

## **CONNECTING PRECAST PRESTRESSED CONCRETE BRIDGE DECK PANELS WITH ULTRA HIGH PERFORMANCE CONCRETE**

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### **ABSTRACT**

*The Oregon Department of Transportation (ODOT) will use Ultra High Performance Concrete (UHPC) to connect High Performance Concrete (HPC) precast prestressed deck panels to precast prestressed concrete Bulb-T girders for the Burnt River & UPRR Bridge. This demonstration project has allowed ODOT to develop design standards and specifications for HPC precast bridge deck panels and UHPC connections for use on this project and future accelerated bridge construction (ABC) projects. The HPC used in the precast prestressed deck panel design is based on abrasion-resistant concrete research conducted by Oregon State University and sponsored by ODOT. The connection design for the Burnt River project is based on Federal Highway Administration (FHWA) research where UHPC was successfully used to connect precast concrete members.*

*The single-span bridge superstructure on this experimental project will consist of 15 full-width precast prestressed concrete deck panels composite with four 90 inch deep Bulb-T (ODOT BT90) precast prestressed concrete girders. Due to the increased bond strength of UHPC, the longitudinal deck reinforcement in the transverse deck panel to panel joints can be fully developed in just six inches. This connection eliminates the need for longitudinal post tensioning. This paper highlights the design of HPC precast prestressed concrete deck panels, unique properties of UHPC, connection details utilized for this project, additional future applications for UHPC and abrasion-resistant HPC, and the ABC advantages these materials will provide on future ODOT bridge projects.*

**Keywords:** Deck, Panels, Ultra High Performance Concrete, UHPC, ODOT

## INTRODUCTION

The Oregon Department of Transportation (ODOT) has developed standards and details for full depth precast prestressed concrete bridge decks. To generate standards and details more efficiently, ODOT built upon internal research and research conducted by the Federal Highway Administration (FHWA) and other state departments of transportation to develop two precast deck systems and associated connection details. ODOT's ultimate goal is to use HPC precast concrete decks as the preferred system for the majority of bridge replacement projects with precast prestressed concrete girder or short span steel girder superstructures.

ODOT's experiment with precast deck panels began as a research project with Oregon State University to develop a more abrasion-resistant bridge deck concrete mix design. For inspection and maintenance purposes, ODOT prefers to leave bridge decks bare and utilize the concrete deck as the wearing surface. However, Oregon allows vehicles to use studded tires during the winter months which results in rutting. Once rutting becomes excessive, it must be mitigated by placement of an overlay.

ODOT's primary purpose in developing precast prestressed concrete decks is to provide a deck system with increased abrasion resistance. Precasting and curing deck panels in a controlled plant environment will result in a superior product with enhanced attributes. These attributes include high strength, abrasion resistance, and reduced cracking. Cast-in-place concrete decks often see significant shrinkage cracking which can weaken the deck and lead to additional load-induced microcracking. These cracks provide a path for corrosion and thereby compromise long-term durability of the deck. Use of precast decks is expected to eliminate most, if not all, deck cracking leading to significantly improved durability and better long term performance.

Field-cast Ultra High Performance Concrete (UHPC) will be used in the precast concrete deck panel connections. UHPC is an advanced cementitious material that utilizes high strength steel fibers in place of coarse aggregates<sup>1</sup>. For this application, the simple panel to panel connections will take advantage of the improved concrete to concrete bond strength and significantly reduced development lengths required with UHPC, eliminating the need for longitudinal post tensioning. The composite precast deck panel to precast girder interface shear connections will also be field cast UHPC. Panel to panel connections used for this project are based on FHWA research. Panel to girder connections are based on project specific geometry and the current version of the AASHTO LRFD Bridge Design Specifications as modified by the ODOT Bridge Design and Drafting Manual. ODOT has also developed longitudinal post tensioned connection details as an alternative for precast decks not utilizing UHPC.

ODOT has received an FHWA Highways for Life Grant (HfL) for the precast prestressed HPC deck panel and UHPC connection components of the Burnt River and UPRR Bridge replacement project. As part of a combined effort between ODOT and FHWA, this demonstration project will include bridge conference presentations, monitoring and reporting

during and after construction, opportunities for site visitations during construction and a Project Showcase.

## **HPC PRECAST PRESTRESSED CONCRETE DECK PANELS**

Full depth precast prestressed High Performance Concrete (HPC) deck panels provide several advantages over traditionally cast concrete bridge decks. The primary advantages are reduced cracking, increased durability of high strength concrete and reduced onsite construction time.

ODOT will implement a concrete mix developed in the Oregon State University research mentioned above. This is an HPC mix developed to maximize abrasion resistance. The key components of the high performance mixture leading to improved abrasion resistance are 7% silica fume and a special aggregate gradation. The mixture has had extensive lab testing, but has not been used for any bridge construction projects to date. This demonstration project will test the constructability of a similar high strength high performance mix in precast prestressed deck panels.

A scan of existing research on abrasion resistance revealed that higher compressive strength was a primary factor leading to better performance. However, ODOT was reluctant to simply require higher strength in cast-in-place concrete bridge decks. ODOT had already seen significant deck cracking using 4.0 ksi High Performance Concrete. Since cracking was thought to be related to shrinkage, increasing the compressive strength would only make the cracking worse. If so, the abrasion-resistance benefit of using higher strength concrete would be offset by increased deck cracking and a higher risk of corrosion.

The solution to this strength/cracking dilemma is to use precast concrete decks. By precasting the deck, all shrinkage will be limited to the individual panels thereby eliminating cracking in the final constructed deck. Because of this method, the compressive strength of the concrete can be increased to whatever level is practically achievable by local precasters.

For this project, the minimum required deck compressive strength will be 8.0 ksi. In Oregon, most precasters can consistently achieve this strength without significant change to their operations. For precast concrete girders, Oregon precasters often achieve over 10 ksi. For approval of a mix design, ODOT requires the mix to achieve a strength at least 15% above the minimum specified. Therefore, the actual constructed panels are likely to achieve more than 9.0 ksi compressive strength.

The size and configuration of the bridge deck and individual panel geometry was developed based on the roadway design standards and bridge geometry requirements for the project site, as well as constructability and hauling capabilities of local PCI precast plants. The bridge deck will consist of 15 full-width precast prestressed concrete deck panels 30'-8" wide by 9'-5" long over four ODOT BT90 precast prestressed concrete girders. Panel length was determined by dividing the bridge deck into equal panel segments with the parameters of

panel and joint uniformity and not exceeding a panel width of 10 feet and overall width of 12 feet for hauling purposes. The typical panel layout is shown in Figure 1.

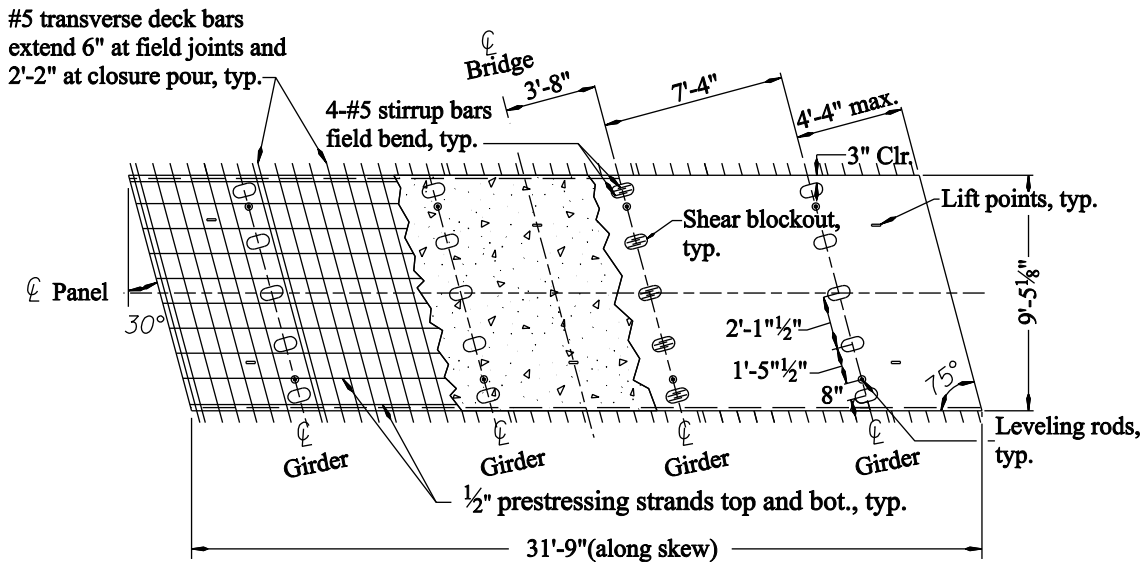


Fig. 1 Precast Concrete Deck Panel

Panel to panel joints will be constructed parallel to the bridge end skew. This layout will allow for uniform end closure pours and deck overhangs. Shear pocket spacing is based on minimum clear edge distance to accommodate mild steel trim bars and edge prestressing strands and a 2-foot maximum interface shear reinforcement spacing. All panels will be 8.5 inches thick with 0.5 inches provided for profile grinding, 0.5 inches for wearing surface and 7.5 inches for design depth. As shown in Figure 2, each panel will have a top and bottom row of 0.5-inch low relaxation prestressing strands running transverse to the span and two rows of No. 5 epoxy coated reinforcement running longitudinal to the span. For adjustment and stability prior to casting the shear blockouts and haunches, the panels will have two erection leveling bolts per girder line.

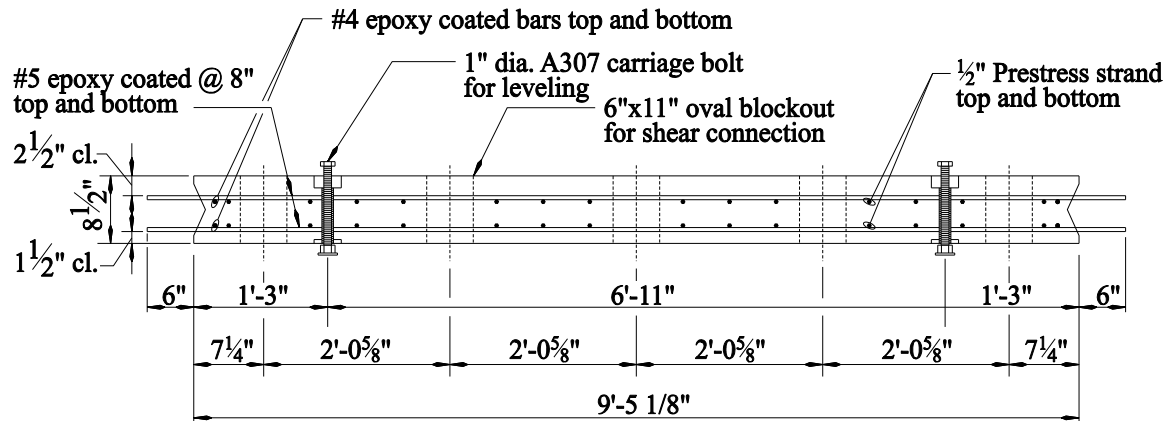


Fig. 2 Precast Deck Panel Typical Section

The primary purpose of this project is to demonstrate precast concrete deck panels. Due to the off-system nature of this highway section and to reduce risk to the Contractor, the project Team decided to not make accelerated bridge construction a requirement. Based on the time allowed by this decision and to accommodate end skew, an HPC closure pour will be used to connect the precast deck panels to the cast-in-place end diaphragms and form the bridge joints. On projects where ABC is a requirement, ODOT would use precast deck panels the full length of the bridge and design connections to precast end diaphragms.

Precast concrete deck panels must be permanently connected with a rigid durable connection system. The connection must be structurally adequate and sufficiently bonded to carry the heavy stresses and endure environmental conditions to ensure long-term integrity of the bridge deck system.

## ULTRA HIGH PERFORMANCE CONCRETE (UHPC)

Ultra High Performance Concrete consists of a cementitious matrix bonded with fiber reinforcement without traditional coarse aggregates. UHPC has high compressive strength, a higher concentration of cementitious materials contents and very low water to cement ratios<sup>1</sup>. Additional UHPC enhanced properties include added ductility, durability, fluidity, extremely low porosity and increased bond strength. Design compressive stresses above 22.0 ksi can be achieved under plant or laboratory conditions<sup>2</sup> and 16.5 to 18.0 ksi in field cast environments.

UHPC can be mixed on site or in a batch plant. For onsite mixing, small approved mixers with capacities of up to three yards are available. The product comes with the dry cementitious constituents premixed. Once the liquid and cementitious components have been thoroughly mixed, the steel fibers are added and mixed for a short prescribed time. The UHPC is then placed by hand methods.

The primary advantages of UHPC are the significant reduction in reinforcement development lengths compared with traditional concrete, increased bond strength to precast concrete, added ductility and tensile capacity provided by internal steel fiber reinforcement.

The basic composition of UHPC that will be used on this project is shown in Table 1 below.

| <u>Typical UHPC Composition</u> | <u>Amount</u>           | <u>% by Weight</u> |
|---------------------------------|-------------------------|--------------------|
| Portland Cement                 | 1200 lb/yd <sup>3</sup> | 28.5               |
| Silica Fume                     | 390 lb/yd <sup>3</sup>  | 9.3                |
| Ground Quartz                   | 355 lb/yd <sup>3</sup>  | 8.5                |
| Fine Sand                       | 1720 lb/yd <sup>3</sup> | 41.0               |
| Steel Fibers                    | 263 lb/yd <sup>3</sup>  | 6.3                |
| Superplasticizer                | 51 lb/yd <sup>3</sup>   | 1.2                |
| Water                           | 218 lb/yd <sup>3</sup>  | 5.2                |

Table 1 UHPC Mix<sup>1</sup>

The primary difference between the UHPC mix and an HPC mix is high tensile strength steel fibers and additional cementitious materials replacing the traditional coarse aggregates. Fiber reinforcement consists of 0.008 inch diameter, 0.5 inch long steel fibers with an average tensile strength greater than 290 ksi<sup>3</sup>. The average water to cement ratio is under 0.20. The higher concentration of cementitious materials combined with the low water to cement ratio results in a discontinuous pore structure. The average pore size is approximately a nanometer in diameter. Due to the decreased average particle size, reduced water to cement ratio and smaller pore size, UHPC has a greater density than traditional concrete. UHPC specific gravity ranges from 2.4 to 2.6<sup>3</sup>. Therefore, designs should account for the additional dead load. These attributes also make UHPC significantly more impervious and durable.

UHPC may be used in a wide variety of concrete transportation and building applications. UHPC has been successfully used in prestressed concrete bridge girders, longitudinal and transverse field-cast bridge joints and architectural building treatments. Research has been conducted on precast prestressed concrete deck panels in a waffle slab configuration with reduced dead load compared to traditional full depth slabs. UHPC can also be used to overlay bridge decks and for repair and retrofit applications to regain or increase design strength.

Due to the available tensile strength of the steel fibers, UHPC has considerable shear capacity<sup>1</sup>. UHPC precast prestressed girders cast without traditional mild steel shear reinforcement have been successfully used on several recent bridge projects. Therefore as design codes become available, designers will likely have the option of designing precast prestressed UHPC girders and columns without traditional shear reinforcement or with reduced shear reinforcement.

Precast prestressed concrete deck panel to panel joints used on this project are based on FHWA research. FHWA tested several configurations of reinforced key joints. Full scale tests were conducted to determine the best joint configuration for the affects of shear, moment, fatigue and permeability. The most efficient joint tested was the female-female configuration shown in Photo No. 1.



Photo 1 Precast Prestressed HPC Deck Panel Joint – FHWA Cyclic Testing<sup>1</sup>

Due to the UHPC material properties described above, transverse panel to panel joints have strength equal to or greater than the adjoining concrete panel sections. This type of joint performs similar to a butt-joint weld between two steel plates where the weld is essentially stronger than the adjoining plates.

Since UHPC bonds extremely well to already cast concrete surfaces, the joint interface between the UHPC and the HPC deck panel is essentially impervious. UHPC has a low tendency to develop micro-cracks, low rapid chloride permeability and a high freeze-thaw resistance<sup>4</sup>. If a micro-crack develops, the steel fiber is engaged to keep the crack from propagating<sup>1</sup>. With the combined effects of little or no cracking, a homogeneous cementitious matrix and extremely small discontinuous pores, the UHPC joint has extremely low permeability, excellent resistance to corrosion and long term durability<sup>2</sup>.

Under conditions where the joint was tested to failure with cyclic loadings that far exceed the design service conditions, the precast panel sections developed a single large crack while the steel fiber reinforced UHPC joint between the panels developed a series of parallel micro-cracks as steel fibers were engaged in each successive crack, as shown in Photo No. 2.

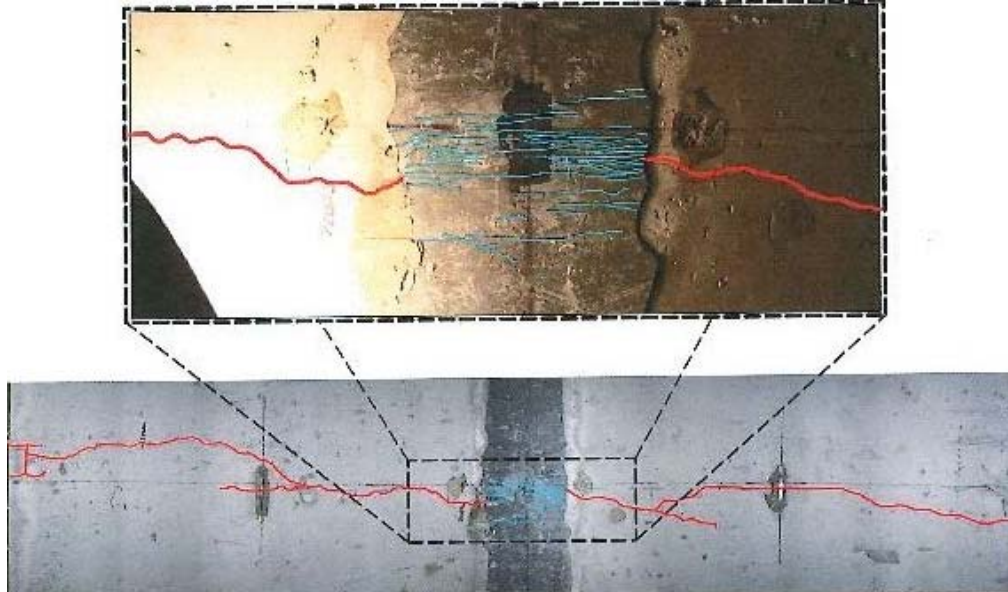


Photo 2 UHPC Panel Joint – FHWA Cyclic Testing Underside Cracking<sup>1</sup>

Due to the very short development lengths required with steel fiber UHPC, longitudinal deck reinforcement can be fully developed in a few inches. Due to the high compressive and bond strength characteristics of steel fiber reinforced UHPC, narrow joint cross section and fully developed deck reinforcement, the deck functions similar to a monolithically cast-in-place concrete bridge deck<sup>2, 4</sup>. Therefore, the need for full length post tensioning on simple-span bridges is eliminated.

For this project, ODOT will use a proprietary (sole source) UHPC material to maintain consistency with the FHWA research. This proprietary material uses a special high-strength steel fiber reinforcement that is only available in Europe. Therefore, in order to use this product, a “Buy America” waiver must be obtained from FHWA. For this project, ODOT has requested and received a “Buy America” waiver based on the requirement to match the product used in the UHPC research performed previously by FHWA.

## UHPC CONNECTION DESIGN AND DETAILING

Design guides and specifications for UHPC have not been formally developed and published. Current research is working toward this aim. Therefore, the precast prestressed HPC deck panel connections used for this project are based on recent FHWA research and testing. The precast deck panels, precast girders and bridge substructure were designed by traditional methods according to the Fifth Edition of the AASHTO LRFD Bridge Design Specifications, PCI Precast Prestressed Concrete Bridge Design Manual and ODOT Bridge Design and Drafting Manual.

Based on FHWA research, the longitudinal epoxy coated No. 5 mild steel deck reinforcement in the transverse panel to panel connections can be fully developed in less than six inches

with steel fiber reinforced UHPC. For field applications, FHWA recommends a six inch bar lap as a practical minimum. In order to develop the longitudinal deck bars and sufficiently connect the precast panels, a UHPC design strength of 14.0 ksi in 14-days and 17.0 ksi in 28-days will be required on this project. Figure 3 details the UHPC joint used on this project.

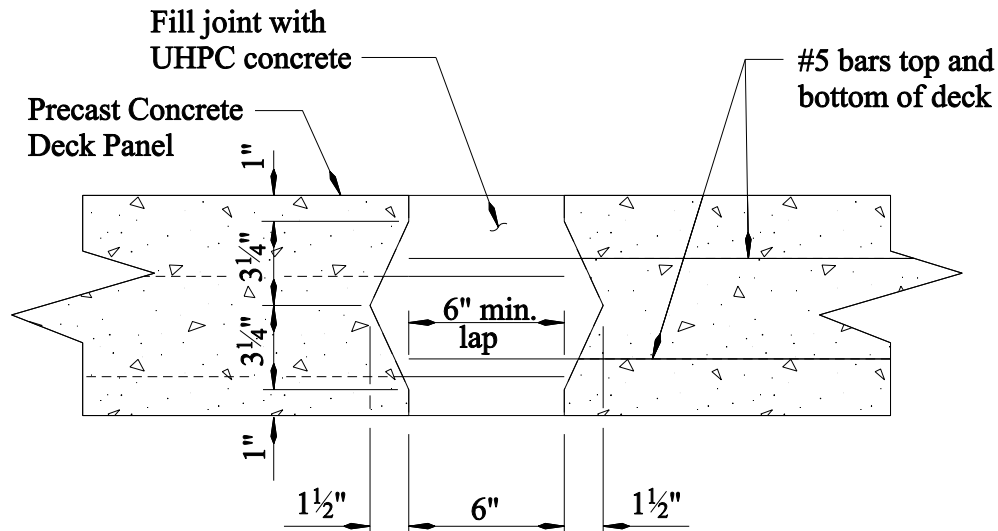


Fig. 3 UHPC Keyed Joint

UHPC will be used in the panel to girder connection shear pockets and built-up haunch sections. Due to the strength properties of UHPC, required surface area for bearing and interface shear, ease of construction and as a cost savings, a haunch width less than the full girder flange width will be used. AASHTO allows for an interface shear reinforcement spacing of up to 4 feet. Currently, ODOT uses a maximum interface shear reinforcement spacing of 2 feet.

To develop composite action between the precast concrete deck panels and precast concrete girders, uncoated mild steel interface shear reinforcement will be cast in the BT90 precast girders in addition to the girder shear stirrups. After erecting the girders and deck panels, the interface shear reinforcement will be field bent to ensure proper alignment within the shear pockets. For traditional cast-in-place decks, the girder shear stirrups are terminated in the monolithically cast deck and haunch. In order to develop the girder shear stirrups below a precast deck, the minimum haunch depth would have to be 6 inches. Furthermore, the spacing of the shear stirrups rarely aligns with the shear blockouts. Therefore, to minimize haunch depth and unnecessary dead load, the girder shear stirrups will be terminated in the girder top flange with hooks as required to develop the reinforcement, as shown in Figure 4.

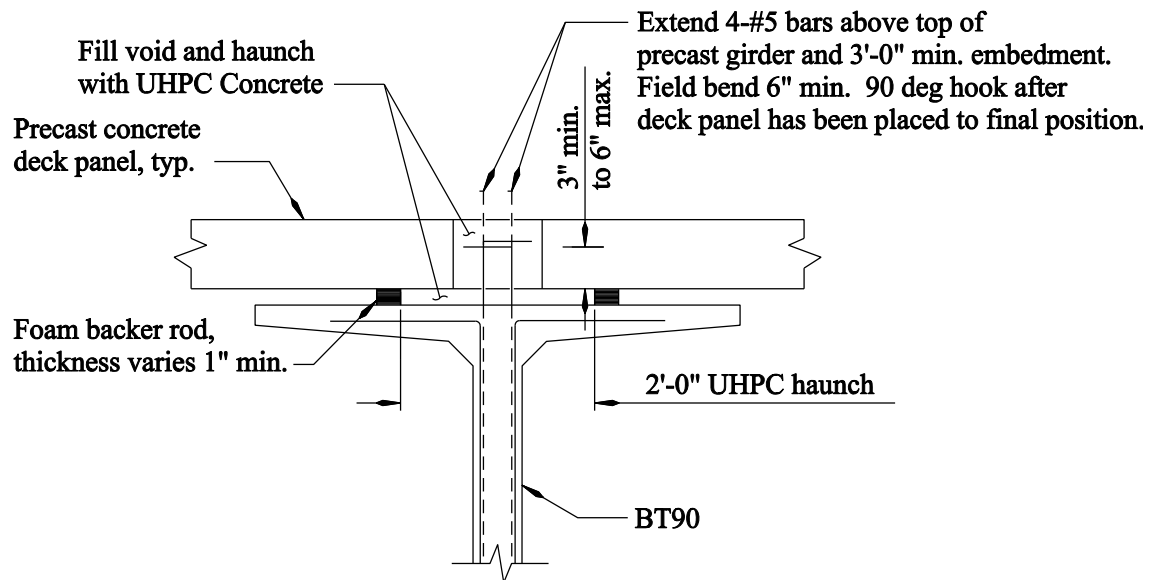


Fig. 4 Deck Panel to Girder Connection

To cast the haunches, UHPC is placed in the shear pockets through a sealed wood chimney or chute that provides approximately one to two feet of static head, as required. With the excellent flow-ability of UHPC no mechanical vibration or pumping is required. To maintain the steel fibers in suspension, vibratory equipment must not be used. Minor rodding of the UHPC can be used in congested areas. Based on UHPC research test samples cast with these methods, annular spaces such as shear pockets and haunches can be completely filled without air voids normally found with traditional grouts<sup>4</sup>.

Compressible foam backer rod is used to form the haunch sections. Seals based on standard mortar-tight specifications are not adequate to contain and maintain the integrity of the mix. The foam backer rod must form a tight seal to contain the very fluid UHPC mixture. To contain UHPC in areas of superelevation or cross slope, exposed joints and shear pockets require a plywood seal or cover. The plywood cover is installed successively upward from the low point as the UHPC is placed. If plastic coated form grade plywood is used to contain and cover exposed areas of UHPC, no additional measures are required for curing. Curing times vary from three to seven days depending on environmental conditions<sup>4</sup>.

As defined in the AASHTO LRFD Bridge Design Specifications<sup>5</sup>, interface shear design takes into account the roughness of the interface shear surfaces. The tops of the precast girders can easily be roughened. However, the precast concrete deck panels will be cast in a casting bed in a PCI certified plant. Therefore, designs need to assume a smooth concrete interface shear surface unless otherwise specified when selecting the cohesion and friction coefficients. The ODOT preference is to add stirrups rather than roughen the top surface.

## **BURNT RIVER BRIDGE SITE**

The existing Burnt River and UPRR Bridge No. 00700 carries US30 Huntington Highway over the Burnt River and Union Pacific Railroad Bridge at track mile point 386.63. The existing bridge is a 204-foot three-span structure as shown in Photo 3.



Photo 3 Burnt River Bridge Site

US30 in the vicinity of the bridge carries local traffic between the I-84 Huntington Interchange and the I-84 Lime Interchange. Local traffic on this section consists of agricultural vehicles and equipment, railroad and utility service vehicles and construction traffic from a new wind farm project. An industrial area along US30 between the interchanges may also contribute to future ADT. Current US30 ADT is 60 with a project design ADT of 115. The new bridge will serve local passenger vehicles, farm trucks, and both present and future trucks accessing the wind farm and industrial area.

The replacement bridge will be a 160-foot single-span structure with an MSE wall and cast-in-place concrete pile cap over HP14x89 steel piles at Bent 1 and a cast-in-place footing and stem wall founded on rock at Bent 2. The superstructure will consist of a precast prestressed HPC deck over four ODOT BT90 precast prestressed concrete girders, as shown in Figure 5.

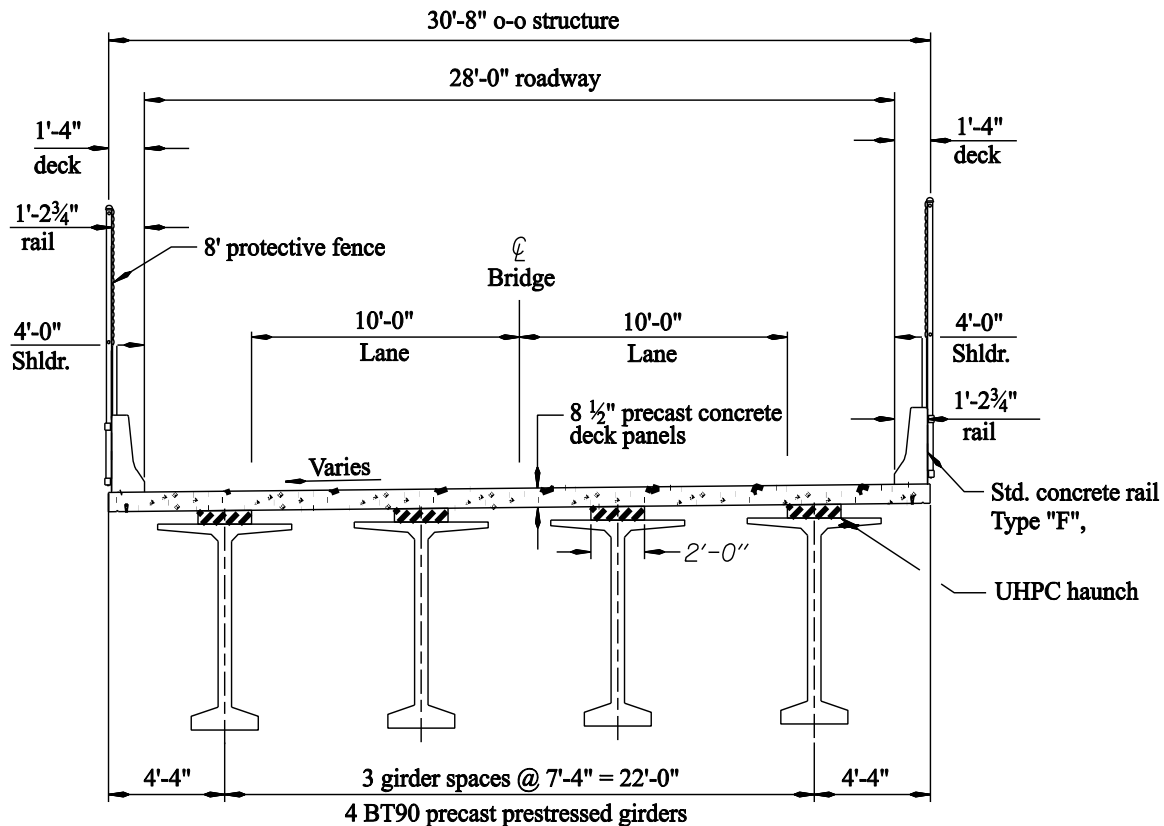


Fig. 5 Typical Section

ODOT chose this bridge replacement project site for the precast deck experimental demonstration project based primarily on timing and least risk to the agency. This bridge is in an off system secondary highway with low ADT. Since there is an acceptable detour, the highway can be closed during construction. This gives ODOT an opportunity to work out any unforeseeable details, adjust the project schedule as required and to minimize risk to the Contractor. Reducing these risks will likely result in a lower project bid price.

## FHWA HIGHWAYS FOR LIFE GRANT AND PROJECT SHOWCASE

The FHWA HfL grant provides an opportunity to further the research of HPC precast prestressed concrete deck panels over precast prestressed concrete girders and field-cast UHPC connections. This project also provides an opportunity to improve upon details, specifications and constructability and to share knowledge with other agencies, precasters, suppliers and consultants.

As part of the HfL grant, ODOT will be monitoring and reporting on the feasibility and performance of the precast elements and UHPC connections during and after construction. During construction, opportunities to share knowledge will be made available through site visitations, collected data, photographs, video and a Project Showcase. The Project

Showcase is anticipated to occur in the fall of 2012. The actual time and details will be posted on the FHWA website when they become available.

## **FUTURE USE OF PRECAST DECKS IN OREGON**

Following successful completion of this project, ODOT anticipates more use of precast deck panels. Even though precast deck panels are not likely to be used on every project, ODOT would like to see this application become routine in locations with high levels of studded tire usage.

This project is an extension of our abrasion-resistant deck research. ODOT intends to follow this project with a second precast deck panel bridge project where the improvement in abrasion resistance can be evaluated and documented. The site for this second project has not yet been determined. It will be a site where studded tire use is a particular concern.

In addition to improved performance and durability, precast deck panels also provide another option for sites requiring accelerated construction. Precast HPC deck panels can save significant on-site construction and cure times required by traditional cast-in-place concrete decks. Precast decks also provide an immediate work platform for labor, materials and small equipment. This allows other processes like bridge rail construction to move up in the project schedule. Other precast components could be incorporated with precast deck panels for projects requiring extremely short duration accelerated bridge construction. For example, utilizing precast pile caps, diaphragms, bridge end panels and concrete bridge rail or curbs for curb mounted bridge rail precast with the deck panels could allow constructing and opening a new bridge to traffic in a matter of days.

The ultimate plan is for precast deck panels to become routine in Oregon. ODOT has already developed standard details for panels using UHPC joint material and using longitudinal post-tensioning.

The “Buy America” provisions (associated with the steel fibers) and the fact that Ductal®<sup>3</sup> is a proprietary product are two issues that must be addressed before the cast-in-place joint option can become standard practice. These issues can be addressed by a combination of additional research on the Ductal® material using domestic steel fibers and by other UHPC manufacturers entering the market. ODOT may also consider development of a generic UHPC material or using a wider cast-in-place joint that does not require UHPC. In any case, ODOT is committed to moving precast deck panel technology forward.

## **CONCLUSIONS**

The opportunity to design and construct a precast prestressed HPC concrete deck with UHPC connections composite with precast prestressed concrete girders will propel Oregon DOT toward the current goals of developing accelerated construction methods and more durable and abrasion resistant bridge decks. ODOT hopes to make precast prestressed concrete bridge decks the preferred choice for new bridge designs and renovations where applicable.

Precast HPC bridge decks provide several advantages over traditional cast-in-place concrete decks. The primary advantages are increased durability, abrasion resistance, reduced cracking and accelerated construction benefits. Due to the ability to control the environment and curing conditions at a precast plant, high strength concrete mixes required to achieve a greater resistance to abrasion and increased durability can be used in precast deck panels. Precast deck systems have greater upfront costs than traditional cast-in-place decks. Designers should consider user costs and long term benefits to justify the additional expenses of casting, hauling and erecting precast decks. Since prestressing strands are used in the precast panels, future bridge rail retrofits or repairing bridge rail collision damage may limit the designer's options. Differential camber in adjoining precast panels will require profile grinding to achieve an acceptable riding surface.

UHPC has a wide variety of transportation applications. UHPC can be used to connect precast elements with connections that perform similar to monolithically cast components. Due to the unique properties of UHPC, more efficient structural shapes have been and will continue to be developed for sections composed entirely of UHPC. As design guides and manuals are developed, designers will benefit from the high strength and short development length characteristics of UHPC. As more suppliers develop and provide UHPC products, this type of concrete will see more frequent use and become more feasible as an optional concrete product used to cast large members and components.

The primary advantages of UHPC are the significant reduction in reinforcement development lengths compared with traditional concrete, increased bond strength to precast concrete, added ductility and tensile capacity provided by internal steel fiber reinforcement. However, when compared to traditional cast-in-place concrete, UHPC does require additional labor and materials. UHPC also has a higher minimum casting and curing temperature requirement.

The lessons learned and experience gained from this project will allow ODOT to take advantage of this technology and expand the use of abrasion resistant HPC precast deck systems. The use of UHPC deck panel connections is one of several methods currently being considered and developed into standard details in Oregon.

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