Cost Comparisons of Prestressed Concrete vs Conventional-Type Highway Bridges

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● INCREASING use of prestressed concrete for bridges poses new problems to the bridge engineer. Each project must be studied as a separate entity unless the case involves a number of similar bridges.

Since the construction of the Walnut Lane Bridge in Philadelphia's Fairmont Park in 1948, the number of prestressed bridges constructed has been numerous. However, up to the present, little data on the reasons for their selection and the relative costs have been tabulated. Mere figures on the cost per square foot of deck area do not tell much unless some pertinent facts are known about the geological location, site conditions, number of beams used, fabrication, plant locations, transportation distances, and availability of contractors willing to bid prestressed concrete projects, since all of these factors play a part in the analyses of cost data.

In New York State, the first prestressed bridge was built for the town of Orangeville, near Warsaw (Figure 1).

It was not a large project, the span being 62 ft and the width 22 ft plus curbs and railing. The four girders were fabricated at the site over the stream bed with one set of forms. After the deck slab was placed, the bridge was prestressed transversely. The total cost of the superstructure based on an area of 64 ft by 25 ft was $8. 35 per sq ft.

The experience and cost data derived from this project stimulated the county to continue their program of prestressed bridge construction. New schemes were developed and studied to attain two basic results: the precast units should be of such weight and size that they could be handled and transported with the equipment already available; and in the winter months, available county forces should fabricate units inside a heated building. The units could be stockpiled in the yard for erection in the spring and summer months.

The forms used on the first prestressed bridge were re-claimed and erected in the shop for the fabrication of similar girders (Figure 2). This time the girders were made in sections 17 ft 3½ in. long, 36 in. deep with a top flange 33 in. wide and a 12-in. web. After the end section was cast, the flexible tubing forming the holes for the prestressing units was withdrawn and inserted a short distance back into the member at the interior end. The required slope for the cables was laid out, and the next section was cast against the first one. This sequence assured an accurate fit for the shear keys at the joint and the holes for the cables. The operation was repeated for the member at the opposite end.

In the spring, the precast members were shipped by truck to the bridge site. Temporary bents were erected to support the members while the prestressing cables were pushed through and tensioned. All cables were grouted solid to insure bond for their entire length. The openings between the girder flanges were then filled with concrete and the bridge deck was prestressed transversely. Figure 3 shows one of the finished structures. The cost of the superstructure using this method was about $8. 35 per sq ft for a deck area of 52 ft by 24 ft.

Since the county has a large number of short span bridges in need of replacement, a scheme was developed for fabricating this type. Solid slabs 2 ft wide, 12 in. thick and about 25 ft long were cast and prestressed in the shop. Each plank was prestressed with three cables of 12 wires each.

These slabs were later erected side-by-side on a prepared bridge seat to form the bridge deck. After the keys between the units were filled with mortar, the deck slab was prestressed transversely.

Figure 4 shows the finished bridge. The cost of the deck using this method averaged $2. 70 per sq ft for a deck area 25 ft by 24 ft.

In October 1953, the New Jersey Highway Authority received bids on Section 11,

Figure 1. Bridge No. 10, Orangeville, New York.

Contracts 28 and 31 of the Garden State Parkway. This eight mile section is west of Atlantic City and is part of the 165-mile north-south toll road. In this contract, a total of 12 bridges was included for 8 grade separations. Bids were invited for reinforced concrete T-beam construction and for an alternate with prestressed concrete beams and cast-in-place concrete deck. Estimates showed the cost of the two types of construction to be about equal. However, contractors submitted bids only on the prestressed alternate.

The designing engineers worked out a scheme for the prestressed design to standardize the beam section irrespective of span length. This was achieved by selecting an I-shaped section which would fit the average span. By varying the number of steel tendons in the beams and the beam spacing in the bridge, it was possible to simplify the fabrication. The typical interior beam was I-shaped, 33 in. deep, 6-in. web, 12 in. wide top flange, and 19 in. wide bottom flange. Fascia beams were rectangular in section to meet requirements for a smooth exposed surface. These members were 33 in. deep and 16 in. wide.

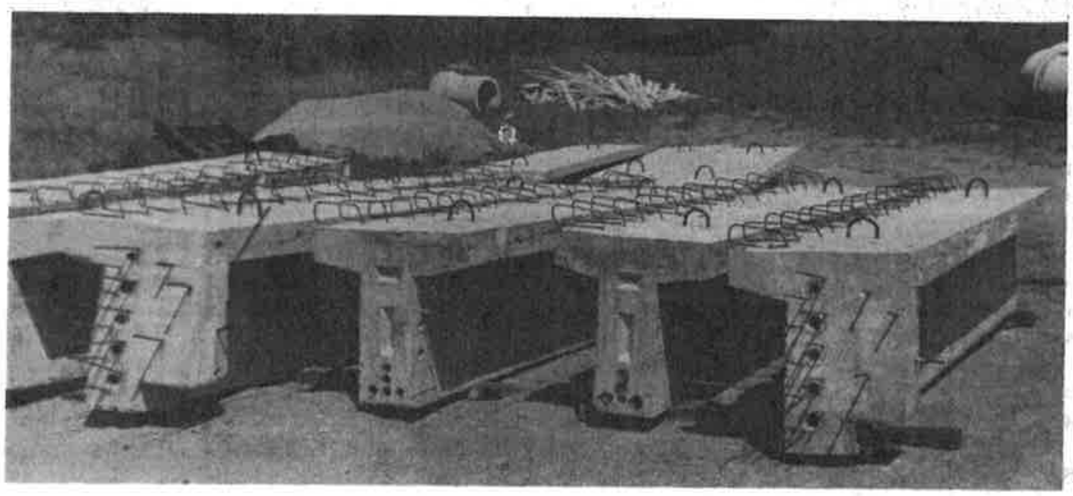


Figure 2. Precast beams for Bridge No.7, Pike, New York.

Figure 3. Bridge, No. 7, Pike, Wyoming County, New York.

The design assumed that the beams would carry all of the dead load during construction to eliminate the need for falsework. For live loads, the deck slab was included as part of the compression flange of the beams. Composite action was developed through the medium of shear keys and conventional stirrups. All of the beams were designed initially for pretensioning. In order to meet tight delivery dates for the construction schedule, the fascia beams were post-tensioned. The low bid was $7,777,777 for the entire work on the eight mile section. The concrete mix was designed so that a 2-day casting cycle could be maintained. Three hours after the concrete was placed, steam was introduced under tarpaulins to the concrete and a temperature of 140 F was maintained for at least six hours. The steam was then reduced and some steam was continued up to the time of stripping the forms and cutting the wires (Figure 6).

When the control cylinders cured with the beams reached a minimum strength of 4,000 psi, the tension on the strands was released and the strands were cut between the

Figure 4. Bridge No. 14, Perry, Wyoming County, New York.

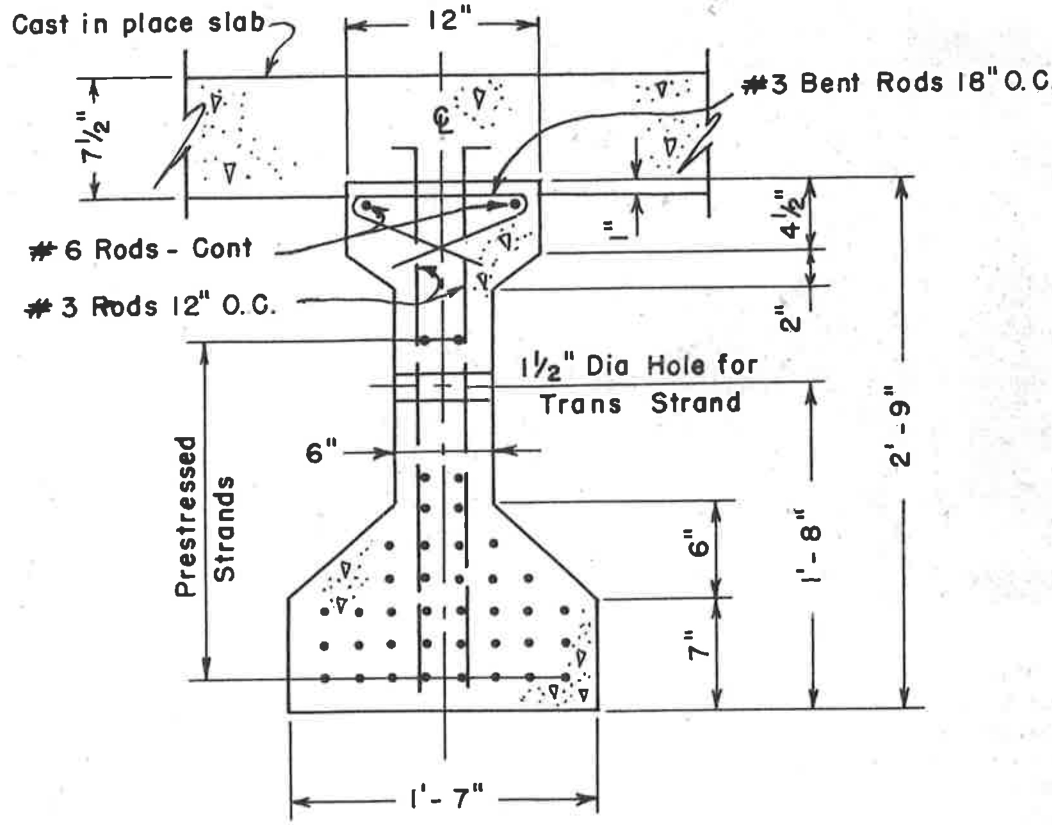


Figure 5. Garden State Parkway, N.J., Section II, Contract 28-31, prestressed girder detail (interior).

TABLE 1

GARDEN STATE PARKWAY — PRESTRESSED GIRDERS

Section 11 Contract 28 and 31

Crossing	Span C-C ft	Beam Length ft	Roadway Width ft	Interior Beams No. Req	Interior Beams Strands[a] in each	Fascia Beams No. Req	Fascia Beams Cables[b] in each
W. Jersey and Seashore RR	39	40	90	20	24	2	4
Blackhorse Pike Interchange (twin span)	48. 8	49. 75	24	10	32	4	7
Zion Road	50. 2	51. 17	40. 2	20	34	4	7
Westcoat Road (2 bridges)	51. 5	52. 5	40. 2	20	36	4	8
Washington Avenue	53	54	90	24	36	2	8
Delilah Road (2 bridges)	56. 3	57. 25	40	20	40	4	8
Blackhorse Pike (twin span)	57. 8	58. 75	90	52	40	4	9
Ocean Heights Avenue (2 bridges)	60. 4	61. 4	40	24	40	4	9

[a] Interior beam strands ⅜-in. diameter made up of 7 wires, total area 0. 0799 sq in.
[b] Fascia beam cables ¼-in. diameter wires with "button heads" at each end (10 wires).

beams. This operation was usually done 18 hours after the concrete was placed. At 28 days, the concrete cylinders had reached a strength of well over 5,000 psi. The beams were moved from the casting bed by an overhead crane and stockpiled (Figure 7). When required, the beams were shipped about 30 miles to the bridge sites by trailer truck and erected by a mobile crane (Figure 8).

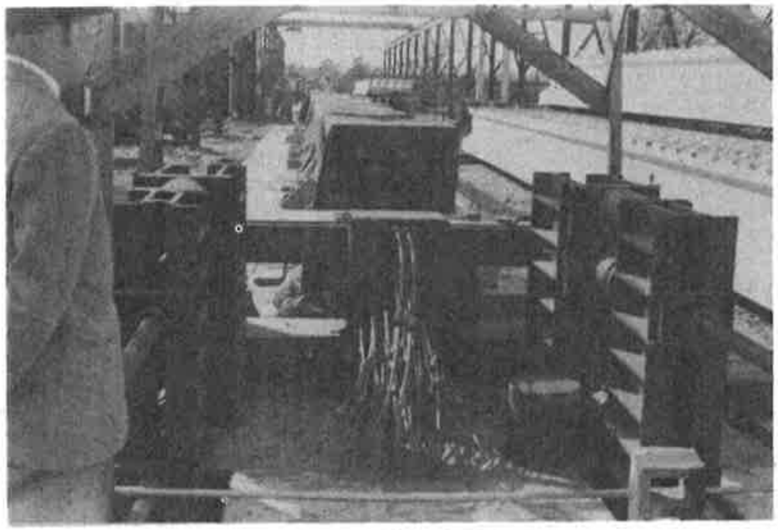


Figure 6. Prestressed beams curing in the prestressing bed, Garden State Parkway bridges, Section II.

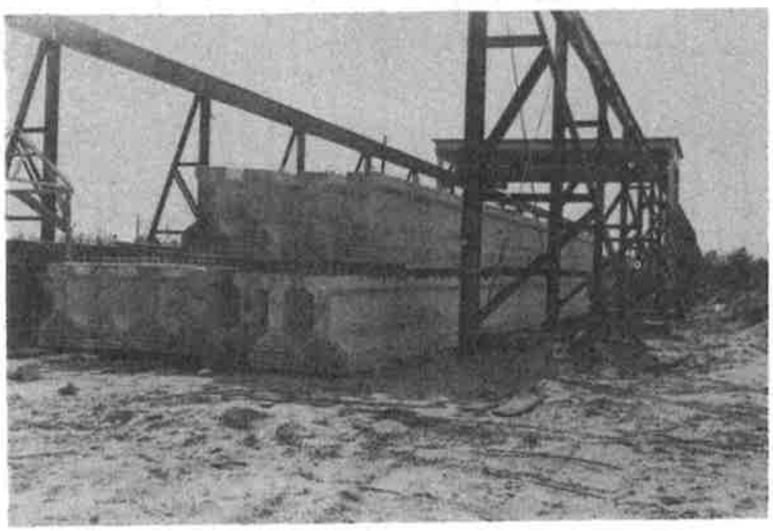


Figure 7. Prestressed beams stored at the casting yard, Garden State Parkway bridges, Section II.

Diaphragms were cast integrally with the $7\frac{1}{2}$-in. concrete deck slab. These were located at the ends and near the third points of the spans. Provision was made for prestressing the diaphragms transversely with a single cable in a flexible conduit at the third points. After the prestressing operation, the cable was grouted.

The prestressed beams were bid on a lump sum basis based on the different lengths required. Analyzing the bid data, the superstructure cost average $9.00 per sq ft. The prestressed beams ranged in length from 40 to 61.5 ft, and their cost averaged slightly over $5. 00 per sq ft of deck area. The average cost per lineal foot per beam amounted to $20. 50 with a variation range from $19. 80 to $21. 60 per lineal ft (Figures 9 and 10). Table 1 shows the data on the beams used for the various locations.

In September 1954, the engineer for Mercer County took alternate bids for the construction of the Sweet Briar Avenue Bridge. This bridge replaced a four-span all-

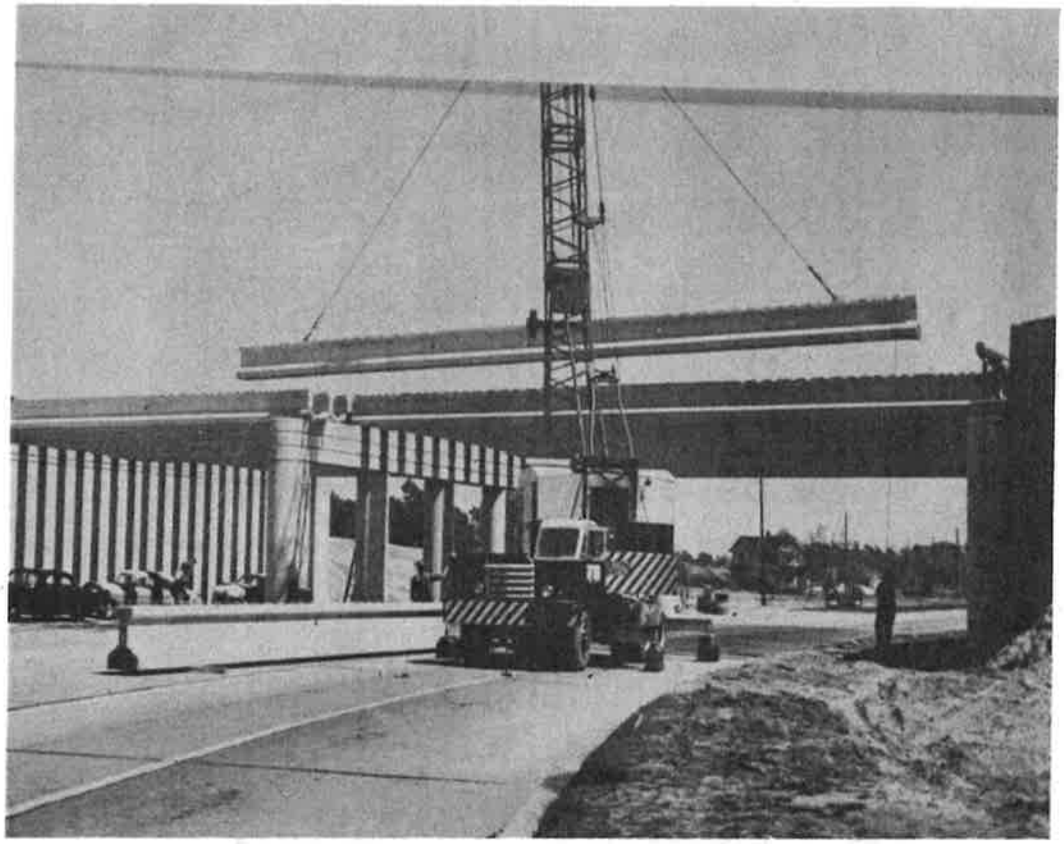


Figure 8. Prestressed beams erected at site over US 322, Garden State Parkway bridges, Section II.

TABLE 2

GARDEN STATE PARKWAY — GREAT EGG HARBOR BRIDGE

Section 11, Contract 173

	Alternates and Bid Prices					
	Alternate A Completion June 1956			Alternate B Completion December 1955		
	Method 1		Method 2	Method 1		Method 2
	1st Option 25' Span	2nd Option 40' Span	40' Span	1st Option 25' Span	2nd Option 40' Span	40' Span
Bidders	Prestressed Slabs	Prestressed Girders	Structural Steel Girders	Prestressed Slabs	Prestressed Girders	Structural Steel Girders
A	-	$2, 289, 788	$2, 289, 980	-	$2, 758, 545	$2, 747, 976
B	-	2, 495, 537	2, 490, 807	-	2, 645, 270	2, 640, 256
C	$2, 622, 317	-	2, 649, 362	$2, 884, 549	-	2, 914, 298
D	-	2, 644, 075	2, 672, 957	-	3, 701, 706	3, 742, 143
E	-	2, 887, 854	2, 896, 624	-	3, 234, 396	3, 244, 218

timber structure 24 ft wide that had been causing excessive maintenance. The new bridge (Figure 12) has three spans 18, 29, and 18 ft long, 50 ft wide on a 20 degree skew.

Bids were asked on designs in structural steel and prestressed concrete. The structural steel design called for 16- and 18-in. WF stringer beams, 4 ft on centers, with an open-deck steel-grid flooring 3 in. thick. The prestressed design (Figure 11) called for precast, prestressed T-shape units, which had a 22-in. wide top flange, $5\frac{1}{2}$-in.

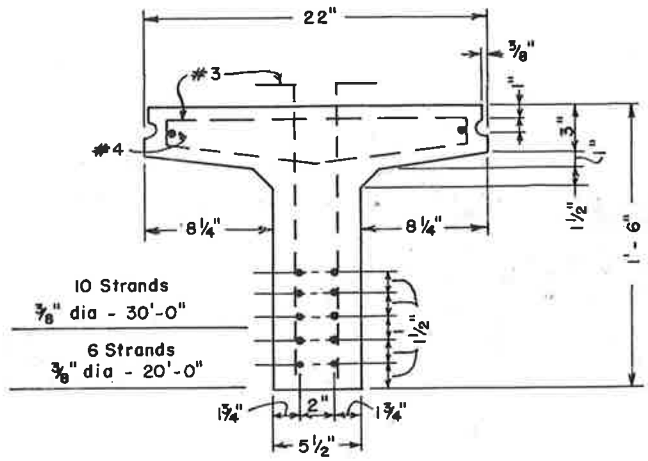
Figure 9. Two-span prestressed bridge over Route 40, Garden State Parkway bridges, Section II.

Figure 10. Single-span prestressed bridge over Route 559, Garden State Parkway bridges, Section II.

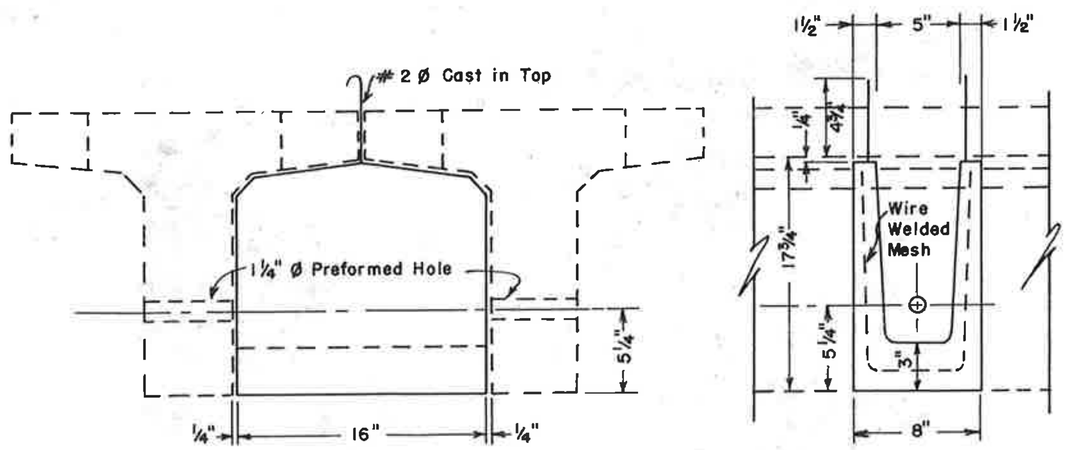
web, and a depth of 1 ft 6 in. These units were placed side-by-side and partially prestressed transversely through the diaphragms. A concrete deck slab varying in thickness from 3 in. to 5 in. at the crown was used as a wearing surface over the beams.

The low bidder submitted equal prices for the two schemes and the choice of construction had to be made by the county on some basis other than cost. The county selected the prestressed design because of the faster delivery of the prestressed beams and an estimated saving in painting cost for the steel structure. The cost of the superstructure was $6. 90 per sq ft of deck area.

In October 1954, the New Jersey Highway Authority received bids for the construction of the Great Egg Harbor Bridge (Section 11, Contract 173) which is also part of the Garden State Parkway. This section joins Beesleys Point to Somers Point in Atlantic County. The work consisted of the substructures (including abutments, piers, and wing walls) trestles, and bridge decks of two structures which carry the parkway across portions of Great Egg Harbor Bay.



TYPICAL SECTION



ELEVATION AND SECTION OF PRECAST DIAPHRAGM

Figure 11. Typical cross-section of prestressed concrete T beam, Sweet Briar Ave Bridge, Trenton, N.J.

The south structure (Figure 13) starts at Beesleys Point, crosses Great Egg Harbor, and extends northward for about 3,650 ft to join a causeway to be built under another contract. The north structure, 750 ft long, (Figure 14) connects with the causeway, crosses Drag Channel, and ends at Somers Point.

Bids were invited on Alternates A and B. A completion date of June 1956 was set for Alternate A while Alternate B had a completion date of December 1955 (Table 2).

Each alternate was sub-divided into Method 1 and Method 2. In Method 1, the contractor could bid on precast prestressed slabs 25 ft long, 13 ft wide, and 12 in. thick. He could also bid on prestressed girders 40 ft long with a cast-in-place concrete deck.

These two schemes were listed as Option 1 and Option 2. A selection had to be made between one or the other for bidding.

Under Method 2, the contractor could bid on structural steel stringer beams with a cast-in-place concrete deck. The same scheme applied to Alternate B except the difference in the completion date. The schemes and bid prices are tabulated in Table 2.

The low bidder selected Alternate A, with the 40-ft spans. The difference in the low bid prices was $8, 808 in favor of Method 2, Alternate A. The construction contract

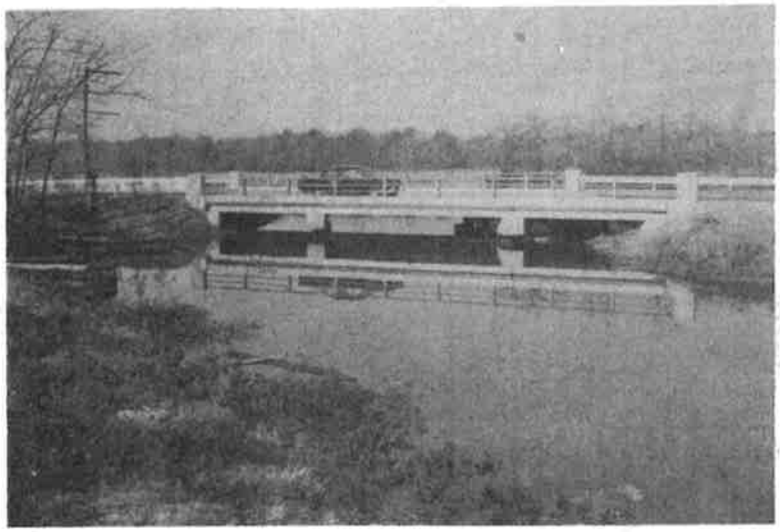


Figure 12. Sweet Briar Ave Bridge over Miry Run Creek, Trenton, N.J.

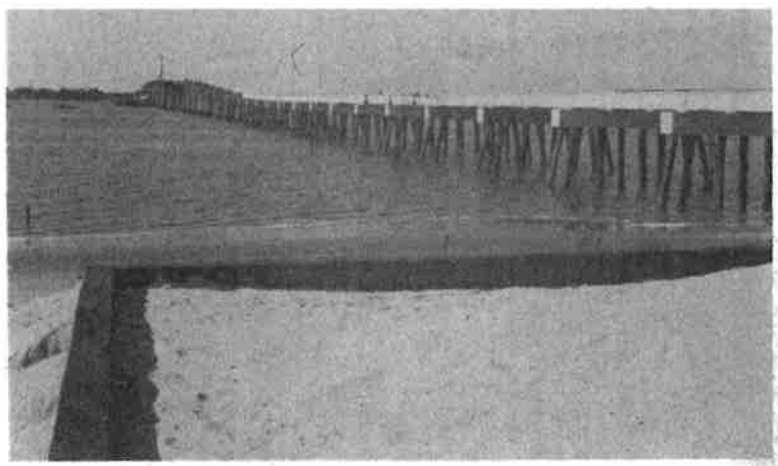


Figure 13. Great Egg Harbor Bay Bridge (looking south), Garden State Parkway, N.J.

was awarded to prestressed concrete on the basis of lower maintenance.

A review of the bid sheets shows that the 168 prestressed beams, each 40 ft long, were bid at $16. 00 per lineal ft. The cost of the beams for the deck area averages less than $2. 00 per sq ft. The approximate cost of the superstructure was $6. 75 per sq ft of deck (Figure 15). The prestressed I-beams were 33 in. deep with a 6-in. web, 12 in. wide top flange, and 19 in. wide bottom flange. The beams were prestressed with 42 $^3/_8$-in. diameter strands. Four beams were used in cross-section to carry a 26-ft roadway curb-to-curb, with an over-all width of 32. 5 ft. Composit action was developed between the prestressed beams and the 8-in. concrete deck slab through shear keys in the top of the beams and stirrups.

In October 1954, the Virginia Department of Highways received bids for the 23-mile bridge and tunnel project connecting Hampton Roads with Norfolk. The construction included 7,470 ft of tunnel and two bridges 3,250 ft and 6,110 ft in length. The north-

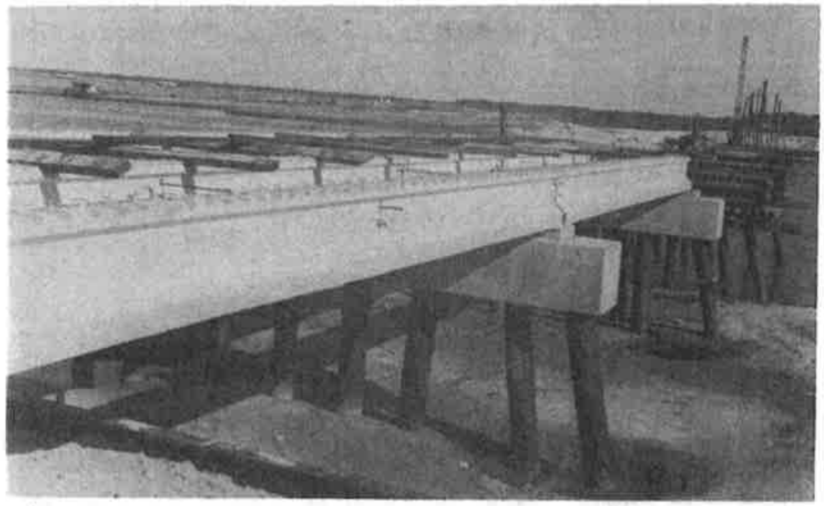
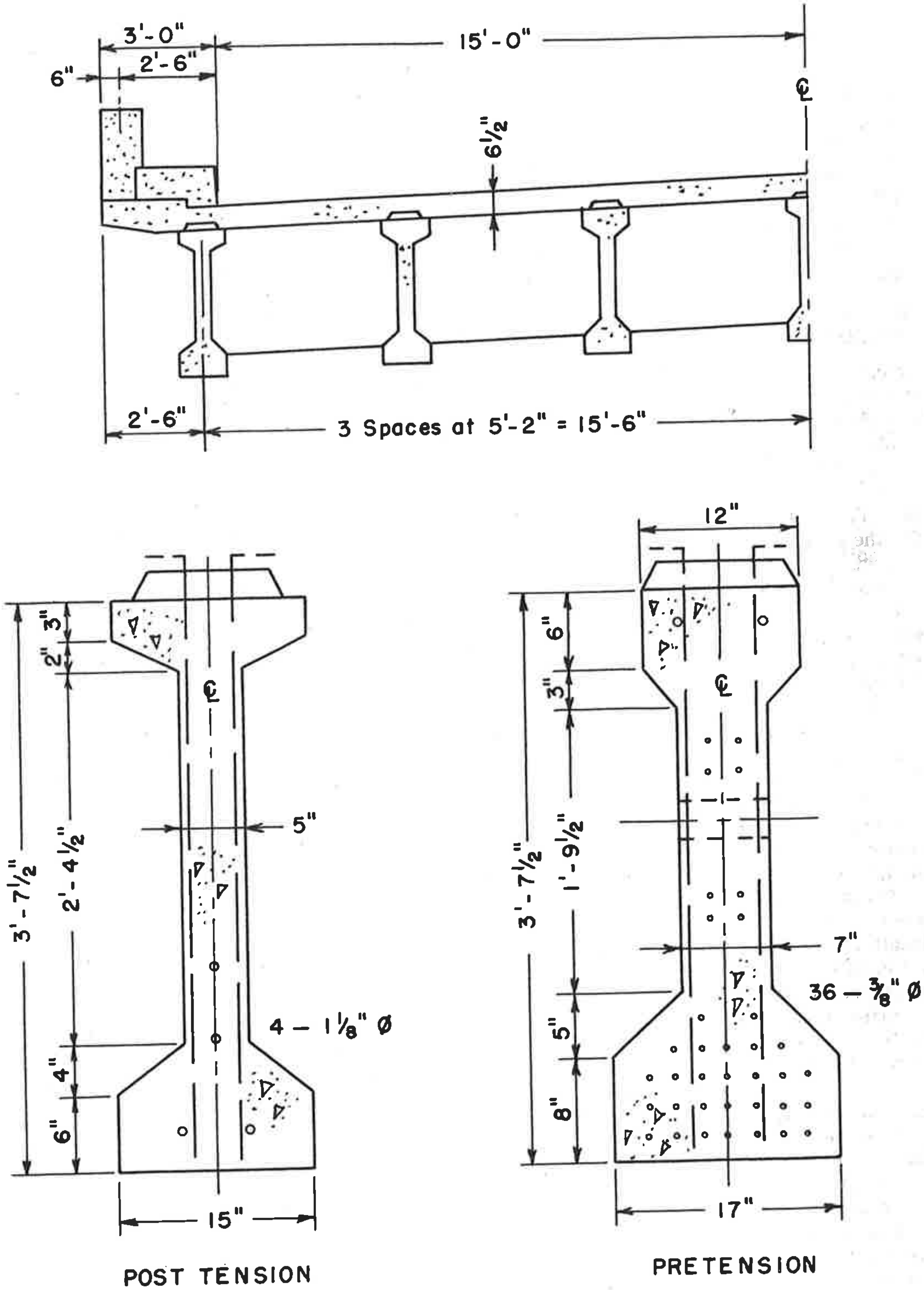


Figure 14. Great Egg Harbor Bay Bridge over Drag Channel, Garden State Parkway, N.J.

Figure 15. Great Egg Harbor Bay Bridge (looking south). Deck slab forms being erected, Garden State Parkway, N.J.

approach trestle, connecting Hampton Roads with a man-made island in the bay, was to be 3,250 ft long with a 30-ft roadway and a total width of 36 ft. The south-approach trestle, connecting Norfolk with another man-made island in the bay, was to be 6,110 ft long with a 30-ft roadway and a total width of 36 ft. The under-water tunnel was to connect the two islands.

The construction work was divided into two sections, one part for the tunnel work and the second part, designated as Contract C-2, for the north- and south-approach



CROSS-SECTIONS, 50' SPAN

Figure 16. Commonwealth of Virginia, Department of Highways, Hampton Roads Project.

TABLE 3

SUMMARY OF COST COMPARISONS - PRESTRESSED BRIDGES

Date	Project	Location	Span ft	No. of Bridges	No. of Spans	Crossing	Beam Cost Sq Ft Deck	Superstructure Cost Sq Ft Deck
1951	Wyoming County	Orangeville, N. Y.	62	1	1	Stream	-	$8. 35
1952	Wyoming County	Pike, N. Y.	52	2	1	Stream	-	8. 35
1953	Wyoming County	Perry, N. Y.	25	4	1	Stream	Plank	2. 70
1953	Garden State Parkway	Atlantic City	39-60	12	1 and 2	Grade Separations	$5. 00	9. 00
1954	County	Trenton, N. J.	18-29-18	1	3	Stream	-	6. 90
1954	Garden State Parkway	Egg Harbor, N. J.	40	1	42	Ocean Inlet	2. 00	6. 75
1954	Hampton Roads	Norfolk, Va.	50	1	128	Ocean Inlet	1. 60	4. 25
1954	Hampton Roads	Norfolk, Va.	80	1	37	Ocean Inlet	2. 45	5. 50

bridges. The north-approach bridge was designed for prestressed concrete, using 50-ft spans, seven beams in cross-section, and a 6½-in. concrete deck slab. Also designed in prestressed concrete, using 50 ft spans, was 3, 150 ft of the south-approach bridge.

The remaining 2, 960 ft of the bridge was designed for 80-ft spans, and this section could be bid in structural steel or prestressed concrete. These latter designs were designated as Alternate 1 and Alternate 2, respectively. The low bid was $19, 050, 461 for the entire project. The selection was Alternate 2. No bid on Alternate 1 was submitted.

The prestressed beam section bid for the 80-ft span was I-shaped, 4 ft 7½ in. deep, with a 1 ft 8 in. wide top and bottom flange, and a 5-in. web. This beam was reinforced with six cables, each having twelve 0. 255-in. diameter wires. At the third points, the structure was prestressed transversely with two cables, each having twelve 0. 255-in. diameter wires.

The 80-ft prestressed beams were bid at $1, 000. 00 each, concrete for the deck slab at $60. 00 per cu yd, and reinforcing steel at $0. 10 per lb. The cost of the prestressed beams was $2. 45 per sq ft of deck area. For the superstructure, the cost averaged $5. 50 per sq ft of deck area.

For the 50-ft spans (Figure 16), the prestressed beams were bid at $414. 00 each, concrete for the deck at $55. 00 per cu yd, and reinforcement at $0. 11 per lb. The cost of the prestressed beams was $1. 60 per sq ft of deck area. The cost for the superstructure was $4. 25 per sq ft.

Prestressed concrete piles were specified to carry the bents for the 50-ft spans. These piles were 24 in. by 24 in. with a 14-in. hollow tube in the center. The average length of the piles was 70 ft. For pile lengths of 70 ft and over, the vertical prestressing consisted of 32, 7-wire strands, each ⅜ in. in diameter. Piles shorter than 70 ft were prestressed, with 28, 7-wire strands, each ⅜ in. in diameter.

After the contract was awarded, the contractor requested permission to change the 80-ft spans to 50 ft and the standard-beam section was used. Also, the foundation design in the deep water area was revised and 54-in. diameter hollow prestressed piles were used. The wall of these circular piles was 5 in. thick, and the vertical prestressing consisted of 12 cables, with a wire area for each cable of 0. 348 sq in.

The prestressed beams and piles were fabricated by the contractor at a site in Norfolk. Four 418 ft long casting beds were used for the project.

The summary of cost comparisons listed in Table 3 demonstrates that prestressed concrete for bridges offers economy in competition with other types.

The increasing number of plants now available to fabricate various types of prestressed sections assures the submission of bids by a number of contractors. At present, beams about 60 ft long seem to be the maximum length that can be shipped from plants over the highways. Longer lengths could be shipped by rail or water if the plant and site locations are suitable.

Site precasting has been used effectively for several projects in the eastern region. This method was generally used because of the number of units fabricated and the area available for stockpiling. The relative cost of renting a large area near the project for site prestressing may in many cases prove more economical from the contractors' standpoint than using a plant where storage facilities are limited.

Standardization of prestressed units seems to be the trend at the present time. In the near future, it should be possible to purchase prestressed bridge units for various span lengths in beam and slab sections.

The scheme used on the Garden State Parkway bridges opens the field to further standardization of such sections. For short span bridges, prestressed solid and hollow slab sections will be available at fabrication plants for various spans and loading conditions. The recent floods in the east, where many bridges were washed out, demonstrated the need for units to replace such bridges in the shortest possible time.

From the construction standpoint, prestressed units offer an efficient and economical solution for bridge replacement. Through the medium of prestressed slab units, it is possible to replace an old bridge while maintaining traffic during construction.

On the longer spans, the use of prestressed concrete eliminates many of the problems with camber, when a partial width of the roadway is constructed in one operation. The need for building a variable haunch in the formwork for the deck slab is also eliminated. Since the prestressed girder is stiffer than other composite types and deflections are less, the need for falsework during construction is eliminated and vibration from traffic is less noticeable to pedestrians.

Much work remains to be done in the field of prestressing continuous structures, both in the design theory and construction. The possibilities of this method for long-span bridges seems promising. Today, contractors are bidding on prestressed designs with the same acceptance as other conventional designs. Like any new construction material or method, prestressed concrete must demonstrate its capabilities above and beyond its normal function before its full potential is exploited.