PRECAST CONCRETE U-BEAMS TO ENERGIZE INDIANA'S ACCELERATE 465

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ABSTRACT

Accelerate 465, a $500 million, 11.9 mile interstate reconstruction project on the west side of Indianapolis with 1 million square feet of new bridge, is the largest project in Indiana Department of Transportation (INDOT) history. INDOT is promoting innovative technologies associated with project management, traffic maintenance, context sensitive design, construction methods, and structure systems. The prestressed, precast concrete U-beam is one of the systems being implemented to improve efficiency, capitalize on high strength materials, improve work zone safety, and reduce maintenance.

INDOT is using this project to develop and implement a new standard section. The Indiana U-beam builds on other state's experiences by introducing improvements to satisfy local climate conditions and maintenance practices. Improvements include cross section optimization, prestress strand pattern development to reduce principal web tensile stresses, inspection access, interior drainage, and internal steel diaphragms.

The design team has worked closely with INDOT to introduce innovative contracting mechanisms including meetings to engage the construction industry, and a direct supply fabrication contract to reduce the precastor's risk regarding equipment investment and labor training required for the new beam.

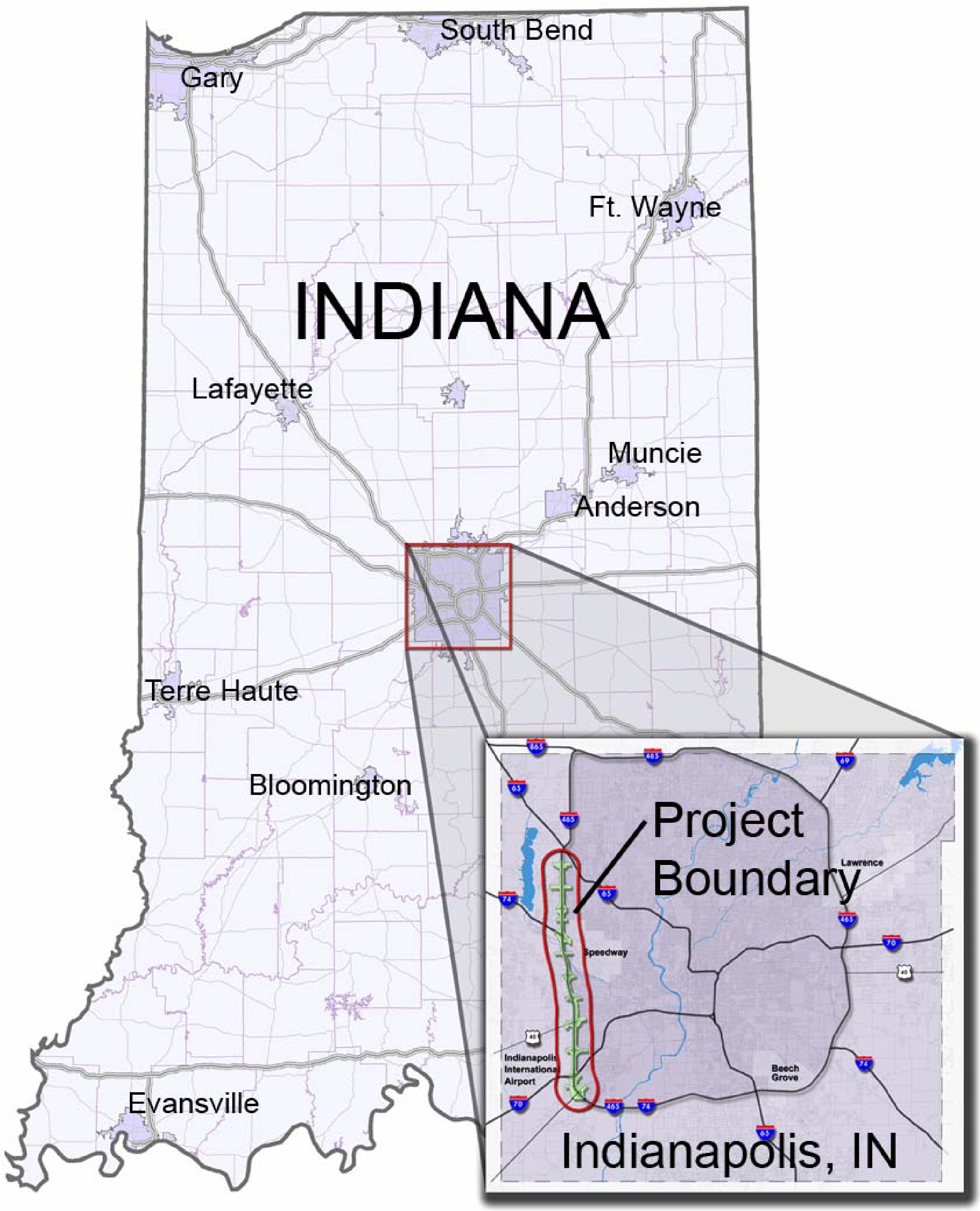
Keywords: *Accelerate 465*, Indiana, U-beam, Prestressed, Precast, Draped Strands, fabrication contract.

INTRODUCTION

Accelerate 465, an 11.9 mile interstate widening and reconstruction project on the west side of Indianapolis with approximately 1 million square feet of new bridges, is the largest project in Indiana history and provides a unique opportunity to implement innovative construction technologies. This $500 million Indiana Department of Transportation (INDOT) construction project is a showcase for several accelerated construction strategies. INDOT is promoting innovative technologies associated with project management, maintenance of traffic, context sensitive design, construction methods, and bridge structure systems. Additionally, because this project is going to be brought through final design by as many as eight separate design firms, called Section Design Consultants (SDC), as part of the final delivery of the project, efforts had to be undertaken to standardize proposed structure systems, design approaches of the individual firms, and the presentation of the contract drawings. The prestressed, precast concrete U-beam is one of the innovative structure systems that was determined to meet the needs of this project and is being implemented to improve structure efficiency, capitalize on new high strength materials, improve work zone safety, and provide a low maintenance structure.

Prestressed, precast U-beams (open-top, trapezoidal shaped beams) have been used in several states as a standard beam section, including Texas, Florida, Colorado and Washington. The proposed Indiana U-beam section builds on the successful experience of other states by modifying their beam templates for INDOT's use. Modifications include changing the beam section properties, using draped strand patterns to improve structural efficiency, developing prefabricated steel diaphragm details to improve constructability, providing external post-tensioning capability for longer spans, providing inspection access and drainage inside the section, and utilizing optimized materials to increase design life and minimize maintenance costs.

In addition to the technical developments, the contracting strategy for implementing this new precast section is an important part the project. The design team has been working closely with INDOT to introduce some innovative contracting mechanisms such as informational meetings to engage the construction industry and a direct supply fabrication contract to reduce the precastor's risk regarding new equipment investment and labor training associated with introducing this new beam section to the Midwest.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U-BEAM MODIFICATIONS

MODIFIED SECTION PROPERTIES

Prestressed, precast concrete U-beams are currently used in the states of Texas, Florida, Colorado, and Washington. These states have developed standard sections, with each state taking a slightly different approach to the shapes and the issues encountered. The proposed shapes herein have been modified to satisfy local climate conditions, design procedures, and infrastructure maintenance practices. They provide a shallower beam depth than I-beams for similar span arrangements, an innovative shape for the state of Indiana, and an aesthetically pleasing look that differs from a typical I-beam bridge.

The prestressed, precast U-beams under consideration for this project are 48", 54" and 63" deep sections. These beam sections accommodate all the span, bridge width, and maintenance of traffic configurations throughout the project. To promote beam standardization and minimize fabrication costs the bottom flange of each beam was set at 56" wide, and the slope of the webs and top flange configurations were fixed. Fixing these elements allows the beam depth variation to be accomplished in the web height, simplifying the formwork variation from beam to beam.

Specific modifications to other state's standard U-beam sections include: increased top flange width for precast panel seats and worker safety during construction; increased web thickness to allow two columns of draped strands, improved web shear performance, and improved transverse bending resistance; sloped inside of U-beam for improved drainage; sloped inner sides of U-beam for easier form removal, with a kink to facilitate concrete pouring; modified sections designed to allow reuse of forms for different height U-beams; modified reinforcing pattern to improve resistance to transverse bending.

The following figures represent the 54" deep Indiana U-beam sections along with comparative sections of both Florida and Texas.

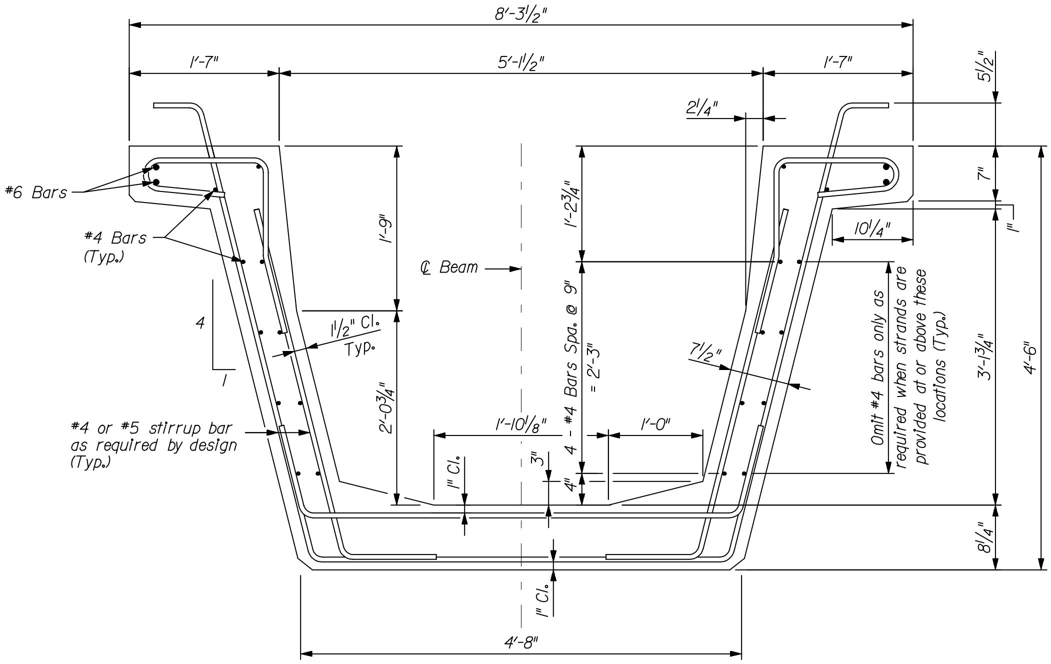

Fig. 1 INDOT 54" U-Beam Dimension and Reinforcement Section

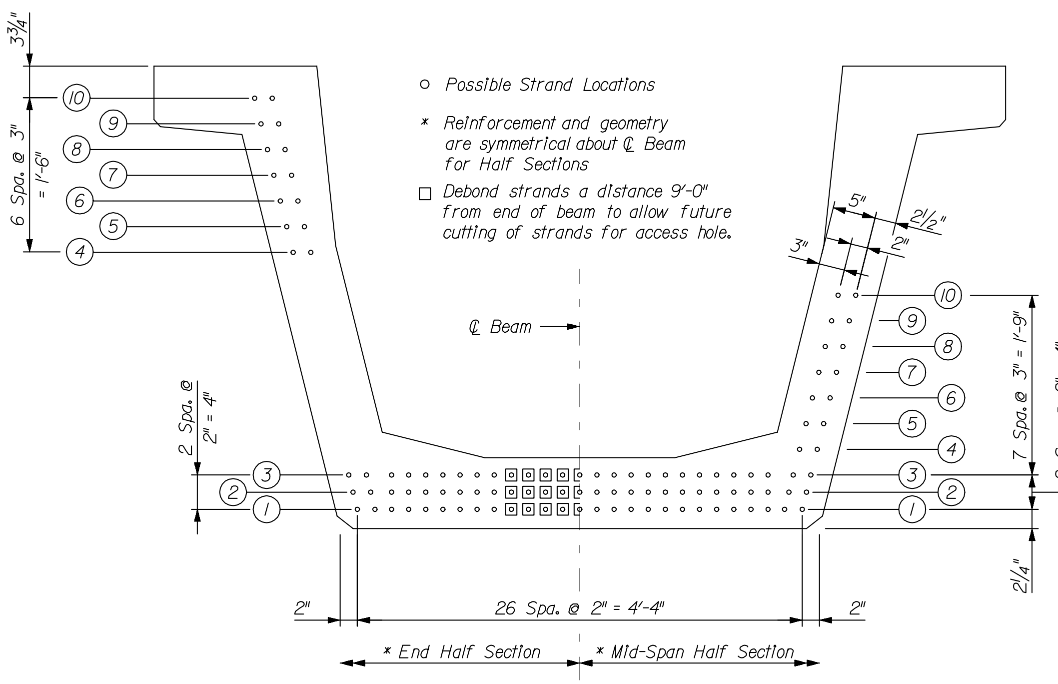

Fig. 2 INDOT 54" U-Beam Strand Pattern Section

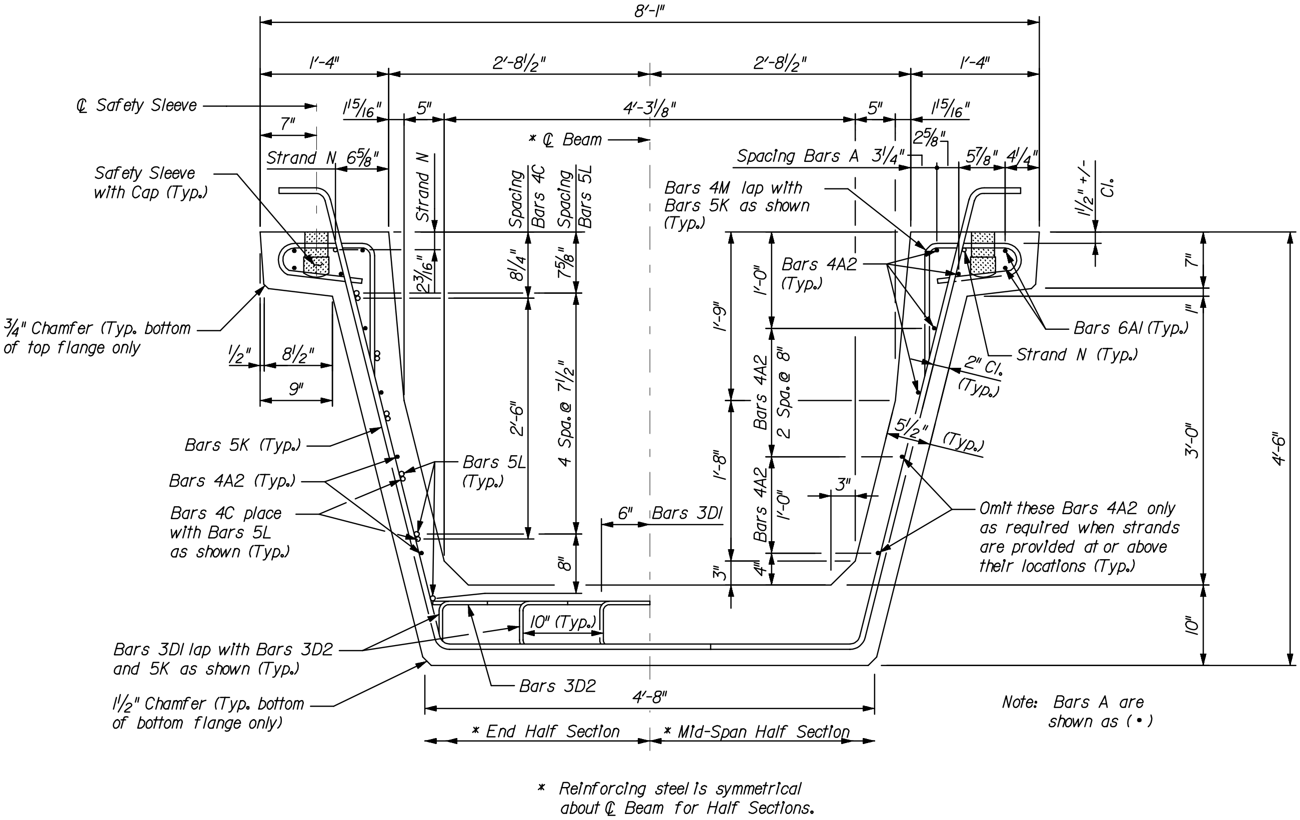

Fig. 3 FDOT 54" U-Beam Dimension and Reinforcement Section

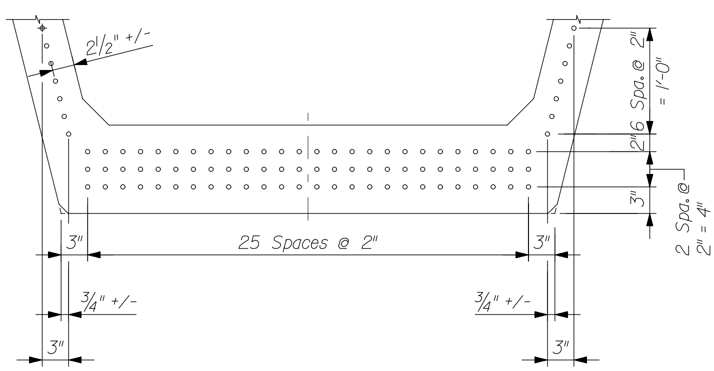

Fig. 4 FDOT 54" U-Beam Strand Pattern Section

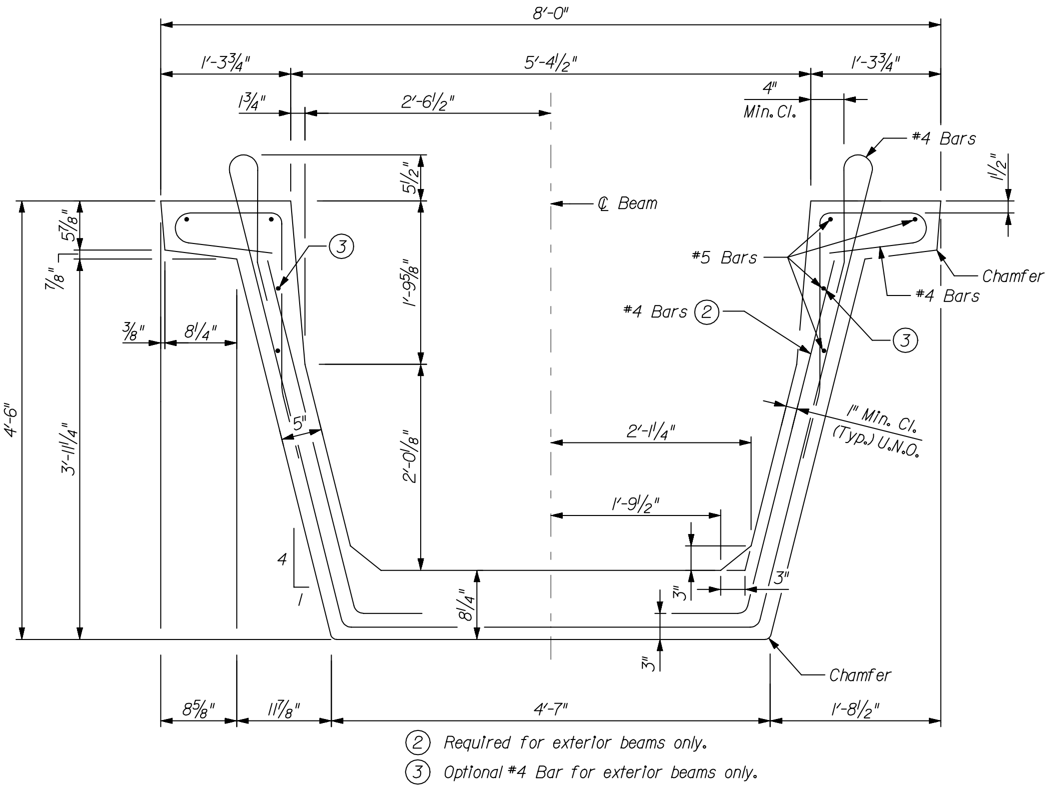

Fig. 5 TxDOT 54" U-Beam Dimension and Reinforcement Section

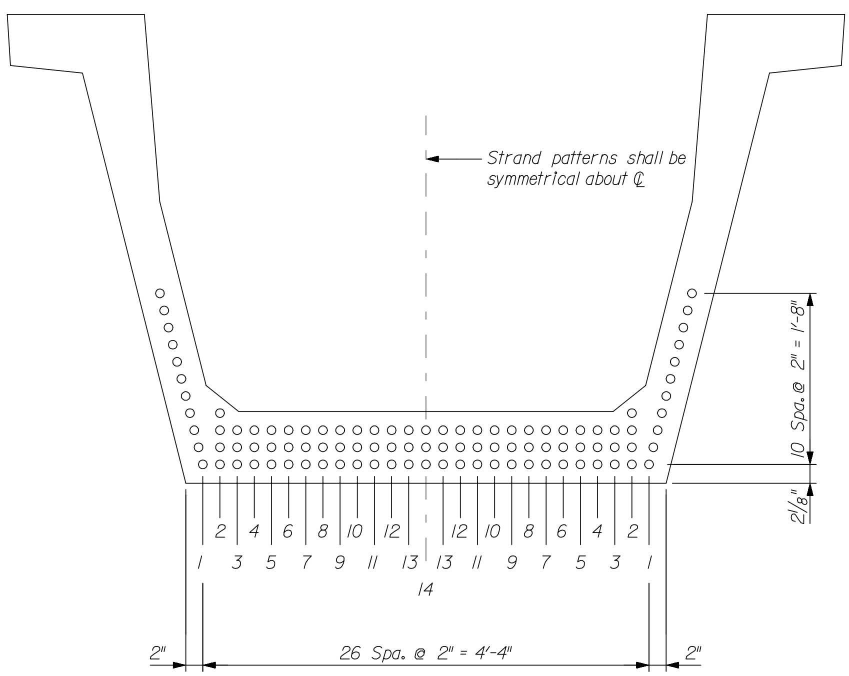

Fig. 6 TxDOT 54" U-Beam Strand Pattern Section

DRAPED STRANDS

Currently, Washington has the only state standard which allows draping of the prestressing strands through the web. For the Indiana U-beam, the majority of the strands are located in the bottom flange, with additional draped strands placed in the two webs. Two columns of strands per web can be accommodated with the thicker 7 ½" web. For span lengths of 100' to 125', in order to offset release stresses, other states have utilized debonding to a higher level than the AASHTO-recommended limit of 25%. By draping the strands in the web, initial and final stresses can be reduced thus allowing span length and beam spacings to be increased while concurrently easing the principle tension stresses in the web. With the forces due to draping all in-plane with the web, out-of-plane bending of the web will not be introduced. Through meetings with local precast suppliers, it has been determined that such draping is feasible. This leads to more efficient structures, with longer spans reducing substructure elements and wider beam spacings reducing the number of beam elements, thereby reducing bridge costs.

INTERNAL INTERMEDIATE STEEL DIAPHRAGMS

The standard INDOT practice for precast I-beams is to form and pour concrete diaphragms between the beams after erection. However, for the U-beams, only internal intermediate steel diaphragms have been proposed in order to minimize the dead load of the beams, and increase the ease and speed of construction. External intermediate diaphragms are not required due to the torsional rigidity of the U-beams. The internal intermediate steel diaphragms will consist of steel angles bolted to steel plates placed in the interior web and bottom flange faces at the time of casting. These diaphragms, which will ease future maintenance and inspection demands, can also be modified to serve as the hold-down elements at the declination points for potential post-tensioning tendons on longer spans.

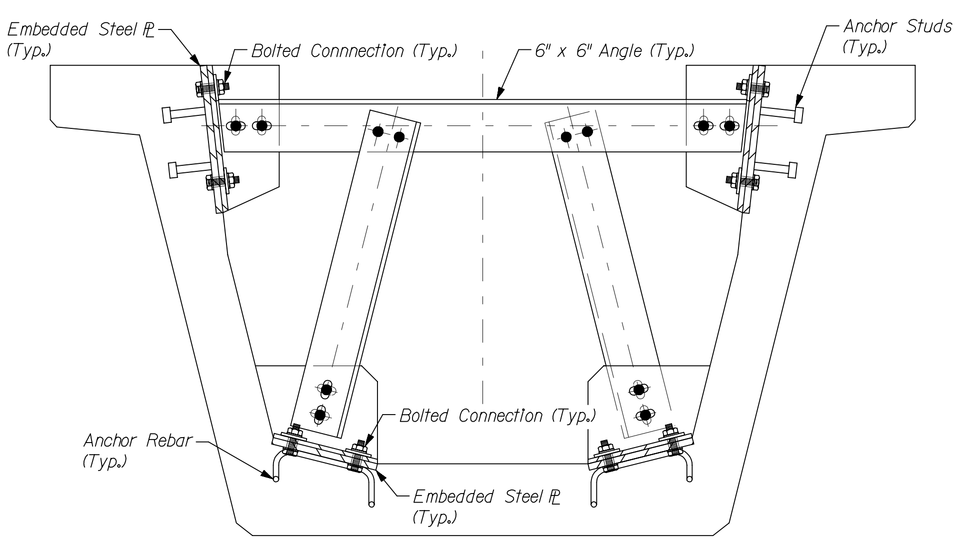

Fig. 7 Alternate 1 Internal Intermediate Diaphragm Detail

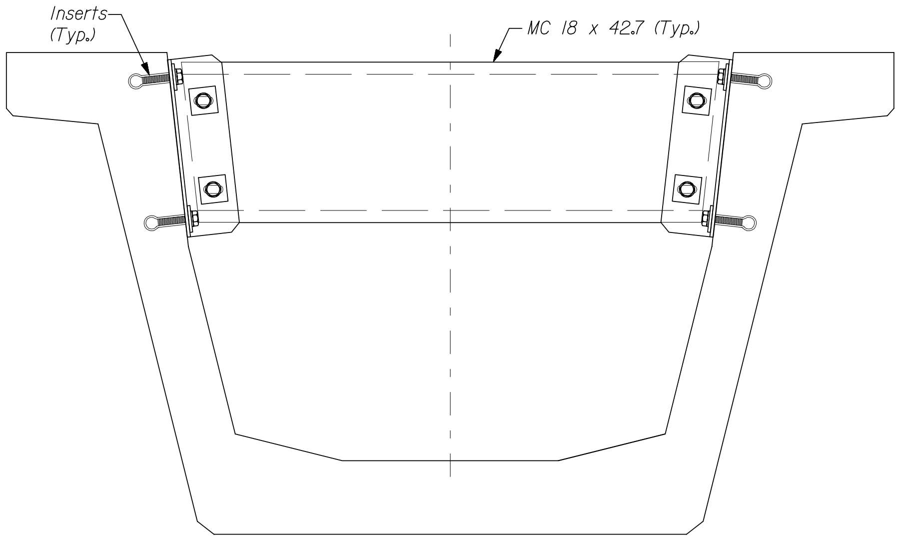

Fig. 8 Alternate 2 Internal Intermediate Diaphragm Detail

EXTERNAL POST-TENSIONING CAPABILITY

For U-beams used on longer spans (up to 145') the structure depth can be minimized by utilizing an exterior post-tensioning system combined with higher strength concrete. Inside the U-beam section, but not within the concrete, post-tensioning tendons can be installed and held down at the declination points by steel diaphragms. Internal to the beam, but external to the concrete post-tensioning eliminates cumbersome duct work inside the forms, provides improved corrosion protection, and offers the possibility of future tendon replacement. The post-tensioning can be staged to first provide the strength necessary to support the non-composite section, then to control long-term deflections and introduce compression in the deck, thereby extending the service life of the deck by minimizing deck micro-cracking.

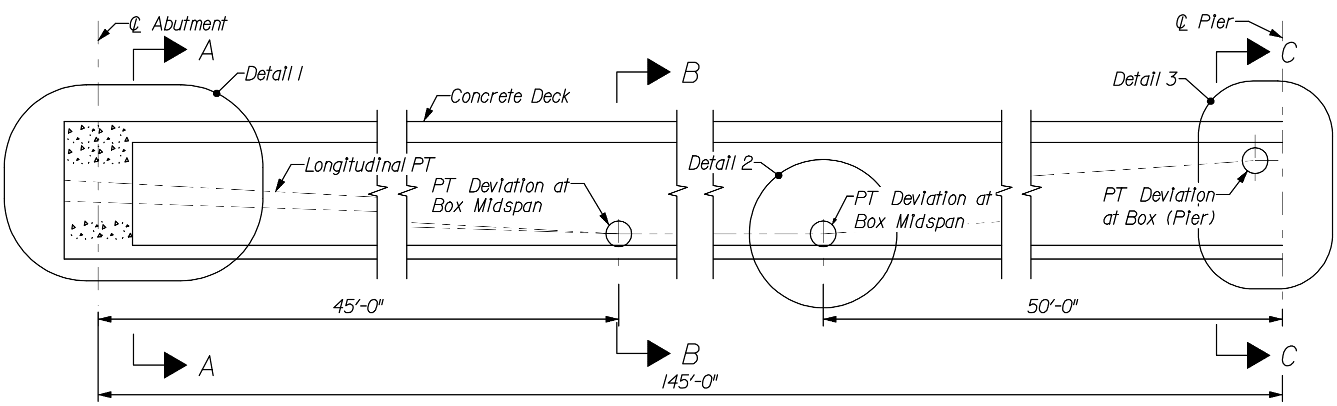

Fig. 9 Elevation of Post-Tensioned Beam

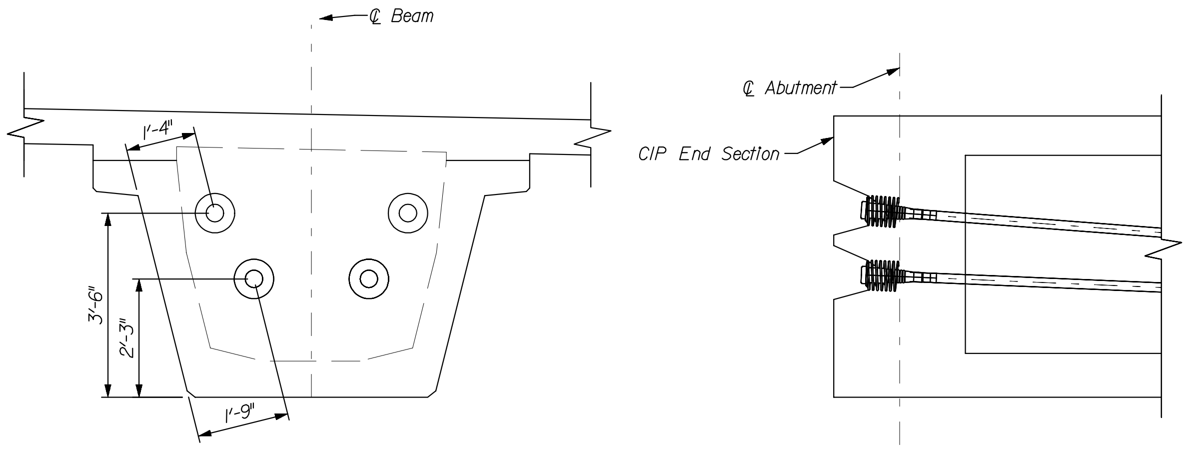

Fig. 10 Section A-A and Detail 1

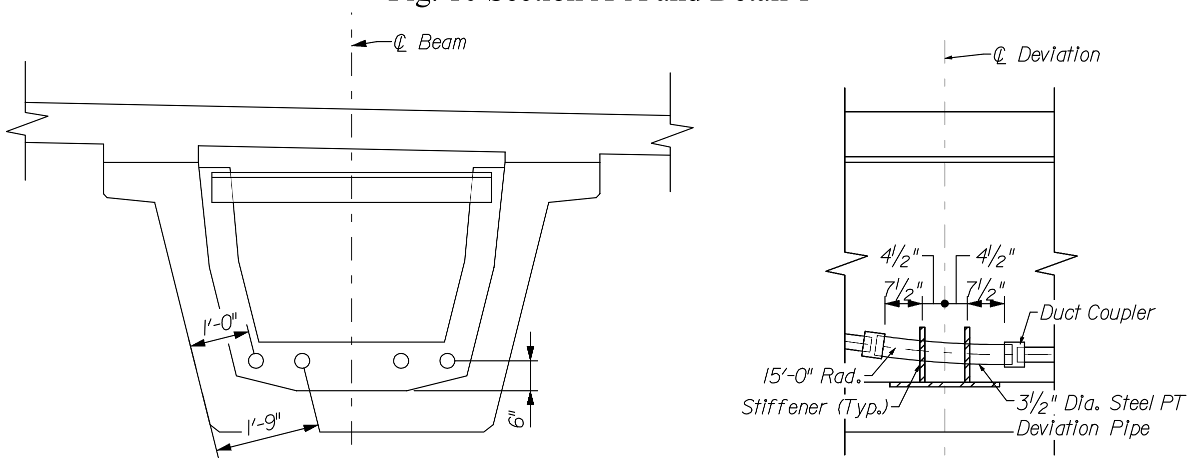

Fig. 11 Section B-B and Detail 2 for Steel Alternate

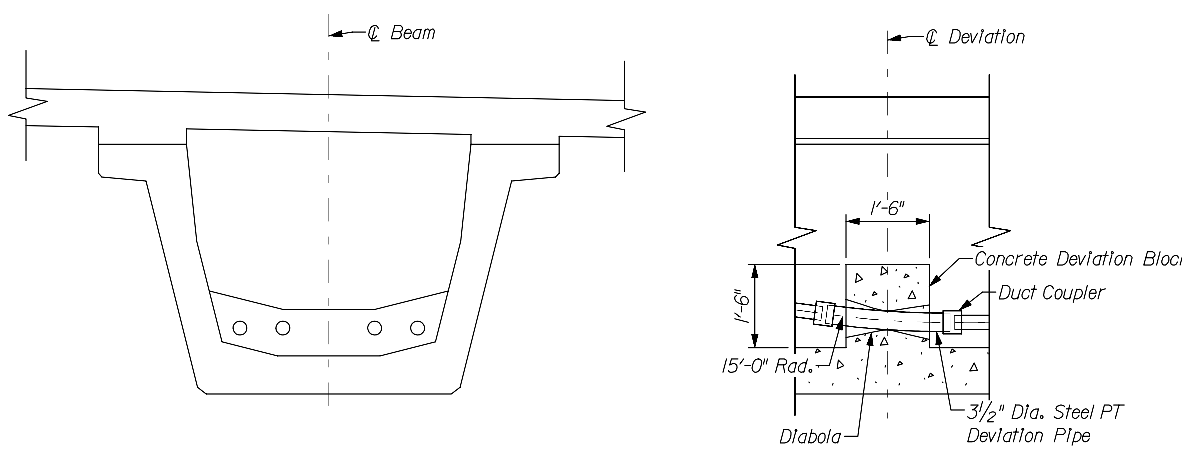

Fig. 12 Section B-B and Detail 2 for Concrete Alternate

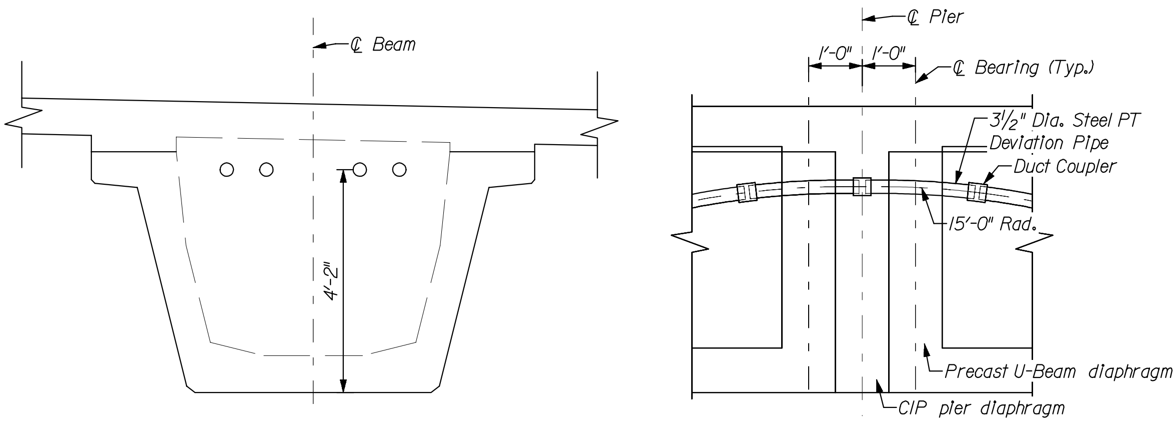

Fig. 13 Section C-C and Detail 3

DRAINAGE & ACCESS HOLE

The sections currently utilized by other states do not provide access holes to allow inspection inside of the U-beam. The sections proposed for this project provide an access hole near each end for inspection access and drainage, cutting through debonded strands grouped side-by-side in the bottom flange, as opposed to the typical alternating debonding pattern. Several design issues were introduced by grouping the debonded strands. The increased bursting force in the vertical direction in the bottom flange will be restrained with closed stirrups. The transverse cracking that can occur with so many strands debonded together will be alleviated by terminating the bonded length of the strands at different locations along the length of the beam. Finally, the shear lag effect will not be an issue due to the length of the beams (100' to 145') distributing the compression.

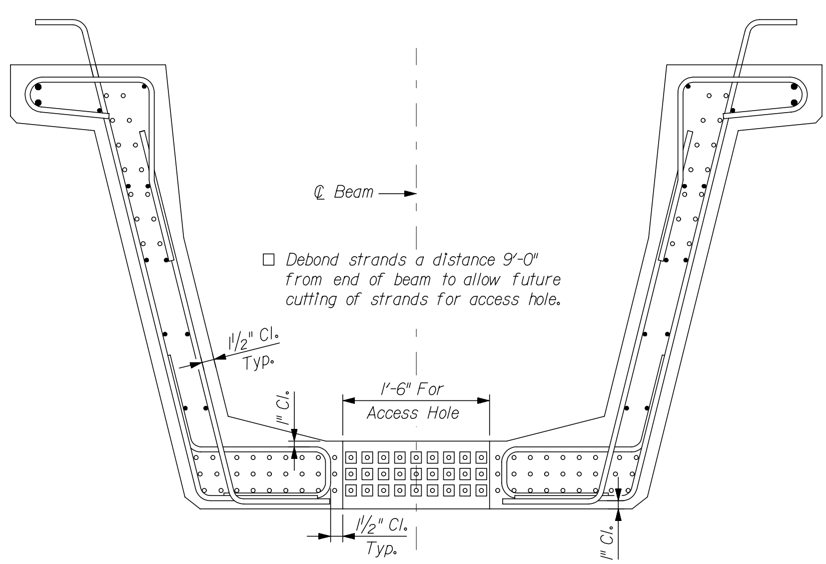

Fig. 14 Section through Beam at Access Hole

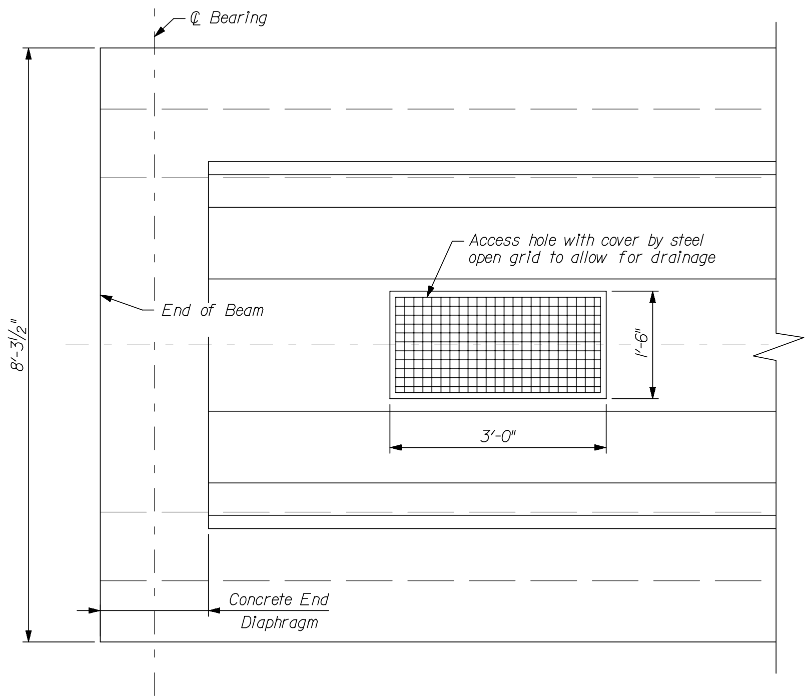

Fig. 15 Plan View of Access Hole

OPTIMIZED MATERIALS

High Performance Concrete (HPC) is proposed for all prestressed, precast U-beams on the *Accelerate 465* project. HPC accommodates longer span lengths and has the additional benefit of being less permeable than conventional concrete. This reduces the ingress of chlorides and slows the corrosion of reinforcing steel. It also provides mechanical properties that make it less prone to cracking during construction and under service loads. HPC has been implemented on numerous bridge projects throughout the country due to its many advantages over normal concrete. Concrete strengths are generally limited to a maximum 8 ksi according to the current practice of local precasters, but can be increased up to 10 ksi when warranted and with INDOT approval.

The use of HPC in precast units will not have a significant impact on the overall cost of the project. Although the price of HPC has fluctuated over the past several years, current information indicates a premium for HPC of approximately 10% may be expected.

WHY ON ACCELERATE 465?

Prestressed, precast concrete U-beams have never been used in Indiana before, so an implementation strategy needed to be developed and presented, demonstrating that the U-beam would cost effectively meet the project goals of improved safety, reduced traffic disruption and enhanced speed of construction while also showing how the U-beam compares favorably with other bridge types relative to design requirements, future rehabilitation, inspection, and structural efficiency. In addition, this implementation strategy illustrates how the beam would be introduced to the Design, Contracting, and Fabricating communities and how it would be presented in the contract plans.

COMPARISION TO OTHER STRUCTURAL SYSTEMS

Design: U-beams compare favorably to other structural systems, in particular prestressed concrete Bulb-T's and structural steel plate girders. The U-beam uses the same basic design principles as other prestressed structural systems, using bonded prestressing strands as the main load carrying elements, the same design procedures and criteria. Typical proprietary design software for precast concrete beams can design both the U-beam and the Bulb-T.

For live load distribution, L / 11 (where L = span) is used for all situations as defined by the TxDOT Design Manual, which is consistent with the requirements for I-sections. For dead load distribution, U-beams assume AASHTO's distribution as a minimum, but also acknowledge a heavier distribution of barriers and other superimposed loadings to the beams adjacent these elements. The result is an additional evaluation considering two thirds of the load to go to the first adjacent beam and one third to the next. These distributions result in conservative DL distributions, but are actually consistent with the TxDOT approach for U-beams, as well as several other agencies' policies for I-sections.

Rehabilitation: While acknowledging that introducing U-beams reduces future maintenance of traffic flexibility because of their width and the requirement of having the slab on both top flanges to maintain stability, there are other benefits to potential future rehabilitations that would be realized by using the U-beam.

The most difficult task during a deck replacement is removing the existing deck concrete that is bonded to the top of the beam without damaging the beam. U-beams are superior to Bulb-Ts in this regard as Bulb-Ts have more top flange area in contact with the slab and thinner top flanges as compared to the U-beam. The thinner top flange is more prone to cracking during the deck removal process.

Additionally, through the introduction of external post-tensioning, the capacity of a U-beam can be increased by up to 40%. To increase capacity on a Bulb-T bridge to that magnitude would warrant complete superstructure replacement. Although a steel girder's capacity can be increased by adding plates, the plates may result in a reduction in vertical clearance and may require jacking and/or roadway re-profiling to accommodate them.

Inspection: U-beams provide smooth external surfaces and fewer beams than traditional I-sections of either concrete or steel. Further, due to the modification made for the Indiana U-beam for drainage, internal inspection can be accommodated via the aforementioned access hole. The smooth face of the U-beam makes any potential problem easier to spot and because there is a reduction in external surface area to inspect, the inspection should take less time resulting in potential savings in both inspection personnel as well as traffic downtime.

Efficiency: U-beams provide a more efficient use of materials than a standard Bulb-T; approximately 20% more efficient with concrete and 5% more in prestressing steel use. Further, this efficiency allows for shallower structure depths than Bulb-T sections accommodating tighter geometric requirements and allowing for additional cost savings in approach roadway embankments, retaining walls and right-of-way. Although structural steel is more flexible in terms of structure depth than the U-beam and can potentially provide even more savings related to the approach roadway embankments, etc. than the U-beam, the shallower structure depths for steel girders typically translate into less efficient structures.

Due to their torsional stiffness, U-beams have better live load distribution than I-beams in general and will therefore not work as hard and should be expected to last longer. U-beams also have a much wider bottom flange than I-beams making them stronger and more redundant than an I-section, which is weaker against horizontal forces and is more vulnerable to vehicle impacts.

IMPLEMENTATION

Design: Since U-beams are a new section in Indiana, it is anticipated that most of the SDCs who will be performing the final designs for a majority of the corridor have never designed a U-beam. Therefore, design workshops will be initiated that will teach the SDCs how the dead and live loads should be distributed, and provide beam standardization through the use of beam templates, standard drawings and special provisions. In addition to the Design Workshops, meetings will also be held for Contractors and Fabricators to establish familiarity with the project requirements and maintain open communication throughout the design and bidding processes.

Fabrication Contract: Because prestressed, precast concrete U-beams have never been used in Indiana, no Fabricators in the area currently have the formwork and set-up necessary to make U-beams. This first led to the impression that there will be a large initial investment required to implement the U-beams, making them an inefficient section to propose. The reality, however, is that for a project the scale of *Accelerate 465* (52 bridges with approximately 1 million square feet of bridge deck), the initial investment in the formwork will have a minimal impact on the overall project cost, and that initial investment in U-beam formwork will benefit future projects.

Another issue related to implementing the U-beams was the number of contracts for the project. Given the overall size and cost for *Accelerate 465,* the project was broken up into multiple smaller contracts to keep the smaller local contractors competitive. This raised another concern about U-beam implementation because even though the initial set-up cost for the U-beam formwork could be amortized over the entire project, there was a potential that the first contract with only two bridges would end up with very high unit price costs for the beams because there was no guarantee that the fabricator winning the first job would win the subsequent contracts. For this reason a direct supply fabrication contract was introduced. The idea behind the fabrication contract is to reduce the precastor's risk regarding new equipment investment and labor training associated with introducing this new beam section.

Initial fixed costs associated with the fabrication of U-beams include:

- Preparation (Preliminary engineering, material storage)
- Infrastructure (electric, water, lighting)
- Lifting equipment
- Forms (foundation, casting bed, steel form, strand template)
- Storage Area (right-of-way, grading, bed covers)
- Miscellaneous Overhead (learning curve, set up)

Using the fabrication contract, these costs will spread out over many beams, reducing the overall impact and unit price for each beam.

To implement the fabrication contract, it will be necessary to closely coordinate with the construction contract schedules in order to accommodate beam delivery when required by the general contractor. This is important to limit excessive creep and shrinkage in the beams prior to erection.

In addition to the fabrication contract, on-site casting is also being promoted as part of this project because the U-beam formwork itself is less complicated than that required for casting Bulb-Ts. Bulb-Ts require movable side forms and hydraulics while the U-beam can be fabricated with a stationary bottom form and a simple U-shaped insert than can be lifted out. This simplicity makes the U-beam better suited for on-site casting which could introduce more competition by attracting more fabricators. Greater competition will keep the U-beam prices lower.

Delivery and Erection: One of the issues associated with the U-beam is its size. Because one U-beam effectively replaces two I-sections, their size is substantial. With that in mind, practical limitations were placed on the beam's length. Shipping lengths are generally limited to approximately 140 feet in length which defines the upper limit of the U-beams for this project. The resulting weight of a 140 foot long, 63" deep U-beam coupled with the corresponding weight of the articulated truck necessary to haul it to the site was determined to be less than the maximum tonnage that can safely travel on Indiana roadways without a permit. If a longer beam were required on another project, the additional costs and permits would have to be considered and factored into the final decision.

Because of the inherent stability of the U-beam, no external, intermediate diaphragms are required, thus eliminating the need to work under and between beams to place and remove formwork. This allows the U-beam construction to be a top-down operation thus improving the safety for both construction workers and the motoring public. Additionally U-beams will require fewer pieces to handle and, unlike I-sections, do not require special bracing during transportation.

CONCLUSIONS

The introduction of U-beams to *Accelerate 465* addresses specific project goals, allows for the innovative use of a proven technology, and will provide Indiana with a new cost-efficient structural system.

The main project goals for *Accelerate 465* are to:

- Maintain work site safety
- Deliver a long life corridor
- Provide context sensitive solutions
- Meet INDOT's construction budget and schedule

These goals are met in various ways by introducing the U-beam. Work site safety is enhanced by eliminating external diaphragms allowing U-beam construction to be a top-down operation, thus improving the safety for both construction workers and the motoring public. The use of HPC will improve the in-service performance of the U-beams and the natural torsional stiffness of the section coupled with the conservatism in both the live load and dead load calculations, should enhance the usable life of these bridges. The smooth lines of the U-beam enhance the structure's appearance, and the Context Sensitive Solutions team for the project indicated that the use of boxes (U-beams) for all bridges would be the single greatest influencer in creating a visually distinct and unified corridor. U-beams were shown to be cost competitive against other structural systems and will allow INDOT to accelerate their construction schedule, thus saving additional funds.

U-beam modifications to accommodate its implementation in Indiana include: modified section properties, draping strands, internal steel diaphragms, external post-tensioning capability, improved drainage and access hole, and optimized materials. A direct supply fabrication contract to reduce the precastor's risk regarding new equipment investment and labor training associated with introducing this new beam will be initiated to lower construction cost.

Implementation of this new U-beam will require further condition monitoring and analytical evaluation through the use of advanced instrumentation to more adequately determine the U-beam's performance. The areas of study will include: monitoring the U-beams to determine a more accurate live load distribution than the current, conservative S/11 value; measuring web bending and more accurately evaluating the web performance under combined bending and shear; and monitoring the bridge deck due to a higher restraint at the beam line, since the U-beam web is stiffer in bending, and due to more transverse bending, since the U-beam will have more live load distribution in the transverse direction. This study will result in more economic designs, potentially large cost savings, development of procedures to reduce maintenance costs and life cycle costs of bridges, and establish the U-beam as a standard beam section for the state of Indiana.

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