Prestressed Concrete in California

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●WITHIN the past six years, prestressed concrete in the United States has grown from an innovation into an accepted method of concrete construction. This growth, a result of a new application of existing materials and theories, is quite phenomenal. In Europe, during the past ten years, shortages of materials and enforced economies in construction have given prestressed concrete a substantial start. The development in the United States, however, has been somewhat slower. Its acceptance has been characterized by some hesitancy, both on the part of designers and contractors, mainly because of lack of experience and reluctance to abandon methods of construction for which they were well experienced and equipped. There have also been difficulties and misunderstandings concerning the various anchorage systems and types of stressing units.

However, there has been much progress. Experience came rapidly, and the quality of the work improved. With increased know-how, the work became easier and the prices dropped.

Each prestressed concrete job still provides new problems and consequently adds to knowledge of the subject. Prices have not dropped to their ultimate level; the drop so far has been merely sufficient to bring prestressed concrete within the range where it can be used occasionally on a straight economic basis without justification by some other advantage peculiar to prestressed concrete. Prices have not yet reached the point where prestressed concrete can be substituted with impunity for conventional concrete design. Contractors still have their own equipment; the crews are trained for conventional construction. In California, they usually bid rather high on prestressed concrete work for which they must secure outside experts or rent special equipment.

Fittings, Patents and Salesmen

The increasing acceptance of prestressed concrete has led many manufacturers into the production of the prestressing rods, wire and cables, and especially the end connections for the tension members. Almost every conceivable method of fastening the wires and rods has been tried. Many methods are covered by patents, and each of the several systems available has its own advantage. The strenuous competition has in some cases acted to the detriment of the prestressed concrete field as a whole.

Designing for specific systems is not a desirable policy on public work. Designs must be prepared with sufficient latitude so that any of the leading prestressing methods may be applied to the work. This often results in oversize beams and end details which are cumbersome or undesirable.

A general contractor making the low bid on a structure containing prestressed elements is immediately besieged by salesmen offering different prestressing systems. Sometimes these systems and devices are new and untried, and the unwary contractor may find that he is paying a sub-contractor to perfect some new device that may or may not be successful. Such tactics do not generate confidence in contractors nor encourage reductions in prices.

Unfortunately, the contractor may not combine the best features of several systems to his own benefit and to the benefit of the job, but he must choose one system to follow through — accepting both its advantages and its disadvantages. The use of the equipment is often tied in with the use of a particular anchorage system because the equipment is specialized and the know-how is still not too widely dispersed.

These factors acted somewhat to the detriment of the prestressed concrete development.

Jacks and Grouting Equipment

Some efficient jacks and holding devices have been developed to do the stressing work on the tension members. The jacks are usually made and operated by the purveyor of a certain type of fastening device so that the advantages or disadvantages of a given type of jack are tied to the chosen type of anchorage.

Although the grouting of the cable or rod enclosures is generally considered to be of vital importance (either from a corrosion protection standpoint or occasionally from the standpoint of achieving full bond), the grouting equipment is often makeshift and impractical. In the early stages of prestressing work, some jobs were halted because of inadequate grouting equipment.

It is pertinent to the economics of prestressed concrete to point out that adequate and efficient methods of grouting the prestressing members must be developed and used generally. This is essential to make prestressed work competitive. Many contractors, although the actual prestressing work may be handled by some subcontractor, shy away from bidding this type of work, or else bid quite high, because of known difficulties with the grouting operation. As long as such factors influence a contractor's bid, the prices for prestressed will remain high.

Post-tension or Pretension?

Prestressed concrete was first introduced through post-tensioned members, but the economic benefits of pretensioning became apparent, and suppliers began to equip themselves to manufacture pretensioned beams.

The possibility of procuring standard prestressed concrete beams from a supplier in the same manner as steel or timber beams is rapidly becoming a reality. After some experimenting with various sections, bridge members are now being standardized so that suppliers will find it economical to provide semi-permanent forms for repeated use.

The benefits of casting pretensioned beams, slabs, and piles on beds as long as 500 ft, steam curing them in place, and then cutting them apart and moving them in as little as 24 hours have already been realized. Large beams also have been simplified by pretensioning. Where the needed prestressing force exceeds the capacity of the tensioning bed, it has been possible to pretension the beam enough to permit moving and, then, add the remainder of the prestressing force by post-tensioning.

The full possibilities for pretensioned concrete manufactured in a plant and sold as a stock commodity are yet to be realized. The basic requirement is that precast pretensioned work requires a precision and attention to detail not involved in concrete work before. With care, excellent work can be and is being done. Greater facility on the part of the manufacturers and greater acceptance on the part of the designers will make this phase of prestressing one of its most interesting developments.

Precast Concrete

Some thirty years ago, the concrete industry became aware of the possibilities of precast concrete work. There was a period when efforts were made to utilize precast units to the fullest, but carrying the method to the point of precasting every part of a structure led to its decline. Structures without adequate joint rigidity eventually collapsed, and the use of precast work fell to a minimum.

Once again the benefits of precasting — the benefits of doing the expensive forming and pouring work in a central yard — are being discovered. Precast work must be designed with full knowledge of the necessity for joint rigidity. The designers must realize that there are practical limits to precasting and that present day structures must be designed with the provision that some of the concrete be poured in the field to tie the members together.

Cost Comparisons with Conventional Designs

The purpose of this paper is to make a definite comparison of the costs as realized to date on some California projects with the cost of conventional design.

California's five years of experience do not offer conclusive evidence on the comparative cost of prestressed and conventional concrete construction.

Since September 1950, when bids were taken for the Arroyo Seco Pedestrian Bridge in Los Angeles, twenty projects have been built using various types of prestressed units.

Approximately the same number of projects are being designed for construction within the next three years.

Prices are available for the twenty completed structures, and an attempt has been made to compare each prestressed concrete structure with a similar structure of conventional design. These twenty structures are composed of a variety of types of prestressed elements. The twenty projects were divided as follows:

Number of Structures	Prestressing Application
2 pedestrian overcrossings	T-shaped girders
1 pedestrian overcrossing	Slab
6 structures	T-shaped girders
1 structure	Inverted T-section
2 structures	I-shaped girders
3 structures	Precast channel sections
1 undercrossing	Slab
2 structures	Box girders
2 miscellaneous structures	Caps and beams

Prestressed concrete is not practical in all situations. Like all other materials, there are special advantages of the system which make it better in one situation than in another. It is of special interest, therefore, to analyze the reasons for selection of prestressed concrete designed for these various structures.

In seven of the cases, prestressed and precast concrete was chosen so that the beams could be swung into place either over water or over traffic with a minimum of interference. Economy and elimination of falsework were the main benefits.

In six cases, the prestressed design was chosen for separation structures to reduce the depth of the member to a minimum and to maintain the maximum clearance between roadway grades. Precast and prestressed construction was chosen in three cases because of the advantages and saving made possible by the mass production of a large number of similar units. Another saving is to be found in construction without falsework.

Three more bridges were made precast and prestressed because of their remote location. It was more economical to precast the elements of the bridge at a plant and haul them out to the job than it would have been to transport all of the component parts and the labor.

The inherent characteristics of prestressing made it suitable for the twentieth structure. A bridge which was to be loaded with three feet of superimposed fill was bolstered up underneath with prestressed beams. The prestressing of the supplementary beams created a camber which brought them into firm contact with the original structure, enabling them to take their intended share of the increased load. This characteristic is also being used in several other structures now being designed. It is far superier to wedging or dry-packing with grout.

One of the difficulties in comparing prestressed concrete structures with conventional designs is that the prestressed type of design is often chosen to satisfy some particular condition for which there is no equivalent in conventional design. An example is a prestressed design chosen to save headroom in a separation structure. In the case of the Hoppow Creek project, for example (Figure 2), the use of prestressed design enabled the depth of girder to be reduced to 27 in. for the 50-ft spans. A conventionally designed T-beam for a 50-ft span would run 42 to 48 in. deep. Since the depth of girder is important at this location, it becomes a factor in making a fair comparison. If the prestressed girder could be made only 26 in. deep, should not the comparative cost of a conventional design also be figured upon a T-beam only 26 in. deep? A comparison of this sort does not present conventional concrete design in its most efficient form.

The comparisons made in this discussion are based upon the most economic use of the two designs. If the conventional design has a greater depth than the prestressed design, it is presumed that the approach grade line will have to be raised to compensate. Although this raise in grade may introduce additional costs chargeable to the conventional design, only the actual cost of the two superstructures is considered.

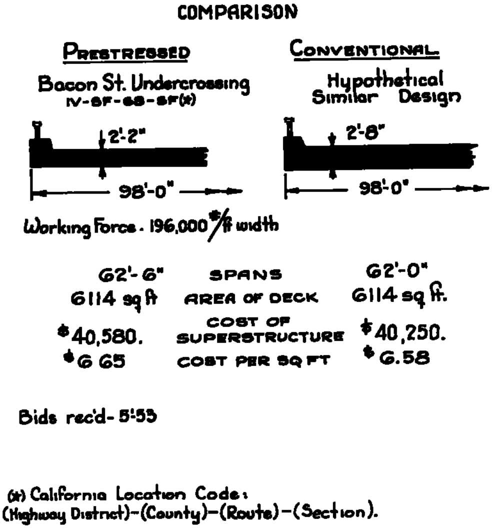


Figure 1.

A number of the applications of prestressed principles were of such a specialized nature that comparison to a conventional design is not possible. These have been eliminated from consideration. There are twelve structures on which it is possible to make a cost comparison.

Nine of the structures are compared to conventional structures which are very closely parallel in span and site conditions. To make a comparison for the other three structures, it is necessary to make a design for a hypothetical structure of the same span and width.

In making these comparisons, only the construction cost for the superstructure is used. Rail and curbing costs are not included. In order to obtain comparative cost per square foot, the areas of the structure are taken to be the rail-to-rail width multiplied by the distance from paving-notch to paving notch.

In the following comparisons a conventional design type is compared with one or more prestressed structures. The grouping is made with approximately equal span lengths. In order to consider only the relative initial structural costs (in the case where steel bridges are used as a comparison), the cleaning, painting and maintenance costs are not included. Where structures were in remote locations, some adjustment was made in order to compare with the cost of structures located closer to the sources of material and labor.

COST COMPARISONS

Slab Bridges

The Bacon Street undercrossing (Figure 1) is a prestressed concrete slab built in San Francisco in 1953. The bridge is wider than it is long, having a 62-ft span with a width of 100 ft. The thickness of the slab is 26 in. The slab was cast-in-place, and was post-stressed using wires grouped in sheaths, and was also prestressed laterally. The superstructure alone cost $40, 580. 00 for a deck area of 6, 114 sq ft. The unit cost of the structure was $6. 65 per sq ft.

Since no comparable bridge of conventional concrete design was available, a hypothetical design was made for a 62-ft slab span, reinforced in a conventional manner. The total cost of the superatructure was estimated at $40, 250. 00, making a total cost of $6. 58 per sq ft.

The comparison shows the two types of designs to be almost identical in cost per sq ft. However, the conventional design would have required 6 in. more depth of slab, which extended to the approach fills would have materially increased the cost. Therefore, the prestressed design was chosen in order to cut the required headroom to a minimum and keep the grades of the two roadways as close together as possible.

Channel Sections

Three prestressed, precast structures having a channel section are compared to a conventional design T-beam (Figure 2). The Hoppow Creek project was built along the sparsely populated northern California coast. Prestressed construction was chosen for three reasons: (1) to get a minimum depth of superstructure so as to obtain as much waterway as possible without having to raise the roadway grade, (2) to obtain a structure which could be formed and poured where labor and materials were more plentiful, (3) to get a concrete structure which would require a minimum of maintenance in this damp location. Figure 2 shows the dimension of the section and the cost statistics of

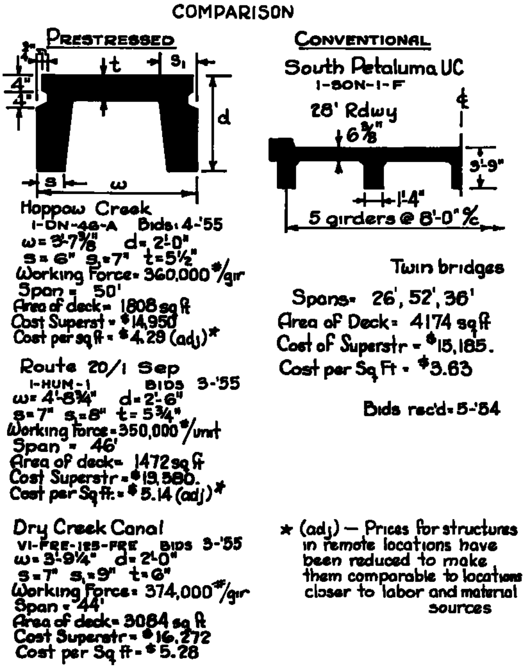


Figure 2.

the structure. The prices were adjusted to make them comparable to locations closer to labor and material sources. The adjusted cost was $4. 29 per sq ft.

The separation structure at the junction of California Routes 1 and 20 was built in 1955. The reasons for the choice of prestressed concrete were similar to those at Hoppow Creek. Figure 2 shows the details of the section and the adjusted price for this bridge was $5. 14 per sq ft.

The third structure in this group was the Dry Creek canal bridge near Fresno. Prestressed design was chosen to allow setting the units in place over a full-flowing canal without the necessity of using falsework. The structure consisted of eighteen 44-ft precast channel sections bolted together and surfaced with asphalt. The approximate weight of each unit was 16 tons. Figure 2 shows the data on the section and the cost was $5. 28 per sq ft.

For comparison, a conventional T-beam design has been used. The South Petaluma undercrossing, built in 1954, has five T-beams 45 in. deep. The undercrossing consists of twin structures both of which are comparable to the three precast structures. The cost for this conventional T-beam structure was $3. 63 per sq ft.

Although the unit cost of the latter is less, there are advantages to prestressed design which do not appear in the price. The cast-in-place T-beam required 15 in. to 21 in. more depth of girder, decreasing the headroom beneath the structure. Furthermore, the falsework had to be built for the cast-in-place structure, whereas the precast units were cast in a yard and hauled to the site. Although the cost of the falsework is included in the unit price, the advantages of construction without obstructing the channel or the roadway are not always reflected.

Precast "T" Sections

The Santa Maria River bridge (Figure 3) consisted of twenty-four 50-ft spans across a wide, flat, gravel river bed. The T-section girders were cast and post-tensioned on the river bank, then, hauled out and set into place. The saving in falsework was, to a degree, offset by the necessity for building a temporary casting yard on the river bank. One hundred twenty of the precast and post-tensioned girders were manufactured. The final unit cost for this superstructure was $3. 53 per sq ft.

The Santa Ana River bridges (Figure 3) consisted of a conventional T-beam design used for parallel bridges. The span lengths were the same, and the river bottom condition was very similar to that at the Santa Maria River site. The Santa Ana River project has possibly a slight advan-

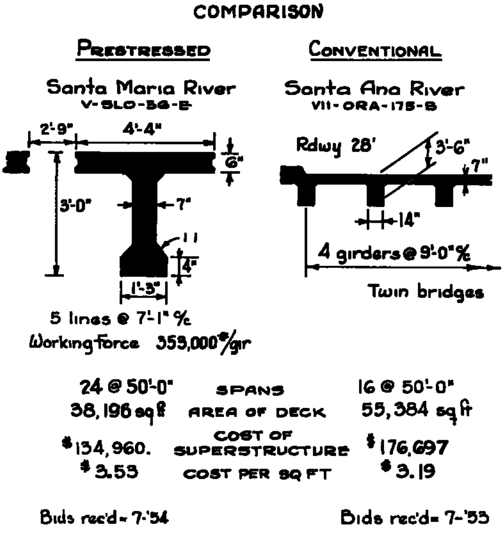


Figure 3.

tage in being somewhat closer to a large labor and material source. However, in this case the conventional T-beam design was cheaper than the prestressed and precast design. The cost for the Santa Ana River project was $3. 19 per sq ft.

The Richardson Bay bridge (Figure 4) was built over an arm of San Francisco Bay where the bottom was covered with a thick layer of thin mud. Falsework would have been prohibitively expensive. The portion of the structure over the water was designed for prestressed and precast beams which were lifted into place from a derrick barge. The beams were cast in a yard which had water access to San Francisco Bay and were hauled about 40 miles to the bridge site. The operation was successful, and the unit cost for the precast portion of the bridge over the water was $3. 94 per sq ft.

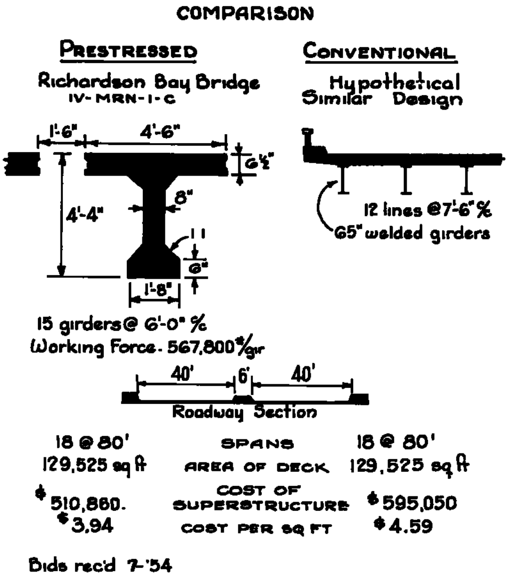


Figure 4.

A hypothetical design was made to compare to the Richardson Bay bridge, with the presumption that, because of the falsework difficulties, it would be necessary to use steel welded girders even though, in this salt water location, the maintenance painting cost would be increased. Maintenance painting costs were not included in the unit costs for this study even though these costs must be included in an over-all economic study to determine the type of structure to be used. The hypothetical design cost, based upon prices for similar work, was $4. 59 per sq ft, a material benefit in favor of the prestressed and precast construction.

In the separation structure (Figure 5) at the junction of California Routes 5 and 107, prestressed section was used to obtain the minimum depth of girder and was precast to get the advantages of construction without falsework. The unit cost was $6. 00 per sq ft. The Collier Road overcrossing, with welded steel girders and a concrete deck had a unit cost of $5. 09 per sq ft and was considerably cheaper than the prestressed structure. The primary probelm was one of erecting the structure over traffic, and the T-beam design minimized the amount of concrete form work which had to be done.

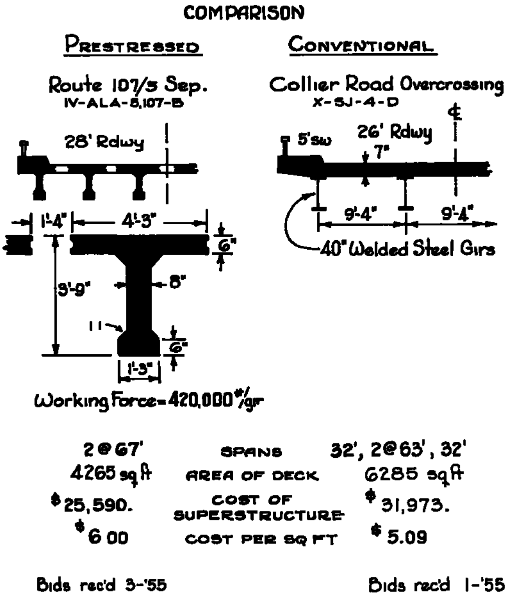


Figure 5.

I-Section Precast Girders

Figures 6 and 7 show I-section precast and prestressed girders compared with steel girders for comparable spans and conditions. In both cases, the precast concrete beam is slightly deeper than its steel counterpart.

The Grant Street undercrossing consisted of five girders 42 in. deep with a maximum width of 18 in. The beams were cast at the site and lifted into place. The unit cost was $5. 15 per sq ft for the superstructure.

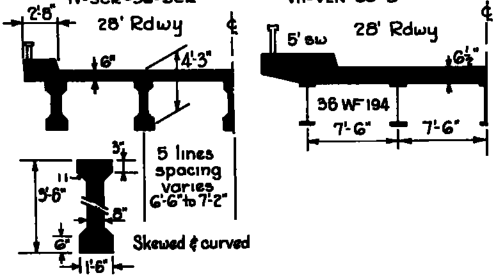
The Frontage Road overcrossing, using 36 in. wide flange steel beams, also had five girders and comparable spans. The cost of the superstructure was $5. 98 per sq ft.

The other precast prestressed I-section was the Ocean Street undercrossing (Figure

COMPARISON

Prestressed — Grant St Underxing, IV-SCR-56-SCR

Conventional — Frontage Rd Over'xing, VII-VEN-60-B



Working force- 348,000#/gir

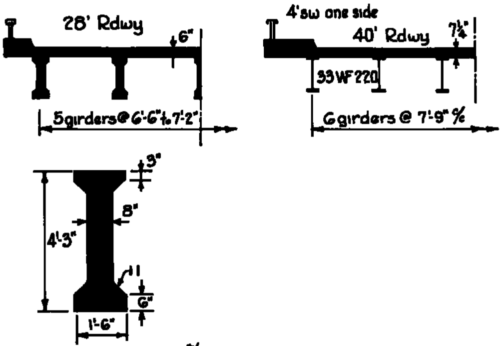
Prestressed		Conventional
53', 2@59', 33'	SPANS	2 @ 50'
5426 sq ft	AREA OF DECK	3718 sq ft
$27,977	COST OF SUPERSTRUCTURE	$22,250.
$5 15	COST PER SQ FT.	$5.98
Bids rec'd 7-'55		Bids rec'd 5-'54

Figure 6.

COMPARISON

Prestressed — Ocean St Undercrossing, IV-SCR-56-SCR

Conventional — Calaveras River, X-SJ-4-C



Working Force= 348,000#/gir

Prestressed		Conventional
49'-7", 47'-2"	SPANS	40', 54', 40'
3275 sq ft	AREA OF DECK	6220 sq ft
$15,044	COST OF SUPERSTRUCTURE	$31,100
$4 60	COST PER SQ FT	$5 00
Bids rec'd 7-'55		Bids rec'd 11-'47

Figure 7.

7). Its cost of $4.60 per sq ft was materially better than the cost of $5.00 per sq ft for the Calaveras River bridge. The Calaveras River bridge was made up of six 33 in. wide flange steel beams, and it had a somewhat wider roadway. However, on a square foot basis the prestressed structure was cheaper in both cases. In neither instance was the depth of girder a critical factor.

These sections represent pioneering efforts on the part of both designers and construction forces. One evidence of the state of flux in this new field is the variation in dimensions of the "I," channel, and "T" sections. Obviously, such variation is not an economical practice. It is essential that a standard section be adopted. California is now standardizing these sections.

Bridges Prestressed in Place

Figure 8 shows a pair of concrete box girders, one of which was post-tensioned. The John Street overcrossing was the first

COMPARISON

Prestressed — John St Overcrossing, V-MON-2-SAL

Conventional — Sixth St Overcrossing, VIII-SBD-26-ONT

Working Force 952,000#/gir
Two spans continuous

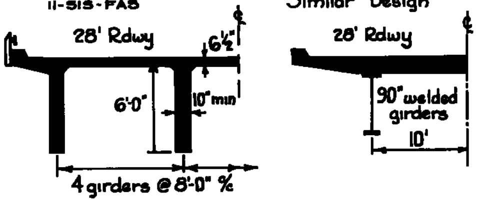
Prestressed		Conventional
100'-6", 93'-6"	SPANS	2 @ 104'-0"
7877 sq ft	AREA OF DECK	8310 sq ft
$56,522.	COST OF SUPERSTRUCTURE	$42,116
$7.18	COST PER SQ FT.	$5 07
Bids rec'd 9-'54		Bids rec'd 7-'52

Figure 8.

COMPARISON

Prestressed — Scott R @ Horn Lane, II-SIS-FAS

Conventional — Hypothetical Similar Design



Working Force= 900,000#/gir

Prestressed		Conventional
120'	SPANS	120'
3660 sq ft	AREA OF DECK	3660 sq ft
$26,790	COST OF SUPERSTRUCTURE	$33,400
$7 32	COST PER SQ FT	$9.12
Bids rec'd: 7-'55		

Note: Because of the remote location, these prices are about 7% above those closer to labor and material markets

Figure 9.

two-span continuous, prestressing job. The prestressing wires were run through the open cells. The depth of girder was of prime importance and the use of prestressed concrete permitted the reductions of the depth to only 4 ft. The job was built in 1954 and, being the first continuous structure of this sort in this area, it is felt that the price was raised somewhat as a result of uncertainty as to what the job would require. Unit cost was $7. 18 per sq ft.

The Sixth Street overcrossing built in 1952 gives a good comparison. Although the unit price of $5. 07 is materially cheaper than the prestressed structure, it must be noted that the depth is also 2 ft greater. Also, this type of construction was being done very economically because of the numbers of concrete box girders which had been built in the Los Angeles area. When a reduced headroom is essential, although more expensive in this case, it is possible to obtain it by the use of prestressed concrete. Future designs of this type should be considerably cheaper. The cost of the first bridge of a type is almost always relatively high.

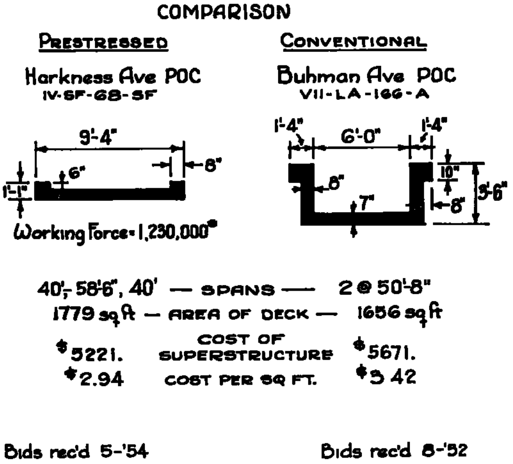


Figure 10.

Incidentally, on the John Street structure, difficulties during construction beset a contractor inexperienced in prestressing, and confirmed his apprehension. The fact that continuous spans are best stressed from both ends was not proved until a great deal of effort had been spent trying to stress from one end. The grouting operation proved very troublesome largely because of lack of know-how, and much delay resulted. These experiences became known and other contractors became wary. Higher prices were the inevitable result.

Figure 9 shows a deep, but thin, section T-beam bridge which was poured in place and then post-tensioned. The 6-ft deep girders worked out very economically for this 120 ft span. The unit cost was $7. 32 per sq ft. It is estimated that this cost is about 7 percent higher because of the remote location of the structure.

No structure was available for comparison to the Scott River bridge, so a hypothetical design was made. Using two 90-in. welded girders with a similar span and width of roadway the unit cost was $9.12 per sq ft, showing a material benefit for the prestressed work.

Pedestrian Overcrossings

Figure 10 compares two pedestrian overhead structures. A pedestrian structure must be light and airy in appearance to be attractive. Prestressed concrete designs improve the appearance of pedestrian structures by making long, thin members feasible. The Harkness Avenue pedestrian overcrossing is a simple slab span 7 in. thick with two shallow side beams 13 in. deep. The deck is surmounted by a 6-ft steel railing made of parallel, vertical bars. The supports are wall-type bents 12 in. thick. The unit cost was $2. 94 per sq ft.

The Buhman Avenue pedestrian overcrossing also strove for a light, thin appearance in conventional concrete design. However, it was necessary to make the edge beams 42 in. deep. The architectural treatment on the outside of the beam created a horizontal shadow breaking up the plain surface, and a low railing, similar to the Harkness Avenue structure, contributed to the open feeling. Neither from the standpoint of appearance nor from that of cost ($3. 42 per sq ft) did the conventional structure approach the clean open lines of the prestressed design.

Conclusion

Prestressed concrete is not a cure-all, and it is not applicable to all situations. It has certain advantages which may give benefits not reflected in unit costs. It permits the construction of long beams which may be lifted into place without the necessity for falsework or for interruption of traffic beneath a structure. It permits more slender and shallow members, allowing greater headroom and decreasing the required depth of a structure. It permits a member to be built in place and then post-tensioned to take its share of the load. When pretensioned, it permits members to be built economically in yards and hauled to the structure site.

It has little advantage on very short spans. It raises the difficulty of tying together precast concrete members. It calls for precision of workmanship beyond that usually found in concrete construction. It requires specialized knowledge and special techniques and equipment. It demands a certain amount of experience and know-how. This last reason has been outstanding in holding construction prices higher than warranted.

Prestressed concrete is a new medium with definite uses. Cost alone is not the entire answer, and cost of prestressed work will decrease with time and experience. In the future, prestressed and precast beams will be bought on the market as a standard stock item. An amalgamation of the various prestressing systems to promote prestressed concrete as a whole and to subdue detrimental competition is probable. The position of prestressed concrete in the construction field will be clarified by these factors.

The time will soon come when the engineer who considers the use of prestressed concrete will find that, for the benefits derived and for the money expended, prestressed concrete adds a new, economical, and exciting medium to the many which the structural engineer may use.

ACKNOWLEDGMENT

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