DESIGN AND FLOAT-IN CONSTRUCTION OF A 500 FT. TRUSS SPAN

Kevin R. Eisenbeis, PE, SE
Harrington & Cortelyou, Inc.
911 Main Street, Suite 1900, Kansas City, MO 64105
Phone: 816-421-8386 | Fax: 816-471-6109

ABSTRACT
Doubling the size of a major inland lock at Kentucky Lake dictated a relocation of the Paducah & Louisville Railroad and a state highway from Kentucky dam to a new location downstream on the Tennessee River. The relocation included a 3,094 ft. single-track railroad bridge constructed adjacent to a new highway bridge.

This paper discusses various design and construction aspects of the 500 ft. navigation span portion of the railroad bridge. Truss configuration, panel length and span to depth ratios were studied. Truss fabrication, balanced-cantilever erection, transfer of truss from temporary bents to barges, and subsequent float-in of the span will be covered. A brief discussion of the Corps of Engineers navigation model studies, performed at the Waterways Experiment Station in Vicksburg, MS, will also be included.

Drilled shaft and pile supported piers were constructed. Design of the piers and the local karst topography will be discussed.

INTRODUCTION
The Kentucky Lock, located at Kentucky Dam near Grand Rivers, KY, was too small to handle modern barge tows. To construct a new lock at this location, the Paducah & Louisville (P&L) rail line and US Highway 62/US 241 had to be relocated downstream. Separate railroad and highway bridges were constructed approximately 1500 ft. downstream, spanning the Tennessee River, a portion of Powerhouse Island, and the main navigation channel approach to the lock.

The US Army Corps of Engineers (USACE) retained Hanson Professional Services to serve as prime consultant for design of the railroad relocation project. Harrington & Cortelyou, Inc. was enlisted as a subconsultant to Hanson to perform preliminary design, final design, and
construction administration services for the main span over the navigation channel. A subsequent USACE design contract was awarded to Entran to design the relocated highway. A cooperative arrangement was maintained during the design phase to allow separate but single construction contracts for all substructure units of both bridges, followed by the superstructures for both bridges.

This paper discusses the design features of the main truss span and support piers on the relocated P&L railway bridge over the navigation span of the Tennessee River. Preliminary design, final design and construction aspects are presented. Design is per the American Railway Engineering and Maintenance-of-Way (AREMA) Manual of Standard Practice, utilizing E-80 loading.

**PRELIMINARY DESIGN**

The navigation span length was established in a Post-Feasibility Design Study. To span the navigation channel and a new downstream guide wall, a minimum span length of 500 ft. is required. Truss spans for railroad bridges are typically economical in this span range, so a simple span truss was selected.

The top of rail elevation and low steel elevation were also established at 395.5 and 389.0, respectively. These constraints dictated a shallow floor system, limited to 6'-6" in depth. Low steel is 87 ft. above normal pool elevation 302.0.

**Truss Span Configurations**

The client desired consideration of a number of truss configurations in the preliminary phase. Parallel chord and variable depth chord spacing approximating a parabola was considered. Warren trusses with alternating diagonals, Pratt trusses with interior tension diagonals, Parker trusses, similar to Pratt with variable depth top chords, and K-trusses were investigated. Preliminary calculations determined the stringers, floorbeams and truss members to calculate the total dead load for each type. For economy based on total steel weight, the variable depth trusses, taller at mid-span proved more economical. Figure 1 shows examples of various truss types considered.

**Truss Depth**

The minimum truss depth must allow a vertical clearance of 23'-0" between top of rail and the sway or portal bracing. For railroad bridges, the minimum depth, chord to chord, is typically around 30 ft. Span depth ratios between 5:1 (100 ft. height) and 12:1 (41'-8" height) were considered. Several preliminary design comparisons were made for parallel top chords vs. variable depth trusses with different panel lengths. Variable chord spacing provided a 2% to 3% savings in dead load for this span length. A span to depth ratio of 8:1 (62'-6" chord to chord at
TYPES OF TRUSSES

Figure 1
center of span), with due consideration of panel spacing, was determined the most economical
truss depth. A plot of span to depth ratio vs. total dead load is shown in Figure 2.

![Graph](image)

**Figure 2. Span to Depth Ratio vs. Total Dead Load**

**Panel Dimensions**
Studies were conducted for panel lengths in the 20 ft. to 50 ft. range. Figure 3 shows the layout of various options considered. Experience has shown that economical panel lengths utilize diagonal slope angles between 40 and 60 degrees from the chords. Longer panel lengths allow structure depths with a favorable span to depth ratios, however, excessive panel lengths require heavier floor systems, which can substantially increase the cost. The objective of the study was to find the most economical combination of panel length, truss depth and floor system. Panel lengths of 25'-0", 31'-3", 35'-9", 41'-8", and 50'-0" were considered. A 14 panel truss utilizing 35'-9" panels was determined the most economical. A plot of panel length vs. total dead load is shown in Figure 4.
WARREN TRUSS

WARREN TRUSS

WARREN – TRUSS
(SELECTED FOR FINAL DESIGN)

WARREN TRUSS

Figure 3
Cross Section
The transverse spacing of the trusses for the single-track bridge was determined by AREMA stability criteria. Chapter 15 establishes this spacing at a minimum of 1/20 of the span, resulting in a 25'-0" spacing between trusses. Simple span stringers, spanning between floorbeams were chosen due to the limited 6'-6" floor system depth requirement.

Material
Grade 50 weathering steel was selected for low maintenance requirements. Trial calculations indicated grade 70 steel would be economical for floorbeams but would not be appropriate for stringers due to excessive live load deflections. The railroad company elected to utilize grade 50 steel so truss members were not investigated for grade 70. An approximate 4% reduction in floorbeam weight could be realized if grade 70 steel were used.

Decks on railroad bridges may be open or ballast. Ballast decks are heavier than open decks and the placement of ballast requires an additional 8" to 12" depth between top of rail and low steel. Therefore, an open timber deck was selected to achieve a lighter dead load and stay within allowable structure depth requirements. Galvanized steel grating walkways were provided adjacent to the track. Every fifth tie is extended to support the walkways.


**Box Chords vs. H-Section Chords**

Preliminary studies to determine the basic truss layout assumed a single box section for the top and bottom chords. High fabrication costs associated with difficulties in welding, bolting and handing box shapes prompted consideration of H-shaped members. An approximate 5% and 2.5% savings in total dead load was realized utilizing H-shaped chords in lieu of box-shaped chords for 35'-9" and 41'-8" panel spacing, respectively. Since H-sections achieved an economy in weight and fabrication, they were selected as the design shape for final design. Wind induced torsional vibration, sometimes associated with H-shaped diagonals and hangers with high slenderness ratios, was investigated in the final design of the members.

**FINAL DESIGN**

**General**

Based on the preliminary studies, a simple span Warren truss, divided into 14 panels of 35'-9" for a total span length of 500'-6" was designed. The depth of the truss varies from 41'-8" at panel point L1 to 62'-6" at midspan. The top chord panel points approximate a parabolic haunch between field sections. H-sections, fabricated from three plates welded together, are used for the chords, diagonals, posts and hangers. Stringers in the floor system are 36" deep W-beams and floorbeams are welded plate girders. The AREMA fracture control plan outlined in Chapter 15 applies to tension chords, tension diagonals, hangers, floorbeams and stringers. All structural steel is Grade 50 weathering steel and all bolts have weathering characteristics. Trusses are cambered for dead load plus a live load of 3000 lbs. per foot of track. Vertical camber built into the truss span was 5.95" at the centerline of the span.

**Float-In Design Concept**

The volume of navigation traffic through Kentucky Lock precludes construction of temporary erection bents in the navigation channel. Preliminary design and conceptual studies indicated a float-in construction scheme would be the likely scenario. In addition to the normal loading conditions of the simple span truss, truss members were analyzed and sized for an anticipated cantilever erection scheme and associated temporary support locations. Members were designed for 125% of allowable stress for gravity loads during the construction condition and 133% of allowable when combined with construction design wind loads. This final design consideration allowed the contractor to erect the truss without modification or additional bracing of truss members.

**Scale Model of Float-In**

High-tension powerlines span the river approximately 600 ft. downstream of the boat basin where truss erection is to occur. The height of the barge/truss configuration is sufficient to strike the lowest point on these lines. Therefore, the configuration must be turned and the
downstream drift with the current stopped before the truss reaches the powerlines. Concerns regarding the logistics of the float-in led to development of a 1:100 scale model. The scale model was made by USACE personnel at the Waterways Experiment Station (WES) in Vicksburg, MS.

To determine how this maneuver could be performed and to anticipate difficulties that might arise, a simplified scale replica of the barge/truss configuration was constructed and the left bank boat basin and project layout was modeled. Two radio-controlled model towboats, one for each barge, were used and were independently operated. A series of flow conditions were modeled for evaluation of various float-in water surface elevations and velocities. Tow tracks were plotted and summarized in report form. This information was made available to contractors bidding the project. Figure 5 shows the barge/truss model configuration as it leaves the boat basin.

![Figure 5. Barge Float-In Model Study at WES, Vicksburg, MS](image)

**Truss Joints**

Bolted truss joints, utilizing 1" diameter, ASTM A-490 bolts, were provided to reduce the number of fasteners required and overall size of the gusset plate connections. Gusset plate thicknesses range in size from 1.5" to 3" in thickness, depending on location. Splices of chord segments occur at the L2, L4, L6, U1, U3, U5 and U7 panel points. Figure 6 shows the truss joint at L0.
Fatigue and Shear Lag Considerations
AREMA Chapter 15 fatigue considerations are followed. Requirements at non-continuous joint locations, such as vertical hanger or tension diagonal joints, require fatigue stress to be carried by the flange elements only. Web plates are not considered in fatigue stress computations at these locations. AREMA reduction factors are applied to effectively reduce plate areas for bolted connections at gusset plates.

Wind Vibration Considerations
Some bridges with “H” shaped members have exhibited wind induced vibrations due to vortex shedding. Vibrations can become pronounced when the frequency of vortex shedding approaches the natural frequency of vibration of individual truss members. The long slender H-shaped center diagonals and hangers were investigated for such dynamic wind oscillations. Weak axis flexural and torsional modes were investigated. Strong axis modes in vertical members are suppressed by sway frames. A critical wind velocity of 114 mph was determined for the controlling hanger, which exceeds the computed 103 mph (100 yr.) design wind. Dynamic wind oscillation did not control the design of these members.

Seismic Design Considerations
The bridge at Kentucky Lake is located approximately 80 miles northeast of the New Madrid Fault zone, centered in southeastern Missouri. Significant earthquakes, estimated to M 8.1,
occurred at the New Madrid fault in 1811-1812. Seismic loading was applied using AASHTO Category B criteria and AREMA Chapter 9 guidelines for seismic design.

A load combination for DL + EQ was considered with 50% allowable overstress. Return periods of 95 years, 380 years, and 2260 years for serviceability, ultimate and survivability were considered. EQ loads were applied transversely to the chords. Panel shear and member loads were not controlled by seismic loads. Additional inverted L-shaped steel plate weldments were provided at bearing devices for hold-down restraint.

**Support Piers**

Reinforced concrete piers supporting the truss span consisted of a large footing, two-12 ft. diameter shafts and cross cap at each pier. The pier cap was notched to accept welded deck plate girder approach spans. An intermediate transverse strut was provided near mid-height of the columns. Pier R16, on Powerhouse Island, was founded on steel HP 14x117 piling driven to bedrock. Pier R17, on the east bank, was cut into the bedrock. Significant fissures, cracks and features in the Karst rock formation, discovered in the geotechnical investigations for the project, dictated that drilled shafts would be provided as the primary support mechanism at this location. Figure 7 shows Pier R16 on Powerhouse Island, prior to superstructure construction.

![Figure 7. Pier R16 on Powerhouse Island](image)
TRUSS FABRICATION AND ERECTION

Truss fabrication was performed by Grand Junction Steel, now Hirschfeld Industries, in Grand Junction, Colorado. Full lay-down of the truss was provided and is shown in Figure 8.

Bolt holes were drilled from the solid utilizing numerically controlled methods. Truss members were shipped to the job site by truck.

Figure 8. Truss Lay-down at Fabrication Shop

FLOAT-IN CONSTRUCTION

As part of the construction of the railroad bridge, the truss span that is to span the downstream navigation approach to the lock is to be built remotely, then moved into position. Truss erection occurred in the boat basin on the downstream descending left bank, approximately 2,000 ft. downstream of the new bridge alignment. A contract to enlarge the boat basin was let in advance of the railroad bridge contract, to create sufficient room for temporary erection bents and barges for transportation of the span.

The truss was built on a four column temporary erection bent utilizing balanced cantilever construction methods. The bent, constructed within the boat basin, is supported on 24 steel H-piles and extends over 91 ft. above normal pool elevation. The floor system, including track and ties, was built as the erection progressed. The fixed and expansion rocker bearings were attached to the truss in the erected position. Figures 9 and 10 show views of the partially completed truss span.
After the truss was erected on the temporary erection bent, two sets of 2-35' x 195' x 10' deep barges were used to float the span approximately 4,000 ft. across the river and upstream to
the final location. Towers with jacking platforms supported the truss. A hydraulic jack and steel shim arrangement was used to transfer the truss to the barge towers. Shims at the top of the erection bent were used to position the truss at the appropriate elevation. Shims were added at a similar arrangement at the bottom of the barge towers as the load was transferred. Shims made up the difference as jacking occurred and barge draft increased. Final load is not totally transferred until barge displacement equals the weight of the floating assembly.

The bottom chord of the truss was over 90 ft. above water elevation during the float-in to allow truss bearing shoes, which were attached to the truss span prior to float-in, to clear the pier cap. Actual transport time across the river was approximately two hours. An addition six hours was needed to winch and lower the truss into final position once it was generally located over the support piers. Anchor bolts were positioned and grouted into pre-drilled holes after the truss was aligned in the correct position. Figure 11 shows the barge / truss assembly during float-in.
CONCLUSION
The float-in construction of the 500 ft. truss at Kentucky Lock proved to be an effective and efficient method to construct the span with minimal impact to navigation traffic. A three-day closure to navigation traffic was allowed and achieved by the contractor. The truss was supported on barge support towers over 90 ft. above water elevation during the two-hour transport across the river.

ACKNOWLEDGEMENTS
Client on the project is the US Army Corps of Engineers, Nashville District. Overall Project Manager was Don Getty, PE. Hanson Professional Services (HPS) provided overall project management for the railroad relocation project and design of the railroad approach spans. Harrington & Cortelyou, Inc. served as a subconsultant to HPS for design of the 500 ft. truss and truss support piers.

Client: US Army Corps of Engineers, Nashville District

Railroad Owner: Paducah and Louisville Railroad (P&L)

Owner: Tennessee Valley Authority (TVA)

Railroad Relocation Prime Consultant: Hanson Professional Services

Truss Designer: Harrington & Cortelyou, Inc.

Contractor for Truss Construction: American Bridge

Truss Fabricator: Grand Junction Steel (Hirschfeld Industries)

Contractor for Pier Construction: C.J. Mahan Construction Company
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