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EVALUATION OF MATERIALS FOR POST-ATTACK PAVEMENT REPAIR.(U)
SEP 78 C L RONE, A L SULLIVAN

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Evaluation of Materials for Post-Attack Pavement Repair

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
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P.O. BOX 631, VICKSBURG, MISS. 39180

SEPTEMBER 1978

FINAL REPORT FOR PERIOD SEPTEMBER 1976-DECEMBER 1977

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CIVIL AND ENVIRONMENTAL ENGINEERING DEVELOPMENT OFFICE

(AIR FORCE SYSTEMS COMMAND)
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This study was conducted to evaluate the performance of candidate materials used to repair small damaged areas in pavement when subjected to traffic by an F4C aircraft loading. The study consisted of preparing simulated damaged areas in portland cement concrete pavement and flexible pavement and repairing the areas with selected materials. The evaluation was based on the performance of the repaired areas when subjected to accelerated traffic with a loading equivalent to one main gear of the F4C aircraft.

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PREFACE

This report was prepared by the US Army Engineer Waterways Experiment Station (WES) under Project Order 7T-61, Job Order Number 21042B23, for Detachment 1 (CEEDO) ADTC, Tyndall AFB, Florida. The investigation was conducted between September 1976 and December 1977 by personnel of the Geotechnical Laboratory.

This investigation was conducted under the supervision of Messrs J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, of the Geotechnical Laboratory, and Mr Ronald L. Hutchinson, Pavement Program Manager. The investigation was conducted by Messrs C. L. Rone and A. L. Sullivan, III, under the supervision of Mr A. H. Joseph, Chief, Pavement Investigations Division, and Mr C. D. Burns, Chief, Experimental Pavement Research Branch. This report was prepared by Mr Rone. Capt Raymond S. Rollings was the project officer for CEEDO.

Director of WES during the investigation and preparation of this report was Col J. L. Cannon, CE. Technical Director was Mr F. R. Brown.

Various proprietary products are discussed in this report and are capitalized for identification. This report evaluates these products under very severe conditions for which they were not designed. No conclusions should be drawn about the performance of the products for normal applications and conditions as specified by the manufacturer.

This report has been reviewed by the information office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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TABLE OF CONTENTS

	Page
SECTION I INTRODUCTION	1
Background	1
Objectives	1
Test Areas	2
Materials Tested	2
Application of Traffic	4
SECTION II PLACING AND PERFORMANCE UNDER TRAFFIC	6
Darex 240	6
Zor-X	6
Hathane 1600A	7
Poly-Products Corporation's Epoxy Resin	8
Cold Mix No. 1	8
Polyester Resin	9
Fondu Concrete	10
Amalgapave	10
Cold Mix No. 2	11
Future Patch	12
Sylvax	12
Field-Mixed Amalgapave	13
Field-Mixed Cold Mix	13
Crushed Limestone and Portland Cement	13
Asphalt Macadam	14
Asphalt-Saturated Polyester Fabric	15
SECTION III CONCLUSION	16

LIST OF FIGURES

Figure	Title	Page
1	Typical 5-Foot-Diameter Area in Portland Cement Concrete Pavement	18
2	Typical 2-Foot-Diameter Area in Portland Cement Concrete Pavement	19
3	Typical 5-Foot-Diameter Area in Flexible Pavement	20
4	Typical 2-Foot-Diameter Area in Flexible Pavement	21
5	Aggregate Gradation for Cold Mixes	22
6	Gradation of Field-Mixed Amalgapave and Field-Mixed Cold Mix	23
7	Gradation of Crushed Limestone Base Course	24
8	Test Vehicle	25
9	Compacting Crushed Limestone in 5-Foot-Diameter Area for Darex 240 Repair	26
10	Surface of Compacted Crushed Limestone Before Placing Darex 240	27
11	Mixing and Placing Darex 240	28
12	Finished Surface of Darex 240	29
13	Surface of Darex 240 in 2-Foot-Diameter Area After 20 Coverages	30
14	Surface of Darex 240 in 5-Foot-Diameter Area After 20 Coverages	31
15	Compacting Crushed Limestone Base Course for Zor-X Repair	32
16	Placing Zor-X	33
17	Compacting Zor-X	34
18	Compacting Zor-X with Pneumatic-Tired Roller	35
19	Surface of Zor-X in 5-Foot-Diameter Area After 10 Coverages	36
20	Surface of Zor-X in 2-Foot-Diameter Area After 10 Coverages	37

LIST OF FIGURES (Continued)

Figure	Title	Page
21	Screeding Washed Gravel Fill Material Before Placing Hathane 1600A	38
22	Hand-Operated Electric Mixer Used to Mix Hathane 1600A	39
23	Pouring Hathane 1600A Over Open-Graded Gravel	40
24	Hathane 1600A During Curing	41
25	Failure Developed on First Pass of Load Wheel in Hathane 1600A	42
26	Screeding Open-Graded Gravel Fill for Poly-Products Epoxy Resin Repair	43
27	Mixing Poly-Products Epoxy Resin	44
28	Pouring Poly-Products Epoxy Resin Over Open-Graded Gravel	45
29	Surface of Epoxy Resin Repair After 10 Coverages	46
30	Compacting Crushed Limestone Base Course for Cold Mix No. 1 Repair	47
31	Compacting Cold Mix No. 1 in 5-Foot-Diameter Area	48
32	Repairing Cold Mix No. 1 in 5-Foot-Diameter Area After Two Coverages	49
33	Surface of Cold Mix No. 1 in 5-Foot-Diameter Area After Total of Four Coverages	50
34	Screeding Gravel Fill for Polyester Resin Repair	51
35	Placing Fiberglass Mat in 8-Foot-Diameter Area for Polyester Repair	52
36	Screeding Gravel Fill in 8-Foot-Diameter Area for Polyester Repair	53
37	Mixing Polyester Resin	54
38	Pouring Polyester Resin Over Gravel Fill	55
39	Surface of Polyester Resin in 2-Foot- and 5-Foot-Diameter Areas After 10 Coverages	56
40	Surface of Polyester Resin in 8-Foot-Diameter Area After 10 Coverages	57

LIST OF FIGURES (Continued)

Figure	Title	Page
41	Mixing and Placing Fondu Concrete	58
42	Finished Surface of Fondu Concrete	59
43	Surface of Fondu Concrete After 20 Coverages	60
44	Placing Amalgapave	61
45	Compacting Amalgapave with Mechanical Tamper	62
46	Finish Rolling Amalgapave with 30-Ton Pneumatic-Tired Roller with 90 psi Tire Pressure	63
47	Surface of Amalgapave After 20 Coverages	64
48	Finish Rolling Cold Mix No. 2 with 30-Ton Pneumatic-Tired Roller with 90 psi Tire Pressure	65
49	Condition of Cold Mix No. 2 After 10 Coverages	66
50	Placing Future Patch in 5-Foot-Diameter Area	67
51	Compacting Future Patch with Mechanical Tamper	68
52	Condition of Future Patch After 20 Coverages	69
53	Placing Sylvax in 5-Foot-Diameter Area	70
54	Condition of Sylvax After 10 Coverages	71
55	Compacting Field-Mixed Amalgapave with Mechanical Tamper	72
56	Condition of Field-Mixed Amalgapave After 10 Coverages	73
57	Compacting Field-Mixed Cold Mix with Mechanical Tamper	74
58	Condition of Field-Mixed Cold Mix After 10 Coverages	75
59	Spreading Portland Cement Over Crushed Limestone	76
60	Adding Water to Dry-Mixed Crushed Limestone and Portland Cement	77
61	Compacting Mixture of Crushed Limestone and Portland Cement with Mechanical Tamper	78
62	Condition of Crushed Limestone and Portland Cement Mixture After 10 Coverages	79
63	Spraying Asphalt Cement on Base Course Prior to Placing Macadam Repair	80

LIST OF FIGURES (Concluded)

Figure	Title	Page
64	Gradation of Crushed Limestone Used in Macadam Repair	81
65	Pouring Hot Asphalt Cement over Coarse Aggregate in Asphalt Macadam Repair	82
66	Heating Asphalt Macadam Repair with Propane Torch	83
67	Finished Surface of Asphalt Macadam Repair	84
68	Condition of Asphalt Macadam After Eight Coverages	85
69	Condition of Asphalt Macadam After Being Repaired and Application of a Total of 18 Coverages	86
70	Finished Surface of Base Course in Asphalt-Saturated Felt Repair Area	87
71	Rolling Asphalt-Saturated Felt with 30-Ton Pneumatic-Tired Roller with 90 psi Tire Pressure	88
72	Finished Surface of Asphalt-Saturated Felt Repair Area	89

LIST OF TABLES

Table	Title	Page
1	Summary of Tests Conducted	90

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
mils	0.0254	millimetres
inches	2.54	centimetres
feet	0.3048	metres
square yards	0.8361273	square metres
gallons (U. S. liquid)	3.785412	cubic decimetres
pounds	0.45359237	kilograms
tons	0.90718474	metric tons
pounds per square inch	0.6894757	newtons per square centimetre
pounds per cubic foot	16.018489	kilograms per cubic metre
Fahreheit degrees	5/9	Celsius or Kelvin degrees*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

SECTION I
INTRODUCTION

BACKGROUND

The practice of disrupting aircraft operation by damaging essential operating facilities with mortar or artillery fire or aircraft-delivered munitions is a normal military practice. Rapid repair of damaged areas in pavement is essential to restore the capability to support aircraft operation as quickly as possible. The need, therefore, exists to have available established means and materials for rapidly repairing damaged areas in pavement. These must be usable in all environmental conditions and should require a minimum amount of special equipment. Materials must have long storage life without environmental control. The relatively small construction volumes involved in repair of damaged areas resulting from these types of attack place primary emphasis on materials, their handling, and behavior.

A review of commercially-available materials having characteristics suitable for rapid repair was conducted by the Air Force Civil Engineering Center, Tyndall AFB, Florida, and candidate materials were selected for field testing under this study.

OBJECTIVES

The objective of this study was to evaluate performance of selected candidate materials by repairing damaged areas in rigid and flexible pavement and applying traffic to the repaired areas. Evaluation was based on the following:

1. Time required to prepare the material for placing.
2. Time required to place material.
3. Equipment required for placing material.
4. Time required for curing before traffic could be applied.
5. Performance of material when subjected to a wheel load of 25,000 pounds[1] at a tire pressure of 250 psi.

[1] A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented in front matter of this report.

6. Number of passes in 10-foot-wide traffic lane before failure if less than 10 coverages (96 passes in 10-foot-wide traffic lane).

7. Maintenance required to prolong life of patched areas if maintenance could be performed in less than 3 minutes.

8. Environmental factors affecting placing and curing.

This report contains a description of the materials tested, equipment and time required for making repair, environmental conditions effecting repair, and evaluation of performance of each material.

TEST AREAS

Simulated damaged areas were prepared in a 15-inch-thick portland cement concrete pavement and in a flexible pavement consisting of 4 inches of asphaltic concrete and 25 inches of cement-stabilized sandy gravel base course. Figures 1 to 4 show typical simulated damaged areas. Tests were conducted in cone-shaped holes 5 feet in diameter and 1 foot deep and 2 feet in diameter and 6 inches deep, and one material was tested in a cone-shaped hole 8 feet in diameter and 2.5 feet deep.

MATERIALS TESTED

DAREX 240

Darex 240 is a fast-setting magnesium phosphate cement. A magnesia aggregate is mixed with a complex phosphate solution to initiate curing. The chemical cement is prepackaged in 50-pound bags in a dry state and is mixed with 1 gallon of phosphate solution per 50 pounds of dry material at the time of placing.

ZOR-X

Zor-X is a premixed and packaged cold mix using well-graded fine aggregate with liquid cold tar and emulsified asphalt as binders. The material is packaged in 55-gallon drums and can be placed from drums used for packaging.

HATHANE 1600A

This is a two-component extended urethane material. At the time of placing, equal amounts of the two components are used in the mixture.

POLY-PRODUCTS CORPORATION'S EPOXY RESIN

This is a mixture of two resins and one hardener. The mixture consisted of 40 percent resin No. 20-100, 10 percent resin No. 22-135, and 50 percent hardener No. 21-116. Resins were preblended and hardener mixed with preblended resins at the time of placing.

COLD MIX NO. 1

Cold-mix asphaltic concrete No. 1 was obtained from a local supplier. A 1/2-inch maximum-size crushed gravel and natural sand were used as aggregate. Extraction tests showed the material to have a bitumen content of 4.0 percent and an aggregate gradation as shown in Figure 5.

POLYESTER RESIN

This material is a liquid polyester resin that hardens when mixed with a catalyst. In the 2-foot- and 5-foot-diameter holes, a mixture ratio of 35 pounds of resin to 0.7 pounds of catalyst was used. In the 8-foot-diameter hole, a mixture ratio of 35 pounds of resin to 0.35 pounds of catalyst was used. Material was mixed immediately before placing.

FONDU CONCRETE

The Fondu concrete consisted of a calcium-aluminate cement; coarse aggregate was uncrushed chert gravel; and fine aggregate was natural sand. Lithium carbonate was used as an accelerator. Mixture proportions per cubic yard were as follows:

Cement	752 pounds
Sand	1400 pounds
Gravel	1600 pounds
Lithium carbonate	240 grams
Water	312 pounds

AMALGAPAVE

Amalgapave is a premixed bituminous material with 1.0 percent diazite used as an additive and is similar in appearance to a conventional cold-mix asphaltic concrete.

COLD MIX NO. 2

Cold mix No. 2 was obtained from a second supplier, and the mixture consisted of a 1/2-inch maximum-size crushed gravel, natural sand, and 5.5 percent bitumen. Aggregate gradation is shown in Figure 5.

FUTURE PATCH

Future Patch is a premixed bituminous-type cold mix.

SYLVAX

Sylvax is a premixed bituminous cold-mix type material.

FIELD-MIXED AMALGAPAVE

Field-mixed Amalgapave was prepared by mixing crushed limestone coarse aggregate, crushed limestone fine aggregate, filler material, 1.5 percent diazite, and 5.5 percent SC-250 bitumen in the field with a front-end loader and a rotary mixer. Gradation of the aggregate blend is shown in Figure 6.

FIELD-MIXED COLD MIX

Field-mixed cold mix was prepared by the same procedure and using the same material as used in the field-mixed Amalgapave except that the diazite additive was not used in the mixture. Gradation of the aggregate blend is shown in Figure 6.

LIMESTONE AND PORTLAND CEMENT

This material was prepared by field mixing, with a front-end loader, a crushed limestone base course having a gradation as shown in Figure 7 with 5.5 bags/cu yd of type I portland cement at a water content determined as optimum for the crushed limestone before cement was added.

ASPHALT MACADAM

Asphalt Macadam was constructed in place in repair areas. A 1-1/2-inch maximum-size crushed limestone was used as coarse aggregate, crushed limestone fines were used as the key aggregate, and a 100 penetration grade asphalt was used for binder.

ASPHALT-SATURATED POLYESTER FABRIC

The asphalt-saturated polyester fabric used as a surfacing membrane over compacted limestone consisted of a 12-oz/sq-yd polyester fabric that had been saturated from one side with a heated 100 penetration grade asphalt cement.

APPLICATION OF TRAFFIC

Traffic was applied to repaired areas using the vehicle shown in Figure 8. To apply the test traffic, the vehicle was driven backward and forward along the same path, then shifted laterally a distance equal to one tire width, and the process repeated. Traffic was applied beginning at least one tire width outside the edge of repaired areas and proceeding across repaired area to at least one tire width beyond the repaired area.

SECTION II

PLACING AND PERFORMANCE UNDER TRAFFIC

The time required for placing material, curing time before traffic could be applied, size of crew, type of equipment used for placing, number of passes of traffic applied, condition of repair after traffic, maintenance performed during traffic, and effects of environment on material are shown in Table 1. During placing and application of traffic, visual behavior of materials was noted, and photographs and motion pictures were taken. Method of placing and performance of each of the materials are discussed in the following paragraphs.

DAREX 240

Darex 240 was used to repair 5-foot- and 2-foot-diameter areas in portland cement concrete pavement. The 5-foot-diameter area was filled to within 2 inches of the surface with compacted crushed limestone having a gradation and Atterberg limits as shown in Figure 7. The crushed limestone was placed in the 5-foot-diameter area in two lifts, and each lift compacted with an impact-type mechanical tamper as shown in Figure 9. Water content of the crushed limestone when placed and compacted was about optimum (4.7 percent). After compaction, crushed limestone was removed from edges of portland cement concrete and the surface shaped to a depth of 2 inches below the surface of surrounding portland cement concrete as shown in Figure 10 before Darex 240 was placed. Base course was not used in the 2-foot-diameter repair area. Darex 240 was mixed in the 2-cubic-foot mixer shown in Figure 11, poured into the area being repaired, and screeded (see Figure 11) flush with the adjacent surface. Darex 240 was used for the full depth of the 2-foot-diameter repair area and screeded off flush with adjacent surface. Figure 12 shows the finished surface of material. During curing, temperatures of 120°F and 110°F were recorded in the 2- and 5-foot repair areas, respectively.

Traffic was applied to the repaired areas 42 minutes after placing. No damage was noted after 20 coverages (192 passes in 10-foot-wide traffic lane) as shown in Figures 13 and 14 for 2- and 5-foot repair area, respectively.

ZOR-X

Zor-X was used to repair 5-foot- and 2-foot-diameter areas in flexible pavement. The 5-foot-diameter area was filled to within 2 inches of the surface with compacted crushed limestone with a gradation as shown in Figure 7.

The crushed limestone was placed and compacted in two lifts with a mechanical impact-type compactor as shown in Figure 15. A base course was not used in the 2-foot-diameter area. Water content of the crushed limestone when placed and compacted was about optimum (4.7 percent). Zor-X was placed directly on the base course, as shown in Figure 16, because literature furnished by the manufacturer stated that a prime or tack coat was not necessary. After placing, Zor-X was compacted with a mechanical tamper (Figure 17) and finished rolled with a 30-ton pneumatic-tired roller (Figure 18) having a tire pressure of 90 psi.

Traffic was applied to the repaired area immediately after material was placed and compacted. During the first 10 coverages (96 passes), the surfacing material moved under the load wheel, and 1-inch ruts, including upheaval at the edge of the tire, developed in the 5-foot-diameter repair area as shown in Figure 19. Uniform deformation of 1 inch occurred in the 2-foot-diameter repaired area as shown in Figure 20. After 10 coverages of traffic, both areas were repaired by raking and adding Zor-X to the surface and compacting with a mechanical tamper. Ten additional coverages of traffic were applied after repair, and the 2-foot-diameter area performed satisfactorily, but material in the 5-foot-diameter area continued to move under the load wheel and worked out of the hole at the edges of the repaired area.

HATHANE 1600A

Hathane 1600A was used to repair 5-foot- and 2-foot-diameter areas in flexible pavement. Areas to be repaired were filled with an open-graded washed gravel having a maximum size of 1 inch. Gravel was placed loose in the holes and screeded level with the surrounding surface as shown in Figure 21. The gravel used to fill the holes was damp on the surface but did not contain free water.

The two components of Hathane 1600A were mixed 15 seconds with a hand-operated electric mixer as shown in Figure 22 immediately before placing. The material was poured over the open-graded gravel (see Figure 23). The material penetrated the full depth of the gravel. During curing, the material foamed and swelled approximately 6 inches above the surrounding area (see Figure 24). This foaming was possibly caused by the moisture on the surface of the gravel.

Although the material had swelled above the pavement surface enough to be unsatisfactory for aircraft operation, traffic was applied to the repaired areas 34 minutes after the last batch of Hathane 1600A had been poured over the gravel. The material would not support the load wheel and failed on the first pass. The failure developed by the load wheel is shown in Figure 25. The failed area was repaired by shaping the areas with hand tools and compacting with a mechanical tamper. After 30 minutes additional time, the material would support the load wheel, but deformation of approximately 3 inches occurred in the 5-foot-diameter area as the load wheel moved across.

POLY-PRODUCTS CORPORATION'S EPOXY RESIN

This material was used to repair 5-foot- and 2-foot-diameter areas in flexible pavement. Both areas were filled with 3/4-inch maximum-size washed gravel. The surface dry gravel was placed loose in the holes and screeded level with the surrounding pavement surface (see Figure 26). Each batch of epoxy resin was mixed with a hand-operated mechanical mixer for 30 seconds immediately before placing the material over the loose gravel in the repair areas. Figure 27 shows mixing of the epoxy resin, and Figure 28 shows pouring epoxy resin over the open-graded gravel in the 5-foot-diameter repair area. The epoxy resin penetrated the full depth of the open-graded gravel, but voids in the gravel were not completely filled. The purpose of the epoxy resin was to bond the open-graded gravel together at points of contact.

The epoxy resin was allowed to cure for 30 minutes before traffic was applied. After 10 coverages of traffic, the only detrimental effect noted was a very small amount of gravel at the surface of the repair had been broken loose. Figure 29 shows the surface of the 5-foot-diameter area after 10 coverages of traffic. An additional 10 coverages of traffic were applied with no distress other than additional gravel breaking loose on the surface.

COLD MIX NO. 1

Cold mix No. 1 was used to repair 5-foot- and 2-foot-diameter areas in flexible pavement. The 5-foot-diameter repair area was filled to within 2 inches of the surface with crushed limestone having a gradation as shown in Figure 7. The crushed limestone was placed in two lifts and compacted with a mechanical tamper (see Figure 30). Base course was not used in the 2-foot-diameter repair area. Water content of the crushed limestone when placed and compacted was about optimum. The cold-mix asphalt was placed directly on the base course in the 5-foot-diameter area and compacted in one lift with a mechanical tamper as shown in Figure 31. Cold mix was placed in the 2-foot-diameter area in two lifts, and each lift compacted with the mechanical tamper.

Traffic was applied immediately after cold mix was placed and compacted. The cold mix rutted under each pass of the load wheel; and after two coverages, the 5-foot-diameter area was repaired by leveling and placing material that had worked out of the area back in the test area (see Figure 32) and compacting with the mechanical tamper. After two more coverages, ruts of approximately 2 inches deep had developed in the 5-foot-diameter area as shown in Figure 33, but the 2-foot-diameter area was in fair condition. Traffic was terminated after four coverages due to rutting in the 5-foot-diameter area. An examination of the base course showed no signs of failure in the crushed limestone base course.

POLYESTER RESIN

Polyester resin was used to repair 2-foot-, 5-foot-, and 8-foot-diameter areas in flexible pavement. The 2-foot- and 5-foot-diameter areas were filled with loose washed gravel that had been screened past the 3/4-inch screen and retained on the 1/2-inch screen. The gravel was screeded off level with the surrounding surface as shown in Figure 34. The 8-foot-diameter area was filled with the same size gravel up to within 6 inches of the surface, then a fiberglass mat was placed on the gravel as shown in Figure 35. After the fiberglass mat was placed, the hole was filled with gravel and screeded level with surrounding pavement surface (see Figure 36). Polyester resin was mixed in approximately 3-gallon batches with each batch mixed 30 seconds with a hand-operated mechanical mixer as shown in Figure 37. The mixed material was poured over the gravel as shown in Figure 38. The polyester resin penetrated the full depth of the open-graded gravel in the 2-foot- and 5-foot-diameter areas and completely filled the voids. The fiberglass mat was placed 6 inches below the surface of gravel in the 8-foot-diameter repair area to prohibit the polyester resin from penetrating deeper than 6 inches; therefore, only the voids in the top 6 inches of the repaired area were filled. During curing, the polyester resin developed shrinkage cracks at the surface and around the edge of repaired area.

Traffic was applied to the repaired areas 29 minutes after the last batch of polyester resin was placed. During traffic, polyester resin at the surface of the 2- and 5-foot areas cracked and loose particles were noted. The 2-foot-diameter area did not bond to the sides of adjacent pavement, and movement of the patch was noted during traffic. After 10 coverages, the 2-foot-diameter area was completely loose from adjacent pavement. Figure 39 shows the condition of the 2-foot- and 5-foot-diameter areas after 10 coverages. The 8-foot-diameter area did not have as thick a film of polyester resin without aggregate at the surface as the 2-foot- and 5-foot-diameter areas, and a less number of loose particles was noted after 10 coverages of traffic. Figure 40 shows the condition of the surface of the 8-foot-diameter area after 10 coverages.

FONDU CONCRETE

Fondu concrete was used to repair a 5-foot-diameter area in portland cement concrete. Aggregates for the Fondu concrete mixture were preweighed and placed in the skip of the mixer along with the Fondu cement. Water and lithium carbonate were added to the mixture as the aggregate and cement were injected into the mixer. The mixture was mixed approximately 2 minutes before being discharged directly into the repair area as shown in Figure 41. Hand shovels were used to level the material flush with the surrounding pavement. Figure 42 shows the finished surface. During placement, six 6- by 12-inch cylinders were taken and compressive strength determinations made at ages of 30 minutes, 1 hour, and 3 hours. Cylinders tested at 30 minutes could not be capped, and the actual compressive strength obtained was 40 psi, but it was estimated that a compressive strength of 100 to 110 psi would have been obtained had the cylinders been capped. Cylinders were capped for 1- and 3-hour tests, and the results were 300 and 3040 psi, respectively.

Traffic was applied to the repaired area 66 minutes after placing. Twenty coverages were applied with no sign of failure. The condition of the repaired area after 20 coverages is shown in Figure 43.

AMALGAPAVE

Amalgapave was used to repair 2-foot- and 5-foot-diam areas in flexible pavement. The 5-foot-diameter area was filled to within 1-1/2 inches of the surface with crushed limestone having a gradation as shown in Figure 7. Crushed limestone was placed in two lifts at approximately optimum water content, and each lift compacted with a mechanical tamper. A base course was not used in the 2-foot-diameter area. Amalgapave was placed directly from bags, spread, and lumps broken up with shovels as shown in Figure 44. Amalgapave was compacted with a mechanical tamper as shown in Figure 45. A 30-ton pneumatic-tired roller as shown in Figure 46 with a tire pressure of 90 psi was used to finish roll the repaired areas.

Traffic was applied to the repaired area immediately after finish rolling. After 10 coverages of traffic, a deformation of 3/4 inches was noted in the 5-foot-diameter area and 1 inch in the 2-foot-diameter area, but no signs of cracking noted in either area. Additional material was added to the 2-foot-diameter area, and another 10 coverages applied to both areas. After a total of 20 coverages, the area appeared in excellent condition with no signs of distress. The condition of the surface of the 5-foot-diameter area after 20 coverages is shown in Figure 47.

COLD MIX NO. 2

Cold mix No. 2 was used to repair 2-foot- and 5-foot-diameter areas in flexible pavement. The 5-foot-diameter area was filled with crushed limestone having a gradation as shown in Figure 7. The crushed limestone was placed in two lifts and compacted with a mechanical tamper. Base course was not used in the 2-foot-diameter repair area. Water content of the crushed limestone, when placed and compacted, was about optimum. The cold mix was placed directly on the base course in the 5-foot-diameter area and compacted in one lift with a mechanical tamper. Cold mix was placed in the 2-foot-diameter area in two lifts, and each lift compacted with the mechanical tamper. After compaction with the mechanical tamper, the repaired areas were finish rolled with a 30-ton pneumatic-tired roller with a tire pressure of 90 psi as shown in Figure 48.

Traffic was applied immediately after areas were repaired. The cold mix shoved and rutted under each pass of the load wheel; at four coverages ruts of 1 inch deep had developed, and the material was working out of the repaired areas. Ten coverages were applied with ruts 1 inch deep measured in each area. The condition of the 5-foot-diameter area after 10 coverages is shown in Figure 49.

FUTURE PATCH

Future Patch was used to repair 2-foot- and 5-foot-diameter areas in flexible pavement. The 5-foot-diameter area was filled to within 1 inch of the surface with crushed limestone having a gradation as shown in Figure 7. Crushed limestone was placed in two lifts at approximately optimum moisture content and compacted with a mechanical tamper. A base course was not used in the 2-foot-diameter area. Future Patch was placed directly into the repair areas from packaging drums as shown in Figure 50. The 5-foot-diameter area was compacted in one lift with a mechanical tamper as shown in Figure 51, and the 2-foot-diameter area was compacted in two lifts.

Traffic was applied immediately after compaction. Only slight movement of the material was noted under the load wheel. After 10 coverages of traffic, a deformation of 1/2 inch was measured in the 5-foot-diameter area and 1 inch in the 2-foot-diameter area. Ten additional coverages of traffic were applied to the areas without any maintenance being performed, and no signs of distress were observed. The condition of the repaired areas after 20 coverages is shown in Figure 52.

SYLVAX

Sylvax was used to repair 2-foot- and 5-foot-diameter areas in flexible pavement. The 5-foot-diameter area was filled to within 1 inch of the surface with crushed limestone having a gradation as shown in Figure 7. The crushed limestone was placed in two lifts, and each lift was compacted with a mechanical tamper. A base course was not used in the 2-foot-diameter area. Sylvax was placed directly from the packaging drum into the repair areas as shown in Figure 53. The 5-foot-diameter area was compacted in one lift with a mechanical tamper, and the 2-foot-diameter area was compacted in two lifts.

Traffic was applied immediately after compaction. The material moved under each pass of the load wheel with upheaval areas at the edge of the tire having a loose noncohesive texture. During trafficking, the material worked out of the repaired areas; and after 10 coverages, rut depths, including upheaval, measured 1-1/2 inches deep. Figure 54 shows the condition of the 5-foot-diameter area after 10 coverages.

FIELD-MIXED AMALGAPAVE

Field-mixed Amalgapave was used to repair 2-foot- and 5-foot-diameter areas in flexible pavement. A compacted crushed limestone base course was placed to within 1 inch of the pavement surface in the 5-foot-diameter area by the same procedures as in other flexible pavement repairs. The field-mixed Amalgapave was placed and compacted in one lift in the 5-foot-diameter area and in two lifts in the 2-foot-diameter area. Compaction was accomplished with a mechanical tamper as shown in Figure 55.

Traffic was applied to the areas immediately after compaction. The material moved under each pass of the load wheel; and after 10 coverages, ruts 1-1/2 inches deep, including upheaval at the edge of the tire were measured. Although the material had lateral displacement under the load wheel, it maintained a cohesive texture. The condition of the 5-foot-diameter area after 10 coverages of traffic is shown in Figure 56.

FIELD-MIXED COLD MIX

Field-mixed cold mix was used to repair 2-foot- and 5-foot-diameter areas in flexible pavement. Crushed limestone base course was placed and compacted in the 5-foot-diameter area to within 1 inch of the pavement surface. Methods of placing and compacting base course were the same as used for other flexible pavement repairs. The field-mixed cold mix was placed and compacted in one lift in the 5-foot-diameter area and in two lifts in the 2-foot-diameter area. Compaction was accomplished with a mechanical tamper as shown in Figure 57.

Traffic was applied to the repaired area immediately after compaction. The material moved under each pass of the load wheel; and after 10 coverages, ruts 1-1/2 inches deep were measured, including upheaval at the sides of the load tire, and the material had a loose noncohesive texture. Figure 58 shows the condition of the 5-foot-diameter area after 10 coverages.

CRUSHED LIMESTONE AND PORTLAND CEMENT

This material was used to repair 2-foot- and 5-foot-diameter areas in portland cement concrete pavement. The crushed limestone was spread in a uniform layer on adjacent pavement, and type I portland cement was spread over the crushed limestone as shown in Figure 59. Cement was applied to the crushed limestone at a rate of 5.5 bags/cu yd of aggregate. The material was dry mixed with a front-end loader by picking it up and turning it over several times, spreading in a uniform layer, and adding water, as shown in Figure 60, to bring the water content up to optimum for the crushed limestone. After water was added, material was remixed with the front-end loader. The mixture was placed in each area in two lifts, and each lift compacted with a mechanical tamper as shown in Figure 61. The surface of the mixture was sprinkled with water during final compaction.

Traffic was applied to the repaired areas immediately after compaction. Ten coverages of traffic were applied to the areas with no sign of failure; however, tire printing was noted at the surface where an excessive amount of water had been sprinkled on the surface during compaction, and a small amount of loose aggregate was observed. Figure 62 shows the condition of the patch after 10 coverages. Ten additional coverages were applied, and no distress was noted other than the small amount of loose aggregate.

ASPHALT MACADAM

Asphalt Macadam was used to repair 2-foot- and 5-foot-diameter areas in flexible pavement. The 5-foot-diameter area was filled to within 2 inches of the surface with compacted crushed limestone having a gradation as shown in Figure 7. The crushed limestone was placed and compacted in two lifts. A base course was not used in the 2-foot-diameter area. After compaction, areas to be repaired were sprayed as shown in Figure 63 with asphalt cement (100 penetration) heated to 300°F. The areas were filled with a 1-1/2-inch maximum-size crushed limestone with a gradation as shown in Figure 64. Hot asphalt cement was poured over the coarse aggregate with a pour pot as shown in Figure 65 because asphalt cement had chilled in the hand spray and would not flow. After asphalt cement was poured over the areas, crushed limestone fines with a gradation as shown in Figure 64 were spread over the coarse material as the area was heated with a propane torch as shown in Figure 66. Repaired areas were compacted with a 30-ton pneumatic-tired roller with a tire pressure of 90 psi. The finished surface of the 5-foot-diameter repaired area prior to traffic is shown in Figure 67.

Traffic was applied to the repaired areas 10 minutes after compaction because materials were still hot when compaction was completed. The Macadam rutted under traffic; and after eight coverages, the 5-foot-diameter area was considered failed. The condition of the 5-foot-diameter area after eight coverages is shown in Figure 68. Both areas were repaired by leveling with hand shovels and compacting with a mechanical tamper. Areas were allowed to cool 45 minutes longer, and 10 additional coverages of traffic applied. Rutting and shoving continued; and after 10 coverages, ruts of 1-1/2 inch deep, including upheaval, were measured as shown in Figure 69. After traffic the Macadam was easily removed with a pick and shovel which indicated a very unstable material.

ASPHALT-SATURATED POLYESTER FABRIC

This material was used to repair a 5-foot-diameter area in flexible pavement. The area was filled with compacted crushed limestone placed and compacted in two lifts with a mechanical tamper. The surface of the finished base course material is shown in Figure 70. The 6-foot-square asphalt-saturated polyester fabric was placed over the repaired area and crushed limestone fine aggregate spread over the surface. The fabric was heated with a propane torch and rolled with a 30-ton pneumatic-tired roller with 90 psi tire pressure as shown in Figure 71. The finished surface of the repaired area prior to traffic is shown in Figure 72.

Traffic was applied to the repaired area immediately after rolling the membrane. Failure occurred in the base course material after two coverages. Failure in the base course was due to inadequate compaction at the edges of the test area and excessive water content in the material.

SECTION III

CONCLUSION

Based on performance of materials tested during this study, the following conclusions are believed warranted.

1. Darex 240 performed satisfactorily as placed during this test; however, curing time would be affected by temperature at the site, and literature furnished indicates the material should not be placed in areas that contain water. Mixing and placing would require special handling equipment.

2. Zor-X rutted during traffic enough that it would probably be hazardous to aircraft traffic.

3. Hathane 1600A was unsatisfactory due to reaction of material with moisture on gravel used as a filler material in the areas being repaired; therefore, it could not be used during rainy weather.

4. Poly-Products Corporation's epoxy resin performed satisfactorily structurally, but enough loose gravel developed on the surface during traffic to possibly cause flying object damage to aircraft.

5. Cold mix No. 1 was not satisfactory due to lack of stability.

6. Polyester resin performed satisfactorily structurally but developed a small amount of loose material at the surface, and mixing and placing required equipment not commonly available at airfields.

7. Fondu concrete performed satisfactorily. Curing time for the material would depend on weather conditions at the site, and mixing and placing would require special equipment for handling the material rapidly.

8. Amalgapave performed satisfactorily and can be placed with normal maintenance equipment; however, past experience has shown that excessive water in repair areas will adversely affect the stability of asphaltic materials.

9. Cold mix No. 2 was not satisfactory due to lack of stability.

10. Future Patch performed satisfactorily, and repairs can be made with normal maintenance equipment; however, past experience has shown that excessive water in repair areas adversely affect the stability of asphaltic materials.

11. Sylvax was not satisfactory due to lack of stability.

12. Field-mixed Amalgapave was not satisfactory due to lack of stability. Due to the scope of this testing program, a laboratory mix design was not determined. The mixture appeared to have an excessive amount of asphalt.

13. Crushed limestone with 5.5 bags/cu yd of portland cement performed satisfactorily structurally, but a small amount of loose aggregate on the surface could cause flying object damage to aircraft. This type repair could not be made during rainy weather because an excessive amount of water would wash cement out of the surface of the repair.

14. Asphalt Macadam was not satisfactory due to lack of stability. This type repair would require time for heating asphalt at any time and during cold weather would be difficult to place because of asphalt cooling in applicator lines.

15. Asphalt-saturated polyester fabric repair was not satisfactory due to failure in base course material because of improper compaction. This was a base course failure and should not be considered as a failure of this type repair.

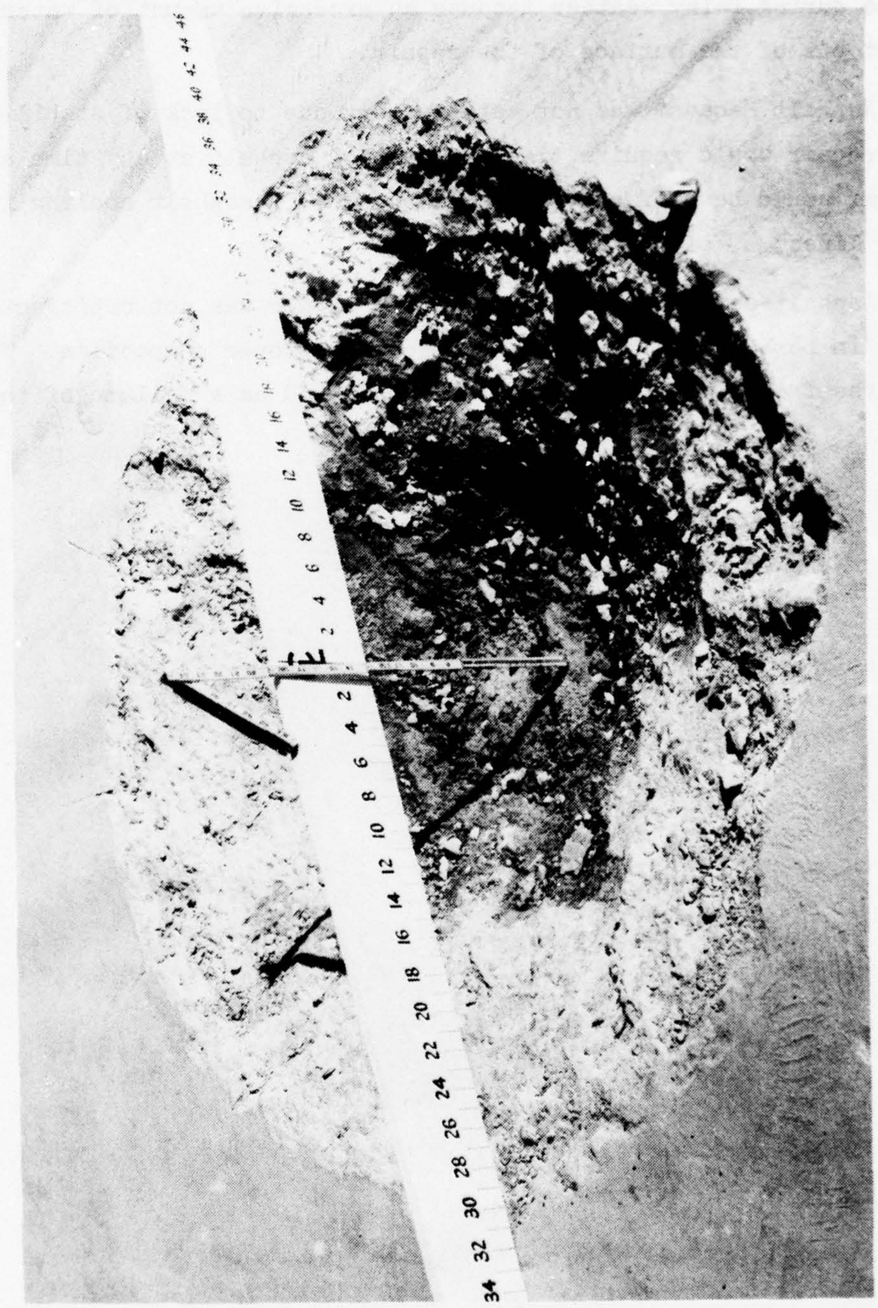


Figure 1. Typical 5-Foot-Diameter Area in Portland Cement Concrete Pavement

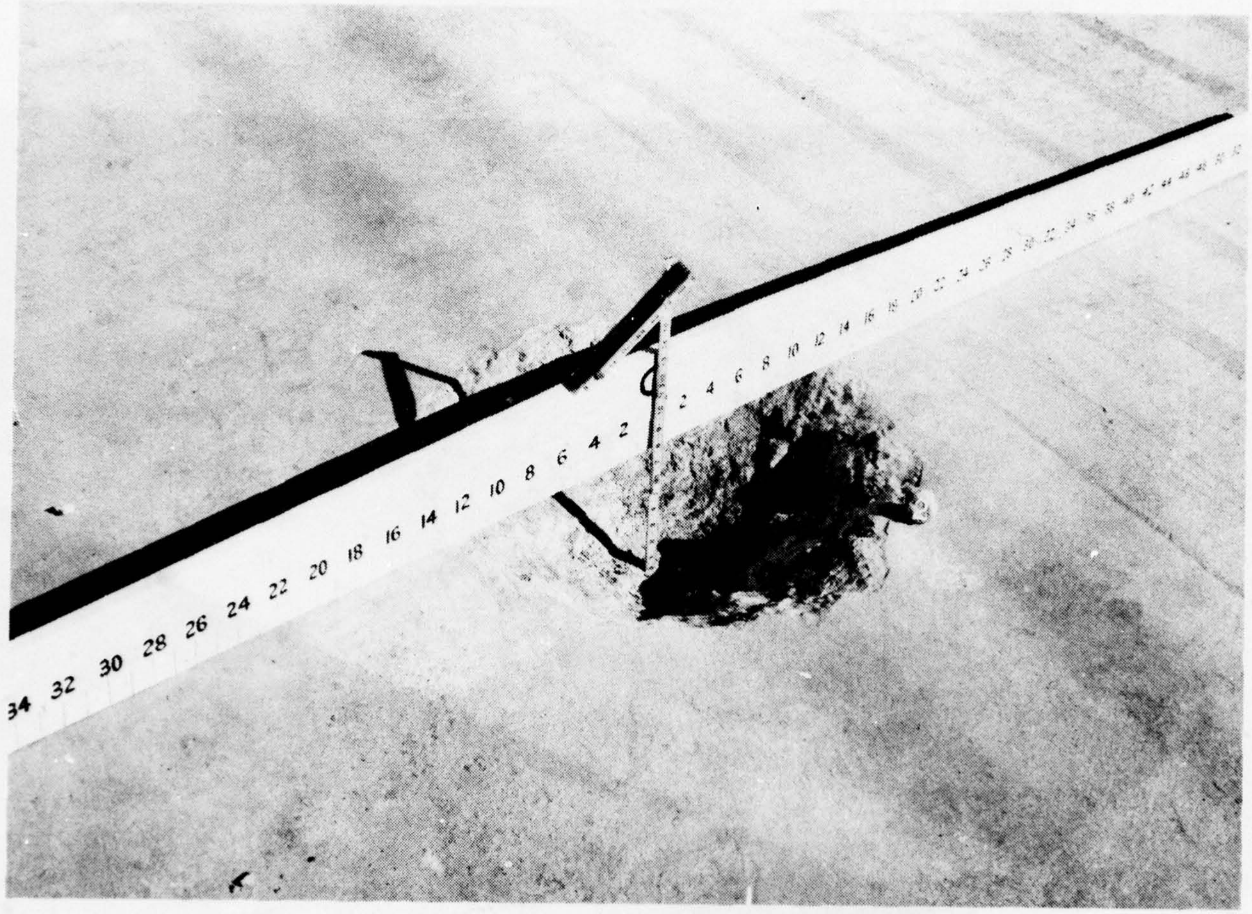


Figure 2. Typical 2-Foot-Diameter Area in Portland Cement Concrete Pavement

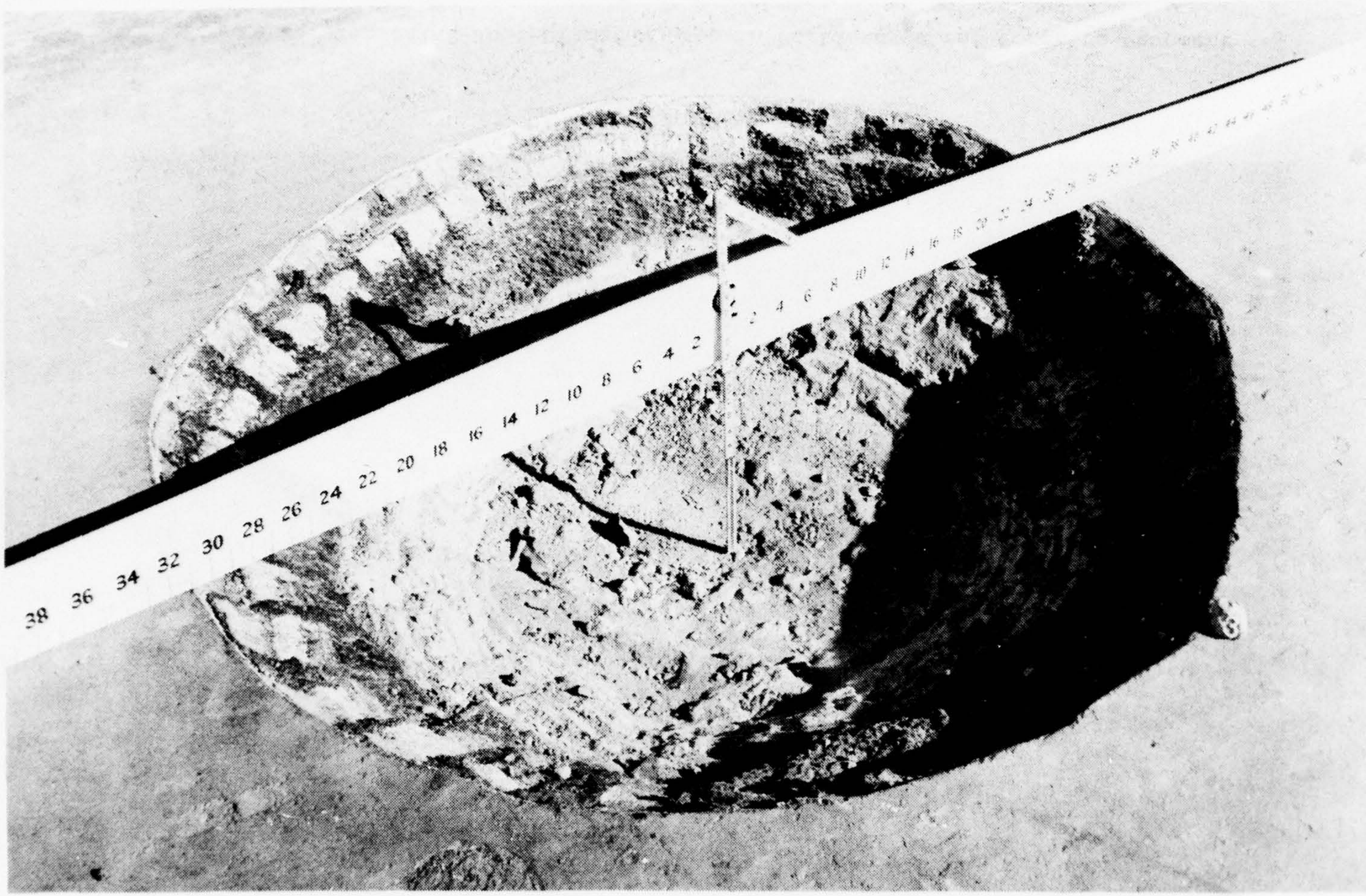


Figure 3. Typical 5-Foot-Diameter Area in Flexible Pavement

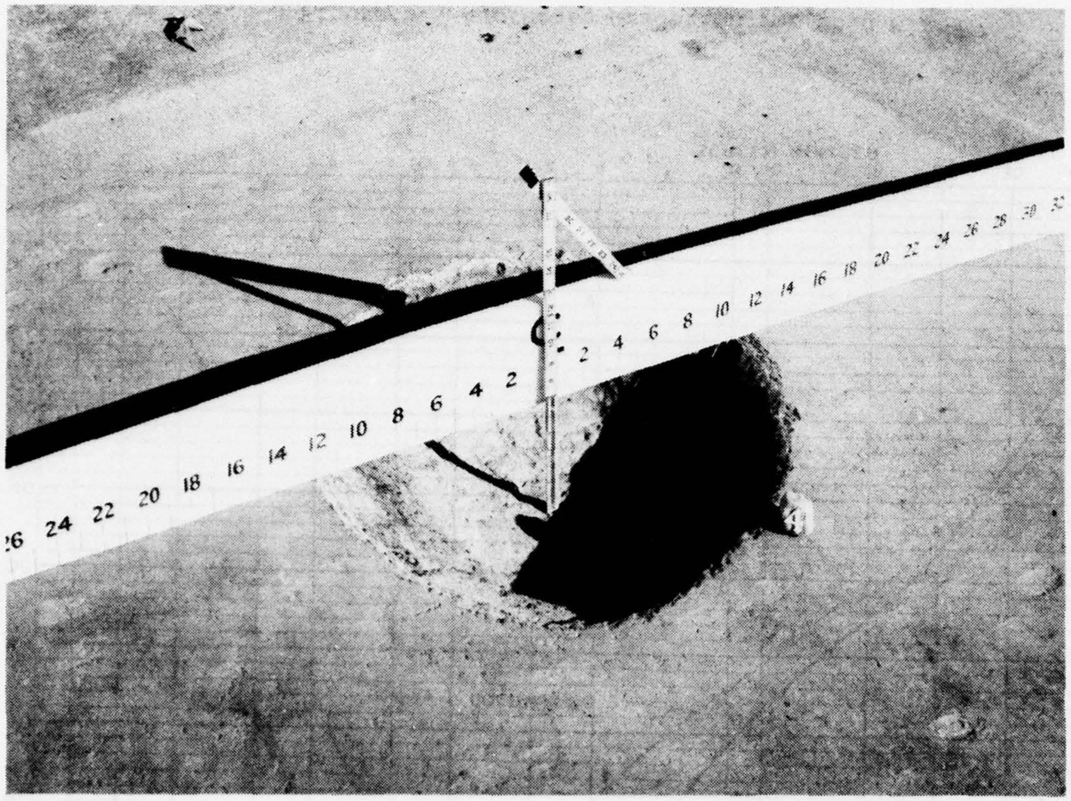


Figure 4. Typical 2-Foot-Diameter Area in Flexible Pavement

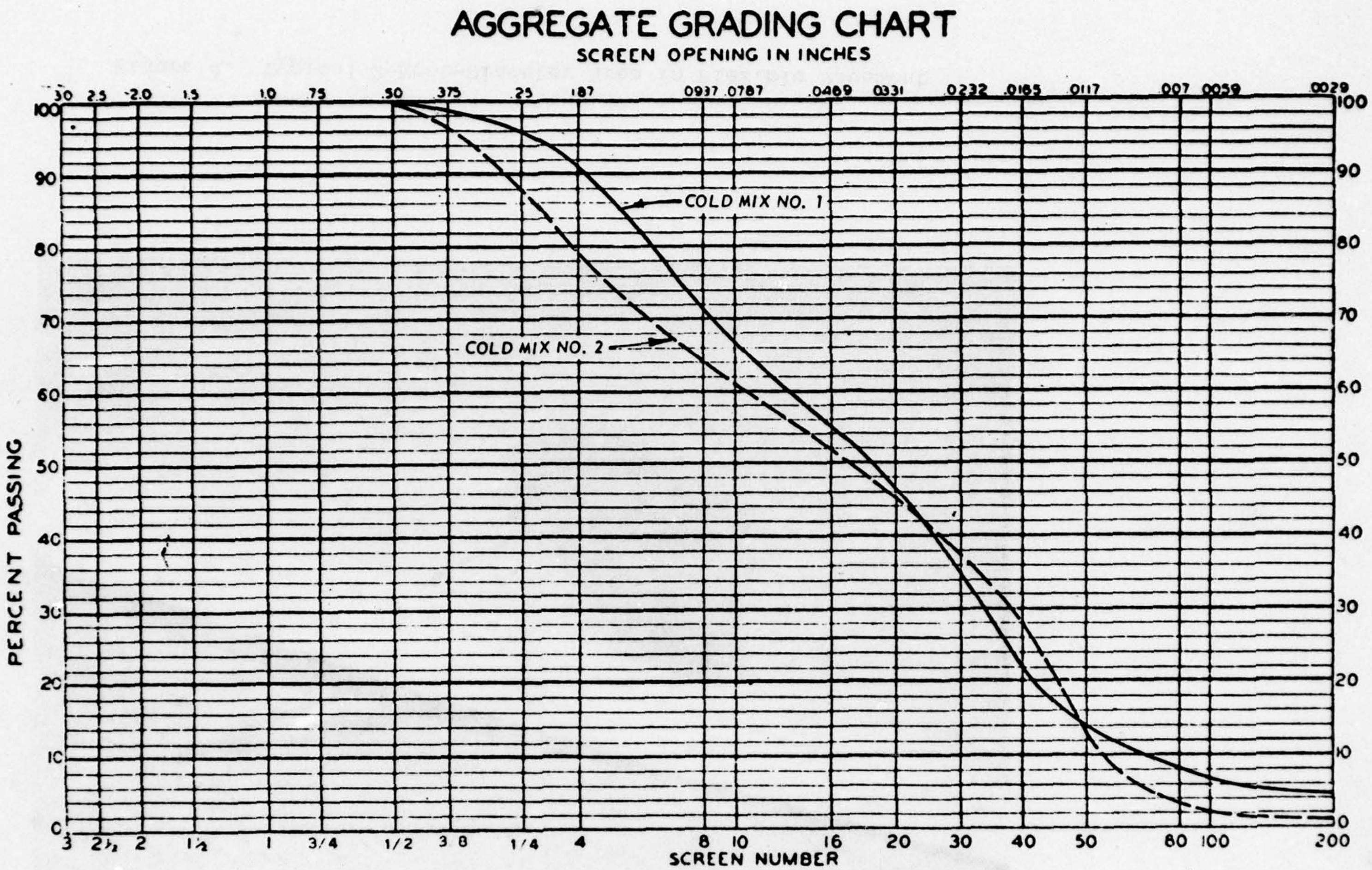


Figure 5. Aggregate Gradation for Cold Mixes

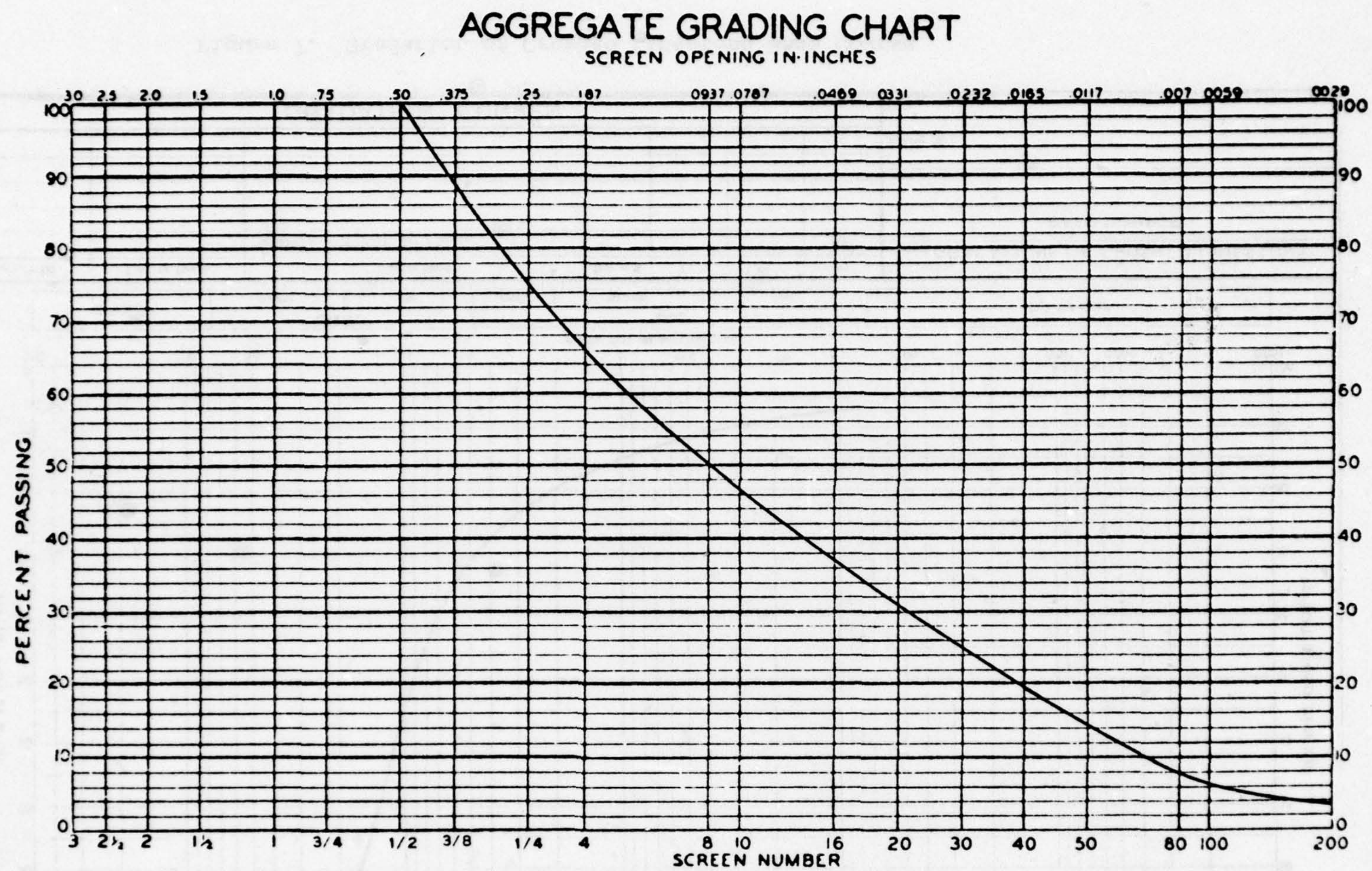


Figure 6. Gradation of Field-Mixed Amalgapave and Field-Mixed Cold Mix

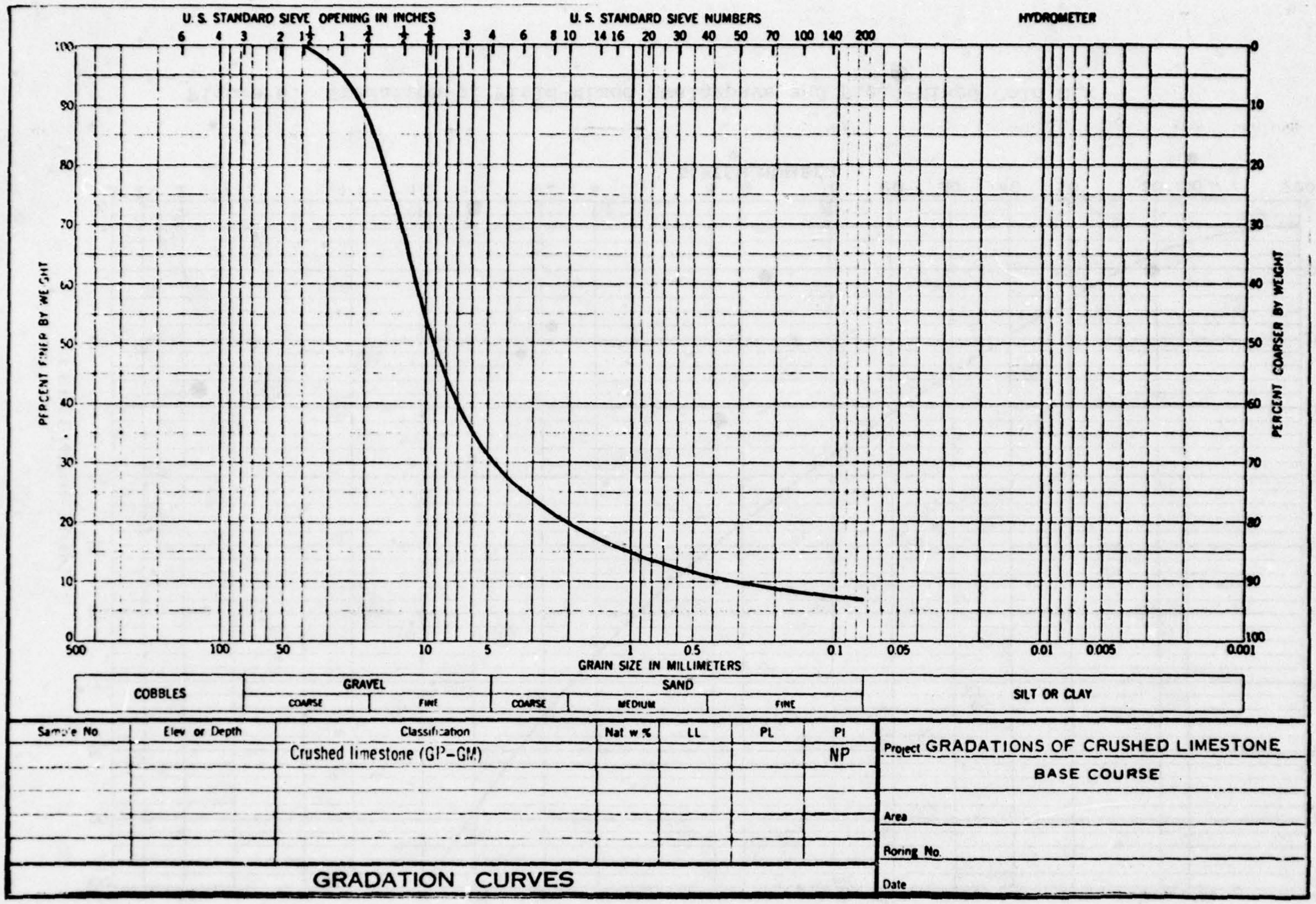


Figure 7. Gradation of Crushed Limestone Base Course

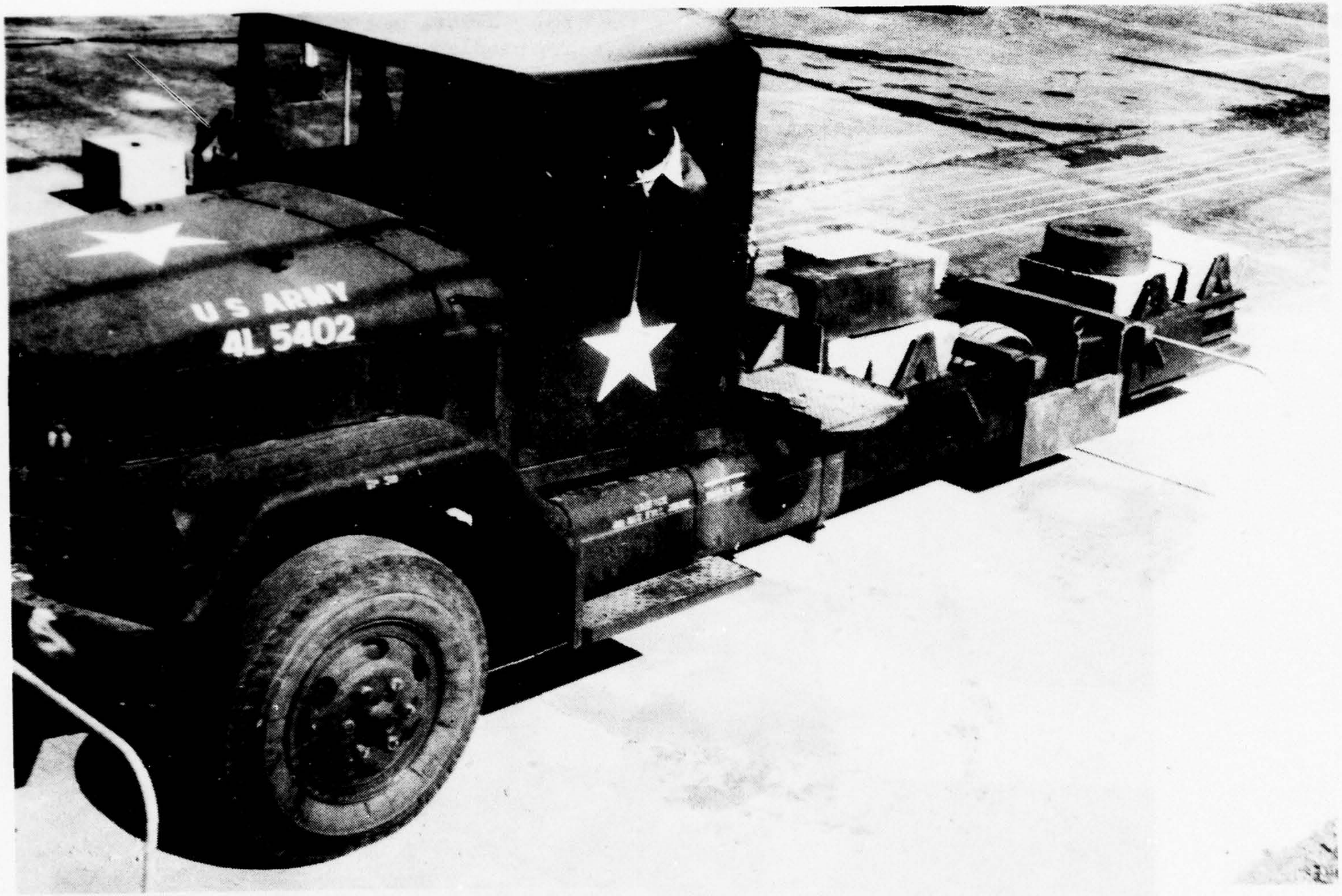


Figure 8. Test Vehicle

Figure 9. Compacting Crushed Limestone in 5-Foot-Diameter Area for Darex 240 Repair

Figure 10. Surface of Compacted Crushed Limestone Before Placing Darex 240

Figure 11. Mixing and Placing Darex 240

Figure 12. Finished Surface of Darex 240

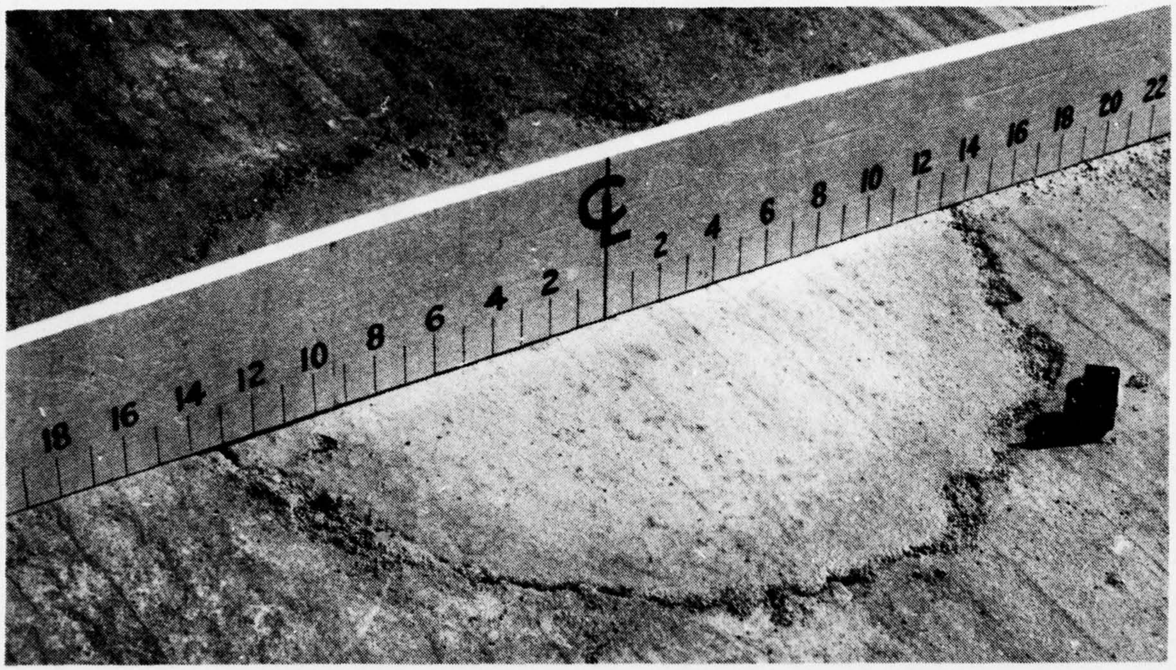


Figure 13. Surface of Darex 240 in 2-Foot-Diameter Area After 20 Coverages

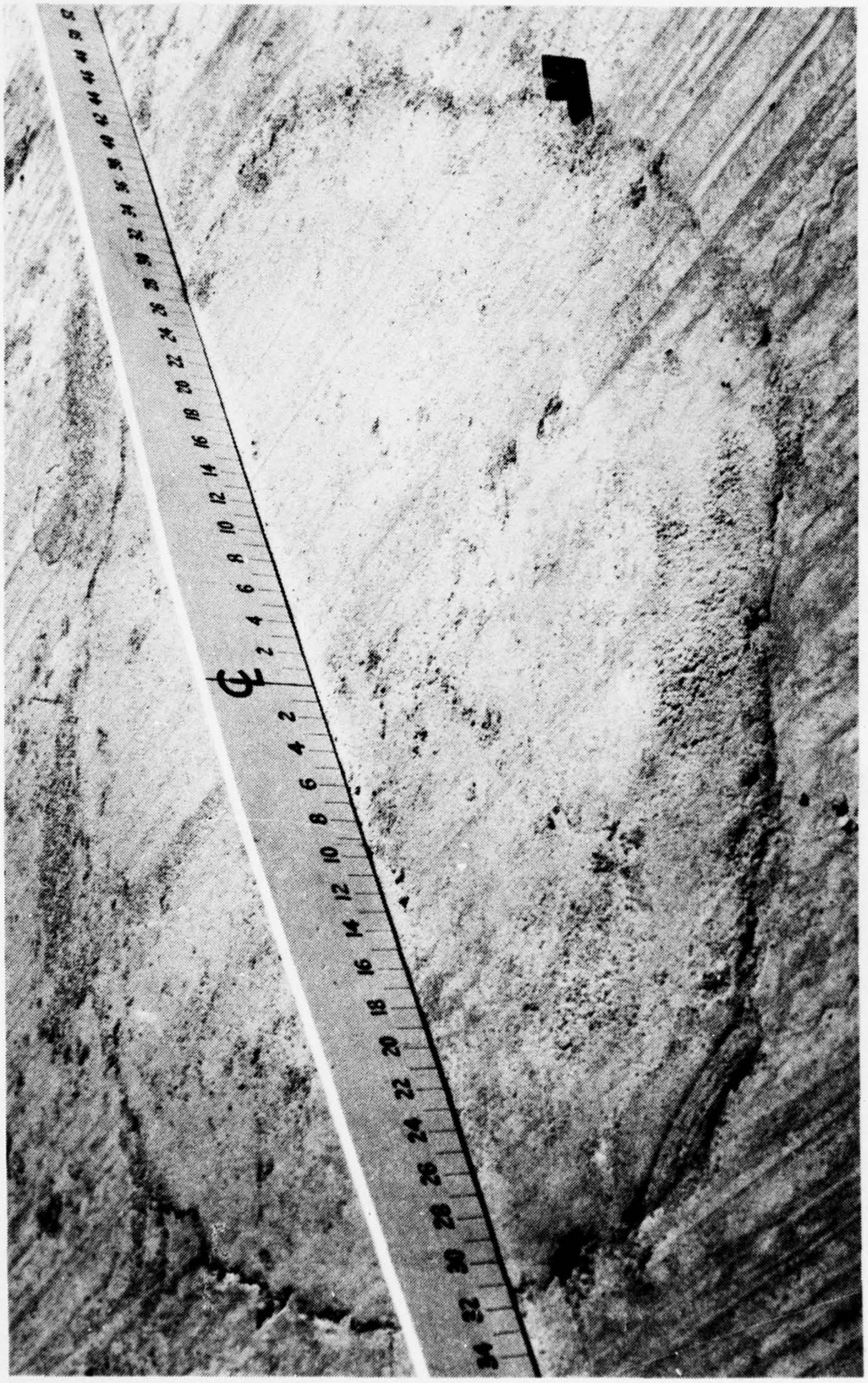


Figure 14. Surface of Darex 240 in 5-Foot-Diameter Area After 20 Coverages

Figure 15. Compacting Crushed Limestone Base Course for Zor-X Repair

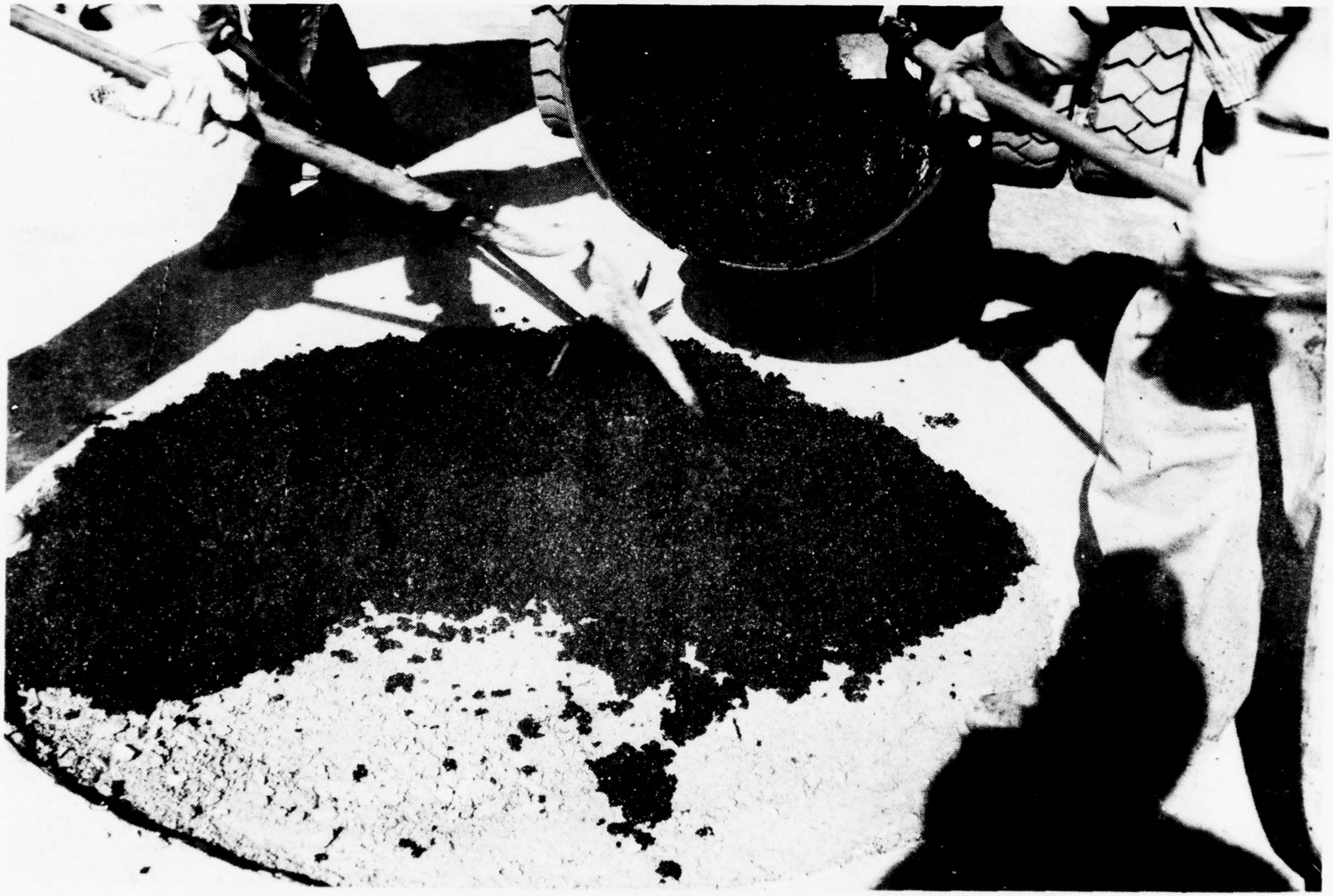


Figure 16. Placing Zor-X

Figure 17. Compacting Zor-X

Figure 18. Compacting Zor-X with Pneumatic-Tired Roller

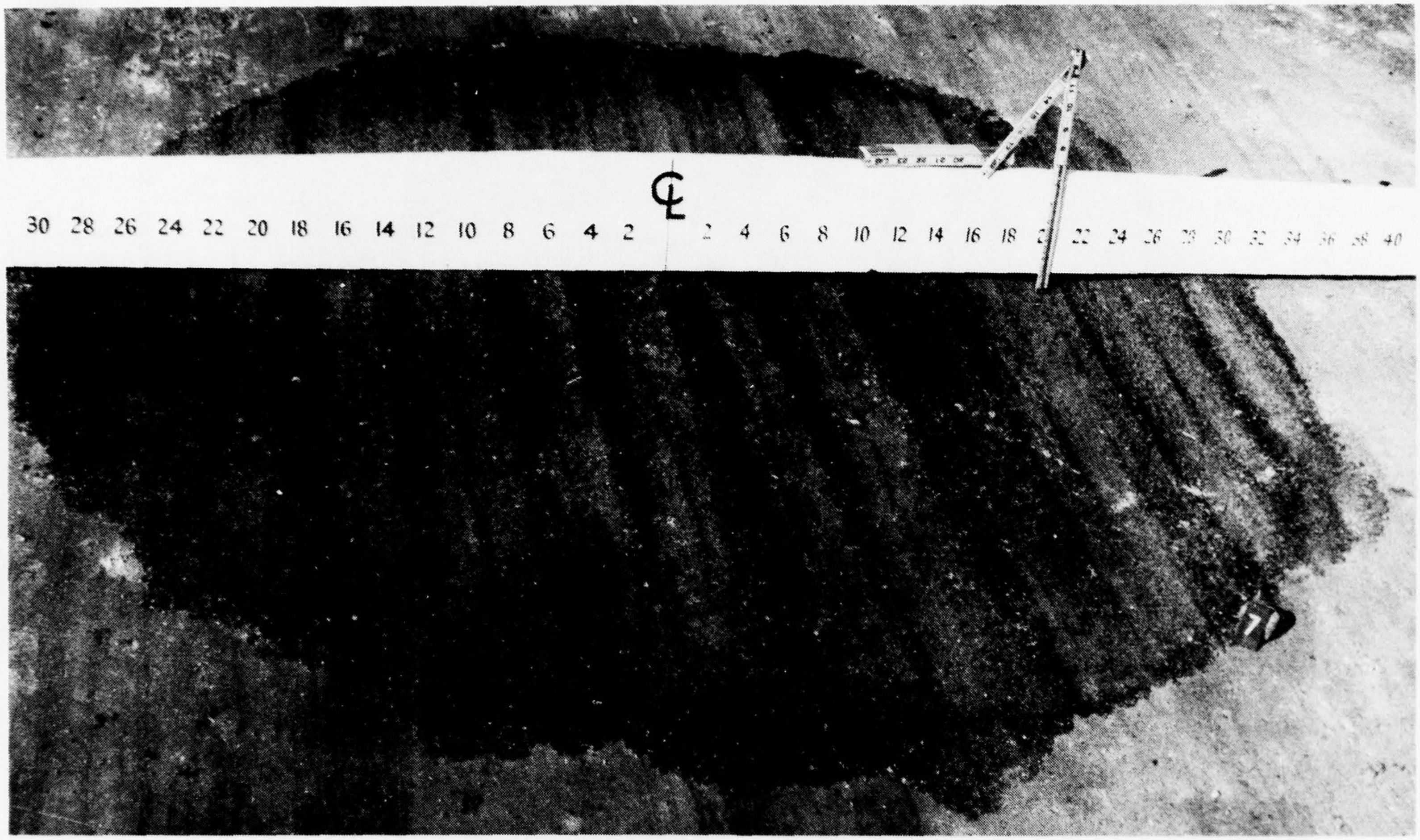


Figure 19. Surface of Zor-X in 5-Foot-Diameter Area After 10 Coverages

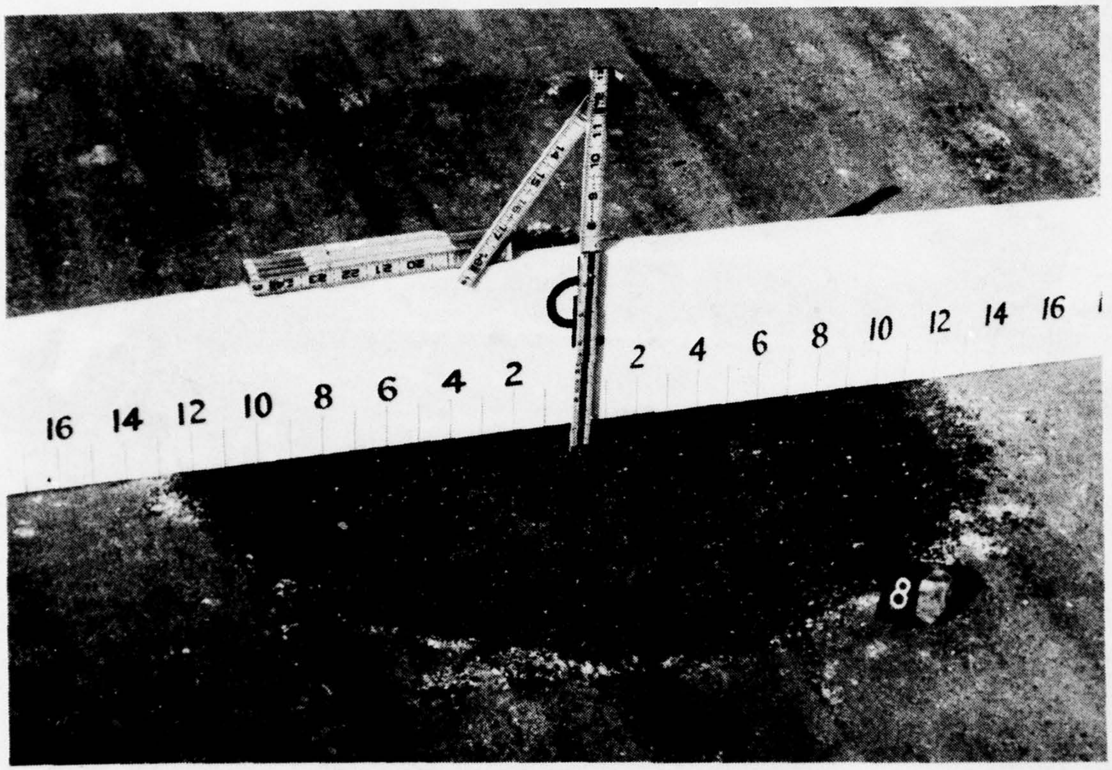


Figure 20. Surface of Zor-X in 2-Foot-Diameter Area After 10 Coverages

Figure 21. Screeding Washed Gravel Fill Material Before Placing Hathane 1600A

Figure 22. Hand-Operated Electric Mixer Used to Mix Hathane 1600A

Figure 23. Pouring Hathane 1600A Over Open-Graded Gravel

Figure 24. Hathane 1600A During Curing

Figure 25. Failure Developed on First Pass of Load Wheel in Hathane 1600A

Figure 26. Screeding Open-Graded Gravel Fill for Poly-Products Epoxy Resin Repair

Figure 27. Mixing Poly-Products Epoxy Resin

Figure 28. Pouring Poly-Products Epoxy Resin Over Open-Graded Gravel

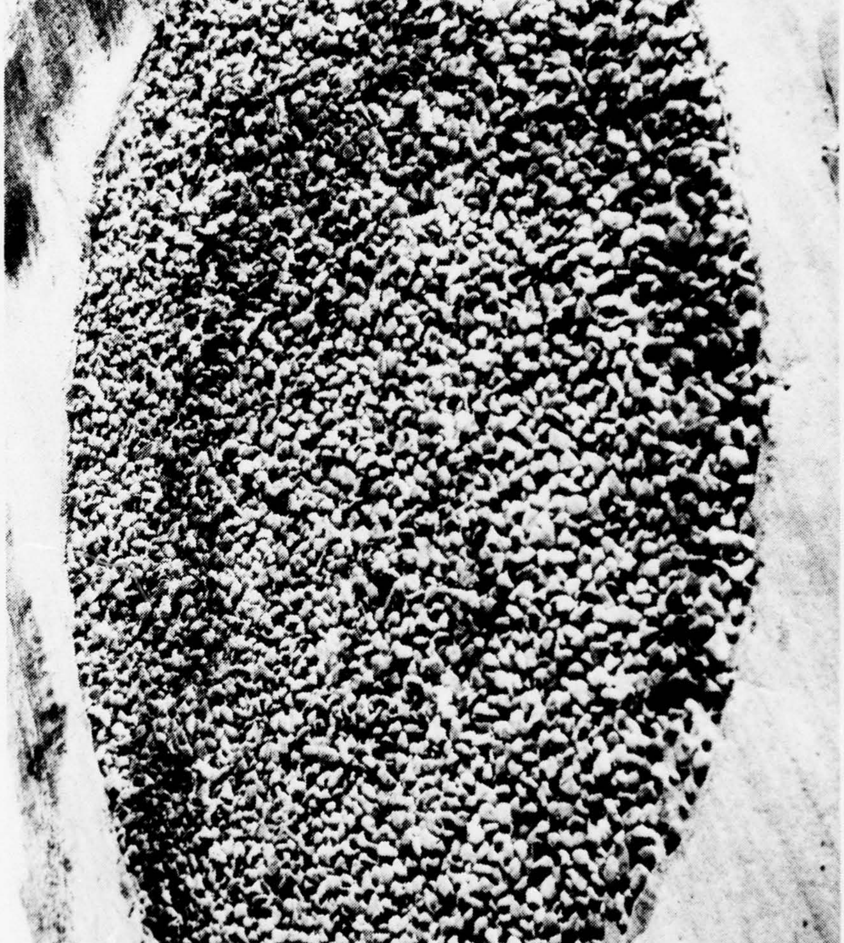


Figure 29. Surface of Epoxy Resin Repair After 10 Coverages

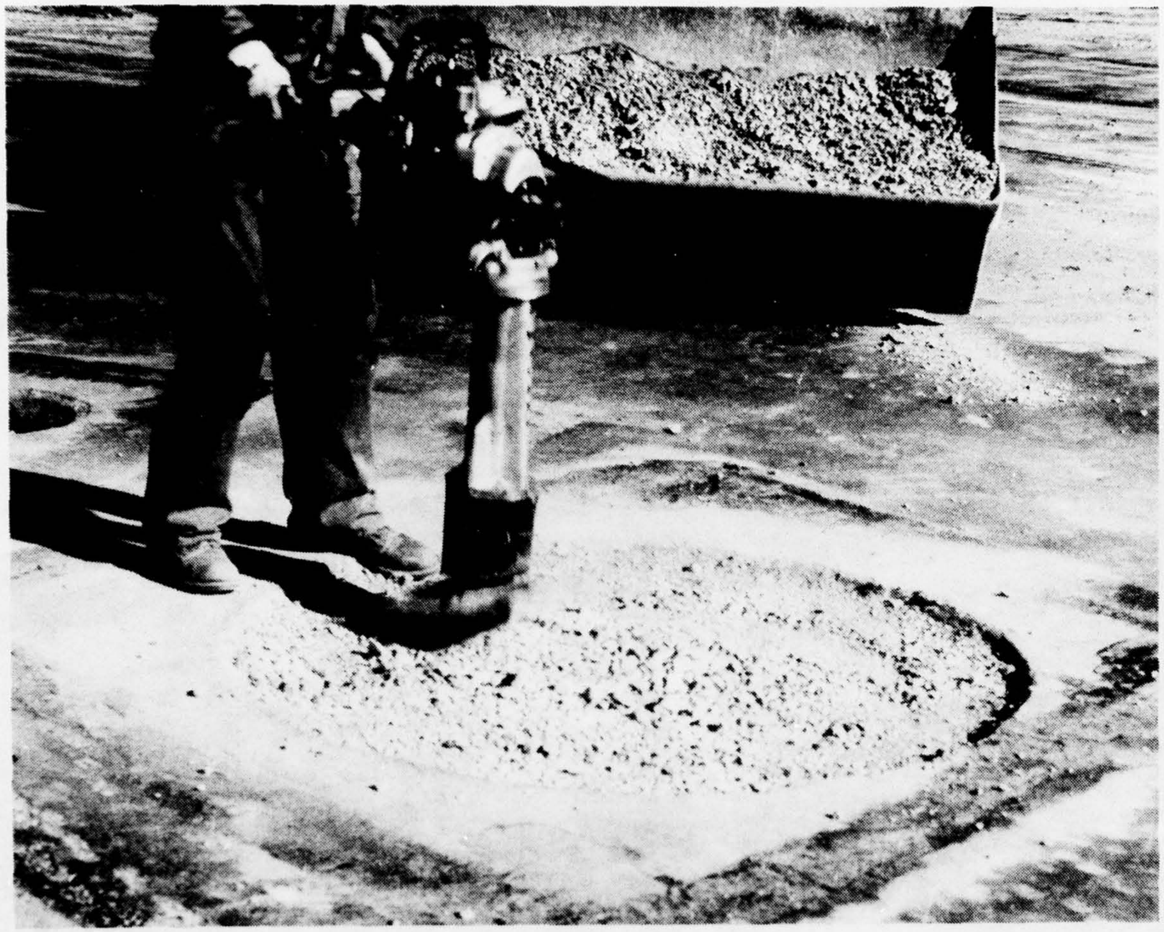


Figure 30. Compacting Crushed Limestone Base Course for Cold Mix No. 1 Repair

Figure 31. Compacting Cold Mix No. 1 in 5-Foot-Diameter Area

Figure 32. Repairing Cold Mix No. 1 in 5-Foot-Diameter Area After Two Coverages

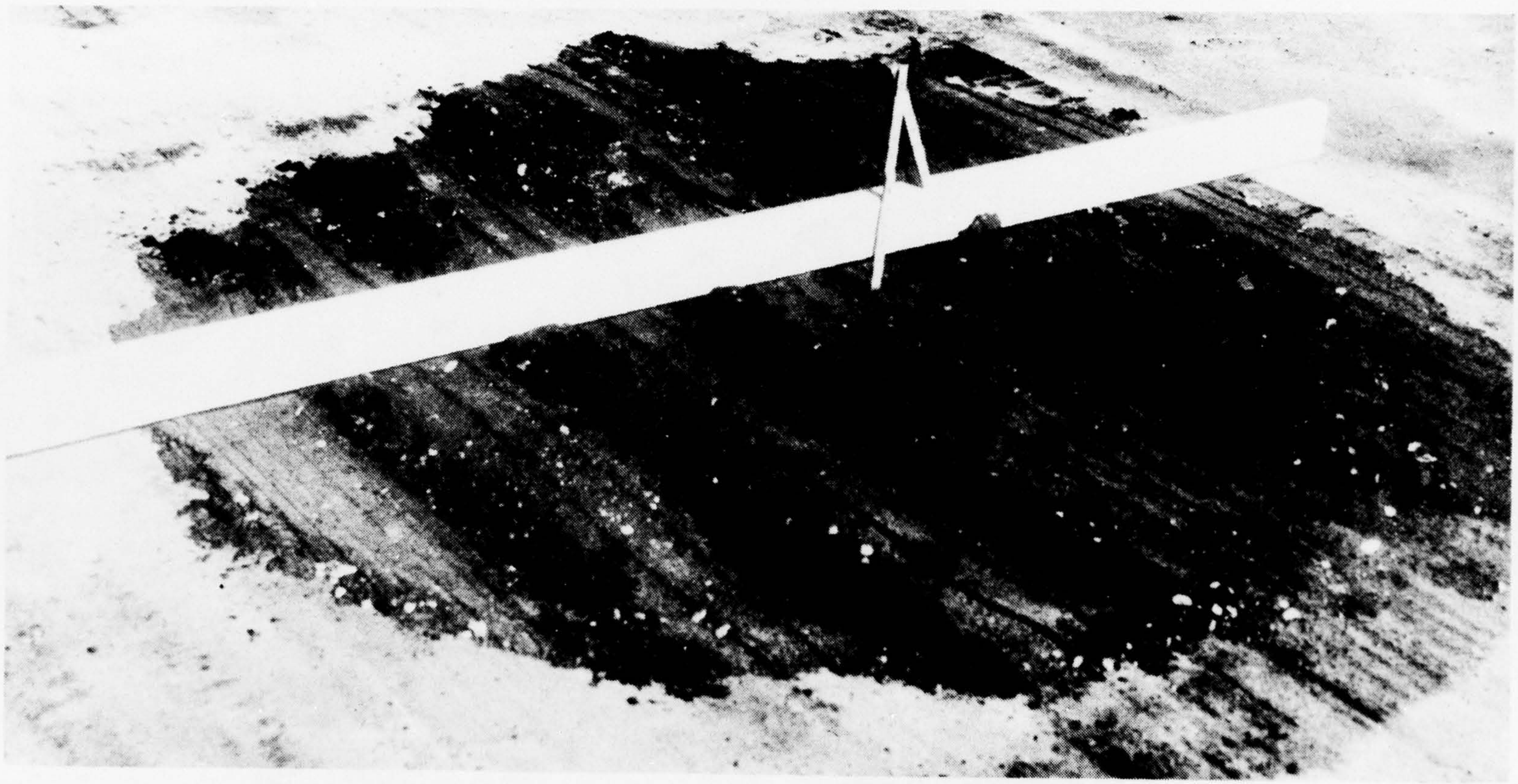


Figure 33. Surface of Cold Mix No. 1 in 5-Foot-Diameter Area After Total of Four Coverages

Figure 34. Screeding Gravel Fill for Polyester Resin Repair

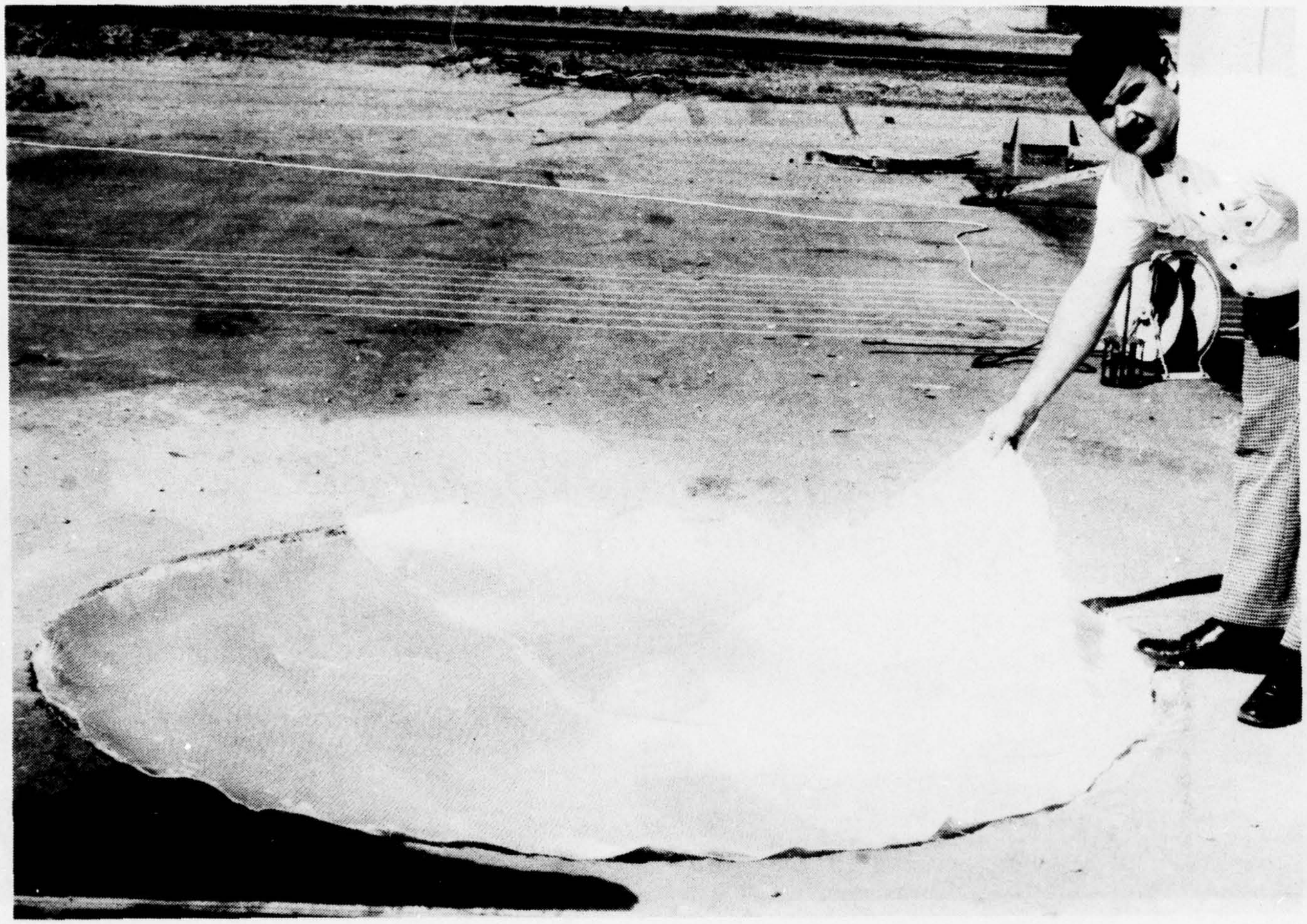


Figure 35. Placing Fiberglass Mat in 8-Foot-Diameter Area for Polyester Repair

Figure 36. Screeding Gravel Fill in 8-Foot-Diameter Area for Polyester Repair

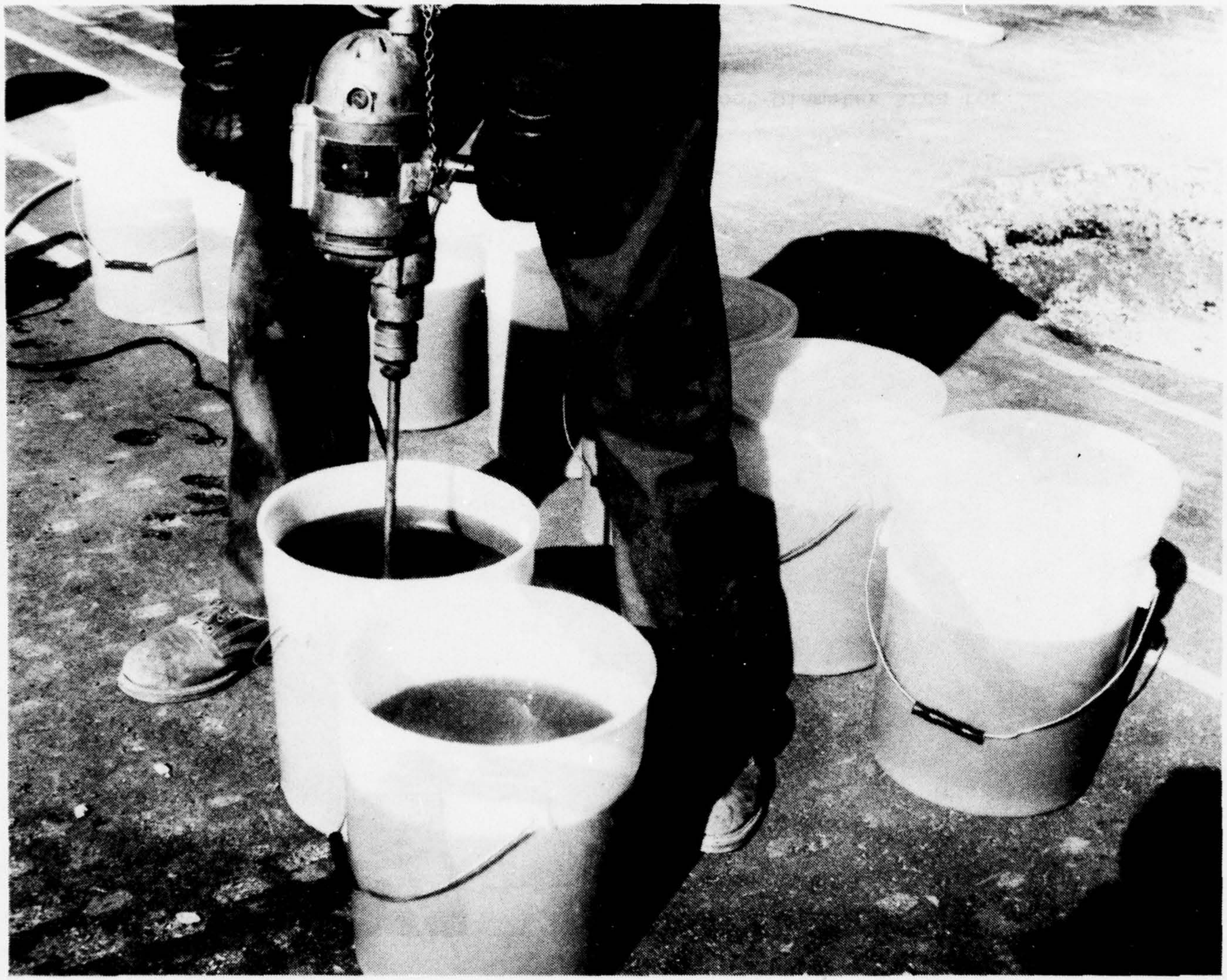


Figure 37. Mixing Polyester Resin

Figure 38. Pouring Polyester Resin Over Gravel Fill

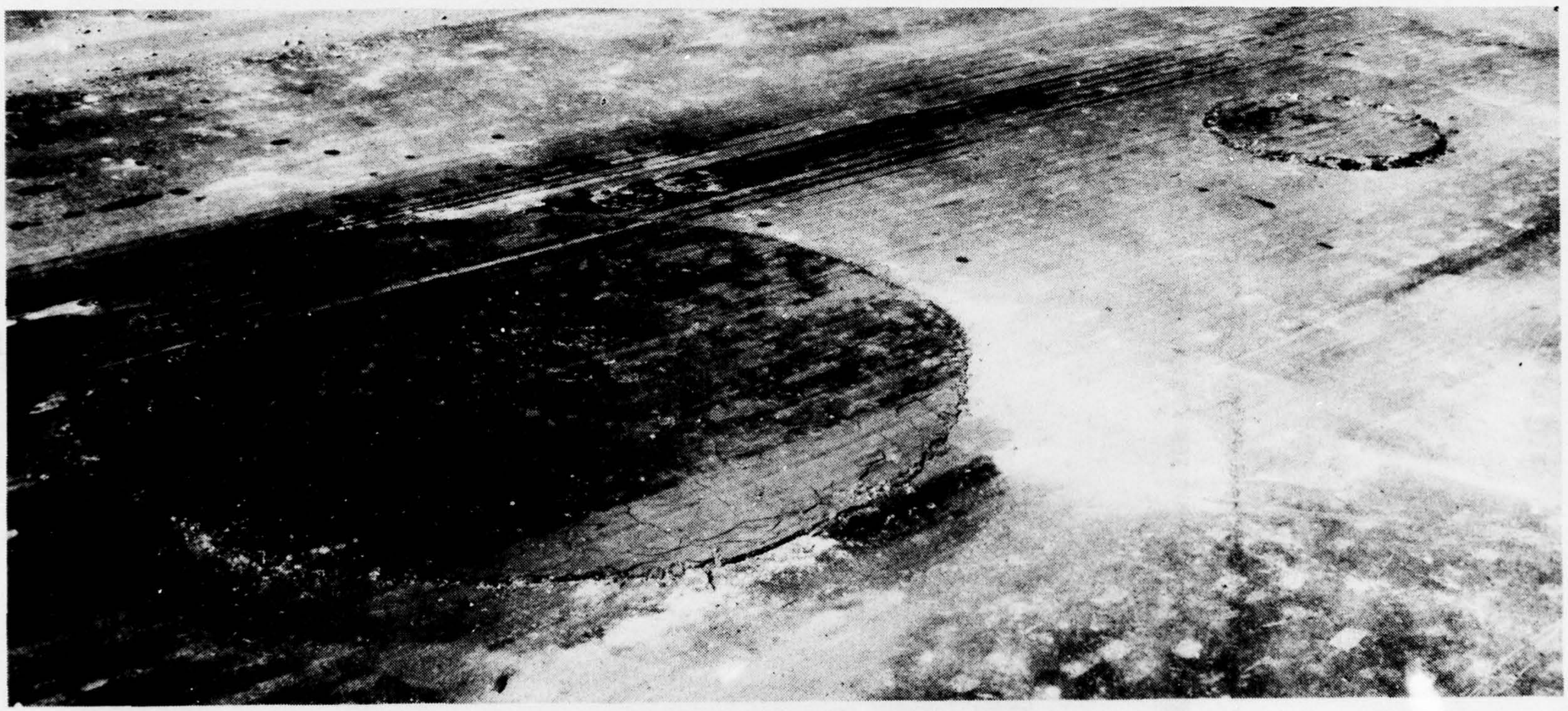


Figure 39. Surface of Polyester Resin in 2-Foot- and 5-Foot-Diameter Areas After 10 Coverages

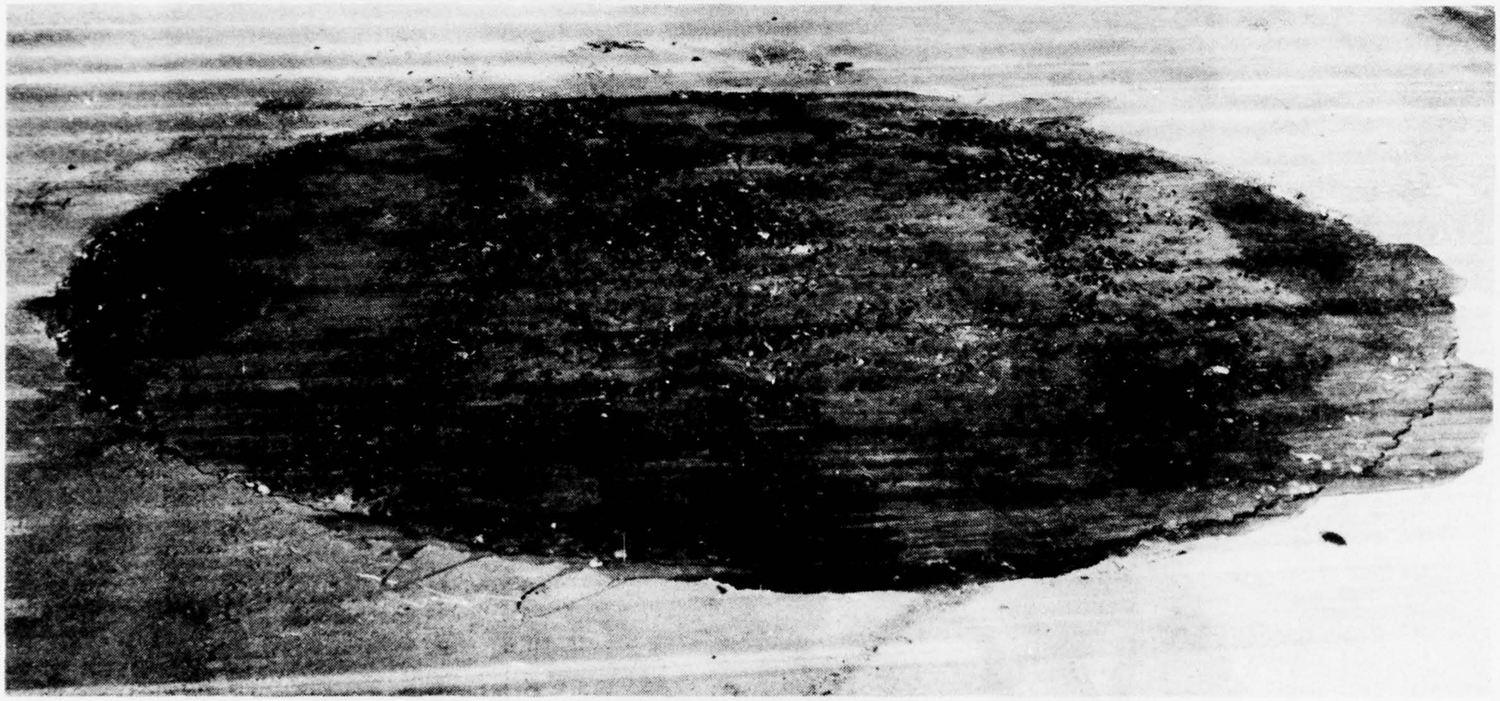


Figure 40. Surface of Polyester Resin in 8-Foot-Diameter Area After 10 Coverages

Figure 41. Mixing and Placing Fondu Concrete

Figure 42. Finished Surface of Fondu Concrete

Figure 43. Surface of Fondu Concrete After 20 Coverages

Figure 44. Placing Amalgapave

Figure 45. Compacting Amalgapave with Mechanical Tamper

Figure 46. Finish Rolling Amalgapave with 30-Ton Pneumatic-Tired Roller with 90 psi Tire Pressure

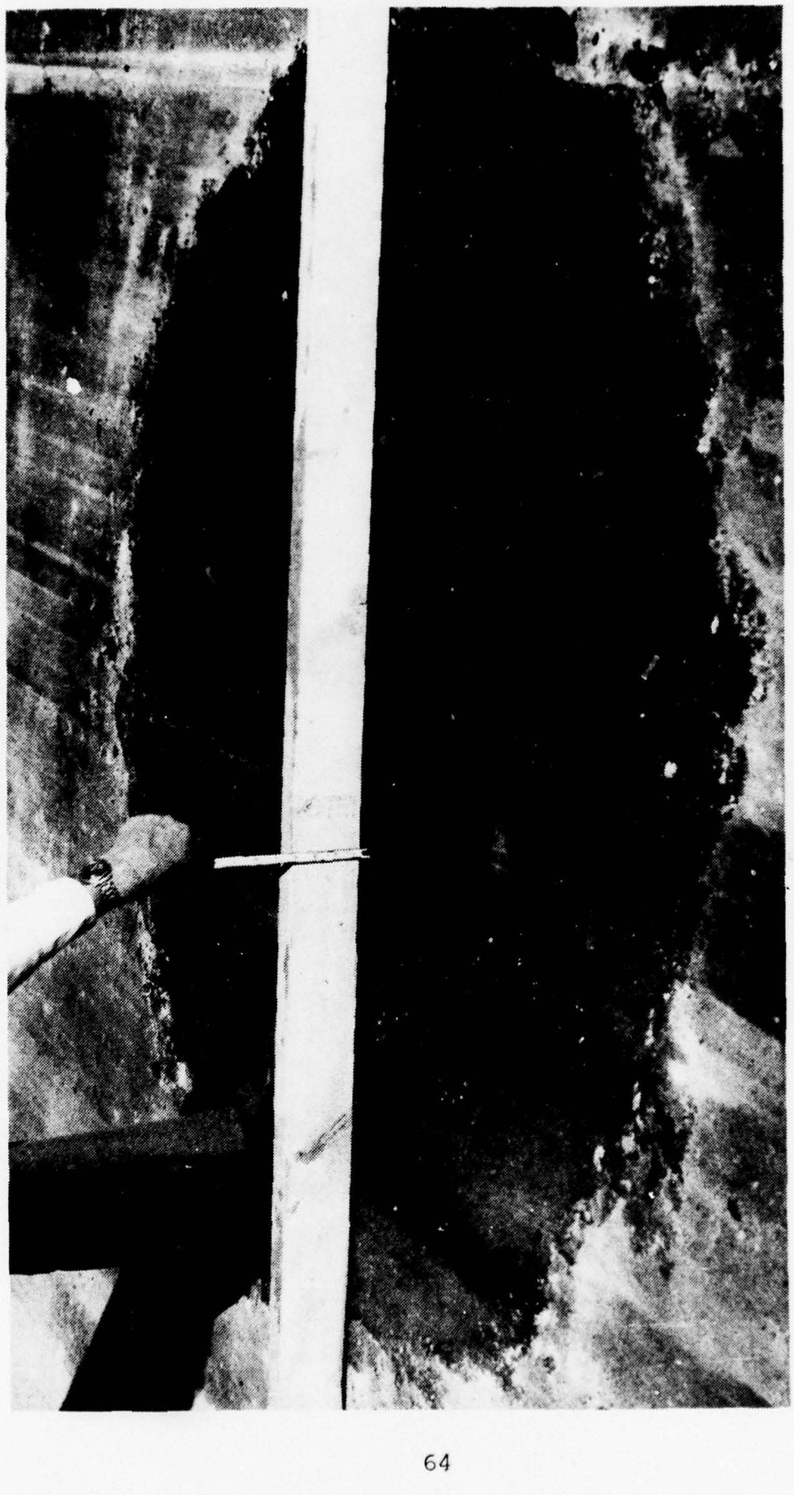


Figure 47. Surface of Amalgapave After 20 Coverages

Figure 48. Finish Rolling Cold Mix No. 2 with 30-Ton Penumatic-Tired Roller with 90 psi Tire Pressure

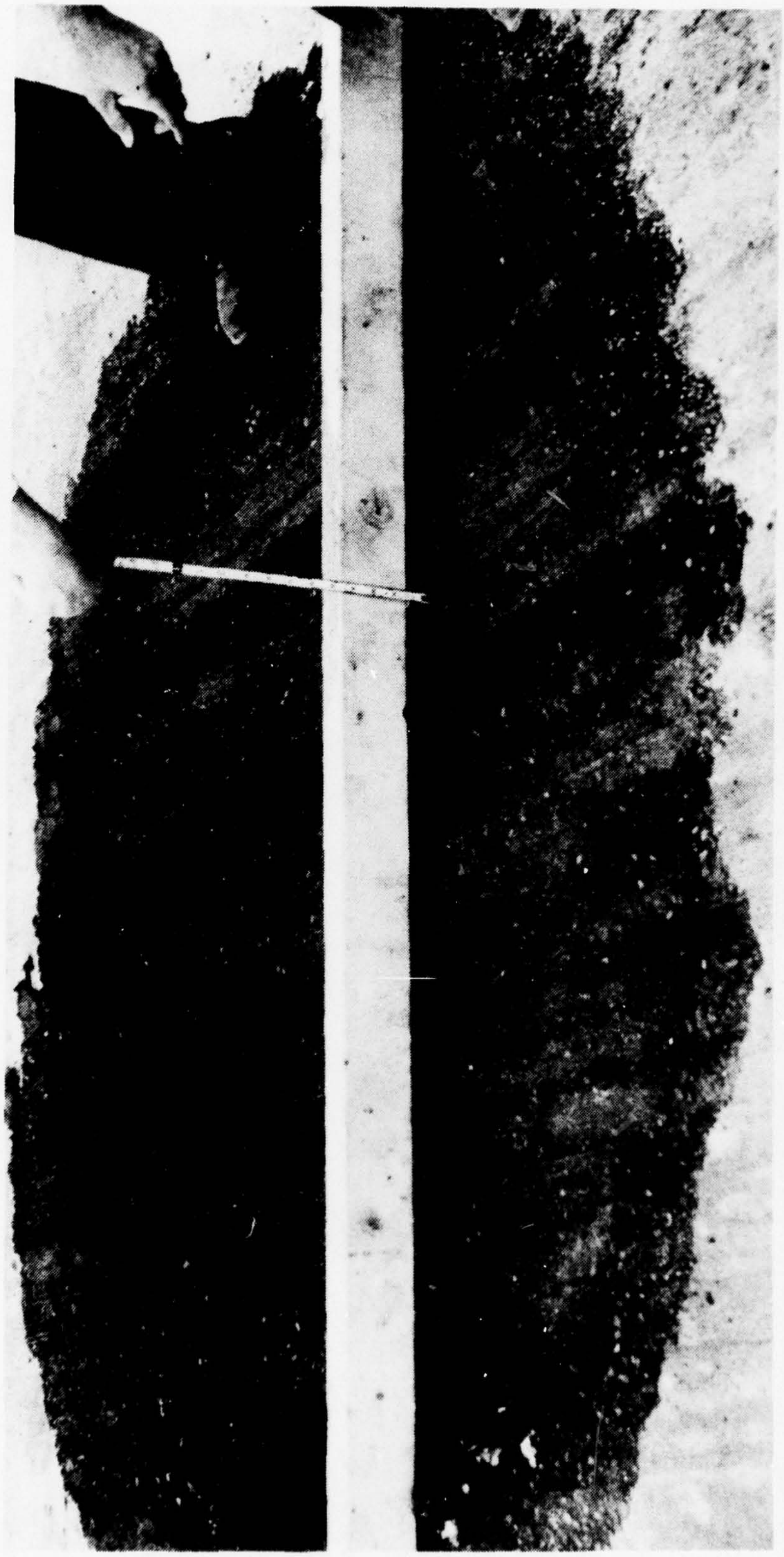


Figure 49. Condition of Cold Mix No. 2 After 10 Coverages

Figure 50. Placing Future Patch in 5-Foot-Diameter Area

Figure 51. Compacting Future Patch with Mechanical Tamper

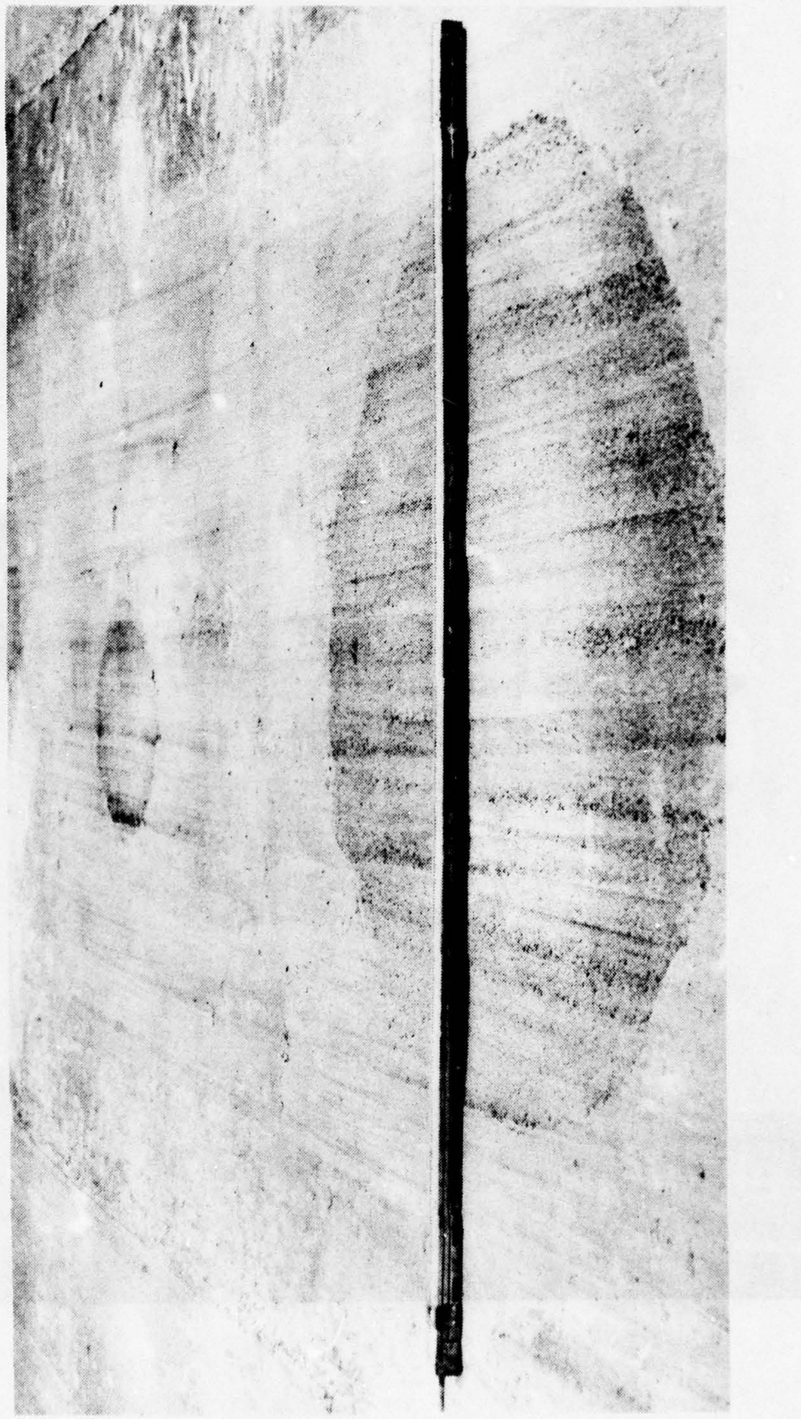


Figure 52. Condition of Future Patch After 20 Coverages

Figure 53. Placing Sylvax in 5-Foot-Diameter Area

Figure 54. Condition of Sylvax After 10 Coverages

Figure 55. Compacting Field-Mixed Amalgapave with Mechanical Tamper

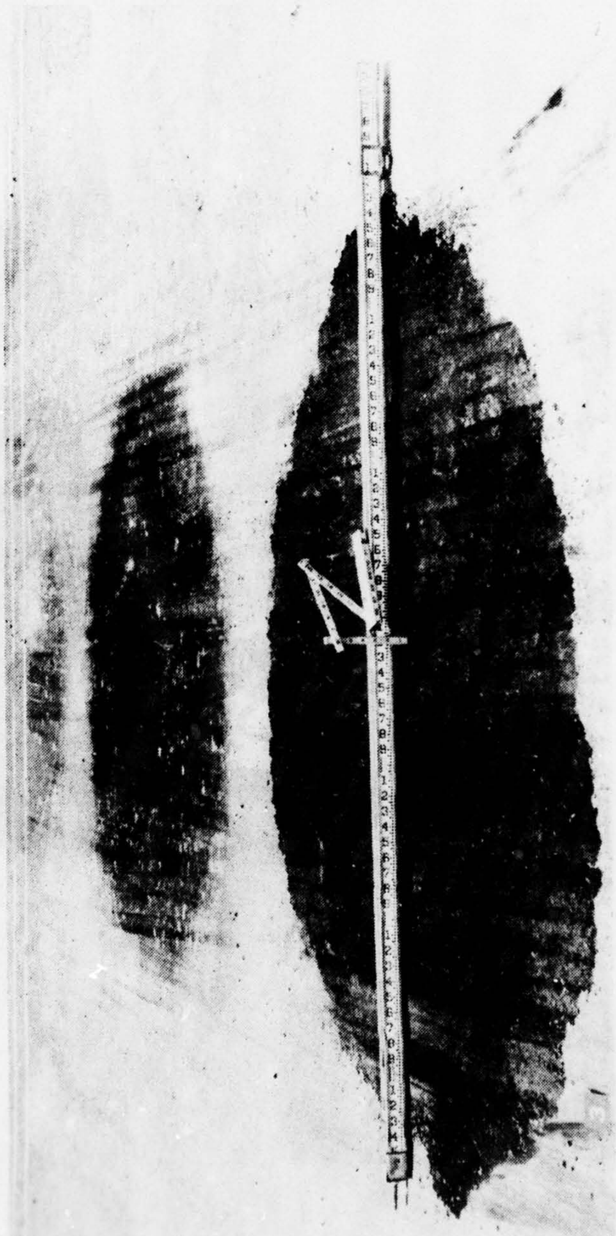


Figure 56. Condition of Field-Mixed Amalgapave After 10 Coverages

Figure 57. Compacting Field-Mixed Cold Mix with Mechanical Tamper

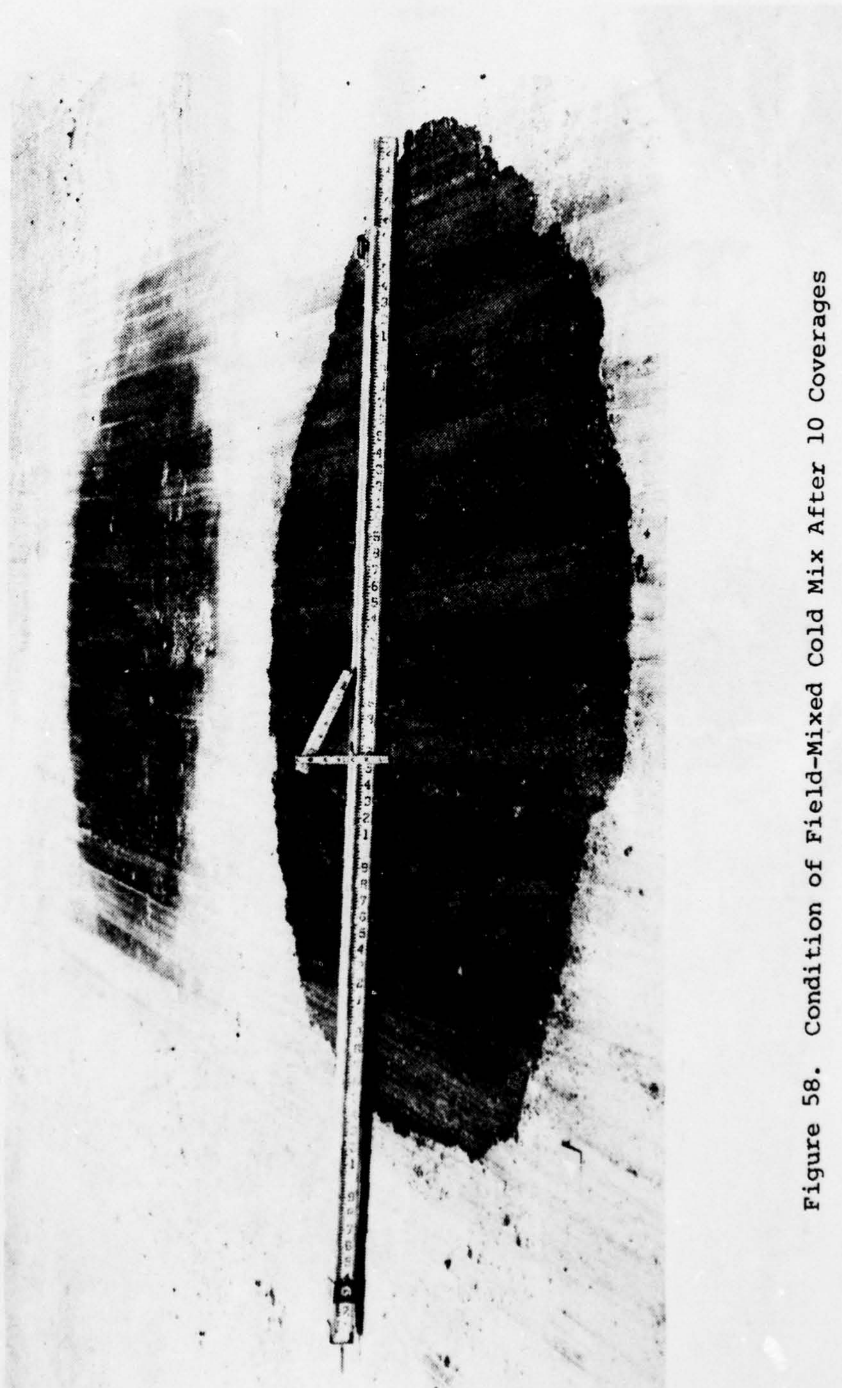


Figure 58. Condition of Field-Mixed Cold Mix After 10 Coverages

Figure 59. Spreading Portland Cement Over Crushed Limestone

Figure 60. Adding Water to Dry-Mixed Crushed Limestone and Portland Cement

Figure 61. Compacting Mixture of Crushed Limestone and Portland Cement with Mechanical Tamper

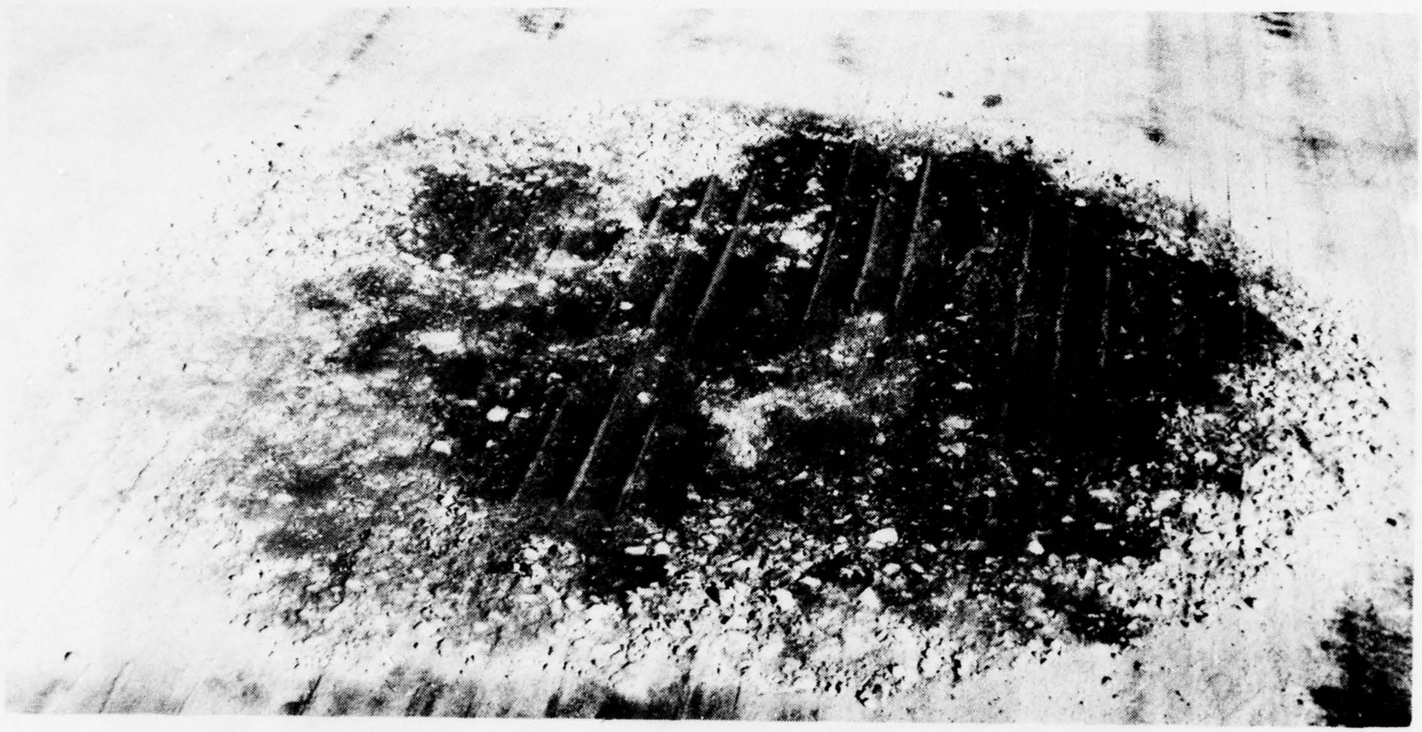


Figure 62. Condition of Crushed Limestone and Portland Cement Mixture After 10 Coverages

Figure 63. Spraying Asphalt Cement on Base Course Prior to Placing Macadam Repair

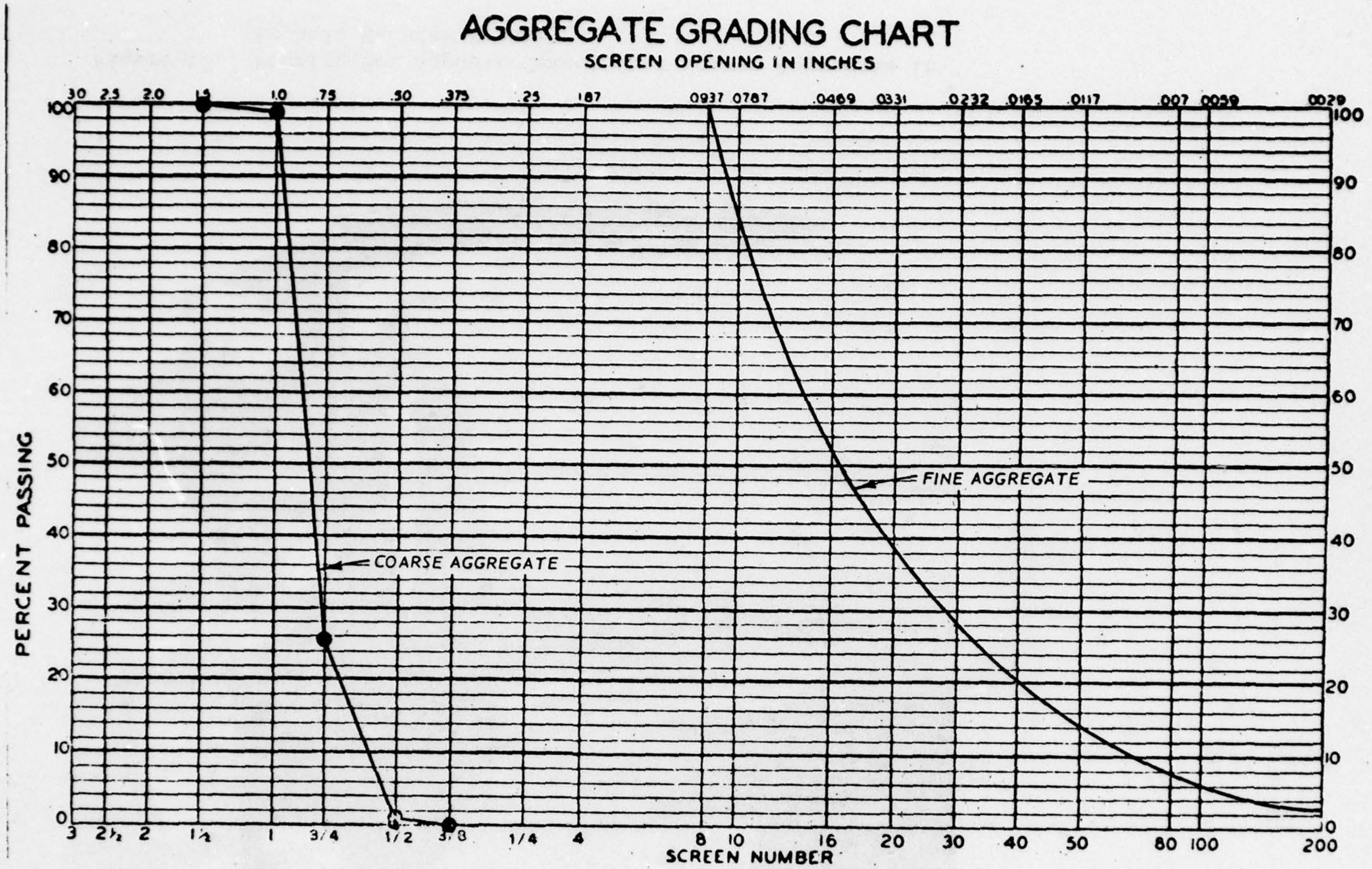


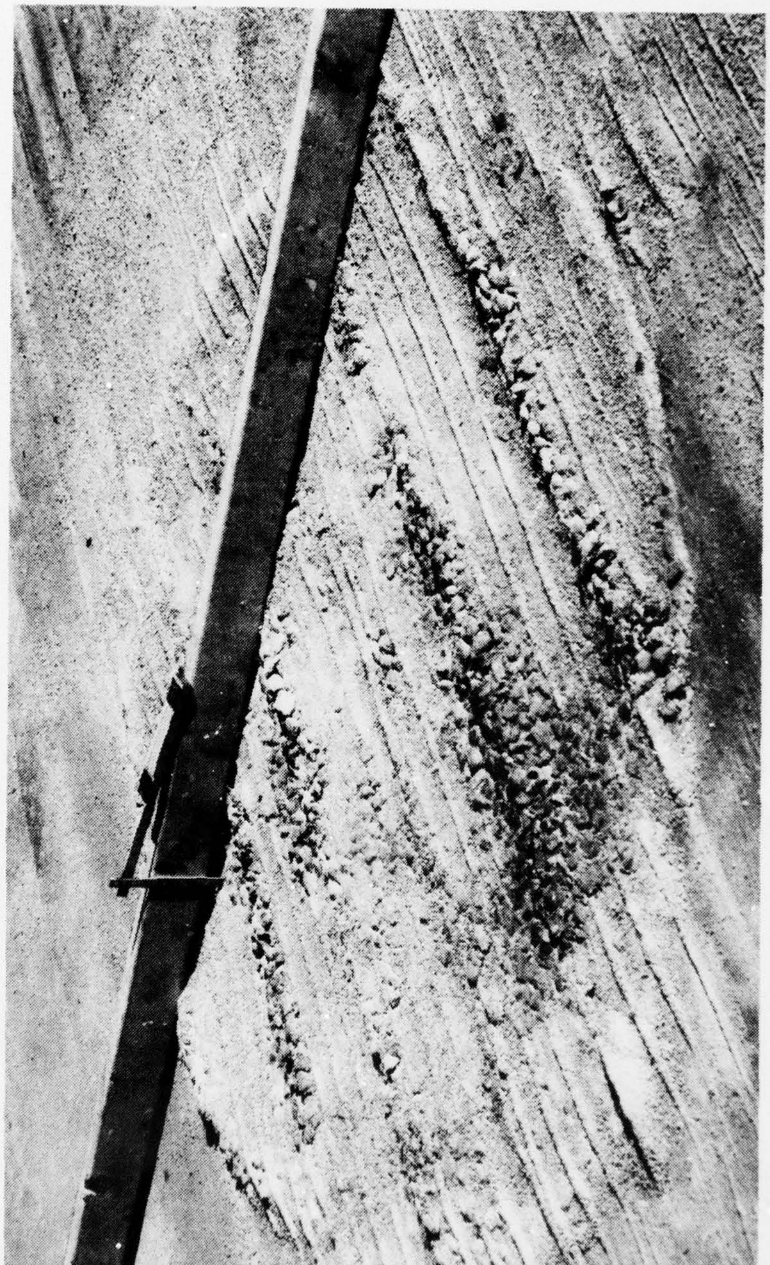
Figure 64. Gradation of Crushed Limestone Used in Macadam Repair

Figure 65. Pouring Hot Asphalt Cement Over Coarse Aggregate in Asphalt Macadam Repair

Figure 66. Heating Asphalt Macadam Repair with Propane Torch

Figure 67. Finished Surface of Asphalt Macadam Repair

Figure 68. Condition of Asphalt Macadam After Eight Coverages



Figue 69. Condition of Asphalt Macadam After Being Repaired and Application of a Total of 18 Coverages

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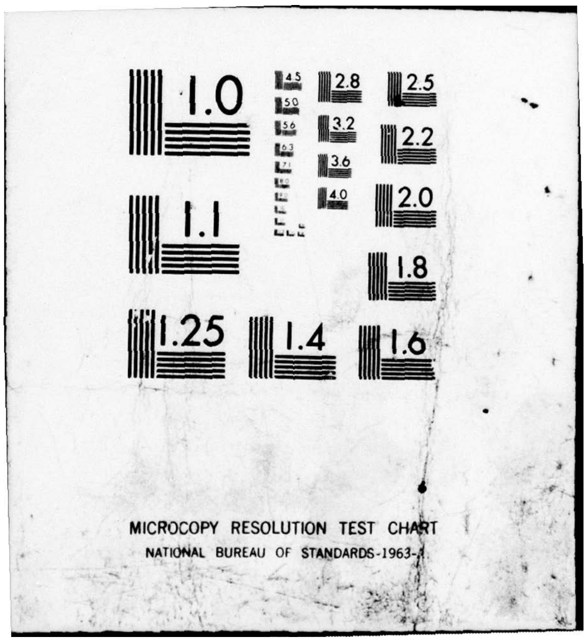
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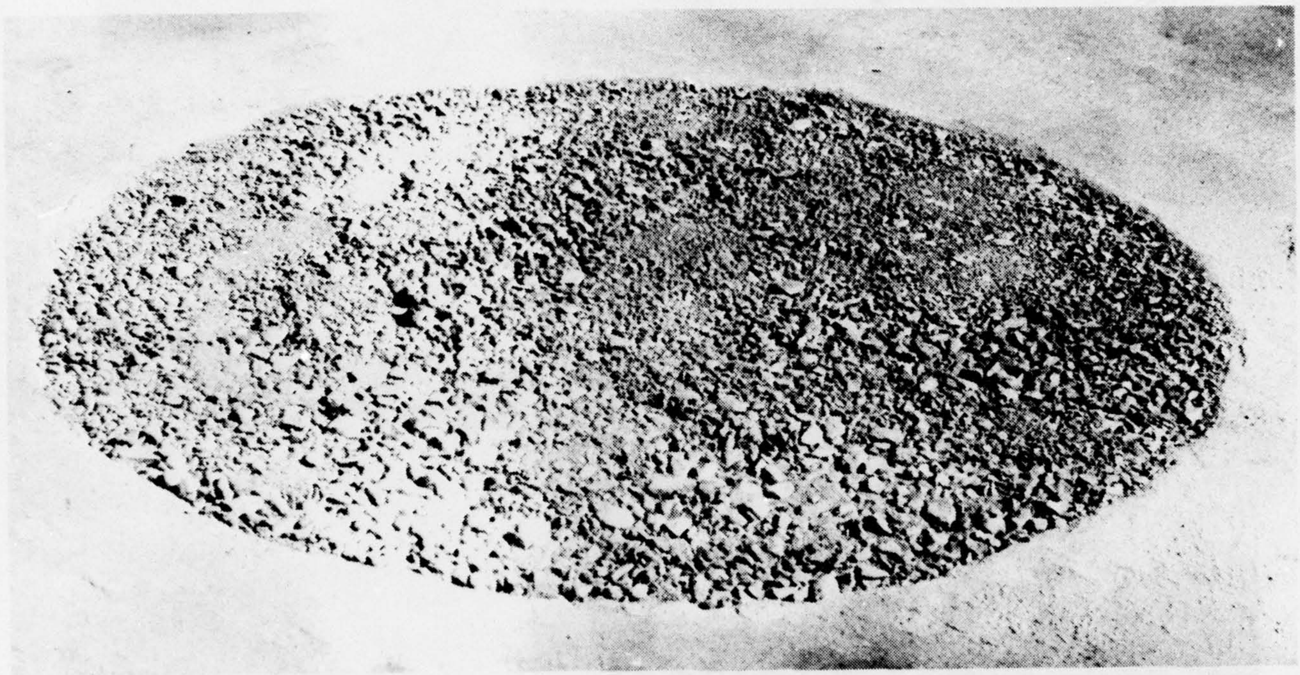

Figure 70. Finished Surface of Base Course in Asphalt-Saturated Felt Repair Area

Figure 71. Rolling Asphalt-Saturated Felt with 30-Ton Penumatic-Tired Roller with 90 psi Tire Pressure

Figure 72. Finished Surface of Asphalt-Saturated Felt Repair Area

TABLE 1. SUMMARY OF TESTS CONDUCTED

Material	Diameter of Area Repaired ft	Time Required, min			Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
		Placing Base Course	Mixing and Placing Material	Curing Before Traffic					
Darex 240	5	9	13	42	4 laborers 2 technicians 1 equipment operator 1 end loader 1 concrete mixer 1 mechanical tamper 2 trowels 1 straight edge	192	No sign of failure	None	Cannot be placed in rain or when water is in areas to be repaired
	2	Not used	4	42	Same as above	192	No sign of failure	None	
Zor-X	5	11	13	None	4 laborers 1 equipment operator 1 end loader 1 pneumatic-tired roller 1 forklift 1 mechanical tamper 1 hand tamper 2 hand shovels 1 rake	96 192	1-in. ruts 1-in. rut and soft	Area repaired by raking and adding material	Water at time of placing will adversely effect stability of the material
	2	Not used	7	None	Same as above	96	1/2-in. rut	Area repaired by adding material	
						192	Satisfactory		

TABLE 1. SUMMARY OF TESTS CONDUCTED (CONTINUED)

Material	Diameter of Area Repaired ft	Time Required, min: Placing Base Course	Mixing and Placing Material	Curing Before Traffic	Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
Hathane 1600A	5	5	7	34	1 engineer 2 technicians 2 laborers 1 end loader 1 hand mixer 2 hand shovels 1 straight edge	1	Failed		Water will cause material to foam and swell
	2	Placed with 5-ft area	Placed with 5-ft area	Same as 5-ft area					
Poly Products Epoxy Resin	5	8	10	30	1 engineer 2 technicans 2 laborers 1 end loader 1 hand mixer 2 hand shovels	192	Satisfactory except for loose rocks on surface	None	Water will adversely effect mixing and placing material
	2	Placed with 5-ft area	Placed with 5-ft area	Same as 5-ft area		195	Same as above	None	
Cold Mix AC No. 1	5	13	8	None	1 equipment operator 3 laborers 1 end loader 1 pick-up truck 1 mechanical tamper 2 hand shovels 1 hand rake	20	Rutting in cold mix	Area was repaired by leveling material and compacting with mechanical tamper	Water at time of placing will adversely effect stability of material
						40	Failed severe rutting		
	2	None	Placed with 5-ft area	None		20	Rutting failed	Area repaired by adding material	
						40	Fair		

TABLE 1. SUMMARY OF TESTS CONDUCTED (CONTINUED)

Material	Diameter of Area Repaired ft	Time Required, min: Placing Base Course	Time Required, min: Mixing and Placing Material	Time Required, min: Curing Before Traffic	Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
Polyester Resin	5	3	8	29	1 engineer 1 equipment operator 1 technician 3 laborers 1 end loader 1 hand mixer 1 straight edge	96	Surface of material cracked under traffic, some loose material noted	None	Mixing and placing during rainy weather would adversely effect the stability of the material
	2	1	2	29	Same as above	96	Patch did not bond at edges and rocked under traffic	None	
	8	28	13	29	Same as above	96	Cracks in surface of material; minor amount of loose material noted	None	
Fondu Concrete	5	None	4	66	1 engineer 3 technicians 3 laborers 1 operator 1 3-bag concrete mixer	192	No sign of failure	None	Excessive moisture will effect strength and setting time; cannot be placed in rain

TABLE 1. SUMMARY OF TESTS CONDUCTED (CONTINUED)

Material	Diameter of Area Repaired ft	Time Required, min: Placing Base Course	Time Required, min: Mixing and Placing Material	Time Required, min: Curing Before Traffic	Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
Amalgapave	5	15	22	None	1 engineer 1 technician 3 laborers 1 operator 1 front-end loader 1 mechanical tamper 1 pneumatic-tired roller	192	3/4-in. deformation; no cracking or raveling	None	Excessive water would adversely effect stability of material
	2	None	13		Same as above	96	1-in. deformation	Added material to surface	
						192	No cracking or raveling		
Cold Mix No. 2	5	15	15	None	1 technician 1 operator 3 laborers 1 front-end loader 1 mechanical tamper	12	Rutting and shoving;	None	Cannot be placed during rainy weather
						24	ruts 1-in. deep;	None	
						96	ruts 1-in. deep, material continually rutted and shoved		
	2	None	Placed with 5-ft area	None	Same as above	12	Rutting and shoving;		
						24	ruts 1-in. deep;	Added material	
						96	ruts 1-in. deep, material continually rutted and shoved under tire		

TABLE 1. SUMMARY OF TESTS CONDUCTED (CONTINUED)

Material	Diameter of Area Repaired ft	Time Required, min: Placing Base Course	Time Required, min: Mixing and Placing Material	Time Required, min: Curing Before Traffic	Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
Future Patch	5	12	11	None	1 equipment operator 4 laborers 1 front-end loader 1 forklift 1 mechanical tamper	192	1/2-in. deformation	None	Water will adversely effect stability of material
	2	None	Placed with 5-ft area	None	Same as above	192	1-in. deformation	None	
Sylvax	5	10	9	None	1 equipment operator 4 laborers 1 front-end loader 1 forklift 1 mechanical tamper	96	1-1/2-in.-deep ruts; material shoved under wheel load	None	Water will adversely effect stability of material
	2	None	Placed with 5-ft area	None	Same as above	96	Same as above	None	
Field-Mixed Amalgapave	5	Base course in place prior to test	7	None	1 equipment operator 4 laborers 1 front-end loader 1 mechanical tamper	96	1-1/2-in.-deep ruts; material shoved under wheel load	None	Placing material in water will adversely effect stability
	2	None	Placed with 5-ft area	None	Same as above	96	1-1/2-in.-deep ruts	None	

TABLE 1. SUMMARY OF TESTS CONDUCTED (CONTINUED)

Material	Diameter of Area Repaired ft	Time Required, min			Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
		Placing Base Course	Mixing and Placing Material	Curing Before Traffic					
Field-Mixed Cold Mix	5	Base course in place prior to test	7	None	1 equipment operator 4 laborers 1 front-end loader 1 mechanical tamper	96	1-1/2-in.-deep ruts; material unstable under wheel load	None	Placing material in water will adversely effect stability
	2	None	Placed with 5-ft area	None	Same as above	96	1-1/2-in.-deep ruts	None	
Crushed limestone with 5.5 bags per cubic yard of Type I portland cement	5	None	31	None	1 equipment operator 3 laborers 1 end loader 1 mechanical tamper 2 hand shovels	192	Small amount of loose rock on surface, otherwise satisfactory	None	Cannot be placed in rainy or freezing weahter
	2	None	Placed with 5-ft area	None	Same as above	192	Same as above	None	
Asphalt Macadam	5	15	30	10	1 engineer 1 technician 3 laborers 1 equipment operator 1 front-end loader 1 pneumatic-tired roller 1 mechanical tamper 1 asphalt kettle 1 LP gas torch	76 96	Failed (rutting and shoving) Failed (rutting and shoving)	Reshaped and recompacted	Cannot be placed in cold or wet weather
	2	None	Placed with 5-ft area	10	Same as above	76 96	Failed Failed	Reshaped	Same as above

TABLE 1. SUMMARY OF TESTS CONDUCTED (CONCLUDED)

Material	Diameter of Area Repaired ft	Time Required, min: Placing Base Course	Time Required, min: Mixing and Placing Material	Time Required, min: Curing Before Traffic	Size Crew and Equipment Used for Repair	No. of Passes in 10-ft-wide Traffic Lane	Condition of Patch	Maintenance Performed on Patch	Environmental Effects
Asphalt-Saturated Polyester Fabric	5	15	15	None	1 engineer 1 technician 3 laborers 1 equipment operator 1 front-end loader 1 pneumatic-tired roller 1 mechanical tamper 1 LP gas torch	24	Base course failed	None	Cannot be placed in rainy weather

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