Scientific Research

Deck Bulb Tee Girder Bridge Problems and Applications

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Abstract: Accelerated Bridge Construction (ABC) has led to the widespread adoption of Deck Bulb Tee girder (DBT) in bridge engineering. Nevertheless, the use of DBT girders in large-span and intercontinental bridges remains restricted due to structural design limitations and material constraints, resulting in joint issues and affecting structural performance. Therefore, this paper aims to summarize typical technical improvements in the structural design of DBT girders, including addressing longitudinal joints issue and exploring the use of Ultra-High Performance Concrete (UHPC) for bridge applications. The results indicate that application of UHPC effectively addresses several technical challenges associated with DBT girders, presenting both new opportunities and challenges.

Keywords: Accelerated Bridge Construction; connection details; existing bridge replacement; UHPC overlay

1 Introduction

DBT girder refers to a bulb tee girder with a top flange designed to support traffic loads and be mechanically connected at the flange edges to adjacent girders in the field. It was developed in the late 1950s. DBT girder is also called as side-by-side bulb tee girder, as shown in Figure 1. It combines the advantages of I-beam and precast slab decks, reducing the use of concrete and steel materials, thereby saving material and time costs.

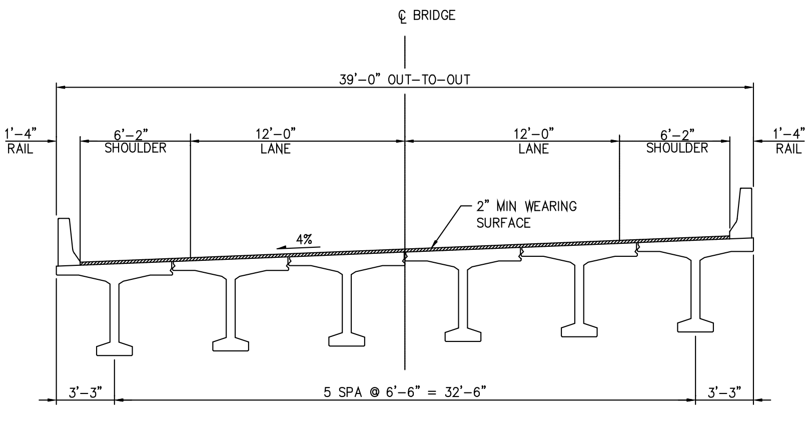

Figure 1 Typical Section of Deck Bulb Tee Girder Bridges

The DBT girder is mostly used for single-span bridges. Although it is occasionally used for multi-span bridges, for spans longer than 100 ft, the cross-section becomes uneconomical. However, post-tensioned bulb-tee girders provide an extremely cost-effective structural system for bridge construction. The use of high-performance materials promises longer spans, up to 320 feet, offering greater economy and applicability.

The primary advantage to using DBT girder is to accelerate bridge construction. In most cases, a concrete deck is not required, and only 2-inch minimum wearing

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surface is applied to the top of girders, eliminating the time needed for maintenance of concrete bridge deck. DBT girder were widely used in Northwest isolated region of the United States in 1960s, and several states gradually developed their own standard girder products. Particularly, in cold region where construction season is short, cast-in-place concrete deck can be expensive. The use of DBT girders becomes a good option to consider. This is also true for fast-track projects where construction schedule is a primary concern. With the improvement of design theory and construction technology, this engineering application has been further developed, leading reduced environmental impact, shortened construction periods, and improved efficiency. ABC technologies have been gradually gaining popularity among numerous Departments of Transportation in the United States, indicating a growing trend toward their adoption and optimization.

Over the years, despite these advantages, DBT girders have primarily been used on roads that carry low traffic, such as county roads with single and short-span bridges. They cannot be used in long-span bridges such as interstate bridges. Thus, the problems with long term performance of longitudinal joints using old connection techniques and the implementation of Ultra-High Performance Concrete (UHPC) in longitudinal joints, state practice details, and deck overlays will be reviewed in this paper.

2 Connections

The primary function of connections in service is to transfer shear forces between adjacent precast members, enabling the lateral distribution of concentrated wheel loads to several members can occur [1]. However, guidelines for the design of joint connections before the 1980s were not provided in the AASHTO Standard Specification for Highway Bridges. Traditional connectors were typically spaced about 4 ft to 8 ft apart and 2 inch thick, connecting the precast units. Unfortunately, they could not help control flexural cracks. Subsequently, Stanton, J. et al. provided a summary of the practice, and studied the mechanical behavior of the connection. They concluded that the strength of the grouted joint is governed by inclined cracking at the tips of the member flanges [1]. According to their research, the joint can be improved by increasing the thickness of the flange concrete and optimizing keyway geometry. Two typical connections are illustrated in Figure 2.

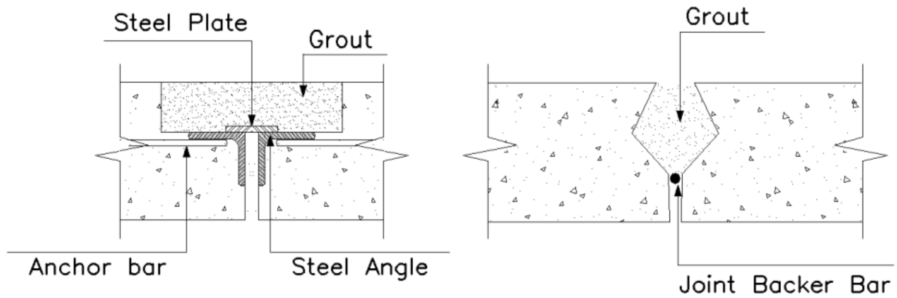


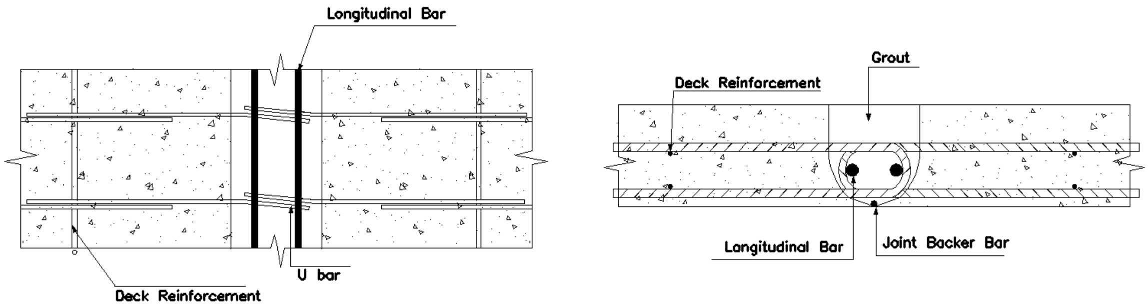
Figure 2 (a) Typical welded steel connection (b) Typical grouted shear key

Due to the impact of cracks on the performance of DBT bridges, authorities in Washington state have imposed certain restrictions on their use [2]. To address these issues, engineers have made further improvements for the joint details and proposed several new connections. The following are some effective techniques for improving mechanical performance.

(1) Replacing traditional connectors with distributed reinforcement or different shape.
(2) Improving joints with spliced headed bar details.
(3) The application of new materials.

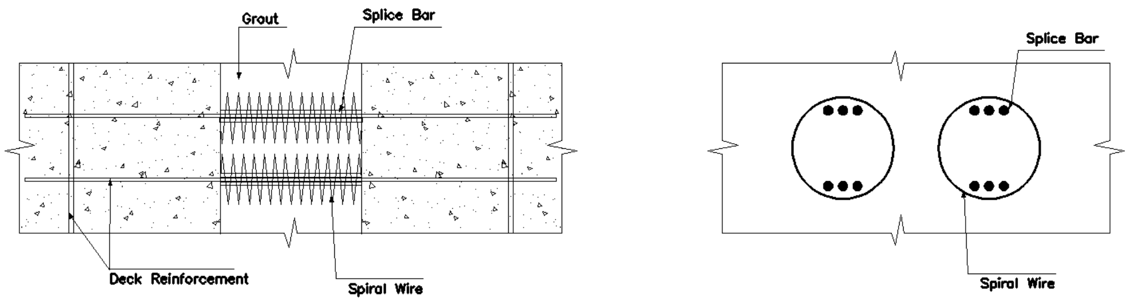
2.1 Distributed and Different Shape Reinforcement

Regarding the first approach above, distributed reinforcement serves not only for shear transfer between adjacent girders but also for moment transfer, making it more effective in controlling cracks compared to traditional connectors. It was only through the dependence on wider joints that they could capitalize on the force, and the ACI committee provided equations for these calculation in the 2005s [3]. However, straight lap-spliced reinforcement requires a much wider joint to develop its strength, which does not facilitate accelerated construction [2]. Another way is to change the shape of the bar, such as a U bar, a head-end bar, and a spiral bar, which can also help to control the crack. However, the U-bar and spiral bars seem to be less straightforward to assemble in the field and may not match perfectly with the other girders. Additionally, the crowded joint space during concrete pouring can result in poor compaction, affecting concrete quality potentially causing additional construction issues [2-6]. Two typical welded and spiral connections are illustrated in Figure 3 and Figure 4.



(a) Top view (b) Elevation plan

Figure 3 U bar longitudinal joint detail



(a) Top view (b) Elevation plan

Figure 4 Spiral bar longitudinal joint detail

2.2 Spliced Headed Bar Details

The desirable joint details for deck bulb tee bridges should have the following characteristics: firstly, they should be full strength joints capable of transferring internal forces such as moment, shear and tension between the girders, with a ductile rather than a brittle failure mode. Secondly, the width of the joint should be minimized to allow accelerated construction [2].

Lungui Li et al. proposed and tested the joint details, evaluating their performance based on flexural capacity, curvature at failure, cracking, deflection, and steel strain. They recommended replacing the current welded steel connector detail. The results indicate that the new joint details are effective in controlling joint cracking and maintaining the accelerated construction features of DBT bridges [7], and joint detail is illustrated in Figure 5.

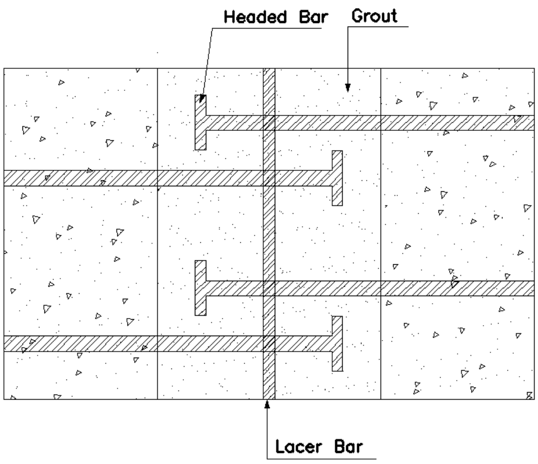


Figure 5 Headed bar longitudinal joint detail

According to the characteristics of DBT bridge: the precast deck is typically thinner. Zhiqi He et al. optimized and tested U-bar joint details, comparing them with traditional joints that use a smaller radius (3db bending diameter), significantly less than the previously suggested value of 8db. In order to reduce the lap length and thickness of precast deck, the high ductility connector was embedded in joint. Moreover, lacer bars were added to enhance the confined compressive strength of concrete. The joint detail is illustrated in Figure 6. The results show that: lacer bars play an irreplaceable role in preventing structural failure, and the joint's bearing capacity is proportional to concrete strength and overlap length. When the U-bar spacing is twice the overlap length, the capacity reaches its maximum value [7].

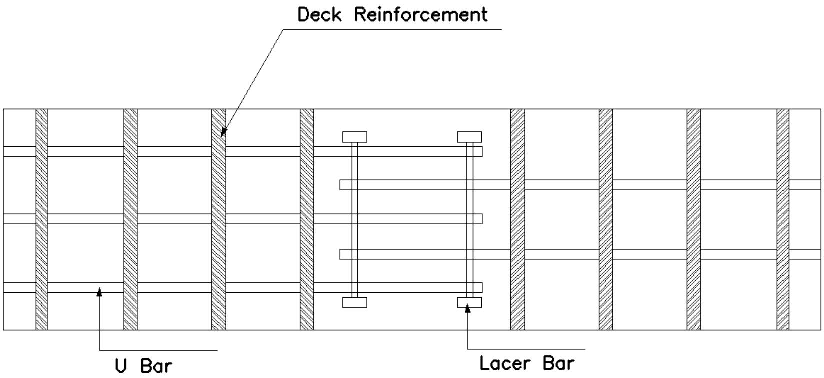


Figure 6 U bar with lacer bar reinforcement joint detail

These optimized connections in DBT bridge have proven adequate resistance under light loads, however, joint is still the weakest part of the beam. Cracks still developed under the action of heavy truck loads.

2.3 The Application of New Materials

In recent years, there have been many new materials used in bridge construction, with high-strength grout and UHPC being commonly employed as filed-cast connection materials. Currently, UHPC has been utilized in over 1,000 bridges around the world, with about 300 bridges of them utilizing UHPC in their main structure. The material has gained increasing popularity due to its low permeability, superior bonding properties, long-term durability, and significantly higher compressive and tensile strength compared to traditional concrete [7]. ABC advantages include high early strength, relatively small joint sizes and simple details, as well as suitable material. Combined, these factors can significantly reduce bridge construction time. Therefore,

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utilizing UHPC as a material for joint connections in DBT bridges is a favorable choice.

At the initial stage of beam utilization, the original joint characteristics are retained. Hooked steel reinforcement dowels, which overlap with adjacent girder dowels, are cast in a flange with UHPC. The closure connection measures approximately 6 inches in width, and a typical connection is illustrated in Figure 7.

Figure 7 Hooked steel reinforcement dowel between flanges

A more recent approach is to fabricate the joint from UHPC. Reinforcing bars extend laterally from the flanges and are spliced into the UHPC longitudinal joint. The bars can be straight, the splice can be short and the joint can be narrow, even with epoxy coated bars, simplifying the formwork and reducing costs [9-12]. Tim Peruchini utilized ABAQUS analysis software to assess the joint's functionality under minimum wheel loads. The findings indicate that the joint would initially fail in shear, rather than bending, at a deck height of 150mm (6 inches) [14]. Therefore, shear strength was used as a guide for study.

As an alternative to UHPC, high-early-strength (HES) concrete with polypropylene fibers is also a well option, which is little expansive than traditional concrete. Arya Ebrahimpour et al. conducted experiments on the optimized concrete mixture and implemented it in a practical bridge program. The closure connection measures 10 inches in width and provides optimal conditions for efficient construction. Moreover, according to data provided by ITD, the cost of HES concrete is lower than UHPC by approximately \$15000/m^3. Over a period of 20 months of monitoring, the material exhibited equivalent efficacy in accelerating construction processes and demonstrated favorable properties [15].

3 DBT Girder Bridge and UHPC Practice

3.1 State Practice Details

3.1.1 Oregon Practice

Oregon started using Deck Bulb Tee girder bridges about 50 years ago. DBT girder bridges are typically used for single span, low-volume traffic routes and non-interstate routes. For interstate routes and routes with 20-year projected ADTT > 1000, a minimum 7-1/4″ high performance concrete cast-in-place deck is required. Because of this requirement, DBT girder is generally used only on low-volume routes [16].

Currently, ODOT bridge drawings provide standard DBT girder details for 3′-0″, 3′-9″, 4′-6″ and 5′-0″ deep girders [17]. The top flange width varies from 5′-0″ to 8′-6″. The minimum top flange thickness is 6 inches. The end view and mid-span section are shown in Figure 8 and Figure 9 respectively.

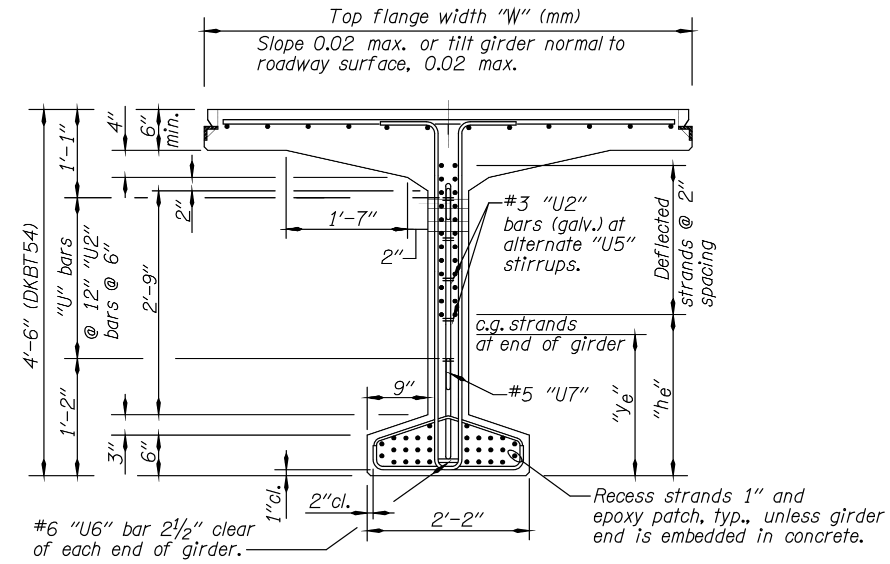


Figure 8 Girder end view (ODOT)

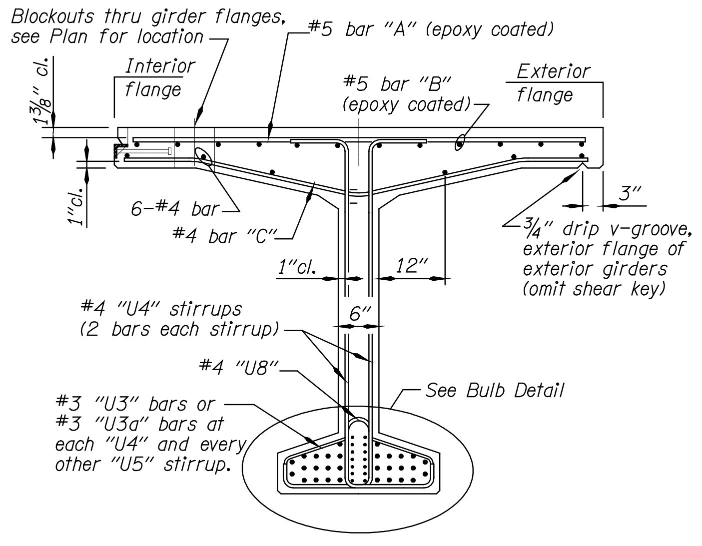


Figure 9 Girder mid-span section (ODOT)

The concrete pour sequence for DBT girder is shown in Fig. 10. The maximum concrete strength for top flange is 6000 psi. This limitation is required to ensure adequate air entrainment and adequate workability. Higher strength concretes are generally less workable and therefore are more difficult to achieve an acceptable finish suitable for a riding surface. The maximum concrete strength for web and bottom flange is 9000 psi [16]. For concrete mix design, entrained air shall be 4% - 7% for top flange concrete. Entrained air is not required for web and bottom flange [18].

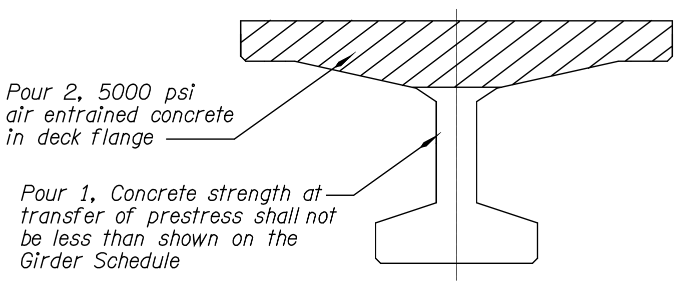


Figure 10 Concrete pour sequence (ODOT)

The flange shear connector details are shown in Figure 11. The typical shear keys are spaced at 5′-0″ and the maximum distance from the first shear key to the end of girder is 7′-6″.

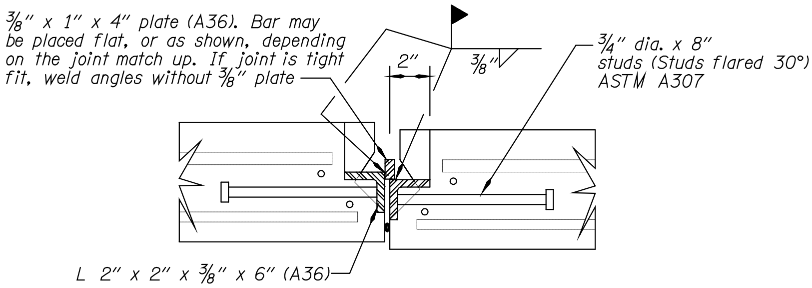


Figure 11 Flange shear connector (ODOT)

3.1.2 Oregon Practice

Idaho started using DBT girder about 50 years ago History of DBT girders in Idaho.

Currently, Idaho Transportation Department (ITD) bridge standard drawings provide standard Deck Bulb Tee girder details for 3′-1″ thru 6′-0″ deep girders. The maximum top flange width is 7′-0″ or 8′-0″ depending on the fabricators. The top flange thickness is 8 inches. The end view and mid-span section are shown in Figure 12 and Figure 13 respectively. For concrete mix design, entrained air shall be 5% with 1% tolerance.

The weld tie connection details are shown in Figure 14. The weld tie connection is spaced at maximum of 5′-0″ and the maximum space at the end of girder is 3′-6″. The equalizing equipment should be used to equalize the girder camber before installing weld tie connections.

ITD specifies the construction sequence as follows:

(1) Erect girders and install temporary bracing;
(2) Equalize girder camber, install weld tie connections (minimum of 3), release equalizing equipment, move equalizing equipment to the next location, and repeat this step as needed;
(3) Install all remaining weld tie connections;
(4) After all weld tie connections have been installed, the following activities may proceed at the contractor's discretion: grout shear key, cast intermediate diaphragms, and cast end diaphragms;
(5) Remove temporary bracing.

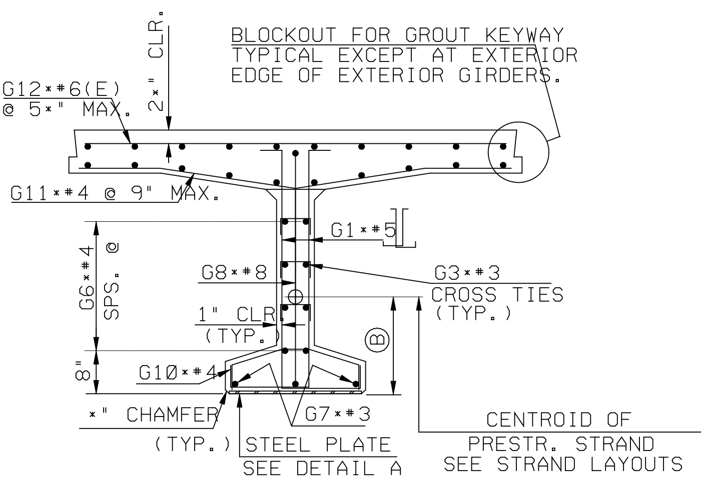


Figure 12 Girder end view (ITD)

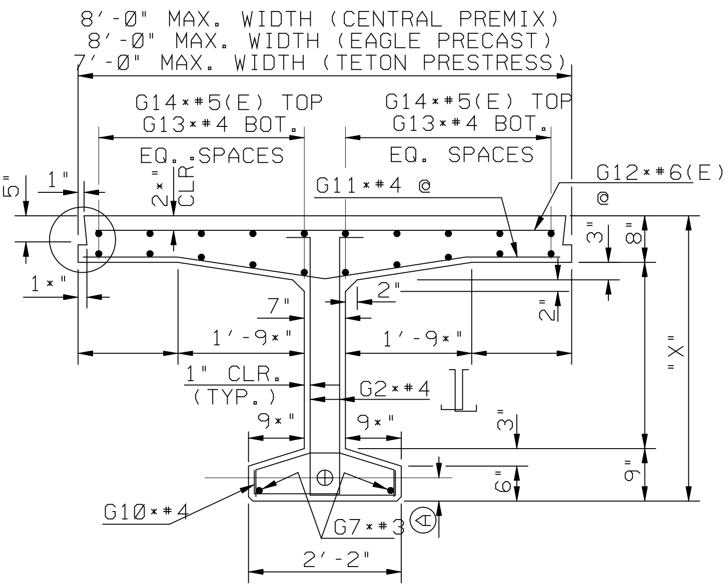


Figure 13 Girder mid-span section (ITD)

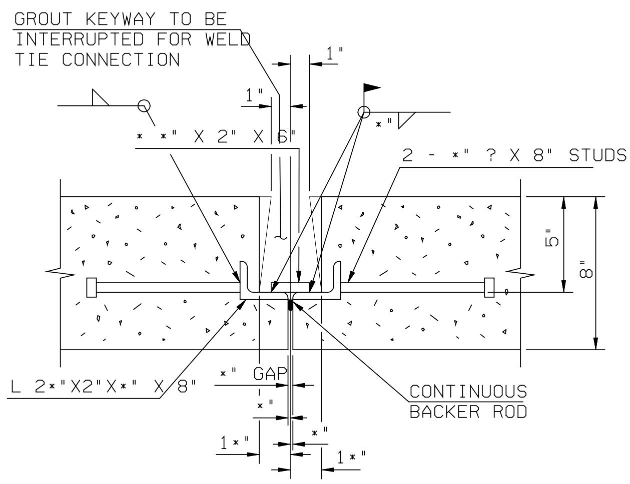


Figure 14 Weld tie connection (ITD)

3.1.3 Design and Construction Issue

During bridge type study, the following factors should be taken into consideration to select Deck Bulb Tee girder:

(1) Excessive asphalt concrete wearing surface (ACWS) built-up at abutments and piers would occur for sagged vertical curves. This is also true if cast-in-place concrete deck is used;

(2) Due to much wider and thicker top flange, DBT girder is much heavier than Bulb Tee girder. Shipping requirements such as girder weights, girder length and girder stability should be consulted with local fabricators;

(3) If the bridge is constructed in stages, temporary barrier attachment to top flange during staged construction should be investigated. In order to meet FHWA requirements for crash tested temporary rail attachments, it is likely to place the anchors thru top flange to prevent temporary barrier from sliding and overturning. In this case, neither drilling holes into top flange in the field nor providing blockout for the holes in the shop are good options. According to Oregon Bridge Design and Drafting Manual [1], restraints will not be required if the barrier can

be displaced 3 feet or more away from the traffic side without infringing with a traffic lane, a work area, or beyond the edge of the deck.

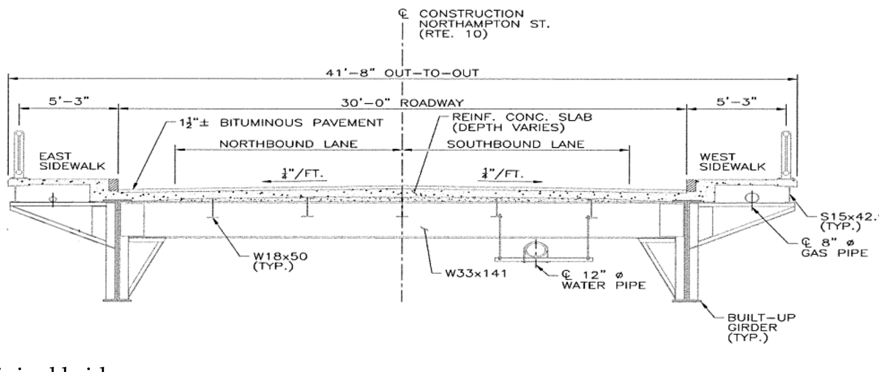
Deck Bulb Tee girder design is similar to Bulb Tee girder design, except when AASHTO LRFD is used for skew bridges. The correction factor for load distribution factors for support shear of the obtuse corner is not defined for DBT girder bridges. Therefore, either refined methods of analysis or engineering judgment should be used to magnify support shear of the obtuse corner.

In Oregon, lower concrete strength is used for top flange and higher concrete strength for web and bottom flange. Typical prestressed concrete girder design programs may not have the capability to handle the different concrete strengths. Therefore, the transformed section shall be use to evaluate stresses and camber at transfer of prestress, and stresses and deflections under full-service loading. The stresses reported in the top of the girder shall be multiplied by the appropriate modular ratio. For strength computations, the lower concrete strength is used for flexural analysis and the higher concrete strength for shear analysis. The gross section properties should be used strength computations.

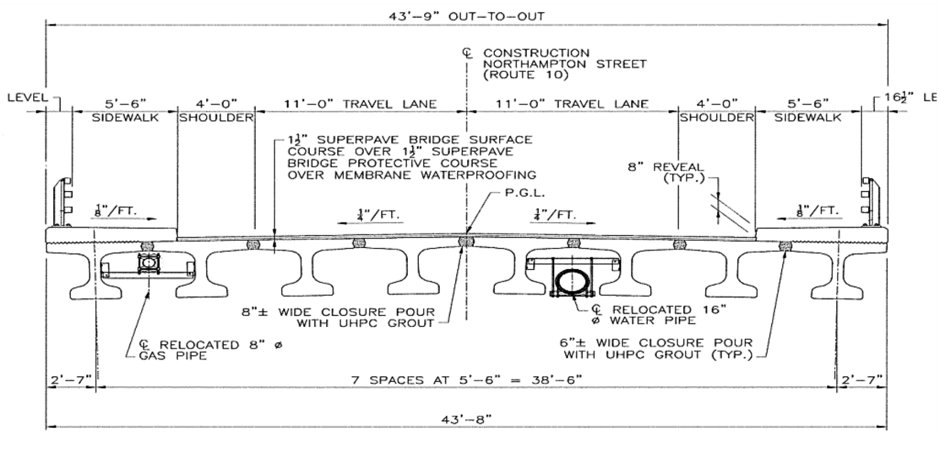
3.2 UHPC Practice

3.2.1 Existing Bridge Replacement

This structure used DBT girders to replace the existing bridge, in addition UHPC grouting for joint closure. The renovation of the bridge was scheduled to be completed in six months. In fact, it was completed one month ahead of schedule. The replacement information is shown in Fig. 15. The renovation of the bridge was on the same foundation, the bridge superstructure consists of 8 precast DBT beams, 8″ wide between two Tee beams. The roadway width is 30′-0″ from curb to curb with two 11′-0″ travel lanes and two 4′-0″ shoulders on either side with 5′-6″ sidewalk on the east and west side of the bridge.



(a) Original bridge



(b) Replacement bridge

Figure 15 Bridge replacement information

3.2.2 UHPC Overlay

Issues such as damage and wear are frequently encountered in the context of practical bridge deck maintenance. To address these problems, one of the most common approaches is to make use of an overlay for repair purposes. However, when using UHPC as an overlay material, there are some certain considerations should come into play:

(1) Inherent property may potentially result in uneven application, especially on bridge decks with irregular surfaces [22, 23].

(2) Implementing UHPC as a paving layer material entails higher expenses compared to traditional options.

(3) Requires the involvement of highly specialized technicians, contributing to significant additional costs.

For example, Non-proprietary UHPC and proprietary UHPC with about one inch overlay thickness will cost 6 and 18 $\$/f_t^2$ respectively (material cost only). Notwithstanding these challenges, UHPC remains the preferred choice for bridge deck overlays. In particular, UHPC has excellent bonding properties when properly bonded to the existing concrete deck after appropriate surface treatment. This robust bond ensures a high-strength bond between the two materials, a critical aspect of bridge deck wearing courses. Ben Graybeal used microstructural analysis to determine the reason, finding that UHPC has a high density, which results in a high degree of direct contact between the UHPC and the concrete surface, resulting in a high tensile strength of the interface [22].

4 Conclusions

The advantage of using DBT girder bridges is to speed up superstructure design and construction. This is especially true when traffic volume is low and cast-in-placed deck is not required.

DBT girders are preferred for single span, straight bridges. When used in continuous spans, special details at pier diaphragms must be considered during bridge type selection process.

In most cases, DBT girders has lower construction costs than I-girders, Bulb Tee girders and adjacent box beams.

UHPC has been preferred choice for addressing longitudinal joint problems. It is possible to reduce the reinforcement construction details and the width of the joint at the joints. Moreover, using UHPC as deck layer has shown superior performance compared to other materials in maintaining old and deteriorating bridge decks.

References

1. Stanton, J.F.; Mattock, A.H. *Load Distribution and Connection Design for Precast Stemmed Multibeam Bridge Superstructures*; No. 287; Transportation Research Board, National Research Council: Washington, D.C, 1986.
2. Li, L.; Ma, R.; Griffey, R.E.; Oesterle, R.G. Improved Longitudinal Joint Details in Decked Bulb Tees for Accelerated Bridge Construction: Concept Development. *Journal of Bridge Engineering* **2010**, *15*, 327-336, doi:10.1061/(ASCE)BE.1943-5592.0000067.
3. 318, A.C. Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05). *American Concrete Institute* **2004**.
4. Lewis, S. Experimental Investigation of Precast Bridge Deck Joints with U-bar and Headed Bar Joint Details. University of Tennessee Knoxville, 2009.
5. Ma, Z.J.; Lewis, S.; Cao, Q.; He, Z.; Burdette, E.G.; French, C.E.W. Transverse Joint Details withTight Bend Diameter U-Bars for Accelerated Bridge Construction. *American Society of Civil Engineers (ASCE)* **2012**.
6. Ma, Z.J.; Cao, Q.; Chapman, C.E.; Burdette, E.G.; French, C.E.W. Longitudinal Joint Details with Tight Bend Diameter U-Bars. *Aci Structural Journal* **2012**, *109*, 815-824.
7. Li, L.G.; He, Z.Q.; Ma, Z.J.; Yao, L.K. Development of Strut-and-Tie Model and Design Guidelines for Improved Joint in Decked Bulb-Tee Bridge. *Struct Eng Mech* **2013**, *48*, 221-239, doi:10.12989/sem.2013.48.2.221.

8. Alkhalaf, A.M. Experimental Investigation of Ultra-High Performance Concrete for Precast Decked Bulb-Tee Bridge Girder Connections. M.S., University of Colorado at Denver, United States - Colorado, 2018.
9. Varga, I.D.l.; Haber, Z.B.; Graybeal, B.A. *Bond of Field-Cast Grouts to Precast Concrete Elements*; FHWA-HRT-16-081; Federal Highway Administration: Washington, D.C: FHWA, 2017.
10. Graybeal, B.A. *Design and Construction of Field-Cast UHPC Connections*; FHWA-HRT-14-084; Federal Highway Administration Research and Technology: Washington, D.C: FHWA, 2019.
11. Haber; Zachary, B.; Graybeal; Benjamin, A. Lap-Spliced Rebar Connections with UHPC Closures. *Journal of Bridge Engineering* **2018**.
12. Peruchini, T.; Stanton, J.; Calvi, P. Longitudinal Joints between Deck Bulb Tee Girders Made with Nonproprietary Ultra-High-Performance Concrete. *Journal of Bridge Engineering* **2021**, 26.
13. Haroon; Hamid, A.; Steinberg, W.; Walsh, E.; Miller, K.; Shahrooz, R.; Bahram. Investigating UHPC in Deck Bulb-Tee Girder Connections, Part 1: Analytical Investigation. *PCI Journal* **2023**, *68*, 62-78, doi:10.15554/pcij68.3-04.
14. Ronald, H.D. Design and Construction Considerations for Continuous Post-Tensioned Bulb-Tee Girder Bridges. *PCI Journal* **2001**, *46*, 44-66.
15. Ebrahimpour, A.; Shokrgozar, A.; Mashal, M. Field Performance of High-Early-Strength Concrete with Polypropylene Fibers as a Cost-Effective Alternative for Longitudinal Connection Between Bridge Deck Bulb-T Girders. *J Perform Constr Fac* **2023**, *37*.
16. Oregon Department of Transportation. Bridge Design and Drafting Manual 2004. Available online: http://www.oregon.gov/ODOT/HWY/BRIDGE/docs/BDDM/apr-2007_finals/pdf/section_1-2004_apr07.pdf (accessed on July 29, 2007).
17. Oregon Department of Transportation. Bridge Standard Details. Available online: http://www.oregon.gov/ODOT/HWY/ENGSERVICES/details_bridge.shtml#Prestressed_Beams (accessed on July 29, 2007).
18. Oregon Department of Transportation. Oregon Standard Specification for Construction. Available online: http://www.oregon.gov/ODOT/HWY/SPECS/2002_std_specs.shtml (accessed on July 29, 2007).
19. Idaho Transportation Department. Bridge Design LRFD Manual. Available online: http://itd.idaho.gov/bridge/manual/manualcover.htm (accessed on July 29, 2007).
20. Washington State Department of Transportation. Bridge Design Manual LRFD. Available online: http://www.wsdot.wa.gov/fasc/EngineeringPublications/BDMManual/chapter05.pdf (accessed on July 29, 2007).
21. American Association of State, H.; Transportation, O.; Olympia. *AASHTO LRFD Bridge Design Specifications*, 4th Edition ed.; American Association of State Highway and Transportation Officials (AASHTO): Washington, DC, 2007.
22. Haber, Z.B.; Graybeal, B.A. *Field Testing of an Ultra-High Performance Concrete Overlay*; FHWA-HRT-17-096; Federal Highway Administration Research and Technology: 2017.
23. Haber, Z.B.; Muñoz, J.F.; Varga, I.D.l.; Graybeal, B.A. *Ultra-High Performance Concrete for Bridge Deck Overlays*; FHWA-HRT-17-097; Federal Highway Administration: 2018.

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