MARQUETTE INTERCHANGE RECONSTRUCTION

HPS TWIN BOX GIRDER RAMPS

By Finn Hubbard, Tony Shkurti and Kenneth D. Price

If anyone has driven into Wisconsin chances are that they passed through Marquette Interchange. This interchange of I-94, I-794, and I-43 was originally called the Central Interchange, and has a fifty-year history. Shown to the public as an artist's sketch in local newspapers in December 1952, the interchange was dedicated and opened to traffic on December 23, 1968. Most of the area's freeways intersect at the interchange, which links about one-third of the state's freeway traffic to the rest of the country. See Figure 1.

Unfortunately, after 35 years of service, it is in dire need for replacement. The bridges in the interchange are rapidly deteriorating. Fifty six of one hundred fifty two bridges are rated "tolerable" or "minimally tolerable" under FHWA guidelines. See *Figure 2*.

Also, functionally the interchange has become obsolete. It was originally designed for half of the 300,000 vehicles a day that it sees today.

Several attempts have been undertaken during the years to patch and repair in order to control the rapid deterioration of the bridges.

It has been decided that it is time to rebuild the Marquette Interchange.

Figure 1

OVERVIEW

The overall Marquette Interchange reconstruction project, estimated at $810 million, has been divided into five major construction contracts. The project comprises several types of structures laid out in different configurations. A total of about 2,000,000 square feet of deck area will be reconstructed divided amongst 63 bridge units. Of these, about 990,000 square feet configured into 34 bridge units will be supported on prestressed girders running East-West along I-794. Most of the South-North bridges along I-43 will be supported on composite steel plate I-girders totaling about 520,000 square feet of deck area. The rest of the structures, comprising eight system ramps, for a total of about 428,000 square feet of deck area divided into 11 bridge units, will be supported on twin composite steel box girders. See *Figure 3*.

These eight curved system ramps are being designed as twin steel box girders combining aesthetics with functionality. The design approach has been to apply different innovative materials and requirements that go beyond "business-as-usual", in order to ensure that a seventy five year projected life for the bridges is achieved.

Figure 2

TWIN STEEL BOX GIRDER RAMPS STRUCTURAL SYSTEM

Superstructure

The high degree of curvature in the system ramps, with minimum radii of about 510-feet, made box girders the preferred structural section because of their high torsional stiffness. While in the preliminary design phase dual designs in concrete and steel were studied, steel box girders were selected for final design as part of cost saving measures.

The superstructure for all eight ramps consists of two similar cross sections (*Figure 4*) with the main difference being the total deck width. The deck

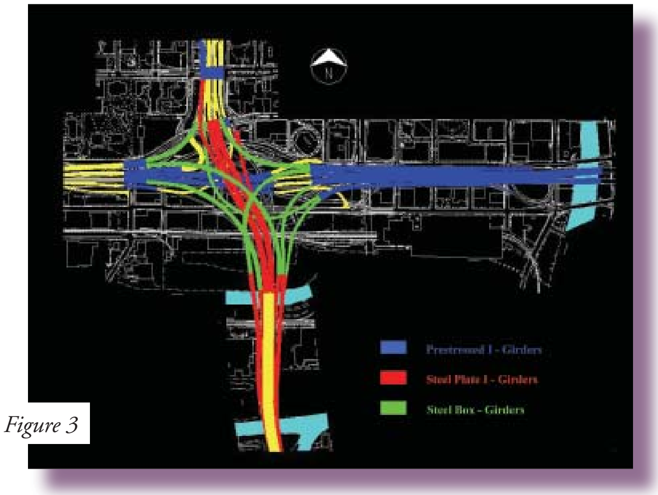
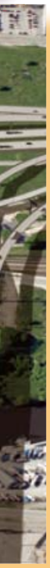


Figure 3



widths were designed as 29.5 feet and 44.5 feet, each applicable respectively to ramps carrying one or two lanes of traffic. The deck for the single lane supports a clear roadway of 27-feet which accommodates one extra wide lane of 15-feeet with shoulders on each side, 4-feet and 8-feet respectively. The deck for the dual lanes supports a clear roadway of 40-feet which, besides the two 12-foot wide regular lanes, accommodates shoulders on each side, 6-feet and 10-feet wide respectively.

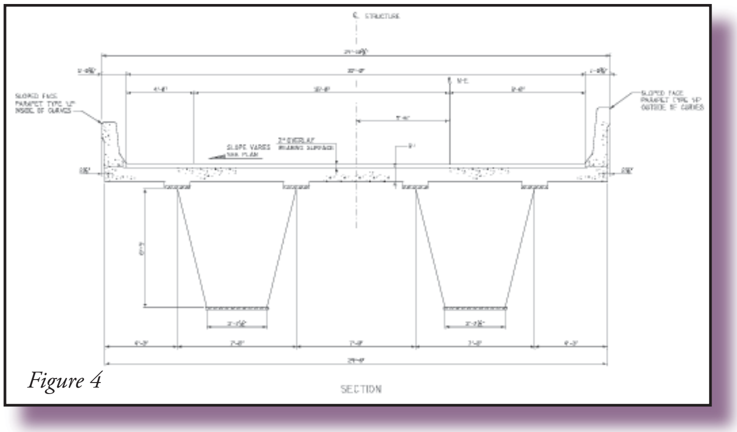


Figure 4

Due to concerns over redundancy in the system, dual boxes were used for both sections. Spans in different ramps vary from about 100-feet to 240-feet, with web depths of the steel boxes varying from a minimum of 5-feet to a maximum of 7-feet 3-inches in the longest spans based on an average span-to-depth ratio of 34. The concrete deck of 9-inches is designed to work compositely with steel boxes, not only converting the tub section into a closed box with considerable torsional stiffness but also providing increased longitudinal strength and stiffness.

In order to ensure integrity of the shape of the tub section, not only during erection but also during service, transverse diaphragms have been provided at each of the supports and intermediate cross frames have been provided at distances less than 30-feet along each of the box girders. The main function of the internal cross bracing system is to control the transverse distortion of the box section. In order to limit warping of the tubs, diagonal members are attached at the top flanges spanning less than 15-feet combined with one extra transverse strut. The additional strut controls spreading and balances the transverse load of the diagonals at every location where there is no internal cross frame. *See Figure 5*. Also, in a few instances where the bottom flange was too wide, longitudinal stiffeners where included to improve the flange's slenderness when in compression.

Single pot style bearings have been used for each box at the supports. External full depth diaphragms have been used between boxes at end supports, enabling the boxes to resist global torsion as one system, both during erection and in-service. In addition, external partial depth diaphragms have been provided at every third point of the span mainly to limit the amount of rotation and differential deflection of the boxes during the placement of the deck. These diaphragms will not be removed after the concrete in the deck has hardened. A corresponding internal cross frame has been placed at each location of the intermediate external diaphragms.

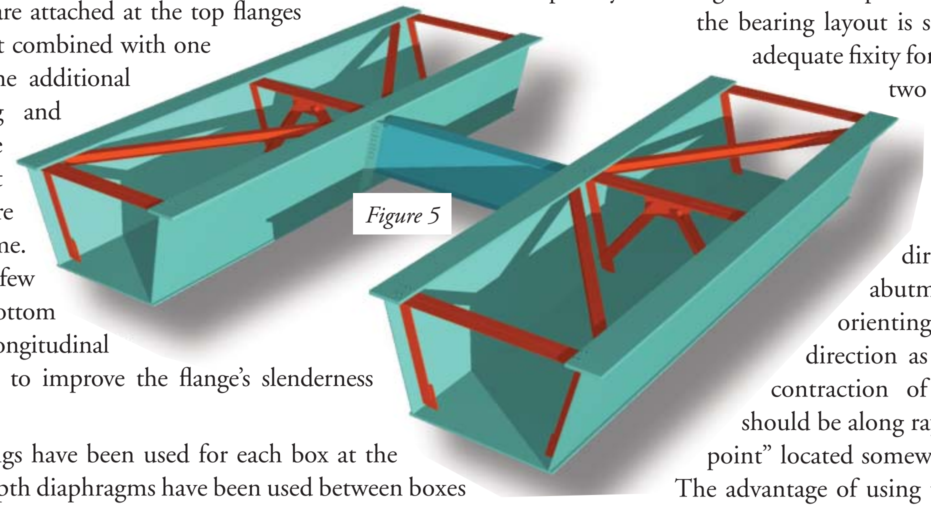


Figure 5

The number of expansion joints has been minimized by using very long units in the system ramps. In order to accommodate large temperature movements at the joints, modular expansion joints have been specified in these structures.

Substructure

The design used for the piers was maintained as consistently as possible through the system ramps by using only two variables: pier heights and width of the superstructure deck. The typical piers vary either by the design of their cap, which is based on the spacing of the tubs, or the shaft cross section which is controlled by the height of the pier. The limiting benchmark between the two types of piers "short" and "tall" was set at about 30-feet of height. *See Figure 6*.

Because of the long spans afforded by the box girder configuration and the tall columns required to accommodate different levels of the interchange, foundation loads were relatively high.

Geotechnical engineers recommended use of high capacity, concrete filled, friction steel piles of two different sections and capacities as follows:

- 14-inch diameter with ½-inch thick wall piles with a 200 ton capacity
- 16-inch diameter with ½-inch thick wall piles with a 250 ton capacity

In order to minimize loads on the substructure while ensuring overall stability for the superstructure, a combination of fixed, guided, and free pot style bearings have been specified in the designs. In general, the bearing layout is selected such that it provides adequate fixity for the superstructure by having two to three middle piers fixed, while still allowing free (or with little friction resistance) expansion/contraction in the longitudinal (chord) direction at the rest of the piers/abutments. This is accomplished by orienting bearing guides in the same direction as the direction of expansion/contraction of the superstructure, which should be along rays emanating from the "fixed point" located somewhere between the fixed piers. The advantage of using these guided bearings is that

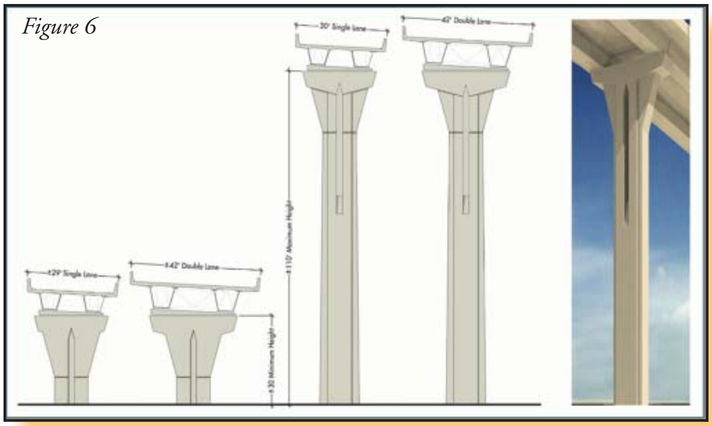


Figure 6

while giving the superstructure room to "breathe" from temperature loading along the lines of the guides, they can provide adequate resistance to all other lateral loads at every pier in the direction perpendicular to the guides. In addition, advantage was taken of the cracked moment of inertia of the pier shafts during the global analysis of the substructure for temperature loading. This way "softer" shafts yielded smaller temperature loads for same temperature radial displacements.

SERVICE LIFE

The decision was made to rebuild the Marquette interchange, and in the conception phase it was agreed that the structures would be designed and built using qualitative requirements that go beyond the "business-as-usual" approach. The main goal has been to achieve a projected service life of 75 years, which is very important due to the high cost of replacement. In order to accomplish this goal, a few rigorous requirements were introduced in the design criteria, additional features were included in the structures, and innovative and improved materials were specified to be used in construction.

Rigorous Design Requirements

The structures have been designed using requirements that go well beyond the AASHTO regular specifications:

- Structures were designed using HS-25 loading, which is 25% larger than the regular HS-20 required by AASHTO Specifications
- Design for L/1200 allowable load deflections. For ramps with no sidewalks, AAHTO specifies L/800

An internal redundancy analysis was performed on each of the dual box girder structures to prove that the system would be able to survive a total failure of one of the boxes.

Additional Features

Structural layout and specific elements include additional features such as:

- Long, continuous unit lengths to minimize deck joint, and improve serviceability and life expectancy for the decks
- Four coat paint system on the outside and two coat system on the inside of the boxes
- Sacrificial deck overlay poured before the structure sees any traffic. It is considered sacrificial as it is intended to be replaceable every time it deteriorates, without the need of having to replace the whole deck.

Innovative and Improved Materials

An array of innovative materials has been specified to be used in the project. These include:

- Use of High Performance Steel (HPS) hybrid members (not sections) for the box girders. HPS70 has been specified to be used in the negative moment region, while the positive moment segments will be built using HPS50. This material was selected based on its superior notch toughness, weld-ability, and weathering characteristics.
- High Performance Concrete (HPC) will be used to build the deck and all column shafts. This material was selected based on its low permeability to chlorides.
- Stainless clad has been specified to be used for reinforcing the deck slab. This material will provide improved corrosion resistance.

REDUNDANCY ANALYSIS

It was a preference from the preliminary phase that no fracture critical members would be included with these bridges where practicable. This is based on the cost of a more rigorous inspection and maintenance plan that is required with such members. Fracture critical inspection measures will be implemented during construction to ensure the highest quality possible, but inspection costs will be reduced by relaxing fracture-critical inspection measures. Hence, a redundancy analysis was required to prove that alternate paths internal to the system existed with enough stiffness and strength to avoid collapse of the bridges in a predetermined damaged limit state, or brittle fracture of one of the main members.

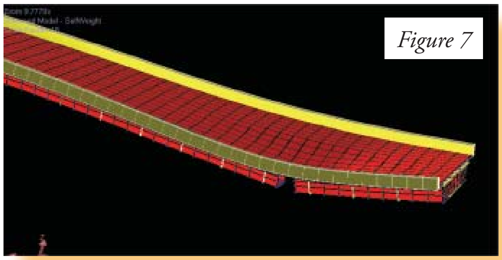


Figure 7

Complete failure analyses of prototype steel box girder structure have been carried out. The failure analyses consisted of 3D "incremental" nonlinear modeling of the superstructure, considering composite action of the deck and girder under self-weight and traffic loading. *See Figure 7.* The analyses take into account the in-plane and out-of-plane behavior of the deck, the failure of girder flanges, plastic residual capacity, and the redistribution load paths. The study intended to either prove the designed configuration as a redundant one, or to add additional features and/or elements as to make it redundant by providing alternate load paths in case of main member failures. The designed configuration was proved redundant; however, the study also presented innovative design and detailing methods and ideas to improve bridge redundancy.

CONCLUSIONS

Through application of practical and creative design principles, which surpass standard project goals, the Marquette Interchange will be a long lasting monument to the bridge engineering profession.■

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