

## FINAL REPORT

## EVALUATION OF CONCRETE PATCHING MATERIALS

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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## SUMMARY

The project evaluated numerous repairs on portland cement concrete pavements and bridge decks made with a number of laboratory accepted, proprietary patching materials and portland cement concrete mixtures of different designs. It was ascertained that in the majority of cases when the patches failed, the failure resulted from the use of improper construction techniques, not from deficiencies in the patching materials used.

Of the three proprietary materials determined not to have performed satisfactorily Embecco 411A, a magnesia phosphate material, has been used for 10 years. Fondu, a high alumina concrete material, and Duracal, a calcium sulfate material, performed so poorly that use of the former should be limited to small patches and use of the latter should not be allowed.

In addition, it was ascertained that portland cement concrete incorporating carefully chosen admixtures can provide satisfactory service at a lower cost than proprietary patching materials.

Upon reviewing the May 1984 final report the FHWA suggested several changes. Those changes have been incorporated into this revised version.

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BACKGROUND

While more than 90% of the 42,500-mile interstate system has been built at a cost of \$75 billion, it is estimated that completion of the less than 1,000 miles remaining to be built will cost \$67 billion, or the equivalent of the cost of the first 37,000 miles. However, the cost of completing the remaining segments of the system is not the biggest problem facing the highway industry today. The main concern is the maintenance and rehabilitation of the large segments that have exceeded their design life and are deteriorating. Because of declining funds, "deferred maintenance" programs have been instituted by many states, with the result that many stretches of highway have deteriorated to a critical condition, and maintenance on primary and secondary roads can be conducted on only approximately one-half of the roads needing repairs. Additionally, in 1980 it was reported that 9% of all paved roads were beyond repair and would have to be rebuilt.(1)

Besides the many miles of pavement requiring maintenance, approximately 105,500 of the 563,500 bridges on the interstate system need to be repaired or replaced. Each year roughly 150 of the bridges on the system deteriorate to a point that they collapse.(1) The New York State Department of Transportation made condition surveys of their highway structures in 1978 and 1980, and estimated that the costs of backlogged repairs totalled \$323 million and were increasing at the rate of \$39 million a year. In order to halt the declining deterioration, an additional \$39 million per year of maintenance was needed.(2)

The most obvious evidence of pavement deterioration, the pothole, occurs on both bridge decks and roadways. For bituminous roadways, patching potholes with asphaltic material generally will suffice until an overlay can be placed. On concrete decks or roadways, however, asphaltic patches provide only a very temporary solution and may even cause accelerated deterioration. Therefore, other patching materials more compatible with the in-place concrete and, in some cases, the reinforcing steel are needed. Several of these materials that have been used are conventional portland cement mortars and concretes, and mixes utilizing latex, epoxy resins, or methyl methacrylate.

In Virginia, over 30 proprietary patching materials have been laboratory tested since the early seventies, and approximately two-thirds have been found acceptable by the Virginia Department of Highways & Transportation for field use. A Special Product Evaluation List (SPEL) of the patching materials evaluated and the results are published by the Department's Materials Division.(3) In addition, a similar list is published by the Federal Highway Administration based on evaluations conducted by state highway or transportation departments.(4)

From the Department's SPEL, contractors can select an acceptable proprietary patching material that meets Department specifications, such as that for compressive strength, for a particular job, while state maintenance personnel may select an acceptable proprietary material that fulfills their needs as required by written Department specifications or agreed upon criteria. In any case, numerous patches on Virginia's portland cement concrete (PCC) pavements and bridge decks made from a number of the accepted proprietary patching materials, as well as portland cement concrete mixtures of different designs, have been installed. Prior to the present study, no one had inventoried the materials used in these patches on all PCC pavements and bridge decks, evaluated their field performance, and compared the field performance with the laboratory evaluation results. For these reasons this study was initiated.

Laboratory evaluations of patching materials have been and are continuously being conducted by the Department's Materials Division, but field evaluations and feedback to the laboratory are limited either in the number or type of patching materials being evaluated or the lane-miles of pavement or number of bridge decks studied.(5,6,7,8) In this study, all sections of the Department's PCC pavement and bridge decks known to be patched and not covered with an overlay were included.

#### APPROACH

The PCC pavements and bridges were surveyed to identify patches and the information outlined below, if known, was ascertained for each patch or series of patches. In conjunction with the field surveys, interviews were conducted with district and residency personnel who were involved in or had been involved in any PCC patching to obtain information in addition to the field data.

1. type of patch material
2. date installed
3. partial or full-depth patch

4. environmental conditions at time of patching -- air temperature, wind, installation during day or at night, etc.
5. preparation of hole -- vertical cuts, method of removal, leveling of bottom, etc.
6. rate of set of patching material
7. results of any field tests performed -- strength, slump, air entrainment, etc.
8. curing process
9. if patch material was specified for this type of application
10. type of joint material used, if any
11. type of load transfer installed with patch, if any
12. type of bonding agent used, if any
13. time closed to traffic
14. estimate of cost of either the patching material or a unit area of patching
15. any problems during installation or later

In addition to the field surveys and interviews, a literature search was conducted to determine if other agencies or firms had performed similar studies. The literature search revealed the citations listed in the Selected Bibliography.

### RESULTS

PCC patches installed by both private contractors and state forces were examined, and the overall performance of those placed by the former was found to be the better. The better performance seems to be attributable to the contractors' use of Department specifications, good inspection, quality control or testing, and use of the construction technique or procedure specified by the Department. Most patches installed by state forces were not covered by specifications, inspections, or quality control, and were installed using the construction techniques or procedures the state forces performing the work believed to be the best. Since, from experience or intuition, different groups of state forces held different opinions concerning particular

techniques or procedures, an assortment of these were used. Not as many were used by private contractors, but there was some variety because the Department changed its specifications as it accumulated experience in PCC patching.

Interviews with district and residency maintenance and inspector personnel involved in PCC patching operations were limited since large turnover and transfer rates had occurred within the Department after the commencement of PCC patching in 1969. However, most of the PCC patching has been done in the Suffolk District and the several Department personnel involved in the earlier patching operations are still in that district and thus were interviewed. From the interviews it was ascertained that present specifications for the patches were adhered to in the majority of cases -- the work was performed when temperatures were above 55°F., the patches were moist cured, the water-cement ratios were at or below 0.49, at placement temperatures of the concrete were between 70°F. and 95°F., slumps were between 1 and 5 in. and air contents were within  $6 \pm 2\%$ . However, the air temperature and wind speed generally are not reported by Department personnel on their project reports and this information is unavailable. The minimum time from placement of the concrete to opening to traffic was 6 hours and the minimum strength requirement at 6 hours was 2,000 lbf./in<sup>2</sup>. At several locations traffic volumes were low enough to permit closing the road for several days, but generally this could not be done. Patching operations were conducted during both the day and night, but traffic conditions generally dictated the time of the operations. Unless they were approved by the engineer, most of the patches not meeting the specifications listed above were removed. Generally, proprietary products were not tested for compliance with the specifications for PCC because they generate high internal temperatures, develop high early strengths, and have a rapid rate of set (minutes versus hours for a concrete mix).

Most patch holes had vertical sides, but some of the more recent ones were sawed at an angle to provide interlocking of the patch with the existing pavement. All interviews indicated that the bottom of the partial-depth holes were cleaned thoroughly while the backfill material for the full-depth holes was not compacted level with the bottom of the existing pavement. However, most patches were odd shaped; that is, not rectangular or square. Small patches (1 ft x 1 ft), patches terminating in the wheel path, and long narrow patches (6 in wide) were common.

In earlier years, load transfer devices were installed prior to placement of the concrete. The process was time-consuming and it was thought that the benefits were minimal; thus, it fell into disuse. Various joint materials were used, but bituminous filler was most commonly used. On one state force project, 4-in pressure relief joints were used in every patch.

From the interviews it was ascertained that the most common problems in installation resulted from the rapid rate of set and the high internal temperature of several of the proprietary materials. Because of the rapid rate of set, the ingredients had to be mixed quickly to avoid problems with workability in placing the mix. In addition, several proprietary products developed thermal cracks early because of the high internal temperatures.

Most interviewees could not remember specific cost data but indicated that the costs of the proprietary patching materials were generally higher than that of a typical PCC mix. Also, where the workmen were unfamiliar with the use of additives for accelerating the set of the PCC mixes, costs were increased. However, in one research study M. F. Creech stated that a contractor in 1974 installed patches in the eastbound lane on Route 44 near Virginia Beach for \$29.80/ft.<sup>2</sup> (5). Creech also indicated that the contractor would probably adjust his cost on future projects to reflect the actual cost per foot.

The construction techniques and procedures listed below have been used in various combinations and were examined during this study.

Techniques

1. precast
2. cast-in-place
3. partial-depth
4. full-depth
5. with and without expansive joint materials
6. with and without joint bonding materials
7. with and without dowel assemblies
8. patches underpinning adjacent ends of slabs (known as the inverted "tee" method)
9. patch holes sawed vertically and at an angle for interlocking (known as "loose" slab method and "wedge" method, respectively)
10. size of the patch -- from 1 ft. x 1 ft. to 30 ft. x 12 ft.
11. shape of the patch -- square, rectangular, or irregular

Procedures

1. ready-mix
2. mobile-mix -- large mixing unit (5 yd.<sup>3</sup> or more)
3. portable -- manually charged mixing unit (2 ft.<sup>3</sup> to 0.5 yd.<sup>3</sup>)

Most of the PCC patching done in Virginia has been on jointed pavements, usually on one or both sides of the joint, and not on the relatively new continuously reinforced pavements. The majority of the PCC patching is being conducted on the older pavements with transverse joints every 50 or 61.5 ft. In addition, there has been little patching of deteriorated areas in bridge decks with a permanent patching material, since most of the deck repair procedures used by the Department have called for removing the deteriorated material and placing an overlay.

Table 1 lists the portland cements and proprietary materials identified in the field surveys and evaluated in this study.

Table 1

## Patching Materials Evaluated

Patching Material	No. of Patches Surveyed	Patches Installed by	Years in Service	Present Condition	Remarks
Asphaltic Mix	> 5,000	State forces	6 mo.- 2 yr.	Usually failed within 1 yr.	Temporary patch material
Duracal	> 200	Contractors	1- 8	Partial depth patches are approximately ½ in. lower within 1 yr.	Poor performance
Embeco 411A	Approx. 25	State forces	10	Needs repair	Satisfactory performance over 10 yr.
Fondu	> 500	Contractors	6 mo.- 12 yr.	Large and full-depth patches need to be repaired	Poor performance in full-depth and large patches
Type I cement without admixtures	> 150	State forces and contractors	1- 10	Okay	Satisfactory performance.
Type II cement without admixtures	> 300	State forces	2- 4	Okay	Satisfactory performance
Type II cement with admixtures	> 65	State forces and contractors	6 mo.- 11 yr.	Okay	Satisfactory performance of the patching material even with construction and placement problems
Type III cement without admixtures	> 900	State forces and contractors	2- 8	Okay	Satisfactory performance but construction problems encountered

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Table 1 (continued)

Patching Material	No. of Patches Surveyed	Patches Installed by	Years in Service	Present Condition	Remarks
Type III cement with admixtures	> 500	State forces and contractors	1-13	Needs repair after 13 yr.	Satisfactory performance
Type III modified cement with admixtures	>1,000	Contractors	1-10	Okay	Satisfactory performance
Precast hydraulically pressed slabs	Approx. 50	Contractor with state forces	10	Okay	30% failure after first 2 yr.; satisfactory performance since 2nd yr.
Precast Wirand slabs	Approx. 20	Contractor with state forces	10	Some slabs need repair after 10 yr.	Better than average performance over 10 yr.

From the field surveys it was ascertained that most of the PCC patching in Virginia was done with three proprietary products and with mixed results. As observed in the surveys and in a study by McGhee,<sup>(9)</sup> the patches made with a high alumina cement concrete (Fondu) had developed thermal cracking following a period of rapid strength gain during which there was excessive heat of hydration. In addition to the thermal cracking, the high curing temperatures associated with Fondu created a crystalline change in the patch that caused a large percentage of the early strength to be lost after several months.<sup>(10)</sup> From observations in this study it appears that Fondu performs well when used in small patches (3 ft. by 3 ft.) or partial-depth patches. Because of the excessive heat of hydration and crystalline change noted above, large patches made with Fondu develop thermal cracks in the top 3 to 4 in. that in turn result in surface spalls. The shallow deterioration was quite evident during removal of several full-depth patches. The lower portions were hard and difficult to break up, whereas the surfaces were not. Through discussions with Department personnel, the writer learned that because of this type of deterioration, the use of Fondu was limited to partial-depth patches. In addition to limiting the depth of the patch, it is recommended that the area patched be limited to 3 ft. by 3 ft.

A proprietary material containing magnesia phosphate (Embeco 411A) and one with calcium sulfate (Duracal) did not perform satisfactorily and the former, a nonshrink, catalyzed, metallic mortar, was included on the Department's SPEL as accepted conditionally and having questionable durability. This product was used extensively in partial-depth patches on Route 44 in Virginia Beach in 1974. During the field surveys patches of this product were cracked to the extent of needing repair as soon as possible. Therefore, after 10 years of service patches of this product were not performing satisfactorily.

Patches made with Duracal and used in bridge deck repair were performing poorly less than 1 year after installation. Similar performance of this product was reported by Hartvigas.<sup>(11)</sup> Thus, it is not advisable to use this material in the future.

From the field surveys and interviews it was concluded that conventional portland cement concrete incorporating carefully chosen admixtures will provide satisfactory service at less cost than the proprietary products. In warm weather, concrete made with Type III cement, with or without admixtures, can provide rapid strength gain to permit early opening of the work area to traffic; however, the strength gain is slow during cool weather. Similar conclusions have been stated in other reports.<sup>(9,12)</sup>

For the most part, the patch failures observed in this study resulted from the use of improper construction techniques. Listed below

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are reasons for most of the failures and ways to prevent the failures.

1. The entire deteriorated area was not removed. Until more accurate methods are developed, a thorough sounding and visual observations should minimize this problem. (The author submitted an NCHRP problem statement related to this cause of failure, and a contractor was being engaged to seek solutions at the preparation of this report.)
2. Small patches were terminated in a wheel path. No patch should be smaller than 2 ft. by 2 ft. If the edge of the patch will terminate in the wheel path, then the patch should be enlarged to avoid this high stress area. Where the patch extends across at least 8 ft. of a 12-ft. lane, then it should be enlarged to 12 ft. to avoid later failures. A small amount of concrete should be sacrificed to avoid a high potential for failure.
3. Narrow patches (less than 15 in.) were installed across the traffic path. No patch should be narrower than 2 ft. since narrow patches fail easier than wide ones.
4. No expansive joint material was used, or not enough joints were installed in large patches. With all patches, joint material should be installed on one side. For large patches (greater than 10 ft. in length) several joints should be formed.
5. Sawing extended into adjacent sound concrete, which eventually broke off. Sawing of patch holes should not extend into the surrounding pavement, since weak areas will be created and failures will occur. To minimize this problem in adjacent lanes where saw cuts would be within 15 in. of each other at the longitudinal joint, the two edges of the patches should be aligned.
6. Odd-shaped patches failed more readily than square or rectangular patches; thus these patches should have straight sides to avoid high stress areas in the corners.
7. Base material did not provide support for the pavement. To avoid failures and problems the base material should be replaced and compacted to the bottom of the pavement prior to placing the patch material.
8. Subsurface water weakened the base support and caused the pumping of fines. Drainage facilities should be installed in areas with subsurface water to eliminate this problem.

9. Patching material was placed in the shoulder. A form should be placed at the edge of the pavement to prevent the patch from being keyed into the shoulder to cause failure during times of differential movement of the pavement and the shoulder.
10. Adjacent lanes bonded together failed near transverse joints. A bond breaker, usually a sheet of polyethylene, should be placed between adjacent lanes during installation of the patch.

It is the opinion of the author, based on the observations and interviews in this study, that serviceable patches at minimal cost can be obtained by adhering to the following.

1. Do not terminate the patch edge in the wheel path of the pavement.
2. Keep the patch edges straight.
3. Keep the patch square or rectangular in shape.
4. Keep the patch larger than 2 ft. by 2 ft.
5. Keep the patch width greater than 2 ft.
6. Use joint material on one side of the patch.
7. Use a bond breaker between adjacent traffic lanes.
8. Use Type II portland cement without admixtures in warm weather (greater than 70°F).
9. Use Type II portland cement with admixtures in cool weather (55°-70°F).
10. Use Type III portland cement with or without admixtures in situations where traffic closure time is minimal (less than 8 hours).

On the basis of information developed in this study, and under financing from HPR funds, the author prepared a slide presentation on patching jointed PCC pavements. This presentation was requested by the Maintenance Division of the Virginia Department of Highways & Transportation for use in preconstruction conferences and in the training of inspectors and state force personnel.

## CONCLUSIONS

From this study the following conclusions can be drawn.

1. Patches installed by private contractors generally perform better than those installed by state forces.
2. Three proprietary patching materials were determined to perform unsatisfactorily.
  - a. Use of Fondu should be limited to partial-depth and small patches.
  - b. Patches made with Embeco 411A, a material that had shown questionable durability in laboratory evaluations, were deteriorated to a point of needing repair after 10 years of service but had performed satisfactorily to time.
  - c. Patches made from Duracal showed severe abrasion or shrinkage less than 1 year after installation.
3. Portland cement concrete containing carefully chosen admixtures will provide satisfactory results at a lower cost than will proprietary products.
4. The majority of patch failures resulted from improper construction techniques, not from the type of patching material used.

## RECOMMENDATIONS

From the work performed in this study, the following recommendations are made.

1. Fondu patches should be limited in size to no larger than 3 ft. by 3 ft.
2. Duracal should not be used because of its poor durability and shrinkage.
3. A field evaluation of concrete patching materials should be conducted every 5 years.

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