PARTIAL-DEPTH REPAIR OF JOINTED PCC PAVEMENTS: CAST-IN-PLACE AND PRECAST PROCEDURES

by

Samuel S. Tyson
Research Engineer

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

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

January 1977
VHTRC 77-R37

SUMMARY

The installation of durable patches on jointed portland cement concrete pavement using several types of cast-in-place concrete is described. The recommended procedures for pavement preparation and patch installation are given, and additional maintenance procedures as cleaning and sealing joints and assuring proper drainage are briefly discussed.

The successful evaluation of proprietary products for repair concretes through a laboratory determination of concrete properties, field use of acceptable products, and the assessment of performance data during and after installation is discussed. Included in this study were some of the cements, admixtures, and other special products for repair concretes from a list maintained by the Materials Division of the Virginia Department of Highways & Transportation to provide assistance in the selection of the proprietary products.

A production chart is presented as an aid in estimating the number of patches that can be installed during typical lane closure periods. Concretes with short curing times increased potential production, however, the selection of a repair product is acknowledged to also be dependent on factors such as cost and availability of materials.

A procedure for installing precast patches for partial-depth repairs is described; however, the rate of pavement preparation is too slow to make this procedure a viable alternative to cast-in-place patching.

PARTIAL-DEPTH REPAIR OF JOINTED PCC PAVEMENTS: CAST-IN-PLACE AND PRECAST PROCEDURES

by

Samuel S. Tyson
Research Engineer

INTRODUCTION

The deterioration of jointed portland cement concrete (PCC) interstate pavement in Virginia was investigated in an earlier phase of this study and discussed in a report that outlined the deterioration process, cited the major contributing factors, and described the resultant failure types.(1) Also, presented in that report were criteria to be used in pavement condition surveys to aid the engineer in determining the time to initiate permanent repairs.

Depending upon the combinations of factors contributing to deterioration and the extent to which the deterioration has progressed, pavement distress may be identified as partial-depth, full-depth, or both at a single joint. Similarly, repair procedures may be specified as being either full-depth or partial-depth.

A report has been issued describing the full-depth repair procedures employed in Virginia using both cast-in-place concretes and precast slabs.(2) On the basis of satisfactory performance, it was recommended that these procedures be continued as warranted by pavement maintenance needs and that they be used under detailed supervision and inspection in both state force and contract work.

PURPOSE

This report presents information concerning the partial-depth repair of jointed PCC pavements in Virginia. The principal topics discussed are —

1. the procedural factors that affect the performance of partial-depth cast-in-place pavement patches;

2. a procedure for evaluating patching materials through laboratory and field trials;

3. a method for use in maintenance planning to obtain guidance in utilizing various acceptable repair concretes; and

4. the findings from an experimental installation of precast patches for partial-depth pavement repairs.

SCOPE

Information has been obtained from sections of approximately 400 miles (644 km) of jointed PCC interstate pavement lanes on which more than 10,000 cast-in-place patches have been installed. Nearly all of these patches have been placed along transverse joints, with only an occasional patch being required away from the joints. The reasons for the type of failure repaired were discussed in an earlier document,(1) and the present report deals exclusively with patches adjacent to transverse joints.

The first section of this report presents information gathered in the study of partial-depth patches made with cast-in-place concretes. Discussed are the major procedural factors that have been determined to significantly affect the performance of partial-depth patches. Also, an evaluation procedure is described that was used to identify concretes with good potential for producing rapid and permanent partial-depth pavement repairs. Finally in this section, the average work rates observed for the installation of partial-depth patches are used to establish relationships among several repair concretes to estimate the number of patches that can be installed during a given lane closure period.

The second section of the report gives a brief description of precast partial-depth roadway patches that were installed in a separate study.(3) The installation and performance of these patches are discussed, and the concept of using precast units for partial-depth repairs is examined with respect to the production that is possible using cast-in-place alternatives.

CAST-IN-PLACE PATCHES

The information in this study concerning partial-depth cast-in-place roadway patches was gathered from a number of projects at various locations and times. Instead of presenting the findings by project or in chronological sequence, the following paragraphs present the information by subject areas and in the sequence that typical repair activities would be anticipated to occur.

Factors Affecting Patch Performance

Many concretes can be selected for use in partial-depth cast-in-place pavement repairs on the basis of satisfactory laboratory evaluations. For the successful employment of any concrete in the field, however, there are numerous procedural factors which, if ignored, can adversely affect the service life cf a patch. These procedural factors are encountered during the preparation of the pavement for patching and during the installation of the repair concrete. Some of them have a strong influence on the service life of the patch. The modification of repair procedures to eliminate the destructive effects of these factors has resulted in durable patches with service lives currently exceeding two years, and having a reasonable expectation of a number of years of additional service.

Other factors that affect the service life of pavement patches are traffic intensity and weather conditions. Requirements dictated by these factors can normally be satisfied by selecting concretes on the basis of satisfactory performance in laboratory evaluations of strength and durability.

Pavement Preparation

A procedure for recording pavement distress through visual condition surveys was presented in an earlier report.[1] A sketch of a typical transverse joint having several areas of partial-depth deterioration, or joint spalls, is shown in Figure 1. With this type of information for each joint in a roadway, a decision can be made as to the appropriate time to initiate permanent repairs. Because of the progressive nature of joint deterioration, such repairs should be considered not later than the time when visual survey results indicate that 20% of the joints are affected by partial-depth distress.

Location of Unsound Concrete

The visual survey results can be used to make a reasonable initial estimate of the extent of needed repairs on a roadway; however, the actual extent will always be greater, since a plane of rupture extends beyond the visually identified limits of joint spalls and in the early stage of spall formation the weakened plane may exist with no visual indications.

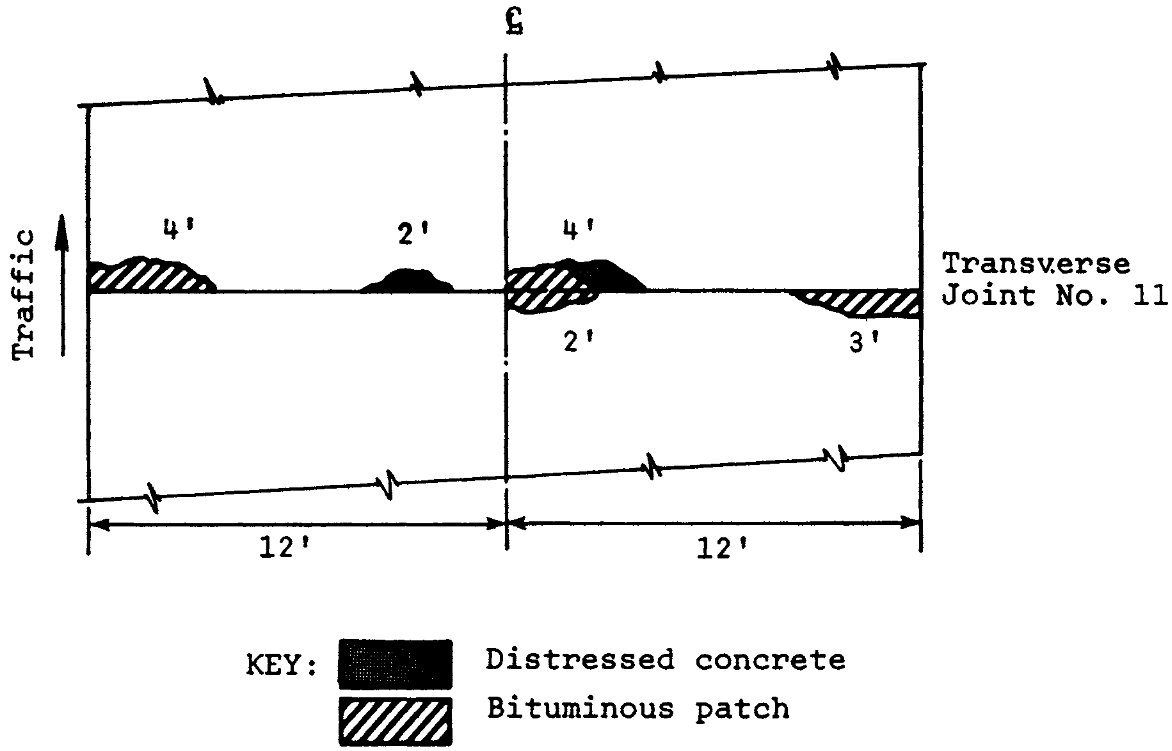


Figure 1. Typical spalls recorded in visual condition survey.

The technique that has been used to identify the total area affected by spalls relies on hammer soundings. A ball peen hammer is tapped on the pavement surface and areas issuing a clear ringing sound are judged to be serviceable, while those emitting a dull sound are considered to be weakened by ruptures and are marked for removal.

Joint spalls usually affect an area extending 6 to 12 in. (150 to 300 mm) from the transverse joint, however experience has shown that it is advisable to remove the concrete a minimum of 12 to 18 in. (300 to 450 mm) from the joint. The areas removed along the joint are typically 1 to 3 ft. (0.3 to 0.9 m) in width; however the area may extend along the full width of the lane.

Sawing

A saw cut having a minimum depth of 1 in. (25 mm) should be made along the perimeter of the pavement area to be removed. The area removed should be rectangular to provide a vertical face against which to cast the repair concrete, to give an aesthetically appealing appearance in the finished patch, and to prevent featheredging and resultant raveling of the repair concrete along the perimeter.

Removal

The partial-depth removal of the designated pavement areas can be accomplished quickly with jackhammers. The removal can be started with an 80 lb. (36 kg) hammer but should be finished with a 20 lb. (9 kg) hammer to allow removal of all loose concrete in the area and prevent damage to the underlying and surrounding concrete.

The depth to which the concrete is removed typically varies from 1 to 4 in. (25 to 100 mm) and averages approximately 3 in. (75 mm) over the majority of the patch areas. This removal technique results in a surface that is very irregular and is ideal for providing mechanical interlock between the cast-in-place repair concrete and the existing pavement.

The occurrence of spalls in areas adjacent to partial-depth patches has been practically eliminated as inspectors and maintenance supervisors have implemented the above procedures for locating, sawing, and removing unsound concrete.

Occasionally in partial-depth patching the full depth of the slab may be removed. This is particularly true for spalls that occur at the corner of the slab adjacent to the shoulder material.(1) However, if full-depth removal is consistently needed to eliminate unsound concrete in this and other areas of the transverse joint, it is probable that a full-depth repair technique is needed for the roadway.(2)

Patch Installation

Regardless of the type of cast-in-place concrete to be used in a patch, the installation must be made in similar logical steps. In the following paragraphs these steps are discussed and, where appropriate, examples are cited to demonstrate the problems encountered if the steps are performed improperly.

Concrete Production

The volume of concrete required for partial-depth patches may vary from 0.5 to 2.0 ft.^{3} (0.014 to 0.057 m^3). The use of ready-mix trucks for the supply of fresh concrete is therefore not desirable, since the maximum allowable mixing times for specified temperature ranges would be exceeded, even with normal Type II cement concrete, after only a small portion of the batch is used.

The production of good quality concretes has been readily accomplished using either drum or paddle type mixers with a capacity of 2 ft.^{3} (0.057 m^3). To provide quality control when numerous small batches of concrete are to be mixed in this way it is necessary to trial batch the concrete under conditions similar to those anticipated during the repair activity. Trial batching also affords an opportunity for personnel to become familiar with the material to be used. The cement, aggregates and admixtures for each field batch should be accurately measured into conveniently handled containers for delivery to the repair site. In Figure 2 a mixing operation that followed this type of preparation is shown. Sealed polyethylene bags on the truck contain preweighed cement and aggregates and the scales for weighing the final component, water, are on the tailgate.

The manufacturers of some products for pavement repairs prepackage all of the ingredients, except water, in a single bag. With proper planning this advantage can be realized for any repair concrete.

Another method of preparing concrete for partial-depth repair operations is to use a continuous mixer in which the materials are continuously batched by volume. The auger feed on such a mixer can be stopped when the correct amount of concrete has been discharged and a minimum of concrete is wasted. The guidance provided by ASTM C 685 will be helpful when a continuous mixer is used. This equipment will not always be available, however, and the size of the job may not be sufficient to effectively utilize its capacity.

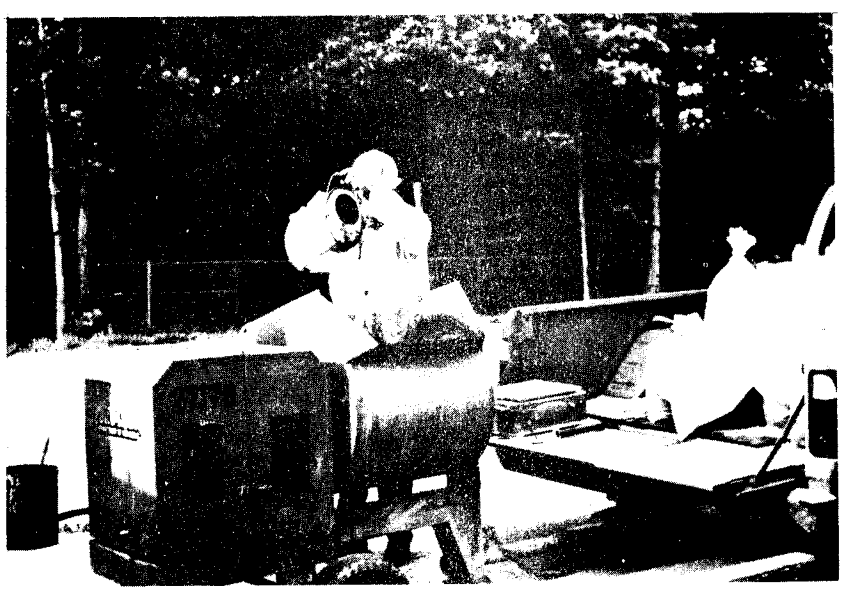


Figure 2. Mixing activity at repair site.

Forming

Prior to the placement of repair concrete in a prepared area it is important that all needed forms be in place. The three locations requiring attention are the centerline and transverse joints, and the shoulder.

The centerline joints between pavement lanes are provided to prevent warping stresses. The patch shown in Figure 3 was cast directly against the adjacent slab at the centerline joint, and raveling and minor spalling resulted from movement at this location due to normal warping stresses. This problem can be overcome by inserting a polyethylene strip along the centerline joint prior to casting the repair concrete.

A large number of partial-depth patch failures have resulted from no forming or inadequate forming at the transverse joint. In Figure 4 two patches are shown that have been cast together across the transverse joint. Before the transverse joint could be sawed and sealed the slab movements had disrupted the patches.

While the problem in Figure 4 is apparent and the disruption occurred soon after the patches were installed, other aspects of inadequate transverse joint forming are equally damaging. Table 1 gives performance data for 1,000 patches on one project on which casting was followed by insertion of a thin metal strip to form the transverse joint. Subsequently, the joints were sawed and sealed. Within 30 days, 9% of these patches had failed, and at an age of 1 year 95% had failed. The failures could not be attributed to continued general deterioration of the pavement because, as shown in Table 1, additional failures in the surrounding concrete were relatively minor.

Further studies showed that the patch failures resulted from a failure to form the total depth of the patches at the transverse joints. The lower portions of the partial-depth patches were therefore in contact with the adjacent slabs and the patches were subjected to the destructive effect of hydrothermal slab movements. The same type of concrete, as well as several other types, has since been installed with complete success in partial-depth patches using the forming technique shown in Figure 5. This technique utilizes a rectangular strip of styrofoam cut to form the full width and depth of the transverse joint for each patch. A polyethylene strip for forming the centerline joint is also visible in Figure 5.

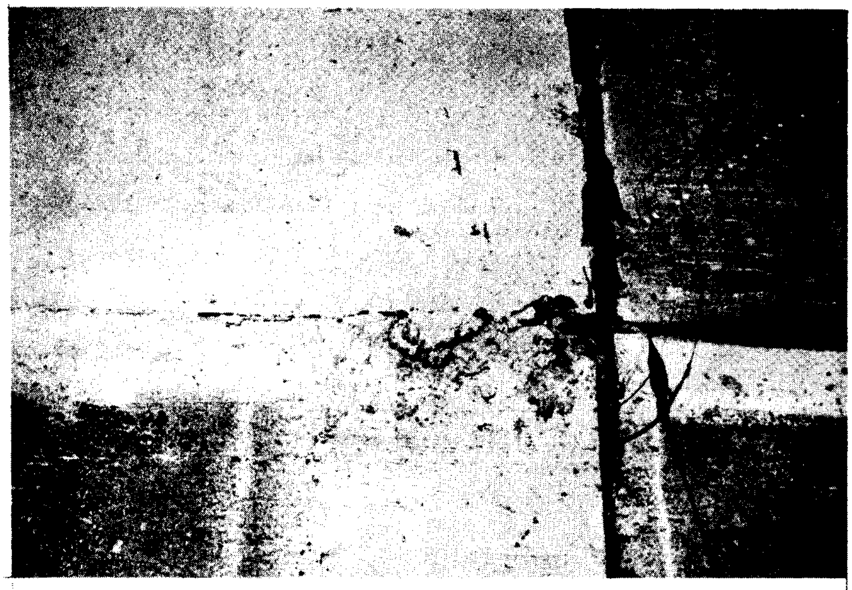


Figure 3. Raveling and minor spalling of partial-depth patch cast without forming at pavement centerline.

Figure 4. Partial-depth patches cast without proper forming at transverse joint.

Table 1

Performance of 1,000 Patches and Adjacent Joint Areas in One Repair Project

Time after patching	Patch failures as a Percentage of total patches	Additional spalls as a percentage of total patches
30 days	9	2
1 year	95	5

A similar problem has occurred in patches at the pavement shoulder. At this location repairs are normally needed for a unique combination of partial-depth and full-depth deterioration. Figure 6 shows a repair location of this type that was formed only in the upper area of the transverse joint face. The unformed lower portion of the transverse joint permits the vertical section of repair concrete to receive disproportionately high compressive loads across the transverse joint from the adjacent slab. After two years, patches of this type developed a splitting tensile failure as shown in Figure 7.

Corner patches with a higher ratio of full-depth to partial-depth contact areas at the transverse joint have developed more severe distress in the same two-year period. In Figure 8, patches of this type are shown, and it may be observed that the high compressive stresses transmitted through the patches have caused spalling to develop in the adjacent pavement areas most distant from the transverse joint.

The poor performance of these and other corner patches has made apparent the need to form the entire vertical face of the transverse joint that is exposed during concrete removal. Since the forming material below the 2-in. (50 mm) level will remain permanently in the joint, it should be composed of a compressible, durable material such as bituminous impregnated fiber boards. This material is available in different thicknesses, including 0.75 in. (19 mm). There is no available information that indicates an optimum form thickness for this application.

If shoulder material adjacent to the pavement is removed by erosion or disturbance during removal of the concrete, a vertical form should be placed parallel to the shoulder to prevent the repair concrete from filling the void and forming a key into the shoulder. Otherwise, the normal hydrothermal movements of the slab can cause the patch to be disrupted by the stationary shoulder.

Figure 5. Proper insertion of styrofoam to form transverse joint (right) and polyethylene strip to form centerline joint (top).

Figure 6. Corner location after removal of concrete showing partial-depth and full-depth zones.

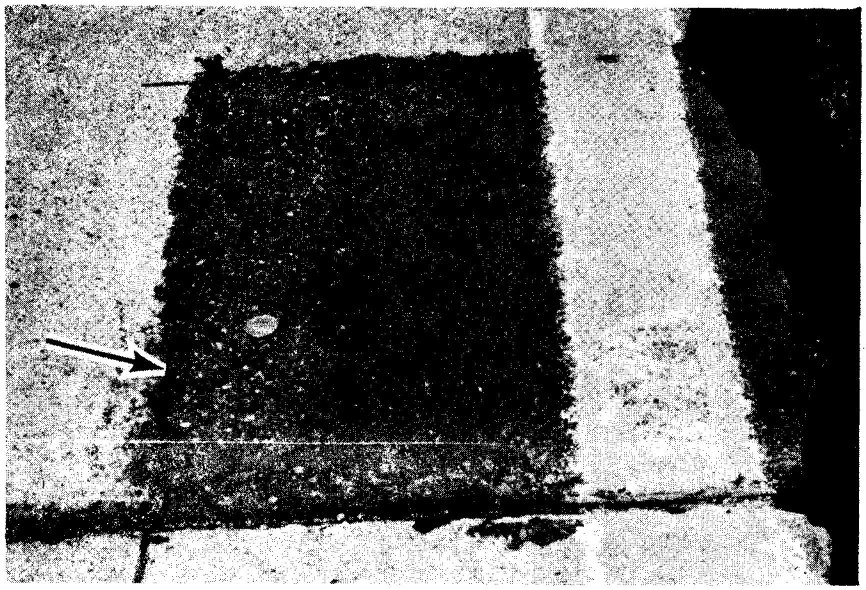


Figure 7. Splitting tensile failure adjacent to patch not formed below 2-inch (50 mm) level.

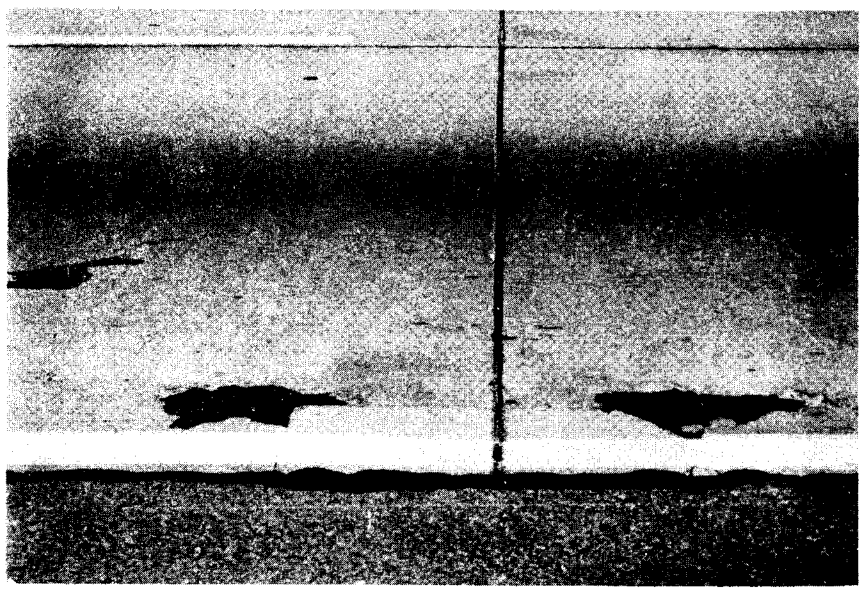


Figure 8. Spalling of adjacent pavement due to high compressive stresses transmitted through patches.

Consolidation and Bonding

In order for repair concrete to become an integral portion of a slab it must fill the space created by the removal of deteriorated concrete, and it must develop an adequate bond to the existing hardened concrete. Both requirements are related to the consolidation of the fresh concrete, since adequate consolidation should result in a patch with a maximum density and should provide the greatest amount of contact between the fresh and existing concretes for development of bond and for mechanical interlocking.

In the following subsection the subject of consolidation is briefly discussed and simple guidelines for the control and assurance of adequate consolidation in partial-depth patches are presented.

Consolidation. Consolidation of concrete is the process of removing randomly located volumes of entrapped air. The remaining mass, containing uniformly distributed entrained air volumes, approaches a theoretical maximum density which can be determined by the volumetric proportions of each constituent. In practice the maximum density is affected by the inhomogeneity of the mix, so an average value of the standard rodded unit weight (ASTM C138) is used to represent the maximum attainable density.

Methods employed in Virginia to consolidate concretes in partial-depth patches have been manual rodding and tamping and the use of vibrating screeds or internal vibrators. Each of these methods has advantages and disadvantages which will not be discussed here, with the exception of stating that of these methods, mechanical vibrators have given the most uniform and best quality of consolidation. Also, since standard models of internal vibrators seem to be more readily available among contractors than are the small versions of vibrating screeds, the trend in Virginia has been to encourage the proper use of internal vibrators for the consolidation of concretes in pavement patches.

Several approaches can be used to determine the adequacy of consolidation. These have included the coring of hardened field concretes both for direct measurements of density (ASTM C642), which can be compared to the standard rodded unit weight, and for determinations of void contents (ASTM C457, which can be compared to similarly determined void contents obtained either from samples of the field mixes (ASTM C172) or from samples of control mixes prepared in the laboratory (ASTM C192). While these two test methods yield quantitative results concerning the density of field concretes, the nature of the major physical problem resulting from the inadequate consolidation of partial-depth patches requires a third, qualitative, approach.

Figure 9 shows a core drilled from the central portion of a patch that emitted a hollow sound when struck with a hammer. The large void in the zone between the repair concrete and the underlying old concrete is clearly indicative of inadequate consolidation. This patch and others emitting a similar hollow sound when struck failed by cracking and spalling after being in service for less than one year. These patches were installed using the manual rodding and tamping method of consolidation.

The vertical section of a core that was drilled to include the horizontal and vertical interfaces between a patch and the existing concrete is shown in Figure 10. This patch was consolidated by the manual method and, although incomplete consolidation is indicated by the large void along the interface, this patch is still performing well after two years of service.

The marginal quality of patches represented by the core in Figure 10 has become apparent, however, in that a significant number of these patches have not provided satisfactory service. An early form of distress in such patches has been the occurrence of separations along the vertical interface between the patches and the existing pavement. The initial appearance of this distress may be seen on the top surface of the core in Figure 11. The vertical sections of this core are shown in Figure 12, where it may be observed that the repair concrete became dislodged from the pavement concrete in the process of preparing the sections. The repair concrete shown in Figure 13 exhibits a honeycombed condition similar to but more extensive than that shown in Figure 10. The distress observed at the pavement surface in Figure 11 is therefore concluded to be primarily the result of inadequate consolidation.

It has been demonstrated in this study that the elimination of visually detectable voids at the interface between the repair concrete and the existing pavement can readily and consistently be accomplished using an internal vibrator. Segregation of the mixes by the vibrator has not been a problem, and the proper consolidation of concrete throughout such patches has been verified quantitatively by void determinations (ASTM C457). An internal vibrator with a head diameter of 1 in. (25 mm) has been successfully used for consolidating repair concretes. After overfilling a patch area with enough fresh concrete to allow for a reduction in volume during consolidation, the vibrator is held at a small angle (15° to 30°) from the horizontal and moved through the concrete in accordance with a planned pattern such as that shown in Figure 14. The speed at which the vibrator is moved is determined by observing the surface of the concrete mix. Adequate consolidation is indicated when there is no further reduction in the concrete depth, the emergence of air bubbles ceases, and a smooth layer of mortar occurs on the surface. A typical core section from a patch that received this treatment is shown in Figure 15, where it may be observed that the irregularities along the interface with the existing concrete are completely filled and that the repair concrete is not segregated.

Figure 9. Large void in zone between patch and underlying old concrete due to inadequate consolidation. Note: Core dimensions are 4 in. x 9 in. (100 mm x 230 mm).

Figure 10. Incomplete consolidation in vertical section of core. Note: Core dimensions are 4 in. x 9 in. (100 mm x 230 mm).

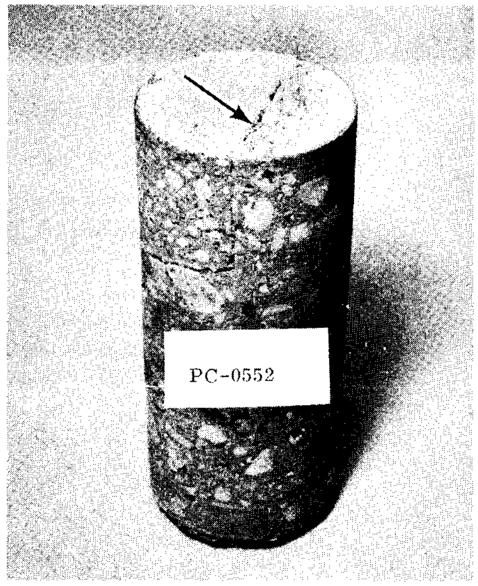
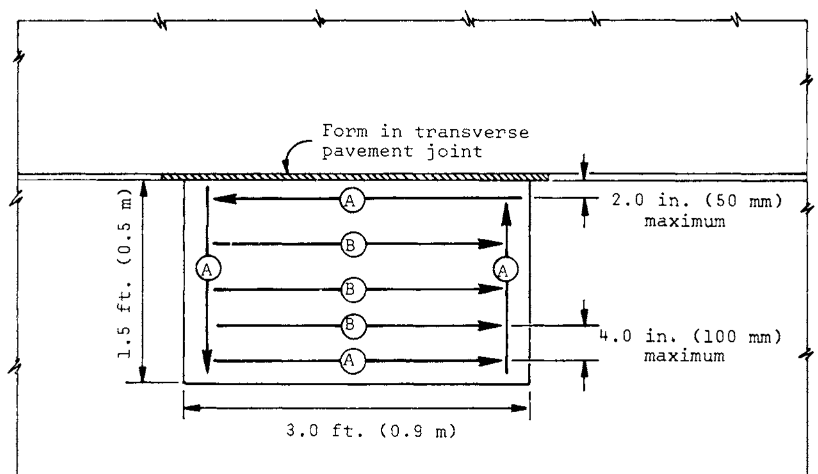


Figure 11. Appearance at pavement surface of distress between patch and existing concrete. Note: Core dimensions are 4 in. x 9 in. (100 mm x 230 mm).

Figure 12. Vertical sections prepared from the core shown in Figure 11.

Figure 13. Inadequately consolidated zone of repair concrete revealed in the core shown in Figures 11 and 12. Core dimensions are 4 in. x 9 in. (100 mm x 230 mm).



Paths marked A — maximum of 2.0 in. (50 mm) from patch periphery.
Paths marked B — maximum of 4.0 in. (100 mm) from other paths.

Figure 14. Plan of typical patch area showing paths for internal vibrator.

Figure 15. Typical core section from patch where planned pattern for internal vibration was used. Note: Core dimensions are 4 in. x 9 in. (100 mm x 230 mm).

The next subsection begins with the premise that adequate consolidation can be obtained, and discusses the findings from a laboratory investigation of several alternative systems for bonding fresh concrete to hardened concrete.

Bonding. The bond strengths between repair concretes and field concretes have not been determined in this study, however an investigation of the bond strengths between fresh and hardened concretes was conducted in the laboratory. Based on the observation that intimate contact between fresh and hardened concretes can be achieved in the field, as was shown in Figure 15, it is reasonable to assume that a similar potential for the development of bond exists in both the field and laboratory.

The laboratory investigation of bond strengths was conducted using hardened base blocks of concrete with depths of 4 in. (100 mm) and moderately textured planar surfaces measuring 6 in. x 7 in. (150 mm x 175 mm) onto which fresh concrete overlays with a depth of 2 in. (50 mm) were placed. The overlay concrete, containing Type II cement accelerated with 2% of $CaCl_2$ by weight of the cement, was consolidated by external vibration from a vibratory table on which the molds containing the base blocks were mounted.

The four bonding systems tested included the base and overlay concretes with a plain interface and with the interface precoated with a Type II cement slurry, a high alumina cement slurry, and an epoxy resin compound. The overlay concrete developed a compressive strength of 2,000 psi (13.79 MPa) in one day. The composite specimens were cured in a moist environment to await testing. The shear strengths were measured by clamping the base portion of the blocks in a special testing apparatus and applying a load to the overlay portion in a direction parallel to the bond interface.

The test results for each system at ages of one day and 28 days are shown in Figure 16. The strengths may be interpreted on the basis of published data from research on bonding systems for pavement overlays which showed that strengths of 200 psi (1380 kPa) are adequate for good performance, and that strengths exceeding 400 psi (2760 kPa) represent excellent bonds. As seen in Figure 16, all of the systems had developed excellent bond strengths at the age of 28 days. The one-day results, however, were best for the two systems incorporating cement slurries.

The early development of bond strength is important for pavement patching applications since, depending on the compressive strength of the particular concrete being used, traffic loadings are normally anticipated after curing periods of one day or less. Therefore the patch area should be painted with a thin coating of cement slurry as shown in Figure 17 just prior to casting the repair concrete. The slurry should be compatible with the repair concrete selected, and if adequate consolidation is provided good bond strengths should develop.

Screeding and Finishing

Cast-in-place patches can be manually screeded to the proper grade using a stiff board. The small size of the patches normally allows space for the board to rest on the adjacent surface of the slab being repaired so that the screed can advance in a direction perpendicular to the transverse joint. If large sections of the transverse joint are being repaired, or if repairs are being made on both sides of the joint, the patch can be screeded across the joint with appropriate precautions to avoid disturbance of the form inserted in the transverse joint.

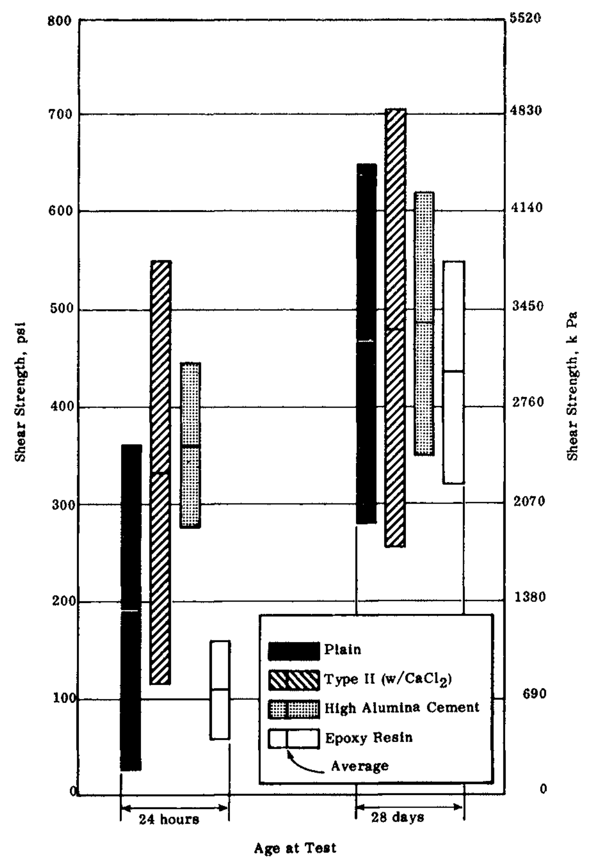


Figure 16. Shear test results for four bonding systems.

Figure 17. Thin coating of cement paste improves early bond development between repair concrete and pavement.

Hand troweling of the patch surface removes any remaining irregularities and, most importantly, provides a good finish for the edge of the patch adjacent to the transverse joint into which a sealant must be installed after hardening of the concrete. Also, following the troweling some mortar from the patch can be used to fill the saw cuts which extend into the adjacent pavement at the patch corners.

Partial-depth patches typically occupy a maximum of 5% of the roadway length measured along any two consecutive slabs. The surfaces of the patches may not have a great influence on the skid resistance of the roadway; however a textured finish can easily be applied to the patches using a broom with stiff bristles so that the patches will have a texture similar to that of the surrounding concrete.

Curing

The application of curing materials to the surface of patches is important, because moisture losses can occur quickly from the relatively large surface of these shallow placements. Moist burlap and polyethylene must be removed when the roadway is opened to traffic and the sudden drying can cause shrinkage cracks. The most effective cure can be provided under hot weather conditions by a white pigmented curing compound since it reflects radiant heat, allows the heat of hydration to escape, and can provide curing protection for several days until worn away by traffic. When patching under cold weather conditions the loss of heat can be reduced by the addition of insulating materials such as blankets, straw, sand or burlap, or heat may be supplied from an external source if conditions are severe.

Subsequent Procedures

The successful installation of partial-depth pavement patches does not indicate an end to maintenance activities that may be needed to assure continued satisfactory performance of the patches and the remaining slab sections at the transverse joints. In order to prevent the recurrence of partial-depth distress and the development of full-depth deterioration at these joints, the destructive mechanisms must be neutralized. The preventive maintenance procedures that will normally be needed to complement pavement patching are the cleaning and sealing of joints and the reconditioning or improvement of drainage components.

Cleaning and Sealing Joints

The contribution of incompressible materials to the problem of spalling was clearly demonstrated in an earlier report which detailed the progressive deterioration of transverse PCC pavement joints.[1] That report also showed the contribution to the spalling problem of corroded tubular metal inserts that were used to form transverse contraction joints and longitudinal joints in many PCC pavements in Virginia. Since both of these conditions are frequently found together at the transverse joints, continued deterioration of these joints is likely to occur after portions of them have been patched.

The procedure used to remove both incompressibles and the embedded remnants of corroded metal inserts consists of making a saw cut 2.5 in. (64 mm) in depth along each face of the joints. After this volume of weakened concrete, along with the corroded metal and incompressibles, is cleaned from the joint a preformed chloroprene sealant is inserted to guard against future intrusions of water and incompressible materials.

Assuring Proper Drainage

The longitudinal joint between the pavement and the shoulders is a primary location for the ingress of water to the pavement subbase. The placement of poured sealants in these joints and the undersealing of slab areas that have lost subbase material due to traffic induced pumping may be the most effective means for halting the deterioration attributable to this drainage problem.

The pavement subbase cannot be protected from the intrusion of all surface water, however, and if the subbase and shoulder materials do not allow the water to flow away from the slab, then additional procedures will be needed to ensure long-term satisfactory performance of the pavement. One solution may be the installation of edge drains, consisting of graded aggregates or perforated pipe, and outlets to allow water to flow through the shoulders.

The analysis of drainage components is beyond the scope of this study, however the subject is being investigated.[4]

Materials Evaluation

The evaluation of patching materials is an ongoing process that begins prior to the initial field usage of a material and, ideally, should continue not only for subsequent usages but also throughout the service life of each installation. It is only through continuing evaluations that patch failures resulting from materials factors can be distinguished from those resulting from the procedural factors discussed previously.

The general approach used by the Virginia Department of Highways and Transportation for the evaluation of concrete patching materials has included both laboratory and field testing phases. The laboratory phase has proved to be an effective means for identifying concretes that have good potential for satisfactory performance when exposed to typical service conditions in the field. This approach is, in fact, part of an overall program used by the Department for the evaluation of special products. An important aspect of this program is the feedback from the field concerning the performance, both good and bad, of materials under service conditions.

Concrete Properties

A large number of proprietary products have been and continue to be marketed for PCC pavement repairs. The majority of such products consist of hydraulic cements or admixtures.

The materials submitted by manufacturers to the Department for evaluation generally are accompanied by results of physical testing and instructions for mixing and placement. This information, supplied by the manufacturer or an independent laboratory, is important since it provides the basis for initial decisions regarding the usefulness of the product and particularly the time after mixing at which initial strength testing should begin. The major physical properties that are then determined from trial batches of a candidate repair concrete are its workability, strength, and durability.

Concretes that have been found to be acceptable for cast-in-place patching during this study are identified in Table 2 in terms of curing times and primary constituent products.

Workability

The workability requirements of a repair concrete include not only the consistency as measured by the slump cone, but also the amount of time allowable for placement of the concrete after mixing. The need for this information becomes apparent when it is recognized that ultimate strengths are developed in periods of hours instead of days, and similarly that the set times are frequently measured in minutes rather than hours. Even though all rapid hardening concretes are not rapid setting, because of the small volumes of concrete associated with individual partial-depth patches, the trend among contractors and state force crews is to produce small batches, as described earlier, from continuous mixers or from small drum or paddle type mixers. Minimum working times of 15 minutes are desirable, and with the equipment normally available for consolidation, slumps in the range of 1 to 5 in. (25 to 127 mm) are acceptable.

Table 2

Products for Cast-in-Place Patching Concretes

Concrete curing time, hours	Product Description
1.5	Portland cement-gypsum blend
4.0	Calcium aluminate cement
7.0	Prepackaged concrete materials with air-entraining, accelerating and shrinkage compensating admixtures.
16.0	Type II cement with $CaCl_2$
16.0	Type I-P cement with $CaCl_2$
16.0	Type II cement with non-chloride water reducing accelerator and wire fiber reinforcement.

Note: Ambient and initial mix temperatures 72°F (22°C).

Strength

Paving concrete in Virginia has a design minimum laboratory compressive strength of 3,000 psi (20.7 MPa) at 28 days. It is apparent that repair concretes should be satisfactory from the standpoint of strength if they can develop an equal or greater strength by the time they receive traffic loadings. On the other hand, in order to minimize lane closures, it would be desirable to allow traffic loadings on a patched area when the repair concrete has attained the minimum strength needed to assure its structural integrity.

Factors that favor the lowering of compressive strength requirements for the release of partial-depth cast-in-place patches to traffic are the lateral confinement and shallow depth of such patches. However, at some point the performance of patches would be affected by failures associated with proportionately lowered tensile and bond strengths and abrasion resistance.

In Virginia, for the last two years, the compressive strength requirements for concrete in partial-depth patches has been reduced to 2,000 psi (13.8 MPa). This reduction has proved to be a positive step since lane closure times have effectively been shortened, additional materials have thereby become qualified for use in permanent pavement repairs, and the performance of the resultant patches has been good. Even lower strengths may be satisfactory, however, sufficient data are not currently available to support further reductions.

Durability

In addition to having the strength characteristics to withstand traffic loadings, repair concretes must be capable of resisting deterioration from freezing and thawing cycles. Because deicing salts are used on pavements in Virginia, the laboratory test used for the evaluation of freezing and thawing resistance of patching concretes consists of ASTM C666, Procedure A, modified by including 2% NaCl, by weight of water in the water surrounding the specimens.

The specimens used in this test are concrete prisms measuring 3 in. x 4 in. x 16 in. (76 mm x 102 mm x 406 mm) that have been moist cured for 14 days and air dried for 7 days. The fundamental transverse frequency and the specimen weight are determined initially, and the test is continued either through 300 cycles or until its relative dynamic modulus of elasticity reaches 60% of the initial modulus. Acceptable repair concretes typically have durability factors of 85% or better. The material is rejected if within the 300 cycle period the durability factor goes below 60%, if the weight loss exceeds 7.0%, or if the visual surface rating exceeds 3.0. These criteria are summarized in Table 3.

Table 3

Freezing and Thawing Test

Performance Criteria		
Minimum Durability Factor, Percent	Maximum Weight Loss, Percent	Maximum Surface Rating*
60	7.0	3.0

*Surface rating system:

0 = no scaling

1 = very slight scaling 1/8 in. (3 mm) max. depth — no coarse aggregate visible

2 = slight to moderate scaling

3 = moderate scaling (coarse aggregate visible)

4 = severe scaling

Evaluation Procedure

The evaluation of new products, including those for pavement repairs, is a primary responsibility of the Materials Division of the Department, however, due to practical considerations such as the determination of a specific need for new materials, the degree of use anticipated, the geographical location of the repairs, and the judgmental factors associated with assessing the performance of individual installations, the responsibility is shared by the Research Council and the eight construction districts.

The general procedures by which the evaluation of new products for the repair of PCC pavements has been accomplished are presented in the flow chart in Figure 18.(5) When a new product is introduced, generally by sales and technical representatives, to personnel in the Materials Division, the Research Council, or one of the construction districts, the need to evaluate the product for pavement repair applications is established on the basis of an individual judgment. The proliferation of available repair materials necessitates the rejection of materials at this point if sufficient test data, either from the manufacturer or from independent users, are not available to substantiate the basic claims concerning the properties and performance of the product.

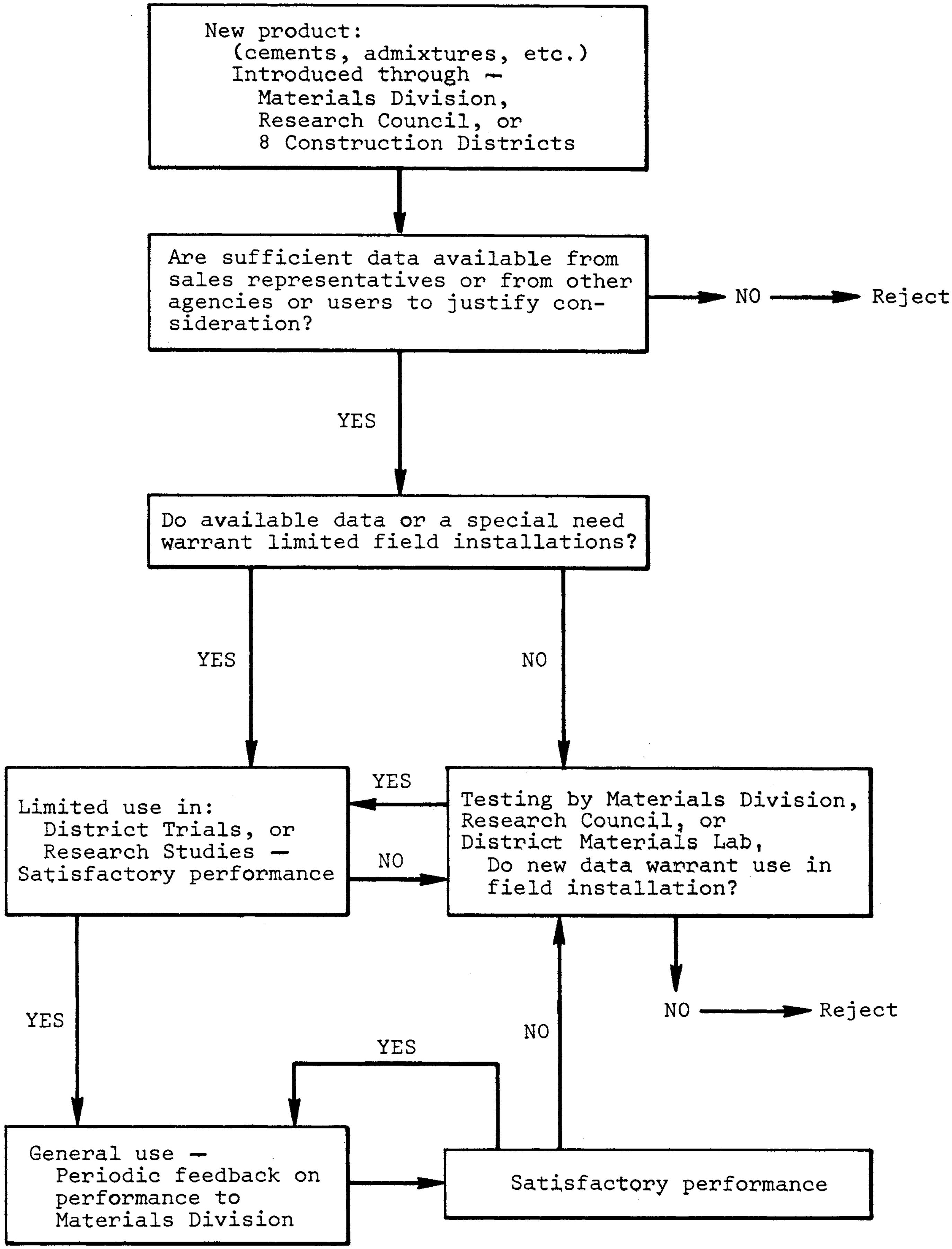


Figure 18. Evaluation of new products for repair of PCC pavements.

Some materials will have sufficient documentation to warrant immediate limited use in field trials; however, most will require additional testing by the Department, primarily because of the different test procedures that other laboratories have used to generate data. If the repair product fails to satisfy the requirements for concrete properties, which were discussed earlier, it is rejected. However, if the product demonstrates good potential for satisfactory performance it is accepted for limited use in pavement repairs. Either route to limited field installations of a product requires that observations of performance be made. If the repairs do not perform satisfactorily and the cause of failures is found not to result from operational factors, the product may then be rejected.

Products that provide satisfactory patch performances in limited field installations for periods exceeding one year are probably suitable for general use in pavement repair operations. At this stage it is still desirable to assess the performance of the product and to distinguish patch failures that are related to concrete properties from those that are related to procedural factors. If the concrete properties are not adequate for field conditions, the product should be rejected for further use.

Evaluation List

The communication of findings is an important aspect of new product evaluations. This is particularly true since there are ten separate offices which could simultaneously be considering the use of a product. The Materials Division has therefore organized a "Special Products Evaluation List" which is circulated throughout the several offices annually. The list includes products that are being evaluated or that have been evaluated for various applications, patching materials being one of the categories. The information listed for each product includes the trade name and manufacturer, notes concerning the date, location, and approximate size of any trial installations, and a recommendation regarding its acceptability.

The list can be used effectively to avoid duplication of effort in the evaluation process, and as a means of identifying products that should and should not be used.

The special products evaluation list does not provide detailed guidance for the mixing and placement of repair materials. Technical information is available from the Materials Division, however, and technical assistance is normally provided by product manufacturers.

Maintenance Planning

The planning of maintenance activities involves input from various sources concerning such factors as the extent of repairs needed, the funding available, and the requirements for traffic control. The selection of a product or products to be used in repair concrete is influenced by each of these factors. It is not simply a matter of selecting the product which produces the most rapid hardening time or the product which costs the least per unit volume of concrete, although these are important considerations. An approach has been developed in this study to simplify the problem of selecting repair materials by demonstrating the production that is possible using various repair concretes during typical lane closure periods.

In a contract repair operation observed for this purpose the crew consisted of ten men assigned to the tasks of concrete removal and patch installation. The location of unsound concrete and sawing of repair limits had previously been accomplished. The partial-depth patches had an average surface area of 4 ft.^{2} (0.4 m^2) and an average depth of 4 in. (100 mm). The concrete was mixed on this operation in a paddle type mixer similar to the one shown in Figure 2. During an eight-hour nighttime period an average of 13 cast-in-place patches per hour were installed using a particular type of repair concrete. At various times during the contract period, an auxiliary crew of state force personnel took over the patch installation activities and installed a total of six types of repair concretes. Only minor variations in the installation rate were observed, and the average rate of 13 patches per hour was determined to be independent of the repair materials used. Therefore, for a repair activity using typical cast-in-place concretes the relationship between the installation period and the total number of patches installed can be depicted as in Figure 19. The relationship has been extrapolated to a total work period of 10 hours, which is a reasonable upper limit on the time a crew might be expected to work.

The average pavement surface area of patches in future repair projects could be significantly different from the area of 4 ft.^{2} (0.4 m^2) cited above, particularly if repairs extend across a full lane width. Therefore, a more generally useful expression for the installation rate may be 52 ft.^{2}/hr. (4.8 m^2/hr.), and the resultant total patch surface areas associated with installation periods are also shown in Figure 19. Throughout the remainder of this report, however, illustrations will be made using the total number of patches installed instead of the total patch surface area, since the average surface area of 4 ft.^{2} (0.4 m^2) per patch is applicable.

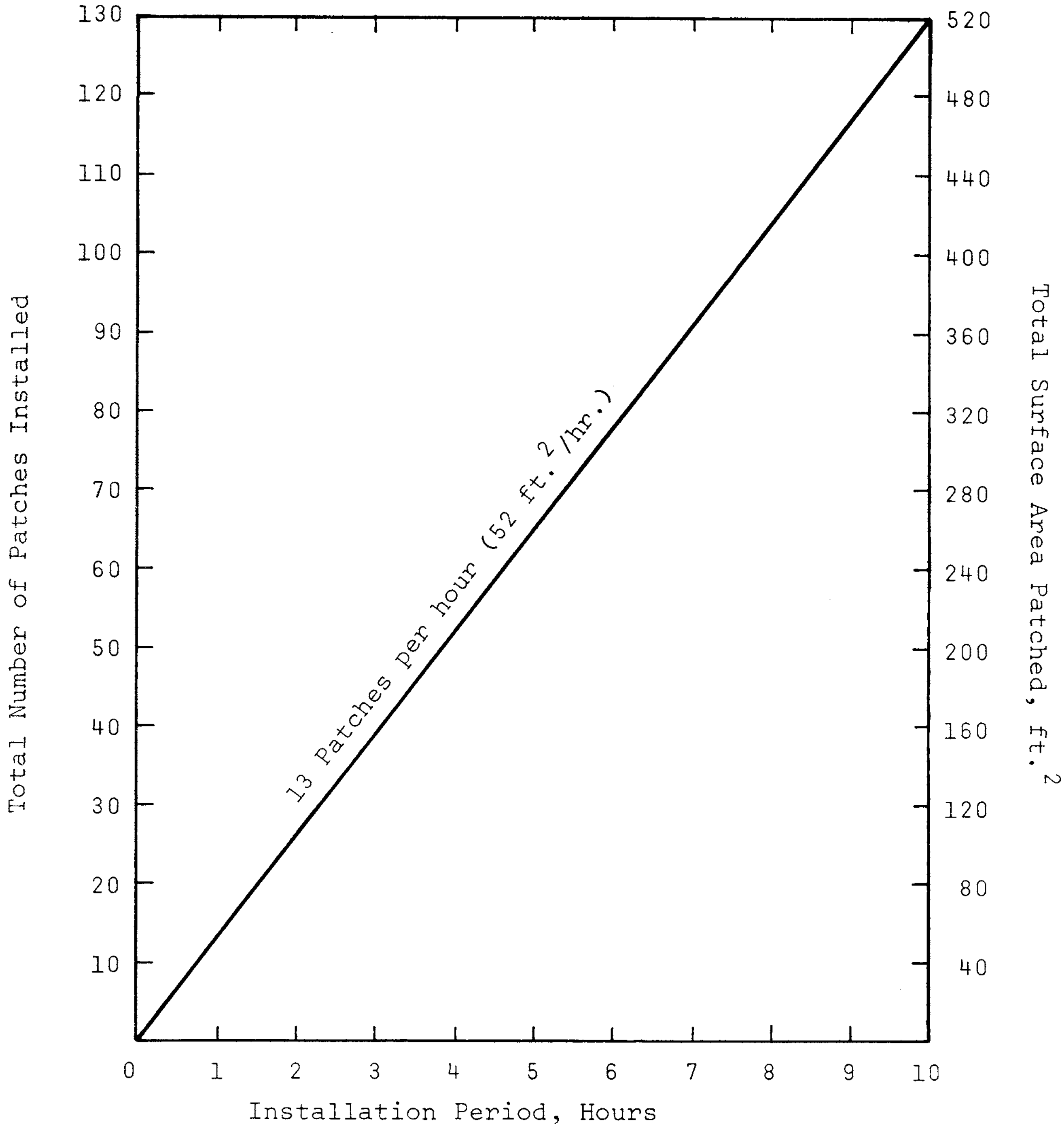


Figure 19. Average installation rate for typical cast-in-place repair concretes. (Conversion: ft.^{2} x 0.093 = m^2)

Regardless of the duration of the installation period, there are fixed times for several activities associated with pavement repair operations that must be recognized. For the placement of traffic control devices and movement of work personnel and equipment into the job site from a planned staging area, plus the removal of traffic control devices at the end of the operation, a minimum total time of one hour is needed. Also, each repair concrete has a predetermined cure period at 72°F (22°C) to attain the design minimum compressive strength of 2,000 psi (13.8 MPa). These fixed times can be added to the installation time to determine the total lane closure period. Different curing temperatures in the field may significantly affect cure times, however, and trial batches should be made for the job conditions.

In the planning stage the maximum allowable lane closure period is normally fixed. Therefore, relationships between the number of patches that can be installed, using given repair concretes, and the total lane closure period have been established. Figure 20 is a production chart for cast-in-place concretes having different cure periods. For each material the beginning of the installation period is offset along the horizontal (lane closure period) axis by an amount of time equal to the one hour fixed period plus the duration of the predetermined cure period, at 72°F (22°C), for each concrete. Similarly any additional repair concrete may be represented on the chart by a line having an equal slope and an intercept on the horizontal axis equal to one hour plus the duration of its cure period.

Once the lane closure requirements for a proposed repair site are determined, a chart such as that in Figure 20 may be used, if appropriately updated to include all acceptable repair concretes, to determine the alternative products that can be used, their predetermined cure periods, the length of the allowable installation period for each concrete, and the number of partial-depth patches that can be installed during each installation period. For example, referring to Figure 20, if an allowable lane closure period of 10 hours were specified, three repair concretes could be considered for use. The first, having a required cure period of 7 hours, would allow a 2-hour installation period in which 26 patches could be installed. The second, with a 4-hour cure period, would allow a 5-hour installation period in which 65 patches could be installed; and the third, with a 1.5-hour cure period, would allow a 7.5-hour installation period in which 95 patches could be installed.

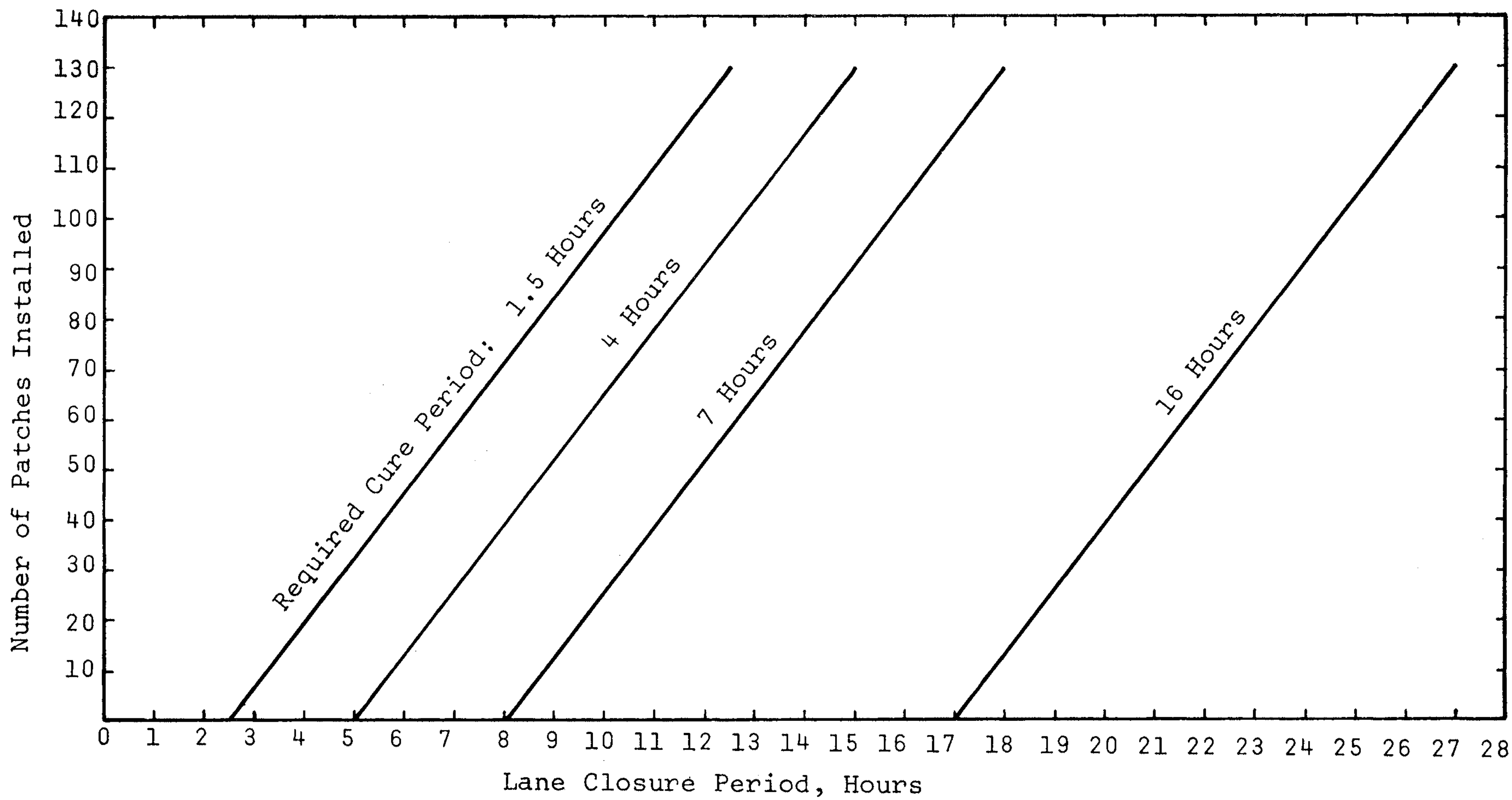


Figure 20. Production chart for concretes having different cure periods.

Finally, if a reasonable estimate of the total number of partial-depth patches needed is specified, the total number of lane closures that would probably be incurred with the use of each concrete can be computed. The safety of the roadway is of prime importance and the minimum number of closures is most desirable; however, the cost and availability of each product may vary with time. Therefore, in order to ensure that a job can be completed in the shortest time for the least cost, the flexibility to make alternative product selections appears essential. Also, it may be beneficial to include two or more products in a single project. Such flexibilities are made possible by the current procedures for new product evaluations, and the production chart in Figure 20 can serve as an aid to the effective utilization of approved products.

PRECAST PATCHING

The study of repair procedures for jointed PCC pavements in Virginia has included the concept of employing precast units. Precast slabs measuring 6 ft. x 12 ft. x 8 in. (1.83 m x 3.67 m x 200 mm) and containing conventional reinforcing steel were initially evaluated for full-depth repairs, the need for such repairs being at isolated joints where excessive spalling or blowups had disrupted the structural integrity of the pavement. This full-depth procedure has enabled state force personnel to respond rapidly to critical repair situations, and lane closure times of 1.5 hours have been achieved. More than 200 full-depth precast slabs have been placed and are providing satisfactory service.[2]

Partial-Depth Installations

Precast patching has also been considered as an alternative to conventional cast-in-place procedures where partial-depth repairs are needed. The feasibility of producing durable repairs using partial-depth precast slabs was demonstrated by the New York Transportation Administration in 1971.[6] Two precast patches having areas of approximately 3 ft.^{2} (0.3 m^2) and thicknesses of 2 in. (50 mm) were installed in the Queen's Midtown Tunnel by city maintenance personnel. The deteriorated pavement was removed using conventional jackhammers and the patches were seated in a Type III cement mortar containing a set accelerator. The total lane closure period for the two repairs was six hours.

An investigation of precast patching was initiated in Virginia in 1974 to evaluate a mechanized approach to pavement repairs. The principal equipment item involved was the Klarcrete cutter. This machine contains a series of pneumatically activated impact hammers which can be positioned over damaged pavement areas and controlled to cut rectangular sections to a maximum depth of 4 in. (100 mm). A detailed description of the machine along with the location records for precast patches installed with the use of the machine has been reported.(3)

Performance

Three types of patches were installed using the Klarcrete machine. A cast-in-place concrete, already accepted for use in pavement repairs utilizing conventional jackhammers for concrete removal, was designated for 22 patch locations to serve as a control section for evaluating the ability of the machine to remove unsound concrete. In Table 4 it can be observed that only 9% of these patches had some cracking at two years, which indicates that the mechanized technique is capable of successfully removing sufficient amounts of deteriorated concrete in most cases.

Table 4

Performance at Two Years of Patches Installed in Areas Prepared by Klarcrete Machine

Type Patch	Number Installed	Number Cracked	Percentage Cracked
Cast-in-place	22	2	9
Precast — hydraulically pressed	50	15	30
Precast — wire fiber reinforced	18	0	0

The second and third types of patches were precast units with a depth of 2 in. (50 mm) and various plan dimensions from 1 ft. x 2 ft. to 2 ft. x 3 ft. (0.3 m x 0.6 m to 0.6 m x 0.9 m), which are comparable to the sizes of typical cast-in-place partial-depth patches. The two types of precast patches consisted of an hydraulically pressed concrete developed in England for use with the Klarcrete machine and wire fiber reinforced patches prepared at the Research Council. Both types of precast units were seated on and bonded to the existing pavement with a sand-epoxy grout. The two-year performance of the precast patches is indicated in Table 4, where it is shown that 30% of the hydraulically pressed units developed cracks in that period, whereas no deterioration of the wire fiber reinforced patches has been observed.[7] Additionally, three of the pressed patches were impregnated, prior to installation, with methyl methacrylate to form polymer impregnated patches. The performance of these patches was similar to that of the other pressed patches.

The probable causes for cracking of the hydraulically pressed slabs are twofold. First, when the units are placed manually on the epoxy mortar bedding there is a likelihood that significant voids will remain under some portions of the patch. The inherent weakness of concrete in tension could thereby have led to cracking by flexural loadings from traffic. Second, since all of the precast patches were 2 in. (50 mm) in thickness, the epoxy mortar was also 2 in. (50 mm) in depth when the maximum removal of depth of 4 in. (100 mm) was required to reach a sound base. Tensile stresses resulting from thermal strain incompatibility between the patch and mortar therefore may have contributed to the cracking of such patches.

The wire fiber reinforced patches were subject to the same conditions the other precast units may have experienced. The superior performance of the wire fiber reinforced patches is attributed to the ability of their reinforcement to resist the formation of cracks, or nominally to inhibit propagation of cracks to the patch surface where they could be observed.

Production

The Klarcrete machine has been successfully used to install durable pavement repairs with wire fiber reinforced patches. The production that is possible with this procedure can be viewed in the proper perspective by comparison with the various cast-in-place alternatives that are available. In Figure 21 the production chart from Figure 20 has been overlaid with similar data from the precast patching activity. The precast procedure can offer competitive lane closure periods in critical situations where one or two patches are required. The only way to increase production with this procedure is to increase the number of machines, as projected in Figure 21, so that the preparation of two or more patch locations may take place simultaneously, but this is probably not feasible due to the large investment in equipment that would be needed.

The current practice in Virginia is to install temporary bituminous patches in joint spalls as they occur. This routine maintenance activity requires a minimum of disruption to traffic and serves to restore the trafficability of roadways for six months to one year, at which time a comprehensive repair activity can be initiated to replace all deteriorated concrete, clean and seal joints, and provide drainage as needed.

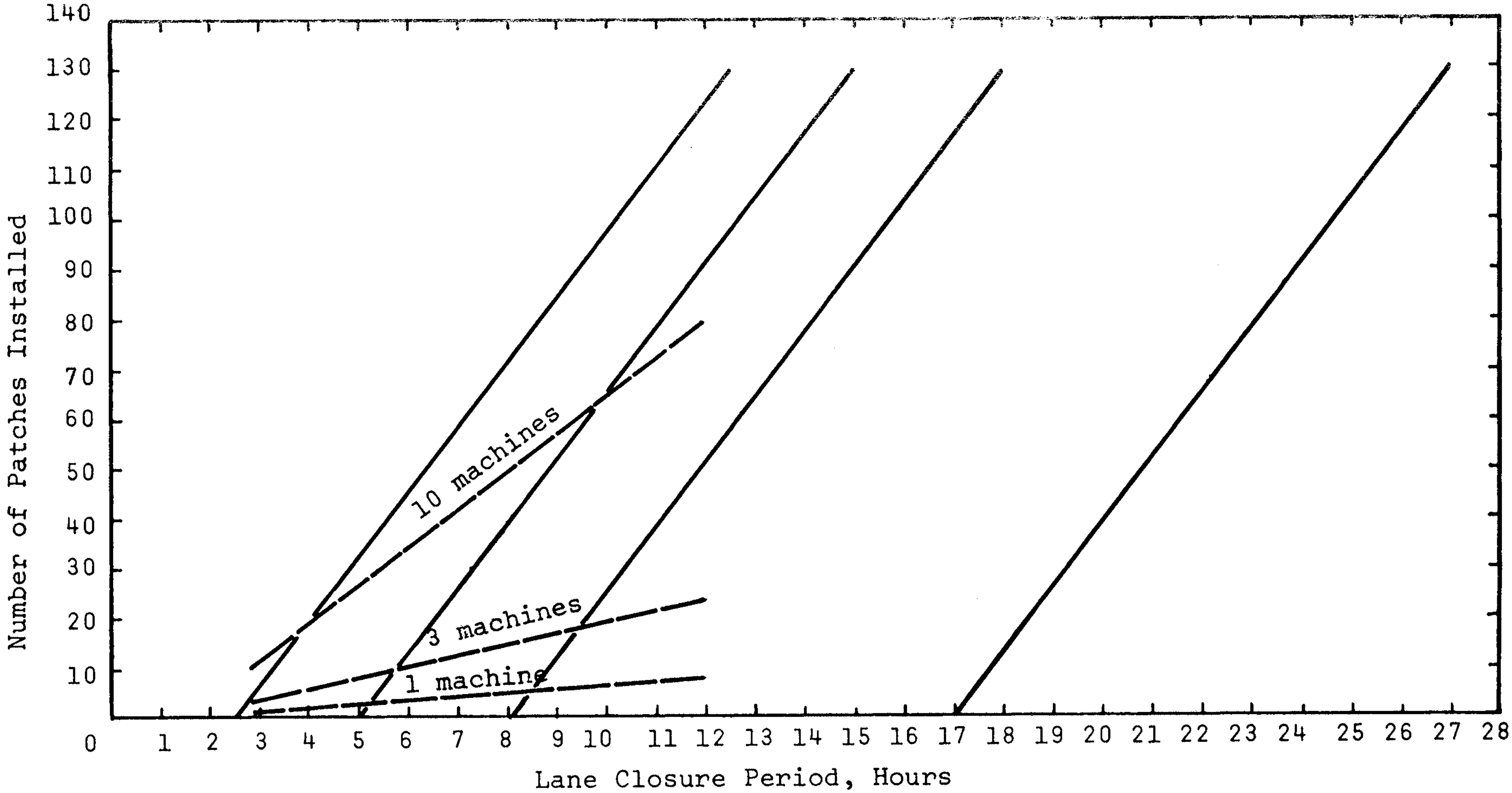


Figure 21. Production chart for precast patches installed using Klarcrete machine(s).

OBSERVATIONS AND CONCLUSIONS

This investigation of procedures for the partial-depth repair of jointed PCC pavements has led to the following observations and conclusions.

1. Durable partial-depth repairs have been installed on jointed PCC pavements using several types of cast-in-place concrete, and the factors affecting the performance of such patches have been identified in the procedures occurring before, during, and after patch installation as outlined below.

   a. Pavement preparation —

      Location of unsound concrete

      Sawing

      Removal

   b. Patch installation —

      Concrete production

      Forming

      Consolidation and bonding

      Screeding and finishing

      Curing

   c. Subsequent procedures —

      Cleaning and sealing joints

      Assuring proper drainage

2. The evaluation of proprietary repair products is being accomplished by an ordered approach that consists of:

   a. establishing minimum criteria for concrete properties as workability, strength and durability, which are determined in the laboratory;

   b. allowing field use of products exhibiting good potential for satisfactory performance; and

   c. obtaining feedback from the field during and after any installation.

3. An average installation rate for cast-in-place patching has been determined and used to show on a production chart the probable number of patches that can be installed during typical lane closure periods using each of several concretes having different curing time requirements. For a particular lane closure period there may be several acceptable concretes; however the actual selection may be dependent on variable factors such as cost and availability of materials.

4. Precast patches have been used to produce durable repairs; however because of the long period needed to prepare partial-depth locations, this procedure is not competitive with normal cast-in-place repair procedures.

RECOMMENDATIONS

1. The procedural factors that affect patch performance, as described in this report, should be used as a guide for the preparation of partial-depth repair areas and for the installation of cast-in-place patches.

2. The procedure for the evaluation of proprietary repair products, first through laboratory testing and, where warranted, through field installations and assessments of performance, is effective and should be continued.

3. The "Special Products Evaluation List" maintained by the Materials Division of the Virginia Department of Highways and Transportation should be consulted in the selection of cements, admixtures, and other special products for repair concretes.

4. There may be several repair products that result in concrete curing times which are compatible with a specified lane closure period, and flexibility should be encouraged in the selection of products to allow for an appropriate response to variable factors such as cost and availability of materials.

5. The limited production capability of the precast procedure for partial-depth repairs does not warrant a continuation of its use at this time.

3002

ACKNOWLEDGMENTS

Information for this report was obtained through the cooperation of personnel from the Culpeper, Fredericksburg, and Suffolk Districts of the Virginia Department of Highways and Transportation. Special assistance with the experimental work in the study was provided by C. M. Clarke of the Suffolk District, R. P. Wingfield and J. M. Gencarelli of the Central Office, numerous other employees of the Department, and C. E. Giannini and R. W. Gunn of the Research Council. Their efforts are gratefully acknowledged. The cooperative efforts of the contractors involved in these repair activities, namely, the Central Atlantic Company of Aberdeen, Maryland and Pavement Specialists Incorporated of Napoleon, Ohio, are also acknowledged with appreciation.

The study was conducted under the general direction of J. H. Dillard, state highway research engineer, and was financed from state research funds.

3004

REFERENCES

1. Tyson, S. S., and K. H. McGhee, "Deterioration of Jointed Portland Cement Concrete Pavements," Virginia Highway and Transportation Research Council, November 1975.

2. Tyson, S. S., "Full-Depth Repair of Jointed PCC Pavements: Cast-in-Place and Precast Procedures," Virginia Highway and Transportation Research Council, March 1976.

3. Creech, M. F., "Partial-Depth Precast Concrete Patching," Virginia Highway and Transportation Research Council, October 1974.

4. Johnson, C. G., "Drainage of Highway Structural Sections," Working Plan, Virginia Highway and Transportation Research Council, March 1976.

5. Suggestion #28, Concrete Research Advisory Committee, Virginia Highway and Transportation Research Council, September 1974.

6. Dickerson, R. F., "Precast Patching," Memorandum Report, Battelle Development Corporation, Columbus, Ohio, February 24, 1972.

7. Creech, M. F., "Durability of Partial-Depth Precast Patches," Memorandum Report, Virginia Highway and Transportation Research Council, August 13, 1976.