TxDOT STANDARD PRESTRESSED BRIDGE PRODUCTS

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ABSTRACT

TxDOT is using over one million linear feet of prestressed concrete beams annually in its bridge building efforts. TxDOT's current inventory of standard prestressed bridge beams include I-, U-, box, slab, and double-T beams—each possessing unique benefits and features which are employed to solve specific bridge design problems. For the future, TxDOT, in collaboration with the Texas precast industry, is developing a new generation of I-beams that will replace its current series of standard I-beams. These new I-beams have extended span capability, provide more stability and durability, and optimize production facilities. To further capitalize on prestressed technology, TxDOT is implementing other new, innovative, prestressed beams such as pre-topped U-beams and decked slab beams. Both of these new beams promise to provide TxDOT rapid-construction alternatives to current systems.

INTRODUCTION

Prestressed concrete beams are the predominant element in Texas bridges. This is a reflection of the durability, low cost, and adaptability of prestressed concrete. A key factor in TxDOT's widespread use of prestressed beams is cross section standardization, facilitating economical mass production of these bridge elements. No one cross section is optimal for all bridges, leading to variations of beam type and size, each targeted to address specific bridge geometries and construction challenges.

TxDOT's standard prestressed beam types will be identified, along with their applications. New beams that TxDOT is employing to address the challenges of rapid construction and the new generation of I-girders being developed in TxDOT/industry collaboration are discussed.

STANDARD BEAM SECTIONS

I-beams are the most frequently used beam section due to their adaptability to a wide variety of span lengths, skew angles, and bridge curvature. TxDOT uses five specific cross sections—its own Types A, B, and C beams along with AASHTO Types IV and VI. Figure 1 shows the typical cross-sections for all the I-beams. The Type IV beam is the most frequently used and the Type C is next. These two sections are most economical in spans of 115' and 75', respectively.

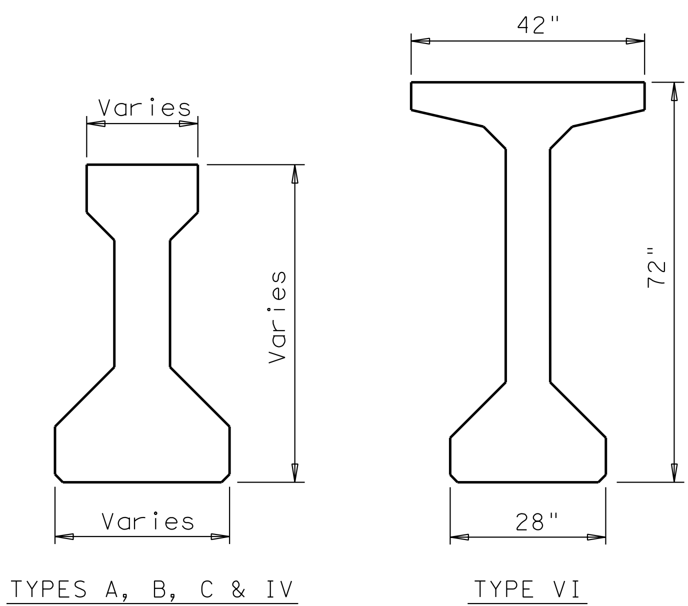

Figure 1 I-beam cross-sections

TxDOT's I-beam bridges are a case study in simplicity—the beams rest on elastomeric bearings, no permanent diaphragms between beams are used, and a deck slab, formed with precast sub-deck panels, is placed continuously over a number of spans, forming multi-span units. This simplicity results in TxDOT's lowest cost bridge system.
Box beams are employed by TxDOT when the section depth of an I-beam exceeds specific bridge constraints and on rapid construction projects. These beam sections, shown in Figure 2, are TxDOT's own and come in two widths — 4' and 5'. They are provided in four depths ranging from 20" to 40" and their sides are based on the side forms of Type A I-beams. Placed side by side on bent caps and set normal to the roadway, the large shear keys are filled with concrete and the beams are then topped with either a concrete deck or an asphaltic concrete pavement (ACP) overlay. Transverse post-tensioning is applied to the beams when they are topped with ACP.

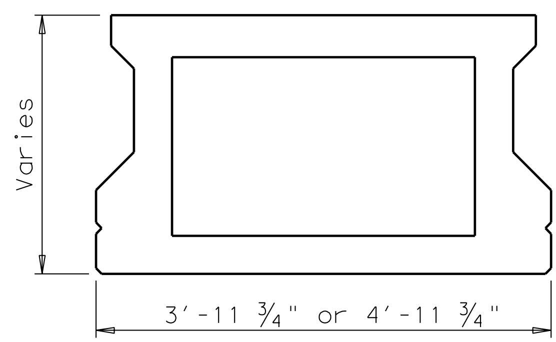

Figure 2 Box beam cross-section

TxDOT's box beams provide exceptional span to depth ratios, up to 30, but the adjacent beam system used by TxDOT restricts their use to the simplest of bridge geometries. Only occasionally has TxDOT employed its box beams in a spread configuration, which will be pursued by TxDOT more in the future. Box beams used in a spread configuration will permit box beam use with more complex roadway geometries.

Similar to box beams, TxDOT uses non-voided slab beams, shown in Figure 3. These are used in adjacent beam decks without shear keys and with a cast-in-place concrete deck. Details are provided for beam widths of 4' and 5', allowing them to be fabricated on box beam precasting beds, and come in two depths—12" and 15". Lacking void forms, they are easier to fabricate than box beams.

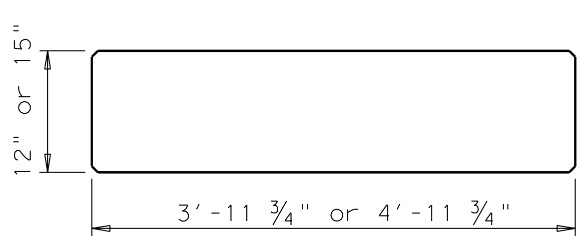

Figure 3 Slab beam cross-section

Slab beams are excellent for short span bridges and especially when high span to depth ratios are necessary. Like box beams, they are best suited for very simple bridge geometries.

TxDOT's standard beam section best suited for rapid construction is the double-T. Details are provided in three depths ranging from 22" to 36" and in 6-, 7-, and 8-ft. widths. Beam to beam connections have evolved over the years and the detail presently used, shown in Figure 4, was developed following a TxDOT-sponsored research project investigating double-T connections.[1] The connection utilizes a longitudinal bar welded in a v-groove formed by steel plates in the flanges. When speed of construction is imperative, the beams are topped with an ACP overlay; the beams are covered with a concrete deck otherwise.

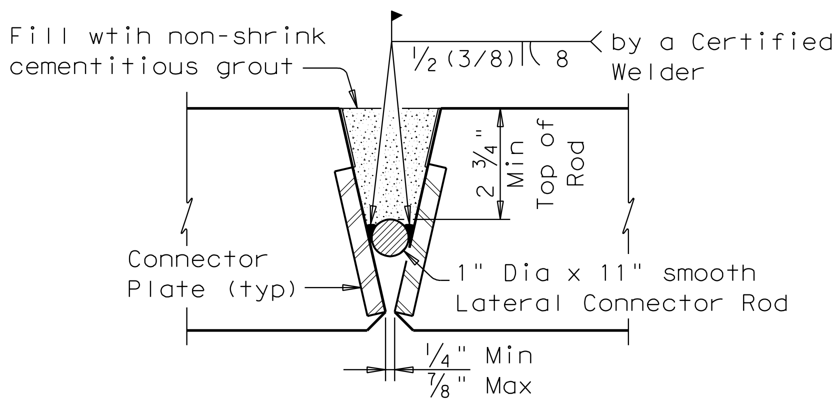

Figure 4 Double-T beam connection

Recent additions to TxDOT's standard double-T sections include beams with wider stems, allowing twice as many strands, as seen in Figure 5. These new sections extend the maximum span capability of double-T beams from 65' to 85'. Double-T beams are utilized for non-skewed bridges with a constant roadway width.

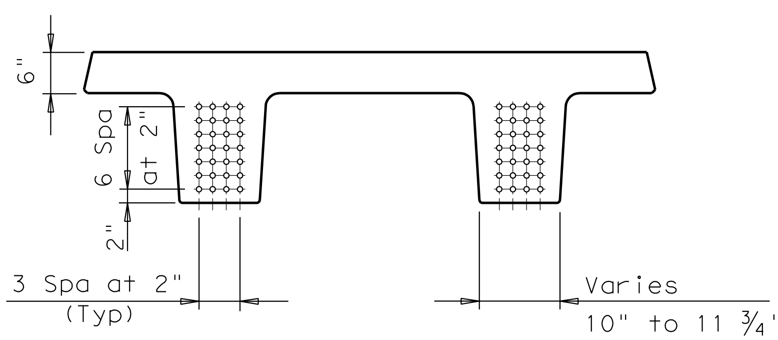

Figure 5 Double-T beam with wider stem

The most unique standard sections are U-beams, developed by TxDOT in close collaboration with industry. These beams, shown in Figure 6, are tub-shaped with sloping webs and provide a more aesthetic option to I-beams. Standard depths are 40- and 54-

inches, with maximum span lengths of 105' and 120', respectively. The 54" deep sections, Type U54 beams, are the most frequently used. No strands are depressed in U-beams; debonding is used to control beam end stresses.

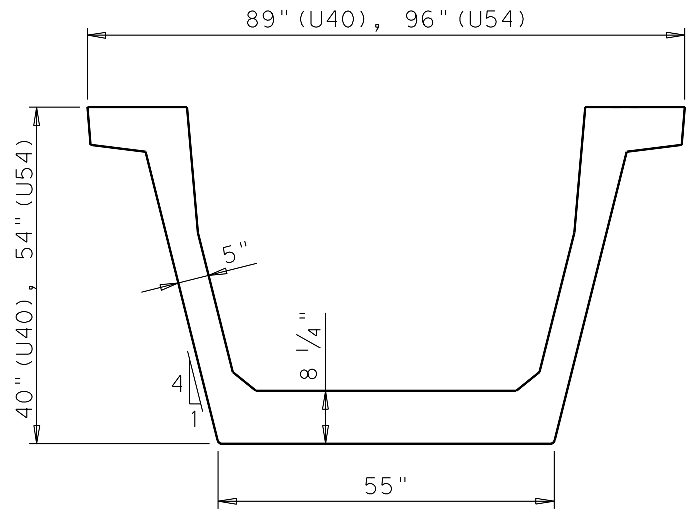

Figure 6 U-beam cross-section

Although more expensive than I-beams, spans framed with U-beams require fewer beams—due to their high structural efficiency—which can result in an economic advantage. U-beams are being used in urban settings and, when coupled with an aesthetic substructure, present a very attractive, clean appearance.

RECENT INNOVATIONS

In 2004, the pre-topped U-beam debuted. This beam was developed at the initiative of Texas' precast industry to provide an alternative section for rapid construction projects. The pre-topped U-beam, shown in Figure 7, is a version of the standard U-beam, with the webs truncated and widened. Instead of using precast sub-deck panels to form the deck, a 7" slab is cast on the beam by the fabricator, providing a total beam depth of 34". The beams are spaced with a 1" to 8" wide gap between flanges, and the deck is completed with a closure pour over the gap and a 4" topping. The total superstructure depth is about 40" and can span 115' when using 0.6" strand, an initial concrete strength of 6,500 psi, and 75% debonding of strands.

The pre-topped U-beam is best suited for long span structures that require a shallow superstructure. The total superstructure depth is less than a U40, but the span length, at 115', is more in line with a U54 or Type IV I-beam. This gives a span to depth ratio of about 35. As noted, high concrete strength and prestressing force are required to achieve this span.

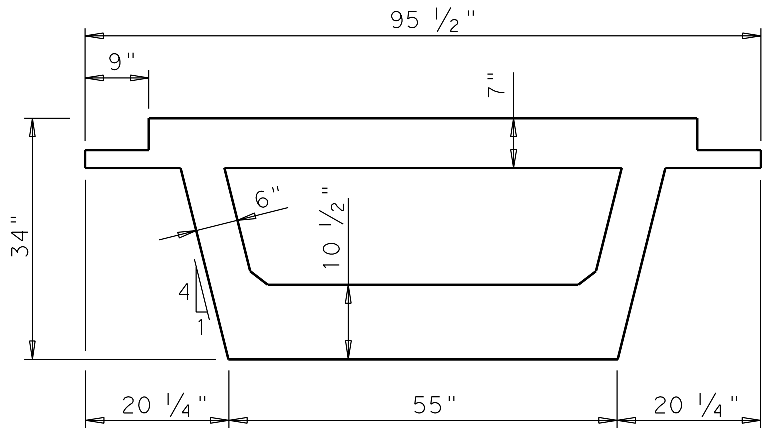

Figure 7 Pre-topped U-beam cross-section

The pre-topped U-beam was developed for and first implemented on a totally prefabricated bridge project in Waco, Texas. The driving factors for the project were speed of construction and ability to control ride quality with the use of a precast deck system. These factors resulted in a construction process that was a departure from normal. All of the beams were erected on false bents in a staging area, the closure pour was blocked out, and the 4” topping was placed with a transverse screed. The parapet for the traffic rail was also cast at this time. Figure 8 shows the beams with topping and parapet. After curing, the beams were lifted into their final position on the bridge. The remaining step was pouring the closure.

Figure 8 Pre-topped U-beams erected in staging area, Waco, Texas

A direct result of pre-placement of the 4" topping and parapet was beam erection and deck finishing with only one traffic closure. This was of huge benefit because the structure crossed IH-35, a major interstate route through Texas. Also, the forming that must be done over the traffic lanes was practically eliminated, making a safer environment for the workers. An alternative to the staging step would have been casting a full depth precast deck on the U-beam by the fabricator. This, though, would have hampered control of the ride quality, which was a high priority on the project. The staging allowed for quality deck placement while accounting for the unique camber and cross-slope of each beam.

While the construction process was unique, the staging step was time-consuming and a staging area may not be available at all future sites. For upcoming projects, TxDOT will move back to a conventional slab placement, except that precast sub-deck panels are not needed because the beams already have integral slabs. The closure pour and 4" topping will be placed simultaneously in the final erected position. The finished Waco bridges have generated much interest around the state, and design for the next round of pre-topped U-beam bridges is already underway.

Another beam developed for rapid construction is the decked slab beam, shown in Figure 9. This beam falls into a class with box beams, double-T beams, and slab beams – well suited to off-system replacements that must be opened quickly to minimize disruptions caused by long detours.

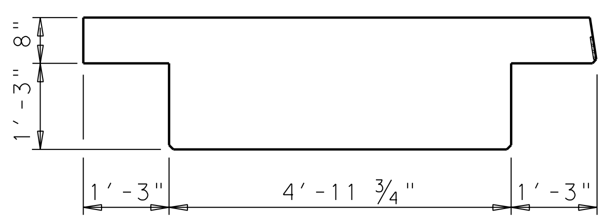

Figure 9 Decked slab beam cross-section, exterior beam

The decked slab beam was developed for County Road 453 over Battleground Creek, an off-system bridge built in February 2006, shown in Figure 10. This bridge needed a superstructure capable of spanning 60' and preferably no deeper than 2' because of frequent high stream flow. An 8" thick, 7'-6" wide slab was integrated on top of a standard 5'-0" wide, 15" deep slab beam, creating a T-shaped beam. The connection detail for double-T beams was adapted to the thicker slab.

The goal of the project was to reduce or eliminate cast in place concrete in the bridge and install it as quickly as possible; the decked slab beam was an essential part of meeting the goal. Precast abutments were connected to steel piles, the decked slab beams installed, and an ACP overlay was placed. Rail anchor bolts were cast into the beam, making the rail installation a matter of bolting the steel posts in place.

Figure 10 County Road 453 over Battleground Creek

The decked slab beam has several advantages over the other rapid construction options. Double-T beams for an equal span length are deeper. Box beams, although slightly shallower, require a substantial volume of cast-in-place concrete for shear keys and transverse post-tensioning with an ACP overlay. Slab beams are also shallower, but require a cast in place deck. The decked slab beam only requires a modest amount of grout for longitudinal connections and then an ACP overlay.

Besides reducing cast in place concrete, the objective of the wide integral slab is to minimize the number of beams needed for a cross-section by utilizing the maximum transportable beam width. The decked slab beam is wider than all but the 8' double-T beam, thus requiring fewer beams and making for faster installation. One downfall is the weight of these beams; at 1,700 pounds per linear foot they require more consideration in moving and placing.

TxDOT intends to develop standard details for both the pre-topped U-beam and decked slab beam cross-sections. With these standard drawings available, these beams will become excellent choices for rapid construction of long span and short span bridges, respectively.

NEXT GENERATION BEAMS

Over the years, many varieties of I-beam and bulb tee shapes have emerged in an attempt to create more efficient beams. TxDOT has long used the I-beam and steered away from bulb tee sections. The I-beam sections TxDOT uses were developed almost 50 years ago and the span lengths they were envisioned for are now routinely exceeded using higher strength materials. Another drawback of these sections occurs at fabrication plants—each beam has a unique bottom flange width, forcing time-consuming form changes to produce different beams on a given production line. To help meet future design challenges with the economical I-beam, TxDOT's Bridge Division invited the Precast Concrete Manufacturers Association of Texas (PCMAT) to collaborate in the development of a new series of I-beam sections with these goals: improve span to depth ratio; facilitate wider beam spacing; provide stability for safe handling and erection; add more depths to optimize vertical clearance; minimize production costs; maintain ease of fabrication; and take advantage of material improvements.

PCMAT and TxDOT representatives met in April 2005 to discuss the impact of web width, flange geometry, web/flange transitions, and one-piece vs. three-piece side forms on production. The result of the discussion was a draft of dimensions for two beam series to be further investigated.

WEB WIDTH

Thinner webs contribute to lighter sections and structural efficiency, while thicker webs minimize concrete placement difficulties and maximize shear strength. Thinner webs are more difficult to fabricate and thicker webs add to beam self weight. PCMAT representatives and TxDOT fabrication inspection personnel noted the difficulty in maintaining a 1" minimum clear cover in 6" thick webs with 0.6" diameter strands. TxDOT personnel also noted the ability to visually trace the draped strand pattern on the finished web through differences in concrete shading along the strands, which led them to question the long term durability of these beams. The AASHTO Type IV and TxDOT Type C beams have 8" and 7" thick webs, respectively, and represent the bulk of Texas I-beam fabrication. No problems were voiced with either of these two web thicknesses.

A 7-in. thick web was agreed upon as the best compromise between structural efficiency, ease of fabrication, and shear strength while still permitting the use of modest sized (3-in.) post-tensioning ducts to accommodate spliced girder construction.

BOTTOM FLANGE

Bottom flange width, tied to the maximum number of strands per row allowed, was discussed thoroughly. The beams with the most strand positions in their flanges' lowest levels minimize strand consumption. PCMAT representatives noted a significant number of their beam production lines would require costly stressing hardware reconstruction if 16 strands per row were required. Using a limit of 14 strands per row, 2 more than the maximum currently required for TxDOT I-beams, would be possible on almost all production lines.

Based on these discussions, TxDOT agreed to evaluate and compare structural performance of beam sections with bottom flanges permitting 16 vs. 14 strands per row. The 16 strand flange was developed with a 1:3 slope on its upper flange surface. The 14 strand flange was given a 1:2 slope, allowing more strand positions in the upper portion of the flange to offset those lost in the lower extremity. A side benefit foreseen with the 1:2 slope is facilitation of air removal during concrete placement.

To optimize production capability, a uniform bottom flange width for all beam depths is necessary. Fabricating beams of different bottom flange width on the same production line forces a change in the bottom formwork, a time-consuming process. PCMAT representatives stated a uniform bottom flange width would help in minimizing fabrication costs.

TOP FLANGE

Several modern precast beam sections possess wide top flanges, 42” and greater. The most common reason stated for such wide top flanges is to reduce slab formwork. A benefit of wide top flanges is also erection and handling stability, provided the extra width doesn’t create a top-heavy section. To minimize top flange weight, thin top flanges are used. Too thin a top flange creates difficulty in form removal—the potential for damage is greatly increased with a delicate top flange—and also creates strength problems with standard slab overhang formwork supports.

A disadvantage of a wide top flange is the very large haunch that results when these beams are used on curved alignments. Also, the precast sub-deck panels TxDOT utilizes are difficult to grade when cross-slopes start getting large and top flanges are wide.

PCMAT representatives stated that wide top flanges would reduce the number of beams they could store at their yards. TxDOT agreed to further study the effects of top flange width on span capability and erection stability in light of PCMAT’s concerns.

WEB/FLANGE TRANSITION

Use of chamfers or fillets at the junction of webs and flanges is good for two reasons—at the top flange they increase the throat to help with concrete placement into the web and at the bottom flange they help with air removal as concrete is placed.

PCMAT representatives had no preference over either and TxDOT preferred a fillet, with an 8” radius at the bottom and a 3” radius at the top, primarily for aesthetic reasons. Subsequent input from a formwork company steered TxDOT away from the large radius fillet to a chamfer that closely mimics the look of the rounded transition. The formwork representative noted a true radius was not possible, and creating a “modified” radius would be a time-consuming and expensive process. The chamfer was, therefore, the best compromise between aesthetics and economy.

SIDE FORMS

The NU series of girders developed by the University of Nebraska feature the ability to utilize three-piece side forms by having constant flange geometry and web filler forms to accommodate varying section depth.[2]

PCMAT representatives indicated a strong preference for one-piece side forms—necessary for formwork durability in a high production environment—and would order their forms as one-piece even if beam sections allow for three-piece side forms. One-piece side forms also eliminate time required to disassemble/assemble formwork.

Having fabricator consensus on preference for one-piece side forms opened the door for more section optimization. Shallower girders would not have to be provided an unnecessarily deep bottom flange, provided for the higher number of strands required for deeper girders and longer spans.

PARAMETRIC STUDY

After this first beam development meeting, TxDOT undertook a parametric study of six sets of beam sections. One group of three beam section sets had a maximum of 16 strands per row with each of the sets having a unique clear cover value—1.75", 2.0", and 2.25". The other group had three sets of beam sections with a maximum of 14 strands per row and the same clear cover values. Clear cover was varied to determine if TxDOT would pay a penalty in span capability to achieve enhanced long-term durability.

Each set of beam sections had seven depths—28", 34", 40", 46", 54", 62", and 70". These depths closely match TxDOT's existing sections and the 46" and 62" deep sections are new to TxDOT. The wide range provides designers with the ability to better optimize structure section depth and vertical clearance for a given span length.

TxDOT's in-house pretensioned beam design software, Prestress14, and the AASHTO LRFD Bridge Design Specifications were used to determine maximum span capability of the draft beam sections. In keeping with TxDOT design practice, concrete was limited to 6,500 psi and 8,500 psi for release and final compressive strengths, respectively. Based on local industry preference, ½" strands were used for all beam designs 54" deep and under. For beams over 54" deep, 0.6" strands were utilized to minimize the number of draped strands. Available strand positions are seen in Figure 11. Interior beam live load distribution was applied for beam spacing of 7', 9', and 11'.

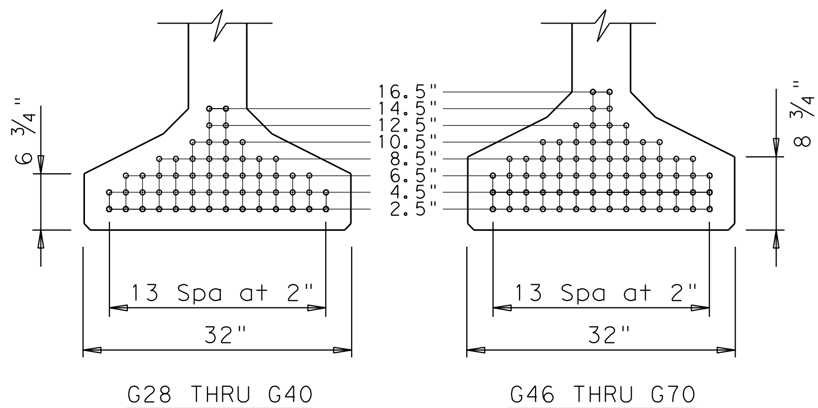

Figure 11 New I-Beam strand positions

From this study, it was concluded that clear cover had little to no effect on maximum span capability. As expected, the beams with 16 strands per row out-performed those with 14 strands, but very slightly and not enough to justify expensive reconstruction of some fabricator's stressing hardware.

Based on the results of this study, TxDOT committed to further evaluation of the set of beam sections shown in Figure 12. One further evaluation was investigation of top flange widths of 32", 36", and 48". When used with a 54" deep section, the 32" and 48" wide top flanges had much lower span capability than the 36" flange.

Since one of the goals of the beam development process was enhanced stability, the new sections' predicted stability was compared to TxDOT's current sections using the criteria presented by Mast.[3,4] This study indicated that the two deepest sections, the G62 and G70, could benefit with more lateral stiffness. Their top flanges were consequently widened from 36" to 42".

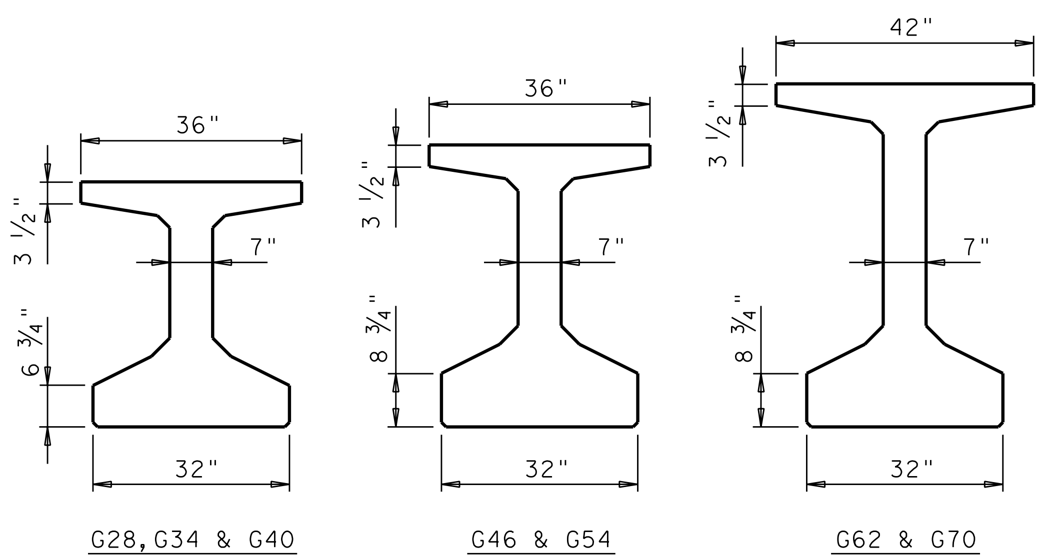

Figure 12 New I-Beam cross-sections

	d (in)	I (in^4)	S_b (in^3)	A (in^2)	Weight (lb/ft)
G28	28	52,772	4,065	585	610
G34	34	88,355	5,697	627	653
G40	40	134,990	7,458	669	697
G46	46	198,089	9,855	761	793
G54	54	299,740	12,749	817	851
G62	62	463,072	16,375	910	948
G70	70	628,747	19,704	966	1,006

Table 1 Section properties for new I-Beams

CURRENT STATUS

TxDOT design engineers have recently being performing companion designs with the proposed beams for bridge spans designed with the current I-beams. The intent of these companion designs is twofold—to familiarize TxDOT engineers with the capabilities of the new sections and to determine how well the new sections meet Texas bridge design needs. These companion designs are indicating, in most instances, a reduction of at least one beam line per span is possible. In some spans, not only can the number of beam lines be reduced, a shallower beam could be used.

The companion designs have also indicated lower concrete release strengths are required with the new beams when compared to current beam sections at the same spacing and span length. These release strength reductions are frequently on the order of 500 to 1,000 psi, which can speed production of pretensioned beams.

To aid designers in their companion designs, charts were created depicting maximum span length for each beam at 7’, 9’, and 11’ spacing at different concrete release strengths. Figure 13 represents the maximum span lengths with concrete release strength of 6,000 psi.

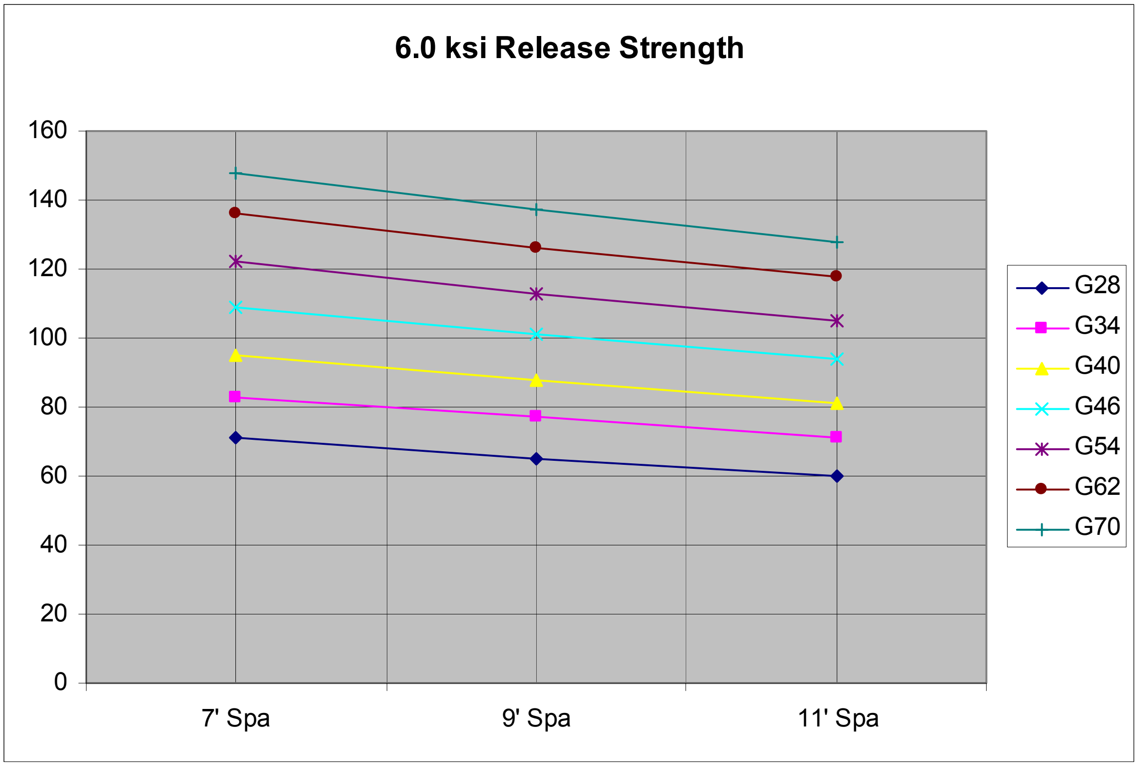

Figure 13 New I-Beam Maximum Span Length, f'ci = 6000 psi

TxDOT initiated a contract with Dr. Oguzhan Bayrak and the University of Texas at Austin to investigate fabrication and performance issues. Full size specimens of the G28, G46, and G70 will be fabricated to examine concrete placement and consolidation around the reinforcement, ducts, and along the gently sloping flange faces. The ease of form removal will also be observed. Bursting force reinforcement requirements will be researched. Tests to determine the strength of the top flange to support conventional slab overhang formwork brackets will be conducted by loading overhang brackets installed on the beams.

Additional evaluations will be undertaken at a Texas fabrication plant, where typical concrete mixes and production crews will be used to cast beams with the new forms. This exercise will be beneficial to determine minimum vibration needs, compare ease of concrete placement with currently produced sections, and to determine if form stripping presents any unforeseen problems under fabrication plant conditions.

The purpose of this testing is to guarantee TxDOT introduces an easily fabricated beam, with excellent durability and performance – a better overall product than the current I-beams. Testing is scheduled for completion in August 2007. Upon a successful conclusion, TxDOT plans to implement its new I-beam sections in phases, beginning with the G46 and G62 sections.

SUMMARY AND CONCLUSIONS

The standard prestressed beam sections discussed here offer many solutions for TxDOT's bridges. I-beams are economical and adaptable to all span lengths and cross-sections. Box beams, slab beams, and double-T beams provide shallow superstructures for bridges with simple geometry. Pre-topped U-beams and decked slab beams offer the most rapid construction method for long span and short span structures.

TxDOT's next generation of I-beams show great promise in balancing the oft-competing needs of structural efficiency, stability, ease of fabrication, and enhanced durability. Implementation of these sections will allow designers to increase span lengths and reduce superstructure depth, further exploiting the capabilities of the economical pretensioned I-beam.

With a library of proven beams and new sections being developed to match new challenges, prestressed concrete beams will continue to meet the needs of Texas' bridge building efforts.

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