## D. Historic context: Reinforced-Concrete Highway Bridges in Minnesota, 1900-1945

NOTE: The original text of this context is included in "Reinforced-Concrete Highway Bridges in Minnesota," National Register of Historic Places, Multiple Property Documentation Form, prepared by Robert M. Frame III, Ph.D., 1988, available in the Minnesota State Historic Preservation Office.

### *Reinforced-Concrete Highway Bridges in Minnesota, 1900-1945*

MATERIALS: An Introduction to the Elements of Concrete

Reinforced concrete universally consists of three elements: binder, filler, and reinforcement. The binder material in concrete is cement, and it is important to remember that concrete and cement are not synonymous. There is no such thing as a cement sidewalk, a cement block, or a cement bridge. There are concrete sidewalks, concrete blocks, and concrete bridges. Cement is a fine gray powder made of calcium, silica, and other minerals.

Cements (and the resulting concrete) are either hydraulic or non-hydraulic, meaning that they either do or do not harden under water and remain durable when wet. All modern cements and concretes are hydraulic.

Hydraulic cement either is produced from naturally occurring cement rock and is termed "natural cement," or it is manufactured from lime and other ingredients and is called "portland cement." Portland cement was first produced and patented in England in 1824. Although it was used in the United States, it was not manufactured here until a Pennsylvania plant was opened in 1871. Minnesota was one of a dozen or more states producing natural cement around 1902-04, but not portland cement.[1]

While the quality of natural cement is determined largely by the rock from which it is made, portland cement is a scientifically controlled product. This control would become increasingly important as the use of concrete escalated rapidly in the early twentieth century and engineers focused on the quality of the ingredients. Cement is the key ingredient in concrete. As demand increased, quantity output naturally became important. Introduced in the 1890s, the rotary cement-kiln provided continuous processing. The mass availability of carefully proportioned portland cement provided the basis for a construction industry utilizing concrete. The natural cement industry was finished. As an engineer remarked in 1894, "the use of Portland cement concrete has wrought a revolution in all branches of civil engineering, and it seems that we are only in the beginning of the radical changes, which in bridge work, sewers, water works, railroads, etc., are following its introduction."[2]

Since cement is only a bonding agent, it is mixed with filler to give it "monolithic bulk," or enough substance to be formed into a unified whole that can stand alone. The filler consists of "aggregate." Generally aggregates are naturally occurring sands (fine aggregate) and gravels (coarse aggregate). (When cement is mixed only with fine aggregate, the resulting compound is termed "mortar.") As with the cement, the origin, size, and nature of the aggregate became more important as engineers and scientists learned more about concrete construction. Simply mixing cement with gravel from a nearby pit was not necessarily desirable for quality concrete.

Finally, to create concrete, water must be added to the cement and the aggregate. The quantity and quality of the water, and the proportioning of all the ingredients, is extremely important and subject to analysis. Specifications for bridge contractors working in concrete will indicate the required ingredients and their proportions.

The nature of the concrete used in concrete bridges affects the quality and economy of the structure. Other factors (outside of bridge design) involved in quality and economy include elements such as formwork, and mixing and placing the concrete. The larger the structure, the more these become critical. In particularly large projects, such as the Mendota-Fort Snelling continuous-arch bridge (Mn/DOT Bridge 4190), the design and engineering of the contractor's work is a gargantuan task that has a major impact on the project's cost. Formwork- "centering" in these large arch bridges- is an engineering specialty all its own.[3]

## ENGINEERING AND DESIGN: Basic Elements and Bridge Types

### *Reinforcement*

The first concrete bridge in the "modern" world (concrete construction was known in ancient Rome) was built in France in 1840; the first in the United States was built in 1871 in Prospect Park, Brooklyn.[4] These were arch bridges without reinforcement; concrete bridge design and construction does not demand reinforcement, since a massive enough concrete structure will absorb any tensile stresses.[5] A major unreinforced or "plain" concrete bridge, the Rocky River Bridge in Cleveland, Ohio was built as late as 1910. With its 280-foot span, this giant was the last of its type.[6] There are no extant concrete bridges in Minnesota that are known be of "plain concrete" (not reinforced).

The monolithic bulk comprised of cement and aggregate (binder and filler) is strong in compression but weak in its resistance to tensile stresses. To overcome the lack of tensile resistance, reinforcement is added in areas that will be subjected to tensile forces. The history of reinforced concrete should be understood in terms of the evolution of reinforcing, as well as in its own right as a building material.[7]

The materials of reinforcement, historically, have been related to systems of reinforcement: i.e., the Melan system used a curved I-beam, the Kahn system used the Kahn Bar, and so forth. Basically the materials have been steel rods or bars, while a variety of forms and shapes have been employed. Systems regarded as being early and significant include: Josef Melan reinforcing system, Fritz von Emperger reinforcing system, W. C. Marmly reinforcing system, Daniel Luten patents, James B. Marsh rainbow-arch patent, George M. Cheney patent (used by Standard Reinforced Concrete Co.), Kahn reinforcing bar (used by Trussed Concrete-steel Co.), Cummings reinforcing bar, and the Thacher reinforcing bar.[8] Even the term "reinforced concrete" was not standardized until the turn of the century.[9] The first national standards on reinforcing came in 1911 when the Committee on Steel, of the American Society for Testing Materials (ASTM) adopted specifications for reinforcing steel, covering plain, deformed, and cold twisted bars. Prior to this, any standards came from individual industry and municipal sources.[10]

### *The Reinforced-Concrete Arch Bridge*

The masonry-arch bridge has been built since ancient times and its basic features have long been well known. The basic arch form was adapted to both plain- and reinforced-concrete construction. Since the mid-nineteenth century, builders had experimented with reinforcing in concrete and in 1889 the first reinforced-concrete bridge was built in the United States. It was the Alvord Lake Bridge in Golden Gate Park, San Francisco, and was the work of English-born Ernest L. Ransome, who had worked with concrete in California since the 1860s and with reinforcing systems since the 1880s. In 1884, he patented a twisted reinforcing bar. During the same period, arch experimentation was continuing using the metal mesh system of Josef Monier.[11]

Most influential of all, however, was Viennese engineer Josef Melan, who in 1894 received an American patent on his reinforcing system. It consisted "of a number of steel I-beams bent approximately to the shape of the arch axis and laid in a parallel series near the undersurface of the arch. The resulting structure might be regarded as a combination of the steel-rib arch and the concrete barrel, the concrete serving a protective as much as a structural purpose." Interestingly, in terms of geography, the first American bridge to embody the Melan system reportedly was a small highway span designed by German-born engineer Fritz von Emperger and built by William S. Hewett at Rock Rapids, Iowa, the same year as the patent.[12] Several small but early Melan bridges were built and designed by Hewett in Minneapolis and Saint Paul for the Twin Cities Rapid Transit and survive today as park structures (Mn/DOT Bridge L-9329, Bridge L-5853, Bridge 92247).

--Open Spandrel and Filled Spandrel Designs

The space between the bridge arch and the bridge floor, known as the spandrel area, can be treated in a number of ways. In a smaller bridge, the floor is partly supported by longitudinal walls termed spandrel walls, which rise from the arch to the deck. The hollow interior space is filled with earth or other material, and the bridge is termed a "filled-spandrel" arch. This design involves a heavy dead load on the arch, which is too great in larger structures. To reduce the weight, the spandrel area is opened up. The walls and fill are replaced by columns or transverse walls that rise from the arch to carry the floor. This is an "open-spandrel" arch. These columns and walls are found in a variety of combinations and arrangements, depending on the size of the bridge. Barrel arch designs may be either filled- or open-spandrel; rib-arch designs are usually--but not always--open-spandrel. Minnesota has at least one example of a rib-arch-with a spandrel curtain-wall (Mn/DOT Bridge 5772), and this type has been built elsewhere.[13] The spandrel wall provides an opportunity for architectural treatment. Minnesota has many examples of both basic spandrel configurations, filled and open.

--Barrel Arch and Rib Arch Designs

In 1897 von Emperger, who built many Melan bridges, received two patents for additions to the Melan system. These incorporated additional steel which led, according to engineering historian Carl Condit, toward rib-arch design: "The division of the continuous arch barrel into separate ribs was achieved in the U.S. by F. W. Patterson, an engineer with the Department of Public Roads in Allegheny County, Pennsylvania. Patterson began in 1898 to design small highway spans in which the deck was supported by two parallel ribs each reinforced with a single curved I-beam."[14] In arch-bridge construction, the arch ring may be constructed either as a single arched structural element (a barrel) or in separate but parallel longitudinal elements (ribs). Ribs usually are interconnected by cross struts and braces. Historically there is a rough evolution from an early reliance on the barrel design to a widespread acceptance of the rib design. In terms of size, the larger the bridge the more likely that it is a rib design, since the rib configuration allows less material to be used, thus reducing cost, and lightens the weight of the bridge superstructure. On the other hand, a rib design involves more complicated formwork, thus adding an expense to an already expensive component. Minnesota has examples of each type.

In some cases it is difficult to say if a particular bridge is composed of ribs or double barrels, and it usually amounts to a distinction without a difference. A variation on this theme is found in the above-noted Rocky

River Bridge, which employs "Luxembourg construction," named after the Luxembourg Bridge (1903) over the Petrusse River in Germany, wherein "two comparatively narrow bridges are built side by side; the space between is then bridged over by a roadway."[15]

### --Early Twentieth-Century Experimentation in Arch Design

Carl Condit views the turn-of-the-century period as one of experimentation and novelty in design, with the Melan system of reinforcing in the ascendant for concrete arches, although the more efficient methods of bar reinforcing, introduced by Ransome in 1889, were beginning to gain new attention. For a decade after 1900, the design of arch bridges tended to be conservative. The problem with Melan was that it required too much steel, making in actuality a steel bridge encased in concrete. A major Minnesota bridge of Melan construction, the Third Avenue Bridge (Mn/DOT Bridge 2440) in Minneapolis, was built at the end of the Melan era in 1914-16.

By 1910, according to Condit, the main line of evolution was moving away from massive construction, "with its echoes of the masonry tradition, toward the flattened parabolic curves of narrow ribs, the slender spandrel posts, and the minimal piers that scientific reinforcing was to make possible."[16] Among the systems that diverged from Melan was that patented in 1903 by Julius Kahn, which introduced the innovative Kahn Bar, actually a flat bar with the outside edges cut and bent upward to form shear reinforcement. In a 1903 article, Kahn argued that "concrete should be reinforced [sic] in a vertical plane, as well as a horizontal one," and further argued that his bar did this:

> "All of these results have been accomplished by taking a bar of cross section... and shearing the web upwards into an inclined position on both sides of the main body bar, thereby forming substantially the tension members of the ordinary Pratt truss."[17]

Another prominent early advocate for reinforced concrete was the Indiana engineer Daniel B. Luten,[18] who began to publish the first of many articles about this time and was responsible for another alternative to Melan:

> A more scientific solution [than the Melan system], closer to Ransome's method and pointing to later techniques of bar reinforcing, was the introduction from Germany about 1900 of the Luten system for reinforcing wide-span culverts. In this system several bars forming a complete loop were laid transversely through the vault and the bed, or invert, of the culvert, and a series of such loops were laid at regular intervals throughout the length of the structure. The bars were bent to conform to the semicircular section of the vault and the shallow curve of the trough-like invert and to lie near the surfaces of maximum tension under live load. In spite of such early uses of the concrete arch for railroad bridges of great size, the form has never been popular for rail service chiefly because of the problem of absorbing high impact loads.[19]

As with reinforcing bars and systems, not all of the arch forms proved to be prototypical, or even particularly influential. For example, the patented Marsh rainbow-arch design was built at several locations throughout Minnesota in the pre-World War I era, producing significant and visually striking structures, while never entering the design mainstream. Nevertheless, a monumental and significant example was built in 1926, St. Paul's Robert Street Bridge (Mn/DOT Bridge 9036)

In passing, it can be noted that arch bridges divide into two large categories, single arch or continuous arch. A continuous-arch bridge is so designed that, at any pier, the presence of one arch is necessary to provide the abutment-like countervailing force for the adjoining arch. If two single (non-continuous) arches are adjacent at one pier, the pier construction itself will provide the necessary abutment force even if one arch is removed. In practice, almost all multiple-span arches are continuous, and Minnesota has many examples.

--Standardization of Reinforced-Concrete Bridge Construction
In Carl Condit's analysis, the period from World War I to the Depression was largely one of refinement and standardization in reinforced-concrete-arch construction. It was marked by two important regional bridge-building programs: one in Minnesota's Twin Cities metropolitan area after 1915, and another in the California Department of Highways system after 1920. These groups epitomized fine design rather than the innovative and experimental work that characterized the earlier, prewar era. Each offered increasingly larger and longer--and longer-span--crossings, as well as more sophisticated versions of reinforced-concrete design. Prominent examples include Minneapolis's Cappelen Memorial Bridge (Mn/DOT Bridge 2441, 1919-23) and the Mendota-Fort Snelling Bridge (Mn/DOT Bridge 4190, 1925-26), both of which set world length records when built, and California's exquisitely proportioned Bixby Creek Bridge (1931-33). The Minnesota group is discussed in greater detail below.

The high point of standard fixed-arch design (i.e., an arch without hinges and therefore "fixed," stable, and rigid[20], a form used almost universally for concrete bridges with span lengths above 100 ft.) came in 1930-31 with the Westinghouse Memorial Bridge over Turtle Creek Valley in Pittsburgh. Its center span of 460 feet was the longest for a concrete arch in the United States.[21]

Much of what followed the Westinghouse Bridge, in reinforced-concrete bridge work, was a move away from increasingly costly arches toward precast and prestressed girders, deck slabs, and bents. The great demand for highway bridges "eventually became so great that they had to be erected by methods equivalent to mass production."[22] Thus, even though a major engineering research study of reinforced-concrete arches was conducted at the University of Illinois in the early years of the Depression, [23] the demands of economics eventually forced bridge design and construction in other directions. By World War II, the great era of reinforced-concrete arch construction had come to an end, superseded in the reinforced-concrete-bridge world by girders, rigid frames, and precast and prestressed construction.[24]

*Reinforced-Concrete Slab, Beam, and Girder Bridges*
The reinforced-concrete bridge may be best known in its arch form, since that has been the type employed for the largest, most spectacular, and ornate structures. Far more common, however, have been simple slab, beam, and girder bridges. Following their quick adoption and standardization by the state highway commissions that were created in the decade after 1900, these bridge forms were recommended everywhere for small to medium spans. By the 1920s arch bridges were recommended only for locations with very sound foundations for the abutments.[25] As late as 1906, however, arch-designer Daniel B. Luten wrote that a reinforced-concrete girder bridge ordinarily was not as economical as an arch, unless the abutments were already in place. Luten's example is a situation where a metal truss or beam span had been removed and, of course, an arch would be almost impossible to build, since the abutments had been designed for compression and not for arch thrust.[26]

For the highway department planner, slab, beam, and girder bridges would differ only in construction cost, according to the noted Oregon bridge engineer Conde B. McCullough, who published a study of the economics of highway bridge types in 1929.[27] Each may be used for a variety of span lengths, but only certain types are economical for certain lengths. For example, a slab bridge theoretically could be constructed to almost any span length desired. To achieve a long span with any load-carrying capacity, however, the slab would have to be unreasonably thick and be built with an uneconomically large amount of materials, compared to another design such as a girder. A secondary consideration is the amount of vertical clearance available with each type.

If the design of the concrete arch grew out of the masonry arch, slab and girder bridges were directly related to developments in concrete-building construction. The first concrete girder used in bridge work came in 1898 in Pittsburgh, Pennsylvania, and was similar to the Melan arch reinforcement. An I-beam was encased in concrete to form a reinforced-concrete girder and these were used as main girders and as stringers. As with the Melan work, the I-beam proved to be less desirable than bar reinforcing, and this method emerged around 1905 and was changed very little thereafter. In fact, according to Condit, "the number of concrete girder bridges is so great and the design and appearance so nearly uniform that it is difficult to select examples that are more noteworthy than many others."[28]

### *Reinforced-Concrete Slab Spans*

In its most basic form, the slab-span bridge is nothing more than a square or rectangular panel of reinforced concrete with each end resting on an abutment or other vertical support, and with a railing mounted along each side of the slab. This simplicity has the asset of requiring uncomplicated and economical formwork and less labor in placing the reinforcing; it has the liability of requiring more concrete and steel than girder spans. Also, the simple slab can be used in locations requiring a minimum of vertical clearance or headroom. Overall, simple slab bridges are economical for only the shortest spans, since longer slabs require too much concrete and reinforcing material compared to a beam or girder of equivalent length, thus increasing the cost of the slab relative to the girder. In 1916 Taylor and Thompson recommended limiting slab length to only 10 to 12 feet for heavy loading (trolleys and trucks) and up to 20 feet for less severe loadings.[29] In 1920 Milo Ketchum stated that slabs could be employed for spans up to 25 feet, but were not economical for spans over 20 feet. Later engineering texts extended the maximum economical length to 30 feet.[30]

Like the girder and arch, slabs may be employed in a series of simple spans or the slab may be designed as a continuous span, where it is extended across a support of some kind. In 1921 Waddell found little difference, economically, between continuous and noncontinuous slabs, although he preferred the continuous from the point of view of paving and drainage. In 1939, however, Taylor, Thompson, and Smulski reported that the continuous design was cheaper, as well as being more rigid. Comparing the continuous slab with the continuous girder, the 1939 text reported advantages and disadvantages that are very similar for those in the simple-span comparison noted above. The continuous slab was simpler in terms of labor for formwork, arrangement of reinforcement, and placing of concrete; it had fewer critical sections in design; it had smaller areas of exposed concrete surface and thus lower surface-finish cost. Its disadvantages were greater cost of materials and larger dead loads. Except in cases where the lower headroom is needed, the added cost outweighed the advantages.[31]

Much of the discussion about continuous slabs involves the type of support, and one of the most significant innovations in slab design was C. A. P. Turner's adaptation of his flat-slab mushroom-column construction to bridge design. The first span to use this was his 1909 Lafayette Avenue Bridge over the Soo Line tracks in St. Paul. It was built only a few years after Turner had applied for his original patents (1905) and had built his first flat-slab building in Minneapolis (1906), and in the same year that he published his own engineering text, *Concrete Steel Construction*.[32] The bridge has been demolished, as has a second known early example, the Mississippi River Boulevard Bridge (Mn/DOT Bridge 92250), which was designed by Turner for the St. Paul Park Board and constructed in 1909. It was replaced in 1987.[33] A single, known surviving example of Turner's reinforced-concrete work is the approach to the Mississippi River bridge at Wabasha (Mn/DOT Bridge 4588), designed by Turner and constructed by the Minneapolis Bridge Company in 1931.

By 1939 the column-supported, flat-slab design was being actively promoted by Taylor, Thompson, and Smulski, who commented that "in bridge construction... flat-slab floors have not been used to as great an extent as their merits would justify." They found this design to be very economical: "Often, by using a properly designed flat-slab construction, the cost of the bridge may be reduced by as much as 25 to 30 per cent of the concrete structure."[34]

In addition to Turner's and others' mushroom-column support (in which the slab is rigidly connected with the column), slabs can carried trestle-like, on concrete piles, concrete piers, or framed concrete bents. The trestle arrangement often is found in discussions of flat-slab designs for railroad bridges.[35]

A variation on slab design is the "T-beam," which is formed "where a concrete floor slab is constructed integrally with the supporting beams so that unity of action is insured."[36] A concrete deck-girder similarly integrated with a slab is much the same thing.[37] As discussed by Ketchum, a T-beam slab bridge can be seen as a transitional structure between a simple slab and a deck girder. Taylor and Thompson in 1916 stated that "when the combination of span and loading is such as to call for a slab thickness of more than 16 to 18 inches the simple slab will not prove as economical as the T-beam or girder type."[38] Generally, the T-Beam has been recommended for spans at the longer end of the slab range (20-35 feet). It uses less material than a simple slab, and it possesses some of the deck girder's disadvantages, i.e. it requires more headroom because of the beam.[39]

In 1916 the Minnesota Highway Commission reported developing a new reinforced-concrete slab design for 23-foot spans called the "cellular slab." Half-round sections of corrugated-pipe were used as forms on the underside of the slab, creating a pattern of hollowed-out "cells" in the finished concrete. The remaining concrete then functioned as longitudinal reinforced T-beams with cross beams. The intent was to reduce by one-third the amount of required concrete. Although construction of an experimental half-size model was reported, no further accounts of the use of this design have been found, nor has any example yet been located.[40]

### *Reinforced-Concrete Girder Bridges*

As Taylor and Thompson stated in 1916, girder construction "becomes practical at the point where the simple slab ceases to be economical, while its maximum economical span is determined not only by the kind of loading provided for but also by the spacing and arrangement of the girders." The girder bridge, they pointed out, "is in reality a modification of the slab bridge whereby a comparatively thin slab spans between a series of relatively deep beams which in turn span from abutment to abutment.[41]

--Single Span and Continuous-Girder Span

Girders are of two main types, single or continuous. The continuous girder bridge, with the girder extending over multiple spans, first appeared about 1910.[42] According to J. A. L. Waddell in 1921, there was not a great deal of economic difference between the two in highway bridges, and the continuous girder often was used, since it gave a solid, monolithic structure. In a multiple-span bridge with any danger of settling, however, a series of simple spans would be preferable. At the time, the balanced-cantilever type of girder was beginning to be used, involving for each unit a pier and two half-spans.[43] It is clear from discussions of girder bridges in Condit that the profile of girders can be misleading, since they are not always simply long rectangles, but may have various curves in their profiles. A girder can be given a slight concave curve along its lower edge for an aesthetically pleasing appearance. Hool and Kinne stated that "it is possible to construct a [cantilever girder] bridge resembling a concrete arch structure in appearance, in locations where the foundation conditions would not permit the construction of an arch...."[44] Without a more complete survey in Minnesota, it is difficult to be certain how many of each type survive, since single and continuous are not always properly designated in the Minnesota Department of Transportation inventory.

--Deck Girder and Through Girder

The fundamental difference between a deck-girder bridge and a through-girder bridge is straightforward: in a deck-girder, the bridge floor slab rests on top of the girders; in a through-girder, the bridge floor is a slab carried between the girders, which act as railings.

Each type has its advantages and its liabilities, and assessments of each remained consistent over two decades from 1920 to 1939.[45] The deck girder's liability is the depth required for its floor construction; the through girder carries the floor between the girders and therefore is preferred where headroom is limited. The situation is reversed when roadway width is a factor. Since the through girder is necessarily limited to the two girders containing the floor, its maximum roadway width is restricted to this outside-supported floor slab, or about 18 to 20 feet. On the other hand, a deck-girder configuration allows for multiple girders beneath the floor, thus extending the width potential. If necessary, the floor slab can be cantilevered beyond the outermost girders to provide additional width for sidewalks. By 1939, through girders were seldom used for highway bridges, although they continued in use for railroad bridges, which were not subjected to ever increasing width demands. Through girders were not being recommended for any road which might require future widening, a necessity by World War II that had not been anticipated twenty years earlier.[46]

*Rigid Frame Spans*

If a solid, horizontal slab is rigidly connected with vertical walls, a simple rigid-frame bridge has been created. The critical point is that the three sides are rigidly connected at the two "knees" or corners, and all work together in carrying a load. In sectional elevation, the rigid frame appears somewhat different from an abutment-supported slab. In the conventional slab arrangement, its abutments are heaviest at the bottom and lighter at the top where the bridge seat is located. In the rigid frame, the reverse tends to be true: the transverse vertical walls, which replace traditional abutments, are wedge-shaped, tapering downward to the footing. Overall, the rigid-frame bridge is considered much more economical than either the T-beam slab or the fixed arch, particularly when unyielding foundations are easily obtainable. In addition, the rigid frame employs a smaller depth of construction, a decided advantage where headroom is limited and the required elevation of the top of the bridge is fixed. This is why rigid-frame bridges often have been used in grade separations, such as in freeway construction.[47]

Based on European precedents, the rigid frame was developed in the United States in the early 1920s by Arthur G. Hayden for parkway construction in Westchester County, New York. According to Condit, the rigid frame was the most important innovation in concrete bridge design after Turner's mushroom slab, and it "ranks second only to prestressing as a money-saving method."[48] In his 1931 text, Hayden stated that the concrete T-beam slab was probably more economical than the rigid frame for spans below 30 feet, but the concrete rigid-frame bridge was more economical from 35 to 80 feet. When built in steel, the rigid frame extended the economic advantage from 80 to 120 feet.

Hayden pointed out some variations of the rigid frame, which gave it a deceptive appearance. At times, the curve of the floor slab (it always has a slight arch in rigid-frame design) was great enough to make it appear to be a low-rise arch bridge. Also, the rigid frame sometimes has been constructed with large ribs instead of a solid barrel or slab, giving a visual suggestion of a low-rise ribbed arch. Some have an elliptical intrados.[49] In a narrow design, two rigid-frame ribs may have been used, one on each side of the bridge. The ribs may be extended above the road, creating a through version. As with other concrete spans, rigid frames could be used in a continuous design, sometimes termed "multi-span rigid frames."[50] It is possible that the true nature of a rigid-frame bridge may not be known until the bridge plans are reviewed and the bridge structure may be studied without its additional decorative pilasters and walls.

Within 15 years of its introduction, the rigid-frame bridge had gained wide popularity, replacing arches, slabs, and girders in many applications. In a 1938 address to the Concrete Reinforcing Steel Institute, "What the Future Holds for Reinforced Concrete," the president of the Portland Cement Association reported: "At the present time the rigid frame bridge is being actively promoted and practically every state in the Union has now accepted this type of construction as standard where it fits the location economically."[51]

## REINFORCED-CONCRETE BRIDGES IN MINNESOTA

### *Before the Minnesota Highway Commission*

There is very little documentation of reinforced-concrete bridge construction in Minnesota for the years prior to state involvement (i.e., basically before 1905). Almost all the evidence exists in the few surviving structures themselves. Fortunately, however, these extant bridges are excellent examples of significant early designs in both urban and rural areas.

In this pre-automobile era of "streetcar suburbs," where the former nineteenth-century "walking city" was being expanded dramatically by rails,[52] it is appropriate that the new reinforced-concrete bridge technology should be employed by the transit companies who were involved in other new technologies, such as electrification. Bridge builder, and concrete designer and promoter, William S. Hewett designed and built the bridges required by the Twin City Rapid Transit company around 1903-05. Surviving from this group are at least three small arch-bridges by Hewett that employ the Melan system of steel I-beam reinforcement to carry road over the rails: the Interlachen Bridge (Mn/DOT Bridge L-9329) in Minneapolis, and two Como Park bridges in St. Paul (MN/DOT Bridge 92247 and Bridge L-5853).[53]

While Hewett was busy erecting Melan-system streetcar bridges to link the twin metropolises of St. Paul and Minneapolis, an obscure mason and general contractor was designing and building small but elegant reinforced-concrete bridges in Rock County, an area so distant from the Twin Cities that it remains remote today. Perley N. Gillham, who built local roads and county buildings from the late nineteenth century to well into the twentieth, is an utterly unknown figure. He has left many small reinforced-concrete arch spans (some dated) on gravel roads, but virtually nothing is known of his background and where he learned his trade. Most of the bridges were built in the early and mid-teens and use a confusion of rod and twisted-bar reinforcement. One clue to the origins of Gillham's technique is the fact that just over the nearby state line in Iowa was the first Melan reinforced-arch in the United States, built by William S. Hewett for Fritz von Emperger at Rock Rapids in 1894. A photograph of the bridge shows a structure not unlike Gillham's in general size and scale. Ten years earlier, in 1883-84, Gillham and Hewett had worked at the same bridge project in Minnesota. Gillham repaired Rock County's Ash Creek Bridge in 1883 and Hewett built the replacement bridge in 1884. It is possible that the two established a relationship that later led to an exchange of information about reinforced-concrete construction techniques.[54]

### *Significance of the Minnesota Highway Commission*

Through the creation of the Minnesota Highway Commission in 1905, the state government began a process of direct intervention in the bridge building process that continues today in enormous proportions that could hardly have been imagined at the outset. The initial era of the MHC was from 1905 to 1921, when the Babcock Trunk Highway Plan was adopted. During this first decade and a half, the state attempted to gain control over a road and bridge construction process whose antiquated, private-sector management was unable to deal adequately with, initially, the Good Roads Movement, directly followed by the introduction of the automobile. The new road systems demanded by vehicular transportation required two things that only the state could begin to provide: large amounts of money, and professional engineering and design.[55]

Bridges existing at the time of the commission's formation were not necessarily up to the loadings of modern vehicles, mainly heavy steam traction-engines. Early commission reports contain stories and photographs vividly demonstrating the bridge failures caused by these new machines. The problem was wooden and lightweight metal-truss bridges built on competitive design and bid by fabricators who sold cheap structures to nonprofessionals on township and county boards. In its first years, the MHC worked to stamp out these kinds of bridges by forbidding wooden bridges, and by appealing and (when possible) insisting that local designs by approved by state engineers. The movement toward concrete construction began in 1908 with state-prepared plans for concrete culverts and bridge floors. A few years later the MHC was recommending "lasting structures," meaning steel beam, Warren truss, and reinforced-concrete bridges. In 1912 specifications and standard plans were issued for steel and concrete bridges and included "reinforced concrete slab and girder bridges."[56] In his 1912 address on "Reinforced Concrete Highway Bridges," given before the Minnesota Society of Engineers and Surveyors, George Herrold of the St. Paul Department of Public Works recommended highway-bridge types and span lengths in accord with national consensus: the slab for spans 8 to 20 feet, the T-beam slab for spans 20 to 30 feet, and a girder design for spans 30 to 60 feet. In light of the new slab and girder designs, the arch was considered often uneconomical for a highway situation, but "a very desirable type"[57] for parks and approaches to towns and cities, where cost is not the first consideration.

Virtually all the major advances in basic reinforced-concrete bridge design were made in the first two decades of the twentieth century. By World War I, the fundamental designs of the "modern" reinforced-concrete arch, slab, and girder had been established. Only the rigid frame remained to be introduced in the 1920s. It was a time of creativity and experimentation for engineers and the new state highway commissions. The Minnesota Highway Commission participated by designing in 1916 a cellular-slab bridge (described above) in an attempt to refine existing slab design by reducing the amount of required concrete.[58] At the same time, the MHC decided to promote the construction of concrete-pile trestle bridges, after reviewing their use in railroad work.[59]

Other than the cellular slab, whose actual construction and use remains to be documented, there is nothing especially novel to report about the MHC and pre-World War I concrete-bridge construction. The essential concern of the state was that concrete (or steel) be used whenever possible, and that designs be professionally prepared and construction be professionally supervised, whenever possible. Exactly which concrete-bridge type was recommended would depend more on national professional standards than state-based opinions. The professional engineering literature clearly delineated the designs indicated for any particular situation. By 1930 the state was reporting that "our bridges are now being designed in substantial accordance with the approved specifications of the American Association of State Highway Officials (AASHO) which safely provides for the legal loadings specified in our own state laws. There appears to be a general tendency throughout the country to pass legislation safeguarding bridges built during recent years in accordance with recognized standard loadings."[60]

After World War I, the state's attention turned to the development of the trunk highway system initiated by the Babcock plan. Many bridges that the state "inherited" at that time were not up to new loadings, widths, or alignments and major efforts were made to upgrade or replace them. Particular concerns with concrete shifted to matters like aesthetics, or "what might be called the artistic features of bridge construction." This involved a reconsideration of railings, moving from the typical pre-war paneled slabs to a more open design. Other general areas of interest in concrete-bridge work were such things like clearances, floor construction, refining construction techniques, and developing better concrete ingredients. In a 1930 discussion of trunk highway bridges, the state's chief bridge engineer, M. J. Hoffmann, chose to emphasize major new structures over the Mississippi, the Minnesota, and the Red River of the North, rather the multitude of anonymous lesser bridges that routinely fulfilled AASHO standards in whatever form necessary.[61]

### *“King Concrete" and the Great Arch Bridges*

If the first decades of reinforced-concrete bridge work had been a time of experimentation, the dramatic focus of years between the wars was on the spectacular monumental structures that extended the size and range of the earlier designs. Reinforced-concrete bridges of heroic proportions were designed and built, dominating the landscape. It was the era of "King Concrete," as characterized by Canadian bridge historian David Cuming.[62]

In its reports, the Minnesota Highway Commission showcased its large concrete arches at Brainerd, Redwood Falls, Fond du Lac, and two at Anoka.[63] The most exciting work, however, was in and around the Twin Cities, where urban expansion and the automobile encountered the great bluffs and gorges of the Mississippi and Minnesota rivers. "Nature has perhaps nowhere provided a more beautiful setting for an arch bridge than in the Mississippi River valley between Fort Snelling and St. Anthony," declared St.

Paul City Engineer George M. Shepard, in 1927.[64] To meet these challenges engineers designed world-record concrete-arch spans.

The Third Avenue Bridge (MN/DOT 112440, 1914-16) above St. Anthony Falls in Minneapolis constitutes a preamble to this work, being the last major use of Melan-rib reinforced-concrete construction in the Twin Cities. Following Third Avenue was a series of open-spandrel, reinforced-concrete bridges recognized by bridge historian David Plowden as "the first really sophisticated American program of concrete highway bridge construction" and considered highly significant by Carl Condit. Included are the Cappelen Memorial (Franklin Avenue) Bridge (Mn/DOT Bridge 2441, 1919-23), the Inter-City (Ford Parkway) Bridge (Mn/DOT Bridge 3575, 1925-27), the Robert Street Bridge (Mn/DOT Bridge 9036 monumental rainbow arch, 1924-26), and the Tenth Avenue (Cedar Avenue) Bridge (Mn/DOT Bridge 2796, 1929). In addition, Hennepin County built the Fort Snelling-Mendota Bridge (Mn/DOT Bridge 4190, Minnesota River, 1925-2b) over the Minnesota River at its confluence with the Mississippi. Most significant of the group were the Cappelen Memorial Bridge, whose 400-foot main span was the longest concrete arch in the world when built, and the Mendota Bridge, at 4,119 feet, the longest continuous-concrete-arch bridge in the world when built. These bridges constitute masterworks by nationally significant Minnesota engineers, including C. A. P. Turner, Walter Hall Wheeler, Frederick William Cappelen, Kristoffer Olsen Oustad, and the firm of Toltz King & Day. This group includes members of Minnesota assembly of Norwegian-American engineers of exceptional quality, whose reputation and fame was earned in Twin Cities reinforced-concrete bridge design: Frederick William Cappelen, Kristoffer Olsen Oustad, Andreas W. Munster, Martin Sigvart Grytbak, and Olaf Hoff.[65]

### *Reinforced-Concrete Park Bridges*

Along with the chronological coincidence of urban expansion, the growth of city and state road systems, and the introduction of reinforced concrete, came the rise of the urban park. As social historian Alan Tractenberg has observed, noting particularly the ideas of park architect Frederick Law Olmsted, the park was meant to be a refuge from, and thus a contrast with, both the commercial and industrial center and the immigrant-crowded neighborhoods of worker housing. With its curvilinear streets, green open space, all carefully landscaped, the urban park was "all pastoral picture, composed views, nature artfully framed as spectacle."[66]

Within the park, the bridge was not merely an expected necessity, but it emerged as an opportunity. Here the city park commission and landscape architect could request special bridge designs, in harmony with the grand park scheme. Bridge engineer and aesthetic critic Henry Grattan Tyrrell declared in 1901: "In the matter of ornamental park-bridges the engineer has opportunity to display more or less artistic taste, and create not only useful works, but architectural ornaments as well." He indicated also that:

> It can not ...be expected to put up ornamental structures in any of the rural districts, or to any great extent for the use of railroads. The opportunity in the line of ornamental bridge-construction lies chiefly in and around our large cities and park systems and it is greatly to be hoped that, as old wooden bridges decay and are removed, our progressive American people will see their opportunity to replace these with suitable ones of iron and stone, made not simply to carry loads, but to be prominent architectural ornaments.[67]

For Tyrrell, particularly appropriate park styles would be based on the arch or suspension bridge, with rustic treatment desirable.[68] The park further provided an ideal opportunity to explore the possibilities of the new concrete and a great variety of forms emerged (with notable early examples illustrated in the works of Tyrrell and others[69]).

Today, since parks seldom have undergone the heavy usage and expansions of all other road systems, many of the original park bridges survive. Parks now provide us with significant extant examples of some of the earliest and most ornate reinforced-concrete bridges.[70] Particularly significant groups of park bridges are found in Minneapolis, St. Paul, and Duluth. Early stone-faced, reinforced-concrete, arch bridges survive as a unique, linear group on so-called "Seven Bridges Road" in Duluth. In Minneapolis, Minnehaha Parkway and the Lake District provide park-bridge examples, as do Como and Phalen parks in St. Paul.

### *"New Deal" Era Bridges*

During the administration of President Franklin Delano Roosevelt, 1933-45, generally referred to as the "New Deal" era, a number of federal programs were created to provide Depression Era work for the unemployed and to stimulate private business. Among the many programs, for example, was the Works Progress Administration (changed in 1937 to Works Projects Administration and both known popularly as "WPA"), funded bridge construction, along with many other highway and transportation projects. The WPA was abolished in 1942, its work being absorbed by the Federal Works Agency. During that period it built some 78,000 bridges nationally, and built or improved 1,400 bridges in Minnesota.[71] For the period 1935-39, before World War II forced the nearly total cessation of bridge construction, the WPA in Minnesota reported building 176 new bridges and improving an additional 324 bridges.[72]

In part because of wartime steel shortages, WPA bridges usually were built of stone, wood, or concrete. At times, they incorporated traditional stone masonry as a way of providing employment. Instead of eliminating labor costs as in traditional bridge building economics, this was an explicit attempt to make the construction projects labor-intensive, thus creating more work. On occasion, this produced seeming anachronisms-stone-arch bridges. In other examples, a finely wrought stone-veneer was applied to a concrete structure.

WPA bridges usually were designed in one or the other of two contemporary architectural style trends: a rustic, traditional style, or a WPA/government Deco Moderne style. The first style looked backward while the other looked ahead. New Deal era bridges might be large or small. Because the WPA funded park projects, many WPA bridges were built in park or park-like settings. These bridges would be built in a version of the rustic mode, either in stone or wood. Here, the WPA bridge category overlaps with the park-bridge category. Other WPA bridges followed the Moderne styles that had been developing prior to the advent of the federal relief programs. A 1939 pictorial summary of Minnesota WPA projects depicts bridges of both varieties. The Moderne examples have pipe railings with masonry posts, a railing design often found on earlier bridges that were remodeled during the 1930s (whether WPA or not).[73]

## Notes

1. Edwin C. Eckel, "Cement Production and Manufacture in the United States," in Engineering Magazine 30 (February 1906): 717-18.

2. See remarks of Carl Gayler (p. 467) following paper of Fritz von Emperger, "The Development and Recent Improvement of Concrete-Iron Highway Bridges," with discussion, in American Society of Civil Engineers Transactions 31 (1894): 438-83.

3. Discussion on concrete adapted from Wisconsin, Department of Transportation, Historic Highway Bridges in Wisconsin, Vol. 1, Stone and Concrete-Arch Bridges, by Jeffrey A. Hess and Robert M. Frame III (1986), pp. 187-205.

4. Carl W. Condit, American Building Art: The Nineteenth Century (New York: Oxford University Press, 1960), pp. 246-47.

5. Carl W. Condit, American Building Art: The Twentieth Century (New York: Oxford University Press, 1961), pp. 196-98, and American Building Art: The Nineteenth Century, p. 340.

6. Carol Poh Miller, "The Rocky River Bridge: Triumph in Concrete," in IA: Journal of the Society for Industrial Archeology 2 (1976), pp. 47-58.

7. Howard Newlon, Jr., "Evolution of Concrete Structures," Structural Renovation and Rehabilitation of Buildings, Papers from a Lecture Sponsored by the Boston Society of Civil Engineers Section/ASCE in Cooperation with the Massachusetts Institute of Technology, Oct. 9-Nov. 13, 1979, p. 91.

8. The reinforcing types, including patents and illustrations, are listed and described in Newlon Evolution of Concrete Structures, pp. 100-05; "Reinforced Concrete," in Scientific American Supplement No. 1547 (August 26, 1905): 24784-85 (includes illustrations of a number of reinforcing systems); "Forms of Concrete Reinforcement," in Iron Age 77 (January 11, 1906): 193-97 (includes discussion and illustrations of many reinforcing forms and bars); A. E. Lindau, "The Development of Concrete Reinforcement," Parts I & II, in Concrete 29 (October 1926): 34-38, and (November 1926): 22-24 (includes discussion and illustrations of reinforcing forms and bars); and F. E. Turneaure and E. R. Maurer, Principles of Reinforced Concrete Construction, 4th ed.(New York: John Wiley & Sons, 1936; first published in 1907), pp. 24-25. For an overview of an example of manufacturing and fabricating an early reinforcing bar, the process used to manufacture the Kahn bar, see "Making Pressed-Steel Reinforcing," in Iron Trade Review 64 (April 24, 1919): 1073-80, which reviews the Youngstown, Ohio, plant of Truscon Steel Co., founded by Julius Kahn about 1902 as the Trussed Concrete Steel Co. with a plant in Detroit. It was originally designed to manufacture the Kahn reinforcing bar. In 1907 the Youngstown plant was opened and the name was changed in 1918. Eventually it produced a variety of pressed metal products, including shells for gas bombs during World War I. For a discussion of the bending and placing of reinforcing bars, see section 3 in George A. Hool and W. S. Kinne, eds., Reinforced Concrete and Masonry Structures (New York: McGraw-Hill Book Co., 1924). George M. Cheney, Indianapolis, Indiana, and received Letters Patent

No. 820,921 in 1906, and his patent was assigned to the Standard Reinforced Concrete Company, of Indianapolis, Indiana. His patent subsequently was used in Minnesota Bridge 112366, Beltrami County, and is documented in the Mn/DOT files for that bridge.

9. See Newlon "Evolution of Concrete Structures," pp. 99-104.

10. See Newlon "Evolution of Concrete Structures," pp. 99-104.

11. Carl Condit, American Building (Chicago: University of Chicago Press, 1968), pp. 171-74; Newlon, "Evolution of Concrete Structures," p. 100.

12. Condit, American Building: The Twentieth Century, p. 250; Condit's information is from Josef Melan, Plain and Reinforced Concrete Arches, authorized translation by D. B. Steinman (New York: John Wiley & Sons, Inc., 1917), opposite p. 7. For a more complete discussion see William Mueser, "The Development of Reinforced Concrete Bridge Construction," in The Cornell Civil Engineer, 33 May 1925): 162-63. It is now reported to be located in a Rock Rapids city park.

13. See discussion and example in C. B. McCullough, Economics of Highway Bridge Types (Chicago: Gillette Publishing Co., 1929), pp. 97, 112.

14. Condit, American Building, 1968, p. 175.

15. Miller, p. 49.

16. Condit, American Building, 1968, p. 251.

17. Newlon, "Evolution of Concrete Structures," p. 100; Condit, American Building, 1968, p. 252; and Julius Kahn, "Concrete Reenforcement," in Railroad Gazette 35 (October 16, 1903): 734-36. For a contemporary discussion of the manufacture of Kahn bars, see "Making Pressed-Steel Reinforcing," in Iron Trade Review 64 (April 24, 1919): 1073-80, on Kahn's Truscon factory in Youngstown, Ohio.

18. Paul B. Israel, "Spanning the Golden State: A History of the Highway Bridge in California," M.A. thesis, University of California--Santa Barbara, 1980, pp. 155-57.

19. See Condit, American Building Art: The Twentieth Century, p. 197, who doesn't give any explanation for the reference to Germany in his notes. Luten was based in Indianapolis.

20. Never popular in the United States, the concrete hinged-arch design is best known through the spectacular and elegant work of Swiss engineer Robert Maillart. See David P. Billington, Robert Maillart's Bridges: The Art of Engineering (Princeton: Princeton University Press, 1979). This design employs metal hinges at the spring lines and at the crown of the arch. Since the arch is thicker at the haunches, the points of stress between the hinges, the three-hinged arch presents a very different profile from the fixed arch, which tends to be heavier where it meets the abutments. In his landmark 1916 work, Bridge Engineering (New York: John Wiley and Sons), J. A. L. Waddell found the hinged

arch to be aesthetically awkward, but safe (p. 941). There are no known examples of concrete hinged-arch bridges in Minnesota.

21. Condit, American Building Art: The Twentieth Century, p. 204-05.

22. Condit, American Building, 1968, p. 251.

23. Jasper O. Draffin, "A Brief History of Lime, Cement, Concrete, and Reinforced Concrete," in University of Illinois Bulletin 40 (June 29, 1943): 36.

24 Condit, American Building, 1968, pp. 258-61.

25. Milo S. Ketchum, The Design of Highway Bridges of Steel, Timber and Concrete, 2nd ed., rewritten (New York: McGraw-Hill Book Co., Inc., 1920), p. 1; C. B. McCullough, Economics of Highway Bridge Types (Chicago: Gillette Publishing Co., 1929), pp. 108113.

26. Daniel B. Luten, "A Reinforced Concrete Girder Highway Bridge of 40 ft. Span," in Engineering News 55 (May 10, 1906): 517-18.

27. C. B. McCullough, Economics of Highway Bridge Types, p. 52.

28. Condit, American Building Art: The Twentieth Century, p. 207-08.

29. Frederick W. Taylor and Sanford E. Thompson, A Treatise on Concrete Plain and Reinforced (New York: John Wiley & Sons, Inc., 1917 [copyright 1916]), p. 694.

30. Ketchum, Design of Highway Bridges, pp. 273, 345; Hool and Kinne, Reinforced Concrete and Masonry Structures, p. 397; and Frederick W. Taylor, Sanford E. Thompson, and Edward Smulski, Reinforced Concrete Bridges (New York: John Wiley & Sons, Inc., 1939), p. 29. Falling in the middle is Clement C. Williams, The Design of Masonry Structures and Foundations (New York: McGraw-Hill Book Company, 1922), who states that "reinforced concrete slab bridges may be used advantageously for spans of about 12 to 24 ft. and are sometimes built up to 30 ft although the girder type will usually be found the more economical for spans above 24 ft." (pp. 331-32).

31. Waddell, Economics of Reinforced-Concrete Bridges (New York: John Wiley and Sons, Inc., 1921), pp. 220-21; Taylor, Thompson, Smulski, Reinforced-Concrete Bridges, pp. 35-36.

32. "Claude Allen Porter Turner," in A Selection of Historic American Papers on Concrete, 1876-1926, Howard Newlon, Jr., ed. (Detroit: American Concrete Institute, 1976), p. 243; C. A. P. Turner, Concrete Steel Construction (Minneapolis: Farnham Printing & Stationery Company, 1909); and C.A.P. Turner, "The Mushroom System as Applied to Bridges," in Cement Age (January 1910): 7-12.

33. Art Werthauser and Eriks V. Ludins, "Mississippi River Boulevard Bridge No. 92250: A Historical Report" (City of St. Paul, Dept. of Public Works, Bridge Bureau, June 1987). Copy in City Bridge Bureau office files. See also Turner, "The Mushroom System as Applied to Bridges."

34. Taylor, Thompson, Smulski, Reinforced Concrete Bridges, pp. 326-27.

35. See, for example, Hool and Kinne, Reinforced Concrete and Masonry Structures, pp. 397, 405-07, and Williams, Design of Masonry Structures and Foundations, pp. 332-40.

36. F. E. Turneaure and E. R. Maurer, Principles of Reinforced Concrete Construction, 4th ed. (New York: John Wiley and Sons, Inc., 1936), p. 54; an almost identical statement is found in Waddell, Bridge Engineering, p. 961.

37. "In deck girder designs, the cross section of the main girders in the center of each span is usually a T-beam, the floor slab forming the compression flanges." Taylor, Thompson, Smulski, Reinforced Concrete Bridges, p. 152.

38. Taylor and Thompson, A Treatise on Concrete, p. 694.

39. Ketchum, Design of Highway Bridges, pp. 273, 354.

40. Minnesota Highway Commission, Report, 1915-16 (St. Paul, 1917), pp. 19-23; "Test of New Type of Reinforced-Concrete Bridge," Engineering News 76 (Sept. 28, 1916): 62021.

41. Taylor and Thompson, A Treatise on Concrete, p. 694.

42. Condit, American Building Art: The Twentieth Century, p. 208.

43. J. A. L. Waddell, Economics of Bridgework, pp. 221-22.

44. George A. Hool and W. S. Kinne, eds., Reinforced Concrete and Masonry Structures, p. 428.

45. See Milo S. Ketchum, The Design of Highway Bridges of Steel, Timber and Concrete, 2nd ed., rewritten (New York: McGraw-Hill Book Co., Inc., 1920), pp. 275, 375; , George A. Hool and W. S. Kinne, eds., Reinforced Concrete and Masonry Structures, pp. 405-432; and Taylor, Thompson, and Smulski, Reinforced-Concrete Bridges, pp. 93-94.

46. Taylor, Thompson, and Smulski, p. 93.

47. See discussions in Arthur G. Hayden, The Rigid-Frame Bridge (New York: John Wiley and Sons, Inc., 1931), pp. 1-4; Condit, American Building: The Twentieth Century, pp. 213-14; and Taylor, Thompson, and Smulski, Reinforced Concrete Bridges, pp. 26869.

48. Condit, American Building Art: The Twentieth Century, p. 213.

49. Hayden, pp. 170-73.

50. Taylor, Thompson, Smulski, Reinforced Concrete Bridges, p. 321 (separate frame, ribs), 148-62 (multi-span).

51. Remarks of Frank T. Sheets, reported in "Trend Toward Continuity in Bridge Design," in Concrete 46 (Nov. 1938): 8.

52. See Sam Bass Warner, Jr., Streetcar Suburbs: The Process of Growth in Boston, 1870-1900 (Cambridge: Harvard University Press and The MIT Press, 1962).

53. "Reinforced Concrete Arch Bridges, Como Park, St. Paul," in Engineering Record 50 (Dec. 3, 1904): 648-49; Henry Grattan Tyrrell, Concrete Bridges and Culverts (Chicago: Myron C. Clark Publishing Co., 1909), pp. 163-66; A Guide to the Industrial Archeology of the Twin Cities, Nicholas Westbrook, ed. (St. Paul & Minneapolis: Society for Industrial Archeology, 1983), p. 18; the background and accomplishments of William S. Hewett and the Hewett firms are discussed in Fredric L. Quivik, "Montana's Minneapolis Bridge Builders," in IA: The Journal of the Society for Industrial Archeology 10 (1984): 35-54.

54. Condit, American Building: The Nineteenth Century, p. 250. Condit's information is from Josef Melan, Plain and Reinforced Concrete Arches, authorized translation by D. B. Steinman (New York: John Wiley & Sons, Inc., 1917), opposite p. 7. Von Emperger's major article on the subject, read and published in 1894, makes no mention of any bridges in Iowa or elsewhere in the Midwest (see von Emperger, "The Development and Recent Improvement of Concrete-Iron Highway Bridges," with discussion, in American Society of Civil Engineers Transactions 31 [1894]: 438-83). However, the Rock Rapids bridge project is recounted in William Mueser, "The Development of Reinforced Concrete Bridge Construction," in The Cornell Civil Engineer, 33 (May 1925): 162-63. On the possibility that Gillham and Hewett met in the 1880s, see statements on the Ash Creek bridge in the Rock County Commissioners Minutes' for March 29, 1883, and December 26, 1884.

55. See discussion in Robert M. Frame III, "Historic Bridge Project" A Report to the Minnesota State Historic Preservation Office (1985) pp. 22-29.

56. See discussion in Frame, Historic Bridge Project Report, pp. 24-26.

57. George H. Herrold, "Reinforced Concrete Highway Bridges," in Tenth Bulletin of the Minnesota Surveyors' and Engineers' Society (1912-13), pp. 84-86.

58. See Frame, Historic Bridge Project Report, p. 27.

59. Minnesota Highway Commission, Report for 1915-16 (St. Paul, 1917), pp. 23-24.

60. Minnesota Highway Commission, Report of the Commissioner of Highways for 1929-30 (St. Paul, 1931), p. 11.

61. M. J. Hoffmann, "Minnesota Trunk Highway Bridge Construction," in The Minnesota Federation of Architectural and Engineering Societies Bulletin 26 (April 1931): 13-18; Minnesota Highway Commission. Report of the Commissioner of Highways for 1920 (St. Paul, 1921), pp. 7-8, and Report of the Commissioner of Highways for 1922 (St. Paul, 1922), p. 17.

62. David Cuming, Discovering Heritage Bridges on Ontario's Roads (Erin, Ontario: Boston Mills Press, 1983), pp. 51-56.

63. Minnesota Highway Commission, Report of the Commissioner of Highways for 1929-30 (St. Paul, 1931), p. 6 (Anoka); Report of the Commissioner of Highways for 1931-32 (St. Paul, 1932), frontispiece (Brainerd); Biennial Report of the Commissioner of Highways for 1933-34 (St. Paul, 1934), frontispiece (Redwood Falls); and Biennial Report of the Commissioner of Highways for July 1, 1940 to June 31, 1942 (St. Paul, 1942), frontispiece (Fon du Lac) and p. 41 (Anoka).

64. George M. Shepard, "Twin City Bridge Construction," in Minnesota Techno-Log 7 (Feb. 1927): 137.

65. Discussed in Westbrook, "Bridges," pp. 14-29, who quotes Plowden; see also Condit, American Building: Twentieth Century, pp. 201-02, and Kenneth Bjork, Saga in Steel and Concrete: Norwegian Engineers in America (Northfield, Minn.: Norwegian-American Historical Association, 1947), pp. 138-55; for further details, consult Appendix A, "Engineers, Fabricators, Builders and Contractors Active in Minnesota Bridge Building," in Frame, Historic Bridge Project Report.

66. See park-bridge discussion in Wisconsin Department of Transportation, Hess and Frame, Stone and Concrete-Arch Bridges, pp. 233-35. Tractenberg, p. 111.

67. Henry Grattan Tyrrell, "American Park Bridges," in The American Architect, March 1901, pp. 100-01.

68. Tyrrell, "American Park Bridges," p. 99.

69. Along with Tyrrell's volume, see also Gilmore D. Clarke's essay on "The Architecture of Short-Span Bridges" in Hayden, The Rigid Frame Bridge, pp. 193-232. The rigid frame originally was introduced as a parkway bridge and it often has been used in this capacity, substituting for the concrete arch and receiving the same architectural treatment. See also the many ornamental bridges in the important volume by Wisconsin engineer Charles S. Whitney, Bridges: A Study in Their Art, Science and Evolution (New York: W. E. Rudge, 1929; reprinted New York: Greenwich House, 1983).

70. For a discussion of a significant and influential park system and its bridges, see Marilyn E. Weigold, Pioneering in Parks and Parkways: Westchester County, New York, 1895-1945, Essays in Public Works History No. 9 (Chicago: Public Works Historical Society, February 1980).

71. U.S. Federal Works Agency. Final Report on the WPA Program, 1935-43 (Washington, D.C.: U.S. Government Printing Office, [1947]), pp. 53, 135.

72. Works Progress Administration of Minnesota, WPA Accomplishments: Minnesota 1935-39 (St. Paul: Works Progress Administration, 1939), unpaginated, see second page of section "Physical Accomplishments."

73. Works Progress Administration of Minnesota, WPA Accomplishments: Minnesota 1935-39, unpaginated, see section on "Minnesota Highways."

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