"A New Precast Concrete Beam Section for Rapid Bridge Construction"

Background

The Texas Department of Transportation (TxDOT) currently has a project under development for expanding the capacity of IH 35 near Waco, Texas. This project includes approximately 200 underpasses, which will either be new structures or replacements. Many of these underpasses have vertical constraints that limit the depth of the proposed bridge superstructures to 38". The maximum required span length is 100 feet and the design live load is HS25.

TxDOT's Rapid Bridge Replacement Program

Departments of Transportation across the country are becoming more sensitive to traffic disruptions and delays caused by construction. They are working on ways to reduce the onsite construction time and to limit traffic disruptions. The TxDOT Bridge Division is participating in this effort through their "Rapid Bridge Replacement Program". The object of the program is to minimize the bridge construction time perceived by the traveling public. The amount of construction performed at the site is reduced through the utilization of elements constructed off-site and then transported to the site for erection or installation.

Due to the high traffic volume in the IH 35 Corridor, TxDOT has decided to make this project one of the first to be designed under their "Rapid Bridge Replacement Program".

TxDOT's Solution

The solution developed by TxDOT utilizes steel "tub" beams (See Figure 1). Each beam is supported by its own column, which eliminates any need for a cap on the columns. In turn, each column is supported by a single drilled shaft, which eliminates the necessity of footings.

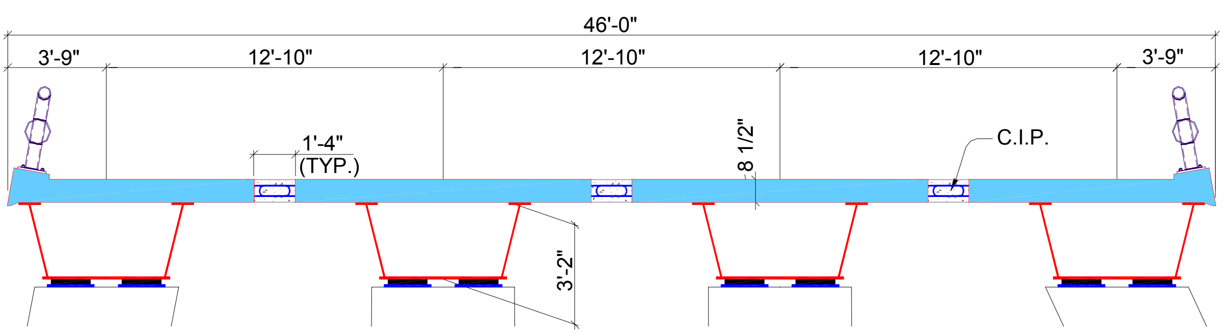

Figure 1 – Transverse Section of Steel Tub Beam Bridge

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The construction process is fairly straightforward. The shafts for the bents and abutments are first constructed. At the same time, the fabrication process of the beams should be underway. The steel beams are composed of steel plates welded together into a u-shape with sloped sides. Each beam will have a full-depth reinforced concrete composite bridge deck. These slabs would be formed and cast at the contractor's yard to save on-site construction time. The width of each of these slabs will allow for closure pours between the adjacent beam bridge decks. To further speed up the construction process, TxDOT is considering the use of precast concrete column "shells" that would serve as formwork for the cast-in-place interior portion of the columns. After the columns are constructed, each beam would then be erected. The closure pours between the composite beams are then made. Once the closure pours have cured sufficiently, the bridge may be opened for traffic.

TxDOT will be using two different composite beam types: an interior beam and an exterior (See Figures 2 and 3). The interior beams are symmetrical, while the exterior beams have a short concrete parapet on one side for the attachment of a rail. To reduce on-site construction time the rail is attached at the contractor's yard.

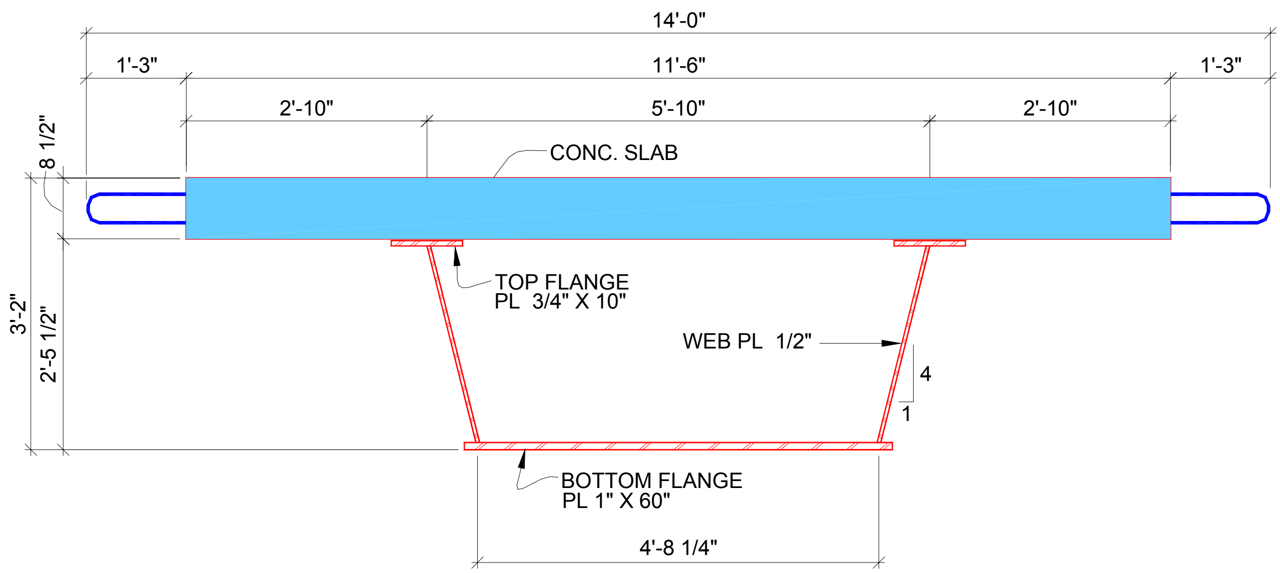

Figure 2 – Section of Typical Interior Steel Tub Beam

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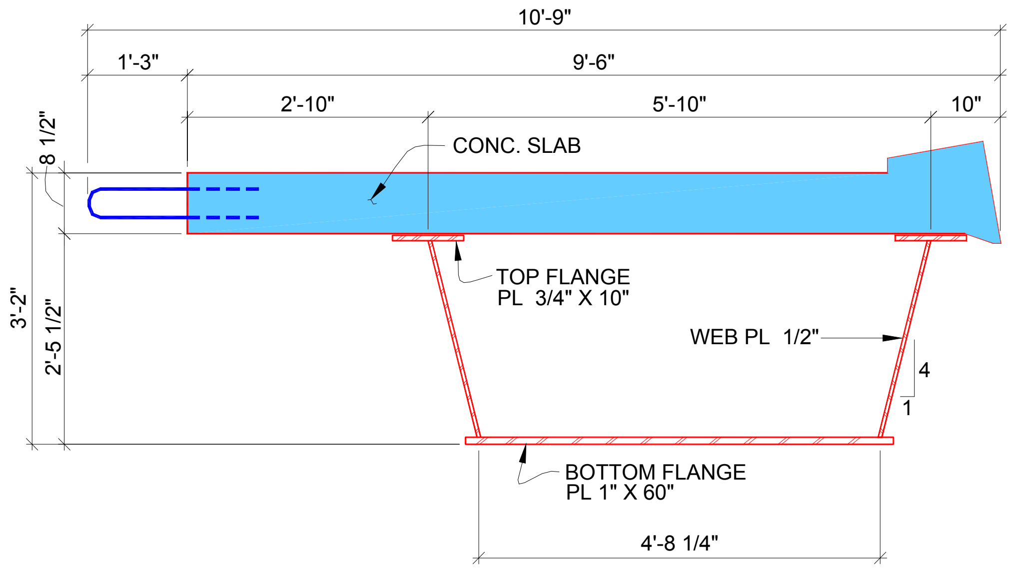

Figure 3 - Section of Exterior Steel Tub Beam

"Pre-topped U-beam" Alternate

The Precast Concrete Manufacturers Association of Texas (PCMA) hired us (Structural Engineering Associates) to develop a new precast concrete beam section as an alternate solution. Rapid Bridge Construction principals were also incorporated into this solution.

Because of the design constraints, none of the standard precast concrete beam sections currently produced in Texas would be capable of carrying the required loads with the required spans. A new section had to be developed.

A U-shaped section was selected for its aesthetic features. It is also similar in shape to the steel tub beams. Due to the required span of 100 feet and a design live load of HS25, a large number of prestressed strands are required. To resist the stresses caused by the strands at transfer of the prestress force to the concrete section, a top flange must be cast on the U-beam prior to transfer, which leads to one of the names given to this section: "The Pre-topped U-beam".

TxDOT has in the past raised concerns about the single stage fabrication of prestressed concrete beams with closed sections. One concern is the difficulty of verifying the bottom flange and wall thicknesses. To alleviate this and other concerns, this beam section will be constructed in two stages. The U-shaped part of the section is cast first and then, after removing the interior forms, the top flange is formed and cast. Once the entire beam section reaches its release strength, the prestress force is transferred to the beam.

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To facilitate the fabrication of the "Pre-topped U-beam", the side slopes and soffit width of the other U-beams currently being produced in Texas are being utilized. This means that this beam may be fabricated using existing prestressing beds (lines) and soffit forms. A great deal of savings is realized, since the precasters will not have to invest in new prestressing lines or soffit forms. The bottom flange of this beam measures 4'-7", while the top of the U-shaped part of the section measures 5'-9" out to out. The top flange width measures 7'-11 ½". The top flange thickness is 6" and the bottom flange thickness is 10 ½", while each web is 8" thick.

These "Pre-topped U-beams" will also have both interior and exterior beam sections. The interior beams will have notches at both edges of the top flange to provide for a closure pour (See Figure 4). The exterior beam will have a notch at the interior edge of its top flange, while at the other edge it will have a concrete parapet with the traffic rail attached prior to erection (See Figure 5). Once the beams are in place, the top flanges of the beams serve as the forms for the cast-in-place closure pours and bridge deck (topping).

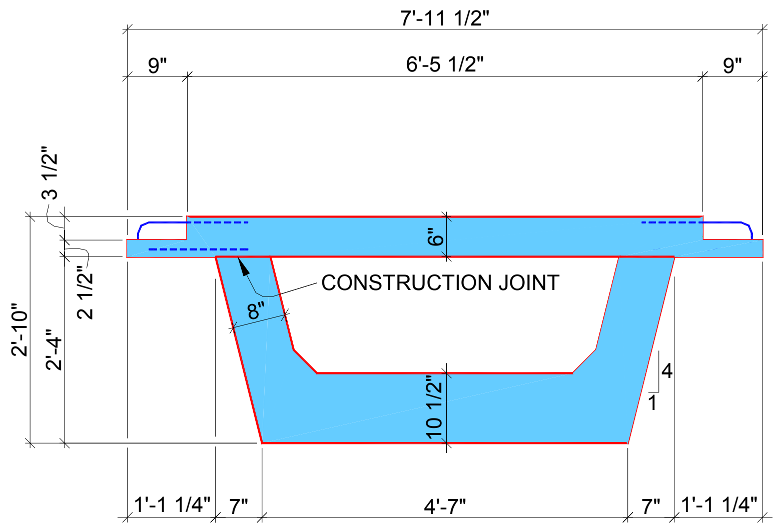

Figure 4 – Section of Typical Interior "Pre-topped U-beam"

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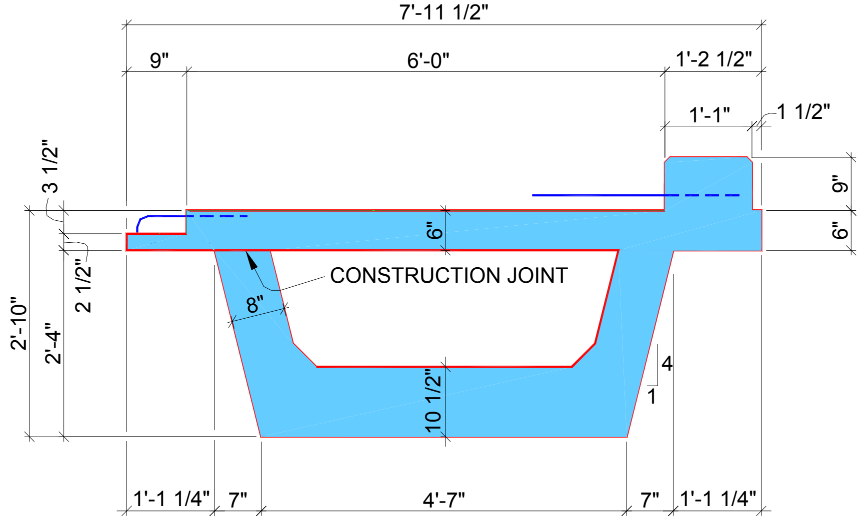

Figure 5 – Section of Typical Exterior "Pre-topped U-beam"

The typical bridge for the IH 35 project will be 46'-0" wide and have spans of 100 feet. Due to our desire to have standard section widths, it was decided to provide bridge widths in increments of 8'-0". Therefore, our solution will provide a bridge width of 48'-0" (See Figure 6). Despite having to use more concrete beams than steel beams per span and additional substructure, our opinion of the probable construction cost of the "Pre-topped U-beam" bridge alternate would be considerably less than that for the steel tub beam bridge.

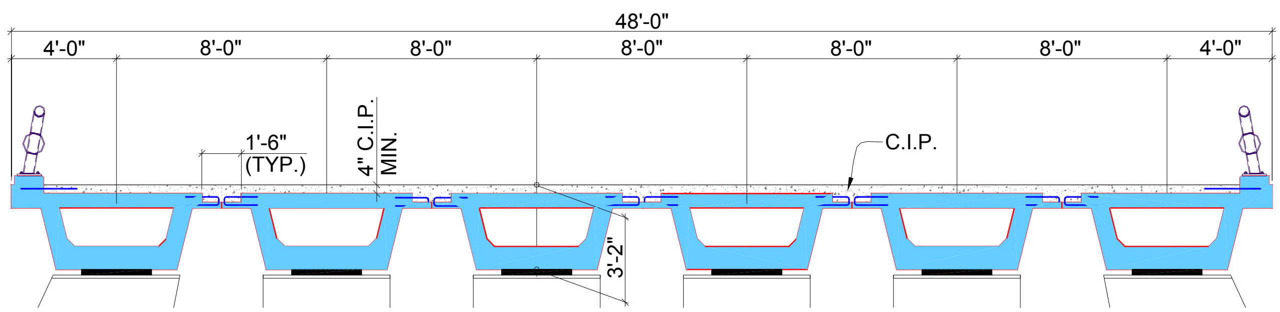

Figure 6 - Transverse Section of "Pre-topped U-beam" Bridge Alternate

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Design Issues

1. From nearly the beginning of the development of the new concrete beam section, one of the more important design issues was the determination of the distribution factor to be used to design the "Pre-topped U-beam". The superstructure with these beams appears to fall in the AASHTO category of "Spread Box Girders". For an interior beam, the distribution factor based on the formula in Section 3.28.1 of the 16th Edition of AASHTO's "Standard Specifications for Highway Bridges" is 0.57. In other words, each beam receives the 57% of the live load + impact applied to one lane. Using Table 4.6.2.2.2b-1 from the 2nd Edition of the AASHTO LRFD Bridge Design Specifications, the distribution factor would be 0.54. On the other hand TxDOT uses in the design of their interior U-beams a formula for the distribution factor of S/11 (where S = Beam Spacing), which yields a distribution factor of 0.73.

   At this stage of section development, the more conservative value of 0.73 has been used to avoid any disagreement. If the "Spread Box Girder" value of 0.57 were used, a significant reduction of required strands and concrete strength would be realized.

   In order to demonstrate the likelihood that the distribution factor of 0.73 is conservative, it will be compared with that used for the steel tub beams. The formula used to determine the distribution factor for the steel tub beams may be found in Section 10.39.2.1 of AASHTO's Standard Specifications. The calculated distribution factor is 0.83 for each of the four beams. Consequently, the bridge with steel tub beams has the capacity to carry (0.83 * 4 beams =) 3.32 lanes of traffic, while the bridge with "Pre-topped U-beams" can carry (0.73 * 6 beams =) 4.38 lanes of traffic. That is to say, one more lane of traffic. Based on this demonstration, it appears likely that the distribution factor used for the concrete beams is overly conservative.

2. Based on the previous design criteria, the beam requires 86 ~ ½" diameter, 270 ksi low relaxation strands and concrete strength at release (or transfer of prestressing force) of 6,021 psi. The required 28-Day concrete strength is actually less than the release strength. The 28-Day Strength required for the cast-in-place topping is 4,000 psi.

3. The maximum live load deflection of L/800 (where L = span length) is a limiting value for both beam types. For the two specific bridges herein considered, it appears that live load deflection is more critical for the steel tub beam bridge.

4. The weights of both beam types were constrained due to crane capacity limitations. The weight of each of the steel tub interior beams @ erection would approximately be 160,000 pounds, while that of the interior "Pre-topped U-beams" would approximately be 148,000 pounds.

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Construction Issues

1. One of the advantages of the steel tub beam option is that the composite slab is full-depth, therefore the only bridge deck concrete that has to be poured at the site is for the closure pours. This advantage leads to a disadvantage; namely, there is very little room for error for the top of bridge deck elevation. Any errors that cannot be corrected by adjusting bearing seats would have to be addressed by grinding the top surface of the bridge deck. The appearance of the ground concrete surface would make a new structure look like it was repaired.

2. A disadvantage of the full-depth closure pour of the steel beam option is that it has to be formed over the traffic lanes. If the forms were not stay-in-place, they would have to be stripped over the traffic lanes.

3. Another disadvantage of the steel beam closure pour is that its concrete color would never match that of the composite slab concrete.

4. The "Pre-topped U-beam" alternate also has an issue of reduced tolerance. Since the beams would be placed nearly directly adjacent to each other, the amount of tolerance permitted for sweep would be small. Sweep should not be a significant problem with these beams, however, since these beams would be very stiff in the horizontal direction.

5. Another construction issue for the "Pre-topped U-beam" is the differential camber that would occur between adjacent beams. No two beams would ever have the same camber, however, the cast-in-place topping on the beams provides the benefit of a smooth riding surface regardless of the camber differences between the beams.

6. The "Pre-topped U-beam" would be easier to transport than the steel tub beam. The interior steel tub beam unit measures 14'-0" wide, while the interior "Pre-topped U-beam" unit measures less than 8'-0" wide. The steel tub beam unit would also be more top heavy, which may reduce its stability during transportation from the contractor's yard to the bridge site.

7. Generally, the quality control at a precast plant is higher than at the construction site or contractor's yard, therefore the overall quality of the "Pre-topped U-beam" bridge should be higher than that of the steel tub beam bridge. Most of the superstructure of the concrete beam bridge would be fabricated at the precast plant. The 4" topping would be the only portion of the superstructure poured at the construction site.

8. Any lifting devices used for the steel beam units would mar the appearance of the top surface of the bridge deck, since after the device is removed, the pocket in which it was located would have to be patched. In the case of the concrete beam units, after the lifting devices are removed or cut, the topping would cover the entire beam surface.

9. Of course, construction time perceived by the travelling public is a major issue. Once the steel tub units are erected, formwork must be installed for the closure pours and then the pours themselves must be made. After the "Pre-topped U-beams" are erected, the reinforcing for the topping must be placed and then the topping poured. The construction of the concrete beam superstructure should take no more than one day longer than the steel beam superstructure. The situation would reverse, if any grinding of the top surface of the steel beam superstructure were required.

Cost Comparison

Despite the attention being paid to aesthetics and speed of onsite construction, economics remains of utmost importance. The most economical bridge that could be constructed in Texas would be composed of pretensioned concrete I-beams. Also, for a modest increase in cost, pretensioned concrete U-beam spans could be used instead of I-beams. Logically then, it should be expected that a bridge utilizing pretensioned concrete beams would be less expensive than one utilizing steel beams. A detailed economic comparison seems to bear this out.

TxDOT has a database of the "Average Low Bid Unit Price" for various items, such as beams, slabs and columns, constructed statewide. The unit price listed for each of the items is the average of the unit prices submitted by all of the successful low bidders on construction projects from across the state. A twelve-month moving average is maintained by the database. Together with industry input, this database was used to develop the opinions of probable construction costs of each of the items. Many of the components of both bridge options such as the rail, backfill and retaining wall will be the same. Below, only those values that are different in the two options will be evaluated and compared, since all of the other items would have the same cost. The difference in the total amount of these values will be the difference in the total opinion of cost of the bridges.

The cost of $1.00 per pound of steel, which is being assumed for the steel tub beams is a conservatively low number. For the slab to be cast on top of the steel tub beams, the cost being assumed is $325/cy, which is the same cost as a typical reinforced concrete deck slab. This cost is also conservatively low, because for typical bridge deck slabs, only the two exterior overhangs must be formed using overhang jacks (trusses), whereas for the steel tub beams, two overhangs per beam or eight overhangs per span would have to be formed this way. This would result in a greater cost, which is not included. Since the closure pour must be formed onsite and the volume of concrete is small, a cost of $400/cy is being assumed. See Table 1 for the cost of those items (for one 46' wide x 200' long, two span Steel Tub Beam Bridge) that are different from the "Pretopped U-beam" Bridge Option. Based on the above unit prices this cost would be $377,495.

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46' WIDE x 200' LONG STRUCTURAL STEEL TUB BRIDGE OPTION				
Item Description	Unit	Quantity	Unit Price	Extension
Steel Tub Beams (800 LF @ 362 PLF)	LB	289,600	$1.00	$289,600
Concrete Deck - Cast on Beams Off-site	CY	241.4	$325.00	$78,455
Closure Pours (3 EA) Cast Onsite	CY	23.6	$400.00	$9,440
TOTAL				$377,495

Table 1 – Opinion of Probable Construction Cost of Differing Components of Steel Tub Bridge

Texas precasters believe that the assumed unit price of $400/CY of concrete in the "Pre-topped U-beam" is reasonable. For the sake of comparison, an AASHTO Type IV Beam has a cost in the neighborhood of $300/CY of concrete according to TxDOT's database. The "Pre-topped U-beams", when placed directly adjacent to each other, provide both the bottom and side forms for the cast-in-place portion of the slab. No forming is required, therefore a unit price of $200/CY used for the topping concrete. Since the steel tub bridge provides one column per beam line to eliminate the necessity of a bent cap, the same will be done for the "Pre-topped U-beam" bridge. Since the "Pre-topped U-beam" bridge will have two more beams per span than the steel tub bridge, then it will have six additional columns and foundations (two per abutment/bent line). A cost for the columns of $425/CY of concrete nearly matches the value from TxDOT's database. According to TxDOT's database, an approximate cost for a 36" diameter reinforced concrete drilled shaft is $115/LF. See Table 2 for the cost of those items (for one 48' wide x 200' long, two span "Pretopped U-beam" Bridge) that are different from the Steel Tub Beam Bridge Option. Based on the above unit prices this cost would be $187,720.

48' WIDE x 200' LONG "PRE-TOPPED U-BEAM" BRIDGE OPTION				
Item Description	Unit	Quantity	Unit Price	Extension
Pretopped U-beams (800 LF @ 0.365 CY/LF)	CY	292.0	$400.00	$116,800
Concrete Deck - Cast on Beams On-site	CY	112.6	$200.00	$22,520
Additional Columns (6 EA @ 5' x 5' x 17')	CY	94.4	$425.00	$40,120
Additional Shafts (6 EA @ 36" Dia. X 12')	LF	72.0	$115.00	$8,280
TOTAL				$187,720

Table 2 – Opinion of Probable Construction Cost of Differing Components of "Pre-topped U-beam" Bridge

Based on the above costs per bridge, a savings of $189,775 per bridge could be achieved by constructing a "Pretopped U-beam" bridge in place of a steel tub bridge. Even if only five bridges out of the approximately 200 are permitted to utilize "Pretopped U-beams", approximately $950,000 could be saved. This beam type deserves at least the opportunity to compete against the steel tub beams as an alternate design. The best way of determining the more economical superstructure is to place details of both options in the contract plans and allowing the contractors to select the option they prefer.

Status

A presentation of the "Pre-topped U-beam" alternate has been made to TxDOT, the PCMA and the Associated General Contractors (AGC). TxDOT has been receptive to this new beam section, however, this beam is not yet slated for use in any projects.

The Future

Our goal is that this beam section be further standardized for use in future bridge projects. The span and design live load, required by the IH 35 project, are pushing the limits of "Pre-topped U-beam" section and the steel tub beams in their current configuration (due to live load deflection limits). For less restrictive conditions, this precast beam section could be provided in nominal widths of 8 feet and 10 feet to provide various combinations of bridge width. Beam flares can be accommodated through blocking out portions of the top concrete flange. For either the steel or concrete beam systems, the number of columns could be reduced by the use of precast concrete bent caps.

Conclusion

Regardless of any difference of opinions over any specific issue, it should be clear that the "Pre-topped U-beam" should at the very least be allowed to compete as an alternate.

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