An Experimental Self-Stressing Concrete Pavement: I. Construction Report

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An experimental reinforced concrete pavement, in which an expansive or self-stressing cement was used, was constructed in September 1963. The purpose of the experiment was to explore the feasibility of producing a thin prestressed concrete pavement in which the tension in the prestress strands results from pavement expansion. The 1,500-ft experimental section contains three slabs 24 ft wide, 6 in. deep, and approximately 490 ft long. The control pavement is of standard 40-ft contraction joint design, 9 in. thick, laid in two 12-ft lane widths.

This report presents information on background, design features, construction processes and experiences, instrumentation and measurements taken during and immediately after construction, and it offers suggestions for the consideration of future experimenters.

Early difficulties with consistency control and, consequently, with concrete finishing were reduced through changes in composition. The expected amount of expansion, as projected on the basis of earlier experimentation, was not achieved in the experimental slabs.

•ABOUT 70 YEARS AGO it was established that the chemical interaction between the tricalcium aluminate in portland cement and calcium sulfate in an aqueous solution imparts expansive properties to concrete. Subsequent research revealed that the resultant salt (calcium sulfoaluminate, of molecular composition $3\,CaO.Al_2O_3.3CaSO_4.30\text{-}32H_2O$) had absorbed water molecules into its final crystalline structure. Approximately 20 years ago a French engineer, Lossier, produced an expansive clinker claimed to be a calcium sulfoaluminate and controlled by regulating the availability of water and the use of blast-furnace slag. Recently Alex Klein of the University of California (1, 2) developed a component for expansive cement which is a clinker proven by X-ray diffraction and petrographic examination to be essentially a true anhydrous calcium sulfoaluminate and free lime. This recent work offered encouragement for the use of expansive cement, under conditions of controlled growth action, to develop self-stressing qualities in resultant concrete.

In December 1962, the Connecticut State Highway Department and other interested parties decided at a meeting to explore the feasibility of constructing an experimental self-stressing concrete pavement in Connecticut. Represented by staff personnel, at the first and also later meetings, were the U. S. Bureau of Public Roads; Concrete Research and Development Corporation (CONRAD), Van Nuys, Calif.; Blakeslee Prestress, Division of C. W. Blakeslee and Sons, Inc., New Haven, Conn.; and the Connecticut State Highway Department.

On the basis of information presented, construction of an experimental section of this new type of pavement was recommended to Commissioner Ives and subsequently authorized. The U. S. Bureau of Public Roads concurred in the decision and offered its fullest cooperation.

Paper sponsored by Committee on Rigid Pavement Design.

TABLE 1

MOISTURE CONTENT AND DENSITY OF GRAVEL SUBBASE DETERMINED BY NUCLEAR PROBE

Station	Subbase and Subgrade	Dry Density (pcf)	Moisture (%)	Sample Depth (in.)	Type of Material
81+00	Subbase	127.5	2.8	0-12	
	Subgrade	102.0	14.7	12-20	Red, silty, sand
83+50	Subbase	116.0	2.6	0-16	
	Subgrade	83.5	22.2	16-24	Brown, silty, fine gravel
86+00	Subbase	117.0	3.4	0-24	
88+50	Subbase	125.0	2.4	0-24	
91+50	Subbase	126.0	4.0	0-24	
	Subgrade	90.0	15.5	24-28	Reddish brown clay
95+00	Subbase	118.0	3.5	0-24	
	Subgrade	83.0	17.5	24-28	Reddish brown clay

Later meetings led to an agreement for a pilot installation of self-stressing pavement at the prestressed concrete plant of C. W. Blakeslee and Sons, Inc., in Hamden, Conn., to obtain further information on this new type of construction before beginning the state project. The pilot installation, consisting of a single slab 185½ ft long, 13⅓ ft wide, and 6 in. deep, was placed on June 14, 1963 (3).

SITE DESCRIPTION

After completion of the pilot installation, the final plans for the experimental pavement were drawn to fit the selected project site, Route 2 in Glastonbury (State Project No. 53-100). The project, a four-lane divided highway with fully controlled access, was then under contract.

The experimental pavement was installed in the southbound roadway from station 81 + 40 to station 96 + 60 (4, 5). This roadway is a tangent section from station 81 + 40 to station 96 + 19.9 with a +1.5 percent grade. Station 96 + 19.9 is the P. C. of a superelevated horizontal curve to the right with the same grade.

At the northern end of the test section, station 81 + 40, the roadway is on fill approximately 10 ft in height, with a 6-in. gravel subbase. Starting approximately at station 82 + 00, there is a transition from 6 to 24 in. of gravel at station 82 + 50, as the roadway enters a cut which continues throughout the remainder of the test section. The cut starts at approximately station 83 + 50 in a sandy gravel, and runs into a reddish brown clay about station 85 + 00, which continues throughout the rest of the test section. Table 1 gives values of the dry density and moisture content for the gravel subbase and subgrade obtained with a nuclear probe.

DESIGN AND PREPARATION

Final design of the test section called for three self-stressing slabs: two end slabs 494 ft long and one middle slab 490 ft long. The slabs were to be placed 24 ft wide and 6 in. deep. Hereafter, the individual slabs will be referred to as I, II, and III. The approximate limiting stations of the slabs are 81 + 51 to 86 + 45, 86 + 55 to 91 + 45, and 91 + 55 to 96 + 49, respectively (Figs. 1 and 2).

Paving

To overcome anticipated problems with the keyway and the formation of a longitudinal joint, the experimental pavement was placed full width (24 ft) with no longitudinal joint rather than by the conventional lane-at-a-time method which was used on the remainder of the project.

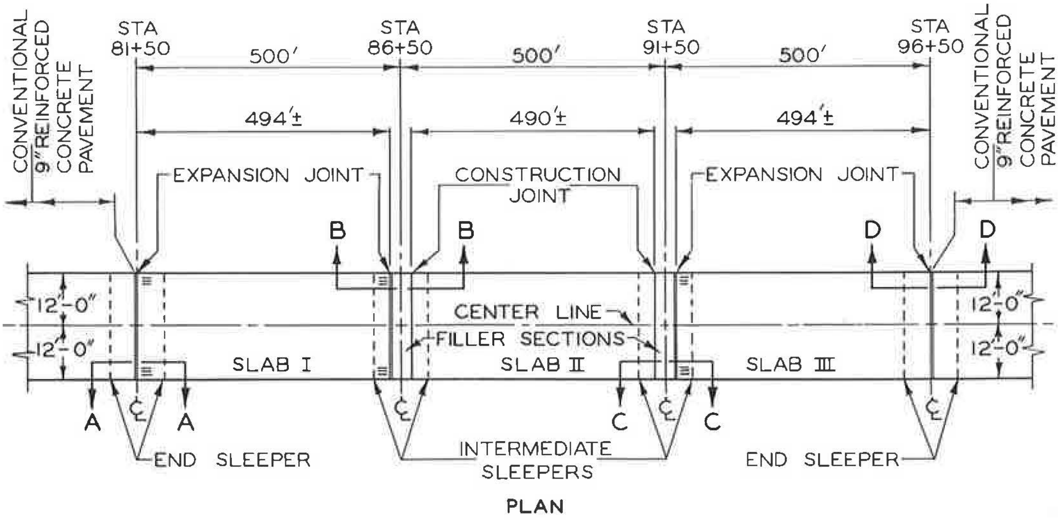

Figure 1. Self-stressing concrete pavement.

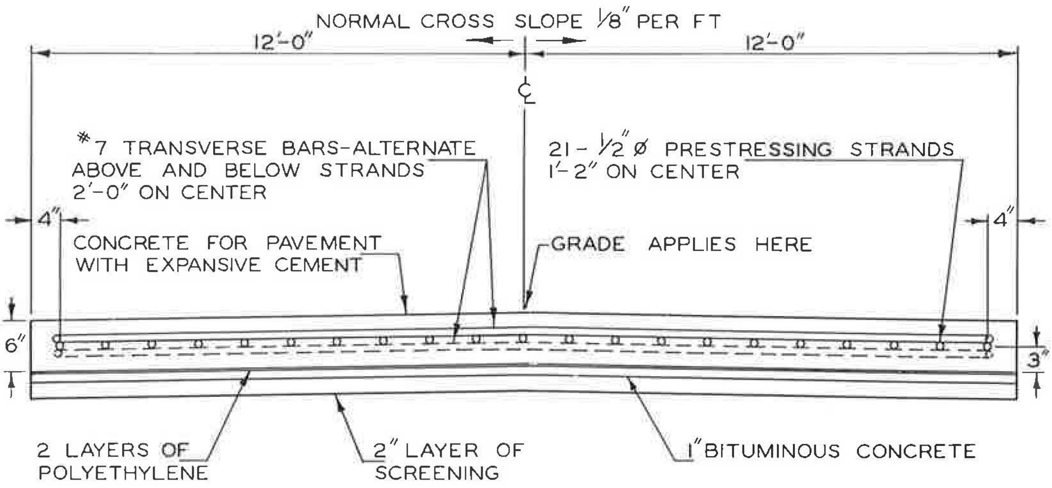

Figure 2. Typical cross-section of pavement.

Figure 3. Backfilling forms with 2-in. layer of trap rock screenings and 1-in. layer of dense-graded bituminous concrete.

Modification for Depth

The subbase was prepared to normal requirements for a 9-in. concrete pavement, using 9-in. forms. The forms were then backfilled with a 2-in. layer of trap rock screenings and a 1-in. layer of dense-graded bituminous concrete to give the required slab thickness of 6 in., as shown in Figure 3. The placement of two layers of polyethylene sheeting, each of 4-mil minimum thickness, was required on the surface of the bituminous concrete to permit slab growth with a minimum of subgrade friction.

Sleeper Slabs

A reinforced concrete sleeper slab was required at each end of the experimental slabs to support the ends of the pavement and to provide anchorage for devices to restrain the thin slab from curling. The sleeper slab was 20 ft long, 24 ft wide, with its surface set flush with the surface of the bituminous concrete. A steel beam (15WF55) was embedded in each sleeper slab, transverse to the roadway. The beams were placed at stations 81 + 45, 86 + 50, 91 + 50, and 96 + 55. Sleeper slabs at these locations are referred to as blocks A, B, C, and D, respectively (Figs. 4 and 5). Each beam was cut into two 12-ft sections and set to the crown of the finished roadway (Fig. 6). Before placing the beam, holes were cut into the web to permit anchoring the longitudinal steel to the web. The beam also served as a rigid header to jack against during the initial tensioning of the longitudinal reinforcement, and was burned off reasonably flush with the surface of the sleeper before the concrete for the filler section was placed.

Six hold-down devices (Fig. 7) were also set in the sleeper slabs to restrain the ends of the experimental slabs from curling without restraining the pavement growth. Figure 1 shows that the hold-downs were located only in slabs I and III. By extending No. 5 deformed steel bars through the bulkheads forming the termini of slab II, it was possible to tie the concrete filler, over the sleeper slab, to the experimental slab. This mass of concrete was considered sufficient to restrain the ends of slab II from curling. The hold-downs were omitted at the terminal end of slab III. To avoid curling, the longitudinal reinforcement was lowered ½ in. below the neutral axis of the slab. The downward component of the resultant longitudinal stress was judged sufficient to resist curling.

Referring again to Fig. 4, blocks B and C are a uniform 9 in. thick, while blocks A and D (Fig. 5) contain a 3-in. vertical step. The step was required to accommodate the conventional 9-in. reinforced concrete pavement on the terminal blocks. Against the vertical face of the 3-in. step, a 3- by 1½-in. block of foam glass was placed to allow for movement due to temperature changes.

In constructing blocks B, C, and D, the contractor merely removed the gravel subbase to the required depth and poured the blocks, using the faces of the excavation as forms (Fig. 8). For block A, he used the forms which he had already set. In each block, class A truck-mixed concrete with an extra bag of cement per cubic yard was used to develop high early strength in the concrete (see Appendix). The surface of the sleeper slabs was finished with a steel float, and the concrete cured with wet burlap. To minimize subgrade friction, the polyethylene sheeting was carried over the surface of the sleeper slab as shown in Figure 9.

Reinforcement

Longitudinal reinforcing for the pavement was ½-in. diameter, 7-wire strand prestressing cable (ASTM 416), spaced 14 in. on centers, with outside strands 4 in. from the edge of pavement. Each longitudinal cable was continuous for the full 1,500-ft length of the experimental section. The cables were initially tensioned to a load of approximately 1,000 lb. The tensioning was accomplished by jacking the individual cables in each slab and clamping the strands to hold them taut, as shown in Figure 10. Tensioning of the longitudinal cables was required to prevent catenary curvature between the transverse reinforcement, and thus to keep the longitudinal reinforcement at the neutral axis of the slab.

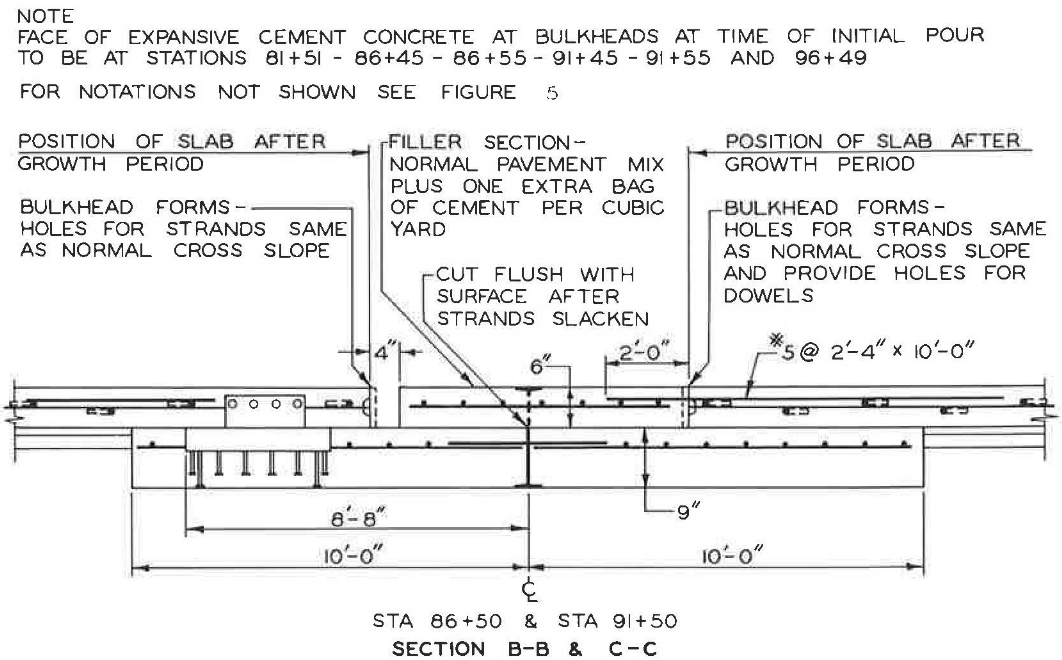

Figure 4. Intermediate sleeper slab.

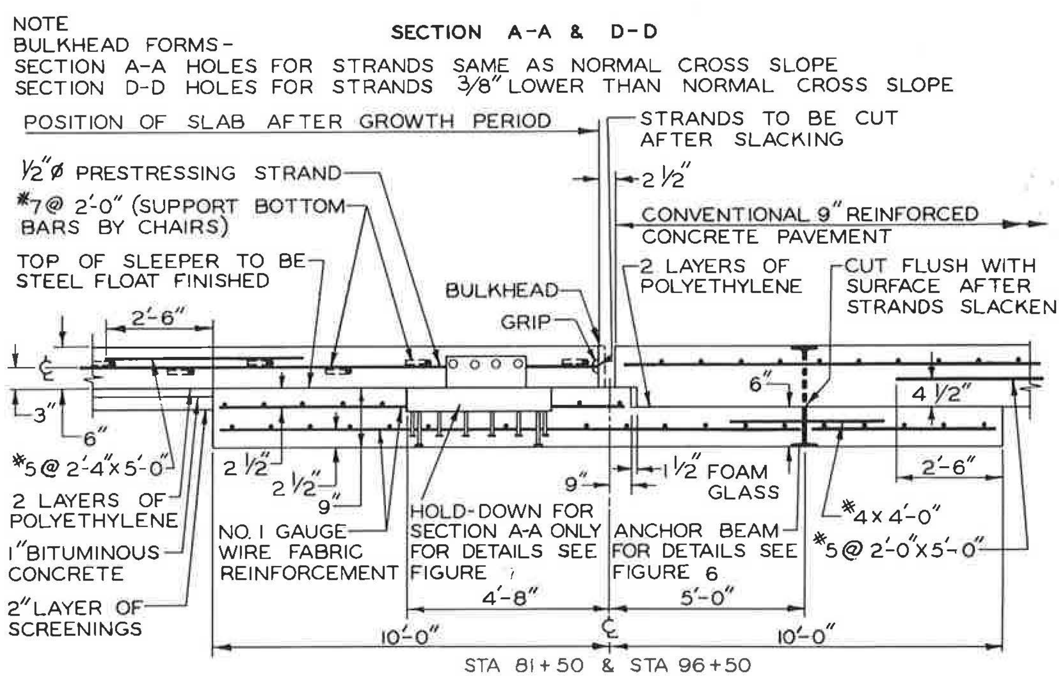

Figure 5. Terminal sleeper slab.

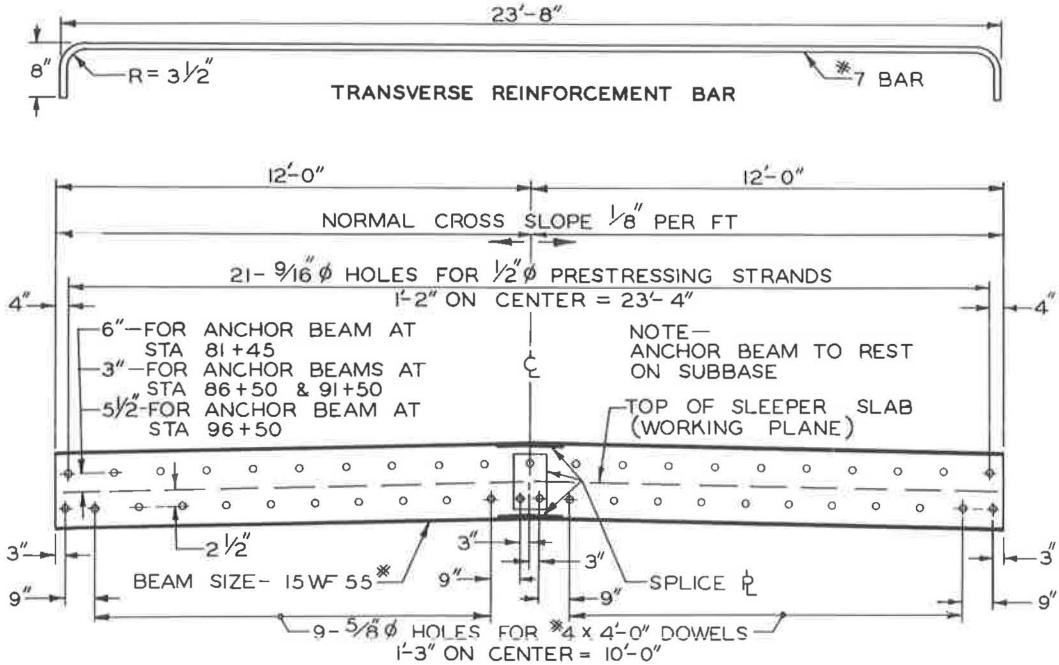

Figure 6. Anchor beam and transverse reinforcement bar.

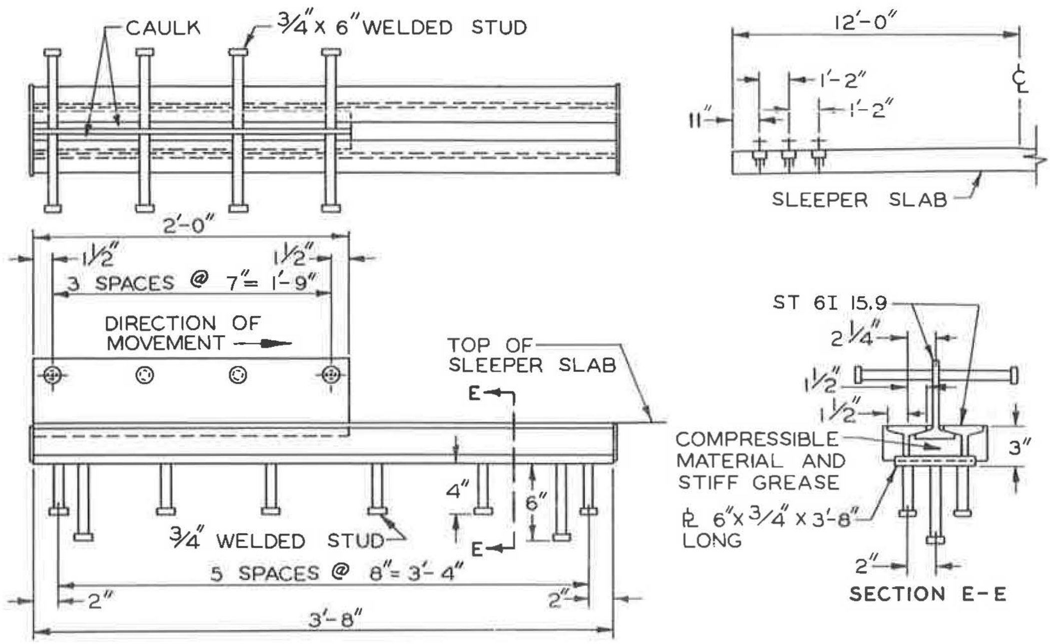

Figure 7. Hold-down device.

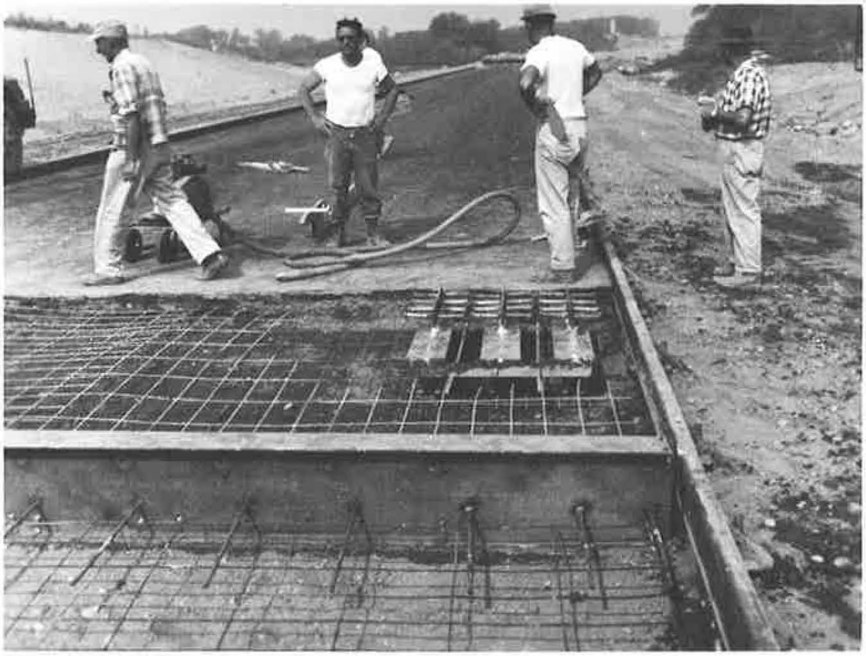

Figure 8. Pouring of blocks B, C, and D, using faces of excavation as forms.

Figure 9. Polyethylene sheeting being carried over surface of sleeper slab.

Figure 10. Tensioning of longitudinal prestressing reinforcement cables.

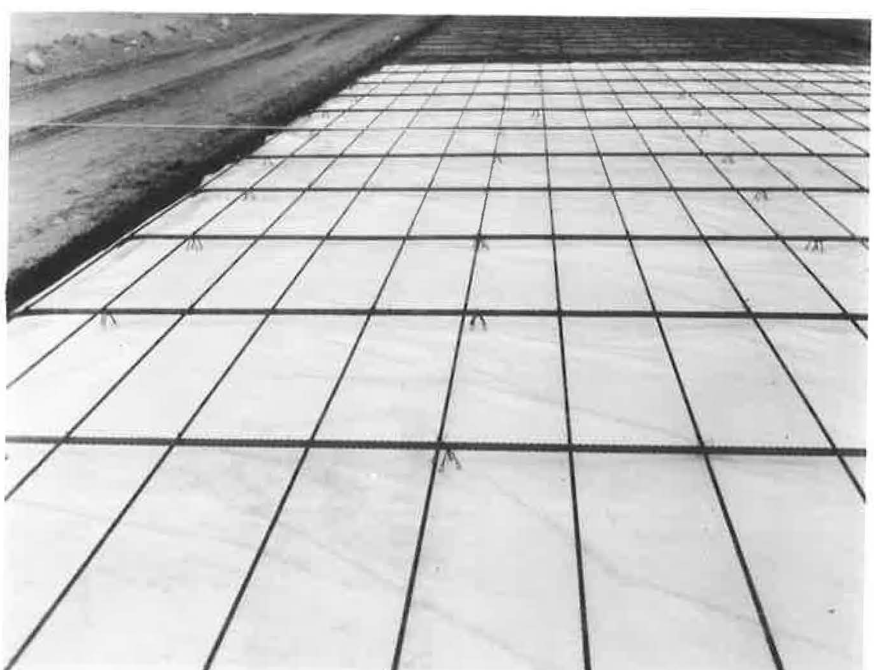

Figure 11. Transverse reinforcement by No. 7 deformed steel bars, tied to longitudinal bars; all steel supported by chairs.

Transverse reinforcement was provided by No. 7 deformed steel bars (ASTM A432 and ASTM A305) spaced 2 ft on centers, alternating above and below the longitudinal strands (Fig. 6). The ends of the deformed bars were bent 90 degrees to form hooks of 8 diameter length which were laid flat to clear the forms by $1\frac{1}{2}$ in. All transverse steel was tied to the longitudinal steel and all steel was supported by chairs as shown in Figure 11.

Mix Design

The preliminary mix design proposed an $8\frac{1}{2}$-bag mix which otherwise conformed to State Highway Department Specifications. A high cement content was deemed necessary to insure the desired growth of the pavement in the field. By using a retarding admixture, it was proposed that the concrete be placed at a slump of $1\frac{1}{2} \pm \frac{1}{2}$ in. with a water-cement ratio of 4.0 gal/sk. It was thought that any increase in the water-cement ratio would be detrimental to the pavement. An air-entraining admixture in an amount sufficient to give 4 to 6 percent entrained air was also required to insure durability of the concrete pavement.

To assure the moisture required for continued growth, fog spray was required for a minimum of 24 hr, followed by a cover of polyethylene sheeting for the remainder of the curing period.

PAVING

The paving operation started at the northern end of slab I on September 13, 1963. The concrete was delivered from a central mixing plant to the paving site in 8 cu yd agitator trucks, over a haul distance of approximately $\frac{1}{2}$ mi. The concrete was placed directly from discharge chutes, using both sides of the forms.

As the first load of concrete was being placed, it was quite evident that the material would be difficult to work, as can be seen in Figure 12. The concrete was to be placed with a $1\frac{1}{2} \pm \frac{1}{2}$-in. slump, but the material from the first truck had no slump within 5 min after it had been placed. Even after prolonged vibration, it was impossible to consolidate the material thoroughly and raise enough mortar to finish the concrete. When the strike-off moved onto the forms it was unable to displace and distribute the concrete across the pavement. When the transverse screed pushed the forms out of line, finishing operations were stopped, the material was removed from the forms, and the paving operation was moved to slab II.

Slab II

When the paving operation was resumed, additional water had been added to the mix, but the workability remained poor. To complicate matters further, the strike-off broke down about 20 ft from the start and the transverse screed was used to strike off the concrete already deposited in the forms. The screed had little success as the material still remained 2 to 3 in. above the forms. It was impossible to finish the concrete even after water had been sprayed on the unfinished concrete. It was now evident that the retarding qualities of the retarding admixture were inadequate to delay the set of the concrete sufficiently.

Before it was possible to finish this section of pavement, the concrete above the reinforcement was removed. The concrete remaining in the forms was sprayed with water and a surface layer of fresh, high-slump concrete was placed and struck off. Segregation was very noticeable as the new material was being deposited, as shown in Figure 13. The fluidity of the material was demonstrated by the waves of aggregate and mortar that were pushed over the forms during the strike-off operation. Since this type of mix offered the greatest workability, it was accepted and slump tests were dropped from the field testing.

Although the concrete was very wet during placement, it became stiff within 10 min after placing, as evidenced by the large roll of stiff mortar carried by the transverse screed. It was decided that no concrete would be accepted at the paving site which had been in transit more than 15 min, and only two trucks were to be dispatched from the

Figure 12. Placement of first load of concrete, showing inadequate slump.

Figure 13. Placement of high-slump concrete, showing considerable segregation.

plant at a time. This slowed the paving operation considerably, but it enabled the finishers to work closely behind the machines.

Finishing the pavement was a difficult task. As the finishers attempted to float the surface of the pavement, coarse aggregate adjacent to the reinforcement was forced over the steel and through the surface of the pavement. Because of the trouble with the coarse aggregate and other surface irregularities, it was necessary to wet the surface of the pavement and finish most of the slab by hand. Final finishing of the slab was to be with a wet burlap drag, but the operation was not successful as the concrete was too stiff. The resultant surface texture of the pavement was, therefore, very rough and irregular in appearance, with pronounced waves in the direction of paving. The waves were attributed to the transverse reinforcement tied to the top of the longitudinal cables. In an attempt to remove the surface irregularities, the contractor used a circular floor finisher on the pavement. This machine was used with some success as it tended to plane the pavement's surface to a fairly uniform height, but the machine could not finish the entire slab because some of the material had been in place for several hours.

The required cure was applied by state maintenance forces as soon as possible after the concrete had been finished, using a Bean hydraulic sprayer with a spray gun fed by a high-pressure water line, as shown in Figure 14.

Because of the expected expansion of the concrete the contractor was required to remove any obstacles which might impede the growth; therefore, all form pins and collars at bulkheads were removed as soon as possible after the paving operation ceased. The unrestrained forms remained in place and were stripped the following day.

Table 2 gives data on weather conditions, entrained air, and temperatures of plastic concrete for the paving dates.

Slab I

On September 16, 1963, slab I was paved. Based on previous experience, changes in the mix design were made resulting in the finished surface of slab I being much smoother than the surface of slab II. The changes were (a) the maximum size aggregate was reduced from 2- to $1\frac{1}{4}$-in. crushed stone and (b) the amount of retarding admixture was raised from 25 to $42\frac{1}{2}$ oz/cu yd as shown in the Appendix. To facilitate storage of the paving equipment, the direction of paving was reversed and the operation proceeded from block B to block A.

Throughout the day the concrete was very fluid as the discharge began and became stiffer as the discharge continued because of segregation in the trucks. However, visual inspection of cores removed from the test section indicated that the resultant concrete was fairly homogeneous. Although the revised mix design reduced difficulties in the machine-finishing operation, it was still necessary to hand finish portions of the slab because of the rapid set.

Approximately 225 ft south of the bulkhead at block A, the concrete adjacent to the median began to puff and crack before the completion of the day's paving. The distress appeared as hair cracks in the surface of the pavement. The edges of the cracked pavement then puffed up and exposed the material beneath the surface. The affected area is shown in Figure 15, the day after the completion of slab I. Unfortunately, the area was subjected to abuse before a complete photographic record could be obtained. A possible explanation for this failure is presented in an article in the Journal of the American Concrete Institute, which stresses the need for close control over extent of expansion and time interval during which it takes place. The article states:

> for unrestrained concrete, the expansion must not take place before the concrete gains sufficient tensile strength to be stressed in tension rather than disrupted by the expanding forces. For restrained applications, the concrete must be enough to withstand the compressive stresses developed. (6)

Conceivably, the distress described fits one or a combination of these cases. Also, the temperature of the plastic concrete in the distressed area was 84 F, which is considerably higher than any other recorded.

Figure 14. Curing of concrete, using hydraulic sprayer with spray gun fed by high-pressure water line.

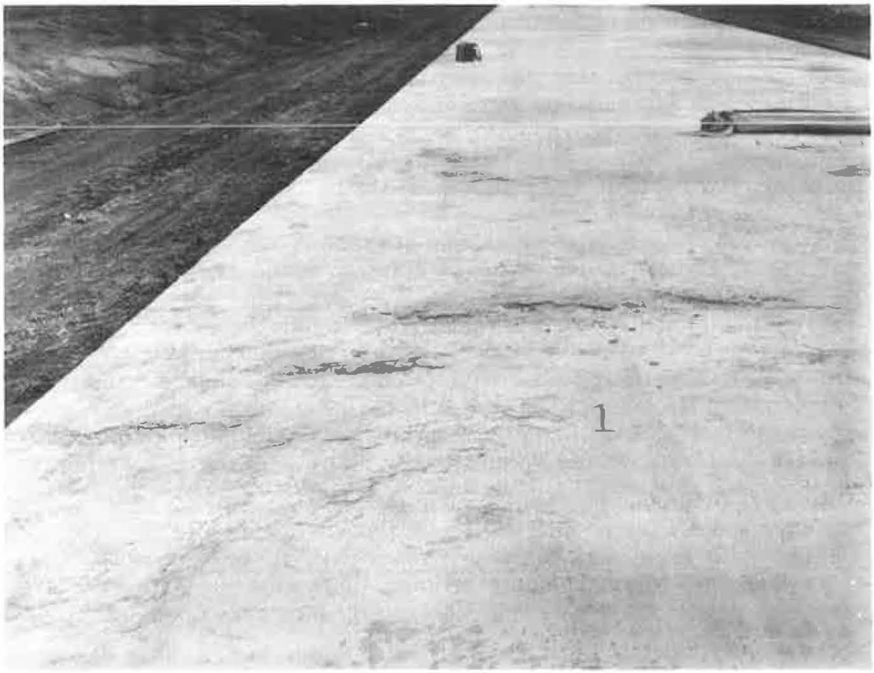

Figure 15. Surface cracks in slab I, day after completion.

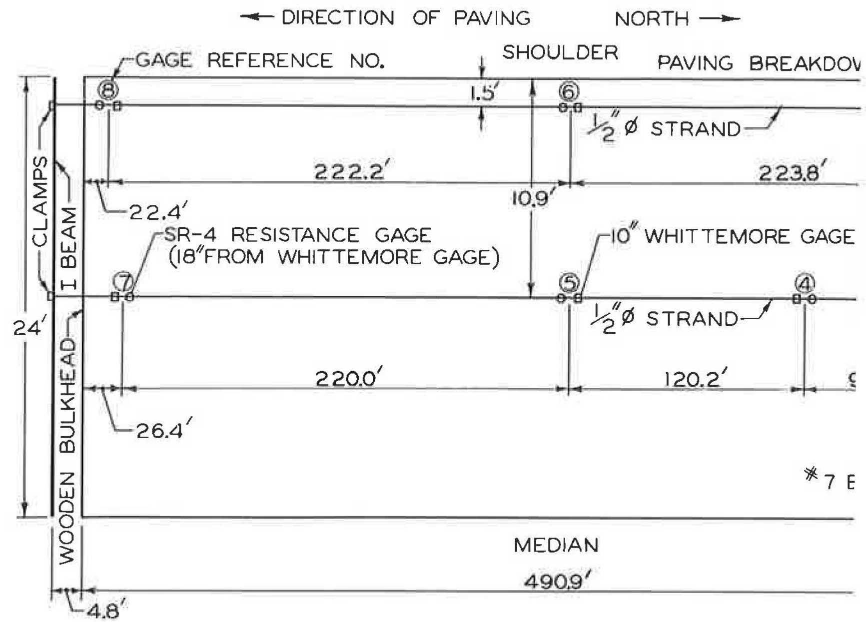

Figure 16. Approximate strain-gage locations slab I]

Figure 17. Strain-measuring devices in place before conci

reference line corresponded to the face of the bulkhead adjacent to th pansive cement concrete slabs. Two monuments were set at each sl reference line could be established using a transit. Monuments were work area to avert any possible damage to them, and were placed ir

TABLE 2

DATA ON TEMPERATURE AND AIR ENTRAINMENT FOR THE DATES OF PAVING

Date	Air Temp. (° F)	Concrete Temp. (° F)	Entrained Air (%)
9/13/63	50 - 68	72 - 75	5 - 5½
9/16/63	48 - 55	72 - 78[a]	4¾ - 5¼
9/17/63	49 - 65	72 - 76	4½ - 5

[a]Temperature of 84° F recorded in vicinity of station 83+75.

Slab III

Slab III was paved on September 17, 1963. Paving was started in a southerly direction proceeding from block C to block D. As previously mentioned, unlike slabs I and II, this slab was not wholly on a tangent. This necessitated the removal of the crown from the transverse screeds, which was done by lowering the crown by hand ¼ in. every 30 ft, starting at approximately station 94 + 00. Full superelevation was reached at about station 96 + 00. As the paving operation was halted during the changeover, it became necessary to wet the concrete already in the forms before placing any new material, and to increase the sand content of the concrete mix to aid in the finishing operation, as shown in the Appendix.

As the paving operation neared the point of full superelevation it became increasingly difficult to retain the high-slump concrete in the forms. The material flowed to the low side, displacing the longitudinal and transverse reinforcement. Subsequently, the water content of the mix was reduced which increased finishing difficulties, but the reinforcement remained in place.

About halfway through the paving operation, surface cracks developed adjacent to the median, at approximately station 91 + 90. When the distress was noticed, the area was immediately saturated with water via the hydraulic sprayer. No signs of distress were found during later inspections of the affected area. The expansive concrete probably healed itself when water was applied in an amount sufficient to sustain the hydration reaction of the expansive component.

In general, the paving operation proceeded smoothly as evidenced by the lack of difficulties in accomplishing the transition from the tangent section to full superelevation. Later in this report, slab III is reported as having the least amount of edge cracking. Consequently, it is believed that slab III reflects improved construction techniques over those used in slabs I and II.

Filler Blocks

Normal paving operations outside of the experimental area were started by the contractor after the completion of slab III. Gaps left in the test section over the concrete sleeper slabs were to be filled in as the contractor's operation approached their location. Gaps over the intermediate sleepers were filled with normal paving concrete plus one extra sack of cement per cubic yard, leaving a 4-in. joint adjacent to slabs I and III.

At the terminal blocks, normal paving concrete was used as the filler with a 2½-in. joint left at the ends of the experimental pavement. No. 5 deformed bars, 5 ft long, spaced 2 ft on centers, were originally required in the filler blocks over the terminal sleepers to augment the pavement's flexural strength and to act as a load transfer unit spanning the end of the sleeper block to the gravel subbase (Figs. 4 and 5). Due to an oversight, the steel was not put in the filler sections. Instead, a Harris load transfer unit and a unitube joint former were installed over the ends of the sleeper slabs at points of unequal subgrade support.

Joints left at the experimental sections will be filled with an extruded n pression seal at a later date. For the present, the joints are filled with w the joint edges and prevent the intrusion of large particles of incompressit Final details on the design of the joint material will be reported later.

INSTRUMENTATION

The task of instrumenting the pavement was shared by the U. S. Bureau Roads and the Division of Research and Development.

Strain Measurements

Strain measurements on transverse and longitudinal reinforcement were the U. S. Bureau of Public Roads personnel. Two methods of measuremer ployed: direct measurement with a Whittemore gage and electrical measu resistance type, SR-4 strain gages. The approximate locations of the stra devices are shown in Figure 16. Whittemore readings were obtained by pl collars on the steel and then placing wooden boxes around the reinforcemer readings were to be taken. The boxes were filled with sand and pinned to t concrete to prevent the intrusion of concrete during the paving operation. gages were glued to a wire taken from a prestressing cable. The wire was to the reinforcement and the device sealed in a metal box. Wires leading f gages to a Wheatstone bridge were taped to the transverse steel and run th in the form to the shoulder. Figure 17 shows the strain-measuring device before concreting. The white box at the left contains the Whittemore colla black box to the right an SR-4 gage.

Although slab II was selected for the strain-measuring instrumentation that slab I would be paved first, the contractor actually paved slab II first, ize himself with this new material.

Before instrumenting the reinforcement, a sample of prestressing cable the job site was loaded to obtain calibration data for the Whittemore and SR the State Highway Materials Testing Laboratory at Portland, Conn. The S read inconsistently with respect to the Whittemore gage. The SR-4 gages i strains of approximately one-half the magnitude of the corresponding Whitt readings.

Initial field readings were taken shortly after concreting. Subsequent re taken throughout the growth period and continued for 5 days. These readin that the elongation of the prestressing tendons practically ceased within 24 placement of the concrete. At the end of 100 hr the Whittemore readings in age unit tensile strains in the longitudinal strands of 0.00184, 0.00138, 0.(0.00145 near the northern end, quarter point, midlength and the southern e respectively. Conversion of these tensile strains in the strands to compres in the concrete results in respective values of 91, 68, 28 and 72 psi. In ad foregoing compressive stresses, subgrade friction also induced compressi in the concrete as the slab expanded. The unit tensile strain at the midleng transverse bar was 0.00115 at the end of 100 hr, which converts to 137-psi stress in the concrete.

The direct readings taken with the Whittemore gage are considered mor than readings taken with the measurement device utilizing SR-4 strain gage the tensile strains in the prestressing strands determined with the strain-g support the values obtained with the Whittemore gage. At the end of 100 hr gage device indicated average unit tensile strains in the longitudinal prestr of approximately 0.00200, 0.00145, 0.00100 and 0.00150 for the previously locations. Corresponding compressive stresses in the concrete are 95, 72 74 psi.

Growth Measurements

Longitudinal expansion of the experimental slabs at the ends was measu tablishing a reference line transverse to the roadway at the end of each sla

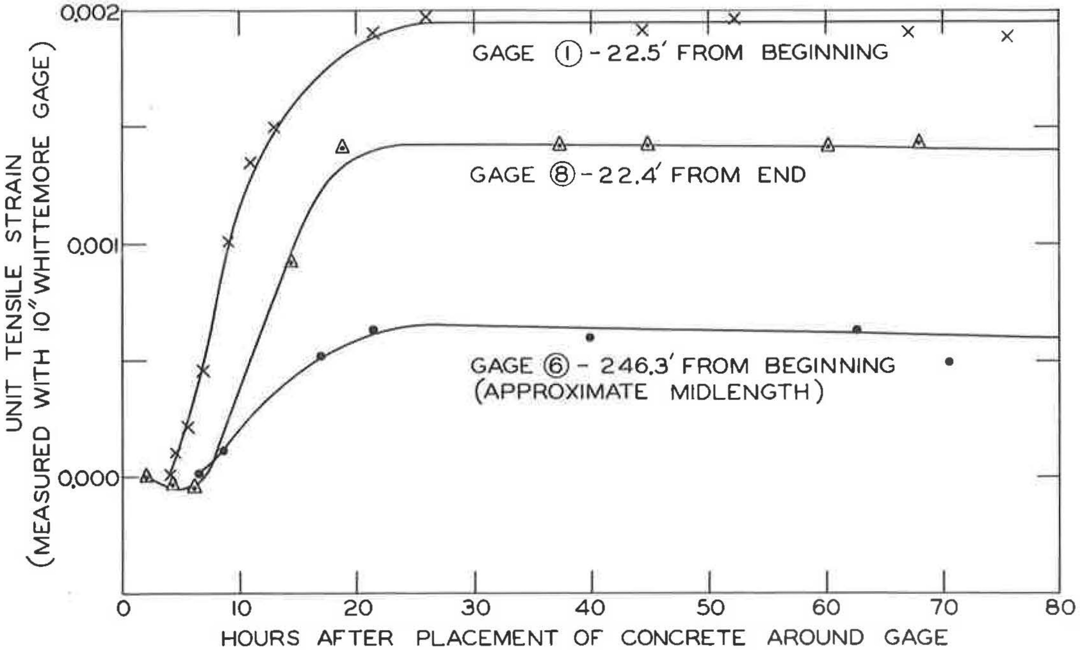

Figure 18. Strains measured in edge strand.

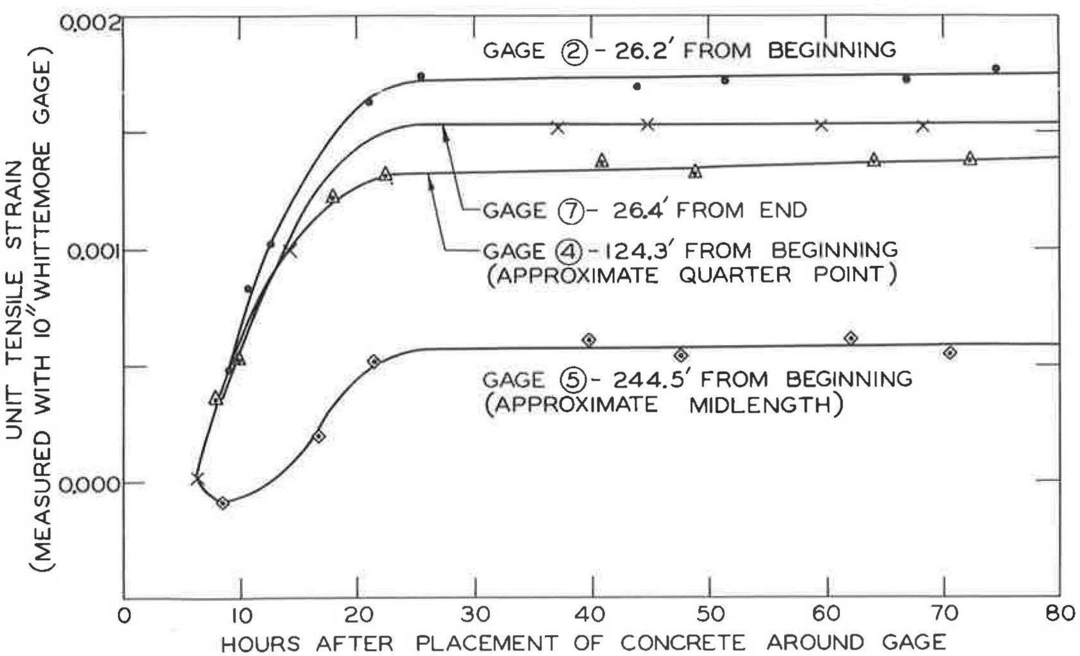

Figure 19. Strains measured in center strand.

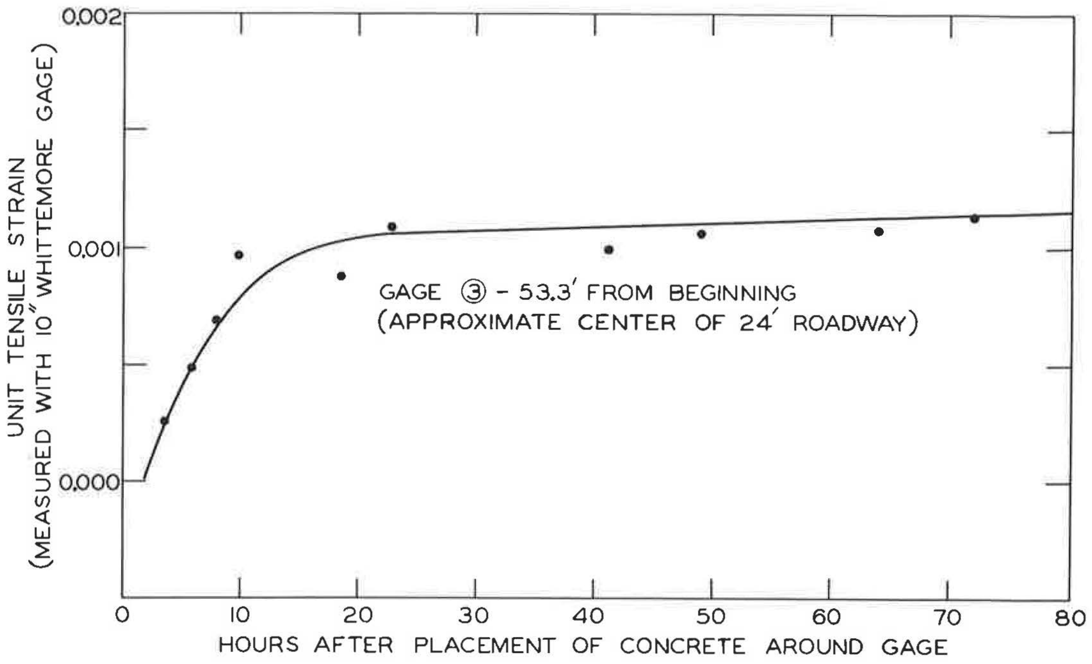

Figure 20. Strains measured on No. 7 transverse bar.

base material to be free from any frost action. Transverse growth measurements were also taken at the ends of the slabs to establish the amount of growth which occurred, and also to estimate the amount of self-stress in the pavement.

Supplementary growth measurements were taken at 50- and 100-ft intervals by placing brass plates in the surface of the concrete pavement in slabs I and III. The plates were placed 6 in. from the edge of pavement, 50 ft on centers adjacent to the shoulder and 100 ft on centers adjacent to the median. Growth measurements taken in this manner were expected to give additional data on the magnitude of the growth throughout the slabs and were to be used as a rough check on readings obtained by a transit.

Pavement Cross-Section

Cross-sections of the pavement were taken by a state survey party to determine if the ends of the slabs would curl. Elevations were taken at the ends of the slabs, 50 ft from the ends, and at the midpoints of the slabs, using reference monuments as bench marks. All foresights were as short as possible and all readings were to the nearest thousandth of a foot. Additional readings will be obtained during the winter and summer months as a check on any possible heaving or curling of the slabs.

Joint Movement

Further instrumentation of the experimental pavement was undertaken to obtain data on thermal expansion of the slabs caused by seasonal variations in temperature. For this purpose, brass plugs were placed in the pavement at all transverse joints in the experimental area. Two groups of plugs were installed at each location, adjacent to the median and the shoulder, with each group consisting of two sets of plugs placed 6 and 18 in. from the edge of pavement. One plug of each set was installed in the filler block and the other in the experimental pavement. Future readings at these locations will give data on the relative amount of movement occurring in slabs of this design. At present, data are insufficient to make any statements about movement at the joints.

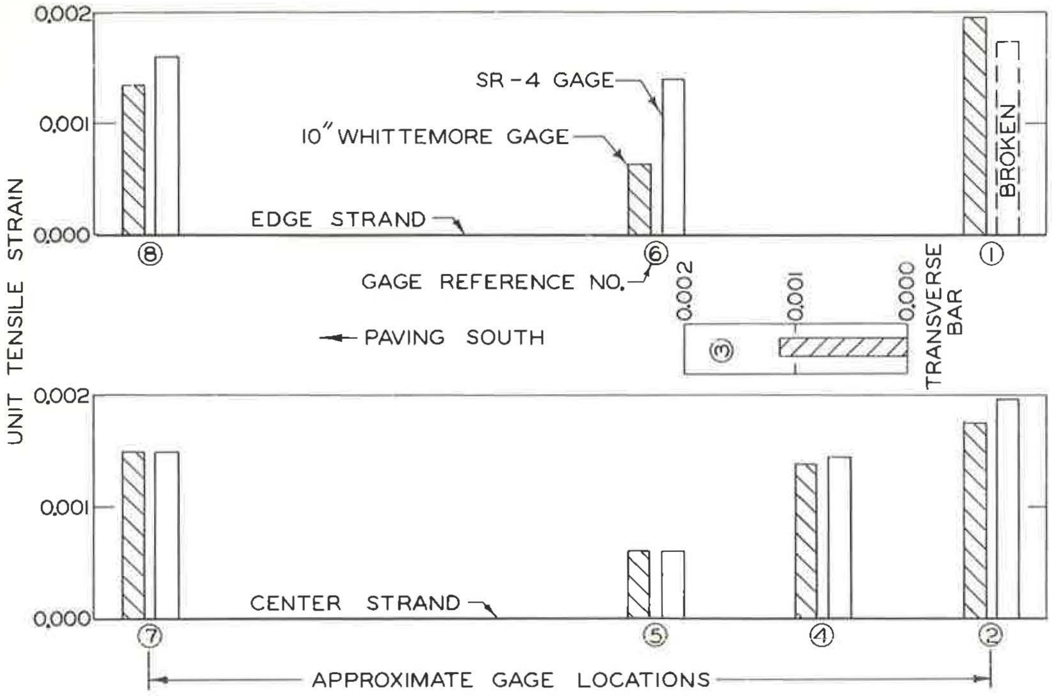

Figure 23. Strains in steel 4 days after placement of concrete.

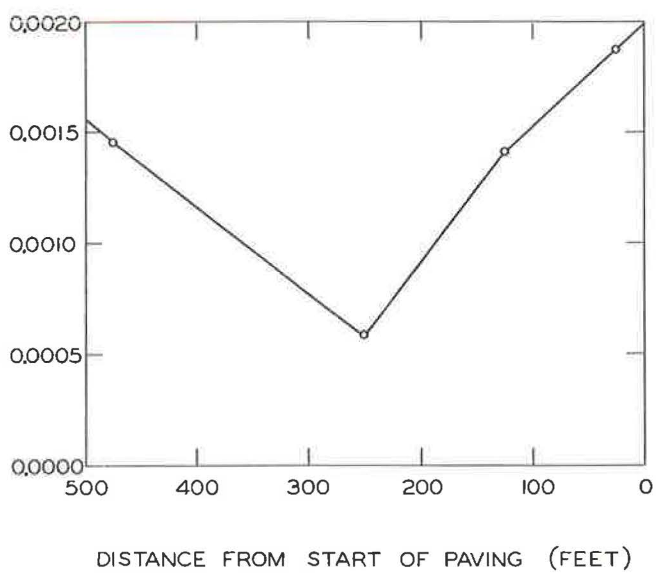

Figure 24. Average strain in the longitudinal strands after 4 days.

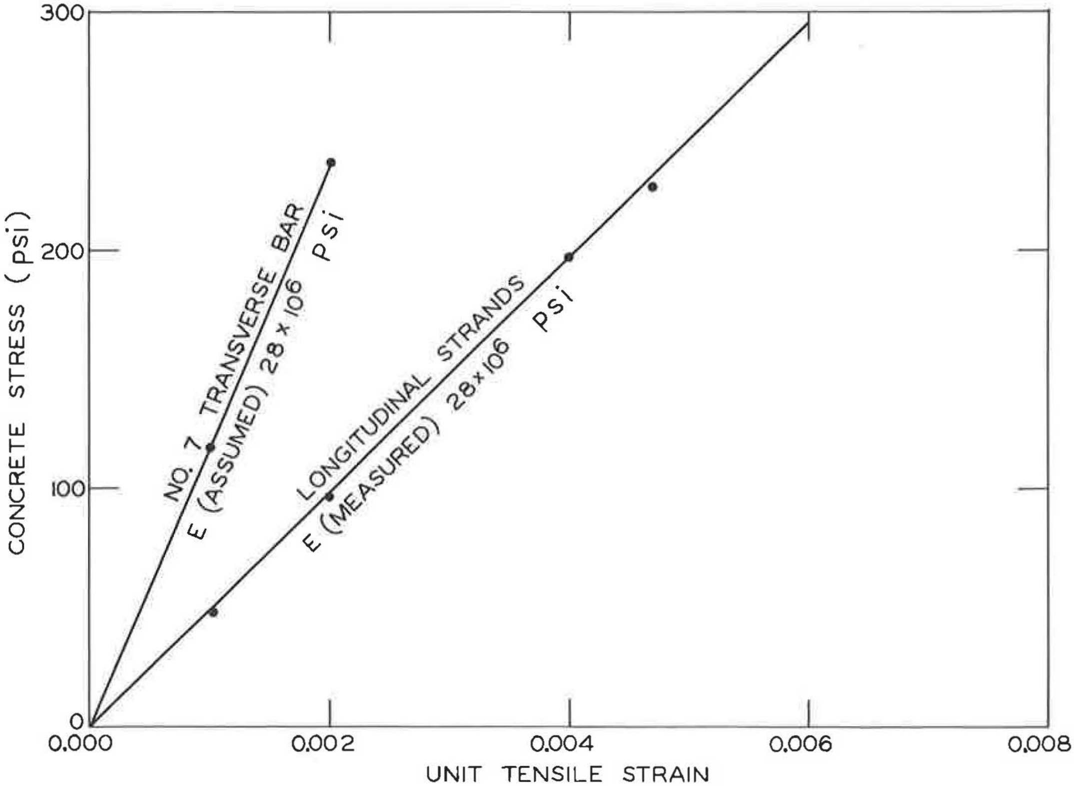

Figure 25. Relationship between tensile strain in prestressing steel and compressive stress in concrete induced by the steel forces.

Pavement Distress

Inspections of the finished pavement showed that the following two types of failures occurred.

1. The spot failure in the form of puffing and cracking was described previously (see Fig. 15).

2. Longitudinal surface cracks 7 to 10 in. long, which occurred about 3 in. from the edges of the slabs, are shown in Figure 29. This cracking is attributed to the heavy transverse reinforcement being close to the surface of the pavement. The crack spacing is about 4 ft, which corresponds to the spacing of the transverse reinforcement above the neutral axis of the slab. The major cause of this failure is now thought to be the restrained and unrestrained concrete within and beyond the 90-degree bent ends of the transverse bars because such cracks were not observed on the low side of the super-elevated portion of slab III where the bent ends of the transverse bars were flush with the the edge face of pavement.

As the paving operation progressed, there was a significant reduction in longitudinal cracking. The number of cracks located from the first to the last day of paving were 103, 62, and 50, respectively. Although slab III contained the least number of longitudinal cracks, this condition is accounted for, in part, by the fact that the hooked ends were flush with the edge of pavement as described previously.

A thin layer of a white deposit was observed on all exposed surfaces of the experimental slabs the day following placement of the concrete. This laitance, or exudation product, could be mistaken for white pigmented membrane-forming curing compound. Under the fog cure, the layer could be easily flaked off by hand; after drying it hardened to a chalk-like consistency and separated locally in the form of blisters as shown in Figure 30. Under traffic, the membrane-like coating was crushed into dust and worn away.

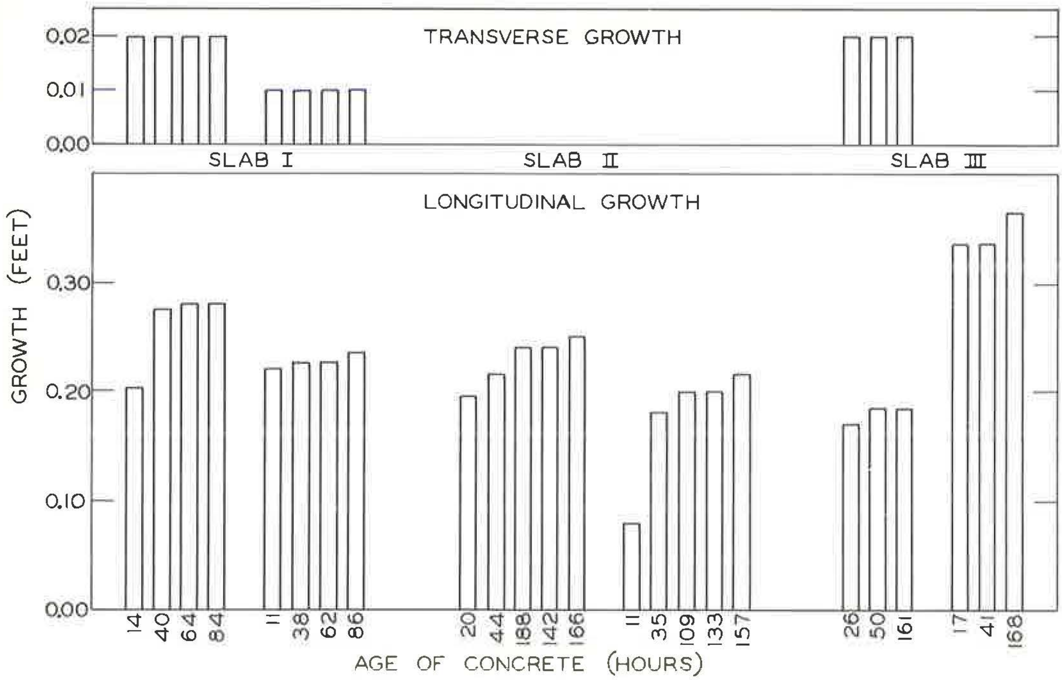

Figure 26. Incremental growth of pavement ends.

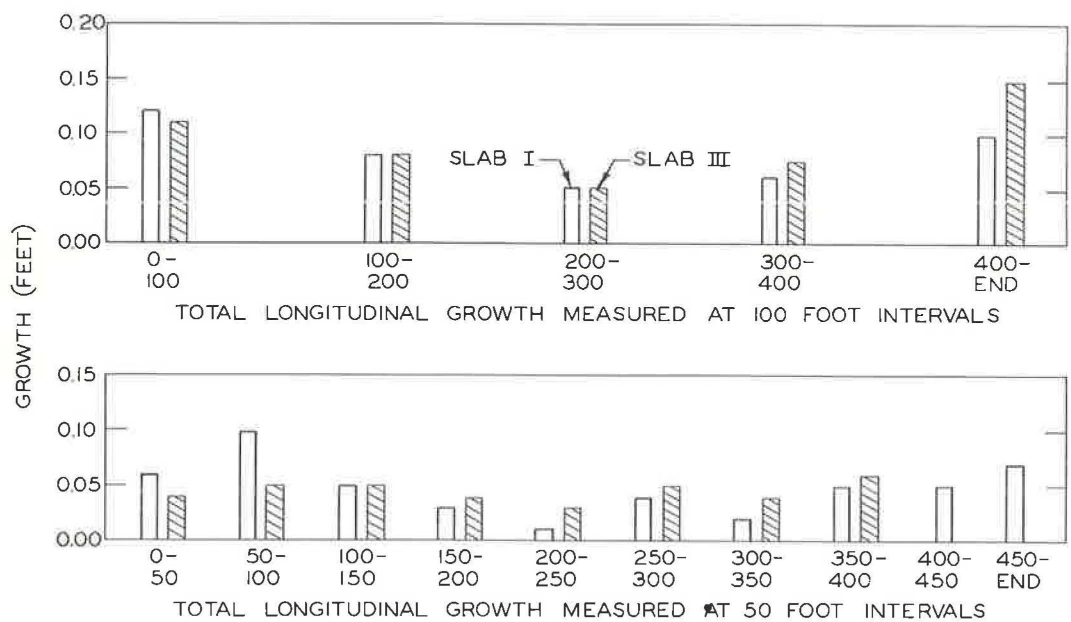

Figure 27. Longitudinal growth measurements.

A sample of the material obtained for laboratory analysis was inadvertently discarded; therefore its chemical composition was not determined. The theory is advanced that expansive forces within the concrete caused water containing one or more chemical

Figure 28. Slack cables protruding from ends of slabs.

substances, in particular, free lime, to be forced to the surface. There is no present indication that the quality of the concrete was affected in any manner.

Compressive Strength

Table 3 gives the compressive strength of 4-in. diameter cores taken from the experimental pavement. Although beams and cylinders are normally used to determine the modulus of rupture and the compressive strength of regular concrete pavement, they were eliminated in the experimental section. It was thought that because the new material has expansive properties, conventional methods of test would not yield reliable results. Cores were taken from each slab to obtain a truer measure of the compressive strength of the expansive cement concrete. The 7-day breaks averaged 4, 030 psi and the 28-day breaks averaged 4, 590 psi.

Visual inspection of the cores, as they were removed from the pavement, indicates that the experimental concrete was fairly homogeneous, despite the difficulties described earlier. Significant voids were found in only 2 of the 29 cores, adjacent to the reinforcement in the pavement.

Suggestions for Future Self-Stressing Pavements

The following suggested revisions in the design and construction of self-stressing pavement may benefit future projects.

1. Subbase.—A smooth, well-rolled gravel subbase, with a bituminous-treated surface, may be adequate to minimize subgrade friction.
2. Hold-down.—Thus far, the effect of curling has been negligible, which suggests that a less complicated apparatus could be used.
3. Reinforcement.—Transverse bars could be placed without the 90-degree bend. This change would eliminate the longitudinal cracking previously discussed.
4. Paving operation.—The time lapse between mixing and placing could be minimized by using a paver. This should make it possible to retain sufficient workability in a low-slump concrete to allow for successful finishing.

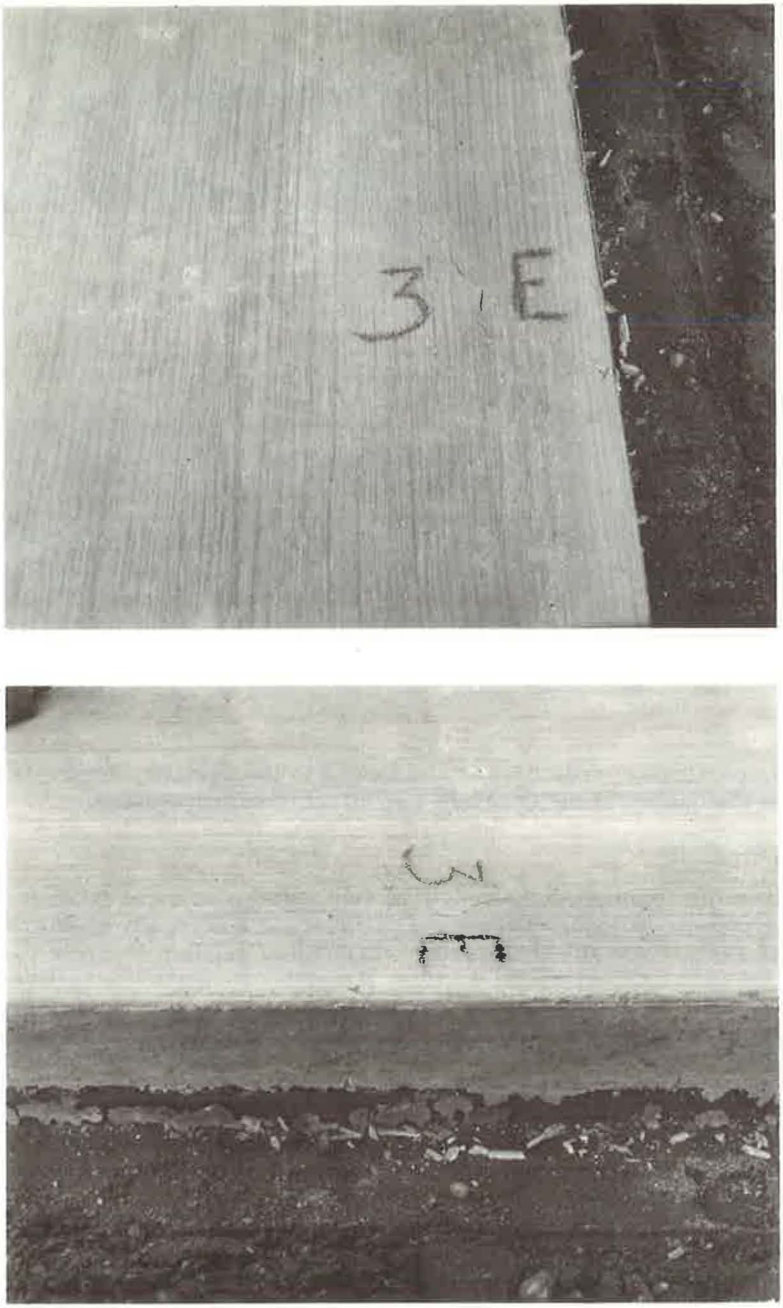

Figure 29. Longitudinal surface cracks occurring at edges of slabs.

5. Mix Design.—Although the retarding admixture probably affected the setting time of the portland cement fraction, the effect on the expansive component was not sufficient to prevent the rapid slump loss throughout construction. Present thinking is that the fineness of grind of the expansive component may be responsible for its excessive water affinity. With a coarser ground expansive component, the rapid slump loss may be eliminated or measurably reduced. Favorable consideration should be given to $1\frac{1}{4}$-in.

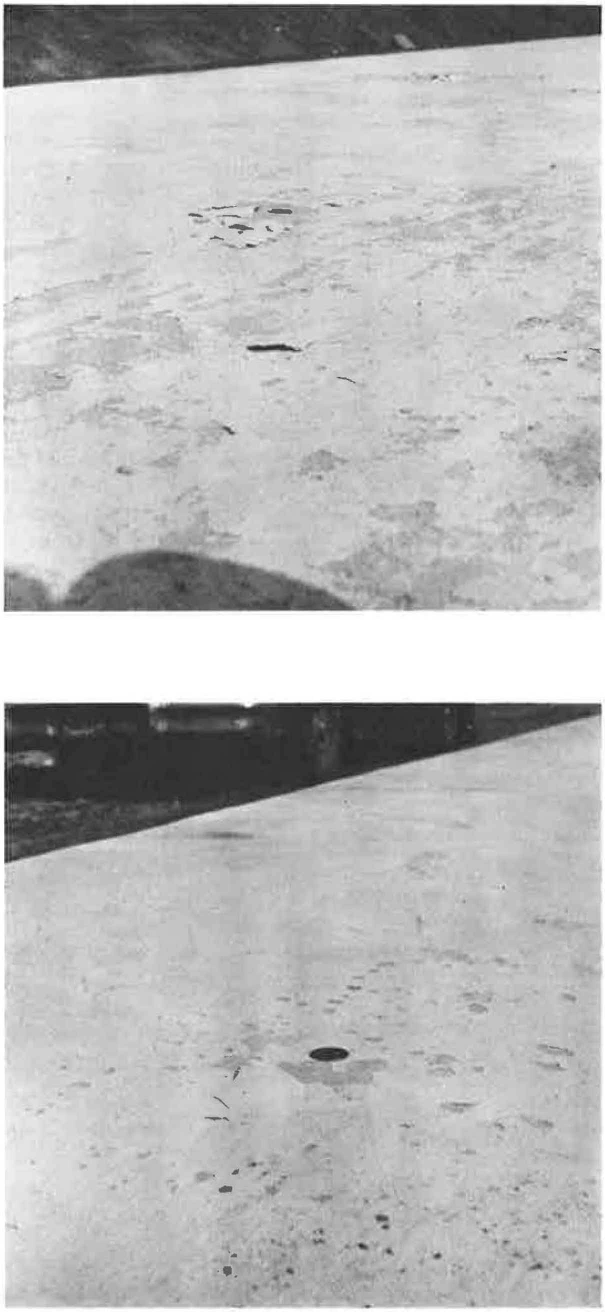

Figure 30. Blisters formed on exposed surface of experimental slab from dried exudation product.

maximum size aggregate because of the thin slab. Experience indicates that the smaller stone would facilitate the paving operation with no appreciable loss in strength to the resultant concrete.

CONCLUSION

The test section of concrete pavement was planned and built to evaluate the potential of expansive cement as applied to one specific type of highway structure. This was in

TABLE 3

COMPRESSIVE STRENGTHS OF EXPANSIVE CEMENT CONCRETE CORES[a]

	Slab I	Slab II	Slab III
(a) 7-Day Breaks (psi)			
	4,490	3,800	4,490
	3,960	3,590	4,080
	4,190	4,140	4,060
	4,470	4,230	2,870
Avg.	4,276	3,940	3,875
(b) 28-Day Breaks (psi)			
	4,490[b]	4,240[b]	4,440[b]
	4,080[b]	4,090[b]	6,010[b]
	4,940	4,970[c]	4,980
	5,080	4,840	2,890[c]
	4,620	5,220[d]	4,380
			4,150
			4,330
Avg.	4,642	4,672	4,454

[a]All compressive strengths are corrected to the required L/D of 2.

[b]Cores taken for 7-day breaks and held for 28 days in moist room at Portland Laboratory (all other values obtained from cores taken from pavement just before 28-day break).

[c]Void in core adjacent to steel in core.

[d]Portion of steel reinforcement remained in core when broken.

keeping with the expressed desire of Commissioner Howard S. Ives to remain constantly alert for new product developments and their use in the highway field.

The purpose of this report is to present a factual account of the work accomplished, including the difficulties which are normal by-products of such experimental undertakings. It is hoped that this account may benefit other experimenters.

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Appendix

MIX DESIGN

The concrete was mixed for 3 min in a central mixing plant. The original mix used for paving on September 13, 1963 was composed as follows:

Cement, 800 lb;
Water, 34 gal;
2 in. stone, 1,010 lb;
¾ in. stone, 1,010 lb;
Sand, 950 lb;
Plastiment (4 oz/sk) 34 oz/cu yd;
Darex - ⅜ to ½ oz/sk or to give 5 percent ± 1 percent; and
Entrained air, w/c = 4 gal/sk.

The composition of the cement was as follows: 35 percent by weight of the cement was the expanding agent and 65 percent was portland cement. Ingredients were ground together and furnished in bulk to the job site. The stone was 50 percent 2 in., 50 percent ¾ in. by weight; absorption, 0.79 percent. The sand's fineness modulus was 2.80; its absorption, 0.93 percent.

Mix used for paving on September 16 and 17. No change in the sources of aggregates. Previous data on the raw materials still apply.

Cement, 800 lb;
1 ¼ in. stone, 1,310 lb;
½ in. stone, 705 lb;
Sand, 925 lb;
Plastiment, 42½ oz/cu yd; and
Darex 3 oz/sk = 25 oz/cu yd.

On September 17, additional sand was put in the mix to aid the finishers as the paving operation started into the banked curve in slab III. The aggregate weights then became the following:

1¼ in. stone, 1,210 lb;
½ in. stone, 610 lb; and
Sand, 1,085 lb.

For September 16 and 17, the water was not tabulated because of the trouble in placing the material. Water was added to the aggregates to give a workable mix as it was being placed.

Class A concrete mix. Material used in sleeper slabs was as follows:

Cement, 644 lb;
Water, 35 gal;
1¼ in. stone, 1,310 lb;
½ in. stone, 705 lb;
Sand, 1,180 lb; and
Darex, 3 oz/batch.

Concrete was truck-mixed at the job site for 3 min. Concrete was placed with an average slump of 2 in.