A Field Evaluation of Factors Affecting Concrete Pavement Surface Patches

FRAZIER PARKER, JR., G. EDWARD RAMEY, RAYMOND K. MOORE, and JOHN W. JORDAN, JR.

ABSTRACT

Field studies were conducted to evaluate the effects of bonding agents, mechanical anchors, and consolidation and curing techniques on the performance of surface pavement patches constructed with Roadpatch and rapid-setting portland cement concrete. Specimens were constructed on the surface of an existing pavement and load tested. One series of load tests was conducted to evaluate portland cement (PC) grout and epoxy bonding agents; mechanical anchor systems made up of 1/8-in.-diameter nails, number 2 U-bars, and a number 6 U-bar; and combinations of bonding agents and anchor systems. A second series of tests was conducted to evaluate combinations of patch materials, bonding agents, and anchor systems when constructed with good to poor consolidation and curing techniques. Bonding agents improve the consistency and reliability of the bond with base concrete. The performance of PC grouts with rapid-setting PC patching material is recommended. The bond strength was insensitive to method of placement of grout, but uniformity and quality, as indicated by low water-cement ratios, are important in bond strength development. To be effective, anchors must have sufficient strength and stiffness. Anchors should have a cross-sectional area of at least 1/2 in.^{2}/100 in.^{2} of bond area. Internal vibration and moist curing have a definite positive effect on early patch strength.

Although the Interstate system is virtually completed, the older and more heavily traveled sections are experiencing a rapid decline in serviceability. Pavements on the primary system are also experiencing similar performance problems that require spot maintenance. A large portion of these pavements are composed of portland cement concrete (PCC), especially in the urban areas. Spot repair maintenance is, at best, difficult to perform because traffic safety considerations require patching materials and construction procedures that minimize the time that the pavement is closed to traffic.

The research discussed here evaluated materials and techniques that can be used in constructing rapid-setting concrete pavement surface patches. The experimental program utilized an abandoned section of PCC pavement located near Auburn, Alabama, and has been reported on in more detail elsewhere (1,2).

TESTING PROGRAM

Several bonding agents, anchorage systems, and combinations of bonding agents and anchorage systems were evaluated in Series A tests. Series B tests evaluated the performance of various combinations of patch materials, surface preparation techniques, anchorage systems, and different consolidation and curing techniques.

The experimental patches were constructed on an abandoned section of US-280 located between Auburn and Opelika, Alabama. The pavement, consisting of 18-ft-wide, 8-in.-thick reinforced PCC slabs with 39-ft joint spacing, was in excellent condition with no visible cracking. The pavement concrete utilized natural sand and gravel with top-size gravel of approximately 1.5 in. Sawing and chipping of the pavement was difficult because of the primarily quartz composition of the aggregate. Although no concrete cores were tested, it appeared that concrete strength was quite high because no failures occurred in the pavement concrete during load testing of the patches.

Test Series A

These tests were designed to isolate and evaluate the effects of various bonding agents and anchorage systems. Test blocks 6 x 12 x 3 1/2 in. of rapid-setting PCC were cast directly on the surface of the existing pavement that had been abraded with an electric Roto Hammer and cleaned with a wire brush. The test specimen geometry had a 72-in.^{2} bond surface area. Two test specimens of each of the following eight combinations of surface preparation and anchorage systems were cast:

1. A portland cement (PC) painted on,
2. A PC grout scrubbed in,
3. An epoxy tack coat,
4. Four number 2 U-bars,
5. One number 6 U-bar,
6. One number 6 U-bar and epoxy tack coat,
7. Eight nails, and
8. Control (no additional surface preparation).

After the load resistance performance of the foregoing specimens had been analyzed a second set was cast in replicas of two with the following surface preparation:

1. A PC grout painted on,
2. A "dry" PC grout broomed in, and
3. Control (no additional surface preparation).

Details of the anchored test specimens are shown in Figure 1.

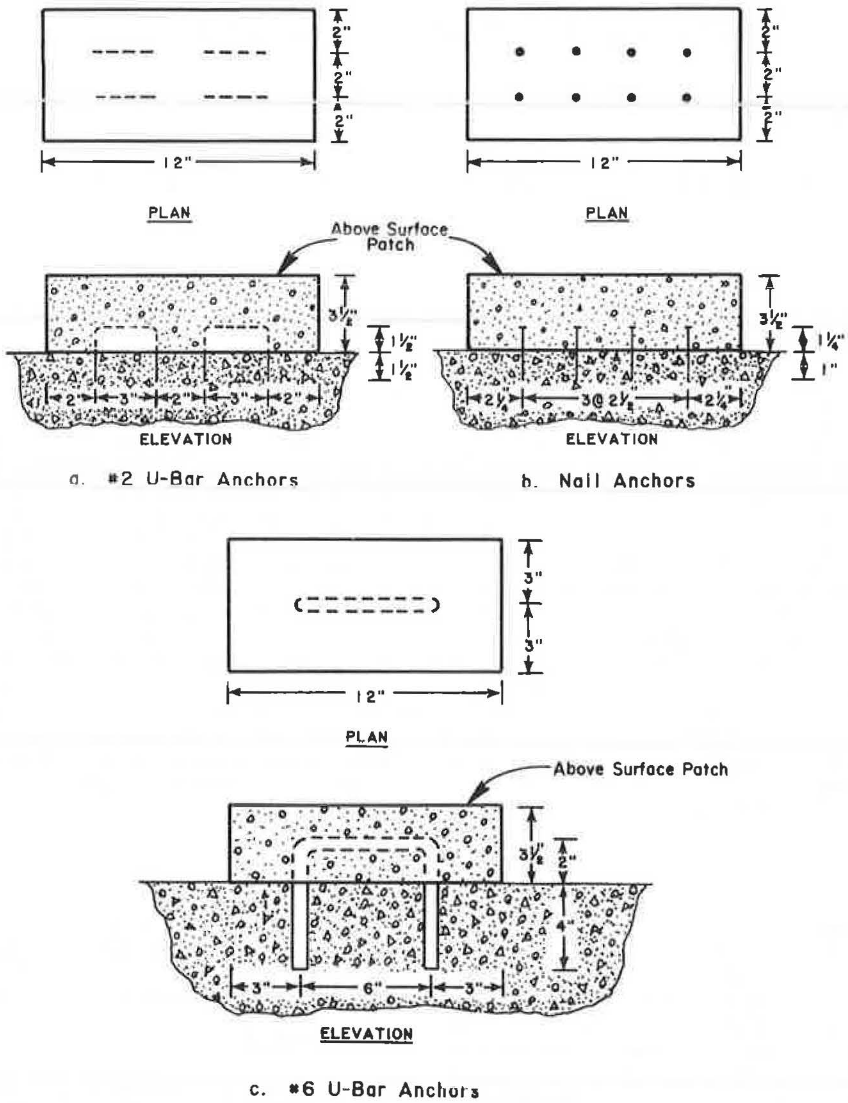

FIGURE 1 Details of anchorage systems, Test Series A.

The PCC pavement surface was scarified with an electric rotary hammer and cleaned with a wire brush to provide a clean, roughened bond surface with exposed aggregate. The second step was the installation of anchors (for the anchored specimens) consisting of nails and number 2 or 6 steel reinforcing bars bent into U-shapes. These anchors were grouted by placing a polyester mixture into holes drilled in the pavement surface.

Once the anchors were in place, forms were constructed, as shown in Figure 2, and the various bonding agents were applied to the roughened pavement surface. Rapid-setting PCC was placed and consolidated by thorough rodding. The specimens were covered with polyethylene sheeting and cured for 10 days before testing.

The jacking pedestal, shown in Figure 3, provided a reaction support for loading the specimens. Loads were applied with a 120-kip hydraulic jack and measured with a 100-kip electric load cell. Specimen movement was monitored with a 0.001 accuracy dial gauge. To eliminate tensile stresses along the bond surface, the load was applied at an angle of approximately 20 degrees with the pavement surface. This ensured that the line of action would pass through the kern of the bond area. Loads were applied until complete bond failure or specimen crushing occurred. When possible, specimen deformations were recorded.

Test Series B

Series B tests evaluated rapid-setting PCC and Roadpatch when utilized with various bonding agents, anchor systems, and consolidation and curing techniques.

The test setup for Series B was similar to that for Series A, shown in Figure 3. Although specimen dimensions and bond area remained the same, two details were different. A coloring admixture was added to the rapid-setting PC and Roadpatch to aid in determining whether failure planes passed through the base concrete, through the patch material, or along the interface. A loading face with an angle of 20 degrees from the vertical, shown in Figure 4, was cast on the specimens to eliminate the need for the angled bearing plate used in Series A.

Table 1 summarizes the comparisons between treatment combinations that can be made. The patch mate-

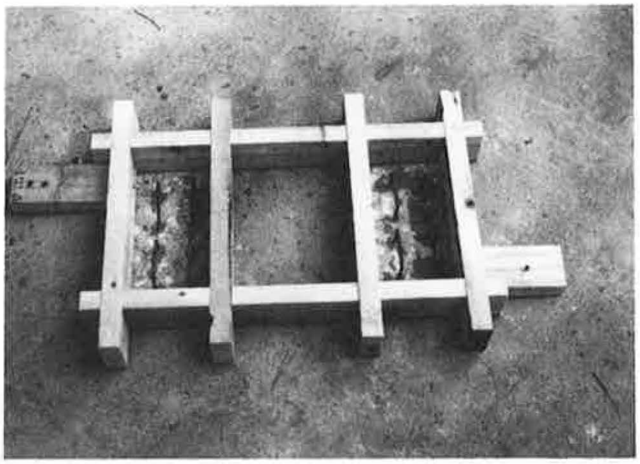

FIGURE 2 Forms for constructing test blocks.

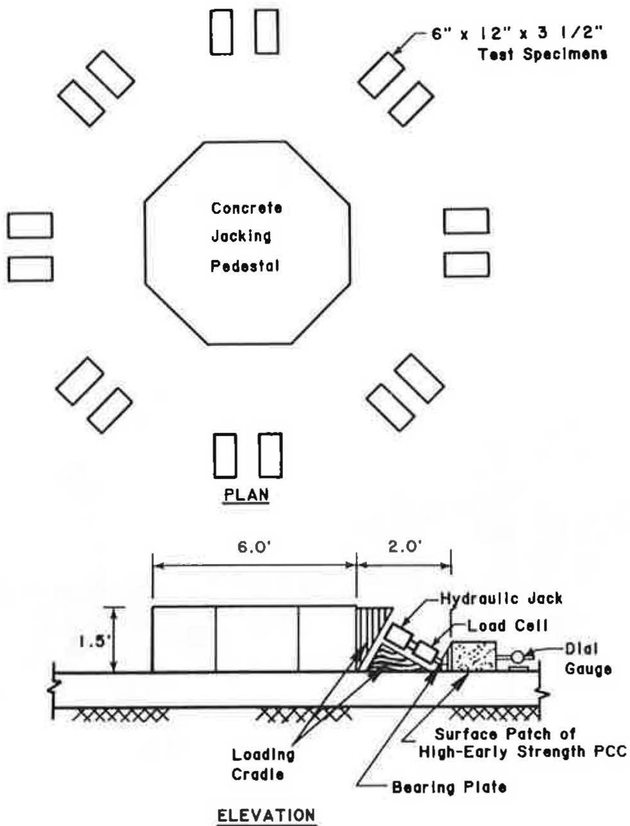

FIGURE 3 Field test set-up, Test Series A.

rials were rapid-setting PCC and Roadpatch. A cement grout was used as a bonding agent for the rapid-setting PCC and the manufacturer's recommendation of an acrylic slurry was used for the Roadpatch. Unanchored and anchored specimens were included and anchor details are shown in Figure 4. A number 4 U-bar anchor was selected as a compromise between the four number 2 and one number 6 U-bar systems used in Series A. Moist curing and simple exposure to existing conditions were employed. Two levels of compactive effort, internal mechanical vibration and minimal rodding, were employed.

Construction of the Series B test specimens was similar to that for Series A tests. That is, the pavement surface was abraded with a Roto Hammer, the number 4 U-bars were grouted into holes in the pavement with a polyester grout, forms were constructed, prime coats were applied to the bond surfaces, and patch material was placed. Twelve of the specimens were consolidated with internal vibrations, and four (two of PCC and two of Roadpatch) were consolidated with only minimal rodding to remove large visible voids.

The specimens were cured for 6 hr before testing. Twelve specimens were moist cured by being covered with wet burlap and polyethylene sheeting. Two samples of PCC and two of Roadpatch were not protected from moisture loss during curing.

EXPERIMENTAL RESULTS

Load test results for the two test series include failure load data, load-deformation responses, and qualitative information concerning modes of failure.

TABLE 1 Load Test Specimens: Test Series B

	No. of Replicas			
Patch Parameter	PCC		Roadpatch	
No anchors, moist cure, internal vibration	2	Material comparison	2	Anchorage effort comparison
Anchors, moist cure, internal vibration	2	Material comparison	2	Curing effort comparison
No anchors, exposure curing, internal vibration	2	Material comparison	2	Consolidation effort comparison
Anchors, moist cure, minimal rodding	2	Material comparison	2	

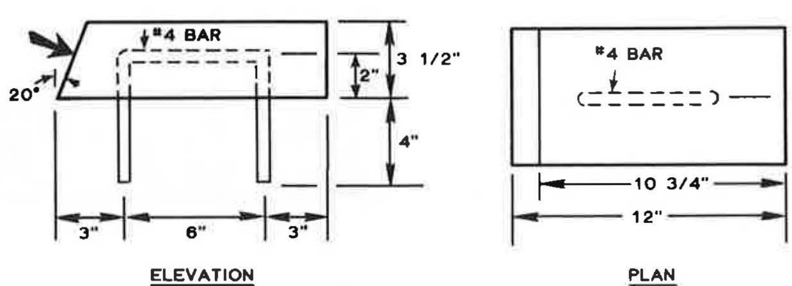

FIGURE 4 Details of specimens with number 4 U-bar anchors, Test Series B.

TABLE 2 Failure Modes and Loads: Test Series A

Surface Preparation	Failure Mode	Avg Peak Failure Load (kips)	Percent Difference
None	Bond failure, brittle-type failure	32	-
PC grout			
Painted on	Bond failure, brittle-type failure	29	-10.3
Scrubbed in	Bond failure, brittle-type failure	34	5.3
Broomed off	Bond failure, brittle-type failure	29	-10.3
Epoxy tack coat	Bond failure, brittle-type failure	45	39.9
One no. 6 U-bar anchor	Bond failure followed by cracking around U-bar and crushing, ductile-type failure	44	36.1
One no. 6 U-bar anchor and epoxy tack coat	Cracking around U-bar and crushing, no bond failure, ductile-type failure	48	48.0
Four no. 2 U-bar anchors	Bond failure followed by cracking around U-bars, ductile-type failure	44	36.1
Eight-nail anchors	Bond failure followed by immediate pullout of nails from the base concrete, brittle-type failure	27	-17.1

Because of differences in anchorage systems, loading conditions, and age at testing, absolute magnitudes of failure loads are only of general interest. Of specific interest are comparisons within a test series to assess the relative benefits of the various materials and techniques.

Test Series A

Results from the load tests in this series are summarized in Table 2. The percent difference relates to the control case, in which there was no surface preparation. In each case, the specimens without mechanical anchors experienced abrupt bond failures as shown in Figure 5 (top). This type of failure was probably caused by tensile stress concentrations resulting from application of the load.

With the exception of the specimens with nail anchors, the anchored specimens exhibited ductile-type failures; that is, the maximum load did not produce an abrupt catastrophic failure. Load-deformation measurements indicated that these specimens were able to sustain applied loads after bond failure. The U-bar anchors should extend the life of a patch by maintaining its structural integrity after bond failure. The nail anchors lacked the stiffness and pull-out strength necessary to provide significant load-carrying capacity after bond failure. The nails were pulled from the base concrete after bond failure occurred. The ratio of anchor cross-sectional area to bond area for the nails was only 0.00014, whereas for the number 2 U-bars and number 6 U-bars these ratios were 0.0055 and 0.0122, respectively.

Failure of specimens with U-bar anchors was characterized by splitting around the bars and crushing of the patch material as shown in Figure 5 (bottom). The U-bar anchors had sufficient strength and stiffness to produce a ductile-type load-deformation response. Typical load-deformation curves for anchored and unanchored specimens are shown in Figure 6. Note the considerable deflection necessary to significantly reduce the load resistance for the anchored specimen. The failure modes experienced by specimens with U-bar anchors suggest that their strength and ductility would be enhanced by a patching material with high tensile strength and ductility such as steel fibrous concrete.

With the exception of the nail anchors, the specimens with anchors performed well. When the specimens with the epoxy tack coat and number 6 U-bar, number 6 U-bar alone, number 2 U-bars, and

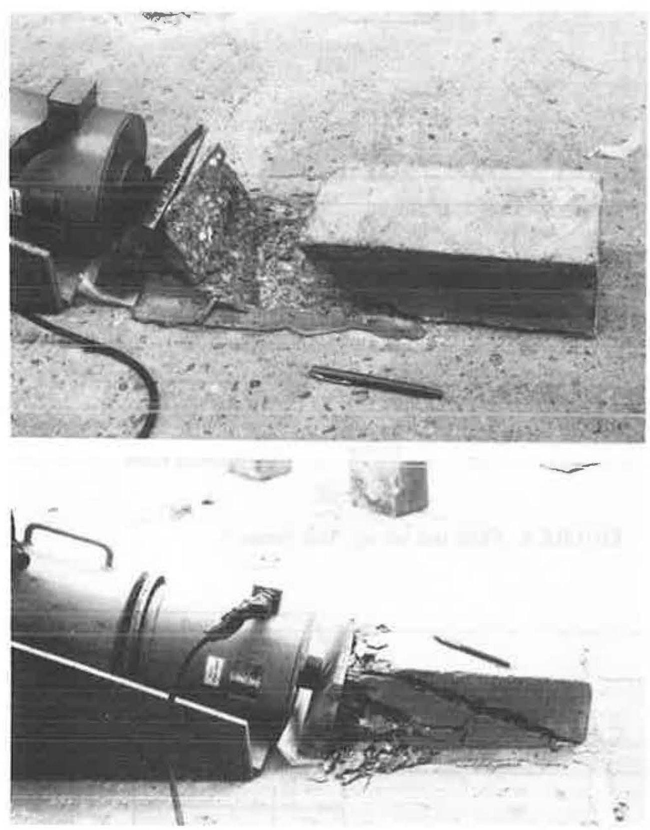

FIGURE 5 Typical failure modes, Test Series A: bond failure, unanchored specimens (top) and splitting and crushing, anchored specimens (bottom).

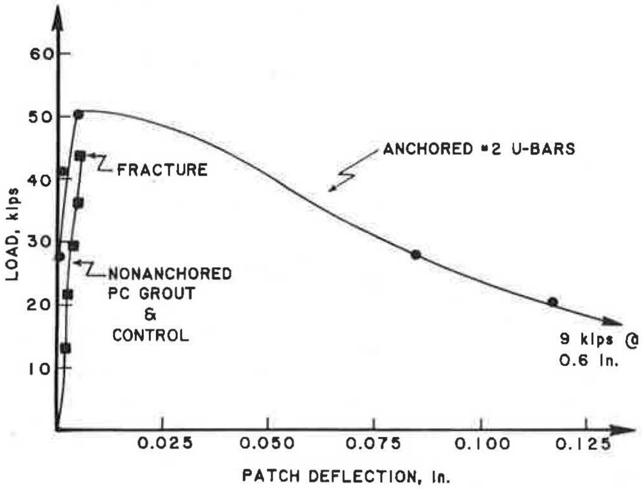

FIGURE 6 Typical load-displacement curves, Test Series A.

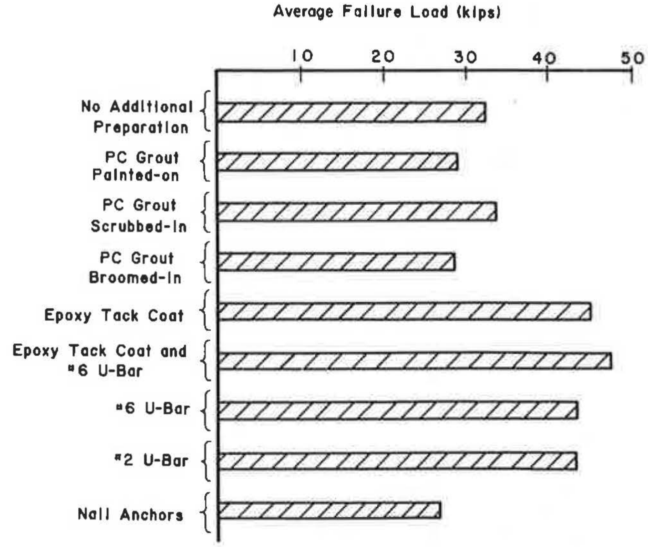

FIGURE 7 Comparison of failure loads, Test Series A.

nail anchors were compared with the control specimens, increases in average strength of 48, 36, 36, and -17 percent, respectively, were found. The increases, combined with improvements in ductility, make the use of anchors appear quite attractive. The role of the anchors in patch performance appears to be similar to that of reinforcing steel in concrete: the steel provides tensile strength, ductility, and toughness. On the basis of consistent and maximum load-carrying capacity, specimens with the epoxy tack coat and number 6 U-bar were superior. These specimens had the smallest variability in load-carrying capacity and exhibited no detectable bond failure. The failures resulted from splitting and crushing of the patching material. The average strength of these specimens was approximately 48 percent higher than that of the control specimens. this average strength is, however, only 6 percent higher than that for specimens with epoxy tack coat only and 9 percent higher than that for specimens with only number 6 U-bars. Further research is needed to fully determine the merits of combining an epoxy tack coat with a mechanical anchorage system. Of particular concern is the epoxy's slow strength gain and sensitivity to temperature.

Average failure loads are shown in Figure 7. Results from the control specimens cast with no bonding agent or anchors exhibited significant variations. Loads ranged from 65 to 7 kips with an average of 32 kips. The average load-carrying capacity for the unanchored specimens was not increased by the use of bonding agents. However, when failure load variability was compared, it was noted that the consistency of load-carrying capacity was significantly improved by using a PC grout bonding agent. Specimens with the PC grout painted or broomed on exhibited average strengths approximately 10 percent smaller than those of the control specimens with no additional preparation. However, these specimens demonstrated consistent failure load results.

Series A tests suggest no strong relationship between patch performance and the method utilized for application of the PC grout. As illustrated in Figure 7, the different methods produced similar results. Epoxy showed more promise as a bonding agent than PC grout. Average loads for the epoxy were higher than those for the PC grout specimens and approximately 40 percent higher than those for the control specimens. The strengths were comparable with those achieved with the number 6 U-bar and the number 2 U-bar anchors. However, earlier laboratory studies (3,4) have shown that the epoxy's rate of strength gain is relatively slow and sensitive to temperature.

Test Series B

Results from Series B load test specimens are given in Table 3. The specimens were loaded after 6 hr of moist curing. The failure modes were similar to those for comparable specimens in Test Series A. Unanchored specimens experienced bond failures, as shown in Figure 5 (top), which are characterized as brittle because of small failure displacements and abrupt losses of load resistance. Anchored specimens were characterized by bond failure, followed by slitting and crushing of the patch material. These were considered ductile because the specimens were able to sustain loads with increasing displacement after the peak load was achieved. The failure modes were similar to that illustrated in Figure 5 (bottom).

TABLE 3 Failure Modes and Loads: Test Series B

Patch Parameter	Failure Mode	Avg Peak Failure Load (kips)
PCC		
No anchors, moist cured, vibration	Bond failure, brittle-type failure	22
Anchored, moist cured, vibration	Bond failure followed by cracking around U-bar and crushing, ductile-type failure	20
No anchors, no curing, vibration	Bond failure, brittle-type failure	18
Anchored, moist cured, rodded	Bond failure followed by cracking around U-bar, ductile-type failure	20
Roadpatch		
No anchors, moist cured, vibration	Bond failure, brittle-type failure	24
Anchored, moist cured, vibration	Bond failure followed by cracking in plane of U-bar, ductile-type failure	18
No anchors, no curing, vibration	Bond failure, brittle-type failure	18
Anchored, moist cured, rodded	Crushing followed by bond failure and cracking around U-bar, ductile-type failure	12

Average values of peak failure loads (which is the maximum load on a load displacement curve) are presented in Figure 8. These loads and the modes of failure were used as the basis of comparison for evaluating the relative performance of the materials, the consolidation and curing procedures, and the anchor systems.

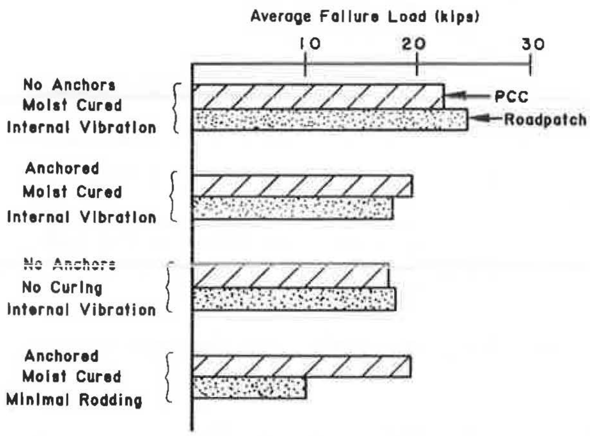

FIGURE 8 Comparison of failure loads, Test Series B.

As seen in Figure 8, the Roadpatch and the rapid-setting PCC performed about the same on the basis of load-carrying capacity. An exception was the minimal rodding case, but the difference was attributed to material sensitivity to consolidation effort. Comparing the average strengths of specimens with similar anchorage, consolidation, and curing conditions reveals no consistent pattern. The PCC specimens exhibited superior strength in two cases, but Roadpatch was stronger in the other two. On the basis of its superior ductility, exhibited through the retention of its structural integrity after displacements in excess of 1 in., Roadpatch appears to be the better of the two materials tested. As displacements approached 1 in., the PCC specimens tended to crack and be crushed.

Comparisons between the anchored and unanchored test specimens appear to contradict the results from Test Series A. In Series A, the anchored patches performed better than the unanchored patches, with the exception of the specimens with nail anchors. In that series, the increases in average strength compared with that of the control specimens for the specimens with epoxy tack coat and number 6 U-bar, number 6 U-bar alone, and number 2 U-bar were 48, 36, and 36 percent, respectively. However, as shown in Figure 8, the unanchored patches exhibited slightly greater load-carrying capacities than the anchored specimens. For PCC specimens, the difference between the unanchored and anchored mechanically vibrated and moist-cured specimens was about 10 percent. The difference between comparable Roadpatch specimens was 25 percent.

The poor performance of the number 4 U-bar anchorage system of Test Series B was due to in part to differences in size or arrangement of the anchors or both as compared with Test Series A. The one number 4 U-bar anchor provided a cross-sectional area of 0.40 in.^{2}, which gave a ratio of anchor to bond surface areas of 0.0055. In Series A, the four number 2 U-bars and the one number 6 U-bar provided, respectively, 0.4 in.^{2} (0.0055) and 0.88 in.^{2} (0.0122) of anchor area. The number 6 U-bars provide approximately twice the area and are stiffer than the number 4 U-bars, whereas the arrangement of four number 2 U-bars offers the advantage of reduced stress concentrations. The anchors, however, in both test series, served to provide ductility by retaining the integrity of the specimens and allowing for load transmittal after initial bond failure.

The importance of proper consolidation can be seen by comparing the specimens consolidated with internal vibration with those consolidated by minimal rodding. For the anchored, moist-cured PCC specimens, the average strengths were the same (19.9 kips). For comparable Roadpatch specimens, the strength of those that were mechanically vibrated was 32 percent larger than that of those that were minimally rodded. These results were influenced by the workability of the mixes used. The PCC mix was wetter and more workable, and thus the means of consolidation had no discernible effect. The Roadpatch mix was, on the other hand, quite dry and contained steel fibers; thus it was not as workable. Therefore, the mechanical vibration improved consolidation and significantly increased the strength of the Roadpatch specimens. Honeycombing was observed in the rodded Roadpatch specimens and further illustrates the need for mechanical vibration. On the basis of these results and the desirability of keeping the water:cement ratios of patching materials as low as possible, internal vibration is considered desirable.

A fourth comparison can be made between the moist-cured test specimens and those left unprotected against rapid moisture loss. Unanchored, vibrated, moist-cured PCC specimens had an average strength 20 percent higher than that of those left unprotected. Comparable Roadpatch average strengths were 26 percent higher. These results illustrate the importance of proper curing to ensure adequate early strength gain.

CONCLUSIONS

Major conclusions drawn from the results of this testing program are as follows:

1. The use of bonding agents improved the consistency and reliability of the patch bond with base concrete for the patches tested. Epoxy exhibited superior strength, but earlier laboratory studies (3,4) have shown that it has a slower rate of strength gain and is adversely affected by low temperature. Therefore, Type III PC grouts should be used as the bonding agent with rapid-setting PCC. The performance of PC grouts was insensitive to the method of placement. Uniformity of the grout and low water-cement ratios appear to be more important than method of placement.

2. The inclusion of mechanical anchors, in general, is beneficial in improving strength and ductility. These improvements are realized only if the anchors have adequate strength and stiffness. The nail anchors employed did not have adequate stiffness and embedment depth. The four number 2 U-bars and the one number 6 U-bar provided adequate stiffness to strengthen the surface patches. However, the one number 4 U-bar did not appear to provide adequate stiffness to strengthen the patch. Optimization of the size and number of anchors to best strengthen a patch was not achieved and should be addressed through additional research.

3. On the basis of the limited results from the anchored tests, it appears that anchors should have a cross-sectional area of at least 1/2 in.^{2}/100 in.^{2} of bond area.

4. Internal vibration and moist curing have a definite positive effect on early patch strength.

5. Rapid-setting PCC manufactured with Type III

cement and an accelerator or the proprietary product Roadpatch can be successfully used for patching PCC pavements.

ACKNOWLEDGMENTS

The work reported in this paper was sponsored by FHWA, U.S. Department of Transportation, through the State of Alabama Highway Department (Alabama Highway Department Project 930-107). The authors are grateful for their sponsorship, assistance, and cooperation.

REFERENCES

1. F. Parker, G.E. Ramey, and R.K. Moore. Evaluation of Rapid Setting Materials and Construction Techniques for Concrete Pavement Patches. HPR No. 99, Research Project 930-107. State of Alabama Highway Department, Montgomery, 1984.
2. G.W. Jordan. Evaluation of the Performance of Various Rapid-Setting Concrete Pavement Patching Materials and Procedures by Field Testing. M.S. thesis. Auburn University, Auburn, Ala., March 1984.
3. A.M. Strickland. An Experimental Evaluation of Rapid-Setting Patching Materials Used in the Repair of Concrete Pavements. M.S. thesis. Auburn University, Auburn, Ala., March 1982.
4. F.W. Foshee. A Laboratory Comparison of Several Rapid-Setting PCC Pavement Patching Materials Used in the Repair of Concrete Pavements. M.S. thesis. Auburn University, Auburn, Ala., June 1983.

Publication of this paper sponsored by Committee on Pavement Maintenance.

Void Detection for Jointed Concrete Pavements

J. A. CROVETTI and M. I. DARTER

ABSTRACT

Procedures for the detection of voids or loss of support under jointed concrete pavements by using nondestructive deflection testing measurements are presented. A rapid field-applicable procedure is presented to quickly determine the presence of voids by analysis of the load and deflection response at slab-corners. A more detailed method is presented in which deflection measurements from center slab and corner locations are used to locate and determine the approximate size of any existing voids. The procedures were developed by using computer modeling of loadings with the ILLISLAB finite-element computer program. The procedures were field verified on several test projects. Basic guidelines for testing, locating joints or cracks requiring subsealing, and estimating grout quantities for jointed concrete pavements are presented.

The loss of support near transverse joints and working cracks because of the pumping of base or subgrade fines or both is one of several major causes of concrete pavement deterioration. Subsealing of locations with poor support by the injection of a grout mixture has become standard practice in many parts of the country. What has been lacking in this process is an established procedure to determine the locations along the pavement where loss of support exists. This deficiency has led many agencies to subseal on a blanket-coverage basis (e.g., all joints and working cracks), which has led to serious problems on several projects because it was not possible to determine (a) whether and where any voids existed in the first place, (b) an estimate of the grout quantity required to fill existing voids, and (c) the extent to which the voids were filled and support was restored.

Procedures were developed under NCHRP Project 1-21 at the University of Illinois for determining areas of loss of support (commonly called voids) by using nondestructive deflection testing (NDT) (1,2). Two different methods were developed:

1. A rapid and simple field method to give an indication of the existence of a void, and
2. A detailed approach to give an indication of the location and size of the void.

Both procedures were field tested at several different project sites.

BASIC APPROACH AND CONCEPTS

Computer modeling based on finite-element analysis was used to establish theoretical relations between