TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/TX-85/20+311-4	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LABORATORY AND FIELD EVALUATION OF RAPID SETTING MATERIALS USED FOR REPAIR OF CONCRETE PAVEMENTS		5. Report Date July 1984 6. Performing Organization Code
7. Author(s) Kevin G. Smith, David W. Fowler, and Alvin H. Meyer		8. Performing Organization Report No. Research Report 311-4
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075		10. Work Unit No. 11. Contract or Grant No. Research Study 3-9-82-311
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Interim 14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges"

16. Abstract

Minimizing lane down-time is of key importance when repairing concrete pavements in high traffic volume areas. As a result, rapid setting repair materials are in great demand. Many such products are available, however, they differ widely in chemical composition, workability, durability, and cost.

The following four proprietary rapid setting materials were chosen for laboratory and field evaluation: (1) Duracal (a water-activated blend of portland cement and gypsum); (2) Set-45 (a water-activated magnesia phosphate); (3) Gilco Highway Patch (a water-activated modified portland cement); and (4) Neco-crete (a magnesia powder which is activated by an ammonium phosphate solution).

The repair mixes contained both fine and coarse aggregate. Techniques used to place and finish the repairs were similar to those used with conventional portland cement concrete. Laboratory results include the following: (1) compressive strengths, flexural strengths and Gilmore Needle set times of materials mixed and air-cured at 40, 72, and 110°F (4, 22, and 43°C); (2) change in length of air-cured specimens; and (3) resistance of specimens to freeze-thaw cycles.

Field repairs were made in the Waco, Amarillo, Dallas, and Houston districts. Several small full-depth punchouts were repaired in each of these districts using the rapid setting materials.

17. Key Words rapid setting materials, repair, portland cement concrete, water-activated, aggregate, compressive strength, freeze-thaw cycle	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	105	

Form DOT F 1700.7 (8-69)

LABORATORY AND FIELD EVALUATION OF RAPID SETTING MATERIALS USED FOR REPAIR OF CONCRETE PAVEMENTS

by

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Research Report Number 311-4

Evaluation of Fast-Setting Repair Materials
for Concrete Pavements and Bridges

Research Project 3-9-82-311

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

July 1984

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ABSTRACT

Minimizing lane down-time is of key importance when repairing concrete pavements in high traffic volume areas. As a result, rapid setting repair materials are in great demand. Many such products are available, however, they differ widely in chemical composition, workability, durability, and cost.

The following four proprietary rapid setting materials were chosen for laboratory and field evaluationn: 1) Duracal (a water-activated blend of portland cement and gypsum); 2) Set-45 (a water-activated magnesia phosphate); 3) Gilco Highway Patch (a water-activated modified portland cement); and 4) Neco-crete (a magnesia powder is activated by an ammonium phosphate solution).

The repair mixes contained both fine and coarse aggregate. Techniques used to place and finish the repairs were similar to those used with conventional portland cement concrete. Laboratory results include the following: 1) compressive strengths, flexural strengths and Gilmore Needle set times of materials mixed and air-cured at 40, 72 and 110°F (4, 22 and 43°C); 2) change in length of air-cured specimens; and 3) resistance of specimens to freeze-thaw cycles.

Field repairs were made in the Waco, Amarillo, Dallas and Houston districts. Several small full-depth punchouts were repaired in each of these districts using the rapid setting materials.

SUMMARY

There are many rapid setting materials available for repair of concrete pavements; however, they vary greatly in workability, durability and cost.

This report presents the results of laboratory and field testing on four proprietary rapid setting materials: Duracal, Set-45, Gilco Highway Patch and Neco-crete. Laboratory results include the following: 1) compressive strengths, flexural strengths and Gilmore Needle set times of materials mixed and air-cured at 40, 72 and 110°F (4, 22 and 43°C); 2) change in length of air-cured specimens; and 3) resistance of specimens to freeze-thaw cycles.

Field repairs were made in the Waco, Amarillo, Dallas and Houston districts. Several small full-depth punchouts were repaired in each of these districts using the rapid setting materials.

IMPLEMENTATION STATEMENT

Rapid-setting concretes are widely used in the repair of portland cement concrete pavements and bridges. As traffic increases, the need for making durable, rapid repairs also increases. The results of this study will be of direct benefit to maintenance work and rehabilitation projects by identifying materials and methods of using the materials to more rapidly and effectively repair highway structures.

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CHAPTER 1
INTRODUCTION

1.1 Background

Repairing deteriorating portland cement concrete (PCC) roadways and bridge decks is an unending task for highway maintenance personnel. The many factors influencing the methods and materials best suited for a particular repair include: 1) actual cost and availability of labor (including traffic control), equipment, and materials for the repair; 2) repair durability; 3) cost of time delays to motorists; and 4) safety hazards to motorists and repair crews. When these factors are considered, minimizing lane down-time appears to be of primary importance, particularly in high-traffic volume areas. Durable, rapid-setting repair materials that enable road crews to open lanes to traffic shortly after placement are thus in great demand.

The many rapid-setting materials now available include: 1) Type III PCC with set accelerator and other admixtures; 2) chemical-setting cements; 3) thermosetting materials; 4) calcium sulphate; and 5) bituminous materials. Material costs, mechanical properties, workability, and performance vary greatly from category to category and from brand to brand in each category. Other factors influencing the suitability of a rapid-setting repair material to a particular repair include (1) design life of the repair, (2) ambient temperature at the repair site, (3) depth of the repair (spall or full-depth), (4) repair boundaries (feathered or saw-cut), (5) repair hole condition (wet or dry); and (6) moisture content of coarse aggregate used to extend the mix.

At present, there is no standard method for evaluating and selecting repair materials.

1.2 Scope of Report

Research Study 311, "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges," is being conducted for the Texas State Department of Highways and Public Transportation and was begun in September 1981. The objectives of the study are to (1) identify candidate materials based on D-9 evaluation tests and a survey of districts and other states, (2) perform laboratory tests on candidate materials, (3) determine optimum mixing, placing, and finishing methods, (4) make field repairs in different districts using candidate materials, and (5) disseminate results. Results of the survey of districts and states and data from laboratory tests performed at 72°F (22°C) were presented in references 1 and 2. This report presents the results of additional laboratory work, including tests performed at 40°F (4°C) and 110°F (43°C), and the results of field repairs made in Waco, Amarillo, Dallas, and Houston.

CHAPTER 2
MATERIALS TESTED

2.1 Introduction

Four candidate rapid-setting materials were selected based on the State Department of Highways and Public Transportation Materials and Tests Division (D-9) experience and the survey of districts and states. These were Duracal, Set-45, Neco-crete and Gilco Rapid Patch.

Shortly after testing began in August 1982, the production of Gilco Rapid Patch was discontinued by Gifford-Hill, the manufacturer. However, testing was resumed on a new Gifford-Hill product, Gilco Highway Patch, in February 1983. Only results of tests on Gilco Highway Patch are presented in this report.

Testing on Neco-crete was suspended in July 1983 when the material failed to meet the D-9 "Performance Specification for Rapid-Setting Cement Mortar". Neco-crete is a two component magnesia-phosphate material produced by Neco Fiberglass & Supply, Inc., a licensee of Republic Steel Corporation. Several districts and states surveyed reported successful use of other materials produced by Republic Steel licensees such as Bostik 276, Horn 240 and Darex 240. Limited laboratory testing of Horn 240 was begun in September 1983 to determine if further laboratory and field testing is justified. Partial results of testing on both Neco-crete and Horn 240 are presented in this report.

Manufacturer's recommendations were followed in proportioning all mixes. An aggregate mix containing binder, fine aggregate and coarse aggregate was used in the majority of the laboratory tests and in all the field repairs. A mortar mix containing binder and fine aggregate was used for 1-in. x 1-in. x 11-1/4-in. (25.4-mm x 25.4-mm x 286-mm) length change specimens and 2-in. x 2-in. x 2-in. (50.8-mm x 50.8-mm x 50.8-mm) compression specimens. Proportions for mortar and aggregate mixes are shown in Tables 2.1 and 2.2, respectively.

A 3/8-in. (9.5-mm) maximum size siliceous gravel from Capitol Aggregates with a 1.4 percent absorption was the coarse aggregate used in all laboratory aggregate mixes, unless otherwise noted. In mixes used to evaluate the effects of coarse aggregate size and type, a 3/8-in. (9.5-mm) maximum size crushed limestone with a 5.4 percent absorption and a 3/4-in. (19.0-mm) maximum size crushed limestone with a 3.8 percent absorption, both from Texas Crushed Stone, were used. The fine aggregate used was a siliceous sand with a fineness modulus of 2.8 and a 2.0 percent absorption. Fine aggregate was required only for Duracal mixes. The other materials are manufactured with sand and binder premixed and packaged together. All aggregates were oven-dried.

Table 2.1. Mortar Mix Proportions.

Brand	Ingredients			
	Packaged Material, lb (kg)	Fine Aggregate, lb (kg)	Coarse Aggregate, lb (kg)	Liquid Component gal (liter)
Duracal	50.0 (22.7)	50.0 (22.7)	—	1.50 (5.68)[b]
Set-45	50.0 (22.7)	—[a]	—	0.44 (1.66)[b]
Hot Weather Set-45	50.0 (22.7)	—[a]	—	0.44 (1.66)[b]
Gilco Highway Patch	55.0 (24.9)	—[a]	—	1.0 (3.79)[b]
Neco-crete	50.0 (22.7)	—[a]	—	1.0 (3.79)[c]
Horn 240	50.0 (22.7)	—[a]	—	1.0 (3.79)[c]

[a]Fine aggregate is included in the packaged material.

[b]Water

[c]The liquid ingredient is ammonium phosphate solution.

Table 2.2 Aggregate Mix Proportions.

Brand	Ingredients			
	Packaged Material, lb (kg)	Fine Aggregate, lb (kg)	Coarse Aggregate, lb (kg)	Liquid Component gal (liter)
Duracal	50.0 (22.7)	50.0 (22.7)	50.0 (22.7)	1.75 (6.62)[b]
Set-45	50.0 (22.7)	__[a]	30.0 (13.6)	0.44 (1.66)[b]
Hot Weather Set-45	50.0 (22.7)	__[a]	30.0 (13.6)	0.44 (1.66)[b]
Gilco Highway Patch	55.0 (24.9)	__[a]	30.0 (13.6)	1.0 (3.79)[b]
Neco-crete	50.0 (22.7)	__[a]	18.0 (8.2)	1.0 (3.79)[c]
Horn 240	50.0 (22.7)	__[a]	13.5 (6.1)	1.0 (3.79)[c]

[a]Fine aggregate is included in the packaged material.

[b]Water

[c]The liquid ingredient is ammonium phosphate solution.

All materials are water activated except the two component magnesia-phosphate materials Neco-crete and Horn 240. The dry magnesia component of these two materials is activated by an ammonium phosphate solution.

All laboratory batches were less than 1/3-ft^3 (0.0094-m^3) in size and were vigorously hand-mixed with a trowel for approximately two minutes to obtain a uniform mixture.

Specimens were air-cured at ambient laboratory conditions, approximately 72°F (22°C) and 50 percent R.H., unless otherwise noted. Specimens used to evaluate high and low temperature effects were mixed and air-cured in an environmental chamber at 110°F (43°C)/50 percent R.H. and 40°F (4°C)/50 percent R.H., respectively.

2.2 Duracal

This material, produced by United States Gypsum, is a blend of portland cement and gypsum (calcium sulphate) and is water activated. The manufacturer's recommendations and limitations for use of Duracal include (1) the temperature must be above 32°F (0°C), (2) a 2-in. (50.8-mm) vertical saw cut must be made along patch perimeter (no feathered edges), (3) patch area must be moistened prior to placing Duracal to minimize water withdrawal from Duracal, (4) materials should be mixed until lump-free, but not more than five minutes, (5) curing compound should be used on hot, windy days to prevent plastic shrinkage cracking; and (6) repair may be opened to traffic one hour or more after set.

The aggregate mix water quantity was not increased to compensate for moisture absorbed by the dry coarse aggregate. The mix was very workable without an increase.

2.3 Set-45

Set-45, produced by Set Products, is a mixture of a magnesia-phosphate powder and fine aggregate. It is water activated. The manufacturer's literature requires (1) a 1/2-in. (12.7-mm) minimum saw cut must be made along patch perimeter, (2) a mortar type mixer should be used; (3) repair depth must be greater than 1/2-in. (12.7-mm), (4) neat material should be used for patches less than 1-in. (25.4-mm) deep or wide, (5) water quantity should be reduced to compensate for damp aggregate, (6) materials should be mixed 1 to 1-1/2 minutes, (7) Set-45 mix should be placed into patch from one side to the other, not in lifts, (8) warm materials must be used for cold weather (below 50°F (10°C)) repairs, and (9) patch should be air-cured, i.e. patch should not be wet cured and a curing compound should not be applied. The manufacturer also notes that Set-45 bonds better to a dry surface. To attain adequate workability, mix water quantities were increased to bring the coarse aggregate to a saturated surface-dry (SSD) condition.

2.4 Hot Weather Set-45

Set Products recommends use of Hot Weather Set-45 for hot weather (over 85°F (29°C)) repairs. This material is similar in composition and use to Set-45. The manufacturer warns that Hot Weather Set-45 may not bond properly to a hot concrete surface and suggests dampening the surface to reduce the temperature.

2.5 Gilco Highway Patch

Gilco Highway Patch (GHP), produced by Gifford-Hill, is a modified portland cement; the modifiers are proprietary. GHP is water activated. The manufacturer's literature recommends (1) a mortar-type mixer should be used; (2) patch edges should be squared by by jack hammering or by saw-cutting a minimum of 1 in. (25.4 mm) deep (no feathered edges), (3) patch depth of not less than 1 in. (25.4 mm), (4) use of neat material for repairs less than 3 in. (76.2 mm) deep, (5) patch area should be dampened and excess moisture removed with rags or compressed air just prior to patching, (6) materials should be mixed 2 to 3 minutes until a uniform mixture is achieved, (7) the moisture content of coarse aggregate should be considered when determining total water quantity, (8) normal PCC curing methods should be used; and (9) keeping ambient and material temperatures between 50°F (10°C) and 90°F (32°C).

2.6 Neco-crete

Neco-crete is a two component magnesia-phosphate material. A premixed magnesia and fine aggregate dry material is activated by an ammonium phosphate solution. The manufacturer's literature recommends (1) indoor repair areas should be ventilated to expel ammonia released during the reaction, (2) dry coarse aggregates should be used; (3) patch area should be dried with compressed air, and (4) materials should be mixed 1 to 2 minutes.

2.7 Horn 240 Concrete

This material is produced by A.C. Horn, a licensee of Republic Steel Corporation. Horn 240 Concrete is a two-component magnesia-phosphate similar to Neco-crete. A.C. Horn instructions require (1) repair depth should be 1/2-in. (12.7-mm) minimum; (2) patch edges should be saw-cut or jack hammered (no feathered edges); (3) materials should be mixed 1 to 2 minutes; (4) repair areas should be ventilated; (5) batches should be placed side by side in repair hole, not in lifts, (6) if batches are placed in lifts, each lift should be allowed to cool before the next lift is placed, and (7) no curing compound is required.

CHAPTER 3
EVALUATION TESTS

Study 311 objectives include the performance of laboratory tests to establish which material properties are relevant in predicting field repair durability. Reference 2 presents the results of tests run at ambient laboratory conditions, approximately 72°F (22°C) and 50 percent R.H.

Beer evaluated the following tests to determine their applicability in testing rapid setting materials (1) mortar cube compressive strength, (2) cylinder compressive strength, (3) modulus of elasticity, (4) flexural strength, (5) Gilmore needle set time, (6) penetration resistance set time, (7) peak exotherm, (8) flow, (9) direct shear bond, (10) flexural shear bond, (11) flexural bond, and (12) sand blast abrasion. Beer concluded that, of these, the cylinder compression test, flexural test, Gilmore needle set time, and shear bond test were most useful for evaluating rapid setting materials.

The results of three additional tests are presented in this report. These tests are (1) length change, (2) coefficient of thermal expansion, and (3) freeze-thaw resistance.

The nature of the rapid-setting materials required slight modification of the ASTM test methods used. These modifications include (1) thinly covering contact surfaces of metal molds with a heavy lubricating grease (oil is not adequate for magnesia-phosphate materials), (2) hand mixing all batches vigorously for two minutes (a mechanical mixer is not used), and (3) air-curing all specimens. Chemically, the rapid setting materials differ greatly from conventional PCC. Air-curing, therefore, appeared more appropriate than moist-curing. Typically specimens were removed from molds approximately one hour after mixing.

3.1 Compressive Strength

3.1.1 Mortar Cubes

The compressive strength of mortar cubes was determined in accordance with ASTM C109-80, "Compressive Strength of Hydraulic Cement Mortars." Mortars were proportioned as shown in Table 2.1. Flow was not determined. Specimens were cast in 2-in. x 2-in. x 2-in. (50.8-mm x 50.8-mm x 50.8-mm) metal molds. Specimens were loaded at a rate of 10,000 lb (44.5 kN)/min.

3.1.2 Cylinders

The compressive strength of cylinders was determined in accordance with ASTM C39-81, "Compressive Strength of Cylindrical Concrete Specimens." Disposable, wax-coated, cardboard molds were used to form specimens. Three-in. dia. x 6-in. (76.2-mm dia. x 152-mm) cylinders were used for mixes containing 3/8-in. (9.5-mm) maximum size coarse aggregate. These specimens were loaded at a rate of 20,000 lb (89.0 kN)/min. Six-in. dia. x 12-in. (152-mm dia. x 305-mm) cylinders were used for mixes containing 3/4-in.

(19-mm) maximum size coarse aggregate. These specimens were loaded at 60,000 lb (267 kN)/min. Cylinder ends were capped to provide a plane loading surface.

3.2 Flexural Strength

Tests for flexural strength were run according to ASTM C78-75, "Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." Two-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 305-mm) beam specimens were cast in metal molds. Equal concentrated loads were applied at the third points of a 6-in. (152-mm) span. The total load was applied at a rate of 300 lb (1.33-kN)/min., thus increasing the extreme fiber stress between the third points at a rate of 225 psi (1551 kPa)/min.

3.3 Set Time

3.3.1 Gilmore Needle

Gilmore Needle set times were determined in accordance with ASTM C 266-77, "Time of Setting of Hydraulic Cement by Gilmore Needles." Three-in. dia. x 1/2-in. (76.2-mm dia. x 12.7-mm) thick pats were molded using mortar mixes (Table 2.1) rather than pastes. The needles were lightly applied at several points on the pat to avoid misleading results from the needles bearing on fine aggregate particles.

3.3.2 Peak Exothermic Temperature

The peak exothermic temperature at the center of 3-in. dia. x 6-in. (76.2-mm dia. x 152-mm) cylindrical specimens was measured using an imbedded thermocouple. The purpose was to relate measured peak exothermic temperatures to set times. Specimens were cast in cardboard cylinders.

3.4 Length Change

The length change of the rapid setting materials was determined in accordance with ASTM C 490-77, "Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar and Concrete." Both 1-in. x 1-in. x 11-1/4-in. (25.4-mm x 25.4 x 286-mm) mortar specimens and 2-in. x 2-in. x 11-1/4-in. (50.8-mm x 50.8-mm x 286-mm) aggregate mix specimens were tested. Aggregate mixes (Table 2.2) contained 3/8-in. (9.5-mm) maximum size siliceous coarse aggregate. The effective gage length for all specimens was 10 in. (254 mm). Measurement of length change was started immediately after removal of specimens from the molds, approximately one hour after mixing. All specimens were air-cured at ambient laboratory conditions, approximately 72°F (22°C) and 50 percent R.H.

3.5 Freeze-Thaw Resistance

The resistance of the rapid setting materials to freeze-thaw cycles was determined in accordance with ASTM C 666-80, "Resistance of Concrete to Rapid Freezing and Thawing." Procedure "A", rapid freezing and thawing in water, was followed. Three-in. x 3-in. x 16-in. (76.2-mm x 76.2-mm x 406-mm) aggregate mix specimens were tested. Specimens were air cured at 72°F (22°C) and 50 percent R.H. for 6 days after mixing. They were then stored in tap water at 72°F (22°C) for 24 hours prior to being placed in the freeze-thaw cabinet. For convenience, the initial reading for the fundamental transverse frequency was taken after one freeze-thaw cycle at a specimen temperature of approximately 42°F (6°C). Limitations of the freeze-thaw cabinet used required 6-hr. freeze-thaw cycles, i.e. 4 cycles/day.

The results are presented in terms of the relative dynamic modulus of elasticity, P_c, after c cycles:

where

$$P_c = (n_c^2/n^2) \times 100, \text{ percent} \tag{3.1}$$

n = fundamental transverse frequency after one freeze-thaw cycle,

n_c = fundamental transverse frequency after c freeze-thaw cycles.

3.6 Coefficient of Thermal Expansion

The length change specimens, shown in Fig. 3.1, were also used to determine the coefficients of thermal expansion of the rapid setting materials. Specimens were air-cured for approximately 8 months at ambient laboratory conditions, 72°F (22°C) and 50 percent R.H., prior to testing.

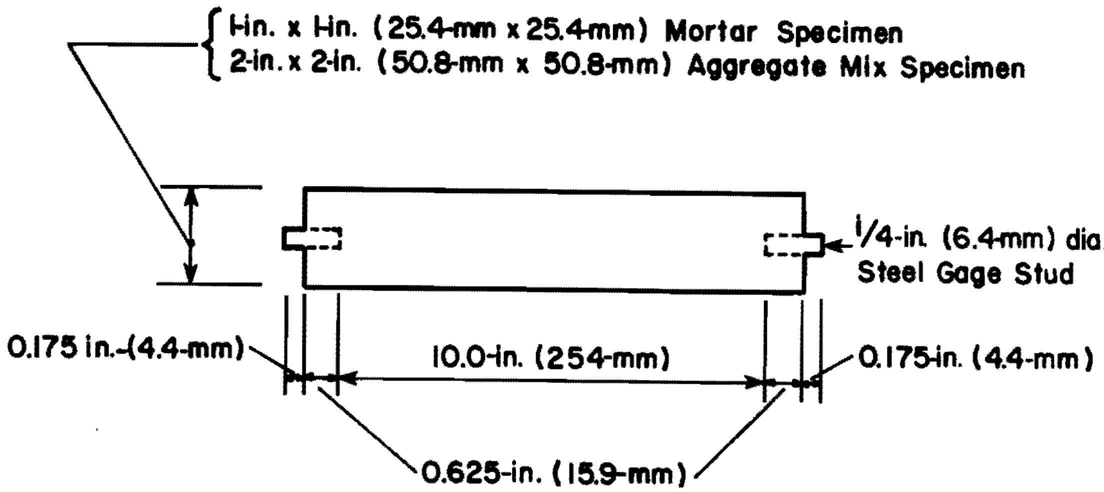

Fig. 3.1. Coefficient of Thermal Expansion Specimen

The coefficients of thermal expansion, $_c$, were calculated as follows:

$$\Delta L = \Delta T \left[\alpha_c(10.0) + \frac{(\alpha_c A_c E_c + \alpha_s A_s E_s)(0.625)}{A_c E_c + A_s E_s} + \alpha_s(0.175)\right], \text{ in.} \tag{3.2}$$

Solving for α_c:

$$\alpha_c = \frac{\frac{\Delta L}{\Delta T} - \alpha_s \left[0.175 + \frac{(0.625)\alpha_s A_s E_s}{A_c E_c + A_s E_s}\right]}{10.0 + \frac{(0.625)\, A_c E_c}{A_c E_c + A_s E_s}}, \text{ in./in. per °F} \tag{3.3}$$

where

ΔL = specimen change in length due to change in temperature, in.

ΔT = change in temperature, °F

α_s = coefficient of thermal expansion of steel, 6.5×10^{-6}-in./in. per °F (11.7×10^{-6}-mm/mm per °C)

A_s = area of steel gage stud, 0.049-in.^{2} (31.7-mm^2)

E_s = modulus of elasticity of steel, 29000 ksi (2.0 x 10^8 kPa)

A_c = area of specimen minus area of steel gage stud, 0.95-in.^{2} (613-mm^2) for mortar specimens and 3.95-in.^{2} (2549-mm^2) for aggregate mix specimens

E_c = modulus of elasticity of rapid setting materials, approximatey 4000 ksi (2.8 x 10^7 kPa).

An invar reference bar was used to correct for the length change of the length comparator itself in the different ambient temperatures. The coefficient of thermal expansion of invar was assumed to be 8.3 x 10^{-7} in./in. per °F (15.0 x 10^{-7} mm/mm per °C).

CHAPTER 4
TEST VARIABLES

4.1 Temperature

The rapid setting materials were mixed, placed, and air-cured in 40, 72, and 110°F (4, 22, and 43°C) environments. Cylinder compressive strength, flexural strength, peak exotherm, and Gilmore needle set time tests were performed to determine material properties and working characteristics over this temperature range. Tests at 40 and 110°F (4 and 43°C) were conducted in a walk-in environmental chamber with adjustable temperature and R.H.

Two sets of tests were run at the high and low temperatures. For one set, the temperature of the mixing ingredients was the same as the environmental chamber ambient temperature. Equilibrium was achieved by storing the materials in the chamber for 24 hours prior to mixing. A second set of tests were run using 72°F (22°C) ingredients. The purpose of these tests was to simulate repairs in extreme temperatures using materials stored indoors. Specimens were air cured at the ambient environmental chamber temperature and 50 percent R.H.

4.2 Coarse Aggregate Type, Size, and Quantity

Mixes containing variable (1) type of coarse aggregate (siliceous or limestone) and (2) size of coarse aggregate, 3/8-in.

(9.5-mm) or 3/4-in. (19.0-mm) were tested for cylinder compressive strength at ambient laboratory conditions. These mixes were proportioned as shown in Table 2.2.

Batches with varying quantities of coarse aggregate were also tested for cylinder compressive strength. Three-eighths-in. (9.5-mm) maximum size siliceous aggregate was used for these tests. Mixes with ratios of coarse aggregate weight to total concrete weight of approximately 0.10, 0.20 and 0.30 were tested. Table 4.1 shows mix proportions used.

4.3 Water Content

The sensitivity of the rapid setting materials to changes in batch water quantities was investigated using mortar compression cubes. Tests were performed on mixes ranging from very stiff to very wet.

Table 4.1. Proportions for Mixes with Varying Coarse Aggregate Quantities.

Brand	Ratio of C.A. Wt. to Unit Concrete Wt.		Packaged Material lb (kg)	Fine Aggregate lb (kg)	Coarse Aggregate lb (kg)	Water gal (liter)
	Approx.	Exact				
Duracal	0.10	0.08	50.0 (22.7)	50.0 (22.7)	10.0 (4.5)	1.50 (5.68)
Set-45	0.10	0.10	50.0 (22.7)	___[a]	6.0 (2.7)	0.44 (1.66)
GHP	0.10	0.09	55.0 (24.9)	___[a]	6.0 (2.7)	1.0 (3.79)
Duracal	0.20	0.21	50.0 (22.7)	50.0 (22.7)	30.0 (13.6)	1.65 (6.25)
Set-45	0.20	0.25	50.0 (22.7)	___[a]	18.0 (8.2)	0.44 (1.66)
GHP	0.20	0.22	55.0 (24.9)	___[a]	18.0 (8.2)	1.0 (3.79)
Duracal	0.30	0.30	50.0 (22.7)	50.0 (22.7)	50.0 (22.7)	1.75 (6.62)
Set-45	0.30	0.36	50.0 (22.7)	___[a]	30.0 (13.6)	0.44 (1.66)
GHP	0.30	0.32	55.0 (24.9)	___[a]	30.0 (13.6)	1.0 (3.79)

[a]Fine aggregate included in packaged material.

CHAPTER 5
TEST RESULTS

5.1 Compressive Strength vs Temperature

Figure 5.1 shows compressive strength versus time curves for materials mixed and air-cured at 40°F (4°C). Use of warm materials significantly accelerated the early strength gain for all the materials except Duracal. The magnesium-phosphates, Set-45 and Neco-crete, displayed the highest early strengths.

Figure 5.2 exhibits compressive strength as a function of time for materials mixed and cured at 72°F (22°C). Again, with the exception of Horn 240 at 1 hr., the magnesium phosphates have the highest early strengths. D-9's "Performance Specification for Rapid Setting Cement Mortar" requires 2000 psi at 2 hr., 3000 psi at 24 hr., and 6000 psi at 14 days. Only Duracal failed to satisfy the 2-hr. requirement. All materials had 24-hr. strengths greater than 3000 psi. The Duracal curve shows characteristics of its portland cement and gypsum components. The gypsum portion sets rapidly, and the strength levels off for several hours until the strength of the portland cement component becomes significant. Set-45 and Neco-crete exhibit high 1-hr. strengths; however, the strength gain after that is small.

The compressive strength versus time curves for materials mixed and cured at 110°F (43°F) are shown in Fig. 5.3. The temperatures of the mixing ingredients, 72°F (22°C) and 110°F (43°F), had

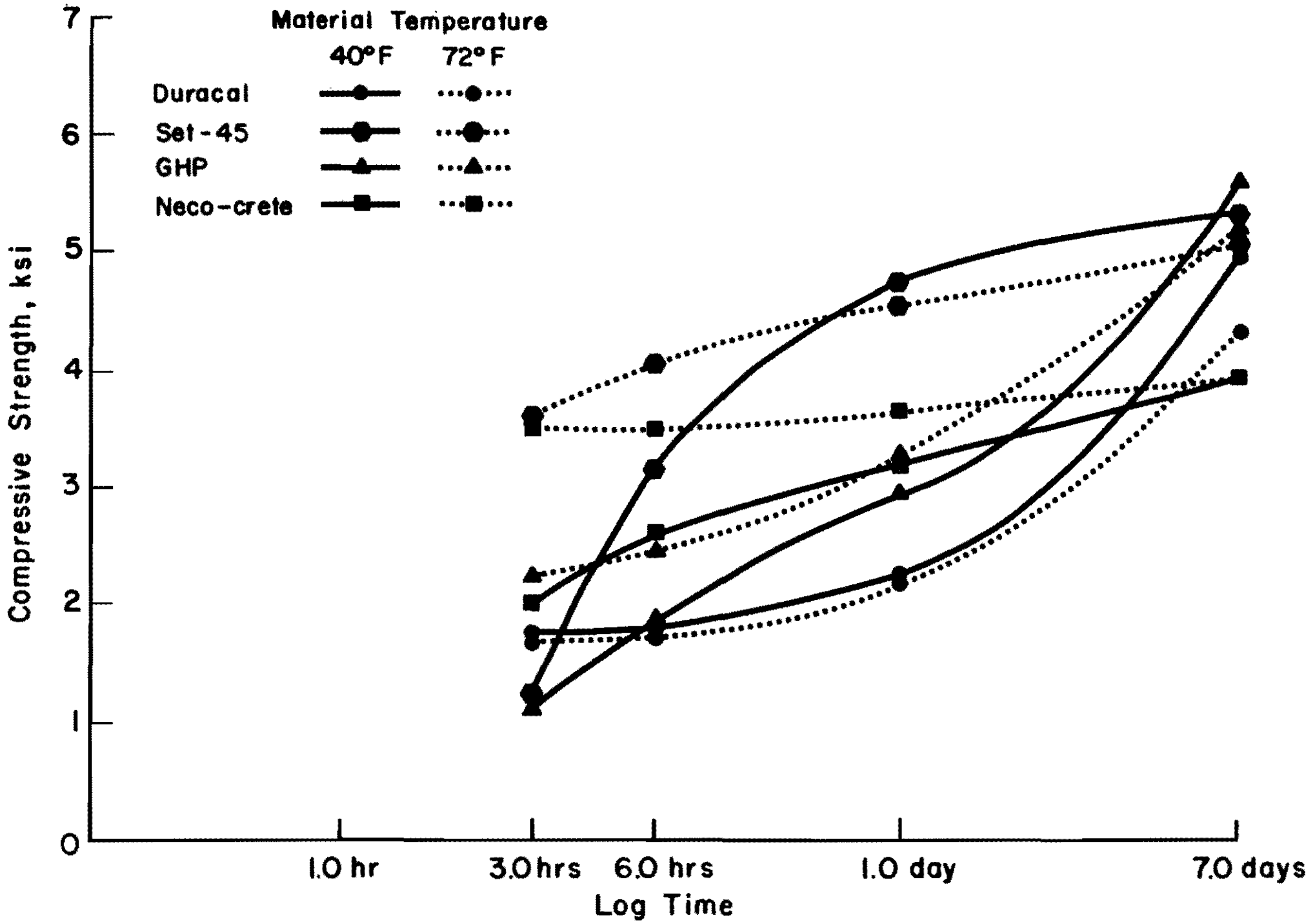

Fig. 5.1. Compressive Strength as a Function of Time - Mixing and Curing Environment at 40°F.

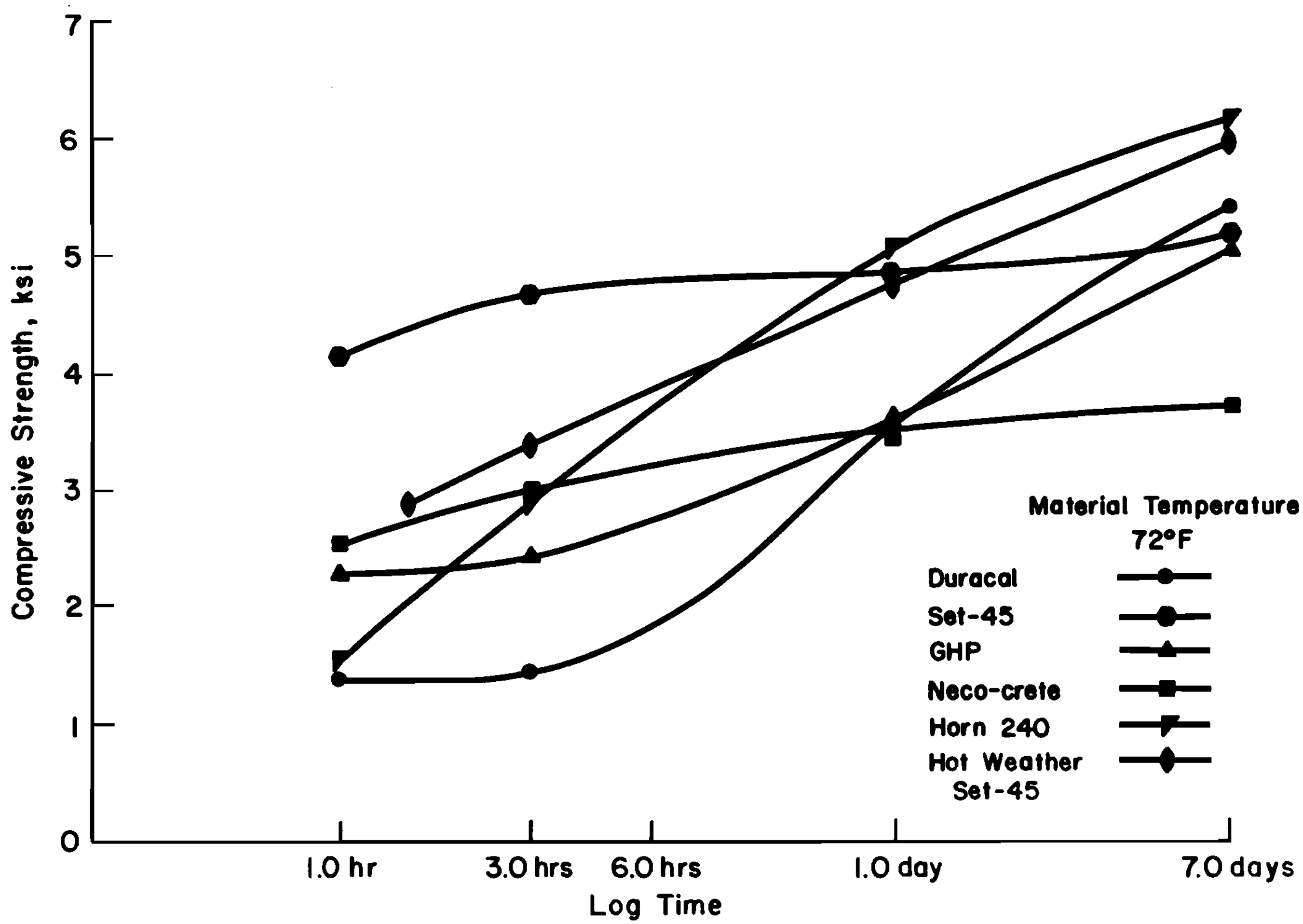

Fig. 5.2. Compressive Strength as a Function of Time - Mixing and Curing Environment at 72°F.

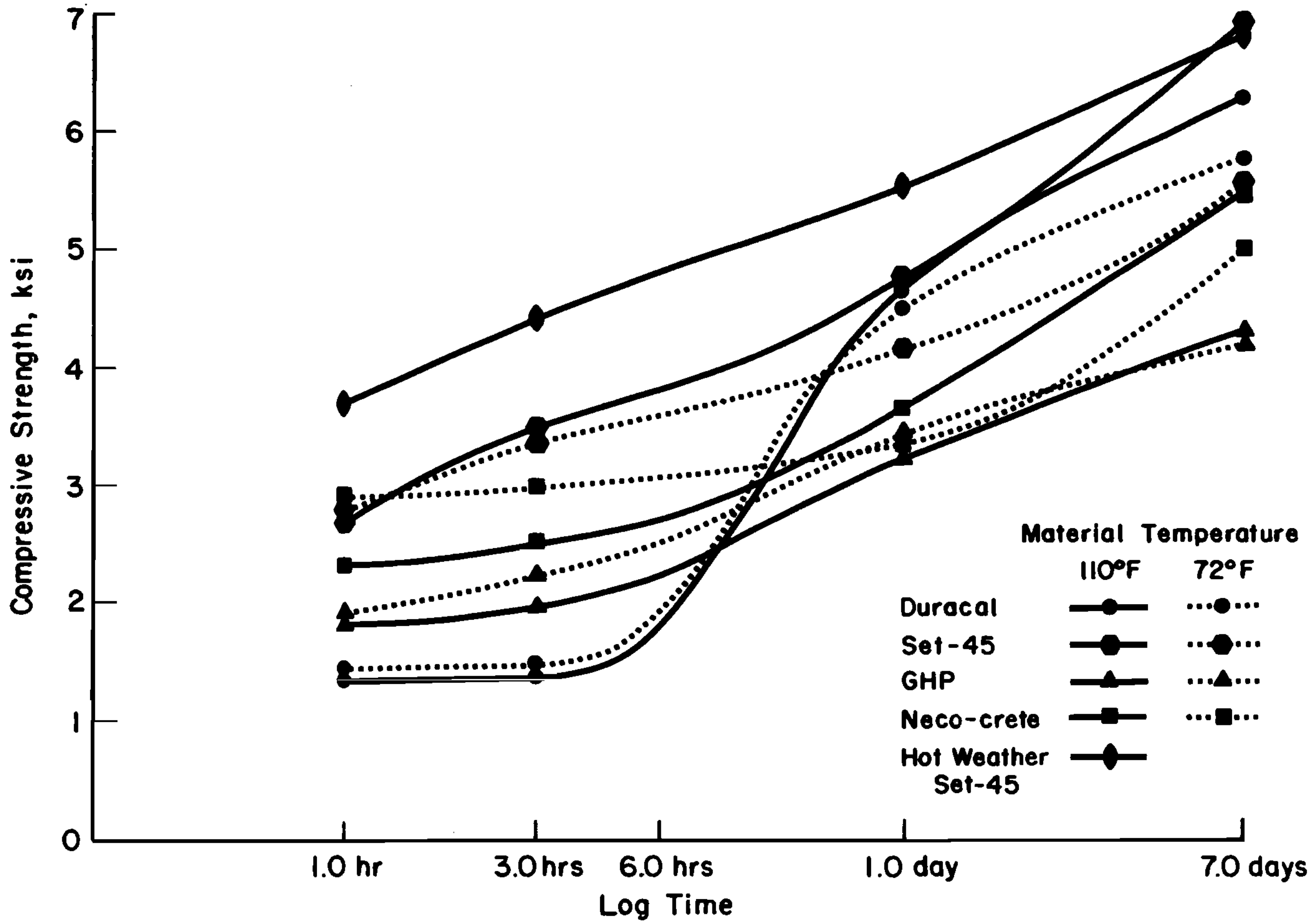

Fig. 5.3. Compressive Strength as a Function of Time - Mixing and Curing Environment at 110^{o}F.

no significant effect on the strength curves. Again, the magnesium-phosphates exhibited the highest early strengths.

5.2 Flexural Strength vs Temperature

Figure 5.4 displays flexural strength versus time curves for materials mixed and cured at 40°F (4°C). Surprisingly, Duracal had the highest 3-hr. and 6-hr. strengths. The 40°F (4°C) magnesium phosphates, Set-45 and Neco-crete, had the lowest 6-hr. strengths. However, use of warm materials significantly improved the early strength gain of the magnesium-phosphates.

Figure 5.5 shows flexural strength as a function of time for materials mixed and cured at 72°F (22°C). Set-45 and Neco-crete achieved the highest 1-hr. and 3-hr. strengths.

The flexural strength versus time curves for materials mixed and cured at 110°F (43°C) are shown in Fig. 5.6. Duracal exhibits the slowest strength gain at this temperature. However, comparison of the Duracal curves in Figs. 5.4, 5.5, and 5.6 reveals that Duracal's early flexural strength gain is insensitive to temperature.

5.3 Set Time

5.3.1 Gilmore Needle Set Time vs Temperature

Figure 5.7 shows set times by Gilmore needles as a function of temperature. D-9's "Performance Specification for Rapid Setting Cement Mortar" requires a minimum of 15 minutes to initial set and a maximum of 40 minutes to final set. At 72°F (22°C), all the

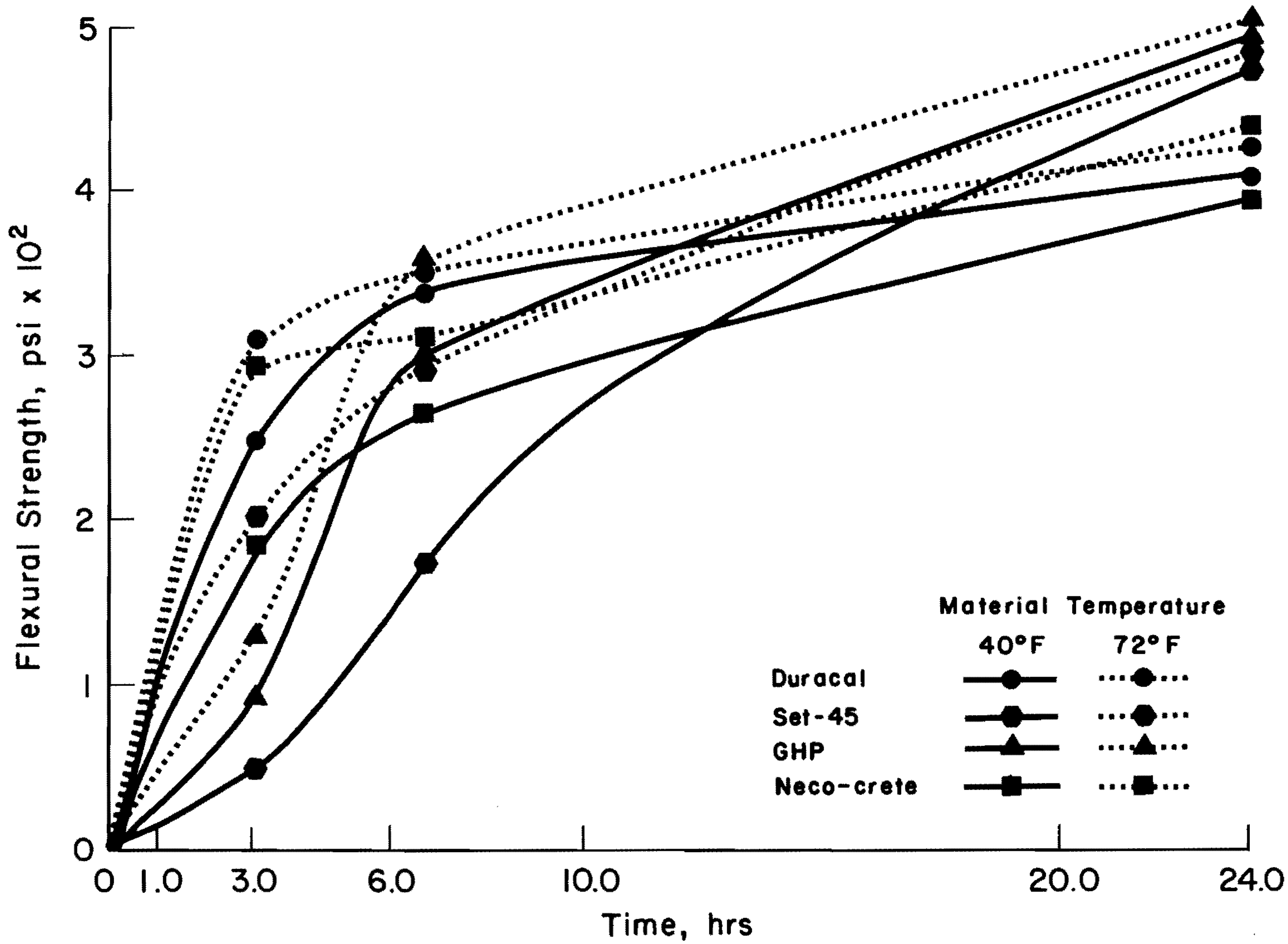

Fig. 5.4. Flexural Strength as a Function of Time - Mixing and Curing Environment at 40°F.

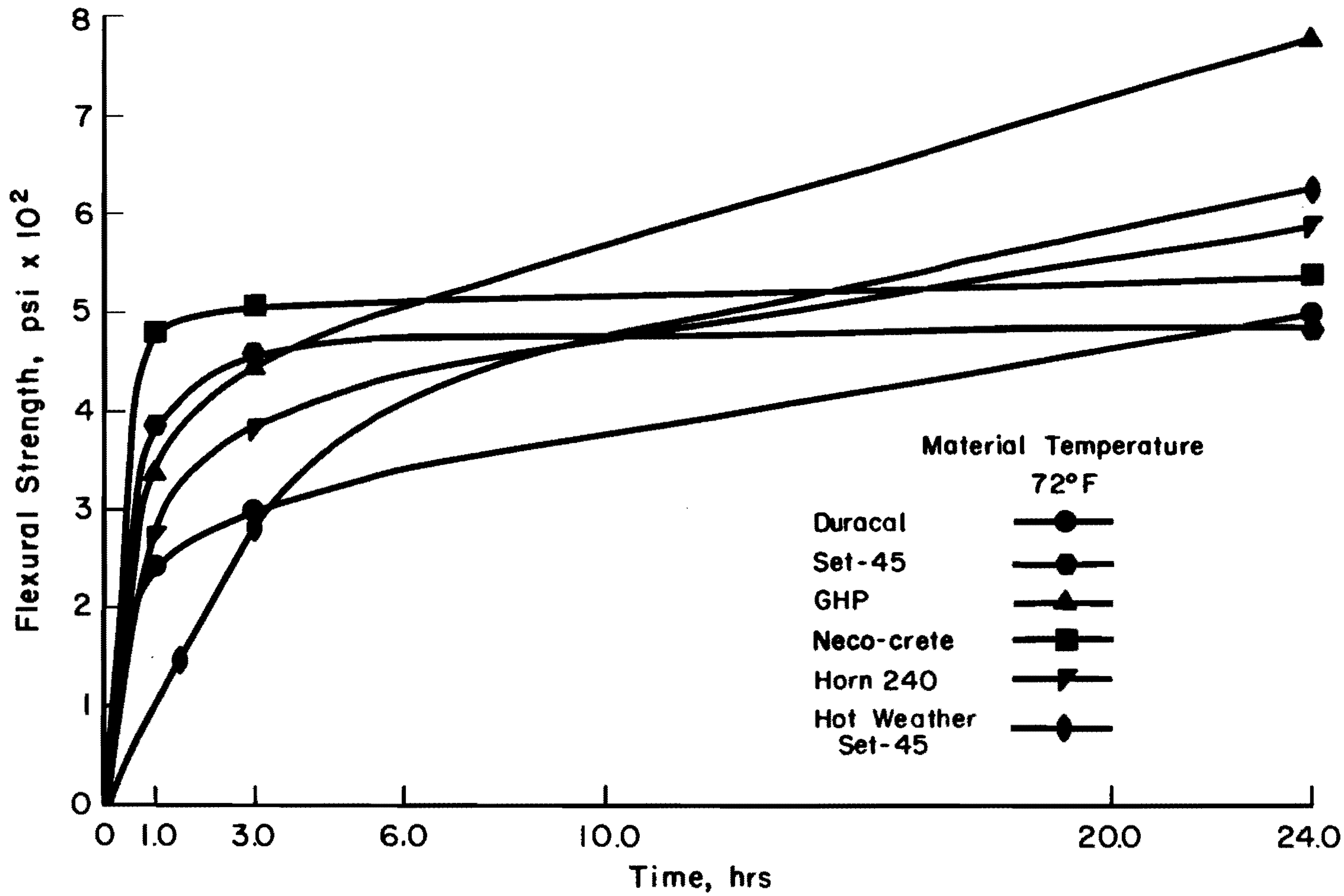

Fig. 5.5. Flexural Strength as a Function of Time - Mixing and Curing Environment at 72°F.

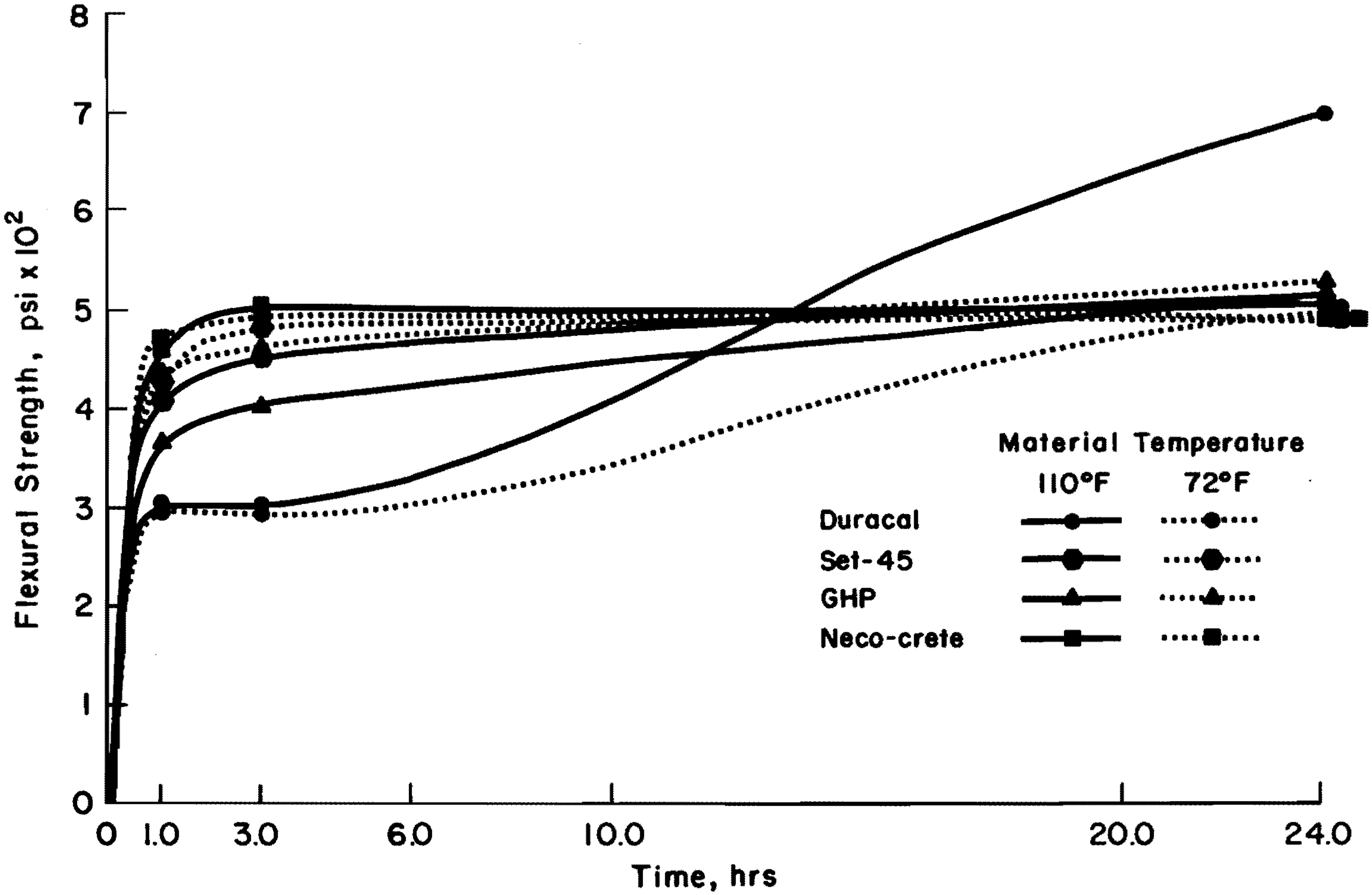

Fig. 5.6. Flexural Strength as a Function of Time - Mixing and Curing Environment at 110°F.

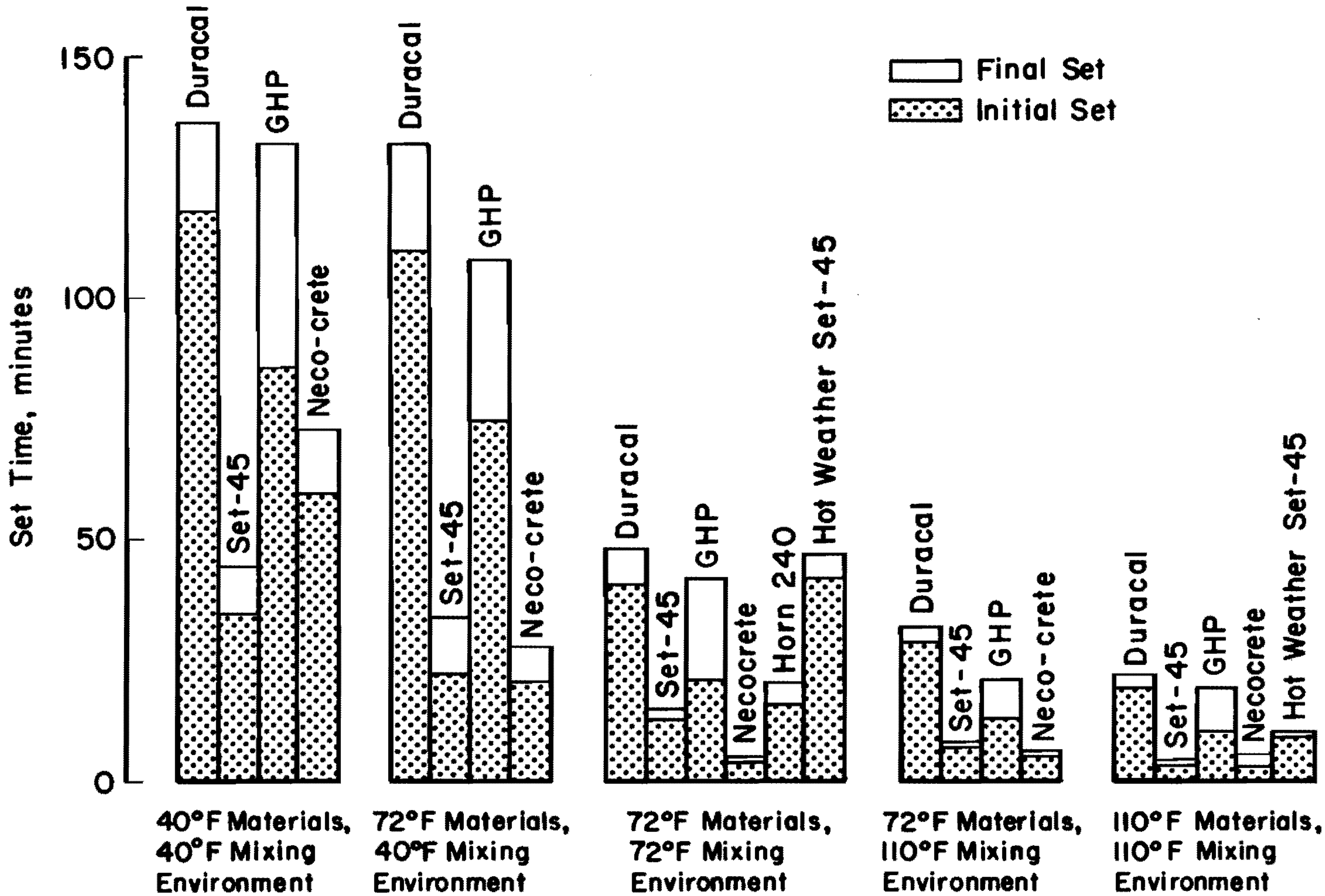

Fig. 5.7. Set Times by Gilmore Needles as a Function of Temperature.

materials, except Neco-crete, are reasonably close to meeting these requirements Neco-crete. Neco-crete's 4-minute initial set time does not allow sufficient working time.

The magnesium-phosphates display the earliest set times at all temperatures. At 40°F, these materials set significantly faster than either Duracal or GHP.

At 110°F, both Set-45 and Neco-crete set too rapidly. However, Duracal, GHP and Hot Weather Set-45 all allow reasonable working time.

5.3.2 Peak Exotherm vs Temperature

The exothermic temperatures of 3-in. dia. x 6-in. (76.2-mm dia. x 152-mm) cylinders as a function of time is shown in Fig. 5.8. The higher environmental temperatures accelerate the setting reactions, resulting in (1) greater temperature rises and (2) earlier peaking of exothermic temperatures. The exothermic temperature rise of the magnesia-phosphates (Set-45 and Neco-crete) was significantly greater than that of the materials containing portland cement (Duracal and GHP). Comparison of the Gilmore Needle set times (Fig. 5.7) with the times of peak exothermic temperature reveals no useful relationship. At 40°F (4°C), Neco-crete reaches final set after the exothermic temperature has peaked, whereas the opposite is true for the other materials. At 72°F (22°C) and 110°F (43°C), all the materials reach peak exothermic temperatures before achieving final set.

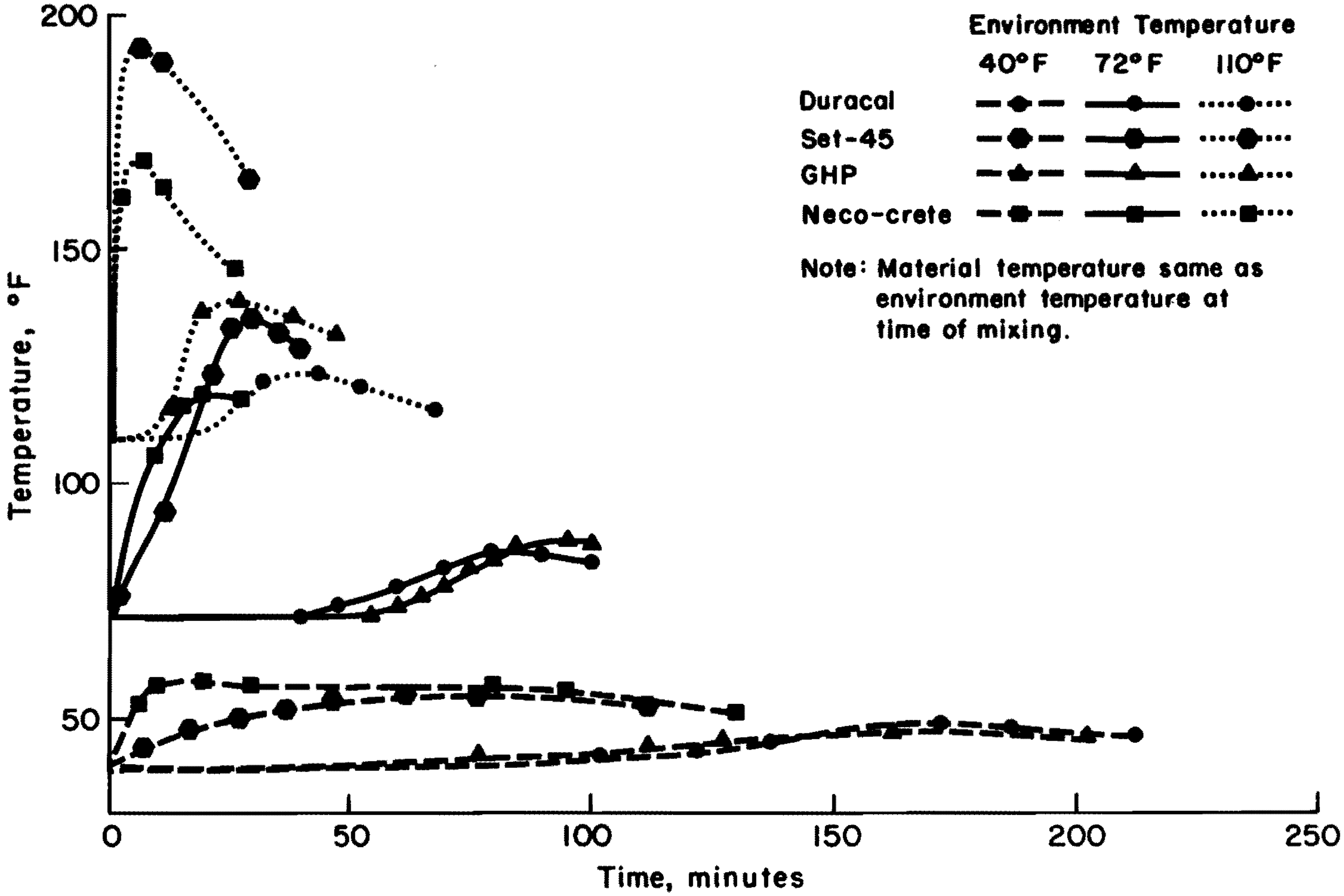

Fig. 5.8. Exothermic Temperature of 3-in. Dia. x 6-in. Cylinders as a Function of Time.

5.4 Length Change

The change in length of air-cured mortar and aggregate mix specimens is shown in Figs. 5.9 and 5.10, respectively. Both Set-45 and Duracal exhibit initial expansion followed by slight shrinkage. When final length change readings were taken at approximately 200 days, the shrinkage of the GHP specimens was more than three times greater than that of any of the other specimens.

5.5 Freeze-Thaw Resistance

As shown in Fig. 5.11, the relative dynamic modulus of elasticity of all the materials fell below 60 percent prior to reaching 300 cycles of freezing in water and thawing in water. D-9's "Performance Specification for Rapid Setting Cement Mortar" requires the relative modulus of elasticity to be a minimum of 60 percent after 100 cycles of freezing in air and thawing in water.

The magnesium-phosphates performed poorly. The relative modulus of elasticity of the Set-45 and Neco-crete specimens fell to 60 percent after 86 and 50 cycles, respectively. The top, troweled surface of the magnesia-phosphate specimens began to deteriorate after only a few cycles. This weak top surface may be caused by "bleeding" of the liquid component upward, which results in a weakened top layer due to excess liquid.

The relative dynamic modulus of elasticity of the Duracal and GHP specimens fell to 60 percent after 170 and 254 cycles, respectively.

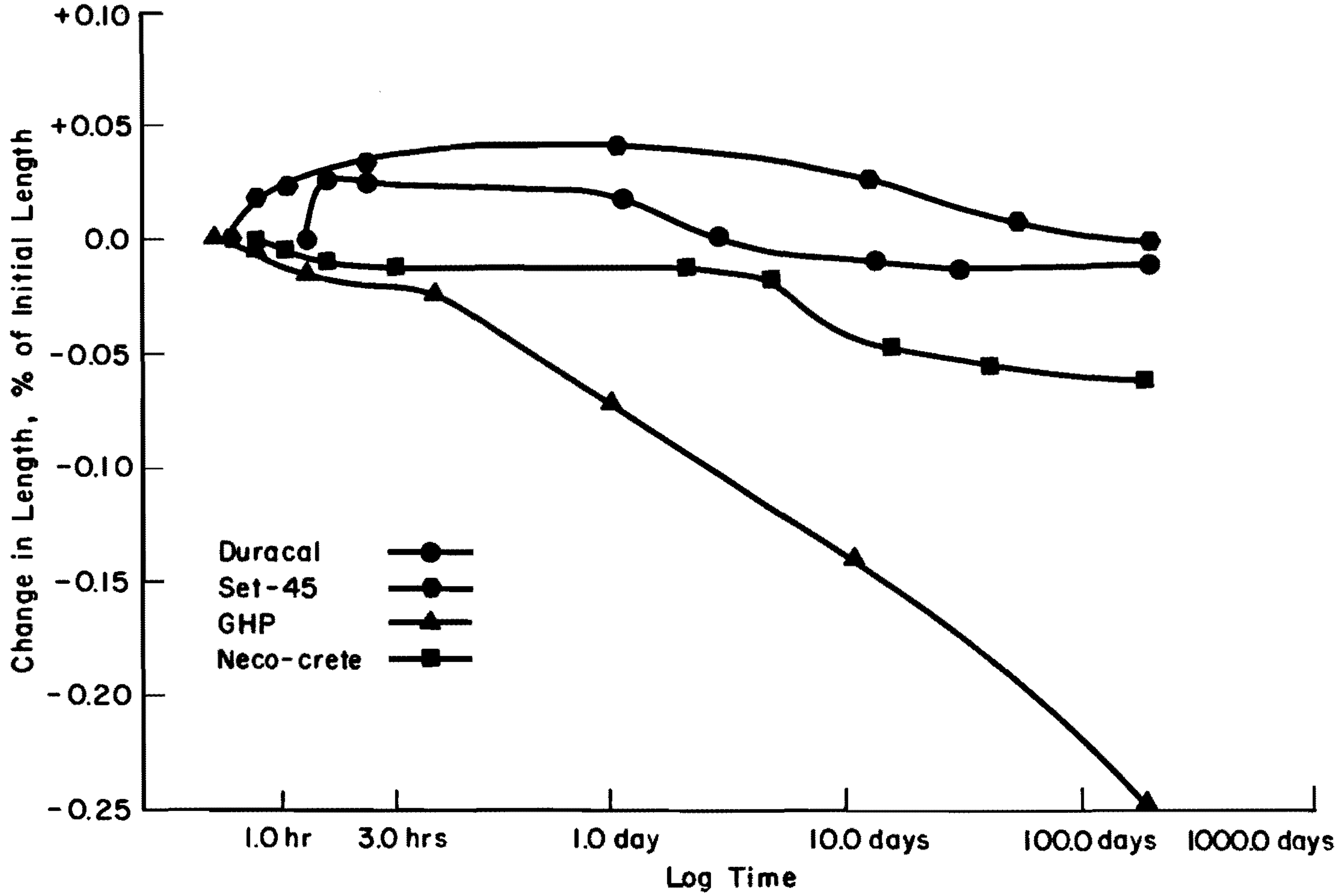

Fig. 5.9. Change in Length of Mortar Specimens as a Function of Time.

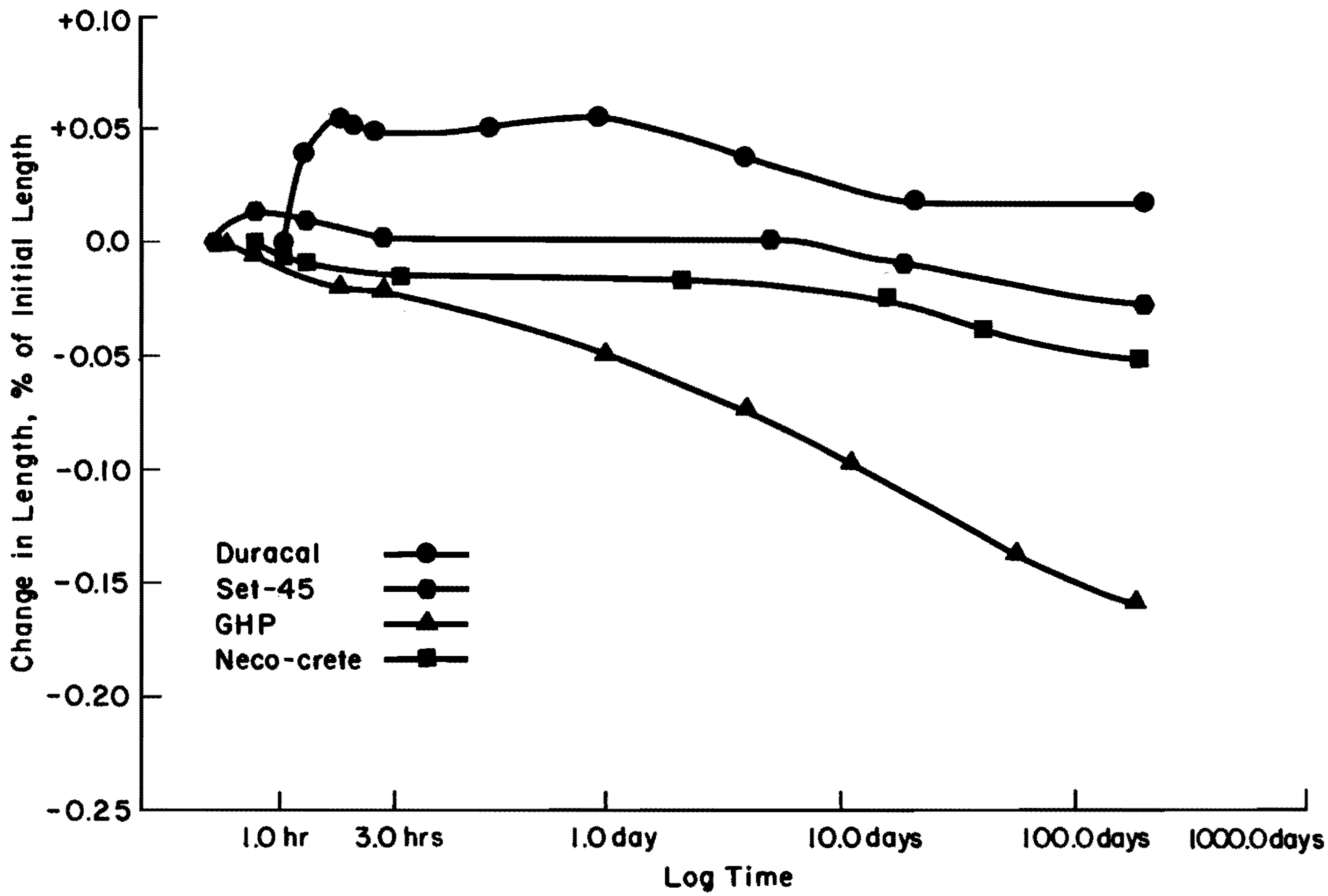

Fig. 5.10. Change in Length of Aggregate Mix
Specimens as a Function of Time.

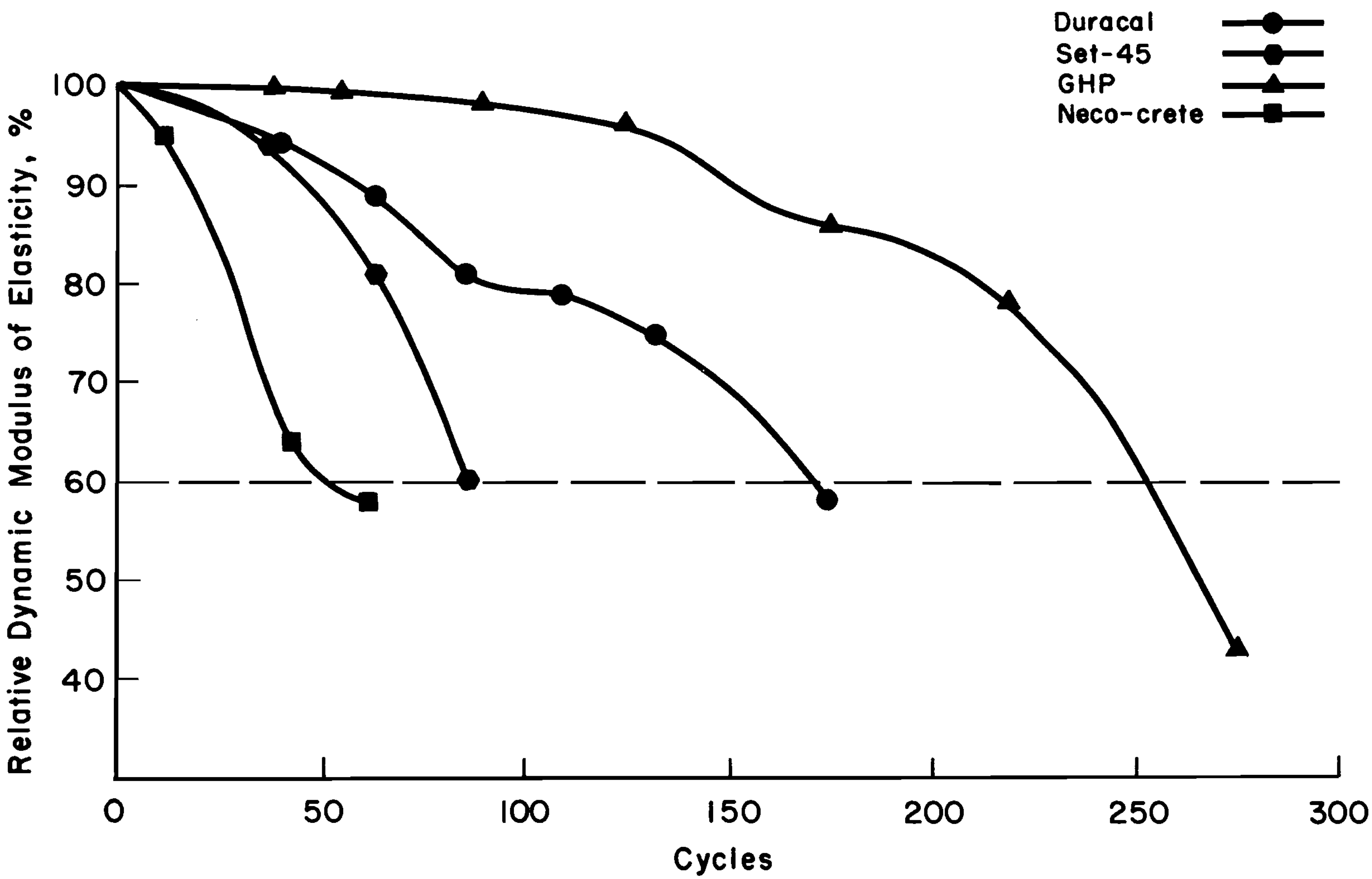

Fig. 5.11. Change in Dynamic Modulus as a Function of Freeze-Thaw Cycles.

5.6 Compressive Strength vs Coarse Aggregate Type and Size

Figure 5.12 shows compressive strength versus time curves for aggregate mixes containing 3/8-in. (9.5-mm) maximum size siliceous aggregate, 3/8-in. (9.5-mm) maximum size limestone aggregate, and 3/4-in. (19.0-mm) maximum size limestone. The 3/8-in. (9.5-mm) siliceous aggregate, 3/8-in. (9.5-mm) limestone, and 3/4-in. (19.0-mm) limestone had 24-hr. absorptions of 1.4, 5.4, and 3.8 percent, respectively.

As previously noted, coarse aggregates were oven-dried prior to mixing. Set-45 and GHP batch water quantities (Table 2.2) were adjusted for moisture absorbed by the coarse aggregate. No adjustments were made to Duracal batch water quantities.

It appears that the coarse aggregate in the Set-45 and GHP mixes did not fully absorb the added water after 1 hr. Thus, excess water remained in the paste, which resulted in lower compressive strengths. Compressive strengths were lowest for mixes with the greatest quantity of water added, i.e., mixes containing aggregates with the highest absorptions. Since no water corrections were made for Duracal mixes, the mixes using aggregates with the highest absorptions had the least free water and were, therefore, the strongest.

At 7 days of age, it appears that the greater internal friction and surface area of the limestone aggregate give specimens containing this aggregate slightly greater strength than specimens containing siliceous gravel.

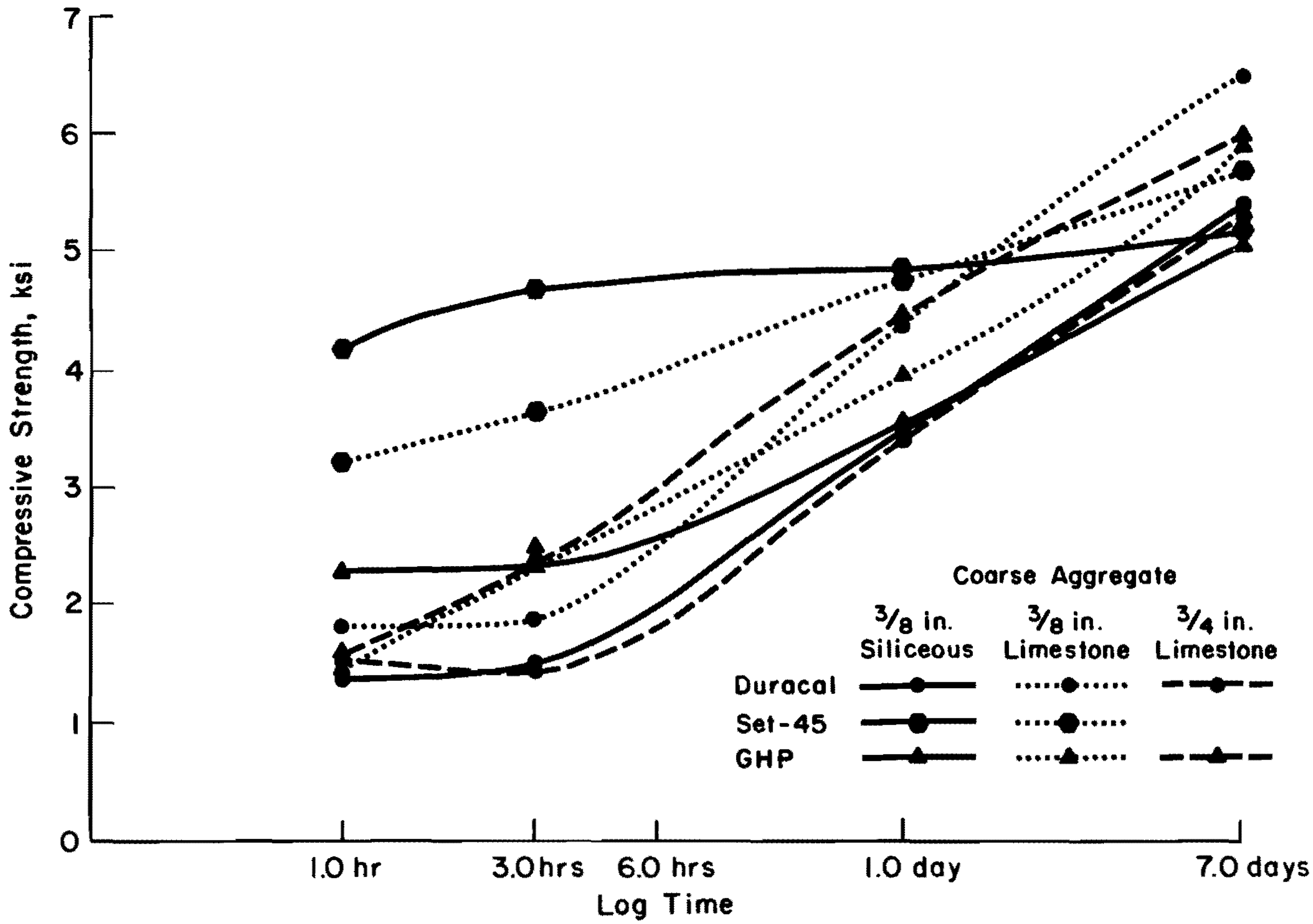

Fig. 5.12. Compressive Strength as a Function of Time for Mixes with Varying Types of Coarse Aggregate.

5.7 Compressive Strength vs Coarse Aggregate Quantity

The compressive strength of mixes with varying quantities of coarse aggregate (Table 4.1) was determined at 1, 3, and 24 hrs. The results are shown in Fig. 5.13. The compressive strength of the specimens increased as the quantity of coarse aggregate decreased. The 1-day compressive strength of Set-45 increased from 3250 psi (2.24×10^4 -kPa) to 5200 psi (3.59×10^4-kPa) when the ratio of coarse aggregate weight to unit concrete weight was reduced from 0.30 to 0.10. Duracal and GHP mixes were less sensitive to the quantity of coarse aggregate.

5.8 Compressive Strength vs Water Content

The compressive strength of mortar cubes as a function of water content is shown in Fig. 5.14. As expected, the compressive strength decreased as the water content increased. The strength of the Set-45 mixes peaked and then began to decline due to honeycombing as the water quantity was further reduced.

Laboratory mortar and aggregate mixes were proportioned according to the manufacturer's instructions Tables 2.1 and 2.2). The Duracal mixes were very workable. However, the Set-45 mixes were less workable and the GHP mixes were stiff and almost unworkable. As discussed in Chapter 7, "Field Repairs," the water quantities in the Set-45 and GHP field mixes had to be increased a minimum of 15 percent and 25 percent, respectively, to achieve adequate workability. Figure 5.14 suggests that lower strengths

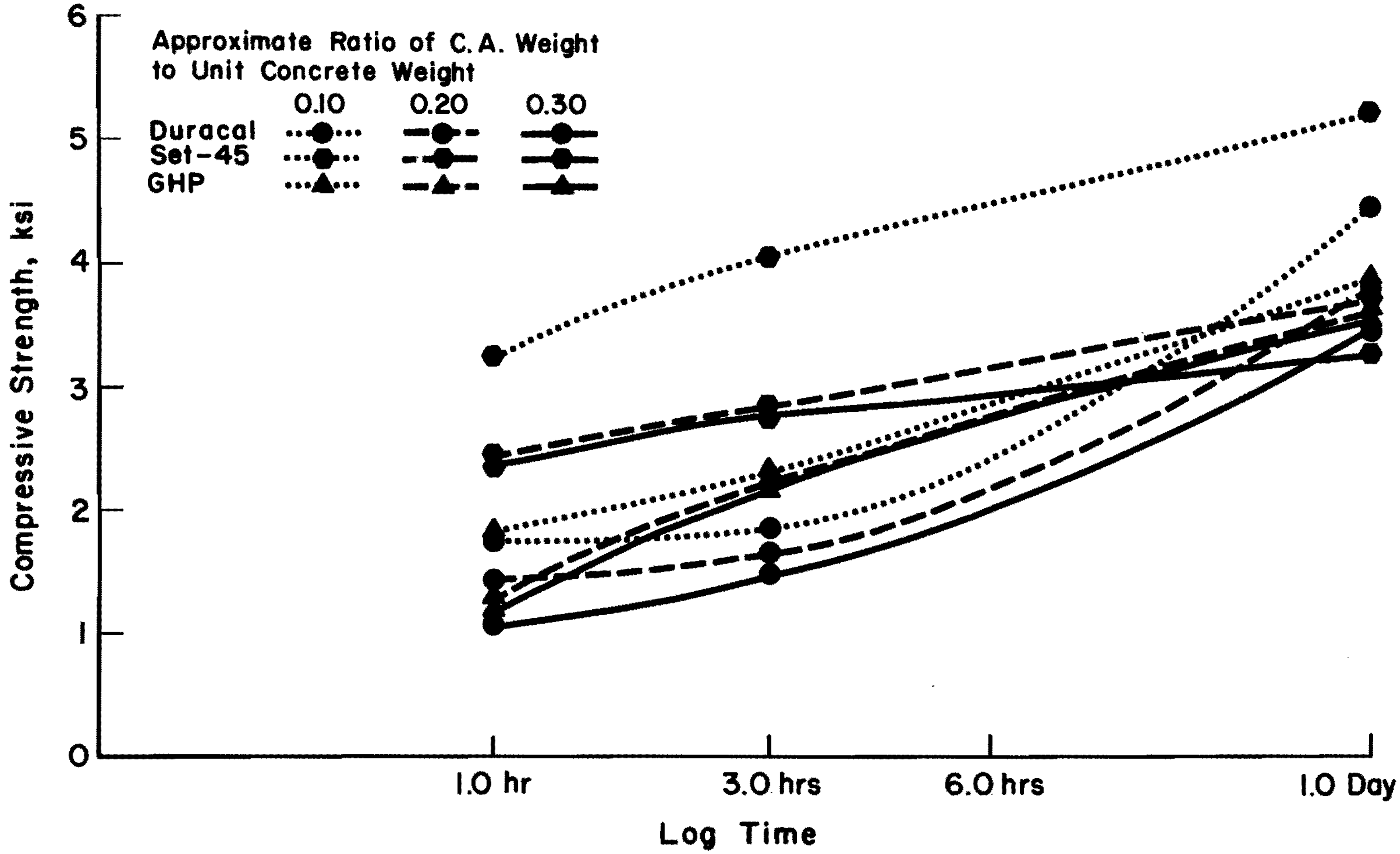

Fig. 5.13. Compressive Strength as a Function of Time for Mixes with Varying Quantities of Coarse Aggregate.

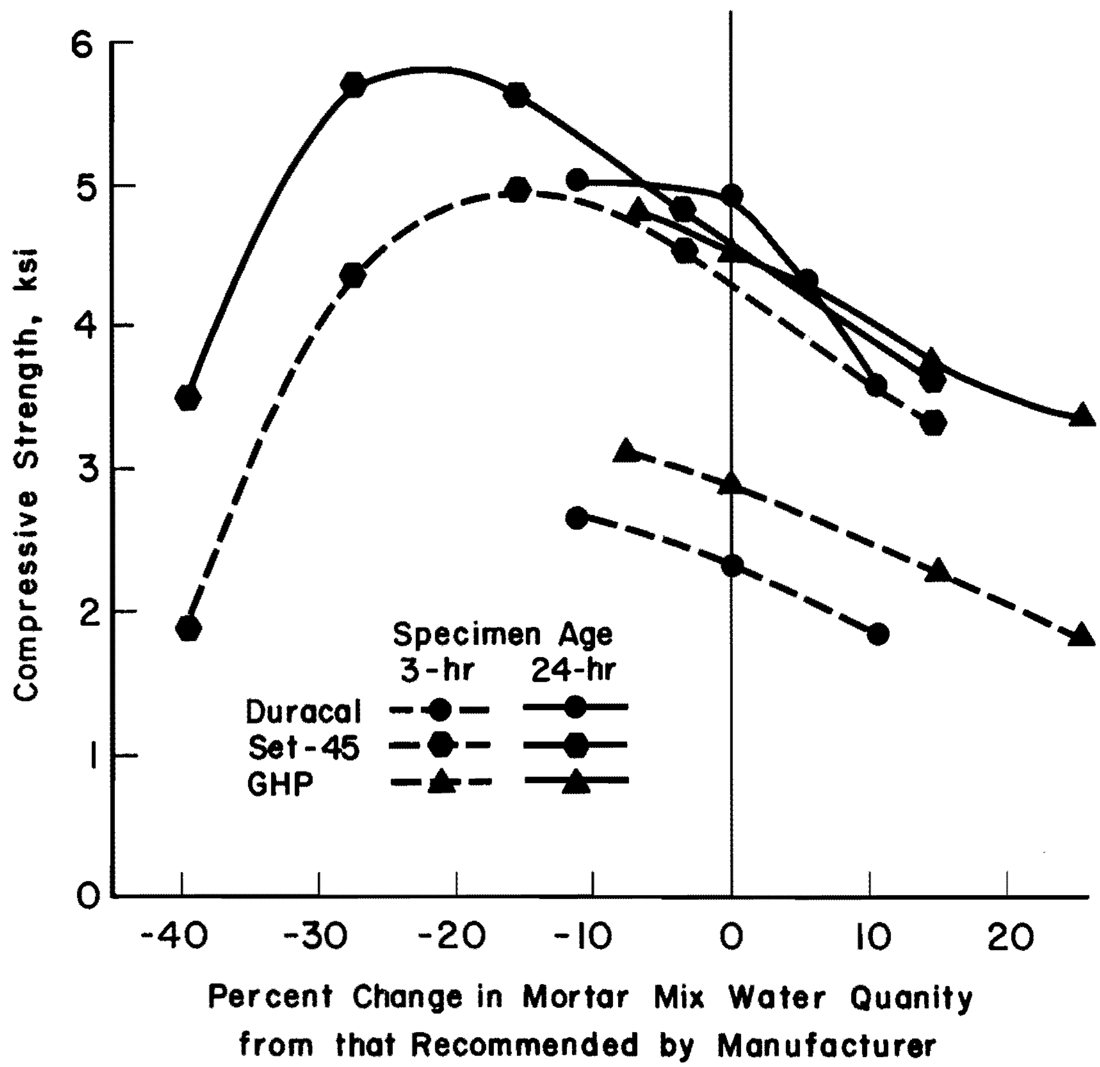

Fig. 5.14. Compressive Strength of Mortar Cubes as a Function of Water Content.

can be expected from these field repairs as compared to laboratory tests.

5.9 Coefficients of Thermal Expansion

The lengths of the coefficient of thermal expansion specimens (Fig. 3.1) were measured at temperatures of 72.5°F (22.5°C) and 110.5°F (43.6°C). After correcting for the change in length of the length comparator and the invar bar, the changes in lengths of the specimens over the 38°F (21.1°C) temperature change were used to calculate the coefficients of thermal expansion, α_c. These values for mortar and aggregate mix specimens are shown in Table 5.1. The values are approximately the same as those for conventional portland cement concrete.

Table 5.1. Coefficients of Thermal Expanison.

Material	Coefficents of Thermal Expansion, α_c, x 10^{-6} in./in./°F (x 10^{-5} in./in./°C)	
	Mortar Mix	Aggregate Mix
Duracal	9.0 (1.6)	7.6 (1.4)
Set-45	9.7 (1.7)	6.9 (1.2)
GHP	8.7 (1.6)	7.6 (1.4)
Neco-crete	9.7 (1.7)	7.4 (1.4)

CHAPTER 6
QUALITY CONTROL

To evaluate material uniformity from bag to bag and from batch to batch, six mortar cube specimens were prepared from material from each bag. Specimens were air-cured at 72°F (22°C) and 50 percent R.H. Three specimens were tested at 3-hrs. and the other three were tested at 24-hrs. The average compressive strengths of the specimens from each bag are shown in Tables 6.1, 6.2, 6.3 and 6.4 for Duracal, Set-45, GHP, and Neco-crete, respectively. Also listed are the manufacturer's batch number, the date the material was received at the laboratory, and the date the material was tested.

A statistical summary of the data in Tables 6.1, 6.2, 6.3 and 6.4 is given in Table 6.5. The Neco-crete data should be interpreted with care since only five bags were tested and all were received at the same time. Although the coefficient of variation is greatest for the Set-45 specimens, there is some evidence that this variation may be partly due to segregation of the Set-45 ingredients in each bag. Thus, the 5-lbs of Set-45 randomly taken from each bag for the quality control mixes might not be representative of the bag as a whole. Table 6.5 shows GHP to be the most uniform material from bag to bag.

Table 6.1. Compressive Strength of Duracal Quality Control Mortar Cubes.

Bag	Manufacturer's Bag Number	Date Received	Date Tested	3-hr. Compressive Strength psi (MPa)	24-hr. Compressive Strength psi (MPa)
1	05012S	11/8/82	2/8/83	2330 (16.1)	4350 (30.0)
2	05012S	11/8/82	5/4/83	2020 (13.9)	4180 (28.8)
3	05012S	11/8/82	5/4/83	2050 (14.1)	3640 (25.1)
4	08162S	1/5/83	5/4/83	2280 (15.7)	4310 (29.7)
5	08162S	1/5/83	5/4/83	2340 (16.1)	5160 (35.6)
6	08162S	1/5/83	5/4/83	2330 (16.1)	4480 (30.9)
7	08162S	1/5/83	6/7/83	2380 (16.4)	4830 (33.3)
8	----	1/5/83	6/7/83	2430 (16.8)	4490 (31.0)
9	02023S	7/7/83	10/14/83	2060 (14.2)	4040 (27.9)
10	02023S	7/7/83	10/14/83	1710 (11.8)	3630 (25.0)
11	02023S	7/7/83	10/14/83	1780 (12.3)	3450 (23.8)

Table 6.2 Compressive Strength of Set-45 Quality Control Mortar Cubes.

Bag	Manufacturer's Bag Number	Date Received	Date Tested	3-hr. Compressive Strength psi (MPa)	24-hr. Compressive Strength psi (MPa)
1	----	11/23/82	2/2/83	5830 (40.2)	7120 (49.1)
2	----	11/23/82	4/27/83	4620 (31.9)	5350 (36.9)
3	320621	11/23/82	4/27/83	5160 (35.6)	4980 (34.3)
4	----	11/23/82	4/27/83	4890 (33.7)	5660 (39.0)
5	11211	2/7/83	4/28/83	3610 (24.9)	5260 (36.3)
6	320621	2/7/83	4/28/83	3660 (25.2)	4560 (31.4)
7	320621	2/7/83	4/28/83	3930 (27.1)	4130 (28.5)
8	320621	2/7/83	7/12/83	3720 (25.7)	4150 (28.6)
9	630471	6/14/83	7/12/83	5740 (39.6)	7390 (51.0)
10	630471	6/14/83	7/12/83	3300 (22.8)	3570 (24.6)

Table 6.3. Compressive Strength of Gilco Highway Patch Quality Control Mortar Cubes.

Bag	Manufacturer's Bag Number	Date Received	Date Tested	3-hr. Compressive Strength psi (MPa)	24-hr. Compressive Strength psi (MPa)
1	IO 107 1983 JAN 1984	2/14/83	2/21/83	2710 (18.7)	4370 (30.1)
2	HO 1011 1983 JAN 1984	2/14/83	3/29/83	2870 (19.8)	4270 (29.4)
3	HO 1011 1983 JAN 1984	2/14/83	4/4/83	2700 (18.6)	4040 (27.9)
4	IO 107 1983 JAN 1984	2/14/83	7/11/83	2730 (18.8)	4430 (30.5)
5	IO 107 1983 JAN 1984	5/9/83	7/8/83	2890 (19.9)	4760 (32.8)
6	IO 107 1983 JAN 1984	5/9/83	7/8/83	2880 (19.9)	4720 (32.5)
7	IO 107 1983 JAN 1984	5/9/83	7/11/83	2530 (17.4)	4330 (29.9)
8	IO 107 1983 JAN 1984	5/9/83	7/8/83	2910 (20.1)	4830 (33.3)
9	IO 107 1983 JAN 1984	5/9/83	7/11/83	3120 (21.5)	4510 (31.1)
10	JO 1012 1983 JAN 1984	6/21/83	8/8/83	2610 (18.0)	4280 (29.5)
11	JO 1012 1983 JAN 1984	6/21/83	8/8/83	2540 (17.5)	4180 (28.8)
12	JO 1012 1983 JAN 1984	6/21/83	9/13/83	3020 (20.8)	4890 (33.7)
13	JO 1012 1983 JAN 1984	6/21/83	9/13/83	2950 (20.3)	4530 (31.2)
14	JO 1912 1983 JAN 1984	6/21/83	9/13/83	2620 (18.1)	4440 (30.6)

Table 6.4. Compressive Strength of Neco-Crete Quality Control Mortar Cubes.

Bag	Manufacturer's Bag Number	Date Received	Date Tested	3-hr. Compressive Strength psi (MPa)	24-hr. Compressive Strength psi (MPa)
1	----	2/10/83	4/18/83	2180 (15.0)	3380 (23.3)
2	----	2/10/83	4/29/83	2680 (18.5)	2830 (19.5)
3	----	2/10/83	4/29/83	2490 (17.2)	3000 (20.7)
4	----	2/10/83	4/29/83	2040 (14.1)	2670 (18.4)
5	----	2/10/83	6/7/83	2030 (14.0)	3480 (24.0)

Table 6.5. Quality Control Statistical Summary.

Material	Specimen Test Age, hrs.	Average Compressive Strength, psi (MPa)	Standard Deviation psi (MPa)	Coefficient of Variation, percent
Duracal	3	2160 (14.9)	240 (1.6)	11.0
	24	4230 (29.2)	500 (3.4)	11.8
Set-45	3	4450 (30.7)	880 (6.1)	19.8
	24	5220 (36.0)	1190 (8.2)	22.7
GHP	3	2790 (19.2)	180 (1.2)	6.3
	24	4470 (30.8)	240 (1.7)	5.5
Neco-crete	3	2280 (15.7)	260 (1.8)	11.3
	24	3070 (21.2)	310 (2.1)	10.2

CHAPTER 7
FIELD REPAIRS

In a meeting with D-9 personnel in July 1983, four Texas sites were chosen for field evaluation of the rapid setting materials. The selected sites were Waco, Amarillo, Dallas, and Houston. These sites were thought to be representative environmental conditions and traffic volumes encountered in Texas. Duracal, Set-45, and GHP were to be used in the field repairs. Necocrete had failed to meet consistently D-9's "Performance Specification for Rapid Setting Cement Mortar" and, therefore, was not included in the field testing. The repairs will be inspected periodically in the future to evaluate their performance.

7.1 Waco

In its response to the Study 311 survey of the districts, the Waco district reported no use of the candidate rapid setting materials. Their policy was to make full lane width repairs of damaged areas using accelerated PCC.

The Waco field repairs were made on September 28, 1983, in the southbound outside lane of IH 35. Three full-depth punchouts were repaired. Their locations are shown in Fig. 7.1.

A Waco district maintenance crew provided the required labor, equipment, tools, water, and aggregates. Study 311 personnel provided the rapid setting materials.

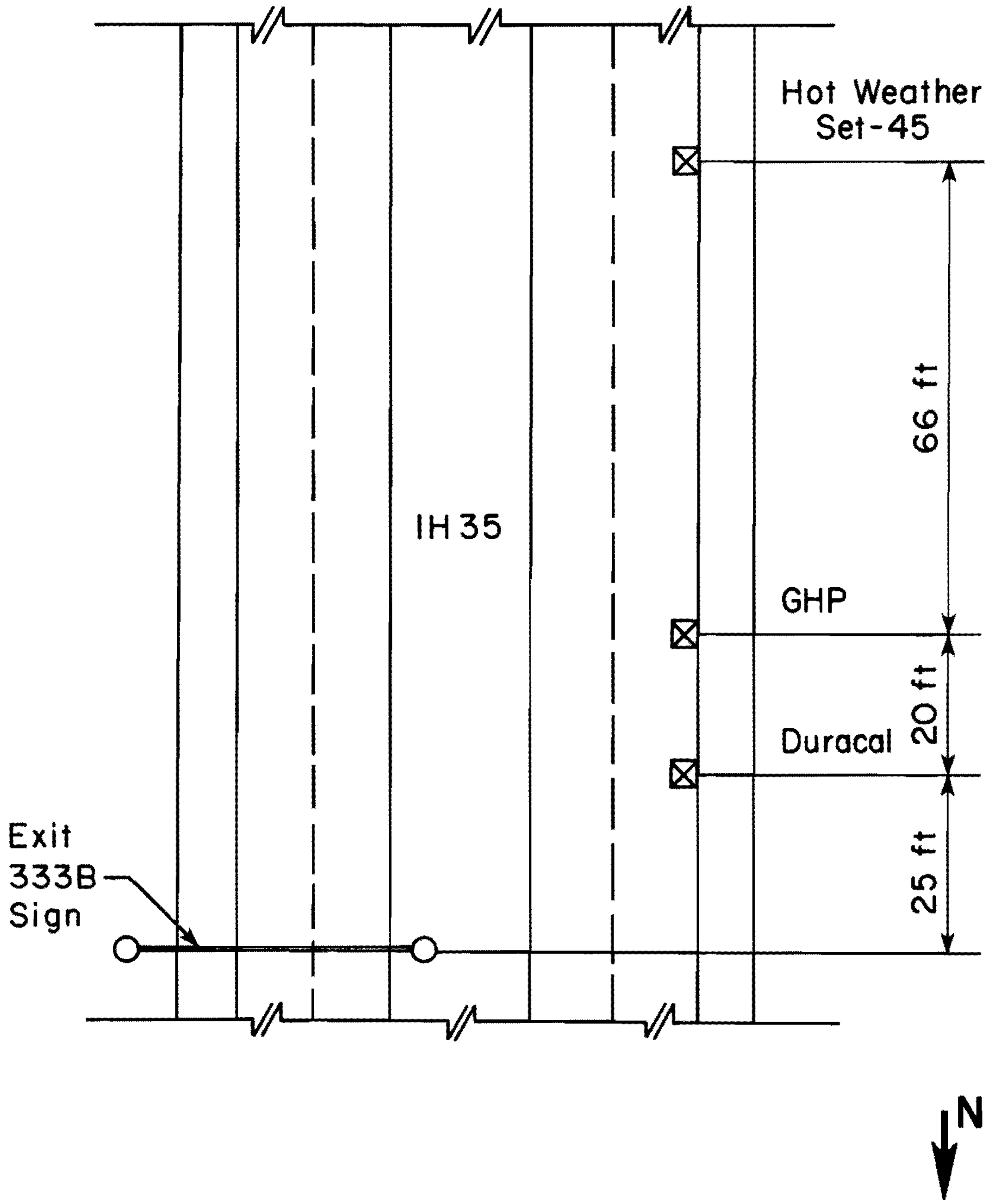

Fig. 7.1. Waco Repair Locations.

The approximate weather conditions at the site were 1) ambient temperature of 90°F (32°C); 2) winds gusting from the north at 5 to 10 mph (8 to 16 km./hr.); and 3) 70 percent R.H.

The repair edges were jackhammered full depth. Figure 7.2 shows the jack hammering in progress on the Duracal and GHP repairs. The existing continuous reinforcement was left intact. The repair materials were mixed in a 3-ft^3 (0.085-m^2) drum mixer. The aggregates and water were placed in the mixer prior to adding the rapid setting materials. A #5 pea gravel was used for the coarse aggregate. A siliceous sand was used for the fine aggregate in the Duracal mixes. Repair mixes were initially proportioned as shown in Table 2.2; however, additional water was required for the Hot Weather Set 45 and GHP mixes. Although not normally recommended, we used three horizontal lifts for each repair. This was because the punchouts were small enough that we were able to mix and place the last lift before the first lift had set, thereby avoiding horizontal plane cold joints which later might cause the top lift to delaminate. The mixing, placing, and finishing of each repair was completed in approximately 30 minutes. All three repairs were made between 1:00 and 2:30 PM. The lane was to be opened to traffic at 5:00 PM.

Figure 7.4 shows a sketch of the Duracal and GHP repairs. Existing reinforcement and cracks are shown. The cleaned Duracal repair hole is shown in Fig. 7.3. The Duracal mix had a high slump and was easy to mix, place, and finish. Figure 7.5 shows the Duracal mix being placed into the hole. For these repairs,

Fig. 7.2. Jack hammering Duracal and GHP Repairs, Waco.

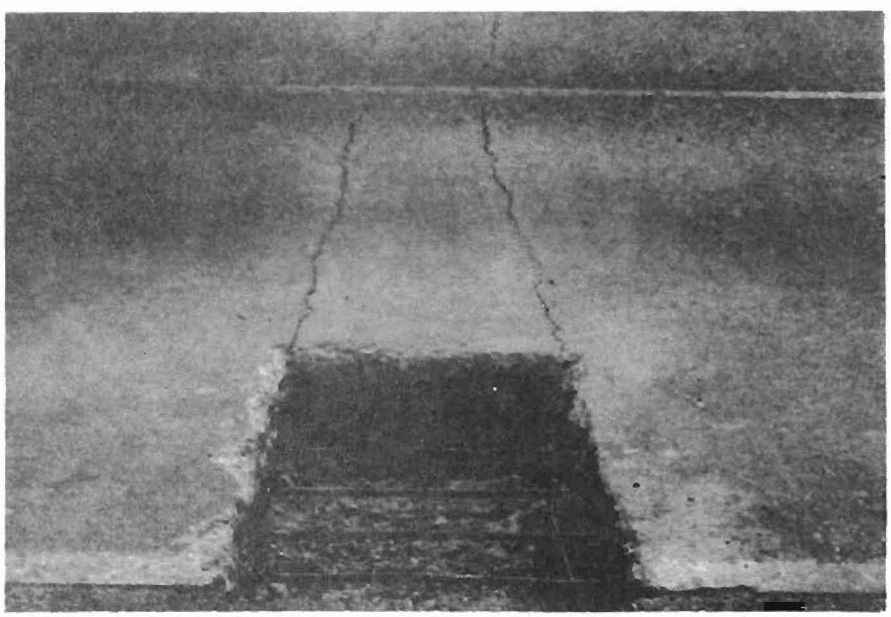

Fig. 7.3. Clean Duracal Repair Hole, Waco

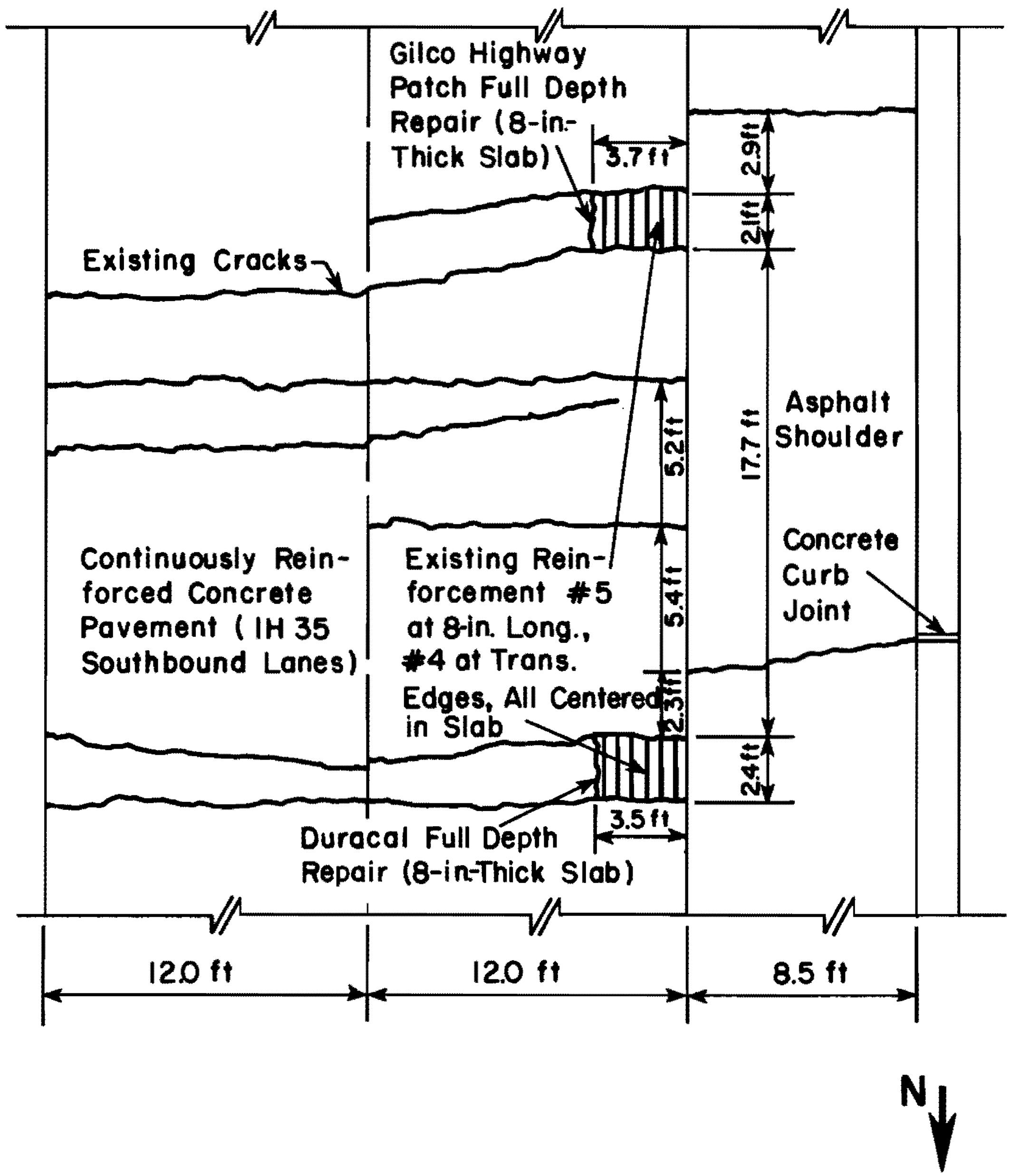

Fig. 7.4. Sketch of Duracal and GHP Repairs, Waco.

the mixed material was transported to the repair hole using a wheelbarrow. However, it is more convenient to discharge the materials directly into the hole from the mixer when possible
Using the slowly rotating drum mixer required that the GHP mix water quantity be increased by 30 percent to attain adequate workability. However, the GHP mix was still stiff and required mechanical vibration, as shown in Fig. 7.7. Plastic shrinkage cracks were soon noticeable in the GHP repair. The finished Duracal repair is shown in Fig. 7.6. A closeup of the finished GHP repair, Fig. 7.8, shows the shrinkage cracks.

Hot Weather Set-45, rather than Set-45, was used to allow adequate working time in the 90°F (32°C) environment. The Hot Weather Set 45 mix was dry in the mixer. A very workable mix was attained by increasing the mix water quantity by 15 percent. A sketch of the Hot Weather Set-45 repair is shown in Fig. 7.9. The material is shown being placed into the hole in Fig. 7.10 and the finished repair is shown in Fig. 7.11.

Three 3-in. dia. x 6-in. (76.2-mm dia. x 152-mm) cylinders and three 2-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 305-mm) beams were cast from material from each repair mix. The specimens were tested in the laboratory at 24 hrs. of age. The average strengths of the field specimens are shown in Table 7.1. The 24-hr. compressive and flexural strengths of the Duracal specimens are approximately the same as those shown in Figs. 5.2 and 5.5, respectively. However, the compressive strengths of both Hot Weather Set 45 and GHP are approximately 30 percent lower. Similarly, the

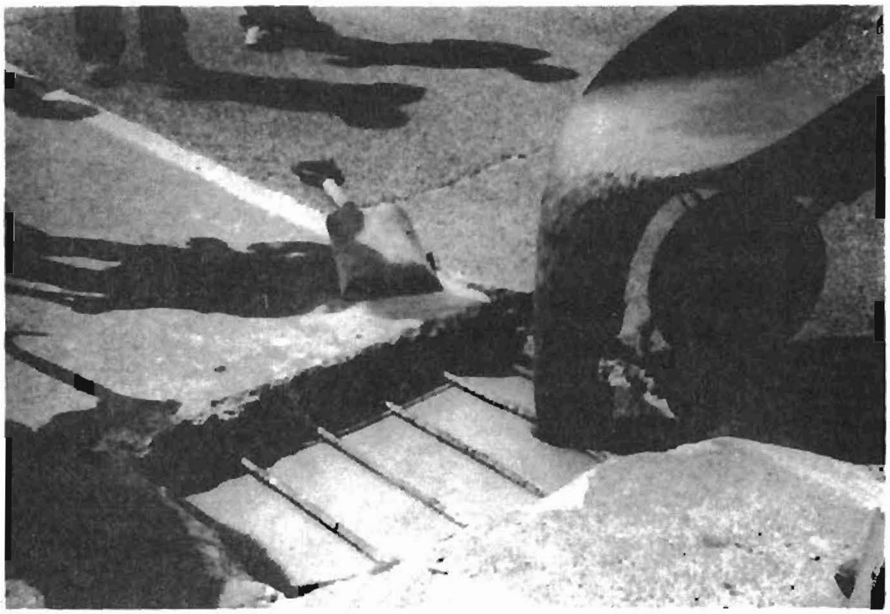

Fig. 7.5. Placing Duracal Repair Mix, Waco.

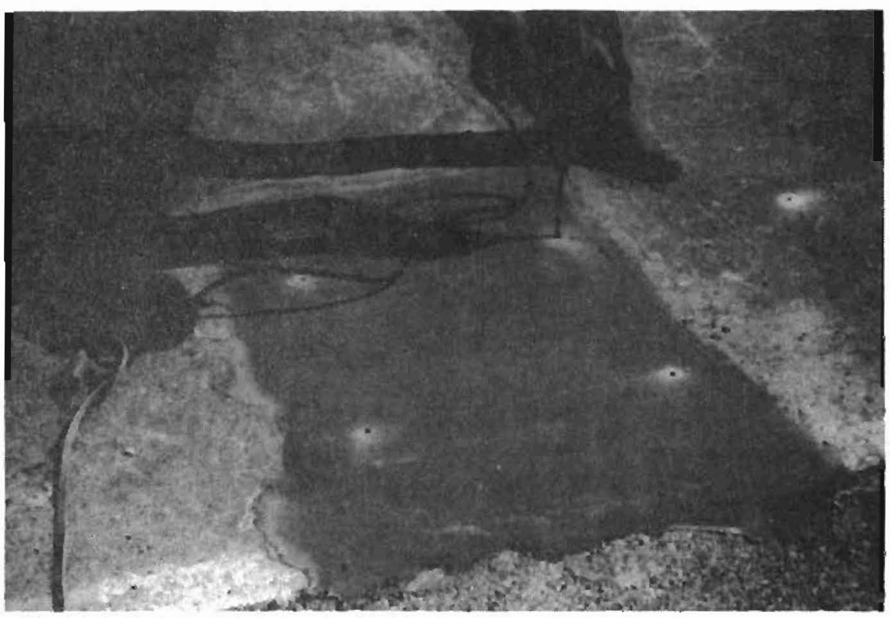

Fig. 7.6. Finished Duracal Repair, Waco.

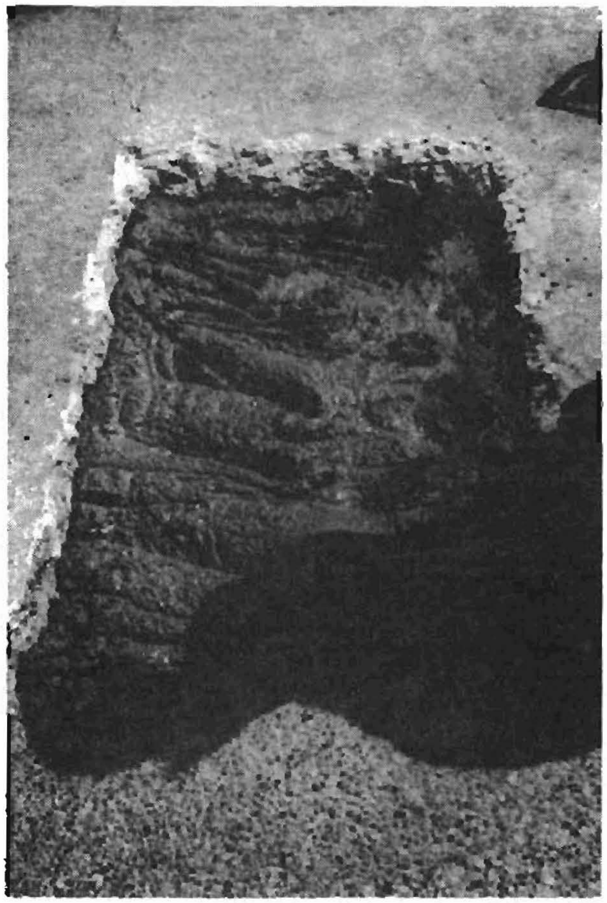

Fig. 7.7. Vibrating GHP Repair
Mix, Waco.

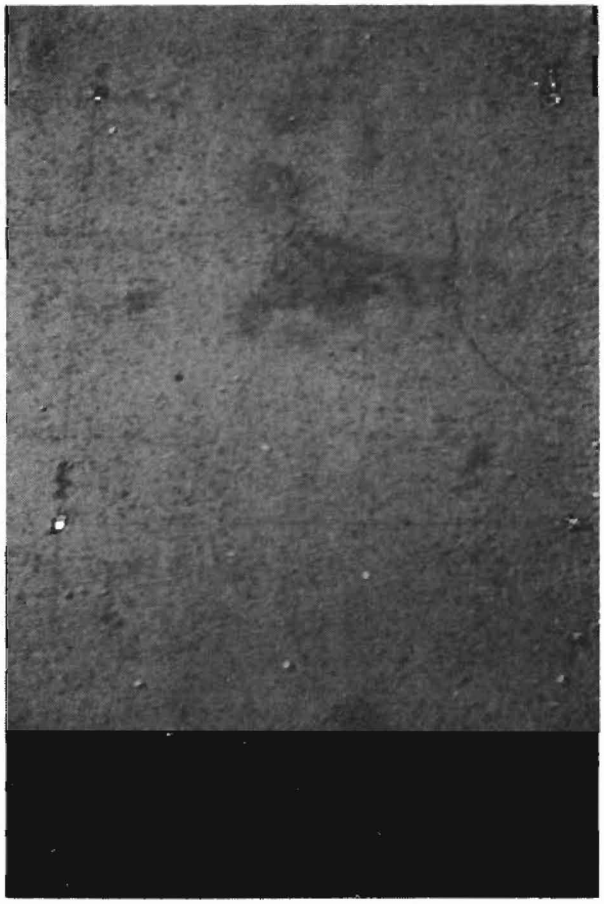

Fig. 7.8. Finished GHP Repair, Waco.

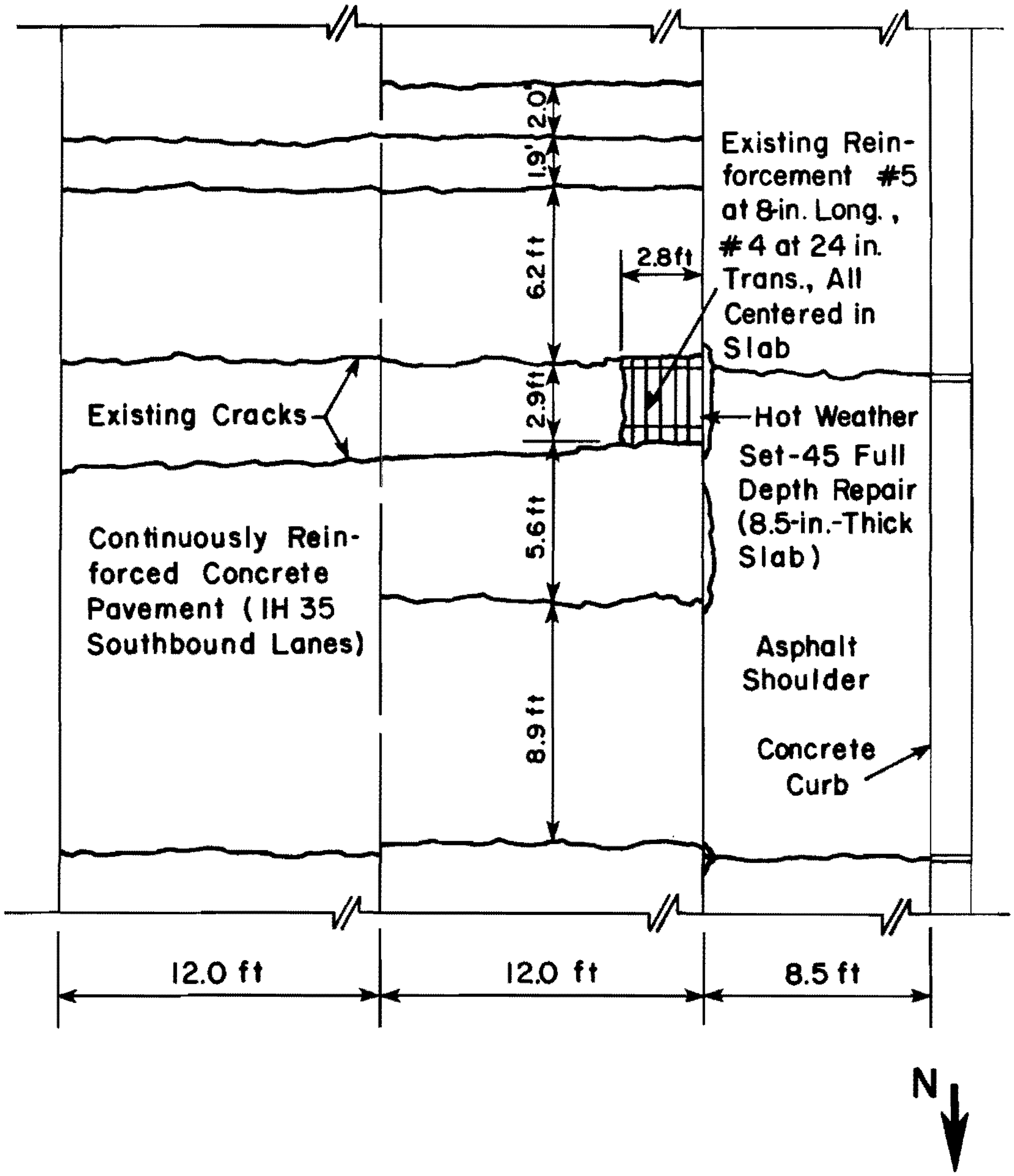

Fig. 7.9. Sketch of Hot Weather Set-45 Repair, Waco.

Fig. 7.10. Placing Hot Weather Set-45 Repair Mix, Waco.

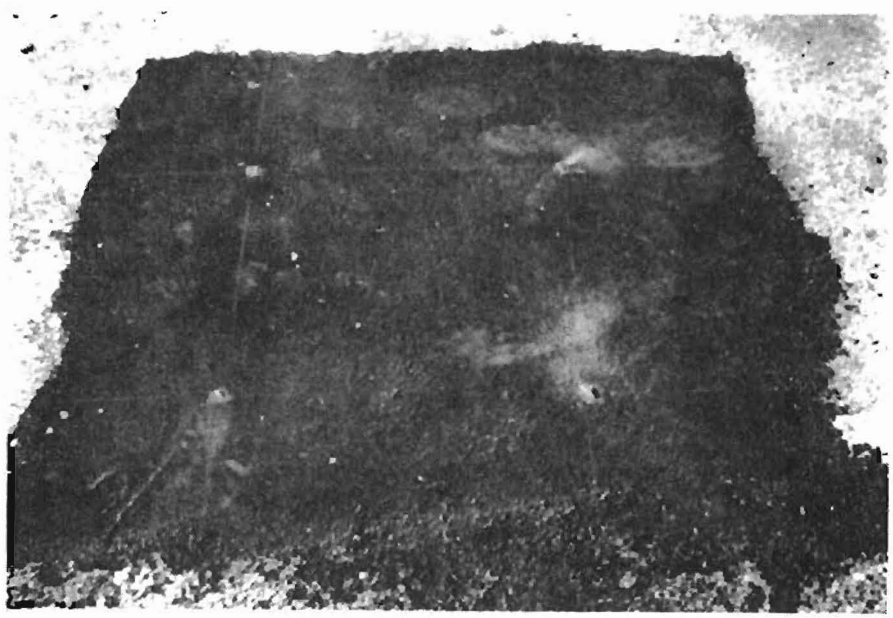

Fig. 7.11. Finished Hot Weather Set-45 Repair, Waco.

flexural strengths are approximately 40 percent lower. The lower strengths are apparently the result of increasing mix water quantities.

7.2 Amarillo

Field repairs in the Amarillo district were made on October 27, 1983. Two full depth punchouts were repaired in the westbound outside lane of IH 40. The repair locations are shown in Fig. 7.12. The repairs were made using Duracal and Set-45. A repair using GHP was not made due to insufficient time.

Duracal was the only rapid setting material that the Amarillo district had reported experience with. The district reported good performance from the Duracal repairs and estimated that it used 100,000 lbs of Duracal per year.

An Amarillo district maintenance crew provided the required labor, equipment, water and aggregates. Study 311 personnel supplied the Duracal and Set-45.

The weather conditions at the site were approximately (1) ambient temperature of 60 to 70°F (16 to 21°C); (2) 20 mph (32 km/hr) winds, and (3) 20 percent R.H.

The areas to be repaired had been previously overlaid with asphalt. Repair boundaries were saw-cut approximately 2-in. (51-mm) deep. Concrete within the boundaries was then jackhammered out to the full depth. The existing continuous reinforcement was left intact; however, it was then cut near mid-repair to allow for compacting of the base materials. The bars were then spliced back together.

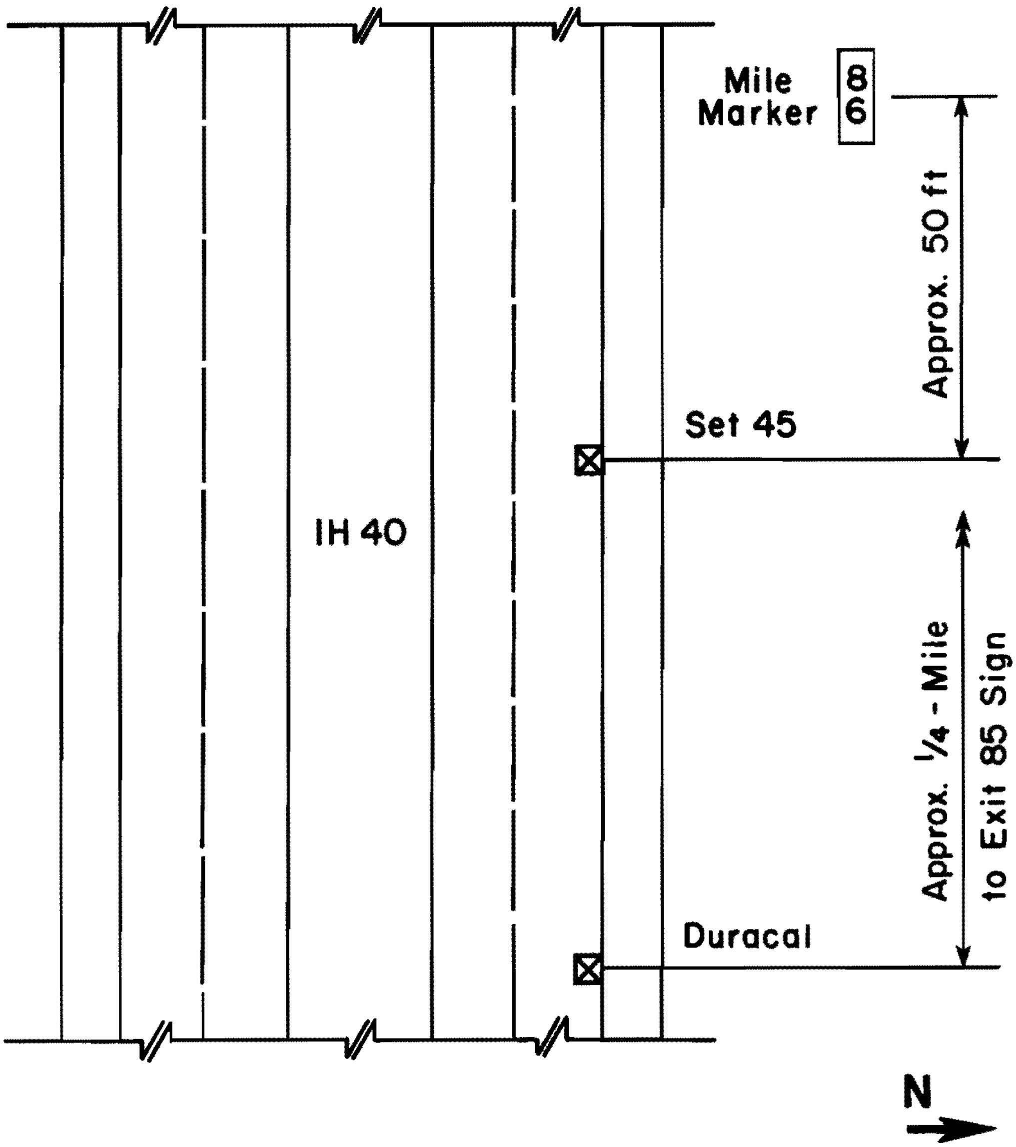

Fig. 7.12. Amarillo Repair Locations.

A 2-ft^3 (0.057-m^3) masonry mixer was used to mix the repair materials. A siliceous sand was used for the fine aggregate in the Duracal mixes. The Amarillo district provided the moisture content of the sand and corrections were made to the Duracal mix water quantity. A #4 crushed siliceous gravel was used for the coarse aggregate. No corrections to mix water quantities were required with this coarse aggregate. The aggregates and water were placed in the mixer prior to adding the rapid setting materials.

The materials for each repair were placed in three horizontal lifts. The materials were consolidated with a shovel and finished smooth with a steel trowel.

Mixing, placing, and finishing of the Duracal repair was completed in 30 minutes (3:00 to 3:30 PM). The Duracal mix water quantity was increased by 5 percent to increase the workability. The material was placed and finished easily. There was not adequate material to cast field specimens. A sketch of the Duracal repair is shown in Fig. 7.13. The Duracal repair is shown being finished in Fig. 7.14.

The Set-45 material was mixed, placed, and finished from 4:30 to 5:00 PM. The mix water quantity had to be increased by 15 percent to attain workability. The material was easy to work and finished well. The Set-45 repair sketch is shown in Fig. 7.15. The finished repair is shown in Fig. 7.16.

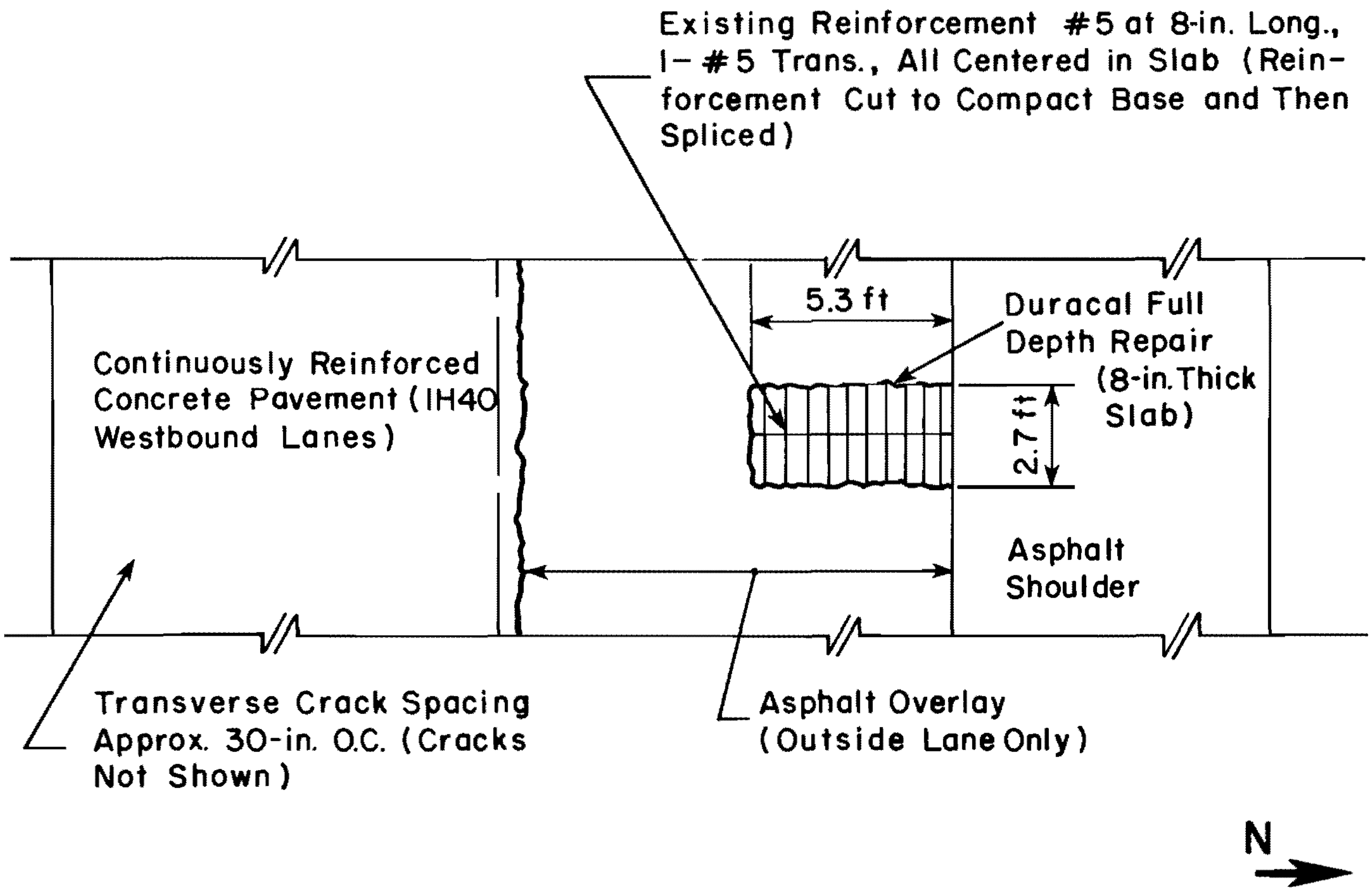

Fig. 7.13. Sketch of Duracal Repair, Amarillo, Texas (10/27/83).

Fig. 7.14. Finishing Duracal Repair, Amarillo.

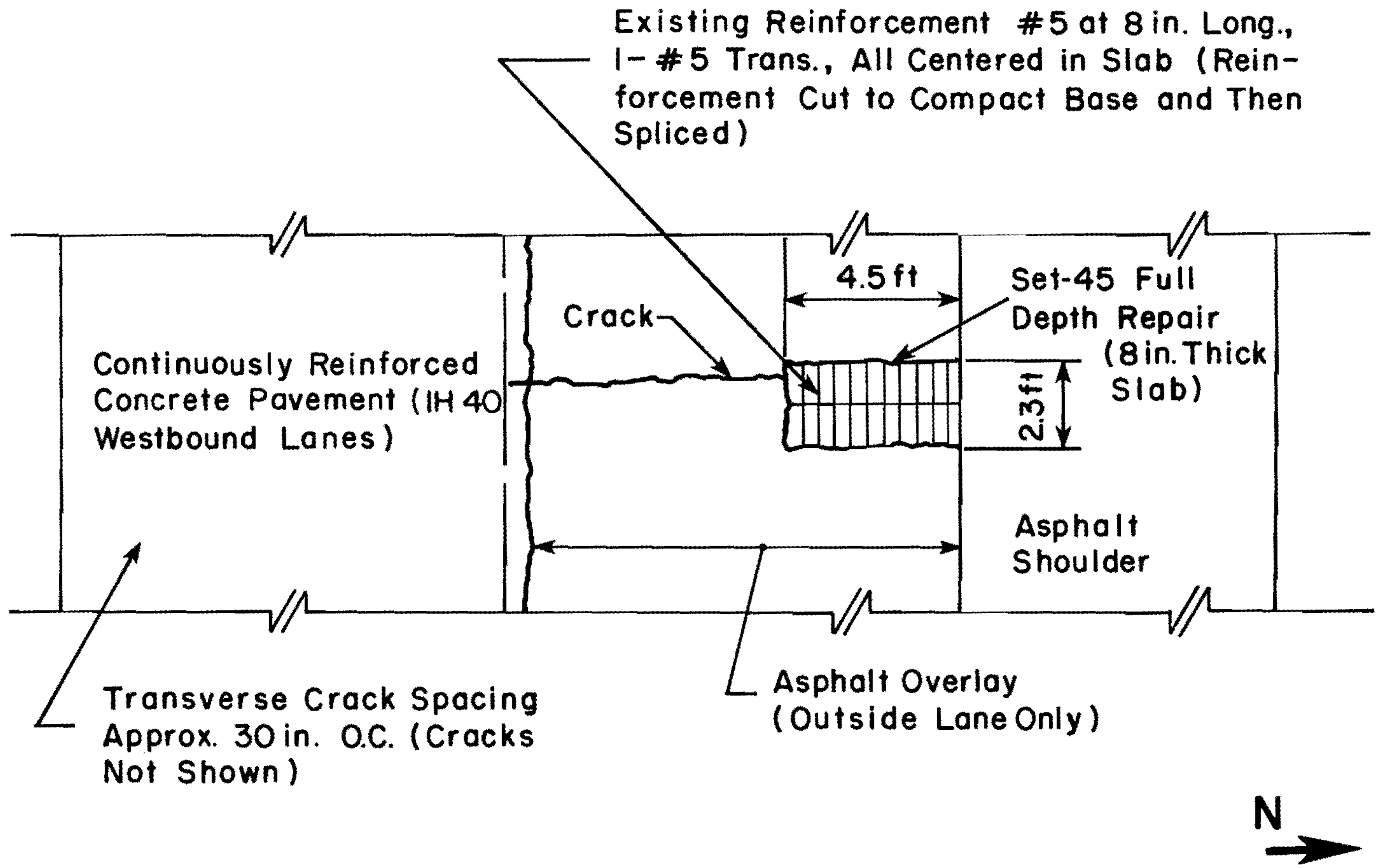

Fig. 7.15. Sketch of Set-45 Repair, Amarillo, Texas (10/27/83).

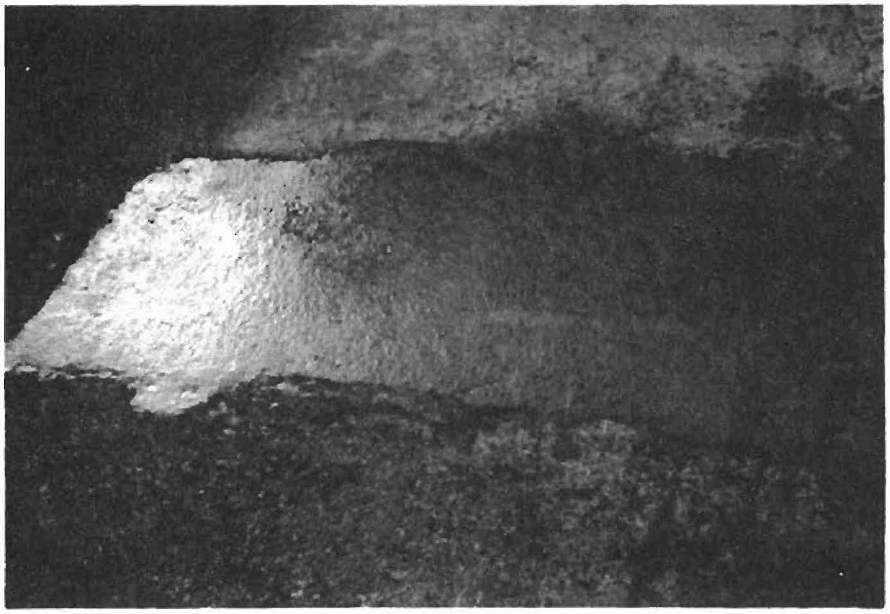

Fig. 7.16. Finished Set-45 Repair, Amarillo.

The strengths of the Set-45 field specimens are shown in Table 7.1. The 4-day compressive strength is approximately 30 percent lower than that shown in Fig. 5.2. Again, the lower strengths are apparently the result of increasing the mix water quantity.

The mortar mixer was significantly more effective at mixing the rapid setting materials than the drum mixer used in Waco. Both the Set-45 and GHP manufacturers suggest using a mortar mixer. A stiff batch can be mixed and discharged more easily than when the drum mixer is used, thus decreasing the water quantity required to attain a mixable batch.

7.3 Dallas

The Dallas district had reported considerable use of both Set-45 and Hot Weather Set-45. The district estimated it used 20,000 lb/year of Set-45 and 50,000 lb/year of Hot Weather Set-45. The Set-45 materials were used primarily for the repair of punchouts and bridge deck spalls.

The Dallas field repairs were made in the southbound center lane of IH 45 on November 22, 1983. The repair locations are shown in Fig. 7.17. Four full depth punchouts were repaired using Duracal, Set-45, and GHP.

The weather conditions at the site were approximately: (1) ambient temperature of 76°F (24°C), (2) 15 mph (24 km./hr) winds out of the south, and (3) light intermittent rain.

Table 7.1 Field Specimen Strengths.

Repair Location	Repair Material	Test Age	Compressive Strength, psi (MPa)	Flexural Strength, psi (MPa)
Waco	Duracal	24-hrs.	3590 (24.8)	550 (3.8)
	H.W. Set-45		3290 (22.7)	380 (2.6)
	GHP		2440 (16.8)	450 (3.1)
Amarillo	Set-45	4-days	3610 (24.9)	430 (3.0)
Dallas	Duracal (with fibers)	3-days	3890 (26.8)	600 (4.1)
	Set-45 (with fibers)		6220 (42.9)	----
	Set-45		3990 (27.5)	----
	GHP		3870 (26.7)	600 (4.1)
Houston	Duracal	24-hrs.	90 (0.6)	150 (1.0)
	Set-45		5240 (36.1)	690 (4.8)
	GHP		930 (6.4)	160 (1.1)

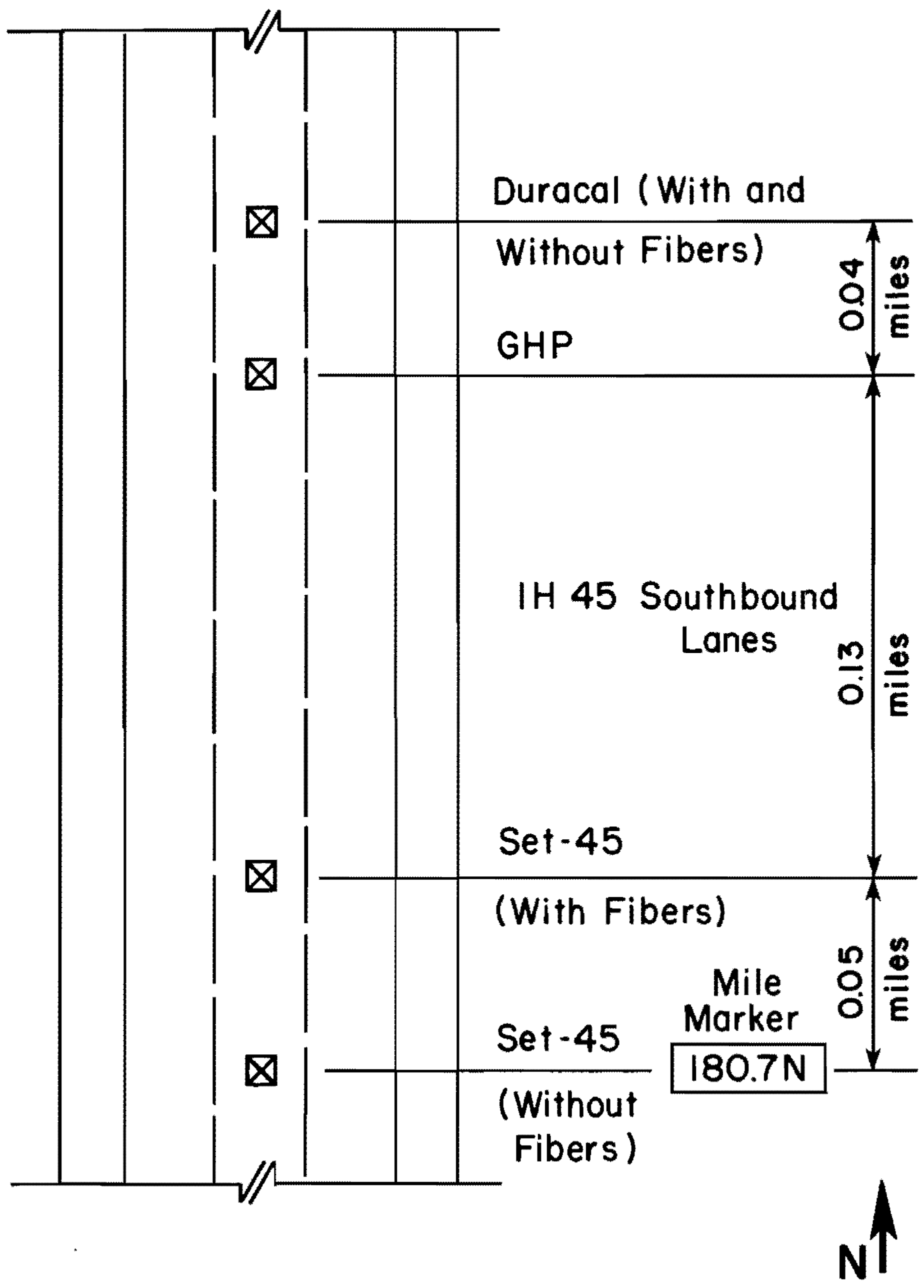

Fig. 7.17. Dallas Repair Locations.

Future Study 311 laboratory work will include evaluating the effects of steel fibers in the aggregate mixes. To supplement this laboratory work, two Dallas repairs were made using fibers. Fibers used were 0.002-in. dia. x 1.2-in. (0.05-mm dia. x 30-mm) hooked brass fibers manufactured by Bekaert and proportioned into the mixes at the rate of 85 lb/yd^3 (495 N/m^3) of repair material.

Study 311 personnel provided the repair materials and fibers. A Dallas district maintenance crew prepared the repair holes and mixed, placed, and finished the repair materials. The repair area was jackhammered out to the full depth, leaving the existing reinforcement undamaged. The materials were mixed in a 3-ft^3 (0.085-m^3) drum mixer. A siliceous sand was used for the fine aggregate and a siliceous pea gravel was used for the coarse aggregate. The aggregates and water were added to the mixer prior to adding the repair materials. The materials were mixed until a uniform mix was attained, approximately 2.5 minutes. The mixing time for mixes with fibers was increased to approximately 4 minutes to help separate the fibers which were bound together by a watersoluble adhesive.

A sketch of the Duracal repair is shown in Fig. 7.18. A temporary cardboard divider was placed down the middle of the repair hole to separate the Duracal mixes with fibers from those without fibers. Both halves of the repair were placed in two horizontal lifts. Both mixes, with and without fibers, were easy

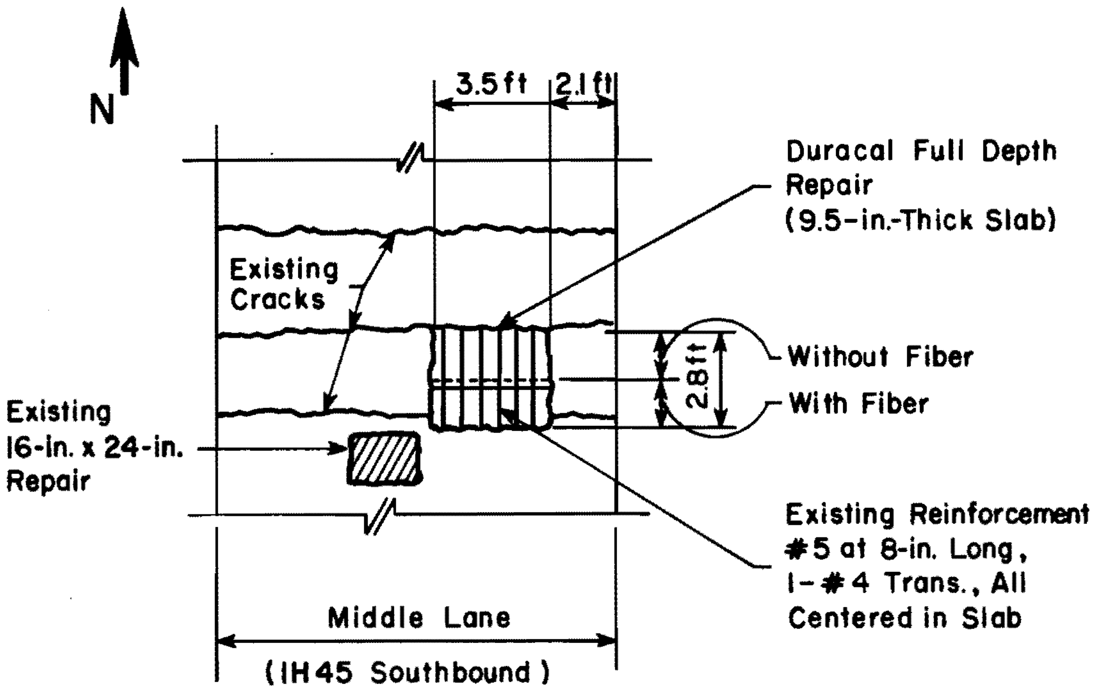

Fig. 7.18. Sketch of Duracal Repair (with and without fibers), Dallas.

to mix, place, and finish. The repair is shown being finished in Fig. 7.19.

A sketch of the GHP repair is shown in Fig. 7.20. No fibers were used. The mix water quantity was increased by 40 percent to attain a mixable batch. The materials were placed in two horizontal lifts. The modified mix was workable and finished easily. A broom finish is shown being applied to the GHP repair surface in Fig. 7.21.

Fibers were included in the Set-45 mix used to fill the repair hole shown in Fig. 7.22. Again, the mix water quantity had to be increased by 15 percent. The increased mixing time of the fiber mix reduced the allowable working time. The mix began to set after approximately 6 minutes and could not be properly finished. The maintenance crew tried to finish the Set-45 like a portland cement concrete, i.e., then sprayed water on the surface while troweling to increase workability as the material began to set. However, the surface was only damaged by further attempts to finish it once the material began to set. Figure 7.23 shows this repair being screeded.

A sketch of the repair made with Set-45 without fibers is shown in Fig. 7.24. Since the Set-45 repair with fibers had set too rapidly, the maintenace crew increased the water quantity of this repair mix to delay the set time slightly. They increased the water quantity by 35 percent over that shown in Table 2.2.

Fig. 7.19. Finishing Duracal Repairs (with and without fibers), Dallas.

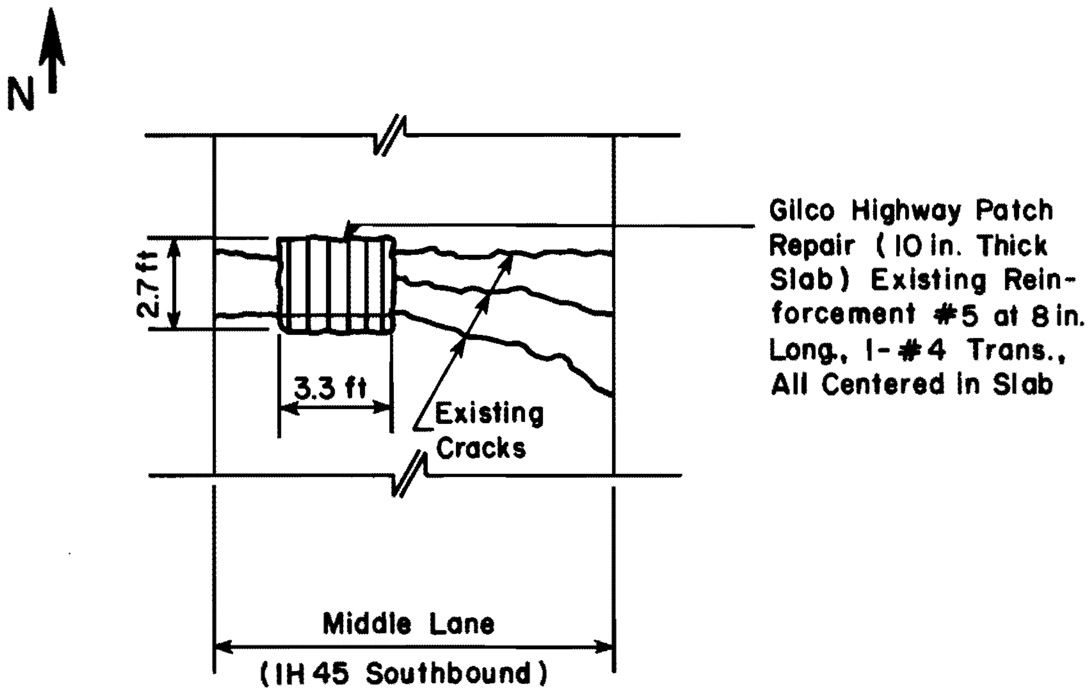

Fig. 7.20. Sketch of Gilco Highway Patch Repair (without fibers), Dallas.

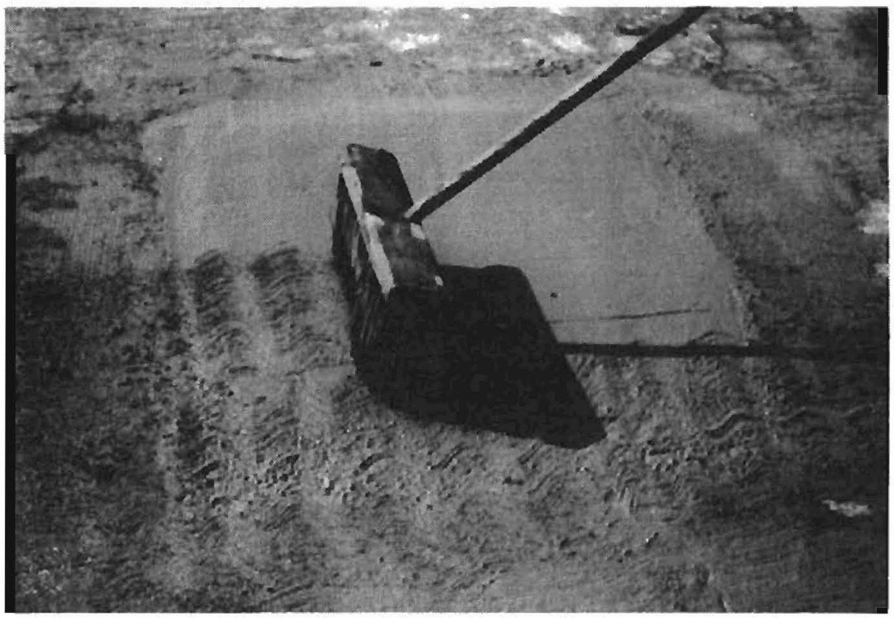

Fig. 7.21. Applying Broom Finish to
GHP Repair, Dallas.

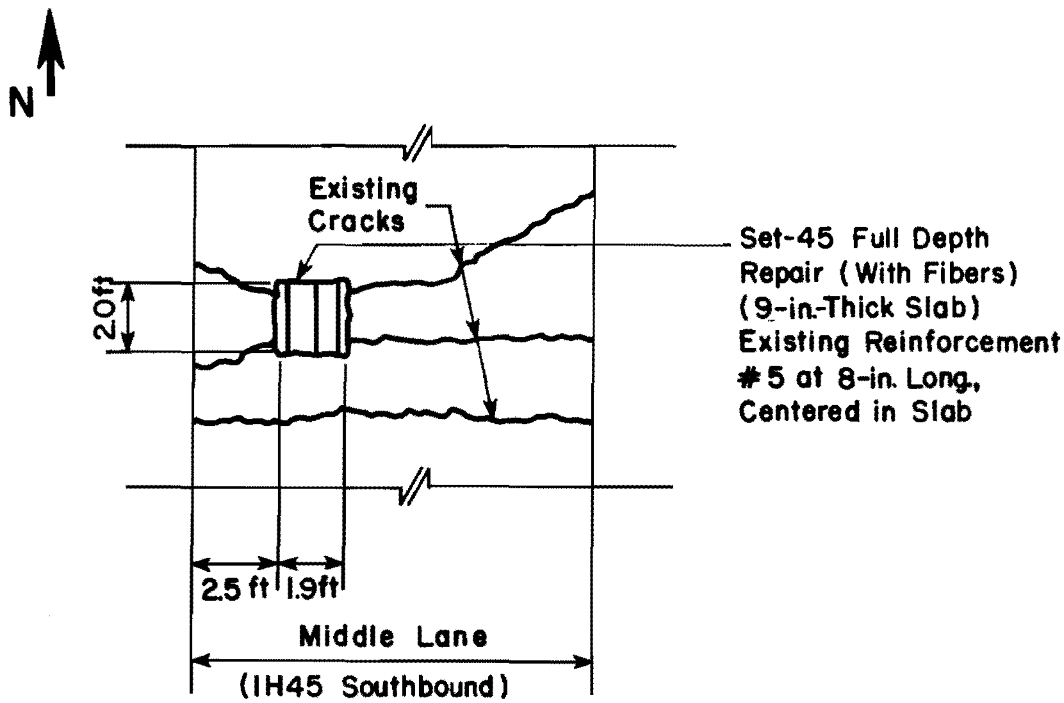

Fig. 7.22. Sketch of Set-45 Repair (with fibers), Dallas.

Fig. 7.23. Screeding Set-45 Repair Mix (with fibers), Dallas.

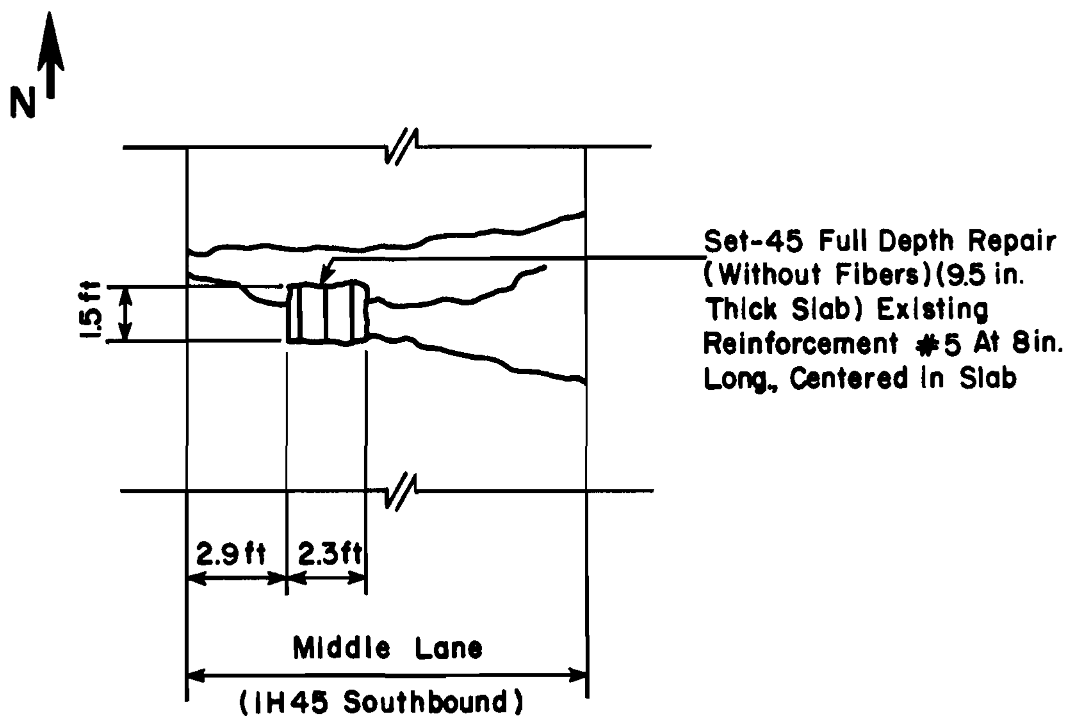

Fig. 7.24. Sketch of Set-45 Repair Mix (with fibers), Dallas.

However, this mix was clearly too fluid. The finished repair is shown in Fig. 7.25.

The strengths of the Dallas field specimens are shown in Table 7.1. Compared to laboratory values shown in Fig. 5.2, the compressive strengths of the Duracal (with fibers), Set-45, and GHP are 18, 20, and 13 percent low, respectively. However, the compressive strength of the Set-45 (with fibers) specimen was 24 percent high. The higher water quantity in the Set-45 repair without fibers apparently lowered its strength significantly.

7.4 Houston

Field repairs in the Houston district were made on December 8, 1983. Three full-depth punchouts were repaired in the westbound outside lane of IH 10 using Duracal, Set-45, and GHP.

The temperature at the site was approximately 65°F (18°C). Skies were cloudy.

A local contractor's crew prepared and cleaned the repair holes. Repair boundaries were saw-cut 1 in. (25 mm) and then the concrete in the repair area was jackhammered out full depth. Existing reinforcement was also cut through and removed. At each repair, four to five dowels (#6 rebar) were epoxied into drilled holes in the adjoining concrete. A layer of welded wire mesh was then placed at mid-depth of the slab repair.

The aggregates used were obtained by Study 311 personnel at a nearby highway maintenance storage site. A siliceous sand was used for the fine aggregate. A 1/4-in. (6-mm) maximum size

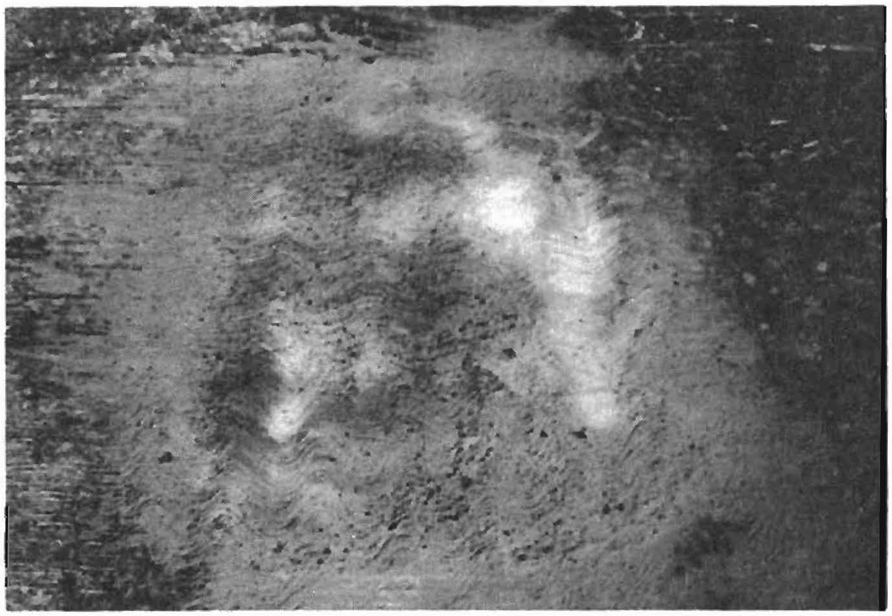

Fig. 7.25. Finished Set-45 Repair (without fibers), Dallas.

saturated crushed limestone was used for the coarse aggregate required. The Duracal, Set-45, and GHP repair materials were supplied by Study 311 personnel. Water was provided by the contractor from a portable water tank.

The materials were mixed in a 2-ft^3 (0.057-m^3) mortar mixer. Again, the aggregates and water were placed in the mixer prior to addition of the rapid setting materials.

A sketch of the Set-45 repair is shown in Fig. 7.26. The pavement was jointed and fewer cracks were visible than in the continuously reinforced concrete pavements. Similarly to the other field repairs with Set-45, the water quantity had to be increased by 15 percent to attain a mixable batch. The Set-45 mix was placed in horizontal lifts and consolidated with a shovel. The mixing was started at 3:15 PM and the repair was completed less than 30 minutes later. The surface finished easily. The repair hole is shown in Fig. 7.27 and the completed repair is shown in Fig. 7.28.

The mixing of the materials for the GHP repair was started at 3:45 PM. The repair hole was 25-in. x 37-in. x 11-in. deep (635-mm x 940-mm x 279-mm deep). Again, the GHP mix water quantity had to be increased by 25 percent. This modified mix was placed and finished easily with no apparent problems.

The Duracal aggregate mix was used to repair a 39-in. x 28-in. x 12-in. deep (991-mm x 711-mm x 305-mm deep) hole. The mixing was started at 4:20 PM and the repair was completed in approximately 30 minutes.

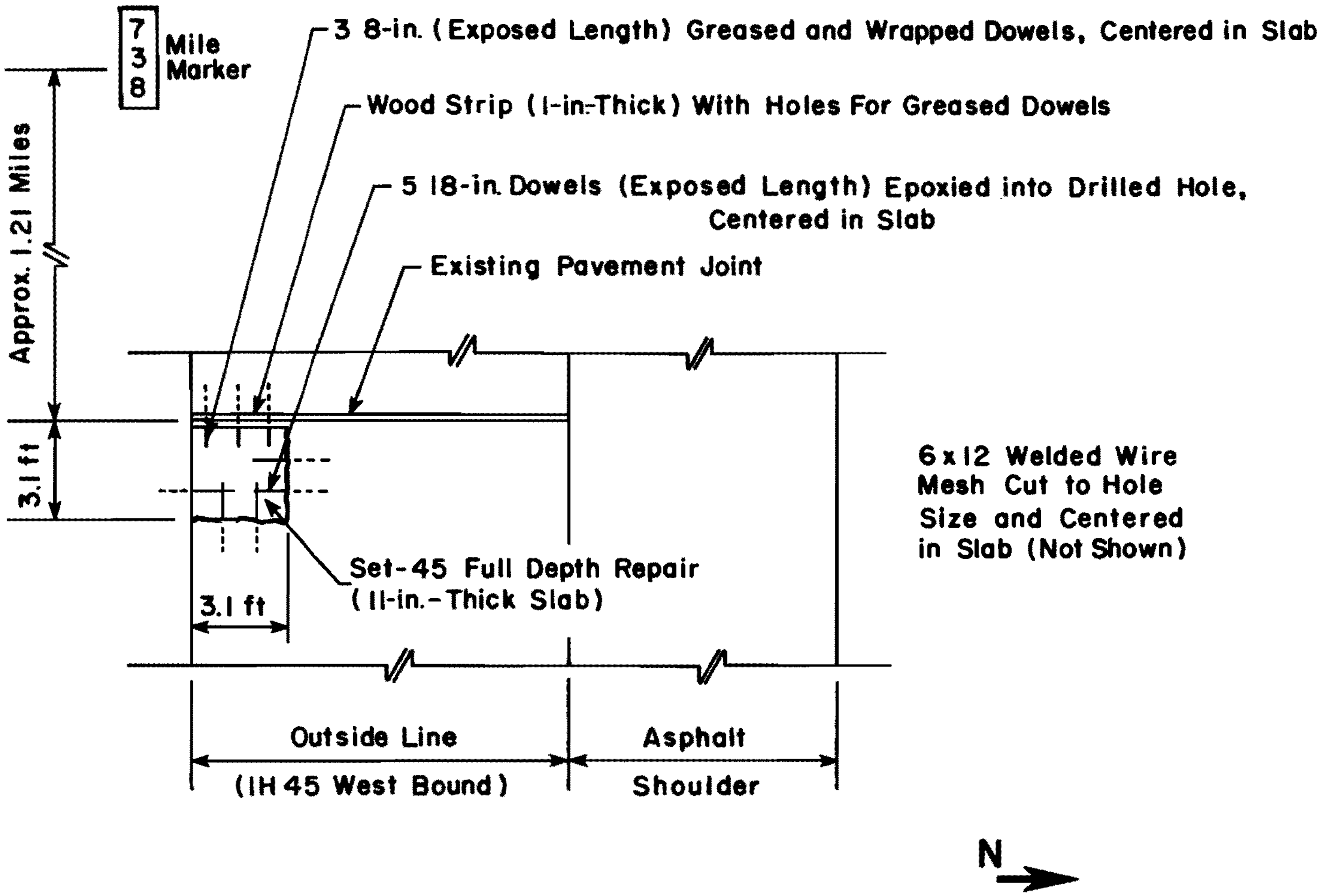

Fig. 7.26. Sketch of Set-45 Repair, Houston.

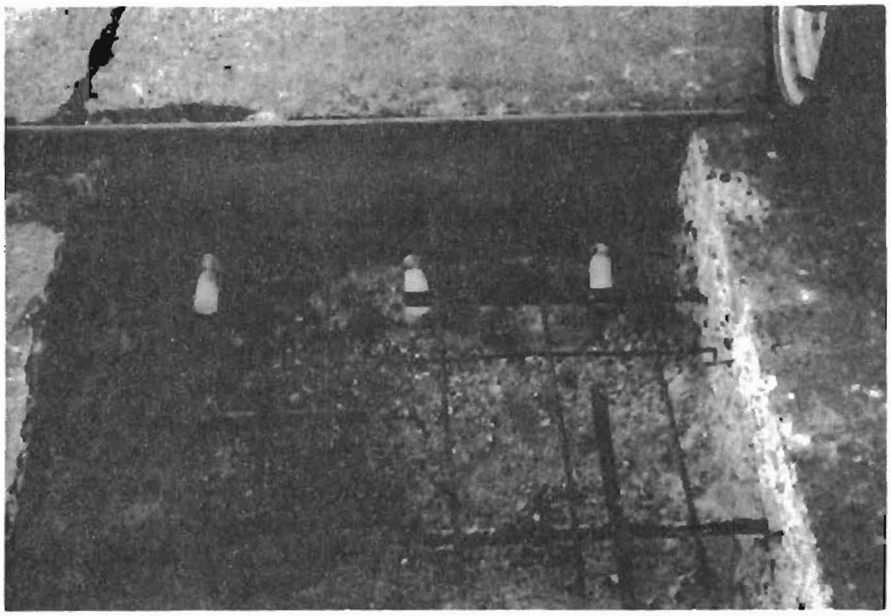

Fig. 7.27. Clean Set-45 Repair Hole, Houston.

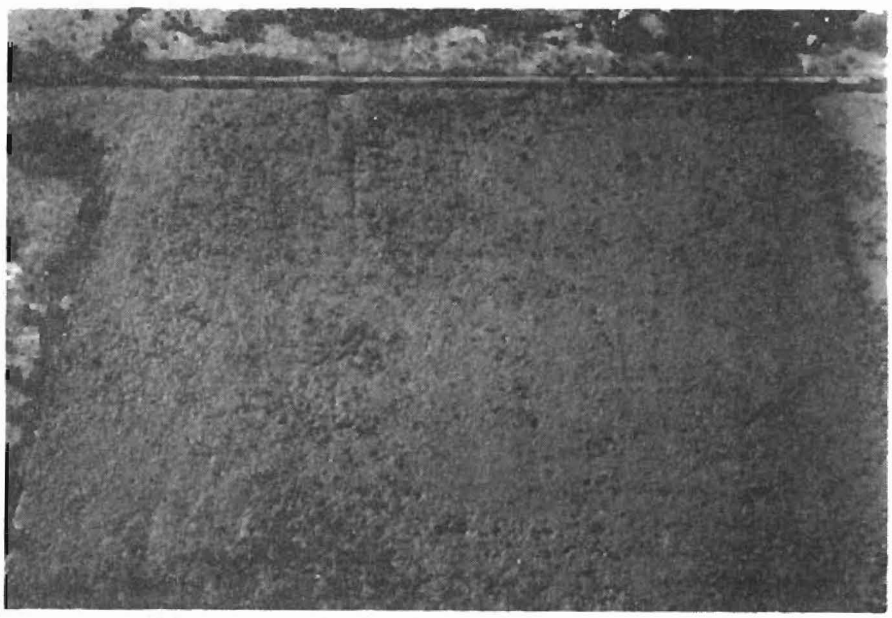

Fig. 7.28. Finished Set-45 Repair, Houston.

The repairs were opened to traffic at 5:30 PM. Both the Duracal repair and the GHP repair failed that night. The field specimen strengths shown in Table 7.1 are evidence that these materials did not set properly. The water used in all the mixes was murky and clearly not potable. Contaminated water may be the reason for the low strengths and resulting failures. The strengths of the Set-45 field specimens were very close to the 24-hr. laboratory strengths shown in Fig. 5.2.

CHAPTER 8
MATERIAL COSTS

An evaluation of all the factors that influence the cost-effectiveness of a highway repair is beyond the scope of this report. Some of these factors were mentioned in Chapter 1. The actual costs of the repair materials may or may not be a significant portion of the total repair costs. However, as a basis for further evaluating the repair materials, the cost per cubic yard of each of the aggregate mixes (Table 2.2) is presented in Table 8.1. The costs do not include shipping costs or taxes and were current as of January 1984. The Set-45 mix unit cost is 4.1 times that of the Duracal mix. The GHP mix is 2.6 times more costly than the Duracal mix.

Table 8.1. Cost of Aggregate Mixes.

Material	1-Bag Mix Quantities		Unit Costs		Cost/ 1-Bag Mix
Duracal	50-lb (222-N) Duracal bag	x	$ 9.80/bag	=	$ 9.80[a]
	50-lb (222-N) Fine Aggregate	x	4.75/2000-lb (8896-N)	=	0.12[d]
	50-lb (222-N) Coarse Aggregate	x	6.00/2000-lb (8896-N)	=	0.15[d]
	14.6-lb (65-N) Water (1.75-gal)	x	0.0	=	0.0
	164.6-lb				$10.07

Duracal Aggregate Mix Cost/yd³ $= \frac{\$10.07}{164.6\text{-lb}} \times \frac{145\text{-lb}}{ft^3} \times \frac{27\text{-}ft^3}{yd^3} = \$239.51/yd^3$

Material	1-Bag Mix Quantities		Unit Costs		Cost/ 1-Bag Mix
Set-45	50-lb (222-N) Set-45 bag	x	$ 21.00/bag	=	$21.00[b]
	30-lb (133-N) Coarse Aggregate	x	6.00/2000-lb (8896-N)	=	0.09
	3.7-lb (16-N) Water (3-1/2-pints)	x	0.0	=	0.0
					$21.09

Set-45 Aggregate Mix Cost/yd³ $= \frac{\$21.09}{83.7\text{-lb}} \times \frac{145\text{-lb}}{ft^3} \times \frac{27\text{-}ft^3}{yd^3} = \$986.47/yd^3$

Material	1-Bag Mix Quantities		Unit Costs		Cost/ 1-Bag Mix
GHP	55-lb (245-N) GHP bag	x	$ 14.85/bag	=	$14.85[c]
	30-lb (133-N) Coarse Aggregate	x	6.00/2000-lb (8896-N)		0.09
	8.3-lb (37-N) Water (1.0-gal)	x	0.0		0.0
					$14.94

GHP Aggregate Mix Cost/yd³ $= \frac{\$14.94}{93.3\text{-lb}} \times \frac{145\text{-lb}}{ft^3} \times \frac{27\text{-}ft^3}{yd^3} = \$626.90/yd^3$

[a]Duracal cost quoted by David Hawn Lumber Co., Dallas
[b]Set-45 cost quoted by Rufus A. Walker, San Antonio
[c]GHP cost quoted by Shepler Quipment Co., Houston
[d]Aggregate costs quoted by Capitol Aggregates, Austin

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary

The use of rapid-setting materials for the repair of concrete roadways considerably reduces the lane down-time as compared to the use of conventional PCC. There are many available rapid-setting materials; however, they vary greatly in workability, durability, and cost. An effective method for evaluating these materials is needed to assist highway maintenance personnel in selecting cost-effective repair materials.

The objective of Research Study 311, Evaluation of Fast-Setting Repair Materials, was to select candidate materials and evaluate these materials in both the laboratory and the field. References 1 and 2 present the results of initial Study 311 work. These references summarize the responses to a survey sent to the State Department of Highways and Public Transportation districts in Texas and nine other states. Four candidate materials were selected for evaluation, based on the survey results and D-9 testing. These materials were Duracal, Set-45, GHP, and Neco-crete. Beer also presents the results of initial laboratory tests, run in a 72°F (22°C) environment.

This report presents the results of further laboratory testing and field repairs in four districts.

Laboratory results presented herein include the following (1) compressive strengths, flexural strengths, and Gilmore Needle set times of materials mixed and air-cured at 40, 72 and 110°F (4, 22 and 43°C), (2) change in length of air-cured specimens, (3) resistance of specimens to freeze-thaw cycles, and (4) coefficients of thermal expansion. Tests were run according to ASTM standards, although slight modifications were required.

Tests were also run to determine how the material compressive strengths are affected by variations in mix proportions. The coarse aggregate quantity was varied in one series of tests while the water quantity was varied in another series. A comparison of mixes using both siliceous and crushed limestone aggregates is also given.

The uniformity of the packaged repair materials from bag to bag was evaluated by testing mortar compression cubes cast from each bag. A statistical analysis of these results is reported herein.

Limited testing was also done on Horn 240 and Hot Weather Set-45. Testing of Horn 240, a material similar to Neco-crete, was begun when testing of Neco-crete was discontinued. Hot Weather Set-45 is similar to Set-45 but is designed for use at higher temperatures.

Field repairs using Duracal, Set-45, GHP, and Hot Weather Set-45 were made in the Waco, Amarillo, Dallas, and Houston districts. Repair materials were mixed using both drum type and mortar type mixers. The cost, mixability, and workability of the repair mixes are summarized. Repair mixes containing fibers were placed in Dallas. The durability of the repairs will be reported by Study 311 personnel in the future.

9.2 Conclusions

Upon reviewing Study 311 laboratory and field work to date, the following conclusions can be made:

(1) The magnesia-phosphates, Set-45, Neco-crete, Horn 240, and Set-45, achieved the highest 3-hr. compressive strengths at 40, 72 and 110°F (4, 22 and 43°C).

(2) The 24-hr. compressive strengths of all the materials exceeded 3000 psi (20.7 MPa) at 72 and 110°F (22 and 43°C).

(3) In a 40°F (4°C) environment, the compressive strengths of the magnesia-phosphates will exceed 3500 psi (24.1 MPa) in 3-hrs. if the mix ingredients are warmed to 72°F (22°C).

(4) In a 110°F (43°C) environment, the magnesia-phosphates, Set-45 and Neco-crete, achieve initial set in 3 minutes. This does not allow adequate working time. The Duracal, GHP, and Hot Weather Set-45 initial set times were 19, 10, and 9 minutes, respectively.

(5) The Duracal aggregate mix specimens exhibited a 0.018-percent expansion after 200 days. Set-45, Neco-crete, and GHP specimens displayed shrinkages of 0.026, 0.050, and 0.16 percent, respectively.

(6) Duracal and GHP were significantly more resistant to freeze-thaw cycles than the magnesia-phosphates. The relative dynamic modulus of Neco-crete, Set-45, Duracal, and GHP, fell below 60 percent at 50, 86, 170, and 254 cycles, respectively.

(7) The compressive strength of the Duracal, Set-45, and GHP mixes was not greatly increased by reducing the coarse aggregate quantity. Thus, considering the high cost of the rapid setting materials, it is advisable that aggregate mixes, rather than mortar mixes, be used for all full depth repairs.

(8) The coefficients of thermal expansion ranged from 6.9×10^{-6} to 7.6×10^{-6} in./in./°F (1.2×10^{-5} to 1.4×10^{-5} in./in./°C) for the aggregate mix specimens and from 8.7×10^{-6} to 9.7×10^{-6} in./in./°F (1.6×10^{-5} to 1.7×10^{-5} mm/mm/°C) for the mortar specimens. These values are within the normal range of values for PCC.

(9) Compression cubes were made from material from each bag. The coefficients of variation in strengths, from bag to bag, were 11.8, 22.7, and 5.5 percent for the 24-hr. Duracal, Set-45, and GHP specimens, respectively.

(10) The Duracal field mixes were easily mixed and very workable using mix proportions recommended by its manufacturer. However, the water quantities of the Set-45 and GHP field mixes had to be increased by a minimum of 15 and 25 percent, respectively. As compared to the Set-45 and GHP laboratory results, these field mixes will have lower strengths, less durability, and greater

shrinkage. This should be considered in evaluating the laboratory results presented herein.

Prior to starting laboratory testing on new materials, it is suggested that a field type mixer be used to mix a full batch using proportions recommended by the material manufacturer. If the liquid quantity must be increased to attain mixability or workability, it is advisable that the modified mix proportions be used in all laboratory testing.

(11) The mortar type mixer is significantly more desirable for use in mixing the rapid setting materials than the drum type mixer. Stiff mixes can be more readily mixed and discharged using the mortar mixer.

(12) The magnesia-phosphates differ greatly from PCC. The final set occurs only 1 or 2 minutes after initial set. Therefore, there is little time to complete finishing once the materials begin to stiffen. Further attempts to finish at this time will only destroy surface integrity.

(13) The Duracal aggregate mix costs $240/yd^3$. The GHP aggregate mix cost of $627/yd^3$ is 2.6 times the cost of the Duracal mix. The Set-45 aggregate mix cost of $986/yd^3$ is 4.1 times the cost of the Duracal mix.

(14) Beer recommended that the cylinder compression test, flexural test, Gilmore Needle set time test, and shear bond test be used to evaluate the rapid setting materials. The results presented in this thesis indicate that the freeze-thaw resistance

test and the length change test (air-cured) are also useful. Since the coefficients of thermal expansion of the rapid setting materials were all similar to PCC, this test appears necessary only if the chemical composition of a material is greatly different from these tested.

9.3 Recommendations

Although Study 311 laboratory and field work is essentially complete, it is recommended that work be continued in the following areas.

(1) It appears that the magnesia-phosphates can be used at temperatures below freezing if the materials are warm. Field repairs in low temperature environments should be made using materials stored in a warm vehicle.

(2) Field repairs in high temperature environments are needed.

(3) Further field and laboratory testing using mixes containing fibers is needed.

(4) Field repairs made to date have required less than 10-ft^3 (0.28 m^3) of material. The use of a ready-mix truck or a concrete mobile for making larger repairs should be investigated.

(5) A thorough cost evaluation of all repair phases is needed to determine how important material costs are.

REFERENCES

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