PATCHING OF PCC PAVEMENTS

FIELD EVALUATION OF MATERIALS & CONSTRUCTION TECHNIQUES

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Final Report

Frazier Parker and Lee Shoemaker
Highway Research Center
Auburn University

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ABSTRACT

Laboratory and field studies were conducted to evaluate three rapid setting PCC pavement patching materials, the effects of temperature during patch construction, the effects of anchors on patch performance and the effects of sawing to outline patch area on patch performance. Patches were constructed on I-59 in Gadsden and I-85 in Montgomery.

Mix design studies revealed that PCC with and without steel fibers could be produced that provided adequate rapid-setting strength. Four-hour strengths of these materials were lower than the proprietary material Roadpatch but after 5 to 6 hours they provided higher strengths.

Anchor optimization studies revealed that the ultimate load that could be resisted by a simulated patch was linearly proportional to the amount of steel and that smaller anchor sizes provided better performance.

Field studies revealed that outlining deteriorated areas with a 1-2 inch deep sawcut aided in patch area preparation. Vibration of patch materials was essential for proper consolidation.

Steel fibrous PCC patches performed best. Patches constructed during warm weather performed better than those constructed during cool weather. Anchors did not appear to improve patch performance. Sawing did not dramatically improve patch performance but did aid in patch construction.

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INTRODUCTION

Most Portland cement concrete (PCC) pavements in Alabama are on the interstate system and are concentrated in heavily traveled urban areas. The older and more heavily travled sections have begun to show the effects of wear due to weathering and traffic volumes that have often far exceeded design values. As deterioration develops cracked and spalled areas must be patched to maintain serviceability. Damage is normally initially concentrated around joints and can usually be repaired with small partial depth patches. However, as deterioration progresses, damage severity increases and full depth complete slab replacement also becomes part of required maintenance operations. The research described herein examines materials and construction techniques for small partial depth patches, but the information relative to patch materials will also be applicable for full depth complete slab replacement.

A key requirement for any patch is that it be durable and long lasting. For heavily traveled roadways, the requirement of rapid constructibility must be added in order to minimize disruptions to traffic flow. For routine operations this means that the patch must be constructed betwen morning and afternoon peak flow periods. This gives total construction time of less than eight hours which translates into even shorter curing times. Six hours curing time was the target time for development of strength sufficient to prevent patch damage when opened to traffic. Six hours was suggested by Ross (1) as reasonable for construction within an eight-hour work shift and was used in earlier laboratory studies (2). Since the rate of strength gain is a function of temperature, time of construction was also a factor that was considered. The need for economical yet durable patches that could be rapidly constructed led to the research described herein.

Research Objectives

The objectives of the research were 1) to identify patch materials and construction techniques that would produce economical durable patches when constructed and cured in one working day, 2) to construct a series of patches under a variety of conditions and monitor their performance, and 3) to develop recommendations for PCC pavement patch construction.

Scope of Research

To accomplish the research objectives, a testing plan was developed that included the construction and monitoring of patches at two locations (I-59 in Gadsden and I-85 in Montgomery) with three materials (Roadpatch II[1], rapid-setting PCC, and rapid-setting steel fibrous PCC). Patches were constructed during two seasons (hot and cool), with two anchor schemes (anchored and unanchored), and with two patch area preparation techniques (outline sawing and unsawed). Mix design studies were conducted to develop mixture proportions for the three patch materials with local coarse and fine aggregate. A series of tests with simulated patches were also conducted to optimize anchor design.

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(1) Commercially available patching material marketed by Thoro Systems Products.

MIX DESIGN STUDIES

Design studies were conducted to select ingredient proportions for a rapid setting PCC mixture and a rapid-setting PCC mixture with steel fibers. Manufacturer recommendations were followed for a Roadpatch II[1] mixture. The goals of the mix design process were proportions that would provide adequate strength for construction within an eight-hour workday while maintaining reasonable cement content (shrinkage control), accelerator content (manufacturer recommendations), mixability (in small portable mixers), workability and finishability.

A laboratory study (2), predecessor to this study, indicated that six hour compressive strength of 2000 psi and greater were possible with Roadpatch mixes and PCC mixes containing Type III cement and 2% calcium chloride accelerator. These mixtures had cement contents that were somewhat higher than desirable for shrinkage and slumps that were less than desirable for mixing in small portable mixers and placing and finishing by hand. Therefore mixability, workability, and finishability were prime considerations in mix evaluation criteria. Six hour compressive strength of approximately 2000 psi was still considered a desirable, although not a controlling, target.

Subsequent field patch construction revealed that a four-hour cure was a more reasonable minimum cure time and that six hours was a maximum that could be expected in an eight-hour work day. The field studies also revealed that strengths achieved with less than six hours curing were, with few exceptions, sufficient to prevent ravelling, abrasion, deformation, and cracking when initially opened to traffic. This implies that 6 hour 2000 psi compressive strength should not be considered as minimum strength criteria. No clues were found pointing to exactly what the minimum strength criteria should be, but the strengths achieved appeared adequate.

Materials

Local coarse and fine aggregates were used for mixes in Gadsden and Montgomery. The coarse aggregate was pea gravel size (3/4" maximum size -- *78 AHD designation) crushed limestone in Gadsden and river gravel in Montgomery. This size coarse aggregate produced a fine mix needed for patching spalled areas with limited depth. This size is also consistent with recommendations for Roadpatch II and with what has generally been used for steel fibrous concrete (3). Fine aggregate was natural concrete sand (*100 AHD designation) at both locations.

Type III cement with a "nonchloride" accelerator (ASTM C494, Type C) was used to increase rate of strength gain. The particular brand accelerator used was Master Builders, Inc., Pozzolith 555 Accelerator. Dosage rates were maintained within manufacturer recommended ranges. No air entraining admixture was used and resulting air contents averaged about 3%. Steel fibers 3/4" long with 0.01" x 0.022" cross section from Mitchell Fibercon, Inc. were used in the rapid-setting fibrous mix.

Roadpatch II[1] ingredients include a cement-sand grout mixture, 3/8" long 0.01" diameter steel fibers and an acrylic polymer type latex (Acryl 60) modifer. To these ingredients were added coarse aggregate and water to produce a rapid-setting patching mixture.

Mixture Proportions-- Rapid-Setting PCC

Results from mix design tests for rapid-setting PCC, using Gadsden aggregate, are shown in Table 1. Compressive strength specimens, 4 inch diameter and 8 inch long, were made according to AASHTO T126 and tested according to AASHTO T22. Four inch diameter specimens were used to reduce material requirements. They were cured in their molds by covering with polyethylene in the laboratory at approximately 70° ambient air temperature. Disposable molds were removed immediately prior to testing.

Mixes A7, A8, and A9 produced reasonable 6-hour strength values with good workability and finishability. Based on these results the following proportions for a 1-ft^3 batch were used for the warm weather placements:

<u>Warm Weather Gadsden Rapid Setting PCC (1-ft^3)</u>

Cement	- 33 lb.
Water	- 16 lb.
Coarse Aggregate	- 61 lb.
Fine Aggregate	- 40 lb.
Accelerator	- 5 oz (15 oz/100 lb. cement)

For cool weather placements, mix proportions were modified to compensate for the slower rate of hydration and reduced evaporation rate. The amount of water was decreased and the accelerator dosage rate was increased to maximum manufacturer recommendations. The following proportions were used:

<u>Cool Weather Gadsden Rapid-Setting PCC (1 ft^3)</u>

Cement	- 33 lb
Water	- 15 lb
Coarse Aggregate	- 61 lb
Fine Aggregate	- 40 lb
Accelerator	- 6.5 oz (20 oz/100 lb cement)

Table 1. Rapid-Setting PCC Mix Design Test Results - Gadsden

Mix Designation	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Cement (pcf)	22.9	35.5	37.1	33.8	35.2	30.2	29.6	33.3	36.0	40.0
Water (pcf)	8.0	12.4	13.0	13.5	14.1	13.0	14.8	15.0	16.0	13.5
Water:Cement Ratio	0.35	0.35	0.35	0.40	0.40	0.43	0.50	0.45	0.43	0.40
Fine Aggregate (pcf)	26.2	31.8	36.2	31.6	40.8	52.6	41.9	40.5	43.9	46.1
Coarse Aggregate (pcf)	104.8	75.1	67.6	74.0	61.3	57.0	62.8	60.8	53.6	46.1
% Fines	0.21	0.30	0.35	0.30	0.40	0.48	0.40	0.40	0.45	0.50
Accelerator fl. oz. per 100 lb. cement	15	15	15	15	20	20	20	10	15	20
Slump (inch)	6.5	0	0	0.5	0	0	2	2	4	0.5
*6 Hour Compressive Strength (psi)	589	1520	3380	2347	4854	3501	2068	2348	1631	2943

*Average of three tests.

Rounded river gravel coarse aggregate was used for the Montgomery patches. Because of the rounded particle shape it was anticipated that more cement would be needed for strength and less water would be needed for workability. Differences in aggregate absorption was also expected to affect water requirements. Results from mix design tests for rapid-setting PCC, using Montgomery aggregate, are shown in Table 2. Based on these results the following proportions for a 1-ft^3 batch were used for warm weather placements:

Warm Weather Montgomery Rapid-Setting PCC (1 ft^3)

Cement	- 36 lb.
Water	- 15-1/2 lb.
Coarse Aggregate	- 57 lb.
Fine Aggregate	- 38 lb.
Accelerator	- 5.3 oz. (15 oz/100 lb. cement)

For cool weather placement the only change made was to increase the accelerator dosage rate to 7.2 oz/ft^3 (20 oz/100 lb. cement)

Mixture Proportions-- Fibrous PCC

The inclusion of steel fibers in PCC creates some unique mix design problems. The large surface area to volume ratio of the fibers increases paste requirements for adequate coating, and their large aspect ratio (length to diameter) increases mix harshness. Slump becomes a poor measure of workability and workability and finishability evaluation becomes more subjective.

Results from mix design tests for fibrous PCC are shown in Table 3. Mixes F1 through F7 used Gadsden aggregate and F8/I85-1 and F9/I85-2 used Montgomery aggregate.

Table 2. Rapid-Setting PCC Mix Design Test Results - Montgomery

Mix Designation	B1	B2	B3	B4	B5	B6
Cement (pcf)	33.0	34.4	36.0	38.8	36.0	36.0
Water (pcf)	14.8	15.5	15.5	15.5	15.5	15.5
Water:Cement Ratio	0.45	0.45	0.43	0.40	0.43	0.43
Fine Aggregate (pcf)	39.7	38.5	38.0	37.0	47.4	56.9
Coarse Aggregate (pcf)	59.5	57.7	57.0	55.6	47.4	37.9
% Fines	0.40	0.40	0.40	0.40	0.50	0.60
Accelerator fl. oz. per 100 lb. cement	15	20	15	15	15	15
Slump (inch)	0.5	3	3	1	3	1
*6 Hour Compressive Strength (psi)	1353	1751	2069	1154	1074	875

*Average of three tests.

Table 3. Fibrous PCC Mix Design Test Results

Mix Designator	F1	F2	(1) F3	F4	(2) F5	(3) F6	(4) F7	F8/I85-1	(5) F9/I85-2
Cement (pcf)	50.0	50.0	50.0	62.5	70.0	30.0	40.0	41.8	45.0
Water (pcf)	21.5	21.5	20.0	25.0	28.0	12.9	17.2	18.0	18.0
Water: Cement Ratio	0.43	0.43	0.40	0.40	0.40	0.43	0.43	0.43	0.40
Fine Aggregate (pcf)	19.42	17.57	27.96	18.71	12.79	43.19	43.8	32.2	31.4
Coarse Aggregate (pcf)	48.57	43.93	41.73	28.05	19.18	64.75	52.1	48.3	47.0
Steel Fibers (pcf)	3.70	5.93	9.46	4.73	4.73	5.93	5.93	5.93	5.93
% Fiber by Volume	0.8	1.2	2.0	1.0	1.0	1.2	1.2	1.2	1.2
Accelerator fl. oz per 100 lb. cement	20	20	20	20	20	20	17	none	15
6 Hour Compressive Strength (psi)	1989	2943	3500	2506	4416	--	1945	318	2188

Notes:

(1) Hard to consolidate and had a tendency to form fiber balls.
(2) Very sticky, too much cement.
(3) Mix tended to segregate and was difficult to consolidate.
(4) Good strength and workability with a moderate amount of cement
(5) Basically a good design but a little sticky.

Mix F7 provided reasonable 6-hour compressive strength and workability with a moderate amount of cement and was selected for warm weather Gadsden placement. Keeping cement content as low as possible to minimize shrinkage was a goal for all mix design. The following proportions for a 1-ft^3 batch were selected for warm weather placements:

<u>Warm Weather Gadsden Fibrous PCC (1 ft^3)</u>

Cement	- 40 lb.
Water	- 18 lb.
Coarse Aggregate	- 52 lb.
Fine Aggregate	- 35 lb.
Fibers	- 6 lb. (1.2% by volume)
Accelerater	- 6 oz (15 oz/100 lb. cement)

The accelerator dosage rate was initially reduced from 17 to 15 oz/100 lb. cement because it was felt that the high cement content and high temperatures might cause flash sets. The field strengths achieved were considered adequate and the dosage rate of 15 oz/100 lb. cement was continued.

For cool weather placements the water was reduced to 17 pcf because of reduced evaporation rates. The accelerator dosage rate was increased to the manufacturer's maximum recommended rate of 20 oz/100 lb. cement (8 oz per ft^3 mix). Other ingredient proportions were the same as for warm weather placememts.

Mix F9/185-2 provided reasonable workability and strength and the following proportions were selected for warm weather Montgomery placements:

<u>Warm Weather Montgomery Fibrous PCC (1 ft3)</u>

Cement	- 45 lb.
Water	- 18 lb.
Coarse Aggregate	- 47 lb.
Fine Aggregate	- 31 lb.
Fibers	- 6 lb (1.2% by Volume)
Accelerator	- 6.7 oz (15 oz/100 lb. cement)

For cool weather placements in Montgomery the only change that was made was to increase the accelerator dosage rate to 20 oz/100 lb. cement (8.8 oz/ft^3 mix).

Mixture Proportions-- Road Patch

Roadpatch is provided prepackaged in units that produce approximately 1/2 ft^3 of mix when coarse aggregate is added. Each prepackaged unit contains 50 lb. of cement/fine aggregate mixture and 2 lb. of steel fibers. To these was added 15 lb. coarse aggregate as per recommendations for patches 1" thick or greater. Latex is added with mixing water. Recommended mixing fluid consists of 1 part Acry 60 and 2 parts water.

The Roadpatch mixture was very sensitive to mixing fluid content: going from "too dry" to "too wet" with the addition of very little mixing fluid. Therefore, the water was added carefully for each batch and the following mix proportions reflect a range of mixing fluid:

Roadpatch (Prepackaged Unit)

Cement & Fine Aggregate	- 50 lb.
Coarse Aggregate	- 15 lb.
Fibers	- 2 lb.
Water	- 9-1/2 to 10-1/2 lb.
Acry 60	- 4-3/4 to 5-1/4 lb.

The above were used in Gadsden and Montgomery for both warm and cool weather placements. Larger mixing fluid contents were required during warm weather.

Rate of Strength Gain Studies

After mixture proportions were selected for mixes to be placed during warm weather in Gadsden, a study of the rate of strength gain that could be expected from these mixes was conducted. Strength data is shown in Table 4.

Strength values for 0 - 7 hours curing are plotted in Figure 1. The curves indicate differences in the rate of early strength gain. Initial set for the Roadpatch occurs between 0 and 1 hour and the rate of strength gain begins to decrease after about 2 hours and the curve becomes flat. For the plain and fibrous PCC mixes (with Type III cement and accelerator), initial set occurs between 3 and 4 hours and the strength gain to 7 hours is very rapid. This rather rapid rate of strength gain continues for some time as illustrated in Figure 2 which shows longer term strength gain.

No long term strength tests were run for Roadpatch but field strength data presented later indicate that the strength with time curve for Roadpatch remains below those for plain and fibrous PCC. This is as expected since rapid early strength gain is normally detrimental to long term strength gain. Implications of the strength development response illustrated in Figure 1 is that if 1 to 4 hour curing is necessary then Roadpatch would be required, but if 4 or more hours of curing is available then the plain or fibrous PCC would be preferred because of the potential for greater long term strength. During patch construction, with only two exceptions, the strength developed in all materials was sufficient to resist early traffic damage.

Although not quantifiable, there is some concern that the rapid

Table 4. Time-Strength Data

Age	Rapid-Setting PCC Strength (psi)	Fibrous PCC Strength (psi)	Roadpatch Strength (psi)
0.5 hr	--	--	338
1.0 hr	--	--	557
1.5 hr	--	--	687
2.0 hr	--	--	800
2.5 hr	--	0	898
3.0 hr	0	39	950
3.5 hr	202	--	990
4.0 hr	415	--	1017
4.5 hr	699	--	1033
5.0 hr	1253	1114	1060
5.5 hr	1499	--	--
6.0 hr	1558	2066	1120
7.0 hr	2476	--	1290
2 day	--	5451	--
3 day	3739	5800	--
14 day	--	7269	--
17 day	5000	--	--
28 day	5800	--	--

Specimens up to 7 hours old kept in molds until tested at ambient air temperature approximately 70°F.

2 to 28 day specimens cured at 75°F and 100% RH.

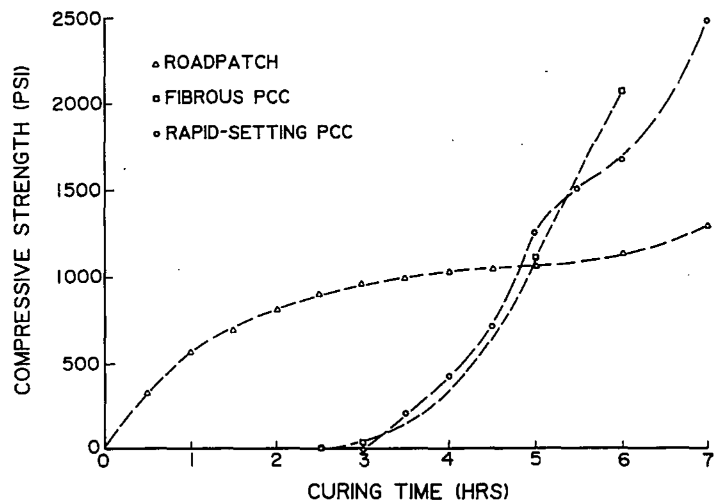


Figure 1. Laboratory Early Strength Development Curves

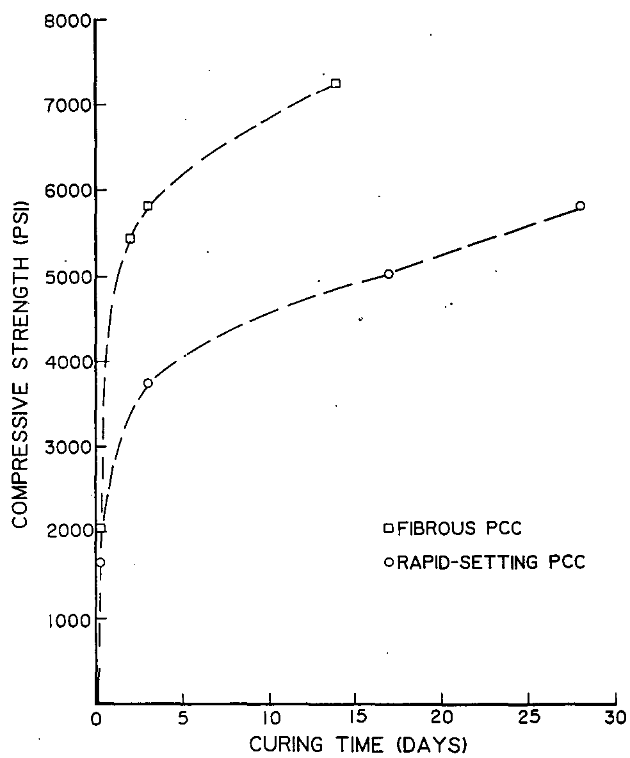


Figure 2. Laboratory Strength Develoment Curves

hydration and high heat generation of Roadpatch may accentuate shrinkage. However, the inclusion of the short steel fibers and latex should diminish this influence.

ANCHOR OPTIMIZATION STUDIES

The laboratory study (2) that preceded this study provided some indication that anchors might improve the resistance of patches to loads. The primary benefit appeared to be the ability to sustain load after bond between old and new concrete was broken. This capacity would theoretically keep a patch in-place after bond is lost. A second benefit suggested, but not conclusively verified in the earlier study was that bond strength was enhanced by anchors. Anchor stiffness appeared to be the key. Bond failure occurs at very low relative movement and anchors must be able to pick up portions of applied load at low deflections in order to be effective. However, determination of when bond failure occurs makes quantification of this improvement difficult.

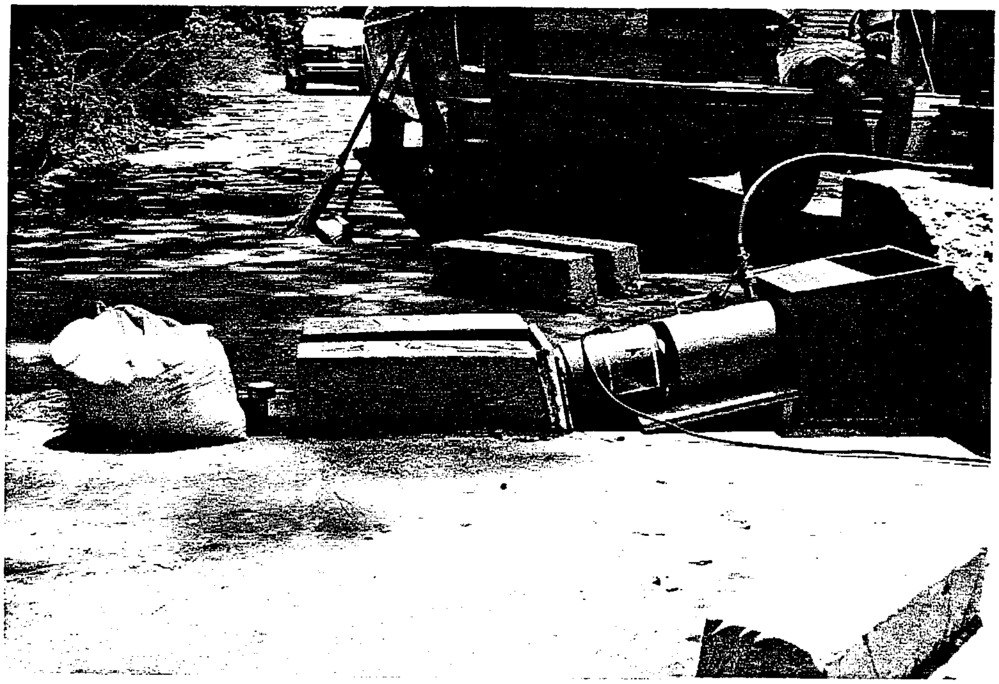
A series of tests were conducted to extend the earlier study, and to develop rudimentary data that could be used to select the amount, size and type anchor steel for inclusion in field patches. Blocks of concrete (18" x 6-1/2" x 5-1/2") with various anchor configurations, were cast on the surface of an old concrete pavement slab and loaded horizontally as described in reference 2. Reinforcing bars (#3, #4, and #6) bent into a "U" shape and shear connectors (1/2" and 3/4" diameter), as used in composite design, were used as anchors. Holes were drilled in the pavement slab and anchors attached with quick-setting polyester grout. The surface of the pavement slab was cleaned and lightly scarified prior to placing concrete.

Figure 3a shows forms and shear connectors in-place and ready for concrete placement. Figure 3b shows test specimens cast around a reaction pedestal. Figure 3c illustrates the set up for loading and measuring deflection. Figure 3d illustrates several failed specimens that

a. Forms and Shear Connectors In-Place

b. Test Specimens Around Reaction Pedestal

Figure 3. Anchor Optimization Tests



c. Loading Specimens

d. Failed Specimen

Figure 3. Anchor Optimization Tests

contained reinforcing bar anchors. The specmen in the background illustrates the cracking that develops at complete failure and the specimen in the foreground shows the reinforcing bars after the outer cracked concrete was removed.

Figure 4 shows typical load-deflection curves obtained with controlled loading procedures. The deflections are small and the relationship between load and deflection is approximately linear to about the maximum load. Cracking was initiated near the maximum load, deflection increased rapidly and the load that could be sustained decreased.

It is difficult to determine the parameter that would be most useful in assessing anchor effectiveness. Maximum load, apparent yield load, and ratio of yield load to deflection were considered. For simplicity, and lack of reasons to choose otherwise, maximum load was selected for analysis. Table 5 contains maximum loads and anchor data for all tests. The percent anchor steel is based on the ratio of the cross-sectional area of the reinforcing bars or shear connectors, A_s, to the bond area of the concrete block, A_b = 18" x 6-1/2" = 117 in^2.

To illustrate the relationship between type anchors, size anchors, and percent anchor steel the data in Table 5 is plotted in Figure 5. Observations from Figure 5 are as follows:

1. Scatter and points that are contrary to general trends are attributable to only one specimen per point.
2. There was generally a linear increase in maximum load with percent anchor steel. Least square linear regression equations for 1/2" and 3/4" diameter anchors are shown in Figure 6. Both coefficients of determination (r^2) are 0.9 and larger. This

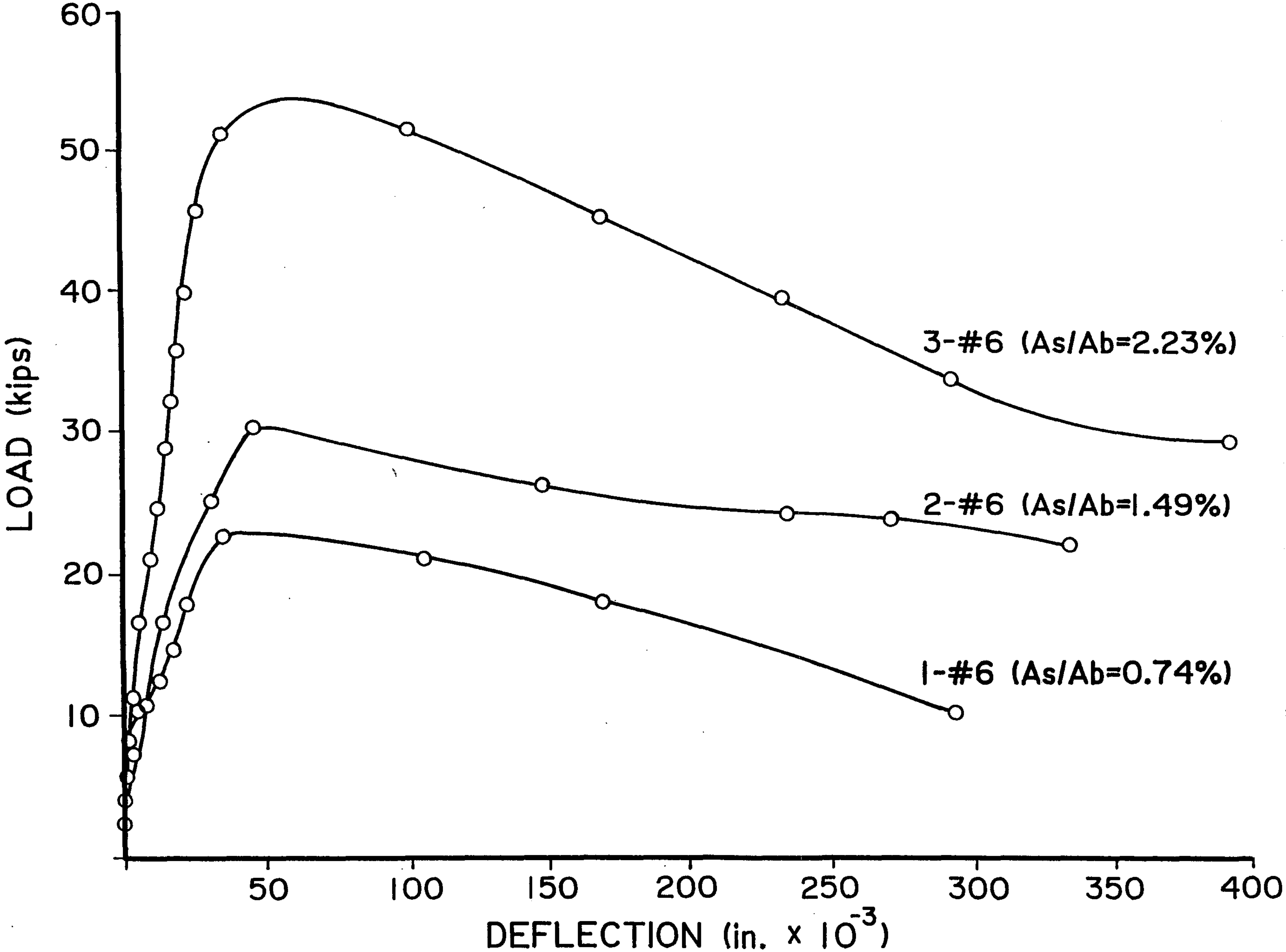


Figure 4. Typical Load-Deflection Curves (#6 Bar Anchors)

Table 5. Summary of Results from Anchor Optimization Study

% Anchor Steel (A_s/A_b x 100)	Quantity-Size of Shear Connector or Rebar	Maximum Load (kips)
0.34	1- #4 bar	9.9
0.34	2- 1/2" SC	11.0
0.37	1- 3/4" SC	9.3
0.56	3- #3 bars	31.3
0.68	2- #4 bars	29.4
0.68	4- 1/2" SC	28.5
0.74	4- #3 bars	28.6
0.74	1- #6 bar	22.8
0.74	2- 3/4" SC	24.5
1.01	6- 1/2" SC	30.3
1.35	4- #4 bars	40.4
1.35	8- 1/2" SC	42.4
1.49	2- #6 bars	30.6
1.49	4- 3/4" SC	38.7
2.23	6- 3/4" SC	36.6
2.23	3- #6 bars	52.8

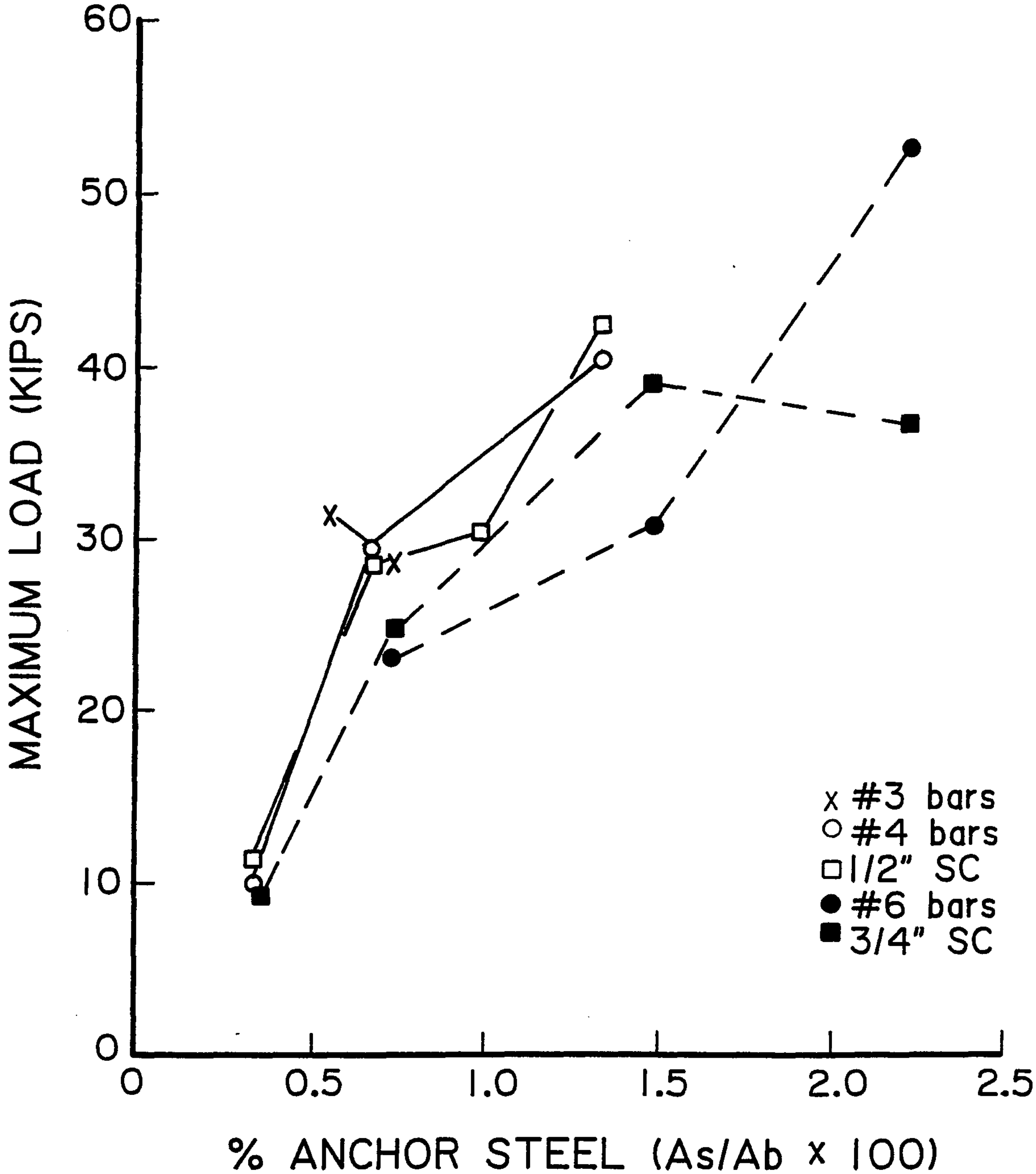


Figure 5. Maximum Load vs Percent Anchor Steel

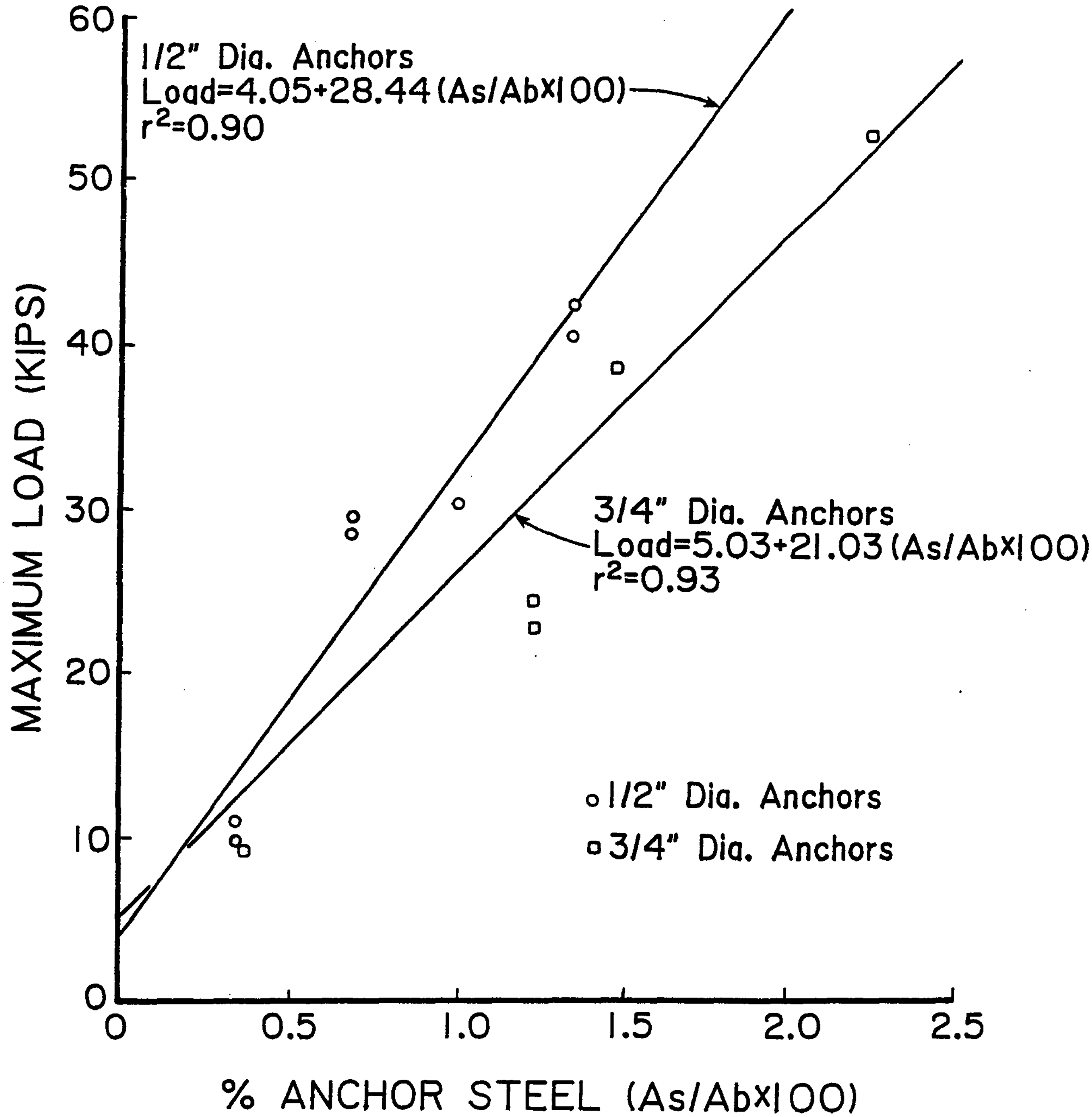


Figure 6. Least Square Linear Regression Equations

implies small unassociated variation and a reasonable linear relationship between load and percent anchor steel.

3. One-half inch diameter shear connectors and reinforcing bars were more efficient than 3/4" diameter. Two points for 3/8" reinforcing bars strengthens this conclusion.
4. There was no discernible difference between the effectiveness of reinforcing bars and shear connectors with the same diameter.

Based on these tests, anchors comprised of #4 reinforcing bars were selected for use in field patches. A target of 0.5% anchor steel was selected. However, as will be discussed in the following section, construction considerations prevented achievement of this target. An average 0.3% steel was placed in anchored patches.

PATCH CONSTRUCTION

Gadsden patches were constructed on the southbound lanes of I-59 between the US 431 and I-759 intersections and on the southbound entrance ramp from US 431. The pavement was jointed PCC that had required little previous patching. Deteriorated areas where concrete had been broken out had been filled with asphalt mix. Twenty-one warm weather patches were constructed on the entrance ramp and the inside lane during August 6-11, 1986. Maximum daily air temperature ranged from 90 to 96°F. Twenty-two cool weather patches were constructed on the outside lane during December 4-18, 1986. Maximum daily air temperature ranged from 50 - 60°F. Patch size ranged from 1 to 25 sf plan area with an average of about 6-1/2 sf. The average depth after shaping with a jack hammer was about 4 inches. Patches were constructed by AHD Third Division, District Three maintenance personnel.

Montgomery patches were constructed on the southbound lanes of I-85 between the Eastern Bypass and Perry Hill Road intersections. The pavement was jointed PCC that had undergone extensive rehabilitation; including undersealing, side drain installation, slab replacement, patching, grinding and joint sealing; several years earlier. Twenty-five warm weather patches were constructed on the inside lane during October 31, 1986 to November 10, 1986. Maximum daily air temperature ranged from 70 to 80° F. Fourteen cool weather patches were constructed on the outside lane during February 11-20, 1987. Maximum daily air temperature ranged from 50 to 65°F. Patch plan area size was smaller than the Gadsden patches ranging from 1/2 to 15 sf with an average of about 4 sf. The patch depth, however, was somewhat greater with some extending below the welded wire fabric at 5 inch depth. The average depth after shaping with a jackhammer was 4 to 5 inches. Patches were constructed by AHD Sixth Division, District Three maintenance personnel.

Construction Techniques

Patches were constructed by AHD district maintenance personnel with available equipment. As with any maintenance operation, equipment for traffic control and transportation was necessary. Specific items required for patch construction included a concrete saw; air compressor, and jackhammer; generator, impact drill and concrete vibrator; and a portable concrete mixer.

The multiple photographs in Figure 7 illustrate the construction process. Figure 7a illustrates a typical cracked area along a transverse contraction joint. As mentioned earlier, the deteriorated areas on I-59 in Gadsden were larger than those on I-85 in Montgomery. At both locations deteriorated areas were adjacent to a transverse joints. Some were along the interior of transverse joints, as shown in Figure 7a, while others were at corners along the pavement edge or along longitudinal centerline contraction joints. In most cases the deterioration was only on one side of a transverse joint, but occasionally was on both sides.

On I-59, the deterioration was concentrated on the upstream side of transverse joints, while on I-85 it was more uniformly distributed on both sides. On I-59, there were several deteriorated areas completely across a lane. On I-85, quite a few of the deteriorated areas were adjacent to previously placed patches or replaced slabs. A few completely replaced old deteriorated patches. Along I-85 there were several locations where relief expansion joints with full depth full width slabs on both sides had been constructed to alleviate buckling problems. Deteriorated areas associated with these were not patched.

Patch Area Preparation

The first step in the patch construction process was to identify the area of deteriorated concrete to be removed. In a portion of the patches a sawcut, 1-2" deep, was made around the area as illustrated in Figure 7b and c. The sawcut made removal of the deteriorated concrete easier and gave a more uniform edge patch depth. As will be discussed later, removal of all damaged concrete is critical to patch performance. Sawing seems to increase the likelihood of complete removal.

The next step is the removal of damaged concrete with a jack hammer as illustrated in Figure 7d. The size jackhammer should be kept as small as possible to prevent cracking of the concrete around the patch area. A 30 lb. maximum size is recommended.

In part of the patches reinforcing bar anchors were installed as shown in Figure 7e. Holes were drilled in the slab and the anchors fixed with rapid-setting polyester grout. With the drills available, drilling slowed the construction process considerably. A larger bar size to reduce drilling was considered, but because of limited patch depth and cover requirements, #4 bars were the largest practical size.

Expanded polystyrene insulation board, 3/4 in. thick, was shaped and placed along joints as shown in Figure 7f. The soft polystyrene protects the patch against expansion forces from adjacent slabs and provides a reservoir for sealant. In several patches where deterioration was on both sides of a joint no joint was formed in the patch; and, as expected, a crack matching the joint formed.

Figure 7g and h show a large (25 sf) full lane width area on I-59 and a small (1/2 sf) corner area on I-85 ready for concrete placement. The photographs illustrate the diversity in patches. Patch areas were blown clean with compressed air to remove dust and the sides and bottom dampened prior to placing patch material to promote bond development.

<u>Patch Material Production</u>

Portable concrete mixers as shown in Figure 7i were used to mix patch materials. Construction time limitations will likely keep needed daily volumes and rates of patch material so low that the use of ready mix will be uneconomical. This will mean that even for routine patching operations, where only one patch material is used, small portable mixers will be most practical. Special care will be required to insure uniform quality patch material. The key will be accurate proportions which can only be achieved by weighing each ingredient. Water-cement ratio will also be critical to rapid strength gain and the addition of extra water must be carefully controlled.

<u>Patch Material Placement</u>

Figure 7j shows a completed patch. Conventional techniques for consolidating and finishing the patches were used. None of the patch materials required any special attention. Vibration of the patch material is necessary to consolidate the material and to insure that all voids are filled. Vibration also seems to enhance bond development. A small internal type vibrator was used and appears adequate.

<u>Patch Curing</u>

Patches were initially wet cured by covering with wet burlap, polyethylene sheet and fiberglass insulation mats as shown in Figure 7k. For warm wather patches, loss of moisture was critical. For cool weather patches insulation to prevent heat loss was critical to insure rapid strength gain. Hot mixing water was tried for some of the cool weather patches to accelerate strength gain. However, the rate of heat loss from the relatively small patches to the relatively large slab and to the air during consolidation and finishing was so large that using hot water did not significantly affect the rate of strength gain. During placement of the cool weather I-85 patches, a cover was constructed and a source of heat provided for several of the patches. There was no apparent appreciable increase in the rate of strength gain and the effort required to provide heat precludes consideration of this technique as a viable means for providing rapid early strength gain. After initial curing and prior to opening to traffic, membrane curing compound was applied to patches.

A patch that develops early strength sufficient to resist damage when opened to traffic is the first priority of patch construction. Certainly, long term performance is the ultimate goal, but getting and keeping the patch in place allowing strength to develop is critical. Only two cool weather patches were damaged immediately after opening to traffic as illustrated in Figure 71. There was some surface deformation and abrasion in these patches which were replaced during the next work day.

Field Strength Development

Four inch diameter, 8 inch long compressive strength specimens were made according to AASHTO T23 and tested according to AASHTO T22. Every effort was made to simulate patch curing conditions since the early (4-hr) strength will be very dependent on temperature and possibly sample disturbance. Samples were kept on the job site as long as possible before transporting to a laboratory for testing. Despite obvious differences in

a. Cracked Area Along a Joint

b. Sawcut (1-2" Deep) Around Failed Area

Figure 7. Patch Construction

c. Failed Area Outlined
with Sawcut

d. Jackhammer Removing
Damaged Concrete

Figure 7. Patch Construction

e. Anchor Installation

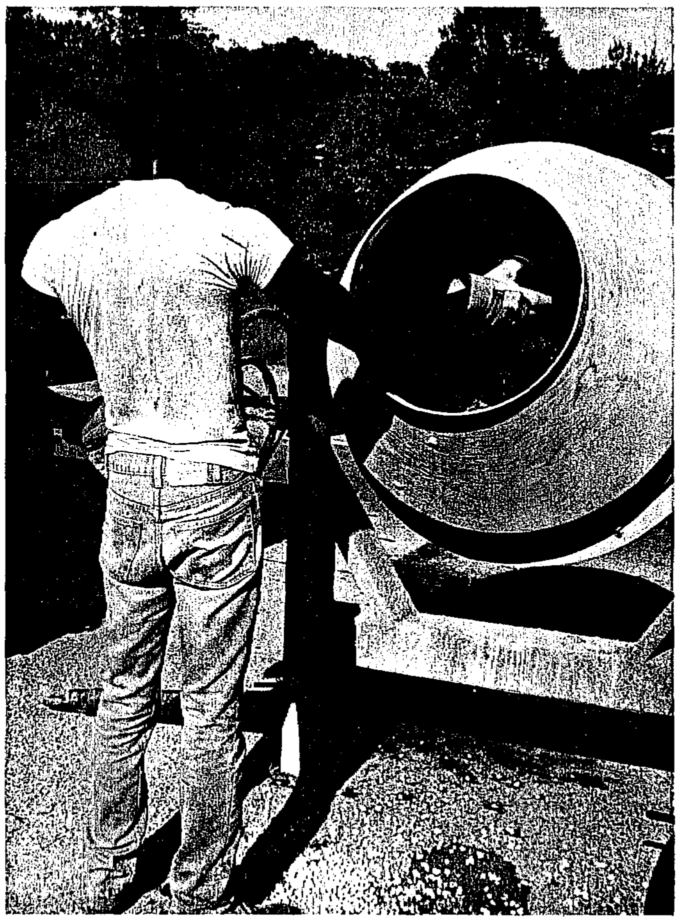
f. Joint Filler Installation

Figure 7. Patch Construction

g. Large Patch Area with
Anchors Ready for Concrete

h. Small Patch Area with
Anchors Ready for Concrete

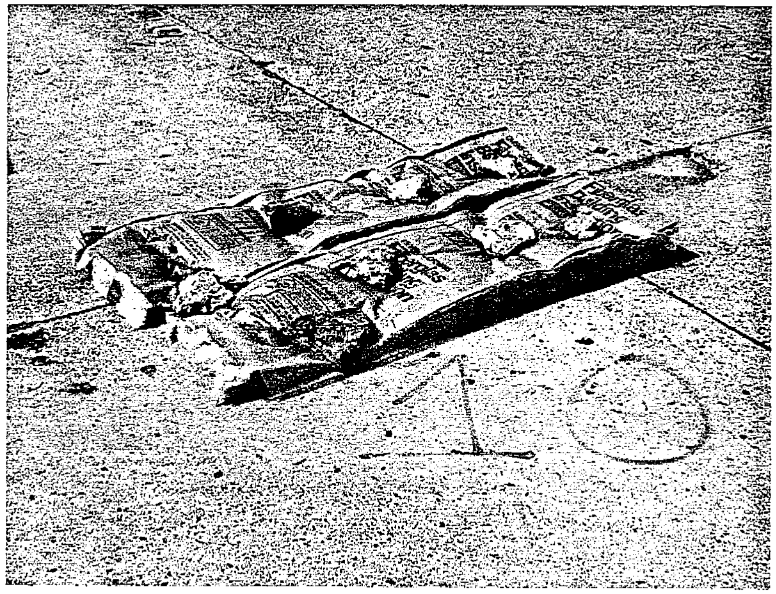
Figure 7. Patch Construction



i. Patch Materials Mixed in Portable Mixer

j. Completed Patch-- Consolidated and Finished with Conventional Techniques

Figure 7. Patch Construction



k. Patches Insulated During Curing to Accelerated Rate of Hydration

l. Tire Damage to Unset Patch

Figure 7. Patch Construction

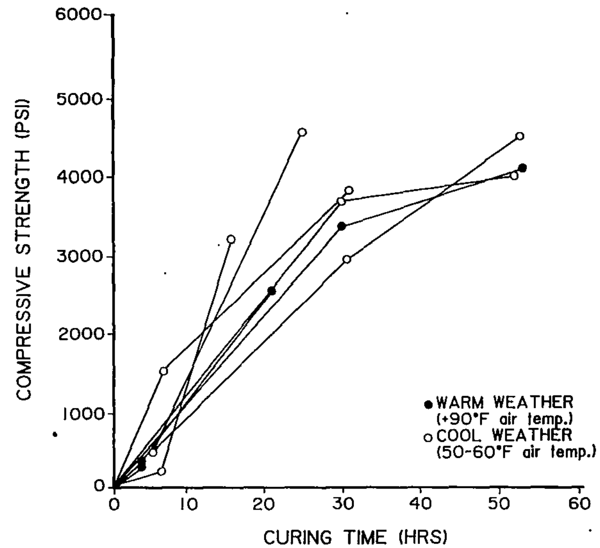
curing, the strengths obtained are felt to be reasonably representative of strengths in the patches.

Field strength data for I-59 and I-85 are shown in Figures 8 and 9, respectively. Even though the data exhibits considerable scatter, attributable to widely variable conditions, several definite trends are apparent. As expected from the laboratory studies, Roadpatch seems to develop higher 4-6 hour strengths than the plain or fibrous PCC. However with time, the plain and fibrous PCC strengths exceed the Roadpatch strengths. For example, 2 day rapid setting PCC strength is roughly 3000 psi, fibrous PCC strength is roughly 3500 psi and Roadpatch strength is roughly 1500 psi. Although scatter makes precise comparisons difficult, there are similarities in the trends exhibited by the I-59 and I-85 strengths.

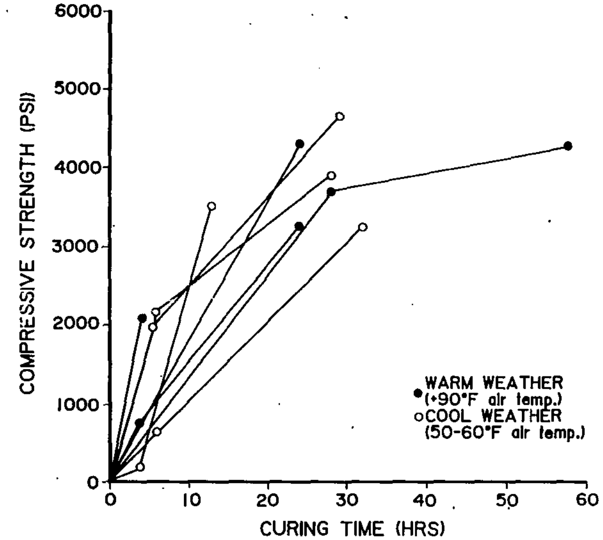
Comparison of Lab and Field Strengths

Field strength values are plotted on early and long-term lab strength curves in Figures 10 and 11, respectively. For rapid-setting PCC, the early field strengths were generally higher while for fibrous PCC the early field strengths were generally lower. For the Roadpatch, the laboratory curve roughly splits the field strength values.

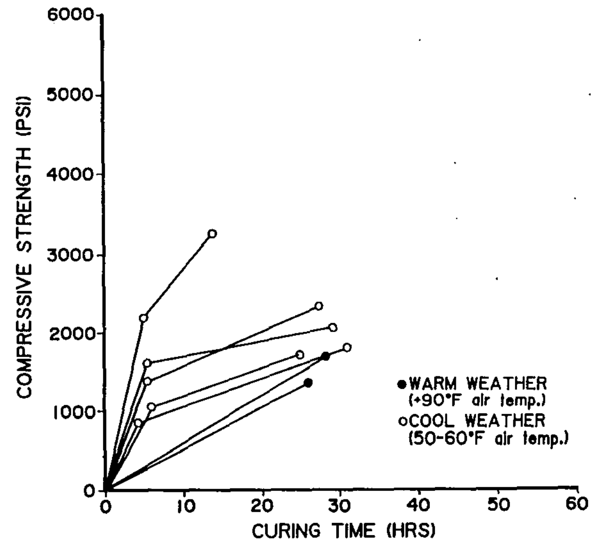
For long term strength, Figure 11, the trends observed are the same as for early strengths. The field strengths for rapid-setting PCC are generally higher than the lab curve and the field strengths are generally lower than the lab curve for the fibrous PCC. A possible explanation is that extra water may have been added to increase workability of the fibrous PCC. The steel fibers increase mix harshness and reduce



a. Rapid-Setting PCC

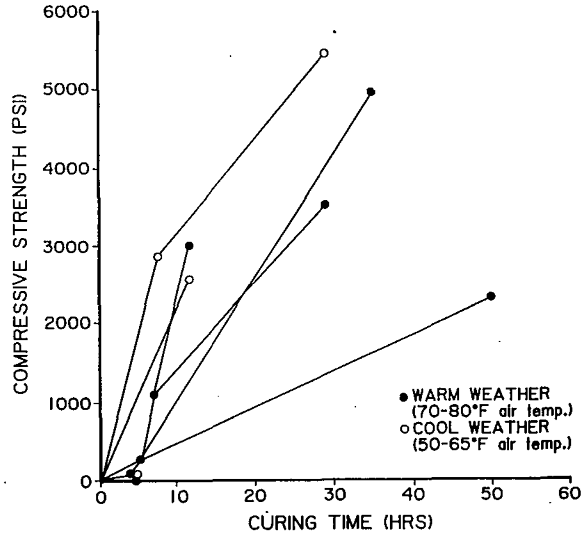


b. Fibrous PCC

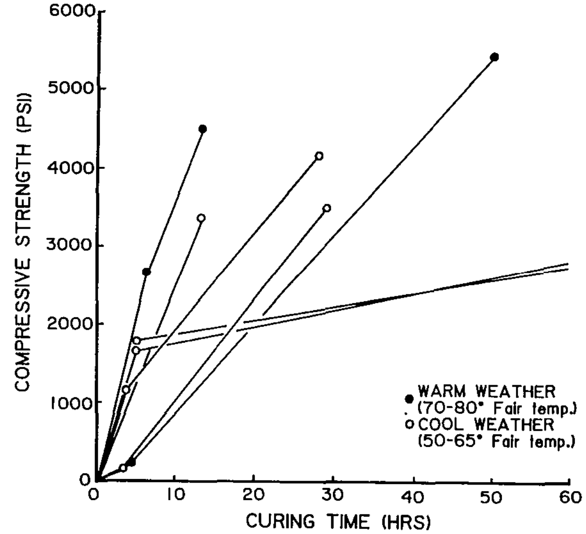


c. Roadpatch

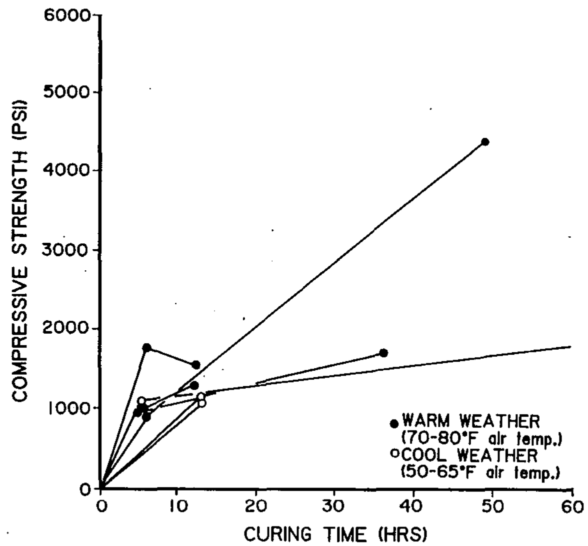
Figure 8. I-59 Strength Development Curves



a. Rapid-Setting PCC

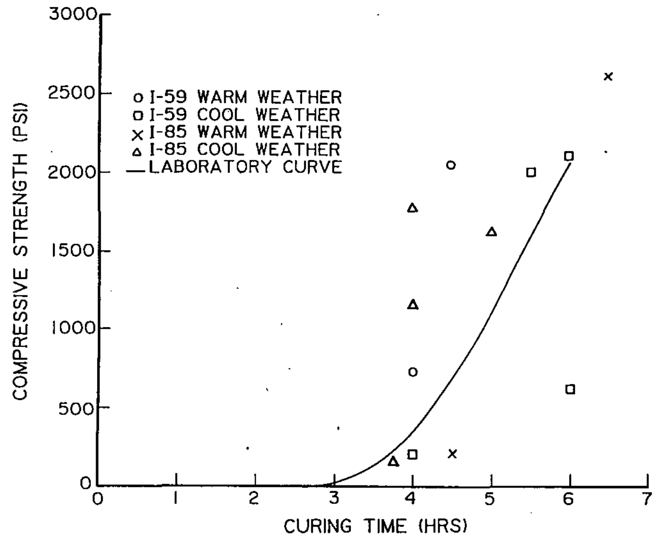


b. Fibrous PCC

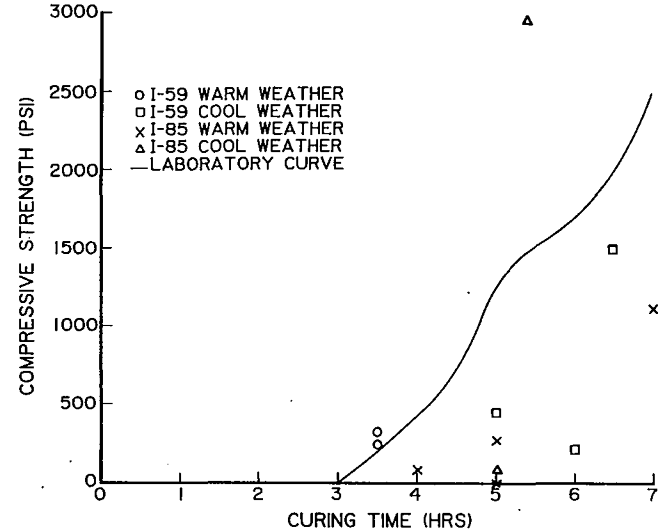


c. Roadpatch

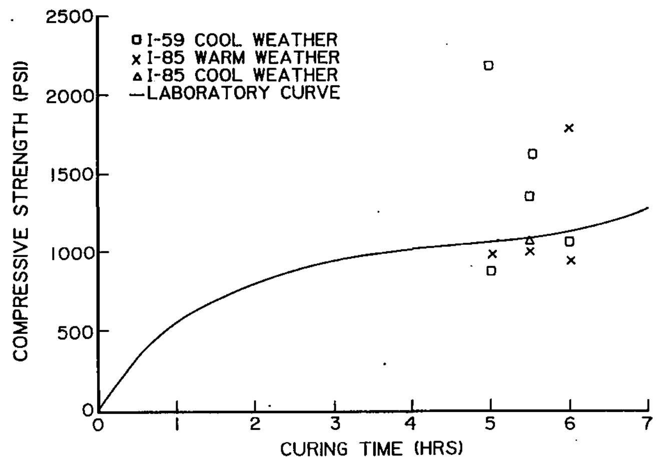
Figure 9. I-85 Strength Development Curves



a. Rapid-Setting PCC

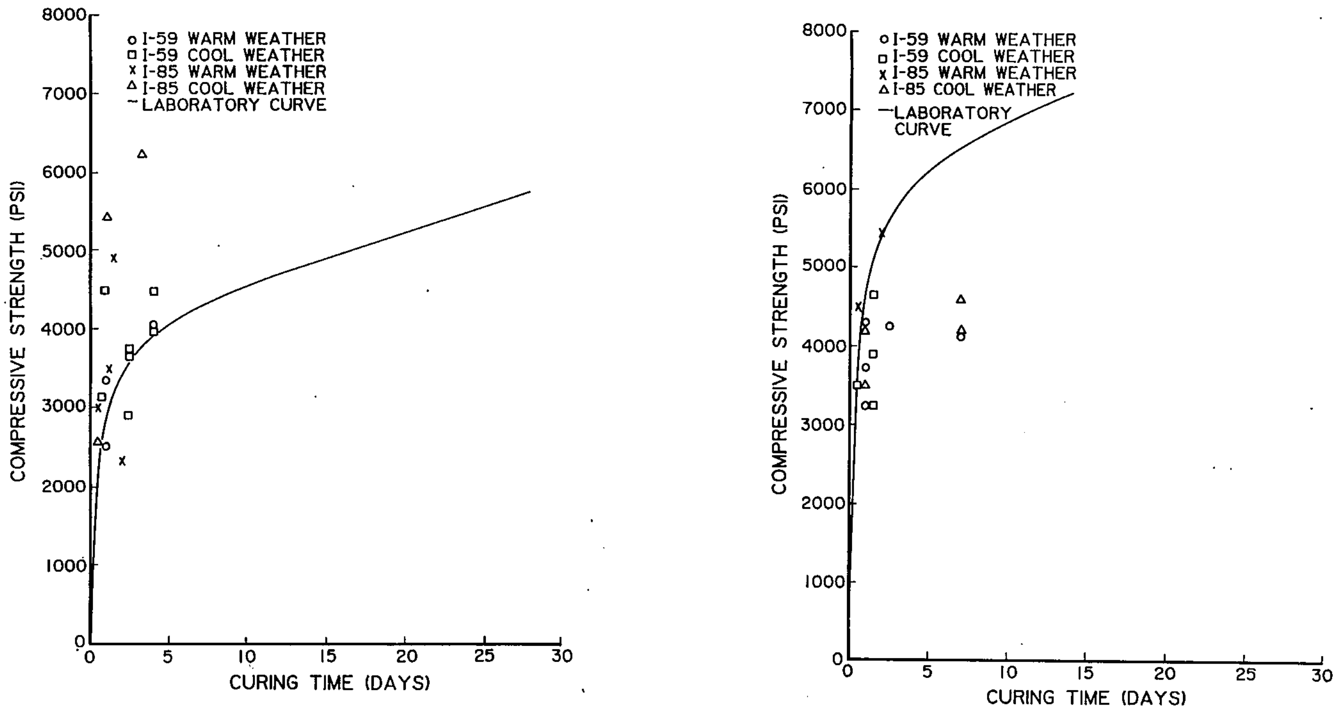


b. Fibrous PCC



c. Roadpatch

Figure 10. Comparison of Early Lab and Field Strengths



a. Rapid-Setting PCC

b. Fibrous PCC

Figure 11. Comparison of Long-Term Lab and Field Strengths

workability and, although no extra water was supposed to have been added, some may have mysteriously appeared. Considering field variability, the comparisons indicate that desired strengths were achieved reasonably well in the field.

PATCH PERFORMANCE

Patch performance was monitored visually. In addition, an attempt was made to use accoustic emissions to assist in this evaluation (4). Acoustic emission techniques provide relative measures of internal microcracking and debonding. The basis for using acoustic emissions was that higher levels of internal microcracking and debonding would be indicative of higher probabilities of patch failure. Acoustic emission surveys were conducted on selected patches at 1/2, 1, 3, and 6 month age. Based on these surveys, the patch structural condition was evaluated. These evaluations were compared with the final distress categorizations. The comparisons indicated poor agreement. Therefore, the patch performance evaluation will rely on the visual monitoring.

Visual Monitoring

Performance of the patches were monitored by periodically observing and documenting their condition. The following summarizes the observation schedule for the patches:

I-59 Warm Weather	- 4, 8 & 15 month observations
I-59 Cool Weather	- 4 & 11 month observations
I-85 Warm Weather	- 4, 6 & 11 month observations
I-85 Cool Weather	- 2 & 7 month observations

The following discussion of deterioration mechanisms is based on these observations and the performance ranking and evaluations are based on the final observations for each patch grouping.

Patch Deterioration

Patch deterioration developed in several stages beginning with localized cracking as illustrated in Figure 12a. In two patches on I-59 joints were not placed in patches and working cracks, as illustrated in Figure 12b, developed. In neither case have these working cracks contributed to further deterioration. Localized cracking progressed until large spalls began to break loose, as shown in Figure 12c filled with asphalt mix. In some, this progressed until it became necessary to completely remove the remaining patch material and replace with asphalt mix as illustrated in the patch (#27) in the background of Figure 12d.

In a few patches shallow spalling developed along joints and around the patch-slab boundary, as illustrated in Figure 12a. In no cases has this been a serious failure mode unless accompanied by cracking.

Loss of bond did not appear to be a serious problem; and, as will be discussed later, may account for the ineffectiveness of anchors. No patches were displaced as a whole without being accompanied by cracking. It should be noted, however, that localized cracking may have been caused or, at least, aggravated by partial bond loss.

Figure 12e and f show patches which are still intact, but where the slab adjacent to the patches has continued to deteriorate. In both cases the slabs have been patched with asphalt mix. This behavior may be caused by one or a combination of two factors. All damaged concrete may not have been removed when the patch was placed. The subsequent deterioration may only have been the worsening of an existing condition. When outlining the area to be removed for patching a good practice to follow is to be conservative and then to add one foot to all sides.

The second factor is that the patching is not correcting the condition that initially caused the deterioration. The deterioration around the patch may be only a manifestation of these continuing conditions. The response

a. Initial Cracking and Spalling

b. Working Crack Where Joint Not Replaced

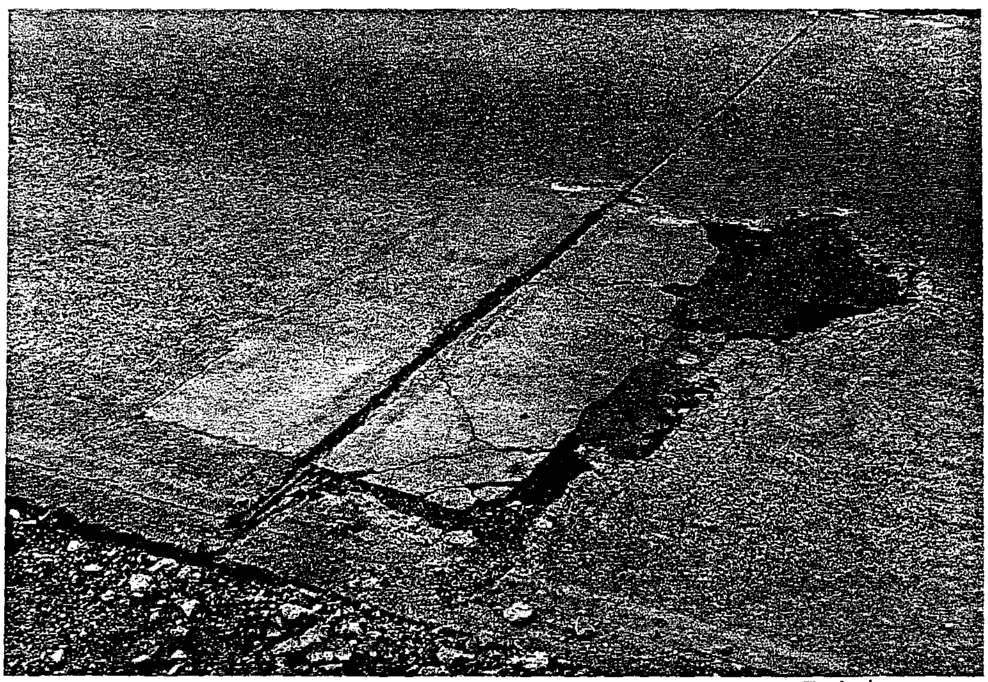
Figure 12. Patch Deterioration

c. Partial Patch Removal-- Filled with Asphalt Mix

d. Complete Patch Removal-- Filled with Asphalt Mix

Figure 12. Patch Deterioration

e. Deterioration Around Periphery of Unsawed Patch



f. Deterioration Around Periphery of Sawed Patch

Figure 12. Patch Deterioration

of five cold weather I-59 patches further reinforces this notion. All five patches (#26-#30) were placed sequentially on the outside lane just upstream of the intersection with the US 431 entrance ramp. They were placed in December 1986, were in good condition in April 1987 (4 months) and completely failed (removed and filled with asphalt mix) during the summer of 1987. Patch 27 is shown in the background of Figure 12d. A possible explanation for this behavior is that the ramp entrance may restrict the cyclic movement of the slabs which may have been the cause of the initial deterioration along the joints. As summer temperature increased, the same restraint and resulting compressive forces may have caused failure in the patches.

Patch Performance Evaluation

Based on visual observations of the patches during the final survey they were grouped, according to the amount of distress, into the following three distress categories:

- o No distress
- o Moderate distress - localized cracking & light spalling
- o Severe distress - severe cracking & deep spalling requiring maintenance

Results from the surveys are summarized for the I-59 patches and I-85 patches in Tables 6 and 7, respectively. The data for all patches is combined in Table 8.

Comparison of the performance of patches placed during warm and cool weather reveals better performance for those patches placed during warm weather. Evidence of this is the larger percentage of warm weather patches falling into the no distress category and the smaller percentages falling in the severe distress category. This conclusion is strengthened by the age of the patches at the final survey. For I-59 the warm weather

Table 6. Performance Evaluation: I-59 Patches

Variable	Percent Patches in Distress Category N*	M*	S*
Warm (21)	76	24	0
Cool (22)	36	41	23
Type III (15)	40	47	13
Roadpatch (14)	43	43	14
Fibrous (14)	86	7	7
Unanchored (22)	50	36	14
Anchored (21)	62	29	9
Not sawed+ (10)	30	20	50
Sawed (33)	64	36	0
All patches (43)	55	33	12

*Distress Category:
- N - No distress
- M - Moderate distress
- S - Severe distress

+Patches that were not sawed placed only in winter.
Numbers in parentheses indicate number of patches.

Table 7. Performance Evaluation: I-85 Patches

Variable	Percent Patches in Distress Category		
	N*	M*	S*
Warm (25)	44	56	0
Cool (14)	14	43	43
Type III (14)	21	71	8
Roadpatch (13)	8	62	30
Fibrous (12)	75	17	8
Unanchored (20)	35	55	10
Anchored (19)	32	47	21
Not sawed (13)	38	62	0
Sawed (26)	31	46	23
All patches (39)	33	51	16

*Distress Category:
- N - No distress
- M - Moderate distress
- S - Severe distress

Numbers in parentheses indicate number of patches.

Table 8. Performance Evaluation: All Patches

Variable	Percent Patches in Distress Category N*	M*	S*
Warm (46)	59	41	0
Cool (36)	27	42	31
Type III (29)	31	59	10
Roadpatch (27)	26	52	22
Fibrous (26)	81	12	7
Unanchored (42)	43	45	12
Anchored (40)	47	38	15
Not sawed (23)	34	44	22
Sawed (59)	50	40	10
All patches (82)	44	42	14

*Distress Category:
- N - No distress
- M - Moderate distress
- S - Severe distress

Numbers in parentheses indicate number of patches.

were 15 months old and the cool weather 11 months. For I-85 the warm weather were 11 months old and the cool weather 7 months. Improved performance of warm weather patches can likely be attributed to the more rapid rate of strength gain which will reduce early damage when opened to traffic.

Comparison of the performance of the three patch materials reveals that the fibrous PCC patches performed best. Fibrous PCC had, by far, the largest percentage of patches in the no distress category. It also had the smallest percentage in the severe distress category. The superior performance of the fibrous PC is attributed to several factors. The larger tensile strength and ductility of the fibrous PCC enables the patches to better resist cracking and subsequent spalling. In addition, the fibers provide resistance to shrinkage and microcracking during curing. For rapid setting materials these may be significant. Reductions in shrinkage should improve bond and, therefore, performance. The level of microcracking determines brittleness and, therefore, reducing it will increase ductility.

Roadpatch contains fibers but the quantity used and the fiber length are both considered too small to provide required properties. In addition, roadpatch did not exhibit the long term strength gain potential of the PCC materials. The mixture formulation appears to be designed for very rapid early strength and, as a consequence, long term strength is adversly affected.

Comparison of the performance of anchored and unanchored patches reveals no appreciable differences. The percentages in all three distress categories for each location is approximately the same. This may be explained by examining the manner in which the patches failed. Loss of bond did not appear as significant as originally thought. As discussed

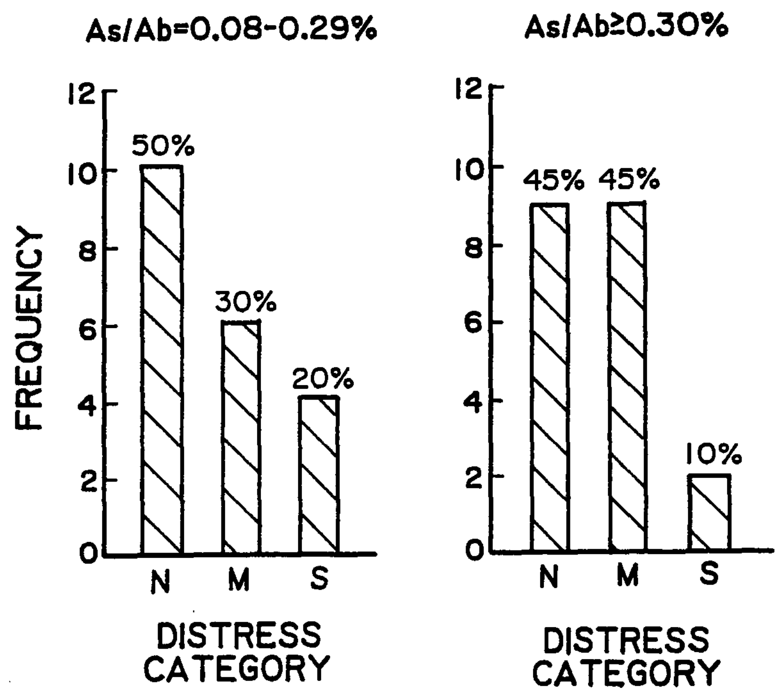


Figure 13. Frequency Diagrams for Percent Anchor Steel

earlier, failure appeared to start with localized cracking which progressed until large pieces or spalls broke loose. Anchors did not decrease the propensity for this to happen. Because of limited patch depth, resulting in limited cover, the anchors may have accelerated cracking and breakup for some patches.

The ineffectiveness of anchors is further demonstrated by examining the influence of amount of anchor steel on patch performance. Percent anchor steel to patch bond area varied from 0.1 to 0.6% with an average of 0.3%. Patches were separated into two groups (of 20 patches each) with percent anchor steel smaller and larger than the average of 0.3%. The frequency of patches in the three distress categories for each group are plotted in Figure 13. Although there are differences in frequencies and percentages, they are often contradictory and are not considered large enough to conclude that patch performance is improved by increasing the amount of steel.

Comparison of the performance of patches with sawed edges with those that were not sawed reveals some contradictory implications. For I-59 patches, the percentages in the no distress and severe distress categories indicate that sawing was beneficial. For I-85 patches, the opposite is indicated. However, when combined, as in Table 8, a moderate beneficial effect of sawing is indicated. Even if this were not sufficiently strong justification for sawing, construction considerations make the effort required worthwhile. As noted earlier, sawing makes damaged concrete removal easier, provides more uniform patch edge depth, and reduces damage to sound concrete with the jackhammer when preparing the patch area.

Comparison of the performance of I-59 and I-85 patches reveals better performance for I-59 patches. Three possible reasons for this are

1) the greater traffic volume on I-85, 2) the poorer overall condition of the I-85 pavement, and 3) the higher quality workmanship for the I-59 patches.

Even though the overall experiment design and data analysis may lack statistical rigor, particularly variable interaction, the conclusions drawn seem reasonable when combined with patch material properties and patch deterioration mechanisms. Fibrous PCC placed during warm wather conditions will provide the best patch performance. A sawcut around the patch area will improve performance but anchors will probably not. Placement of patches does not correct the basic condition causing distress and patch performance will likely be directly related to the overall pavement condition.

CONCLUSIONS AND RECOMMENDATIONS

Patch material can be produced using Type III cement and a nonchloride accelerator that will develop strength rapidly enough to allow patch construction and reopening to traffic in one working day. The inclusion of 1.2% by volume, 3/4 in. or longer steel fibers will enhance patch performance. The inclusion of anchors in the patch will not significantly improve performance. Patches constructed during warm weather (+70°F) will perform better than those constructed during cooler weather. A sawcut to outline the patch area will aid in construction. There is some evidence to indicate that the sawcut may also improve patch performance.

Fibrous PCC patching mixes should be designed with Type III cement and a nonchloride accelerator to achieve a six-hour compressive strength of approximately 2000 psi. Patches should be constructed when the maximum daily temperature will be greater than 70°F. Construction operations should be scheduled to provide a minimum of 4 hours wet curing of the patch prior to opening to traffic. The patches should be covered with insulation to prevent heat loss and speed hydration during wet curing. A membrane curing compound should be applied prior to opening to traffic.

During patch construction areas of deteriorated concrete should be identified and outlined with a sawcut 1 to 2 in. deep. The area outlined with the sawcut should be about 1 ft. larger on all sides than the deteriorated area. The smallest jackhammer possible should be used to remove damaged concrete; if possible 30 lb. or less. Patch material should be consolidated with vibration.

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