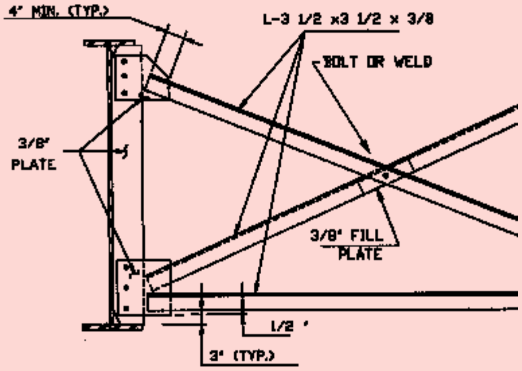

BRIDGE CROSSINGS

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Practical Information For The Bridge Industry

High Performance Steel Bridge Concepts

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This month's *Bridge Crossings* presents conceptual designs for innovative short and medium span bridges. The designs combine high-performance steel (HPS) and prestressing to improve bridge performance, constructibility, aesthetics, efficiency, and economy. All designs use the AASHTO LRFD specifications. HPS is a steel that has a yield strength of Grade 70, high levels of fracture toughness, little or no preheat requirement for welding, and weathering properties. The alternates contain prestressing both longitudinally through the structure and transversely in the deck and cap beams. The prestressing is applied as pretensioning, post-tensioning, or a combination of both. The combination of steel and prestressed concrete is based on the incentive to use each respective material where it is traditionally found to be the most economical. The structure at each stage of construction is designed to support the loads for the next stage only. Each stage of construction optimizes the design for that and the next stage of support conditions and loads.

The following concepts were developed:

- Two-span Plate Girder
- Split Single Steel Box Girder
- Two-span Twin Warren Truss
- Two-span Modular Space Truss

Industry review of the concepts at each phase has been an important part of this study to ensure that the results are feasible from the point of view of the fabricators, erectors, FHWA, DOT's, academia, and other bridge designers.

This information is based upon a report prepared for the American Iron & Steel Institute (AISI) and was sponsored by the Transportation Structures Committee. The complete report can be obtained from AISI.

The designs shown are at the concept level only and do not represent complete designs.

Design Alternates

- **Common Characteristics**

Certain common characteristics apply to the alternates developed. Specifically, these can be categorized as serviceability, structural behavior and economy.

Serviceability—Serviceability issues include durability, maintainability, and inspectability of the structure. Also considered in serviceability issues are possible future deck replacement and bridge widening.

Durability—Durability of steel bridges can be improved with the following measures.

- Elimination of deck joints and bearings.
- Use of uncoated weathering steel.
- Elimination of points which may collect moisture or debris on the steel superstructure.
- Increased fracture toughness of HPS.
- Use of high-strength concrete, subsequently referred to as a high performance concrete (HPC).
- Placing the superstructure into compression with longitudinal and transverse prestressing to limit deck cracking.
- Use of polyethylene (PE) post-tensioning ducts in the deck.
- Use of an applied wearing surface on the bridge deck. Use of an integral wearing surface is not recommended if the section properties of the girder and the deck with prestressing is an aspect of the design.
- Use of a well-drained deck with adequate slope.

Maintainability—Maintainability is improved with the increase of durability described above.

Inspectability—Inspectability is improved by permitting access to all points of the structure.

Deck Replacement—All alternates provide the possibility of deck replacement. The girders and supporting trusses are designed to carry the deck weight without prestressing. The supporting girders and trusses provide a working platform to avoid disruption of traffic below. The exception to this is the modular space truss which would require supporting falsework.

Bridge Widening—All bridges can be widened with the addition of girders or trusses. Extension of the deck on the cantilever wings is not feasible due to the length of the overhangs and amount of prestressing provided.

Structural Behavior—These aspects of the design alternates include seismic loading, fatigue, and redundancy of the structure.

Seismic—Seismic behavior is improved with the use of steel components in the superstructure which reduces the mass and thus, reduces the forces transmitted into the piers, abutments, and foundations. Steel components perform well under seismic loading due to increased ductility. Connections between the superstructure and the supporting piers and abutments are critical and must be examined for strength, ductility, and relative displacement. Elimination of bearings by using integral connections at piers and abutments ensures seismic performance of the system.

Fatigue—Fatigue concerns can be reduced with the elimination of details which are more critical than Category C, use of HPS with higher levels of energy absorption and ductility, and use of prestressing to reduce the tension stress range. Connections of the space truss must be designed in accordance with current criteria for HSS, such as the CIDECT and CISC guidelines.

R**edundancy**—Redundancy can be ensured by the use of continuous structures, providing alternate load paths, and reducing or eliminating fatigue considerations in fracture critical members. Alternate load paths can be provided with integral connections, prestressing, cross-bracing to bridge a failure, and use of composite design.

Side impact of a main girder from traffic passing beneath the bridge is a concern and must be evaluated. The area of impact is usually in a tension area so that compression buckling of the damaged bottom flange plate is not a concern. The impact force can be transmitted to the abutments using the top slab as a rigid plate diaphragm. Longitudinal prestressing adjacent to the bottom flange is also a means to provide redundancy if it can be shown that the structure does not fail in the event that the bottom flange plate is removed. Continuous draped post-tensioning is effective in providing this redundancy.

Redundancy of two girder systems is a concern since a fracture of a single girder may lead to the failure of the structure. A failure analysis was performed for the twin plate girder structure. The objective of the failure analysis was to demonstrate that alternate load paths exist and that the structure does not collapse under its own weight during an extreme event. The results of this analysis confirm that the two plate girder structure has sufficient inherent redundancy to prevent collapse during an extreme event and to continue service under full live load.

Economy—Economy can be improved by reviewing all aspects of the structural details, design features, and construction methods. Use of weathering steel, HPC decks, prestressed decks will significantly reduce life-cycle costs.

In general, the specifications and design documents should be reviewed to ensure that they do not contain excessive material, design, detailing, or construction requirements.

Details—Use of the following details may reduce the cost of in the structure:

- Use of prestressing both longitudinally and transversely in the deck slab and longitudinally in the main structural components.
- Increasing the girder shipping lengths.
- Reduction in the number of field splices. Place field splices at the center pier.
- Reducing superstructure depths to reduce approach fill requirements.
- Use of wider girder spacing.
- Use of jointless bridges.
- Reduction or elimination of bearings.
- Eliminating cross-frames and bracing systems.
- Use of concrete diaphragms at piers and abutments and at intermediate points. Diaphragms may be reinforced with mild reinforcing or prestressing or a combination of both.

Design—Economy can be achieved with a review of the following design aspects.

- Eliminate or reduce multiple plate thickness to simplify mill orders and reduce the number of shop splices.
- Optimization of the substructure design including pier shafts and caps, abutments and foundations. Use integral or semi-integral abutments.
- Use of the AASHTO LRFD design methodology.
- Use of high-performance steel with greater yield strength (Grade 70), increased weldability and ease of fabrication, higher levels of fracture toughness, and greater ductility and corrosion resistance.
- Combined efficient use of concrete, steel and prestressing.
- Use of transverse prestressing in the deck slab. The slab is typically a minimum of nine inches thick at the cantilever tips and haunched over the girders. This post-tensioning permits longer cantilever overhangs and a greater girder spacing.
- Use of longitudinal prestressing in the deck slab or in the girders. Longitudinal prestressing reduces or eliminates the tension stresses in the top concrete slab over the pier which controls or eliminates cracking of the deck. Effective prestressing stresses are reduced due to creep and shrinkage of the deck concrete and the top flange of the girder. The area of the top flange should be kept to a minimum to avoid reduction in prestressing effects in the concrete at these locations. Consideration must be given to shear connectors between the steel top chord and the concrete deck. Shear connectors may be cast directly into the slab or grouted into the slab later in grout pock-

ets. Composite behavior with longitudinal prestressing results in several design considerations which can be readily accommodated. This includes redistribution effects due to the different moduli of steel and concrete, and eccentricity effects.

- Provide the ability in the future to add longitudinal tendons to increase the load capacity of the bridge. This is often done in concrete box girder bridges and is referred to as contingency post-tensioning.
- The structure at each stage of construction is designed to support the loads for the next stage only. The design of each stage of construction is optimized for that and the next stage of support conditions and loads.
- Use of concrete bottom slabs at negative moment regions in steel box girders for double composite action increases stiffness and reduces steel weight.

Construction—Economy of construction can be improved with the following measures.

- Increase girder shipping lengths to lengths over 100 feet with a maximum length of 120’ to 140’.
- Increase the speed of construction with a review of erection methods which are integral to the design of the structure. Lifting, rolling, launching, or sliding bridge sections into place should be considered to speed up erection. If lifting weights are provided, the contractor can assess the feasibility of specialized erection methods.
- Provide for sub-assembly of bridge components on-site which would reduce the number of lifts.

Design Alternates

There are several detailing elements that are common to all of the design alternates as follows.

- All primary girder or truss components are fabricated from HPS
- All secondary framing or bracing elements can be fabricated from A588 Grade 50.
- The contractor is to provide for the stabilization of structural steel during all phases of erection and construction.
- Painting of the steel girders is not necessary but may be required by the owner in some cases.
- Removable forms are recommended for inspectability, but permanent corrugated metal forms may be more economical in some cases.
- Cleaning of the weathering steel is recommended in the shop in all cases to enhance welding and aesthetics.

Two-span Plate Girder

This composite bridge consists of a concrete deck supported by two or more steel plate girders. The concrete deck is haunched over each girder to allow for an increase in the unsupported cantilever length of the deck and the spacing between girders.

Two sub-alternates have been designed. The prestressed twin girder sub-alternate uses draped longitudinal post-tensioning to reduce the flange plate sizes. The longitudinal post-tensioning is draped over the pier as high as possible in the pier diaphragm. At midspan, the tendons are near the bottom flange of the girder and run through the stiffener plates attached to the web of the girders. Longitudinal post-tensioning is also added to the deck over the piers to control shear lag effects and deck tensile stresses. Transverse post-tensioning is added in the deck to carry the long, unsupported cantilever.

The non-prestressed multi-girder sub-alternate omits all post-tensioning and adds additional plate girders. The concrete pier diaphragm for both sub-alternates is integral with the girders and the piers.

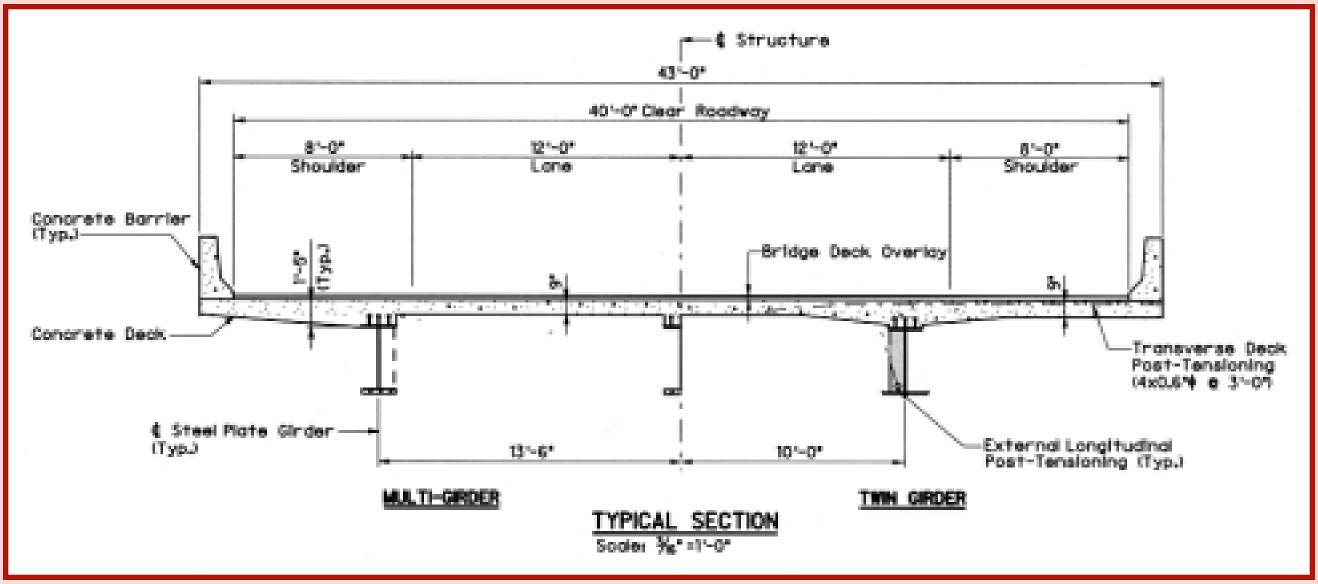
Two girder splice alternates over the piers have been investigated. The first splice alternate consists of a bolted top flange and welded bottom flange. A small plate is bolted to each web for alignment purposes. This connection creates a continuous girder for live load, superimposed dead load, and deck self weight. The second splice alternate relies on the composite behavior between the girder and the concrete deck. This bolt- and weld-free connection consists of two end-plates with shear studs. The concrete between the end-plates carries the compressive forces while the longitudinal reinforcement or post-tensioning in the deck carries all tensile forces. This connection creates a continuous girder for superimposed dead load and live load only, thus reducing the compressive and tensile forces in the connection.

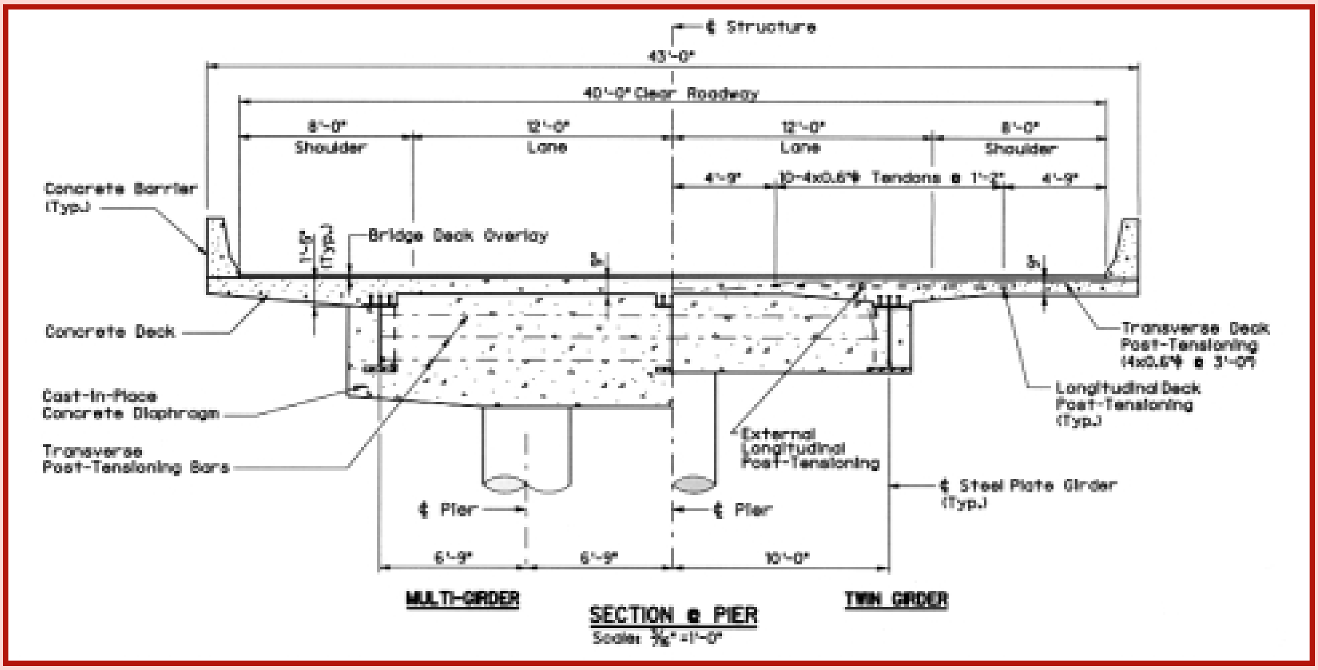
Owners and consultants continue to be concerned over the ability of a two girder steel bridge to survive a lateral impact or fatigue failure without collapsing under its own weight or the weight of ongoing traffic.

A complete failure analysis was undertaken as part of this study. It consisted of modeling the deck as a two-dimensional plate, taking into account the in-plane and out-of-plane composite behavior with the steel girders. The bottom flange at the center of one girder of a two-girder system was removed. The balance of the girder was replaced with a plastic hinge to represent the residual capacity of the damaged girder, and full live loading was applied. The results of the failure analysis indicate that an alternate load path is provided. The loads are redistributed through the deck into the second (intact) girder. No collapse occurred under self-weight or under full live loading. However, because large deformations are expected, a plastic joint forms in the deck which must be adequately reinforced.

Split Single Steel Box Girder

This composite bridge consists of a concrete deck





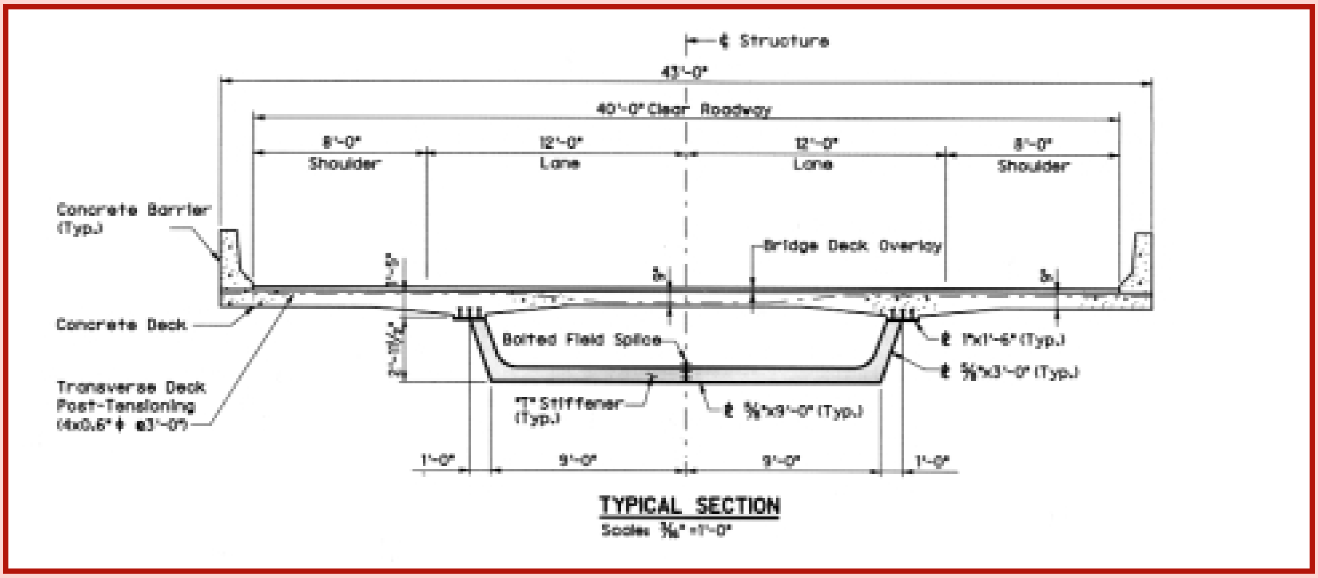
Two-span Plate Girder

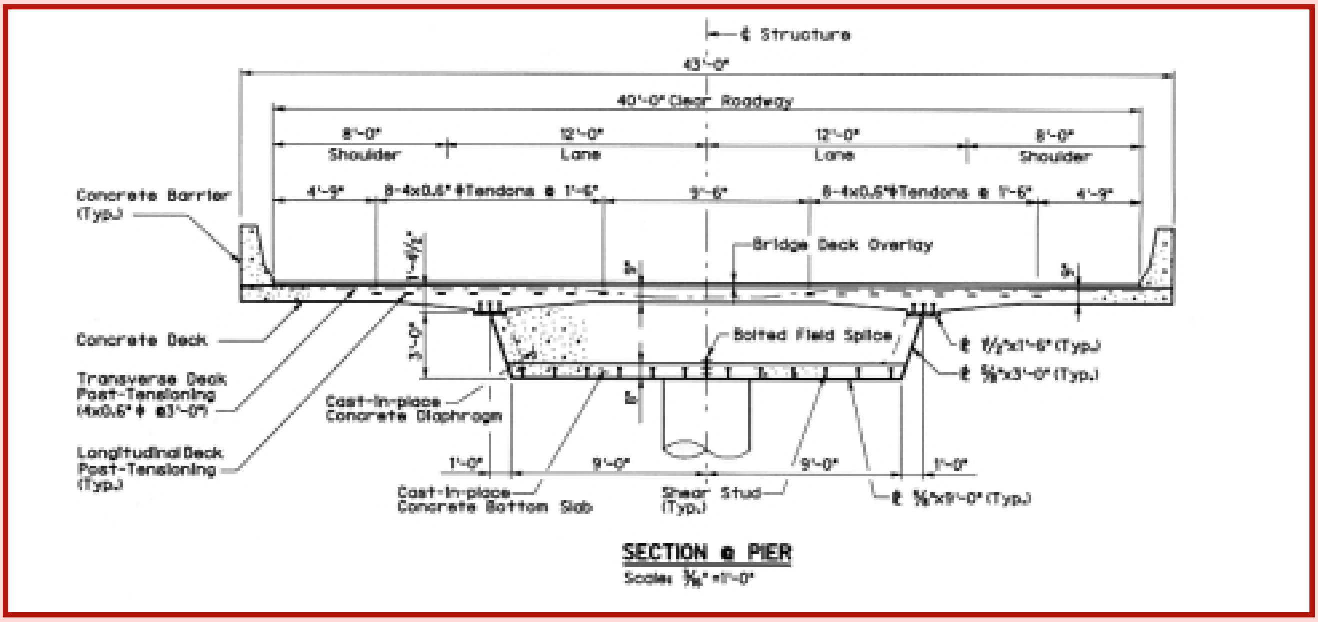
which is post-tensioned transversely and is supported by a single steel box girder. Web stiffeners and distortion bracing are fabricated as a single "T" section which is connected to the bottom flange and web plates. The bottom flange is split into two halves to meet transportation width requirements and is bolted together at the site. The concrete deck is haunched over each top flange to allow for an increase in the unsupported cantilever length of the deck and the spacing between the boxes.

Two sub-alternates were designed: one with two spans of 100 feet; the other with one span of 180 feet. In the two-span configuration, post-tensioning is added to the deck over the pier to control deck and girder stresses. The concrete pier diaphragm is integral with the pier and the box girder. The box girder near the pier has a concrete slab poured directly on the bottom flange plate to avoid increasing the bottom flange plate thickness due to large compressive forces.

Two-span Modular Space Truss

This composite bridge is similar in appearance to the Twin Warren Truss, however, its construction is quite different. It consists of precast, prestressed concrete deck panels supported by a steel space truss continuous between abutments. The superstructure is post-tensioned externally. The bottom chord of the space truss is a single steel





Split Single Steel Box Girder

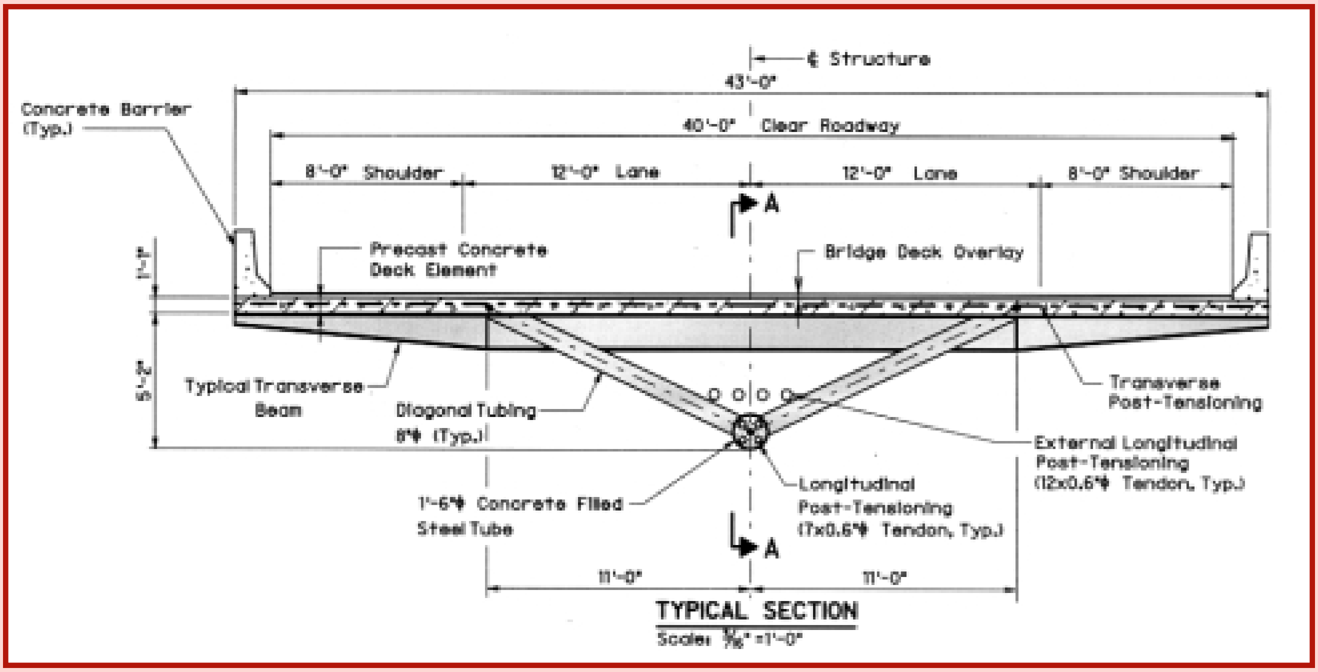
tube filled with concrete and concentric post-tensioning. Two inclined warren-type trusses carry the shear in the bridge under applied loads and consist of hollow steel tubes. These diagonal members of the warren truss are welded to the steel bottom chord and to transverse floor beams directly beneath the deck. The transverse floor beams are I-shaped steel sections.

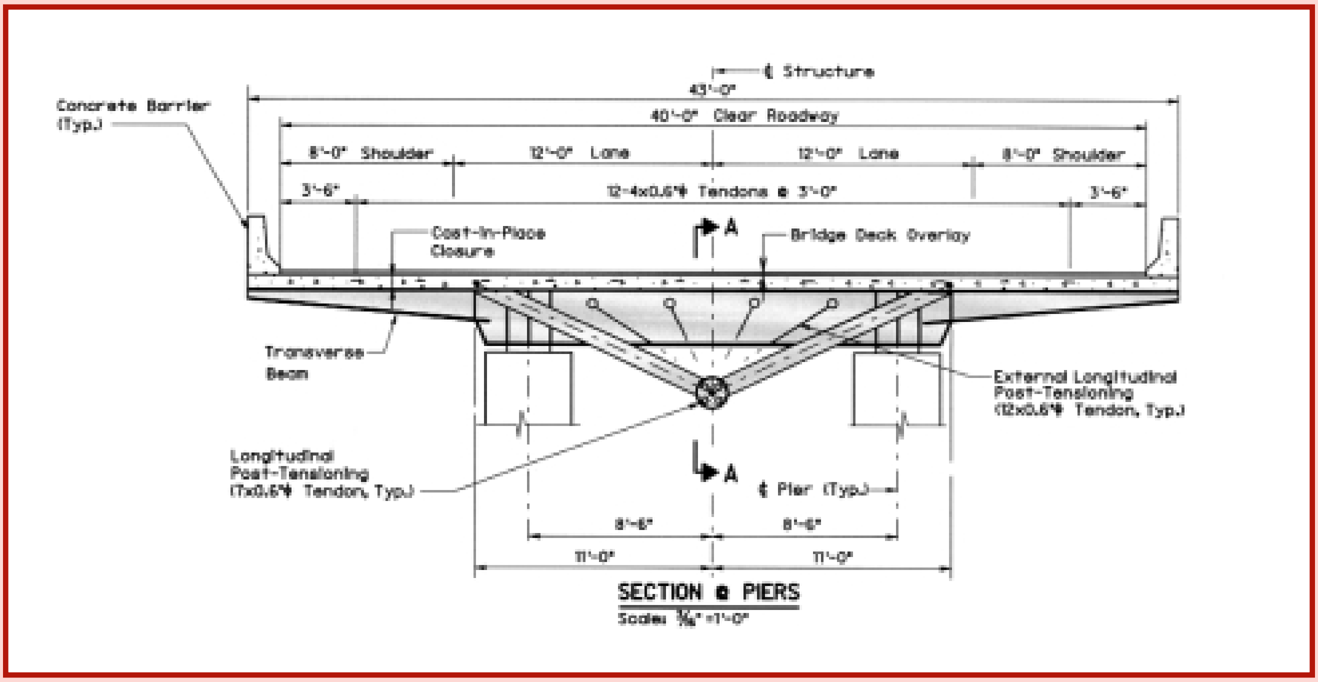
The top chord of the floor beams support the edges of the precast deck slabs and are used as formwork for the cast-in-place concrete transverse closure joints between deck panels. At the intersection of the diagonals and the steel transverse I-section, the steel section is extended into the closure pour to assist in the transmission of transverse forces.

The precast deck panels are the full width of the deck and span longitudinally between the transverse steel I-sections. Each panel is pretensioned longitudinally using bonded strand. The prestressing in the deck panels assist in carrying the local bending forces between the transverse beams and reduces the effects of creep by precompressing the concrete. Two tendons located on each side of the floor beams are post-tensioned transversely. The draped longitudinal tendons assist in carrying shear forces near the abutment and the pier.

Two-span Twin Warren Truss

This structure consists of a cast-in-place concrete deck supported by two parallel warren trusses continuous between abutments. The deck is





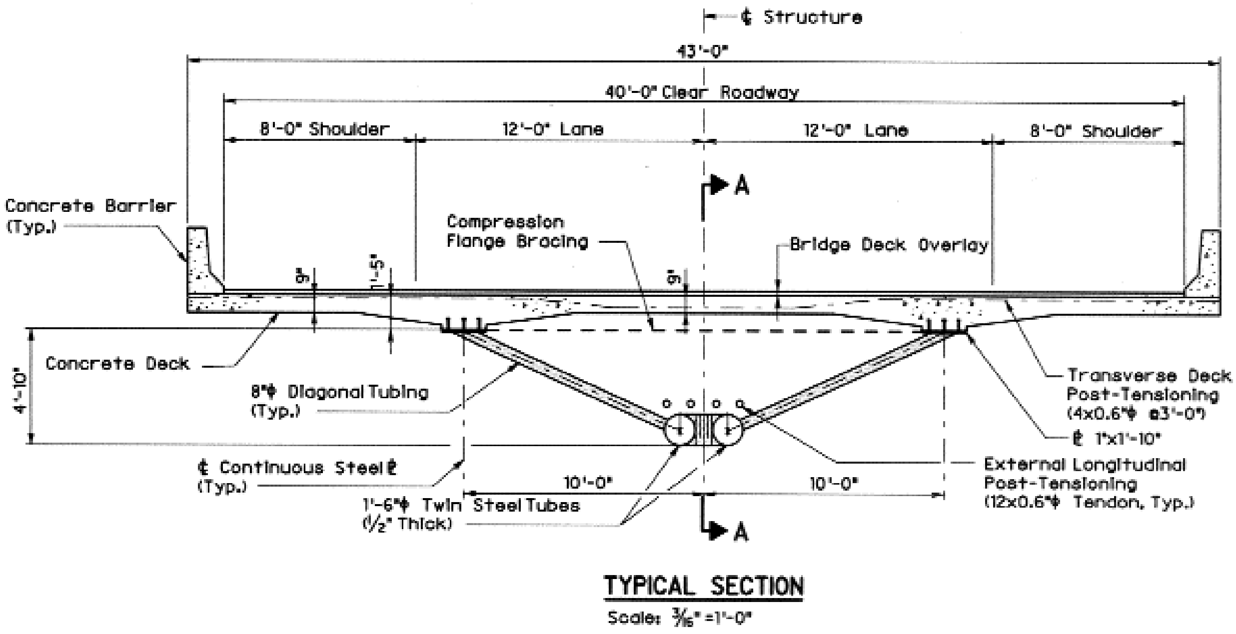
Two-span Modular Space Truss

post-tensioned transversely with internal prestressing and longitudinally with external prestressing located within the trusses. The two inclined warren trusses are fabricated with both top and bottom chords in 100-foot lengths. The diagonal and bottom chord members are steel tubes.

The cast-in-place top slab is connected to the pair of trusses by a longitudinally continuous steel voided plate and shear studs. The deck is haunched along this interface to provide local strengthening and transmission of forces into the diagonals. Longitudinal external prestressing is draped as required to assist in carrying the applied loads. To simplify the construction process, each warren truss is connected together at the bottom chord upon installation.

Conclusion

Innovative composite steel bridges have the potential to greatly impact the bridge industry in



Two-span Twin Warren Truss

the coming years. The serviceability, structural behavior, and economy of short and medium span steel bridges can be improved by investigating and optimizing every aspect of the structure.

On a steel weight basis, the innovative concepts described are expected to be more economical than current steel bridge designs.

The effort to create economical, serviceable, and practical steel bridges through innovative techniques is an ongoing process. The concepts proposed in this study are by no means a final solution, but provide innovative concepts for future development.

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