Cost Comparison of AASHTO Type IV and Modified Type IV Bridge Beams with 54- and 63-in. Bulb-Tees

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Standard AASHO precast, prestressed concrete beams are widely used throughout the United States. The standard sections were developed in the 1950s taking into account the casting and handling techniques and the concrete mix design technology of the 1950s. In 1982, in a survey of bridges throughout the United States by the FHWA, it was determined that the AASHTO shapes were less efficient and less cost-effective than the bulb-tee shapes. Cost comparisons of an actual project are presented that was originally designed using Type IV and Type IV modified beams but was redesigned and constructed using 54- and 63-in. bulb-tee beams. The replacement of AASHTO beams with bulb-tee beams was permitted on a one-for-one replacement basis; therefore, the cost analysis reflects the cost differences of the beams in exactly the same load-span conditions. Comparative designs are shown and cost analyses of the designs are summarized, indicating total estimated cost savings of the bulb-tee solution over the standard AASHTO beam design.

The information generated in the past few years concerning the efficiency of precast, prestressed bulb-tee bridge beams has produced a keen interest on the part of many producers and designers throughout the United States.

Recently, major projects have been constructed using bulb-tee bridge beams in applications formerly reserved for standard precast, prestressed AASHTO beams. Such projects, for the first time, permit a comparison of bridge costs between the standard AASHTO shapes and the bulb-tee beams. The Interstate spur I-565 from I-65 west to Huntsville, Alabama, is one such project. Other recent major projects that use bulb-tee beams are located in the states of Illinois, Missouri, and Oklahoma.

A review of the development of the precast, prestressed concrete bridge industry reveals that bulb-tee shapes have been in existence for some time and have been used rather routinely in isolated parts of the country. For example, the states of Washington and Colorado each have standard bulb-tee shapes (see Figure 1). There are several reasons for the lack of widespread use, until recently, of the bulb-tee beam shapes.

One of the primary reasons bulb-tees have not been used more extensively to date is that the AASHTO standard bridge beams are widely and successfully used throughout the United States.

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Standardization of the AASHTO shapes, which occurred in the late 1950s, made possible the investment by the industry in forms, casting facilities, and equipment conducive to the production of AASHTO standard beams and has contributed to their successful use and the lack of interest in searching for a better solution.

At the time the AASHTO standards were developed, the standard sections of the precast, prestressed concrete industry had to be configured and designed in such a way that they could be produced economically and of high quality by using the equipment, casting procedures, and concrete mix design technology available.

Although it was certainly possible in the 1950s to design a more efficient beam configuration than the AASHTO standard beams, from a production standpoint it has not always been entirely feasible to manufacture the more efficient shapes.

In February 1982, FHWA published a final report entitled *Optimized Sections for Major Prestressed Concrete Bridge Girders* (*1*). In the conclusion of that report, the first two statements are as follows:

1. "In all states surveyed, except California, the most economical bridges for spans for approximately 70 to 130 feet are constructed with pretensioned bridge girders."
2. "When compared with other sections, AASHTO standard bridge girders are not the most structurally efficient or cost-effective for spans of 80 to 140 feet."

Item 9 of the report's conclusion states:

> For girders with 6-in.-thick webs, most cost-effective sections are modified bulb-tees. For spans of 80 to 120 feet, modified bulb-tees have 17 percent less in-place cost of girder and deck compared to AASHTO girders. . . . (*1*)

Rabbat and Russell (*2*) stated, "Modified bulb-tees are recommended for use as national standards." They also noted that there is a continuing search within the industry to develop new, more efficient products to compete in the construction market. Second, among the precast prestressed concrete bridge producers, there has been a need in many sections of the country for an efficient bridge beam that has span capabilities in excess of 100 ft.

The information that Rabbat and Russell presented indicated that the bulb-tee would address both of these points for the bridge producers of the precast, prestressed concrete industry.

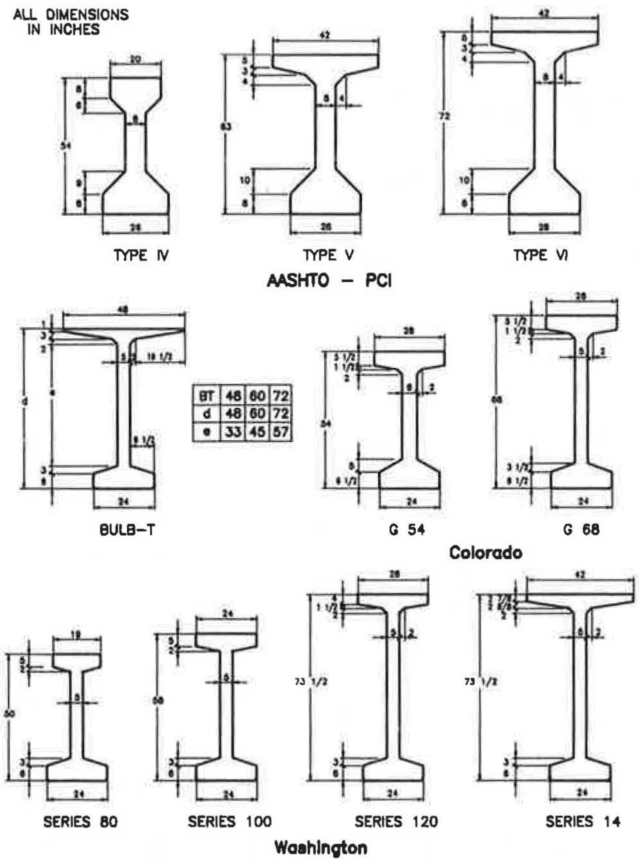


FIGURE 1 Existing girders analyzed (2).

PROMOTION ON THE LOCAL LEVEL

By late 1983, the Gulf South Prestressed Concrete Association (GSPCA) representing prestressed concrete producers in Alabama, Louisiana, and Mississippi retained a consulting engineer to research and propose to the Association a bulb-tee bridge girder that, first, would have span capabilities of up to 150 ft and second, would provide a more efficient beam than the AASHTO Type IV and Modified IV beams.

By late 1984, the GSPCA had in-hand design information and drawings of some detail for the bulb-tee to present to the state highway departments and departments of transportation in the Gulf South area (see Figure 2).

In January 1985, the GSPCA made a presentation of the information on a proposed new bulb-tee section to the Alabama Highway Department (see Figure 3). The bulb-tee design information was reviewed with considerable interest by a number of the department's engineers during the presentation.

In July 1986, the PCI Bridge Committee issued a three-sheet summary of their recommended bulb-tee sections that agreed with the GSPCA section configurations (see Figure 4).

Because of the interest of the Alabama Highway Department and the encouragement of the FHWA representatives in Montgomery, the first opportunity to use the bulb-tee sections on a major project in Alabama surfaced in mid-1988.

THE MADISON COUNTY PROJECT OVERVIEW

The construction of a major Interstate system spur (I-565) off I-65 to the city of Huntsville, some 23 mi to the east, was designed using standard AASHTO Type IV and Modified Type IV beams. An alternate approach permitting a redesign on a one-for-one replacement basis of the AASHTO girders with 54- and 63-in.-deep bulb-tee girders was included in the bidding instructions. The alternative, therefore, permitted the contractors and material suppliers the option of bidding either the standard AASHTO shapes, as shown on the bid drawings, or substituting bulb-tees as an alternative. There was also a stipulation in the bid package that the contractor was responsible for the redesign and preparation of the revised record drawings that replaced the drawings of the AASHTO girders. In addition to revised beam details showing bulb-tees instead of AASHTO shapes, the precast supplier was required to provide revised pier cap elevations for the contractor and for the state to supplement their record drawings. No allowance for foundation, pier, or deck redesign was considered

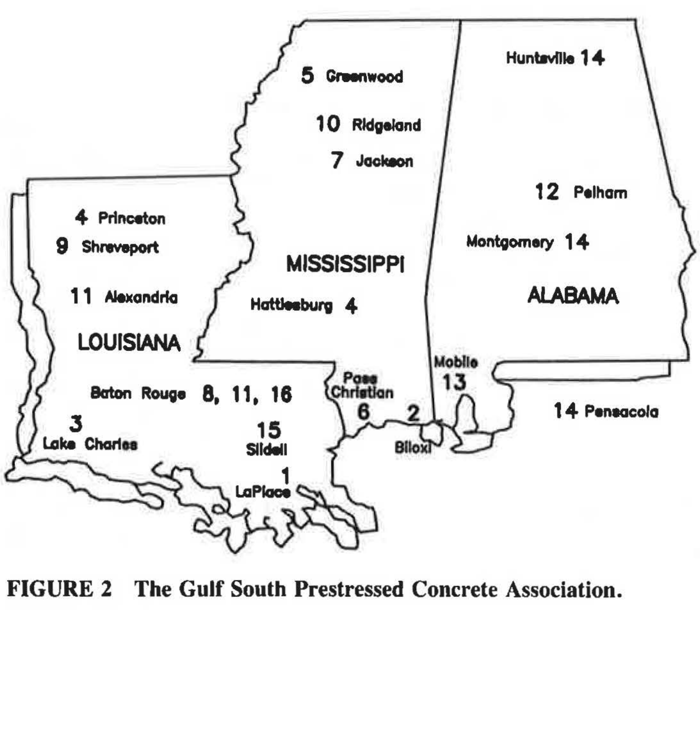


FIGURE 2 The Gulf South Prestressed Concrete Association.

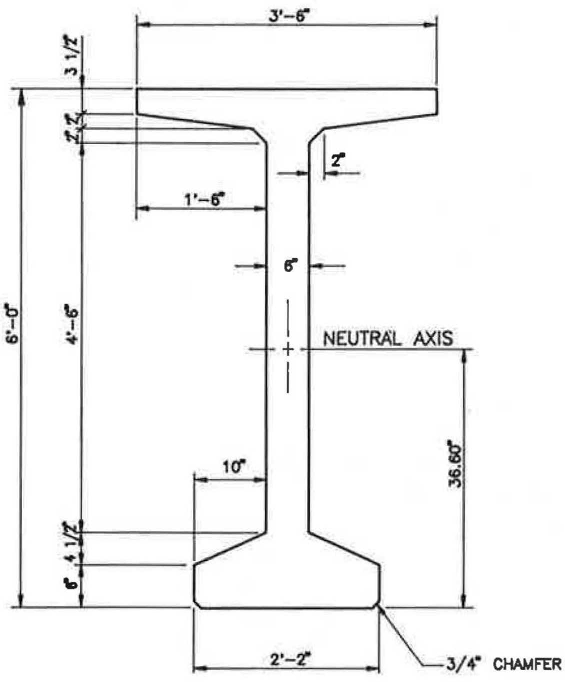


FIGURE 3 72-in. bulb-tee section.

by this alternative. Because the bulb-tee alternative provided a lighter superstructure, the piers and foundations were more than adequate. The wider top-flange configuration of the bulb-tee should also be considered in the design of the bridge deck. The project schedule, however, would not allow time for deck, foundation, and pier redesign.

The last 2.4 mi of the Madison County project contained 168,000 linear ft of bridge girders on both elevated main-line highway and interchange ramps, and was let in six separate contracts.

As designed, there were 88,034 linear ft of AASHTO Type IV girders, 73,119 linear ft of Modified AASHTO Type IV girders and 7,051 linear ft of AASHTO Type III girders.

In all, there were 1,729 beams totaling 168,203 linear ft (see Figure 5).

Because there was a complete design of the standard AASHTO beams and the complete design for comparable bulb-tee shapes had to be produced, the result was an excellent comparison of the two-beam configurations. As stated previously, however, only the girder design changed. The effect of any savings that could have been achieved by redesigning the deck or substructure is not part of the comparison.

THE REDESIGN COMPARISONS

The 54-in. bulb-tee was substituted for the standard AASHTO Type IV beam.

Figure 6 shows the side-by-side comparison of the two beams. Note that there is an approximate 19¾ percent weight reduction with a corresponding 14 percent increase in the section modulus with respect to the top of the beam. The combination of these two factors has a significant effect on the prestressing required for a beam of any given span.

In order to achieve spans of up to about 120 ft, the Alabama Highway Department has used a Modified Type IV beam that is a standard AASHTO Type IV beam with the top flange

SECTION PROPERTIES

SECTION	A (in²)	I (in⁴)	Y_b (in)	S_b (in³)	S_t (in³)	Wt.(plf)
BT-54	659	268,077	27.63	9,702	10,166	686
BT-63	713	392,638	32.12	12,224	12,715	743
BT-72	767	545,894	36.60	14,915	15,421	799

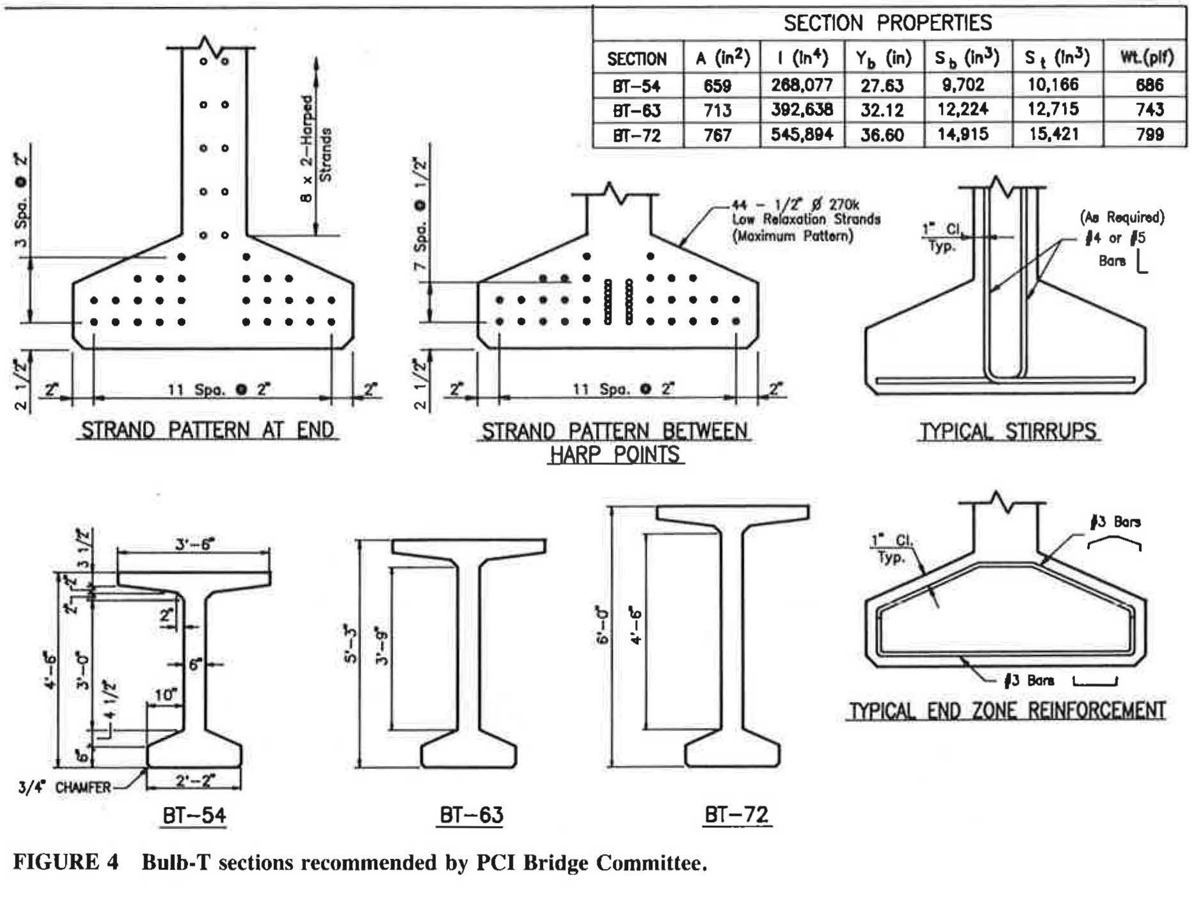


FIGURE 4 Bulb-T sections recommended by PCI Bridge Committee.

BRIDGE BEAM QUANTITIES

AASHTO TYPE III	AASHTO TYPE IV	AASHTO TYPE IV (MODIFIED)	JOB TOTALS
7,050 L.F.	88,034 L.F.	73,119 L.F.	168,203 L.F.
96 PCS.	954 PCS.	679 PCS.	1,729 PCS.
1,015 C.Y.	17,862 C.Y.	17,095 C.Y.	35,972 C.Y.

FIGURE 5 Madison County, Alabama I-565, summary of six projects.

extended 6 in. resulting in a beam of 60 in. in depth. Figure 7 shows the comparison between the modified Type IV and the 63-in. bulb-tee. The weight reduction in this case is 21½ percent and the section modulus with respect to the top of the beam increase is about 6½ percent.

The most typical length of the 54-in. bulb-tee was estimated to be between 95 and 100 ft on the Madison County project. In a 95-ft 54-in. bulb-tee, there is a concrete savings of 3.2 yd/beam over the Type IV beam and a corresponding 12,350-lb weight reduction.

For the 63-in. bulb-tee, the most typical beam length was between 105 and 110 ft. For a 107-ft 6-in. beam, there is a savings of 5.4 yd of concrete when compared with the Modified Type IV beam, and a corresponding 21,940-lb weight reduction/beam.

Strand reductions in the bulb-tees were significant, in every case, when compared with the standard AASHTO shapes they replaced.

The type of strand was also changed from stress-relieved to low-relaxation strand in the redesign, resulting in additional savings in strand. In cases in which the ultimate strength of the girders controlled the design, little benefit was realized from the use of low-relaxation strand. For stress-controlled designs, savings are estimated to average about 5 to 7 percent strand reductions. The increased section modulus of the bulb-tee shapes and the reduced weight are the major factors affecting the required number of strands and whether or not draping of strands is required.

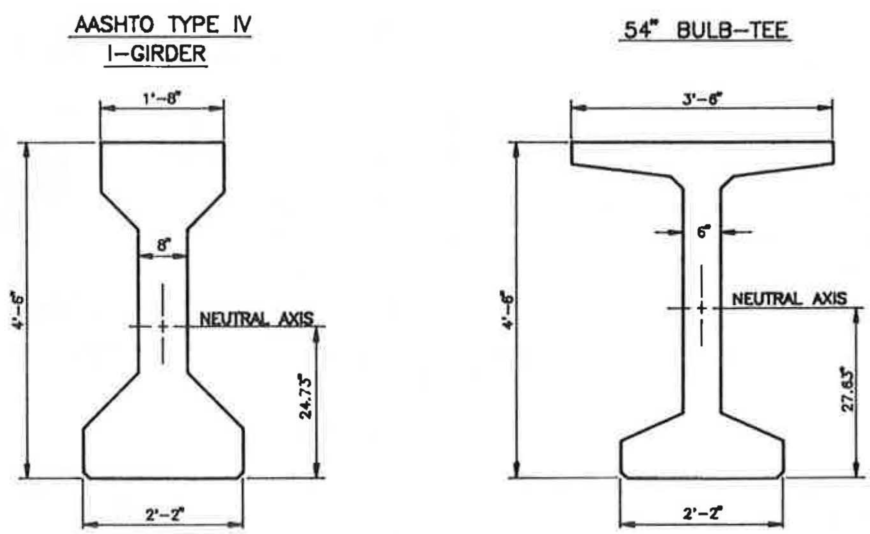
The reduction in the number of strands required in the 54-in. bulb-tee over the Type IV beam ranged up to replacement of 44½-in.-diam 270-kip strands in the Type IV beam with 32½-in.-diam special low-relaxation strands in the bulb-tee.

Figure 8 shows one of the more dramatic comparisons. The 98-ft span AASHTO Type IV beams had 40½-in.-diam 270K stress-relieved strands (area = 6.12 in.^{2}) with eight of the strands draped or harped. The 54-in. bulb-tee had 28½-in. special low-relaxation strands (area = 4.676 in.^{2}) a reduction in area of prestressing steel of 1.44 in.^{2} or 23½ percent. It is significant that the draped-strand condition was eliminated, thus resulting in a reduction in labor and production time.

An average decrease in stranding of nine strands (0.943 in.^{2}) for 54-in. bulb-tees or a 14 percent reduction in strand area was estimated.

Figure 9 shows a Modified Type IV with 46½-in.-diam 270-kip stress-relieved strand (area = 7.038 in.^{2}), 10 of which are draped. The 63-in. bulb-tee beam that replaced it has 33½-in.-diam special low-relaxation strand (area = 5.511 in.^{2}). The difference is 1.527 in.^{2} of prestressing steel or a savings of 21.7 percent; also the drape was not required in the bulb-tee beam, which again results in a measurable reduction in production labor.

The average strand reduction is estimated to be about 11 strands in the 63-in. bulb-tee, 1.193 in.^{2}/beam, or about 17

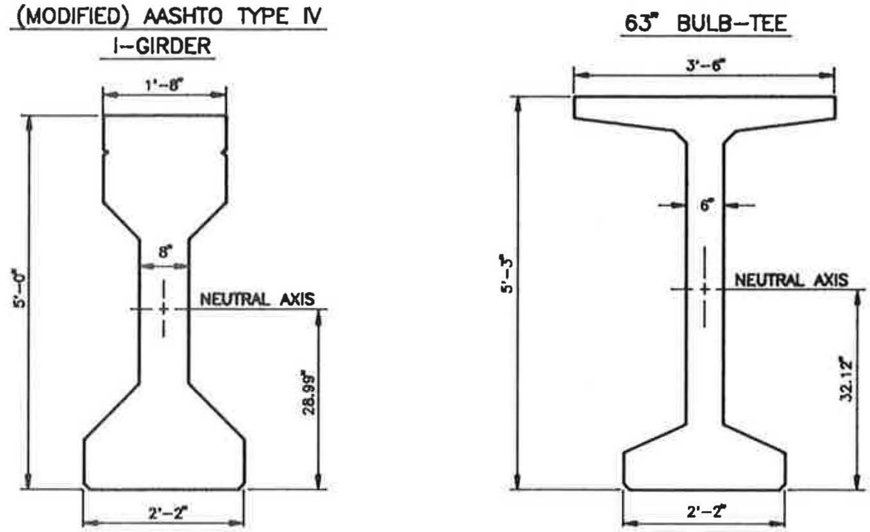


SECTION PROPERTIES

TYPE	AREA (in²)	WT. (lb/ft)	I_x (in⁴)	Y_b (in)	S_b (in³)	S_t (in³)
TYPE IV	789	822	260,730	24.73	10,543	8,908
54" BT	659	686	268,045	27.63	9,701	10,165

APPROXIMATE SPAN RANGE OF 70–100 FEET – HS20 LOADING

FIGURE 6 Bridge girder comparison (Type IV versus 54-in. bulb-T).



SECTION PROPERTIES

TYPE	AREA (in²)	WT. (lb/ft)	I_x (In⁴)	Y_b (in)	S_b (in³)	S_t (in³)
TYPE IV MOD	909	947	369,500	28.99	12,746	11,916
63" BT	713	743	392,509	32.12	12,220	12,711

APPROXIMATE SPAN RANGE OF 100–120 FEET – HS20 LOADING

FIGURE 7 Bridge girder comparison (modified Type IV versus 63-in. bulb-T).

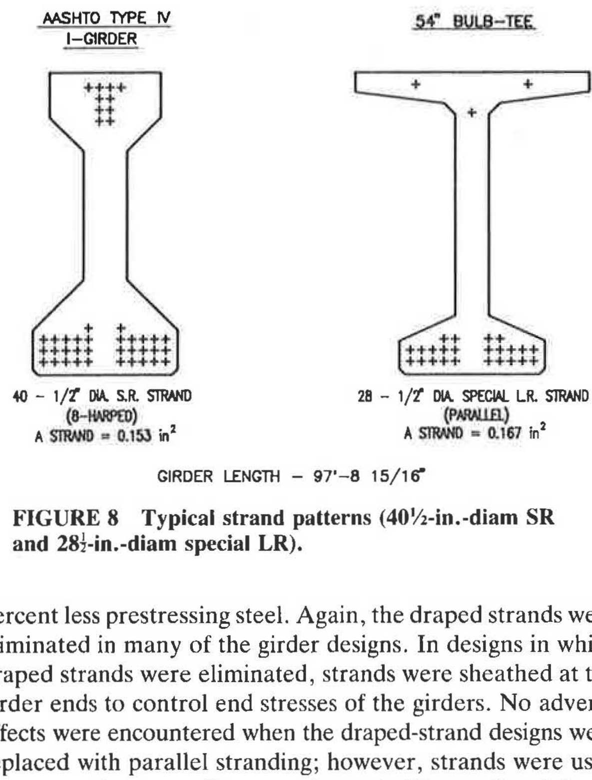


FIGURE 8 Typical strand patterns (40½-in.-diam SR and 28½-in.-diam special LR).

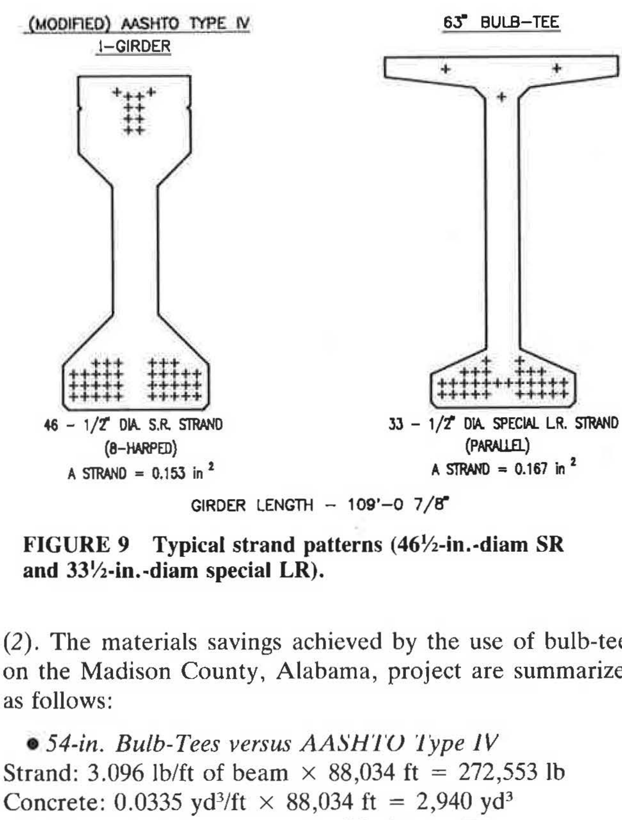


FIGURE 9 Typical strand patterns (46½-in.-diam SR and 33½-in.-diam special LR).

percent less prestressing steel. Again, the draped strands were eliminated in many of the girder designs. In designs in which draped strands were eliminated, strands were sheathed at the girder ends to control end stresses of the girders. No adverse effects were encountered when the draped-strand designs were replaced with parallel stranding; however, strands were used in or near the upper flange as shown in Figures 8 and 9.

Typically, there was little difference in the amount of stirrups and other reinforcement between the AASHTO beams and the bulb-tees.

The materials reductions on the project were quite significant and bear out the projections made by Rabbat and Russell (*2*). The materials savings achieved by the use of bulb-tees on the Madison County, Alabama, project are summarized as follows:

- *54-in. Bulb-Tees versus AASHTO Type IV*

Strand: 3.096 lb/ft of beam × 88,034 ft = 272,553 lb
Concrete: 0.0335 yd³/ft × 88,034 ft = 2,940 yd³

- *63-in. Bulb-Tees versus Modified Type IV*

Strand: 4.136 lb/ft of beam × 73,119 ft = 302,420 lb
Concrete: 0.0504 yd³/ft × 73,119 ft = 3,685 yd³

The total savings of prestressing strand for the entire project was 574,973 lb and the concrete savings was 6,625 yd³.

The estimated cost differences as summarized in the following paragraphs are based on the average reduction in stranding of nine strands in the 54-in. bulb-tees and an 11-strand reduction in the 63-in. bulb-tees when compared with their AASHTO beam counterpart. The material cost differences are well defined on the basis of reductions of concrete and prestressing steel. The labor cost reductions are based on conservative estimates of the labor required to place those materials in a typical casting operation.

A summary of estimated cost differences follows.

	AASHTO Type IV	*54-in. Bulb-Tee*
Strand:	42½-in.-diam 270-kip SR	33½-in. special LR
Cost/foot of beam	$8.33	$6.26
Estimated labor for stranding	0.91	0.72
Material and labor	$9.24	$6.98
Concrete:	0.2029 yd³/ft	0.1695 yd³/ft
Cost in place/ft @ $76/yd³	$15.42	$12.88
Total cost/ft (strand and concrete)	$24.66	$19.86
Cost difference:	$4.80/ft of beam	

	Modified AASHTO Type IV	*63-in. Bulb-Tee*
Strand:	44½-in.-diam 270-kip SR	33½-in.-diam special LR
Cost/ft of beam	$8.72	$6.84
Estimated labor for stranding	0.95	0.72
	$9.67	$7.56
Concrete:	0.2338 yd³/ft	0.1834 yd³/ft
Cost in place/ft	$17.77	$13.95
Total cost/ft.: (strand and concrete)	$27.44	$21.51
Cost difference:	$5.93/ft of beam	

On the basis of these estimated cost differences, the total cost savings achieved by using the bulb-tee alternate on the Madison County, Alabama, project are as follows:

- 54-in. bulb-tees:

$4.80/ft. of beam × 88,034 Linear ft = $422,563.

- 63-in. bulb-tees:

$5.93 per foot of beam × 73,119 Linear ft = $433,596.
Thus the project total is $856,159.

Because of variations in material and labor costs and production methods, the actual savings realized from the use of the PCI bulb-tee bridge beams vary from location to location and from plant to plant. However, the savings are measurable and significant and the present day prestress concrete producer is capable of producing the bulb-tee shape with little or no more difficulty than he produces the standard AASHTO shapes.

CONCLUSIONS

The increased efficiency and cost savings predicted by the referenced study are verified by the experience with the bulb-tee section.

It was possible for engineers to design a more efficient shape in the 1950s when the standard AASHTO shapes were established but production methods and equipment and concrete mix design technology of the day had to be taken into account.

For today's technology, the bulb-tee is a viable product for the average precast, prestressed concrete bridge producer. For producers to make the switch from the AASHTO standard shapes to the bulb-tee may require great effort. The initial cost of new forms is not easy to overcome on small jobs. A common national standard should be adopted by the individual states. Where precast, prestressed concrete producers cross state lines, the cost savings are lost on form cost and relearning of details when each state has its own version of the bulb-tee.

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