SPLICING DECKED PRECAST GIRDERS TO ACCELERATE BRIDGE CONSTRUCTION

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ABSTRACT

Bridges with spans between 150 and 300 feet have exceeded the range of the applicability of traditional precast prestressed concrete girders. For this span range, many bridge projects have demonstrated that spliced girders provide cost-effective and durable solutions, especially for waterway crossings. I-shaped, bulb-tee and trapezoidal tub girders are most frequently used for such applications. A decked girder is a prefabricated element with deck and girder cast integrally as one precast unit. After the girders are erected, only closure pours need to be made in the field but no deck pour is required for decked girder bridges, thus greatly reducing construction time. Decked girders have been used in many applications in traditional precast bridges to accelerate construction. However, very few examples can be found for their use in spliced girder bridges. Though there are some application constraints, for instance difficulty in deck slope transitions, decked girders have many advantages, including: 1) significantly reducing construction time; 2) effectively utilizing post-tensioning for longer spans; and 3) combining balanced cantilever and drop-in erection methods. This paper reviews applications of decked girder bridges and investigates rational design techniques used in splicing decked girders to accelerate bridge construction, including: a) design and detailing of longitudinal deck strip joint and transverse girder joints; b) post-tensioning and erection procedures of spliced deck-girders and c) the use of high strength and high performance concrete in decked girder bridges. Several recommendations are made in this paper to help engineers design spliced-deck girder bridges.

Keywords: Decked Girder, Construction, Spliced Girder, Precast Connections, Post-tensioning

INTRODUCTION

Bridges with spans between 150 and 300 feet have exceeded the range of the applicability of traditional precast prestressed concrete girders. For this span range, many bridge projects have demonstrated that spliced girders are able to provide cost-effective and durable solutions, especially for waterway crossings. According to a survey conducted by Castrodale and White[1], more than 250 spliced girder bridges had been constructed in the world. The maximum single span length of a spliced girder bridge had reached 320 ft. (Moore Heaven Bridge, Florida, 1999). I-shaped, bulb-tee and trapezoidal tub girders are most frequently used for such applications. A decked girder is a prefabricated element with deck and girder cast integrally as one precast unit. After the girders are erected, only closure pours need to be made in the field but no deck pour is required for decked girder bridges, thus greatly reducing construction time. Decked girders have been used in many applications in traditional precast bridges to accelerate construction. They are more frequently used in the Northwest of the U.S. However, very few examples can be found for their use in spliced girder bridges. One of the reasons for the limited applications of spliced-deck girders is because the self-weight of a decked girder is often larger than traditional precast girders, which causes some issues for handling, transportation and erection. Another concern with the use of spliced girder is the durability of longitudinal joints between spliced-deck girders, which may cause deck maintenance issues. These issues need to be resolved through engineering research so that the span length of decked girders can be expanded by using the spliced girder techniques.

This paper reviews applications of decked girder bridges and investigates rational design techniques used in splicing decked girders to accelerate bridge construction including: a) design and detailing of longitudinal deck strip joint and transverse girder joints; b) post-tensioning and erection procedures of spliced-deck girders and c) the use of high strength and high performance concrete in decked girder bridges. Several recommendations are made in this paper to help engineers design spliced-deck girder bridges.

SPLICED-DECK CONCRETE GIRDERS

DECKED CONCRETE GIRDERS

In this paper, a decked concrete girder is defined as a precast presstressed girder prefabricated with an integral precast deck (top flange). The girder can be prestressed I-shaped, bulb-tee, double tee or trapezoidal tubs (See Fig.1). For a concrete bridge with decked girders, no cast-in-place deck pour is required in the field. The length of a decked girder varies with the type of girder and the width of the top flange. The depth of a decked girder varies from 1 ft. to about 5.5 ft. with a maximum span length varying from 40 ft. to 145 ft.

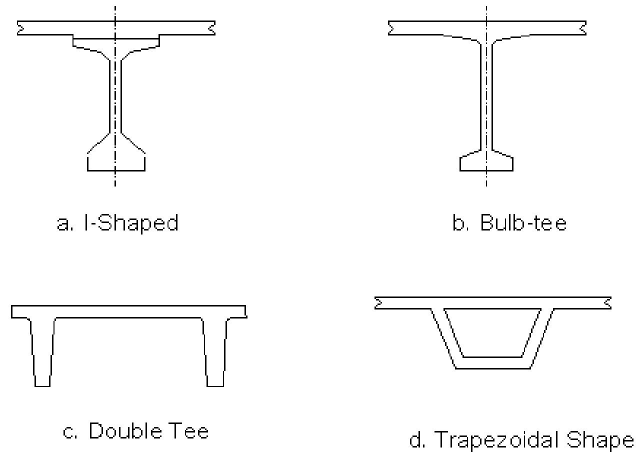


Fig. 1 Different Types of Decked Girders

Decked concrete girders have been found to be more structurally efficient and more cost-effective than traditional concrete girders with cast-in-place decks. A typical concrete bridge with prefabricated decked girders has:

- A better concrete quality because the girders are cast in a controlled environment;
- A lower cost for similar span/depth ratios,
- Fewer prestressing strands required for prestressed girders,
- Flexibility in cross-section selections,
- No deck slab formwork,
- No deck slab pour,
- A much shorter construction time, and
- Improved safety conditions for workers.

Because of the advantages offered by decked concrete girders, they have been used over the past 40 years, primarily in the Northwest, where it is popular for aiding fast construction. The number of the bridges with decked girders is anticipated to increase in the near future in order to meet the increasing demands of accelerated bridge construction.

As mentioned above, decked concrete girders are typically used for a span length up to 145 ft. Their application to a longer span is greatly limited because of their increased self-weights. A solution to expand the length of decked girders is to prefabricate smaller girder segments and splice them together to achieve longer pieces in the field.

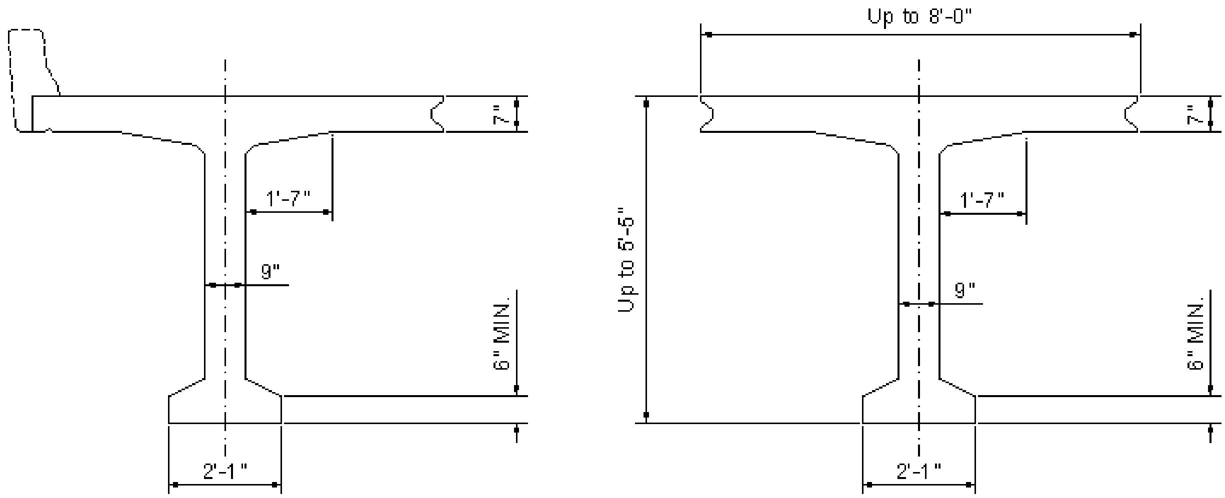
A recent example of such type of application is Perry Street Bridge crossing Maumee River in the state of Ohio[2]. The bridge has seven spans with a single span length of 103 ft. To help the new bridge reproduce the original bridge's appearance while speeding construction, precast concrete spliced-deck bulb-tee beams were used with only three types of haunched precast segments. The haunched pier segment is approximately 50 ft. long. Fig. 2 shows the first pier segment installed over the pier cap. With the aid of spliced-deck girders, the replicated historic bridge opened to traffic in less than a year.

Through the use of spliced-deck girders, some geometry constraints to short-span decked girders have been reduced, such as short span and small horizontal curve radius. By splicing smaller segments, the span of a spliced-deck girder bridge can be much larger than a standard decked girder bridge. With girder segments spliced within a girder span, a curved bridge alignment can be realized by positioning girders along the chords.

Fig. 2 Pier Segment of a Spliced-Deck Bulb-tee Girder Bridge (Perry Street Bridge, Ohio)

SPLICED-DECK BULB-TEE GIRDER SECTION AND SPAN LENGTH

Though several types of cross-section shapes can be used for decked girders, the bulb-tee shape is most efficient to be used for a longer span because it has a relatively large moment of inertia and less self weight. A decked bulb-tee section for spliced girder bridges can be obtained based on standard bulb-tee sections. Fig. 3 shows a revised bulb-tee cross section based on the standard W65DG decked girder used in Washington State[3]. The thickness of the stem is revised from 6 inches (in.) to 9 in. which can provide enough space for a duct to hold 19 strands with a diameter of 0.6 in. The top flange of the bulb-tee is thickened from 6 in. to 7 in. to provide a larger moment resistance. The depth, *H*, and the flange width, *B*, vary to meet the bridge geometry and structural strength requirements. The bottom flange has a minimum thickness of 6 in. It can be thicker when spliced girders are haunched.



a. Exterior Girder   b. Interior Girder

Fig. 3 Revised Decked Bulb-Tee Girders Based on Type W65DG Decked Girder[3]

The primary limitation of the decked concrete girders is the span length. Due to the extra weight of the deck, the self-weight of a decked girder is much larger than the girder itself. Therefore, the length of a decked girder has to be limited to meet the requirement of the maximum weight for transportation and handling. For ground transportation, if the maximum weight for transportation is 150,000 pounds, based on the section shown in Fig. 3, the maximum single span length of spliced-deck bulb-tee girder bridges can reach 210 ft. If the girder segments can be delivered from a waterway, this length limit could be increased to approximately 250 ft.

LONGITUDINAL DECK JOINTS

In the field, decked concrete girders are connected to each other with longitudinal closure joints consisting of grout-filled shear keys, mechanical fasteners, and/or transverse post-tensioning. Closure joints present the biggest challenge to achieving long-term durability of decked girder bridges. Many instances of cracking and spalling have been reported in decked girder bridges without wearing courses. Cracking has also been found in the overlay of decked girder bridges, which occurs directly over the longitudinal closure joints and runs the length of the bridge[4,5]. Cracking makes the longitudinal joints vulnerable to leakage, which can cause deterioration of the underneath prestressed girders and substructure members, and create a driving hazard for bridges with highway underpasses. The following methods have been used in the past to improve the durability of longitudinal joints:

a. The use of asphalt wearing courses to help prevent cracking that occurs in concrete overlays[3];
b. The use of thick wearing courses,

c. The use of overlays with water proofing membranes,
d. The use of sufficient transverse post-tensioning,
e. Preventing the use of decked girder bridges without cast-in-place decks in regions where deicing salts are commonly used,
f. Preventing the use of decked girders in bridges with an ADT over 10,000[3], and
g. Improving the design and detailing of longitudinal joints for long-term durability.

Among these solutions, enhancing the design and detailing of the longitudinal joints is most critical to resolve the durability issue from the basis. For decked precast girders, there are many types of longitudinal joint details available in the engineering practice and research. In general, these joints can be classified into three categories including: 1) joints with lapped reinforcement, 2) post-tensioned joints, and 3) joints with mechanical connectors.

JOINTS WITH LAPPED REINFORCEMENTS

Joints with lapped reinforcing bars utilize projecting lapped transverse reinforcing bars and grout for load transfer. At the joint, transverse reinforcing bars are lapped with straight short bars, looped or hook bar to improve rebar development. Confining spirals are sometimes used to improve the shear resistance at the joint. Fig. 4 shows details of one of the longitudinal joints proposed by Shah et al.[6] At the joint, both top and bottom mats of transverse reinforcement are lapped to provide sufficient moment resistance. The width of the joint on top of the flange is selected as 16 in. to meet rebar development and joint geometry requirements. Shear keys are provided at the ends of girder flanges.

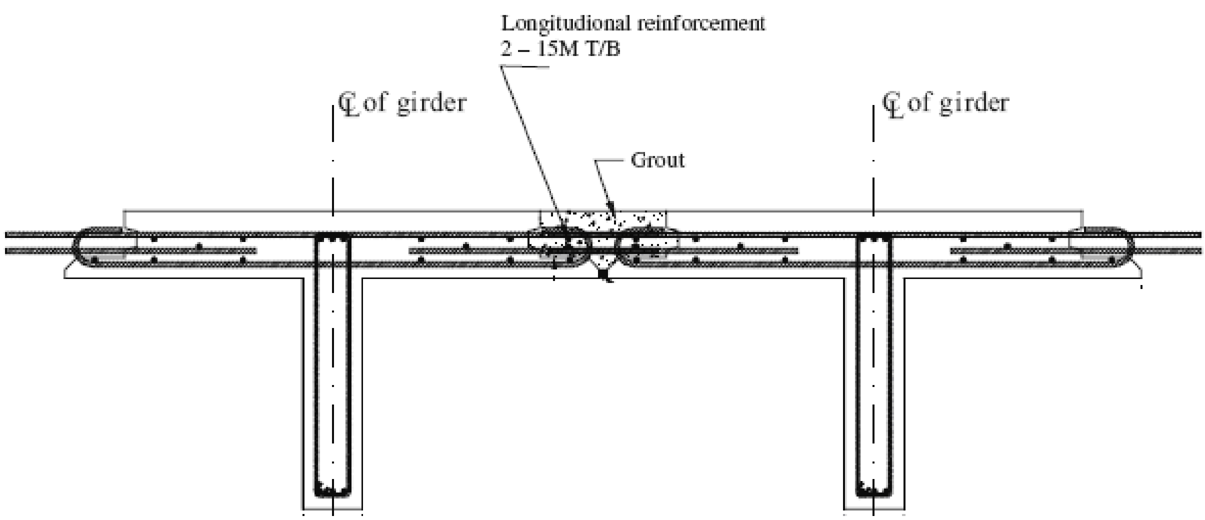
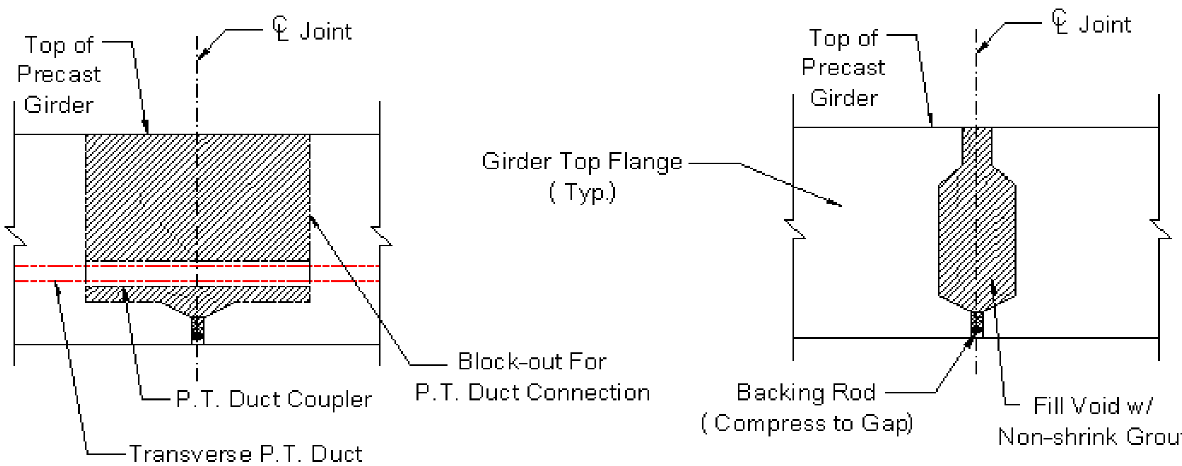


Fig. 4 Typical Passively Reinforced Longitudinal Joint[6]

POST-TENSIONED JOINTS

Used widely to link the precast panels in the transverse direction, post-tensioned joints can also be used to provide connections between the decked precast girders. The post-tensioning adds compression to the joint, reducing cracking due to service loads. It also increases the joints' capacity to resist shear and moment. Fig. 5 illustrates details of a typical post-tensioned longitudinal joint. At the location of post-tensioning tendons (P.T.), couplers are used to connect P.T. tendons within a block-out to be grouted with non-shrink concrete. At other locations, narrow shear key ways are used between girder flanges. Compared to joints with passive reinforcement, post-tensioned joints have narrower joints and less grout is required. However, post-tensioning the top flanges of decked girders requires special equipment and stressing expertise during bridge construction; which may increase construction time.



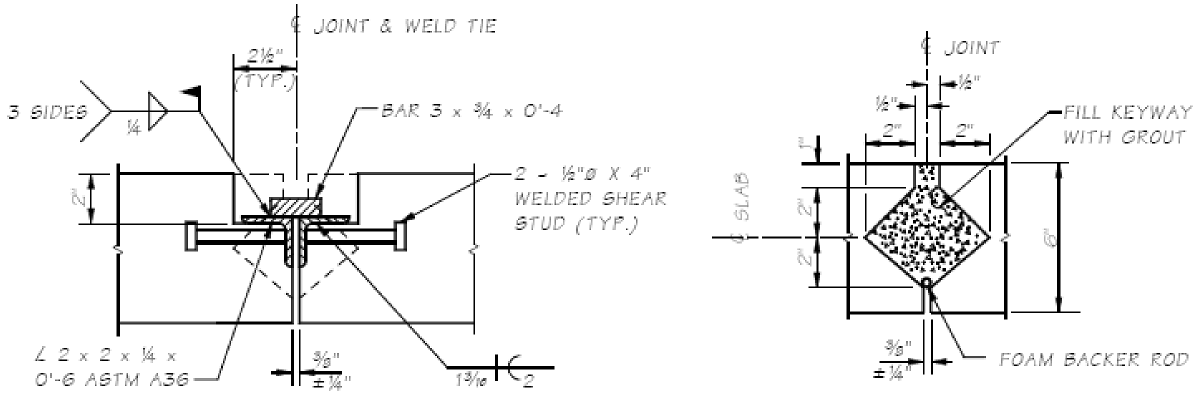
a) Section at P.T. Locations b) Section at Other Locations

Fig. 5 Typical Post-tensioned Longitudinal Joints

JOINTS WITH MECHANICAL CONNECTORS

Mechanical connectors have been used in the longitudinal joints to carry tensile loads between the girders because of shrinkage, torsion effects, and the shear, due to differential camber between girders. Weld-tie details (Fig. 6) have been widely used for longitudinal joints though other types of connections (such as bolting etc.) are also used in certain conditions. For a weld-tie connection, vertical or inclined welded plates or angles are embedded in the flanges of precast girders at a discrete spacing. These plates or angles are anchored into the flanges of precast girders with shear studs or deformed bar anchors. After decked girders are positioned in the field, the embedded plates (or angles) in adjacent flanges are welded together through a steel bar or rod. Fig. 6 shows a type of welded connection used by the Washington State Department of Transportation (WSDOT). When compared to other types of longitudinal joints, the joints with mechanical connectors are easy to install and they perform well without a composite deck topping for bridges with lower Average Daily Traffic

(ADT). The main reason to limit the use of this type of connection on the bridges with high ADT is because the field weld details have limited fatigue resistance.



a) Section through Bar/Plate b) Section at Other Locations

Fig. 6 Typical Longitudinal Weld-Tie Joint [3]

For spliced-deck concrete girders, selection of the type of longitudinal joint details should be based on specific project situations. All three types of connections mentioned above have their pros and cons. Project location, traffic situation, constructability and construction costs can all become key factors in selecting an appropriate joint detail.

It should be reminded that durability of longitudinal joints is still a primary concern in bridge industry for the application of decked girders. Significant amount of research is still undergoing to improve the joint details for a better durability. Bridge designer should not only select a durable joint, but also investigate if the location of longitudinal joint can be optimized to reduce the live load moment. Designer should also work with contractor to find out if there is a better solution to enhance the durability of the longitudinal joints.

CONSTRUCTION SEQUENCE

The construction sequence of a spliced-deck girder bridge is similar to that of a standard spliced girder bridge except that the stage of the cast deck is eliminated for spliced-deck girder bridges. Fig. 7 shows construction of a three-span spliced-deck girder bridge.
The six construction stages are listed as follows:

Stage 1: Construct intermediate piers and two temporary supports. Position the pier girder segments. Brace pier segments using temporary braces for lateral stability.

Stage 2: Lift and position each end girder segment with one end supported on top of the pier and the other end attached to the pier segments with strong-backs. Brace end girder segments using temporary braces for lateral stability.

Stage 3: Lift and position drop-in girder segments with both ends attached to the pier segments with strong-backs. Brace drop-in girder segments using temporary braces for lateral stability.

Stage 4: Cast concrete in splices and diaphragms (If precast diaphragms are used to accelerate construction, position precast diaphragms before casting splice concrete). After concrete in splices reaches the required strength, stress longitudinal post-tensioning tendons in girders to limit the tensile stress in the concrete deck to below cracking levels at negative moment regions. Remove all temporary supports.

Stage 5: Cast longitudinal closure joints. After grout reaches required strength, stress transverse post-tensioning tendons in the girders if applicable.

Stage 6: Cast traffic barriers/parapets and complete the bridge, including approach slabs, sidewalk, median, expansion joints, etc.

This is a typical construction approach used for haunched spliced-deck girder bridges crossing a channel waterway. Strong-backs are used in girder erection to avoid construction of temporary supports within the channel span, which could be very expensive. The longitudinal tendons are assumed to be stressed in a single stage though multiple-stage stressing is also feasible.

Because the self-weight of the pier segment of the decked girder is much larger than the corresponding standard girder's weight, erecting the pier segment as a single piece is sometimes not feasible. A solution to this problem is to further divide the pier segment into smaller segments and connect them on site using the cantilever construction approach (Fig.8). The small pieces of pier segments are match-cast in the prefabrication yard and installed on site. Similar to precast segmental box girders, the cantilever tendons in decked girders are positioned in the portion of girder top flange near the web. The continuity tendons for girder splicing are positioned in the web and they are typically stressed after the pier cantilevers are erected and the drop-in segments are installed.

Combining balanced cantilever construction and drop-in approaches help resolve issues related to large self-weight of decked girder segments. It makes it feasible to utilize spliced-deck girders in a long span bridge.

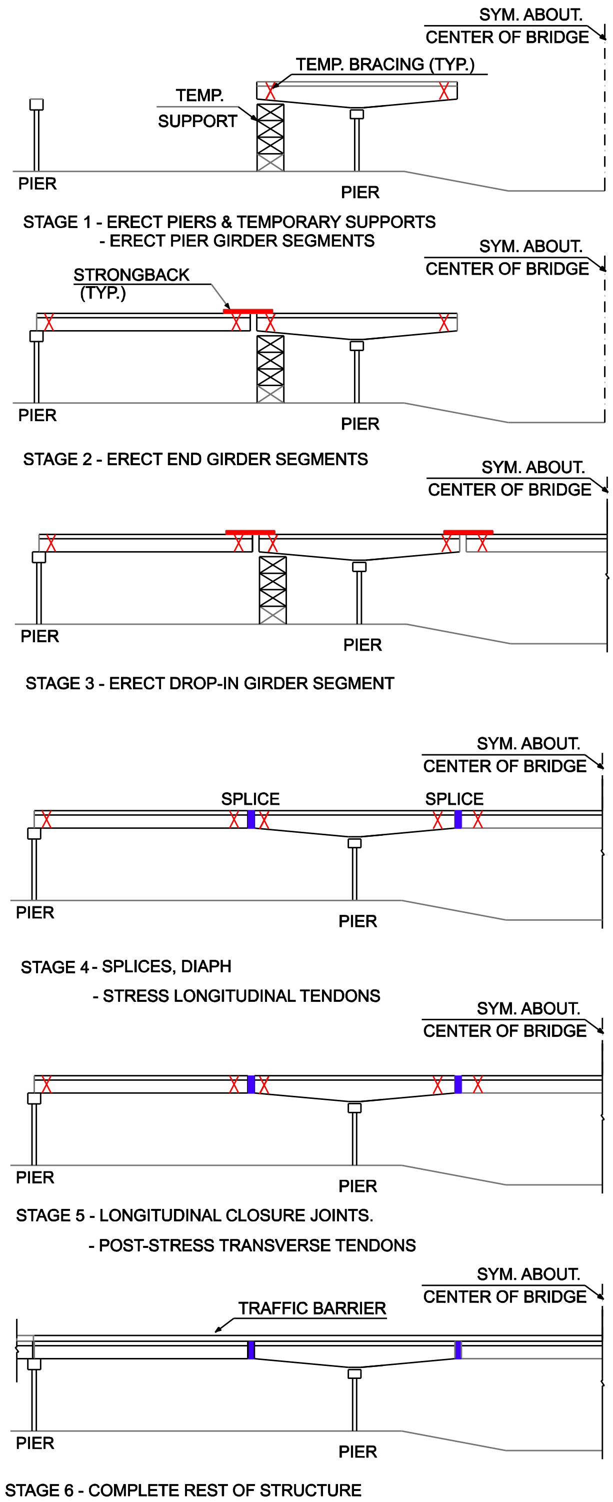


Fig. 7 Construction Sequence of a Three-Span Spliced-Deck Girder Bridge

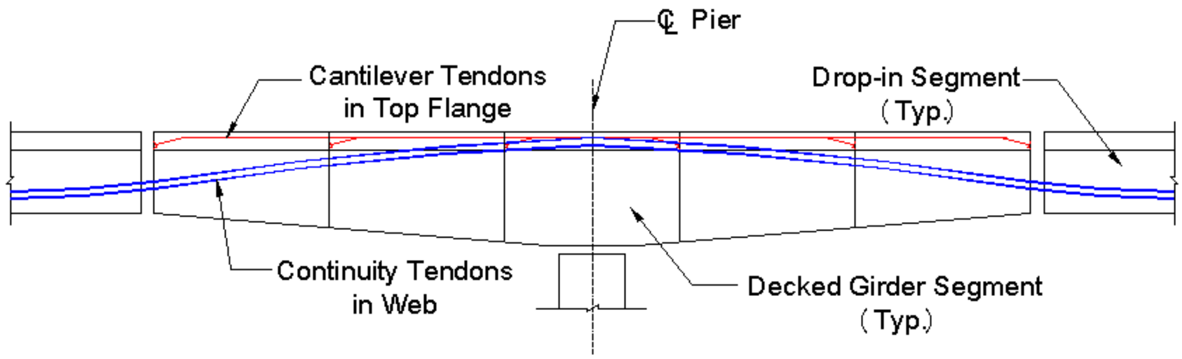


Fig. 8 Balanced Cantilever Construction of Spliced-deck Girder Segments near Piers

ADVANCED CONSTRUCTION MATERIAL

Advanced construction materials such as light-weight concrete, high-performance concrete and advanced grout material for longitudinal joints help improve the durability of the bridge and increase the bridge span length. High-performance concrete (HPC) is generally a type of concrete with improved efficiency, strength or durability. HPC can be used to extend the span of precast girders and improve the performance of spliced-deck girder bridges. In the following section the discussion will be limited to high-strength concrete and light-weight concrete.

HIGH-STRENGTH CONCRETE

High-strength concrete (HSC) refers to concrete that has a specified design compressive strength of at least 10 ksi. Today, concrete with a compressive strength of 10 ksi is widely available with a minor cost increase over regular concrete. High-strength concrete also has the advantage of a high modulus of elasticity and tensile strength. In addition, it almost always has a lower creep and shrinkage coefficient, along with a lower permeability, which improves the durability. With high-strength concrete, a higher level of prestressing can be achieved in the precast girders, which increases the girders' load capacity. This can be very useful to increase the span length of decked precast beams or to decrease the girder depth, provided there is sufficient space in the bottom flange of the beam to place the additional strands. A shallower superstructure may reduce the overall structure cost further due to reduced costs of walls and embankments.

LIGHTWEIGHT CONCRETE

Lightweight concrete (LWC) has a unit weight of 110 to 125 pounds per cubic foot and often has the added benefit of an improved durability. It could reduce the self-weight of a decked girder by as much as 15 to 20 percent. Pretensioned lightweight concrete beams can be used in spliced-girder applications to extend span lengths by reducing the superstructure dead load.

GROUT MATERIAL

Advanced grout materials such as magnesium ammonium phosphate mortars and polymer modified concretes exhibit superior bond strength, greater compressive strength and lower permeability[7,8]. These materials can be implemented to improve the long-term durability of longitudinal closure joints.

SUMMARY

This paper discussed the design and construction of spliced-deck girder bridges. The following conclusions are drawn from this paper:

1) Spliced-deck girder expedites the construction of the bridge by eliminating almost all forming and casting in the field.
2) Three types of longitudinal closure joints are being used in precast bridges. The selection of the type of longitudinal joint detail for a spliced-deck girder application should be based on specific project situations such as bridge locations, traffic situation, constructability and construction costs, etc.
3) Combining balanced cantilever construction and drop-in approaches help resolve issues related to large self-weight of decked girders and expand the length of spliced-deck girders.
4) The maximum span length of a spliced-deck girder bridge is anticipated to be between 210 and 250 ft. The bridge length of a spliced-decked girder is primarily limited by the relatively large self-weight.
5) Advanced construction materials help to increase the bridge length and enhance the bridge durability. These materials include high-strength concrete, light-weight concrete and durability-enhanced grouts.

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