

Innovative Vertically Segmented Precast Concrete I-Girders Span the Tigris River

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Located in one of the most prominent urban districts in Baghdad, Iraq, Al-Masafi River Crossing Bridge forms a key component of a 2.24 mile (3.60 km) transportation corridor spanning the historic Tigris River. Because this bridge is positioned within a highly visible and architecturally sensitive setting adjacent to one of the city's landmark suspension bridges, it was important that the project present a structural solution that would deliver efficiency and durability without competing visually with its iconic neighbor. The new bridge is a three-span structure featuring a 360 ft (110 m) main span and two 262 ft (80 m) back spans.

Meeting Multiple Design Objectives

From the early stages of design development, the project team pursued a solution that would reconcile three primary objectives: structural efficiency, construction within site constraints, and architectural appeal. Multiple structural systems were evaluated and then narrowed to two options: a conventional cast-in-place, balanced-cantilever segmental box-girder system, and a precast concrete spliced I-girder system. While the box-girder solution offered structural efficiency and torsional rigidity, it was ultimately deemed less favorable due to its high construction complexity and the need for specialized formwork, heavy erection equipment, and an extended construction timeline.

In contrast, the precast concrete solution offered improved constructability and speed of erection, which were major advantages in the congested urban environment with limited staging areas. However, this approach had its own challenges. It was difficult to design a precast concrete system capable of achieving the required span lengths

while maintaining a slender structural profile. Additionally, when designing the components, the design team had to consider the weight limits and vertical clearances of the bridges on the hauling route between the precast concrete facility and the project site.

Additional constraints further shaped the design direction. The bridge had to maintain adequate navigational clearance over the Tigris River. The combined requirements led the design team to choose an innovative solution.

Vertically Segmented Precast Concrete I-Girders

The superstructure system consists of a vertically segmented precast concrete I-girder configuration. This is the first bridge where segmentation is done in the horizontal direction between I-girder segments, and vertically between certain I-girder segments and the haunches below them at the piers. The design accommodates segment weights of up to 330 kip (150 metric tons) and maximum segment depths of 9.8 ft (3.0 m). These specifications were governed by hauling conditions through a carefully mapped route. This design approach significantly simplified logistics while meeting structural performance requirements.

A critical engineering challenge emerged at the intermediate piers, where negative moment regions demanded a structural section that was significantly deeper than the precast concrete girders (approximately 14.75 ft [4.50 m] versus 8.2 ft [2.5 m] maximum). To resolve this issue, the design team developed a variable-depth, U-shaped precast concrete haunch that integrates vertically with the I-girder to produce a fully composite girder varying in depth from 8.2 to 14.75 ft (2.5 to 4.5 m) (Fig. 1). The connection

was detailed to ensure full structural continuity, enabling the assembled system to behave as a monolithic member under both service and ultimate (strength) load conditions. This innovative concept builds on findings from earlier full-scale experimental testing performed by Tadros and Girgis at the University of Nebraska.¹

Structural Configuration

The bridge superstructure is composed of four continuous girder lines, each assembled from seven precast concrete I-girder segments and two U-shaped precast concrete haunched segments ranging between 131 and 164 ft (40 to 50 m) in length (Fig. 1). These girders have wide top flanges that also act as "subpanels" for a cast-in-place concrete deck slab, thus avoiding the need for deck forming. The gaps between the top flanges of adjacent I-girders were filled using narrow hanging formwork from the top deck.

The superstructure is supported by architecturally expressive cast-in-place Y-shaped piers at the intermediate supports and by a single-column pier at the ends of the back spans. Beyond their visual impact, the Y-shaped piers improve load distribution, reduce effective span lengths, and enhance the overall stiffness of the structure.

Jointless Superstructure, Integral with Piers

An important feature of the 885-ft-long (270-m) bridge is that it has a fully continuous, jointless superstructure. Expansion joints are eliminated within the main river span and are only located at the ends of the back spans. Furthermore, there are no bearing devices between the superstructure and the piers; such devices would require significant maintenance and periodical replacement. This strategy

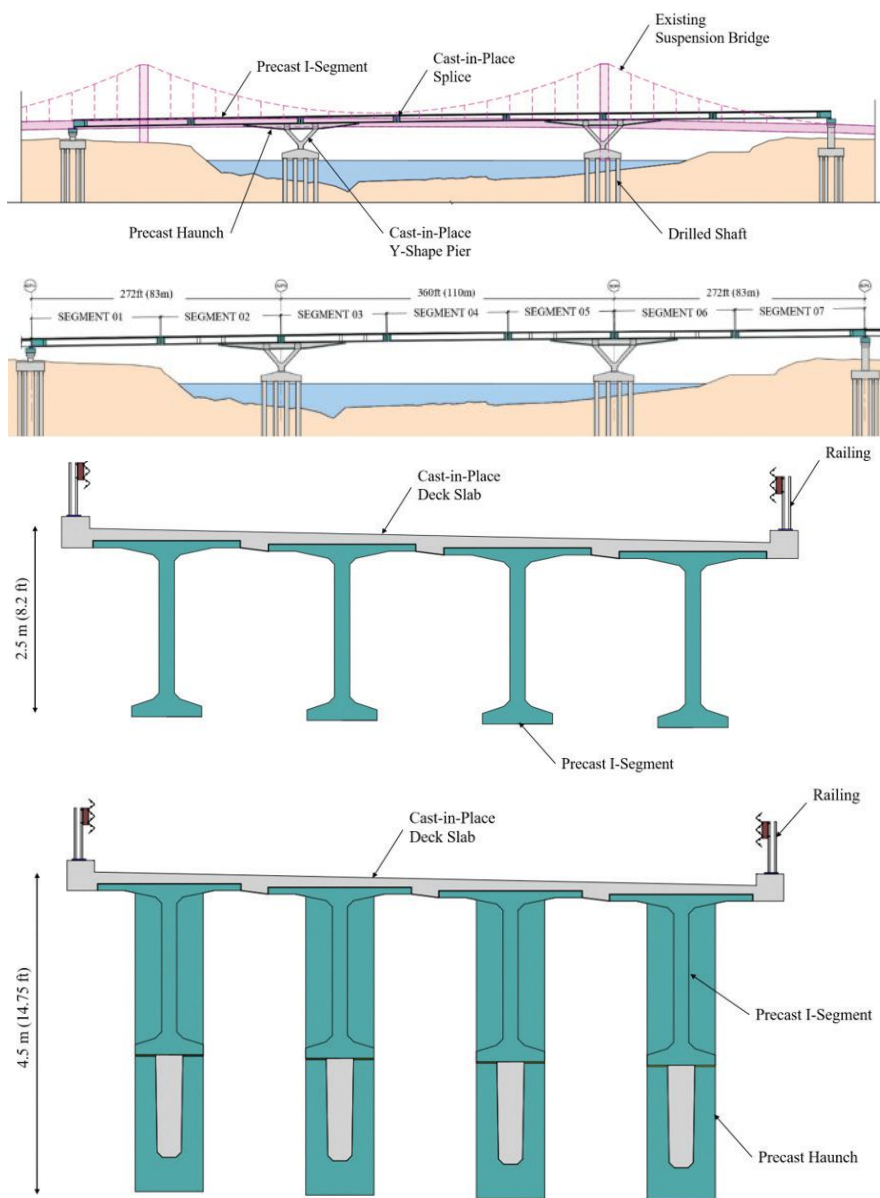


Figure 1. Rendering of the Al-Masafi River Crossing Bridge showing, from top to bottom, the proposed bridge elevation with the nearby existing bridge in the background, bridge segmentation, typical cross section at midspan, and typical cross section over the Y-shaped pier. All Figures and Photos: e.construct.

should help improve rideability and reduce maintenance.

Design Verification Processes

The selected precast concrete solution was developed as a value-engineered alternative to the cast-in-place box-girder concept. Comprehensive structural analysis was performed using three-dimensional structural engineering and finite element analysis software, including detailed construction-stage modeling to evaluate time-dependent effects such as creep, shrinkage, and prestress losses. To further validate the design, the engineer arranged for two independent third-party reviews. The multiple studies provided confidence in the predictions of structural behavior throughout production, erection, and long-term service conditions.

As the project advanced, the project team developed custom solutions for each of the engineering and construction challenges they encountered. These challenges and custom solutions included the following:

- The top flange of the I-girder was extended to eliminate the need for stay-in-place deck subpanels.
- The spans were shortened by designing an efficient Y-shaped pier at the main span.
- Attempts to develop a self-supporting erection system without shoring were abandoned due to the resulting excessive deflections.
- Even with the addition of the significant haunch, the negative moment section at the face of the haunch was enhanced with additional reinforcement and steel plate to meet flexural strength requirements.

Substructure Modeling

A major analytical consideration for this project involved accurately representing the substructure behavior and its interaction with the superstructure. The design team evaluated several modeling assumptions before adopting a final scheme that incorporated partial shaft length with fixed supports at the design scour depth. The shaft caps were modeled using their actual geometry and stiffness properties, resulting in a realistic simulation of the bridge's lateral response.

Two shaft cap locations were studied: one above the river level and another below the riverbed. The submerged option theoretically offered structural advantages due to lower lateral stiffness, leading to reduced restrained forces in the superstructure; however, the above-water configuration was selected because it promised improved constructability.

Construction-Stage Stability

Construction-stage analysis identified the need for temporary shoring systems to control deflections during erection. These systems provided geometric precision, alignment control, and structural stability before fully composite action among the bridge elements was established.

Composite Connections

Special attention was given to the interface regions between bridge elements, particularly at the connections between the cast-in-place Y-shaped piers, precast concrete haunch segments, and precast concrete I-girders. High-strength, nonshrink grout was specified for these joints to provide reliable shear transfer, dimensional stability, and long-term durability, and to ensure fully composite behavior under the final loading condition. Although the original research by Tadros and Girgis³ demonstrated that cast-in-place concrete could be used successfully for these joints, the designers for this project took a more conservative approach by specifying a highly flowable, nonshrink grout. In addition to improving constructability by facilitating placement within the confined joint regions, the nonshrink grout provides excellent bond characteristics and minimizes shrinkage, contributing to the long-term performance of the connection.

Three interface shear-critical planes (identified by the blue, red, and green

color coding in Fig. 2) were evaluated at the vertical segmental connection between the precast concrete haunch girder and the precast concrete I-beam to ensure fully composite action of the assembled component. Each interface was designed in accordance with the interface shear provisions in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*² to provide reliable horizontal shear transfer across the precast concrete-to-precast concrete connection. Although the AASHTO LRFD specifications permit a demand-to-capacity (D/C)

ratio of up to 1.0, additional interface shear reinforcement was intentionally provided to limit the D/C ratio to 0.60 or less. Because this innovative vertical segmental connection detail was being implemented for the first time in a bridge project, the design team chose this conservative design approach to provide additional design margin and boost confidence in the long-term performance of the connection.

Compared with a U-beam or box beam, an I-beam has a relatively small bottom flange. Therefore, at the termination of the precast concrete haunch section, the

ultimate flexural capacity of the I-girder section is governed by compression-controlled behavior. To enhance the load-carrying capacity at this location, a hot-dipped galvanized steel plate was integrated into the bottom flange region of the girder (Fig. 3). The steel plate provided additional compressive resistance. In addition, large compression reinforcing bars were placed in this highly congested area.

Prestressing Strategy

Pretensioning was used during fabrication to resist handling and self-weight forces. Thirty-six 0.6-in.-diameter (15.7-mm)

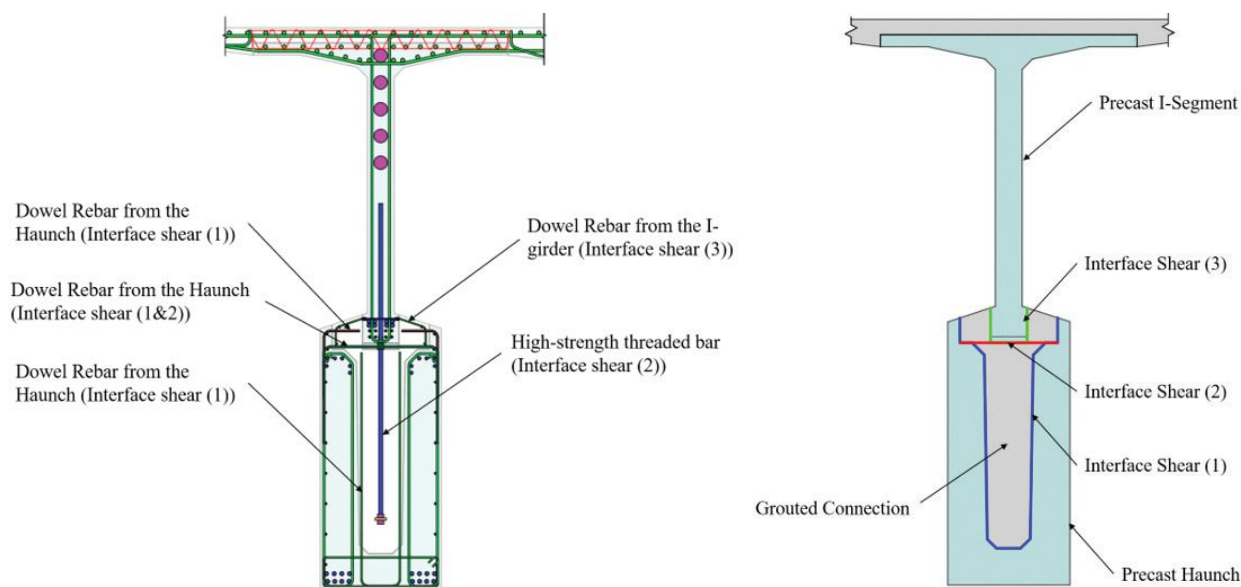


Figure 2. The vertical segmental connection between the precast concrete haunch girder and the precast concrete I-girder was designed using interface shear reinforcement (left) and by evaluating the critical planes for interface shear (right) to ensure that the haunch behaves with full composite action.

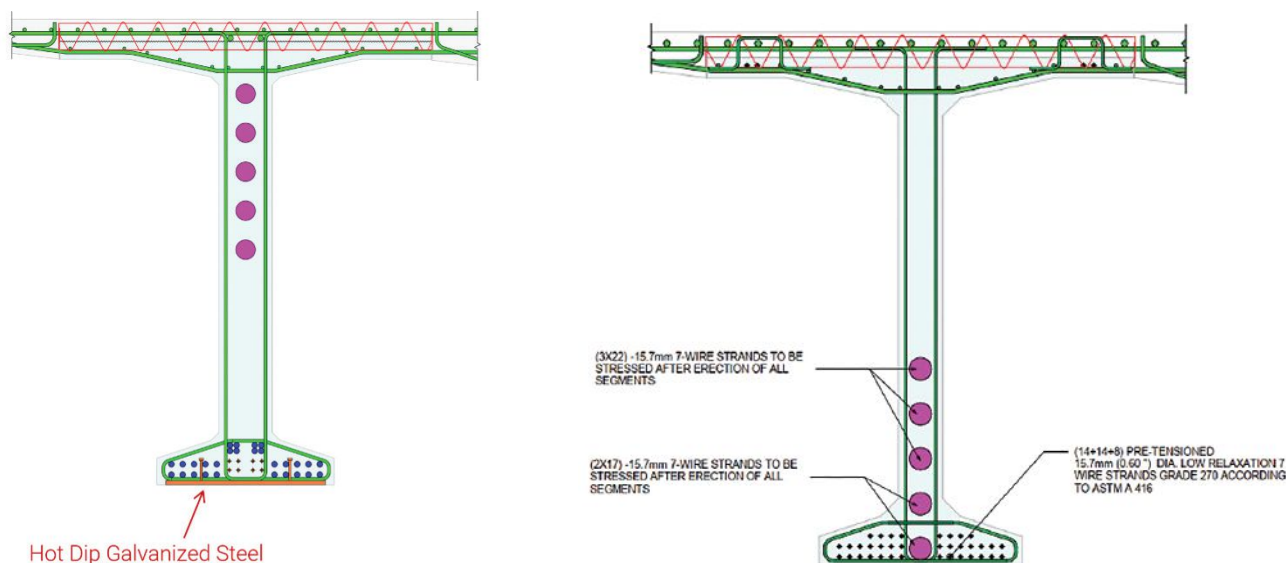


Figure 3. Hot-dipped galvanized steel plate details at the termination of the precast concrete haunch section.

Figure 4. Arrangement of post-tensioning and pretensioning reinforcement in the I-girder cross section at midspan.

straight strands, which were debonded at the ends, were used (Fig. 4). Following erection, continuity was established using draped post-tensioning tendons. The bonded tendons were tensioned from both ends.

Quality Assurance with Full-Scale Assembly at the Plant

To mitigate construction risk, a trial assembly of the critical connection of the precast concrete haunch to the I-girder was conducted at the fabrication facility using the actual components. This “measure, verify, and adjust” approach allowed the project team to validate dimensional tolerances, connection geometry, and erection procedures under controlled conditions (Fig. 5).

Construction Sequence Strategy

The construction of the bridge followed a carefully planned sequence. Construction began with the installation of cast-in-

place drilled shafts and caps, with precast concrete wall panels serving as cofferdams and permanent formwork for the shaft caps to reduce temporary work and accelerate the construction schedule. The cast-in-place Y-shaped piers were then constructed, with temporary shoring systems used for support during the early stages of girder erection (Fig. 6).

Following completion of the substructure, workers erected precast concrete haunch segments over the intermediate piers (Fig. 7), and the precast concrete pier caps for the back spans were installed, enabling efficient integration of the substructure and superstructure. Precast concrete I-girder segments were subsequently erected and connected through cast-in-place splice joints and diaphragms to establish structural continuity.

Once the girder system was assembled, post-tensioning was performed to develop

full continuity and achieve the required structural performance. Next, the cast-in-place composite concrete deck slab was constructed, and then the temporary supports were removed, allowing loads to be transferred to the completed structure. The bridge was completed with the installation of precast concrete barriers and the application of the wearing surface to the final road profile.

Conclusion

The Al-Masafi bridge, which is expected to be opened to traffic in mid-2027, represents the early adoption of an innovative segmented precast concrete I-girder system. The challenging urban environment of Baghdad inspired the team to develop a composite haunch that was spliced to the I-girder. The record span achieved in this design gives hope for many more similar applications of spliced I-girder bridges that are spliced both horizontally and vertically. This vertically segmented concrete system has now moved from concept to reality and can be used to extend spans around the globe.

References

1. Girgis, A. F. M., and M. K. Tadros. 2007. “An Innovative Approach for Vertically Segmented Bridges: Extending Precast Concrete I-Girder Spans.” *PCI Journal* 52 (5): 80–95. <https://doi.org/10.15554/pcij.09012007.80.95>.
2. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO. 



Figure 5. Trial fit-up at the precast concrete producer's yard using actual I-girder and haunch segments.

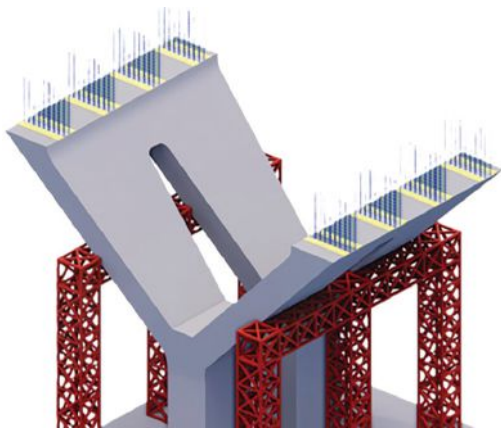


Figure 6. Rendering of the Y-shaped pier showing projecting dowels for the connection to the precast concrete U-shaped haunch segment..



Figure 7. Installation of the first and second precast concrete U-shaped haunch girders.