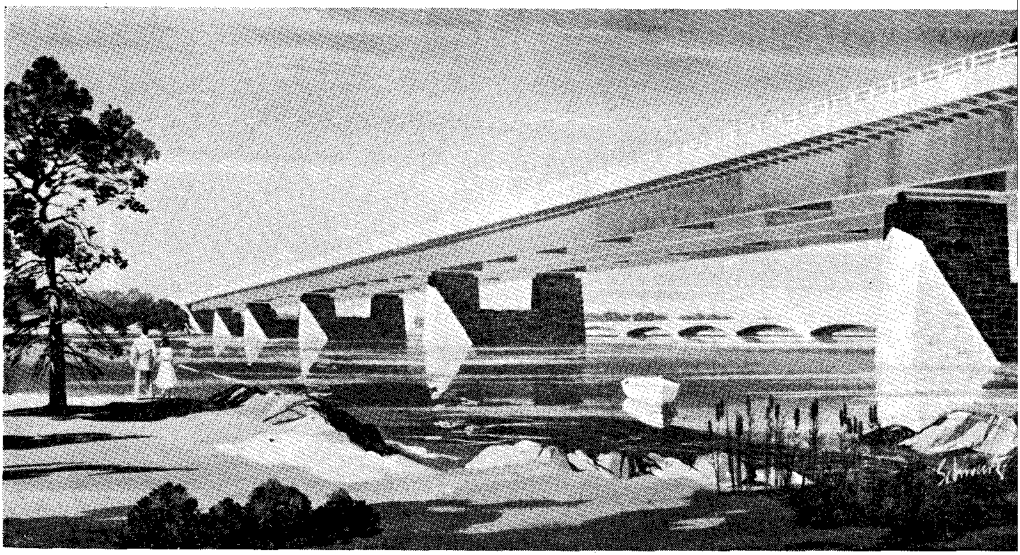


Fig. 22 — Perspective of imposing prestressed concrete bridge across the Potomac River in Washington, D. C.

STRUCTURAL AND ECONOMIC ADVANTAGES OF CAST-IN PLACE PRESTRESSED CONCRETE FOR LARGE SPAN BRIDGES . . .

By Curzon Dobell

M. A S C E, Consulting Engineer

It is most fitting to be holding this convention in the State of Florida which has done so much to advance the use of prestressed concrete for highway bridges under the able direction of the State Bridge Engineer, William E. Dean. Right after the war he foresaw the advantages of using prestressed concrete for many of the bridges required in meeting the backlog of highway construction. He recognized the need of standardizing design and construction procedures so that the theory of prestressing could be applied to assembly-line techniques to produce rapid and economical construction. The success of his efforts can be seen in many parts of the state where some 50 prestressed bridges have been built. They were not only cheaper than steel or reinforced concrete, with which they competed, but were also cheaper than most prestressed bridges built in other parts of the country.

In his paper to the Highway Research Board in January, Mr. Dean reported on the design, construction and cost of 15 of these bridges having a total length of 43,121 feet, of which 36,396 feet are built with post-tensioned precast girders, 4,325 feet with pre-tensioned precast girders and 2,400 feet using combined pre-tensioning and post-tensioning. Span lengths varied from 25-72 ft. and superstructure costs from $2.95-$5.75 per square foot.

The large numbers of prestressed bridges constructed and planned in Florida are all based on the use of precast members, either pre-tensioned or post-tensioned. This preoccupation with precasting may be justified in Florida where the terrain and foundation conditions in most parts of the state lend themselves to short span trestle-type structures, but is not justified in other parts of the country where prestressing has yet to make a dent in the market for spans of 100-400 feet which are still monopolized by plate girder construction. Only cast-in-place prestressed construction can tap this lucrative market.

Transportation facilities, site conditions and lifting equipment, limits the length of precast members to about 80 feet, and at the upper limit it is often necessary, in order to minimize unit lifting weights, to use a number of closely-spaced members. This results in considerable waste of materials and excessive dead weight. Within the span lengths suitable for precasting prestressed members must compete with rolled structural steel shapes which are always erected at considerably lower cost per pound than longer span plate girders. We are promoting prestressed concrete in its least competitive area and neglecting longer span structures where the advantages of prestressing will produce much greater savings in capital cost and maintenance.

Just because precasting and prestressing were both born about twenty years ago it doesn't follow that they were born for each other or that they must forever be united in unholy deadlock until death do them part. Precasting and prestressing go well together for members up to 70-80 ft., but prestressing becomes increasingly important in long heavily-loaded members which can only be built with cast-in-place methods.

Much work in Europe, particularly in Germany, which has an economy similar to our own, shows us that the economic advantage of prestressed construction over the older methods of construction increases rapidly for longer cast-in-place spans up to the point where truss or suspension systems take over, and even for these prestressing is starting to be used with impressive savings in dead weight and cost.

During the past five years I have made annual trips to Europe where I have observed the advances being made with cast-in-place prestressed construction for long bridge and building spans. The few longer span cast-in-place prestressed structures which we have designed, or are designing, in this country show we can expect to develop, under our competitive bidding, much greater percentage savings in cost for such structures than can be obtained in the range of span suitable for precasting.

In 1949, when we designed the Walnut Lane Bridge in Philadelphia in collaboration with the late Professor Magnel, we were still laboring under the delusion that precasting and prestressing were complementary. We ended up using 13 girders, each weighing 150 tons, for the center span 160 feet long by 62.5 feet wide. Because we could not close Lincoln Drive under the bridge to traffic, we first considered casting the girders at one end of the bridge and moving them into position on a temporary cableway. This was abandoned because of the high cost of the cableway system. We finally resorted to building a narrow falsework, bridged over Lincoln Drive, on which the girders were cast one at a time and then jacked across the piers into position. As I will show later, it would have been much cheaper and quicker to have formed up the whole bridge and cast girders and slab monolithically in their final position.

Cast-in-place prestressed construction has many advantages over precasting for long spans, in particular:

a) Monolithic construction of webs, slab and diaphragms permits spacing girders to 10-30 ft. apart without consideration of their individual weight, and thus the most economical cross-section for concrete is obtained.
b) Transverse load distribution can be developed with mild steel instead of costly prestressing, and large concentrations of prestressing force in single casings can be used to greatly reduce the number of prestressing operations.
c) Skews, horizontal and vertical curves in the deck are readily accommodated.
d) Forming and grouting between precast members and separate casting of wearing surfaces are eliminated.
e) Large concrete sections may be used similar in dimension to what our general contractors are accustomed to forming and concreting for ordinary reinforced bridges of shorter spans.
f) Continuity over supports, when foundation conditions permit, increases economy of materials and cost.
g) Precasting plant, transport equipment and lifting equipment, needed for precast members, are not required.

What then are the arguments against this type of prestressed construction? They usually follow the same pattern we used to hear about any kind of prestressing. They include:

a) Difficulty of design, scarcity of trained engineers, and greater number of engineering man-hours required.
b) Problems of design and construction of falsework.
c) Greater difficulty in concrete quality-control.
d) Fear of restricted competitive bidding by general contractors.
e) Fear of possible patent infringements.
f) In general, fear of sticking the neck out

so far it becomes necessary to use the head instead of the handbook.

Let's consider some of these arguments –

It is true that with longer span cast-in-place structures, particularly when continuity is used, design calculations are somewhat more difficult and much more lengthy. Without considerable experience a good deal of trial and error is needed to find the most economical cross-section and balance of forces. It is always necessary to calculate stresses for both elastic theory and ultimate load. As no standards are available, it is necessary to make many more detail drawings and calculations. However, we are no longer pioneering in this field. Considerable research data is available and more than 100 cast-in-place multi-span prestressed bridges have been built. Dr. Fritz Leonhardt's new German book "SPANNBETON Fur Die Praxis," published in 1955, gives a good account of these works. This kind of design requires considerable study before it can be practiced with confidence or efficiency, but, there are now at least two consulting firms in this country which have experienced staffs for this work. Modesty precludes me from naming them.

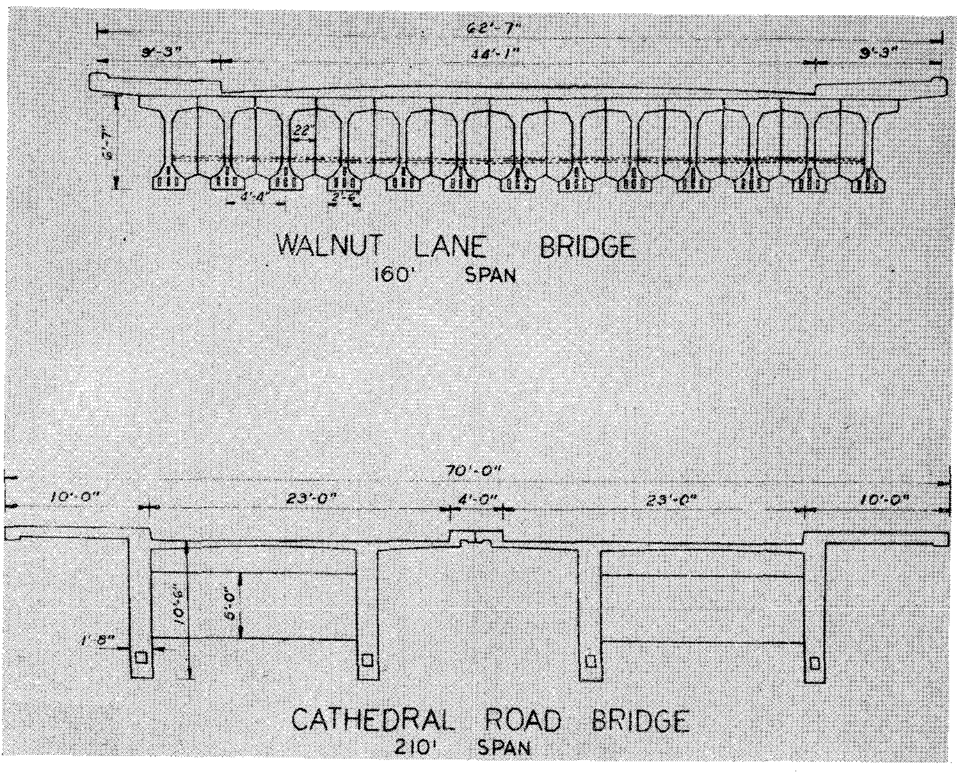
Because of the greater number of engineering man-hours required for such designs, owners must be prepared to pay consulting fees at least equal to A S C E Scale A, but, as will be shown, they will be rewarded by 20-40% savings in cost compared with structural steel, virtual elimination of maintenance cost and quicker construction time.

Just because the average highway department or general consultant may not have the experienced personnel to design such structures economically should be no reason for shunning its use in the face of such large savings in capital cost and maintenance. Owners do not hesitate to hire engineering specialists to design large suspension bridges and tunnels knowing that their experience will produce savings in construction cost many times greater than their fees. It is no different with the design of large prestressed structures which also requires specialization of design.

Now about falsework and forming, which is usually a source of argument. To permit uninterrupted concrete placing it is usually necessary to form up 3-4 spans, or series of spans for continuity. However, this is not as formidable as it may appear. When media strips are required the bridges can be designed symmetrical on each side of a longitudinal joint so that only half the deck needs to be formed at a time. Forms are progressively moved on a 2- to 3-week cycle to match up with concreting and prestressing cycles.

Three basic types of falsework can be

Fig. 1



used, the choice of which depends on many location factors:

1. Built up falsework in timber or steel. Where spans are below 120 ft. this type of falsework can be framed out from the piers without requiring intermediate supports. For longer spans intermediate temporary bents are required at about 60 ft. spacing which can be carried with 36 inch wide flange girders.
2. Self-centering falsework. This type of falsework is built around steel trusses of full span length. It is floated into position between piers. Then hoisted and secured in place with pipe pins through the piers and sand jacks.
3. Suspended falsework. Temporary towers are erected on piers to carry suspension cables from which hangs the falsework. It is necessary to provide adequate adjustment in the suspenders to maintain the elevation of the deck during concreting.

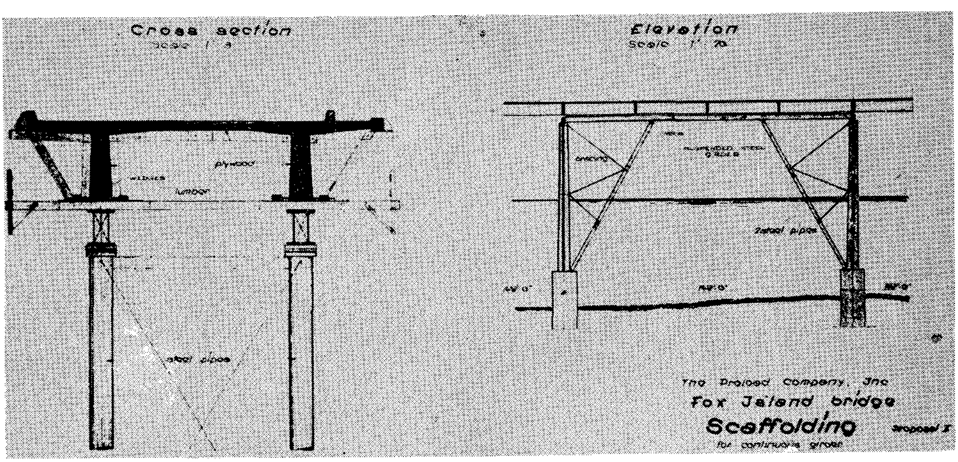
The fabrication cost of falsework by any one of these three methods will run from $2.50-$7.00 per sq. ft. which, of course, is divided by the number of re-uses. Cost of lowering, moving and resetting the falsework runs $0.50-$1.50 per square foot. The average cost for four or more re-uses, without regard to salvage, runs from $1.50-$3.00 per square foot. This is usually more than offset by the cost of precasting plant, transportation and erection of precast members, to say nothing of the other advantages enumerated earlier.

Another argument against cast-in-place is the difficulty in concrete control. This has to be viewed in two parts, (a) concrete manufacture and (b) concrete placing. The control of raw materials, batching and mixing of concrete is now a routine and standardized procedure whether the manufacture is done at a central mix plant or at the production yard. However, the control of placing and vibrating concrete is more difficult for cast-in-place than for precasting at a central plant. On the other hand, it is not so critical. Because concrete dimensions are usually more substantial than the minimum necessary for concrete placing, high concrete strength and stresses are not so important. For most cast-in-place construction a 28 day strength of 3500-4500 psi is usually the most economical. This is in the range of what is usual for large reinforced concrete spans and arches, and can be consistently maintained by experienced general contractors without resorting to unfamiliar techniques.

Now about competitive bidding by general contractors. Right here in Florida you have seen what contractors will do if given a chance. In the bidding to the Florida Roads Department on November 22, 1955, for the Manatee and Palma Sola bridges, eight bids were received for the prestressed concrete designs (which were low for both bridges), only two bids for the structural steel design and not a single bid on the reinforced concrete design. The same thing will be true with cast-in-place construction with which general contractors have wider experience than with precasting.

There is also the question of patents. There are now about 300 U. S. patents on prestressing but most of them are gadgets or relate to some minor construction procedure which can easily be avoided. However, as with all new engineering methods, it is important for the designer to keep abreast of patents so that he will not inadvertently stumble into infringement. In most cases, where a patented feature has any advantage, the designer can make an agreement with the patent owner for its use on a particular job at a modest price which can be stipulated in the specifications so that all contractors bid on an equal basis. If the patent owner is stubborn it is only necessary to make the primary design without the patented feature, details of which can be shown as an alternate with notice to contractors. The patent situation is not nearly

Fig. 2



as complicated as it was in the early days of flat slab design on which there were more than 1000 patents issued, but this did not prevent it becoming a standard procedure.

Now, to provide more graphic support for my theme,

ILLUSTRATIONS

Fig. 1 shows a comparison of cross-sections for precast and cast-in-place construction.

The main span of Walnut Lane is 160 ft. long by 62.5 ft. wide using 13 T-head girders each weighing 150 tons. In contrast is the cross-section of a study for the Cathedral Road bridge designed just three years later. It has three 210 ft. continuous spans 70 ft. wide. Because it is based on cast-in-place construction it is possible to carry the span with only 4 girders cast monolithically with the deck and diaphragms. The contrast in quantities per sq. ft. of deck is significant.

Walnut Lane —
    Concrete .0915 c. y.   Steel 16.5 lbs.
Cathedral Road —
    Concrete .064 c. y.   Steel 13.8 lbs.

The steel quantities include prestressing steel and anchors at 11.5 lbs. per sq. ft. for Walnut Lane and only 6.3 lbs. for Cathedral Road—a saving of nearly 50% in prestressing steel despite the larger span. The actual cost

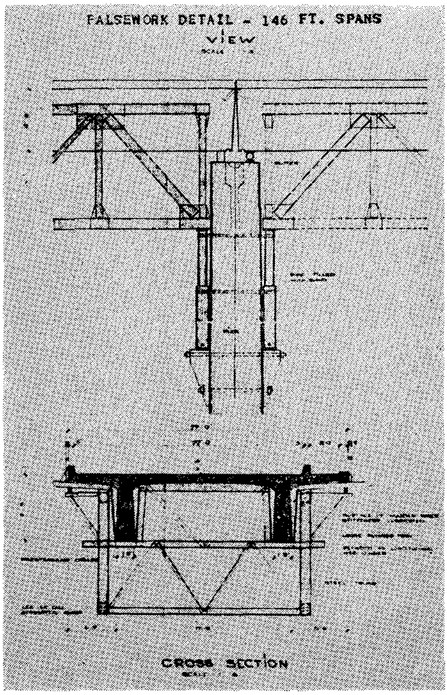
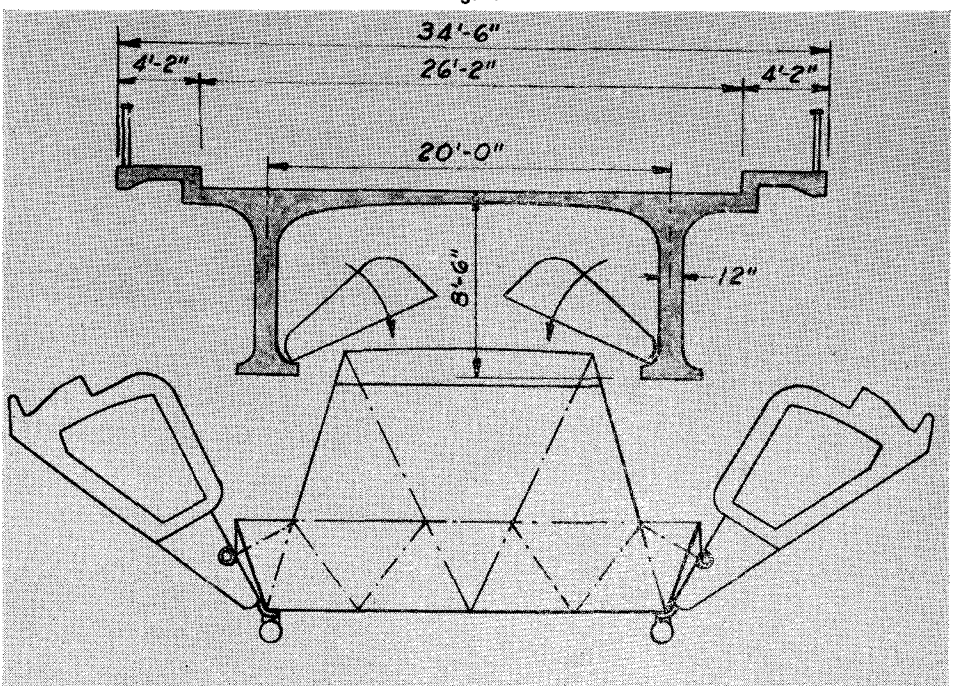


Fig. 3

Fig. 4



DETAILS OF SELF-CENTERING FALSEWORK
USED FOR 130 FT. SPANS
OF PORTO ALEGRE BRIDGE IN BRAZIL

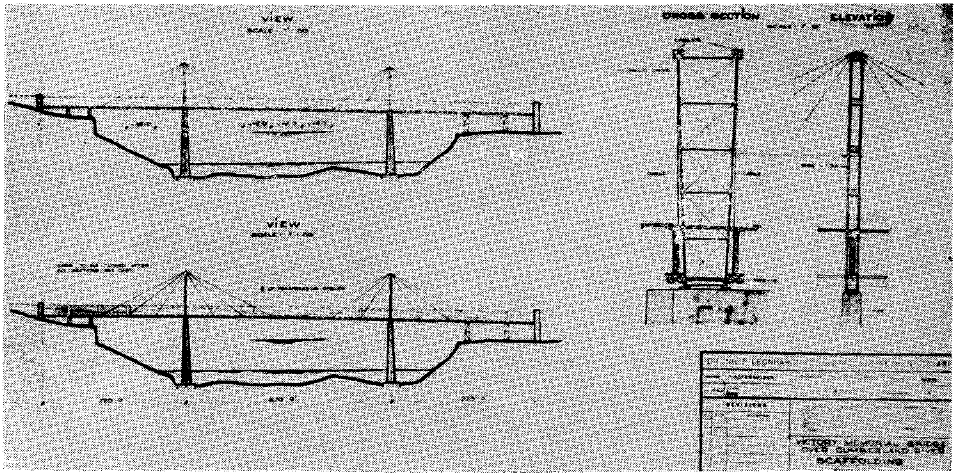


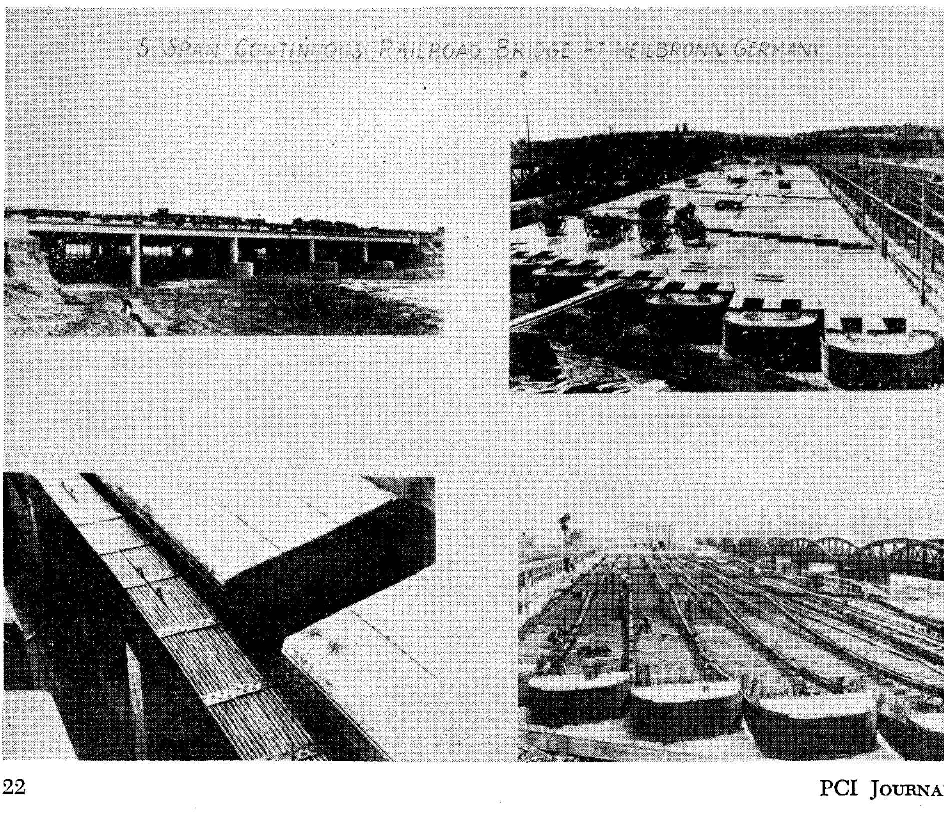
Fig. 5

of Walnut Lane was $21.50 per sq. ft. for the deck, erected. The estimate cost for Cathedral Road is only $13.60 per sq. ft., or 30% less.

Fig. 2 shows the falsework for a bridge with multiple spans of 148 ft. by 27 ft. wide. Two pairs of 36 inch wide flange girders carry the falsework between piers with pipe struts from the pier footings to the third points of the span. This arrangement is necessary because the water depth is 90 ft. and the deck is 50 ft. above water level. A timber platform is erected on the falsework carrying the formwork for the concrete cross-section.

Fig. 3 shows an arrangement for the same

Fig. 6



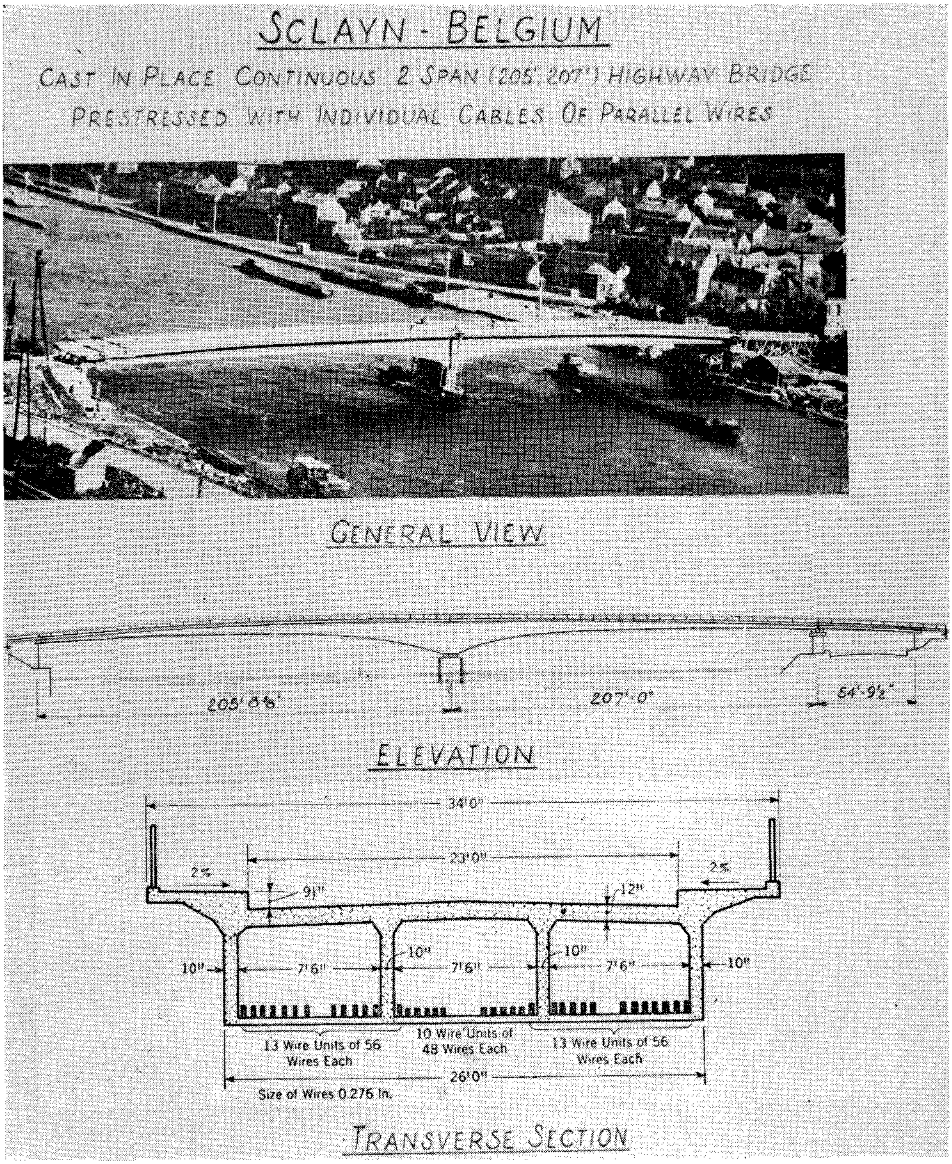


Fig. 7

span using two exterior trusses spanning the full length carried on sand jacks which in turn rest on temporary corbels on the piers. In this case the drop of the sand jacks must be equal to the depth of the girder members so that the falsework can be dropped clear of the concrete section before moving horizontally. The exterior of the formwork is sheeted so that it may be moved by floating.

Fig. 4 shows a more elaborate arrangement of self-centering falsework. The principles are the same as shown in Fig. 3 but in order to use I-section webs the outside forms are hinged to clear the bottom flange and separate filler-boxes are used on the inside of the web. This falsework is being used in the construction of the Porto Alegre bridge near Sao Paulo, Brazil, which is 6 kilometers in length composed of multiple 120 ft. spans continuous over three spans and simply-supported spans 74 ft. in length for approaches. The bridge is 34 ft. 2 in. wide. The self-centering falsework requires 23 lbs. of structural steel per sq. ft. of deck.

Fig. 5 shows a suspended system of falsework developed for a bridge with three spans 225 ft. – 320 ft. – 225 ft. In this case the spans are too long for self-centering falsework and the elevation of the deck too high above the bottom of the river to consider the use of temporary bents. Temporary towers are erected on the piers from which a platform is hung from sloping suspenders. The formwork is erected on this platform as shown in the cross-section with the suspenders passing through holes in the

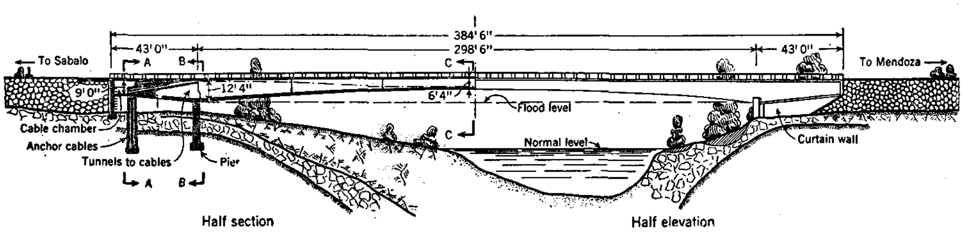


Fig. 8—Typical design details of several bridges in Cuba using exposed unbonded prestressing tendons.

deck on the inside of the web. For this type of falsework it is necessary to have adequate adjustment in the suspenders to correct for deflections as concrete is placed.

Fig. 6 shows construction details for a five span continuous flat slab railway bridge designed by Leonhardt in Germany. The spans are 69 ft. x 60 ft. – 60 ft. – 72 ft. – 64 ft.

The lower righthand corner shows the prestress casings carried on chairs resting on the formwork erected for the whole length of the bridge. Semi-circular end-blocks are used at each end of the bridge which rests on runners for subsequent movement.

As shown in the bottom lefthand corner the prestress casings are filled with multiple layers of 7-wire strands with spacers to keep them relatively positioned both vertically and horizontally. The strands are placed by means of a tractor which carries a loop of strand from one end of the bridge and deposits it over the opposite end-block and repeats the operation on the return journey. When the boxes are filled they are closed with waterproof sectional cover.

The upper righthand corner shows the placing of concrete with two cavities left behind each end-block for jacks. Open construction joints are provided over the piers to be filled after the formwork has taken the deflection from the added weight of the concrete. When the concrete has attained its required strength, jacks are inserted in pairs behind each end-block and are connected in series to a power-driven pump which jacks out the end-blocks simultaneously at both ends of the bridge until the required stress is reached in the strands. This is cross-checked by measuring the elongation through windows left in the casings at various points throughout the length of the bridge. When the end-blocks have reached their final movement concrete is placed between the block, and end of the slab and jacks are removed. The jack cavities are then filled with concrete which also surround the end-blocks which become part of the slab, and the prestress casings are pressure-grouted. This system of construction has been widely used for long span bridges in many countries.

Fig. 7 shows a different arrangement for a bridge of two continuous 205 ft. spans designed by Professor Magnel in Belgium. A box-section with four webs is used to carry the 34 ft. wide deck. Prestressing units are not built into the webs but are left exposed within the boxes. A deep haunch is used at the center pier so that even with straight

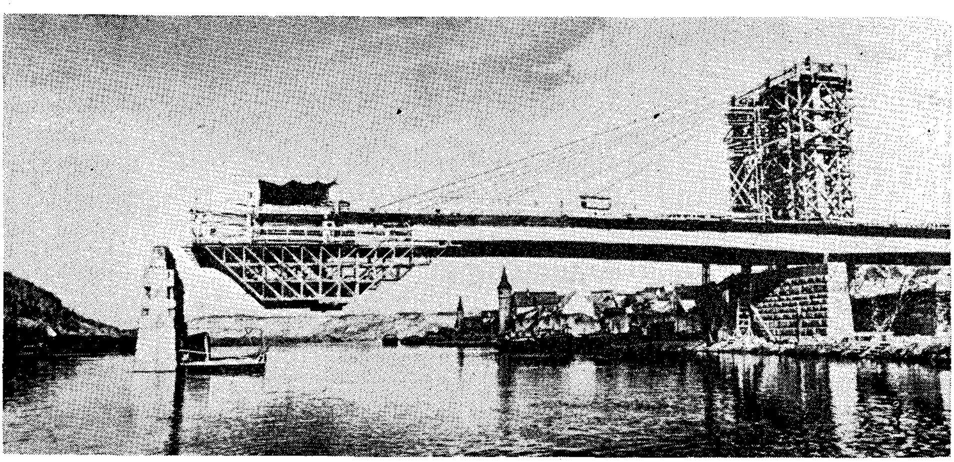


Fig. 9—Bridge over River Main at Karlstadt built in 1952—Dywidag Prestressed Concrete—temporary steel cable supports and progressive formwork.

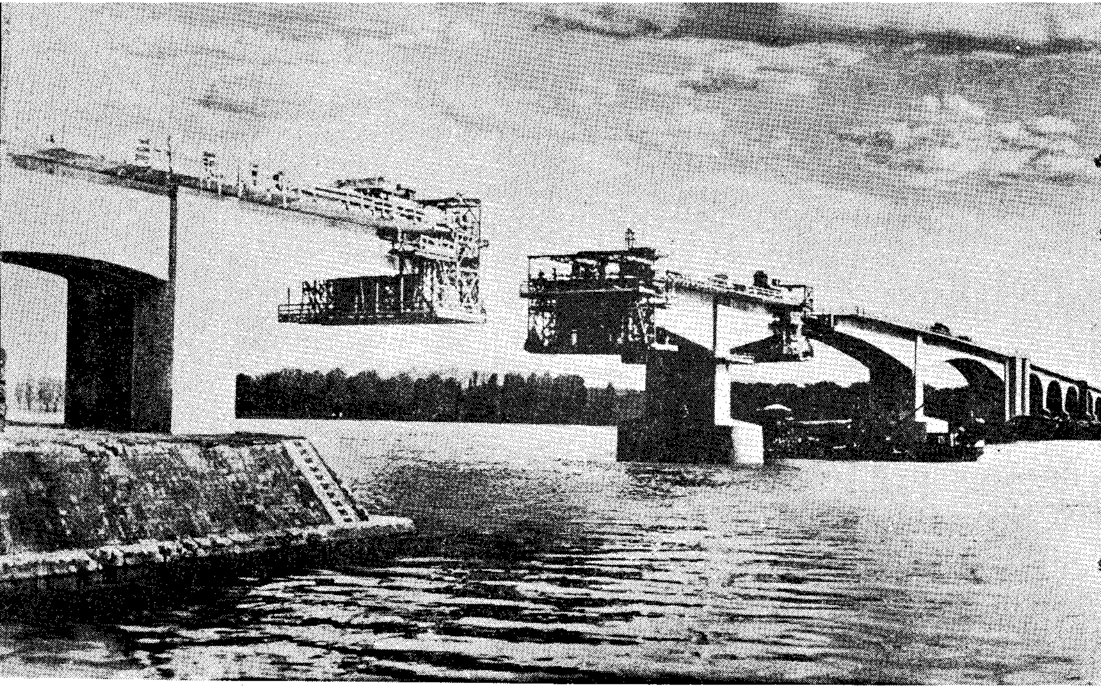


Fig. 10A—Nibelungen-Bridge at Worms—progressive formwork.

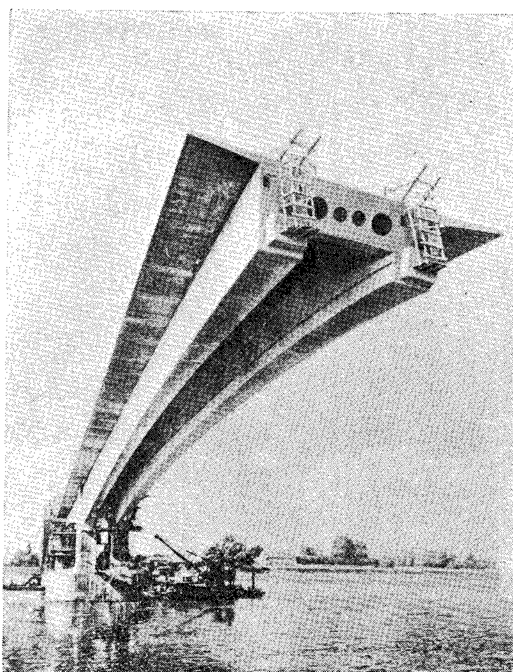
cables continuity is developed over the supports.

Fig. 8 shows details of similar construction which has been used for several large span bridges in Cuba designed by Prof. Luis Saenz. In this case a double-box section is used to carry the 20 ft. wide deck with haunches at supports to develop continuity with reduced deflections of prestressing cables which are unbonded and exposed within the boxes. Roebling cables and end anchorages have been used in these Cuban bridges.

Fig. 9 shows a system of progressive cantilever construction developed by Dr. Ulrich Finsterwalder of Dyckerhoff & Widmann of Munich, Germany. This particular bridge has four spans of 130 ft. each. A temporary tower is built over the pier with suspenders extending out to the deck. The cross-section of the bridge is poured in increments of 30 ft. in cantilevered formwork and is prestressed to previous sections by use of high strength rods before the cantilever formwork is advanced for the next pour. With the use of high early strength cement Dr. Finsterwalder claims that their average rate of production is about one form-length of 30 ft. per week for this kind of construction. Many beautiful large span bridges have been built in Germany by this method. This type of construction is probably too costly to use where self-centering falsework or temporary bents are suitable, but it is probably competitive with suspension systems for high level spans.

Figs 10A and 10B show another use of the progressive cantilever type of construction for the well-known bridge at Worms, Germany, with three continuous spans of 335 ft. – 375 ft. – 333 ft. In this case the temporary suspension system was unnecessary as the forms were advanced equally on each side of the piers balancing out the construction loads. Careful allowance for temperature changes, humidity and deflections must

Fig. 10B—Nibelungen-Bridge at Worms—Dywidag Prestressed Concrete progressive cantilever construction—under view showing detail of center hinge.



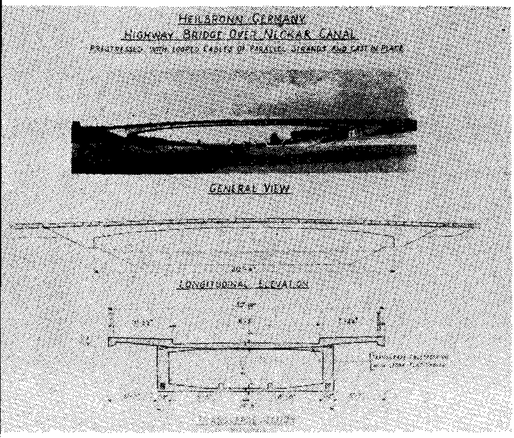


Fig. 11

be made in setting the forms to insure that the deck surface will match up when the forms meet at mid-span.

I would now like to show a number of illustrations of bridges built or designed by the different methods discussed.

Fig. 11 is the Neckar Canal bridge in Germany designed by Leonhardt. It has a center span of 312 ft. 6 in. with flanking spans each side of 62 ft. which are camouflaged with curtain walls to give the appearance of an abutment. A single box girder section is used with wide cantilever overhangs to carry the total width of 30 ft. 10 in. Only one prestressing cable is used in each web to carry this long span. Transverse prestressing is used in the deck to develop the overhangs. At mid-span the depth span ratio of this bridge is 1/61 which gives a very slender graceful appearance.

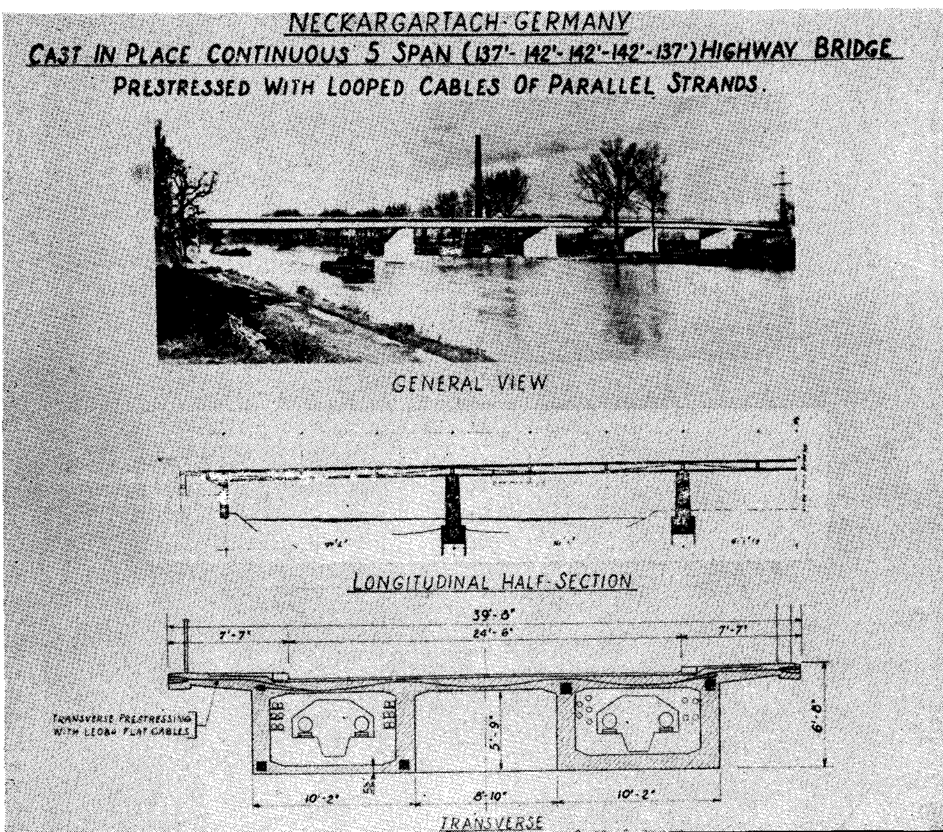
Fig. 12 shows a bridge continuous over five spans of approximately 140 ft. each using parallel cords throughout. Two box girders cast monolithically with the deck are used in this case with four prestressing cables carried in the webs. The entire area of the bridge was formed up with temporary falsework so that it could be cast in one continuous monolithic pour and prestressed in a single operation. I think you will agree it is a satisfactory type of design with a nice clean appearance which would be suitable for many of our expressway bridges.

The quantities of material per square of deck required for this bridge were:

Concrete	.061 cu. yds.
Prestressing Steel	5.53 pounds
Mild Steel	8.4 pounds

Fig. 13 shows a more spectacular prestressed bridge over the Danube Valley with five continuous spans. The three center spans are 230 ft. and the end spans 203 ft., also designed by Leonhardt. I made two visits to this bridge during construction and

Fig. 12



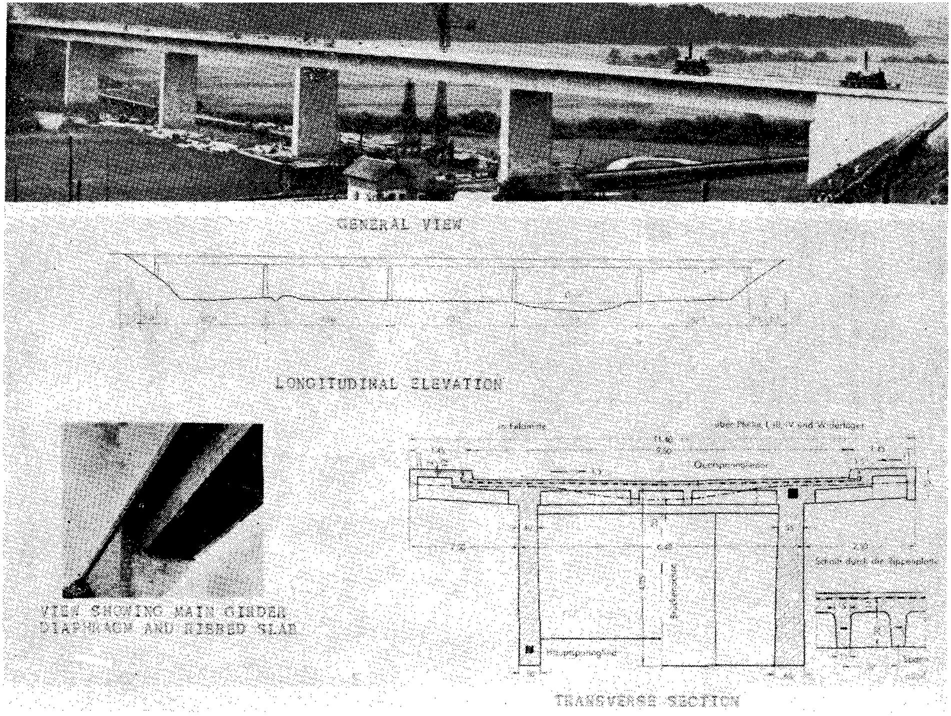


Fig. 13—Continuous Prestressed Concrete bridge over Danube Valley at Untermachtal, Germany; five spans: 203′ — 230′ — 230′ — 230′ — 203′.

was fortunate to be there on the day when the prestressing was done. Because it is comparatively narrow the entire width was cast monolithically. A gridded deck as shown in the bottom righthand corner was used to reduce dead weight with transverse prestressing being used in each transverse web to develop the negative moment over the supporting girders.

The quantities of material per square of deck required for this bridge were:

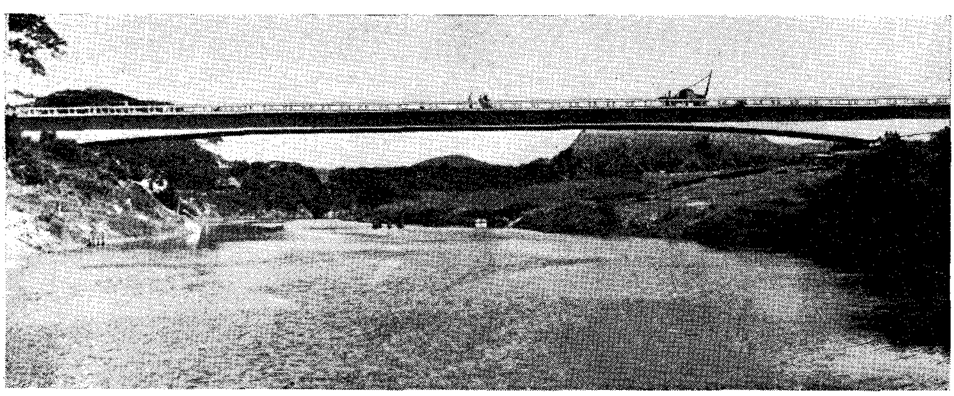
Concrete	.084 cu.yds.
Prestressing Steel	6.81 pounds
Mild Steel	8.2 pounds

Fig. 14 shows the Rio Cuyaguateje bridge in Cuba designed by Professor Saenz for the Pan American Highway at the western end of the island. It has a center span of 298 ft. with flanking spans of 43 ft. at each end. A good description of this bridge is given in the December 1955 issue of Civil Engineering.

Fig. 15 shows a fine example of a completed bridge design by Dr. Finsterwalder. It is the Worms bridge discussed earlier in the description of his method of construction.

Fig. 16. Movable spans are frequently required in these long multiple span bridges which often works to the disadvantage of prestressing. The movable spans are always designed in structural steel. When they know they are competing with prestressed concrete for the fixed span the steel companies have a tendency to raise their price of the movable span and take the difference off the cost of the fixed span, or give the contractors quoting only on the prestressed design such a high cost for the movable span alone that it puts prestressing out of the running. This problem was overcome at the

Fig. 14



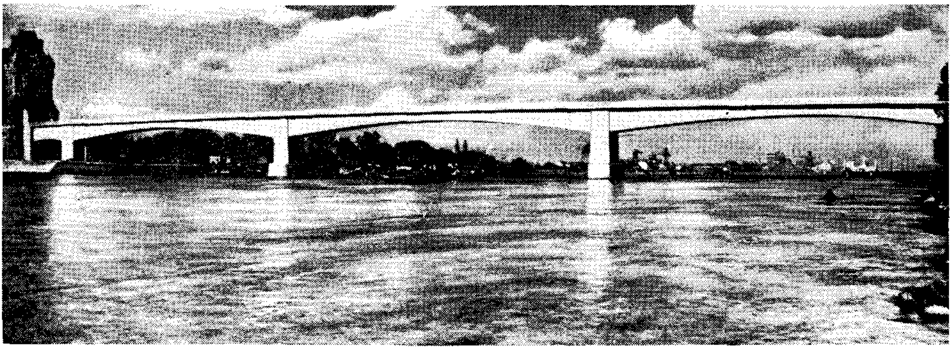


Fig. 15—Road bridge across the Rhine at Worms—cantilever construction in Prestressed Concrete, Dywidag System; spans: 335′ — 375′ — 333′

Porto Alegre bridge in Brazil by designing a lift span in prestressed concrete. Fig. 16 shows a rendering of this span which is 131 ft. long by 34 ft. wide. Both the towers and span are designed in prestressed concrete. The weight of the prestressed concrete span is about 50% greater than a corresponding span in structural steel which requires increasing the size of the cables and counterweights proportionately.

Fig. 17 shows details of a design of a typical expressway overpass developed by The Preload Company for State of Massachusetts. A flat slab continuous over four spans and cored to reduce weight is carried on circular columns. In order to eliminate an exterior cap over the columns heavy prestressing is used transversely in the deck over columns to develop the punching shear. The slab thickness is only 22 inches, giving a depth span ratio of 1/32. While this type of design requires more prestressing steel than what would be needed for a deeper section the added cost is often more than offset by the reduction in the volume of cut and fill required to maintain the sight lines. A similar bridge in structural steel required an over-all depth of 42 inches. The extra 20 inches of depth called for an additional 6000 cubic yards of cut and fill to maintain the same sight lines.

A more economical type of expressway overpass in which the center pier is eliminated, results in a main span of 120 ft. with flanking spans of 40 feet. Five webs are used in the cross section with a closed soffit. The prestressing is carried in the webs and is continuous over supports. Bond is developed by pressure grouting after prestressing.

The quantities of material and unit cost per sq. ft. of deck required in this design are:

Concrete	0.063	cu. yds.	@	$60.00 =	$3.78
Prestressing Steel	3.3	lbs.	@	0.70 =	2.21
Mild Steel	7	lbs.	@	0.12 =	.84
TOTAL unit cost of deck					$6.83

Where a center pier is used quantities and unit costs of materials per sq. ft. of deck for a corresponding steel bridge would be:

Structural Steel	26	lbs.	@	$ 0.18 =	$4.68
Concrete	.022	cu. yds.	@	50.00 =	1.10
Mild Steel	4.5	lbs.	@	0.12 =	.52
TOTAL unit cost of deck					$6.30

Fig. 16—Prestressed Concrete lift span—131′x43′, Porto Alegre Bridge, Brazil.

The cost of the center pier would just about offset the extra $0.53 per sq. ft. for the prestressed bridge which would be free of maintenance and eliminate the accident-hazard of the center pier. I have not seen a similar design for a steel bridge without a center pier, but this would add about 24 lbs. of structural steel per square foot or about $4.32 per sq. ft. in cost.

Fig. 18 shows a bridge designed by The Preload Company for the Corps of Engineers crossing the Potomac Canal at the new Little

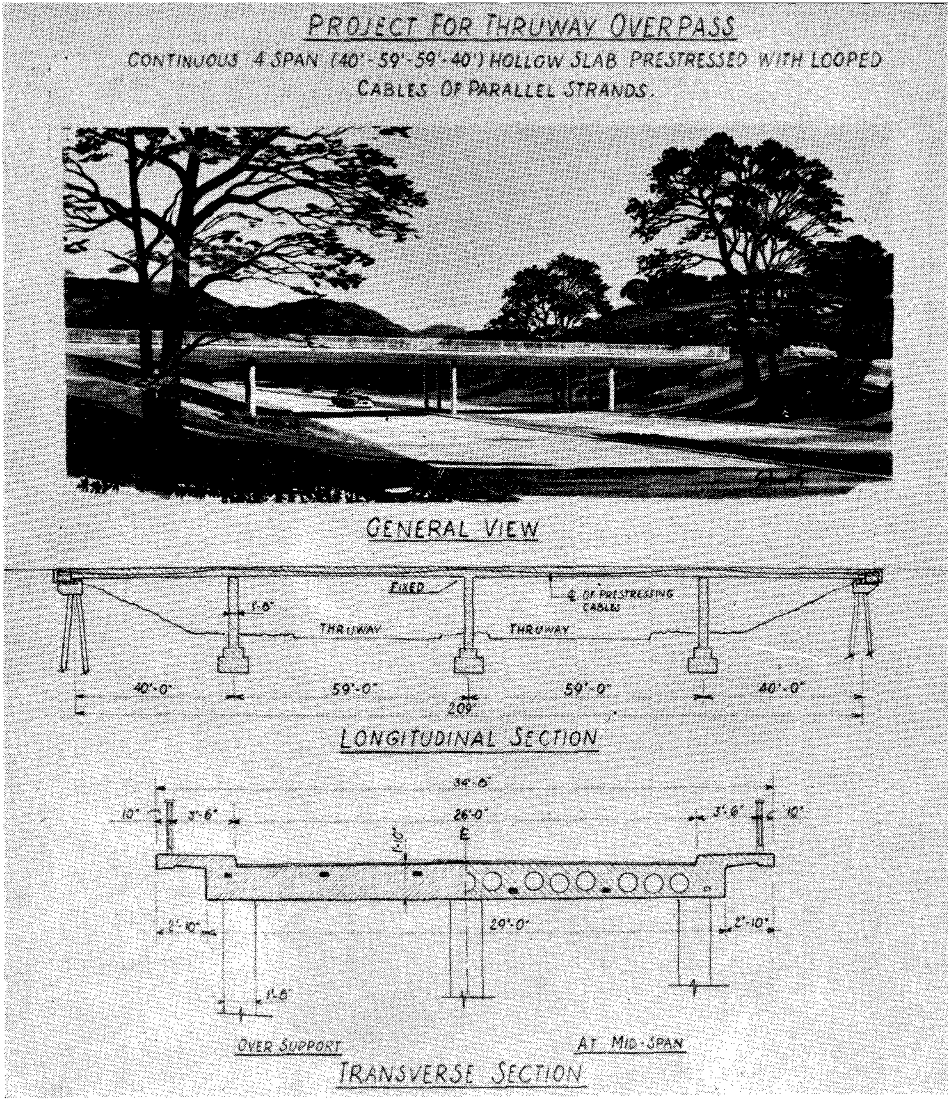


Fig. 17

Falls Pumping Station west of Washington. While the main span of 216 ft. is insignificant compared with some of the European bridges discussed earlier, I believe this is the longest prestressed concrete span yet to be placed under contract in the United States. The design is somewhat similar to the 315 ft. Neckar Canal bridge using a single box girder section with one large prestressing casing in each web and overhanging spans at each end to develop the negative moment over supports. The girder depth at mid-span is 7 ft. which gives a depth span ratio of 1/31.

An imposing prestressed concrete bridge has recently been designed across the Potomac River in the heart of Washington. With the concurrence of the District of Columbia a co-venture was formed between the Freyssinet and Preload companies to undertake this design and a toss of a coin decided that the name of the co-venture would be "Freyssinet-Preload." Moore & Hutchins of New York are associate architects. Two contracts were let by the District of Columbia to prepare preliminary designs and renderings for this bridge which lies just north of the Memorial Bridge in view of the Washington Monument and the Lincoln Memorial. One contract is for a prestressed concrete design and the other contract for a structural steel design. Certain requirements were laid down governing the architecture of the bridge. Spans must not be less than 160 feet. Parallel cords must be used so that the bridge would not compete in appearance with the multiple-arch Memorial Bridge. Piers had to be stone-faced.

Fig. 19 shows an elevation rendering of this prestressed bridge. It has three 184 ft. spans on the Virginia side, shown on the left; an elevated filled section over Roosevelt

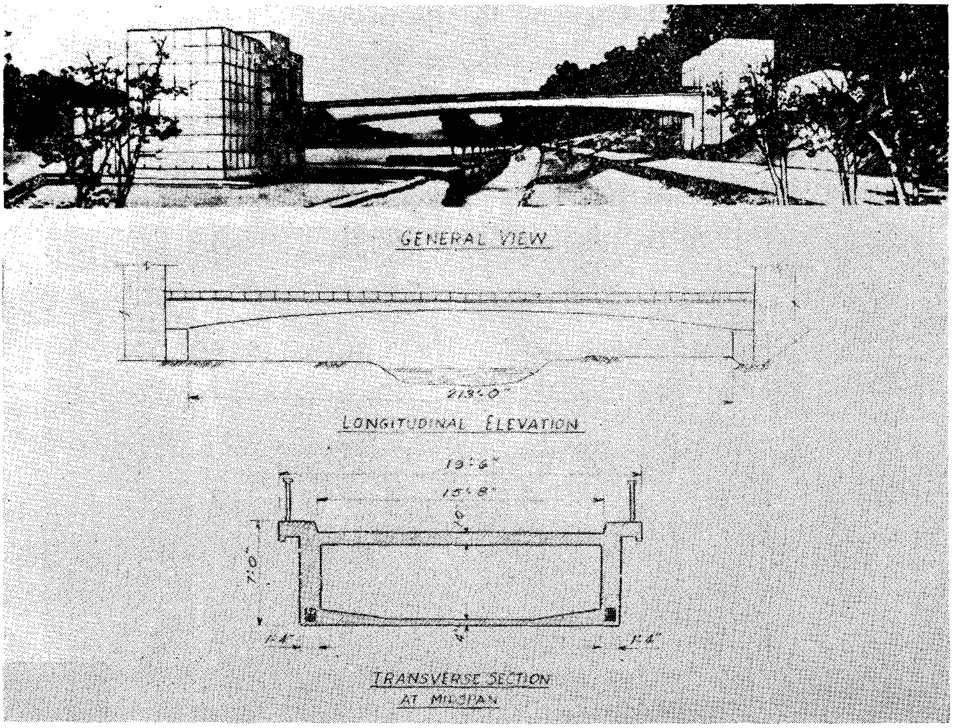


Fig. 18—Little Falls Bridge, Potomac Canal, Washington, D. C.—Prestressed Concrete continuous cast-in-place bridge—single span 216'—girder depth mid-span, 7' 0"—depth span ratio 1/31.

Island 475 ft. in length, and nine 184 ft. spans on the Washington side shown on the right.

Fig. 20 shows a cross-section of this bridge. The bridge has a width of 92 ft. carrying three lanes of traffic in each direction. It has a 5 ft. sidewalk each side and 4 ft. media strip. The bridge is designed for continuity over groups of three spans with two webs spaced 29.6 ft. apart in each half section and cantilever overhangs of 10 ft. on each side. The deck is designed as a waffle-slab to reduce dead weight. This general arrangement will permit four re-uses of falsework which will be the floating self-centering type described earlier.

The architecture of this bridge with the distinctive treatment of piers and wide overhangs was approved with favorable comment by the Fine Arts Commission of the District of Columbia.

The quantities of materials for the superstructure per sq. ft. are:

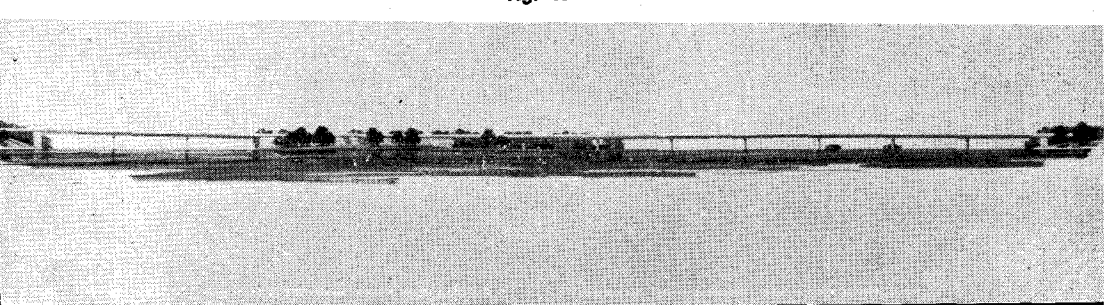
Concrete	.065 cu. yds.
Prestressing Steel	4.6 pounds
Mild Steel Reinforcing	11 pounds

The engineers' estimate for this design, subsequently checked and confirmed by several large contracting companies, is $4,751,000. The unit cost per sq. ft. of deck for the various elements are:

Superstructure	$13.10
Substructure including stone-facing of piers	$ 8.04
Total Bridge Structure	$21.14
Elevated fill section over Roosevelt Island	$18.60

The engineers' estimate for a corresponding bridge in structural steel was $7,900,000 or approximately 40% higher to which must be added the capitalized cost of the maintenance for painting estimated at $14,000 per year.

Fig. 19



This job is as good an example of the important saving which can be realized with cast-in-place prestressed concrete design for long multi-span bridges.

I might cite just one more example of a bridge we are now designing for five 120 ft. spans 68 ft. wide on a 1700 radius curve. Competitive bids are to be taken for prestressed concrete and structural steel designs. The prestressed concrete design calls for the following superstructure quantities per sq. ft. to which are applied conservative unit cost:

Savings of 30-50% compared with structural steel are not unrealistic for structures of this kind. This compares with savings of 2-18% shown in competitive bidding against structural steel and reinforced concrete for the short span precast prestressed bridges constructed to date by the State Roads Department of Florida.

Fig. 21 shows a cross-section of the Montevideo stadium covering a circular building 308 ft. in diameter. At the outside wall the cable terminated in a large horizontal com-

Concrete	0.64	cu. yds.	@	$80.00 =	$5.12
Prestressing Steel	3.4	lbs.	@	0.55 =	1.87
Mild Steel	7	lbs.	@	0.12 =	.84
TOTAL unit cost of superstructure					$7.83

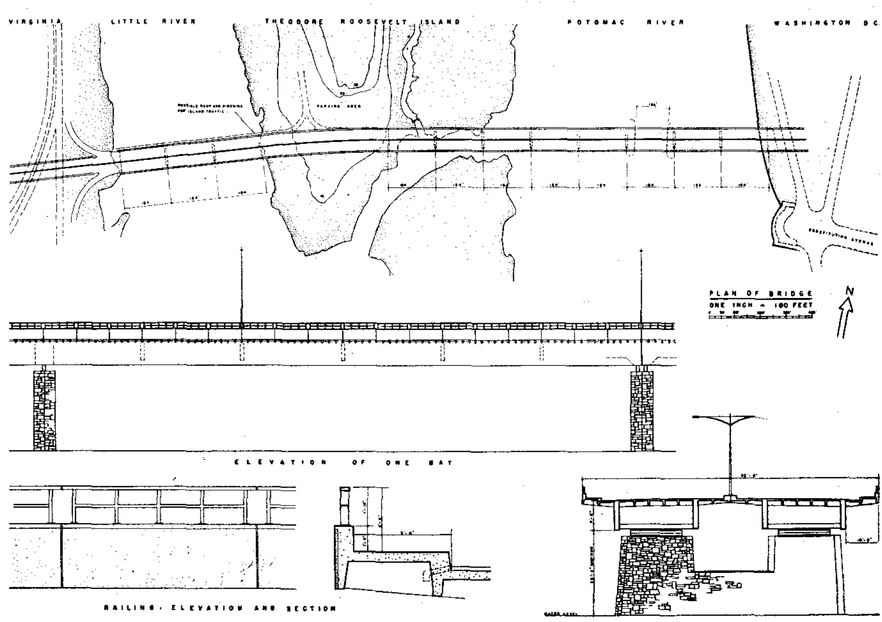
The corresponding quantities for the superstructure per sq. ft. of the structural steel design with unit costs applied are:

Structural Steel	52	lbs.	@	$ 0.20 =	$10.40
Concrete	0.22	cu. yds.	@	60.00 =	1.32
Reinforcing	4	lbs.	@	0.12 =	.48
TOTAL *unit cost of superstructure*					$12.20

Looking at it another way, the structural steel would have to be erected for 11.6c per lb. for the cost of both bridges to be equal. I think you will agree this would be impossible at today's steel prices for a bridge built on a curve.

pression ring carried on top of the wall and at the inside terminates in a structural steel tension ring 19 ft. in diameter. Trapezoidal precast concrete panels 2 inches thick are hung on these cables by means of projecting reinforcing hooks at the four corners as

Fig. 20



PRESTRESSED CONCRETE DESIGN - CAST IN PLACE CONSTRUCTION. FOR THE PROPOSED
CONSTITUTION AVENUE BRIDGE OVER THE POTOMAC RIVER. WASHINGTON. D. C.

FREYSSINET - PRELOAD, CONSULTING ENGINEERS. NEW YORK, N.Y.
MOORE AND HUTCHINS, ARCHITECTS

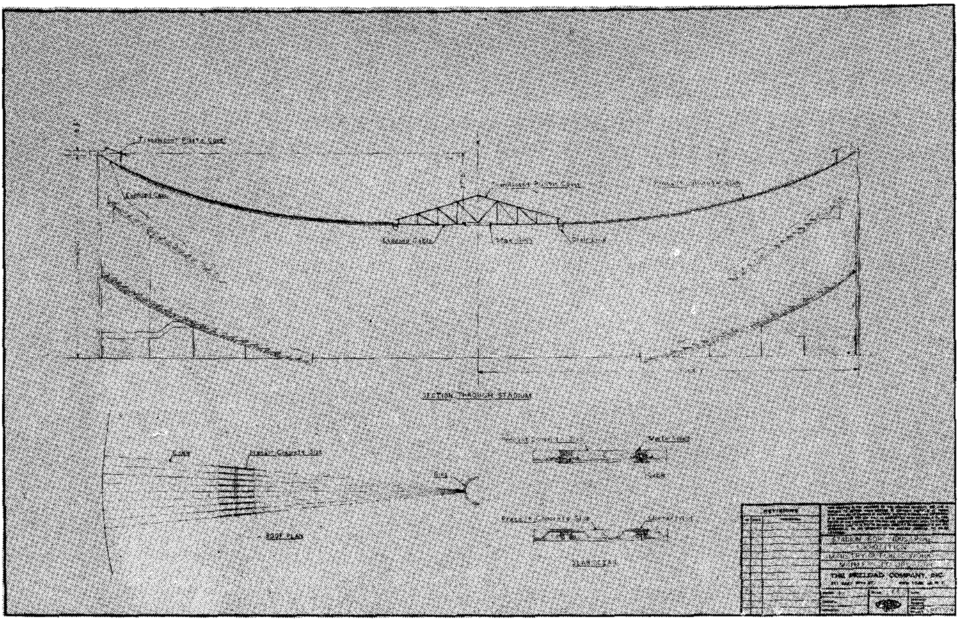


Fig. 21

shown on the small cross-section. In order to provide some prestressing in this roof system to insure tight joints and give additional stiffness for wind loads, Mr. Viera came up with a brilliant but simple suggestion for prestressing the roof. After the panels were all set in place each panel was loaded with concrete block equivalent in weight to the maximum live load which elongated the cables and expanded the joints between panels. In this condition the joints were grouted and when the grout had attained sufficient strength the superimposed dead weight was removed leaving a prestress in the cables and a compression in the slab and joints. In order to avoid the high bending moments which occurred at the supporting edges of such systems the concrete panels were terminated 5 ft. from the outer ring and the space covered with an articulated plastic housing. The center of the roof is covered with a light steel truss with a translucent plastic covering to provide natural flood lighting to the interior.

Fig. 22 shows a rendering of the exterior of the sports arena which is now nearing completion, and also an interior view of the stadium filled to capacity with 24,000 happy spectators showing little concern in the fact that they are under a prestressed concrete roof, 2 inches thick, spanning 308 ft.

Such a roof system cannot, of course, be used in a country which is ever likely to have snow, but we are developing this general concept of prestressing suspended roofs for large diameter tank and other structures where a central tower can be used carrying the cables at the center at a higher elevation than the outside wall to provide drainage to outside. This type of prestressed suspended construction because of its very low cost provides the most economical method of covering large areas without any intermediate supports, or just a single central column.

CONCLUSION

Now, gentlemen, I don't want to detract in any way from the fine work which we have done in developing and standardizing our design procedures and construction method for prestressed concrete for relatively short spans lending themselves to precast construction, but I hope I have given you enough data to convince you that our big job in the future is to develop prestressed concrete for long span heavily-loaded structures where it will show much greater saving in costs compared with older methods of construction than our work heretofore might indicate.

Convincing the people who have to pay for these structures of what we know to be true will not be an easy task. In competing with structural steel we are up against a wealthy and highly-organized industry which does not hesitate to discredit prestressed concrete wherever possible and drastically cut prices on individual jobs where prestressed concrete may offer a competitive threat. For these larger structures we cannot afford to give the owners free designs merely for the privilege of competing with other methods of construction for which an ample fee for design has been paid which does not have to be included in the construction price.

Some highway and bridge authorities are precluded by law from giving out consulting contracts for design of structures and yet

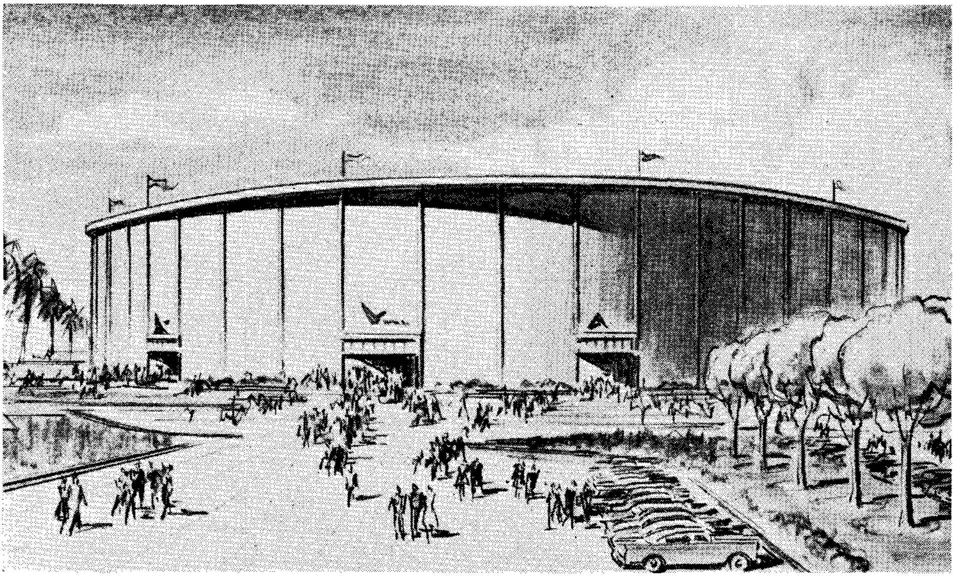
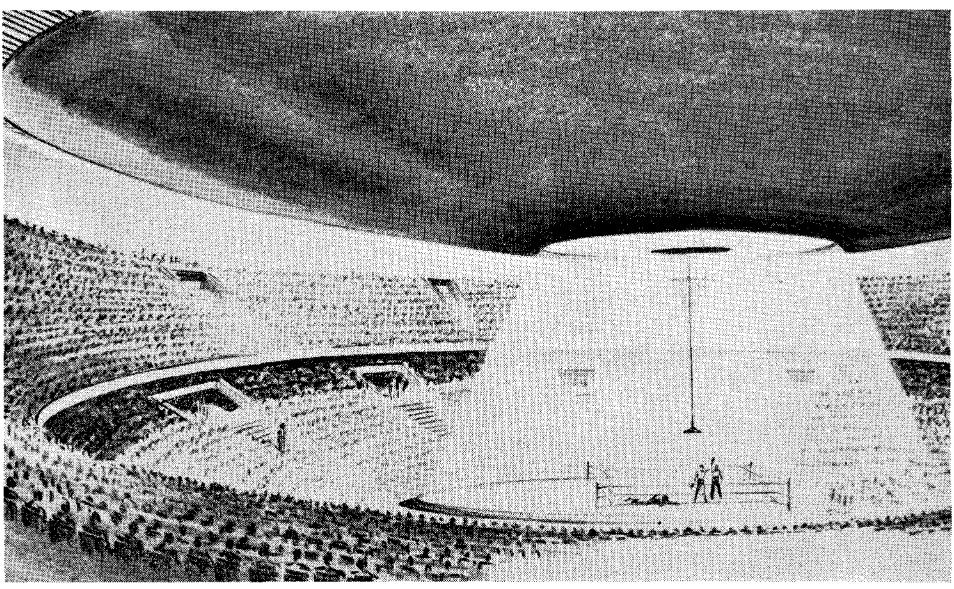


Fig. 22—Stadium for National Industries Exhibition, Montevideo, Uruguay—310′ diameter stadium, 83′ high, with suspended roof system.



they do not have the trained personnel to make efficient prestressed design for these larger structures. Other authorities follow the traditional pattern of awarding omnibus consulting contracts to the large general consulting firms for large sections of highway including structures at comparatively low fees. These firms, even when they admit that prestressed designs would save in construction costs many times the added cost of engineering, simply cannot afford at the low over-all fee to subcontract the design of major bridges to specialists.

Even when we convince owners that large savings can be made with p/c they often feel it necessary to insure their own judgment by insisting that alternate designs be made and bids taken for prestressing and some older method of construction only to find that their engineering budget will not stand the cost of making two complete sets of alternate designs and specifications.

In order to overcome these obstacles we must have patience in the knowledge that big things never come easily. We must refrain from recommending p/c where its advantages are marginal and concentrate on selective jobs where we must convince highway and bridges authorities that to obtain the full benefits of prestressing they must be prepared to exclude major structures from general consulting contracts and award these separately to specialists in this field at adequate fees to cover the higher cost of engineering involved.

When we have successfully done this on a few major structures, such as I have described, the inertia and resistance will evaporate and owners and their financial underwriters will hasten to take advantage of the large savings in cost and maintenance which we have to offer.

Unfortunately, we do not yet have a well-financed national organization, as do the older methods of construction, to promote the interest of prestressed concrete and fight our battles in the lobbys of Washington and the state capitols. I would like to conclude with this thought — why don't you expand the Prestressed Concrete Institute into a truly national organization with headquarters in Washington and officers chosen from all parts of the country representing the interests of the consultants, contractors, material suppliers and manufacturers. To give it national stature this Institute should seek to represent the United States in the Federation Internationale de la Precontrainte and should join with A S C E and A C I in sponsoring the Recommended Practice for Prestressed Concrete discussed in Mr. Germundsson's paper. It should also have authority, under its by-laws, to prevent its members from indulging in unethical practices, such as making exaggerated claims for any particular proprietary methods, blue-sky promotion of prestressing where it is not justified and unfair competitive practices amongst its members. We need such a national organization and I think our industry has now reached the size where we can support it financially.

If we do these things, there is no reason in the world why we should not be building as high a proportion to the total of prestressed concrete bridges in this country as they are doing in Europe, but long before we attain this goal prestressing will have become a large and important industry in this country.

In its report to the President published in 1952, the President's Materials Policy Commission, under the chairmanship of William S. Paley, recommended the wider use of prestressed concrete as a means of conserving our national resources to meet our expanding economy. It is up to all of us to get behind this recommendation and push prestressed concrete over the top for both large and small structures.

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