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## BOMB CRATER REPAIR TECHNIQUES FOR PERMANENT AIRFIELDS

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REPORT 2 SERIES 2 A (U) ARMY ENGINEER WATERWAYS

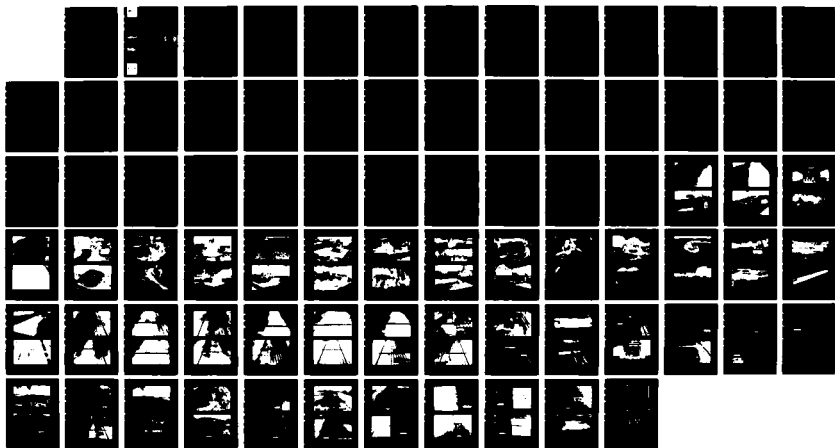
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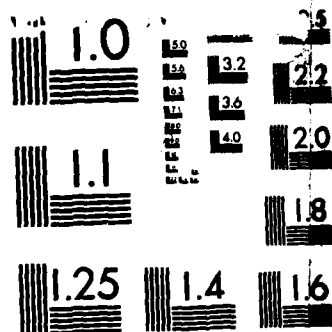
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TECHNICAL REPORT GL-81-12



US Army Corps  
of Engineers

AD-A164 394

# BOMB CRATER REPAIR TECHNIQUES FOR PERMANENT AIRFIELDS

Report 2  
SERIES 2 AND 3 TESTS

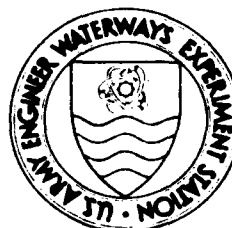
by

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Geotechnical Laboratory

DEPARTMENT OF THE ARMY  
Waterways Experiment Station, Corps of Engineers  
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Report 2 of a Series  
October 1985

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Work Unit 002

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20. ABSTRACT (Continued).

➤ Two series, Series 2 and 3, of tests were run to determine if (a) the loose stone problem at the surface could be eliminated from the well-graded crushed limestone, (b) materials could be used that would neither be affected by the weather nor require any compaction equipment, (c) a crushed aggregate that engineering troops in Germany were trying to use could be stabilized under traffic, (d) a way could be found to place grout with a minimum of equipment, (e) it was possible to cut down on portland cement concrete curing time, and (f) an unconventional pavement repair could be used. Testing consisted of accelerated traffic using either single- and/or multiple-wheel gear assemblies.



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## PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers, US Army, and was conducted under Project AT40, Task CO, Work Unit 002, "Repair and Restoration of Paved Surfaces (REREPS)," during the period August 1979 to July 1980.

Personnel of the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES) actively engaged in the planning and execution of work that led to the preparation of this report were Mr. A. H. Joseph, Mr. J. W. Hall, Jr., Dr. G. M. Hammitt II, Mr. P. S. McCaffrey, Jr., and Mr. S. J. Alford. This project was under the general supervision of Dr. W. F. Marcuson III and Mr. J. P. Sale, Chief and former Chief, GL, respectively. This report was prepared by Mr. Alford and Dr. Hammitt.

COL Allen F. Grum, USA, was Director of WES during the preparation of this report; Dr. Robert W. Whalin was Technical Director.

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

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

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons (U. S. liquid)	3.785412	cubic decimetres
gallons per square yard	4.5273	cubic decimetres per square metre
inches	25.4	millimetres
kips (force)	4448.222	newtons
pounds (force)	4.448222	newtons
pounds (force) per square inch	175.1268	newtons per metre
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic inch	27.6799	grams per cubic centimetre
pounds (mass) per cubic yard	0.5932764	kilogram per cubic metre
pounds (mass) per square foot	4.882428	kilograms per square metre
square feet	0.09290304	square metres
square inches	645.16	square millimetres
tons (2,000 lb, mass)	907.1847	kilograms

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\* 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:  $K = (5/9)(F - 32) + 273.15$ .

## BOMB CRATER REPAIR TECHNIQUES FOR PERMANENT AIRFIELDS

### SERIES 2 AND 3 TESTS

#### PART I: INTRODUCTION

##### Background

1. The responsibility for emergency war damage repair of U. S. Air Force air base facilities, including pavement and structures, is assigned to the U. S. Air Force for accomplishment within their organic service capabilities. The U. S. Air Force normally uses specially designed landing mat bomb crater repair kits for emergency repair of pavements. All war damage repairs beyond emergency, as well as emergency war damage repairs which exceed the organic capabilities of the U. S. Air Force, are the responsibility of the U. S. Army. The Army is further assigned the responsibility of developing improved repair and restoration systems for paved surfaces (REREPS) that would consider both the variations in damage levels from aggressor attacks and the operational requirements of U. S. forces. The systems to be evaluated were to include materials, equipment, and procedures that are designed to reduce manpower requirements, repair time, and cost as well as to improve the permanency of the repair. During early stages of hostilities, REREPS are among the most vital engineer support missions. Experience in recent conflicts has vividly illustrated the criticality of rapid repair of specific air base facilities.

2. This is the second in a series of reports and it addresses the repair and restoration of war damage beyond emergency repair to permit utilization by logistic aircraft as well as continued operations by tactical aircraft.

3. The 18th Engineer Brigade in Germany and the U. S. Army Engineer Waterways Experiment Station (WES) have been collaborating to seek a solution to the REREPS problem. In April 1977, WES and the 18th Engineer Brigade demonstrated an Army capability for REREPS using

regulated-set concrete. Subsequently, full-scale loading studies were conducted at WES on regulated-set concrete. As a material, the regulated-set was adequate, but as a total Army system, it has many disadvantages, such as limited shelf life, all-weather constraints, very large number of ready-mix trucks required, etc. However, training expertise in the use of regulated-set concrete is being maintained while other methods are being researched to determine the best one for European airfields.

4. Report 1 was a follow-up study (Series 1 tests) to the regulated-set concrete study (Hutchinson, Rone, and Denson 1981). These Series 1 tests were performed at WES in 1978 and 1979 (Cooksey 1981). Six fabricated craters were each repaired with one of the following materials:

- a. A well graded crushed limestone.
- b. An open-graded crushed limestone and grout.
- c. Portland cement concrete (PCC).
- d. Asphaltic concrete (AC).

5. When trafficked with full-scale loading, problem areas needing improvement or elimination became visible, as follows:

- a. Loose stone from the surface of the well-graded crushed limestone which would be a foreign object damage (FOD) problem under aircraft traffic.
- b. Additional compaction equipment is required to reach compaction requirements within the crater. Currently, there is no such equipment within the engineer battalion.
- c. The amount of equipment required to place the grout.
- d. Reduced the curing time for PCC from 7 days to 24 hr.

For these reasons the possibility of using something other than conventional pavement repairs was investigated.

#### Purpose

6. This investigation was conducted to further evaluate the field methods of repair and restoration of bomb craters employed in Series 1 tests. The test runway and the simulated gear loading were the same as

those described in Report 1 of this series. The object was to determine if the problems encountered in Series 1 tests could be surmounted and to explore other methods of repair that would be reliable and feasible during and after a hostile atmosphere. Concepts were discussed with military field personnel to delete any concept that was not practicably implementable by engineer troop units.

#### Scope

7. A series of tests (Series 2) were run to determine if the loose stone problem (FOD) could be eliminated from the well-graded crushed limestone repair and to test materials that would neither be affected by the weather nor require any compaction equipment. Another series of tests (Series 3) were run to (a) explore possible ways to use a particular crushed aggregate with which engineering troops in Germany are having problems, (b) find a way to place grout with a minimum of equipment, (c) cut down on the PCC curing time, and (d) test an unconventional pavement repair, a repair consisting of wooden timbers, not conventional pavement materials, crushed aggregate, asphalt, and PCC. Testing consisted of accelerated traffic using either single and/or multiple wheel gear assemblies. The construction techniques, material used for each of the crater repairs, and the behavior of these repair methods under traffic are described herein.

## PART II: CONSTRUCTION OF TEST CRATERS

### Series 2 Construction

8. Series 2 testing was performed in craters 1 through 3 at the original test site. Figure 1 shows the plan and profile of that section.

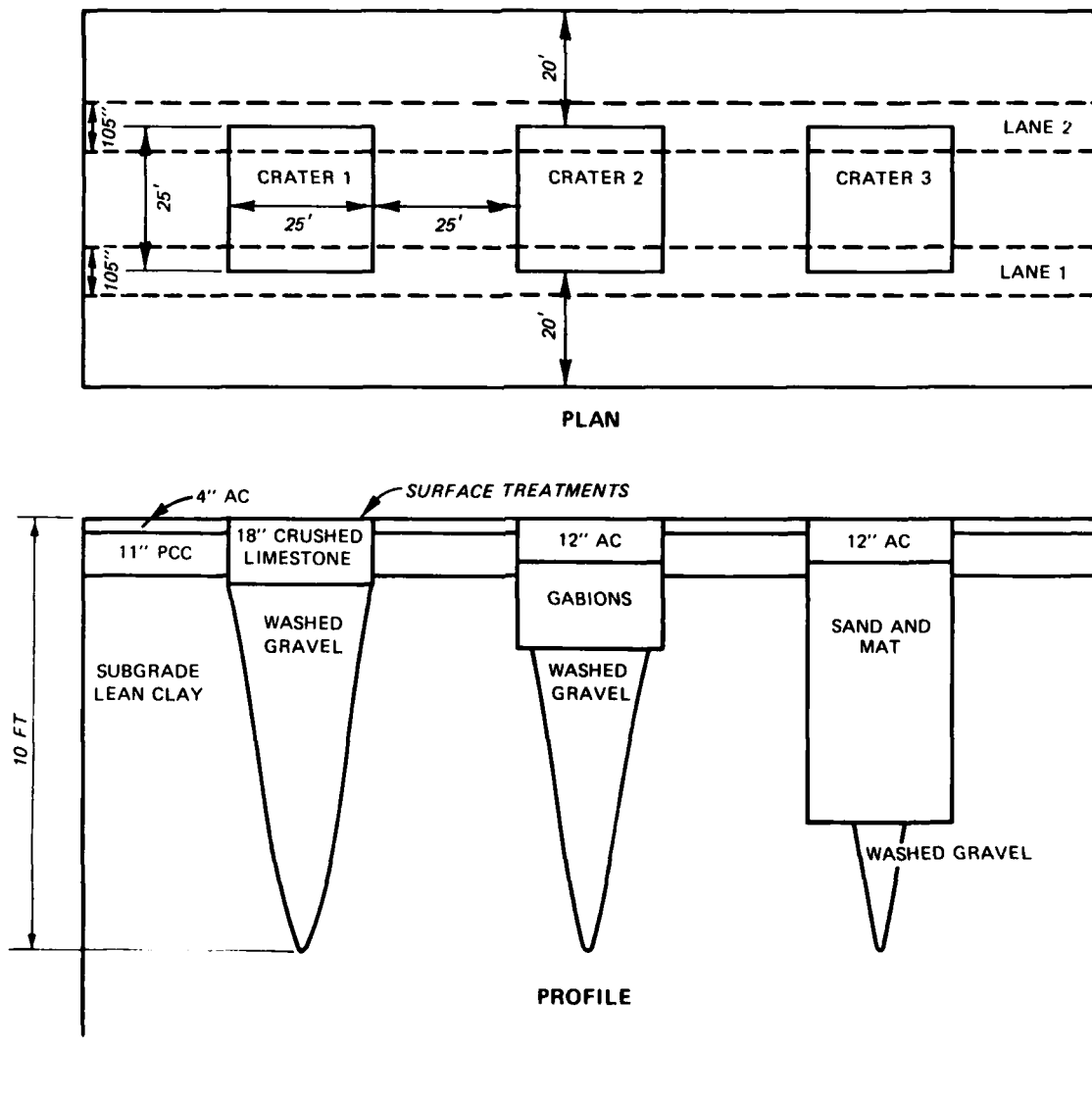


Figure 1. Plan and profile for Series 2 crater tests

### Crater 1

9. The repair of crater 1 consisted of 18 in.\* of crushed limestone over approximately 8.5 ft of washed gravel. This crater repair was constructed and tested in Series 1 tests as an unsurfaced crater repair method. After 5100 passes of C-141 traffic had been applied, the crater repair was in good condition with the exception of the loose stone (FOD) problem at the surface. In Series 2 testing, the state of the repair upon completion of Series 1 testing was left unchanged and was surface treated to try to correct the loose stone problem. Additional traffic was applied.

10. A single surface treatment (SST) was applied to lane 1 and a double surface treatment (DBST) to lane 2. The traffic lanes were swept with a power broom prior to placement of the surface treatments. Photo 1 shows lane 1 after sweeping. A cutback asphalt, grade MC250, was applied to the surface of the limestone (Photo 2) at the rate of 0.5 gal/sq yd. Photo 3 shows the traffic lane before applying 3/8-in. crushed limestone, which was used as the aggregate for the surface treatments. Photo 4 shows the limestone being placed on lane 2; lane 1 was covered in the same manner. The surface treatments were then rolled eight coverages with a self-propelled roller having a gross weight of 50,000 lb and 90-psi tire pressure (Photo 5). For the second layer of DBST on lane 2, MC250 was applied at the rate of 0.3 gal/sq yd (Photo 6). Limestone was spread over this and rolled eight coverages with the self-propelled roller. Photo 7 is a general view of the finished surface treatments.

### Crater 2

11. Crater 2 was excavated to a depth of 3 ft below the surface of the asphalt. The 7 ft of washed gravel in the bottom of the crater from a previous test (Series 1) was left in place. Two layers of wire gabions filled with 3-in. open-graded crushed limestone were placed over the washed gravel and capped with 10 to 12 in. of AC.

12. The wire gabions were fabricated from 4-ft, 12-gage chain link fencing (Photo 8). Two sizes of gabions were used. The fencing

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\* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

was cut into 8- and 10-ft lengths and folded to make gabions 4 and 5 ft long. Two sides of the fencing were then laced with 1/4-in. cable. Two stands were made to hold the gabions for filling from a front-end loader (Photo 9). After filling, the opening was laced with the cable used to lace the sides. Photo 10 shows a gabion ready for placement. Initially, the 5-ft gabions were placed in the crater (Photo 11) using a 10-ton crane. A second layer of 4-ft gabions was used to cover voids left by the bottom layer of gabions (Photo 12). The gabion ends were not square and neither the depth nor the thickness of the gabion was uniform, thus causing voids when placed end to end. These voids in the 4-ft gabions and around the edges of the crater were filled with loose 3-in. limestone (Photo 13). The crater was filled to within 10 to 12 in. of the surface of the pavement. To seat the gabions, the north traffic lane (lane 2) was rolled with one pass of a vibratory steel wheel roller at 27-kip dynamic force (Photo 14). The south lane (lane 1) was not rolled. Photo 15 shows the crater prior to placement of AC.

13. The AC was placed in two lifts. The first lift was dumped from trucks along the edge of the crater and spread with a front-end loader (Photo 16). The lift was then rolled three passes with a vibratory steel wheel roller at 27-kips dynamic force (Photo 17). The second lift was dumped from the trucks and spread and shaped with a motor grader and rolled four passes with the vibratory roller (Photo 18). The AC was placed late in the afternoon and the temperature was 250-300°F; therefore, the AC was not rolled until the following morning. The temperature of the AC was 140° when it was rolled four passes with the vibratory steel-wheel roller and eight coverages with the self-propelled roller, with 90-psi tire pressure and 50,000-lb gross weight (Photo 19).

### Crater 3

14. Crater 3 was excavated to a depth of approximately 7 ft. A wellpoint was placed in the bottom of the crater and covered with washed gravel (Photo 20). This wellpoint was used to remove the water used in achieving compaction of the sand. Aluminum landing mat panels, 2 by 12 ft, were placed on edge at 3-ft centers, perpendicular to the direction of traffic, in the bottom of the crater. The purpose of the mats

was to work as shear piling in the sand. The areas between the mats were filled with sand. The sand was dumped by front-end loader into the crater (Photo 21). Since a backhoe was unsuccessful in leveling the sand (Photo 22), it was leveled to the top of the mat by hand (Photo 23). Water was sprayed on the sand for compaction (Photo 24) and pumped out using the wellpoint and a pump (Photo 25). No mechanical compaction devices were used for compaction. The mats for the second layer were placed parallel to traffic. The sand was spread and wet in the same manner as the first layer. The mats for the third layer were placed in the same way as the first layer but were offset so they would not be in line with the bottom layer. The sand was placed in the same manner as the first two layers. Photo 26 shows the crater prior to the placement of the AC. Following the same procedure used in crater 1, 10 to 12 in. of AC were placed over the sand. The density of the sand averaged 98.7 pcf with a 9.1 percent water content.

### Series 3 Construction

#### Washed gravel base

15. Series 3 testing was performed in craters 1-5 at the original test site. A washed gravel was used as fill material in all the craters. The depth of the washed gravel base ranged from 8.5 to 9 ft depending on the thickness of the top layer of material used in the crater repair (Figure 2). Materials in the craters other than washed gravel at the end of the Series 2 test program were removed and replaced with washed gravel. After such placement to the desired elevation in each crater, 2- by 12-ft aluminum landing mat panels were laid side by side over the washed gravel and rolled four passes with a self-propelled, steel-wheel, vibratory roller at 36-kip dynamic force (Photo 27). The mats were used because the washed gravel was very unstable and could not be rolled without them. The washed gravel was graded by hand for final elevation, and modulus of subgrade reaction,  $k$  (Department of Defense 1964b) tests were run in craters 2-5 (Table 1).



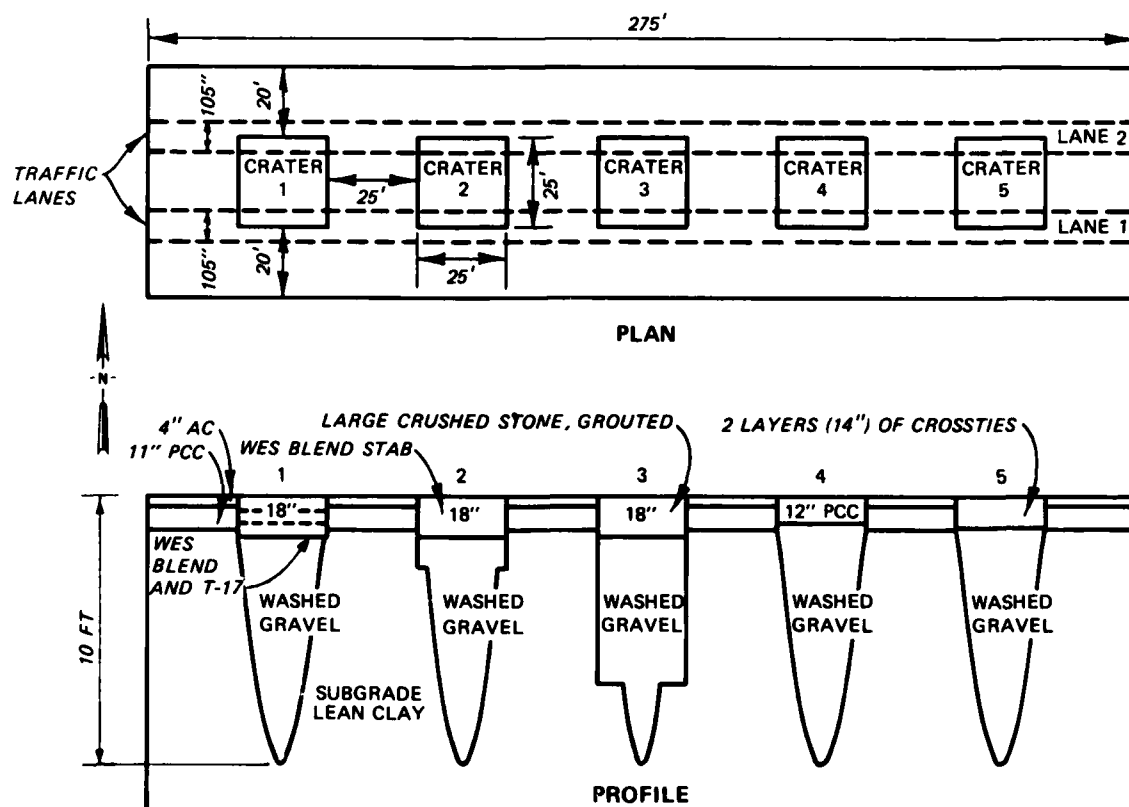


Figure 2. Plan and profile for Series 3 crater tests

Table 1  
Soils Data Series 3

Location	Modulus of Subgrade Reaction k, psi	CBR %	Density pcf	Water Content %	Material
Crater 1					
1st lift			118.5	2.7	WES blended
2nd lift		2	118.5	3.1	
3rd lift		3.4	117.6	4.7	
Crater 2					
Base	232				Washed gravel
Surface of the repair		150+	123.2	7.5	WES blended material stabilized with 8 percent portland cement
Crater 3					
Base	158				Washed gravel
Crater 4					
Base	200				
Crater 5					
Base	188				

### Crater 1

16. To simulate a particular crushed aggregate (0-32 mm)\* native to Germany, which was previously tested by the 18th Engineer Brigade and proven unstable under traffic, 18 in. of a WES blended material (gradation shown in Figure 3) and a T-17 membrane were used in the crater

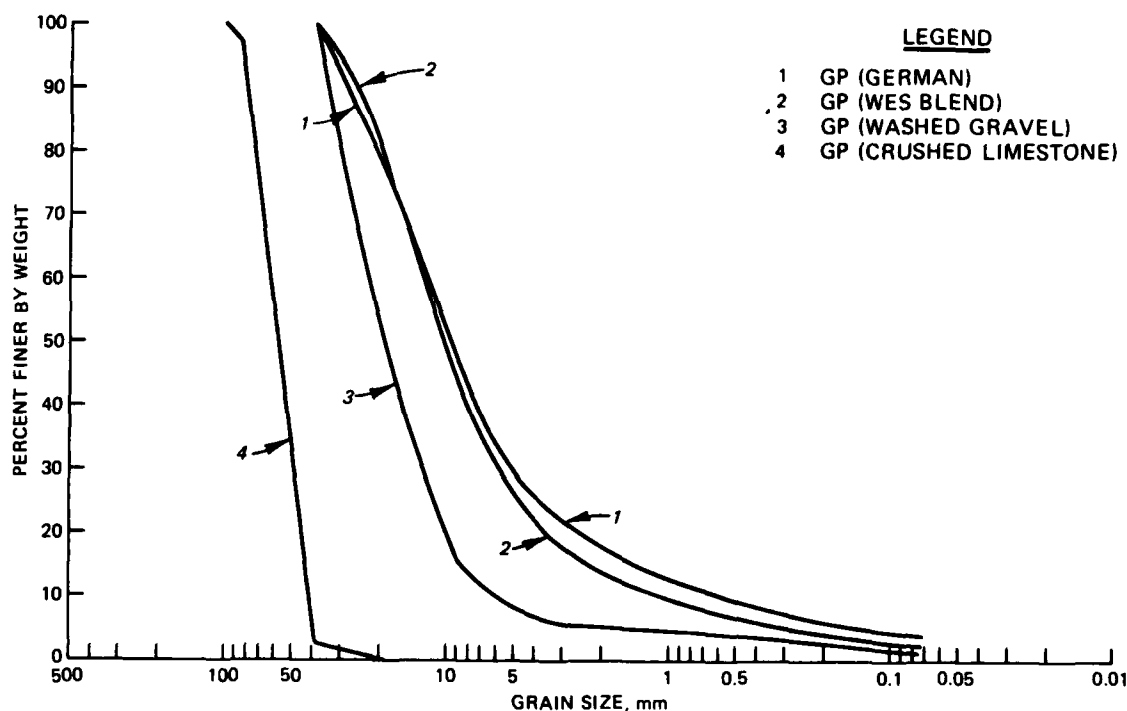


Figure 3. Gradation curves for aggregates used in the crater tests

repair. A piece of T-17 membrane, cut to fit, was placed over the washed gravel base. T-17 is a neoprene-coated, 2-ply nylon fabric designed to provide a waterproof and dustproof wearing surface for soil subgrades used as landing areas and roadways. The membrane consists of 54-in.-wide runs of fabric joined together with factory-glued lap joints. The dimensions of the membrane can be varied to fit the area to be covered. The membrane weight is 0.33 psf. Six inches of the WES blended material was placed on the membrane (Photo 28) and rolled three passes

\* The 0-32 mm gradation consists of primarily a one-size aggregate with no unconfined strength under traffic.

with a self-propelled, steel-wheel, vibratory roller (Photo 29) at 10-kip dynamic force. This material was very unstable and could not be rolled with a greater force. The rubber tires on the roller rutted the material and this was smoothed out by hand before placing the next lift. Placement of the T-17 membrane and the blended material was repeated twice more. The top two lifts were rolled with the vibratory roller at 18-kip dynamic force.

17. CBR's (Department of Defense 1964a), density, and water contents during construction of the crater repair are shown in Table 1.

18. After placement of the final lift of blended material, a piece of T-17 was placed over the crater repair with a 5-ft overlap onto the AC over jointed concrete (JC) pavement. This overlap was glued to the pavement using a synthetic rubber resin base adhesive. The glue was spread on the pavement and the membrane. When the glue became tacky the membrane was placed on the pavement and the joint was rolled with the rear wheels of a dump truck.

#### Crater 2

19. Eighteen inches of the WES blended material were stabilized with 8 percent (by weight) of portland cement and placed into the crater in three lifts. The blended material was spread approximately 1 ft thick on a processing area over which bags of portland cement were evenly placed. The bags of portland cement were broken and the cement was spread by hand (Photo 30). A pulvimixer was then used to mix the cement and blended material. This material was then piled with front-end loaders for further mixing and loading into dump trucks.

20. Water was added as the stabilized material was dumped into the crater and spread into 6-in. lifts with a front-end loader (Photo 31). Each lift was rolled three passes with the vibratory roller at 18-kip dynamic force. The crater was covered with polyethylene and cured for 7 days. CBR's were 150+ after the curing (Table 1).

#### Crater 3

21. For the repair of crater 3, an open-graded, normal 3-in. size crushed limestone (Figure 3) was dumped into the crater and grouted from the top. With a front-end loader the limestone was spread and leveled

approximately 2 in. above the AC over PCC pavement.

22. The grout mixture, which is familiar to German contractors, consisted of 759 lb of type I portland cement, 3034 lb of mortar sand (0-2 mm), 7.6 lb of calcium chloride, and 379 lb of water per cubic yard.

23. The grout was delivered to the crater in a ready-mix concrete truck in 8-cu-yd batches. The calcium chloride for the batch was hand mixed into 10 gal of water and mixed into the grout just before placement on the limestone. As the grout was placed on the limestone, it was spread by hand tools. The grouted limestone was rolled four passes with the vibratory roller at 36-kip dynamic force (Photo 32). This should have vibrated the grout to the bottom of the limestone (18 in.), but due to the stiffness of the grout mix only about 5 in. of penetration were obtained. Rolling of the grout and limestone was started in lane 1. At first, the 2-in. overfill of limestone compacted well under the roller. As the roller moved over the area, however, the overfill would not compact, probably because of some side movement of the limestone. Lane 2 had a 2-in. hump at the edge of the crater repair. After rolling the entire width of the crater there were surface voids (0.5 to 1.0 in.) due to the vibration of the roller. A cap of grout was spread over the crater using shovels and a 30-ft straightedge. A broom finish was applied and the repair was covered with 6-mil polyethylene for approximately 19 hr for curing. If this method of repair is used, the limestone should be graded level with the sides of the crater before grouting to avoid the overfill that would not compact.

#### Crater 4

24. PCC consisting of the following mix was placed to a depth of 12 in. in crater 4.

	<u>lb/cu yd</u>
Type I portland cement	611
Fine aggregate (minus 3/8-in. natural sand)	984
Coarse aggregate (1-1/2 maximum size chert gravel)	2052
Calcium chloride	6.1
Water	231

25. The PCC was delivered to the crater in a ready-mix concrete truck in 8-cu-yd batches. The calcium chloride for the batch was mixed into 10 gal of water and mixed into the PCC just before placement into the crater.

26. The PCC mixture was placed using hand tools and hand-held electric stinger-type vibrators. Two small gasoline-engine-driven vibrators mounted on two 30-ft aluminum straightedges (Photo 33) were used to screed the crater repair. Then the repaired area was bullfloated and a broom finish applied. The PCC was covered with 6-mil polyethylene for approximately 20 hr for curing.

#### Crater 5

27. Two layers of crossties were used for the crater repair in crater 5. The dimensions of the crossties were approximately 7 in. by 9 in. by 8.5 ft (Photo 34). The layers were placed on the gravel base parallel to traffic in order to stagger the joints, cutting crossties to fit where necessary (Photo 35). In like manner, the second layer of crossties was placed directly on the first layer perpendicular to traffic. The gravel base had been graded to an elevation such that the crossties would extend approximately 1 in. above the sides of the crater. This was done so the crossties could be seated into the gravel base with four passes of the vibratory roller at 36-kip dynamic force. Because of a slight variance in the size (width and height) of the crossties, there were cracks between the crossties and bumps on the surface after placement (Photo 36).

### PART III: TRAFFICKING ON TEST SITE

28. Only C-141 traffic was applied to the test craters in Series 2 testing. F-4 and C-141 traffic was applied to the test craters in Series 3 testing. F-4 was applied in lane 1 only, C-141 in both lanes. Figure 4 shows the traffic distribution pattern used for the traffic.

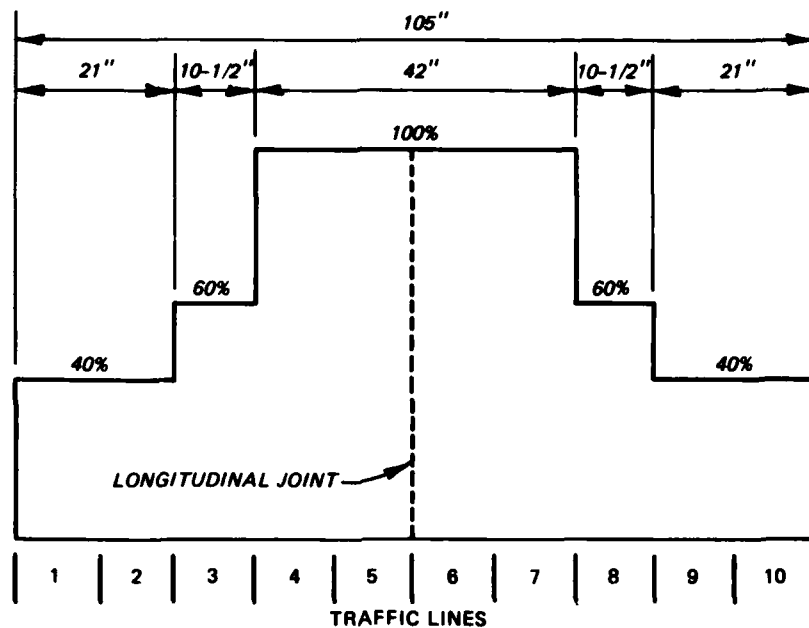
#### Series 2 Traffic

##### Crater 1

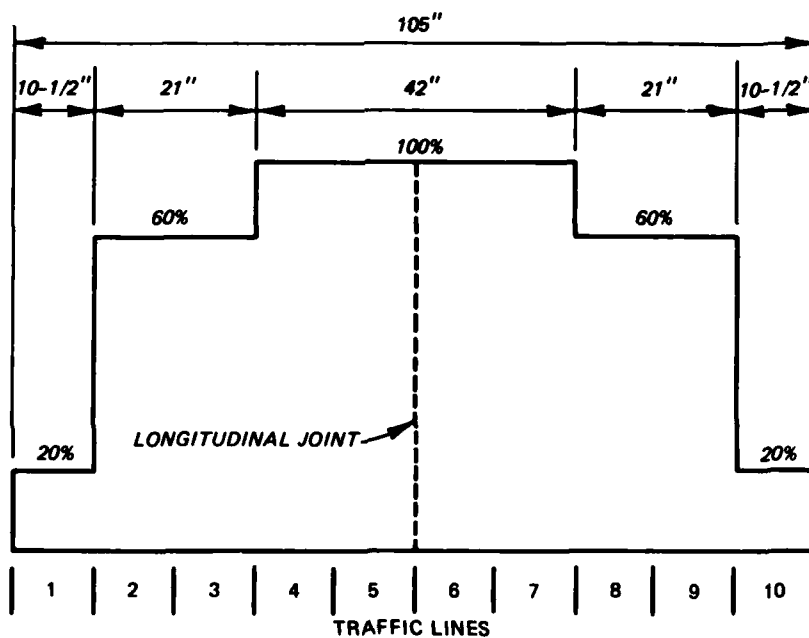
29. Lane 1. A total of 1360 passes or 400 coverages of C-141 traffic was placed on this crater repair which consisted of SST over 18 in. of crushed limestone. Photo 37 shows the traffic lane prior to traffic. After 340 passes or 100 coverages, the asphalt had started to bleed (Photo 38). Photo 39 shows the surface condition at 850 passes or 250 coverages. A 0.3-in. (Table 2) rut depth had developed in the crater repair at this traffic level. The surface treatment started to peel off the base at 1360 passes or 400 coverages (Photo 40). Traffic was stopped at this time (1360 passes).

30. Lane 2. Photo 41 shows DBST prior to traffic. There was more bleeding of the asphalt in this traffic lane than in lane 1. After 340 passes or 100 coverages the surface was tacky and should have been dusted with a fine limestone dust (Photo 42). After 510 passes or 150 coverages, a 0.25-in. rut was measured in the crater repair and this increased to 0.4 in. after 680 passes or 200 coverages (Table 2). Traffic was stopped after 850 passes or 250 coverages. At this pass level, asphalt was being tracked from the repair onto the regular pavement and the grooves in the tires were leaving impressions on the tacky surface (Photo 43).

31. Discussion. The surface treatments over the crushed limestone kept the limestone in place and corrected the loose stone problem that developed in the unsurfaced limestone repair in the Series 1 test. The bleeding problem experienced in this test was apparently due to the incorrect grade and quantity of asphalt. A material with faster set



**C-141 TRAFFIC PATTERN**



**F-4C TRAFFIC PATTERN**

Figure 4. Traffic distribution patterns used in Series 2 and 3 crater testing



Table 2  
Ten-Foot Straightedge Measurement of Rut Depth Across the  
Traffic Lane, Series 2 Testing

<u>Passes</u>	<u>Coverages</u>	<u>Crater 1, in.</u>		<u>Crater 2, in.</u>		<u>Crater 3, in.</u>	
		<u>Lane 1</u>	<u>Lane 2</u>	<u>Lane 1</u>	<u>Lane 2</u>	<u>Lane 1</u>	<u>Lane 2</u>
34	10					0.5	0.25
170	50			0.9	1.0	1.5	1.25
340	100			0.9	1.6	1.9	1.7
510	150		0.25	1.7	1.8	2.8	2.4
680	200	0.3	0.4	1.7	2.4		
850	250	0.3	0.4	2.0	3.0		
1360	400	0.3		2.0			

properties, such as an asphalt cement or emulsified asphalt, would give better performance. The SST performed better than the DBST. The SST did not bleed as much and the reveling did not develop as early.

#### Crater 2

32. Lane 1. This lane did not receive any compaction on the gabions prior to the placement of the AC. Photo 44 shows the crater at the start of traffic. After 170 passes or 50 coverages, the rut depth averaged 0.9 in. (Table 2) and increased with traffic to 2.0 in. after 850 passes or 250 coverages. At this point the crater repair stabilized. Traffic was continued to 1360 passes or 400 coverages (Photo 45).

33. Lane 2. The gabions in this lane received one pass with a vibratory steel-wheel roller before placement of the AC. Photo 46 shows the repair prior to traffic. As shown in Table 2 the rut measurement at 170 passes or 50 coverages was 1.0 in. and increased to 3.0 in. after 850 passes or 250 coverages, when traffic was stopped. Photo 47 shows the condition after 850 passes; the asphalt in the photo was tracked from crater 1, lane 2.

34. Discussion. The wire gabions offer a solution in the bottom of a wet crater, but were not an adequate semipermanent crater repair for C-141 traffic. They would serve for fighter aircraft loadings and

reduce time by reducing compaction effort.

#### Crater 3

35. Lane 1. Photo 48 shows the traffic lane prior to traffic. With the start of traffic the crater repair began consolidating, especially along the edges of the crater. Cold mix asphalt was placed at each end of the repair after 34 passes or 10 coverages to form a smooth transition between the regular pavement and the repair. The rut depth average was 0.5 in. (Table 2) at this pass level. As traffic continued a crack developed along the edges of the crater, as the AC used on the repair separated from the regular pavement. After 340 passes or 100 coverages the rut depth had increased to 1.9 in. Traffic was stopped at 510 passes or 150 coverages; the rut depth was 2.8 in. (Photo 49).

36. Lane 2. Photo 50 shows the crater repair before traffic. The performance was almost identical to lane 1. The rut depth did not increase as fast as in lane 1. After 34 passes or 10 coverages, the rut depth was 0.25 in.; 340 passes or 100 coverages, 1.7 in.; 510 passes or 150 coverages, 2.4 in. (Photo 51).

37. Discussion. The sand was compacted by saturation with water; however, this was not adequate to achieve densities necessary to prevent significant consolidation.

### Series 3 Traffic

#### Crater 1

38. Lane 1. Photo 52 shows the T-17 membrane in place over the WES blended material, prior to traffic. The F-4 tracking rig became stuck on the first pass over the crater repair (Photo 53). Photo 54 shows the tear in the membrane and a 5-in. rut left by the one pass. No further traffic was applied to this lane. Figure 5 shows typical cross-section data and the elevation of the T-17 used in the layers.

39. Lane 2. Photo 55 shows lane 2 before traffic. The C-141 tracking rig became stuck on the first pass. The average rut depth was 5.5 in. for both ruts (Photo 56); however, the membrane did not tear. Figure 6 shows cross-section data and the elevation of the T-17 used in construction.

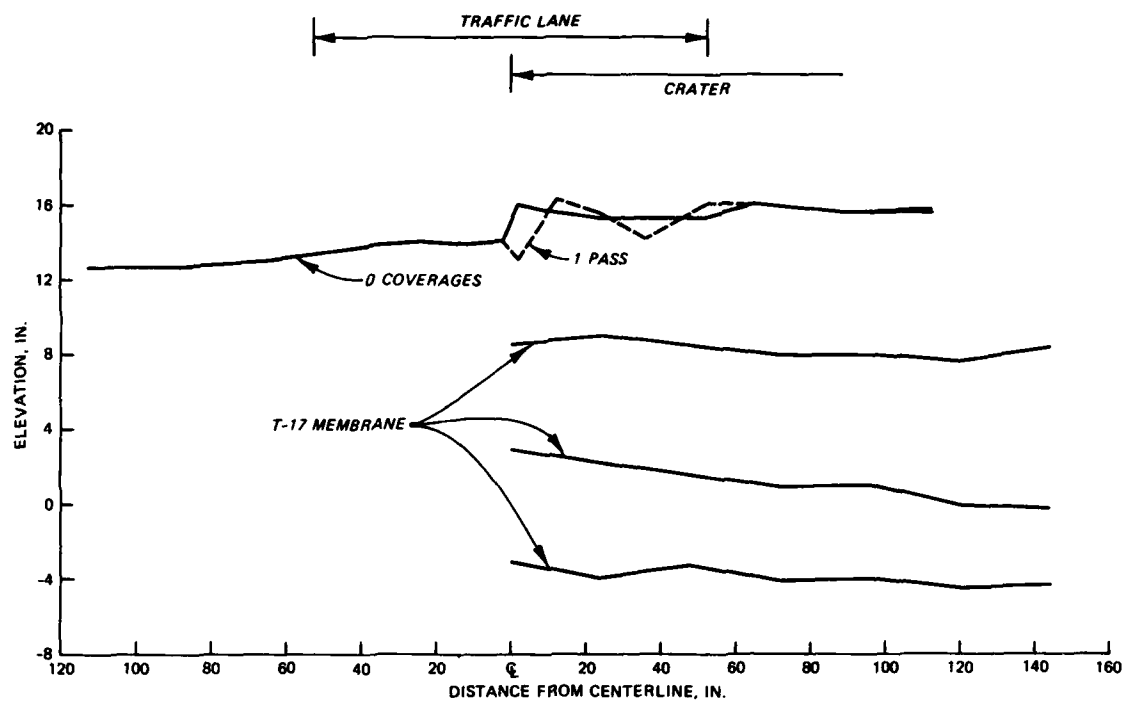


Figure 5. Cross section, crater 1, lane 1

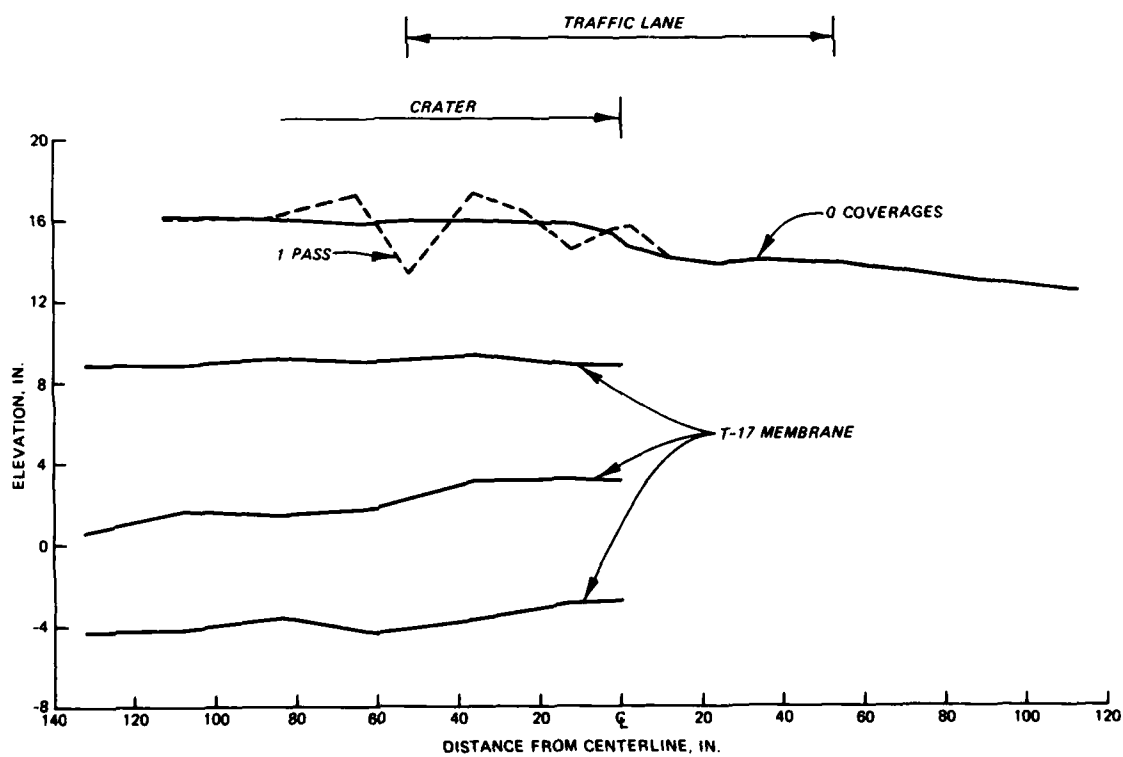


Figure 6. Cross section, crater 1, lane 2

40. Discussion. The WES blended material performed the same as the 0-32 mm German crushed aggregate, that is, it was very unstable. This material needs more fines added or chemically stabilized before it can be used as a crater repair material.

#### Crater 2

41. Lane 1. Photo 57 shows the surface conditions before traffic. Damage caused by F-4 traffic after 550 passes or 72 coverages was only a slight amount of raveling, with a small loss of surface aggregate (Photo 58).

42. C-141 traffic was applied after the F-4 traffic. The slight amount of raveling had stabilized or stopped after 340 passes or 100 coverages. At this time, the average deformation measured on a 10-ft straightedge was 0.8 in. A total of 2380 passes or 700 coverages of C-141 traffic was applied with no apparent damage. The average deformation at this coverage level was 1.0 in. (Photo 59). Figure 7 shows cross-section data for the C-141 traffic.

43. Lane 2. Photo 60 shows the surface condition of lane 2 prior to traffic. As in lane 1 the only damage was the raveling of the aggregate at the surface and it stabilized after approximately 340 passes or 100 coverages (Photo 61). The deformation measured on the 10-ft straightedge averaged 0.9 in. at 340 passes or 100 coverages, 1.5 in. after 1700 passes or 500 coverages, and 1.5 in. at 2380 passes or 700 coverages, at which time traffic was stopped (Photo 62). Typical cross-section data for this lane are presented in Figure 8.

#### Crater 3

44. Lane 1. Photo 63 shows surface conditions of the crater repair before traffic. F-4 traffic was begun the following day, 19 hr after placement of the grout. A total of 550 passes or 72 coverages of F-4 traffic was placed on this lane over a 24-hr period. Approximately six cracks developed in the traffic lane (Photo 64); these were probably shrinkage cracks.

45. C-141 traffic was started after the F-4 traffic 43 hr after placement. After 20 passes there were cracks along the edge of the crater, outlining the crater repair. Breaks started in the west end of

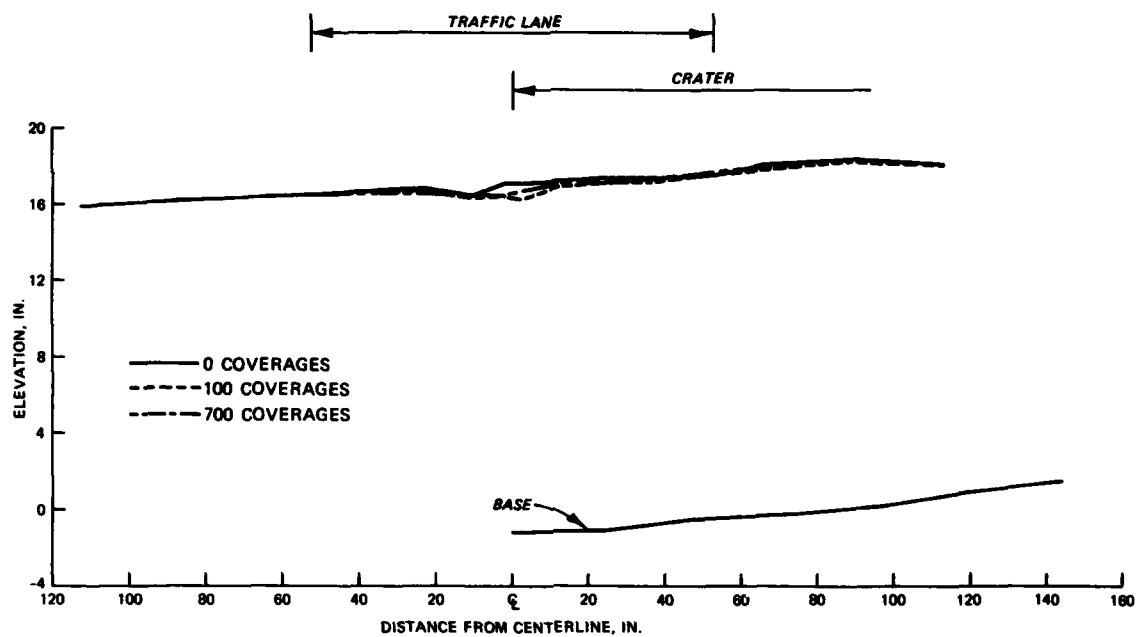


Figure 7. Cross section, crater 2, lane 1

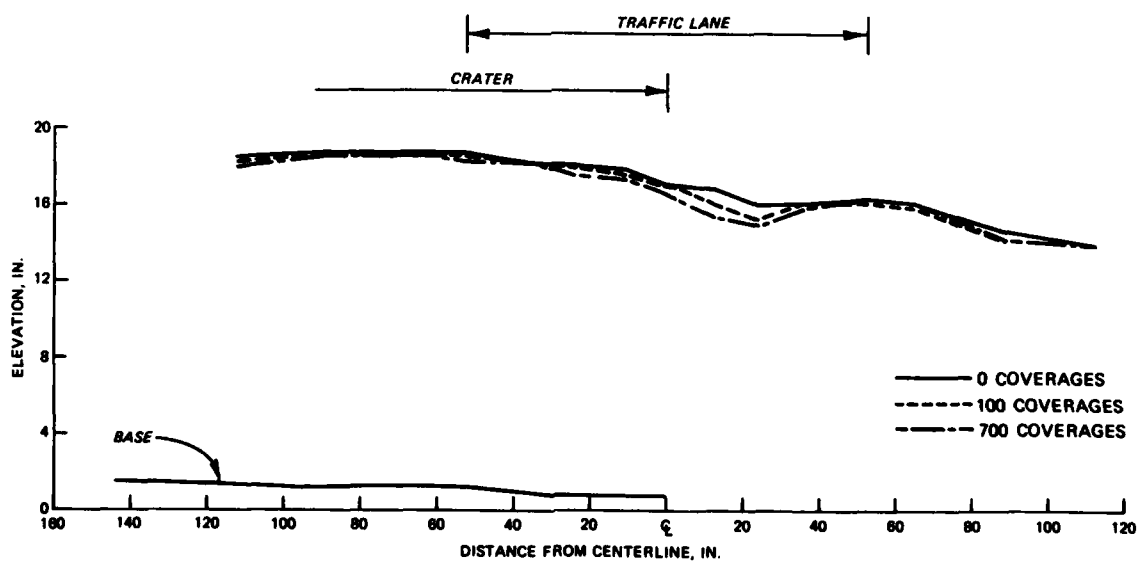


Figure 8. Cross section, crater 2, lane 2

the crater repair after 68 passes or 20 coverages. After 170 passes or 50 coverages the west end of the traffic lane started to consolidate, break up, and spall. As traffic continued the surface began to deteriorate, the grout breaking down into sand and cement. After 272 passes or 80 coverages this sand and cement were approximately 1 in. deep in an area 1.5 by 9 ft. At 340 passes or 100 coverages the maximum deformation was 3 in. (Photo 65). This was due to continuing consolidation and grout displacement under traffic. At 612 passes or 180 coverages the maximum deformation had increased to 4 in. in the west end of the traffic lane where the greatest amount of consolidation and grout displacement had occurred. Photo 66 shows conditions at 680 passes or 200 coverages when the deformation averaged 3 in. over the traffic lane and traffic was stopped. Figure 9 shows cross-section data from the center of the traffic lane.

46. Lane 2. C-141 traffic was started 22 hr after placement of the grout. Photo 67 shows the condition prior to traffic. Cracks along the edge of the crater started after 20 passes. After 102 passes or 30 coverages, block cracks started to develop inside the crater repair and minor spalling appeared on the west end. The surface started to deteriorate and consolidate at 136 passes or 40 coverages, and at 204 passes or 60 coverages the grout was approximately 0.5 in. deep (Photo 68). At 340 passes or 100 coverages approximately 0.5 in. of grout was displaced from an area 2 by 6 ft on the west end and from an area 2 by 3 ft on the east end. Consolidation under traffic and grout displacement resulted in a 2.75-in. maximum rut at this coverage level. Consolidation and grout displacement continued under traffic after 578 passes or 170 coverages. The maximum deformation was 3 in. inside the traffic lane, with loose aggregate (limestone) at each end of the traffic lane. After 680 passes or 200 coverages the crater repair was completely broken up with a 3-in. average deformation over the entire traffic lane. Photo 69 shows the breaks and areas where the grout was displaced. Figure 10 shows typical crosssection data for this lane.

#### Crater 4

47. Lane 1. F-4 traffic was applied to lane 1 20 hr after

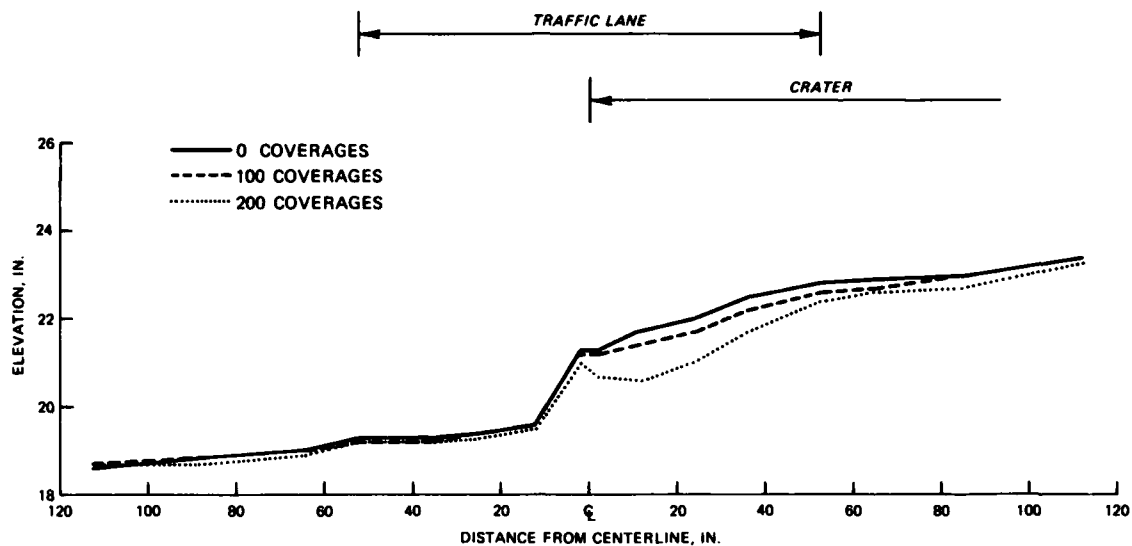


Figure 9. Cross section, crater 3, lane 1

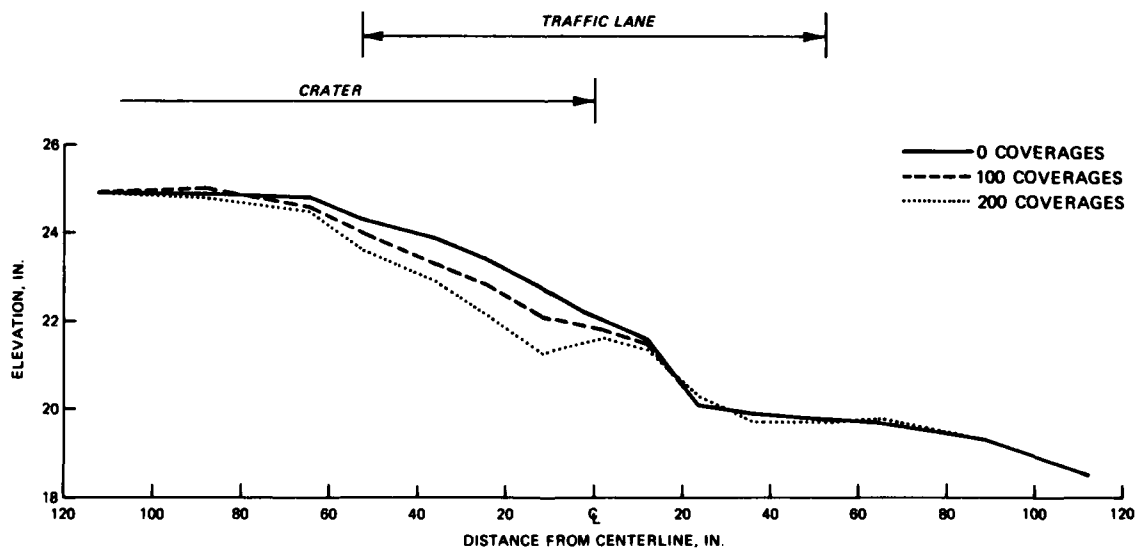


Figure 10. Cross section, crater 3, lane 2

placement of the PCC (Photo 70). Test methods CRD-C 16-76 and CRD-C 14-73 (WES 1949) were used at this time to determine flexural and compressive strengths of 415 and 2650 psi, respectively. There was no damage to the crater repair after 550 passes or 72 coverages of F-4 traffic.

48. C-141 traffic was started approximately 44 hr after placement of PCC. After 68 passes or 20 coverages a transverse crack appeared in the center of the crater repair. After 272 passes or 80 coverages a longitudinal crack appeared on the outside of the traffic lane in the crater repair. At 100 coverages there were three transverse cracks and the one longitudinal crack (Photo 71). At this time 7-day breaks were made on the PCC; the flexure strength was 650 psi and the compressive strength 4740 psi. Traffic was continued to 2380 passes or 700 coverages with no further damage to the PCC repair (Photo 72). Traffic was stopped 6 days before the 28-day breaks; the flexure strength was 775 psi and compressive strength 5690. Cross-section data for this lane are shown in Figure 11.

49. Lane 2. C-141 traffic was started 24 hr after placement of the PCC (Photo 73). At 204 passes or 60 coverages one transverse crack occurred in the center of the crater repair. A longitudinal crack was noted outside the traffic lane but in the crater repair area after 340 passes or 100 coverages; no traffic was being applied to the lane when the crack was found. This may have been a shrinkage crack. After 578 passes or 170 coverages there were three transverse cracks and the longitudinal crack in the crater repair. Photo 74 shows surface conditions at 680 passes or 200 coverages. This was the coverage level when the 7-day breaks, mentioned in lane 1, were broken. Traffic continued to 2380 passes or 700 coverages with only a minor amount of additional cracks (Photo 75). Figure 12 shows cross-section data for this traffic lane.

50. Discussion. Due to the way the PCC performed under traffic, it might be possible to start traffic sooner on this type of repair. The cracks in the PCC did not open up or spall during traffic. Additional cracks occurred in the PCC after traffic was discontinued. This may



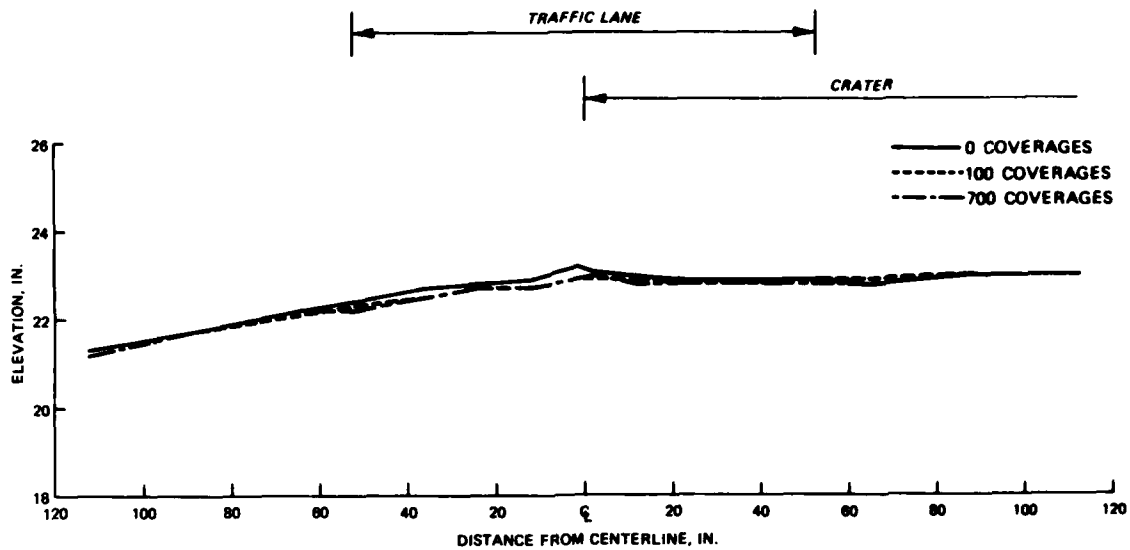


Figure 11. Cross section, crater 4, lane 1

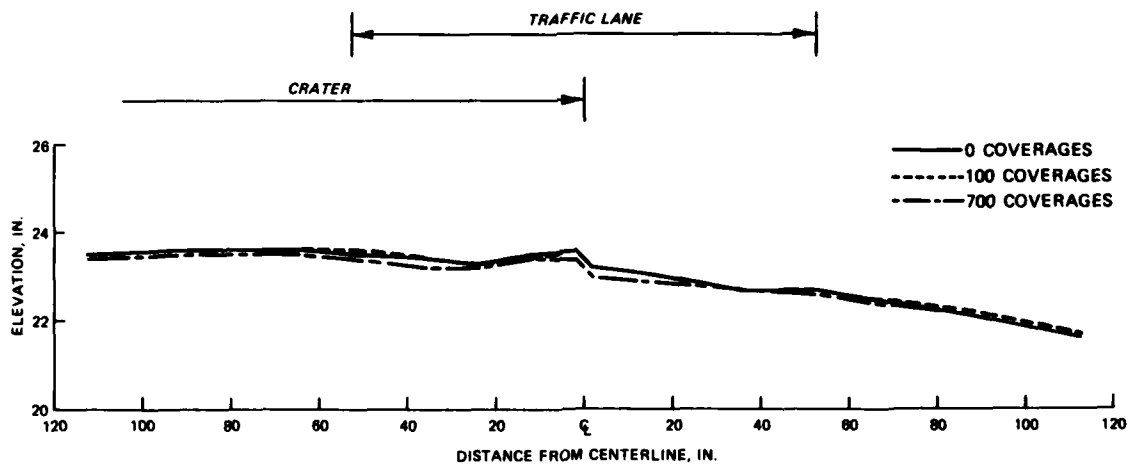


Figure 12. Cross section, crater 4, lane 2

indicate that the cracks were due to incomplete curing of the PCC and may not be load associated.

#### Crater 5

51. Lane 1. Photo 76 shows surface conditions of lane 1 prior to F-4 traffic. When the F-4 wheel rolled onto the end of a short crosstie, it forced up the other end approximately 1 in. Under traffic, the washed gravel base started consolidating at the edge of the crater. After 304 passes or 90 coverages there was 0.5 in. of deformation at the edge of the crater. After 550 passes or 72 coverages the deformation had increased to 0.75 in. (Photo 77).

52. With the start of C-141 traffic the washed gravel base consolidated at a faster rate. After 170 passes or 50 coverages the deformation averaged 1.5 in. The movement of the crossties stopped at this coverage level because C-141 traffic was placed in lane 2 prior to lane 1 and the traffic in lane 1 produced tension on the crossties with a slight bow up in the middle of the crater repair. The average deformation was 2.0 in. after 340 passes or 100 coverages. At 612 passes or 180 coverages cold mix was placed in the west end of the traffic lane to make a smooth transition between the crater repair and the AC over JC pavement. There was a 3-in. difference in elevation in the area where the cold mix was placed and the AC over JC pavement. After 918 passes or 270 coverages the average deformation was 2.6 in. Traffic was stopped after 1530 passes or 450 coverages; the average deformation was 3.2 in. (Photo 78). The cross-section data for lane 1 shown in Figure 13 indicate deformation in the pavement outside the crater repair. This could have been due to the lack of load transfer between the crossties and the other pavement. Figure 13 also shows the consolidation of the washed gravel base.

53. Lane 2. Photo 79 shows surface conditions before C-141 traffic. The washed gravel base started consolidating with traffic. After 136 passes or 40 coverages the average deformation was 1.5 in. at the edge of the crater repair. This increased to 2 in. at 340 passes or 100 coverages (Photo 80). There was some movement in the crossties under traffic but they were not forced up on the ends as in lane 1 under

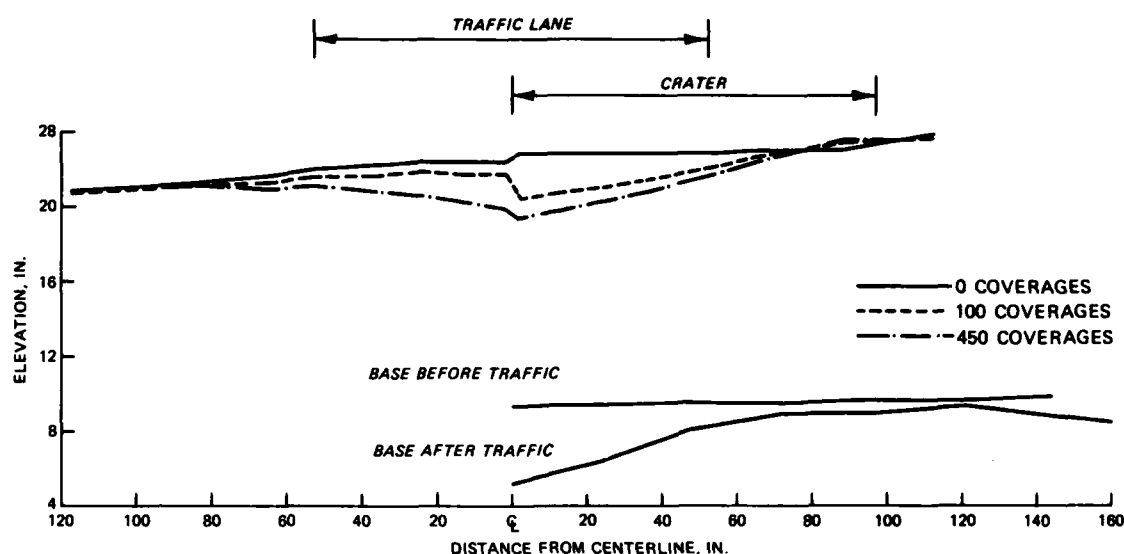


Figure 13. Cross section, crater 5, lane 1

the F-4. This movement stopped after 170 passes or 50 coverages had been placed in lane 1 as mentioned before. Cold mix was placed in the west end of the crater repair as in lane 1 at 340 passes. After 952 passes or 280 coverages the average deformation was 2.6 in. Traffic was continued to 1530 passes or 450 coverages; the average deformation was 3.0 in. (Photo 81). Figure 14 shows cross-section data at the surface of the traffic lane and the consolidation in the base. As in lane 1 there was movement in the pavement outside the crater repair.

54. Discussion. Photo 82 shows surface conditions of the crater repair after 1530 passes or 450 coverages of C-141 traffic had been applied in both traffic lanes. Note the unevenness of the crossties in the center of the crater and the permanent deformation at the edges. The pipe shown in the photograph was to be used to pump out water if it had rained an excessive amount during testing.

55. This crater test shows that when there is a 3-in. difference in elevation and this difference is almost vertical between the crater repair and the adjoining pavement, traffic will damage the pavement joining the crater because of uneven load transfer at the edge of the crater.

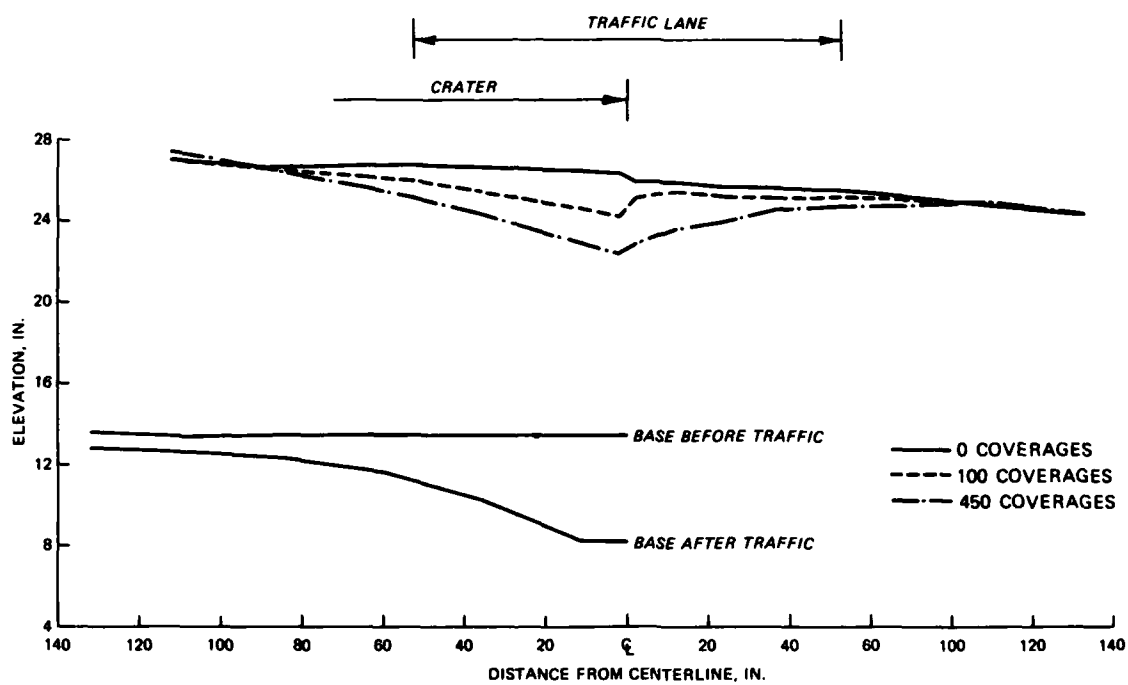


Figure 14. Cross section, crater 5, lane 2

#### PART IV: CONCLUSIONS AND RECOMMENDATIONS

56. The following conclusions and recommendations regarding crater repair methods are based on the findings of tests reported herein:

- a. A single surface treatment is a solution for the loose stone (FOD) problem if a crushed aggregate crater repair is used. But an asphalt material with fast set properties, such as an asphalt cement or emulsified asphalt, should be used and applied at the rate recommended for the size of the cover aggregate used for the single surface treatment (Series 2, crater 1).
- b. Gabions will not work unless all the voids between them are filled and adequate compaction placed on them before capping. However, they could be placed in the bottom of a large or a wet crater for a subbase material and another material used for the base (Series 2, crater 2).
- c. If sand is used in a crater repair, it must be compacted in layers with some type of compaction equipment; flooding with water was not adequate. The sand-landing mat reinforcement system as built was not satisfactory (Series 2, crater 3).
- d. To use the WES blended material simulating the German 0-32 mm gradation for a crater repair, it is necessary to stabilize such material with added fines or a stabilization material, such as asphalt or portland cement (Series 3, crater 1).
- e. The WES blend (German 0-32 mm crushed aggregate) performed well with the exception of the time required for the cement to hydrate and the surface aggregate which loosened under traffic. A single surface treatment or a membrane cover should eliminate the loose aggregate (Series 3, crater 2).
- f. Without penetration of the grout, the grout and open-graded coarse crushed limestone will not perform satisfactorily. If restricted to the grout mixture used in Series 3 testing, the grout should be placed in the crater and the limestone added. A neat grout (cement, water, calcium chloride, and friction reducer) (Series 1, crater 3) will work if the grout is placed in the crater first (Series 3, crater 3).
- g. The PCC crater repair performed excellently. There were cracks in the repair, but they did not impair the operation of traffic. These cracks were probably shrinkage cracks due to incomplete curing of the PCC. The cracks did not open up or spall under traffic. With the PCC mixture used, C-141 could be started earlier than the 24-hr

curing time used in Series 3 testing (Series 3, crater 4).

- h. The crossties showed that timbers could not be used for a surface material on a runway or taxiway because of their roughness, but it might be possible to use them on an apron. The timbers offer potential for a crater fill material capped with some proven type of capping material (Series 3, crater 5).
- i. There will be damage to the pavement adjoining the crater unless a smooth transition is maintained between the crater and adjoining pavement. This is caused by uneven load transfers between the crater and adjoining pavements.
- j. The SST and DBST were considered undesirable due to the uncertainty of the availability of asphalt products during wartime and also the difficulty in correct placement at correct temperatures.
- k. The wire gabions performed adequately after seating with the vibratory compactor, but the wire confinement offered no time advantage over unconfined rock placement. The need also existed for a relatively thick structural cap.
- l. The wetting of the sand for consolidation and inclusion of inverted landing mat for shear transfer did not perform adequately at the edges of the crater. Consolidation began noticeably from the beginning of traffic. The sand compacted by saturation with water did not achieve necessary densities.
- m. The 0- to 32-mm crushed aggregate with a membrane covering is an inadequate repair. More fines are needed to give the required densities at the surface.
- n. The blended crushed stone and 8 percent portland cement could be trafficked before the 7-day curing period and performance was adequate. Blending and mixing necessary to achieve adequate strengths is very time-consuming.
- o. The 5 in. of grout penetration into the open-graded 3-in. maximum size crushed limestone was not adequate for C-141 traffic. The grout mix must not be stiff to allow penetration. The percolation of the grout from the surface into the stone is difficult.
- p. The 12 in. of portland cement concrete and calcium chloride performed very satisfactorily for the anticipated traffic. Traffic was applied after 20 hr of curing and performance was outstanding. This type of repair is recommended for the semipermanent airfield repair if host nation ready-mix concrete trucks are available.
- q. Two layers of 7-in. wooden crossties would support the C-141 traffic on the parking aprons but not on the runway areas.

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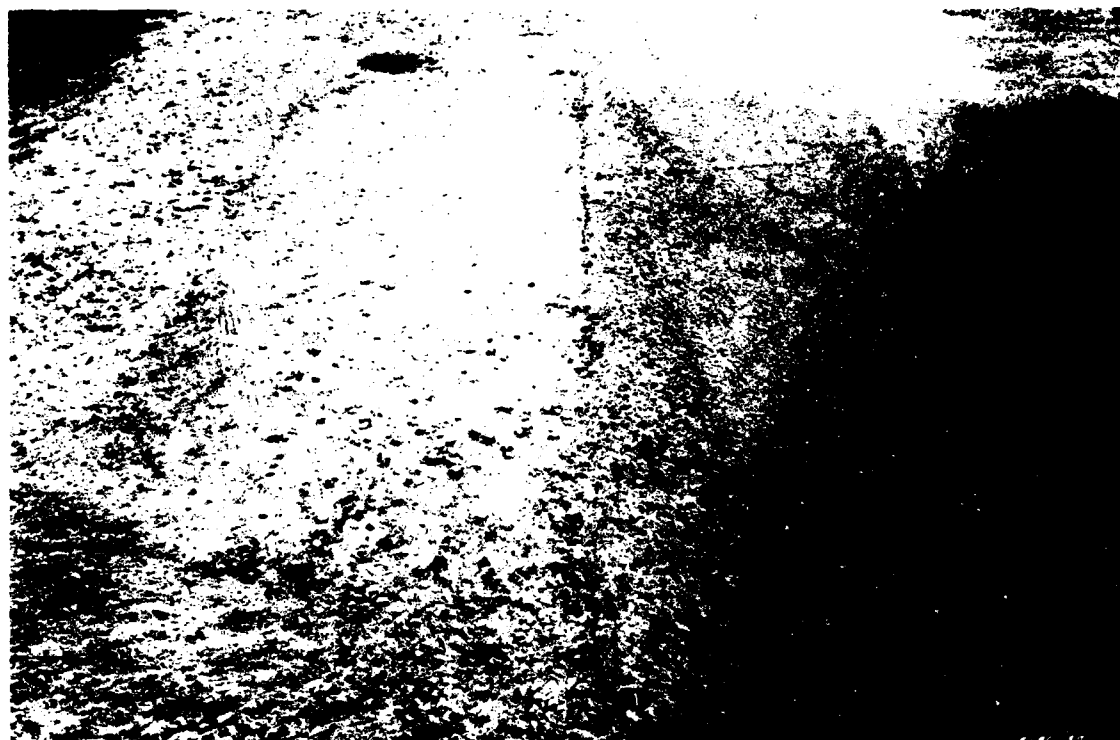


Photo 1. Crater 1, lane 1, after sweeping



Photo 2. Prime coat being applied to surface of crater 1



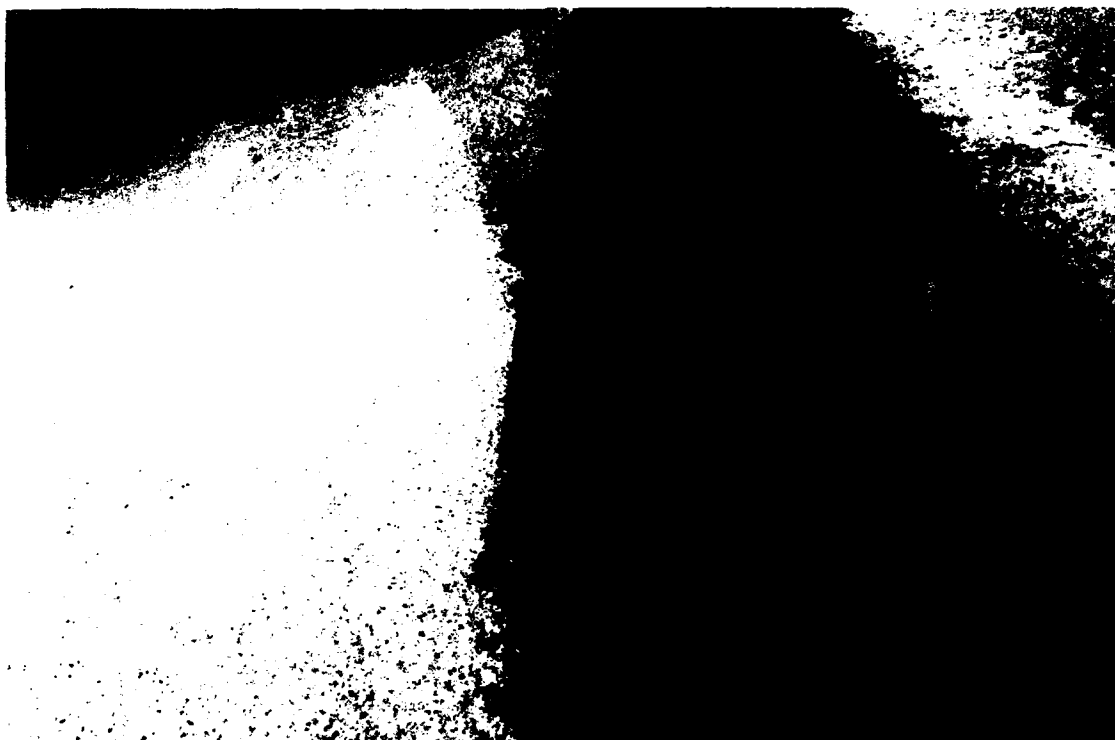


Photo 3. Condition before application of crushed limestone



Photo 4. Limestone being placed on lane 2



Photo 5. Rolling SST with self-propelled roller



Photo 6. MC250 being applied for DBST (lane 2)



Photo 7. Completed surface treatments

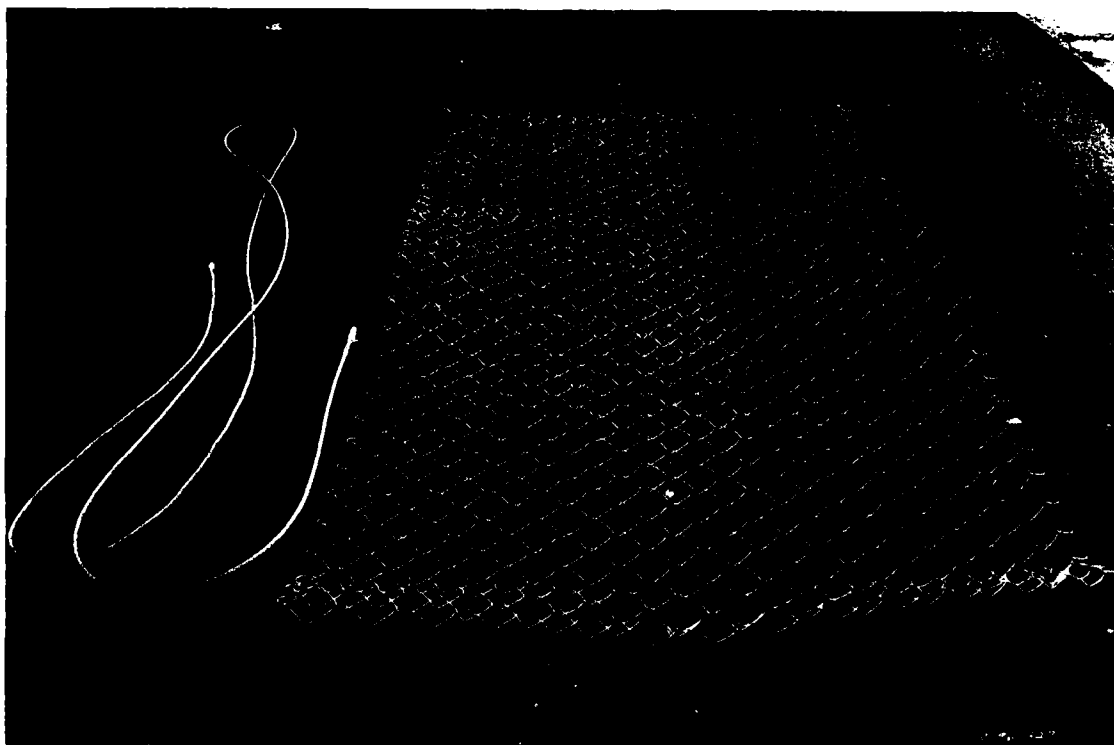


Photo 8. Chainlink fence and cable used for gabions in crater 2



Photo 9. Gabion being filled using a front-end loader

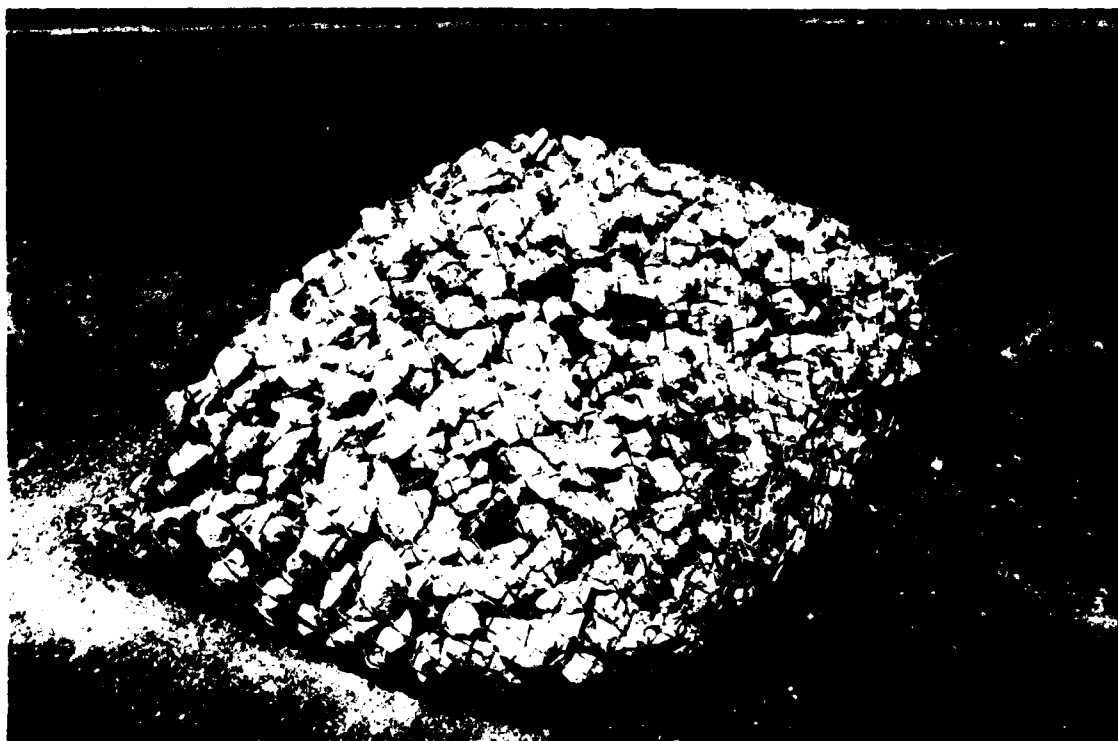


Photo 10. Gabion ready for placement



Photo 11. Placing gabions in crater



Photo 12. Placing second layer of gabions

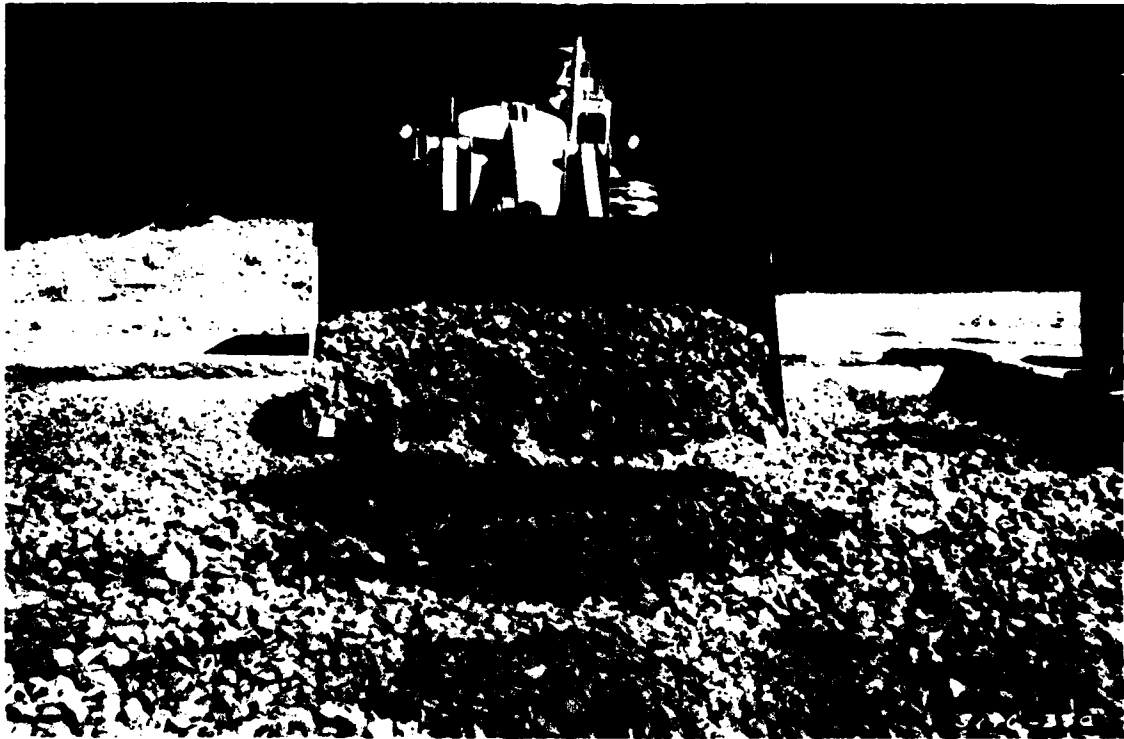


Photo 13. Voids being filled



Photo 14. Rolling lane 2 with vibratory roller

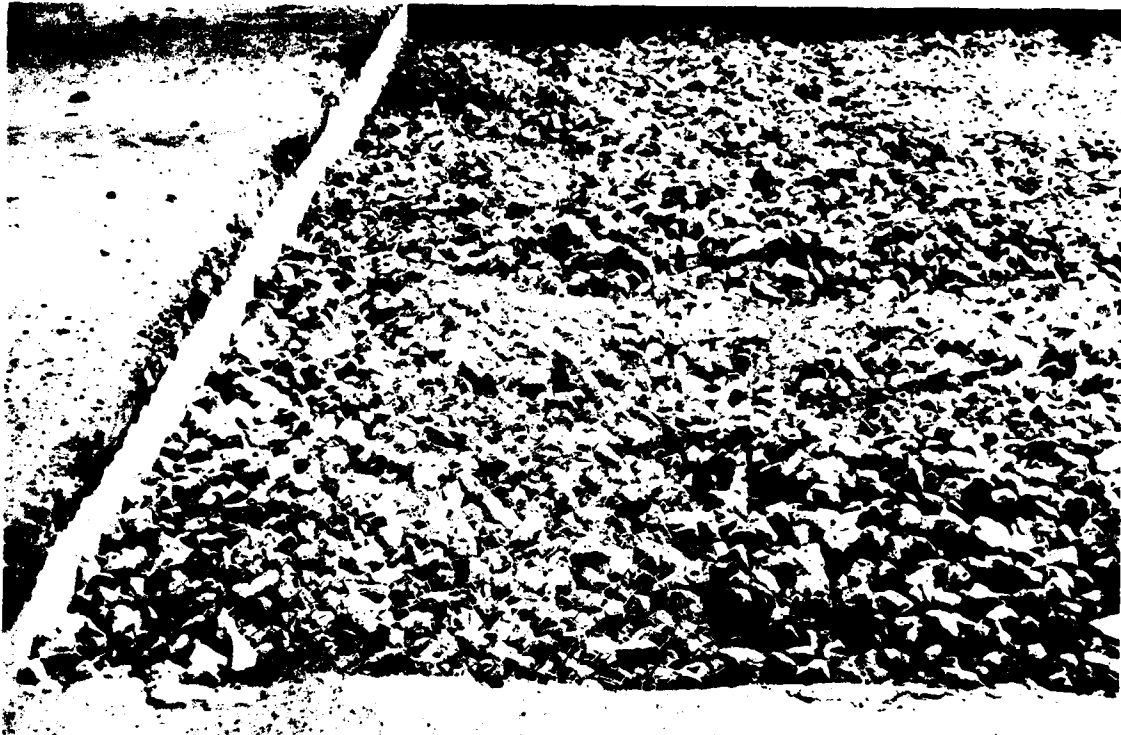


Photo 15. Crater prior to placement of AC



Photo 16. Front-end loader spreading first lift of AC

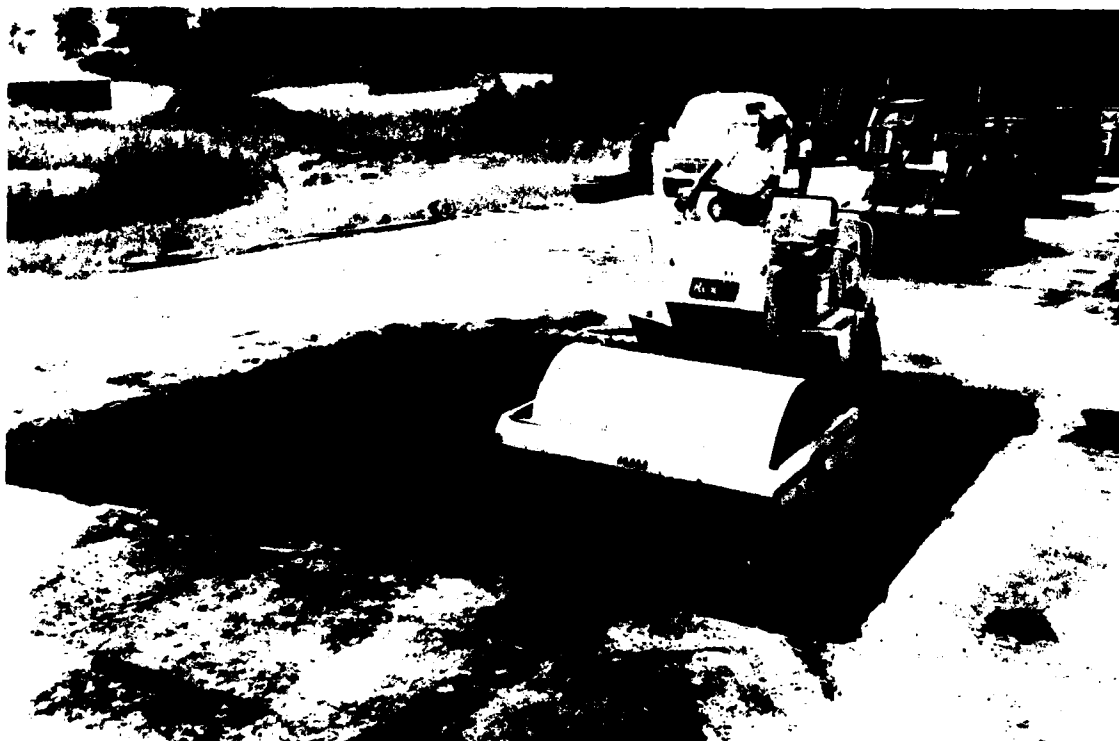


Photo 17. Rolling AC with vibratory roller

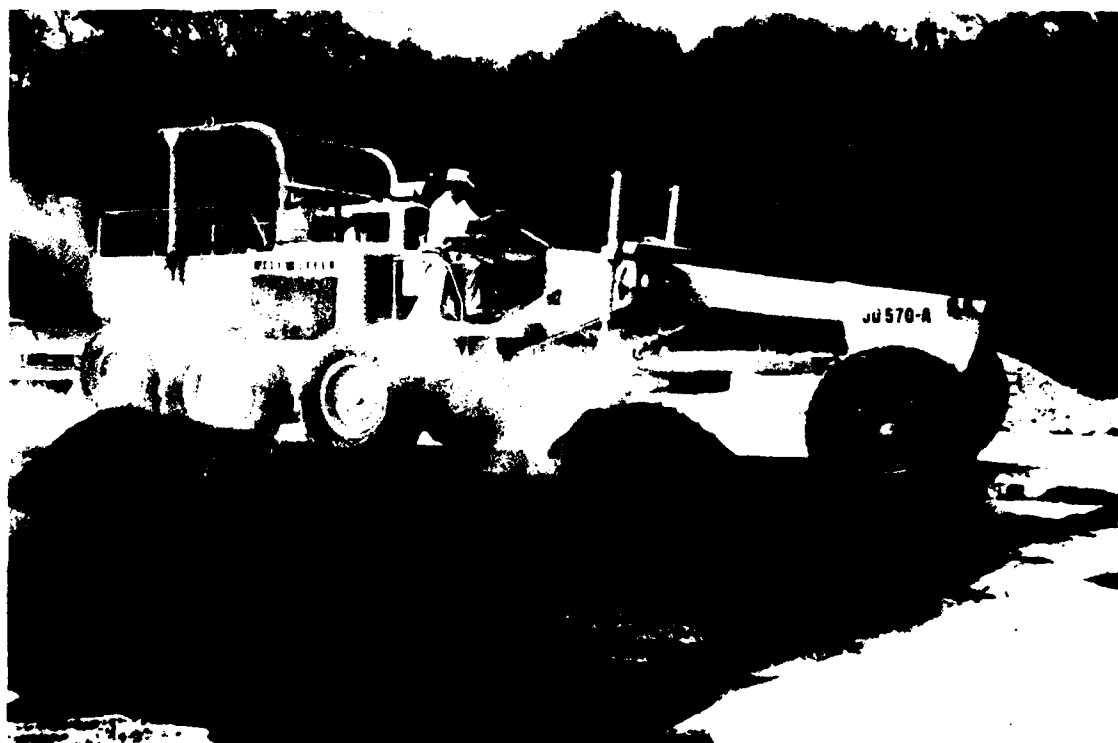


Photo 18. Motor grader spreading and shaping second lift of AC





Photo 19. Crater repair being rolled with vibratory roller  
and self-propelled roller



Photo 20. Placement of wellpoint in the bottom of crater 3

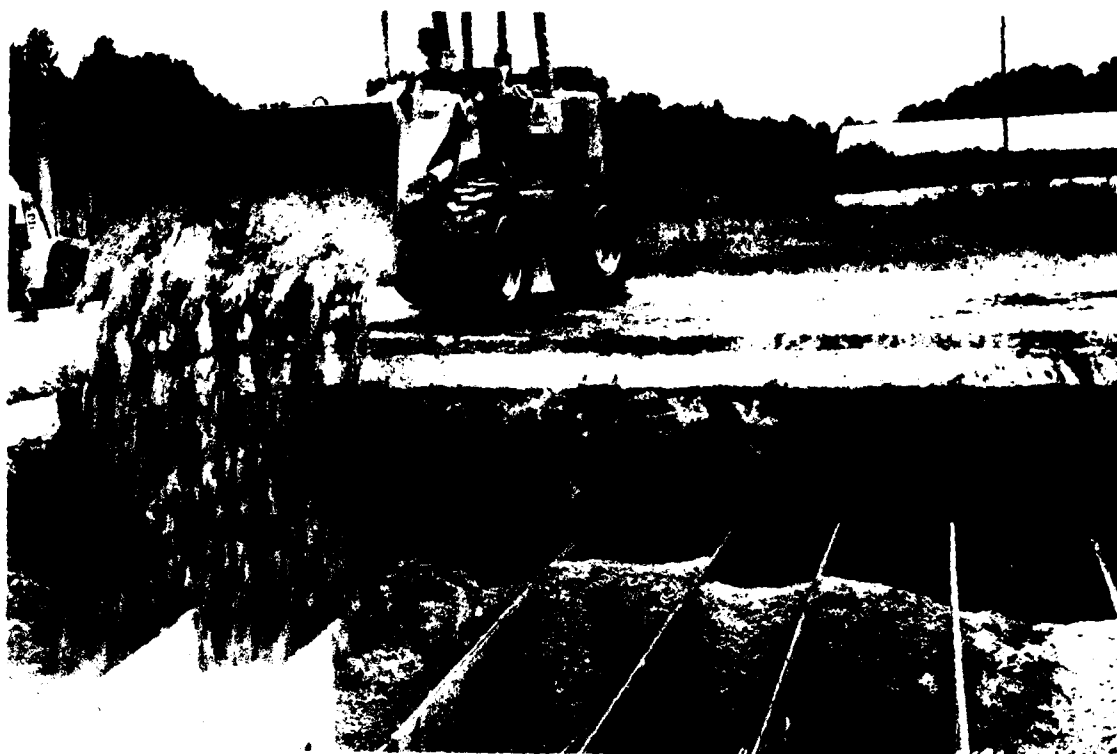


Photo 21. Placement of mat panels and filling with sand

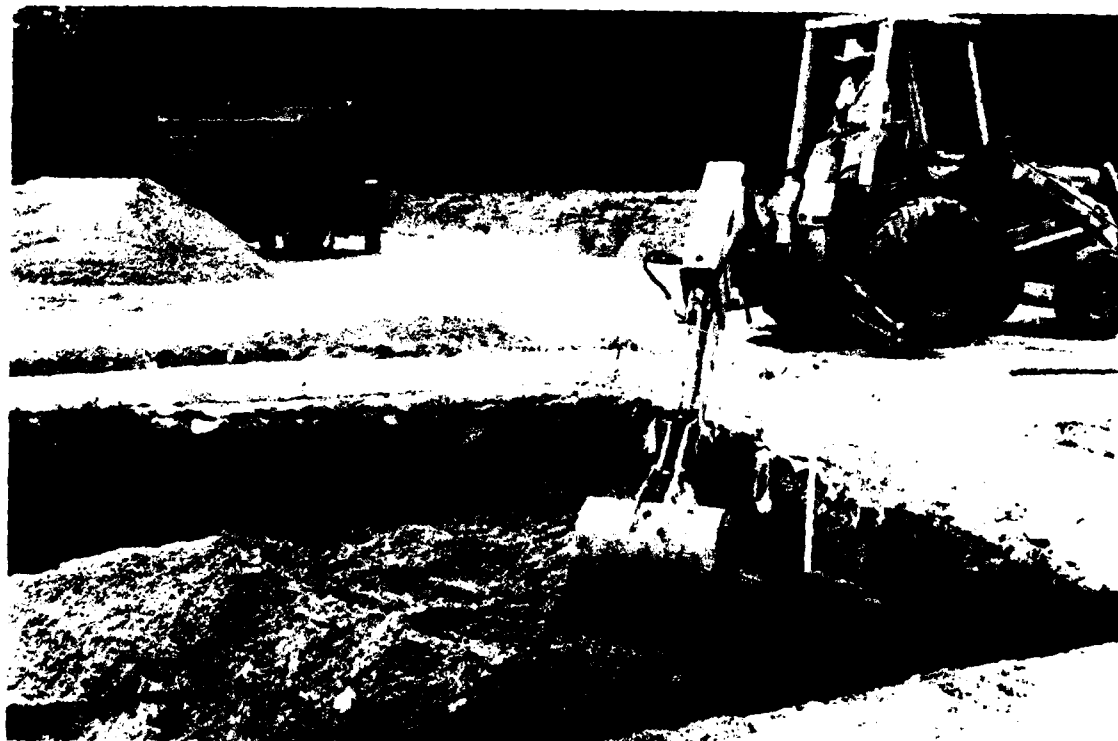


Photo 22. Unsuccessful attempt to level sand with backhoe



Photo 23. Leveling sand by hand

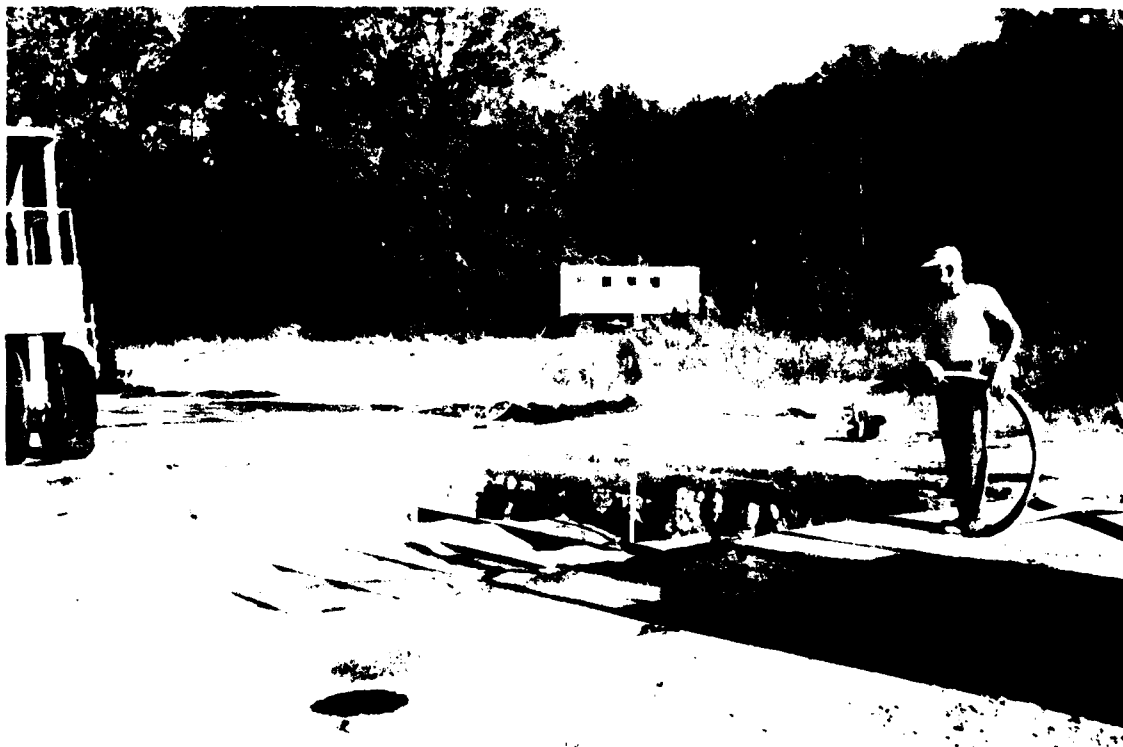


Photo 24. Sand being saturated for compaction



Photo 25. Water being pumped from crater 3



Photo 26. Crater prior to placement of AC



Photo 27. Rolling the washed gravel base



Photo 28. WES blended material on T-17 membrane



Photo 29. Rolling WES blended material



Photo 30. Spreading portland cement used in stabilization



Photo 31. Spreading of and adding water to stabilized material



Photo 32. Vibrating the grout into the open-graded limestone



Photo 33. Screeding and bullfloating PCC

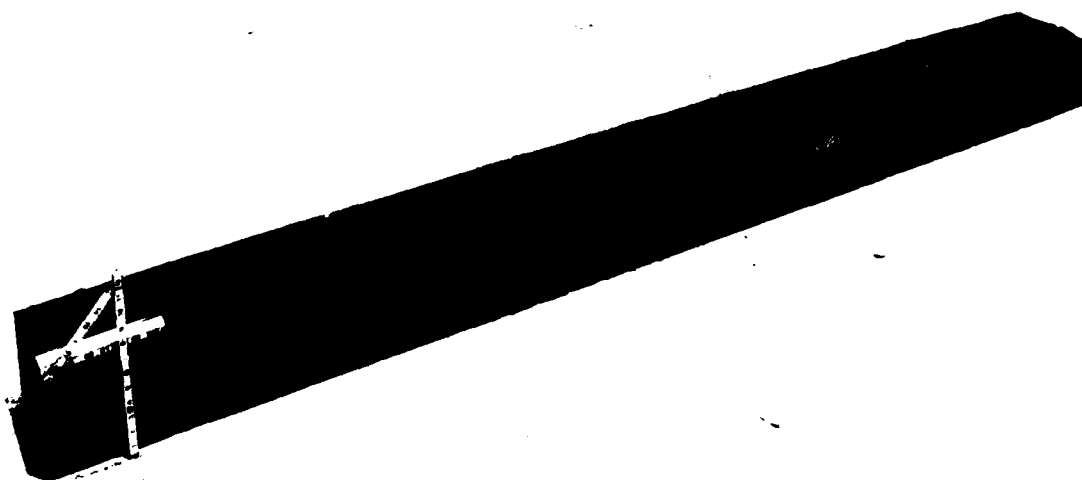


Photo 34. Crosstie used in crater 5





Photo 35. Placement of first layer of crossties



Photo 36. Surface of crossties after placement

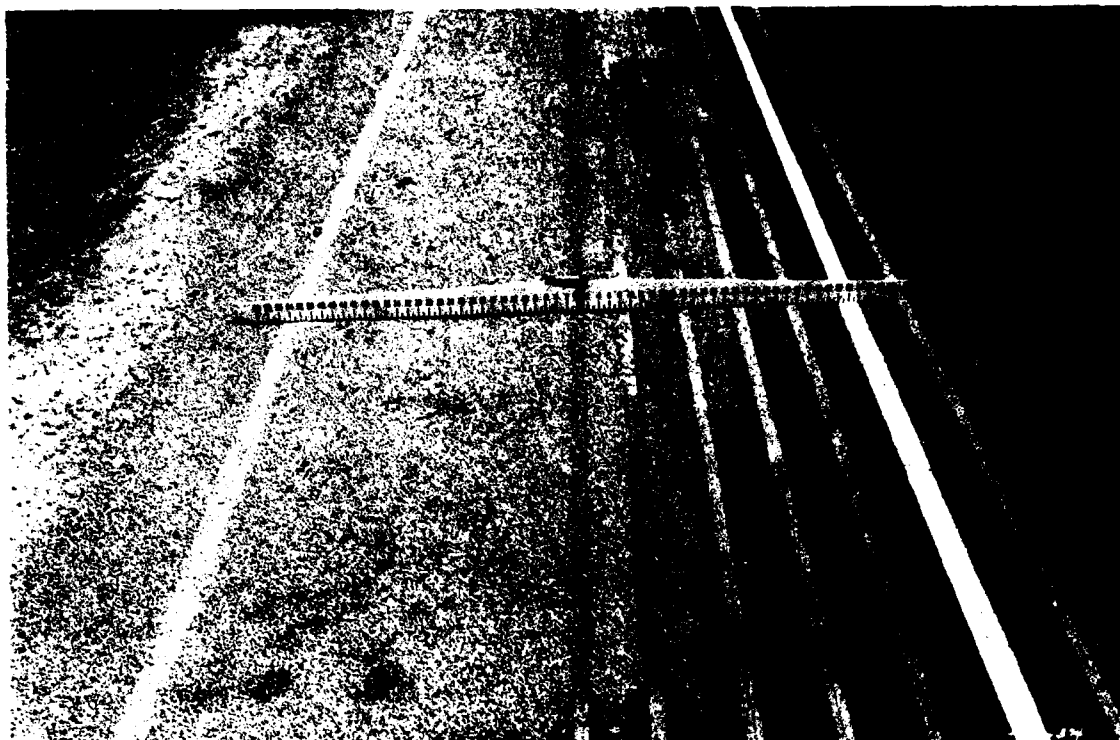


Photo 37. SST before traffic; series 2, crater 1, lane 1

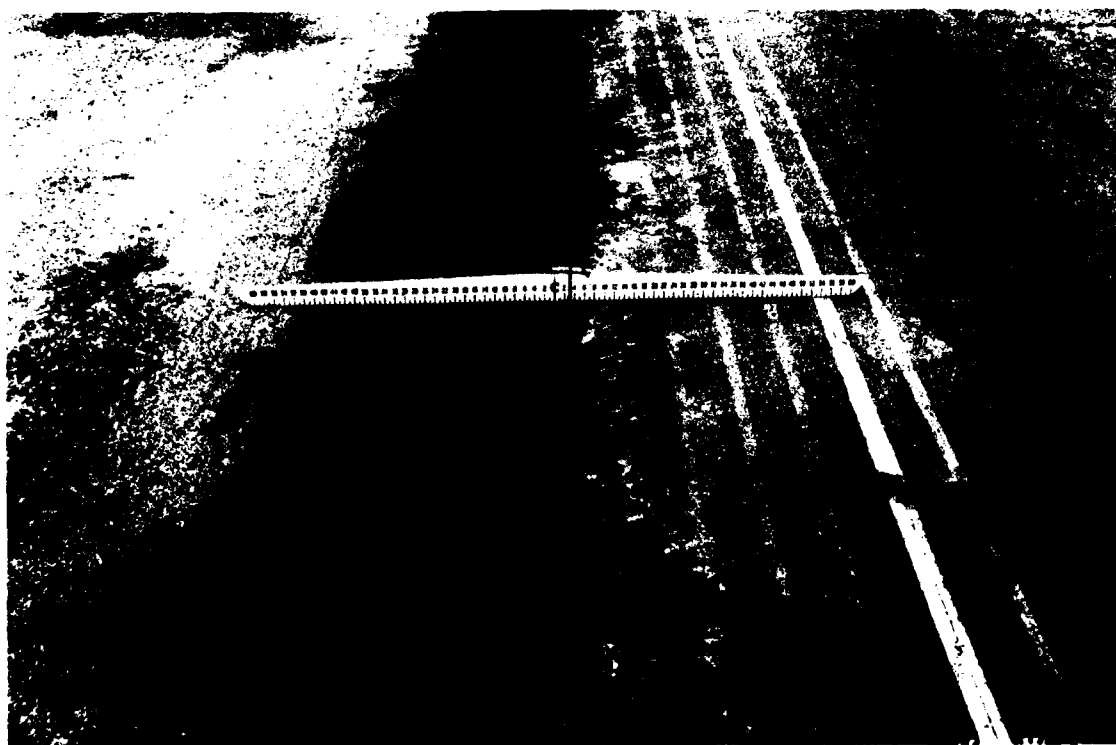


Photo 38. SST at 100 coverages; asphalt starting to bleed

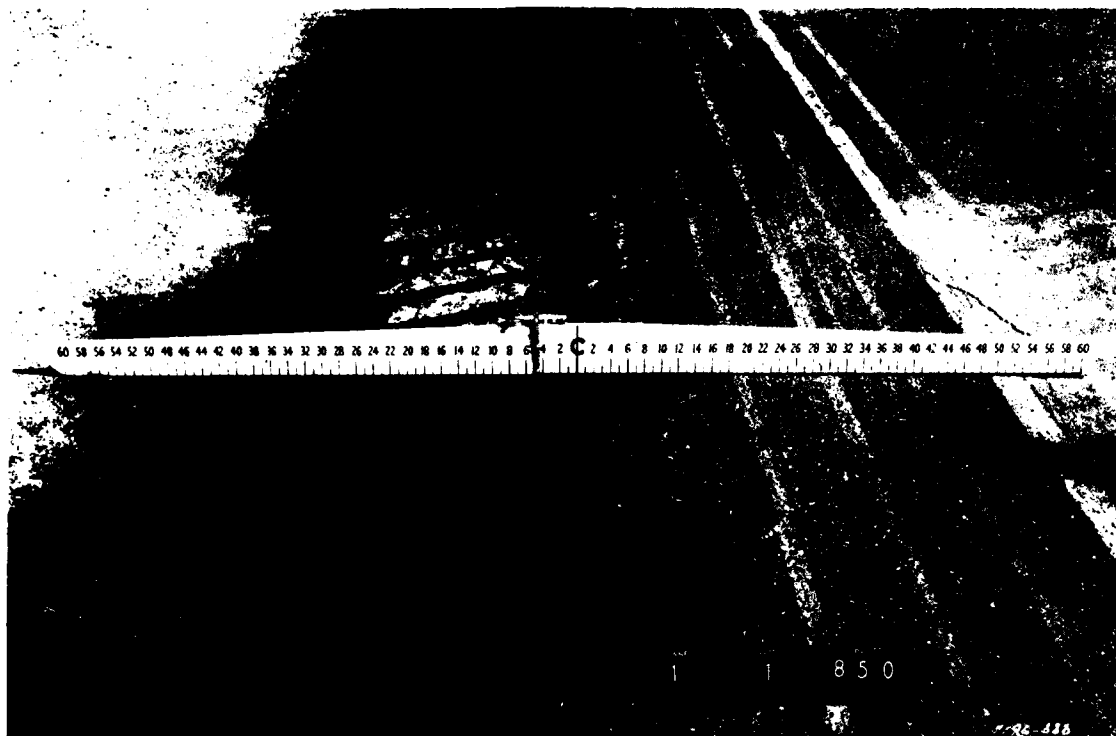


Photo 39. Surface conditions of SST after 250 coverages



Photo 40. SST after 400 coverages; note asphalt bleeding and raveling

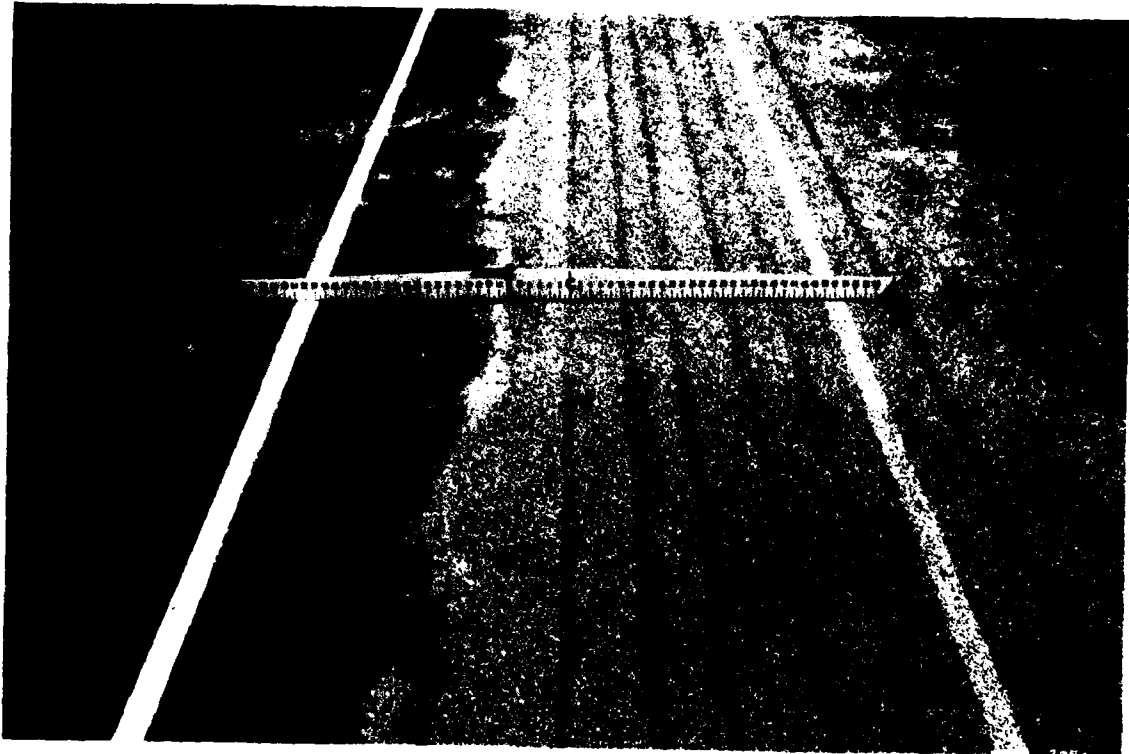


Photo 41. DBST before traffic; series 2, crater 1, lane 2

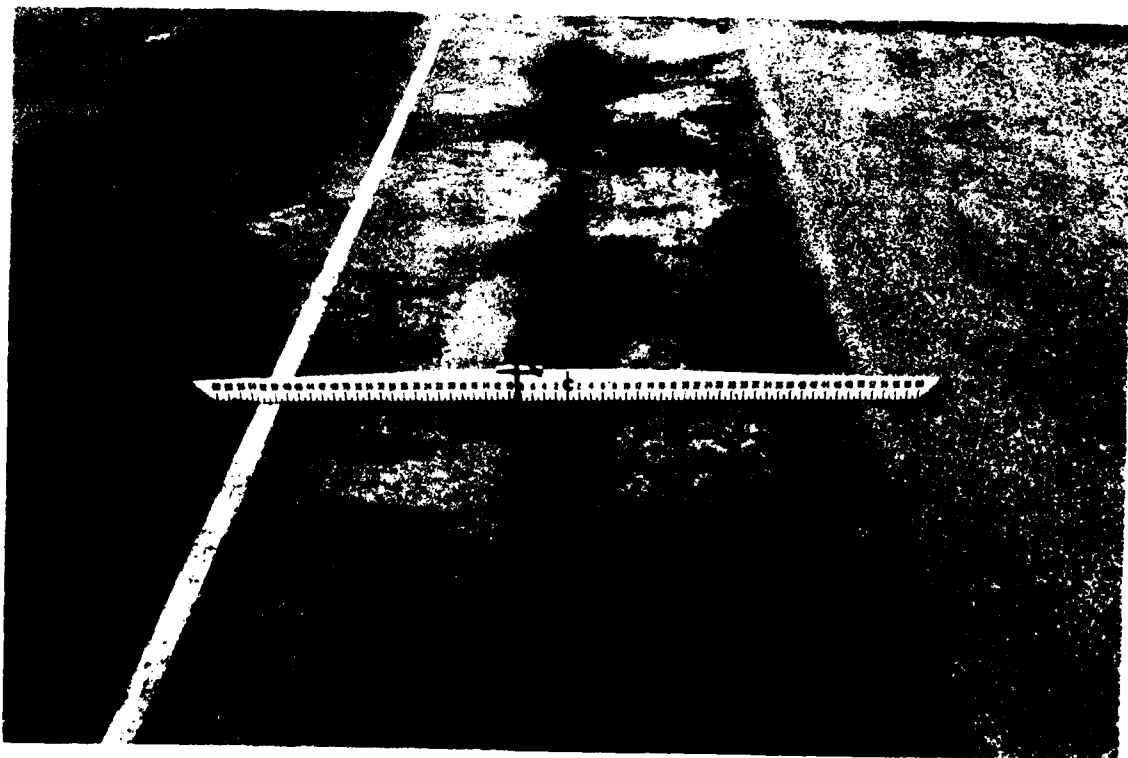


Photo 42. DBST after 100 coverages

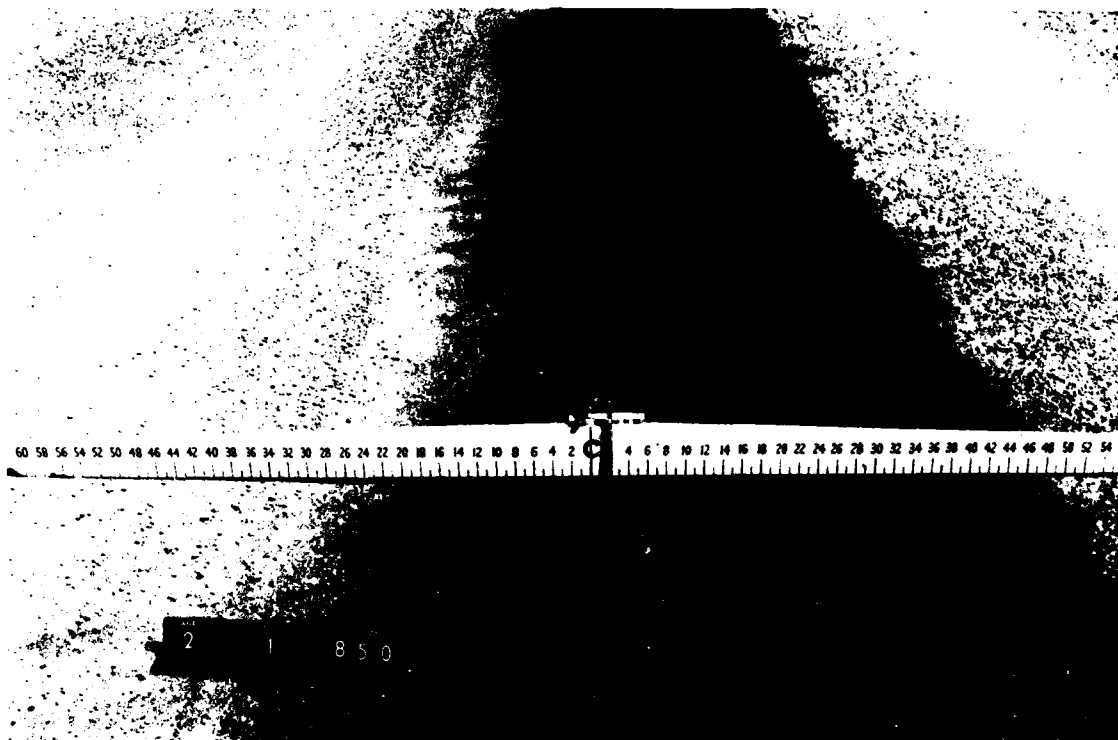


Photo 43. Bleeding of AC from the DBST after 250 coverages

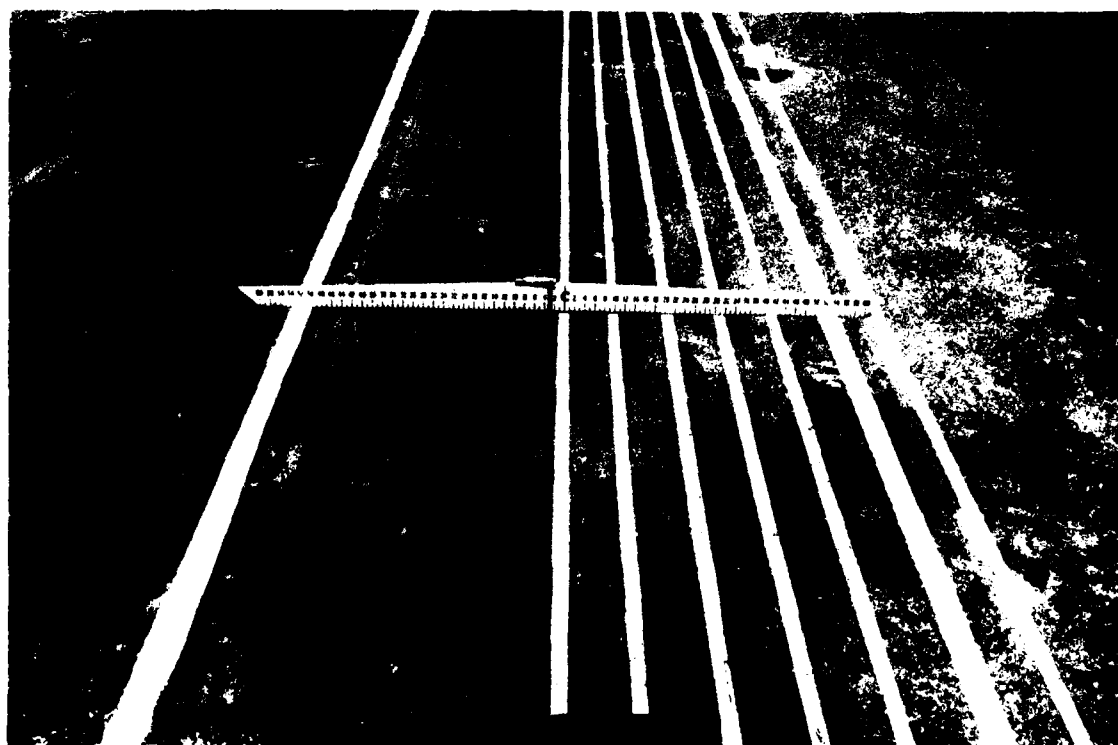


Photo 44. Series 2, crater 2, lane 1, prior to traffic

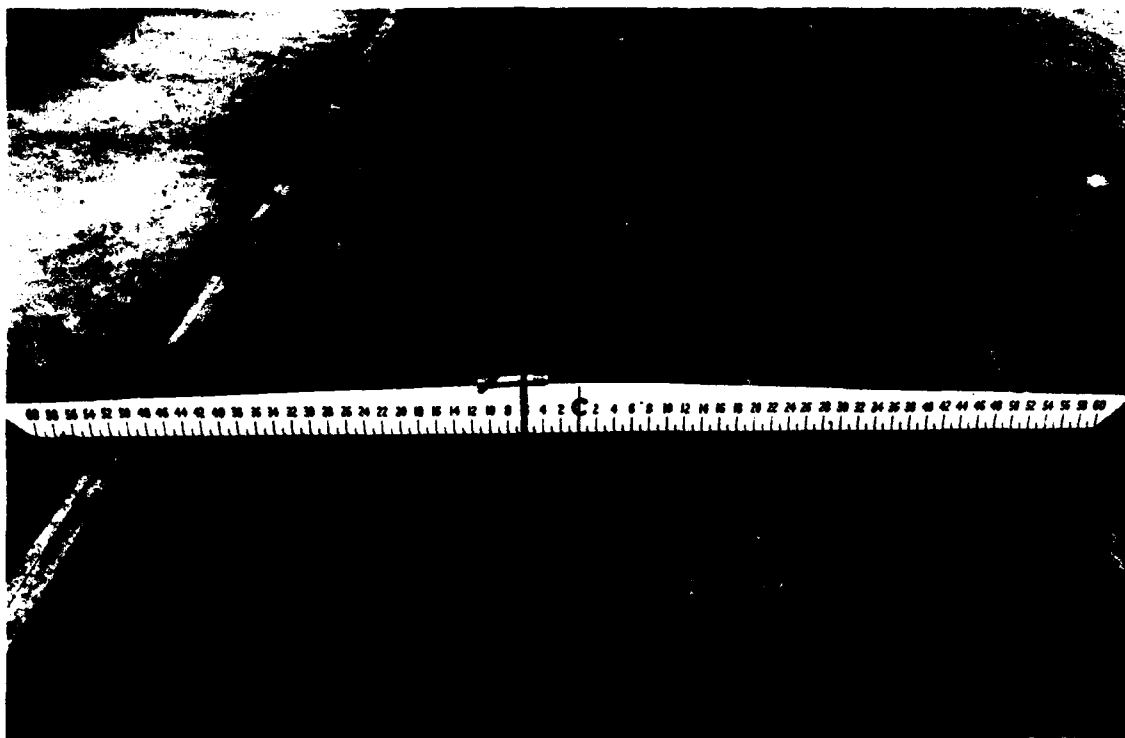


Photo 45. Series 2, crater 2, lane 1, after 400 coverages

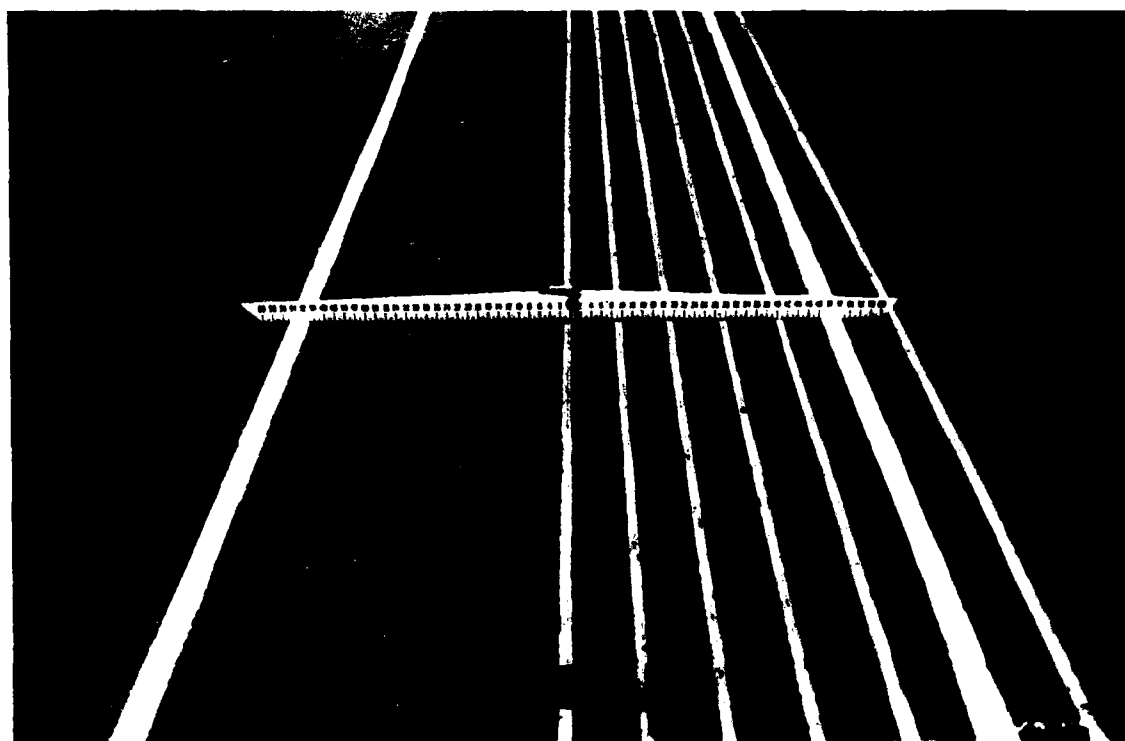


Photo 46. Series 2, crater 2, lane 2, before traffic

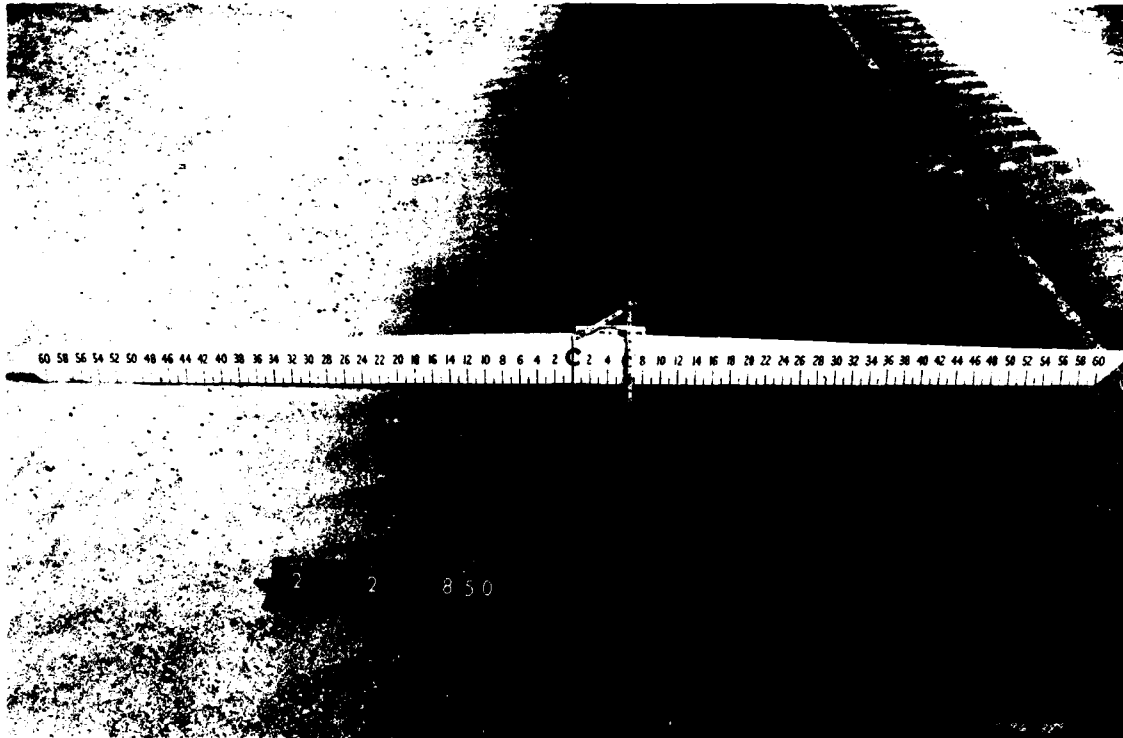


Photo 47. Series 2, crater 2, lane 2, after 250 coverages

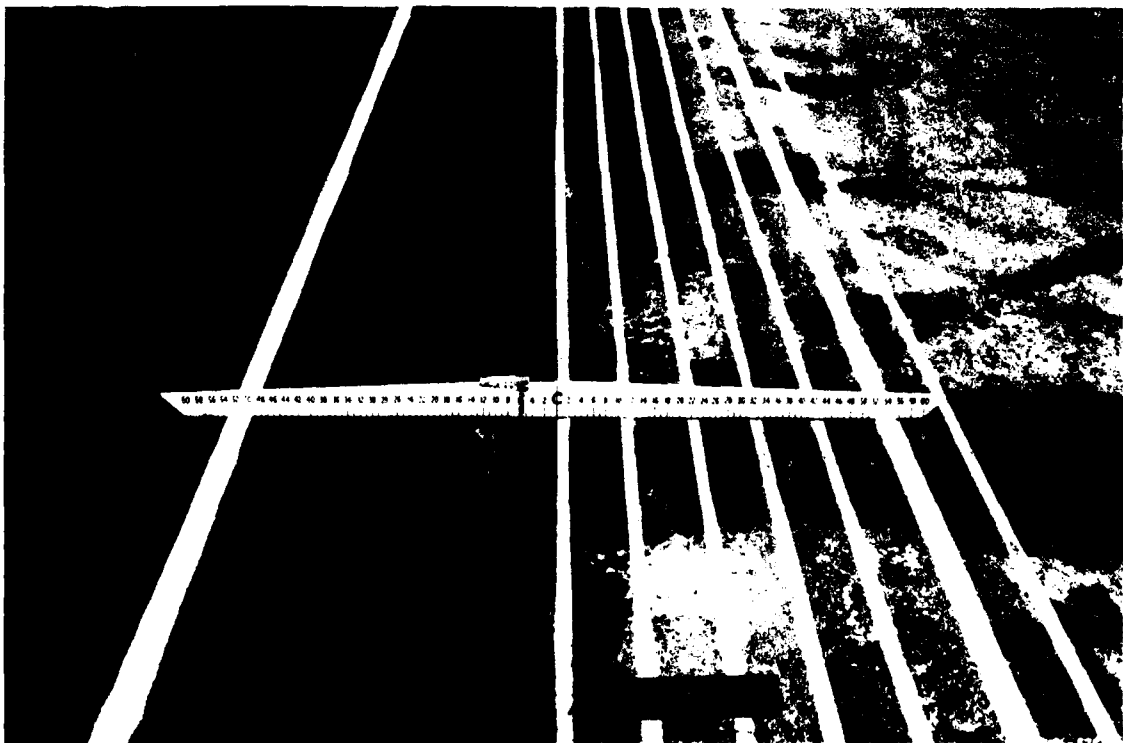


Photo 48. Series 2, crater 3, lane 1, before traffic

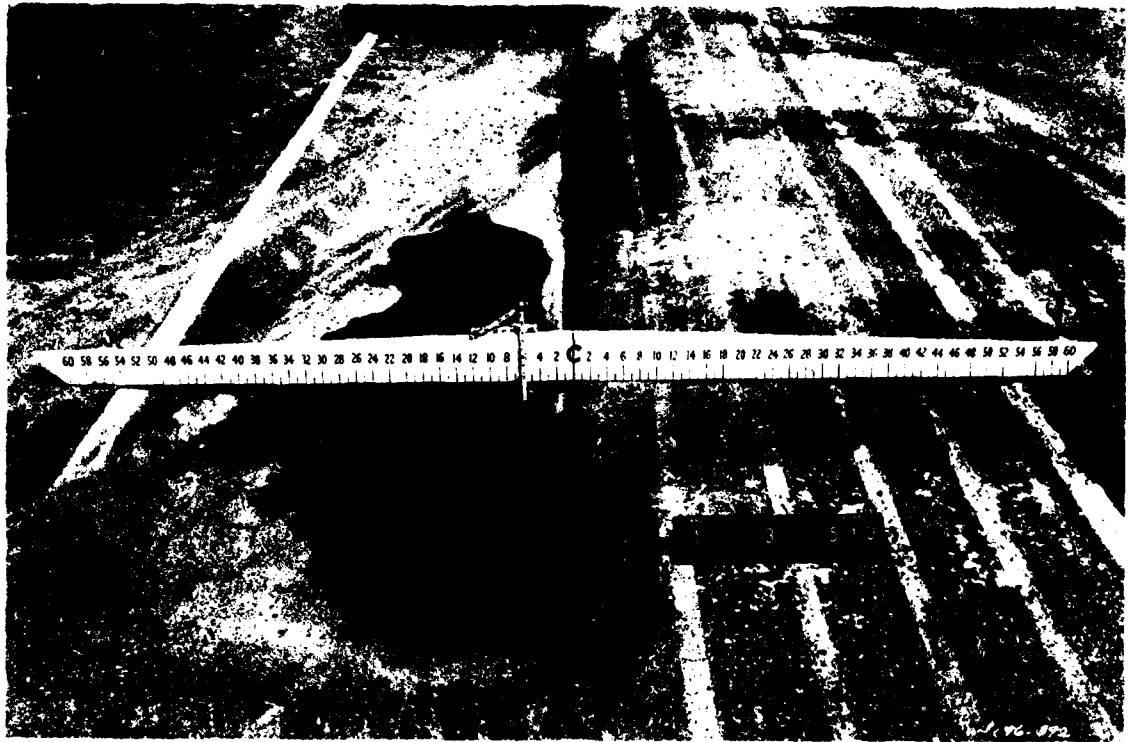


Photo 49. Series 2, crater 3, lane 1, after 150 coverages

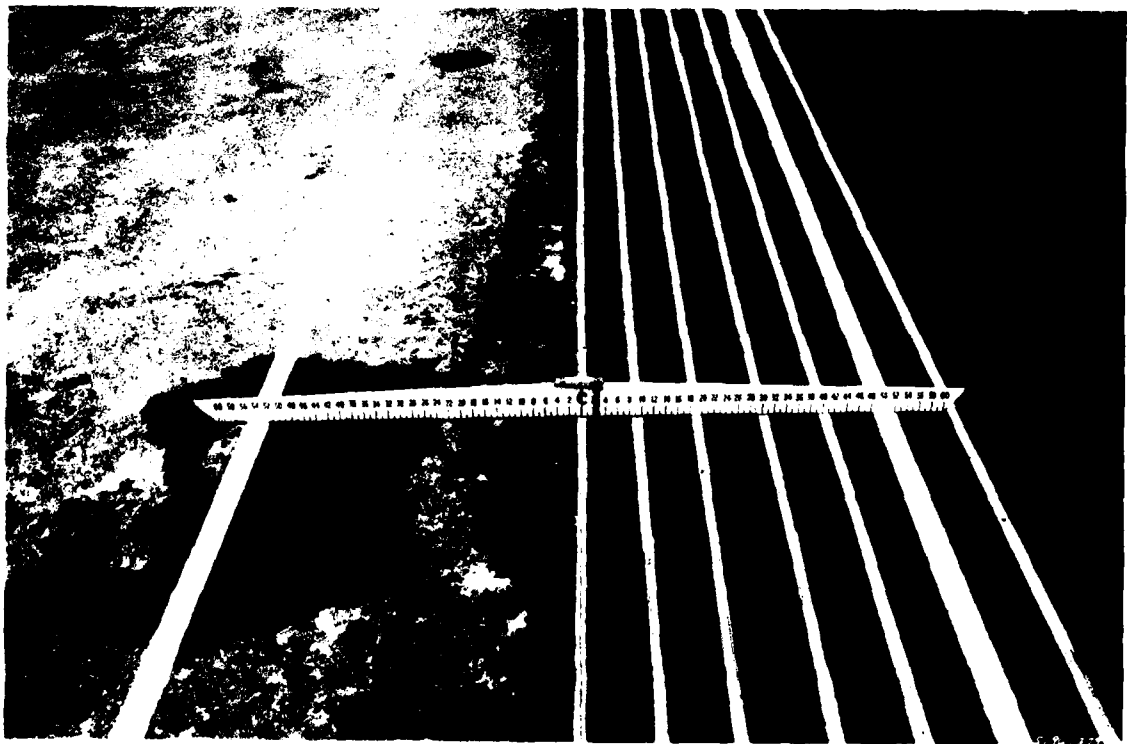


Photo 50. Series 2, crater 3, lane 2, before traffic



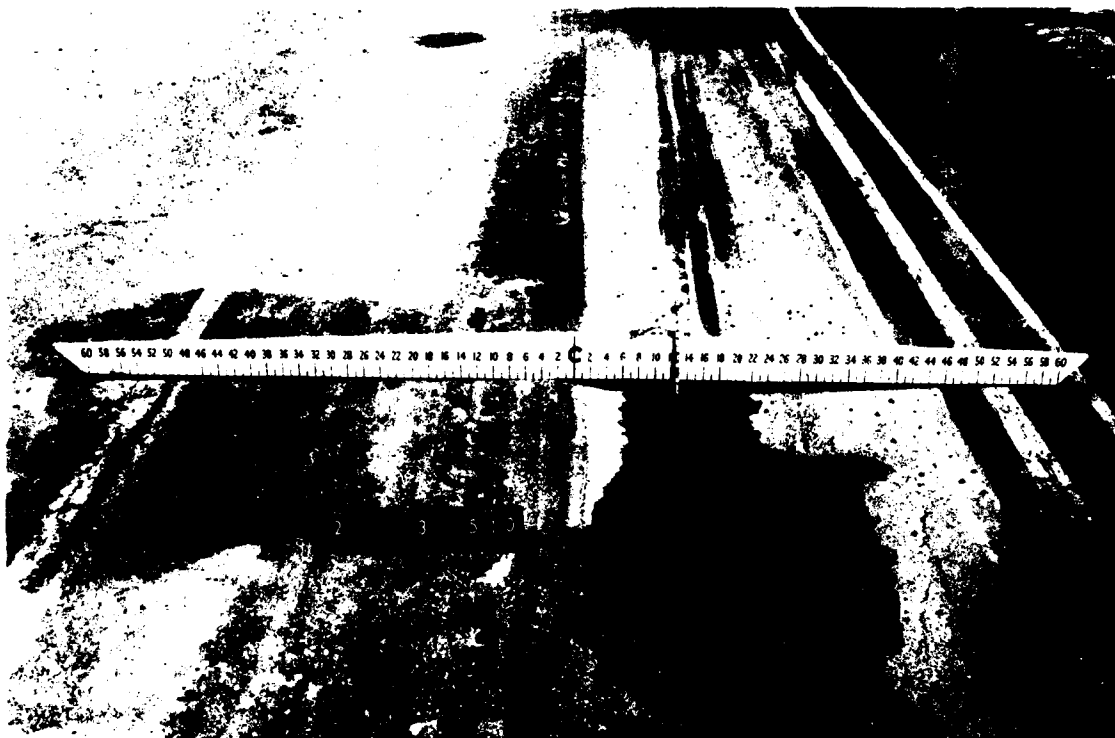


Photo 51. Series 2, crater 3, lane 2, after 150 coverages

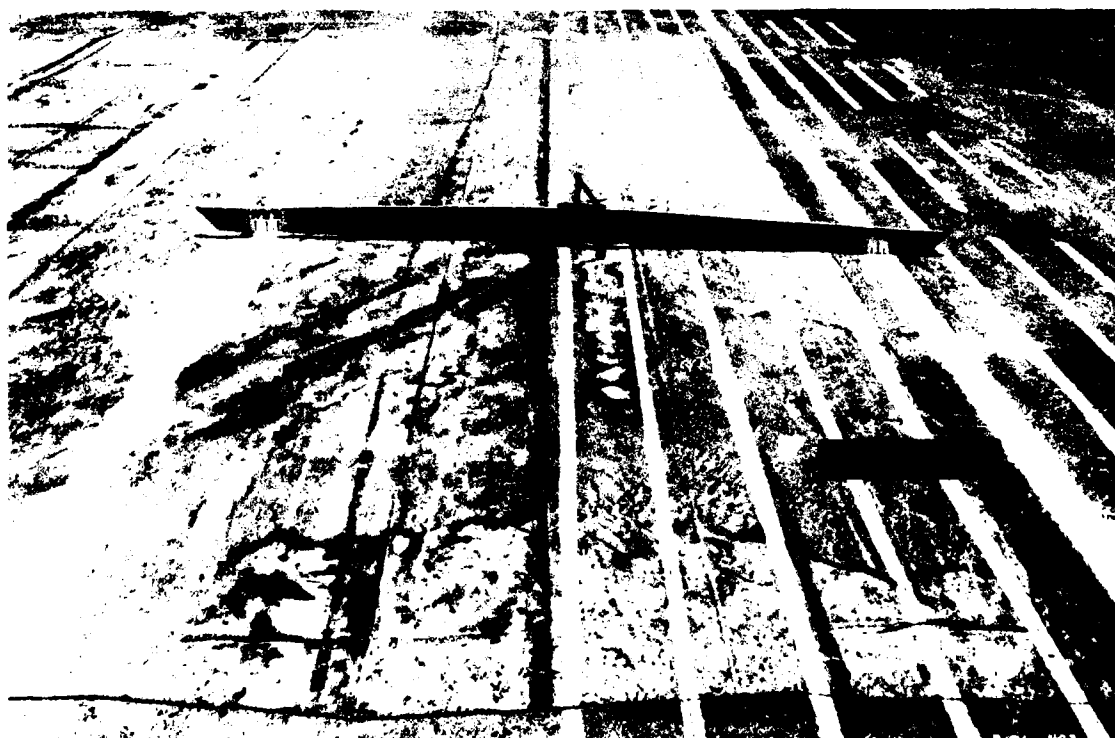


Photo 52. Series 3, crater 1, lane 1, before traffic



Photo 53. F-4 tire stuck, one pass

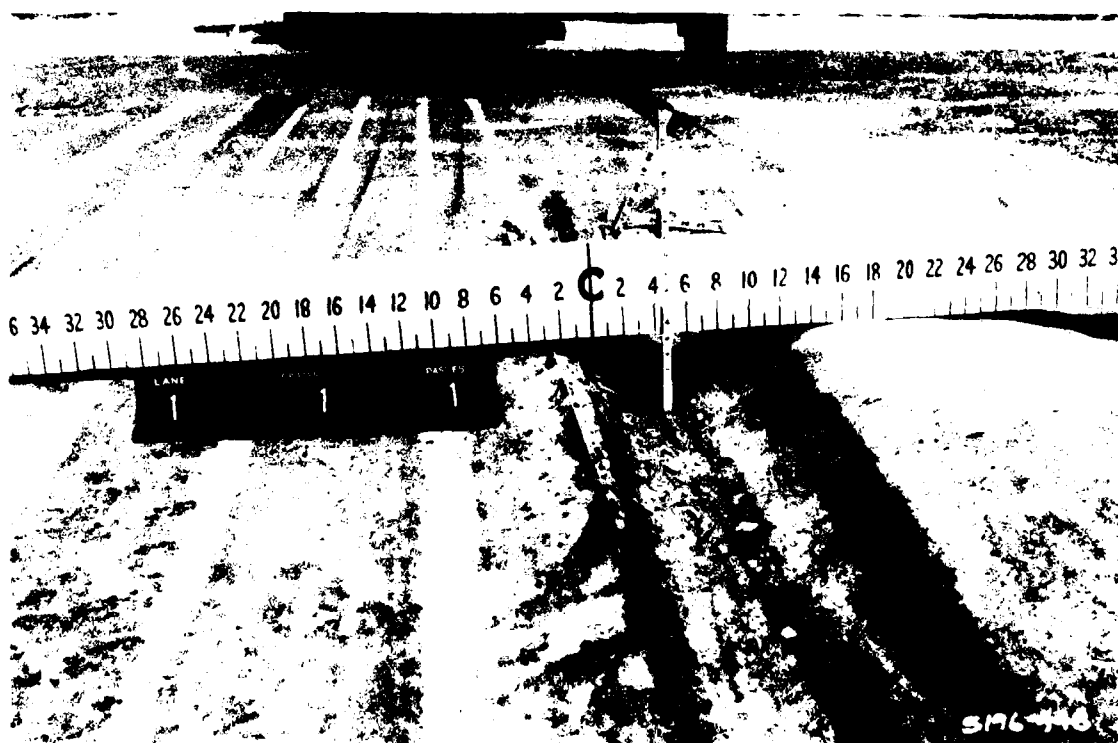


Photo 54. Damage caused by one pass of the F-4



Photo 55. Series 3, crater 1, lane 2, before traffic



Photo 56. C-141 tracking rig stuck, one pass

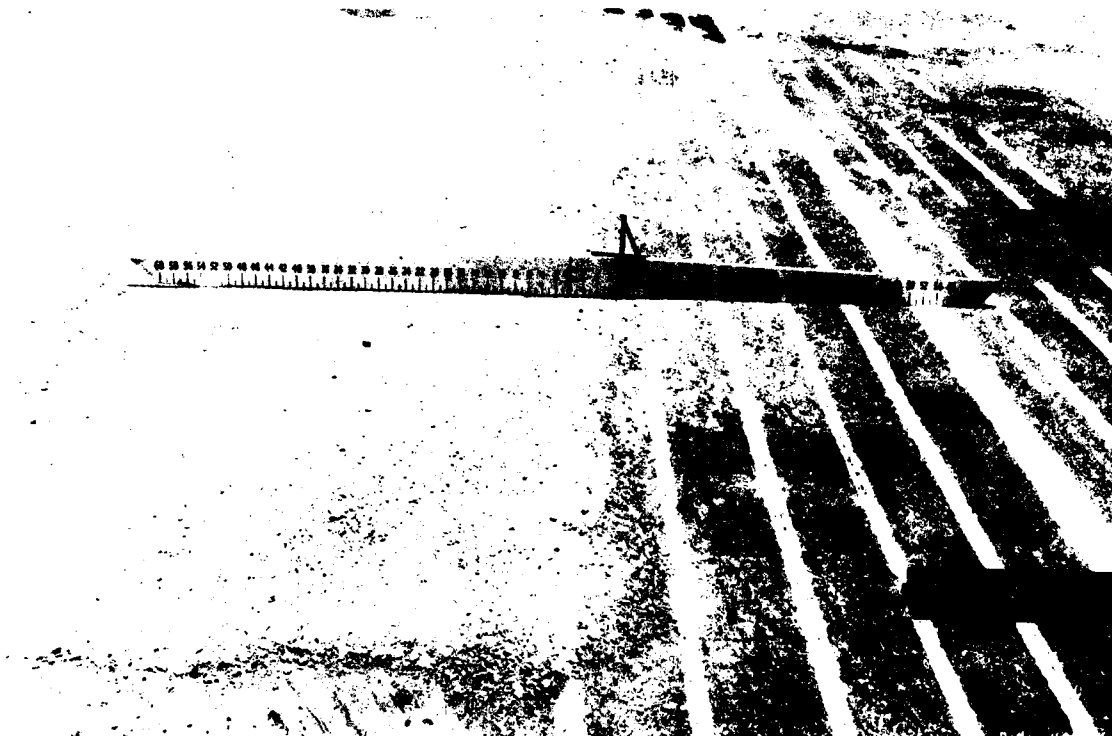


Photo 57. Series 3, crater 2, lane 1, before traffic

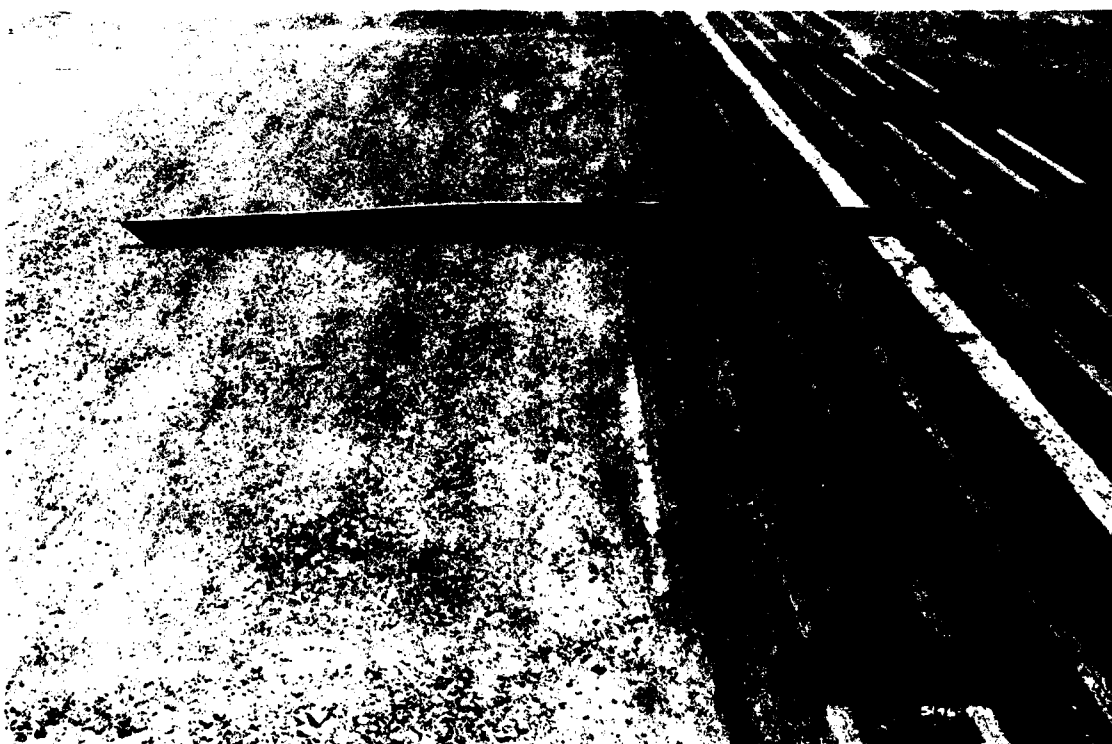


Photo 58. Surface conditions after 72 coverages of F-4 traffic

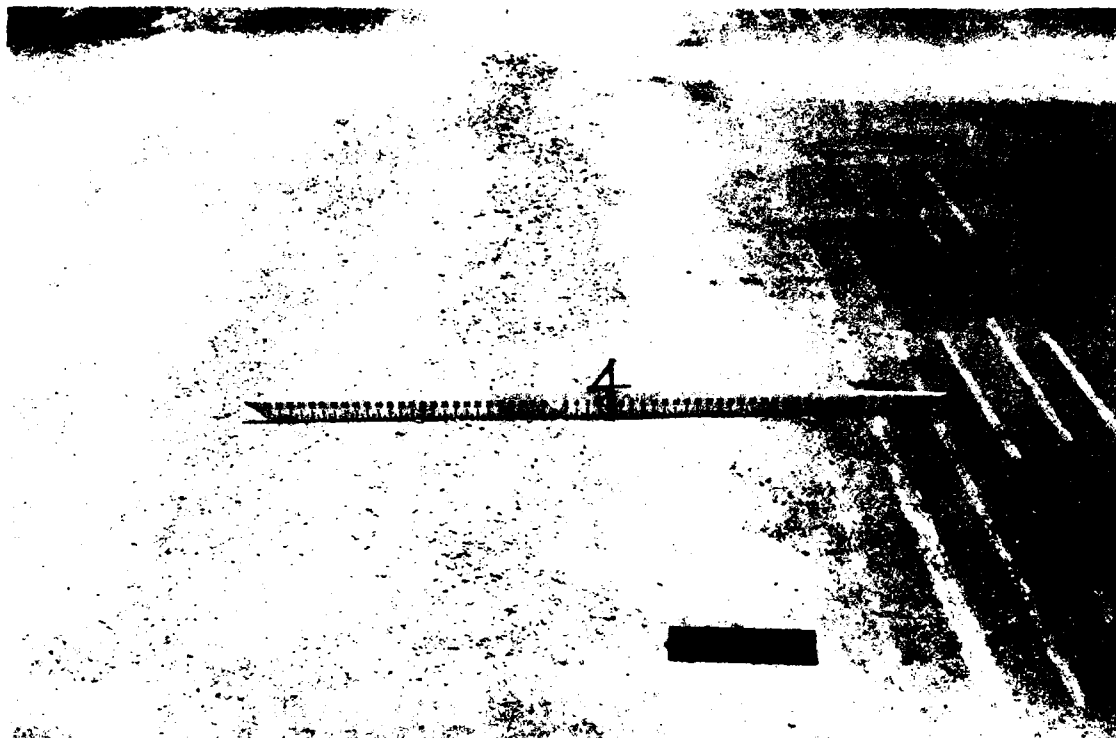


Photo 59. Series 3, crater 2, lane 1, after 700 coverages

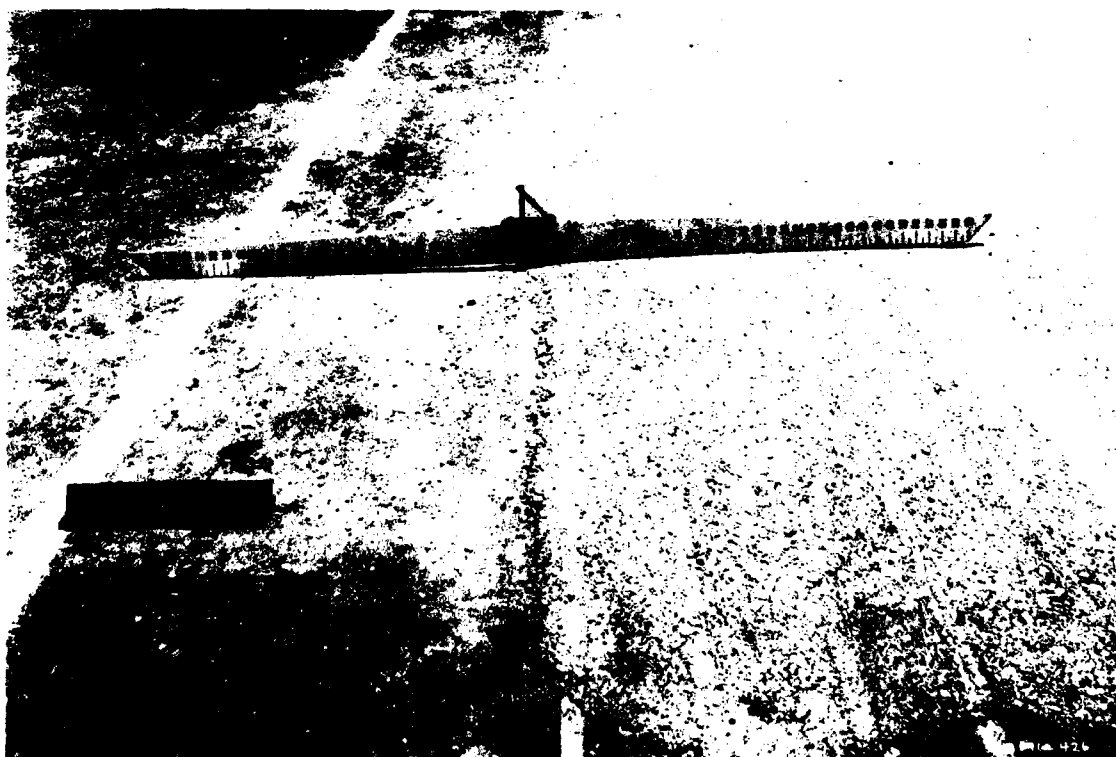


Photo 60. Series 3, crater 2, lane 2, before traffic

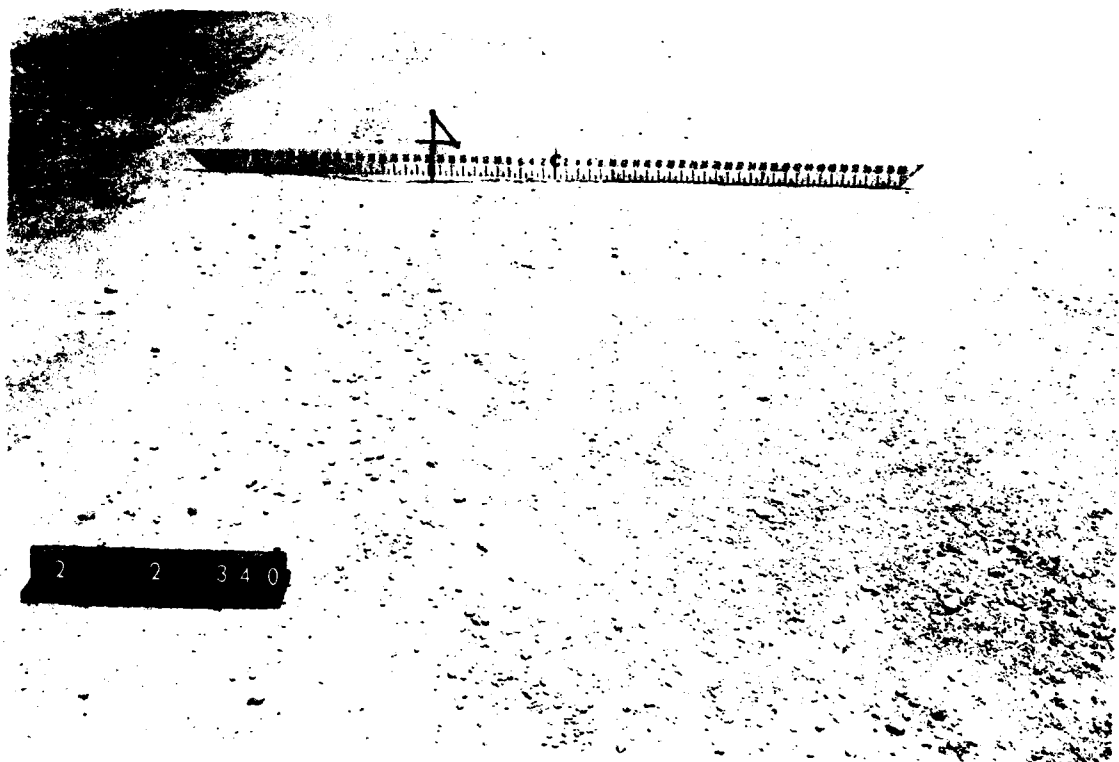


Photo 61. Surface conditions after 100 coverages of C-141

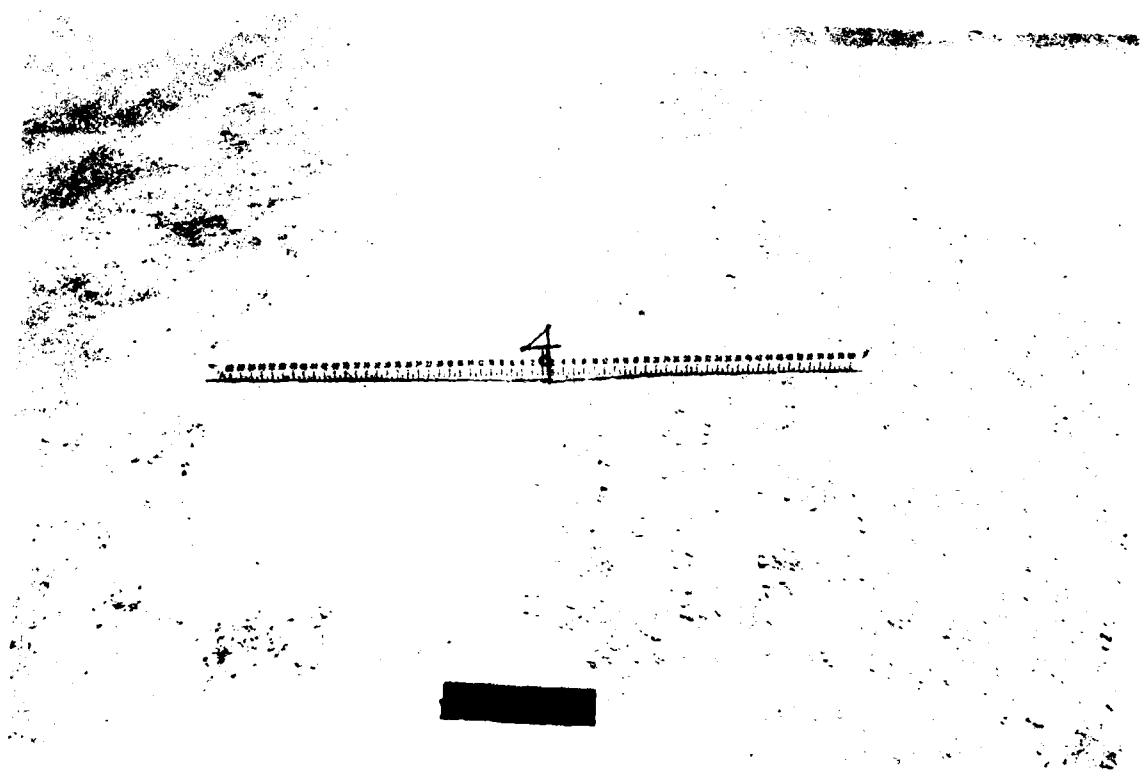


Photo 62. Series 3, crater 2, lane 2, after 700 coverages

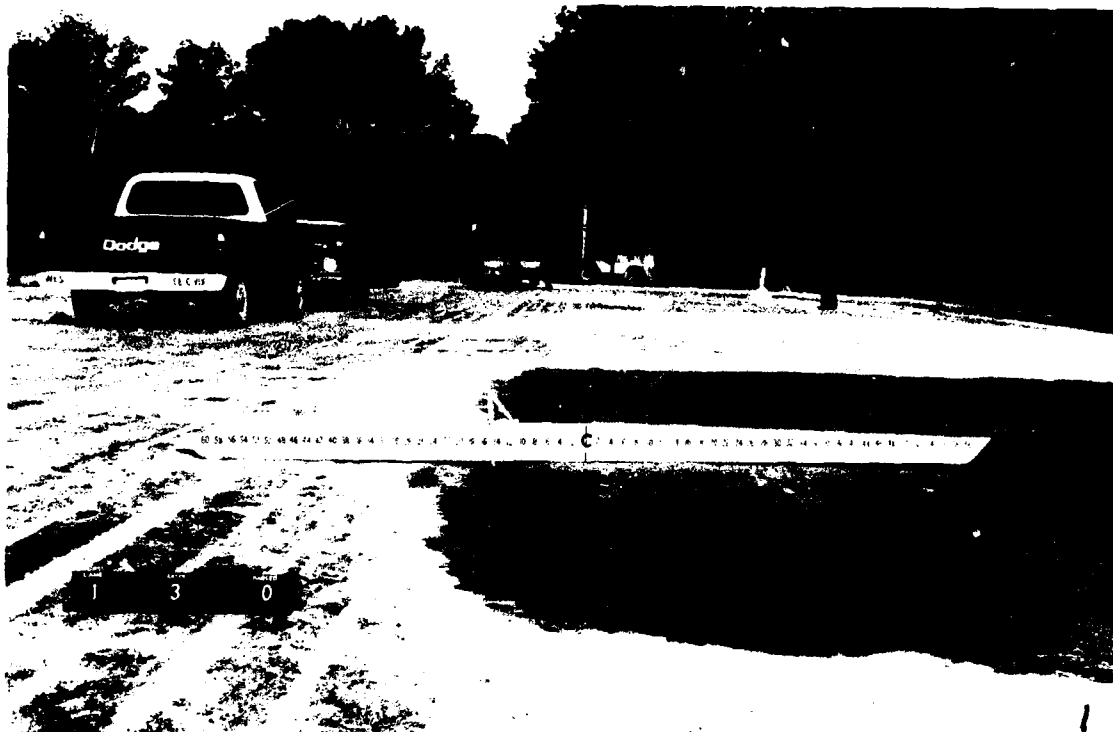


Photo 63. Series 3, crater 3, lane 1, before traffic

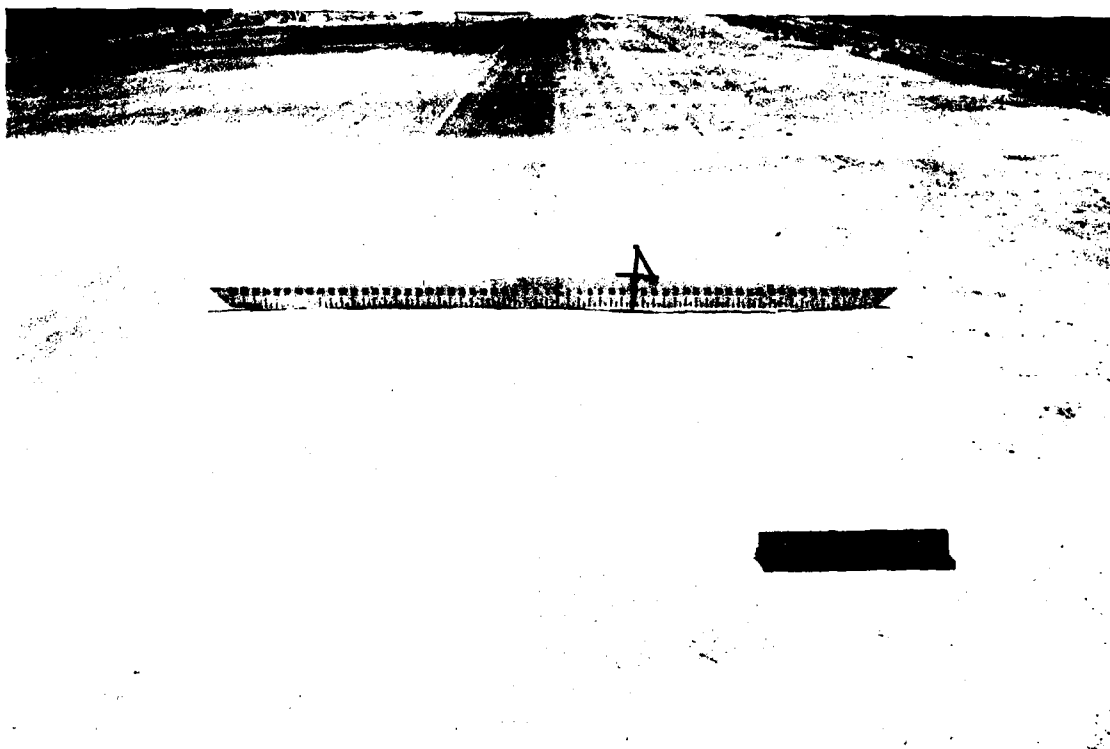


Photo 64. Series 3, crater 3, lane 1, after 72 coverages of F-4

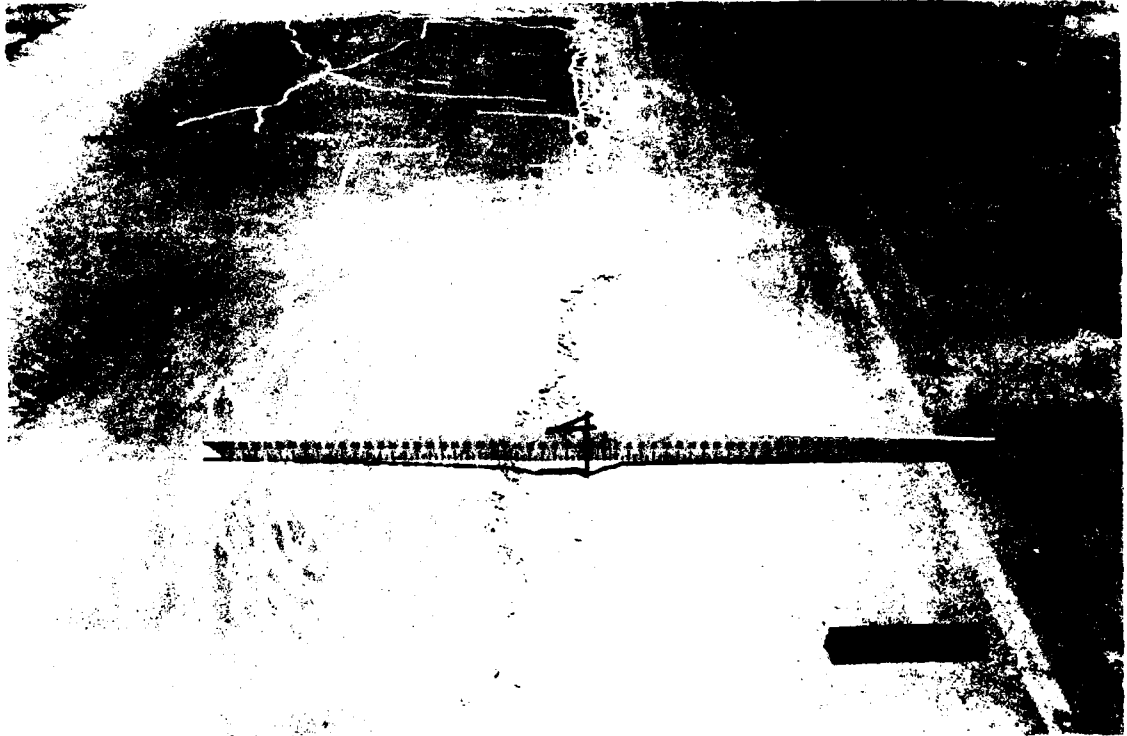


Photo 65. Series 3, crater 3, lane 1, after 100 coverages of C-141.  
Note displaced grout area

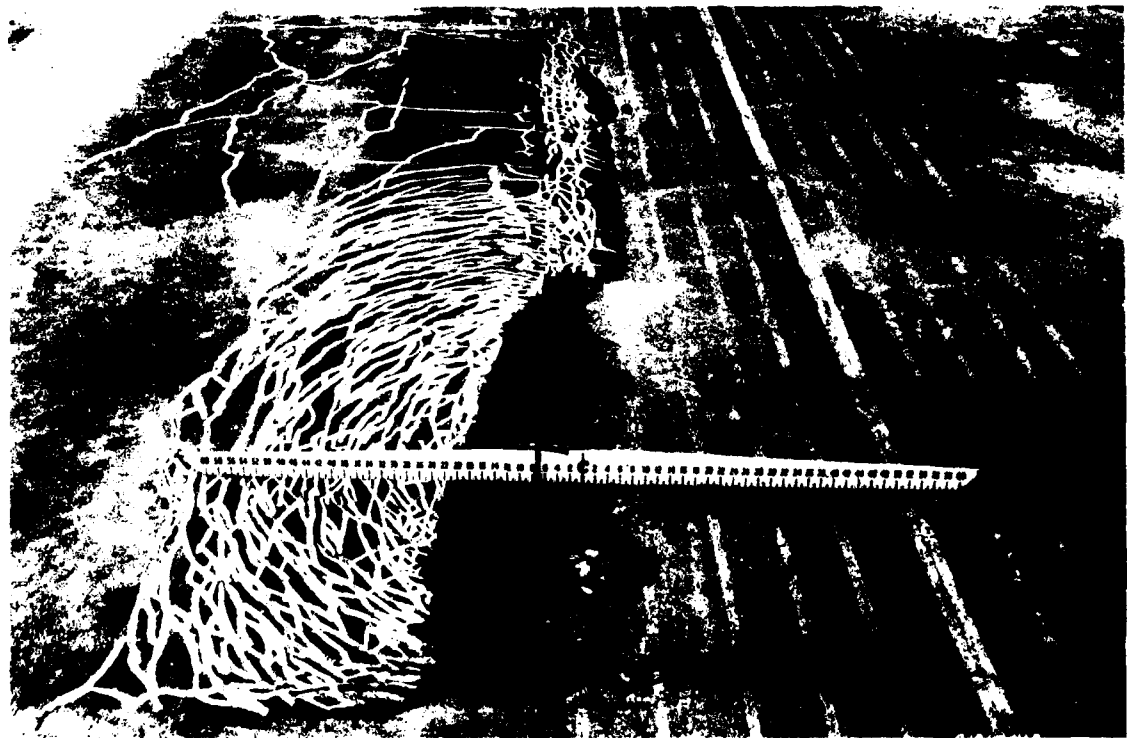


Photo 66. Series 3, crater 3, lane 1, after 200 coverages



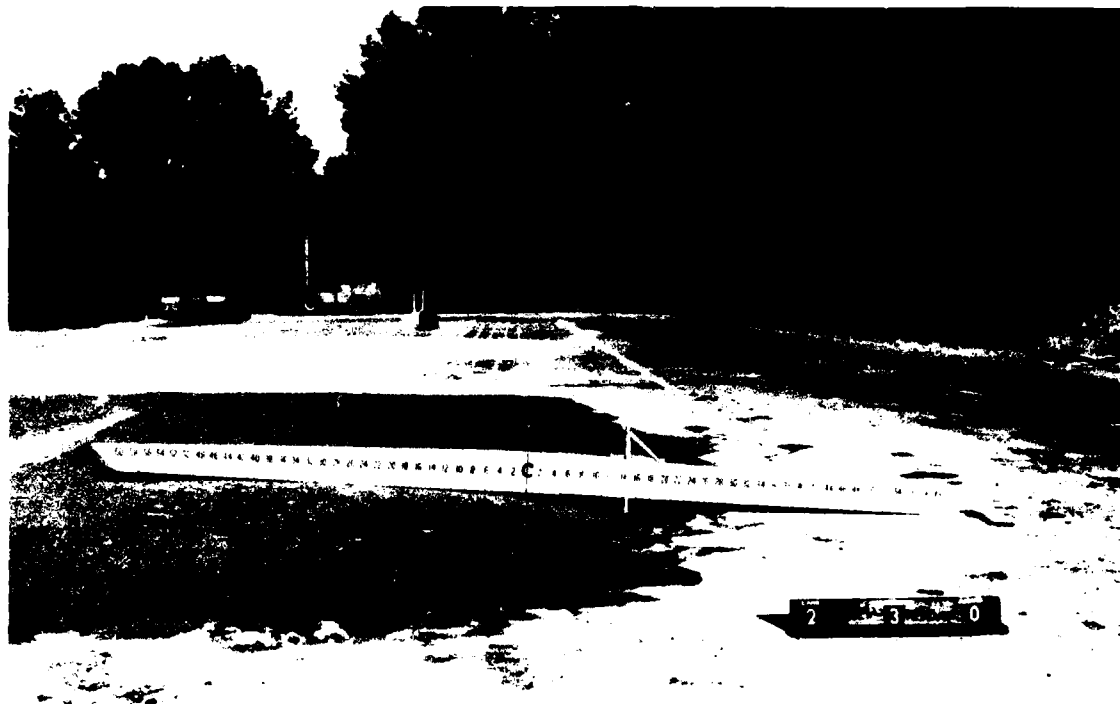


Photo 67. Series 3, crater 3, lane 2, before traffic

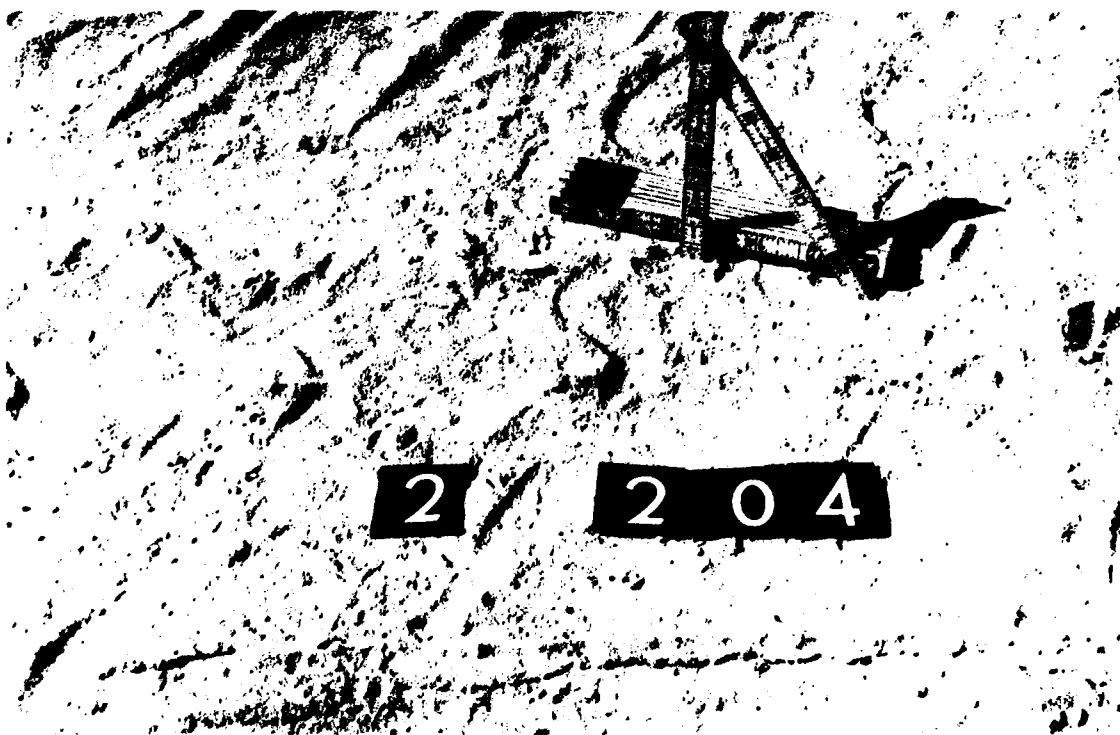


Photo 68. Surface deterioration after 60 coverages

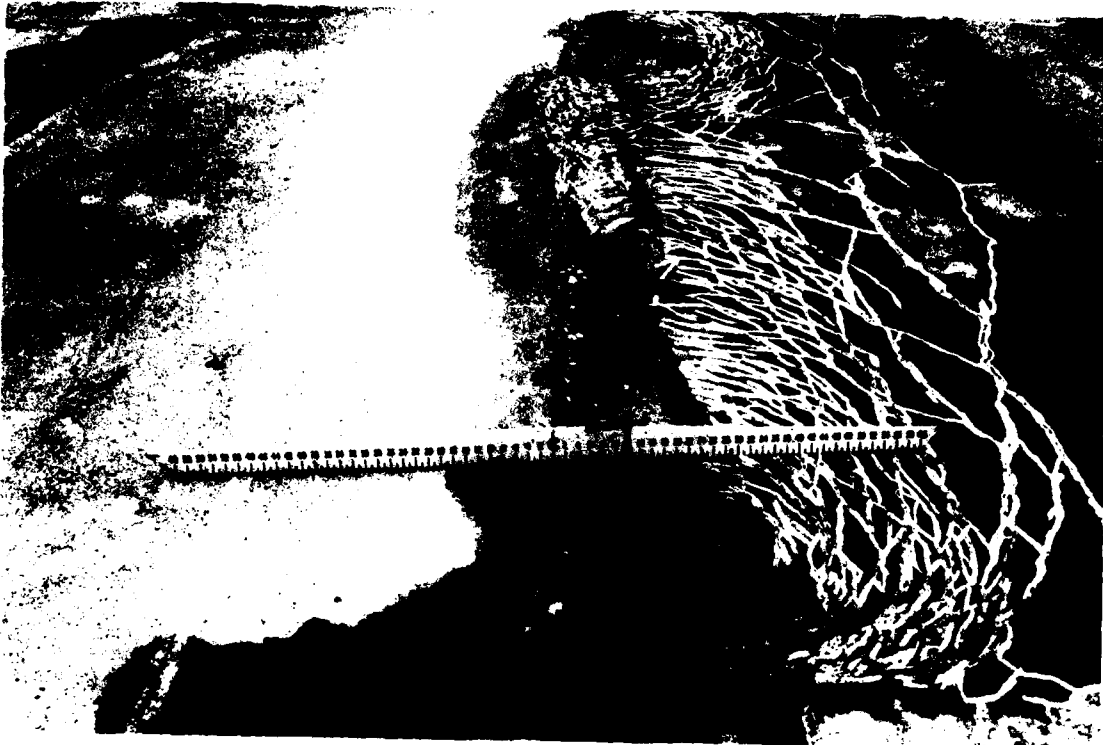


Photo 69. Series 3, crater 3, lane 2, after 200 coverages

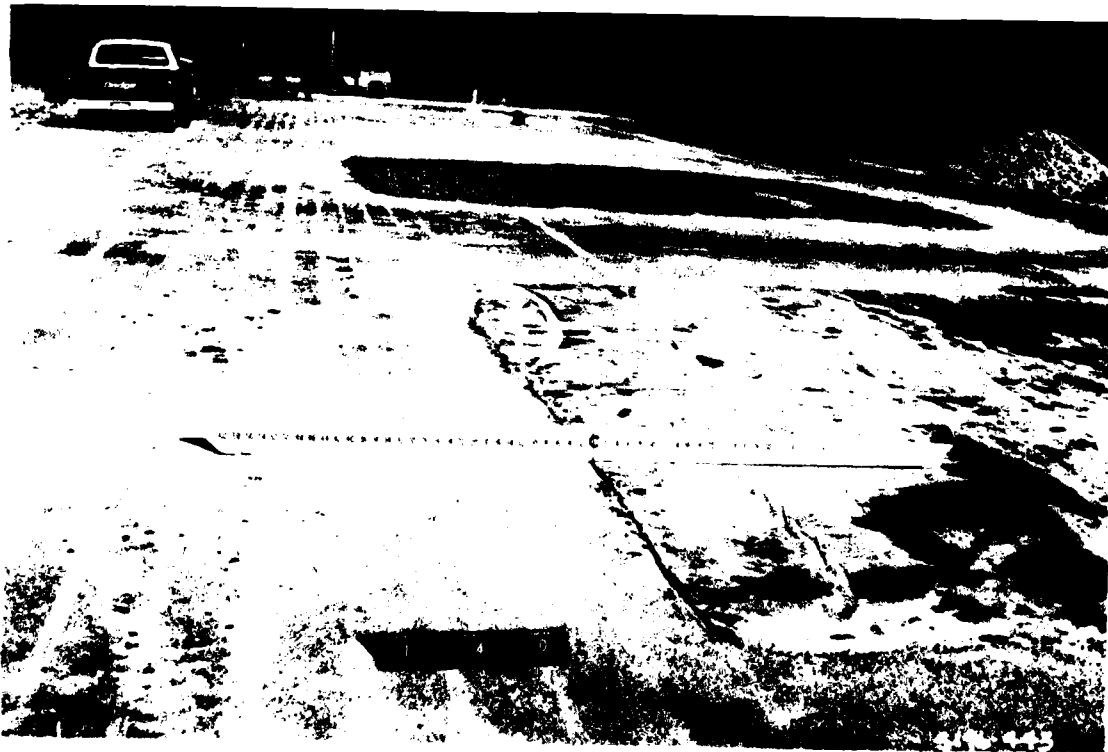


Photo 70. Series 3, crater 4, lane 1, before traffic

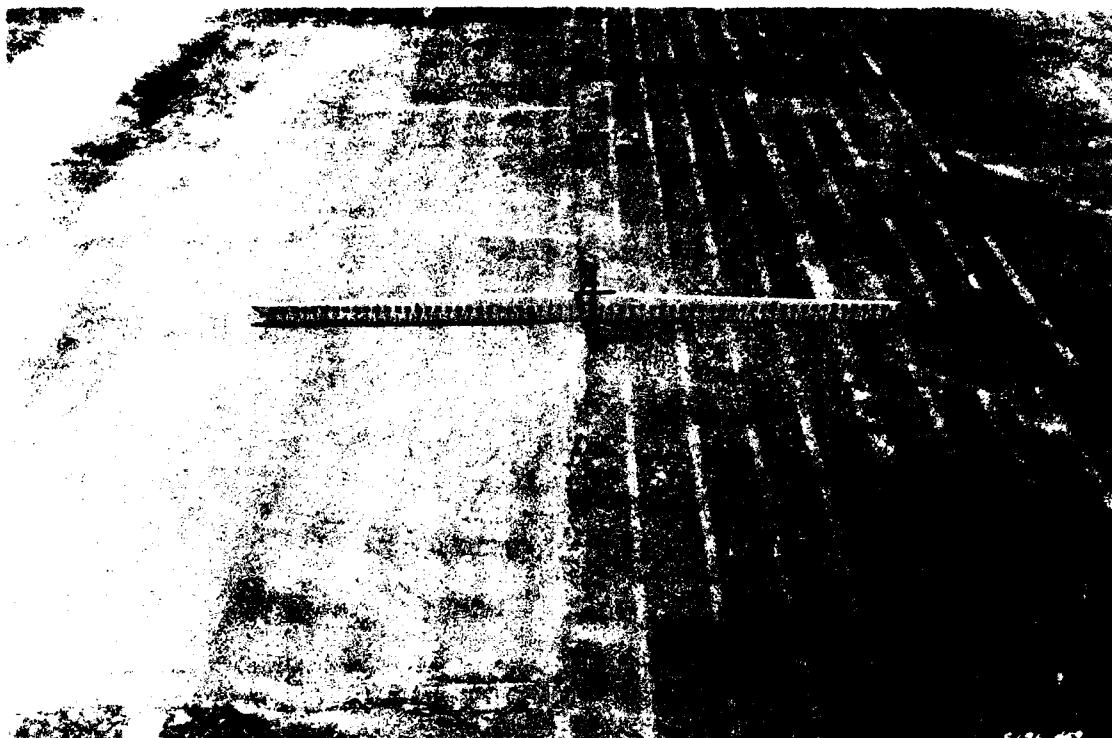


Photo 71. Series 3, crater 4, lane 1, after 100 coverages of C-141

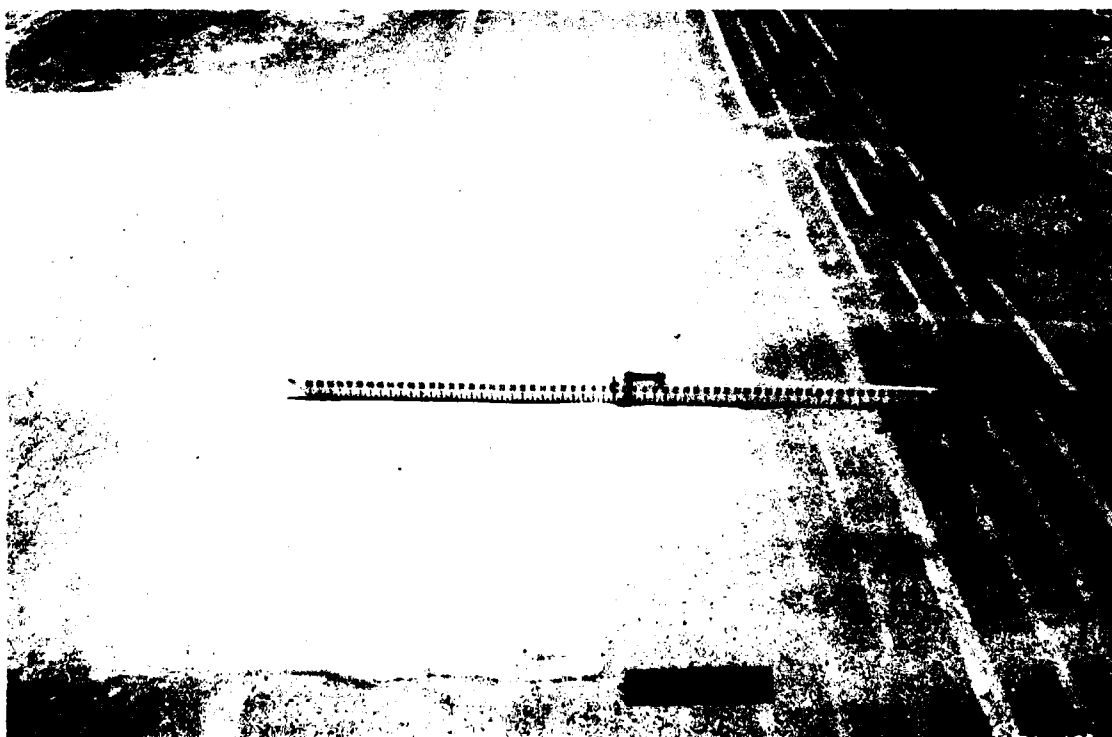


Photo 72. Series 3, crater 4, lane 1, after 700 coverages



Photo 73. Series 3, crater 4, lane 2, before traffic

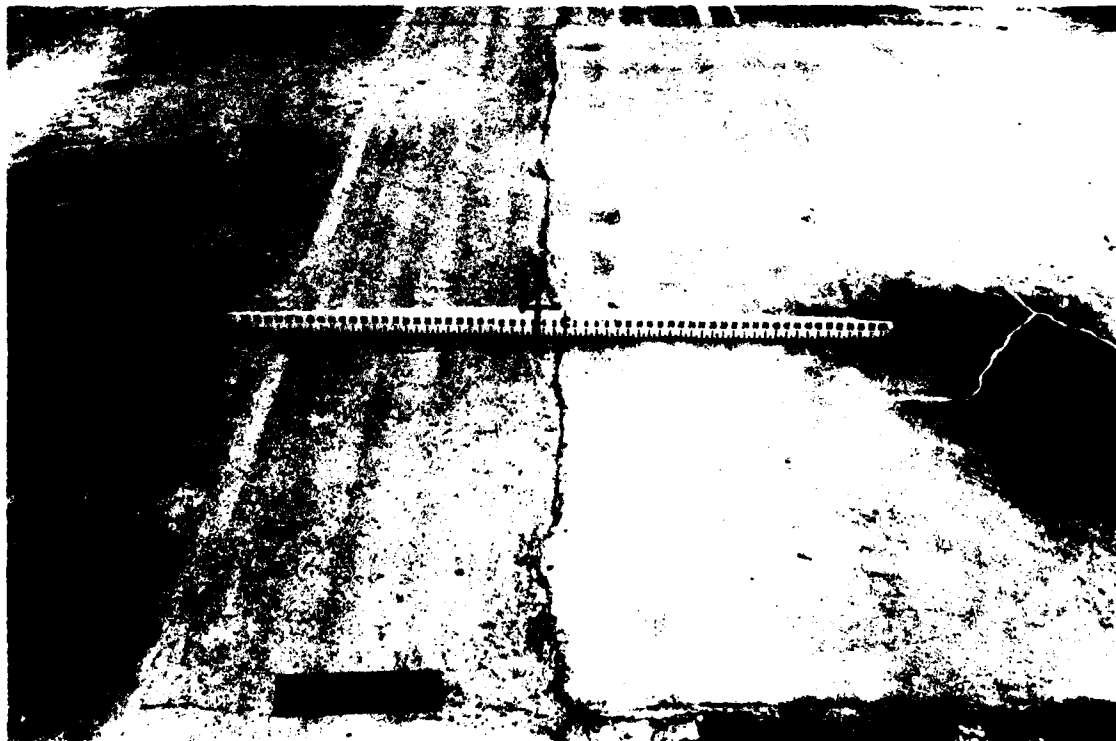


Photo 74. Series 3, crater 4, lane 2, after 200 coverages

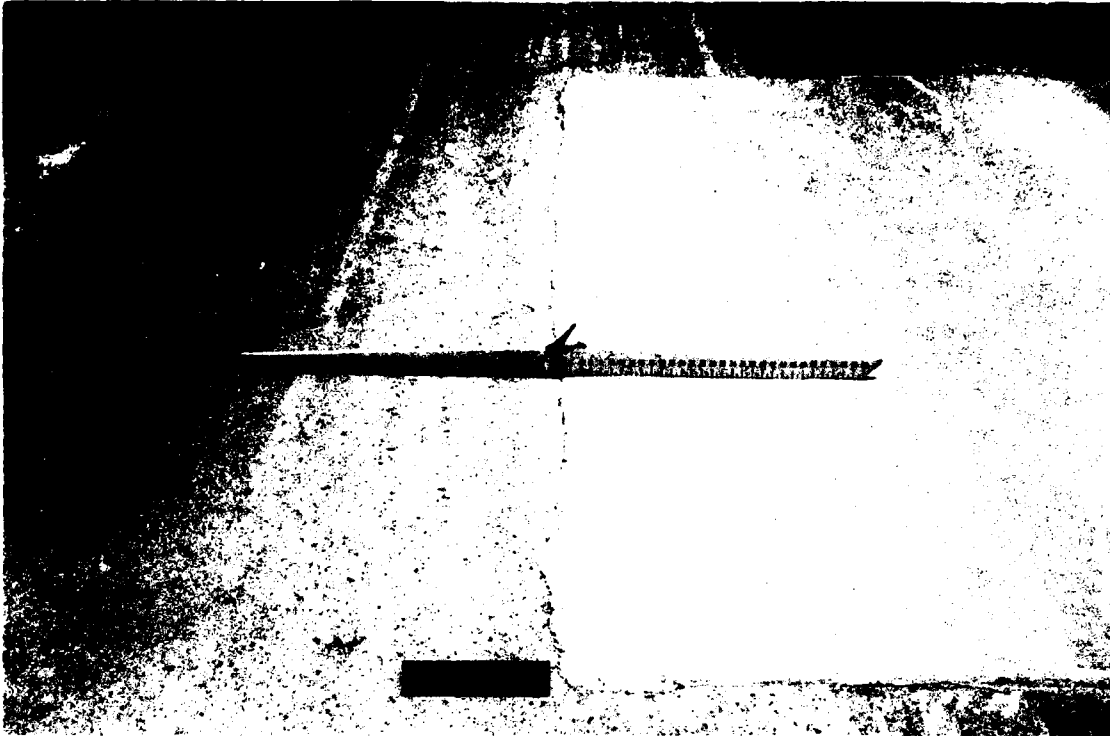


Photo 75. Series 3, crater 4, lane 2, after 700 coverages

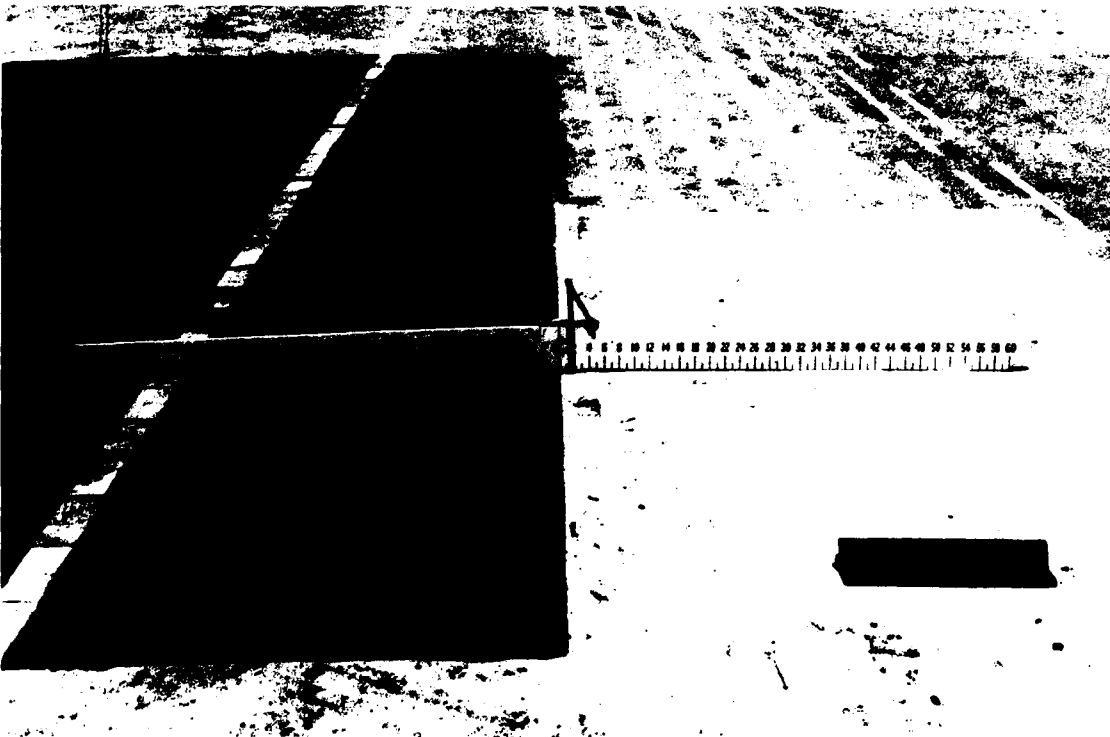


Photo 76. Series 3, crater 5, lane 1, before traffic



Photo 77. Deformation after 72 coverages of F-4



Photo 78. Series 3, crater 5, lane 1, after 450 coverages of C-141

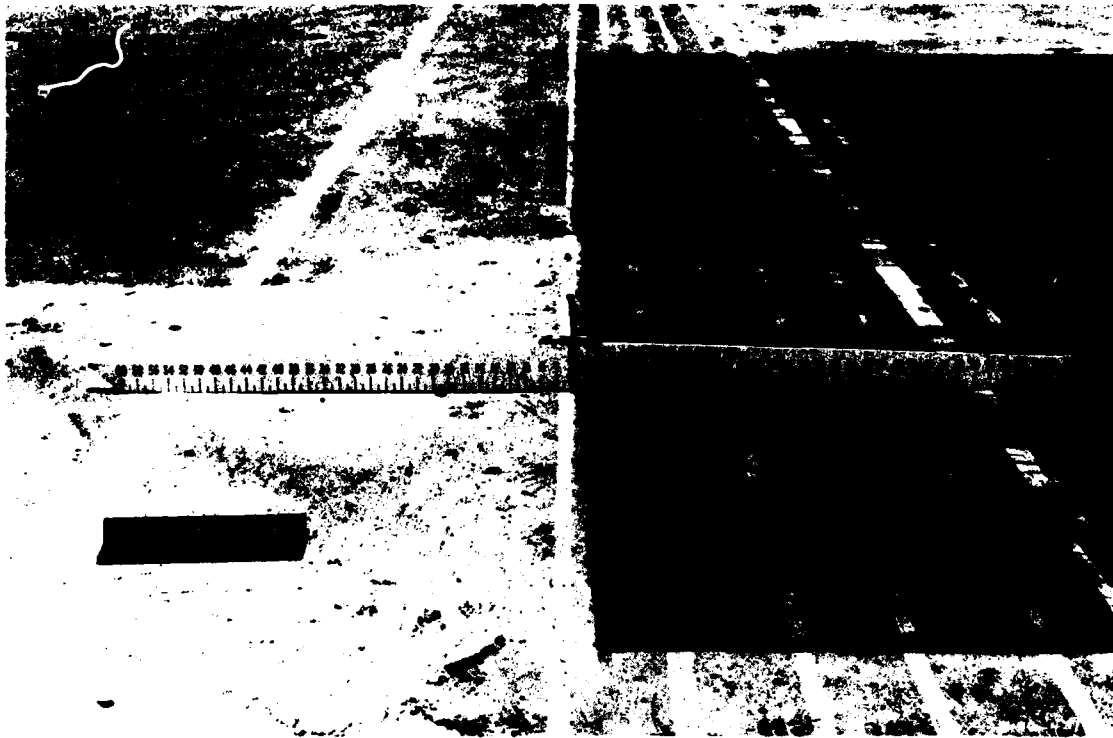


Photo 79. Series 3, crater 5, lane 2, before traffic

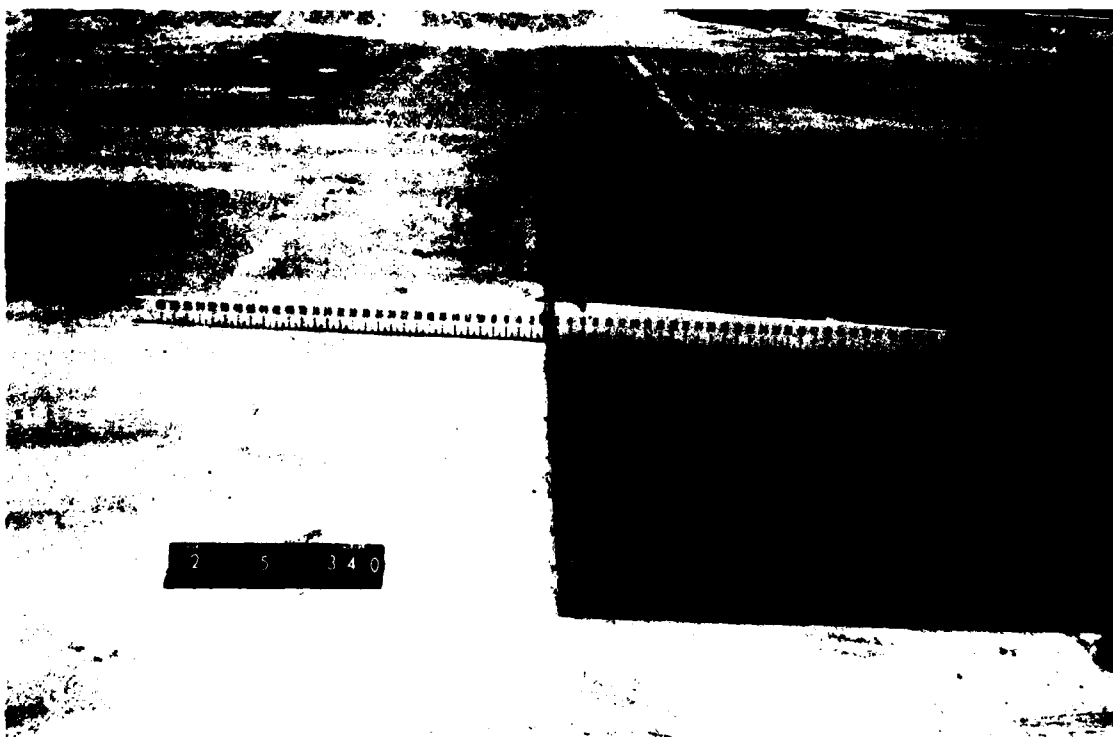


Photo 80. Deformation after 100 coverages of C-141

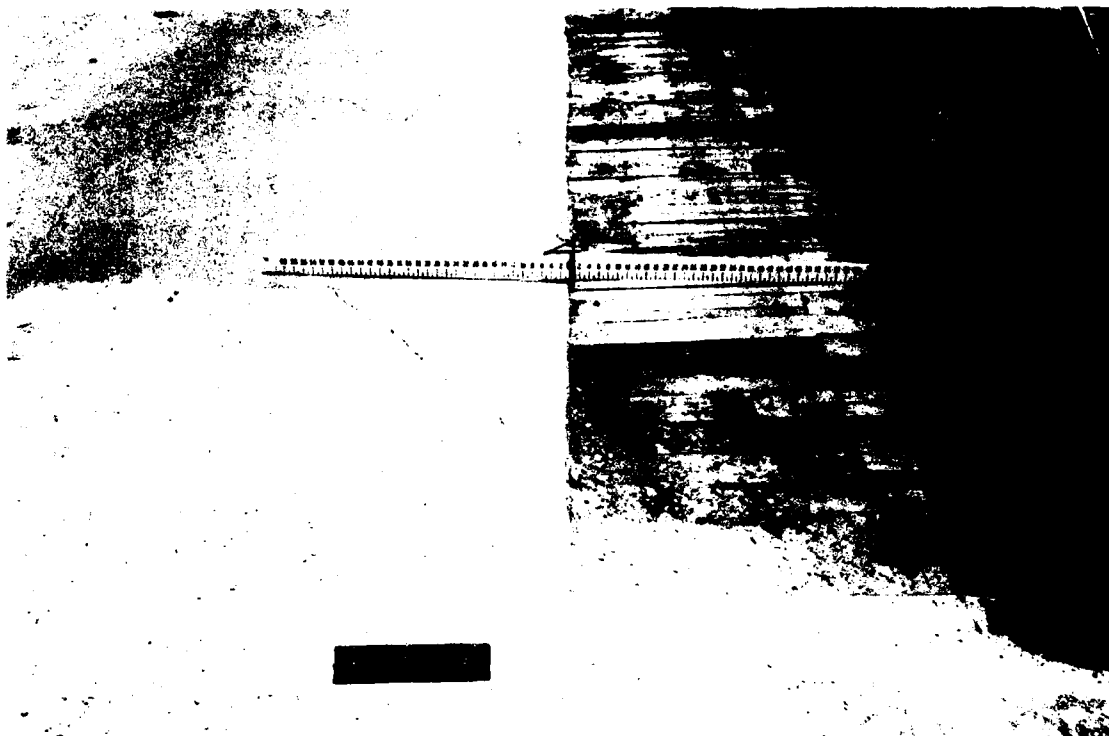


Photo 81. Series 3, crater 5, lane 2, after 450 coverages



Photo 82. Crater 5, series 3, after 450 coverages in each traffic lane



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