INNOVATIVE PC/PS BRIDGE CONSTRUCTION ENABLES “TOTAL ENVIRONMENTAL AVOIDANCE”

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ABSTRACT

The Daggett Road Bridge consists of a 3-span spliced bulb tee girder bridge, with integral bent caps. Each girder line is comprised of three segments: two over the piers/end-spans and one middle drop-in segment. The 100-ft middle span drop-in segments had to be installed from cranes operating on top of the partially-completed deck over the end spans. Both the framing plan and the erection scheme were necessary to avoid working in the channel. The unusual erection scheme produced some design challenges that had to be addressed.

The project’s environmental constraints played a key role in determining the type of bridge and construction techniques used. The project’s funding was tied to a total avoidance strategy, which required virtual elimination of all impacts to the sensitive resources and their habitats; consequently, the required permitting processes were reduced from formidable to programmatic for most of the regulatory agencies involved.

Keywords: Spliced Girders, Integral Bents, Continuous Bridges, Bulb Tee Girders, Post-tensioning, Bent Caps, Seismic Design

INTRODUCTION

The subject bridge carries Daggett Road over Burns Cut-off. Daggett Road provides the link between State Highway 4 and Rough and Ready Island, a former US Navy facility that was recently decommissioned and turned over to the Port of Stockton, CA. The new structure replaces the old steel truss swing-span bridge over Burns Cut-off with a 4-lane spliced precast concrete girder bridge. See Figure 1.

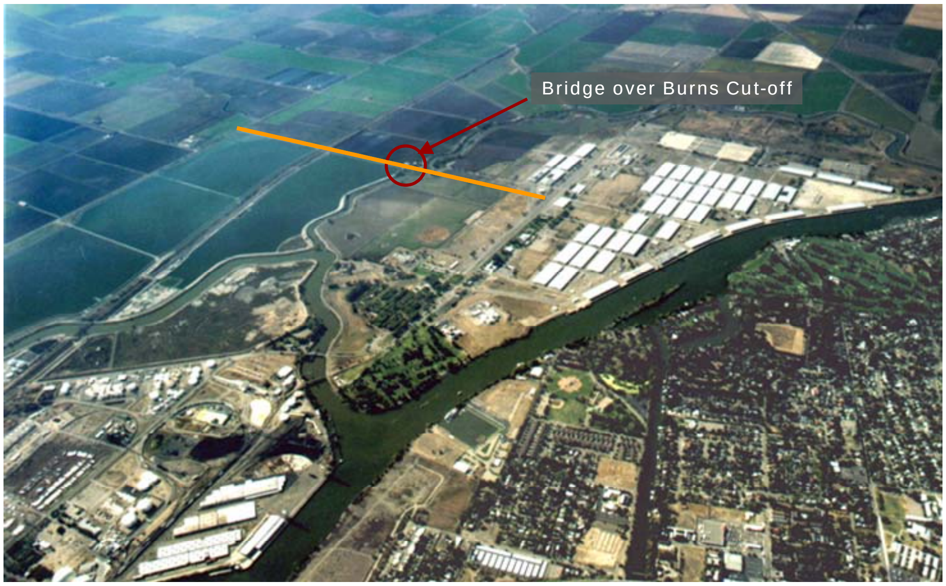


Fig. 1 Aerial Photo of Bridge Site

The Daggett Road Bridge consists of a 3-span spliced bulb tee girder bridge, with integral bent caps. Each girder line is comprised of three segments: two over the piers/end-spans and one middle drop-in segment (Figure 8). The 100-ft middle span drop-in segments had to be installed from cranes operating on top of the partially-completed deck over the end spans. Both the framing and the erection schemes were necessary to avoid working in the channel.

The project's environmental constraints played a key role in determining the type of bridge used. The project's funding was tied to a "sunset clause" with a fixed expiration date. In order to meet the funding deadline set by this agreement, it was necessary to accelerate the project by adopting a "total avoidance" alignment. As implied by the name, the alignment avoided impacts to sensitive resources and their habitats, thus reducing permitting processes from formidable to programmatic for most of the regulatory agencies involved. However, as a result of this strategy, no work could be performed in the channel below the ordinary high-water (OHW) elevation at any time during construction. These constraints precluded many standard bridge types from consideration, and left precast concrete as the only economically viable alternative. Even with all the versatility and adaptability offered by the selected precast girder system, a special erection scheme was necessary to stay out of the channel and above the specified OHW elevation.

The unusual erection scheme produced some design challenges that had to be addressed. Most of these issues were related to the critical bending moment section at the face of the bent cap. The choice of pretensioning and post-tensioning steel chosen to satisfy the stress limits resulted in exceeding the maximum reinforcement limit, which was overcome using a combination of design changes and analysis techniques.

ALTERNATIVES ANALYSIS

SUPERSTRUCTURE

Several bridge types were considered for the replacement structure. While many of these bridge types met the basic design requirements for functionality, it was obvious that the environmental goals could only be economically met using either a precast bulb tee or steel plate girder superstructure. Other important criteria requirements that had to be satisfied by the successful candidate include:

- *Channel Hydrology/Hydraulics*
- *Navigation Clearances*
- *Environmental Issues*
- *Levee Access/Maintenance*
- *Roadway Geometrics*
- *Seismic Considerations*
- *Construction Staging/Requirements*

The Precast Alternative

Use of the spliced Precast/Prestressed (PC/PS) bulb tee girder system eliminates both temporary and permanent supports from the channel, while minimizing structural depth. Precasting the girders in short segments, then splicing them using post-tensioning tendons after placement, permits the design to take advantage of the efficiency of a continuous structure without the need for extensive falsework in and around the waterway.

The Steel Alternative

A number of steel girder bridge configurations were considered, ranging from rolled beams to continuous plate girders. The most promising steel alternative consisted of a single span girder configuration supported by seat type abutments located on the waterway side of each of the levees (north and south). The minimum span considered was approximately185 feet between points of bearing. The length was set to minimize encroachment into the limits of the 100 year flood flows.

Type Selection Recommendation

The site constraints precluded many standard bridge types from consideration, and left precast concrete and steel as the only viable alternatives. The two candidates were approximately equal in the initial estimate of construction cost; however, the estimates did not consider the significant difference in structure depth between the two and its impact on the approach roadway embankment quantities. The single span steel alternate would have been, at a minimum, 2.5 to 4.5 feet deeper than the minimum PC/PS bulb tee system. This would have resulted in significant extension of the conform points, both on and off the island. Furthermore, the use of structural steel for bridge construction in California is not as common as either reinforced or prestressed concrete, and therefore comes at a premium price.

As a result, the preferred alternative consisted of 3-span, field-spliced, PC/PS concrete bulb tee girder bridge. The system is the least intrusive to the sensitive environmental areas, provides reduced structure depth, facilitates more flexibility for the incorporation of aesthetics and reduces approach roadway costs associated with the structure depth. Even with all the versatility and adaptability offered by the selected precast girder system, a special erection scheme was necessary to stay out of the channel and above the high water elevation.

SUBSTRUCTURE

The geotechnical investigation indicated the use of either cast-in-drilled-hole (CIDH) or driven piling. Discussion with the geotechnical engineer and reclamation district resulted in preference for drilled, rather than driven, piling because of the reduced disturbance to the levee materials during construction. As a result, the bent caps are each supported on four 3-ft circular columns founded on 4-ft diameter CIDH piles.

The end supports consist of seat type abutments located on the waterway side of the levees. Each abutment is supported on thirteen 2-ft diameter CIDH piles, arranged in a single row.

DESCRIPTION OF BRIDGE SYSTEM

SYSTEM DEVELOPMENT BACKGROUND

Following a decline in the precast concrete market share during the 1980's and early 1990's, the Precast Concrete Manufacturers Association of California (PCMAC) developed an initiative to revive the precast bridge girder market. Studies indicated that precast girder bridge form had not kept pace with the increasingly stringent requirements placed on structures in areas of high seismicity. Precast girders were still being used as simple girders supported on bearings, which in turn were supported on drop cap bents – a system that is very inefficient in resisting high lateral forces generated by earthquakes - particularly in the longitudinal direction.

Working with Caltrans, research professionals, and the engineering consulting community, PCMAC helped develop concepts that would return precast girders to a state of competitiveness with the typical California cast-in-place, post-tensioned box girder bridge[2]. The system developed made the superstructure continuous through post-tensioning. Recognizing the benefits of superstructure/substructure continuity, the developed system also introduced use of integral bent caps with precast girders.

To demonstrate its performance, the system was tested at the University of California, San Diego (UCSD), in a joint Caltrans-PCMAC sponsored research program. Performed on 40% full scale models, the main focus of this research was to study the effects of fully reversed longitudinal seismic forces on the column-superstructure continuity. Testing of the first model was successful under simulated seismic loads. Ductile plastic hinges formed at the top and bottom of the column with little strength degradation at ductility levels well above (up to twice) the design values. The superstructure performance was equally impressive, remaining essentially elastic under simulated longitudinal seismic response with only minor cracking observed. Due to prestressing, the cracking in the bent cap and the girders closed up upon removal of the seismic loads. This indicates that only minor repairs of the superstructure would typically be required following a design level earthquake[1].

PRECAST SYSTEM

Typical Section:

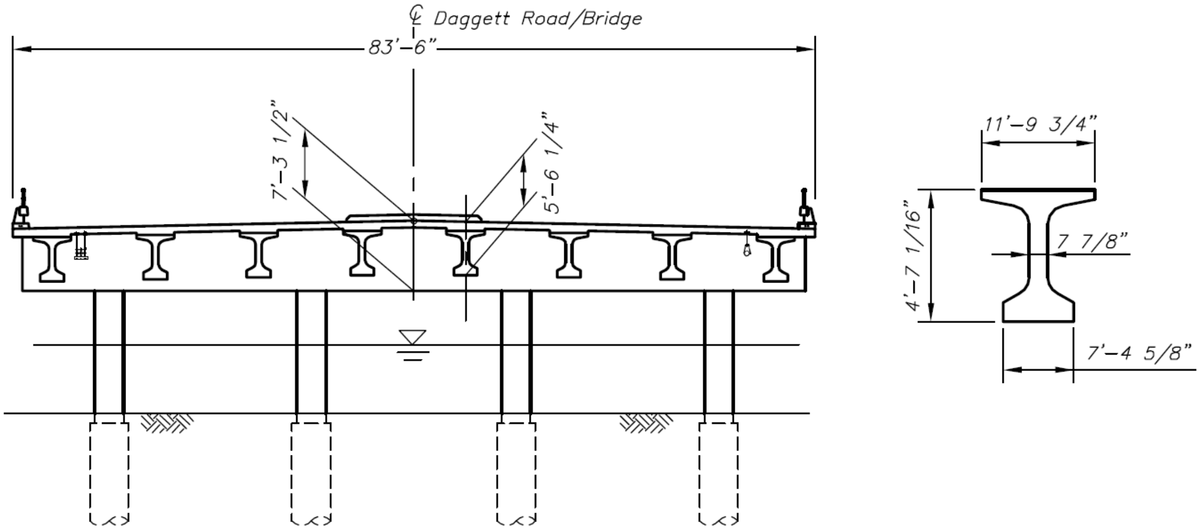


Fig. 2 Daggett Road Bridge – Cross Section

Framing Scheme

The system utilizes field splices in the middle span, thus enabling the girder segments to be shipped in reasonable lengths (≈ 110 ft). The splices were located near the span inflection points, which resulted in nearly equal drop-in and pier segment lengths. The superstructure of this bridge system consists of three main components: the end span/pier segment, the middle span drop-in segment, and the cast-in-place integral bents (Figure 8); these components are described in the following paragraphs:

End Span/Pier Segment

The end span/pier segment is comprised of a prismatic bulb tee section that spans between each abutment and the nearest bent, and cantilever nearly 24 ft into the middle span. The section is pretensioned for shipping and handling stresses. The pretensioning strands are all straight and are located in the bottom flange of the girder, clear of the web area that houses the post-tensioning ducts. Over the piers, this arrangement resulted in stresses that were additive to the stresses caused by gravity loads. The use of straight pretensioning was possible only because the negative moment section near the pier became composite, prior to the erection of the middle drop-in segments. A number of the pretensioning strands were debonded near the ends of the segment to help reduce stresses. The Pier Segment also contains ducts for two stages of longitudinal post-tensioning: one for the girder-only section and one for girder-deck composite section.

Middle Span Drop-In Segment

This drop-in segment spans between the cantilever ends of the end span/pier segments. It also consists of a constant-depth bulb tee shape that covers the positive moment region. It is pretensioned for lifting and handling stresses and contains ducts for the two-stage post-tensioning of the continuous girder and composite sections.

Cast-in-Place Integral Bent

This portion of the system provides the connection of the precast Pier Segment to the column as shown in Figure 3. Each bent is a four-column, rigid frame supported on large-diameter CIDH piles. The integral cap is formed and poured around and under the end span/pier Segment, and later stressed using transverse post-tensioning ducts passing through the end span/pier segments. Conventional reinforcement in the deck slab and in the cap below the girders further improves the monolithic response of the integral connection. The resulting joint is capable of transferring longitudinal moment between the column and the superstructure through torsion and shear-friction at the bent cap/girder interface.

Fig. 3 Transversely Post-tensioned Integral Bent Cap

A critical feature of the integral cap system that contributed in no small part to the success of this project is that it enabled the elimination of temporary shoring supports under the girder splices. This is possible due the inherent stability of the end/piers segments after being rigidly connected to the columns and the subsequent casting of the deck.

a) Temporary Falsework b) Falsework Attachment Detail

Fig. 4 Temporary Girder Support at Bents

Figure 4.a shows the temporary falsework that was used to support the pier segments while the bent cap was formed and poured; while Figure 4.b shows a typical falsework connection to the column. Figure 5 shows the Strongback used to support the span (drop-in) girders prior to forming and pouring the field splice.

Fig. 5 Strongback Used to Support the Middle Span Drop-in Segment

GIRDER DESIGN CONSIDERATIONS

An important feature of the system is the use of a two staged continuity post-tensioning. The first stage consists of stressing the "girder only" system after the integral caps and splices had been formed, poured and stressed. The second stage consists of stressing the composite system after the deck has been poured and cured to an appropriate strength. The benefits of the two stage post-tensioning include the reduction in pre-tensioning demands (since the girders resist the dead load of the wet slab as a continuous girder) and reduced deck cracking.

The unusual erection scheme produced some design challenges that had to be addressed. Most of these issues were related to the critical bending moment section at the face of the cap. Specifically, the following code limits had to be met at the said section:

- Tensile Stress limit
- Compressive Stress limit

The choice of pretensioning and post-tensioning steel to satisfy these limits generally resulted in exceeding a third code limit:

- Maximum Reinforcement Limit

The bridge was designed using AASHTO Standard Specification. A combination of design changes and analysis techniques were necessary to simultaneously meet all of the above code requirements. More specifically, the following measures were used:

1. Re-adjustment of pretensioning strand pattern in the end/pier segment (end span plus cantilever)
2. Introduction of high strength compression steel (MMFX) in the compression flange
3. Use of transformed section properties

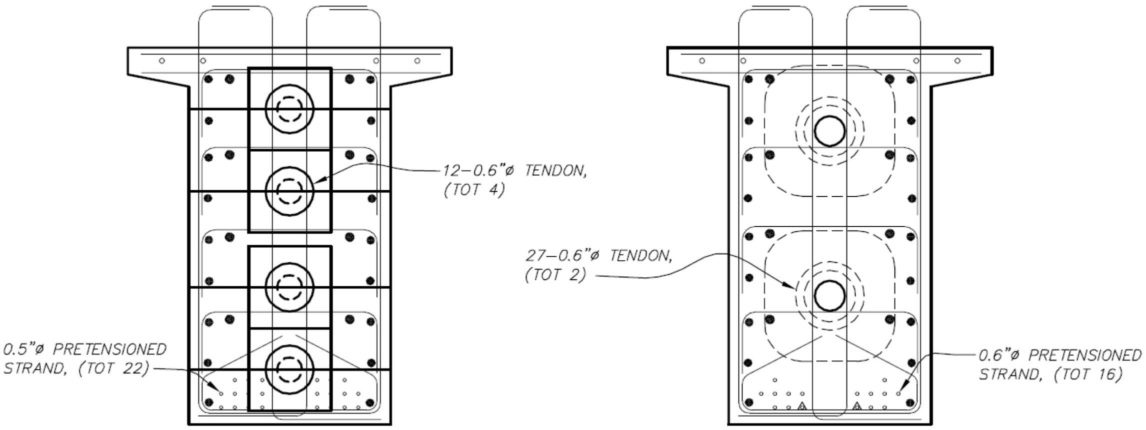
GIRDER FABRICATION AND CONSTRUCTION

GIRDER FABRICATION

The girder fabrication and shop drawings review went relatively well. The following two modifications to the girder design were proposed by the precast girder fabricator (see Figure 6):

1. The Precaster identified a conflict between the pre-tensioning strands located within the bottom flange and the bottom post-tensioning anchor plate. To resolve the conflict, the fabricator proposed reducing the number of strands by using 0.6”φ strands instead of the 0.5-in. strands specified on the plans; additionally, minor adjustments to the post-tensioning tendon layout was proposed. The Precaster proposals were reviewed and accepted and the design was changed accordingly.

2. The post-tensioning tendon layout was changed from 4 tendons with 12-0.6”φ strands each by combining the top two and bottom two tendons into the resulting 2 tendons with 24-0.6”φ strands each. This shifted the bottommost anchor plate upward, but made the plate larger. The number of pre-tensioning strands in the each bottom flange changed from 22-0.5”φ strands to 16-0.6”φ strands. The pre-tensioning strand layout pattern was changed by moving strand locations outside the area of the bottommost tendon anchor plate.



a) Original b) Modified

Fig. 6 Girder Prestressing Modification (View at End Block)

CONSTRUCTION SCHEME / SEQUENCE

The construction sequence is outlined in Figure 8. The key step in this sequence corresponds to the erection of the middle span drop-in segment (Step #3 in the sequence). This was necessary to avoid setting the cranes up on the levees or behind the abutments, where their carrying capacity would have been significantly reduced. Setting up and operating the cranes on the partially-completed deck over the end/pier segments was considered and seemed to provide the needed solution (see Figure 7).

However, extensive analysis and verification was necessary to ensure that this solution was structurally viable and safe. Consultation with the precasters and crane companies yielded information about the crane's required capacity and the magnitude of its maximum anticipated reactions. This information was then used to delineate permissible crane operations that do not violate the girders' (temporary) stress limits.

The project plans and the specification provided adequate detail to the contractor to devise his own erection scheme within these limits. As an example, the plans required that intermediate diaphragms be centered under the crane legs, as determined by the contractor. This requirement was added to protect the deck slab and distribute the crane rear leg loads evenly among the girders. The design plans provided a variable dimension to locate the intermediate diaphragm, since the dimensions of the crane were unknown at the time of design. This process proved to be effective in avoiding potential problems and construction went exceptionally well.

Fig. 7 Erection Sequence of a Middle Span Drop-in Segment

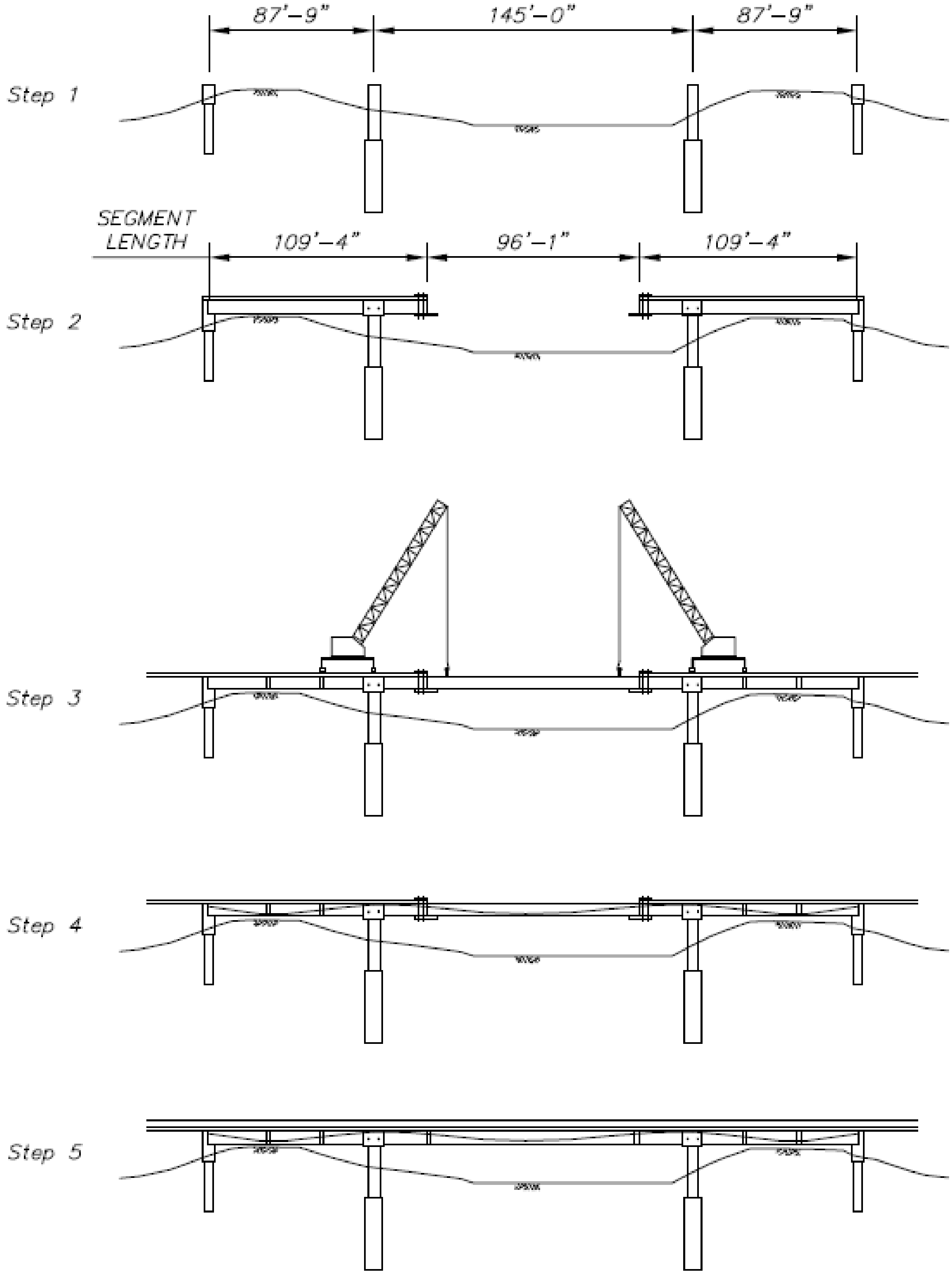


Fig. 8 Daggett Road Bridge – Construction Sequence

CONCLUSIONS

The selection of a spliced, precast girder bridge with integral bent cap enabled the adoption of a "Total Avoidance" strategy, which minimized environmental impacts to the bridge site. This made it possible to substantially reduce the permitting requirements and time, and hence secure funding for the project. The constructed bridge is a durable, low maintenance solution that blends well with its surroundings.

Fig. 9 Completed Bridge

The main features offered by the selected system include:

- Introduction of construction techniques that utilize the full potential of precast girders as an effective solution to environmentally sensitive sites.
- Use of continuous girder systems with integral bent caps benefits both superstructure and substructure due to the creation of a longitudinal frame, improving seismic performance.
- The use of integral cap construction provided the necessary stability to support the weight of the drop-in segments, without the use of temporary in-span towers.
- The use of longitudinal (girder) and transverse (bent cap) prestressing theoretically eliminates cracking under service loads, and hence provides improved durability.
- Where unconventional construction methods are used, it becomes especially important to closely coordinate the plans and specifications with the shop drawings. Doing so improves safety and helps ensure relatively trouble-free construction.

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CREDITS

Owner:	Port of Stockton, CA
Contractor:	Shasta Construction Co.
Precaster:	Con-Fab California Corporation, CA
Engineer:	DMJM HARRIS | AECOM

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