Suggestions for Reducing Costs in Prestressed Concrete Bridges

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The objective of this report is to offer a number of ideas for decreasing the cost of prestressed concrete bridges. With the exception of the proposal for increased tensile stresses, all of the ways can be incorporated within the existing 1961 AASHO Standard Specifications for Highway Bridges or the 1961 Interim Specifications. The primary theme here is "keep it simple." About one-half of the suggestions must be incorporated during the initial conception of the bridge design, but the other one-half deals with details. Several of the schemes advanced are especially worthwhile where headroom is critical. If headroom is not critical, a design using large sections with wide spacing is suggested.

• PRESTRESSED CONCRETE has now been established as economical and practical for bridges ranging from 40 to 100 ft in all parts of the country. With the exception of a half dozen states, prestressed concrete is almost always considered at some phase of the planning for bridges in the medium-span range.

Bridge engineers are generally not considering prestressed concrete for short-span bridges (below 40 ft) and long spans (120 to 500 ft). Bridge engineers might also investigate the material for these span ranges because experience both here and abroad indicates that prestressed concrete is often competitive. With the existing AASHO-PCI standards, prestressed concrete is not generally competitive with reinforced concrete on spans below 30 ft. However, the solid and cored flat slabs have often been an economical solution for spans of 30 to 40 ft (Fig. 1). The slabs can be designed with either a composite concrete topping left exposed with grouted joints or covered with an asphaltic wearing surface.

Prestressed concrete should also be seriously considered for long-span bridges. There are numerous examples of long-span structures designed within alternate materials that have resulted in awards to prestressed concrete. An outstanding example is the Lake Maracaibo Bridge in Venezuela (Fig. 2) with five 771-ft spans of stayed girder construction that are 148 ft above the shipping channels; reinforced concrete towers 300 ft high; 620-ft post-tensioned cantilever girders for the long span; a prestressed drop-in span 151 ft connecting the cantilevers; and staying elements for the cantilever girders also of prestressed concrete. Another example is the Medway Bridge in England (Fig. 3) which will have a 500-ft center span and 312-ft side spans when completed. The approach spans are of precast post-tensioned I-girders; the center span consists of two 200-ft box-section cantilevers with a 100-ft drop-in span; and the bridge is approximately 144 ft wide and about 107 ft above high water.

The United States has the materials and the design and construction know-how, but is lagging far behind European countries in this area. So much for short- and long-span bridges. Because the main objective of this report is to suggest ways for saving money on medium-span bridges, the following will apply to designs in this range.

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Figure 1. Prestressed flat slab bridge at Eureka, Calif. Spans are 30 ft except for navigation span which is 105 ft composed of post-tensioned I-girders. The piers are of 20-in. square pretensioned square piles.

Figure 2. Lake Maracaibo Bridge.

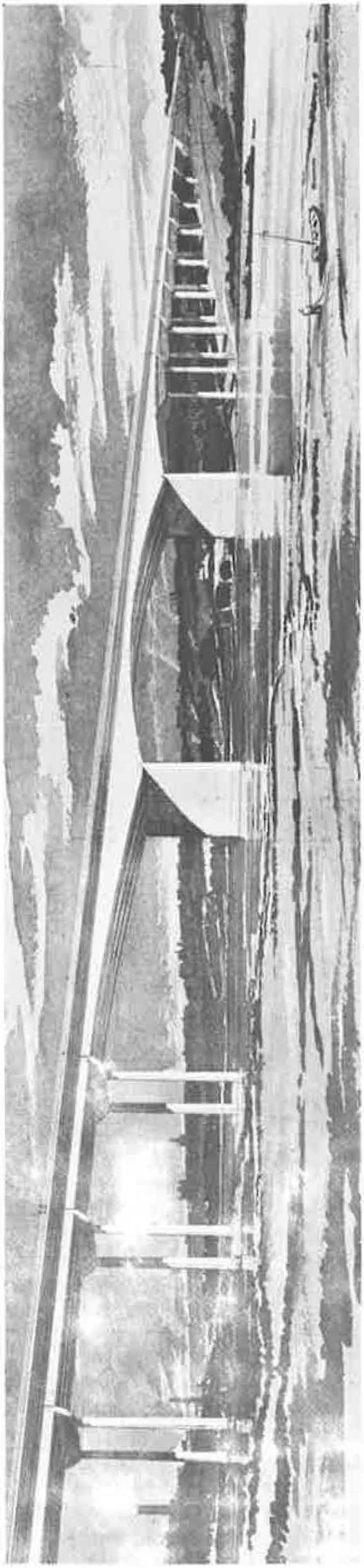

Figure 3. Medway Bridge.

Suggestions one through seven deal with ideas that would usually be considered in the initial planning of the bridge. Suggestions eight through sixteen pertain to schemes for simplifying details to cut production and construction costs. Almost all of the suggestions proposed herein have one common principle: the design should be so made that production and construction operations will be as simple as possible.

1. Use standard sections.—The use of standard bridge sections has become such a common practice that this suggestion is hardly worth mentioning. But departments that do not now have a set of practical and economical standards for prestressed concrete girders would be well advised to settle on the proven AASHO-PCI standards rather than trying non-standard sections. Single purpose steel forms are the only acceptable answer for casting prestressed concrete beams. These forms are expensive, and in order to reduce write-off costs they should be used over and over. States that have used standard sections for a period of years are now paying almost nothing for form write-off. For example, Florida has been using standard AASHO-PCI sections since 1957. Former Assistant State Highway Engineer William E. Dean told a Purdue University Conference that bid prices on type II beams came down four percent, type III beams more than six percent, and type IV beams almost ten percent between 1959 and 1961. This drop in prices occurred even though Florida was buying fewer beams in 1961 than in 1959.

2. Wherever practical make parts in bridge identical.—Naturally it is not often possible to make a bridge composed of identical spans and girder sizes with the same pier design, etc., but this should still be considered as the most desirable solution. If the principle of repetition is held to be of utmost importance, it is often possible to rework the design in such a way that many aspects of the bridge design are identical. For example, on overpass structures it is often possible to use the same girder section throughout by expanding the spacing on the short spans (Fig. 4). Prestressed concrete manufacturers and bridge contractors offer better bids on work that allows repetitive operations. Labor costs are always much higher during the early stages of an operation involving repetitive work than after the team gets coordinated and into a routine. Experience has shown that producers and contractors attach a great deal of importance to this consideration and for good reason.

3. Use as few girders as possible in each span.—This means that if there is a choice of using four type IV girders or six type III girders, choose the four-girder design. This, of course, assumes that headroom is not a problem. The wider spacing of girders may require a thicker or

a more heavily reinforced deck slab, but the savings in girder costs will usually more than offset higher slab costs. It is also often possible to use fewer girders per span without going to larger sections by prestressing them higher (Figs. 6 and 7).

4. Prestress sections higher.—The AASHO-PCI standards can be prestressed to the upper limits allowed by the AASHO specifications without ill effects. A review of present practice shows that many States could prestress their sections considerably higher and either get longer spans or reduce the number of girders in each span. An AASHO-PCI type III girder will span up to 80 ft with a 5-ft spacing (H 20-S16-44 loading), and a type IV girder will span 100 ft on 6-ft centers. To aid the designer in choosing the most economical beam size and spacing, it is often helpful to prepare a set of beam-spacing charts for standard sections. This task is made easier with the use of a computer. Figure 8 shows a simplified version of a design chart prepared for this purpose by the Office of Bridge Engineer, State Highway Commission of Wisconsin.

5. Consider possibility of specifying higher release strength to prestress sections higher.—The AASHO specifications allow a net prestress of 60 percent of the strength of the concrete at release. Almost all States are now releasing at a concrete strength of 4,000 psi. This means that the maximum permissible prestress in the bottom of the girder is 2,400 psi. If the release strength was set at 5,000 psi, one could precompress the same section to 3,000 psi. With 6,000-psi release, the prestress could be increased to 3,600 psi. Figure 8 shows the influence of release strength on the girder design.

Higher release strengths may require (or at least induce) higher 28-day strengths, but concrete technology has now advanced to the point where 7,000-8,000 psi concretes are practical for routine production in many areas. This idea is especially useful where headroom is critical, because it may allow the use of a smaller section. The approach could also save

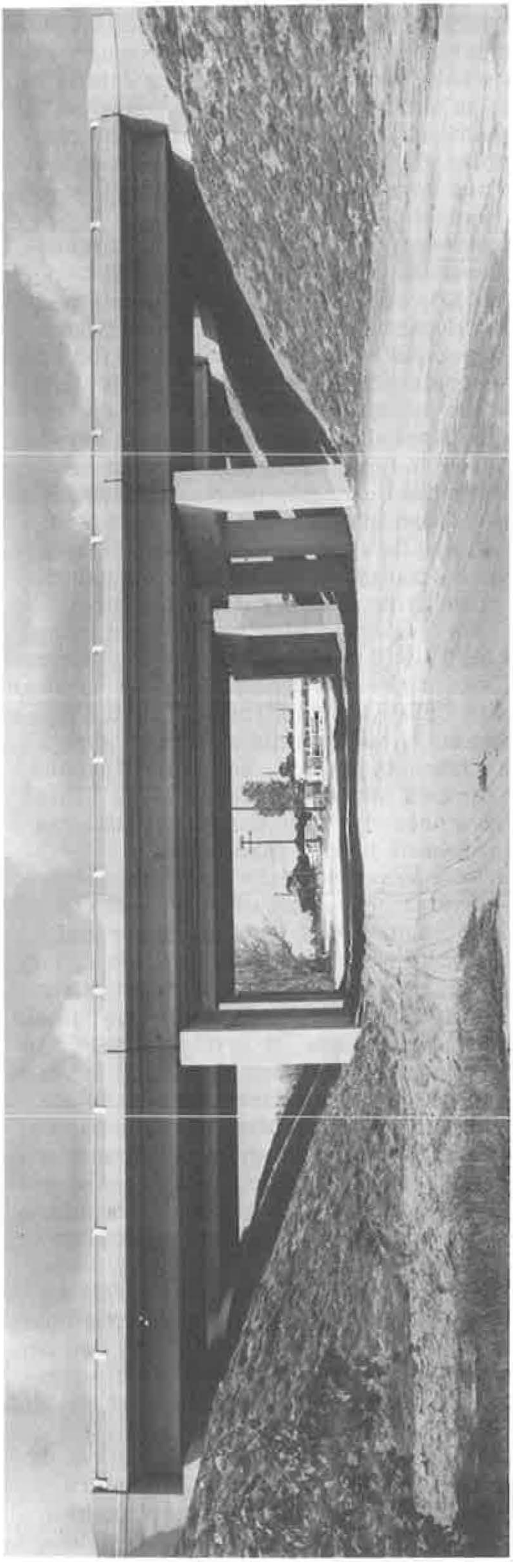

Figure 4. Typical overpass on Sunshine State Parkway, Florida. Structure is a fine example of design simplicity which is a key factor in low-cost prestressed bridges.

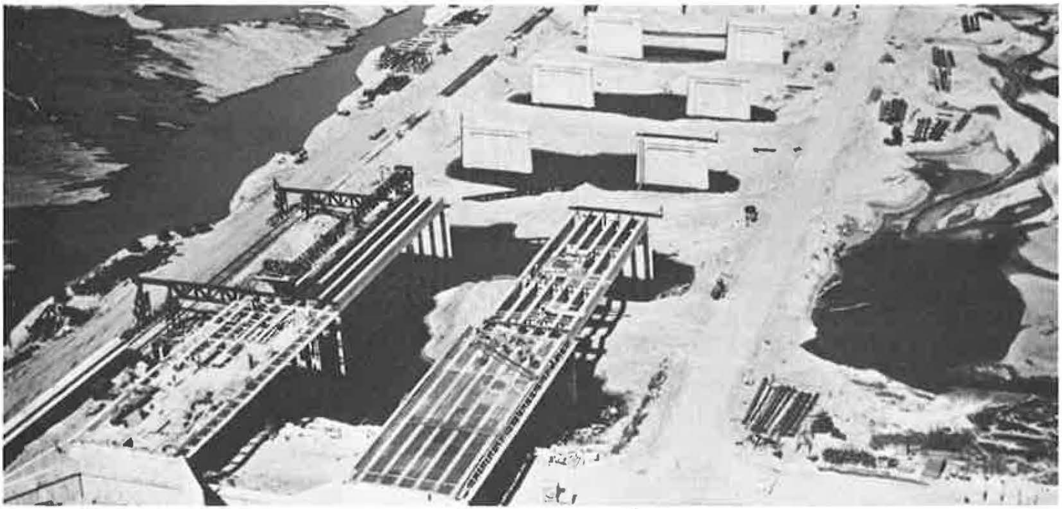

Figure 5. On larger bridges it is easier to get good repetition. This bridge over the Platte River near Ashland, Nebr., used 168 identical beams 110 ft long. The pilings for the piers were also of one size (14-in. octagonal) although the lengths necessarily varied (65 to 95 ft).

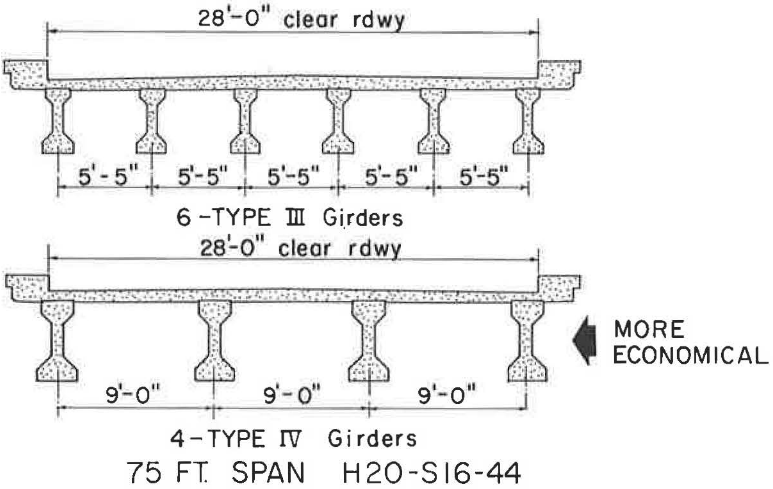

Figure 6.

money even when headroom is not critical if the increase in prestress would allow stepping down to a smaller standard. For example, if a design calls for four type III girders per span but they are only lightly prestressed, it may be possible to put more prestress into a type II girder by calling for a higher concrete release strength and thus save money on each girder.

The bridge for the elevated roadway at Chicago's O'Hare Field was designed with a very low depth-to-span ratio by using pretensioned I-sections released at strengths as high as 6,600 psi. The 28-day strength for the concrete exceeded 8,000 psi (Fig. 9). The prestressed concrete fabricator carefully prepared for these requirements and was completely satisfied with the project.

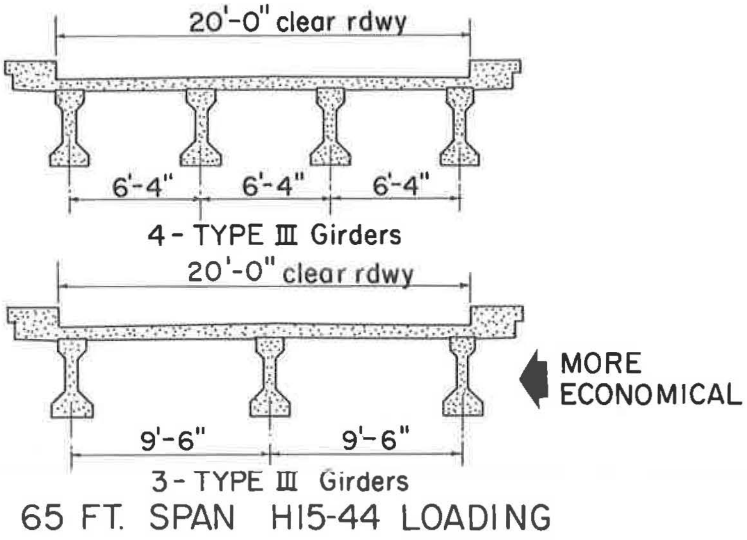

Figure 7.

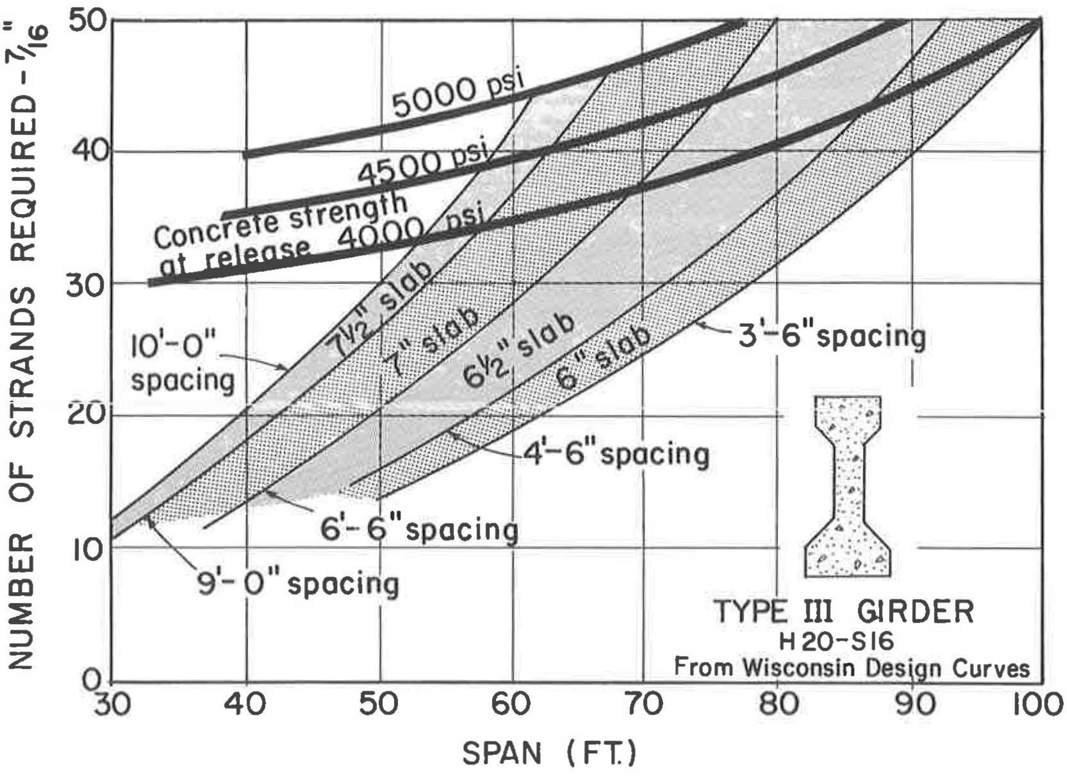

Figure 8. Typical simple design chart for prestressed bridge girders.

Figure 9. Elevated roadway structure at Chicago's O'Hare Field.

6. Use mild steel continuity in composite deck. —Due to the many considerations in continuous design, it is not possible to say that mild steel continuity will always make a more economical design than simple spans. But the idea is worth investigating, because aside from the possible immediate savings, continuity offers several fringe benefits. Perhaps one of the best benefits is the elimination of the costly and troublesome joints in a bridge. Continuity also improves the appearance of overpass structures by closing the gaps between the girder ends. Mild steel will also increase the rigidity and ultimate strength capacity of the bridge, although under the existing specifications there is certainly no need for this. The Portland Cement Association conducted some rather extensive research on this type of bridge (1) (Fig. 10).

Prestressed concrete box beams and cored slabs which have a low depth-to-span ratio to start with can be designed for even longer spans with the use of continuity. In urban interchange structures where headroom is important, this could be an economical solution.

7. Use prestressed piles to double as foundations and piers. —If the L/D ratio is not greater than 25, it is entirely practical to use prestressed piles to double as columns for the piers. This can be considerably more economical than using a separate foundation and pier (Figs. 1 and 11). When more than four square prestressed piles are required for each pier, the structure may not present the most pleasing appearance from below; however, this is not an important factor in many river crossings. Cylindrical prestressed piles can even solve the appearance problem, making an acceptable design for urban and freeway structures.

Washington has had good success with the pretensioned cylindrical pile pier (Fig. 12). Bridge Engineer Winfred T. Robertson told the Seattle ACI fall convention that its bridges built with prestressed pile piers average about $11 psf, whereas structures resting on piles, conventional footings, and piers cost between $15 and $18 psf. He also reported that for stream and lake crossings, the cost difference between bridges supported by pile piers and those of more conventional design equals or exceeds the cost of cofferdams, seals and footings.

The details in a prestressed bridge can also make the difference between an expensive design and an economical one. Following are some ideas for paring costs in the bridge details.

8. Eliminate end blocks in pretensioned girders. —The 1961 Interim Specifications now allow use of pretensioned I-girders without end blocks. Laboratory research and field tests have proven that they are not necessary. The end block has always been a problem for prestressed concrete producers. End block forms cost more money than straight forms but the big cost has been in production setup time. Side forms for every

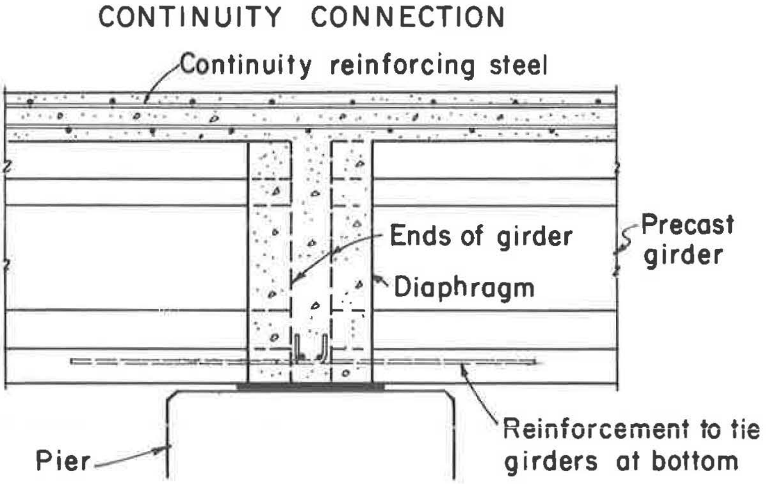

Figure 10. Typical section at pier of precast prestressed concrete bridge made continuous by use of mild steel in deck.

Figure 11. Four 24-in. square prestressed piles extend to provide pier columns for typical Florida crossing.

Figure 12. Driving pretensioned cylinder piles for a bridge in Tacoma, Wash.; 48-in. piles driven plumb to act as columns for piers.

end block type girder have to be individually assembled. Without end blocks the forms can be assembled into one continuous line with end bulkheads set in where required (Fig. 13). States making the change to girders without end blocks will notice a decrease in prices reflecting the reduction of labor costs for assembling and dismantling forms.

9. Eliminate projections from sides of girders whenever possible. —When steel bearing plates must project beyond the sides of the girder, it is better to add this plate after the girder is cast by welding or other fastening methods. Projecting plates and bars that are to be cast in the beams require that the side forms be cut to receive the projecting items. Of course, the location of these holes changes with each different girder. These cutting and plugging operations are not only time-consuming, but they ruin the forms prematurely (Fig. 14).

10. Eliminate shear keys. —Depending on how they are designed, shear keys can be a nuisance at best or a significant cost item at worst. In any event they do not contribute to improving composite action as has been shown by laboratory and full-scale

tests. This is just one more cost item that can be eliminated without sacrificing structural behavior. Portland Cement Association Bulletin D35 reports on horizontal shear research and includes references to several other studies.

11. Hold down amount of mild steel in prestressed girders. —There are many bridge offices designing prestressed girders on a "don't skimp on the reinforcing" policy. Although this sounds commendable, such practice can easily lead to uneconomical designs. The extra steel usually serves a very limited purpose and simply makes an important contribution to high costs. Shear reinforcing should be computed as recommended in the AASHO specifications. The amount of steel required at the quarter point is carried back to the end. End zone steel should be designed according to provision 19 in the 1961 Interim Specifications. When mild steel in a girder starts to exceed 8 lb/ft for a type II, 10 lb for a type III, or 12 lb for a type IV, the designer should take a careful look at each piece to see if it is really necessary.

Figure 13. A line of finished girders with end blocks (left), and a line of forms for similar girders (right). Due to presence of end block, each beam must be formed up individually. Without end blocks forms are set up in one continuous line with sections permanently assembled in easily handled lengths.

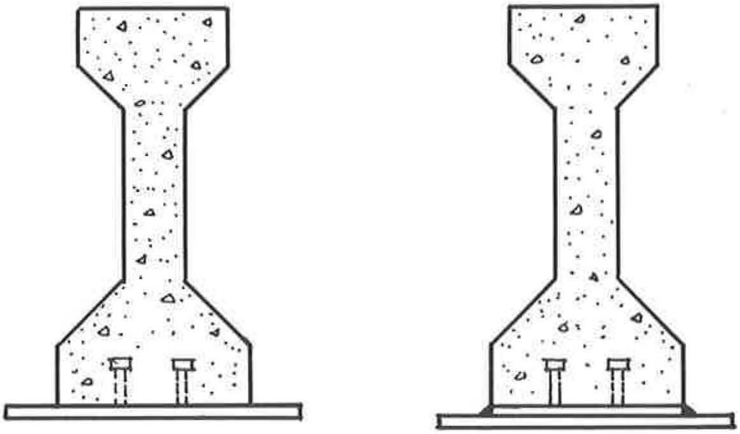

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Figure 14.

12. Design stirrups so that fabrication is simple.—It is very helpful to the producer if the stirrups are detailed in such a way that he can make prefabricated cages of the reinforcement. If the stirrups cannot be made into cages, then they should be designed so that they can be easily tied into place after the strands are tensioned. It is not necessary to have the stirrups surround the strands, and such a procedure greatly increases fabrication costs. If the designer feels that he must have stirrups surrounding the strands, he should place just a few at close intervals at the ends of the beam. An even simpler practice is to use metal strapping (Fig. 15). Beyond the bond transfer zone of the strand (about 50 strand diameters) there are no significant lateral stresses in the beam, and wrap-around stirrups or metal straps serve no useful purpose. Notice that the second beam line from the right in Figure 13 shows the strands tensioned and the end bulkheads set, but the mild steel reinforcing has not yet been placed. This is the normal sequence of operations. It can be seen here that surrounding stirrups would either have to be bent in place or threaded on the strands prior to tensioning and then spaced out. Either way the operation is expensive and time-consuming. Of course, metal strapping can be placed on the strands after tensioning with no difficulty. Notice that a prefabricated cage similar to that in Figure 16 C can be placed over the tensioned strands whether they be straight or deflected. The AASHO specifications require a transverse bar in the bottom of pretensioned girders. This can be easily handled by tying in a small straight bar. An alternate to the prefabricated cage is a design employing two bars (Fig. 16 B). This bar provides a tie for the composite slab, vertical shear reinforcement and the bottom transverse tie all in one piece.

13. Use largest and strongest strand available.—Use of large diameter strand and strand with higher ultimate strength will reduce costs. The material cost is lower in the first place, but labor costs are reduced also. As an example, consider a beam designed with 65 strands ($^3/_8$-in. diameter) with an ultimate strength of 250,000 psi. The same net prestressing force can be provided by 31 strands ($^1/_2$-in. diameter) with an ultimate strength of 270,000 psi, but the material cost will be 14 percent lower. The larger diameter strand will often provide an added bonus because of the opportunity to increase the eccentricity of the smaller strand pattern.

14. Use elastomeric pads instead of metal bearing assemblies.—Laboratory tests and field experiences indicate that synthetic rubber pads are perfectly satisfactory for bridge bearings. The use of these pads in place of metal bearing assemblies can mean large savings in the cost of prestressed bridges. Metal bearing assemblies often represent a sizeable proportion of the cost of a bridge superstructure. Elastomers can reduce bearing costs as much as 95 percent and may even do a better job.

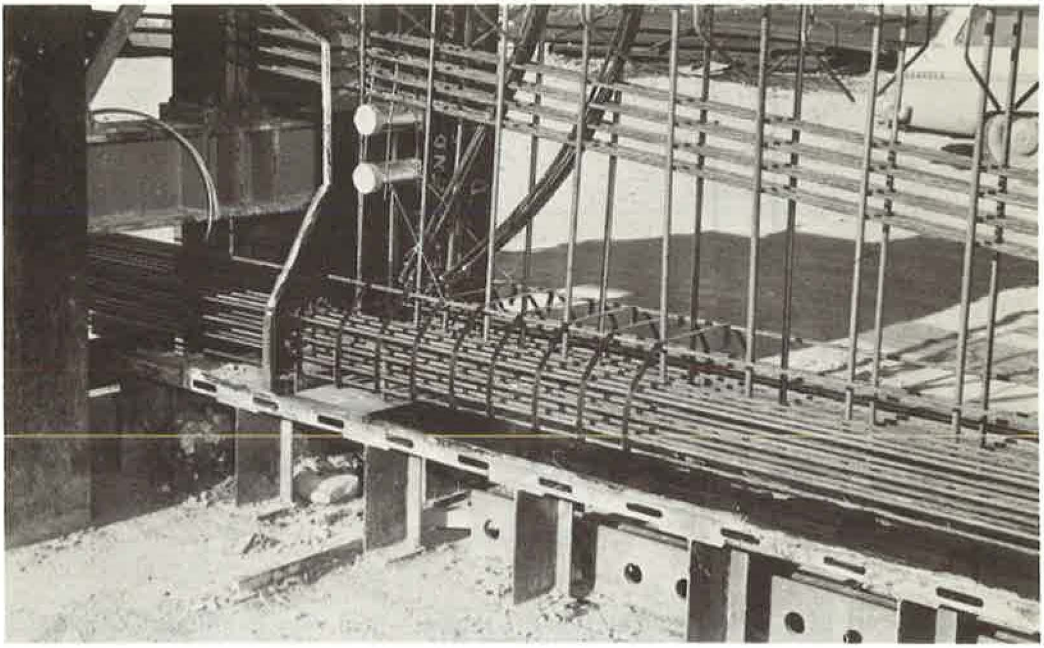

Figure 15. Use of metal strapping.

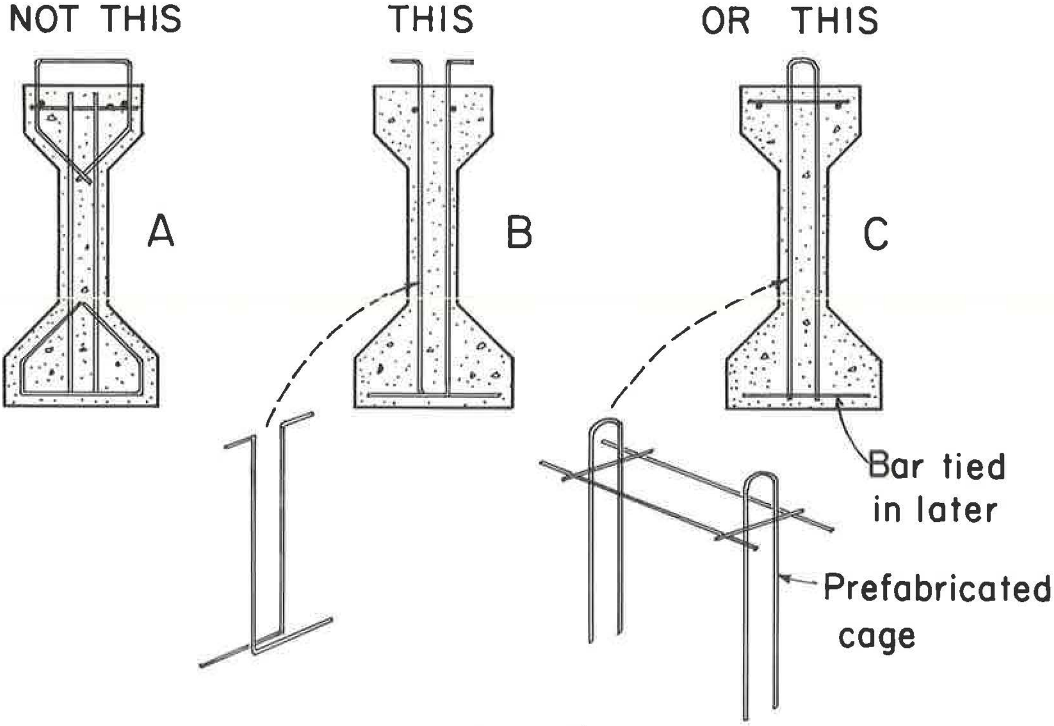

Figure 16.

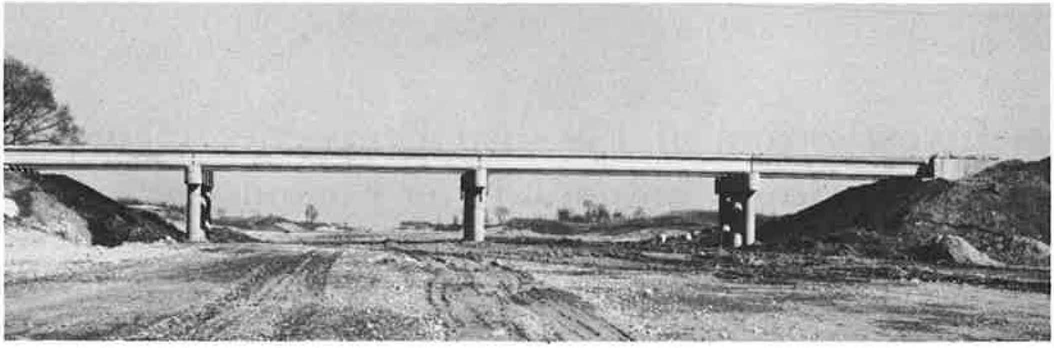

Figure 17. Typical structure on Illinois Toll Highway incorporated many of the cost-saving ideas listed herein.

15. Eliminate steel base plates for elastomeric pads. —This may not be practical if the bridge is on a skew or on a superelevated curve because there must be some positive method of keeping the bearings in place. But for a straight bridge, the steel base plates can be safely eliminated. When the plate is eliminated the bottom of the girder must be true and smooth in the bearing area.

16. Eliminate or reduce diaphragms. —Casting concrete diaphragms on prestressed bridges is a costly problem for bridge contractors. If the diaphragms are cast prior to casting the deck, the contractor must make elaborate preparations for a very small amount of concrete. If they are cast with the deck, his formwork is complicated considerably over a straight deck-forming job. From a design standpoint, the deck will provide at least as much distribution as assumed in the 1961 AASHO Interim Specifications. (S/5.5 for I-girders.) The diaphragms add little or nothing to the distribution of live loads depending on how they are designed. The often used design which consists of a concrete rib with a tie bolt running through the middle adds almost nothing to the distribution of live loads because of its inadequate ability to transmit transverse bending moment (2).

All of the previous suggestions for reducing costs have been tried in actual field experience and have proven satisfactory. As a point in fact, suggestions 1, 2, 6, 7, 8, 9, 10, 12, 14, 15 and 16 were incorporated in prestressed concrete structures on the Illinois Tollroad, completed in 1958 (Fig. 17). As a result of these measures, the Northern Illinois Toll Highway Commission was able to get an unusual value for its money in these structures which have performed almost flawlessly. George Jackson, Chief Engineer of the Commission, says that in these four years they have had no maintenance expense for the prestressed girders.

The proposals suggested in this paper are all possible within the existing AASHO Specifications for Highway Bridges. Another design procedure that would greatly reduce the cost of prestressed bridges is to allow tensile stresses in the bottom of the beams under full live load. The AASHO test road has shown that with 300-psi tension under design load, a prestressed bridge will perform perfectly even under 1½ million loading repetitions. For a fully prestressed section (i.e., maximum precompression) the allowance of 300-psi tension would reduce strand requirements 15 percent. For sections not prestressed so heavily the reduction would be even greater. It is understood that the HRB Bridge Advisory Committee has recommended that tensile stresses be allowed in pretensioned beams. Bridge engineers may wish to note this future specification change so that they may take advantage of it as soon as it goes into effect.

REFERENCES

1. PCA Development Department Bull. D34, D35, D43, D45, D46, and D51.
2. Janney, Jack, and Eney, W. J., "Full Scale Test of Bridge on Northern Illinois Toll Highway." World Conference on Prestressed Concrete Proc. (See also PCA Dev. Dept. Bull. D51.)