Construction of a Thin-Bonded Portland Cement Concrete Overlay Using Accelerated Paving Techniques

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The Virginia Department of Transportation's first modern experience with the construction of thin-bonded portland cement concrete overlays of existing concrete pavements through the use of fast-track paving is described. The study was conducted in cooperation with FHWA, and paving mixtures tested in a FHWA mobile laboratory were used. The study showed that the pavement could be overlaid and opened to traffic within 48 hr. Of special interest was the finding that the overlay concrete bonds to the base concrete with or without the use of a bonding grout.

The placement of new portland cement concrete (PCC) overlays on old PCC pavements is not a new technology. In fact, several such overlays were constructed in Virginia as early as the 1920s (*1*). Even thin-bonded overlays are not particularly new; they have been used for a number of years as an acceptable rehabilitation alternative for old PCC pavement, both jointed and continuously reinforced (*2*). A general requirement is that the underlying (old) concrete should be in reasonably good structural condition to adequately support the overlay. Thus, thin-bonded overlays typically have been used to structurally enhance sound pavements in anticipation of increased traffic volumes and loads.

The construction of such overlays using slip form pavers in a fast-track mode (rapid construction) is a relatively new technology that was first introduced in Iowa in 1986 (*3,4*). The promoters of this technology are candid in admitting that a major impetus to its development is an attempt to provide and demonstrate a construction window (lane closure time) that would compete favorably with that of asphaltic concrete overlays and would, therefore, make PCC overlays more acceptable to both the traveling public and maintenance engineers.

Recognizing that a competitive climate between the two paving industries is an important economic issue, the Virginia Department of Transportation (VDOT), through the Virginia Transportation Research Council and in cooperation with FHWA, selected a suitable Virginia location on which to try a thin-bonded PCC overlay. Among a number of sites considered were several on Interstate routes on which the limited access feature lends itself well to the construction operations involved. Sites with high traffic volumes were not considered acceptable because of the experimental nature of the work. The site selected was an old PCC pavement on U.S. Route 13 in Northampton County. This pavement was still in reasonably good condition with moderate traffic volume. The 1-mi section chosen for the fast-track project has only one side entrance to be accommodated during construction of the overlay.

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PURPOSE

The major purpose of the project was to evaluate the feasibility of constructing a thin-bonded portland cement concrete overlay of an existing concrete pavement in a fast-track mode to minimize lane closure times. A secondary purpose was to evaluate the performance of the overlay during a 5-year period. Unfortunately, the experimental nature of the project prohibited any realistic evaluation of costs that might apply to a similar nonexperimental project.

HISTORY OF EXISTING PAVEMENT

The existing PCC pavement on the fast-track project was constructed in 1965. The original design consisted of a native sand and gravel subgrade topped with a sand and gravel select material used as a subbase. The concrete pavement was 8-in. thick with transverse joints spaced at 20 ft. No dowels were used in the joints, which were sealed with a hot-poured rubberized asphalt. Traffic records indicate that the section had sustained approximately 2.2 million 18-kip equivalent single axle loads (ESALs) in the outside lane. Although project records did not indicate the design ESAL, traffic records indicate a rather modest growth of approximately 2.5 percent annually since 1980.

The major distresses manifested by the old pavement were joint faulting and a few instances of joint spalling. Some slabs had failed because of longitudinal cracking. Preliminary distress surveys available in VDOT files provided background material for evaluation of the performance of the overlay.

SPECIFICATION DEVELOPMENT

The development of construction specifications for the project was a cooperative effort of VDOT, FHWA, and the American Concrete Paving Association (ACPA). Because of the time constraints inherent in the process, several iterations were necessary before an acceptable specification was realized and made available for bidding purposes. A list of the major elements of the project, many of which will be discussed in more detail, follows.

1. The project consisted of the design and placement of a nominal 3 ½-in.-thick thin-bonded overlay applied to the prepared surface of the old pavement.
2. The old pavement was repaired to restore any areas of structural failure in order to give the overlay a more uniform foundation.
3. The paving portion of the project was constructed in a fast-track mode with a lane closure time of 48 hr, beginning with the initiation of concrete placement and ending with the removal of the curing blanket.

PRELIMINARY TESTING

Trial Concrete Batches

For the fast-track overlay, the following concrete specifications were required:

- Minimum compressive strength at 24 hr: 3,000 psi,
- Aggregate size number: 57 or 68,
- Nominal maximum aggregate size: 1,
- Minimum cement content: 750 lb/yd^3,
- Maximum w/c: 0.42,
- Slump: 0 to 3 in.,
- Air content: 6 ± 2 percent, and
- Water-reducing admixture: AASHTO M194.

Special provisions stated that for bonding the overlay to the base concrete, a grout (portland cement and water) should be applied on the clean dry surface when the ambient temperature was 90°F or below. At higher temperatures, the base concrete surface should be in a saturated surface dry condition. The grout should contain the same portland cement as the overlay and should have a maximum water/cement ratio (w/c) of 0.45. Thus, the grout quality would approximate that of the paving concrete. Curing of the overlay should be with a liquid membrane seal applied at a dosage of 1.5 times the standard rate. The membrane seal was followed by insulating blankets consisting of closed-cell polystyrene foam having a minimum *R* value of 0.5 and protected on one side by a plastic film.

The contractor selected a prestressing plant at Cape Charles, Virginia, close to the job site, to furnish the concrete. Two sets of trial batches were used to develop mixture proportions and evaluate the bonding of the overlay.

The first trial set was made in April 1989 in cooperation with the FHWA Demonstration Projects division using the council's laboratory facilities and FHWA's mobile concrete laboratory and included a trip to the plant with the mobile laboratory and some batching at the plant. The second set of trial batches was made in May 1990 at the plant.

First Set of Trial Batches

In the first set, 11 batches of concrete were prepared using the materials furnished by the plant at Cape Charles as well as materials available in the laboratory. These batches are explained in detail in the FHWA report on the study (*5*). Two cements were used. One was a finely ground Type II cement obtained from the plant; the other was a Type III cement available in the laboratory. The coarse aggregate furnished by the plant was crushed granite from Stafford County, and the fine aggregate was siliceous sand from King George County. The w/c was variable, with a maximum of 0.42. Either a water-reducing admixture (WR) or a water-reducing and retarding admixture (WR + R) with minimal retardation at low dosages (as claimed by the producer) was used. Experimental batches were made using the previously mentioned materials and admixtures. Some of these included a sand having a better particle shape than the one used in normal plant production. Others contained a high-range water-reducing admixture (HRWR) or fly ash in order to provide the range of workability and strength that could be achieved at early ages with the available materials. All of the batches contained a neutralized vinsol resin as an air-entraining admixture to provide the specified air content (6 ± 2 percent). Compressive strengths were determined at different early ages by testing 4-in. × 8-in. cylinders in accordance with AASHTO T 22 using neoprene pads in retaining rings. The results indicated that the various combinations of w/c and HRWRs with the job materials were capable of reaching the required strength of 3,000 psi within 24 hr. This strength was attained as early as 12 hr with a w/c of 0.35 and an HRWR. However, because of economy, better control of workability, and a close resemblance to a mixture commonly used at the plant, trial mixture TB 11 (see following table) was chosen for the experimental installation. The w/c of 0.415 and the 3-in. slump were attained without the use of an HRWR. This mixture attained 3,000 psi in about 23 hr. The following table presents the mixture proportions (lb/yd^3).

	TB11	*Job*
Cement	750	750
Maximum water	311	315
Coarse aggregate	1,902	1,877
Fine aggregate	1,065	1,045

Subsequently, the mobile concrete laboratory was moved to the plant, and a 2-yd^3 batch with the same proportions as TB11 was prepared using a 4-yd^3 capacity stationary concrete mixer. The results indicated that 3,000 psi was achieved with this batch in 24 hr.

Both at the laboratory and at the plant, the maturity method (ASTM C 1074) and the pulse-velocity method (ASTM C 597) were used to predict the strength of the concrete. These methods are explained in the FHWA report (*5*). One significant advantage in these methods besides their convenience is that testing is in situ; consequently, the actual strengths developed in the pavement are determined. This is in contrast to conventional concrete testing, in which strengths are obtained using test cylinders. Because of their small mass, much lower heats of hydration are usually generated in the cylinders, which leads to lower early strengths than those in the structure the cylinders represent. Because of the need to open fast-track projects to traffic as soon as possible, determination of the actual early strength of the concrete in the pavement is needed, and conventional test methods are not suitable.

The data on temperature gradients are also useful in predicting the possibility of thermal cracking.

Although the maturity and pulse-velocity methods appear useful in estimating the early strength of concrete, the variability in test results, the need for specialized equipment, and the need for correlation of the pulse-velocity and conventional test results using job concretes limit their usefulness for formal acceptance testing.

Second Set of Trial Batches

The specifications required the use of grout as a bonding material and a minimum bond strength of 200 psi at 24 hr when tested in tension using the method described in ACI 503R. Most bonded fast-track overlays have used a bonding grout, but ACPA representatives indicated that a satisfactory bond could be achieved without a grout. Thus, in May 1990, more trial batches were made to determine whether a bonding material was necessary, and also to determine the workability and finishing characteristics of the concrete using admixtures available commercially. Tests were also conducted to determine whether a type or brand of cement other than that used in the paving concrete and with a higher w/c than the 0.45 maximum specified was adequate for the bonding material should it be required. A WR from one producer and WR + R at two different dosages from another producer were tried. Thus, three batches of concrete were prepared using the job proportions presented in the following table. The maximum w/c of the overlay concrete was 0.42. A 3.5-in. overlay was placed in three sections (see following table) over an existing concrete slab at the plant. The surface of the slab was shot-blasted in the same manner as it would be in an actual job to properly clean the surface of the base concrete. The grout was prepared using two different proportions and two different cements (Type I and Type II), as shown in the following table, and was pumped and scrubbed on the surface. Grout in Section 1 had 5 gal of water for 1 bag of cement (w/c = 0.44), which met the specifications (maximum w/c = 0.45), but was difficult to pump. Therefore, in other sections, 6 gal of water for 1 bag of cement (w/c = 0.53) was used. The following table presents grout proportions and type of cement.

Section	*w/c*	*Cement*
1	0.44	Type I
2	0.53	Type I
3	0.53	Type II

At an age of 24 hr, the compressive strengths of the concretes were determined at the plant. The results are summarized in Table 1 and indicate that 3,000 psi could be achieved in 24 hr. Some of the 4-in. × 8-in. specimens were kept in an insulated box; others were left under the curing blanket. As expected, the retention of heat was an important factor in achieving the early strengths. The specimens in the insulated box had about 37 percent higher strength than the ones under the blanket. The temperature of the insulated box was about 120°F at 24 hr, whereas the 4-in. × 8-in. specimens under the blanket had lower temperatures (see Figures 1 and 2, which display the temperature of the air, the mid-depth of the slab, and the specimens in sections 1 and 2). The contractor selected the use of WR + R at the lower dosage rate of 25 oz/yd^3 (Section 1) for economic reasons and to minimize possible retardation. The temperature profiles in the overlays for sections 1 and 2 indicate a delay of about 3.5 hr before a temperature rise occurred.

TABLE 1 24-hr COMPRESSIVE STRENGTH FOR TRIAL SECTIONS

Section	Admixture	Insulated Box	Under Blanket
1	WR + R	4,020[b]	2,950
2	WR	4,460	3,200
3	WR + R[a]	—	3,000

[a]Twice the dosage rate used in Section 1.
[b]Test values are averages of two cylinders for those in the insulated box and three for those under the blanket.

To determine the effects of bonding material, two methods of testing were used. In one (the shear test), 4-in.-diameter cores were drilled from the concrete test slab, and then the bond area was sheared. In the other (the pull-off test), 2-in.-diameter cores were drilled through the overlay and into the base concrete to a depth slightly below the bond interface. A cap was attached to the top of the core by an epoxy resin, and a load was applied to pull off the cap. This procedure applies a direct tensile stress to the bond area. The tests were conducted 24 hr after placement. Because of difficulties in controlling the rate of loading on the machine at the plant, a definite conclusion could not be drawn in the shear test. With the direct tension test, it was difficult to apply a uniaxial load on the cap and a continuous rate of loading. In view of the difficulties in controlling tests in the plant environment, it was decided to discontinue bond testing at that site. However, having abandoned the plant bond tests, it was still necessary to evaluate the need for grout on the project. Therefore, in a final effort to determine the bond strength, 4-in.-diameter cores were drilled from the test slabs at the plant and brought to the research council for shear tests at an age of 2 days. The results (summarized in Table 2) show that satisfactory and comparable bond strengths (exceeding 200 psi) were achieved with and without a bonding grout. The results also show that the type and brand of cement can be different than that in the overlay and the w/c in the grout can be higher than that in the overlay. These findings were supported by a petrographic examination of lapped vertical slabs cut from the cylinders and examined at the research council. The examination indicated that adequate bonding was achieved in all of the specimens. Thus, based on the limited lab results, it was decided that bond strength with and without the grout would be evaluated in the field. The job grout with a w/c of 0.53 and Type I cement was used for half of the overlay, and the other half was placed without a bonding material. The shear test was used to determine the bond strength.

JOB CONCRETE

The PCC overlay was placed using mixture proportions designated as job concrete that were presented previously. Concretes were air entrained with a commercially available neutralized vinsol resin. A WR + R was added at a dosage of 25 oz/yd^3.

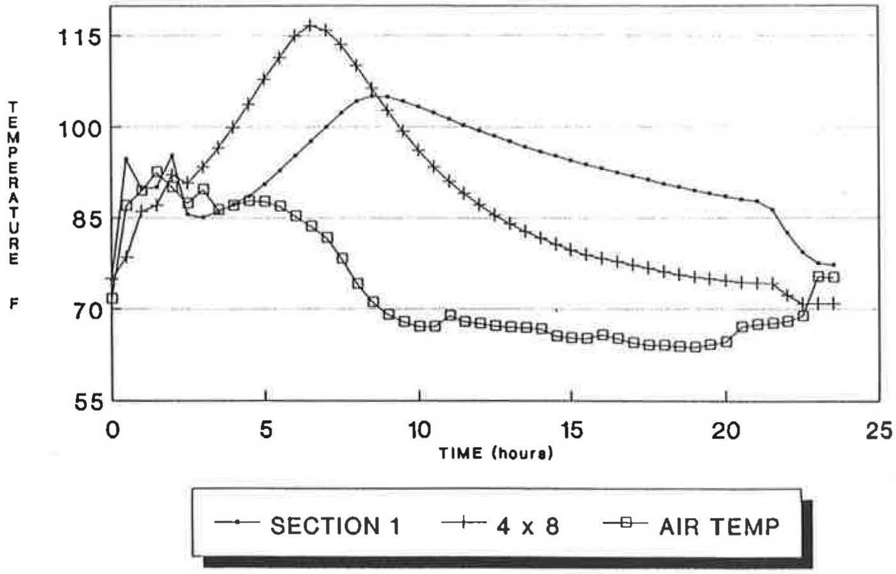

FIGURE 1 Temperature data for trial, Section 1.

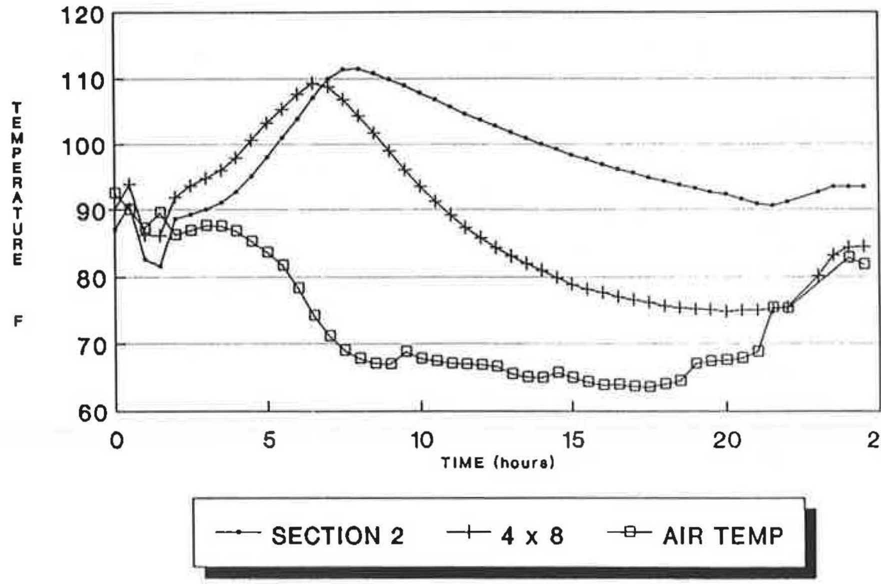

FIGURE 2 Temperature data for trial, Section 2.

TABLE 2 2-DAY BOND STRENGTH FOR TRIAL SECTIONS

Section	Grout	Specimen 1	Specimen 2	Average
2	Type I	215	365	290
2	None	395	275	335
3	Type II	430	265	345

NOTE: Strength values are in pounds per square inch.

The overlay was placed June 14 and 15, 1990. Concrete placed each day was tested for compressive strength (AASHTO T 22), splitting tensile strength (ASTM C496), flexural strength (ASTM C 78), and rapid chloride permeability (AASHTO T 277). The specimens from each of the two batches were cured under blankets near the pavement. For the first batch, additional cylinders were made to determine the compressive strength using the temperature-matched curing concept (TMC).

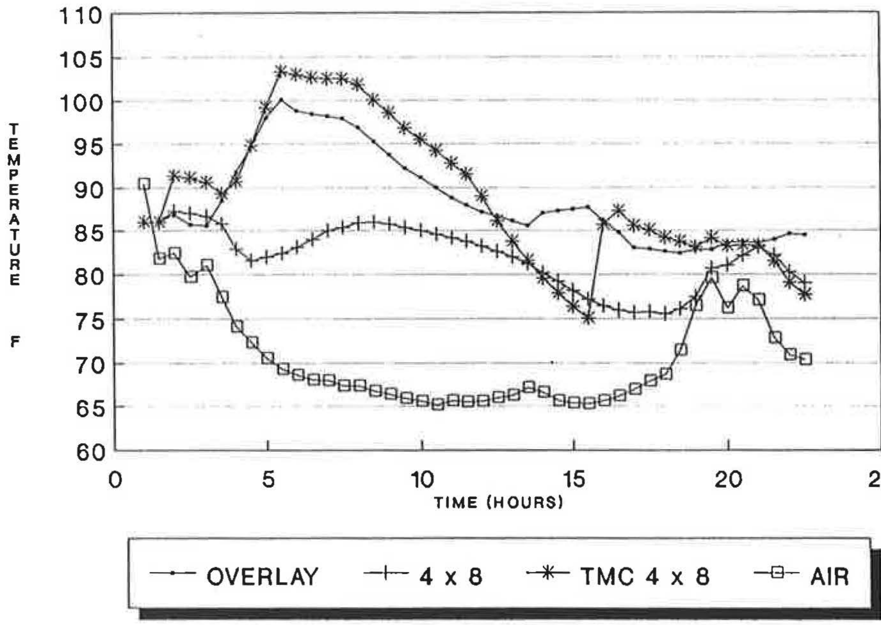

FIGURE 3 Temperature data from job.

Special molds with heating elements were used to match the temperature of the 4-in. × 8-in. specimen in the mold with that of the concrete by monitoring the mid-depth temperature of the overlay with a thermocouple. At the same time, air temperature, wind velocity, and relative humidity were continuously measured. The temperatures of the air, at mid-depth of the overlay, in the 4-in. × 8-in. cylinder kept under the insulating blankets and in the specimen in the TMC mold are shown in Figure 3. The data on environmental conditions (air temperature, relative humidity, and wind velocity) given in Figures 3–5 indicate that favorable conditions existed for placement of concrete. The rate of evaporation from the concrete surface was minimal, and the air temperatures were high enough to provide an adequate rate of hydration. The temperature data indicate that, initially, the TMC molds follow the actual temperature of the overlay closely but are several degrees above the overlay temperature. However, about 12 hr after placement, failure of a generator resulted in a drop in the temperature in the TMC molds. The temperature profile for the 4-in. × 8-in. cylinders shows that the same temperature rise achieved in the overlay or the TMC mold was not obtained by curing under the insulating blankets.

The compressive strength values given in Table 3 indicate that 3,000 psi were easily achieved in less that 24 hr. In the TMC mold, higher early strengths were obtained than with the regular molds cured under blankets. This was expected

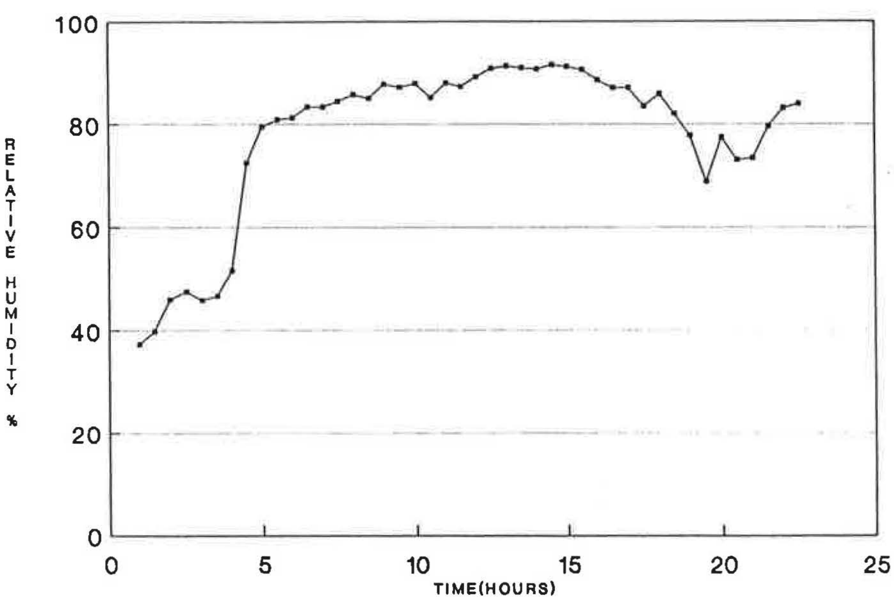

FIGURE 4 Relative humidity data from job.

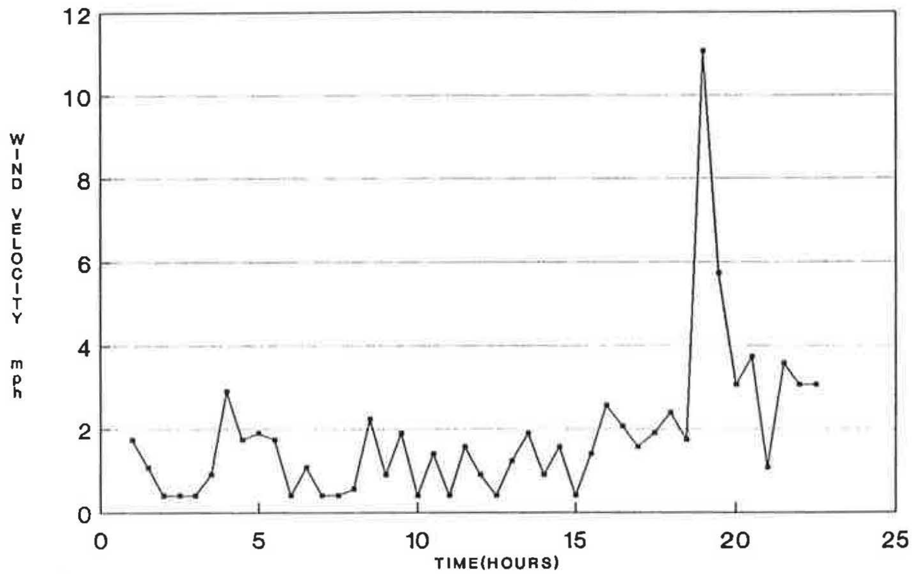

FIGURE 5 Wind velocity data from job.

because higher temperatures were developed in the TMC molds. The different strength tests for various ages summarized in Table 3 were all satisfactory. The chloride permeability (coulomb) values at 28 days were in the high range, but, at 90 days, they were either in or close to the moderate range. The temperature data indicate that the job concrete temperature rise occurred at about 3.5 hr after batching as it did in the trial batches. This is a considerable delay, and should concretes with higher early strengths than required in this project be desired, the possibility of using an accelerator instead of a retarder should be considered.

Half of the overlay was placed without a bonding agent, and half was placed with a grout that contained Type I cement at a w/c ratio of 0.53. To determine the bond strengths at different sections with and without the bond, cores were taken and tested for shear strength at 7 days in the laboratory. The results are summarized in Table 4. These results indicate that excellent bond strengths are achieved with and without the grout, and that 7-day bond strengths at the interface were close to the shear strengths of both the base concrete and the overlay concrete.

TABLE 3 TEST RESULTS FOR JOB CONCRETE

	No. of Specimens	B1	B2
Air content, %	1	5.4	5.7
Slump, inch	1	2.8	2.2
Compressive strength, psi:			
TMC 17 hour	2	3,450	—
TMC 24 hour	2	4,040	—
17 hour	2	2,940	—
18 hour	2	—	3,560
24 hour	2	3,760	4,090
7 day	2	5,240	5,590
28 day	2	6,060	6,750
Splitting tensile strength, psi:			
24 hour	2	360	345
7 day	2	460	475
28 day	2	545	550
Flexural strength, psi:			
28 day	3	835	795
Permeability, coulombs:			
28 day	2	5,290	4,220
90 day	2	4,070	2,690

CONSTRUCTION OPERATIONS

Traffic Control

Traffic control was accomplished through the provision of temporary detours on each end of the 1-mi-long site. The detours set up the two northbound lanes on the four-lane, divided highway for two-way operation to accommodate the southbound traffic during working hours. During the initial pavement preparation and the final finishing work after the overlay, southbound traffic was permitted to use the test site during nonworking hours, generally overnight and on weekends.

Preparation of Existing Pavement

Pavement Repairs

The preparation of the existing pavement began in spring 1990 with the removal and replacement of concrete considered to

TABLE 4 SHEAR STRENGTHS AT 7 DAYS

Specimen	Bonded With Grout	Bonded Without Grout	Base Concrete	Overlay
1	595	650	835	765
2	605	760	630	775
3	900	740	940	680
Average	700	715	800	740
Standard Deviation	173	59	158	52

be too badly damaged to leave in place under the overlay. Replacement concrete was standard pavement repair concrete with design strength of 3,000 psi in 24 hr. Compressible material ½-in. wide was placed on one side of each repair in the old pavement. All joints in the old pavement were cleaned and resealed with hot-poured joint sealing materials conforming to AASHTO Specification M173.

Surface Preparation

Preparation of the surface of the existing concrete pavement to ensure full bonding of the thin overlay was a major issue throughout the planning and conduct of the project. As was finally agreed on and specified, final preparation was accomplished through the use of shotblasting machines traveling in tandem, triplicate, or quadruple. In order to preclude surface contamination by traffic, actual sandblasting operations did not begin until the lanes were closed to traffic early on the first day of the placement of the overlay. Each machine covered approximately an 18-in.-wide path with each pass. Although some trial and error was necessary to achieve the texture finally agreed on by all parties, once the speed of the machines and other details were established, no further problems occurred in that operation. The texture was considered to be acceptable when coarse aggregate particles in the existing surface had a clean exposed face. Final touch-up of the surface was by use of a portable sandblasting machine placed about 100 ft ahead of the paving machine in order to catch oil spills and the like from the paving operation. Adequate bond strengths were obtained both with and without the application of a grout.

Paving

Placement of Concrete

Paving with a Gomaco slip form paver began at 1:00 p.m. June 14, 1990. Concrete was deposited from 8 yd^3 transit mix trucks in front of the paver directly on the existing pavement. Once the paver had moved forward enough to carry a "head" of concrete, the portland cement slurry grout (where used) was sprayed from a grout machine onto the surface immediately in front of the paver and then swept into place with brooms. For approximately the second half of the project, the grout was omitted.

Early in the paving operation, plywood pads were used to cover the shotblasted old pavement as a protection against oil drippings and the like from the concrete trucks. Soon, however, it became clear that the pads were not needed because the trucks were relatively new and well maintained. Because use of the pads was cumbersome, the contractor was glad to discontinue that portion of the operation.

During placement, two major difficulties were encountered in the supply of concrete. First, the supply was somewhat slow because of the number of trucks assigned to the project. Although the haul distance was short, project layout was such that trucks furnishing concrete early in the work had to back most of the 1-mi length of the project. In the grouted section, delays in concrete delivery caused some concern that the grout might dry out before concrete placement. This was soon overcome by a decision to rake concrete from the paver head forward to cover the grout until delivery resumed. A second concrete supply problem occurred for a short time when the mixture contained excessive water, and several loads had to be rejected because of high slump.

Finishing

In general, the mixture was of such a consistency that the paver, with spud vibrators at about 18-in. centers, produced an overlay with well-formed edges requiring little handwork. Magnesium floats were used to close the surface while some hand work was done on the edges. A fine texture was applied by means of a burlap drag attached to a hand-operated bridge, which was moved at intervals judged by the finishers. The transverse tining specified by VDOT (⅛in. × ⅛-in. with ¾-in.-wide land areas) was applied by a hand-held wire tine.

Curing

Liquid membrane-curing compound was applied from a rolling bridge as soon as the tining was completed. This was followed by the application of a curing blanket having a minimum R value of 0.5 and intended to hold the heat of hydration and contribute to early strength development. As noted earlier, air temperatures, relative humidities, and wind velocities were such that curing was not considered to be a major concern on the project.

Joint Sawing and Sealing

The virtual certainty that all joints and cracks in the underlying old pavement will reflect through the overlay in a short time dictated that a great deal of attention be paid to ensure that the new cracks were directly above the old. With the help of project inspectors, the contractor used a stringline across each transverse joint and crack to place paint marks on each shoulder where a second stringline could be stretched after the overlay.

As soon as the overlay was sufficiently hardened to hold the equipment, the second stringline was used to mark the locations of early saw cuts. These cuts, approximately ⅛-in. wide, accommodate the early shrinkage cracking and prevent the formation of random or uncontrolled cracks. The location, configuration, and depths of these saw cuts were the subject of a preconstruction discussion and ultimately were done in compliance with ACPA suggestions. Transverse sawcuts were ½-in. deeper than the thickness of the overlay to ensure positive control. On the other hand, because of the difficulty in precisely locating longitudinal joints in the old pavement after application of the overlay, the decision was made to saw the overlay to a depth of only 1¾-in. over those joints. The thinking in this case was that the provision of some room for vertical "wander" of the reflection crack could prevent twin cracking, which might occur if a full-depth sawcut was to miss the joint in the underlying pavement.

At the earliest possible time, most transverse joints were resawed and sealed with preformed compression seals. Longitudinal joints and transverse joints over repair joints containing expansion material were sealed with a hot-poured rubberized asphalt joint-sealing material.

OPENING TO TRAFFIC

The project was opened to traffic 58 hr after the first load of concrete appeared on the job. Although this length of time did not meet the 48-hr target, project personnel were convinced that only a few logistical modifications in the transportation of concrete and sawing operations would have permitted that target to have been met easily.

EARLY PERFORMANCE

Roughness tests conducted on the project at an age of about 1 week showed that the original international roughness index of some 160 in./mi was not substantially changed by the provision of the 3½-in overlay. This finding was not surprising to project personnel in view of the relatively good original ride and in view of the frequent interruptions in the paving operation because of the erratic supply of concrete.

A thorough evaluation of the project in March 1991 revealed only one narrow uncontrolled crack. The slight spalling of some sawed joints appeared related to the harsh texture and not to a materials or structural condition. All joint seals appeared to be in excellent condition. Early performance of the project was judged to be excellent.

CONCLUSIONS

The following conclusions are based on the construction experience from this project, during which there were favorable weather conditions, and on the observations of early performance.

1. Concrete overlays achieving compressive strengths of 3,000 psi within 24 hr can be placed using either Type III or finely ground Type II cements with a w/c of 0.42 or less.
2. The generation of external heat or retention of the heat of hydration of the concretes assists in faster strength development at early ages.
3. Overlays can be bonded to properly prepared base concrete with or without the bonding grout.
4. Thin-bonded concrete overlays applied in a fast-track mode appear to be a suitable alternative for rehabilitation of jointed concrete pavements when those pavements are not seriously distressed but are in need of structural enhancement.
5. Nondestructive test methods of maturity and pulse velocity can provide rapid evaluations of in situ concrete strengths. When using the maturity method, information on temperature gradients is also obtained, which indicates whether there is a possibility of thermal cracking.

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