New Development in Accelerated Bridge Construction in Washington State

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ABSTRACT

Precast concrete deck girders are preferred solution for projects where Accelerated Bridge Construction (ABC) is considered. The use of precast concrete superstructures results in speed of construction, while minimizing traffic disruption and environmental impact. Precast concrete superstructures are made with high performance/high strength concrete, and tend to be more durable, economical and cost competitive than other superstructure types.

The Washington State Department of Transportation (WSDOT) has developed new wide flange deck girders to accommodate accelerated bridge construction. The new wide flange deck girders could be fabricated using either normal weight or light weight aggregates concretes. Ultra-high performance concrete (UHPC) in lieu of the welded ties and grouted keys is considered for connection between girders to improve the performance of the connection between girders. This paper summarizes the development of new wide flange deck girders for accelerated bridge construction. Current WSDOT research project on the use of UHPC for precast concrete deck girders is presented.

Keywords: Precast, Wide Flange, Deck Girder, Connection, UHPC, ABC

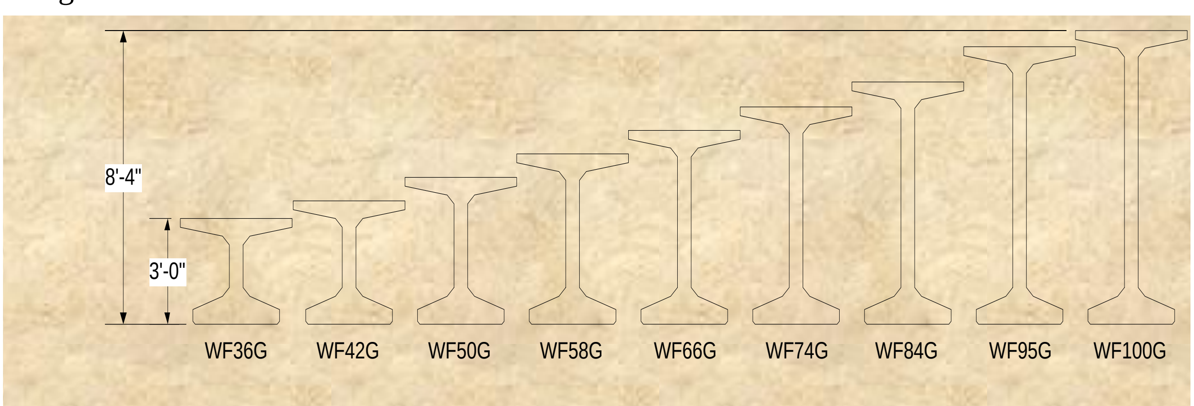
INTRODUCTION

The use of precast prestressed deck girders has the potential to produce higher quality, more durable bridge decks. However, the required connections often prove lacking, resulting in less than desirable overall system performance. Advanced cementitious composite materials, whose mechanical and durability properties far exceed those of conventional concretes, present an opportunity to significantly enhance the performance of field cast connections, thus facilitating the wider use of modular bridge deck systems. UHPC represents a class of such advanced cementitious composite materials. UHPC can significantly shorten the development length of embedded discrete steel reinforcement and can exhibit exceptional bond with previously cast concrete. These properties allow facilitating accelerated bridge construction and enhanced long term system performance.

The goal of the research is to investigate two possible approaches to successfully connecting the new wide flange deck girders. The research objectives include developing a UHPC mixture that depends on locally sourced materials, and to investigate subassemblies and then complete joints for stiffness and strength in bending. The subassemblies will be used to determine fundamental joint characteristics using a range of different details, to allow optimization of the joint details prior to testing the complete joint specimens.

WSDOT PRECAST PRETENSIONNED WIDE FLANGE GIRDERS

In Washington State, the use of prestressed I-girders started in the early 1950s. At that time, construction of highways and freeways was greatly accelerated under the Interstate Highway Program. The challenge was to quickly and cost effectively build grade separations at highway crossings. The economy, quality of fabrication, and ease in construction of pretensioned I-girder bridges met the challenge. Today, the majority of new highway bridges in Washington State are prestressed concrete girder bridges. The current WSDOT standard pretensioned I-girder designations are WF36G, WF42G, WF50G, WF58G, WF66G, WF74G, WF83G, WF95G, and WF100G are shown in Figure 1. The prestressed girders are desighed per AASHTO LRFD Bridge Design Specifications[1] as amended by the WSDOT Bridge Design Manual[2]. References 3 through 6 describe the WSDOT development, design, and construction of wide flange precast prestressed girders, and their advantages for accelerated bridge construction.



The new wide flange deck girders are designated as WF39DG, WF45DG, WF50DG, WF61DG, WF69DG, WF77DG, WF86DG, WF98DG, and WF103DG with girder depth varying from 39 to 103 inches. The new WSDOT standard prestressed concrete wide flange deck girders span up to 190 ft to 220 ft (depending to the top flange width) with conventional concrete mixes, and 220 ft to 255 with light weight concrete Girders[2]. The new girder cross sections vary both in width and depth to accommodate the desired span length and bridge width as shown in Figure 2.

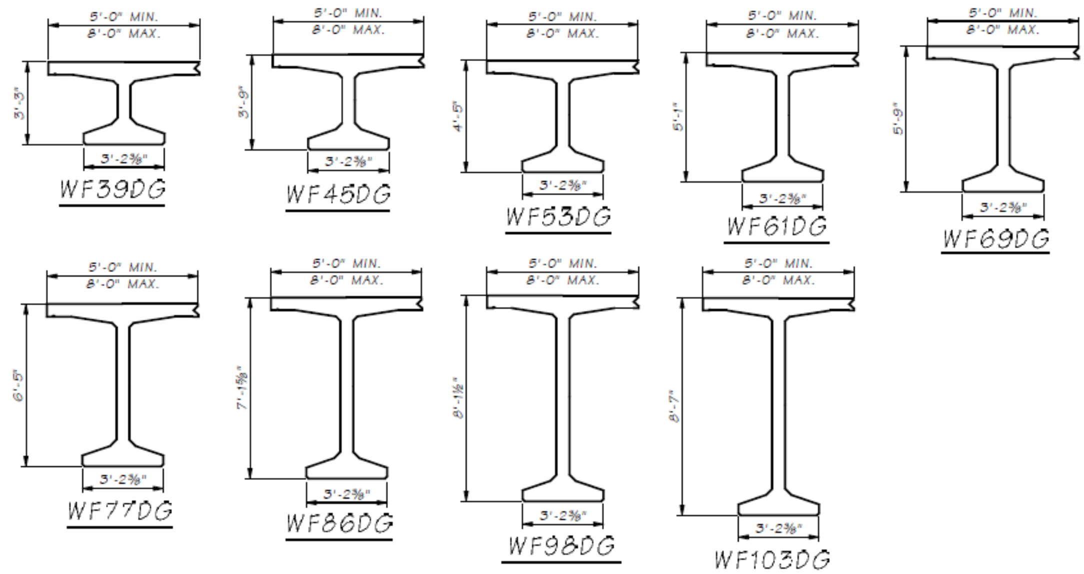


Figure 2. WSDOT Pretensioned Wide Flange Deck Girders.

The structural efficiency of wide flange deck girders are calculated using Guyon's equation[3]. Guyon's equation is based on the cross-sectional properties of the girder and is expressed as equation 1:

$$\rho = \frac{r^2}{y_b y_t} \qquad (1)$$

where ρ is the efficiency factor, y_t and y_b are the distance from the center of gravity of the section to the top and bottom fibers of the girder, respectively, and r is the radius of gyration of the cross section, and is equal to I/A_g. Higher ρ represents higher girder efficiency. On average, the girders with the wider flanges provide 20 percent more span capability than the current standards as shown in Figure 3. WSDOT standard deck girders are being phased out in favor of the new wide flange deck girders.

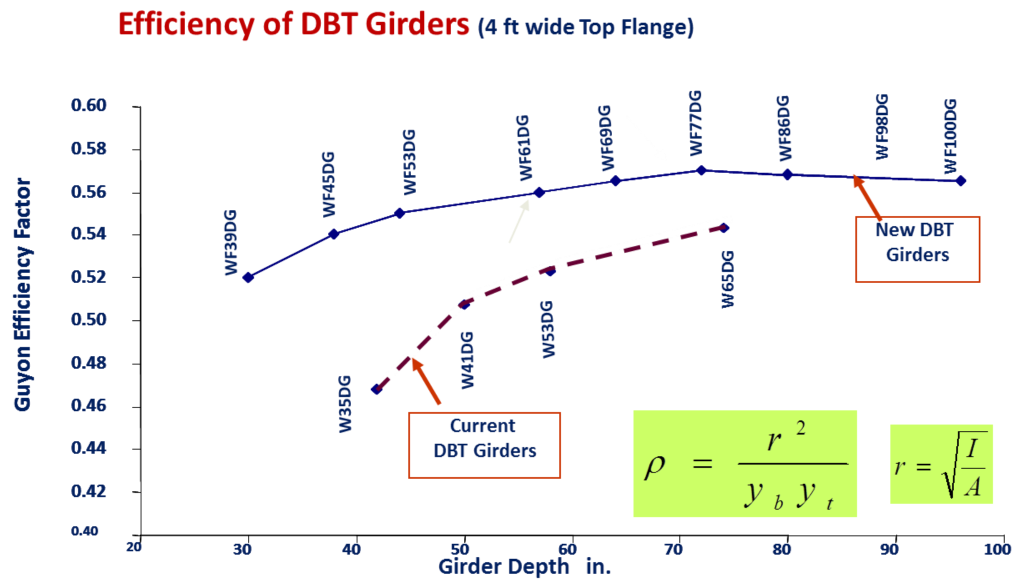


Figure 3: Efficiency of wide flange deck girder

Differential camber between the adjacent members is a challenge for use of long spans deck girders. The differential camber could be adjusted using leveling beams before casting concrete at the closures. A concrete overlay is recommended for deck girders to accommodate smooth riding surface and increased durability.

Pre-cambering is an option used for bridges with challenging profile grade, and to optimize the overlay requirement. This process has been used by Washington State precast concrete girder producers for many years. The formwork is either humped or sagged so that net camber is close to the required profile grade for the bridge.

Past WSDOT's standard connection between deck girder flanges consisted of welded plates at approximately 4 ft (1.2 m) on center in combination with a continuous grouted shear key. Although this detail had been used successfully on a multitude of projects, WSDOT was reluctant to employ it because of potential deterioration of the grout in the joint, reflective cracking in the overlay, and leakage through the deck girder flanges. Figure 4 shows the long-term performance issue, and the connection between deck girder flanges with two alternate details for welded ties.

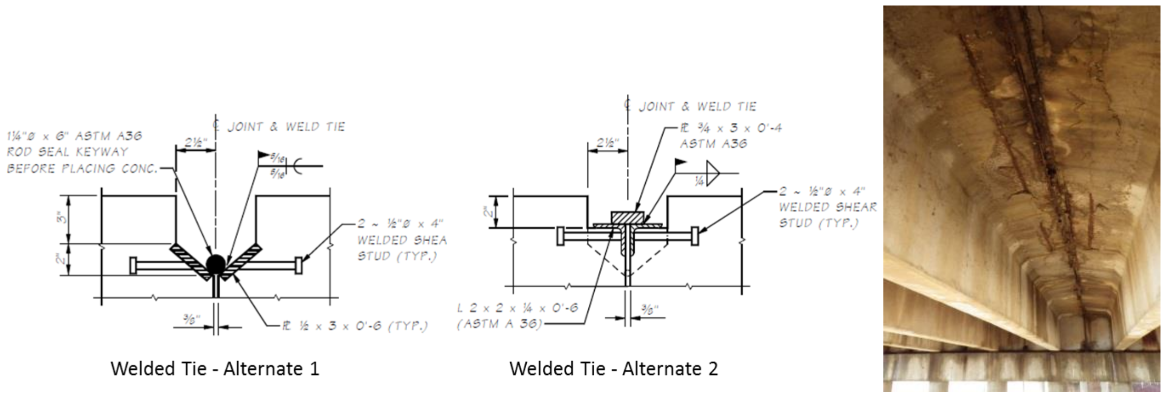


Figure 4: Connection of Deck Beam Elements

The new WSDOT standard wide flange girders require relatively narrow joints with short projecting non-contact lapping bars in combination with cast-in-place (CIP) UHPC closures as shown in Figure 5. The CIP closures with two layers of reinforcement have the design advantages of deck transverse continuity that results in design efficiencies. The UHPC connections had been successfully tested and used in other states. The availability of UHPC may be a challenge for some projects; in these cases a combination of headed bars and higher strength CIP concrete for the connections could be considered[7]. A wider CIP closure could also be used to eliminate the need for headed bars.

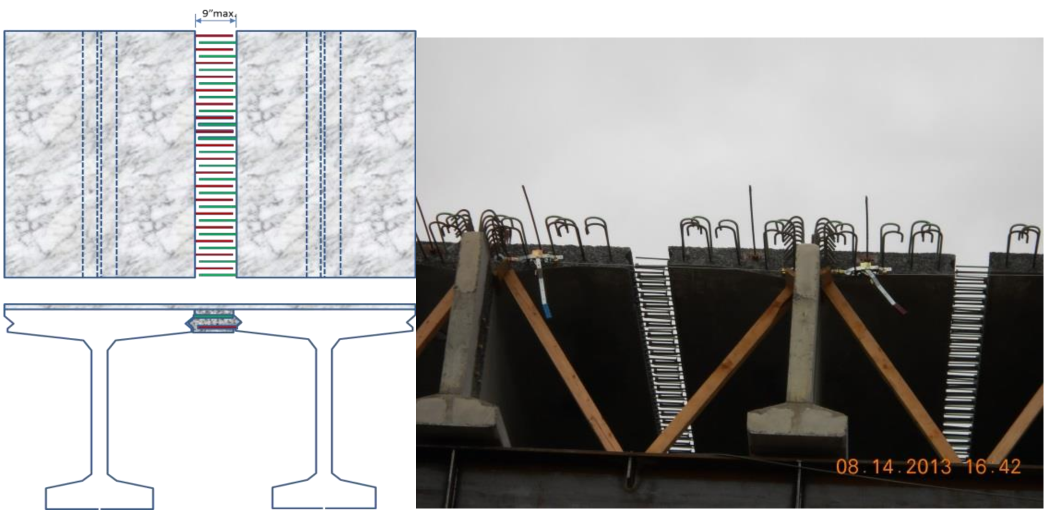


Figure 5. Deck Girder Joint with UHPC closure and non-contact splice

UHPC is a new generation of cementitious materials with very low water-to-cementitious materials ratios, higher compressive strengths and sustained tensile strength resulting from internal fiber reinforcement. UHPC contains no coarse aggregate, so it does not exhibit the early age micro-cracking common to conventional concrete. This, combined with the discontinuous pore structure in the homogeneous cementitious matrix, results in a concrete with an extremely low permeability[8]. A concrete overlay is recommended for deck girders and the UHPC longitudinal joints to improve the riding surface.

Tensile behavior of UHPC also stands in contrast to that of conventional concrete. The discrete steel fiber reinforcement included in UHPC components allows the concrete to maintain tensile capacity beyond cracking of the cementitious matrix. The inelastic straining of the component is resisted by fiber reinforcement that bridges the tight, closely spaced cracks. The mechanical properties of UHPC allow for the full development of non-contact embedded reinforcements in short distances of CIP closures.

PRESTRESSED GIRDER DESIGN CRITERIA

Current WSDOT design practice does not allow any tension in the pre-compressed tensile zone at the Service III limit state. Allowable stresses for prestressing strands are $0.75f_{pu}$ at transfer and $0.8f_{py}$ at the service limit state. Prestressed girders are designed using gross section properties. Transformed section properties may be used but the live load factor shall be taken 1.0 instead of 0.8 at Service III limit state. The allowable tensile stress at Service III limit state is limited to zero ksi. The continuity Policy requires that girders are designed as simple span for all dead load and live load regardless of the actual continuity at intermediate piers. Refined method of estimating prestress losses is used for prestressed girder design and all girders are designed for future overlay.
WSDOT design policy for prestressed girders and decked members has resulted in more durable prestressed girder superstructures. Some of the reasons for the conservative design policies are:

a) Periodical change in Bridge Design specifications. AASHTO design specifications have been changed from allowable stress design (ASD) to (LFD) and to (LRFD).
b) Reserve capacity for girders damaged by over height collisions[9]. The over height load collisions on prestressed girder bridges often results in broken/spliced strands.
c) The zero tension policy ensures that prestressed girders remain uncracked under service load conditions and overloads, resulting in longer service life.
d) Increased shear capacity. Increase in prestressing results in higher shear capacity, with lower θ and higher β.
e) The conservative design assumptions result in longer service life and lesser life cycle cost.
f) Designing for future overlay reduces concerns if bridges are overlaid during their service life.

SHIPPING, HANDLING, AND LATERAL STABILITY

WSDOT specifies the use of temporary top strands to improve the stability of long slender girders during handling and shipping. These strands are either pretensioned along with the permanent strands or are post-tensioned sometime after the forms are stripped. The choice of pretensioning or post-tensioning is left to the manufacturer, depending on the production scheme to be used. Pretensioned temporary strands are bonded within the end 10 ft of the girder only, and are unbonded throughout the remainder of the girder length. Post-tensioned temporary strands are anchored with mono-strand anchor plates at one end, are bonded within 10 ft of the other end, and are unbonded elsewhere[2].

The introduction of temporary strands to the top flange also has beneficial effects on the design of prestressed girders. The temporary top strands reduce the instantaneous deflection and long-term camber, which results in a reduction of the volume of concrete required for the cast-in-place deck haunches. These strands are cut after placement of girders.

CONNECTION OF PRECAST GIRDERS AT INTERMEDIATE PIERS

Connections in precast concrete substructures are typically made at the beam-column and column-foundation interfaces to facilitate fabrication and transportation. However, for structures in seismic regions, those interfaces represent locations of high moments and shears and large inelastic cyclic strain reversals. Devising connections that can accommodate inelastic cyclic deformations and are readily constructible is the primary challenge for ABC in seismic regions. The seismic design of WSDOT bridges are per AASHTO Guide Specifications for LRFD Seismic Bridge Design[10] and use of precast members in accelerated bridge construction in seismic regions are described in references 11 and 12.

Fixed integral diaphragms (moment resisting) are used at the intermediate piers of continuous prestressed girder bridges located in the higher seismic zones. In this case, prestressing strands projecting from the bottom flange of the girder are anchored into the diaphragm, developing the positive moments necessary for plastic hinging in the tops of the columns. Figure 6 shows WSDOT standard details for the fixed integral diaphragm[2].

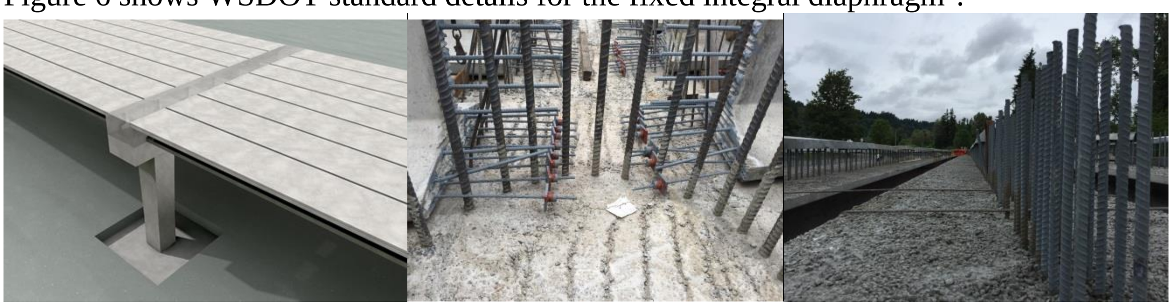


Figure 6. Semi-raised fixed integral diaphragm

CURRENT RESEARCH ON CONNECTION OF DECK GIRDER USING UHPC

The goal of the research is to investigate ways of connecting the flanges of adjacent deck girders. The research will combine two parallel thrusts. The first is to develop a UHPC mixture that depends on locally sourced materials. The second is to investigate subassemblies and then complete joints for stiffness and strength in bending. The subassemblies will be used to determine fundamental joint characteristics using a range of different details, to allow optimization of the joint details prior to testing the complete joint specimens.

The maximum joint width is to be 9” (with 7” bar projections from either girders), and smaller joints are preferred. Bars projecting from the flanges will be offset to avoid conflicts during erection, so the lap splices between them will necessarily be non-contact splices.

Under these circumstances, the use of larger bars at larger spacing exacerbates the effect of the non-contact characteristic of the splice.
Bond capacity tests using pullout specimens with a range of embedded lengths will be conducted on No 5 and No 6 epoxy-coated bars. The goal is to determine the lengths of embedment in UHPC needed to develop yield and fracture in the bars.

CONCLUSIONS

Precast concrete deck girders could advantageously be used for projects where Accelerated Bridge Construction (ABC) is considered. The use of precast concrete superstructures results in speed of construction, while minimizing traffic disruption and environmental impact. Precast concrete superstructures are made with high performance/high strength concrete, and tend to be more durable, economical and cost competitive than other superstructure types.

The Washington State Department of Transportation (WSDOT) has developed new wide flange deck girders to accommodate accelerated bridge construction. The new wide flange deck girders could be fabricated using either normal weight or light weight aggregates concretes. UHPC connection in lieu of the welded ties and grouted keys is considered for connection between girders to improve the performance of the connection between girders.

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