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CHICAGO & NORTH WESTERN RAILROAD VIADUCT HAER No. IA-44
(Boone Viaduct)
(Kate Shelly High Bridge)
(Boone High Bridge)
Iowa Bridges Recording Project
Spanning Des Moines River
at Chicago & North Western right-of-way
Boone Vicinity
Boone County
Iowa

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HISTORIC AMERICAN ENGINEERING RECORD
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HISTORIC AMERICAN ENGINEERING RECORD

CHICAGO & NORTH WESTERN RAILROAD VIADUCT
(Boone Viaduct)
(Kate Shelly High Bridge)
(Boone High Bridge)

HAER No. IA-44

Location:	Spanning Des Moines River at Chicago & North Western Railroad, 4.5 miles west of Boone; Boone County, Iowa UTM: 15.419320.4656540 USGS: Boone West, Iowa quadrangle (7.5 minute series, 1965; photorevised 1976)
Date of Construction:	1901
Designers:	E.C. Carter, chief engineer; W.H. Finley, principle assistant engineer; George S. Morison, consulting engineer
Builders:	Chicago & North Western Railroad, Chicago, Illinois; American Bridge Company, Chicago, Illinois
Present Owner:	Union Pacific Railroad Company, Chicago, Illinois
Present Use:	Railroad bridge
Significance:	This bridge is one of the last projects of noted bridge engineer George Morison, who died two years after the structure was built. The bridge was the longest and heaviest viaduct of its time, and may be the longest extant double-track railroad viaduct in the world. It is listed in the National Register of Historic Places.
Historian:	Robert W. Jackson, August 1995
Project Information:	This document was prepared as part of the Iowa Historic Bridges Recording Project performed during the summer of 1995 by the Historic American

Engineering Record (HAER). The project was sponsored by the Iowa Department of Transportation (IDOT).

In December 1898, plans were drawn in the chief engineer's office of the Chicago & North Western Railroad (C. & N.W.) for a new high level double track line to be built between Boone and Ogden, Iowa, a distance of approximately 7.4 miles. The construction of this line would require the erection of a very high viaduct over the Des Moines River. The 11.3 mile line then in service ran southwest from Boone down the east bank of the river to a low level crossing near the little town of Moingona, then up the west bank of the river to Ogden. The grade at the level of the river crossing was two hundred feet below the level of the main plateau, which required that helper engines push the increasingly heavier trains then coming into use up each side of the river. This line had been in service since 1866, one year before the C. & N.W. became the first railroad to span the state.

As designed, it was anticipated that the Boone-Ogden cut off, as the planned diversion came to be known, would cost approximately $931,000; $251,000 for right of way and grading, $124,000 for track, $10,500 for engineering and miscellaneous expenses, and $545,000 for the bridge itself.[1]

The construction of a high bridge across the river valley had been contemplated ever since the rail line had been built across this part of the state, but it was not financially feasible to build such a structure at the time the railroad first crossed Boone County. The considerable growth in traffic and the enormous increase in train loads would have required the construction of this bridge eventually, but its erection became an immediate necessity due to progress the company made in converting its Chicago to Council Bluffs roadway from a single track to a double track system. Moreover, the financial position

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[1]Chicago & North Western Railway Co., W. Fernie, delineator, "Plan of Proposed High Level, Double Track Line Between Boone & Ogden, Iowa" (Chicago: Chief Engineer's Office, Chicago & North Western Railway Co., 13 December 1898), a document on display at the Museum of the Historical Museum Society of Boone County, Boone, Iowa (an organization different from the Boone County Historical Society, which has its own museum).

of the company at that time was such that the expenditure of the sums involved seemed prudent.[2]

The maximum gradients of the new line would be 1 in 160, as compared to 1 in 66 on the old line; the sharpest curves would be of 2,865 feet radius instead of 955 feet; the total length of the curves would total only half a mile instead of nearly six miles; and the new line would be shorter overall by about three miles. The new line was designed to run directly west from the Boone depot and strike the bluffs overlooking the river at a point where the distance across the valley was approximately 3,000 feet. These figures indicate the operational advantages of the planned improvements, as well as the scope of the task in construction of the most important part of that line, the new bridge.

Because the Des Moines River at the proposed bridge site was neither particularly wide nor deep compared to the width and depth of the river valley, the bridge was planned as a viaduct.

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[2]During construction and after the bridge was completed, the Chicago & North Western Railroad made construction drawings and a description of the bridge available to many of the leading engineering journals of the day. Unless otherwise noted, the information in this report has come mainly from the bridge articles printed in those journals, as follows: "The Des Moines Steel Viaduct," Engineer (London) 94 (24 October 1902) 392-393; "Boone Cut-Off and Des Moines River Viaduct, Chicago & Western Ry.," Supplement to Engineering News (22 August 1901), n.p.; "The Boone Viaduct," Engineering Record 44:8 (24 August 1901), 171-173; "The Boone Viaduct, Chicago & Northwestern Ry.," Railway and Engineering Review 41 (25 May 1901), 330-331; "The Boone Viaduct, Chicago & Northwestern RY.," Railway and Engineering Review 41 (6 July 1901), 462-465; "The Boone Viaduct," Engineering Record 44:2 (13 July 1901), 29-31; "Double-Track Railway Viaduct Over the Des Moines River," Scientific American (1 June 1901), 340. In addition, a report by Chicago & North Western resident engineer W.C. Armstrong, "The Boone Viaduct," Iowa Engineer 1:1 (June 1901), 6-19, was consulted for a least one of these journal articles and for this report. See also James G. Gallup, History, Description and Illustrations, of the Great Boone Viaduct (Boone, IA: W.H. Gallup), an undated commemorative booklet published in 1901, contained in the files of the Maime Eisenhower Birthplace Museum and Library, Boone, Iowa. This document was reprinted with additional illustrations and photographs as: James Gallup, "Des Moines River Viaduct: Kate Shelly Bridge - Still An Engineering Marvel," North Western Lines 8:2 (April 1981), 8-21.

This type of bridge was described by C. & N.W. resident engineer W.C. Armstrong as:

> That form of bridge construction evolved in accordance with a minimum of limiting conditions. It is usually employed in building structures over deep and wide chasms where the question of waterway is only of secondary importance; where the designer can place his piers wherever he wishes, make his spans of any length he desires, and where there are no limits imposed except those of safety and economy.[3]

To this definition it might be added that the lack of limiting conditions allows the designer to support the bridge spans on individual towers composed of two or more bents braced together, which makes for a very strong and stable structure.

At the time the Boone Viaduct was originally planned, there had only been three viaducts built in the world that compared to the proposed bridge in terms of height, length, or weight. In 1882 the Erie railroad built a 1,400 ton viaduct over the Kinzua Creek Valley near Kushequa, Pennsylvania. This single-track structure was approximately 302′ high and 2,052′ long. It was rebuilt for heavier loads in 1900 with an increased weight of 3,352 tons. In 1882, English engineers working for the Antofagasta Railway in Bolivia built the 1,115 ton Loa Viaduct over a narrow, but very deep canyon. This single-track, narrow gauge bridge was approximately 800′ long and about 336′ high. The Southern Pacific Railroad Viaduct, stretching about 320′ above the Pecos River in Texas, was built in 1892. It was an approximately 2,180′ long, single-track bridge weighing 1,820 tons. In comparison the Boone Viaduct, as designed and built, was approximately 2,685′ long, about 185′ above the water, weighed approximately 6,196 tons and featured a double track.

The immense weight of the Boone Viaduct as compared to the three which preceded it is attributable not only to the fact that it is a double track structure, but also to the great increase in weight of locomotives and rolling stock that took place towards the end of the century. This increase is reflected in the necessity of rebuilding the Kinzua Viaduct, and in the weight of the 4,310 ton Gokteik Viaduct built in 1900 in Burma by the Rangoon Mandalay Railway. This structure was 2,260 feet long and 335 feet high.

The Boone Viaduct has an approximately 300′ long, 60′ deep deck channel span composed of two deck Pratt trusses with the panels

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[3]Armstrong, 6.

divided into five sub-divided panels by means of sub-verticals which support the middles of the top-chord sections. It is carried on A-shaped towers at the ends, each about 80′ high, which are supported by eight cylindrical steel piers about 10′ in diameter; four under each end of the span. The piers consist of a steel shell 5/8" thick, made in sections about 5′ in height (except for the bottom section which was 8′ high), which were added and riveted as the piers were sunk. The piers were sunk by the pneumatic process to a sandstone stratum 42′ to 62′ below the surface. The piers were all filled with concrete.

The trusses of the channel span are seated on ordinary shoes, which are pin-connected to the lower ends of the end vertical posts and are riveted to the tops of the steel towers. The ends of the stiff lower chords engage the 10" shoe pins with slotted holes 14 1/2" long which permit expansion and contraction due to temperature changes. The end longitudinal struts also have slotted holes for the pins through the middles of the vertical posts, but there is no provision for expansion or contraction in the top chords. The end posts at one end of the trusses were constructed as rocker bents, fixed at the bottom but allowing the pins at the foot of these posts to slide longitudinally back and forth in slotted pin holes of the bottom chord.

There are four lines of plate-girders, two under each track, of a uniform depth of 7′. Beginning on the east end there are two 75′ plate-girder spans on a rocker bent; then six 45′ plate-girder spans, alternating with six 75′ plate-girder spans; then thirteen 75′ plate-girder spans. The 45′ plate-girder spans are carried on and form the tops of towers consisting of four columns each, rigidly braced together on all sides. The 75′ plate-girders span the opening between consecutive towers. The 75′ girders were designed for a live load of 6,100 lbs. and a dead load of 1,400 lbs., per lineal foot of track. The 45′ girders were designed for a live load of 7,600 lbs., with a dead load of 1,250 lbs. per lineal foot of track. All material is of soft steel, as specified by the railroad. Rivets, unless otherwise specified, were 7/8" in diameter.

There are thirty-six viaduct trestle bents, braced together in pairs to make towers 45′ long and 75′ apart, which are 19-1/2′ wide on centers at the top and batter 1:6 traversely on each post, giving a width of 69′-7" between centers of pedestals of the tallest tower. The tower columns are made of three I-beams placed together in the form of the letter H. Two 20" beams form the sides, and one 15" beam makes the connection between the sides. The longitudinal and sway braces are all stiff members made of two 12" channels laced together. All braces are diagonal and intersect each other at the center. There are no horizontal struts, except at the bottom of the tower, where all four columns are connected by 15' channel struts.

According to resident engineer W.C. Armstrong, the common practice at the time of construction was to make the tower span of a viaduct about half the length of the open span. But a difficulty arises in terms of the depth of the girder when this ratio is adopted. The longer the span the deeper the girder for structural capacity must be. Therefore it is necessary to make a 60' span much deeper than a 30' span, which usually creates some problems in connecting the two spans to the same column. It is possible, however, to vary the depth of a girder up to a foot from the theoretical economic depth with a very slight sacrifice of material; and by reason of this fact it was sought to overcome this problem by adopting the 45' and 75' lengths of the girder spans. Each was made uniformly 7' deep as a medium economic depth.

The floor beams are seated on the top chord, and the stringers are placed on top of the floor beams. This was done in order to reduce the height of the towers supporting the span to a minimum. The floor beams are knee-braced to the top chord by bent angles riveted to each side at both ends, and their bottom flanges are riveted to horizontal tie-plates projecting inside the top chords and receiving the pairs of angles which form the top lateral diagonals. The floor was originally constructed of 8" square yellow pine ties, 12' long and spaced 12" center to center. To their ends were bolted 10" x 12" yellow pine tie guards, and on either side of each rail there was a 4" x 10" planks spiked longitudinally. Between the rail and the inner plank there was a 6" x 4 1/2" spiked angle iron, which served to protect the ties in case a derailed truck crossed the bridge. The tracks were originally 13' apart on centers, and it was 35' from out-to-out of the two cantilevered sidewalks and hand-car refuges, of which there were four on each side. On each side of the floor there was a railing supported by a brace running from the lower flange of the plate-girder.

The abutments are rectangular blocks of masonry, 50' x 30' at the base, with reinforcing buttresses at the front. The piers supporting viaduct towers are 5' square at the top. They were built with a batter of 2" per foot, and the bases vary from 12' to 20' square, according to their height or the pressure they exert on the foundation material. The masonry was all of Mankato limestone laid in Portland-cement mortar. The pedestal blocks supporting the steel columns on top of the piers are of Ableman's sandstone, secured to the coping by anchor bolts through the column bases.

Work in preparation for actual construction of the Boone Viaduct was begun in the spring of 1899. After the grounds were cleared of trees and brush, a temporary service track for the distribution of material was built alongside the line of the permanent structure. This temporary line included a bridge on pile and trestle bents built about twenty-five feet above the water. A power plant with two 60 horsepower boilers, pumps, an electric light dynamo, and two Ingersoll-Sergeant air compressors was established on one side of the river and the pipes and wires were carried across to the opposite side under the roadway of the service bridge.

Next, three gasoline powered drills were used to sink test holes for the purpose of determining the character of the underlying material upon which the foundations would rest. The material found was characteristic of coal regions such as Boone County with a great deal of clay, shale, sandstone, fireclay and coal. Great care was taken to determine the amount and character of surface deposit and the stratified material underneath, and to locate the "surface of erosion" between the two. It was feared that if inclined piers such as the ones which were to be used on the valley slopes were founded on the super-imposed surface material that slipping might occur.

The abutments and piers supporting the low towers were constructed in pits dug in clay to a depth of 12′ or 14′ and founded on beds of concrete from 4′ to 6′ in depth. The area of the concrete base was made such that the pressure per square foot would not exceed two tons. Farther down the valley slopes, where stratified material was nearer the surface, the excavations went down into the stratified material and usually rested on black shale. The foundations were prepared in the same manner as for those resting on clay but with an allowed pressure of three tons per square foot. Near the river, where sand overlaid the stratified material, and where the surface of erosion was approximately level, wooden piles were driven and then cut off at the water surface. Concrete was then poured around and on top of the piles to provide a masonry foundation with an allowed pressure of fifteen tons per pile.

Construction of the foundations located in the river channel required the use of a pneumatic caisson. The eight cylindrical piers supporting the approximately 300′ channel span had a bottom section 8′ in height, with a steel diaphragm framed in one foot from the upper edge, which formed the roof of the 7′ high working chamber below. Through the center of this diaphragm there was a hole 3′ in diameter for the air shaft, which was a steel tube of the same diameter. At the top of the shaft there was a Moran air lock, through which excavated material was hoisted, and through which workers passed from the open air to the working chamber.[4]

The Moran air lock differs somewhat from the type usually used in bridge caissons, and was especially adapted to pneumatic work where, due to limited space, only one air shaft can be used for both men and material. In large bridge caissons two air shafts are usually used with an air lock on each. But the Moran design is a double lock with one compartment for passing out material and one for the men. It also has the advantage of being removable and reusable, whereas bridge caissons usually are abandoned and filled with concrete when the proper depth is reached.

After the working chamber is placed in position a section of the air shaft was then bolted in place with the air lock on top. A section of the outer steel shell of the pier was then rivetted on, and the air pipes connected. Enough concrete to sink the chamber was then filled in between the outer shell and the air shaft, and on top of the roof of the working chamber.

The upper and lower doors of the air lock are not placed with their vertical axis in the same line. To begin operation of the lock the upper door is open and the lower one is closed. A bucket is then let down into the lock, moved to one side, and the upper door is closed. The rope passes through a hole in the door frame. A valve is opened allowing air from the shaft and working chamber to enter and pressurize the air lock, and as soon as the pressure in the top chamber nearly equals that of the chamber below, the lower door opens and the bucket is free to let down. The lower door remains open as long as the bucket is below. Men who have entered the working chamber through the air lock dig up the material from under their feet and shovel it into the bucket, which is hoisted out through the top compartment of the air lock. The lower door is closed, and the valve turned to connect the lock with the outside air, thus allowing the pressure in the upper lock to drop to an ambient level. The upper door is then opened and the bucket is hoisted out. Both doors are circular gasketed steel plates operated by exterior counterweights. The upper door is sometimes provided with a stuffing box to permit the passage of the hoisting rope when the door is closed.

At the Boone Viaduct site the maximum air pressure of 23 lbs. per square inch above atmospheric was used. It was found that any

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[4]A detailed description of the Moran Air-lock is contained in Henry S. Jacoby and Roland P. Davis, <u>Foundations of Bridges and Buildings</u> (New York: McGraw-Hill Book Co., 1914), 352-355.

man of sound condition could labor several hours under this pressure without harm, and the work proceeded rapidly.[5] When one pier had been sunk until the top of the concrete filling was about to the water surface, the air lock would be removed and placed on another pier and the process would be repeated. A rate of progress as high as 16′ per day was made through the sand that lay near the surface, but in the hard shale and other stratified material encountered at depth it averaged only about 2′ per day. The caisson work began on February 7, 1900 and the piers were all completed and the coping set on June 6.

The superstructure was erected from both ends simultaneously by overhead traveling derricks running on top of the structure as it was completed, each lifting and lowering the metalwork into position. There were also four derricks for unloading material from cars as it arrived, with two at each end of the bridge, and two gasoline-powered air compressors for running the pneumatic riveting machines, with one on each end. The traveling derricks consisted of a steel framed bent about 50′ high made of three posts framed together and mounted on a platform carrying a hoisting engine, coal, water, and the hundreds of feet of rope used in handling the steel. At the bottom of this bent were attached two booms; one called the 90-foot boom and designed to carry ten tons at the extreme end, and the other called the trolley boom and designed to carry sixteen tons at the end.

The 90-foot boom, so called because it was 90′ in length, was made of two 9" channels laced together, and stiffened against buckling vertically and sideways by longitudinal truss rods. It was made to swing through a vertical arc of 75 degrees from the horizontal position, and was arranged for a lateral swing of about the same extent. It was raised and lowered by means of

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[5]By the turn of the century, bridge builders had become knowledgeable about caisson′s disease, otherwise known as decompression sickness or "the Bends." This debilitating and occasionally fatal condition is caused by the formation of gas (mainly nitrogen) bubbles in the body because of rapid transition from a high-pressure environment to one of lower pressure. The greater the pressure under which a worker labors, and the greater the length of time the worker is in a high-pressure environment, the longer the period of decompression required to prevent illness or pain. In the case of caissons sunk to great depths, the pressure required to keep water out of the caisson was so great that men could only work for short periods of time without having to endure lengthy decompression. The builders of the Boone viaduct found that at the relatively low caisson pressure required in the shallow Des Moines River, there was essentially no decompression required for fit men who only worked a few hours.

block and tackle connecting the end of the boom with the top of the braced bent and operated by the hoisting engine. The side movement was controlled by hand lines run to the ground, which was also the method used for the horizontal trolley boom.

The trolley boom was 51' long and was made of two 18" I-beams, the upper flanges of which formed a track upon which were run two carriages or trolleys on which the material was run forward. This boom was given a lateral swing of about 30 degrees and was supported in the horizontal position by means of stay rods extending from the end and from two intermediate points to the top of the braced bent. The trolley boom was used for lowering and setting the girders in place and also for lowering material for the towers from the deck of the structure to the ground, where it was picked up with the 90-foot boom and raised to its place in the tower.

The river span was the only part of the structure built on falsework. This falsework was very heavy and made of 8" x 16" Oregon fir. The span was assembled by one of the travelers running on the top chord of the assembled trusses and setting two panels in advance. The field rivets for this and all other spans were driven by pneumatic hammers operated by gasoline powered compressors. The erection of the superstructure was begun in November 1900 and the first crossing by a construction train was on May 16, 1901. Several men were killed during construction.

The testing of the completed bridge was conducted on May 18 by a method commonly used at that time. Several cars were heavily loaded with sand and then started across the bridge at a high rate of speed. At a given signal the emergency brakes were set and the wheels of the engine reversed, stopping the train within 60 feet. First one train and then two trains at the same time were used for the test. The next day the new line was officially opened, and on May 28 the bridge was crossed by the special train of President William Mckinley, who was on a trip through the region.

The new line would bypass the old route and thus take out of regular service the Kate Shelly Bridge, which was the former main railroad crossing of the Des Moines River near Moingona. This bridge was named in honor of the fifteen year old heroine who, on the night of July 6, 1881, risked her life in crossing the bridge to warn an oncoming train of a washout into which an engine had already run and been wrecked. Ms. Shelly, who still lived within a short distance of both bridges in 1901, was in attendance at the opening ceremonies of the new viaduct and it was named the Kate Shelly Bridge in her honor. The old bridge continued in limited service until the 1930s and the track was torn out in the 1950s. The bridge no longer exists, and it is generally assumed by knowledgeable individuals in Boone County that the bridge was partially destroyed by severe flooding in 1954.

There have been a variety of figures reported for the final cost of the Boone Viaduct, with the most commonly quoted figure being in the neighborhood of $1 million. This figure is almost certainly too high, given that the total cost of the entire Boone-Ogden cut off was projected in 1898 by the C. & N.W. chief engineer's office to be $931,000. The railway company had a great deal of experience in laying track, and thus it is reasonable to assume that their projections for right-of-way and grading ($251,000), track ($124,000) and engineering ($10,500) were fairly accurate. The cost of the bridge, which was the one component of the total cost they had no experience with, having never built a structure of this magnitude, was the one figure likely to have gone over budget. Even though the bridge was built under contract by the Chicago office of the American Bridge Company, it is likely that the contract contained provisions that would allow the bridge company to recover cost overruns from the railroad.

The final cost of the entire cut off was reported by Poor's Manual of Railroads in 1902 as precisely $1,108,326.96. If this figure is assumed to be correct, and all of the cost overrun is applied against the bridge, it may be estimated that the cost of the bridge was approximately $722,000. Applying less than 100% of this overrun to the bridge cost would, of course, reduce this figure. An article in the May 25, 1901, edition of The Railway and Engineering Review gives a figure of $625,000 for the cost of the bridge and a sum of $1,250,000 for the total cost including approaches. The sum quoted for the aggregate cost is far above any other given, and may have been a projection arrived at before final accounting. The best guess is that the final cost of the bridge is therefore in the range of $625,00 to $700,000.

Although George Morison was consulting engineer for this bridge it is unknown just how much direct involvement he had in its design. His name is only mentioned in passing in the several articles published in contemporary engineering periodicals, and a June 1901 article published by resident engineer W.C. Armstrong mentions neither Morison nor any other designer. Given Morison's early experience as engineer in charge of construction of the Portage Viaduct over the Genesee River (1875), and his general experience with railway bridges and large river spans, it is probable that he had considerable input into the bridge's design. However, none of the biographies or obituaries that list Morison's work include mention of the Kate Shelly Viaduct, which is unusual given that it was the heaviest and longest viaduct built by 1900 and should have stood as one of the last great achievements of a long and distinguished career.

The Kate Shelly High Bridge still serves the needs of the Chicago and North Western Railroad, with numerous train crossing each day. The Viaduct remains in essentially original condition, possesses a high degree of historical and structural integrity, and stands as one of the most significant railway viaducts in the United States.

APPENDIX
IMPLICATIONS FOR FURTHER RESEARCH

Several questions concerning the Kate Shelly High Bridge arose during the research and writing of this report. Some of these questions, due to limitations in the scope of the Iowa Historic Bridges Recording Project, have remained unanswered. It is suggested that scholars interested in this bridge consider pursuing the following:

1. How much, exactly, did construction of the bridge cost?
2. What role did George Morison play in the design of the bridge?
3. What impact did construction of the Boone-Ogden Cut Off have on the operations of the Chicago & North Western Railroad, if any?

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ADDENDUM TO
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This appendix is an addendum to a 14-page report previously transmitted to the Library of Congress.

APPENDIX: ADDITIONAL REFERENCES

Interested readers may consult the Historical Overview of Iowa Bridges, HAER No. IA-88: "This historical overview of bridges in Iowa was prepared as part of Iowa Historic Bridges Recording Project - I and II, conducted during the summers of 1995 and 1996 by the Historic American Engineering Record (HAER). The purpose of the overview was to provide a unified historical context for the bridges involved in the recording projects."