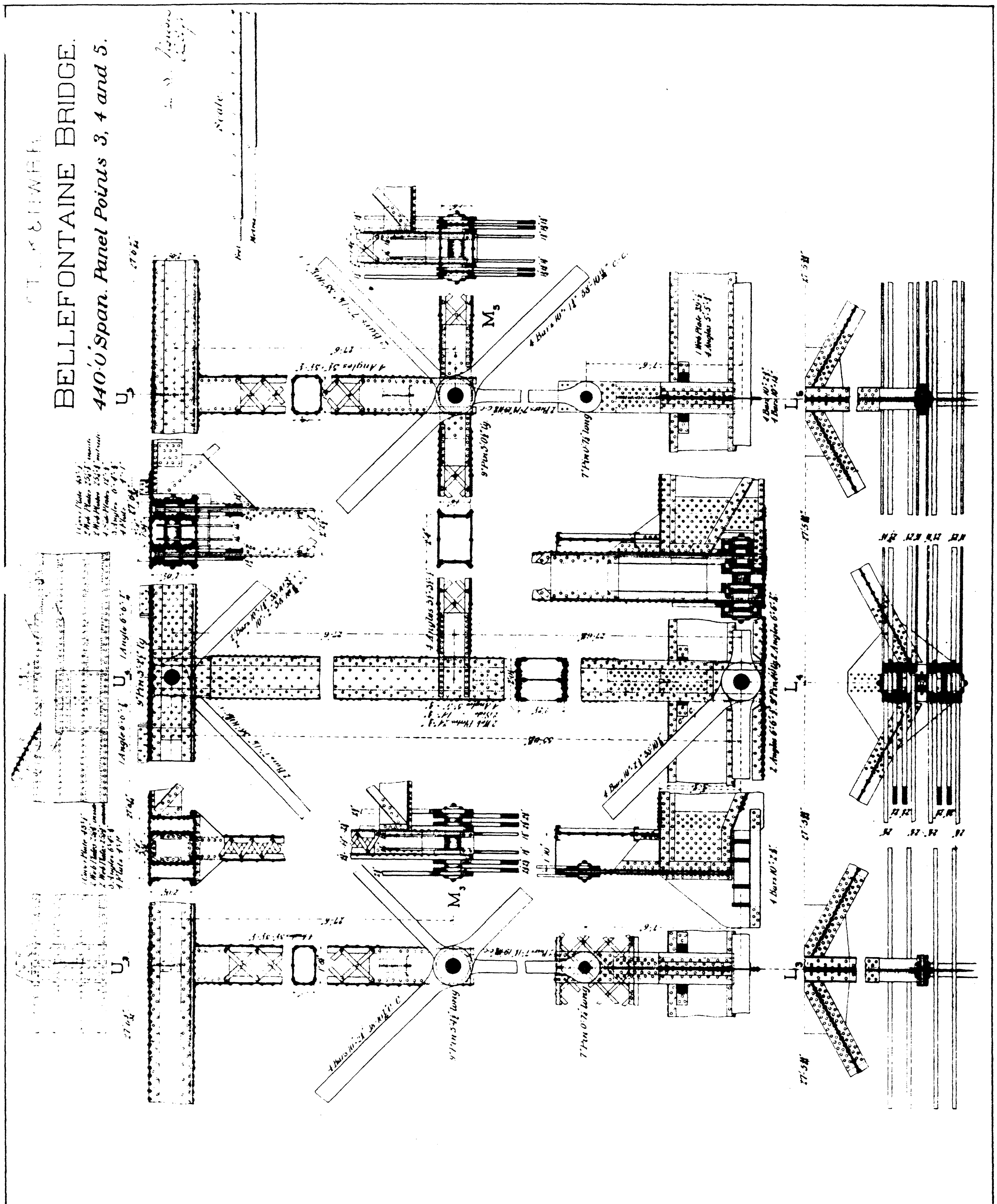

BELLEFONTAINE BRIDGE.
440'0" Span. Panel Points 3, 4 and 5.
U5
M5
L5
U4
L4
M3
U3
L3

Figure 178

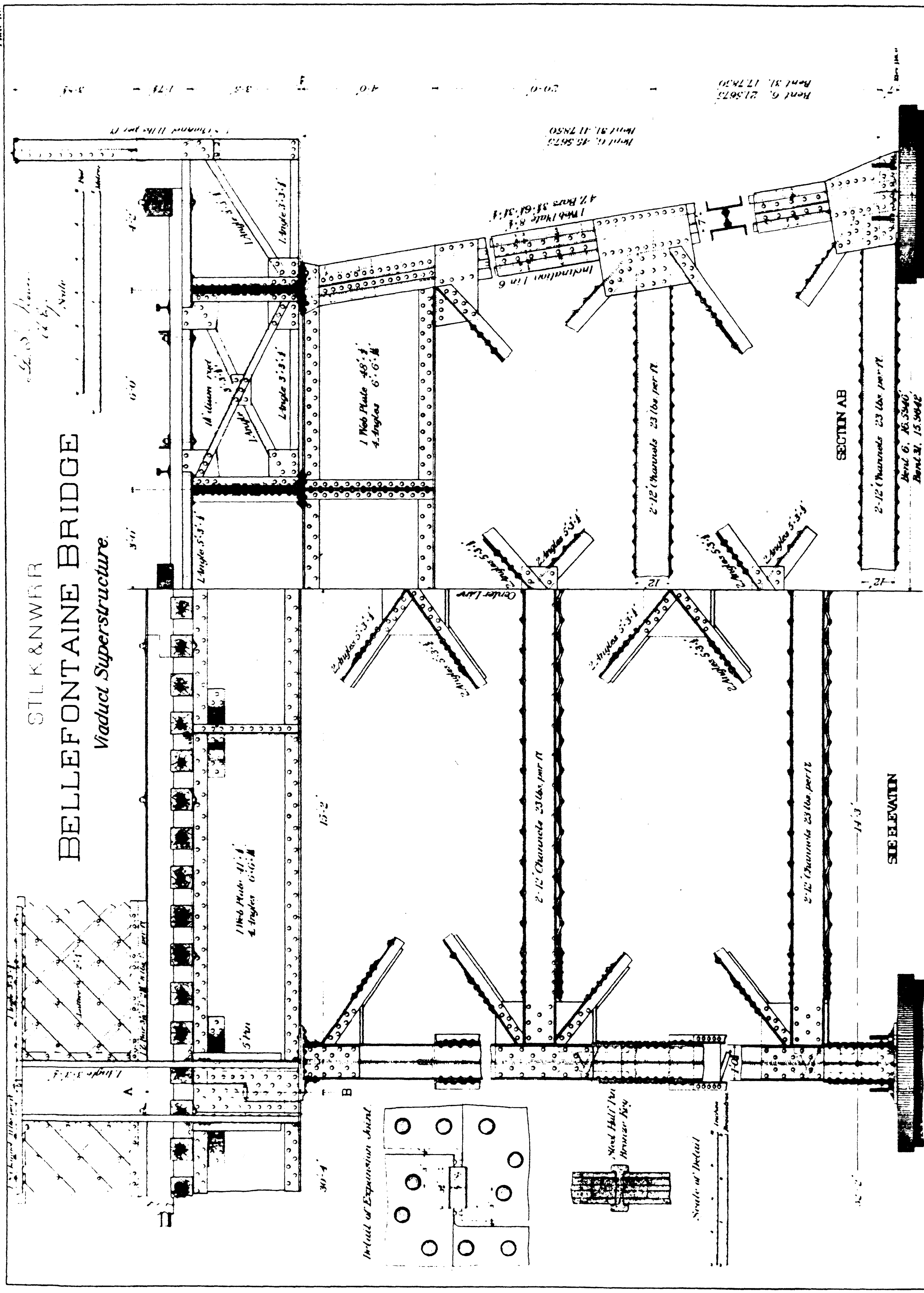

STL K &NWRR
BELLEFONTAINE BRIDGE
Viaduct Superstructure.
SECTION AB
SIDE ELEVATION

Figure 179

time since 1858. The slope of the river opposite the City of St. Louis was, however, somewhat abnormal, and it is probable that the river at the site of the Bellefontaine Bridge was higher than it has been at any time since 1844. On the 18th day of May it reached elevation 115.1; the zero being a datum plane 100 feet below the St. Louis City directrix, to which datum all levels on the work were referred. This high water prevented any considerable amount of work being done during the first half of the year."[11]

Actual construction began on July 4, 1892, with the excavation for the south abutment. Two weeks later work began on the caisson for the first channel pier. Work on the substructure of the Bellefontaine Bridge followed the pattern that Morison had established on his earlier Missouri River bridges, with the pneumatic caissons sunk by railroad employees. The Chicago firm of Christie and Lowe contracted to build the masonry piers. Morison's ex-assistant George Lederle acting as the resident partner and supervisor. "The work was handled under rather more than ordinary difficulties," Crosby stated wryly, "owing to the fact that during the greater part of the time that the foundation work was in progress there was no railroad communication with the bridge, and all material and supplies had to be brought up the river on barges, which added considerably to the expense and was a constant source of worry to those in charge of the work."[12] Without a nearby town, the railroad was forced to build boarding houses for the workers and sheds in which to store the materials. The ever-exuberant citizens of Alton nearby, on the other hand, saw the bridge's remote location as one more opportunity for self-aggrandizement. "This will not only serve to furnish an immense amount of labor hereabouts for the next two years," enthused the Alton newspaper, "but will be of great service in advertising Alton. The amount of advertising received by reason of the Missouri bridge will thus be scarcely less than from the Alton bridge itself."[13]

The last stone was set on Pier II in July 1893, exactly one year after construction started. After trying fruitlessly throughout the summer to coax the New Jersey Steel and Iron Works to commence the superstructural erection, Morison finally called upon William Baird for help. He contracted with the Pittsburg-based contractor, "whose experience in this class of work is greater than that of any other man living," on September 9.[14] On September 13, Baird arrived in Alton to begin the work.[15] With the veteran steelworker supervising the work, the erection of the superstructure proceeded without incident. The first steel was placed over the pile falsework for the southernmost span immediately after he arrived. The erection crew swung the last span on December 18, 1893. Costing $1.3 million, the Bellefontaine Bridge was essentially completed. The component costs of the bridge are itemized in table on the following page:

Substructure	$ 428,734.44
Superstructure	545,045.84
North approach	150,272.92
Permanent track.	8,511.26
Shore protection	64,075.16
Tools, service tracks, etc.	73,131.67
Engineering.	49,323.26
Total	$1,322,719.39 [16]

Located in an inaccessible no-man's land between two cities, construction of the Bellefontaine Bridge proceeded in relative obscurity. No cheering citizens' group was at hand when the first train crossed the bridge on December 27th, 1893. The first regular time table went into effect March 4th, 1894, at which time the bridge was put quietly into regular service as a double track structure.[17]

LEAVENWORTH BRIDGE

As the work on the Alton and Bellefontaine Bridges was winding down in December 1893, the Railroad Gazette noted their progress, saying: "It is a very striking fact that these two bridges should be built simultaneously over the Mississippi and Missouri within less than four miles of each other, one three miles and the other five miles from the confluence of those two great streams. And it is also interesting to note that the engineer of these two bridges is at this moment building another bridge over the Missouri at Leavenworth."[18] The engineer was, of course, George Morison. The third bridge then under construction was the Terminal Railway Bridge at Leavenworth, Kansas. Unlike most of his other great river structures, however, the Leavenworth, or Terminal, Bridge was not the first structure to span the river at this point. Although Morison's bridge over the Missouri River at Leavenworth was the second span over the river at this point, it was nevertheless an important structure to the city and to the railroad which it served.

The Terminal Bridge over the Missouri River at Leavenworth had its beginning in 1883 with another engineer. A.J. Tullock, president of the Leavenworth-based

Missouri Valley Bridge and Iron Works took soundings of the river with the thought of erecting a bridge. In 1889, Judge Stillings secured a charter and right-of-way for a moveable pontoon bridge and built the structure that year. Stillings' pontoon bridge answered the purpose for wagon traffic, but the first high water washed it out. Stillings and others made repeated efforts to reconstruct and maintain the bridge, but the river current was too swift, and within a year the bridge was abandoned. The charter, however, remained effective and was later used as the basis for the Terminal Bridge.

In 1890, the charter was modified to allow construction of a permanent draw bridge. That year, E.W. Snyder, president of the Manufacturer's National Bank in Leavenworth, organized the Leavenworth Terminal, Railway & Bridge Company. The purpose of the company was to erect a wagon/railroad bridge over the Missouri River, lay trackage into town and build terminal facilities for trains crossing the bridge into Leavenworth.

On the night of February 5, 1892, the Leavenworth Board of Trade met to consider the bridge company's proposal for the bridge. Despite the miserable weather in Leavenworth that night, the meeting was, by all accounts, a rousing event. Beginning with patriotic speeches, the meeting proceeded on an ebulient note. Snyder then laid out the conditions under which the bridge would be built. First, the town would have to guarantee a suitable crossing site over the Missouri River, accessible to the Union Station. Snyder no doubt had in mind an earlier bridge proposed for Leavenworth, which had to be abandoned when speculators bought up land on the Kansas approach and demanded an exorbitant amount for it.[19] Second, Snyder asked for a municipal ordinance granting a right-of-way from the end of the proposed bridge across the levee to connect with the existing tracks of the Leavenworth, Topeka and Southwestern Railroad. He also requested a right-of-way for other connecting tracks. Finally, Snyder demanded $40,000 from the citizens of the town to help defray expenses. His presentation was followed by still more testimonials. "I say accept the proposition," Colonel Anthony boomed. "Let us drop out the rascality of the past and look for better things in the future. When reliable men come and make us a proposition like this, you should extend aid. To be prosperous and to be respected by the world at large we must be honest with ourselves, honest with our public acts and honest with each other."[20]

Snyder negotiated a bond sale to raise the funding necessary for construction and secured contracts with both the Burlington and Rock Island railroads to cross the bridge and use the terminal facilities. He then contracted with the Missouri Valley Bridge Company to engineer the proposed bridge. Tullock, in turn engaged George Morison as consulting engineer for the project.

The bridge that Morison designed for Leavenworth represented a synthesis of his previous thirteen bridges over the Missouri and Mississippi rivers. It combined the swing span configuration of his Mississippi River structures with the

caisson-footed piers of his previous Missouri River bridges. Morison's bridge consisted of one 440-foot draw span and two 330-foot Parker fixed spans, totaling about 1,100 feet in length. The all-steel trussed spans were supported by five masonry piers. The extreme east and west piers, removed from the scouring action of the river channel, were founded on driven timber piles. The three channel piers were built over timber-framed pneumatic caissons similar to those he had designed for several other fixed-span bridges. Compared with the sizes and engineering features many of of Morison's previous great river structures, the Leavenworth Bridge appeared technologically unremarkable.

When Morison presented his design for Leavenworth to the Secretary of War, the Secretary delayed approval, complaining that too many low structures already spanned the Missouri and were impeding river traffic. The Secretary finally relented, however, allowing construction of the bridge as drawn. Ironically, given Morison's stated penchant for high, fixed trusses over the Missouri River, the Leavenworth Bridge was to be the lowest bridge erected over that watercourse.

As engineers for the Union Pacific and Missouri Pacific railroads surveyed the proposed bridge site in March, the Board of Trade circulated a petition around town for a bond election to raise $30,000 of Snyder's required pledge. This was later approved. In April, the City Council passed the right-of-way resolutions. In June, the Terminal Railway Company signed connecting agreements with the two larger railroads and signed a construction contract with the Missouri Valley Bridge and Iron Company. The Leavenworth Bridge appeared finally underway.

Missouri Valley began preparation for building the bridge in July 1892 by building the barges to attend the substructural work. The project immediately stalled, however, following disputes with the bridge company and with the railroads. The Burlington and Rock Island lines intervened in autumn, and in November, the Terminal Railway contracted with the Union Bridge Company for the superstructure of the bridge. Under the new agreement, Tullock's company, which was originally to have built the entire structure, was relegated to constructing the approaches and the substructure of the bridge proper. "The delay was needless," the Leavenworth Times complained, "and has caused much ill feeling and disappointment to our people, who had hoped to have the new bridge completed by July 1, 1892... One year's delay is a great loss to Leavenworth, which cannot be estimated. The pontoon bridge was always in the way and an obstacle which had blocked every attempt to build the bridge. It is said the pontoon has made nothing and every honorable man will rejoice that the obstructionist has not profited by the delay. But now is not the time to growl. The bridge will now be built and that speedily."[21]

Late in December, Morison's assistant George T. Nelles moved to Leavenworth to take charge of the rectification work. The dike at the bridge was 3,500 feet long, extending from the Missouri riverbank to an existing sand bar in the river. From there, the dike curved to the west to the east end of the bridge approach. While one crew wove the willow mattresses which would form the foundation for the dike, another group of men excavated a 100-foot wide bed onto which the mattresses were laid. They then layered the willow mats - the butts of which were 2" or more thick - with heavy stone riprapping to form the height of the dike. The ferryboat Belle of Browneville busily carried ton after ton of the stones in wagons, making some 125 trips per day to the rectification site. The dike was capped with a final 20-foot wide layer of stone, which was in turn covered with earth.[22]

Construction of the bridge proper began on January 1, 1893, with the pile driving for the east and west piers. The masons completed the stonework for these by April, and Missouri Valley stopped the project under Morison's orders to wait for the seasonal ice melt and flood. After the high water had subsided and the dike repaired, the work crew resumed work in July with the caissons for the channel piers. As the sand hogs lowered the caissons slowly through the riverbed to the underlying stone, some observors wanted to prospect for gold in the chambers but were denied the opportunity.[23] A reporter for the Leavenworth Times described the huge caisson for Pier 4 in August colorfully: "Picture in your mind a huge square dry goods box covered on the outside with thick boards put on slant wise and the whole set in a great iron socket, the box set in first and the standing boards shaved to an edge at the ends and driven down beside the sides of the box between the latter and the inner sides of the iron cap, the boards bolted to the sides of the box and the concern set floating in water that goes up one half the distance from the bottom to the top of the box, and you will have an idea of the caisson that has been launched for the pivotal pier for the new bridge. To complete the idea see in the mind picture the corners of the box slightly rounded and covered with plates of iron. The bottom cap is call [sic] a "shoe" and has below its floor a rim of steel that is called a "cutting edge" projecting downward about two feet. This edge will set on the bed rock under the bottom of the river and will be the base of the pier."[24]

The slow-paced construction continued on the caissons and piers throughout the summer and autumn. To help compensate for the six-month delay at the start of the project, Morison pushed the bridge work round-the-clock. Adding the third shift speeded the construction, but the nighttime work proved extremely dangerous. Workers occasionally fell into the darkened river and were swept away without notice. Laborer Steven Luke was walking along a plank one Sunday evening in August and in the poor light walked off the edge into the river. He was pulled along the river bottom beneath a barge until he hit one of the timber piles. Luke then climbed the pile to safety "and reached the surface and was pulled out by his companions."[25] Frederick Theisinger fell into the

river later in the month while walking a plank between two barges during the night. "There was a cry and a splash," the Times reported, "and poor Theisinger was lost to sight."[26] His body was never found. Two months later, another member of the night crew was killed when his skull was crushed by a falling timber.[27]

While the substructural work dragged on at Leavenworth, the Union Bridge Company was fabricating the all-steel superstructure for the bridge at its Pennsylvania plant. At the end of October, the steelworkers began assembling the west section of the pivot span using the standard traveler and pile falseworks. A month later, this span was completed and the men had begun coupling one of the fixed trusses.[28]

On December 13, 1893, the erection crew drove the last pin in place on the last span, substantially completing the bridge superstructure. It was a procedure that had been performed hundreds of times before by the men. But to the townspeople the placement of the last pin represented the final coupling of the structure, "attaching by a link of fortune the city of Leavenworth with all the outside world," according to the Times. The newspaper reported the celebratory din which accompanied this event:

> When the pin was driven to its place a signal was given and there were two sharp blasts from the bridge works. These were followed by shrieks of joy from the locomotives in the railroad yards. Then the ringing of engine whistles and the sound was taken up at the foundries and machine shops, rounding up the chime with the sonorous clang of the Court house bell, creating such a chorus of jubilant sound as to wake the unthoughtful on the streets and cause one to ask of another, "What is the matter?" "It's the bridge! it's the bridge," cried one, and soon it was in everybody's mouth. "The bridge is done. They've got the bridge together!" So they had. The ceremony was performed at 5:20 p.m. and the chorus of whistles and bells made the city alive with sound for a quarter of an hour.[29]

Two days later, the bridge workers received news of a fatal accident on the Louisville Bridge over the Ohio River. One span of the bridge had collapsed into the river as it was under construction by the Phoenix Bridge Company. "An unusual fatality and ill-fortune seems to have attended the building of this bridge from the start," Morison's resident engineer M.A. Waldo commented, "A very serious disaster overtaking the contractors for the substructure, Gen. Sooy Smith & Co., during the progress of their work by which they lost a caisson and six or eight men." At least two of the men killed in Louisville in December had earlier worked on the Leavenworth Bridge.[30]

On Tuesday, January 2, 1894, the bridge was officially dedicated by the people of Leavenworth. The reporter for the Times was ebullient:

> The bridge which Leavenworth has desired so long is built at last. For many years our people have looked across the wide stretch of water and sand and have thought: "If only this could be bridged, what a grand thing it would be for our city." Over there they saw the great Platte county, one of the richest counties in the west only a small part of whose trade reached us because there was no sufficient means of crossing the river. They saw, too, one of the greatest railroads of the country stopping there instead of coming here and giving us a first class road. Years ago they saw other roads heading in this direction and anxious to cross the river here. Had the bridge been built then what greatness would be ours now!... To-day brings a new era for our city. To-day our people celebrate the opening of the bridge over which two great railroads will find their way into the city and which will bring to us the trade of Plate county. The latest accession will give new life to our city, a new impulse to our business and will inspire our citizens to work with greater energy for the upbuilding of the city.[31]

The total cost of the bridge, including approaches and rectification works, had been about $300,000: surprisingly modest by Missouri River standards. The total construction time on the bridge proper was little over six months: also a remarkable accomplishment. The Missouri River by the early 1890s was no longer the unfathomable barrier to interstate traffic. Although the earliest bridges built over the Missouri in the 1870s and early 1880s had been attended by lengthy construction schedules and enormous amounts of money, bridging the great river only ten years later had become a commonplace operation with substantially reduced costs. It was George Morison, with his standardization of superstructure and substructure design and construction sequence, with his extensive publication of his findings and with the sheer volume of his work, who had single-handedly changed the complexion of bridge building on the Missouri River.

OTHER PROJECTS

As the 19th century drew to a close, George Morison held a distinguished position in civil engineering. The number and sheer magnitude of his bridge projects by the 1890s represented a tremendous technological accomplishment. His pioneering use of steel and his inventive capabilities bolstered his reputation, but, above all, his mastery of the long-span bridge had kept his services in constant demand throughout the 1880s and into the 1890s. The year

1893 marked a watershed in Morison's bridge building career, with the simultaneous construction of five important long-span structures: the Leavenworth and Bellefontaine bridges over the Missouri River, and the Burlington, Alton and Memphis bridges over the Mississippi. His time, typically, was devoted entirely to his work.

The year 1893 also marked a turning point for America's railroads, as the industry responded to a national depression by sliding into a dramatic depression of its own. Most track laying and bridge building projects were shelved, effectively eliminating a large amount of work for civil engineers. Morison remained principally engaged in railroad projects not involving bridge construction during the depression years. He had by that time, however, ceased to consult on railroad matters for the Baring Brothers. His last assignment for the firm, an extensive report on the Atchison, Topeka and Santa Fe Railroad, had terminated his long association with them in 1889. The split was apparently motivated by a clash over the policies of the American representatives who succeeded the Wards.[32] Morison's principal clients in the 1890s included the Colorado and Southern Railroad and several lesser railroad lines.

In the early 1890s, Morison reported on the proposed International Bridge over the Detroit River between Detroit, Michigan, and Windsor, Ontario - a major suspension span which drew proposals from several leading engineers of the time. Reengaged in this study immediately before his death, his selection as the engineer of this bridge was believed to be eminent.[33] The International, or "Ambassador Bridge", completed in 1929, was ultimately the product of several brilliant civil engineers. A technological landmark, the 7400-foot structure featured the longest suspension span (1850 feet) and the longest span of any bridge in the world.[34]

During this period, Morison took an active role in the various engineering societies to which he belonged. He served as a Trustee of the Western Society of Civil Engineers from 1893 to 1895 and was appointed President of the American Society of Civil Engineers - one of the highest honors bestowed in the engineering profession. Additionally, Morison maintained membership in a multitude of other professional organizations, including the American Institute of Mining Engineers, the American Society of Mechanical Engineers, the Institution of Civil Engineers in London, and the Mexican Society of Engineers and Architects. He also offered his patronage as an Associate of the American Academy of Arts and Sciences and as a Fellow of the American Academy for the Advancement of Science. He maintained club memberships in many American cities among men of commerce and industry. In 1895, for example, he belonged to the Chicago and Union Clubs in Chicago; the University and Engineers' Clubs and the Downtown Association in New York; the Union Club in Boston; and the St. Louis Club in St. Louis.[35]

An all-consuming career left little time for outside pursuits, and for the most part Morison regarded such activities as wasteful distractions. One particular project, however - the improvement of the Phillips Exeter Academy, his prep school alma mater - did claim his long-standing devotion. Elected to the Board of Trustees of the Academy in 1888, Morison served in that capacity for the next fifteen years, presiding over the Board as Chairman for the last five. During his trusteeship, he dedicated himself unflaggingly to the school's improvement and resigned only when he became too ill to continue, a month before his death.

Chief among his contributions to Exeter was the construction of several new dormitory buildings. As Chairman of the Buildings Committee, he planned and supervised the construction of Soule, Peabody, and Hoyt Halls. Morison's design for the buildings was, like his monumental truss bridges, characteristically utilitarian and austere. "He was always willing to depart from established practices if the results justified, and in designing Soule Hall he did not hesitate to construct a dormitory which in its conception is unique," his nephew, George Abbot Morison stated, "The exterior, like some of his other buildings, was conspicuous for its plainness, even its eves were so narrow as to be hardly noticeable. One of his associates on the Board of Trustees said that Soule Hall was built by such a confirmed bachelor that he would allow no Eves about the building."[36]

Morison also gave the academy an endowment to establish the Morison Professorship of Latin, which, as his nephew observed, was "a tribute to his belief that the Classics must always be considered as indispensible factors in training the mind to think clearly and accurately, and that no man could be considered a really cultured individual without a sound knowledge of the Classics."[37] Morison retained his own classically-stressed studies for a lifetime, studding his conversations often curiously with classical allusions. This habit astounded many of his contemporaries to whom he appeared strictly a man of science.

The consummate professional, Morison enjoyed virtually no personal life away from his career. He remained a bachelor throughout his life and did not settle into a permanent home until his later years. Yet, the strong ties he felt for his native New England always held him. In 1893 he began construction of a house on the Peterborough property he had acquired from his father in 1867. Disdaining the work of the prominent architects of the time, Morison designed the house himself and supervised erection of the house, a barn and a windmill.[38] He watched over the workmen carefully, often stopping construction completely when his consulting practice took him away from the site. As a result, the buildings required four-and-a-half years to complete. A substantial 2-1/2 story Federal Revival edifice, the massive brick house typified Morison's conservative philosophy: thoroughly functional with no superfluous details. In November 1897, the famous engineer settled into the only permanent home he had known since leaving New England some forty years before.

In 1896, just prior to the completion of his Peterborough house, Morison returned to New York City. The move enabled him to attend more closely to the construction of the building. Moreover, his practice required that he spend increasingly more time in that city. The great Midwestern bridge projects which had brought him to Chicago in the late 1880s were completed, with no others in the foreseeable future. He therefore shifted his headquarters back to the Wall Street Office, maintained as a branch office during his Chicago residency, and rented a room in the city while he awaited completion of his house.

Throughout the depression years, George Morison maintained a thriving business as a consulting engineer. Widely respected for his broad-based engineering expertise, he accrued a significant body of work as an appointee to various government advisory boards consulting on proposed engineering projects. Among these were the Board of Engineers for the New York and New Jersey Bridge (1894); a board to locate a deep-water harbor in Southern California (1897); a board to address the improvement of the New York waterfront (1895-97); an advisory board on the improvement of the Erie Canal (1900-01); the Isthmian Canal Commission (1899-1903); and the Manhatten Bridge Commission (1903).

Morison was appointed to the first of these commissions - the New York and New Jersey Bridge Board - by President Grover Cleveland in 1894. A distinguished group of civil engineers, the board also included William H. Burr, Theodore Cooper, Major C.W. Raymond, and L.G. Bouscaren. It was charged with two primary functions: to recommend the maximum practical span length for a suspension bridge and to recommend a span length suitable for a bridge over the Hudson River to be located between 59th and 60th streets in New York City.[39]

The board returned two reports, addressing the two parts of the query. The first determined 4,335 feet as the longest practical suspension length; the second suggested 2,000 feet for the Hudson River Bridge. The engineers presented a variety of preliminary configurations for the bridge. Morison submitted a design for an innovative hybrid form of suspension bridge, subsequently described in a paper entitled, "Suspension Bridges - A Study," published in the Transactions of the American Society of Civil Engineers in December 1896. Morison's design, a 3,000-foot stiffened suspension bridge, featured wire cables, steel towers on masonry foundations, and suspended steel trusses. The plans delineated a 4,100-foot continuous stiffening truss with a 2,800-foot suspended central span. The design included two particularly novel features; one being the use of twisted rope cables instead of the commonly used straight wire type, socketed at the top of the towers and in the anchorages; the other, the method of anchoring the stiffening truss. Morison justified the first feature as a more efficient and time-saving modification over standard suspension design. The second feature, which had 150-foot cantilevers projecting from each end of the stiffening truss anchored by 500-foot shore spans, allowed

the omission of the suspenders in the 150 feet next to the towers, thus confining the stiffening truss proper to a 2,800-foot length. He further stressed the advantage of leaving the 150 feet between the towers and end suspenders within which the cables could adapt to changes in length due to variables in temperature and load.[40]

Morison did not get the opportunity to test his innovative structural system on the Hudson River Bridge, or on any other. After commissioning the initial study in 1894, the government failed to act on its construction for thirty years. The bridge which ultimately resulted - the monumental George Washington Bridge, completed in 1931 - represented an important technological leap, doubling the length of any other bridge erected to that date.[41]

In 1896, President Cleveland appointed George Morison to another commission, this time to locate a deep-water harbor in southern California. Following a thorough study of several possible locations, the board recommended San Pedro as the most advantageous location. The site was subsequently selected by the War Department for the harbor of the City of Los Angeles.

From 1895 to 1897, Morison served on another board of consulting engineers to assist the New York Dock Department in implementing extensive improvements to the city's water- front. With General Thomas L. Carey, Chief Engineer of the U.S. Army, and Professor William H. Burr of Columbia University, Morison proposed plans to widen congested West Street, which fronted on the Hudson River. The proposed improvement required the construction of a bulkhead wall west of the old bulkhead line, increasing the width of the street from an average of about 70 feet to a uniform width of 250 feet. For the enlarged street, the board outlined a three-section division: the first 50 feet along the bulkhead for pier service sheds, the next 80 feet for storage of nonperishable heavy commodities, and the last 120 feet left clear for traffic.[42] In the construction proposal, the engineers noted that the variable character of the river bottom required adoption of two methods for the founding of the bulkhead: directly on a rock bottom with concrete bags used to provide a level bed, and elsewhere upon piling driven to the greatest possible depth. The granite-faced wall was to rest on 70-ton concrete blocks moved into place by a huge floating derrick.[43]

On yet another commission, Morison advised the State Engineer and Surveyor of New York on the enlargement of the Erie Canal in 1900. The project involved major reconstruction and relocation along the existing waterway to allow for a 1,000-ton barge canal between Lake Erie at Buffalo and he Hudson River at Albany. The board developed several different plans for consideration, the principal variable being the use of Lake Ontario for a portion of the waterway versus construction of an inland course throughout. Morison and the board found persuasive arguments for each route - the Lake Ontario alternative being the less expense by some $25.5 million.[44] The lake route, however, posed weather

difficulties and special vessel considerations. The board's failure to reach a satisfactory conclusion resulted in an extension of the study for another year. (George Morison apparently had no role in the later investigation.) The debate over the canal did not subside until 1903, when the State of New York appropriated $101 million for improvements to the inland waterway.[45]

Of all the consulting boards on which George Morison served, undoubtedly the most significant was the Isthmian Canal Commission, to which he was appointed June 10, 1899. Superceding the Nicaragua Canal Commission, created to examine the feasibility of a Nicaragua canal route, the new commission assumed a much broader task. With a million-dollar appropriation from Congress, the Isthmian Canal Commission was to make a "thorough engineering investigation of the whole isthmus" to determine the best location for a canal to connect the Atlantic and Pacific Oceans.[46] The body selected by President McKinley included several of Morison's close collegues and friends. The engineers of note were Admiral John G. Walker, with whom he had served on the Southern California Harbor Board; William H. Burr, a member of several earlier commissions; Louis M. Haupt, Professor of Civil Engineering at the University of Pennsylvania; and Colonel Peter C. Hains and Lieutenant Colonel Oswald H. Ernst of the Army Corps of Engineers. To address the economic and political aspects of the project, the President had also appointed Emory R. Johnson, Professor of Commerce and Transportation at the University of Pennsylvania, and Florida Senator Samuel Pasco.

Commission members sat on one or more of five subcommittees: three to investigate the various routes (the Nicaragua route, the Panama route and all others); one to investigate the industrial, commercial, and military value of the proposed canal; and the last to assess the rights, priveleges, and franchises involved with the canal.[47] As a member of the subcommittee on the Panama Canal and Chairman of the subcommittee to study all other routes, Morison devoted himself almost exclusively to the investigation and report preparation, leaving time for few other engagements. During his exhaustive three-and-a-half-year study, the meticulous engineer traveled twice to Europe to pore over the records of the French Panama Canal Company and to study European canals. Additionally, he spent four months at the end of 1900 visiting Nicaragua, Panama, and other isthmian sites which would use the Magdalena, Atrato, or other rivers.[48]

By the end of 1901, the Isthmian Canal Commission was concluding its study. Investigations had narrowed the selection of a canal route to Nicaragua and Panama; the only other possible route at Darien was dismissed as commercial impracticable. Most of the Commission members, many having served on the former Nicaragua Canal Board, favored the Nicaragua route.[49] While preliminary estimates placed the construction of the Nicaragua route slightly more than Panama, the former site had two practical advantages: it was about 500 miles closer to California and clear title could be secured for the right-of-way.[50]

The difficulties encountered by the French company in building a canal at Panama had given it a poor reputation, and, more to the point, the company's exorbitant request of $109 million for the property transfer was unacceptable to the majority of the Commission members.[51]

On August 10, 1901, the Isthmian Canal Commission issued its report recommending adoption of the Nicaraguan route. All members but one approved and signed the document. The lone dissenter was George Morison, who favored the Panama route. Two years of painstaking research had led him to a typically unshakable conclusion, creating some suspicions about his motives among those unfamiliar with his deliberately paced decision-making:

> When he entered upon his work with the Commission he had not allowed himself to reach an opinion as to the best route of the canal... There were those who said that he sought the glory of identifying his name with some other route other than the two which had come to be accepted as the practical ones. This would not have been an ignoble ambition; but his passion for thoroughness is a sufficient explanation of his reluctance to make up his mind. When he decided in favor of the Panama Route he had canvassed the matter so completely that no doubt remained and he could speak with the conviction and power of knowledge.[52]

Morison responded to the Commission's findings with a minority report citing his objections. He argued that the Panama route featured a $67 million cost saving over Nicaragua; that the largely excavated channel at Panama indicated more clearly the necessary work, with existing railroad, harbors, and nearby population centers; that the Panama route was less than half the length of the other, reducing operating costs and minimizing the possibility of international complications stemming from accidental interruptions.[53] Finally, he stressed the difficulties in securing the right-of-way for the Nicaraguan route, stating, "No Central or South American Government has ever granted a franchise under which the United States could undertake the construction of a canal. Concessions have been limited in length or charged with unreasonable payments to the grantors, and frequently encumbered in both ways."[54]

On the other hand, Morison argued, the exclusive rights to the Panama Canal were already held by French interests, making purchase possible. In making a case for the Panama route, Morison revealed a racism which was common for the time, saying, "Of course you know the value of the average negro in the South, and when I tell you that one negro is worth about half a dozen natives of that section, you can judge for yourself as to his general capabilities and friendship for work."[55]

Morison's singular stance against the majority report had the immediate effect of delaying the publication of the Commission's conclusions. Continued negotiation problems over the Panama rights, however, assured the adoption of the

Nicaraguan route, and on November 12, 1901, the Isthmian Canal Commission completed its final report, unanimously recommending the Nicaragua route. The Commission's report reached the press some days later but received only a fraction of the attention attracted by the subsequent publication of Morison's minority report in the New York Journal and the Chicago American. Several newspapers responded by refuting sharply the accounts published in the Hearst papers:

> Considerable commotion has been occasioned by the publication in a sensational New York newspaper of what purports to be a minority report in favor of the Panama route by George S. Morison, an engineer of distinguished attainments on the Isthmian Canal Commission. This publication is dishonest and a great injustice to him. It may be stated on the authority of the commission itself that there is to be no minority report of any sort... The history of this particular paper is very interesting, it was prepared by Mr. Morison many months ago as the strongest argument that could be made in behalf of the Panama project and was prepared for test purposes. It does not represent his opinions now, as his signature of the Nicaraguan route report shows and perhaps did not then. But in purloining papers from the offices of the commission, the employee who doubtless furnished this paper to the press got hold of something of no present relevancy. Were all the opposition arguments considered by the commission from time to time to be printed they would fill the newspapers for some months. The commission stands squarely for the Nicaraguan project, weighing all the circumstances entering into the case. Doubtless a strong appeal in behalf of Panama will be made in Congress and hence it is important to know the true status of the alleged minority report.[56]

Despite assertions by the press discrediting the Panama argument, Morison, in fact, continued to speak out publicly in favor of the Panama route. Both Congressional and public support for Panama were also growing, largely as a result of Morison's persuasive minority report. The stage was set for a last-minute reprieve when the New Panama Canal Company finally acted, offering all of its interests to the United States for $40 million, the value of its assets as fixed by the Isthmian Canal Commission in its report.[57] The impediment to acquisition thus removed, the Isthmian Canal Commission reconvened in January 1902 to draft a supplementary report unanimously recommending the acquisition of the Panama property.

With the publication of the supplementary report, the work of the Isthmian Canal Commission was essentially complete. Not merely contented with the instrumental role he had played in the selection of the Panama route, Morison continued his dedication to the Panama study for the remaining eighteen months of his life. In subsequent lectures and papers, he thoroughly detailed the requirements for construction of the Canal. He published two major papers, "The

"The Bohio Dam," and "The Panama Canal," on this theme in the Transactions of the American Society of Civil Engineers. The latter paper represented the culmination of Morison's Panama research, bringing together the data of the New Panama Canal Company, the Isthmian Canal Commission, and the author's own conclusions. Presented to the Society on February 18, 1903, the paper described the principal features of the canal and detailed plans for two types of canals - a tide-level canal and one which involved the construction of several locks. Morison's involvement in the construction of the canal was virtually assured by his immensely valuable understanding of the project. His untimely death prevented the realization of this great desire.[59]

George Morison's last major truss bridge construction project involved the replacement of an earlier railroad superstructure, fittingly for a bridge over the Missouri River. In 1900, he accepted a commission from the Atchison and Eastern Bridge Company to rebuild the iron bridge at Atchison, Kansas - one of the first permanent spans over the Missouri. The original bridge at this bustling railroad center had been authorized by Congress in 1873, funded through a local bond issue, and erected in 1874-75 by the American Bridge Company of Chicago under the supervision of Chief Engineer, Major O.B. Gunn. An 1144-foot structure (excluding approaches), the Atchison Bridge consisted of three 260-foot wrought iron Whipple fixed spans and one 364-foot swing span, all supported by pneumatically founded masonry piers.

A notable engineering feat for its time, the 1875 iron superstructure had become obsolete by the turn of the century. Early in 1900, the bridge company engaged Morison to engineer replacement steel trusses of approximately the same dimensions as the original spans. As on the Omaha Bridge, the company stipulated that traffic was to be maintained uninterrupted during construction. Morison's design for the Atchison Bridge differed little from its predecessor, and, other than the fact that it was the last of his long-span bridges, it was an undistinguished example in the engineer's lengthy repertoire. Fabricated at the Lassig shops of the American Bridge Company, the superstructure consisted of three 255-foot fixed Pratt spans, a 361-foot swing span, and a 48-foot deck plate approach girder.

A somewhat difficult component of the Atchison Bridge construction involved driving the long transverse rows of piles upon which the falsework was erected.[60] These bents supported the railroad track, the old trusses during removal, the new trusses and their traveler during erection, and the temporary carriage road cantilevered outside the trusses. One pile of each bent was located in the center of the railroad track, but the work was so expertly engineered that it never interfered with train service.

In 1902, George Morison was appointed to one final government bridge commission established to review Gustav Lindenthal's design for the Manhatten Bridge

over the East River in New York City. Lindenthal, who had inherited the project upon his employment as New York City Engineer in 1902, proposed major modifications to the proposed bridge design. The most important of these was the substitution of four stiffened eyebar chains for the wire cables in the main suspension members. The use of eyebar chains was not widely accepted among contemporary engineers, and the resulting controversy prompted Mayor Low to appoint the three member commission which included, in addition to Morison, his former assistant C.C. Schneider and Henry W. Lodge.[61] The commission's report generally favored Lindenthal's design while conditioning final approval on the results of the eyebar testing. Plans to proceed with the project, however, halted abruptly when Lindenthal was replaced by another engineer by the following administration. The bridge plans were again revised, returning to the use of a wire cable system. This design was finally adopted for the 2,920-foot Manhattan Bridge, completed in 1909.[62]

As the principal of one of the earliest successful consulting businesses in America, George Morison has been referred to as "the father of consulting engineers."[63] He worked in some capacity with almost every notable bridge designer of his time, including some who began their professional careers under his tutelage. He deserved his reputation as an extremely difficult man to work with and displayed a marked intolerance for those whose ideas he regarded as incorrect, frequently labeling them with contemptuous nicknames. Still, the exacting engineer maintained several successful consulting partnerships during his career and gained the unfaltering respect from those with whom he worked most closely. The divergent and parallel paths followed by other engineers with whom Morison was associated provide an interesting comparison to his own career and role in the development of American bridge technology.

Octave Chanute (1832-1910), in whom Morison had found a mentor, remained in bridge engineering for several years after Morison left his employ. His greatest accomplishment was undoubtedly the Kansas City Bridge - the first permanent permanent span over the Missouri River. In 1889, Chanute became involved with early aviation investigations, authoring several important articles that documented the mechanical progress in the field.[64]

E.L. Corthell (1840-1916), Morison's close colleague and partner, enjoyed a dynamic engineering career and, like Chanute, apparently discontinued his bridge building after dissolving the partnership with Morison to devote more time to engineering matters abroad. He had first won recognition in 1875 for the Chicago and Alton's bridge across the Mississippi River at Louisiana, Missouri, which featured the longest draw span (444 feet) in the world at the time. His principal bridge achievements closely aligned with Morison's, as nearly all of his other notable bridge projects were built during their two year partnership. The two engineers collaborated on the bridges at Cairo, Nebraska City, Sioux City, Portland, Jacksonville, Memphis and St. Louis.[65]

The engineering career of C.C. Schneider (1843-1916) presents a greater contrast to Morison's. Like George Morison, Schneider had apprenticed under the supervision of Octave Chanute on the Erie Railroad in 1878. Later that year, he opened an independent engineering practice in New York, marking the beginning of a long-term association with the Canadian Pacific Railway. During this time, he worked with Morison on the superstructure designs for the Plattsmouth, Bismarck, and Blair Crossing Bridges over the Missouri and the Riparia Bridge near Ainsworth, Washington. In stark contrast to these simply supported Whipple trusses so characteristic of Morison's style, Schneider's next two bridge commissions resulted in the revolutionary steel cantilevers for which he is renowned. Credited with a number of major bridges and contributions to international bridge specifications and standards, his innovations in cantilever construction are still regarded as his greatest achievement.

His Niagara Gorge cantilever bridge, built in 1883 for the New York Central's Canada Southern Railroad, represented the first truly modern bridge of this type in America. The first execution of this configuration, the Niagara Gorge Bridge actually followed Schneider's 1882 design for the Fraser River Bridge of of the Canadian Pacific Railway, completed in 1886. His ultimate recognition for cantilever construction came in 1911 as a member of the Canadian Government's three-man board of engineers in the reconstruction of the Quebec Bridge - the immense structure that had collapsed four years earlier, taking eighty lives in one of the worst bridge disasters in history. Designed with C.N. Monsarratt and another Morison associate, Ralph Modjeski, the 2,830-foot bridge featured riveted connections - the first major truss span in North America to use the new technology.[66]

Ralph Modjeski (1861-1940) had entered engineering in America as a student of George Morison on the Omaha Bridge and, like Schneider, worked with the elder engineer on several Whipple-truss bridges during the 18880s and 1890s. Of all of the Morison's assistants, Modjeski was perhaps the most successful and undoubtedly the most prolific, with almost fifty years of subsequent practice. In contrast to the conservative Morison, however, he later developed a highly individualistic style of his own. "Unlike Morison, whose contributions were largely in the field of truss design, Modjeski was equally at home working with all forms of steel bridge construction," states David Plowden. "Even when working for the railroads who favored traditional forms, Modjeski usually turned the conventional into an exceptional bridge."[67]

Modjeski left Morison after completion of the Memphis Bridge in 1893 to establish an independent practice. His first major commission was for the immense double-deck, swing-span steel bridge over the Mississippi River at Rock Island. Active as an engineer until his death in 1940 at the age of 79, he executed the construction of thirty of America's major bridges, several of which have become technological landmarks.[68] His most remarkable achievements were the massive cantilever bridges over the Mississippi at Thebes, Illinois,

completed in 1904 and patterned closely to Morison's Memphis Bridge, and over the St. Lawrence at Quebec.

In the years between 1905 and 1922, Modjeski amassed a repertoire of bridge commissions as numerous as Morison's had been during his peak years in the 1880s and early 1890s. The sheer variety of these bridges in contrast to Morison's standard trusses serves to illustrate the vast stylistic difference between the two engineers. Modjeski's bridges of the period included the Crooked River Bridge, a 340-foot two-hinged arch in Oregon; the Broadway Bridge, a bascule span over the Willamette River in Portland; the Cherry Street Highway Bridge, a concrete arch over the Mammee River in Toledo; and the Harahan Bridge, a steel cantilever over the Mississippi River at Memphis. This last structure was erected immediately beside Morison's' earlier bridge and shared the same general profile as its predecessor, with a heavier, double-track configuration.[69]

While George Morison is not known as a particularly innovative bridge designer, he did experiment with structural forms other than the long-span steel truss for which he was best known. He displayed a particular penchant for the steel suspension bridge and the masonry arch, configurations which more properly belong in the 20th century, when they were tested an refined. In fact, Morison only began developing designs for these bridge types toward the end of his career. Had he lived longer, it seems likely that his bridge building practice would have further developed along more varied lines.

The design of masonry structures captured Morison's interest after the turn of the century. Praising the versatile and durable characteristics of the material in an 1898 paper, "Masonry," Morison affirmed his belief in the coming-of-age of concrete construction. "Concrete is in very general use in Europe; its use is extending rapidly in America," he stated. "Prejudices have been raised against it, through inferior work done in this country when it was first introduced, but it is within the limits of possibilities that an artificial stone can be made in this way, which will be as good and as durable as the natural stones which are commonly used; when this is accomplished the advantages of a truly monolithic construction will make concrete the best building material and, except for the facing of monumental works, where nothing can take the place of the finest stones from nature's laboratory, it may be universally used."[70]

In Morison's view, "the one material adapted to monumental work," it is not surprising that he used masonry in his design for the Connecticut Avenue Bridge in Washington, D.C., completed in 1908 according to the engineer's prize-winning design.

A work specifically intended to be of monumental character, the proposed Connecticut Avenue Bridge was to span Rock Creek on the prominent 130-foot wide

boulevard which extended five miles from the vicinity of the Executive Mansion to the limits of the District of Columbia. Prestigious suburban development had reached Rock Creek and beyond in the 1890s, creating the urgency for a bridge which would satisfy both functional and aesthetic needs. Accordingly, Congress called for competitive designs for the Connecticut Avenue Bridge late in 1897. The commissioners of the District solicited proposals from three eminent engineers - W.H. Breithaupt, L.L. Buck, and George Morison. A total of five bridge designs were submitted: proposals for Melan concrete and steel arches by Breithaupt and Buck, a masonry arch by Morison.[71]

Morison's single design featured a 1,341-foot structure consisting of nine full-centered masonry arches five 150-foot spans and two 82-foot approach spans on each end. The 52-foot overall width provided for a 32-foot roadway width and 10 feet on either side for sidewalks and conduit electrical railways carried on cast iron brackets. For the estimated 12,743 cubic yards of masonry on the arches, Morison proposed granite or a less expensive stone. Masonry for the piers was to be of granite or stone above the belt course to match the arch and spandrel masonry, and concrete or rubble was specified for the backing material. Morison noted, however, that a substantial cost reduction could be achieved if the structure were built in concrete.

In February 1898, the District Commissioners selected the three prize-winning designs. Morison won the first prize. In their report to Congress, the commissioners justified the award:

> The principal considerations leading to this decision were that the proposed bridge, being so conspicuously located on a fine residence avenue, and in full view of a large area, within which was the National Zoological Park, should be of a monumental character, and the masonry type, above all others, fulfilled this condition as well as that of suitability. The history of metallic viaducts is one of continual outlay for maintenance and repair, with a frequent ending by the replacement of the structure by one of masonry. The advantage of economy of first cost in the metallic structure is thus largely offset by the necessary annual outlay for its proper preservation, and where the cost of masonry and metallic viaduct can be brought within the same class of figures, as in this case, the decision in favor of the more substantial construction is easily justified.[72]

The commissioners further recommended the adoption of Morison's concrete version as the more economical choice, and the engagement of his services as consulting engineer. The promise of Morison's engagement on the Connecticut Avenue Bridge was never realized, however. Work on the arches did not proceed until 1904, a year after his death. In any case, the bridge, completed in 1908, followed the design of its creator in large part. A large staff of consulting engineers responsible for the final plans modified Morison's design by omitting one 82-foot arch span at each end, leaving seven arches supported

by abutments at either end. One of the largest concrete arches of its time, the Connecticut Avenue Bridge was built entirely of molded concrete facing block and monolithic, unreinforced, poured-in-place concrete. Although the engineers chose all-concrete construction (totaling 50,000 cubic yards of material) over granite to reduce cost, the design did not exclude aesthetic consideration. Workers applied a bush-hammered finish over the entire bridge surface, giving a deceptive, granite-like appearance.

The treatment of the cast block details, a controversial feature, represented the most crucial test of success: "The point on which the engineers must stand trial is, of course, whether the device of molded concrete blocks instead of cut granite was justified," reported Engineering News. "The prime question of course is whether the same beauty of appearance can be secured with dressed concrete block as with granite. An examination of the finished blocks placed in the bridge gives no alarm as to their possible inferiority in appearance to dressed granite. They present a somewhat duller and more dead appearance but the difference is not so striking but that an observer not familiar with the texture of the stones might easily mistake the concrete blocks for granite."[73]

Ornament for the Connecticut Avenue Bridge included embellished cast iron lamp posts at each pier and four cast concrete lions mounted on pedestals at the approaches. At a time when casting of large concrete figures was still a novel process in the hands of but a few specialists, the heroic size crouching lions were possibly the most remarkable features of the bridge. Made in two models for the opposite sides of each end, the 9-foot high figures came from the designs of R. Hinton Perry, the noted New York sculptor who designed the Neptune fountain at the entrance to the Library of Congress. For months after the opening of the $850,000 bridge early in 1908, the lion's pedestals stood vacant as the Erkins Company of New York hurried the plaster molds and cast-in-place work. The completion of these impressive figures later that year contributed the finishing touch to Morison's only monumental work.[74]

A credit to both Morison an the engineers that executed the construction, the Connecticut Avenue Bridge stands as a standard of excellence. Stated an architectural critic in 1927: "Considered either from the viewpoint of the engineer or architect this work must be conceded to be one of the finest, if not the best executed concrete bridge yet built. After twenty-two years of service it exhibits no defects or deterioration."[75] Indeed, the bridge represented an appropriate final monument to the engineer's prolific career.

A large, robust man, always in good health, George Morison's death occurred quite unexpectedly. In May 1903, he was gripped by a disabling illness, the first serious illness he had experienced since childhood. Initially diagnosed as a fever, probably resulting from a malarial infection contracted during his isthmian canal work, his condition rapidly worsened. He was eventually

diagnosed as having an inoperable abscess. Confined to his apartment in New York City with his beloved sister at his side, George Morison died quietly on July 1, 1903.

"Every engineering work is built for a special ulterior end; it is a tool to accomplish some specific purpose," Morison stated in his presidential address to the American Society of Civil Engineers in 1895.[76] Engineering works were to be judged solely by their ability to function as designed, with no consideration for sentiment or aesthetics. If steamboats could not compete economically with the railroads, he maintained, then scuttle them. If a bridge could no longer safely carry its intended load, then replace it. "A bridge is a tool which carries traffic over unoccupied space," he stated in 1893, "A monument commemorates what is done, and the fundamental ideas is indefinite endurance. The thought of indefinite endurance without rest is torture... As the object of a tool is to accomplish a specific work it is from its very nature a commercial thing. By doing work it earns money. When a monument is built its cost is planted in it never to return. If a bridge cannot return its cost it should not be built."[77] Bridges as commercial tools was a recurring theme in Morison's lectures and papers.[78]

It is ironic, then, that George Morison, who was often criticized for his starkly functional structures, felt that bridges could eventually serve as monumental works. Civil engineering, he felt, wrongly as it turned out, would progress to the point that bridges could be considered eventually as more than straightforward tools, and he was moving toward this goal on his last bridge commission - the monumental arch bridge for Connecticut Avenue. But Morison was nothing if not a pragmatist. With so much at stake on his major railroad bridges and with the overwhelming need for economy, he stripped the structures to their essential components: trusses as multi-million-pound stress diagrams. Rarely would he even nod to aesthetics with so little as a decorative portal plate.

It is indicative of this philosophy that Morison used essentially the same all-purpose pier for every one of his Western river bridges. "Fourteen years ago I had occasion to design a pier for what was then considered a large bridge across one of our western rivers," he stated, referring to the Plattsmouth Bridge, "and with a somewhat mistaken idea I tried to make an ornamental pier. When the plans were completed I did not like them; one change after another was made, all tending to simplicity; finally the plans were done... I had started wrong; my work had been done backwards; I had started to make a handsome pier, but I did not feel that I had succeeded until I had eliminated everything which was specially intended to make it look well. The pier that was exactly what was wanted for the work was the only one that satisfied the demands of beauty. I have no wish ever to change this simple design."[79]

Slowly, deliberately, George Morison had developed his adopted profession as a civil engineer, and in doing so he incrementally advanced bridge technology. Each of his structures, from the first long-span truss at Plattsmouth to the monumental Connecticut Avenue Bridge, bore his distinctive engineering mark. As the bridge designer who held a virtual monopoly over the Missouri River during America's great railroad expansion of the 1880s, as the engineer for the longest steel structure in the world and the longest cantilevered span in America, as a consultant for many of the largest engineering projects in the country around the turn of the century, and as the man who almost single-handedly shifted the opinion of the nation about the Panama Canal, his influence over his profession was clearly national in scope. A group of his peers summed up Morison's impact on the profession in a memoir published in the Journal of the Western Society of Engineers:

> In his work he was original and not merely an imitator or developer of existing ides. He sought to make the best possible solution of a problem, and not necessarily a solution which had been shown to be a success under similar circumstances. He sought and had a reason for everything and had the courage to act according to his reason. He did not, however, carry his originality to extremes. Every previous example bearing on a case was carefully studied, and if he found that some existing idea suited his purpose better than any other, he did not hesitate to make use of it and properly gave credit where it was due. Nor did he fail to consider the commercial practicability of his designs. His work was no doubt of the very highest order of his time, but he did not make it of such extreme character that it could not be practically attained. It was always a little better than had been done before, but never out of reach, and thus he led in the development of bridge-building, the better standards of to-day being about up to his requirements of a decade ago.[80]

Morison's career can be represented by an incident which occurred on one of his Missouri River bridges. When one of the immense caissons became lodged deep beneath the river bottom, he descended the long passage into the dark, steamy chamber to ascertain the problem. As Morison clambered back out through the air lock, someone asked him why he would risk the considerable dangers of the caisson. "Duty," he replied simply and walked away.

ENDNOTES

1 J.Y. Oleson, "The Missouri River and Its Bridges," Engineering News, 29 April 1909, pages 460-61.

2 Missouri River bridges were divided into four classes: high bridges, low bridges, drawbridges and pontoons. The War Department fixed the height and span requirements as follows: Bridges from Sioux City to the Platte River must be at least 50 feet above standard high water, and no spans may be less than 300 feet. From the mouth of the Plate to the mouth of the Kansas, the height must be 50 feet, the channel span 400 feet and all other spans 300 feet. From the mouth of the Kansas to the mouth of the confluence with the Mississippi river, the height must be 55 feet above standard high water and all spans 400 feet.

3 J.Y. Oleson, "The Missouri River and Its Bridges," pages 460-61.

4 "On Certain New Work in and about St. Louis," Railroad Gazette, 15 December 1893.

5 George S. Morison, The Bellefontaine Bridge (Chicago: Knight, Leonard & Company, 1894), page 3.

6 George Morison, The Bellefontaine Bridge, page 10.

7 Engineering News, 25 January 1894.

8 "The Bellefontaine Bridge," Engineering, 6 September 1895; George Morison, The Bellefontaine Bridge, page 10.

9 George S. Morison, "Expansion Bearings for Bridge Superstructures," (Paper presented before American Society of Mechanical Engineers, June 1895, Detroit Michigan); George Morison, The Bellefontaine Bridge, page 10.

10 George Morison, The Bellefontaine Bridge, page 10.

11 George Morison, The Bellefontaine Bridge, page 3.

12 B.L. Crosby, "The St. Louis Extension of the St. Louis, Keokuk and Northwestern Railroad," Journal of American Engineering Societies, January 1895, page 68.

13 "Contracts to be Let on Saturday," Alton Daily Telegraph, 22 March 1892.

14 George Morison, The Bellefontaine Bridge, page 10.

15 "Bellefontaine Bridge," Alton Daily Telegraph, 14 September 1893.

16 George Morison, The Bellefontaine Bridge, page 13.

17 George Morison, The Bellefontaine Bridge, pages 3-4.

18 Engineering News, 20 July 1893, page 45.

19 Mary S. Combs, untitled article, Leavenworth Times, 25 October 1975.

20 "They Want It!," Leavenworth Daily Times, 5 February 1892.

21 "It Is Agreed," Leavenworth Daily Times, 22 November 1892.

22 "The New Bridge," Leavenworth Daily Times, 9 December 1892; "Actual Work," Leavenworth Daily Times, 21 December 1892; "The Bridge Dike," Leavenworth Daily Times, 3 January 1893.

23 "First Symptoms," Leavenworth Daily Times, 8 September 1893.

24 "Work on the New Bridge," Leavenworth Daily Times, 19 August 1893.

25 "Nearly Drowned," Leavenworth Daily Times, 15 August 1893.

26 "Another Victim," Leavenworth Daily Times, 27 August 1893.

27 "Instant Death," Leavenworth Daily Times, 18 October 1893.

28 "Bowling Along," Leavenworth Daily Times, 28 October 1893.

29 "Bells Rung and Whistles Blew," Leavenworth Daily Times, 15 December 1893.

30 "Louisville Bridge Accident," Leavenworth Daily Times, 16 December 1893.

31 Leavenworth and Platte County: The Union That Has Long Been Desired Has at Length Been Consummated," Leavenworth Daily Times, 2 January 1894.

32 George A. Morison, George Shattuck Morison, 1842-1903: A Memoir (Peterborough, New Hampshire: Peterborough Historical Society, 1940), page 11.

33 "George Shattuck Morison," Engineering Record, 11 July 1903, page 51.

34 David Plowden, Bridges: The Spans of North America (New York: The Viking Press, 1974), pages 241-42.

35 "George S. Morison, President, American Society of Civil Engineers," Engineering News, 31 January 1895, page 68.

36 George A. Morison, George Shattuck Morison, page 16.

37 George A. Morison, George Shattuck Morison, page 16.

38 Bridge and construction drawing index of George Morison (Collection of John R. Morison, Peterborough, New Hampshire).

39 "Memoir of Gustav Lindenthal," Transactions of the American Society of Civil Engineers, Volume CV (1940), page 1791.

40 George S. Morison, "Suspension Bridges: A Study," (Paper presented to American Society of Civil Engineers, 21 October 1896.)

41 David Plowden, Bridges: The Spans of North America, page 249.

42 "The Improvement of the North River Waterfront, New York City," Scientific American, Volume 74 (6 June 1896), page 360.

43 "The Improvement of the North River Waterfront, New York City," page 360.

44 "Proposed Improvements in the Erie Canal," Scientific American, Volume 55, No. 1411 (17 January 1903), page 22615.

45 Engineering, 15 July 1910, page 77.

46 "The Panama Canal," Engineering, 4 July 1902, page 3.

47 Engineering Record, 1 July 1899, page 110.

48 George A. Morison, George Shattuck Morison, page 12.

49 George A. Morison, George Shattuck Morison, page 12.

50 "Mr. Morison Talks on Canal Project," Nashville Tennesseean, 14 January 1901.

51 "The Panama Canal," page 3.

52 "Memoir of George Shattuck Morison," Transactions of the American Society of Civil Engineers, Volume LIV (1905), page 518.

53 "Here Is the Report for the Panama Route," New York Journal, 21 November 1901.

54 "Here Is the Report for the Panama Route," New York Journal, 21 November 1901.

55 "Mr. Morison Talks on Canal Project," Nashville Tennesseean, 14 January 1901.

56 "All for Nicaragua Route," Lincoln Transcript, 25 November 1901.

57 George A. Morison, George Shattuck Morison, page 13.

58 "The Bohio Dam," Transactions, Volume XLVIII (February 1902), page 235; "The Panama Dam," Transactions, Volume XXIX (January 1903), pages 15-44.

59 "George Shattuck Morison," Engineering Record, 11 July 1903, page 51.

60 "Driving Difficult Piles for a Bridge Renewal," Engineering Record, 19 January 1901.

61 David Plowden, Bridges: The Spans of North America, page 181.

62 David Plowden, Bridges: The Spans of North America, page 181.

63 Dr. William B. Conway, Modjeski, Masters and Associates, oral interview with Clayton Fraser, 23 February 1985.

64 "Memoir of Octave Chanute," Transactions of the American Society of Civil Engineers, 1910, page 486.

65 "Memoir of Elmer Lawrence Corthell," Transactions of the American Society of Civil Engineers, 1917, page 1658.

66 David Plowden, Bridges: The Spans of North America, page 175.

67 David Plowden, Bridges: The Spans of North America, page 171.

68 "Ralph Modjeski," unpublished report by Modjeski and Masters, n.d.

69 "Biographical Data: Ralph Modjeski," unpublished report by Modjeski and Masters, n.d.

70 George S. Morison, "Masonry," Journal of the Western Society of Engineers, December 1898, page 1286.

71 "Competitive Designs for the Connecticut Avenue Viaduct, Washington, D.C." Engineering News, 27 January 1898, pages 54-55.

72 Engineering News, 10 February 1898, page 95.

73 Engineering News, 10 February 1898, page 95.

74 "Connecticut Avenue Bridge, Washington, D.C.," Engineering News, 26 March 1908, pages 327-28; "Casting the Concrete Lions for Connecticut Avenue Bridge, Washington, D.C.," Engineering News, November 1908.

75 Wilbur J. Watson, Bridge Architecture (New York: William Helburn, Inc., 1927).

76 George S. Morison, "Address at the Annual Convention at the Hotel Pemberton, Hull, Mass., June 19th, 1895," Transactions of the American Society of Civil Engineers, June 1895, page 474.

77 George S. Morison, "Bridge Construction," reprint of paper presented before American Society of Civil Engineers, 14 April 1893, pages 51-52.

78 George S. Morison, "Bridges Regarded as Commercial Tools," New York: Evening Post Job Print, 1 February 1890. Privayely published pamphlet reproducing paper read by George Morison to St. Louis Commercial Club in March 1889.

79 George S. Morison, "Bridge Construction," pages 54-55.

80 "George Shattuck Morison: A Memoir," Journal of the Western Society of Engineers, Volume IX, No. 1 (February 1904), page 88.

APPENDIX A

SPECIFICATIONS FOR MASONRY - PLATTSMOUTH BRIDGE (1879)

There will be six piers, Pier I being on the west bank, Piers II and III in the river and Piers IV, V and VI on the sand-bar on the east side.

All this work is to be built strictly in accordance with the plans furnished, and the lines and levels given by the Engineer of the Plattsmouth Bridge.

FIRST CLASS MASONRY (PIERS)

The six piers will be of first-class, rock-faced masonry, laid in regular courses. A draught line three inches wide shall be cut on each side of the nose of the downstream starling of Piers I, II and III, below the lower coping. The entire face of the up-stream starling of these three piers shall be cut smooth and bush-hammered below the lower coping. A draught line two inches wide shall be cut immediately below the copings. All other surface structures will have a rough, quarry face, no portion of which shall project more than two inches from the pitch line of the joints. The face stones of the up-stream starlings of Piers I, II and III, below the lower coping, shall be doweled together with dowels of 1-1/8-inch iron twelve inches long, extending six inches into each course.

No course shall be more than twenty-six inches thick nor less than fourteen, and no course shall be thicker than the course below it.

Joints shall be pitched to a true line on the face, and dressed to one-quarter of an inch for at least twelve inches back from the face.

Beds shall be pitched to a true line of the face and dressed to one-quarter of an inch. Neither bed of a stone shall be less than two feet wide, nor less than one-half greater than the thickness of a course.

There shall be two headers in each course on each side of the piers. These headers shall be disposed in one of the following arrangements:

1st. - The headers shall extend entirely through the piers or

2nd. - The headers of one side shall reach to, and make a rough joint with the stretchers which the headers of the course below join against; or

3rd. - The headers of the two sides shall be placed opposite each other. When this arrangement is followed, a stone not less than three feet long, with dressed beds, shall be placed over the joint in the course below; or

4th. - When the thickness of the pier exceeds twelve feet, the headers of one side may be opposite stretchers on the other side, with an intermediate stone, not less than three feet long, with dressed beds, making rough joints with both headers and stretchers. When this arrangement is followed, there

shall be a header in the course above it placed over the stretcher and a stone with dressed beds over the interior joint.

The general results of this arrangement of headers is to tie the pier across with four rough walls of large stones with full-dressed beds.

The backing, except as already described, shall be of rubble, with good, undressed beds, no stones to be less than eight inches thick, nor to have less than four square feet of surface.

All stones shall be laid in full mortar beds, and brought to a bearing with a maul. No spalls will be allowed, except to fill very small vertical interstices. The face joints shall be packed full with mortar and afterwards scraped and cleaned.

Joints shall be broken at least twelve inches on the face.

All stones shall be good and free from seams, cracks and other imperfections.

Mortar will be composed of best Portland cement, which will be furnished by the Railroad Company, and clean, sharp sand, the general proportions being one part of cement and two parts of sand.

The copings* will be of Beton coignet, and are not included in the masonry.

There will be two recesses in the east side of Pier No. III to receive the pedestals for the deck truss.

SECOND CLASS MASONRY (VIADUCT PIERS)

The small piers on which the iron viaduct rests will be of second-class masonry.

The shall be laid in regular courses, with stones not less than eight inches thick, with beds and joints dressed to one-half inch, and joints broken at least eight inches. No stone shall have a bed less than one and a half times its thickness.

Where the shaft of the piers is only three feet square, there shall be only two stones in each course, and a single stone will be preferred.

All stones shall be laid in full mortar beds without spalls.

The mortar shall be of the same quality as that required for the six large piers.

The copings* will be of Beton coignet, and are not included in the masonry.

A wrought-iron rod shall be placed in the center of each pier, extending from the concrete foundation to above the coping. These rods will be furnished by the Railroad Company.

THIRD CLASS MASONRY (ABUTMENTS)

The abutments shall be of good rubble masonry, all stones to have good beds, and to be well bonded together. No stone shall be less than six inches

thick, nor have an area of less than four square feet.

The bed of every stone shall be at least one-half greater than its thickness.

Joints shall be broken at least six inches.

The work shall be laid in full mortar beds, the mortar being made of good American hydraulic cement, which will be furnished by the Railroad Company, and clean sharp sand.

The portion of the abutment which is not buried in the embankment will be finished with an ashlar face, similar to that of the first-class masonry, with a draught line three inches wide, on the two front corners.

The copings will be of Beton coignet, and is not included in the masonry.

CONCRETE FOR FOUNDATIONS

Concrete will be used for the foundations of Pier VI, of the small viaduct Piers, and of the abutments.

Concrete will be made of broken stone and hydraulic cement - five parts of stone, two parts of sand and one and a half parts of cement. The cement will be furnished by the Railroad Company.

The cement and sand shall first be mixed together thoroughly dry; this dry mixture shall then be thoroughly mixed with stone; an amount of water, no more than enough to dampen the whole mixture well, shall then be added, and the whole worked over as rapidly as possible. The mixture shall then be put in position in layers not more than six inches thick, and well rammed.

*Modified

APPENDIX B

LIST OF ENGINEERS, CONTRACTORS, etc. ENGAGED ON THE PLATTSMOUTH BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service
George S. Morison, Chief Engineer	
H.W. Parkhurst, First Assistant Engineer	Nov. 10,1879, to Dec. 28, 1880
B.L. Crosby, Assistant Engineer	July 10, " " Sep. 6, "
S. W. Y. Schimonsky, Draughtsman	Sep. 1, " " June "
Walter G. Dilworth, Rodman and Asst. Eng.	July 16, " " July 15, "
Gorham P. Low, First Assistant Engineer	July 10, " " Oct. 31, 1879
W.B. Smith, Office Assistant	July 10, " " Sep. 10, "
O.F. Whitford, Storekeeper and Insp.	Aug. 19, " " Apr. 13, 1880
L.L.C. Bartlett, Asst. Eng./Timber Insp.	Aug. 8, " " Apr. 15, "
Robert Ross, Masonry Inspector	Oct. 2, " " Apr. 16, "
C.C. Schneider, Asst. Eng./Superstructure	July 1, " " Oct. 31, 1880
A. Lavandeyra, Draughtsman/Steel Insp.	July 18, " " Mar. 31, "
Jacob Jung, Inspector/Superstructure	Dec. 26, " " Aug. 20, "
J.D. Starritt, Supt./Carpenters, Bridge Fl.	Feb. 5, 1880, to July 15, 1880
R.P. Stitt, Foreman of Laborers	Aug. 1, 1879, " Dec. 5, "
J. McKeen, Rodman and Sub. Foreman	Oct. 7, " " Aug. 31, "
R.L. Lester, Foreman of Painters	Apr. 24,1880, " Oct. 6, "
Chas. Wheelock, Foreman of Pile Drivers	Oct. 1, " " Dec. 31, 1879

Contractors

Name	Nature of Work
William Sooy Smith	Pneumatic Foundation
J.C. Goodridge, Jr.	Beton and Beton Concrete
Reynolds, Saulpaugh & Co.	Masonry
J. Crubaugh, Resident Partner and Supt.	
Patrick Durack, Foreman of Masons, &c.	
Antoine Calogne, For. of Stone Cutters.	
W.H.B. Stout	Masonry
Jenkinson & Drexel	Masonry
Keystone Bridge Company	400 foot Spans
William Baird, Supt. of Erection	
Kellogg & Maurice	200 foot Spans and Iron Viaduct
S.V. Ryland, Supt. of Erection	
N.S. Young	Earthwork of Approaches.
Eaton, Young & Co.	Wooden Trestle, East Approach

APPENDIX C

SPECIFICATIONS FOR SUBSTRUCTURE - BISMARCK BRIDGE (1880)

The substructure will be understood to include the masonry and foundations of the bridge proper.

There will be four piers, numbered from the east to the west, the cast pier being No. 1, and the west No. IV.

PIER I

Pier I will stand back of the shore line on the east side.

An open pit about 50 feet long and 20 feet wide shall be excavated to such depth as may be necessary to reach a bottom of solid rock, or of such material as may be satisfactory to the Engineer. This excavation shall be filled with concrete to an elevation not lower than three feet below low water.

The masonry shall be started on the surface of the concrete, and the pit shall be filled with earth and rammed around the masonry to the elevation of the natural surface of the ground.

PIERS II AND III

Piers II and III will be in the channel of the river.

Each of these piers shall be founded on a pneumatic caisson, which shall be sunk to the underlying bed-rock, and to such depth into the rock as may be determined by the Engineer.

The caissons shall be constructed according to the plans furnished by the Engineer. The frames shall be of pine timber; the outside sheathing shall consist of two thicknesses of three-inch oak plank, the planks of the inside course to be inclined at an angle of 45 degrees; the working chamber shall be lined with three-inch pine plank, joined and calked, and shall be painted with two heavy coats of Cleveland Iron Clad Paint (purple brand) before sinking. Each course of timber in the sides shall be fastened to the course below with a drift bolts not more than three feet apart, these drift bolts to be 7/8 of an inch square and to reach through two courses of timber and six inches into a third course, being, generally, 30 inches long. The oak at least two spikes to each square foot of each course of planking. The corners of the caisson shall be plated on the outside with boiler-plate, the plates to be 30 inches wide and 5/16 of an inch thick, bent to a quarter circle and fastened with 7 by 3/8-inch wrought iron boat-spikes, at distances not exceeding six inches apart on a line one inch back from each edge. All timber shall be thoroughly sound and strong. The wrought iron used shall be of a tough, fibrous character, as tested by

cutting and bending. The workmanship throughout shall be thorough and satisfactory to the Engineer.

The caisson shall be filled above the working chamber with concrete, the surface of which shall always be kept above water. Such opening shall be left in the concrete filling as may be necessary for working and supply shafts.

The position of the cassion will not be allowed to vary more than 18 inches in any direction from the true position of the pier, as located by the Engineer, at any time during the progress of the sinking. The caisson shall not be allowed to vary more than 18 inches from a true level in its length, nor more than six inches in its width, and shall be brought to a true level when the sinking is completed.

When the sinking is completed, a joint shall be made between the cutting edge of the caisson and the bedrock, either by cutting away the rock or by ramming bags of concrete into the spaces between the cutting edge and the rock, as may be directed by the Engineer; the sand and mud shall be cleaned from the surface of the rock, and the entire working chamber shall be filled with concrete, special pains being taken to ram the concrete thoroughly against the roof.

The masonry shall be begun when the concrete filling is ready for it, on the level of the top of the caisson, and shall be built with openings for working shafts conforming to those in the concrete. The surface of the masonry shall be kept above water as the sinking progresses. When the filling of the working chamber is completed, the shafts in the concrete and masonry shall be filled with concrete and the masonry shall be finished.

PIER IV

Pier IV will stand on the sand-bar on the west side of the river, south of the dike.

This pier will have a pile foundation.

An excavation shall be made on the site of the pier to a depth about six feet above low water. In this excavation an open cassion or curb shall be built; it shall be 28 feet wide, 55 feet long and 12 feet high, built of 12 by 12-inch pine timber, the sides being pinned together with oak treenails and planked on the outside with one course of three-inch oak plank; it shall be sunk by excavating inside till the lower edge is six feet below low water. In this curb 160 piles shall be driven; the piles shall be of oak, not less than 10 inches in diameter at the small end, nor less than 3,500 lbs. The average penetration below the bottom of the curb shall not be less than 28 feet, and no pile shall be driven less than 25 feet. The piles shall be cut off square and level, four feet below low water, and shall be capped with two courses of 12 by 16-inch oak timber, the lower course being fastened to each pile with a one-inch square drift bolt 30 inches long, and the timbers of the second course fastened to those of the first course with 7/8-inch square drift bolts 22 inches long. The space around the piles and between the timbers shall be

filled with concrete, on the surface of which the masonry shall be started.

About 1,000 cubic yards of riprap, consisting of field boulders or other suitable stone, shall be piled around this pier, in a manner satisfactory to the Engineer.

CONCRETE

Concrete shall be formed of cement and sand or gravel, in proportions varying from two to four parts of sand or gravel to one of cement, as may be directed by the Engineer, for different parts of the work. It shall be mixed in a machine mixer, of such pattern as may be approved by the Engineer, with as small an amount of water as is consistent with thorough moistening of the mass. It shall be laid under the direction of the Engineer, and when required thoroughly rammed with a 40-pound ram. Rubble-stone of irregular size and shape shall be thrown in with the mass, in as large quantities as is consistent with a complete bonding of the concrete mass around every stone, the stones being handled separately, and bedded in the soft concrete mass. The grouting of quantities of loose stone will not be allowed.

The concrete used to fill the working chamber will be entirely of cement and sand or gravel.

MASONRY

The masonry will be first-class rock-face work, laid in regular courses, to be built of granite from quarries in Minnesota. The piers shall conform in all respects to the plans furnished by the Engineer.

No course shall be less than 16 inches thick, and no course shall be thicker than the course below it. The upper and lower beds of every stone shall be at least one-half greater in both directions than the thickness of the course.

In general, every third stone of each course shall be a header, and there shall be at least two headers on each side of each course between the shoulders. No stone will be considered a header that measures less than five feet back from the face. The headers shall be so arranged as to form a bond entirely through the pier, either by bonding against a face-stone in the opposite side of the course, or by bonding with a piece of backing not less than three feet square, which shall bond with a face-stone on the opposite side. In all cases the interior bonding shall be further secured by placing in the course above a stone at least three feet square over the interior joints. Special care shall be taken with the bonding of the ice-breaker cut-water, the stones of which shall be so arranged that the face-stones are supported from behind by large pieces of backing.

All joints shall be pitched to a true line and dressed to one-quarter of an inch for at least 12 inches from the face. Beds, both upper and lower, shall be pitched to a true line and dressed to one-quarter of an inch. Joints

shall be broken at least 15 inches on the face.

The ice-breaker starling of Piers II and III shall have a smooth, bush-hammered face. There shall be a draft line three inches wide around the lower edge of the belting course below the coping. The coping over the whole pier shall have a smooth, bush-hammered surface and face. All other parts of the work shall have a rough quarry face, with no projection exceeding two inches from the pitch line of the joints.

The stones in the coping under the bearings of the trusses shall be at least four feet wide, and shall reach back six feet from the face. They shall have good beds for their entire size, and shall have a full bearing on large stones with dressed beds in the belting course below the coping.

The large stones used in the backing to bond with the headers, and to support the icebreaker face-stones as above described, shall be of the same thickness as the face-stones and shall have dressed beds. The remainder of the backing shall be formed of good rubble-stone, thoroughly bedded in mortar.

All stones shall be sound, free from seams or other defects.

All stones shall be laid in full mortar beds; they shall be lowered on the bed of mortar, and brought to a bearing with a maul. No spalls will be allowed, except in small vertical openings in the backing. Thin mortar joints will not be insisted on, but the joints shall be properly cleaned on the face and pointed in mild weather.

The face stones of each course in Piers II and III for a height of 30 feet, beginning about three feet below low water, shall be doweled into those of the course below, with round dowels of 1-1/8-inch iron extending six inches into each course; the dowels shall be from eight to twelve inches back from the face, and six inches on each side of every joint; the stones of the upper course shall be drilled through before setting, after which the drill-hole shall be extended six inches into the lower course; a small quantity of mortar shall then be put in the hole, the dowel dropped in and driven home, and the hole filled with mortar and rammed.

The mortar will be composed of cement and clean, coarse sand, satisfactory to the Engineer, in proportions varying from one to three parts of sand to one of cement, as may be directed by the Engineer for different parts of the work. When stone is laid in freezing weather, the contractor shall take such precautions to prevent the mortar freezing as shall be satisfactory to the Engineer.

TERMS

The Railroad Company will furnish free transportation for the contractor's tools and men on the lines of the Northern pacific Railroad, and free transportation of stone from the quarries to the bridge site.

The Railroad Company will furnish the cement for the masonry, which must be unloaded and stored by the contractor, he to be responsible for it afterwards.

The contractor will be required to furnish all boats, barges, derricks and tools of every description, both at the quarries and on the works. The stone shall be cut at the quarries. The Railroad Company will furnish no tools nor material except cement.

No material shall be measured or included in the estimate, which does not form a part of the permanent structure.

APPENDIX D

SPECIFICATIONS FOR SUPERSTRUCTURE - BISMARCK BRIDGE (1880)

GENERAL DESCRIPTION

There will be three spans of through bridge, each 400 feet long between centers, and two spans of deck bridge, each about 125 feet long.

In the through spans, the top chord, the end posts, the ten central panels of the bottom chord, the bolsters, rollers and bearing plates, and all pins of every description will be of steel; the other parts will be of wrought iron except the pedestal castings, the filling rings and portal ornaments, and the washer plates on lateral struts, which will be of cast iron. Each span will contain approximately 330,000 pounds of steel and 580,000 pounds of iron.

The deck spans will be entirely of wrought iron, except the pins, which will be of steel.

PLANS

Full detail plans, showing all dimensions, will be furnished by the Engineer of the bridge. The work will be built in all respects according to these plans. No allowance will be made to the contractor for any fitting of parts during erection, but he will be required to satisfy himself, by inspection of the plans, what fittings will be required.

The detail plans of the through spans will be ready for delivery to the contractor on the award of the work. The detail plans of the two deck spans will be ready on or before July 1, 1881, and the Railroad Company reserves the right to change the length and other dimensions of these two spans at any time prior to that date, provided that the length shall not exceed 150 feet.

MATERIALS

All materials shall be subject to inspection at all times during their manufacture, and the Engineer and his inspectors shall be allowed full access to any of the works in which any portion of the materials are made.

The steel may be manufactured by the open-hearth process or by the Bessemer process, and laboratory tests shall be made of a sample bar rolled from a small ingot taken from every charge, and if this bar fails to meet the specifications the whole charge shall be rejected. Steel used in the compression members, bolsters, bearing-plates, pins and rollers shall contain not less than 34/100, nor more than 40/100 of one per cent of carbon and less than 1/10 of one percent of phosphorus. A round sample bar not less than 5/8

inches diameter shall bend 180 degrees around its own diameter without sign of crack or flaw. The same bar tested in a lever machine shall have an elastic limit of not less than 50,000, nor more than 55,000 pounds, and an ultimate strength of not less than 80,000, nor more than 90,000 pounds per square inch; it shall enlongate at least 12 per cent before breaking, and shall have a reduced area of 20 per cent at the point of fracture.

Steel for rivets and eye-bars shall contain not less than 16/100, nor more than 20/100 or one per cent of carbon, and less than 1/10 of one per cent of phosphorus. A round sample bar not less than 5/8-inch diameter shall bend 180 degrees, and be set back on itself without showing crack or flaw; when tested in a lever machine it shall have an elastic limit of not less than 40,000, nor more than 45,000 pounds per square inch, and an ultimate strength of not less than 70,000, nor more than 45,000 pounds per square inch, and an ultimate strength of not less than 70,000, nor more than 80,000 pounds per square inch. It shall enlongate at least 18 per cent, and shall show a reduction of at least 30 per cent at the point of fracture. In the finished full-sized bars, this steel shall have an elastic limit of at least 35,000 pounds per square inch, and an ultimate strength of at least 65,000 pounds per square inch, and shall enlongate 10 percent before breaking.

Facilities for testing the sample bars shall be furnished by the contractor at a point convenient to the steel works, the test to be made at the expense of the contractor and under the direction of the Engineer of the bridge.

The iron used in the eye-bars and other tension members shall be double-rolled refined iron, or iron of at least equivalent character. It shall have an ultimate strength of 50,000 pounds per square inch, and an elastic limit of at least 26,000 pounds per square inch; it shall enlongate at least 15 per cent, and show a reduced area of at least 6 inches, which shall be prepared by the contractor, shall give the foregoing results. When tests are made of full-sized bars, a reduction of from 5 to 10 per cent, according to the size of the bars, will be allowed, provided the character of the iron as shown by the fracture and by a uniformity of stretch is satisfactory. The fracture shall be of uniform fibrous character, free from any crystalline appearance.

Iron used in shapes, plates and other miscellaneous forms, when tested in small samples, which shall be prepared by the contractor, having a minimum length of 6 inches, shall show an elastic limit of at least 24,000 pounds, and an ultimate strength of at least 47,000 pounds per square inch, shall enlongate at least 10 per cent before breaking, and shall show a reduction of at least 15 per cent in area at the point of fracture.

Cast iron shall be of the best quality of tough grey iron.

WORKMANSHIP

In riveted steel work the steel shall be punched with holes not larger than 3/4 inch diameter, the several parts of each member shall then be

assembled, and the holes shall be reamed to 1 inch diameter, at least 1/16 being taken out all around. The sharp edge of the reamed hole shall be trimmed, and the parts shall be riveted together without taking apart. All rivets in steel members shall be of steel; they shall be of such size that they will fill the hole before driving, and, whenever possible, shall be driven by power. All bearing surfaces shall be truly faced; the beveled surfaces on the end posts and the end chord sections shall be truly faced so as to allow 1/16 inch play in erection. The chord pieces shall be fitted together in the shop in lengths of at least five panels and marked; when so fitted together, there shall be no perceptible wind in the length laid out. The pin-holes shall be bored truly, so as to be equally distant, truly parallel with one another and at right angles to the axis of the member.

All wrought iron work shall be punched to accurate templets with holes 1/16 inch larger than the size of rivet, and when put together a cold rivet shall pass through every hole without reaming. So far as possible all rivets shall be driven by power. The holes for the rivets connecting the floor beams with the posts and with the bolsters, which must be driven after erection, shall be accurately reamed to a templet.

The steel eye-bars shall be rolled by the Kloman process, unless some other process of manufacturing heads is approved by the Engineer. The contractor will be required to furnish three additional bars of every size without charge, these bars to be tested at such place as the Engineer may select. If the tests are satisfactory, the expense attending them shall be paid by the Railroad Company. If the tests are unsatisfactory, the whole lot of bars shall be rejected. If, however, the tests indicate that the defect is one which can be removed by annealing, a second set of bars shall be annealed and then tested; if the tests of the annealed bars are satisfactory, then the whole set of bars shall be annealed. All steel bars shall be tested to 20,000 pounds per square inch before shipment. If contractors desire to make use of some other process they will be required, at their own expense, to satisfy the Engineer of its excellence by a series of tests, such as he shall direct.

The heads of the iron eye-bars and the enlarged ends for screws in laterals shall be formed by upsetting and forging to shape or by forging with a a plate welded on the side. The character of the work must be such that the enlarged head or end will break the body of the bar. An extra number of bars, not exceeding six in all, shall be furnished for testing, besides small samples.

All pins shall be accurately turned to a gauge and shall be of full size throughout. All pin-holes shall be bored to fit the pins with a play not exceeding 1/50 inch. These clauses apply to all lateral connections as well as the main connections of the truss.

All workmanship, whether particularly specified or not, must be of the best kind now in use in first-class bridge work. Flaws or surface imperfections or irregular shapes will be sufficient ground for rejection of material.

All iron and steel work shall be painted with one coat of Cleveland Iron Clad Paint (purple brand) before it leaves the shop.

TERMS

The Railroad Company will furnish free transportation for men, tools and materials from St. Paul or from Duluth to Bismarck, and from Bismarck on completion of the work to either of these points.

The contractor will be required to furnish all false work and tools of every description, and to erect the bridge superstructure.

The contractor will be required, under a penalty of $250 a day, to have the work completed and ready for the track on or before July 1, 1882.

PRICES

Proposals for this work should be by the pound for three classes of materials delivered at the bridge site, namely: Steel per pound, wrought iron per pound, cast iron per pound; the prices to include all patterns and other work of every description. Cast iron includes the large pedestals and filling rings and portal plates; the cast washer plates riveted to the lateral struts will be classed as wrought iron.

Also a single gross sum for the erection of the entire superstructure.

No material will be paid for which does not form a part of the permanent structure.

The right is reserved to accept any proposal for material delivered at the bridge site without erection.

APPENDIX E

LIST OF ENGINEERS, EMPLOYEES AND CONTRACTORS - BISMARCK BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service		
Geo. S. Morison, Engineer and Superintendent			
H.W. Parkhurst, First Assistant Engineer	Jan. 1, 1881	to	June 12, 1882
B.L. Crosby, Assistant Engineer	Apr. 16, "	"	Aug. 1, 1883
Geo. A. Lederle, Asst. Eng./Draughtsman	July 16, "	"	Nov. 1, 1882
David R. Alden, Leveler	Feb. 5, "	"	Sept.1, 1881
C.C. Schneider, Asst. Eng. of Superstructure	Jan. 1, "	"	Oct. 31, 1882
W.F. Zimmerman, Insp. of Steel and Iron	Mar. 3, "	"	Aug. 8, "
James S. Sanderson, Insp. of Shop Work	May 1, "	"	Aug. 30, "
Robert Ross, Insp. of Masonry	July 13, "	"	June 5, "
B.S. Sawyer, Insp. of Quarries	June 11, "	"	Apr. 30, "
F.S. Sylvester, Insp. of Transportation	Oct. 26, "	"	Sep. 11, "
John A. McKeen, Foreman in charge of Borings	Feb. 10, "	"	Dec. 16, 1881
John McGee, Foreman of Laborers	Jan. 1, "	"	Apr. 11, "
R.P. Stitt, Foreman of Laborers	Feb. 22, "	"	July 1, 1883
Wm. L. Bechtel, Foreman of Superstructure	Nov. 21, 1882	"	Aug. 1, "

Contractors

Name	Nature of Work
Saulpaugh & Company	Substructure
J. Crubaugh, Resident Partner and Supt.	
Patrick Durack, Foreman of Masons	
Oliver Davis, Foreman of Stone Cutters	
Rust & Coolidge, Subcontractors for Pneumatic Work	
Detroit Bridge and Iron Works	Superstructure
John W. Stoughton, Supt. of Erection	
Bellows, Fogarty & Company	Earthwork on Approaches
Winston Brothers	Trestle-work, West Approach
Charles W. Thomson	Riprap Stone

APPENDIX F

LIST OF ENGINEERS, EMPLOYEES, AND CONTRACTORS - BLAIR CROSSING BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service
Geo. S. Morison, Chief Engineer	
H.W. Parkhurst, First Assistant Engineer	June 14, 1882 to Nov. 10, 1883
Emil Gerber, Assistant Engineer	Aug. 1, " " Nov. 1, "
" " , Resident Engineer	Nov. 1, 1883 " date.
S.W.Y. Schimonsky, Draughtsman	Apr. 18, " " July 15, 1883
G.W. Lilly, Assistant Engineer	Sep. 6, 1882 " Mar. 30, "
W.S. MacDonald, Office Assistant	Dec. 8, " " Nov. 8, "
A.C. Shelley, Insp. of Transportation	Nov. 2, " " Jan. 15, "
C.C. Schneider, Asst. Eng. of Superstructure	
W.F. Zimmerman, Insp. of Superstructure	
G.C. Henning, Insp. of Superstructure	
Robert Ross, Insp. of Masonry	Dec. 23, 1882 to May 15, 1883
P. Aylward, Foreman of Pressure Work	Oct. 10, " " Apr. 30, "
Dennis Brophy, Steam Engineer and Machinist	Sep. 15, " " May 17, "
Joseph Saguin, For. Carpenters, Cassion Bg.	Sep. 20, " " June 15, "
J.A. McKeen, Foreman of Laborers	Dec. 10, 1881 " date.
N. Oman, For. Carpenters, Bridge Floor	June 1, 1883 " Nov. 17, "

Contractors

Name	Nature of Work
Lyman Brothers	Earth-work of Approaches
N. Desparois	Trestle-work of Approaches
T. Saulpaugh & Company	Masonry
P. Durack, Foreman of Masons	
O. Davis, Foreman of Stone Cutters	
Keystone Bridge Company	Superstructure
Baird Bros. Erection of Superstructure	
W.H.B. Stout	Riprap
Le Grand Quarry Company	Riprap
Jasper Stone Company	Riprap
A.G. Seney	Riprap

APPENDIX G

LIST OF ENGINEERS, EMPLOYEES, AND CONTRACTORS - NEW OMAHA BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service
Geo. S. Morison, Chief Engineer	Dec. 16, 1885 to June 1, 1887
H.W. Parkhurst, Assistant Eng./Foundations	Sep. 19, " " Dec. 15, 1885
Lewis Blickensderfer, Assistant Engineer	Oct. 26, " " Mar. 31, 1886
Ralph Modjeski, Assistant Engineer	Oct. 16, " " Aug. 15, 1887
E.P. Butts, Insp. at Quarries and Asst. Eng.	Feb. 10, 1886 " Mar. 15, "
M.A. Waldo, Assistant Engineer	Sep. 1, " " Nov. 24, 1886
G.J. Bell, Assistant Engineer	Nov. 25, " " Jan. 20, 1887
E. Duryea, Jr., Resident Engineer	June 7, 1887 " Nov. 17, "
S.W.Y. Schimonsky, Draughtsman	Aug. 10, 1886 " Apr. 15, 1887
Alfred Noble, Chief Insp. of Superstructure	Feb. 8, " " June 30, 1886
R.W. Hildreth, Insp. of Superstructure	Mar. 1, " " June 31, 1887
James Saguin, Foreman of Erection	Apr. 1, " " May 31, "
Robert Ross, Insp. of Masonry	Jan. 15, " " Mar. 31, "
Dennis Brophy, Master Mechanic	Oct. 9, 1885 " July 6, "
Patrick Aylward, Foreman of Pressure Work	Nov. 5, " " Feb. 10, 1886
Dennis Leonard, Foreman of Pressure Work	Feb. 11, 1886 " Feb. 27, 1887
William Wride, Sub-foreman of Erection	May 2, 1886 " Aug. 17, "

Contractors

Name	Nature of Work
T. Saulpaugh & Company	Masonry
Chas. Stears, Foreman of Masons	
Oliver W. Davis, For. of Stonecutters	
Union Bridge Company	Superstructure
Walter A. Smith	Earthwork of Roadway Approaches

APPENDIX H

LIST OF ENGINEERS, CONTRACTORS AND EMPLOYEES - RULO BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service
Geo. S. Morison, Chief Engineer	
Benjamin L. Crosby, Resident Engineer	Sep. 13, 1883 to Dec. 31, 1889
Edwin Duryea, Jr., Assistant Engineer	Mar. 22, 1886 " Nov. 21, 1886
Mark A. Waldo, Assistant Engineer	May 29, " " June 16, 1887
W.S. MacDonald, Assistant Engineer	Aug. 9, " " Feb. 25, 1889
A.J. Himes, Assistant Engineer	July 7, 1888 " Oct. 31, "
W.R. Johnson, Rodman	Nov. 17, 1885 " Oct. 31, "
J.M. Richardson, Clerk	July 18, 1886 " Oct. 31, "
R.F. Thayer, Timekeeper	June 23, " " Aug. 13, 1887
E.P. Butts, Insp. of Stone at Quarries	Sep. 1, " " July 15, "
John Naegeley, Insp. of Superstructure	Sep. 20, " " Oct. 6, "
Paul Willis, Asst. Insp. of Superstructure	Dec. 15, " " July 13, "
P.H. Aylward, Supt. Pressure Work	Feb. 12, " " Sep. 1, "
Charles Connor, Master Mechanic	Dec. 10, 1885 " July 23, "
J. Rick, Foreman of Carpenters	Dec. 11, " " May 13, 1886
S.S. Warrington, Foreman of Carpenters	June 10, 1886 " Apr. 7, 1887
Birton Reed, Insp. of Masonry	Nov. 19, " " Feb. 25, "
Charles Stears, Insp. of Masonry	May 4, 1887 " July 18, "
John Newman, Foreman of Laborers	Nov. 28, 1884 " Feb. 25, "

Contractors

Name	Nature of Work
Drake & Stratton	Masonry
James Doig, Supt. at Rulo	
Edgemoor Iron Company	Superstructure
Baird Bros., Sub-Contractors/Erection	
S. Dwight Eaton	Grading Approaches
J.S. Wattles	East Approach Trestle

APPENDIX I

LIST OF ENGINEERS, EMPLOYEES AND CONTRACTORS - SIOUX CITY BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service		
George S. Morison, Chief Engineer		to	Apr. 30, 1887
Morison & Corthell, Chief Engineer	May 1, 1887	"	Apr. 30, 1889
George S. Morison, Chief Engineer	May 1, 1889	"	Completion.
E. Gerber, Resident Engineer	June 15, 1887	"	Dec. 31, 1888
A.B. Corthell, Assistant Engineer	July 3, "	"	Apr. 4, "
J.W. Fiege, Assistant Engineer	Apr. 15, 1888	"	Aug. 8, 1889
E.H. Mayne, Assistant Engineer	June 24, 1887	"	Sep. 21, 1888
Andrew Thompson, Assistant Engineer	Dec. 10, "	"	Dec. 31, "
O. Gunkle, Chief Clerk	Aug. 15, "	"	May 1, 1888
C.H. Schaad, Chief Clerk	May 1, 1888	"	Mar. 11, 1889
Paul Willis, Insp. Superstructure/Shops	Sep. 20, 1887	"	Nov. 2, 1888
R.W. Hildreth, Insp. Superstructure/Shops	Dec. 26, "	"	Nov. 7, "
R. Modjeski, Insp. Superstructure at Shops	Mar. 20, 1888	"	Sep. 30, "
H.W. Parkhurst, Insp. Stone at Quarries	Nov. 15, 1887	"	Jan. 1, "
Z.W. Craig, Insp. Stone at Quarries	Dec. 1, "	"	June 30, "
William Hill, Insp. of Masonry	July 5, "	"	Oct. 31, "
Dennis Brophy, Master Mechanic	July 7, "	"	Oct. 31, "
Dennis Leonard, Foreman of Pressure Work	Sep. 8, "	"	Oct. 12, "
William Wride, Foreman of Carpenters	Aug. 23, "	"	Jan. 20, 1889

Contractors

Name	Nature of Work
T. Saulpaugh & Company	Masonry
Chas. Stears, Foreman of Masons	
O.W. Davis, Foreman of Stonecutters	
Union Bridge Company	Superstructure
Baird Brothers	Erection
Geo. Buchan, Superintendent	
McNamara & McCarty	Earthwork
Wakefield & Hill	Trestlework

APPENDIX J - ACT OF CONGRESS AUTHORIZING CONSTRUCTION OF NEBRASKA CITY BRIDGE (1872) AND CONTRACT WITH WAR DEPARTMENT (1887)

ACT OF CONGRESS

AN ACT AUTHORIZING THE CONSTRUCTION OF A BRIDGE ACROSS THE MISSOURI RIVER OPPOSITE TO OR WITHIN THE CORPORATE LIMITS OF NEBRASKA CITY, NEBRASKA

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, that it shall be lawful for the Nebraska City Bridge Company, a corporation having authority from the State of Nebraska and from the State of Iowa, to build a railroad, transit, and wagon bridge across the Missouri River, opposite to or in the immediate vicinity of Nebraska City, in the county of Otoe, and State of Nebraska: and that when constructed, all trains of all railroads terminating at the Missouri River at or near the location of said bridge shall be allowed to cross said bridge, for a reasonable compensation, to be paid to the owners thereof; and that all other property, goods, passengers, teams, and other modes of transit shall be allowed to cross said bridge; and that said bridge shall not interfere with the free navigation of said river beyond what is necessary in order to carry into effect the rights and privileges here by granted; and in case of any litigation arising from any obstruction, or alleged obstruction, to the free navigation of said river, the cause may be tried before the district or circuit court of the United States of any State in or opposite to which any portion of said obstruction or bridge may be.

SEC. 2. That the corporators named in the above incorporation shall hold the said charter here granted in trust for the sole and exclusive use and benefit of any person or persons, company or companies, corporation or corporations, who shall build, erect, and complete such bridge herein provided in accordance with the provisions of this act; and said original incorporators shall transfer and assign, without any remunerative compensation, all their rights to any party or parties, company or companies, corporation or corporations, who shall erect said bridge; and if said corporators, or any of them, shall refuse or fail to make such transfer, upon the payment of the reasonable expense thereof, they may be compelled to do so by any court having jurisdiction: Provided, That the said Nebraska City Bridge Company, and their associates, shall fail to commence in good faith the erection of said bridge within one year from the passage of this act, and complete the said bridge without unnecessary and unreasonable delay in accordance with the provisions of this charter.

SEC. 3. That any bridge built under the provisions of this act, may, the option of person or persons, or corporation building the same, be built as a drawbridge, with a pivot-draw, or with unbroken or continuous spans: Provided,

That if the same shall be made of unbroken or continuous spans, it shall not be of less elevation, in any case, than fifty feet above extreme high water mark, as understood at the point of location, to the bottom chord of the bridge, nor shall the spans of said bridge be less than two hundred and fifty feet in length; and the piers of said bridge shall be parallel with the current of the river, and the main span shall be over the main channel of the river, and not less than three hundred feet in length: And Provided Also, That if a bridge shall be built under this act as a drawbridge, the same shall be constructed as a pivot drawbridge, with a draw over the main channel of the river at an accessible and navigable point, and with spans of not less than one hundred and sixty feet in length in the clear on each side of the central or pivot pier of the draw, and the next adjoining spans to the draw shall not be less than thirty feet above low water mark, and not less than ten feet above extreme high-water mark, measuring to the bottom chord of the bridge, and the piers of said bridge shall be parallel with the current of the river: And Provided Also, That said draw shall be opened promptly, upon reasonable signal, for the passage of boats whose construction shall not be such as to admit of their passage under the permanent spans of said bridge, except when trains are passing over the same, but in no case shall unnecessary delay occur in opening the said draw during or after the passage of trains: And Provided Further, That the corporation building said bridge may, if not unauthorized by the provisions of its charter of incorporation, enter upon the banks of said river, either above or below the point of the location of said bridge, for a distance of seven miles, and erect and maintain break-waters, or use such other means as may be necessary to make a channel for said river, and confine the flow of the water to a permanent channel, and to do whatever may be necessary to accomplish said object, but shall not impede or obstruct the navigation of the said river; and all plans for such works or erections upon the banks of the river shall first be submitted to the Secretary of War for his approval.

SEC. 4. That any bridge constructed under this act, and according to its limitations, shall be a lawful structure, and shall be known and recognized as a post-route, upon which, also, no higher charge shall be made for the transmission over the same of the mails, the troops, and the munitions of war of the United States than the rate per mile paid for their transportation over the railroads or public highways leading to the said bridge.

SEC. 5. That all railway companies desiring to use the said bridge shall have and be entitled to equal rights and privileges in the passage of the same, and in the use of the machinery and fixtures thereof, and of all the approaches thereto, under and upon such terms and conditions as shall be prescribed by the Secretary of War and upon such terms and conditions as shall be prescribed by the Secretary of War upon hearing the allegations and proofs of the parties in case they shall not agree.

SEC. 6. That the plan and specifications, with the necessary drawings of said bridge, shall be submitted to the Secretary of War, for his approval, and until he approve the plan and location of said bridge it shall not be built or

commenced; and should any change be made in the plan of said bridge during the progress of the work thereon, such change shall be subject to the approval of the Secretary of War; and all changes in the construction of said bridge that may be directed by Congress shall be made at the cost and expense of the owners thereof.

SEC. 7. That the right to alter or amend this act, so as to prevent of remove all material obstructions to the navigation of said river by the construction of bridges is hereby expressly reserved.

Approved, June 4, 1872.

CONTRACT WITH WAR DEPARTMENT

Whereas, by an Act of Congress approved June 4, 1872, entitled "An Act authorizing the construction of a bridge across the Missouri River opposite to, or within the corporate limits of Nebraska City, Nebraska," it was enacted that it shall be lawful for the Nebraska City Bridge Company, a corporation having authority from the State of Nebraska and from the State of Iowa, to build a railroad, transit and wagon bridge across the Missouri River, opposite to or in the immediate vicinity of Nebraska City, in the county of Otoe, and State of Nebraska; and

Whereas, it is provided by Section 2 of said act, "That the corporators named "in the above corporation shall hold the said charter here granted in trust for the sole and exclusive use and benefit of any person or persons, company or companies, corporation or corporations who shall build, erect and complete such bridge herein provided in accordance with the provisions of this Act, and said original incorporators shall transfer and assign, without any remunerating compensation, all their rights to any party or parties, company or companies, corporation or corporations, who shall erect said bridge;" and

Whereas, it is further provided by the Act of Congress, aforesaid, that the corporation building said bridge may enter upon the banks of said river, either above or below the point of location of said bridge, and erect and maintain breakwaters of use such other means as may be necessary to make a channel for said river, and to use such other means as may be necessary to make a channel for said river, and to confine the flow of the water to a permanent channel, and to do whatever may be necessary to accomplish said object, but shall not impede or obstruct the navigation of said river; and all plans for such works or erections upon the banks of the river shall first be submitted to the Secretary or War for his approval; and further, that the plan and specifications, with the necessary drawings of said bridge, shall be submitted to the Secretary of War for his approval, and until he approves the plan and location of said bridge, it shall not be built or commenced; and should any change be made in the plan of said bridge, during the progress of the work thereon, such change shall be subject to the approval of the Secretary of War; and

Whereas, the Nebraska City Bridge Company, in pursuance of the Act of

Congress aforesaid, and in consideration that the Nebraska Trailway Company, a corporation in the State of Nebraska, shall immediately enter upon the construction of said bridge, and shall complete the same without unnecessary delay, and shall thereafter maintain the said bridge, the aforesaid, the Nebraska City Bridge Company aforesaid, all the rights, title, charter, privileges an franchise that is or ever has been vested in the said Nebraska City Bridge Company; and

Whereas, the Nebraska Railway Company has accepted the transfer of all the rights, title charter and privileges conferred upon the said Nebraska City Bridge Company by the Act of Congress aforesaid, and has also accepted all of the provisions, restrictions and limitations of the Act of Congress aforesaid, in regard to the construction of said bridge, and subject to the further condition that in the event of the Nebraska Railway Company failing to comply with the conditions of construction and the terms of the transfer as aforesaid, the rights and privileges so transferred shall revert to the Nebraska City Bridge Company aforesaid; and

Whereas, the Nebraska Railway Company aforesaid; and aforesaid, has submitted for the approval of the Secretary of War a map showing the location of said bridge, and the works designed to confine the flow of the water to a permanent channel, together with the plan and specifications and a drawing of said bridge; and

Whereas, the Acting Chief of Engineers, United States Army, has reported that the papers now presented are believed to fulfill all the requirements of the case, and are recommended for approval:

Now, therefore, I, William C. Endicott, Secretary of War, having examined the plans and specifications for the construction of said bridge, and the map of location of said bridge, and the works designed to confine the flow of the water to a permanent channel, submitted by the Nebraska Railway Company, do hereby approve the same, subject to the condition, however, that the engineer officer of the United States Army in charge of the district within which the bridge is to be erected, may supervise its construction, so far as may be necessary, in order that the plans approved by the Secretary of War shall be complied with, and the bridge built accordingly.

Witness my hand this 5th day of July, 1887.
Wm. C. Endicott,
Secretary of War.

The words "of the United States Army" in line ten of this page were inserted before the execution of this instrument.

This instrument is also executed by the Nebraska Railway Company, by its president, G.W. Holdredge, thereto lawfully authorized, this twenty-seventh day of June, 1887, in testimony of its acceptance of the provisions, conditions and limitations of the Act of Congress.
The Nebraska Railway Company

APPENDIX K

SPECIFICATIONS FOR MASONRY - NEBRASKA CITY BRIDGE (1887)

There will be two masonry piers and one abutment.

The masonry will be first-class rock face work laid in regular courses.

The piers and abutment shall conform in all respects to the plans furnished by the Engineer. The face stones, including coping, above the elevations designated on the plans, shall be limestone from the quarries near Mankato, Minnesota.

Four lines of four-inch vitrified drain-pipe shall be laid through the front wall of the abutment at the first masonry joint.

The stone shall be cut and coursed out at the quarries, every dimension stone being marked, and full course plans being sent at time of shipment.

No course shall be less than sixteen inches thick and no course shall be thicker than the course below it. The upper and lower bed of every stone shall be at least one quarter greater in both directions than the thickness of the course, and no face stone shall measure less than thirty inches in either horizontal direction.

In general, every third stone of each course shall be a header, and there shall be at least two headers on each side of each course between the shoulders. No stone will be considered a header that measures less than five feet back from the face. The headers shall be so arranged as to form a bond entirely through the pier, either by bonding with a piece of backing not less than three feet square which shall bond with a face stone on the opposite side. In all cases the interior bonding shall be further secured by placing in the course above a stone at least three feet square over the interior joints. Special care shall be taken with the bonding of the icebreaker cut water, the stones of which shall be so arranged that the face stones are supported from behind by large pieces of backing.

All joints shall be pitched to a rule line and dressed to one-quarter inch for at least twelve inches from the face. Beds, both upper and lower, shall be pitched to a true line and dressed to one-quarter inch. Joints shall be broken at least fifteen inches on the face. The bottom bed shall always be the full size of the stone.

The face of the up-stream starlings of Piers II and III shall be fine-pointed, with no projections exceeding one-half inch. There shall be a draft line three inches wide around the lower edge of the belting course below the coping, and on the edge of the down stream starling of Piers II and III. The coping over the whole pier and the small copings over the pointed starlings of Piers II and III shall have a smooth cut surface and face. All other parts of the work shall have a rough quarry face, with no projections exceeding three inches from the pitch line of the joints.

The stones in the coping under the bearings of the trusses shall be built

according to special plans, to be furnished by the Engineer. They shall have good beds for their entire sizes, and a full bearing on large stones with dressed beds in the belting course below the coping.

The stones of the backing shall be of the same thickness as the face stones, and shall have dressed beds. All stone shall be sound, free from seams or other defects, and all limestone shall be laid with the natural beds horizontal.

All stone shall be laid in full mortar beds. They shall be lowered on the bed of mortar and brought to a bearing with a maul. No spalls will be allowed except in small vertical openings in the backing. Thin mortar joints will not be insisted on, but the joint shall be properly cleaned on the face and pointed in mild weather, the pointing to be driven in with a calking iron.

The face stones of each course in Piers II and III for a height of 26 feet, beginning about three feet below low water, shall be doweled into those of the course below with round dowels of 1-1/8 inch iron, extending six inches into each course; the dowels shall be from eight to twelve inches back from the face, and six inches on each side of every joint; the stones of the upper course shall be drilled through before setting, after which the drill hole shall be extended six inches into the lower course; a small quantity of mortar shall then be put into the hole, the dowel dropped in and driven home, and the hole filled with mortar and rammed. The three courses below the copings to have the joints bound with cramps of 7/8-inch round iron, 20 inches long between shoulders, the ends sunk three inches into each stone.

The mortar will be composed of cement and clean coarse sand satisfactory to the Engineer, in proportion varying from one to three parts of sand to one of cement, as may be directed by the Engineer for different parts of the work. When stone is laid in freezing weather, the contractor shall take such precautions to prevent the mortar's freezing as shall be satisfactory to the Engineer.

No material shall be measured or included in the estimate, which does not form a part of the permanent structure.

All necessary tools and materials of every description whatsoever, except cement, shall be furnished by the contractor taking the same from the storehouse.

The Railroad Company will pay for the transportation of the stone from Des Moines, Iowa, to the bridge site, but any stone transported and left over from the work will be the property of the Railroad Company.

In the appropriate monthly estimates, stone quarried but not cut, shall be estimated at four dollars per cubic yard, and stone quarried and cut, at eight dollars per cubic yard, these prices being simply assumed for the purpose of estimating unfinished work.

July 16th, 1887.

APPENDIX L

SPECIFICATIONS FOR SUPERSTRUCTURE - NEBRASKA CITY BRIDGE (1887)

GENERAL DESCRIPTION

The superstructures will consist of two through spans and deck span.

Each through span will be 400 feet long between centers of end pins, divided into fifteen panels of 26 feet eight inches each. The trusses will be 50 feet deep, and placed 22 feet apart between centers. Each span will weigh approximately 1,100 pounds.

The deck span will be 325 feet long between centers of end pins, and divided into thirteen panels of 25 feet each, the trusses being 37 feet deep and placed 20 feet apart between centers.

PLANS

Full detail plans, showing all dimensions, will be furnished by the Engineer. The work shall be built in respects according to these plans. The contractor, however, will be expected to verify the correctness of the plans, and will be required to make any changes in the work which are necessitated by errors in these plans, without extra charge, where such errors could be discovered by an inspection of the plans.

MATERIAL

All parts, except nuts, swivels, wall pedestal plates and ornamental work, will be of steel. The nuts and swivels may be of wrought iron; the pedestal plates and ornamental work of cast iron. The web of the East Approach Span may be of wrought iron.

All materials shall be subject to inspection at all times during their manufacture, and the Engineer and his inspectors shall be allowed free access to any of the works in which any portion of the material is made. Timely notice shall be given to the Engineer, so that inspectors may be on hand.

Steel. Steel may be made by the open hearth or by the Bessemer process, but no steel shall be made at works which have not been in successful operation for at least one year. Steel made by the Clapp-Griffiths process will not be accepted. All melts shall be made from uniform stock low in phosphorous, and the manufacturer shall furnish satisfactory evidence to the Engineer that this class of material is being employed, it being understood that the finished product is to be one in which the phosphorus does not average more than 8/100 of one per cent and never exceeds 1/10 of one per cent.

A sample bar 3/4 inch in diameter shall be rolled from every melt, the method of obtaining the piece from which this sample bar is rolled shall be the same for all samples, and the amount of work this sample bar shall be as nearly

as practicable the same as on the finished product. The laboratory tests shall be made on this sample bar in its natural state without annealing.

The laboratory tests of steel made on the sample bar shall show an elastic limit of not less than 40,000 pounds per square inch; an ultimate strength of not less than 67,000 pounds nor more than 75,000 pounds per square inch; an enlongation of at least 20 per cent in length of eight inches; and a reduction of at least 42 per cent at the point of fracture; this enlongation and reduction being the minimum and not the average requirements. In a bending test the sample bar shall bend 180 degrees and close back against itself without showing crack or flaw on the outside of the curve. Steel having an ultimate strength of 60,000 pounds per square inch will be accepted for rivets.

Should the contractor desire to use British steel, the quenching and bending tests specified in the Hawksbury Bridge specifications will be required, and the elastic limit requirement may be waved.

Every piece of steel shall be stamped with a number identifying the melt, and a statement of the results of the laboratory tests of each melt shall be furnished by the contractor, certified by some person acceptable to the Engineer, and accompanied by the tested specimens. Tests shall also be made from time to time on samples cut from finished plates, shapes and bars, which shall show results substantially conforming to those shown by the sample tests of the same melts.

All sheared edges or punched holes in steel work shall be subsequently planed or drilled out, so that none of the rough surface is ever left upon the work. Steel for pins shall be sound and entirely free from piping.

Wrought Iron. Small samples having a minimum length of eight inches, shall show an elastic limit of at least 24,000 pounds, an ultimate strength of at least 47,000 pounds per square inch, an enlongation of at least ten per cent, and a reduction of 15 per cent at the point of fracture.

Cast Iron. Cast iron shall be the best quality of tough, grey iron.

RIVETED WORK

All plates, angles and channels shall be carefully straightened before they are laid out; the rivet holes shall be carefully spaced in truly straight lines; the rivet heads shall be of hemispherical pattern, and the work shall be finished in a neat and workmanlike manner. Surfaces in contact shall be painted before they are put together. The dimensions given for rivets on the plans are the diameters of the rivets before driving.

Power riveters shall be direct acting machines, capable of exerting a yielding pressure, and holding on to the rivet when the upsetting is completed.

The several parts of each member shall be assembled, and the holes shall be drilled, the sharp edge of the drilled hole shall be trimmed so as to make a slight fillet under the rivet head, and the pieces shall be riveted together without taking apart. Should the contractor desire the parts may be punched with a punch at least 3/32 inch smaller than the diameter of the rivet as given

on the plans, working in a die only 1/64 inch larger than the rivet; the several parts of the member shall then be assembled and the holes reamed so that at least 1/16 inch of metal is taken out all around, and the sharp edge of the reamed hole shall be trimmed and the pieces riveted together as above. All rivets shall be steel; the rivet holes shall be of such size that the rivet will fill the hole before driving, and whenever possible, the rivets shall be driven by power. All bearing surfaces shall be truly faced. The chord pieces shall be fitted together in the shop, in lengths of at least five panels, and marked. When so fitted there shall be no perceptible wind in the length laid out. The pin holes shall be bored truly, so as to be at exact distances, parallel with one another, and at right angles to the axis of the member.

The holes for the rivets connecting the floor-beams with the posts and bolsters and the stringers with the floor-beams, and, in general, the holes for all rivets which must be driven after erection, shall be accurately drilled to an iron templet. The holes for rivets connecting the floor-beams with the posts shall be one inch in diameter, and the rivets of corresponding diameter. The pin holes in the vertical posts shall be truly parallel with one another and at right angles to the axis of the posts. The posts shall be straight and free from wind.

FORGED WORK

The heads of eye-bars shall be formed by upsetting and forging into shape by such process as may be accepted by the Engineer. No welds will be allowed. After the working is completed, the bars shall be annealed by heating them to a uniform dark red heat throughout their entire length, and allowing them to cool slowly. The form of the heads of steel eye-bars may be modified to suit the process in use at the contractor's works, but the form of the head adopted must be such as to meet the requirements of the tests of full-sized bars.

The heads and the enlarged ends for screws in laterals, suspenders and counters, shall be formed by upsetting by a process acceptable to the Engineer.

TESTS OF FULL-SIZED STEEL BARS

Ten full-sized eye-bars of sections and lengths, used in the actual work, shall be selected from bars made for the bridge, by the inspector for testing. Each of these full-sized bars shall be strained till an enlongation of ten per cent is obtained, and if possible, broken. If broken, the fracture shall occur in the body of the bar, and shall show a uniform and ductile quality of material.

The contractor will be required to furnish facilities for testing full-sized bars, within a reasonable distance of his works. Should the contractor be unable to furnish such facilities, he shall be required to furnish bars at 20 per cent larter sections than those called for, without charge for the increased weight.

The full-sized bars shall be selected from time to time as work proceeds, the last bar not to be selected till all the eye-bars are selected. When three bars have been tested, the bars manufactured up to the time of the selection of these three test bars shall be accepted or rejected on the results of such tests, and the same shall be done again when three more bars are tested. In these tests, the failure of one bar to develop a stretch of eight per cent, or of the lot to develop an average of ten per cent before breaking, shall be sufficient reason for rejecting the lot from which these bars are taken. A failure to break in the body of the bar shall not be sufficient ground for condemnation if it does not occur in more than one-third of the bars tested; but the above requirements as to enlongation shall apply to the bars so breaking in the head, as well as to the others. The Engineer shall, however, examine carefully into the cause of breakage of any bar which does not meet the requirements, and, if the defect is explained, may order additional tests, and make the acceptance dependent on further results.

MACHINE WORK

The bearing surface in the top chord shall be truly faced. The ends of the stringers and of the floor-beams shall be squared in a facer. All surfaces, so designated on the plans, shall be planed. All sheared and punched edges shall be planed or bored out.

All pins shall be accurately turned to a gauge, and shall be of full size throughout. Pins more than four inches in diameter shall be drilled through the axis. Pin-holes shall be bored to fit the pins, with a play not exceeding /50 of an inch. These clauses apply to all lateral connections as well as to those of the main trusses. Pins shall be supplied with pilot nuts, for use during erection, four of each size of pin.

All screws shall have a truncated V thread, United States standard sizes.

MISCELLANEOUS

All workmanship and material, whether particularly specified or not, must be of the best kind now in use in first-class bridge work. Flaws, ragged edges, surface imperfections or irregular shapes will be sufficient ground for rejection. Rough and irregularly finished work will not be accepted. Machine finished surfaces shall be coated with white lead and tallow before shipment. All other parts shall be given a coat of hot boiled linseed oil.

TERMS

Monthly estimates will be made at the end of each month for the work done during that month. In these monthly estimates the material delivered at the contractor's shop, but not manufactured, shall be estimated at 50 per cent of the contract price for finished material in Chicago, and manufactured material

at 75 per cent of the contract price for finished material in Chicago. Payments will be made on or about the 15th day of the following month, according to these estimates, the completion of the entire contract.

No material will be paid for which does not form a part of the permanent structure.

All expenses of testing shall be borne by the contractor.

TIME

The trusses of the first through span shall be completed and shipped by January 1st, 1888; Those of the second through span by January 20th, 1888, and the whole work by February 10th, 1888. The railroad company may exact a penalty, not exceeding $150 per day, for failure to complete the work at these specified times.

July 16th, 1887.

APPENDIX M

LIST OF ENGINEERS, EMPLOYEES AND CONTRACTORS - NEBRASKA CITY BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service				
George S. Morison, Chief Engineer					
E. L. Corthell, Associate Chief Engineer					
B.L. Crosby, Resident Engineer	Feb. 7,	1887	to	Oct. 31,	1889
Addison Conner, Assistant Engineer	Feb. 1,	"	"	June 2,	1887
Edwin Duryea, Assitant Engineer	May 1,	"	"	June 16,	"
M.A. Waldo, Assistant Engineer	June 16,	"	"	Oct. 32,	1888
W.S. MacDonald, Assistant Engineer	Nov. 1,	1888	"	Feb. 25,	1889
L.V. Rice, Assistant Engineer	Oct. 19,	1887	"	July 6,	"
A.J. Himes, Assistant Engineer	June 24,	"	"	July 9,	1888
Geo. R. Ferrall, Rodman	July 1,	"	"	Nov. 6,	"
H.B. Ellett, Rodman and Insp.	Nov. 22,	"	"	Apr. 9,	1889
J.L. Mendenhall, Clerk	July 25,	"	"	Oct. 31,	"
R.F. Thayer, Timekeeper	Aug. 13,	"	"	May 15,	1888
F.H. Crafts, Inspector at Quarries	Sep. 1,	"	"	Nov. 4,	1887
H.W. Parkhurst, Inspector at Quarries	Nov. 1,	"	"	Dec. 10,	"
Z. W. Craig, Insp. at Quarries	Dec. 10,	"		May 31,	1888
Paul Willis, Insp. of Superstructure	Sep. 20,	"	"	June 1,	"
R.W. Hildreth, Insp. of Superstructure	Sep. 22,	"	"	July 3,	"
R. Modjeski, Insp. of Superstructure	Nov. 26,	"	"	May 8,	"
W.A. Nettleton, Insp. of Superstructue	Jan. 15,	1888	"	June 5,	1888
P.H. Aylward, Foreman of Pressure Work	Sep. 1,	1887	"	Feb. 23,	"
Charles Connor, Master Mechanic	July 24,	1887	"	July 23,	"
J.E. Griffin, Foreman of Carpenters	Aug. 9,	"	"	July 31,	"

Contractors

Name	Nature of Work
T. Saulpaugh & Company	Masonry
Charles Stears	Foreman of Masons
O.W. Davis	Foreman of Stonecutters
Union Bridge Company	Superstructure
Baird Brothers	Erection
George Buchan	Superintendent
Andrew Sheridan	Earthwork, Riprap, Stone and Mattress Brush
Dorwin & Lundquist	Earthwork
Frank I. Marsh	Mattress Brush

APPENDIX N - ACTS OF CONGRESS, 17 DECEMBER, 1872, AND 14 FEBRUARY, 1883, AUTHORIZING CONSTRUCTION OF BRIDGES OVER THE OHIO RIVER.

ACT APPROVED 17 DECEMBER, 1872

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That any persons or corporations having lawful authority therefor, may hereafter erect bridges across the Ohio River, for railroad or other used, upon compliance with the provisions and requirements of this Act.

SEC. 2. That every bridge hereafter erected across the Ohio River, above the mouth of the Big Sandy, shall have at least one span of a height of not less than ninety feet above low water, and of not less than forty feet above local highest water, measured to the bottom chord of the bridge; that every bridge hereafter erected across the Ohio River below the mouth of the Big Sandy, shall have at least one span of a height of not less than one hundred feet above low water, and of not less than forty feet above highest water, measured to the bottom chord of the bridge; that this high span shall give a clear opening of at least four hundred feet between the piers, measured at right angles to the current at every stage, and that it shall be placed over the main channel of the river used by the boats during ordinary stages of water: Provided, however, That any one company, lawfully authorized by the State of West Virginia and Ohio, is hereby authorized to construct a bridge across the Ohio River, from the City of Wheeling, in the State of West Virginia, to the opposite side of the said river within the State of Ohio, with a span over the main channel of not less than three hundred and fifty feet in length, and all other respects conformable and subject to the provisions of this act, so far as the same are applicable to bridges above the mouth of the Big Sandy: and provided, That in case this high span is not over the low water channel, suitable arrangements be made elsewhere to permit the passage of single boats under the bridge at low water; that all bridges over the Ohio River, below Covington and Cincinnati suspension bridge, shall have, in addition to the high span prescribed above, a pivot-draw, giving two clear openings of one hundred and sixty feet each, measured at right angles to the current at the average stage of water in the river, and located in a part of the bridge that can be safely and conveniently reached at that stage; and that said draw shall be opened promptly, upon reasonable signal for the passage of boats, whose construction shall not be such as to admit their passage under the stationary spans of said bridges, except when trains are passing over the same; but in no case shall unnecessary delay occur in opening the said draw before or after the passage of trains.

SEC. 3. That the piers of the high span and the piers of the draw shall be built parallel with the current at the stage of the river which is most important for navigation; and that no rip-raps or other outside protection for

imperfect foundation will be permitted in the channel-way of the high span, or of the draw openings.

SEC. 4. That any person, company, or corporation, authorized to construct a bridge across the Ohio River shall give notice, by publication for one week in newspapers have a wide circulation, in not less than two newspapers in the cities of Pittsburgh, Cincinnatti, and Louisville, for bridges above the mouth of the Big Sandy, and in the cities of Pittsburgh, Cincinnatti, Louisville, Saint Louis, Memphis, and New Orleans, for bridges below the mouth of the Big Sandy; and shall submit to the Secretary of War, for his examination, a design and drawings of the bridge and piers, and a map of the location, giving, for the space of at least one mile above and one mile below the proposed location, the topography of the banks of the river, the shore lines at high and low water, the direction of the current at all stages, and the soundings accurately showing the bed of the stream, the location of any other bridge or bridges, and shall furnish such other information as may be required for a full and satisfactory understanding of the subject by the Secretary of War; and if the Secretary of War is satisfied that the provisions of the law have been complied with in regard to location, the building of the piers may be at once commenced; but if it shall appear that the conditions prescribed by this act cannot be complied with in regard to location, the building of the piers may be at once commenced; but if it shall appear that the conditions prescribed by this act cannot be complied with at the location where it is desired to construct the bridge, the Secretary of War shall, after considering any remonstrances filed against the building of said bridge, and furnishing copies of such remonstrances to the board of engineers provided for in this act, detail a board composed of three experienced officers of the corps of engineers, to examine the case, and may, on their recommendation, authorize such modifications in the requirements of this act, as to location and piers, as will permit the construction of the bridge; not, however, diminishing the width of spans contemplated by this act: Provided, that the free navigation of the river be not materially injured thereby.

SEC. 5. That all parties owning, occupying, or operating bridges over the Ohio River shall maintain, at their own expense, from sunset to sunrise throughout the year, such lights on their bridges as may be required by the lighthouse board for the security of navigation; and all persons owning, occupying, or operating any bridge over the Ohio River shall, in any event, maintain all lights on their bridges that may be necessary for the security of navigation.

SEC. 6. That any bridge constructed under this act, and according to its limitations, shall be a lawful structure, and shall be recognized and known as a postroute, upon which, also, no higher charge shall be made for the transmission over the same of the mails, the troops, and the munitions of war of the United States than the rate per mile paid for the transportation over the railroads or public way for postal-telegraph purposed across any such bridge under this act, the cause or question arising may be tried before the

District Court of the United States of any State in which any portion of said obstruction or bridge touches.

SEC. 7. That the right to alter or amend this act, so as to prevent or remove all material obstructions to the navigation of said river by the future construction of bridges, is hereby expressly reserved, without any liability of the government for damages on account of the alteration or amendment of this act, or on account of the prevention or requiring the removal of any such obstructions; and if any change be made in the plan of construction of any bridge constructed under this act, during the progress of the work thereon or before the completion of such bridge, such change shall be subject to the approval of the Secretary of War, and any change in the construction, or any alteration on any such bridge that may be directed at any time by Congress, shall be made at the cost and expense of the owners thereof.

SEC. 8. That joint resolution number ten, approved April seventh, eighteen hundred and sixty-nine, authorizing the construction of a bridge over the Ohio river at Paducah, be, and the same hereby is, repealed.

SEC. 9. That the provisions of an act entitled "An Act to provide for the better security of life on vessels propelled in whole or in part by steam," etc., approved February twenty-eighth, eighteen hundred and seventy-one, so far as they relate to the limitation of steam pressure of steamboats used exclusively for towing and carrying freight on the Mississippi River and its tributaries, are hereby so far modified as to substitute for such boats one hundred and fifty pounds, as provided in said act for the pressure in place of one hundred and ten pounds, as provided in said act for the standard pressure of standard boilers of forty-two inches' diameter and of plates of one-quarter of an inch in thickness; and such boats may, on the written permit of the supervising inspector of the district in which such boats shall carry on their business for a period of twelve months for and after the passage of this act, be permitted to carry steam above the standard pressure of one hundred and ten pounds, but not exceeding the standard pressure of one hundred and fifty pounds to the square inch.

ACT APPROVED FEBRUARY 14, 1883.

AN ACT SUPPLEMENTARY TO AN ACT APPROVED DECEMBER 17, 1872, ENTITLED "AN ACT TO AUTHORIZE THE CONSTRUCTION OF BRIDGES ACROSS THE OHIO RIVERS, AND TO PRESCRIBE THE DIMENSIONS OF THE SAME".

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the act of Congress approved December seventeenth, eighteen hundred and seventy-two, entitled "An Act to authorize the construction of bridges across the Ohio River, and to prescribe

the dimensions of the same," shall be, and the same is hereby, amended by striking out sections two and four of said act and submitting therefor the following:

SEC. 2. "That every bridge hereafter erected across the Ohio River shall have its axis at right angles to the current at all stages, and all of its spans shall be through spans. Every such bridge shall have at least one channel span placed over that part of the river usually run by descending coal fleets, said channel span to give a clear waterway between the piers of five hundred feet, measured on the low water line. Said channel span shall be at least forty feet above local highest water measured to the lowest part of the span, and shall be at least ninety feet above low water in bridges built above the mouth of the Big Sandy River, and at least one hundred feet above low water in bridges built below the mouth of the Big Sandy River, measured to the lowest part of the span: Provided, however, that all bridges over the Ohio River below the Covington and Cincinnatti Suspension Bridge shall have, in addition to channel span prescribed above, a pivot draw giving two clear openings of one hundred and sixty feet each, measured at right angles to the current at high stages, and located in a part o the bridge that can be safely and conveniently reached at such stages; that said draw shall be provided with suitable rest piers above and below the pivot pier, and suitable floats or crib work connecting said rest piers with the pivot pier, to enable boats to pass through said draw with safety; that in case said draw span is near either shore, the bridge company, by purchase or otherwise, shall extinquish the right of mooring boats or other water craft to the adjacent shore for a distance of at least seven hundred feet above and seven hundred feet below the bridge; and that said draw shall be opened promptly, upon reasonable signal, for the passage of boats whose construction shall not be such as to admit of their passage under the stationary spans of said bridge, except when trains are passing over the same, but in no case shall unnecessary delay occur in opening said draw before or after the passage of a train. Provided, further, That in lieu of the high draw prescribed above, bridges over the Ohio River below the Covington and Cincinnatti Suspension Bridge may be built as continuous bridges, with a clear height of fifty-three feet above local highest water, measured to the lowest part of the channel span."

SEC. 4. That any person, company, or corporation, authorized to construct a bridge across the Ohio River, shall give notice, by publication for one week in newspapers having a wide circulation in not less than two newspapers in the cities of Pittsburgh, Cincinnatti, and Louisville, for bridges above the mouth of the Big Sandy, and in the cities of Pittsburgh, Cincinnatti, Louisville, St. Louis, Memphis. and New Orleans, for bridges below the mouth of the Big Sandy, and shall submit to the Secretary of War, for his examination, a design and drawings of the bridge and piers, and a map of the location, giving, for the space of at least one mile above and one mile below the proposed location, the topography of the banks of the river and the shore lines at high and low water.

This map shall be accompanied by others, drawn on the scale of one inch to two hundred feet, giving, for a space of one-half a mile above the line of the proposed bridge and a quarter of a mile below, an accurate representation of the bottom of the river, by contour lines two feet apart, determined by accurate soundings, and also showing over the whole width of this part of the river the force and direction of the currents at low water, at high water, and at least one intermediate stage, by triangulated observations on suitable floats. The maps shall also show the locations of other bridges in the vicinity, and shall give such other information as the Secretary of War may require for a full and satisfactory understanding of the subject. Said maps and drawings shall be referred to a board of engineers for examination and report, which board shall personally examine the site of the proposed bridge, and shall hold a public session due to notice and invitation to be present shall be given to all interested parties; and, it said board of engineers reports that the site is unfavorable, the Secretary of War shall be authorized, on the recommendation of said board, to order such changes in the bridge or its piers, or such guiding dikes or other auxiliary works as may be necessary, at the expense of the proprietors or managers of such bridge or piers and other works for the security of navigation; and the proposed bridge shall only be a legal structure when built as approved by the Secretary of War."
SEC. 5. "That the right to alter, amend or repeal this act as set forth in section seven of the act hereby amended is hereby reserved."

APPENDIX O

CONTRACT WITH WAR DEPARTMENT - CAIRO BRIDGE

Whereas, by an Act of Congress, approved December 17, 1872, entitled, "An Act to authorize the construction of bridges across the Ohio River, and to prescribe the dimensions of the same," it was enacted, that any persons or corporations, having lawful authority therefor, may hereafter erect bridges across the Ohio River for railroad or other used, upon compliance with provisions contained in said act;

And whereas, by section four of an Act supplementary to the act aforesaid, approved February 14, 1883, it was further enacted that any person, company, or corporation, authorized to construct a bridge across the Ohio River, shall submit to the Secretary of War, for his examination, a design and drawings of the bridge and piers, and a map of the location, giving, for the space of at least one mile above and one mile below the proposed location, the topography of the banks of the river and the shore lines at high and low water. This map shall be accompanied by others, drawn the scale of one inch to two hundred feet, giving, for the space of one-half mile above the line of the proposed bridge and a quarter of a mile below, an accurate representation of the bottom of the river by countour lines two feet apart, determined by accurate soundings, and also showing over the whole width of this part of the river the force and direction of the currents at low water, at high water, and at least one intermediate stage, by triangulated observations on suitable floats. The maps shall also show the locations of other bridges in the vicinity, and shall give such other information as the Secretary of War may require for a full and satisfactory understanding of the subject. Said maps and drawings shall be referred to a board of engineers for examination and report, which board shall personally examine the site of the proposed bridge, and shall hold a public session at some convenient point to hear all objections thereto, of which public session due notice and invitation to be present shall be given to all interested parties; and if said board of engineers reports that the site is unfavorable, the Secretary of War shall be authorized, on the recommendation of said board, to order such changes in the bridge or its piers, or such guiding dikes or other auxiliary works as may be necessary, at the expense of the proprietors or managers of such bridge or piers and other works, for the security of navigation; and the proposed bridge shall only be a legal structure when built as approved by the Secretary of War;

And whereas, the Chicago, St.Louis and New Orleans Railroad Company, a duly organized corporation, having authority to build a railroad bridge across the Ohio River at Cairo, in the State of Illinois, pursuant to the Acts of Congress aforesaid regulating the construction of bridges across the Ohio River, and having accepted the provisions of said Acts, has submitted, for the

approval of the Secretary of War, the design and drawings of its proposed bridge and piers and a map of the location of the same, together with maps giving a representation of the bottom of the river and the force and direction of the currents;

And whereas, the Chief of Engineers, United States Army, reports that said design, drawings and maps, in his opinion, conform to the requirements of the board of engineers, and also with the provisions of the Act of December 17, 1872, and the supplementary Act of February 14, 1883, authorizing the construction of bridges across the Ohio River.

Now, therefore, I, William C. Endicott, Secretary of War, having examined and considered the design, drawings and maps submitted by the Chicago, Saint Louis and New Orleans Railroad Company as aforesaid, and hereto annexed, do hereby approve the same.

But it is understood and agreed that this approval is given upon the express conditions following:

1. That the said bridge shall be built at the point indicated in the map of location submitted, and constructed in accordance with the design and drawings hereby approved and the laws regulating the constructions of bridges across the Ohio River.

2. That should any change be deemed necessary to be made in the design and drawing of said bridge during the progress of construction, such change shall be subject to the approval of the Secretary of War.

Witness my hand this first day of April, 1887.

(Signed) Wm. C. Endicott
Secretary of War

This instrument is also executed by the Chicago, Saint Louis and New Orleans Railroad Company, by Stuyvesant Fish, its Vice-President, thereto lawfully authorized, this thirty-first day of March, 1887, in testimony of the acceptance by said Company of the conditions herein imposed.

Stuyvesant Fish
Vice-President of the Chicago, Saint Louis and New Orleans Railroad Company
In presence of
E.T.H. Gibson
W.E. Ruttan

APPENDIX P

CONTRACT FOR CAIRO BRIDGE (1887)

This agreement, made and entered into on this the fourth day of May, 1887, by and between George S. Field, Edmund Hayes, C.S. Maurice and Charles MacDonald, who as individuals, and also as a partnership firm, doing business under the firm name of "Union Bridge Company," of New York, contract, as hereinafter set forth, as parties of the first part, and the Chicago, St. Louis and New Orleans Railroad Company, a corporation existing under the laws of Kentucky, Tennessee, Mississippi and Louisiana, and acting herein under authority granted by the State of Kentucky, contracts as hereinafter set forth as party of the second part, witnesseth as follows:

First - The parties of the first part aforesaid contract and agree with the party of the second part aforesaid that they will, according to the annexed plans and specifications, and under the directions of the Chief Engineer, construct a railroad bridge across the Ohio River, between Ballard County, in the State of Kentucky, and Alexander County, in the State of Illinois, at a place where the Chief Engineer of said bridge has located the same, upon the terms and conditions following, to-wit:

The parties of the first part agree to furnish the necessary materials, means and appliances, and to perform and do in accordance with the plans and specifications aforesaid, and under the direction of the Chief Engineer aforesaid, the work of sinking foundations for the river piers of said bridge, and constructing then in the manner described in the accompanying specifications aforesaid, and under the direction of the Chief Engineer aforesaid, the work of sinking foundations for the river piers of said bridge, and constructing them in the manner described in the accompanying specifications, for five and five-tenths (5-5/10) cents per pound for the iron and steel; forty-two dollars ($42) per thousand feet, board measure, for the timber; forty (40) cents per cubic foot for the concrete used therein, and thirteen (13) cents per cubic foot for materials removed in sinking such foundation. The amount of such material to be estimated as equal to the area of the base of the foundation multiplied by the depth from low water to the bottom of the cutting edge.

Second - To construct the pile foundations of the shore piers as described in the accompanying specifications, and furnish all the materials, means and appliances therefor, at twenty-five (25) cents per cubic yard for necessary earth excavation; thirty-five (35) cents per lineal foot for the necessary piles left in the completed work, and forty (40) cents per cubic foot for the concrete used therein.

Third - To furnish stone and all other materials to be used in the masonry and all the necessary means and appliances, and construct the masonry, as required in the accompanying specifications, in the river piers of said bridge

of eighteen dollars ($18) per cubic yard of such masonry when complete.

Fourth - To furnish the materials and manufacture the superstructure of said bridge -

Two (2) five hundred and eighteen and five-tenths (518-5/10) feet spans;
Seven (7) four hundred (400) feet spans;
Three (3) two hundred and fifty (250) feet spans;

according to the annexed specifications, at four and three-tenths (4-3/10) cents per pound for finished material delivered at Chicago.

Fifth - To erect the superstructure complete, ready for the cross-ties, for the following prices:

Each 518-5/10 foot span at twenty-five thousand dollars ($25,000).
Each 400 foot span at fourteen thousand dollars ($14,000).
Each 250 foot span at two thousand dollars ($2,000).

Sixth - The work herein specified shall be executed under the direction of the Chief Engineer of the bridge and his assistants, by whose measurements and calculations of the quantities and amount of the several kinds of work done and materials furnished, the monthly estimates shall be made and the final estimate determined, and the said Chief Engineer shall have power to reject all work and materials which, in his opinion shall not be in accordance with the plans and specifications hereto attached, and with the spirit of this agreement. During the progress of the work, he shall determine any questions as to what is required by the plans and specifications, and he shall decide whether the work is from time to time proceeding with such diligence as to insure the completion of the several parts, and of the whole work, as herein contracted and by the times mentioned in this contract; and if, in the opinion of said Chief Engineer, said work, or any part thereof, shall not be so proceeding, he shall require such additional force to be put upon the same within such time as he may, in writing, designate, and upon the failure of the parties of the first part to comply with such requirements, the said Chief Engineer may put upon said work the additional force so required at the expense of the parties of the first part to comply with such requirements, the said Chief Engineer may put upon said work the additional force so required at the expense of the parties of the first part.

Or the said Chief Engineer, upon the failure of the parties of the first part to comply with such requirements or any of them within the time so designated, or of their failure to perform any of their covenants or agreements as herein convenanted or agreed, for thirty days after notice of the breach thereof, may, and on the demand of the party of the second part shall, declare that the parties of the first part have broken this contract and have failed to comply with its terms, and thereupon have broken this contract and have failed to comply with its terms, and thereupon said parties of the first part shall forfeit all claim to the reserved fund or any part thereof which is hereinafter mentioned, and this contract shall be, by their said default so declared, terminated.

Seventh - The work shall be at all times under the supervision of the said

Chief Engineer of said bridge and his assistant engineers, all of whom are to be appointed by the second party, and said Chief Engineer shall have authority to discharge disorderly or inefficient foremen of other employees of the parties of the first part engaged in said work, if in his judgement their presence or employment upon the work is detrimental to its character, progress or interests; provided, the parties of the first part fail to discharge them upon his request to do so.

Eighth - The rate of progress and time of completion shall be as follows: the foundations of the three large river piers shall be completed in the year 1887, and the masonry of these piers before July 1888. the two longest spans shall be raised in the fall of 1888. The seven remaining foundations shall be put in during the year 1888, and the masonry of these piers completed before July 1889. The seven remaining river spans shall be erected in the fall of 1889, and the entire bridge, including all piers and spans and other work mentioned in this contract shall be completed on or before December 31, A.D. 1889.

The work on said bridge and piers and foundations shall be continued without unnecessary delay to completion, and there shall be no unnecessary delay in furnishing the materials nor in any part of the work of construction, nor any haste in the work or any part thereof which may affect injuriously the stability of foundations, piers or superstructures of any part thereof, nor shall any material mentioned in or allowed by the specifications be used which is not the best for the purpose used according to the opinion of the Chief Engineer of said bridge.

In case any change in the location, specification or plans of said bridge, prior to its final completion, is required by the Secretary of War, or the party of the second part, the prices of the material furnished therefor or work done thereon shall not exceed those herein mentioned for similar material or work.

Ninth - In case the entire work is not completed on the said 31st of December, 1889, then and in that case the parties of the first part shall pay to the party of the second party three hundred and fifty dollars ($350) per day as liquidated damages for each day beyond said date that the entire work remains incomplete.

Tenth - It is further agreed between the parties hereto, that the parties of the first part shall have no right or power to assign this contract in whole or in part, nor to assign any right arising thereunder; and in case of the insolvency or bankruptcy of said parties of the first part, or any of them, prior to the final completion of said bridge, there shall be nothing due them under this contract save for such parts of materials furnished and accepted, and for work theretofore done that had not been at that time estimated, or, if estimated, had not been paid; but the failure from insolvency to progress with or finally complete said work and its several parts, or either of them, as an at the dates hereinbefore mentioned, or the failure from any cause to finally complete said bridge as herein contracted, shall, ipso facto, be a forfeiture

of the reserved fund, and neither of said parties of the first part, nor any assignee in bankruptcy or otherwise, shall have any right or claim thereto or to any part thereof. And it is further agreed that no part of the work mentioned herein shall be sublet or in any way removed from the control of the parties of the first part, under the direction and supervision of the Chief Engineer as aforesaid, except as herein provided.

Eleventh - The character of the work, the kind of materials furnished and all other requirements of the annexed specifications and plans, and the times limited for the completion of each part, and of the whole, are agreed to be essential parts of this contract.

Twelfth - The terms of payment for the work shall be as follows: During the progress of the work the Chief Engineer shall cause estimates to be made of the work done and materials delivered during each calendar month, and about the 15th day of the succeeding month, the amount of the same shall be paid to the parties of the first part, less, however, a reserved fund of ten (10) per cent, which reserved fund shall be held by the second party as security for the completion of the whole work and its several parts; and if at the times herein contracted, each and every part of said bridge has been built in accordance with the specifications and plans, and is delivered up to the second party free from all their convenants and undertakings herein, then the party of the second part is to pay over to the parties of the first part all of said reserved fund.

And provided further, that when the last foundation shall have been completed in accordance with the terms of this contract, then the party of the second part shall pay over to the parties of the first part so much of such reserved fund as shall be necessary to reduce the amount held by the party of the second part to the sum of one hundred thousand dollars ($100,000), and said sum of one hundred thousand dollars, and no more, shall be retained by the party of the second part as security for the completion of the whole work.

It is agreed that, after the completion of the entire work in accordance with the specifications and directions of the Chief Engineer, and before the final settement is made, any differences or controversies arising under this contract between the parties hereto may be finally settled by a body of arbitrators consisting of three persons: one to be the Chief Engineer of said bridge, one to be named by the contractors, to wit, the parties of the first part, and the third to be selected by the other two. The arbitrators shall judge by a majority vote, and their decision shall be final and binding on both parties, and their award shall be performed within fifty (50) days after the work is finally completed and accepted and the award announced; but the party asking said arbitration shall, in writing, specify the particular thing to be arbitrated, and the arbitrators shall be confined to the things so specified by the one or both parties.

Thirteenth - It is further agreed that no material shall be estimated until delivered at the bridge site, except steel for the superstructure, which shall be estimated when delivered at the shops of the party of the first part; and such steel shall be marked and set apart for use in said bridge, and the

parties of the second part shall have special lien thereon to the extent of the advances thus made; nor shall any material be paid for on final estimate or otherwise which does not form an actual part of the finished structure or is not of the class and quality required by the specifications.

In making monthly estimates the following prices shall be used:

Dimension stone, cut and delivered, ten dollars ($10.00) per cubic yard.

Backing, cut and delivered, seven dollars ($7.00) per cubic yard.

Timber for foundation, delivered, sixteen dollars ($16.00) per thousand feet, board measure.

Iron for foundation, delivered, four cents ($.04) per pound.

Steel for superstructure, manufactured at shop, eighty (80) per cent of finished price at Chicago.

No claim for extra work shall be paid unless it be presented within fifteen (15) days after the end of the month in which said work is performed, and then only when approved by the Chief Engineer as having been ordered by him to be done.

Fourteenth - It is further agreed that the materials of the superstructure of said bridge which said parties of the first part may ship from Chicago to Cairo over the Illinois Central Railroad, and also any necessary switching of the same at Cairo or East Cairo, or transferring across the Ohio River between the inclines at Cairo and East Cairo, shall be carried and done without unreasonable delay and without cost to said parties of the first part, but all losses or damage during such transportation, switching or transfer shall be borne alone by said party of the first part.

Fifteenth - In Witness Whereof, the parties of the first part, as individuals and also as a partnership firm, have hereunto set their several and their partnership names and private seals, and the party of the second part has caused its corporate name to be hereto signed and its corporate seal to be hereto affixed this the day and year first above written.

(L.S.) George S. Field,
(L.S.) Edmund Hayes,
(L.S.) C.S. Maurice,
(L.S.) Charles MacDonald,
Union Bridge Co., by C. MacDonald
Chicago, St. Louis & New Orleans Railroad Co., by Stuyvesant Fish, Vice Pres.
(L.S.) E.T.H. Gibson, Secretary C., St. L & N.O. R.R. Co.

SPECIFICATIONS FOR CAIRO BRIDGE

GENERAL DESCRIPTION

The bridge will consist of two channel spans, seven river spans and three approach spans. There will be eleven masonry piers in the river, founded on

pneumatic caissons, these eleven piers supporting the ten channel and river spans; and three smaller piers, founded on piles, supporting the approach spans.

The Substructure of the bridge will be understood to include these thirteen piers, both masonry and foundations.

The Superstructure will include the twelve spans above named.

Full detailed plans of both substructure and superstructure will be furnished by the Engineer of the bridge.

The work shall be built in all respects according to these plans. The contractor, however, will be expected to verify the correctness of the plans and will be required to make any changes in the work which are necessitated by errors in these plans without extra charge, where such errors can be discovered by inspection of the plans.

SUBSTRUCTURE

The three piers next to the Illinois shore, which support the two main channel spans, will finish 12 feet thick, and 29 feet long between shoulders and 41 feet long over all under coping. The other seven river piers will measure 10 feet thick, 25 feet long between shoulders, and 35 feet long over all under the coping. The three shore piers will measure 8 feet thick, 20 feet long between shoulders, and 28 feet long over all under the coping.

The masonry of the ten channel and river piers shall begin 25 feet long below low water, or at elevation 75 above the assumed datum.

The masonry of the shore piers shall begin 10 feet below the natural surface of the ground.

The pneumatic foundations of the river piers shall be sunk 75 feet below low water, or to an elevation 25 feet above datum, unless otherwise specially directed.

PNEUMATIC FOUNDATIONS

The pneumatic caissons for the three channel piers will be 30 feet wide and 70 feet long. Those of the seven river piers 26 feet wide and 60 feet long. The caissons will be surmounted by a timber crib work which shall make the total height from cutting edge to top of crib work 50 feet, the sides being vertical and the top of the crib finished of the same dimensions as the caisson.

The caissons and crib work shall be built of thoroughly sound yellow pine timber or such other timber as may be approved by the Engineer of the bridge, ans shall be planked on the outside with two thicknesses of three-inch oak plank, the inner thickness being put on at an angle of 45 degrees. The timber work shall be accurately and closely framed, the timbers being sized so as to secure immediate contact throughout, and the inner course of plank being planed

to uniform thickness so as to secure an exact fit for the outer course. The timbers shall be bolted together with long rods and with drift bolts, as shown on the plans.

The cutting edge of the caissons shall be of iron and of the form shown on the plan. An iron working shaft shall be built into the caisson and crib work for a height of 20 feet above the roof of the working chamber, which distance may include the shell of the air lock. A supply shaft, 24 inches in diameter, shall also be built into the caisson, crib work and masonry. One four-inch pipe, one five-inch water pipe and two four-inch discharge pipes shall also be built into the caisson, crib work and masonry.

The space above the working chamber and within the outer walls of the caisson and crib work shall be filled with concrete. The concrete within two feet of the top of the roof of the working chamber shall be formed of Portland cement and sand, three parts of sand to one part of cement, into which sound stone may be rammed after it is put in position. The upper one foot of the concrete shall be formed in the same way. The remainder of the concrete shall be made of Louisville cement, sand and stone, two parts of sand to one of cement, and not over 60 per cent of the whole volume in broken stone, the amounts of cement not to exceed two barrels per cubic yard. In Portland cement, the sand and cement shall be mixed together dry, then run through a satisfactory machine mixer. The mass of concrete shall always be thoroughly rammed after being put in position. The Louisville cement concrete shall be worked in a mixer approved by the Engineer.

The caissons shall by sunk to the height specified above and shown on plans, unless otherwise specially directed by the Engineer, and shall not vary more than fifteen inches from correct position. The sand shall be excavated by the process used at the Rulo and Omaha bridges, unless some other plan is approved specially. When the required depth is obtained, the caissons shall be filled with concrete, the lower two feet of concrete reaching to the shoulder of the cutting edge and to the cross beams shall be formed of Portland cement and sand, three of sand to one of cement. The remainder of the filling may be of Louisville cement, sand and stone, in the proportion mentioned above. The working shaft and supply shaft and pipes shall not be filled, but shall be closed at the ends with iron or wooden bulk heads.

PILE FOUNDATIONS

The piles shall be arranged according to detailed plans to be furnished by the Engineer. They shall be straight, and of good, sound white or burr oak or cypress or other hard wood that may be driven to refusal without splitting; they shall be at least eleven inches in diameter at the small end.

They shall driven in a pit excavated about twelve feet deep and so as not to go more than the one-half inch at the last blow of a hammer weighing 3,000

lbs., and falling twenty-five feet. They shall be cut off level and finished clear of splinters.

Concrete made of Portland cement and mixed as prescribed elsewhere in these specifications shall be placed between the piles and shall be well rammed and shall extend at least two feet below the head of the piles and two feet above them and shall then be perfectly leveled off.

On this concrete foundation, when it has become well set, shall be built masonry piers according to the general plans now furnished, and more detailed plans to be furnished by the Engineer in charge, after which pit shall be refilled with earth well rammed.

MASONRY

The stone must be strong, compact, and of uniform quality and appearance and free from any defect, that, in judgement of the Engineer, may impair its strength or durability.

The stone from the quarries in Bedford, Indiana, will be acceptable stone for dimension work. The Engineer may authorize the acceptance of other stone, which, in his judgement, is equal in quality and similar in appearance to the Bedford stone. The corner stone in each course of the up-stream nose of the ten river piers shall be of granite.

There shall be no course less than sixteen inches in thickness, and no course shall be thicker than the one immediately beneath it.

The joints shall be broken at least fifteen inches; each bed of every stone shall be at least one and a half times the thickness of the course in both directions, and there shall be none less than thirty inches, and no stone shall have an over hanging top bed.

The stretchers shall not be less than four feet, nor more than seven feet long. Stretchers of the same width shall not be placed together vertically.

The headers shall be from five to six feet long; every second or third stone in each course must be a header, and there shall be at least five headers in each course between the shoulders. They must hold 75 per cent size from face to back.

The joints of the face stones shall be cut 12 inches back from the face. The horizontal joints shall average 1/2-inch and shall never be less than 3/8-inch.

No leveler shall be put under a stone to bring it up to the proper level.

No hammering will be allowed after the course is set; if any inequalities occur, they must be carefully pointed off.

All stones, whether face, coping or backing, shall be laid with the natural beds horizontal and in full flush beds of mortar, mixed fresh as required for work. All stone must be carefully cleaned and moistened before being laid on any stone already set until the latter had been thoroughly cleaned and wet.

Each course must be completed and the mortar in the vertical joints well rammed before the next one is begun.

The face work shall be in Ashlar (rock face), but no projection greater than three inches will be allowed nor will any hollow stone.

The up-stream starlings below high water shall be fine pointed to 1/2-inch

The top coping and the coping of the projecting starlings shall be bush-hammered throughout.

The top coping shall have a wash 12 inches wide and 6 inches high. The coping shall be made according to special plans, so as to give proper bearing for the bridge seats.

There shall be a draft line of three inches on the corners of the piers and along the lower edge of the belting course under the coping.

The face stones of every course of the up-stream starlings between high water and low water shall be dowelled into those of the course below with round dowels of 1-1/8-inch iron, extending six inches into each course; the dowels shall be placed from 8 to 12 inches back from the face and six inches on each side of every joint. The stones of the upper course shall be drilled through before setting, after which the drill hole shall be extended six inches into the lower course; a small quantity of mortar shall then be put into the hole, the dowel dropped in and driven home and the hole filled with mortar and rammed. The three courses below the coping shall have the joints bonded with cramps of 7/8-inch round iron, 20 inches long between shoulders, the ends being sunk three inches into each stone.

The dimension stone shall be laid in Portland cement mortar of two parts of sand and one part of cement. The backing shall be laid in mortar of American cement of two parts of sand and one part of cement.

The Portland cement shall be an imported cement, equal in quality to O.F. Alsen & Sons' best quality, and the American cement shall be equal to the best grades of Louisville cement.

When masonry is laid up in freezing weather, the backing shall be laid in Portland cement, three parts of sand and one part of cement, and such other precautions taken against freezing as the Engineer may direct.

The joints of the face stones shall be picked out and pointed in mild weather, with two parts of sand and one part of Portland cement, which shall be driven in with a calking iron.

SUPERSTRUCTURE

All parts except nuts, swivels, wall pedestal plates and ornamental work will be of steel. The nuts and swivels may be of wrought iron, the pedestal plates and ornamental work of cast iron.

MATERIALS

All materials shall be subject to inspection at all times during their

manufacture, and the Engineer and his inspectors shall be allowed free access to any of the works in which any portion of the material is made. Timely notice shall be give to the Engineer so that his inspectors may be on hand.

Steel may be made by the open hearth or by the Bessemer process, but no steel shall be made at works which have not been in successful operation for at least one year. Steel made by the Clapp-Griffiths process will not be accepted. All melts shall be made from uniform stock low in phosphorus, and the manufacturer shall furnish satisfactory evidence to the Engineer that this class of material is being employed, it being understood that the finished product is to be one in which the phosphorus does not average more than 8-100 of one per cent, and never exceed 1-10 of one per cent.

A sample bar 3/4-inch in diameter shall be rolled from every melt; the method of obtaining the piece from which the sample bar is rolled shall be the same for all samples, and the amount of work on this sample bar shall be as nearly as practicable the same as on the finished product. The laboratory tests shall be made on this sample bar in its natural state without annealing.

The laboratory tests of steel made on the sample bar shall be an elastic limit of not less than 40,000 pounds per square inch, an ultimate strength of not less than 67,000 pounds nor more than 75,000 pounds, an enlongation of at least 20 per cent in a length of eight inches, and a reduction of at least 42 per cent at the point of fracture - this enlongation and reduction being the minimum and not the average requirements. In a bending test, the sample bar shall bend 180 degrees and close back against itself without showing crack or flaw on the outside of the curve. Steel, having an ultimate strength of 60,000 pounds per square inch will be accepted for rivets.

Should the contractor desire to use British steel, the quenching and bending test specified in the Hawksbury Bridge specifications will be required, and the elastic limit requirement may be waived.

Every piece of steel shall be stamped with a number identifying the melt, and a statement of the results of the laboratory tests of each melt shall be furnished by a contractor, certified by some person acceptable to the Engineer and accompanied by the tested specimens. Tests shall also be made from time to time on sample cut from finished plates, shapes and bars, which shall show results substantially conforming to those shown by the sample tests of the same melts.

All sheared edges or punched holes in steel work shall be substantially planed or drilled out, so that none of the rough surface is ever left upon the work. Steel for pins shall be sound and entirely free from piping, and more than four inches in diameter shall be drilled through the axis.

RIVETED WORK

All plates, angles and channels shall be carefully straightened before they are laid out; the rivet holes shall be carefully spaced in truly straight lines; the river heads shall be of hemispherical pattern, and the work shall be

finished in a neat and workman-like manner. Surfaces in contact shall be painted before they are put together. The dimensions given for rivets on the plans are the diameters of the rivets before driving.

Power riveters shall be direct acting machines, capable of exerting a yielding pressure and holding on to the rivet when the upsetting is completed.

The several parts of each member shall be assembled and the holes shall be drilled; the sharp edge of the drilled hole shall be trimmed so as to make a slight fillet under the rivet head, and the pieces shall be riveted together without taking apart. Should the contractor desire, the parts may be punched with a punch at least 3-32-inch smaller than the diameter of the rivet as given on the plans, working in a die only 1-64-inch larger than the rivet; the several parts of the member shall then be assembled and the holes reamed so that at least 1-16-inch of metal is taken out all around, and the sharp edge of the reamed hole shall be trimmed and the pieces riveted together as above. All rivets shall be of steel; the rivet holes shall be be of such size that the rivets will fill the hole before driving, and whenever possible, they shall be driven power. All bearing surfaces shall be truly faced. The chord pieces shall be fitted together in the shop in length of at least five panels, and marked; when so fitted there shall be no perceptible wind in the length laid out. The pin-holes shall be bored truly so as to be at exact distances, parallel with one another, and at right angles to the axis of the member.

The holes for rivets connecting the floor beams with posts and bolsters and the stringers with the floor-beams, and, in general, the holes for all rivets which must be driven after erection, shall be accurately drilled to an iron templet. The holes for the rivets connecting the floor-beams with the posts shall be one inch in diameter, and the rivets of corresponding diameter. The pin-holes in the vertical posts shall be truly parallel with one another and at right angles to the axis of the posts. The posts shall be straight and free from wind.

FORGED WORK

The heads of eye-bars shall be formed by upsetting and forging into shape by such process as may be accepted by the Engineer. No welds will be allowed. After the working is completed, the bars shall be annealed by heating them to a uniform dark red heat throughout their entire length, and allowing them to cool slowly. The form of the heads of steel eye-bars may be modified to suit the process in use at the contractor's works, but the form of head adopted must be such as to meet the requirements of the tests of full-sized bars.

The heads and the enlarged ends for screws in laterals, suspenders and counters shall be formed by upsetting by a process acceptable to the Engineer.

TESTS OF FULL-SIZED STEEL BARS

Thirty full-sized eye-bars of sections and lengths used in the actual work

shall be selected from bars for the bridge by the inspector for testing; each of these full-sized bars shall be strained till an enlongation of ten per cent is obtained, and, if possible, broken; if broken, the fracture shall occur in the body of the bar and shall show a uniform and ductile quality of material.

The contractor will be required to furnish facilities for testing the full-sized bars within a reasonable distance of his works. Should the contractor be unable to furnish such facilities, he shall be required to furnish bars of 20 per cent larger section than those called for, without charge for the increased weight.

The full-sized bars shall be selected from time to time as the work proceeds, the last bar not to be selected till all the eye-bars are manufactured. The tests shall be made from time to time as he bars are selected. When three bars have been tested, the bars manufactured up to the time as the bars are selected. When three bars have been tested, the bars manufactured up to the time of the selection of these three test bars shall be accepted or rejected on the results of such tests, and the same shall be done again when three more bars are tested. In these tests, the failure of one bar to develop a stretch of eight per cent, or of the lot to develop an average stretch of ten per cent, before breaking, shall be sufficient reason for rejecting the lot from which these bars are taken. A failure to break in the body of the bar shall not be a sufficient ground for condemnation if it does not occur in more than one-third of the bars tested, but the above requirements as to enlongation shall apply to the bars so breaking in the head, as well as to the others. The Engineer shall, however, examine carefully into the cause of breakage of any bar which does not meet the requirements, and, if the defect is explained, may order additional tests, and make the acceptance dependent on further results.

MACHINE WORK

The bearing surfaces in the top chord shall be truly faced. The ends of the stringers and of the floor-beams shall be squared in a facer. All surfaces so designated on the plans shall be planed. All sheared and punched edges shall be planed or bored out.

All pins shall be accurately turned to a gauge, and shall be of full size through-out; pin-holes shall be bored to fit the pins, with a play not exceeding 1/50 of an inch. These clauses apply to all lateral connections as well as to those of the main trusses. Pin shall be supplied with a pilot nuts for use during erection.

All screws shall have a truncated V thread, United States standard sizes.

MISCELLANEOUS

All workmanship and material, whether particularly specified or not, must be of the best kind now in use in first-class bridge work. Flaws, ragged

edges, surface imperfections, or irregular shapes will not be sufficient ground for rejection; rough and irregularly finished work will not be accepted.

Machine-finished surfaces shall be coated with white lead and tallow before shipment; all other parts shall be coated with white lead and tallow before shipment; all other parts shall be given a coat of hot boiled linseed oil.

ERECTION

The contractor will be required to erect the superstructure, furnishing all necessary false work, tools and appliances of every description, and to deliver the same to the Railroad Company complete in all respects, ready for the ties and painting. Such surfaces as are in immediate contact or will otherwise become inaccessible shall be painted by the contractor during erection. The superstructure will remain at the contractor's risk until the erection is completed. Each span shall be accurately adjusted so that the lateral system is perfectly straight and the counters are properly strained. All nuts shall be set up tight and checked.

MISCELLANEOUS

All piles, false work, and other obstructions shall be removed to the natural bed of the river, and this shall be done as fast as the foundation are completed so as to leave a clear river bed to receive the mattress or other protection work which the Railroad Company may wish to put in.

No material will be paid for which does not form a part of the permanent structure.

All expense of testing, other than the salary of the shop inspector, shall be borne by the contractor.

March 23, 1887
Geo. S. Morison, E.L. Corthell; Engineers
Union Bridge Co., by Geo. S. Field

APPENDIX Q

LIST OF ENGINEERS, COMPANY'S EMPLOYEES AND CONTRACTORS - CAIRO BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service		
Geo. S. Morison, Chief Engineer			
E.L. Corthell, Associate Chief Engineer			
Alfred Noble, Resident Engineer	July 5, 1887	to	Nov. 30, 1889
Geo. A. Lederle, Resident Engineer	Dec. 1, 1889	"	Feb. 28, 1890
Addison Connor, Assistant Engineer	June 12, 1887	"	Oct. 22, 1889
E. Duryea, Assistant Engineer	Nov. 19, "	"	Apr. 6, "
E.P. Butts, Assistant Engineer	Apr. 16, 1889	"	Nov. 30, "
E.H. Connor, Assistant Engineer	June 13, 1887	"	Dec. 31, 1888
" " , Insp. of Superstructure	Jan. 1, 1889	"	July 26, 1889
E. H. Mayne, Assistant Engineer	Sep. 22, 1888	"	Nov. 7, "
J.M. Heiskell, Assistant Engineer	May 22, "	"	Oct. 21, 1888
Chandler David, Rodman	July 12, "	"	Dec. 22, 1889
Sanford Morison, Rodman	July 31, "	"	Apr. 20, "
R.W. Hildreth, Insp. of Superstructure	Apr. 22, "	"	July 23, "
R. Modjeski, Insp. of Superstructure	Feb. 20, "	"	Dec. 31, 1888
Paul Willis, Insp. of Superstructure	Apr. 20, "	"	July 15, "
O. Benson, Insp. of Superstructure	July 1, "	"	Feb. 28, 1889
J.V.W. Reynders, Insp. of Superstructure	Mar. 1, 1889	"	July 30, "
I. Dickinson, Draughtsman			
Joshua Dixon, Insp. of Masonry	Aug. 14, 1887	"	June 22, "
George Reynolds, Insp. of Masonry	Sep. 30, "	"	May 20, "
F.H. Joyner, Insp./Stone at quarry	Aug. 10, "	"	Feb. 20, "
D.C. Morgan, Insp. of Cement	Sep. 2, "	"	May 31, "
August Holgren, Insp. of Cement	Sep. 5, 1897	"	June 15, "
Julius Thompson, Insp. of Cement	Mar. 1, 1888	"	Nov. 9, 1888
Nelson Joyner, Asst. Insp./Stone at quarry	Apr. 1, "	"	Apr. 28, 1889
John E. Griffen, For./Carpenters bg. floor	Dec. 28, "	"	Jan. 29, 1890
W. McMurray, Foreman of Painters	Apr. 20, 1889	"	Jan. 29, "

Contractors

Union Bridge Company, Contractors for Entire Structure
- Anderson & Barr, Sub-Contractors for Foundations
- L.M. Loss, Sub-Contractor for Masonry
- Baird Brothers, Sub-Contractors for Erection of Main Bridge
- John Grant, Foreman of Erection of Approach Spans

APPENDIX R - ACT OF CONGRESS AUTHORIZING CONSTRUCTION OF MEMPHIS BRIDGE (1888) AND CONTRACT WITH WAR DEPARTMENT

ACT OF CONGRESS

BE IT ENACTED BY THE SENATE AND HOUSE OF REPRESENTATIVES OF THE UNITED STATES OF AMERICA IN CONGRESS ASSEMBLED, That the Kansas City and Memphis Railway and Bridge Company, a corporation created and organized under and by virtue of the laws of the State of Arkansas, its successors and assigns, be and the same are here by authorized and empowered to erect, construct, and maintain a bridge over the Mississippi River, from or near the town of Hopefield in the State of Arkansas, to or near the taxing district of Shelby County, commonly known as the city of Memphis, in the State of Tennessee. Said bridge shall be constructed to provide for the passage of railway trains and wagons and vehicles of all kinds, for the transit of animals, and, at the option of the corporation by which it may be built, for foot-passengers, for such reasonable rates of toll as may be approved from time to time by the Secretary of War.

SEC. 2. That any bridge built under this act and subject to its limitations shall be a lawful structure, and shall be recognized and known as a post-route, upon which also no higher charge shall be made for the transmission over the same of the mails, the troops, and munitions of war of the United States, than the rate per mile paid for the transportation over the railroad or public highways leading to the said bridge, and it shall enjoy the rights and privileges of other post-roads in the United States.

SEC. 3. That the said bridge shall be made with unbroken and continuous spans. Before approving the plans for said bridge the Secretary of War shall order three engineer officers from the Engineer Bureau to be detailed to the duty of examining, by actual inspection, the locality where said bridge is to be built, and to report what shall be the length of the main channel span and of the other spans. Provided, That the main channel span shall in no event be less than seven hundred feet in length, or the other spans less than six hundred feet each in length; and if the report of said officers shall be approved by the Secretary of War, the spans of said bridge shall be of the length so required. The lowest part of the superstructure of said bridge shall be at least seventy-five feet above the extreme high-water mark, as understood at the point of location, and the bridge shall be at right angles to and its piers parallel with the current of the river. No bridge shall be erected or maintained under the authority of this act which shall at any time substantially or materially obstruct the free navigation of said river; and if

any bridge erected under such authority shall, in the opinion of the Secretary of War, obstruct such navigation, he is hereby authorized to cause such change or alteration of said bridge to be made as will effectually obviate such obstruction; and all such alterations shall be made and all such obstructions be removed at the expense of the owner or owners of said bridge; and in case of any litigation arising from any obstruction or alleged obstruction to the free navigation of said river caused by said bridge, the case may be brought in the circuit court of the United States within whose jurisdiction any portion of said obstruction or bridge may be located. Provided further, That nothing in this act shall be so construed as to repeal or modify any of the provisions of law now existing in reference to the protection of the navigation of rivers, or to exempt this bridge from the operation of the same.

SEC. 4. That all railroad companies desiring the use of said bridge shall have and be entitled to equal rights and privileges relative to the passage of railway trains or cars over the same, and over the approaches thereto, upon payment of a reasonable compensation for such use; and in case the owner or owners of said bridge and the several railroad companies, or any one of them, desiring such use shall fail to agree upon the sum or sums to be paid, and upon rules and conditions to which each shall conform in using said bridge, all matters at issue between them shall be decided by the Secretary of War, upon reasonable notice to the parties in interest and upon consideration of such allegations and proofs as may be submitted to him. But the last foregoing provision shall not be held to exclude the ordinary jurisdiction of the courts of the United States in such cases.

SEC. 5. That any bridge authorized to be constructed under this act shall be built and located under the subject to such regulations for the security of navigation of said river, as the Secretary of War shall prescribe; and to secure that object the said companies of corporations shall submit to the Secretary of War, for his examination and approval, a design and drawings of the bridge and a map of the location, giving, for the space of two miles above and two miles below the proposed location, the topography of the banks of the river, the shore-lines at extreme high and low water, the direction and strength of the currents at all stages, and the soundings, accurately showing the bed of the stream, the location of any other bridge or bridges, and shall furnish such other information as may be required for a full and satisfactory understanding of the subject; and until the said plan and location of the bridge are approved by the Secretary of War, the bridge shall not be built or commenced; and should any change be made in the plans of said bridge during the progress of construction, such change shall be subject to approval of the Secretary of War, and shall not be made or commenced until the same is so approved.

SEC. 6. That it shall be the duty of the Secretary of War, on

satisfactory proof that a necessity exists therefor, to require the company or persons owning said bridge to cause such aids to the passage of said bridge of be constructed, placed, and maintained at their own cost and expense, in the form of booms, dikes, piers, or other suitable and proper structures for the guiding of rafts, steamboats, and other water-craft safely through the passage-way, as shall be specified in his order in that behalf; and on failure of the company or persons aforesaid to make and establish and maintain such additional structures within a reasonable time, the said Secretary may cause the said bridge to be removed at the expense of the owners thereof, or may proceed to cause the same to be built or made at the expense of the owners of said bridge, and in that case shall refer the matter without delay to the Attorney General of the United States, whose duty it shall be to institute, in the name of the United States, proceedings in any circuit court of the United States within whose jurisdiction such bridge or any part thereof is located, for the recovery of the amount so expended by the Government and all costs of such proceedings shall be covered into the Treasury of the United States.

SEC. 7. That if the construction of the bridge hereby authorized shall not be commenced within one year from the time this act takes effect, and be completed within four years after the same date, then this act shall be void, and all rights hereby conferred shall cease and determine.

SEC. 8. That an act entitled "An act to authorize the construction of a bridge across the Mississippi River at Memphis, Tennesseee" approved February twenty-sixth, eighteen hundred and eighty-five, be, and the same is, hereby repealed.

SEC. 9. That the right to alter, amend, or repeal this act is hereby expressly reserved, and the right to require any changes in said structure, or its entire removal, at the expense of the owners, whenever the Secretary of War shall decide that the public interests require it, is also expressly reserved.

CONTRACT WITH THE WAR DEPARTMENT

Whereas, by an act of Congress, approved April 24, 1888, entitled "An act to authorize the construction of a bridge across the Mississippi River at Memphis, Tennessee," it was enacted that the Kansas City & Memphis Railway and Bridge Company, a corporation created and organized under and by virtue of the laws of the State of Arkansas, its successors and assigns, be, and the same are hereby authorized and empowered to erect, construct, and maintain a bridge over the Mississippi River from or near the town of Hopefield, in the State of Arkansas, to or near the taxing district of Shelby County, commonly known as the city of Memphis, in the State of Tennessee; and,

Whereas, It is provided by section 5 of the act of Congress aforesaid, That any bridge authorized to be constructed under this act shall be built and

located under and subject to such regulations for the security of navigation of said river as the Secretary of War shall prescribe; and to secure that object, the said companies or corporations shall submit to the Secretary of War, for his examination and approval, a design and drawings of the bridge, and a map of the location, giving, for the space of two miles above and two miles below the proposed location, the topography of the banks of the river, the shore lines at extreme high and low water, the direction and strength of the currents at all stages, and the soundings, accurately showing the bed of the stream, the location of any other bridge or bridges, and shall furnish such other information as may be required for a full and satisfactory understanding of the subject; and until the said plan and location of the bridge are approved by the Secretary of War, the bridge shall not be built or commenced; and should any change be made in the plans of said bridge during the progress of construction, such change shall be subject to approval of the Secretary of War, and shall not be made or commenced until the same is so approved; and,

Whereas, The original plans were submitted to a board of Engineer Officers for examination and report, as provided in section 3 of the act of Congress aforesaid; and,

Whereas, The Kansas City & Memphis Railway and Bridge Company aforesaid has accepted the provisions of the act of Congress aforesaid, and in compliance therewith has submitted to the Secretary of War for his examination and approval a design and drawing of a proposed bridge across the Mississippi River, the main channel span of which is not less than seven hundred feet in length, and the other spans not less than six hundred feet in length, and the lowest part of the super structure is seventy-five feet above extreme high-water mark, and has also submitted a map of the location thereof;

Now, therefore, I, William C. Endicott, Secretary of War, having examined and considered the plans of said bridge, and the map of the location thereof, submitted by the Kansas City & Memphis Railway and Bridge Company aforesaid, and which are hereto attached, do hereby approve the same, subject, however, to the following conditions, viz:

1. That the Kansas City & Memphis Railway and Bridge Company shall provide an independent roadway for wagons and animals on each approach of said bridge, and, for the entire length of the bridge proper, a roadway of sufficient width for wagons to pass each other without inconvenience, to be used by wagons and animals in common with the railroad.

2. That said bridge shall be open for the passage of wagons and animals at all times except when trains are actually crossing.

3. That reasonable signals shall be given when trains are approaching the bridge, and no train shall be permitted to enter the common roadway until the wagons which are on the roadway when the signal is given have passed off of said common roadway.

6. That the Engineer Officer of the United States Army in charge of the district within which the bridge is to be built may supervise its construction so far as may be necessary in order that the plans herein approved shall be complied with and the bridge built accordingly.

Witness my hand this twenty-third day of August 1888.
Wm. C. Endicott,
Secretary of War

This instrument is also executed by the Kansas City & Memphis Railway and Bridge Company, by George H. Nettleton, its President, thereunto lawfully authorized, this twenty-third day of August 1888, in testimony of the acceptance by said company of the provisions of the act of Congress aforesaid, and of the conditions herein imposed.

Kansas City & Memphis Railway and Bridge Company
By Geo. H. Nettleton,
President

In presence of
F.H. Damon

APPENDIX S

SPECIFICATIONS FOR MASONRY - MEMPHIS BRIDGE

PIERS

There will be four piers numbered from east to west and an Anchorage Pier.

The Anchorage pier will stand on the east bluff and back of the present face of that bluff. It will contain approximately 700 cubic yards.

Pier I will be on the East side of the river, standing in nine feet of water at high water. It will contain approximately 2,300 cubic yards.

Piers II and III will be in the river. They will each contain approximately 4,400 cubic yards.

Pier IV will be near the west bank. It will contain approximately 2,800 cubic yards.

Piers I, II and III will finish 12 feet thick, 35 feet long between shoulders and 47 feet long over all under the belting course.

Pier IV will finish 10 feet thick, 37 feet long between and 47 feet long over all under the belting course.

The lower portions of Piers II and III will not be solid, but will contain three hollow spaces extending from the bottom of the masonry to high water.

The piers shall be built in all respects to conform to the plans which will be furnished by the Engineer.

The Anchorage Pier must be built around the anchor rods, which will extend from the bottom to the top of the masonry.

FOUNDATIONS

The foundations will be put in by the company.

The foundation for Pier I will finish at elevation 201, or 20 feet above low water, and the masonry will be started after the foundation is completed.

The foundation for Piers II and III will finish at elevation 141, or 40 feet above low water.

The contractor will be required to lay the masonry for these piers while the pneumatic foundations are being sunk, and to keep up with the rate of sinking, and must be prepared to lay four feet of vertical masonry per day.

The foundation of Pier IV is now finished at elevation 173, or eight feet below low water mark.

It is surmounted by a water-tight curb, and the contractor will begin laying masonry on the completed foundation.

STONE

The masonry below elevation 180 and the footing courses of Pier I may be of limestone. The masonry of Pier I above the footing courses, and of Piers II, III and IV above 180 and in each case below elevation 229 shall be of granite with limestone backing. The masonry above elevation 229 shall be of limestone or of granite with limestone backing, as may be directed by the Engineer.

The limestone used shall be that known as Bedford limestone from the quarries near Bedford, Indiana, unless some other limestone is expressly accepted by the Chief Engineer. The granite shall be a granite specially accepted by the Chief Engineer. All stone of each class shall be subject to the approval of the Engineer.

MASONRY

The masonry shall be first class work, laid in regular courses.

Copings, starling coping included, shall have the upper beds, wash, face and a width of six inches from face on lower beds six cut with true lines and surfaces. Belting shall have a like proportion of the lower bed bush hammered and shall have a face margin draft of four inches along the lower edge. The face of the upstream starling of Piers II and III shall be fine pointed with no projection exceeding one half inch. There shall be a draft of four inches on each side of the point of the pier on both the upstream and downstream ends of all piers below the starling coping. All other parts of the work shall have a rock face with no projections exceeding three inches from the pitch line of the joint and no hollows back of that pitch line.

The interior faces of the walls in the hollow portion of Piers II and III shall have no projections exceeding six inches and no hollows exceeding two inches from the true dimensions of the plans.

The stones shall be cut and coursed out at the quarries, every dimension stone being marked for its place, and full course plans shall be furnished to the Resident Engineer before shipment.

No course shall be less than 20 inches thick nor more than 36 inches thick, and no course, except the main belting and coping, shall be thicker than the course below it. The backing shall be of the same thickness as the dimension work and with beds of precisely the same character.

The bottom beds of the face stones shall never be less than 36 inches in either direction. Headers shall be at least six feet deep measuring from pitch line of the face, and stretchers shall measure at least five feet long in the wall.

Every header shall retain a width of at least 24 inches at the full specified depth from the face. Every stretcher shall retain a length of at least four feet 36 inches back from the face. The beds of the principal pieces

of backing in each course shall average at least eight square feet. The bottom bed shall always be the full size of the stone. The tip bed shall nowhere be more than six inches less than the bottom bed. There shall be not less than three nor more than four headers between the shoulders on each side in each course. In the hollow portions of Piers II and III there shall be at least one stone in each course bonding three feet each way between the cross walls and the face walls of the pier.

The upper and lower beds shall be parallel and dressed closely to true planes with no projections above those planes.

The face edges shall be pitched to true lines. The cutting of joints for a distance of 12 inches from the face shall be the same as that of the beds.

Joints shall be at right angles with face beds unless otherwise shown on special plans. The hollows due to plugging must not exceed eight per cent of the surface of the bottom bed nor fifteen per cent of the surface of the top bed of any stone. No plug hole to be more than nine inches across nor more than one inch deep. Hollows due to plugging will not be allowed in limestone.

Joints shall be broken at least 15 inches on the face.

The stones for the coping shall be cut according to special plans to be furnished by the Engineer; all the beds shall be the full size of the stones, and special pains shall be taken with the bearings on the belting course below the coping.

All stones shall be laid in full mortar beds. They shall be lowered on the bed of mortar and be brought to a bearing with a maul, no spawls being allowed. Thin mortar joints will not be insisted on, but the joints shall be properly cleaned on the face to a depth of one inch and a half and pointed in mild weather, the pointing to be driven in with a caulking iron. the openings in the backing shall never exceed a maximum of six inches or an average of two inches between adjacent stones; these openings shall be filled with small stones thoroughly bedded and well packed in mortar.

The face stones of every seventh course shall be dowelled into those of the course below with round dowels of one and one eighth inch iron, extending six inches into each course; the dowels shall be placed from eight to twelve inches back from the face and eight inches on each side of every joint. The stones of the upper course shall be drilled through before setting, after which the drill hole shall be extended six inches into the lower course; a small quantity of mortar shall then be put into the hole, the dowel dropped in and driven home and the hole filled with mortar and thoroughly rammed.

The four courses under the coping shall have the joints bonded with cramps of one inch round iron twenty inches long between shoulders, the ends being sunk four inches into each stone.

MORTAR

The cement used in masonry will be furnished by the Bridge Company, but the contractor will be required to take care of the cement and will be held responsible for any waste. The mixture of mortar and the selection of the cement shall be directed by the Resident Engineer.

The contractor will be required to furnish his own sand, which shall be subject to the approval of the Resident Engineer.

CONDITIONS

The contractor will be required to furnish all necessary tools and materials of every description whatsoever excepting only cement.

No material shall be measured or paid for which does not form a part of the permanent structure.

No free transportation will be furnished on the lines belonging to the Kansas City, Ft. Scott and Memphis R.R. system. The freight rates for this work will be at the rate of four mills per ton per mile. On other railroads contractors will make their own arrangements for freight.

Approximate estimates will be made monthly as the work proceeds. In these approximate estimates the cost of the freight will be deducted from the contract price on all material not yet delivered at the bridge site.

Stone quarried but not cut shall be estimated at one third the price of finished masonry. Stone quarried and cut shall be estimated at two thirds the price of finished masonry. Payment shall be made on these approximate monthly estimates deducting ten per cent as security for the completion of the work.

TIME

The contractor must be prepared to begin laying the masonry on Piers II and III by August 1st, 1889, and to lay up at least 5,000 yards of the lower portion of these two piers as fast as the foundation work proceeds. He may be held responsible for any delays in sinking these foundations which may be due to his failure to lay four vertical feet of masonry per day whenever required.

The remainder of the masonry shall be completed during the winter and spring of 1890, and the entire masonry shall be finished by July 1st, 1890, unless otherwise ordered.

The right is reserved to suspend the work, and no stone shall be prepared for any portion of the masonry above the elevation 229 until special orders to this effect are given by the Chief Engineer.

(Signed) Lewis M. Loss

(Signed) Kansas City and Memphis Railway and Bridge Company
By Geo. H. Nettleton,
President

APPENDIX T

SPECIFICATIONS FOR SUPERSTRUCTURE - MEMPHIS BRIDGE (1890)

1. GENERAL DESCRIPTION

1. The superstructure is divided into two parts: First, the Continuous Superstructure of the main bridge; Second, the Deck Span at the west end.

2. The Continuous Superstructure will consist of a central span (resting on Piers II and III), 621 feet 0-1/2 inches long, from each end of which will project a cantilever arm, 169 feet 4-1/2 inches long; of an anchorage span (from the Anchorage Pier on the Tennessee shore to Pier I), 225 feet 10 inches long, from which will project a cantilever arm precisely like those projecting from the central span; of two intermediate spans 451 feet 8 inches long (one of which will be suspended at the east end from the cantilever arm projecting from Pier III and will rest at the west end on Pier IV), the entire continuous superstructure being 2,258 feet 4 inches long, divided into one span of 225 feet 10 inches, one of 790 feet 5 inches and two of 621 feet 0-1/2 inches.

3. This Continuous Superstructure will be rigidly fastened to Piers I, III and IV, but will rest on expansion rollers on Pier II. Slip joints will be provided for expansion at the suspended ends of the independent spans.

4. The trusses will be placed 30 feet between centers and will be divided into panels 28 feet 2-3/4 inches long, the right being reserved to shorten the panels by an amount not exceeding one half inch at any time before the work is actually manufactured.

5. The Deck Span at the west end will be 338 feet 9 inches long from the center of Pier IV to the center of the pin on Pier V, divided into twelve panels of 28 feet 2-3/4 inches each, the trusses being placed 22 feet between centers. The east end of the span will be carried in niches on the west side of Pier IV; the west end will have roller bearings over the center of Pier V. This span will include a vertical bent which will carry the west end of the west pair of stringers.

6. The estimated approximate weight of the Continuous Superstructure is 13,000,000 pounds; that of the Deck Span 1,000,000 pounds, making the total estimated weight of the superstructure of the bridge proper 14,000,000 pounds.

PLANS

7. Full detail plans showing all dimensions will be furnished by the engineer. The work shall be built in all respects according to these plans. The contractor, however, will be expected to verify the correctness of the

plans and will be required to make any changes in the work which are necessitated by errors in these plans, without extra charge, where such errors could be discovered by any inspection of the plans.

II. MATERIAL

8. All parts, except nuts, swivels, clevises and wall-pedestal plates, will be of steel. The nuts, swivels and clevises may be of wrought iron, but shall have sufficient strength to break the bodies of the members to which they are attached. The pedestal plates will be of cast iron.

9. All material shall be subject to inspection at all times during its manufacture, and the engineer and his inspectors shall be allowed free access to any works in which any portion of the material is made. Timely notice shall be given to the engineer so that inspectors may be on hand.

SUPPLEMENTARY SPECIFICATIONS, MAY 6, 1890

MODIFICATIONS OF SPECIFICATIONS FOR SUPERSTRUCTURE OF BRIDGE ACROSS THE MISSISSIPPI RIVER, AT MEMPHIS, TENN., ACCEPTED APRIL 22d, 1890.

10. Steel will be divided into three classed: first, High Grade Steel, which shall be used in all the principal truss members; second, Medium Grade Steel, which shall be used in the floor system, laterals, portals, transverse bracing and the lacing of the truss members; third, Soft Steel, which shall be used only for rivets, and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III, shall be of cast steel.

12. In any case where it seems doubtful what quality of steel is required High Grade Steel shall be used.

13. Steel shall be made by the open hearth process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorous, and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the Chief Engineer.

15. In the finished product of acid open hearth steel the amount of phosphorous shall not average more than 8/100 of one per cent and never exceed 1/10 of one per cent.

16. In the finished product of basic open hearth steel the amount of phosphorous shall not average more than 6/100 of one per cent and never exceed 7/100 of one per cent.

17. A sample bar three-quarters of an inch in diameter shall be rolled from a four-inch ingot cast from every melt. The first laboratory test shall be made on this sample bar in its natural state without annealing.

18. A second sample bar having a cross section of one square inch shall be cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, enlongation and reduction shall be made on a length of eight inches.

20. A piece of each sample bar shall be bent 180 degrees and closed up against itself without showing any crack or flaw on the outside of the bent portion. Two successful tests out of a total of three will be accepted as satisfactory.

21. The first laboratory test shall meet the following requirements:

	High Grade and Medium Steel.	Soft Steel
Min. Ultimate Strength, pounds/square inch.	65,000	57,000
Min. Elastic Limit, pounds/square inch.	38,000	23,000
Min. Percentage of Enlongation in 8 inches.	20	28
Min. Percentage of Reduction at Fracture.	40	50

22. The second laboratory test shall meet the following requirements:

	High Grade Steel	Med. Steel	Soft Steel
Max. Ultimate Strength, pounds/square inch. . .	78,500	72,500	63,000
Min. Ultimate Strength, pounds/square inch. . .	69,000	64,000	55,000
Min. Elastic Limit, pounds/square inch.	40,000	37,000	30,000
Min. Percentage of Enlongation in 8 inches. . .	18	22	28
Min. Percentage of Reduction in Fracture. . . .	38	44	50

23. If the ultimate strength comes within five hundred pounds of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected. Cases in which the tests are thought not to give fair representations of the character of the material shall be referred to the Chief Engineer.

25. A full report of the laboratory tests shall be furnished, certified by an inspector accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Three notices of the acceptance of each melt shall be mailed on the day of such acceptance, stating the number of the accepted melt and quality of steel. Two of these notices shall be sent to the Chief Engineer at his Chicago and New York offices respectively and one to the Shop Inspector a the works.

28. Analysis shall be made by the manufacturer of every melt, showing amount of phosphorous, carbon, silicon and manganese, and certified copies of these analyses shall be furnished to the Mill Inspector, who will forward them to the Chief Engineer. The phosphorous and carbon analyses shall always be made. Analyses for silicon and manganese shall be made whenever called for by the Inspector or by the desire of the manufacturer, shall be furnished to the Chief Engineer.

29. Weekly reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office not later than the end of the week succeeding the week in which such test are made.

30. Three notices of the shipment of manufactured material, identifying the melts and dimensions shall be mailed on the day after such shipments are made, in the same manner as the notices of acceptance of material.

31. Every finished piece of steel shall be stamped on one side near the middle of the bar and also on both ends of the bar, with a number identifying the melt. If it is found impossible to stamp any particular piece on the ends, the Inspector may authorize the two end stamps to be put on the surface, within one-half inch of each end, the fact of the stamping being done in this way to be specified distinctly on all notices and invoices; this may be done, however, by an agreed character.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross sections shall never differ more than two per cent from the ordered cross sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed of so that no rough or sheared surfaces shall ever be left on the metal.

35. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be annealed before they are turned and shall be drilled through the axes.

Geo. S. Morison.
Chief Engineer
May 6th, 1890

APPENDIX T. - CONTINUED

36. A sample bar 1-1/4 inches in diameter and 16 inches long shall be cast from every melt. This sample bar shall then be turned down to three

quarters of an inch in diameter and the laboratory tests made upon it.

37. These laboratory tests shall show an ultimate strength of at least 70,000 pounds, an elastic limit of at least 40,000 lbs., an enlongation of at least 15 per cent in 8 inches and a reduction of 18 per cent at point of fracture.

38. Steel castings shall be sound and as free as possible from blow holes.

39. If on the finished surface the blow holes cover more than 1/10000 part of the entire surface, and if any blow holes exceeds one eighth of an inch in diameter, the casting shall be rejected.

CAST IRON

40. Cast iron shall be the best quality of dark gray charcoal iron of a quality suitable for car wheels, the castings to be entirely sound and free from blow holes.

III. MANUFACTURE

41. The work shall be done in all respects according to the detail plans furnished by the Chief Engineer.

42. Where there is room for doubt as to the quality of work required by the plans or specifications, the doubt shall be decided by using the best class of work which any interpretation would admit of.

43. All workmanship, whether particularly specified or not, must be of the best kind now in use. Past work done for the same chief engineer will never be recognized as a precedent of the use of other than the best kind of work.

44. Ragged edges or any kind of irregularities or unnecessary roughness will be sufficient ground for rejection.

45. All surfaces in contact shall be cleaned and painted before they are put together.

46. All work shall be finished in the shop and ample time given for inspection.

47. No material shall be loaded on cars until accepted by the inspector.

48. The finishing or work after loading will not be permitted.

SOLID DRILLED WORK

49. All riveted members which are made of High Grade Steel and all other pieces connecting with such members shall be solid drilled, no punching whatever being allowed, excepting lacing bars which may be punched and reamed.

50. All plates, angles and shapes shall be carefully straightened at the shops before they put together. Mill straightening will not be considered to meet this requirement.

51. The pieces shall be then assembled and held in position by clamps and bolts.

52. Where bolts passing through the metal are used, the holes shall be drilled in all metal more than three quarters of an inch thick, the diameter of the drilled hole to be at least one eighth of an inch less than the diameter of the finished hole.

53. In metal not more than three quarters of an inch thick punched holes may be used for fitting up, the diameter of the punched hole not to be more than three quarters the diameter of the finished hole, and the number of punched holes never to exceed eight in any one plate or four in one flange of any one angle.

54. After assembling, the work shall be drilled, the rivet holes being carefully spaced in truly straight lines and at the exact distances shown on the plans.

55. After the drilling is completed a special reamer shall be run over both edges of every hole, so as to remove the sharp edges and make a fillet of at least 1/16 of an inch under each rivet head.

56. The assembled parts shall then be riveted up without taking apart, unless specially directed by the Chief Engineer.

57. In general, all holes which are to pass through several thicknesses of metal shall be drilled with all those pieces of metal assembled in the exact relative position they are to hold in the bridges.

58. In the case of connections between members having four webs, one member may be finished complete with the splice plates riveted on. The two inside webs of the adjoining member, one end being already faced, may then be fitted up separately in their true position and the rivet holes in the splices drilled. These inside webs may be removed; the member to which they belong shall be assembled, riveted up complete and the ends faced, the facing to agree exactly with the two ends already faced. (See 67) The member shall then be fitted to the adjoining member and the rivet holes in the splices connecting the outside webs shall be drilled.

59. The size of rivets shown on the plans is the size of the cold rivet before heating.

60. The diameter of the finished hole shall not be more than 1/16 of an inch greater than the diameter of the cold rivet. It is intended that the heated rivet shall not drop into the hole, but require a blow from a hammer to force it in. If it is found that rivets will drop easily into the holes, the inspector will condemn those rivets and order a larger size.

61. In all cases where riveting is to be done in the field, the parts so to be riveted shall be fitted together in the shops and the rivet holes drilled while they are so assembled.

62. The riveted connections of the portals, cross frames and floor beams with the posts and chords shall be drilled with the several parts fitted together, excepting in the case of interchangeable floor beams.

63. An iron templet not less than two inches thick may be used instead of the floor beams when drilling the holes in the chords, and the same templet instead of the chords when drilling the holes in the floor beams; a templet may be used in the same manner in drilling the connections between the floor beam and the supported upright at panel points where two inclined members come together; but the connections between the floor beam and the vertical suspenders at panels point L1 and L2 of the intermediate spans, making eight in all, become special; the other floor beams are classed as interchangeable.

64. All rivets shall be driven by power wherever this is possible.

65. All rivets shall be regular in shape, with hemispherical heads concentric with the axis and absolutely tight. Tightening by calking or recupping will not be allowed. This applies to both power driven and hand driven rivets.

66. All pin holes and holes for turned bolts passing through the whole width of a riveted member shall be bored or drilled after all other work is completed.

67. All surfaces in contact shall be carefully faced, the facing to be done after the entire member is assembled and riveted up, except that in the case of chord sections with four webs, the inside webs may have one end faced before they are assembled, these two faced ends to be carefully held against a plane surface when assembled and the corresponding ends of the other two webs to be faced after riveting and to agree with the ends already faced.

68. When two chord pieces are fitted together complete in the shop there shall be no perceptible wind in the length of the two sections. The chords are generally made in two panel lengths, or 56 feet 5-1/2 inches long. In the case of shorter lengths a sufficient number of pieces shall be put together to make a continuous length equal to two of the long sections.

69. All chord sections shall be stamped at each end on the outside with letters and numbers designating the joints in accordance with the diagram plan furnished by the Chief Engineer.

70. The posts shall be fitted together for their entire length and bolted up and when so fitted shall be perfectly straight and free from wind.

71. The same rule shall apply to the marking of the posts as to the marking of the chords.

72. Pin holes shall be bored truly and at exact distances, parallel with one another and at exactly right angles to the axis of the member.

73. Pin holes in the posts shall be truly parallel with one another and shall be at right angles to the axis of the post.

74. Pin holes shall be bored with a sharp tool which will make a clean, smooth cut. Two cuts shall always be taken, the finishing cut never to be more than 1/8 inch. Roughness in pin holes will be sufficient reason for rejecting a whole member.

75. Measurements shall be made from an iron standard of the same temperature as the member measured.

PUNCHED AND REAMED WORK

76. All riveted members which are composed entirely of Medium Steel may be punched and reamed, but this does not apply to the connections between such members and High Grade Steel members, which connections shall be solid drilled throughout.

77. All plates, angles and shapes shall be carefully straightened at the shops before they are laid out. Mill straightening will not be held to meet this requirement.

78. The rivet holes shall be marked from templets and these templets shall lie flat without distortion when the marking is made.

79. The angles of stringers must be square and straight. The web plate must not project above the angles and the top surfaces of the top angles must be such that the outside edges are never above a true plane and never more than one-sixteenth of an inch below a true plane coincident with the roots of the angles.

80. The outside angle at the root of the angles connecting the stringers with the floor beams or the floor beams with the posts, chords or other members, shall never be less than a right angle, and the excess over a right angle shall never be greater than 1/8 of an inch in the longer leg of the angle; the angle shall be perfectly straight.

81. In fitting these angles to stringers or floor beams they shall be so fitted that the exact length is measured to the root of the angle, the two roots being in exactly the same plane; the entire end of the assembled member shall then be faced. The effect of these requirements will be to prevent any reduction of area of the angle at the root by facing and to secure a true surface of the whole width of the connection which will require no strain in the rivets to draw the parts together.

82. After laying out with templets, the rivet holes may be punched with a punch at least 3/32 of an inch smaller than the diameter of the rivets as given on the plans and working in a die only 1/64 of an inch larger than the punch.

83. The several parts of the member shall then be assembled and the holes reamed so that at least 1/16 of an inch of metal is everywhere taken out.

84. After the reaming is completed a special reamer shall be run over both edges of every hole so as to remove the sharp edges and make a fillet of at least 1/16 of an inch under each rivet head.

85. The pieces shall be riveted together without taking apart.

86. All requirements as to size and quality of rivets and manner of riveting and measuring shall be the same as the requirements for Solid Drilled riveted work.

87. All bearing surfaces shall be truly faced.
88. All sheared edges shall be planed off and all punched holes shall be drilled out so that none of the rough surface is ever left upon the work.

FORGED WORK

89. The heads of eye bars shall be formed by upsetting and forging into shape by a process acceptable to the Chief Engineer. No welds will be allowed.
90. After the working is completed the bars shall be annealed in a suitable annealing furnace by heating them to a uniform dark red heat and allowing them to cool slowly.
91. The form of the heads of the steel eye bars may be modified by the contractors to suit the process in use at their works, but the thickness of the head shall not be more than 1/16 inch greater than that of the body of the bar, and the heads shall be of sufficient strength to break the body of the bar.
92. The heads and the enlarged ends for screws in laterals, suspenders and counters shall be formed by upsetting an shall be of sufficient strength to break the body of the bar.
93. Nuts, swivels and clevises, if made of steel, shall be forged without welds; whether made of steel or wrought iron, one of each size shall be tested and be of sufficient strength to break the bars to which they are attached.
94. Eye bars shall be bored truly and at exact distances, the pin holes to be exactly on the axis of the bar, and at exactly right angles to the plane of the flat surfaces.
95. When six bars of the same billed length are piled together the two pins shall pass through both pin holes at the same time without driving. Every bar shall be tested for this requirement.
96. Pin holes shall be bored with a sharp tool that will make a clean smooth cut. Two cuts shall always be taken, the finishing cut never to be more than 1/8 inch. Roughness in pin holes will be sufficient reason for rejecting bars.
97. Twenty full-sized steel eye bars shall be selected from time to time from the bars made for the bridge, by the inspector for testing.
98. No bars known to be defective in any way shall be taken for test bars, but the bars shall be selected as fair average specimens of the good bars which would be accepted for the work.

MACHINE WORK

99. All bearing surfaces shall be faced truly.
100. Chord sections and half-post sections shall be faced after they are riveted up complete, the facing to be perfectly true and square. In the case of four web chords, one end of the two inside webs only may be faced before riveting up.

101. The ends of the stringers and of floor beams shall be squared in a facer.

102. All surfaces so designated on the plans shall be planed.

103. All sheared edges shall be planed off, and all punched holes shall be drilled or reamed out.

104. All pins shall be accurately turned to a gauge, and shall be of full size throughout.

105. Pin holes shall be bored to fit the pins with a play not exceeding 1/50 of an inch. These requirements apply to lateral connections as well as to any other pins.

106. The plans show the distances between centers of pin holes. Shop measurements, however, shall be made between the bearing edges of the pin holes, that is, between the inside edges of compression members and the outside edges of tension members, with a proper allowance for the diameter of the pin. An iron standard of the same temperature as the piece measured shall always be used.

107. All screws shall have a truncated V thread, United States standard sizes.

108. Special pains shall be taken with the roller bearings on Pier II. The castings shall be accurately fitted together and when bolted up, the top surface shall be a perfectly true plane.

109. The rail plates shall be planed on the bottom after being riveted up, then planed on the top and the surface polished. Any roughness or irregularity which prevents an uniform opening between the rail heads shall be planed out.

110. The rollers shall have the hollow sides planed and the bearing surfaces turned to a perfectly true cylinder and polished.

111. The rods passing through the rollers shall fit the holes with a play not exceeding 1/32 of an inch.

112. The side bars connecting the rods shall be drilled to fit the rods with a play not exceeding 1/32 of an inch, and the upper and lower surfaces of these side bars shall be planed.

113. The lower side bar in each instance shall be fitted with a graduated bronze scale, so divided as to register inches of motion of the top bearing and the upper bar shall be fitted with a German silver vernier, so divided as to read to sixteenths of inches as graduated on the scale.

114. The two bearings, including everything between the masonry and the fourteen inch pin, shall be set up complete in a level position at the Athens shops and shall not be shipped before they have been examined and approved by the Chief Engineer. They shall be ready for his inspections on or before January 1, 1891.

115. Special pains shall be taken with the slip joints at the suspended ends of the intermediate spans; the surface of the joints shall be polished and fitted exactly.

MISCELLANEOUS

116. All material shall be cleaned, and, if necessary, scraped and given one heavy coat of Cleveland iron-clad paint, purple brand, put on with boiled linseed oil, before shipment. This applies to everything except machine finished surfaces.

117. The same paint shall be used wherever painting is required.

118. All machine surfaces shall be cleaned, oiled and given a coat of white lead and tallow before shipment. The inspector must see that this is a substantial coat, such as is used on machinery, and not a merely nominal covering.

119. All small bolts, all pins less than six inches in diameter, the expansion rollers and everything with special work on it, shall be carefully boxed before shipment.

120. The contractor will be required to furnish the field rivets for erection, furnishing 20 per cent in excess of each size over and above the number actually required, but this excess will not be estimated, but considered as taking the place of the work which is not done on these rivets.

IV. INSPECTION

121. The mill inspection shall be performed at the expense of the contractor, by an inspector accepted by the Chief Engineer.

122. This inspector will be required to furnish the certificates and notices in the manner specified above.

123. The mill inspector shall from time to time check the manufacturers' analyses by analyses made by an independent chemist.

124. The acceptance of material by such inspector will not be considered final, but the right is reserved to reject material which may prove defective or objectionable at any time before the completion of the contract.

125. The inspection at the shops will be under the charge of an inspector appointed by the Chief Engineer, with such assistants as may be required.

126. Such inspector will be considered at all times the representative of the Chief Engineer, and his instructions shall be followed in the same manner as if given by the Chief Engineer.

TESTS OF FULL-SIZED BARS

127. The tests of full-sized eye bars shall be made in the large testing machine at Athens.

128. These bars will be required to develop an average stretch of twelve per cent and a minimum stretch of ten per cent before breaking. The enlongation shall be measured on a length of not less than twenty feet, including the fracture.

143. Cast Steel shall be estimated as High Grade Steel.

144. Cast and wrought iron shall be estimated at the same price as Medium Steel.

145. The anchorage span, the east cantilever arm and one half the east intermediate span shall be completed and shipped on or before October 1st, 1890.

146. The Deck Span shall be completed and shipped on or before December 1st, 1890.

147. The central span and the two adjoining cantilever arms shall be shipped complete on or before June 1, 1891.

148. The west intermediate span and the second half of the east intermediate span shall be shipped complete on or before August 1st, 1891.

149. Approximate estimates shall be made at the end of each month of the material received and work performed up to that time.

150. In these estimates material received at the shops but not manufactured shall be estimated at 65 per cent of the contract price for finished material.

151. Material manufactured but not shipped shall be estimated at the full contract price.

152. Material completed and shipped shall be estimated at the full contract price.

153. Payments shall be made on these estimates on or about the middle of he following month, deducting therefrom 10 per cent, which shall be held as security until the completion of the entire contract.

154. In these monthly estimates no material will be estimated as received at the shop more than six months befor the date set for the completion and shipment of such material.

155. In these monthly estimates no material will be estimated as manufactured more than four months before the date set for the completion and shipment of such material.

156. The contractors will be required to keep the material at their shops insured from injury by fire to the full amount of the payments made on such material by the Bridge Company.

VI. ERECTION

157. The contractor will be expected to receive all material as it arrives on the cars, to unload this material and store it in a material yard until ready for erection.

158. He will be held responsible for the custody and care of all superstructure material after its arrival.

159. The material of the main Continuous Superstructure will be delivered on cars on the east side of the river.

160. When ready for erection, the Bridge Company will switch any cars on which this material has been loaded, to a point where it can be transferred to barges, no charge being made for such switching.

161. All material for the Deck Span at the west end will be delivered on cars on the west side of the river.

162. A track will be laid to a convenient position for unloading material, near Pier V, and no switching will be done after the material has once been unloaded.

163. The contractor will be required to keep all the material in good condition, and in case of its becoming dirty or rusty, will be expected to clean it before erecting.

164. The contractor will be required to paint all surfaces which will be inaccessible for painting after erection, the paint being furnished by the Bridge Company.

165. The contractor will be required to furnish all tools, barges and false work of every description, excepting power riveters.

166. The contractor will be required to remove all work which he may put in the river so that there will be nothing left either to interfere with navigation or to catch drift.

167. No holes shall be drilled or bolts placed in the piers without the express permission of the engineer.

168. All bolts so put in shall be removed and the holes carefully filled with Portland cement mortar, and any damages done shall be charged to the contractor.

169. The contractor will be required to erect the superstructure complete in every respect including riveting.

170. Everything is to be completed ready to receive the timber floor.

171. The erection shall include the placing and riveting of the iron hand rail.

172. The contractor will be expected to raise the ties for the central span and the adjoining cantilever arms and distribute them without charge. This does not include any framing, fitting or bolting. The ties will be delivered to the contractor loaded on barges.

173. The central span will be raised on false work.

174. The west intermediate span will be raised on false work.

175. The east intermediate span may be raised on false work, or without, at the option of the contractor.

176. The anchorage arm east of Pier I will be raised on false work.

177. The three projecting cantilever arms will be built out without false work.

178. It is expected that the anchorage arm and the cantilever arms projecting from Pier I can be raised in the fall of 1890. That the deck span at the west end can be raised in the following winter. That the false work for

the central span can be put in in August and September of 1891, and the erection of this span completed in the following month. That the cantilevers can be built out and the entire bridge completed by January 1, 1892.

179. All erection shall be done under the direction of the Chief Engineer and in conformity with his requirements.

180. The wall-plate castings shall be set on Piers II and III before the bottom chord is placed.

181. The expansion rollers and the bolster complete shall be set on Pier III. The bottom chords shall then be put together and riveted up complete. The expansion end shall then be adjusted so that the axis of the rollers will be exactly vertical at a temperature of 70 degrees Fahrenheit. This adjustment shall be made at a time when there has been no sun on the steel work for ten continuous hours, and when there has been no sudden change of temperature. The span shall be erected complete and the end rollers shall be examined again, and if any error is found, shall be corrected, the correction being made under the same conditions as to sunshine and sudden change of temperature as the original adjustment. Special care shall be taken with the rollers while the span is being swing, and if by any accident they get out of place, the span shall be wedged again and the rollers be readjusted.

182. They eye bars in the end panel of the top chord shall be stiffened so as to resist compression by fitting planks between the bars and bolting the whole together.

183. When the erection of the central span is completed, the two cantilever arms shall be built out and the two intermediate spans erected, thus completing the bridge.

184. All rivets shall be regular in shape with hemispherical heads concentric with the axis and absolutely tight. Tightening by calking or recupping will not be allowed.

185. All riveted joints which have to resist tension, this including all joints in both chords of the central span and all joints in the bottom chord of the intermediate spans, shall be riveted by power, except in such special cases as the engineer may authorize hand-driven rivets. This authority will never be given for rivets in splices of web plates.

186. A power riveter, with air pump or with hydraulic pump and accumulator, will be furnished by the Bridge Company. The contractor will be required to keep the same in repair and will not be relieved from any responsibility in this connection, the Bridge Company only agreeing to bear the cost of the machine.

187. No extra bills are to be rendered by the contractor, except for new work not embraced in the contract. Charges for reaming holes, fitting bolts in place of rivets and other small work of this class will not be allowed.

188. The setting of the wall plate castings, including the drilling of holes in masonry for the anchor bolts, the packing of rust cement or lead under

the castings and all other work connected therewith, is to be done by the contractor.

189. The contractor will be responsible for any damages which the Bridge Company may be held liable for in consequence of any of his own work.

Geo. S. Morison
Chief Engineer
January 4th, 1890.

APPENDIX U - TABLE OF STEAMBOATS ON LOWER MISSISSIPPI RIVER DEC. 1889, ARRANGED ACCORDING TO HEIGHT OF PILOT HOUSE

Name: Oliver Bierne
Port: New Orleans
Line: Planters & Merchants Packet Co.
Date: 1886
Type: Side

Tonnage: 1117.78
Length : 267'
Stack Hgt. w/o orn.: 78'10"
Stack Hgt. w/ orn. : 83'10"
Pilot Hgt. w/o orn.: 59'9"
Pilot Hgt. w/ orn. : 64'9"

Name: City of St. Louis
Port: St. Louis
Line: Anchor
Date: 1883
Type: Side

Tonnage: 1565.17
Length : 300'
Stack Hgt. w/o orn.: 84'2"
Stack Hgt. w/ orn. : 91'2"
Pilot Hgt. w/o orn.: 59'7"
Pilot Hgt. w/ orn. : 62'7"

Name: City of New Orleans
Port: St. Louis
Line: Anchor
Date: 1881
Type: Side

Tonnage: 1585.28
Length : 290'
Stack Hgt. w/o orn.: 83'1"
Stack Hgt. w/ orn. : 90'1"
Pilot Hgt. w/o orn.: 58'5"
Pilot Hgt. w/ orn. : 62'5"

Name: City of Baton Rouge
Port: St. Louis
Line: Anchor
Date: 1881
Type: Side

Tonnage: 1603.96
Length : 280'
Stack Hgt. w/o orn.: 83'3"
Stack Hgt. w/ orn. : 90'3"
Pilot Hgt. w/o orn.: 57'2"
Pilot Hgt. w/ orn. : 62'2"

Name: Jesse K. Bell
Port: New Orleans
Line: Planters & Merchants Packet Co.
Date: 1879
Type: Side

Tonnage: 921.60
Length : 219.4'
Stack Hgt. w/o orn.: 82'6"
Stack Hgt. w/ orn. : 86'6"
Pilot Hgt. w/o orn.: 56'6"
Pilot Hgt. w/ orn. : 65'6"

Name: City of Vicksburg
Port: St. Louis
Line: Anchor
Date: 1881
Type: Side

Tonnage: 1356.52
Length : 273.7'
Stack Hgt. w/o orn.: 79'2"
Stack Hgt. w/ orn. : 86'2"
Pilot Hgt. w/o orn.: 55'10"
Pilot Hgt. w/ orn. : 60'10"

Name: Arkansas City
Port: St. Louis
Line: Anchor
Date: 1882
Type: Side

Tonnage: 1236.99
Length : 273.7'
Stack Hgt. w/o orn.: 79'5"
Stack Hgt. w/ orn. : 86'5"
Pilot Hgt. w/o orn.: 54'8"
Pilot Hgt. w/ orn. : 57'8"

Name: City of Providence
Port: St. Louis
Line: Anchor
Date: 1880
Type: Side

Tonnage: 1303.81
Length : 273.1'
Stack Hgt. w/o orn.: 79'3"
Stack Hgt. w/ orn. : 86'3"
Pilot Hgt. w/o orn.: 54'8"
Pilot Hgt. w/ orn. : 57'8"

Name: Pargond
Port: Louisville
Line: Planters Packet Company
Date: 1884
Type: Stern

Tonnage: 711.94
Length : 242'
Stack Hgt. w/o orn.: 70'11"
Stack Hgt. w/ orn. : 77'11"
Pilot Hgt. w/o orn.: 54'4"
Pilot Hgt. w/ orn. : 59'3"

Name: Paul Tulane
Port: New Orleans
Line: Planters & Merchants Packet Co.
Date: 1888
Type: Stern

Tonnage: 617.03
Length : 210'
Stack Hgt. w/o orn.: 68'4"
Stack Hgt. w/ orn. : 73'4"
Pilot Hgt. w/o orn.: 54'3"
Pilot Hgt. w/ orn. : 58'3"

Name: Belle of Memphis
Port: St. Louis
Line: Anchor
Date: 1880
Type: Side

Tonnage: 1222.80
Length : 267'
Stack Hgt. w/o orn.: 80'9"
Stack Hgt. w/ orn. : 87'9"
Pilot Hgt. w/o orn.: 54'3"
Pilot Hgt. w/ orn. : 57'3"

Name: City of Monroe
Port: St. Louis
Line: Anchor
Date: 1887
Type: Side

Tonnage: 1038.25
Length : 275'
Stack Hgt. w/o orn.: 79'0"
Stack Hgt. w/ orn. : 86'0"
Pilot Hgt. w/o orn.: 54'0"
Pilot Hgt. w/ orn. : 57'0"

Name: Guiding Star Port: Cincinnatti Line: U.S. Trans. Company Date: 1878 Type: Stern	Tonnage: 1121.97 Length : 304' Stack Hgt. w/o orn.: 70'10" Stack Hgt. w/ orn. : 74'10" Pilot Hgt. w/o orn.: 53'1" Pilot Hgt. w/ orn. : 56'1"
Name: City of Cairo Port: St. Louis Line: Anchor Date: 1887 Type: Side	Tonnage: 1266.12 Length : 271.2' Stack Hgt. w/o orn.: 81'5" Stack Hgt. w/ orn. : 88'5" Pilot Hgt. w/o orn.: 52'9" Pilot Hgt. w/ orn. : 55'9"
Name: Crystal City Port: St. Louis Line: Anchor Date: 1887 Type: Side	Tonnage: 787.43 Length : 234' Stack Hgt. w/o orn.: 72'9" Stack Hgt. w/ orn. : 78'9" Pilot Hgt. w/o orn.: 52'4" Pilot Hgt. w/ orn. : 56'4"
Name: James Lee Port: Memphis Line: Lee Line Date: 1887 Type: Side	Tonnage: 747.94 Length : 237' Stack Hgt. w/o orn.: 68'0" Stack Hgt. w/ orn. : 75'0" Pilot Hgt. w/o orn.: 52'3" Pilot Hgt. w/ orn. : 55'3"
Name: Kate Adams Port: Memphis Line: Memphis Packet Company Date: 1889 Type: Side	Tonnage: 665.93 Length : 247.5' Stack Hgt. w/o orn.: 72'1" Stack Hgt. w/ orn. : 87'1" Pilot Hgt. w/o orn.: 50'7" Pilot Hgt. w/ orn. : 59'7"
Name: Warren Port: New Orleans Line: Missouri & Arkansas Packet Company Date: 1882 Type: Stern	Tonnage: 316.50 Length : 184' Stack Hgt. w/o orn.: 67'1" Stack Hgt. w/ orn. : 72'1" Pilot Hgt. w/o orn.: 50'6" Pilot Hgt. w/ orn. : 56'6"
Name: New South Port: Evansville Line: Date: 1887 Type: Side	Tonnage: 932.95 Length : 257' Stack Hgt. w/o orn.: 66'5" Stack Hgt. w/ orn. : 71'5" Pilot Hgt. w/o orn.: 49'7" Pilot Hgt. w/ orn. : 54'7"

Name: Jay Gould Port: St. Louis Line: St. Louis & Miss. V.T. Company Date: 1880 Type: Stern	Tonnage: 466.25 Length : 186.8' Stack Hgt. w/o orn.: 65'7" Stack Hgt. w/ orn. : 67'7" Pilot Hgt. w/o orn.: 49'2" Pilot Hgt. w/ orn. : 51'2"
Name: Laura Lee Port: New Orleans Line: Date: 1878 Type: Stern	Tonnage: 377.90 Length : 209' Stack Hgt. w/o orn.: 71'6" Stack Hgt. w/ orn. : 72'6" Pilot Hgt. w/o orn.: 48'10" Pilot Hgt. w/ orn. : 52'10"
Name: H.M. Hoxie Port: St. Louis Line: St. Louis & Miss. V.T. Company Date: 1888 Type: Stern	Tonnage: 622.30 Length : 213' Stack Hgt. w/o orn.: 63'1" Stack Hgt. w/ orn. : 65'1" Pilot Hgt. w/o orn.: 48'9" Pilot Hgt. w/ orn. : 51'9"
Name: T.P. Leathers Port: Cincinnatti Line: Natchez & New Orleans Packet Co. Date: 1885 Type: Stern	Tonnage: 458.60 Length : 210' Stack Hgt. w/o orn.: 67'2" Stack Hgt. w/ orn. : 74'2" Pilot Hgt. w/o orn.: 48'7" Pilot Hgt. w/ orn. : 51'7"
Name: Chickasaw Port: Memphis Line: Memphis & White River Packet Co. Date: 1883 Type: Stern	Tonnage: 733.90 Length : 187' Stack Hgt. w/o orn.: 65'7" Stack Hgt. w/ orn. : 70'7" Pilot Hgt. w/o orn.: 48'1" Pilot Hgt. w/ orn. : 56'1"
Name: Belle of the Coast Port: New Orleans Line: Date: 1880 Type: Stern	Tonnage: 480.17 Length : 187.4' Stack Hgt. w/o orn.: 64'11" Stack Hgt. w/ orn. : 67'11" Pilot Hgt. w/o orn.: 48'1" Pilot Hgt. w/ orn. : 56'1"
Name: La Famche Port: New Orleans Line: Date: 1888 Type: Stern	Tonnage: 403 Length : 165' Stack Hgt. w/o orn.: 64'8" Stack Hgt. w/ orn. : 69'8" Pilot Hgt. w/o orn.: 48'0" Pilot Hgt. w/ orn. : 52'0"

Name: St. John Port: Shieldsboro Line: Date: 1878 Type: Stern	Tonnage: 382.33 Length : 176' Stack Hgt. w/o orn.: 66'5" Stack Hgt. w/ orn. : 72'5" Pilot Hgt. w/o orn.: 48'0" Pilot Hgt. w/ orn. : 52'0"
Name: Rose Lee Port: Memphis Line: Lee Line Date: 1887 Type: Side	Tonnage: 1059.71 Length : 210' Stack Hgt. w/o orn.: 68'0" Stack Hgt. w/ orn. : 74'0" Pilot Hgt. w/o orn.: 48'0" Pilot Hgt. w/ orn. : 52'0"
Name: Future City Port: St. Louis Line: St. Louis & Miss. V.T. Company Date: 1873 Type: Stern	Tonnage: 589.30 Length : 187.4' Stack Hgt. w/o orn.: 72'9" Stack Hgt. w/ orn. : 74'9" Pilot Hgt. w/o orn.: 47'7" Pilot Hgt. w/ orn. : 52'7"
Name: De Soto Port: Cincinnatti Line: Cincinnatti Packet Company Date: 1881 Type: Stern	Tonnage: 881.27 Length : 261' Stack Hgt. w/o orn.: 58'10" Stack Hgt. w/ orn. : 60'10" Pilot Hgt. w/o orn.: 47'6" Pilot Hgt. w/ orn. : 50'6"
Name: Lady Lee Port: Memphis Line: Lee Line Date: 1889 Type: Stern	Tonnage: 289.31 Length : 165' Stack Hgt. w/o orn.: 57'5" Stack Hgt. w/ orn. : 62'5" Pilot Hgt. w/o orn.: 46'8" Pilot Hgt. w/ orn. : 51'8"
Name: Golden Rule Port: Cincinnatti Line: Date: 1877 Type: Stern	Tonnage: 881.27 Length : 261' Stack Hgt. w/o orn.: 65'4" Stack Hgt. w/ orn. : 70'4" Pilot Hgt. w/o orn.: 46'7" Pilot Hgt. w/ orn. : 49'7"
Name: Mary Z. Comeaux Port: St. Louis Line: Date: 1883 Type: Stern	Tonnage: 420.06 Length : 177.6' Stack Hgt. w/o orn.: 64'4" Stack Hgt. w/ orn. : 66'4" Pilot Hgt. w/o orn.: 46'6" Pilot Hgt. w/ orn. : 49'6"

Name: Whisper Port: New Orleans Line: Date: 1878 Type: Stern	Tonnage: 362 Length : 180.9' Stack Hgt. w/o orn.: 67'11" Stack Hgt. w/ orn. : 69'11" Pilot Hgt. w/o orn.: 46'3" Pilot Hgt. w/ orn. : 51'3"
Name: Danube Port: New Orleans Line: Red River & Coast Date: 1877 Type: Stern	Tonnage: 250.32 Length : 175.1 Stack Hgt. w/o orn.: 61'6" Stack Hgt. w/ orn. : 64'6" Pilot Hgt. w/o orn.: 46'1" Pilot Hgt. w/ orn. : 49'1"
Name: Coahoma Port: Memphis Line: Lee Line Date: 1876 Type: Side	Tonnage: 249.51 Length : 205.2' Stack Hgt. w/o orn.: 71'2" Stack Hgt. w/ orn. : 75'2" Pilot Hgt. w/o orn.: 45'1" Pilot Hgt. w/ orn. : 50'1"
Name: Bald Eagle Port: St. Louis Line: St. Louis & C. Packet Company Date: 1879 Type: Stern	Tonnage: 454 Length : 202' Stack Hgt. w/o orn.: 50'7" Stack Hgt. w/ orn. : 55'7" Pilot Hgt. w/o orn.: 44'10" Pilot Hgt. w/ orn. : 47'10"
Name: Idlewild Port: St. Louis Line: St. Louis & Miss. River Packet Co. Date: 1879 Type: Stern	Tonnage: 520.36 Length : 207.6 Stack Hgt. w/o orn.: 58'2" Stack Hgt. w/ orn. : 61'2" Pilot Hgt. w/o orn.: 44'7" Pilot Hgt. w/ orn. : 51'7"
Name: Assumption Port: New Orleans Line: Date: 1875 Type: Stern	Tonnage: 238.41 Length : 150' Stack Hgt. w/o orn.: 63'10" Stack Hgt. w/ orn. : 65'10" Pilot Hgt. w/o orn.: 44'6" Pilot Hgt. w/ orn. : 48'6"
Name: John Howard Port: Louisville Line: Date: 1871 Type: Stern	Tonnage: 329.69 Length : 180' Stack Hgt. w/o orn.: 64'4" Stack Hgt. w/ orn. : 66'4" Pilot Hgt. w/o orn.: 44'6" Pilot Hgt. w/ orn. : 47'6"

Name: My Choice
Port: St. Louis
Line: St. Louis & Miss. V.T. Company
Date: 1872
Type: Stern

Tonnage: 462.23
Length : 183'
Stack Hgt. w/o orn.: 63'0"
Stack Hgt. w/ orn. : 66'0"
Pilot Hgt. w/o orn.: 44'0"
Pilot Hgt. w/ orn. : 47'0"

Name: City of Florence
Port: St. Louis
Line: St. Louis & Tenn. River Packet Co.
Date: 1882
Type: Stern

Tonnage: 358.31
Length : 165'
Stack Hgt. w/o orn.: 59'6"
Stack Hgt. w/ orn. : 63'6"
Pilot Hgt. w/o orn.: 43'9"
Pilot Hgt. w/ orn. : 45'9"

Name: Cherokee
Port: St. Louis
Line: Cherokee Packet Company
Date: 1888
Type: Stern

Tonnage: 631.20
Length : unknown
Stack Hgt. w/o orn.: 57'4"
Stack Hgt. w/ orn. : 62'4"
Pilot Hgt. w/o orn.: 43'6"
Pilot Hgt. w/ orn. : 53'6"

Name: John Gilmore
Port: St. Louis
Line: St. Louis & Miss. V.T. Company
Date: 1871
Type: Stern

Tonnage: 503.09
Length : 183'
Stack Hgt. w/o orn.: 63'1"
Stack Hgt. w/ orn. : 68'1"
Pilot Hgt. w/o orn.: 43'4"
Pilot Hgt. w/ orn. : 45'4"

Name: Gus Fowler
Port: Paducah
Line: P. & C. Packet Company
Date: 1880
Type: Stern

Tonnage: 309.62
Length : 160'
Stack Hgt. w/o orn.: 54'1"
Stack Hgt. w/ orn. : 58'1"
Pilot Hgt. w/o orn.: 43'3"
Pilot Hgt. w/ orn. : 46'3"

Name: Sella Winds
Port: Wheeling
Line:
Date: 1886
Type: Stern

Tonnage: 289.12
Length : 155'
Stack Hgt. w/o orn.: 52'4"
Stack Hgt. w/ orn. : 57'4"
Pilot Hgt. w/o orn.: 43'2"
Pilot Hgt. w/ orn. : 47'2"

Name: Ruth
Port: Memphis
Line: Lee Line
Date: 1888
Type: Stern

Tonnage: 217.90
Length : 166'
Stack Hgt. w/o orn.: 53'7"
Stack Hgt. w/ orn. : 58'7"
Pilot Hgt. w/o orn.: 42'11"
Pilot Hgt. w/ orn. : 45'11"

Name: Carnal Goldman Port: Natchez Line: N. & V. Packet Company Date: 1883 Type: Stern	Tonnage: 172.19 Length : unknown Stack Hgt. w/o orn.: 55'11" Stack Hgt. w/ orn. : 57'11" Pilot Hgt. w/o orn.: 42'5" Pilot Hgt. w/ orn. : 45'5"
Name: Teche Port: New Orleans Line: N.O. & B.T. Packet Company Date: 1886 Type: Stern	Tonnage: 485.90 Length : 191' Stack Hgt. w/o orn.: 63'0" Stack Hgt. w/ orn. : 67'0" Pilot Hgt. w/o orn.: 42'4" Pilot Hgt. w/ orn. : 47'4"
Name: Spread Eagle Port: St. Louis Line: Eagle Packet Company Date: 1881 Type: Stern	Tonnage: 529.34 Length : 225' Stack Hgt. w/o orn.: 50'4" Stack Hgt. w/ orn. : 55'4" Pilot Hgt. w/o orn.: 42'1" Pilot Hgt. w/ orn. : 45'1"
Name: E.W. Cole Port: Brashear Line: Date: 1880 Type: Stern	Tonnage: 487.91 Length : 202' Stack Hgt. w/o orn.: 53'8" Stack Hgt. w/ orn. : 55'8" Pilot Hgt. w/o orn.: 41'3" Pilot Hgt. w/ orn. : 44'3"
Name: City of Savannah Port: St. Louis Line: St. Louis & Tenn. River Packet Co. Date: 1889 Type: Stern	Tonnage: 335.55 Length : unknown Stack Hgt. w/o orn.: 59'10" Stack Hgt. w/ orn. : 65'10" Pilot Hgt. w/o orn.: 41'2" Pilot Hgt. w/ orn. : 44'2"
Name: E.M. Norton Port: St. Louis Line: St. Louis & Miss. V.T. Packet Co. Date: 1875 Type: Stern	Tonnage: 549 Length : 174' Stack Hgt. w/o orn.: 57'6" Stack Hgt. w/ orn. : 61'6" Pilot Hgt. w/o orn.: 41'0" Pilot Hgt. w/ orn. : 43'0"
Name: Alto Port: New Orleans Line: Date: 1879 Type: Stern	Tonnage: 363.16 Length : 166' Stack Hgt. w/o orn.: 60'6" Stack Hgt. w/ orn. : 62'6" Pilot Hgt. w/o orn.: 40'7" Pilot Hgt. w/ orn. : 44'7"

Name: Joe Peters
Port: Memphis
Line: Memphis & Arkansas Packet Company
Date: 1883
Type: Stern

Tonnage: 525
Length : 175'
Stack Hgt. w/o orn.: 57'6"
Stack Hgt. w/ orn. : 58'6"
Pilot Hgt. w/o orn.: 40'0"
Pilot Hgt. w/ orn. : 45'0"

Name: Iron Duke
Port: Pittsburgh
Line:
Date: 1880
Type: Stern

Tonnage: 421.25
Length : 177'
Stack Hgt. w/o orn.: 60'11"
Stack Hgt. w/ orn. : 62'11"
Pilot Hgt. w/o orn.: 39'7"
Pilot Hgt. w/ orn. : 42'7"

Name: Chas. D. Shaw
Port: Natchez
Line: N. & V. Packet Company
Date: 1883
Type: Stern

Tonnage: 186.03
Length : 186.30
Stack Hgt. w/o orn.: 49'10"
Stack Hgt. w/ orn. : 51'10"
Pilot Hgt. w/o orn.: 39'4"
Pilot Hgt. w/ orn. : 42'4"

Name: Mable Comeaux
Port: St. Louis
Line:
Date: 1883
Type: Stern

Tonnage: 160.06
Length : 145'
Stack Hgt. w/o orn.: 49'6"
Stack Hgt. w/ orn. : 51'6"
Pilot Hgt. w/o orn.: 38'2"
Pilot Hgt. w/ orn. : 42'2"

Name: H.J. Dickey
Port: New Orleans
Line:
Date: 1881
Type: Stern

Tonnage: 208.54
Length : 167'
Stack Hgt. w/o orn.: 56'9"
Stack Hgt. w/ orn. : 57'9"
Pilot Hgt. w/o orn.: 37'6"
Pilot Hgt. w/ orn. : 39'6"

Name: Alvin
Port: New Orleans
Line: N.O. & G.R.R. Company
Date: 1877
Type: Stern

Tonnage: 201.55
Length : 143'
Stack Hgt. w/o orn.: 52'8"
Stack Hgt. w/ orn. : 54'8"
Pilot Hgt. w/o orn.: 37'3"
Pilot Hgt. w/ orn. : 41'3"

Name: Hallette
Port: New Orleans
Line: Red River & Coast
Date: 1887
Type: Stern

Tonnage: 196.80
Length : 165'
Stack Hgt. w/o orn.: 53'5"
Stack Hgt. w/ orn. : 55'5"
Pilot Hgt. w/o orn.: 36'1"
Pilot Hgt. w/ orn. : 39'1"

Name: John D. Scully
Port: New Orleans
Line: Red River & Coast
Date: 1878
Type: Stern

Tonnage: 285.70
Length : 218'
Stack Hgt. w/o orn.: 65'0"
Stack Hgt. w/ orn. : 65'0"
Pilot Hgt. w/o orn.: 34'9"
Pilot Hgt. w/ orn. : 38'9"

Name: G.W. Sentell
Port: St. Louis
Line: F.A. Str. B. Company
Date: 1882
Type: Stern

Tonnage: 306.76
Length : 180'
Stack Hgt. w/o orn.: 50'10"
Stack Hgt. w/ orn. : 53'10"
Pilot Hgt. w/o orn.: 34'8"
Pilot Hgt. w/ orn. : 39'8"

Name: Alice Leblanc
Port: New Orleans
Line:
Date: 1884
Type: Stern

Tonnage: 81.97
Length : 135'
Stack Hgt. w/o orn.: 46'1"
Stack Hgt. w/ orn. : 49'1"
Pilot Hgt. w/o orn.: 34'2"
Pilot Hgt. w/ orn. : 38'2"

Name: General Newton
Port: U.S. Steamer
Line:
Date: 1878
Type: Stern

Tonnage: 263.74
Length : 160'
Stack Hgt. w/o orn.: 48'11"
Stack Hgt. w/ orn. : 48'11"
Pilot Hgt. w/o orn.: 35'7"
Pilot Hgt. w/ orn. : 36'7"

APPENDIX V

LIST OF ENGINEERS, EMPLOYEES AND CONTRACTORS - MEMPHIS BRIDGE

Engineers and Company's Employees

Name and Occupation	Time of Service					
George S. Morison, Chief Engineer						
A. Noble, Resident Engineer	Oct. 1,	1888	to	May	31,	1892
M.A. Waldo, Assistant Engineer	Oct. 24,	"	"	Dec.	31,	"
J.M. Heiskell, Assistant Engineer	Oct. 22,	"	"	Oct.	31,	1891
W. E. Angier, Assistant Engineer	Feb. 10,	1889	"	May	14,	1892
E.H. Mayne, Assistant Engineer	Nov. 8,	"	"	June	5,	1890
D.A. Molitor, Assistant Engineer	Sep. 8,	1890	"	May	31,	1892
C. Vogel, Draughtsman	Nov. 30,	1891	"	May	30,	"
E.K. Barrett, Rodman	Jan. 5,	1890	"	Apr.	17,	1893
Geo. Reynolds, Insp. of Masonry	Aug. 15,	1889	"	Oct.	14,	1889
Aug. T. Holgren, Insp. of Cement	June 16,	"	"	Nov.	28	"
D.A. Kelsey, Clerk	Feb. 8,	1889	"	Dec.	31,	1892
Sanford Morison, Clerk	Apr. 21,	1889	"	June	5,	"
H.C. Churchill, Clerk	Jan. 1,	1890	"	Sep.	19,	1890
R.F. Thayer, Time-keeper	May 20,	1889	"	June	3,	1892
Julius Thompson, Time-keeper	Nov. 11,	1888	"	May	16,	1891
E. Gerber, Office Engineer						
R. Modjeski, Chief Draughtsman				Apr.	30,	1890
" " , Chief Insp. of Superstructure	Nov. 7,	1890	"	Jan.	31,	1892
Irving Dickinson, Draughtsman						
O.E. Hovey, Draughtsman						
E.H. Conner, Insp. of Superstructure	Jan. 27,	1890	"	Nov.	30,	1890
W.S. McDonald, Insp.of Superstructure	Oct. 1,	1891	"	Dec.	24.	1891
W.R. Edwards, Rodman	May 27,	1889	"	Apr.	14,	1890
" " , Asst. Supt. of Superstructure	Apr. 15,	1890	"	Jan.	2,	1892
R. Khuen, Rodman	July 16,	"	"	Sep.	4,	1890
" " , Asst. Supt. of Superstructure	Jan. 1,	1891	"	Aug.	10,	1891
W.A. Hill, Asst. Insp. of Superstructure	Mar. 9,	"	"	Dec.	28,	"
W.L. Smith, Asst. Insp. of Superstructure	Aug. 10,	"	"	Dec.	9,	"
F.H. Joyner, Insp. at Limestone Quarries	May 19,	1889	"	Mar.	31,	"
O.T. Geese, Insp. at Granite Quarries	May 13,	"	"	Aug.	31,	1891

Contractors

Lewis M. Moss	Masonry

Union Bridge Company	Superstructure
Elmira Bridge Works	Sub-contracting
Lassig Bridge and Iron Works	" "
Scaife Foundry and Machine Company	" "
Keystone Bridge Conmpany	" "
Pittsburg Steel Casting Company	" "
New Jersey Steel and Iron Company	" "
A.& P. Roberts & Company	Superstructure
Pittsburg Bridge Company	" "
Baird Brothers	Erection
Pennsylvania Steel Company	Viaduct Superstructure
Confrode & Saylor	Sub-contractor
William Kelley	Earthwork, West Approach
William O'Mara	" "
James Saguin	West Approach Trestle
Speers & Freeman	Sloping and Paving-East Approach

APPENDIX W

LIST OF ENGINEERS, EMPLOYEES AND CONTRACTORS - BELLEFONTAINE

Engineers and Company's Employees

Name and Occupation	Time of Service
George S. Morison, Chief Engineer	
Alfred Noble, Assistant Chief Engineer	
Ben L. Crosby, Resident Engineer	Feb. 20, 1892 to date.
Ernest G. Freeman, Assistant Engineer	July 1, " " Dec. 31, 1893
Homer Reed Stanford, Assistant Engineer	Apr. 1, " " Aug. 18, 1892
Wm. G. Brenneke, Assistant Engineer	June 23, " " June 30, 1894
Wm. L. Smith, Assistant Engineer	Aug. 20, " " Jan. 31, "
James W.G. Walker, Assistant Engineer	Aug. 25, " " July 31, 1893
Wm. R. Johnson, Inspector	July 1, " " July 15, "
August T. Holmgren, Rodman and Insp.	Mar. 22, 1883 " June 30, 1894
John F. Lindgren, Cement Tester	July 26, 1892 " Dec. 31, 1893
James M. Richardson, Clerk	July 8, " " date.
Robert F. Thayer, Timekeeper	June 4, " " Feb. 16, 1894
David Nowlin, M.D., Resident Physician	Sep. 26, " " July 31, 1893
H.H. Born, M.D., Resident Physician	Aug. 1, 1893 " Dec. 31, "
E. Gerber, Office Engineer	
O.E. Hovey, Chief Superstructure Draughtsman	
I. Dickinson, Record Draughtsman	
Homer Reed Stanford, Insp. of Superstructure	Aug. 19, 1892 to Oct. 31, 1893
Charles Stears, Insp. at Quarries	May 13, " " Sep. 17, 1892
O.W. Davis, Insp. at Quarries	Mar. 1, 1893 " May 31, 1893
L.S. Stewart, General Foreman	May 1, 1892 " May 15, "
Dennis Leonard, Foreman of Pressure Work	June 15, " " May 3, 1893
M.F. Comer, Foreman of Carpenters	June 27, " " June 30, 1894
George Capel, Master Mechanic	July 27, " " June 3, 1893
John M. Gilham, Master of Steamers Pauline and John Bertram	Aug. 25, " " date.

Contractors

Name	Nature of Work
Christie & Lowe	Masonry
Geo. A. Lederle	Resident Partner
Charles Stears	Foreman of Masons
New Jersey Steel & Iron Company	Superstructure
William Baird	Erection
A.P. Roberts & Company	Viaduct
John Eagler	Foreman of Erection
Joseph K. Golike	Mattress Brush and Riprap
Mooresville Stone Company	Riprap

ADDENDUM TO:
NEBRASKA CITY BRIDGE
(Behemoths: The Great River Bridges of George S. Morison)
Spanning Missouri River near Highway 2 between Nebraska & Iowa
Nebraska City vicinity
Otoe County
Nebraska

HAER No. NE-2
NEB,66-NEBCI,5-

HAER
NEB
66-NEBCI,
5-

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C St. NW
Washington, DC 20240

HISTORIC AMERICAN ENGINEERING RECORD

NEBRASKA CITY BRIDGE
(Behemoths: The Great River Bridges of George S. Morison)

This report is an addendum to 509 data pages previously transmitted to the Library of Congress.

Additional research conducted in 2003-2005 found that portions of the original written historical and descriptive data and Sheet 2 of the measured drawings were incorrect. In particular, all references to the Sioux City Bridge as being in South Dakota are wrong. The bridge is actually located in Iowa. Consequently, all references to HAER No. SD-1 are also incorrect. Documentation on the Sioux City Bridge can now be found in HAER No. IA-96.

Submitted by: Jennifer Hall, Heritage Documentation Programs Collections Manager, October 5, 2005.