posttensioned concrete pavement

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This report covers the initial main-line installation of a posttensioned concrete pavement in Pennsylvania. A pavement thickness of only 6 inches was possible through the use of posttensioned strands in the slab. The installation was a single slab 500 feet in length and 24 feet wide. It rests on 3-in. bituminous concrete base and a 9-in. subbase, with a slip plane provided between the base and slab. There are 10 longitudinal strands in the slab as well as transverse reinforcement. The construction methods used and details of placement and materials are discussed. Concrete was placed over the strands by conventional slip-form paving equipment. Hydraulic jacking was used to apply tension in two increments during the curing period. Posttensioning promises to provide a crack-free pavement structure, thereby eliminating a source of deterioration and need for maintenance. It is too soon to make conclusions on the performance of this installation, although cracks have not appeared. The future of posttensioned pavement will depend mainly on cost of construction and benefits in relation to other pavement types.

• A new application of prestressed concrete pavement construction is currently being evaluated. The principle is similar to that used in prestressed beams for bridges and building structures. Steel strands are embedded in the concrete during paving and are posttensioned as the concrete cures.

There are several advantages to the use of posttensioned pavement: a reduction in pavement thickness from the normal 9 or 10 inches to only 6 inches and a reduction in reinforcing steel from about 15 to less than 5 lb/yd^2. It is anticipated that pavement cracking will be eliminated, thus reducing the maintenance and deterioration from this cause. Paving can be done with conventional equipment including slip-form pavers.

The first prestressed concrete pavement slab in Pennsylvania was designed and built by Jones and Laughlin Steel Corporation in 1957 (1). A 5-in.-thick, 12-ft-wide, 530-ft-long pavement section was built and tested under controlled loading conditions. The longitudinally prestressed, 400-ft center slab was flanked by two end slabs to simulate continuous construction. An extensive test series that included both static testing and moving load tests was carried out, but because of the time and cost involved no traffic load testing was included.

In 1962, the then Pennsylvania Department of Highways sponsored a research program at the University of Pittsburgh to evaluate the slab under extreme moving load conditions (2). Repeated loads from a weighted test vehicle were made to determine the magnitude and distribution of stresses and deflections in the slab. The slab performed well, even under subbase failure conditions, and remained free of transverse cracking although longitudinal cracking over the tendons occurred. No follow-up highway test installations were made at that time, since the construction method was not considered economically justified.

Recently, however, there has been renewed interest in this pavement design concept. New materials, new equipment, and advanced technology promise to make the system more practical. In July 1971, a 14-ft-wide, 300-ft-long ramp was posttensioned as a part of the interchange of US-113 and Del-14 near Milford, Delaware. Under the sponsorship of the Federal Highway Administration, 3,200 feet of 24-ft-wide posttensioned pavement was constructed as an access road to Dulles International Airport (3). Although final evaluation of these installations is not yet possible, they have shown the construction method to be valid and worthy of further study.

POSTTENSIONED PAVEMENT PROJECT

The first use of posttensioned pavement for main-line highway construction was installed on US-222 (LR 157-25), the Kutztown bypass, in September 1972. The bypass is a 4.98-mile section of limited-access, four-lane highway in Berks County. The construction was performed by a contractor under the supervision of PennDOT.

Because of the contractor's previous experience on the Dulles job, he was interested in making a similar installation in Pennsylvania and offered to place a short section for the same unit price as conventional pavement. There was an adjusted price made for a portion of treated subbase. Cost details will be discussed later.

One 6-in.-deep, 24-ft-wide, 500-ft-long posttensioned slab was placed in the westbound lane from station 890+00 to 895+00 just east of the interchange with Penn-737. The slab is on tangent alignment with a 2.05 percent grade. The bypass was completed in May 1973.

MATERIALS

The subgrade material was predominantly A-4 soil. A 9-in. subbase course was placed prior to construction of a 3-in. bituminous concrete base course. The same design was used for both the conventional and posttensioned concrete; design data are given below. Mixing was done on the job at the contractor's batch plant.

Factor	Value
Cement factor, bags/yd	6.25
Slump, in.	1.5
Air content, percent	6.5
Cement-sand-stone ratio (adjusted)	1:1.938:3.365
Water, gal/bag	5.08

The prestressing strands were a 7-wire strand of high tensile steel in a polypropylene conduit, prepacked with corrosion-inhibiting grease. The properties of the strand are given in Table 1.

PROCEDURE

The installation began with the placement of a subslab at each end of the experimental section (Fig. 1). Perforated underdrain pipe was placed under each subslab and was connected to the longitudinal underdrain 2 feet from the edge of pavement. A 9-in. aggregate subbase had previously been placed for both the conventional and posttensioned

Table 1. Strand data.

Item	Quantity
Strand diameter, in.	0.6
Steel area, in.²	0.215
Length per pound, ft	1.36
Modulus, psi	28×10^6
Ultimate strength, kips	58.6
Temporary force-maximum (80 percent of ultimate), kips	46.9
Stressing load (70 percent of ultimate), kips	41.0
Design load (60 percent of ultimate), kips	35.2

Figure 1. Subslab and joint detail.

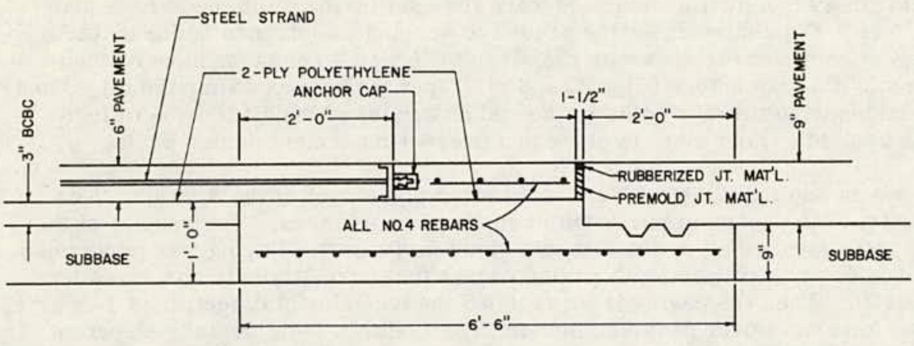
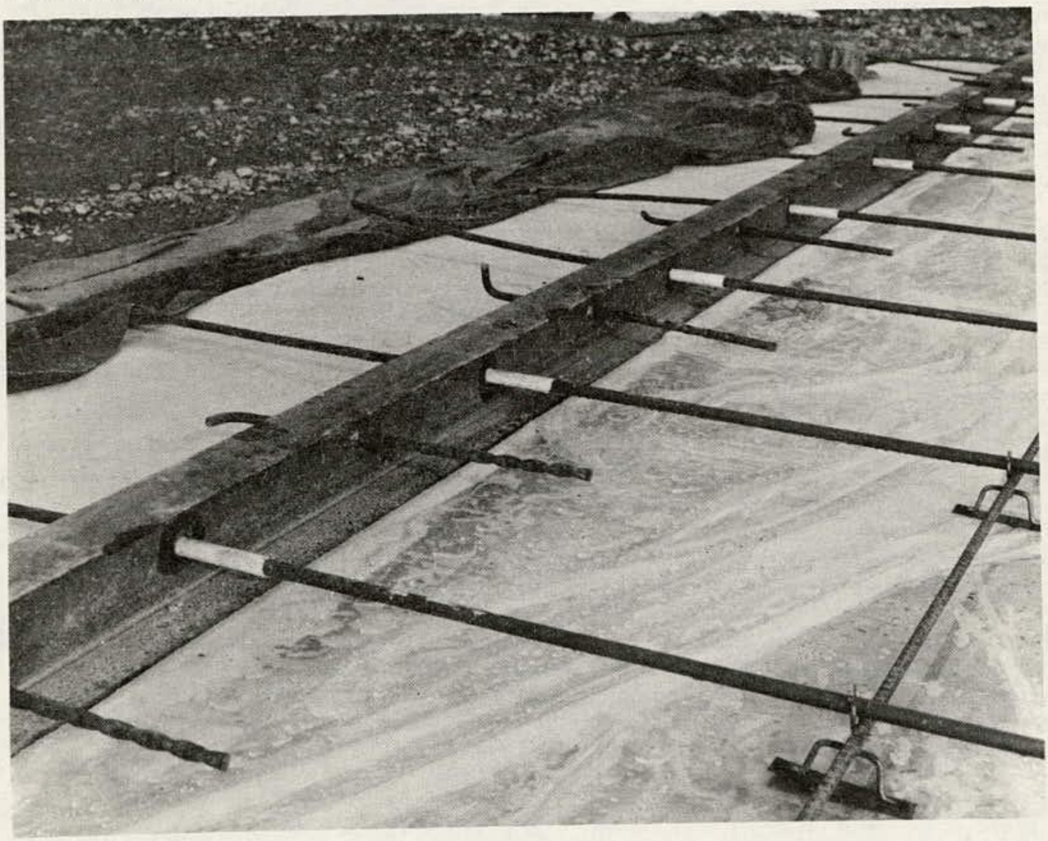


Figure 2. End beam.



pavements. A 3-in. layer of bituminous concrete base course was used under the posttensioned pavement for additional support and to make up the difference in thickness between the 6-in. pavement and the adjoining conventional 9-in. pavement. Sand was swept over the surface of the bituminous concrete base course to fill the surface voids and prevent any interlocking action between the slab and base course. Two layers of polyethylene sheeting were then placed on the base.

A 6-in. steel channel section was placed on each subslab to distribute the load from the strands across the slab (Fig. 2). The channels were temporarily held in place by welding them to reinforcing rods that had been embedded in the subslab (Fig. 3). The rods were cut off after paving.

Prefabricated transverse steel assemblies were then set on the bituminous base and spaced at 2½ feet. The chairs and clips needed to support the strands had been tack welded to them at each intersection with the strand (Fig. 4). Ten strands were then laid in place on 2-ft 5-in. centers (Figs. 5 and 6). They were snapped into the clips, and their ends were inserted through holes in the end channels. A small tension of less than 1 kip was applied to hold them in place and prevent movement during paving.

Paving was done on September 14, 1972, 3 days after placement of the strands. The contractor used a CMI slip-form paver with two Maxon spreaders. The results of the air and slump tests performed on the site are given in Table 2. Paving was performed in the same manner as in conventional paving except that normally only one spreader would be required. When the paving train reached the experimental section, a 1-hour delay occurred for changeover of the equipment from 9-in. to 6-in. depth. A section of conventional 46.5-ft pavement adjoining the subslab at each end was left out to provide a changeover area.

Paving of the posttensioned slab began at 12:30 p.m. and was completed in 2 hours. Concrete was placed in two layers and was given a standard transverse broom finish. A white-pigmented curing membrane was applied, and white polyethylene sheeting was used to cover the slab. The weather during paving was partly cloudy and breezy with temperatures in the 80s (Table 3). Temperatures during the curing period ranged from 48 to 83 F (Table 4). A 2-in.-deep by ⅜-in.-wide longitudinal center joint was sawed the next morning. The polyethylene sheeting was removed at the same time.

Tensioning of the strands was specified in two stages. The first load of 10 kips was to be applied to each strand when the concrete compressive strength reached 1,000 psi. The purpose of this loading was to control shrinkage and eliminate early cracking. The final load of 46.9 kips was to be applied at a strength of 2,500 psi. This load is 80 percent of ultimate for the tendons; the design load for the slab is 60 percent of ultimate or 35.2 kips. This allows for losses due to friction, strand relaxation, and concrete shrinkage.

Tests on the morning of September 15 showed the strengths to be well above the 1,000 psi required for the initial loading (Table 5). Because only one strand could be stressed at a time, an alternating pattern was used, from the center outward toward the edges (Fig. 7). Tensioning was done with a hydraulic jack on all strands first at one end and then at the other to reduce the effect of frictional loss in the strand. Elongation data are given in Table 6. Final tensioning was accomplished on September 17.

The end of each strand is anchored by a collar with a two-piece wedge set that grips the strand. The collar bears against a 3-in.-diameter washer that has a pipe coupling welded to it. After jacking was completed and the excess strand cut off, a cap was screwed into the pipe coupling, enclosing the collar. Grease was injected into the cap to prevent corrosion of the wedges and strand ends.

Figure 3. Temporary strand anchor.

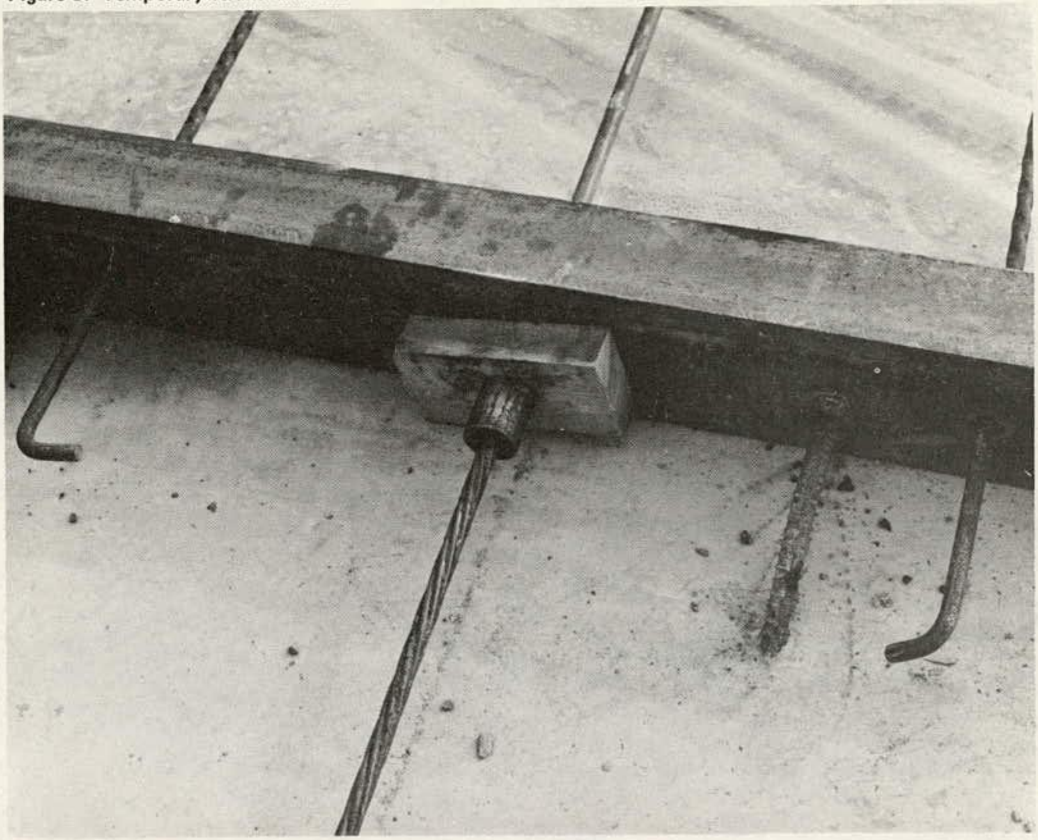


Figure 4. Chair and clip detail.

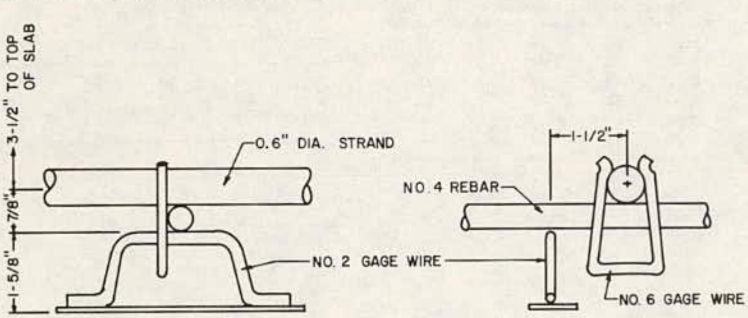


Figure 5. Pavement cross section.

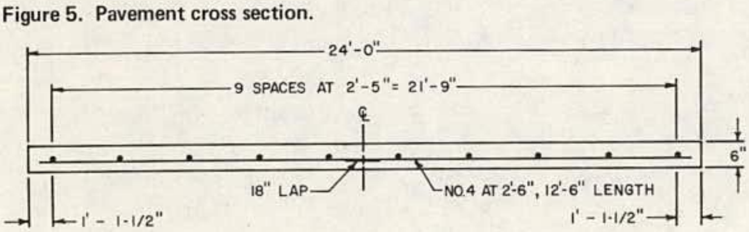


Figure 6. Steel layout.

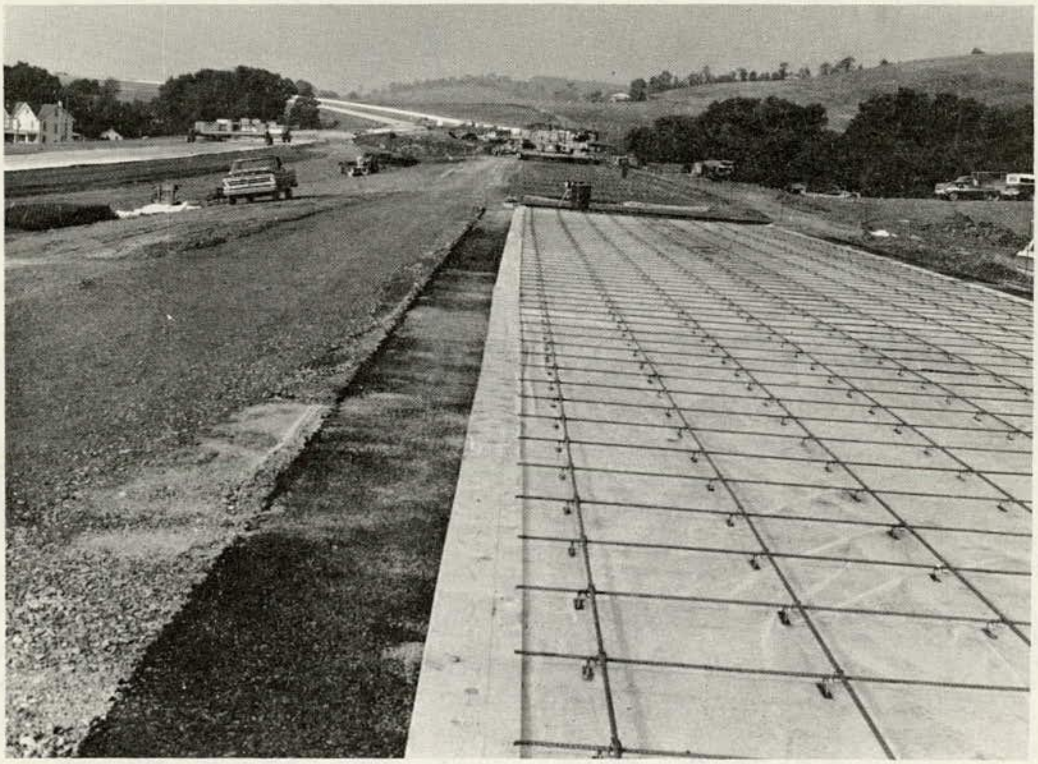


Table 2. Results of air and slump tests.

Time	Slump (in.)	Air Content (percent)
12:35	1½	
12:40		5.3
12:45	1¾	
12:50		5.7
1:05	2¾	
1:10		6.4
1:20	2½	
1:25		6.9
1:35	3	
1:40		7.0
1:45	2¾	
1:50		6.6
2:00	2¾	
2:10		7.5
2:15	1½	
2:20		5.7

Note: Design slump was 1.5 in.; design air content was 6.5 percent.

Table 3. Temperatures during paving.

Time	Air	Concrete	Base
12:30	88	78	94
12:50	86	80	92
1:30	84	78	92
1:50	82	80	88
3:00	80	74	—
4:06	80	84	—

Table 4. Concrete curing temperatures.

	Concrete		Air	
Date	High	Low	High	Low
9-15	89	70	74	50
9-16	87	63	78	48
9-17	93	55	83	52

The short slab adjoining the end of the posttensioned slab was placed last. It encases the collar assemblies and is jointed to the end channel by 10 hook dowels. Polyethylene sheeting between the end slabs and the subslab allows them to move as part of the posttensioned slab. Premolded joint filler and rubberized joint sealer at the ends completed the installation.

OBSERVATIONS

1. The time between paving and initial tensioning should be carefully considered on future projects. Strength gain and hydration temperature must be related to ambient temperature changes. Rapid evaporation of moisture from the concrete could lead to shrinkage cracking if tensioning is delayed. Although this did not occur on the Kutztown project, it is an important factor. Under ideal curing conditions it may be possible to tension in only one stage.
2. The sand used to fill the voids in the surface of the bituminous concrete base course was taken from the concrete mix stockpile and contained particles as large as ¼ in. Some of these larger particles were left on the surface to create an interlocking action between the slab and the base. The severity of this interlocking is probably negligible, but a finer grade sand should be used in future installations with this type of base, or the base gradation should provide a smooth surface.
3. The initial stress of less than 1 kip, which was applied to hold the strands in place, had been lost by the time paving was done. This was probably due to a change in temperature and appeared to cause no problems in paving.
4. The clips on the transverse steel assemblies, which held the strands, were too tight. Approximately 40 percent of the clips cut through the polypropylene conduit, allowing the protective grease to seep out.
5. When the first layer of concrete was spread, it was necessary for the spreader operator to take care that the concrete did not pile up and get pushed by the machine. The transverse steel assemblies were pushed along with the concrete and were displaced as much as 6 inches. The problem was solved when the operator became aware of it and took appropriate precaution.
6. A test was made before final jacking to determine the friction loss in the strands. Strand No. 5 was released and a load cell was placed on the end at station 895+00. The other end was jacked, and readings from both the load cell and the jacking gauge were taken. Readings at several loads are given in Table 7. These readings represent the loss for a 500-ft length.
7. The theoretical strand elongation at the final load of 46.9 kips for 500 feet is 46.7 in., calculated as follows:

$$\text{Theoretical elongation} = \frac{PL}{AE} = \frac{46.9 \text{ kips} \times 500 \text{ ft} \times 12 \text{ in./ft}}{0.215 \text{ in.}^2 \times 28 \times 10^3 \text{ ksi}} = 46.7 \text{ in.}$$

Actual average strand elongation was 12.9 percent less than theoretical.

8. No cracking of the posttensioned slab had been observed 6 weeks after paving. A hairline crack had formed between each end slab and end beam. These are unavoidable and should cause no problems.

PennDOT will continue to periodically observe the project's performance and serviceability.

COST DATA

The future of posttensioned pavement will be determined by its ability to compete economically with conventional paving methods. Savings in materials and maintenance are somewhat canceled by increased labor costs. The contractor's costs for the Dulles Airport experiment were \$7.46 per yd² for this type of construction (4). This same

Table 5. Concrete compressive strengths.

Cylinders	Age (hours)	Average Compressive Strength (psi)
1, 2	18	1,611
3, 4	22.5	1,841
27, 28	21	1,434
5, 6	28	1,593
29, 30	26	1,815
7, 8	46	2,611
31, 32	44	2,009
33, 34	48	2,210
9, 10	50	2,684
35, 36	67	2,570
11, 12	65.5	2,629

Note: Cylinders 1 to 24 were molded at station 890+00; cylinders 25 to 48 at station 895+00.

Figure 7. Strand indentification and loading sequence.

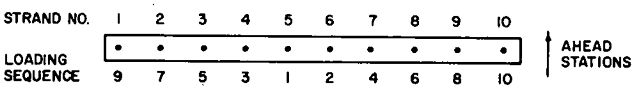


Table 6. Strand elongations in inches.

Strand No.	Tension Applied (kips)		
	0 to 10	10 to 46.9	0 to 46.9
1	$6\frac{1}{8}$	$32\frac{5}{8}$	$38\frac{3}{4}$
2	$6\frac{5}{8}$	$33\frac{3}{8}$	40
3	$5\frac{15}{16}$	$33\frac{1}{2}$	$39\frac{7}{16}$
4	$7\frac{1}{8}$	$32\frac{3}{8}$	$39\frac{1}{2}$
5	$6\frac{7}{8}$	$38\frac{1}{4}$	$45\frac{1}{8}$
6	$7\frac{1}{16}$	$33\frac{1}{2}$	$40\frac{9}{16}$
7	$7\frac{1}{16}$	$33\frac{1}{2}$	$40\frac{9}{16}$
8	$7\frac{3}{16}$	$34\frac{3}{16}$	$41\frac{3}{8}$
9	$6\frac{3}{8}$	$34\frac{11}{16}$	$41\frac{1}{16}$
10	$6\frac{11}{16}$	$33\frac{15}{16}$	$40\frac{5}{8}$
Average	6.71	33.99	40.70

Table 7. Friction loss in strands.

Load on Jack (kips)	Load on Cell (kips)	Friction Loss (percent)
28.0	22.1	21
41.3	34.0	17.5
46.9	41.2	12

contractor expects a cost of \$6.02 per yd^2 for longer projects. These costs do not include joints. The contract price for conventional 9-in. pavement on the Kutztown bypass was \$6.00 per yd^2.

Costs are expected to decrease if the method is put into general use. Treated subbase has been used on previous projects rather than separate base and subbase courses. It has been suggested that elimination of the transverse steel may be possible, and it may be possible to use four strands per lane instead of five. The strands could be laid directly on the base and picked up by holding devices on the paver to position them at the proper height. Specialized gang jacking equipment could also be used.

REFERENCES

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3. Prestressed Concrete Pavement Demonstration at Dulles International Airport. Public Roads, Vol. 37, No. 1, June 1972, p. 16.
4. Concrete Construction, Vol. 17, No. 10, Oct. 1972, p. 478.