ARIZONA DEPARTMENT OF TRANSPORTATION

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CONCRETE PAVEMENT PATCHING

State of the Art

Final Report

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Current Arizona Department of Transportation practice regarding acceptance of concrete patching materials involves preapproval of a product based on laboratory testing only. Experience has shown this process may not assure product performance under field and traffic conditions. This study is intended to develop a process of involving both field and laboratory testing to assure higher levels of field performance for any and all approved concrete patching materials. The practices of several state highway agencies with sizable mileages of concrete pavements were reviewed to define the state of the art in partial depth patching. No concrete pavement patching material is totally predictable in terms of laboratory testing versus field performance. Portland cement concrete patching mixtures appear to have the best overall record, although several proprietary rapid-sets have good service records in certain geographic areas. Recommendations for standard tests and field performance analysis is presented that will lead to pre-approval of any product based on a three-step approval procedure.

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PREFACE

This report was sponsored by the Arizona Transportation Research Center through the man-year faculty agreement with the Center for Advanced Research in Transportation. The objective of the study was to summarize the state-of-the knowledge of portland cement concrete pavement patches.

The content of this report reflects the views of the authors who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views of the Arizona Department of Transportation or the Arizona Transportation Research Center. This report does not constitute a standard, specification, or regulation.

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CHAPTER I INTRODUCTION

Effective repair of spalls, cracks and related disresses in portland cement concrete pavement has been in a state of evolution since the early 1900's. In the past decade, however, more deliberate attention has been focused on the problem in an effort to find economical, time-sensitive and long-lasting methods to patch and repair concrete pavement.

Rigid concrete pavements, although capable of being designed and built to last relatively long periods of time, do require repair of distressed and damaged portions of individual slabs. The effected areas are small in size and usually isolated. The effected concrete has a mode of distress and failure that is cumulative. In many cases this begins as an undetectable minor weakness in the original concrete, as placed. A progression of failure then takes place within this small area as the slab absorbs traffic loadings. There is a concentration of distress at this critical area, and with time, sections begin to crumble and separate from the slab. Remedial efforts are then required if the effected slabs are to successfully function as an integral part of the pavement system. Additionally, the timing of the repairs is all-important. There are recognized adverse consequences to the pavement's performance that result from delays in restoring the distressed areas back to a serviceable condition.

A variety of repair methods and materials are being utilized by highway agencies in an effort to "keep up" with this problem. The success and/or service life of various efforts and products seems to be unpredictable. In addition, the increases in traffic numbers and weights has increased the instances of slab deterioration. This has led, quite naturally, to a number of studies and research projects. Their aim was to identify the most

effective method for repairing the various deteriorations, and choose repair products that would assure some degree of long term serviceability at reasonable or acceptable costs.

effective method for repairing the various deteriorations, and choose repair products that would assure some degree of long term serviceability at reasonable or acceptable costs.

CHAPTER II OVERVIEW OF VARIABLES RELATED TO SLAB FAILURES

In reviewing materials related for the preparation of this state of-the-art report on concrete patching, five distinct variables were considered:

1. The type/design of the original portland cement concrete pavement. There are five (5) widely used rigid pavement designs in North America, including one still considered experimental;
   - [a] Non-reinforced, undoweled
   - [b] Non-reinforced, doweled
   - [c] Dowel-mesh
   - [d] Continuously reinforced concrete pavement
   - [e] Prestressed (Considered experimental)

2. The type of distress modes effecting a pavement slab section;
   - [a] Crack and spall at the transverse joint
   - [b] Crack and spall at the longitudinal joint
   - [c] Crack and spall at the intersection of the transverse and longitudinal joint
   - [d] Full depth cracking between joints

3. Size and configuration of repair:
   - [a] Full-depth, partial slab
   - [b] Full-depth, full slab
   - [c] Partial-depth, partial slab

4. The types and varieties of repair materials;
   - [a] Portland cement based concrete mixtures

[b] Portland cement based concrete mixtures modified with various mineral and chemical admixtures

[c] Polymerized concrete

[d] Proprietary rapid-set compounds

5. Possible contributing factors in the failure of patching materials.

[a] Mix variations caused by improper field mixing

[b] Extremes in ambient temperatures

[c] Temperature differentials between patching materials and the in-place slab

[d] Lack of bonding

[e] Modulus of elasticity differentials between slab concrete and patching material

[f] Variability among manufacturers' packages of the same rapid-set material.

In considering the five variables and their inter-relationship, the following preliminary observations are evident:

1. Non-reinforced pavements with short joint spacings have similar joint-related distress in both doweled and undoweled designs. The doweled pavements, however, may be exhibiting less joint repair needs, particularly in mild climatic areas.

2. Dowel-mesh pavements differ only in the manner in which the patch must be placed considering the reinforcing steel and its location in the patch area. There is some evidence that the longer transverse joint spacing of this pavement design contributes to greater joint distress and a corresponding increase in repair needs. Western states do not use this

design and no attention will be paid, in this report, to repair methodology peculiar to that type of rigid pavement.

3. Continuously reinforced concrete pavements have a unique failure mode. The absence of a regular joint pattern results in a majority of the repair needs being along the longitudinal edge or wheel path. The wheel path failures are "punch-out" in nature and are a form of slab distress uncommon to pavements currently in Arizona's highway system. The outer-loop system of pavements to be constructed in Maricopa County, however, will include CRC pavements; therefore, rehabilitation of CRC pavements will have to be addressed in the future.

4. Partial depth pavement repairs are by far the most common and most often occurring rigid pavement repair need. This report addresses the techniques, materials, and methods for partial depth repairs of rigid pavements.

There are two major components of the repair process; the preparation of the slab for repair, and the material used for the new patch. To insure proper pavement repair, specifications and tests that relate to those materials and procedures are addressed.

CHAPTER III SPECIFICATIONS FOR PARTIAL DEPTH CONCRETE PAVEMENT REPAIR

The permanent repair of partial depth failures of portland cement concrete pavements requires a material that will permanently bond to concrete and be as durable and abrasion resistant as the original concrete. Specifications for partial depth repairs fall into two broad categories:

1. Construction specifications
2. Material specifications

In general, the construction specifications cover preparation, placement, and curing of the patch in the following order:

1. Identify the spalled areas
2. Remove unsound concrete
3. Prepare the repair area
4. Reestablish the joint
5. Place and consolidate the patch material
6. Cure the patch material

The material specifications cover the ability of the material to bond with the existing concrete, the set time, strength gain versus time, etc. In addition, there will be some product specific specifications. It must be recognized there is an interaction between the material selected and the construction process to meet the mixing, placing, and curing requirements of different materials.

This section of the report reviews the state-of-the-art in specifications for partial depth concrete pavement repairs. Sources available for this review include reports on concrete pavement repair by Smith et al. (1) and NCHRP Report 281 (2). In addition, specifications from several states were assembled by ATRC and provided to the authors:

1. Arizona (3)
2. California (4)
3. Iowa (5)
4. Michigan (6)
5. Texas (7)
6. Illinois (8)
7. Pennsylvania (9)
8. New York (10)

The specifications from California, Texas, and Michigan only covered material requirements.

CONSTRUCTION SPECIFICATIONS FOR PARTIAL DEPTH PATCHES

The construction recommendations from NCHRP Report 281 and five states are summarized in Table 1. Each agency except Illinois recommends determining the extent of the deteriorated concrete by sounding with a hammer or steel bar. New York is the only agency with a specification on the size hammer, (16 oz.). In New York and Illinois the engineer defines the extent of the material to be removed, while the other agencies recommend removing material 3" past the area of delamination.

All the agencies, except New York, require saw cutting of the area to be removed. NCHRP Report 281 recommends a 2" deep saw cut (1" acceptable when there are hard aggregates). Iowa uses a maximum saw cut depth of 1", if the patch needs to be deeper, a chipping hammer is used. Illinois and Arizona use a minimum saw cut of 1 1/2" when portland cement concrete is used for the patching material. Illinois allows a maximum depth of 3 1/2" to be removed while in Pennsylvania the maximum depth for removal is 5". If there is unsound concrete below the 5" level in Pennsylvania, a full depth patch is used. There seems to be a general concensus that full depth

TABLE 1 SUMMARY OF SPALL REPAIR CONSTRUCTION PRACTICES IN SELECTED STATES

SOURCE	Identify Spall Area	Removal			Clean			Joint	Placing Patch Material/Consolidation		Curing
		Saw Cut	Chip	Mill/grind	Air	Sand	Water		PCC	Rapid Set	
NCHRP	Sounding-steel rod, hammer, chain, other, 2-6" past	2" normal 1" hard agg	30 lb max	OK		clean residue	dry before placing patch	inserts, saw for sealant reservoir	Epoxy bonding agent for rapid repairs Sand mortar for longer periods Temp >40°, 3000 psi in in 24 hrs, 8 sack type III w/CaCl	Test for 2 years before wide use follow manufacture specs	Standard for PCC Manufacture Specs for Rapid Set materials
Arizona	3" outside area of delamination	1 1/2" for PCC, 3/4" min for RS 1 1/2" for epoxy	light to medium	--	to clean after sandblast	sand blast clean residue	NA	temporary inserts	"place or consolidate to eliminate voids texture, type III w/ CaCl "approved bonding agent"	Manufacture recommendations Preapproval List	
Iowa	Min 3" wide rectangular	1" max saw cut depth	3" removal "light" hammer	allowed must square edges 3" removal	to clean after sandblast	sand-blast		joint boards w/ bond breaker recommended	Vibrate, Temp > 45°F, Class B,	follow manufacture Class A Texture if w > 1 ft Temp > 45°F Cement-sand-water groat	Insulation boards for PCC
Illinois (CRCP)	Engr. determines limits	3/4" min 3 1/2" max removal	45 lb max above rebars, 15 lb max below bars		air first	none	final cleaning must allow time to dry	(CRCP spec)	grout-sand-PCC mix vibratory screed if area > 4 ft^2, internal vibrate if thick > 3"		wet burlap 72 hrs
Pennsylvania	10SF max area, 5" max depth, 3" beyond delamination, 6" min on a side	1 1/2" min	15 lb max			either sand	or water	Temporary inserts	grout or epoxy vibrate or tamp	manufacture specs. manufacture rep must be on site one day	wet burlap 24 to 72 hr. RS-manufacture specs
New York	Sound w/ 16 oz hammer Engineer defines area	No sawing required	45 lb max 1600 blows/min 100 psi air pressure	acceptable	to clean after sandblast or vacuum	sand-blast to clean	high pressure water blast can be used for concrete removal 60,000 psi	forms w/ bond breaker coat	vibrate when T > 2" One lift Majority are full depth	vibrate except polymer concrete Min. depth 1"	Polyethylene sheet & insulating material after 2000 psi apply curing compound

patches should be used whenever the delaminated concrete is more than one-half the depth of any slab.

All agencies allow the use of pneumatic and chipping hammers for removal of the delaminated concrete. New York allows a 45 lb. hammer and controls the number of blows per minute and the maximum air pressure. Illinois also allows a 45 lb. hammer but only above the level of the reinforcing steel. (The Illinois specification was for continuously reinforced concrete pavement.) Below the reinforcing steel, a 15 pound hammer is used. NCHRP Report 281 recommends a 30 pound hammer. Arizona specifies a "light to medium" hammer while Iowa requires a "light" hammer. Pennsylvania only allows the use of a 15 pound chipping hammer.

Iowa and New York allow milling for removal of the unsound material. Following milling, saw cuts and chipping are used to square the face of the patch area. New York will also allow the unsound material to be removed by water blasting with water pressures of 10,000 psi.

All states require cleaning of the area to be patched. Sand blasting followed by compressed air and/or vacuum is required or accepted by all agencies. Cleaning of residual sand is required by all agencies. Illinois and NCHRP Report 281 allow water blasting but the pavement must be allowed to completely dry before the patch is placed. If the patching material has an adverse reaction with water, then cleaning with water is not permitted.

All the agencies, except Illinois (specification for CRCP only), recognize the need to reestablish the joint during the patch construction. Temporary inserts of styrofoam or another suitable material, coated with bond breaker, are used to construct the joint to the proper width. The sealant reservoir can be established by saw cutting according to NCHRP Report 281.

A study in Pennsylvania (1) found voids between the patch and original PCC as a key factor leading to patch failure. All agencies, except New York, require use of a bonding agent with portland cement based patches. In most cases a sand-cement grout is used but an epoxy bonding agent may be required depending on the material used for the patch. Internal vibration of the patch is required when the thickness is greater than 2" in New York and 3" in Illinois. A vibrating screed is also required in Illinois for patches larger than 4 square feet.

Generally all the agencies require manufacturers recommendations be adhered to when using rapid setting materials. The NCHRP Report 281 recommends a two year field evaluation of patching materials before approval for routine applications. However, none of the states contacted have adopted a policy of evaluating patching materials in the field for the two year period.

Proprietary rapid set materials must be cured in accordance with manufacturer recommendations, a requirement followed by all states using these materials. For portland cement based patches, standard curing methods such as wet burlap, thermal blankets, curing compounds, etc. are used.

RECOMMENDATIONS FOR CONSTRUCTION SPECIFICATIONS

This review of the construction procedures for partial depth patches shows a high degree of uniformity between the many agencies. The following would constitute a generalized set of criteria.

a) Hammers or steel rods should be used to identify the delineated areas.

b) The patch should extend 3" laterally into the sound concrete.

c) Edges of the patch should be saw cut to a depth of 1 1/2" to 3 1/2".

d) Chipping hammers in the range of 15 to 30 pounds should be used to remove the unsound concrete.

e) The patch area should be sand blasted and then cleaned with compressed air.

f) The residual sand must be cleaned from the road surface and shoulders.

g) Temporary inserts should be used to form joints.

h) If a portland cement concrete patch is used, sand-cement grout should be used to promote bonding of the patch and the slab.

i) The patch material should be placed and vibrated or tamped into place to ensure the removal of all voids.

j) Manufacture specifications should be followed for placing and curing rapid set materials.

k) Standard concrete curing procedures must be invoked whenever a portland cement concrete patch is used.

CHAPTER IV LABORATORY TESTING OF RAPID SET MATERIALS

There are more rapid set patching materials available than can feasibly be evaluated in field trails. Through March 1986 over 80 commercially available rapid-set products were evaluated in the ADOT Materials Testing laboratory as possible candidates for use as rapid-set patches. Very few of these have been field evaluated. It is important, however, that new materials be evaluated in the laboratory to ensure they meet certain minimum requirements before they are field tested. Table 2 is a summary of the laboratory test requirements as performed by a cross-section of states.

MATERIAL SPECIFICATIONS

All of the states surveyed use a compressive strength specification for the rapid set materials. New York has the most stringent requirement with 2500 psi in one hour. Illinois and Iowa require 1500 psi in one hour and Arizona requires 1400 psi in one hour and 3000 psi at 3 hours. Michigan and Texas require 2000 psi after two hours. The strength requirement at 28 days in the range of 4000 to 5000 psi is used in New York, Michigan, and Illinois. Arizona and Iowa have a strength specification for three hours but do not require any minimum strength development after that time. Texas and Georgia final compression test requirement is 3000 psi at 24 hours.

Texas and California are the only states with flexural strength requirements. Texas has requirements at one and three hours and California requires a break at 24 hours. California requires the patch material to be extended with the maximum permissible amount of 3/8" pea gravel for flexural strength tests.

Several states require shear bond tests, although the test procedures vary significantly between the agencies. California requires shear bond

TABLE 2 SPALL REPAIR SURVEY RESULTS FOR STATES WITH EXTENSIVE CONCRETE PAVEMENTS

STATE	SURFACE SCALING	COMPRESSION hr.-psi	SET TIME I/F*	SHEAR BOND hr.-psi	FREEZE-THAW %	MAX. EXPANSION %	SHRINKAGE %
NEW YORK		1-2500 24-3500 28 days-5000	5/-	24 hours 200	94	0.4	0.05
MICHIGAN	12 cycles F/T	2-2000 4-2500 8-3000 28 days-4500		2-200a 4-225a 8-250a 28 days-200a			0.1
CALIFORNIA		3-3000	15/25	24-400 S.S.D 300	150 cycles		0.13
ILLINOIS	xa	1-500 24-2500 7 days 4300 14 days-4500 28 days-5000	5/20	x	4600 psi @ 300 cycles	0.01	0.04
PENNSYLVANIA	xa	3-1000 24-3000 7 days 4000				+0.15b	-0.15b
IOWA	100 cycles F/T	1-1500 3-2500 5-3500	10/40	24 hrs 350	70		<0.2 (24 hrs.)
ARIZONA		1-1400 2-1400 3-3000	-/60	14 days 1500		slight	
TEXAS		2-2000 24-3000	10/40	1-100 3-300	@ 60 100 cycles	.15	
GEORGIA		3-1500 24-3000		Requires epoxy bonding			

a - includes freeze-thaw cycle
b - difference not more than 0.2
x - test performed but actual values not known
* - I/F = initial and final times in minutes

tests on both dry samples and samples where the PCC is in a saturated surface dry condition prior to placing the patch material. Michigan uses freeze-thaw cycles in their bonding test.

Initial set time minimum requirements range from 5 minutes for New York and Illinois to 15 minutes for Texas and California. Minimum time for final set ranges from 20 minutes in Illinois to 60 minutes in Arizona.

There is wide variation in the shrinkage and expansion limits allowed by the many states. For example, the expansion limit for Illinois is 0.01, while Texas and Iowa allow as much as 0.15. Three states have limits for both expansion and shrinkage, while three other states only control shrinkage. Texas and Arizona, on the other hand, only control expansion. The Arizona specification allows "slight" expansion, which should be quantified. Michigan is the only state to specify limits on modulus of elasticity and thermal contraction.

TEST METHODS

Table 3 summarizes the standard test methods used for the evaluation of rapid set patching materials. California and New York have "stand alone" testing manuals or procedures which cover all the tests they perform on these materials. Thus, information was not available on the individual procedures used for the measurement in each category.

1. Compressive strength is determined on 2" x 2" mortar cubes using ASTM procedure C-109 by three of the states. Iowa performs a compressive strength test but did not provide information on the test procedure.
2. Set time is determined with ASTM test C-266 except in Michigan where no procedure is specified.
3. Each state uses its own procedure for evaluating bonding.

TABLE 3 SUMMARY OF STANDARD TEST METHODS

Test	Iowa	Michigan	Texas	Illinois
Compressive Strength	N*	ASTM C-109	ASTM C-109	ASTM C-109
Flexural Strength			ASTM C78-75	
Set Time	ASTM C-266	N	ASTM C-266	ASTM C-266
Bonding	Iowa 406-b	N		N
Durability	ASTM C-666B		ASTM C-666B	ASTM C-666B
Shrinkage	N	COE-CRD-C621 80		
Expansion in Water			ASTM C157	
Modulus of Elasticity		ASTM C-469		
Thermal Expansion		ASTM C-490		
Surface Scalling		N		ASTM C-672

*N indicates a test is performed but no standard is given.

4. Procedure B of ASTM C-666 is used to evaluate durability. Iowa uses a modification of this procedure.
5. Pennsylvania uses ASTM C-928 for accepting rapid-set patch materials (including magnesium phosphates).
6. Michigan uses a Corps of Engineers test procedure for evaluating shrinkage and Iowa uses a procedure developed in state.
7. Surface scaling is measured by Michigan and Illinois but the procedures for the test are not identified.

CHAPTER V MATERIALS USED IN RAPID-SET PATCHING OF RIGID PAVEMENTS

An overview of the practices of the various DOT's with regard to their preferences between the many proprietary rapid-set products can best be summed up as:

1. There is little consistency in how or why certain products are used, accepted, or rejected when viewed from a continental U.S. basis.
2. There are a number of states whose experiences have led them to essentially reject the use of any rapid-set packaged product, and use only a high-strength portland cement concrete patch which can be opened to traffic in 6 hours or less.

Table 4 is a summary of practices in 14 states. A number of the practices are worthy of broader comment:

California has just completed an extensive study on this subject and based on 1986 test work found the following to be the best performers based on extensive lab studies:

Set-45 (CALTRANS formula)

Durapatch Hiway

Celroc 10-60

5 Star

Duracal

Sonoset

Rapid Set Concrete

Michigan uses a portland cement concrete partial depth patch whenever they can keep traffic closed off for 8 hours or more. If less time is allowed, their product list of rapid sets is limited to 3 based on 1986 testing:

Table 4. Rigid Pavement States and their Rapid-patch Experience

	AZ	CA	GA	IL	IA	MI	MN	LA	MO	NY	PA	TX	WI	VA
Partial-Depth Rapid-Set Products Approved	Celroc 1060 Durapatch Hiway Set-45 (Cal-Trans) MC64 Percol	Set-45 (CalTrans) Durapatch Hiway Celroc 10/60 Burke 928 5-Star Duracal Sonoset Rapid Set Conc.	Seldom used No approved list	Duracal* Set-45 Road patch 5-Star Set instant Rapid Rd. Rpr. Rapid Set Speed Crete	Set-45, Durapatch Hiway Hvy. Tfc. Sonoset (20 others tested & rejected)	5-Star, Durapatch Hiway Set-45 Burke FP928 (8 others tested & rejected)	6 appr., but not published Seldom used due to costs.	None used or allowed	Set-45 & Duracal (Bridges only)	Set-45 (Long Island only)	25 approved state-wide. Set-45 excl. for Turnpike	Duracal. Set-45 (Hot) Gilco Hwy. Horn 240	Set-45 & Duracal (Green Bay & Milw. only)	Embeeo 411A
Portland cement concrete repair mix	9-bag Preferred Type III + Duracel		8-bag mix with Ca Cl_2	700# PC + Super + $CaCl_2$ w/c $\leq$0.36	Preferred to rapid-sets;	Preferred if 8-hour delay OK	830#/cy.+ w/r accel	Several w/c ratios + $CaCl_2$	Preferred all pavement repair.	825#/cy + $CaCl_2$ 2000 psi/ 4 hrs.	1000 psi @ 2-4 hrs	OK with acel. admix's	Most repairs full depth with 9 bag mix & $CaCl_2$	Preferred with 11-year svc. record.
Miscellaneous Notes:	Above rapid-set products under field perf. testing Approvals pending.	25 min. set time by Gilmore	Most repair work by contract	*Approved list for Chicago area (partial depth) All other full depth using PCC mix. Polymers not used due to cost.	Contract- or option of rapid set or PCC patch mix. Polymers consid-ered toxic	Polymers consid-ered too costly.	Majority of repair project by con-tract.	Some field mixes @ 3000 psi 6-hrs. failed while some @ 890 psi OK	Urban repairs by con-tract; rural by maint. forces.	Some polymers used with 1" depths; Rapid set with 2" depth.	Magnesium phos-phate best rapid set perform-Have OK 2 latex-modified & 2 poly-mers.	Set-45 (cold) rejected Warming materi-al had signf. effect on all rapid sets.	Very little lab test performed	Duracal rejected. Contract patching better perform-ing than maint. crews.

5 Star Highway Patch

Durapatch Hiway

Burke Fast Patch 928

Nine others were tested and rejected, including Set-45. Michigan also uses PCC exclusively for all full depth patching.

New York tends to use full depth patching with PCC only. The exception to this is on Long Island, where Set-45 has been used successfully on the expressway system for 7-years. The traffic (200,000 ADT) required a 1-hour strength of 2500 psi. for rapid opening.

Wisconsin uses asphalt for temporary patching until a full depth PCC repair is made using a 9-10 bag mix. Very little testing is done. The exception to this is in the urbanized areas of Green Bay and Milwaukee where Duracal and Set-45 are used routinely for partial depth patching.

Illinois also follows the NY and Wisconsin methodology. They prefer portland cement based repair material, and limit their use of rapid set products to the Chicago area where eight (8) products are now in use:

Duracal

Road Patch

Set Instant Conc. Repair

Speed Crete

Rapid Set Concrete Mix

Set-45

5 Star Hwy Patch

Rapid Road Repair

Iowa does a majority of repair work by contract and costs usually results in a high strength portland cement based mixed be chosen by

contractor. They have tested 24 rapid-set products and rejected 20. The approved products are Set - 45, Durapatch Hiway, Heavy Traffic, and Sonoset.

Missouri generally performs full depth patches and opens them to traffic in 4-hours. They are a PCC patching mix, even in the few partial depth repairs they do. Rapid set material is confined to use in bridge repairs where Set-45 and Duracal Hiway are the usual choices based on field experience. Again, costs are the reason behind the extensive use of portland cement based patching material.

Georgia and South Carolina are also states that use portland cement based patching for a majority of their repair work. The usual practice is for the state to establish the limits of each patch area by sounding with a steel rod. They then have a contractor saw and chip, and then repair with a portland cement based mix containing 8-bags of portland cement and calcium chloride. It should also be noted they try not to place patches at less than 50°F (ambient), but have no hot weather limitations.

Minnesota has an approved list of six (6) rapid set products, but avoids their use due to costs. Their widespread use of portland cement based patches has led to their recent approval a pre-packaged mixture in a 75lb. bag using a 9-bag mix with a special, dry, admixture. These packages of dry-mix materials are used by the contractors. Minnesota and Florida seem to be the only states pre-packaging a PCC repair mix. This method has the potential of being adopted by other states if the anticipated success is achieved.

Pennsylvania, one of the states still firmly committed to rapid set products, have found magnesium phosphates the best performers on their state system of highways. This is based on over two decades of use and extensive field investigations. On the Turnpike, Set-45 is used almost exclusively.

CHAPTER VI AN OVERVIEW OF ARIZONA'S EXPERIENCE AND CURRENT REPAIR PHILOSOPHY

Over the years, Arizona has performed a large number of laboratory tests on a variety of materials considered and proposed for the repair of portland cement concrete pavement. The accumulation of these data led to the general acceptance of 80 different commercial products as potentially capable of serving as satisfactory rapid-set patching materials for PCCP. From this vast array of test data, a more select list of four products was recently chosen for extensive field use and evaluation. These four rapid-set materials have been used in an engineered test program of repair for segments of Interstate 17 in the Phoenix metropolitan area. The four materials include:

1. Celroc 10-60
2. Durapatch Hiway
3. Set-45 (CALTRANS formula)
4. Percol

A 9-bag mix of a portland cement based concrete patch material was used as a base standard. These products have been in service since November 1986. Additionally, MC-64, a 2 part epoxy with rubber, was placed on a section of I-17 in March 1987. Condition surveys are being made at time intervals consistent with a program being administered by the Arizona Transportation Research Center. After a two year service period, a report will be prepared documenting each products performance.

Future approval of new rapid set materials might take the form of a three-step approval procedure. First, the manufacturer shows documented proof of meeting certain laboratory test requirements for freeze-thaw resistance, volume change and compressive strength at three and six hours.

The Department could then elect to place these materials in service on test sections of the urban Interstate systems under the same control conditions presently used to evaluate rapid-sets materials. Acceptance for inclusion on the approved list of rapid-sets would be contingent on passing the two-year field evaluation study successfully.

CHAPTER VII CONCLUSIONS AND RECOMMENDATIONS

An overview of the concrete patching procedures of many of the state highway agencies across the United States indicate the following:

1. A significant number of states consider the use of proprietary rapid-set materials a proven method of repairing portland cement concrete pavements. They have developed laboratory test requirements and field performance standards which allows them to accept and reject products accordingly.
2. Another group of states has less than satisfactory experience with rapid-set products. These states use patch materials with a base of portland cement concrete plus a variety of admixtures to attain the high early strength needed for early openings to traffic.
3. A third set of states has had good experience with both types of patching, and in some cases allows a contractor the option to select the repair method. Urban area geographics seems to be an important element in this regard.

The long term performance of either commercial rapid sets or portland cement based patch materials varies widely. However, there is sufficient evidence to indicate portland cement concrete patches rarely fail to perform if mix design, placing, and curing are properly performed.

The somewhat erratic performance of the proprietary rapid-set materials is somewhat puzzling at first glance. Even across short state-to-state distances the success rate of any given rapid-set material can vary appreciably. However, one can speculate on reasons for these inconsistencies. The packaged materials may well be somewhat more difficult to use consistently, as their set-rates and related workability could have a significant impact on bond strength, a property that will have important

bearing on both the short and long term performance capabilities of each material. Additionally, set-rate variability (especially as effected by changes in temperatures) results in the field laborers having to "fight" the placement of a patch and this will surely lead to less than satisfactory performance.

The matter of costs has a direct bearing on the choices of repair materials by the respective agencies. Rapid-sets are more expensive, although the cost differentials can be justified from the standpoint of both time and convenience, particularly in urban areas. In states where comparatively large repair programs are being implemented, however, these cost differentials can be significant. Finding a rapid-set material that will work satisfactorily in patches prepared without the need for sawing and other related high cost preparations, may well offset these cost premiums.

CONCLUSIONS

This review of the state-of-the-art in partial depth repair of portland cement concrete pavements has demonstrated the ability of the various patching materials to both perform satisfactorily and to fail. Unfortunately, there is insufficient knowledge at this time to predict which materials will perform well and under what conditions. When there is adequate curing time, portland cement concrete patches appear to have the best overall record.

By comparison, a few of the proprietary rapid-sets seem to be performing satisfactorily in given geographic areas. Set-45 is perhaps the obvious leader in this regard. However, even with Set-45, chemical reformulation is apparently necessary to allow it to meet the requirements in warmer climates.

There are a large number of variables which can affect the performance of a patch; material properties, construction variability, weather conditions, etc. Current practices for laboratory evaluation do not capture all of these variables. The result is a lack of correlation between the performance of the materials in the laboratory and in the field. This has led to the need for costly field evaluation of materials before they can be placed on an approved list.

Successful patching of portland cement concrete pavements requires control of the construction process as well as the use of appropriate materials. The construction practices include identification and removal of unsound material, cleaning the area, reforming the joint, applying a bonding agent, if necessary, mixing and placing the material, and curing as required. Identification of the unsound area is accomplished by tapping the pavement with a steel bar or hammer and listening for a hollow sound; an unsophisticated yet apparently successful technique. A chipping hammer is usually used to remove the unsound material after the perimeter of the affected area has been saw cut to a depth of 1 1/2 to 3". The area is cleaned by sand blasting. The patch material is proportioned and mixed to specification. This step is more delicate than normal mixing of portland cement concrete because smaller quantities of materials are usually used. A small error in measuring can have a large effect on the performance of the material. In addition, the materials used for rapid repairs react at a much faster rate than conventional materials. This could result in improper placement of the materials unless the construction crew is properly trained and experienced.

Placing the material requires vibrating or tamping, depending on the depth of the repair, to ensure there are no voids at the interface between

the existing slab and the patch material. Bond at the interface is extremely important. The patch material is leveled to be even with the existing surface and textured if appropriate. Curing the material depends on manufacturer specifications. However, if the patch material is based on portland cement, it should probably be moist cured, although membrance curing compounds can be used if carefully monitored in terms of application rates.

RECOMMENDATIONS

As evidenced by the fact that over 80 materials passed the laboratory evaluation program at ADOT and yet a number of these materials failed in the field, it is clear that current laboratory testing of these materials is inadequate.

We recommend a laboratory evaluation program be designed to include the many variables that evolve from construction procedures. Only a few actual tests are needed:

1. Set time
2. Thermal expansion and freeze-thaw cycling
3. Bonding with the original concrete slab
4. Modulus of elasticity
5. Compressive strength versus time.

Standard test methods can be used for the evaluation. A unique part of the evaluation plan would be the introduction of variability in the tests. The materials should be mixed with slight variations in proportions of the ingredients. For example, in portland cement based products, the water content should be 90, 100 and 110 percent of the required amount. Other variations will depend on the specific material being evaluated. For the bonding test, the amount of time between mixing the samples and molding the

sample should be varied. For example, samples could be prepared immediately after the ingredients are mixed and at five-minute intervals up to the initial set time. Temperature is the third factor that can be varied. The properties of rapid set materials could be very sensitive to the ambient air temperature and the temperature of the slab being repaired. The evaluation tests should be performed across the range of expected conditions. Night-time pavement temperatures should be measured to establish the required range.

Until it can be demonstrated that the results of such a proposed evaluation plan can be correlated with field performance, the field evaluation procedures currently used by ADOT (12) should be continued. In fact, the materials currently being field tested should be the primary candidates for the initial laboratory evaluation program.

Future approval of new rapid set materials might take the form of a three-step approval procedure. First, the manufacturer must show documented proof of meeting certain laboratory test requirements for freeze-thaw resistance, volume change, bonding/shear strengths and compressive strength at one, three and six hours. If these tests are successfully passed, the Department could then elect to place the material in service on test sections of the urban interstate system under the same control conditions presently used to evaluate rapid-set materials. Full and final acceptance for inclusion on an approve list of rapid-sets would be contingent on passing both the lab tests and a one-year field evaluation study.

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APPENDIX A

ANNOTATED BIBLIOGRAPHY AND TELEPHONE INTERVIEW RESULTS REGARDING REPAIR PRACTICES BY VARIOUS DEPARTMENTS OF TRANSPORTATION

California[15]*

1. They run chemical tests on rapid-sets to detect potential hazardous materials and to determine quantity of chlorides & sulfates.
2. They are more concerned with thin-bonded overlays than with patches & many of their new test methods, such as flexural strength, abrasion resistance, and bond strength, were developed in this regard.
3. The new tests are difficult for most rapid-sets to pass, and few products comply. There is no list of approved products.

Florida

1. They have done a limited amount of testing on rapid-sets & have developed a specification on those findings.
2. There is an approved list of rapid set products.
3. They prefer portland cement-based material for their pavement repairs and are prepackaging this material in two types; one that reaches a required strength of 500 psi in 3 hours, the other (called very rapid hardening) requires 2000 psi in 3 hours.
4. They use maintenance forces in rural, northern Florida. In the southern sections, particularly near Miami and Dade County, they use contracts almost exclusively.

Illinois[14, 18]

1. On their CRCP repairs, only full-depth repairs allowed, using Type III portland cement mixes.
2. Opening to traffic 270 psi flexural strength seems to be important factor in performance. They require 300 psi.
3. Strength in field patches apparently stronger than lab patches due to heat build-up in the field patch.
4. They use insulating covers to elevate temperatures of patch, but never 90°F.
5. They liked super-plasticizer mixes for workability, but little benefit found from these higher, earlier strength values.
6. They have used microwave devices to polymerize resin materials, but safety can be a problem. This is especially true for cleanup with methylene chloride (potentially hazardous to heart & lungs). They will not use polymers as alternative to rapid sets or PCC type III.

*Refer to Bibliography following.

Iowa[10]

1. Had approved four (4) rapid-sets (1985); Dayton Heavy Traffic, Durapatch Hwy., Set-45, and Sonoset.
2. They require 2500 psi. at 3 hours.

Louisiana[3]

1. Reported experience somewhat dated (1975)
2. Their tests indicated that after only 8 months of field trials, performance not related to compressive strength alone. Some low 6-hour strengths of 890 psi performed satisfactorily, while 3000 psi failed. No explanation given.
3. No rapid-sets used -- all Type III concrete with variety of w/c ratios & admixtures.

Minnesota

1. Few rapid-sets used. A portland cement concrete mix with 9-bags and a water-reducing accelerator has wide-spread use & application.
2. They have recently allowed this PCC mix to be prepackaged into 75 lb. dry bags for use by both contractors & state maintenance forces.
3. Although used only occasionally, & under special circumstances, rapid-sets are allowed based on an approved list of 12 products including SET-45.

Missouri

1. This is another state that uses portland cement concrete mixes predominately.
2. They require Type III portland cement and accelerators.
3. Rapid sets are seldom used for pavement repairs, but they are used extensively for bridge deck repairs.
4. Their PCC mix requires 2000 psi in 4-hours; although 6-hours may be needed in cool weather.
5. They have successfully used Duracal & SET-45 for pavement repairs, but costs dictate use of PCC mix.
6. Most problems are at the joints on 66 ft. panels (reinforced) These are usually full-depth patches.
7. Most urban repairs by contract; rural by maintenance forces using special crews trained in concrete patching techniques -- one per district.
8. No approved list of rapid-sets.
9. Their research efforts are mainly aimed at PCC mixes & placement improvements.

Nebraska[1]

1. Repairs based on numerical rating system for spalls & cracking.
2. Uses Type III + CaCl for both full & partial depth repairs.
3. Epoxy injection of cracks not found to be successful.
4. Patch area opened using 2" saw-cuts & 15 lb. chip hammer.
5. Air, water or sand blast for cleaning.
6. Rapid-set packaged materials not used by this state.

Pennsylvania[2,13]

1. Defines spalling as cracking, breaking or chipping within 2 ft. of joint or major crack.
2. Most repairs partial-deptn.
3. Extensive list (25) of pre-approved rapid-set materials.
4. Also approve two latex-modified concretes, two polymers, and a Type III concrete with CaCl.
5. Repairs to CRCP in three categories by size.
    a. Small (1 sq. ft.): Polymers did well
    b. Medium 9to 10 sq. ft.): Set 45 and 3 others failed within one year. Polymers not much better. Type III PCC patches performed better.
    c. For larger spalls and severe punchouts, repairs require Type III PCC patches exclusively.

Texas[4,5,7,16,22]

1. Warming rapid-sets above 40°F had significant effect on strength for most of those investigated.
2. Costs varied from $239/cy for Duracal to $986/cy for SET-45.
3. Polymers had high shrinkage & coefficient of thermal expansion.
4. Cool temperatures definitely advisable for rapid-set patching. They also recommend keeping patches small.
5. They tried steel & Polypropolene fibers with varied results.
6. Requires 2000 psi in 1-hr; 6400 psi in 24-hrs.
7. Their experience with regular SET-45 in hot weather resulted in low (206 psi) strength at 1 hour. Use of hot weather formulation improved this and allowed for its approval, by District evaluation study, along with Fondu C3A, Plexicrete, Tapecrete & Gilco Hwy. Patch.
8. Their survey of other state DOT's indicates the most important characteristics of a rapid-set material are set time, working time & durability. In terms of mechanical properties; bond strength, shrinkage, flexural strength & compressive strength are most important.
9. In polymer concrete repairs, their experience, although limited to MMA based polymers, indicates little evidence of such patches failing to perform. Their cost (up to $1800/cy), however, was considered excessive.

Virginia[8,9]

1. Patches by private contract more effective & better performing than those placed by force account. This is related to the contractor's tendency to closely follow state specs. & guidelines.
2. They had poor performance from Duracal & Fondu patches. Embeco 411A & portland cement-based patches had satisfactory performance after ten years experience.
3. Patch failures usually related to one or more of the following:
   a. Lack of adequate sounding resulting in not removing entire unsound portions
   b. Patches should not be smaller than 2 ft. x 2 ft.
   c. No patch should be larger than 8 ft. in any direction. If so, replace entire slab.
   d. For most joint related distresses, use a 2 ft. minimum patch along entire 12' joint width.
   e. Never terminate any patch in a wheel path
   f. Use all straight lines, square or rectangular (and avoid triangles)

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