DECK BULB TEES USING STANDARD AASHTO I-BEAMS AND THE AASHTO LRFD SPECIFICATIONS

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ABSTRACT

The use of highway bridges comprised of Deck Bulb Tees, in which the deck is precast and prestressed with the beam, has been primarily limited to the northwest part of the United States and Alaska. The system has significant advantages in speed of construction because field-cast concrete in the deck is eliminated. However, little research has been published on this type of construction, and none using the AASHTO LRFD Specifications.

This paper reports the results of research in which the span ranges of Deck Bulb Tee bridges are compared to conventional construction. Deck Bulb Tee sections considered in this study are based on standard AASHTO I-Beam shapes. The results demonstrate the increased span capabilities of this type of construction. Constructability issues related to the system are also identified such as handling and shipping (since the deck is cast monolithically with the prestressed concrete beam which significantly increases the weight of the beam) and connections between adjacent Deck Bulb Tees. Splicing of Decked Bulb Tees is mentioned as an option to deal with situations where beams are too heavy or too long to handle or ship in one piece.

Keywords: Deck Bulb Tee, AASHTO, LRFD, Bridge, Pretensioning, Conventional, AASHTO I-Beams, Concrete Strength, Strands

INTRODUCTION

Deck Bulb Tees are precast, prestressed concrete beams that are cast and prestressed with the deck as an integral part of the cross-section. Deck Bulb Tees are erected with the edges of the deck (flanges) touching. Connections are made between the edges of the deck in adjacent beams, usually by welding. After grouting the joints between adjacent beams, the roadway is completed. In most cases, field-placed concrete for constructing the deck is completely eliminated.

Deck Bulb Tees have been produced and used for bridge construction since the 1950s. This type of bridge construction is almost exclusively produced and used in the West and Northwestern portions (including Alaska) of the United States. In most cases, the shape of Deck Bulb Tees is based on a bulb-tee beam rather than one of the standard AASHTO I-Beam shapes. Little research has been published for these Deck Bulb Tees and no known published research has used the AASHTO LRFD Specifications[3] to design Deck Bulb Tees using standard AASHTO I-Beams. However, in the early 1970s, two papers were published describing longer span capabilities of segmental construction using a Deck Bulb Tee system with what was then called AASHO-PCI Beams Type III and IV (Anderson[1] and CTA[2]).

Rapid construction and ever-increasing spans are currently important issues in bridge construction. A Deck Bulb Tee is well suited for both these applications. Since the deck is cast with the AASHTO I-Beam, the casting of the in-situ bridge deck is eliminated, resulting in a significant savings in time of construction. With the increase in beam area being prestressed, longer spans are easily obtainable.

In areas of the country where Deck Bulb Tees are not currently used, sections can be developed using standard AASHTO beam shapes. The following analytical study is intended to demonstrate the span capabilities of Deck Bulb Tees using standard AASHTO I-Beams. The study also identifies constructability issues related to the use of these sections. The potential for increased span lengths for this system and span comparisons with traditional design techniques (precast prestressed concrete beams with a cast-in-place deck) are the main focus of this study.

DESIGN CONSIDERATIONS

The AASHTO LRFD Bridge Design Specifications[3] (LRFD) is used as the design code for this study. This design method was chosen because it will soon become the design method for projects with federal funding. In addition to the LRFD, the PCI Bridge Design Manual[4] and the PCI Design Handbook[5] are used for guidelines. For the purposes of this study, the design methods presented in the LRFD are followed exactly.

GENERAL ASSUMPTIONS FOR ANALYSIS

For the analysis presented in this study of Deck Bulb Tees based on standard AASHTO I-Beams, the following assumptions are used:

- Only simple span bridges are evaluated.
- Sections are only prestressed (pretensioned) prior to transfer. No post-tensioning of sections is considered.
- Interior beams are assumed to govern design.
- Only flexural design is considered. Conditions at both the Service and Strength Limit States are considered. While allowed in the Specifications, overreinforced sections are not used for this study. This does not significantly affect design results.
- Shear design is neglected because it will not control design.
- Sections are only evaluated at midspan. It is assumed that measures can be taken to satisfy stress limits at the ends of the beams.
- Reinforcement is not considered (transformed) in computing section properties.
- An eight (8) inch constant deck thickness is used for all sections.
- A constant 1.5 inch build-up was included as a dead load but was not included in computing section properties for any sections.
- Prestress losses are estimated using the refined method of the LRFD.
- Maximum strand eccentricity is assumed for all designs.
- Live Load Distribution factors for moment given in AASHTO LRFD Table 4.6.2.2.2b-1 are used for both Deck Bulb Tee and traditional designs. Factors for two (2) lanes of traffic are used.

DESIGN PARAMETERS

Parameters were chosen to reflect typical values for bridges today. Ranges for these parameters were selected and designs performed. Parameters were changed one at a time and designs re-analyzed. A spreadsheet was used to perform the design calculations. The following parameters and the ranges were considered for this study.

Beam Shapes

The standard AASHTO I-Beam shapes considered in this study are the Type II, III, IV, V and VI Beams.

Concrete Strength

Concrete strengths (f'_c) considered in this study for the standard AASHTO I-Beams and Deck Bulb Tees include: 5, 6, 7, 8, 9 and 10 ksi. The range of concrete strengths is intended to reflect a range of typical concrete strengths currently used in prestressed concrete bridges.

For designs using traditional construction with a cast-in-place deck, the deck concrete strength is held constant at 4.50 ksi. For Deck Bulb Tee designs, the beam concrete strength is also used for the deck.

Beam Spacing

Six beam spacings, covering the range of practical designs, are considered: 5 ft., 6 ft., 7 ft., 8 ft., 9 ft. and 10 ft. for both conventional and Deck Bulb Tee designs. For Deck Bulb Tee beams, the beam spacing is equal to the width of the deck attached to the beam. A spacing of 5 ft. is more typical for smaller AASHTO I-Beams, while the 10 ft. spacing is more typical for larger beams.

Prestressing Strand

For each AASHTO I-Beam cross-section type, concrete strength and beam spacing, designs are performed for both 0.5 inch (A_{ps} = 0.153 in^2) and 0.6 inch (A_{ps} = 0.217 in^2) diameter low relaxation seven-wire pretensioning strand (270 ksi).

RESULTS OF PARAMETRIC STUDY

In the following, the effect of varying the design parameters is shown and reviewed. Results are presented for standard AASHTO I-Beams with a cast-in-place deck and for the corresponding Deck Bulb Tee sections. The first set of results gives the maximum spans achievable for combinations of parameters using conventional designs and Deck Bulb Tees using the standard AASHTO beam shapes. The second set of results reveals the minimum number of pretensioning strands required to satisfy Service and Strength Limit State requirements in the LRFD Specifications.

For both sets of results, figures are presented and discussed for AASHTO Type II and IV beams and the Deck Bulb Tee sections based on these beam types. Tables of maximum spans (first set of results) are presented for AASHTO Types II, III, IV, V and VI and the corresponding Deck Bulb Tee sections.

Some of the figures presented in the following are similar in content and format to the preliminary design charts found in Chapter 6 of the PCI Bridge Design Manual[4]. Therefore, these figures may be used to compare designs using the AASHTO LRFD and Standard Specifications[6].

MAXIMUM SPAN LENGTH

Figure 1 demonstrates the significant improvement in maximum spans for Deck Bulb Tees over conventional AASHTO beam bridges for a single concrete strength (7 ksi) and strand size (0.6 in. diameter) for different cross sections as the beam spacing is varied. For this part of the study, the strength of the concrete at transfer was allowed to vary up to 7 ksi (the specified concrete strength). The beam spacing (or deck width) is varied from 5 to 10 ft. Figure 2 presents the same information but as the percent increase in the maximum span for Deck Bulb Tees compared to conventional construction. The increase in span length from conventional construction to Deck Bulb Tees is significant, ranging from 25 to 68% for these two beam types. This is a very significant increase in spans for no significant increase in material quantities or section size.

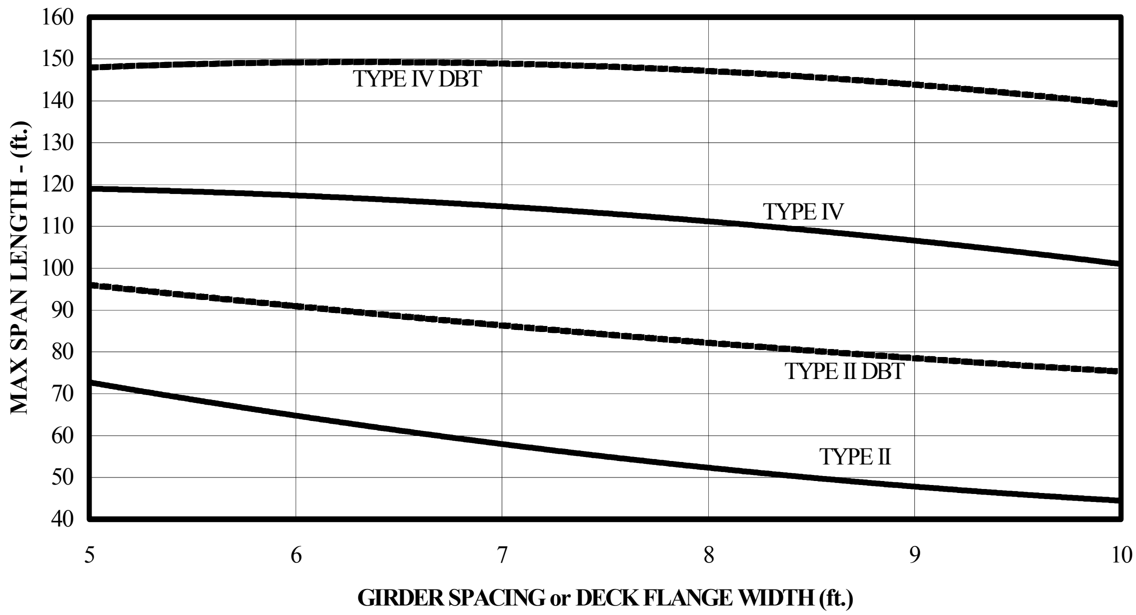

Figure 1: Maximum Span Lengths for Conventional and Deck Bulb Tee Beams using 7 ksi Concrete and 0.6 in. Diameter Strands

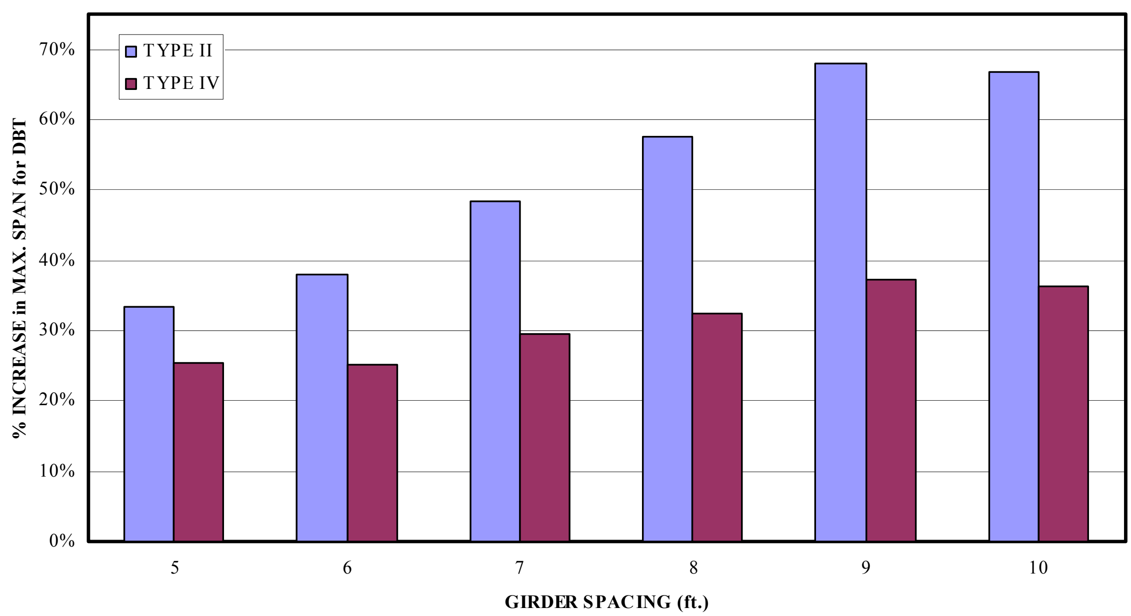

Figure 2: Percent Increase in Maximum Span Lengths for Deck Bulb Tee Beams over Conventional Construction

Additional comparisons for maximum spans were developed by varying the concrete strength from 5 ksi to 10 ksi. The strength of the concrete at transfer was allowed to be as high as the specified concrete strength for the purposes of this study. In this paper, maximum span lengths are only shown for the 0.6 in. diameter pretensioning strands. The 0.6 in. diameter strands control the maximum span length in all cases except for the Type II beams at closer beam spacings and lower concrete strengths for the conventional beam design. In these cases, the difference in span capabilities for the two sizes of strand is small. The beam spacing was varied from 5 to 10 ft.

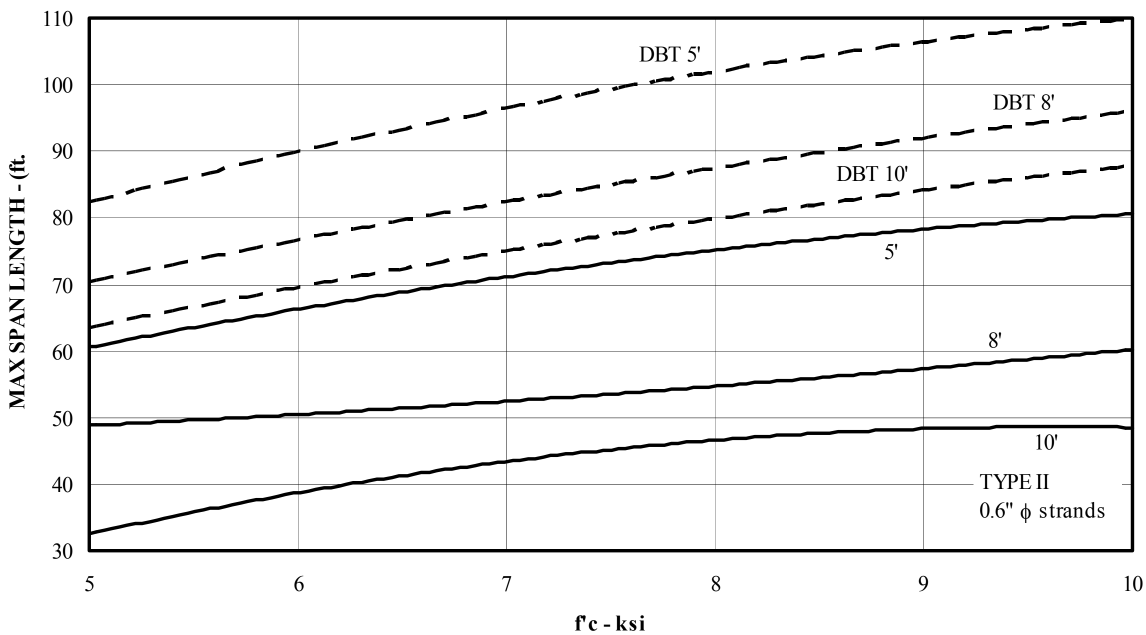

Figure 3: Maximum Span Length for AASHTO Type II Beams

A minimum average increase in span capability of the Type II Deck Bulb Tee, approximately 38% for the 5 ft. beam spacing and up to 100% for the 10 ft. spacing can be seen in Figure 3.

Figure 4 shows the maximum span comparisons of the Type IV AASHTO I-Beam, conventional and Deck Bulb Tee.

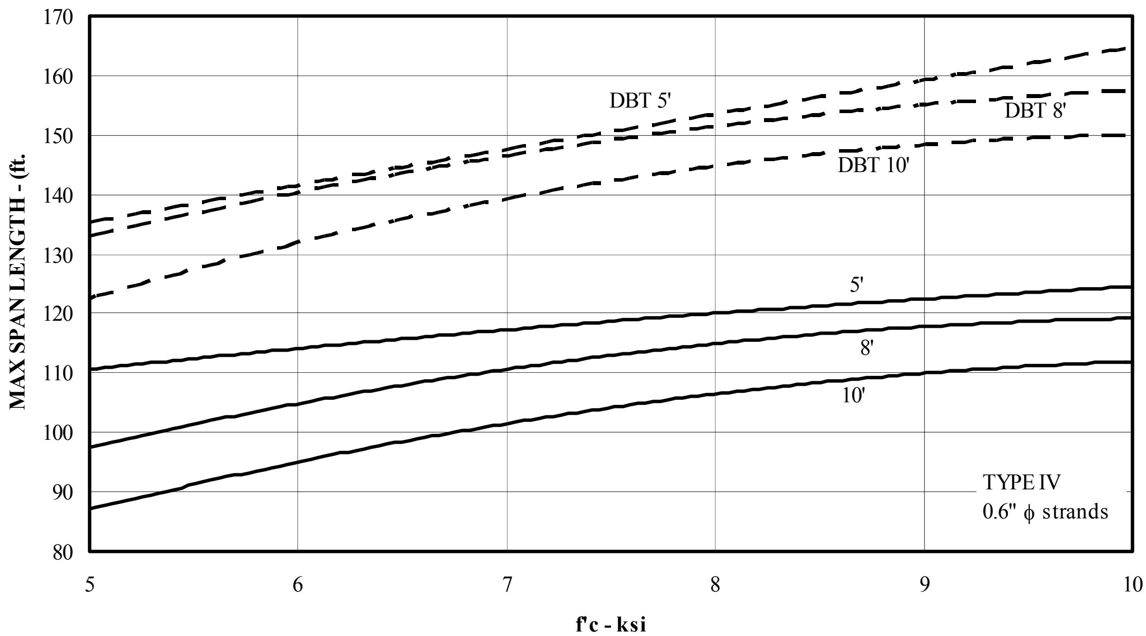

Figure 4: Maximum Span Length for AASHTO Type IV Beams

For the larger Type IV AASHTO I-Beam, the average increase in span length of the Deck Bulb Tee over its conventional counterpart is not quite as high, approximately 23% and 41% for the 5 ft. and 10 ft. beam spacing, respectively. Since the deck is cast with the beam in a Deck Bulb Tee, the increased area of the section allows for longer span capability for a given beam type as has been shown. Tables 1 and 2 give a complete listing of the maximum spans achievable for the conventional and Deck Bulb Tee AASHTO beam sections (using the assumptions listed above) for both 0.5 in. and 0.6 in. diameter strands.

0.5 in. STRAND				
Beam Spacing or Deck Flange Width (ft.)		5	8	10
$f'_c = f'_{ci} = 5$ ksi	II	**63**	**52**	**30**
	DBT II	**85**	**72**	**65**
	III	**87**	**74**	**66**
	DBT III	**117**	**102**	**94**
	IV	**110**	**97**	**88**
	DBT IV	**134**	**134**	**125**
	V	**129**	**119**	**109**
	DBT V	**143**	**148**	**146**
	VI	**145**	**133**	**122**
	DBT VI	**157**	**162**	**159**
$f'_c = f'_{ci} = 8$ ksi	II	**75**	**64**	**58**
	DBT II	**97**	**84**	**76**
	III	**101**	**89**	**81**
	DBT III	**127**	**116**	**107**
	IV	**116**	**113**	**106**
	DBT IV	**149**	**142**	**133**
	V	**137**	**133**	**127**
	DBT V	**163**	**160**	**153**
	VI	**163**	**149**	**140**
	DBT VI	**179**	**175**	**168**
$f'_c = f'_{ci} = 10$ ksi	II	**75**	**64**	**59**
	DBT II	**98**	**85**	**78**
	III	**104**	**91**	**84**
	DBT III	**132**	**117**	**108**
	IV	**122**	**115**	**107**
	DBT IV	**157**	**144**	**135**
	V	**143**	**136**	**129**
	DBT V	**174**	**164**	**155**
	VI	**169**	**151**	**142**
	DBT VI	**190**	**179**	**171**

Table 1: Maximum Spans using 0.5 in. Diameter Strands

0.6 in. STRAND				
Beam Spacing or Deck Flange Width (ft.)		5	8	10
$f'_c = f'_{ci} = 5$ ksi	II	**60**	**48**	**32**
	DBT II	**83**	**71**	**64**
	III	**87**	**73**	**67**
	DBT III	**117**	**100**	**92**
	IV	**110**	**98**	**87**
	DBT IV	**135**	**132**	**123**
	V	**131**	**118**	**108**
	DBT V	**146**	**151**	**145**
	VI	**149**	**132**	**121**
	DBT VI	**158**	**165**	**161**
$f'_c = f'_{ci} = 8$ ksi	II	**74**	**55**	**45**
	DBT II	**102**	**87**	**79**
	III	**103**	**88**	**81**
	DBT III	**131**	**120**	**111**
	IV	**119**	**115**	**106**
	DBT IV	**153**	**150**	**146**
	V	**138**	**135**	**128**
	DBT V	**165**	**167**	**163**
	VI	**166**	**154**	**143**
	DBT VI	**180**	**183**	**179**
$f'_c = f'_{ci} = 10$ ksi	II	**81**	**67**	**49**
	DBT II	**109**	**95**	**87**
	III	**107**	**94**	**86**
	DBT III	**139**	**129**	**120**
	IV	**125**	**119**	**112**
	DBT IV	**165**	**158**	**150**
	V	**146**	**140**	**134**
	DBT V	**181**	**177**	**172**
	VI	**175**	**162**	**151**
	DBT VI	**197**	**194**	**189**

Table 2: Maximum Spans using 0.6 in. Diameter Strands

NUMBER OF PRETENSIONING STRANDS

For preliminary designs, it may be helpful to know the number of strands required for a bridge configuration (span and beam spacing) in order to obtain price estimates. Therefore, calculations were performed to determine the minimum number of strands required for different spans and beam spacings. Results of this study are summarized below. Similar figures appear in Chapter 6 of the PCI Bridge Design Manual[4].

For computing the minimum number of strands required to satisfy the controlling condition of either limiting service limit state stresses or capacity at strength limit state for a specific span, concrete strengths of 7 ksi and 10 ksi are considered for the beam or Deck Bulb Tee. Specified concrete strength at transfer (f'_{ci}) is limited to 5.5 ksi and 7 ksi, respectively. The minimum number of strands required is computed as the span length is increased in 1 ft. increments up to the maximum span length.

Figures 5 and 6 show the minimum number of pretensioning strands required for increasing span lengths for a Type II standard AASHTO I-Beam with a conventional composite deck.

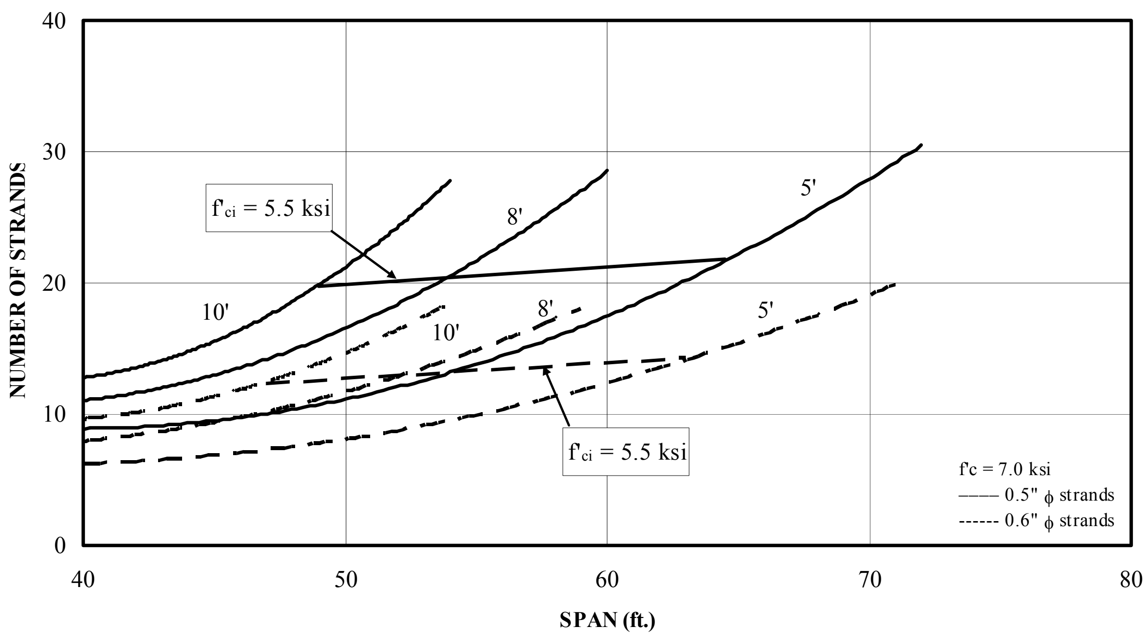

Figure 5: Number of Strands Required as Span Increases for Conventional AASHTO Type II Beams using 7 ksi Concrete

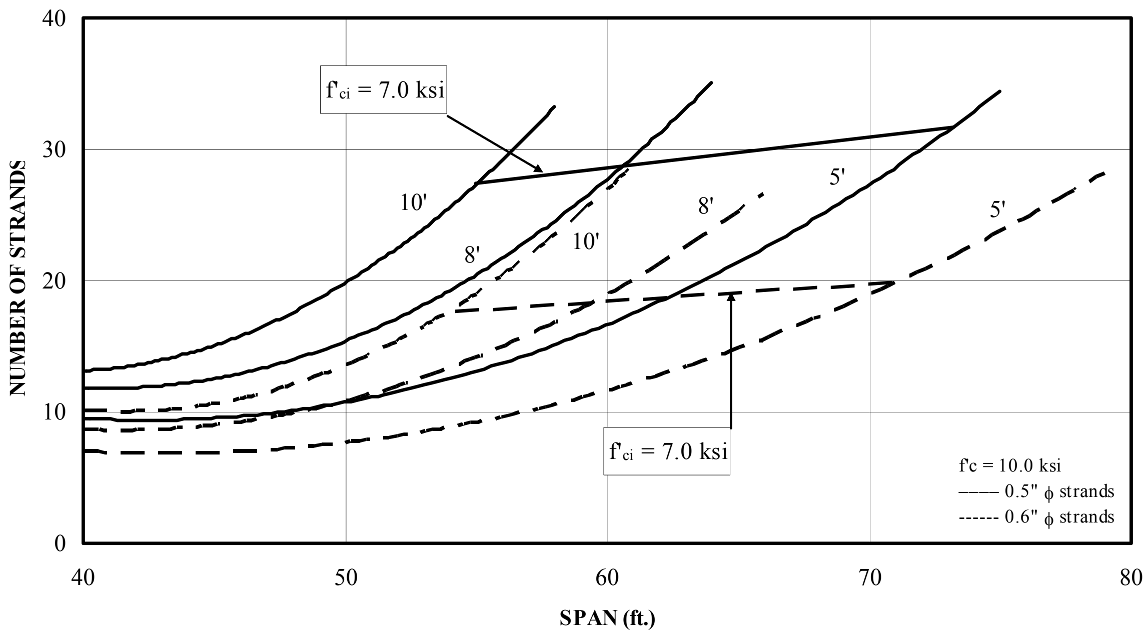

Figure 6: Number of Strands Required as Span Increases for Conventional AASHTO Type II Beams using 10 ksi Concrete

Figures 5 and 6 show that for a Type II AASHTO I-Beam with conventional construction, there is not any significant advantage in span capability using either the 0.5 in. or 0.6 in. diameter strands. However, with this small size beam, the 0.5 in. pretensioning strands actually allow slightly larger span lengths with lower concrete strengths. With the use of more 0.5 in. strands, the same maximum attainable span lengths are possible. Peaking at 32-0.5 in. strands and 20-0.6 in. strands, a 73 ft. span is possible at 10 ksi concrete strength. The Type II I-Beam achieves maximum span at the expected smallest beam spacing, 5 ft. These figures also show that, when compared with the charts in the PCI Bridge Design Manual that are computed using the AASHTO Standard Specifications, the AASHTO LRFD Specifications require more strands for the same span and do not allow maximum spans to reach the same lengths.

Figures 7 and 8 present the same information for a Type II AASHTO Deck Bulb Tee.

Immediately, the increase in the number of strands required as well as span capability is evident. With the Deck Bulb Tee's larger area (deck area equal to beam spacing) for pretensioning, more strands can be used and longer spans are achieved. As with conventional beam designs, the same maximum span can be achieved using either the 0.5 in. or the 0.6 in. strands and 10 ksi concrete strength and the 5 ft. beam spacing (smallest). Allowing the use of up to 50-0.5 in. strands and 32-0.6 in. strands, the Deck Bulb Tees allow the designer to pack strands well into the web and even into the top flange of the AASHTO I-Beam to achieve a maximum span of 99 ft. As with conventional beam designs, the minimum concrete strength at transfer continually increases as maximum spans are stretched.

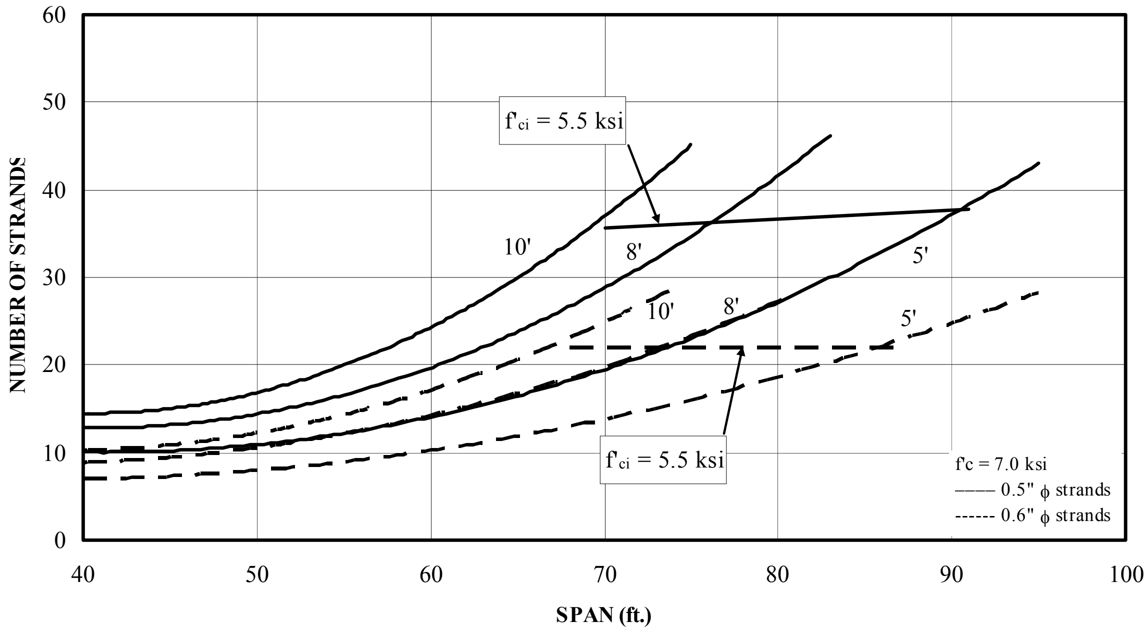

Figure 7: Number of Strands Required as Span Increases for Deck Bulb Tee with AASHTO Type II Beam using 7 ksi Concrete

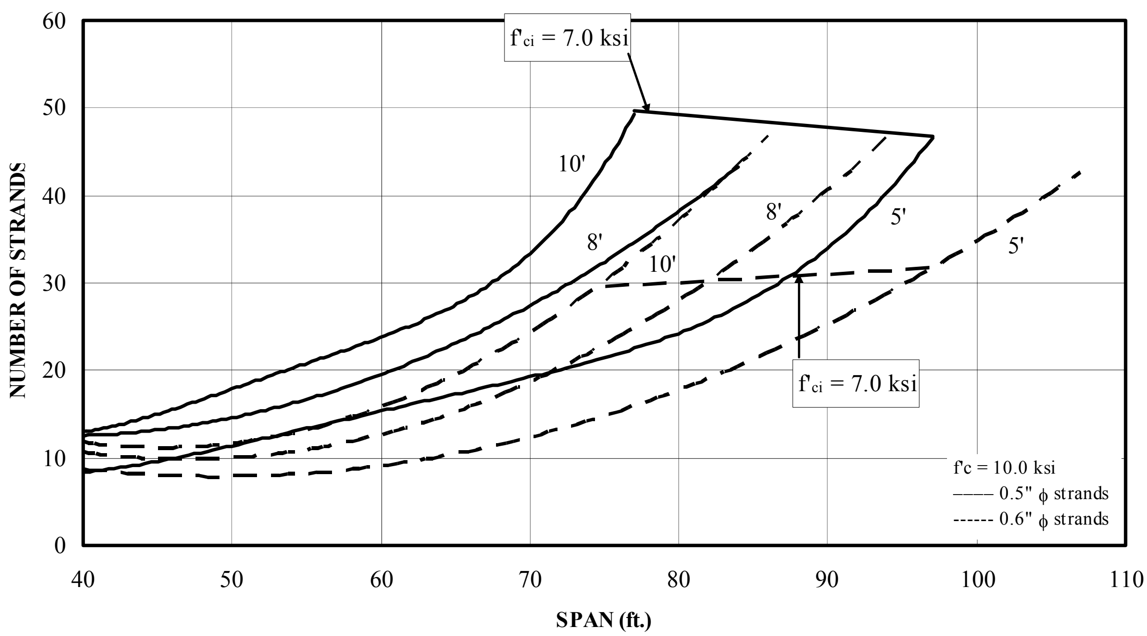

Figure 8: Number of Strands Required as Spans Increase for Deck Bulb Tee with AASHTO Type II Beam using 10 ksi Concrete

Considering designs using larger AASHTO I-Beams, Figures 9 and 10 show the minimum number of strands required for a Type IV AASHTO I-Beam with a conventional composite deck.

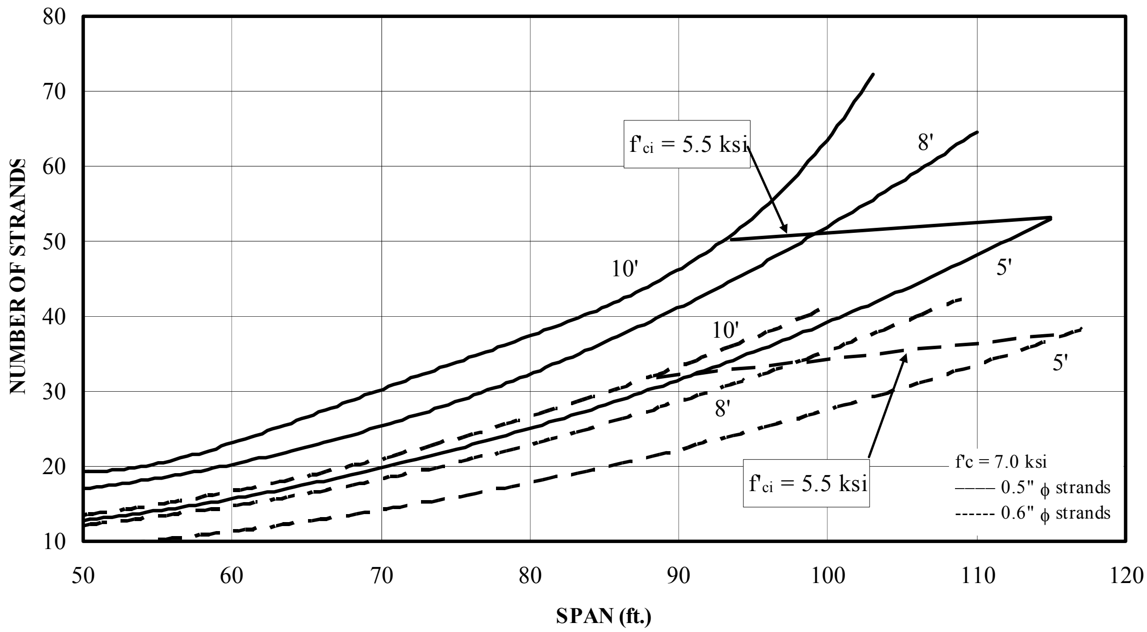

Figure 9: Number of Strands Required as Span Increases for Conventional AASHTO Type IV Beams using 7 ksi Concrete

Here again, there is no real advantage in span length capability with either diameter size pretensioning strand. For each of the concrete strengths shown, there is virtually no difference in maximum spans except the number of strands required. The difference from the smaller Type II is that the larger area (more than double the area) of the Type IV allows greater utilization of 0.6 in. strands for maximum span lengths. The larger Type IV compares more closely to that found in the PCI Bridge Design Manual[4] computed using the AASHTO Standard Specifications. However, as seen in the smaller Type II, the AASHTO LRFD appears to limit the span capacity while requiring a larger number of strands.

Figures 11 and 12 show the minimum number of strands required for specific span lengths for the AASHTO Type IV Deck Bulb Tee.

It is easily seen that the Deck Bulb Tees can utilize a substantially greater number of strands because of the area gained by the deck being cast with the beam. The Deck Bulb Tee can use approximately 25% more strands to achieve the maximum span lengths, when compared to beams with conventional cast-in-place decks.

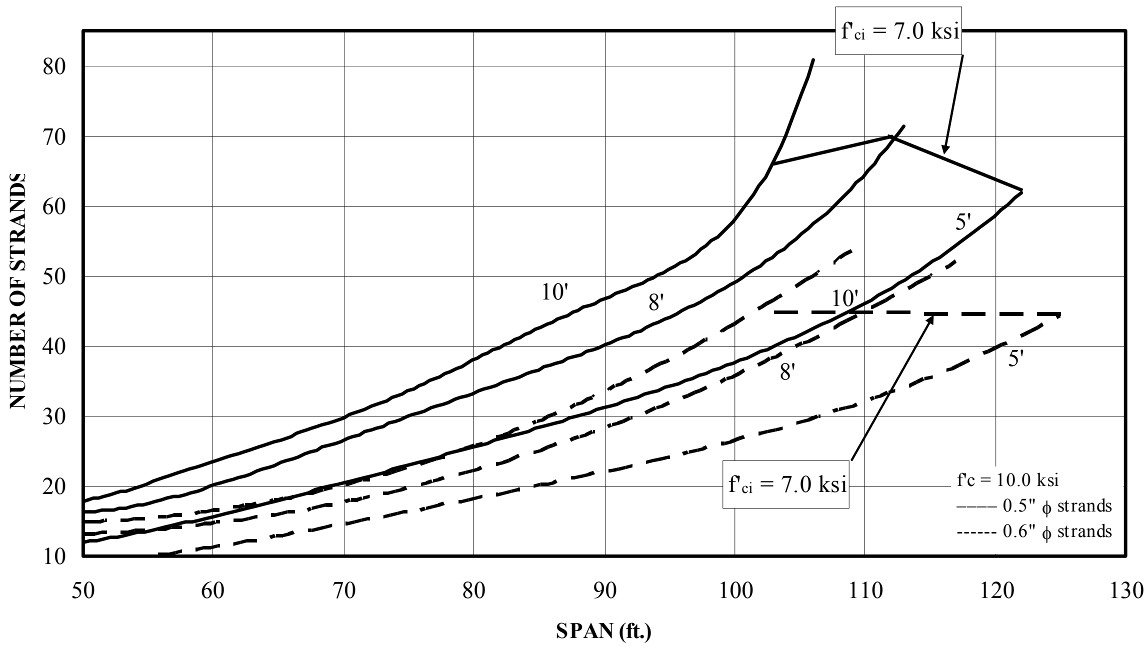

Figure 10: Number of Strands Required as Span Increases for Conventional AASHTO Type IV Beams using 10 ksi Concrete

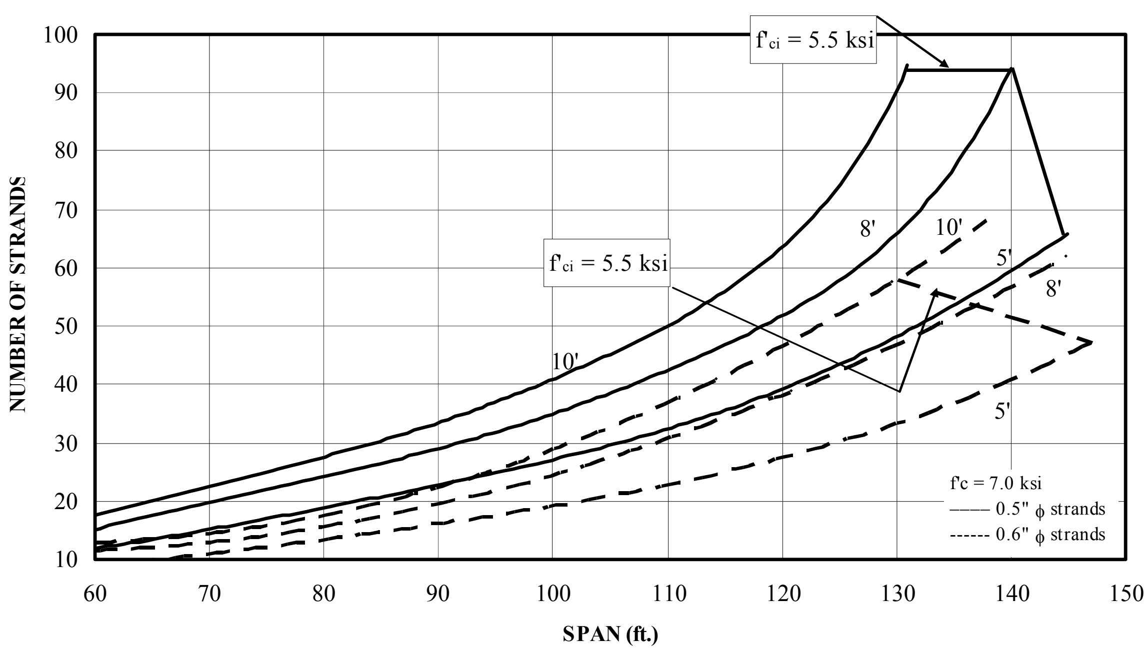

Figure 11: Number of Strands Required as Span Increases for Deck Bulb Tee with AASHTO Type IV Beam using 7 ksi Concrete

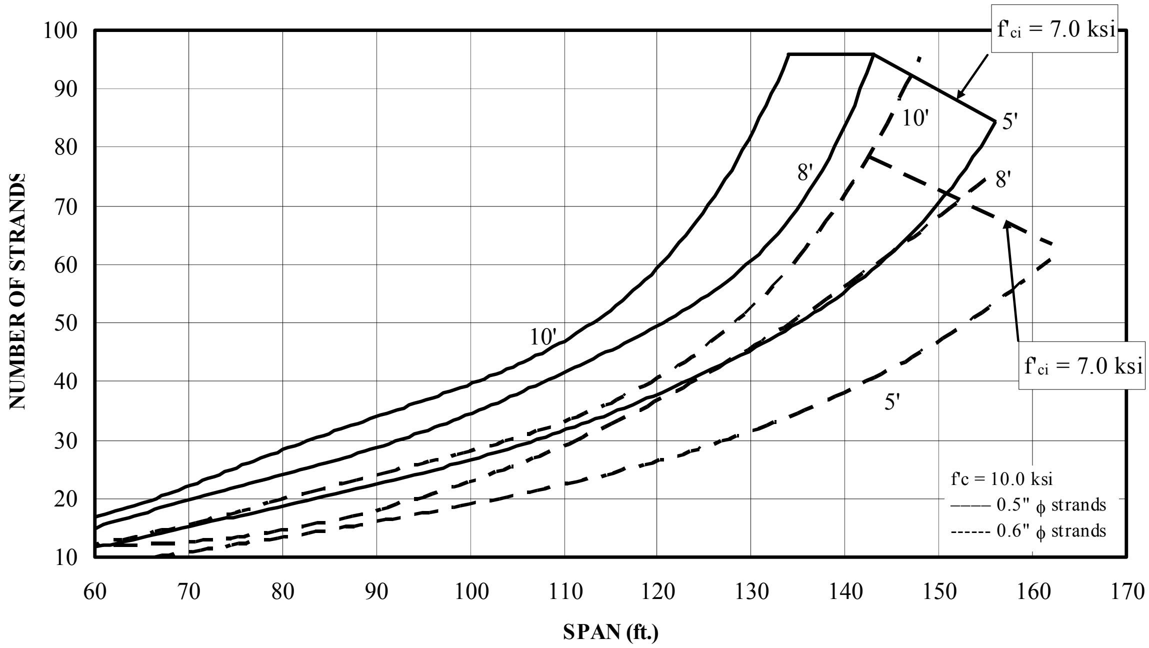

Figure 12: Number of Strands Required as Span Increases for Deck Bulb Tee with AASHTO Type IV Beam using 10 ksi Concrete

CONSTRUCTABILITY AND DESIGN ISSUES

With the larger span capabilities of the Deck Bulb Tees using standard AASHTO I-Beams, certain aspects of construction must be considered.

Most obvious of these are the issues of weight and shipping. The smaller Type II Deck Bulb Tee weighs 884 plf that gives an acceptable shipping weight of approximately 97 kips for the maximum span of 109 ft. However, for the larger Type IV Deck Bulb Tee, the maximum span is 165 ft. with a 5 ft. wide deck that weighs 942 plf resulting in an excessive shipping weight of 155 kips. For cases such as this, the larger heavier Deck Bulb Tees may be fabricated in segments with splicing and post-tensioning in the field as discussed in Anderson[1] and CTA[2], for even longer span capabilities than those shown in this study.

Connections between individual Deck Bulb Tee beams must also be considered. Current practice addresses this connection with weld tabs embedded in the edges of the deck that are welded together in the field after final alignment adjustments are complete. Transverse post-tensioning would be another option to consider. Both Anderson[1] and CTA[2] mention this as viable options to allow the bridge system to act monolithically.

Other issues related to the construction of Deck Bulb Tee bridges that must be considered during design include camber, skews and cross-slopes. As seen in this study, with the large number of strands that can be placed in the Deck Bulb Tees, camber may be a significant issue for some bridges. Differential camber between adjacent Deck Bulb Tees can be handled by casting threaded inserts in the deck that are used to pull out the differential camber before welding the connections. This has been the practice for Deck Bulb Tees in the northwestern U.S. Skew and cross-slopes must also be addressed during design and may limit applicability of Deck Bulb Tees for some bridges.

Design issues and patterns were noticed during the design process. Most noticeable was the ability to keep adding strands while the minimum concrete strength at transfer continues to get smaller. This was mostly for the larger Deck Bulb Tee sections due to the dead load of the beams overcoming the prestress applied. Analyzing only midspan sections, transfer did control about half of the larger sections' maximum span capability. The other half was simply governed by the concrete strength used. The overreinforced assumption resulted in some sections, mostly in the Type IV's, being controlled by the strength limit where allowable stresses normally govern.

SUMMARY AND CONCLUSIONS

Deck Bulb Tees offer a system for achieving longer spans while serving as a rapid construction technique. While Deck Bulb Tees based on standard AASHTO I-Beams differ from conventional precast prestressed concrete girder bridge construction, they have been shown to provide a significant increase in span capability and only require relatively minor modifications to existing formwork. The smaller AASHTO I-Beams prove to be a more efficient solution, as well as a more practical alternative to conventional beam construction. With the larger area for pretensioning, Type II Decked Bulb Tees can be stretched up to 109 ft., while the larger Type IV can be used for spans up to 165 ft. for the assumptions used in this study.

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