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BOMB CRATER REPAIR TECHNIQUES FOR PERMANENT AIRFIELDS

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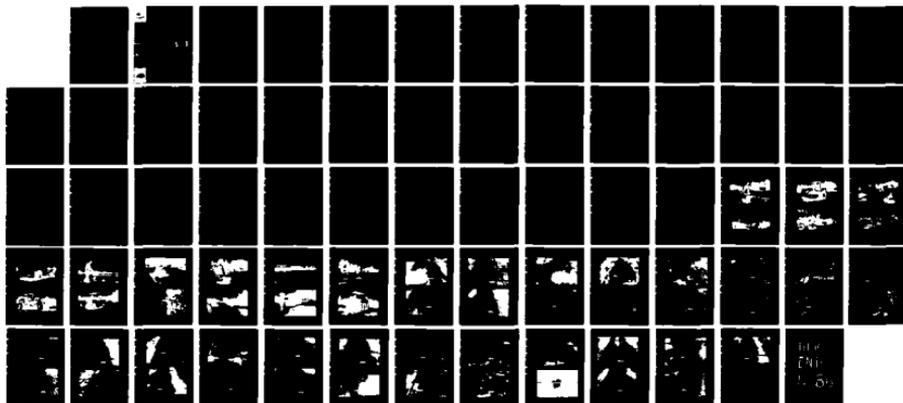
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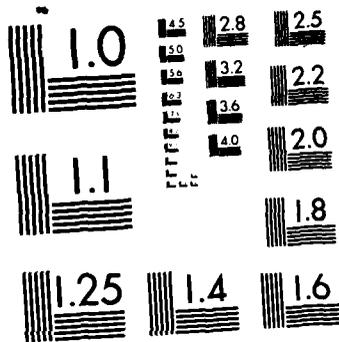
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TECHNICAL REPORT GL-81-12

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BOMB CRATER REPAIR TECHNIQUES FOR PERMANENT AIRFIELDS

Report 3
SERIES 4 TESTS

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>This study is a continuation of Reports 1 and 2 of this series which described Series 1, 2, and 3 tests, which were performed using different field methods of repairs and restoration of bomb craters. Results from these tests showed problem areas that needed correction when the crater repairs were trafficked with full-scale loading.</p> <p>Series 4 tests were run to determine (a) a way to place grout with a minimum of equipment and verify thickness requirements, (b) whether a poor-quality</p> <p>(Continued)</p>			

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20. ABSTRACT (Continued).

material could be stabilized with high early-strength cement and trafficked early, (c) whether the loose stone problem (foreign object damage (FOD)) encountered with the well-graded crushed limestone could be corrected with a cap of neat grout placed over the limestone, and (d) whether an asphalt with an indefinite storage life could be used for the binder in surface treatments and to obtain additional data with surface treatments as a possible solution for the loose stone problem (FOD) encountered with the crushed limestone. Testing was by accelerated traffic using single- and 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 Surfaced (REREPS)," during the period March-May 1981.

Personnel of the Pavement Systems Division, 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 Messrs. A. H. Joseph, J. W. Hall, Jr., R. W. Grau, C. W. Dorman, S. J. Alford, and Dr. G. M. Hammitt II. This project was performed under the direct supervision of Mr. H. H. Ulery, Jr., Chief, PSD, and under the general supervision of Dr. W. F. Marcuson III, Chief, GL. The report was prepared by Mr. Alford and Dr. Hammitt.

COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES during the conduct of the work and preparation of this report; Mr. Fred R. Brown was Technical Director. During the publication of this report, COL Allen F. Grum, USA, was Director of WES; 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:

Multiply	By	To Obtain
cubic inches	16.38706	cubic centimetres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons per square yard	4.5273	cubic decimetres per square metre
inches	25.4	millimetres
kips (force)	4448.222	newtons
pounds (force) per cubic foot	157.0874585	newtons per cubic metre
pounds (force) per square inch	175.1268	newtons per metre
pounds (mass)	0.4535924	kilograms

* 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 4 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 U. S. Forces operational requirements. 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. The construction effort required will necessitate the combined efforts of U. S. Forces and the participation of host nations. The Army Engineer forces have the following primary responsibilities:

- a. Provision of systems for the repair/restoration of war damage to air bases beyond that of emergency repair.
- b. Assistance to the Air Force as necessary in the emergency repair of war damage to air bases when that requirement exceeds the Air Force in-service organic capability.
- c. Base development, excluding Air Force beddown responsibility.
- d. Construction management of repair/restoration of war damage and base development.

3. This report 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.

4. The 18th Engineer Brigade in Germany and the U. S. Army Engineer Waterways Experiment Station (WES) have been working together 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 (Hutchinson, Rone, and Denson 1981). 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.

5. Follow-up studies (Series No. 1 (Cooksey 1981), 2, and 3 (Alford in publication) tests) to the regulated-set concrete study were made at WES in 1978, 1979, and 1980 in which 14 fabricated craters were 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).
- e. Surface treatments over a well-graded crushed limestone.
- f. AC over wire gabions.
- g. AC over a sand base.
- h. T-17 membrane and a WES-blended material to simulate a crushed aggregate native to Germany.
- i. WES-blended material stabilized with portland cement.

6. 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. The amount of equipment required to place grout. (Four large commercial units of equipment design for oil field work were used in Series 1 tests.)
- c. The type of asphalt used for the binder in the surface treatments.

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

Purpose

7. This investigation was conducted to further evaluate the field methods of repair and restoration of bomb craters employed in Series 1, 2, and 3 tests. The test runway and the simulated gear loading were the same as those described in Report 1 of this series. The objectives were to determine if the problems encountered in Series 1, 2, and 3 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

8. A specially designed test section containing fabricated bomb craters was constructed; the craters were repaired as described herein. Series 4 tests were run to determine:

- a. A way to place grout with a minimum of equipment and verify thickness requirements.
- b. If a poor quality material could be stabilized with high-early strength portland cement and trafficked early.
- c. If the loose stone problem (FOD) encountered with the crushed limestone could be corrected with a cap of neat grout placed over the limestone.
- d. If an asphalt with an indefinite storage life could be used for the binder in surface treatments and to obtain more data with surface treatments as possible solution for the loose stone problem (FOD) encountered with the crushed limestone.

Testing consisted of accelerated traffic using either single- or multiple-wheel gear assemblies or both. 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

9. A washed gravel base was used for 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 materials used in the crater repair (Figure 1). After placement of the washed gravel at the desired elevation, 2- by 12-ft aluminum landing mat panels were laid side by side over the washed gravel and rolled 4 passes with a self-propelled steel-wheel vibratory roller at 36-kip dynamic force. 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 soil reaction k tests (Department of Defense 1964) were run in the crater (Table 1).

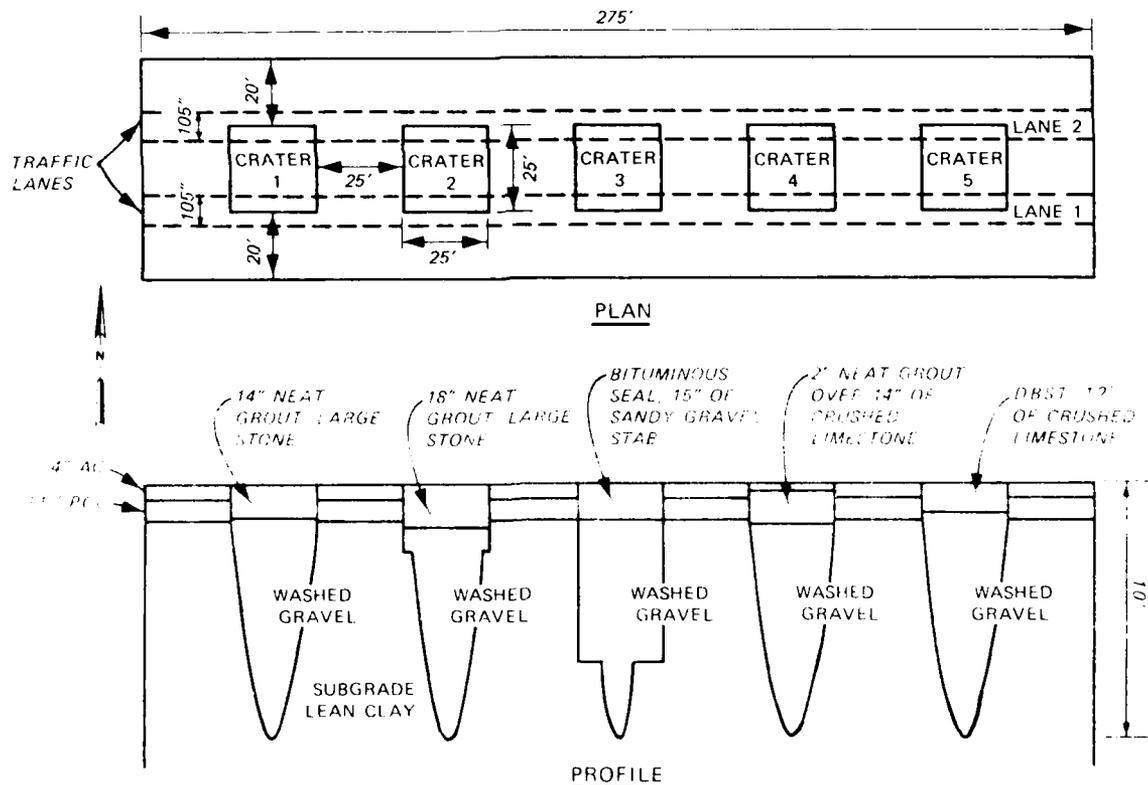


Figure 1. Plan and profile for Series 4 crater tests

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

Table 1
Soils Data Series 4

<u>Location</u>	<u>Modulus of Soil Reaction, k</u>	<u>CBR</u>	<u>Density pcf</u>	<u>Water Content %</u>	<u>Material</u>
Crater 1					
Base	370				Washed gravel
Crater 2					
Base	455				Washed gravel
Crater 3					
Base	357				Washed gravel
Crater 4					
First lift		115	148.6	4.1	Crushed limestone
Second lift		100	143.7	3.5	Crushed limestone
Third lift		75	142.0	3.5	Crushed limestone
Base	476				Washed gravel
Crater 5					
First lift		120	148.3	4.2	Crushed limestone
Second lift		80	144.7	3.7	Crushed limestone
Base	278				Washed gravel

Crater 1

10. Crater 1 was repaired with 14 in. of an open-graded crushed limestone placed in a neat grout. Curve 1, Figure 2, shows the gradation of the crushed limestone. The grout mixture consisted of 2161.9 lb of Type 1 portland cement, 996.3 lb of water, 32.4 lb of calcium chloride, and 8.64 lb of cement friction reducer per cubic yard.

11. A sheet of 6-mil-thick polyethylene was placed over the washed gravel base to prevent the grout from penetrating the base. The grout was delivered to the crater in a ready-mix concrete truck in 6-cu-yd batches. The grout was placed into the crater until the crater was approximately half full (Photo 1). The limestone was then dumped into the crater using front-end loaders (Photo 2). After placement of the limestone level with the edges of the crater, the limestone and grout were rolled two passes with the vibratory roller at 36-kip dynamic

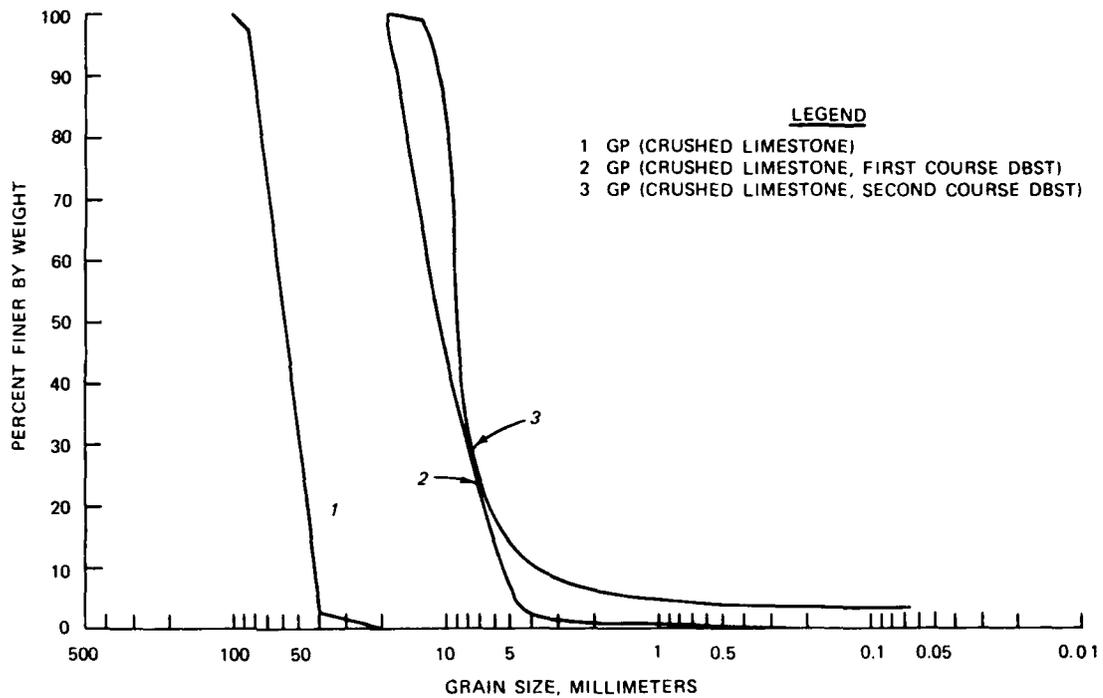


Figure 2. Gradation of crushed limestone used in craters 1, 2, and 5

force (Photo 3). Additional grout was placed after rolling to fill any surface voids and to provide a smooth surface. The grout was spread and leveled with the AC/PCC pavement using a 30-ft aluminum straightedge (Photo 4).

Crater 2

12. This crater repair was the same as crater 1, except 18 in. of limestone and grout were used. The construction techniques were the same.

Crater 3

13. Fifteen inches of sandy gravel (Figure 3) were stabilized with 8 percent (by weight) of Type III, high early-strength portland

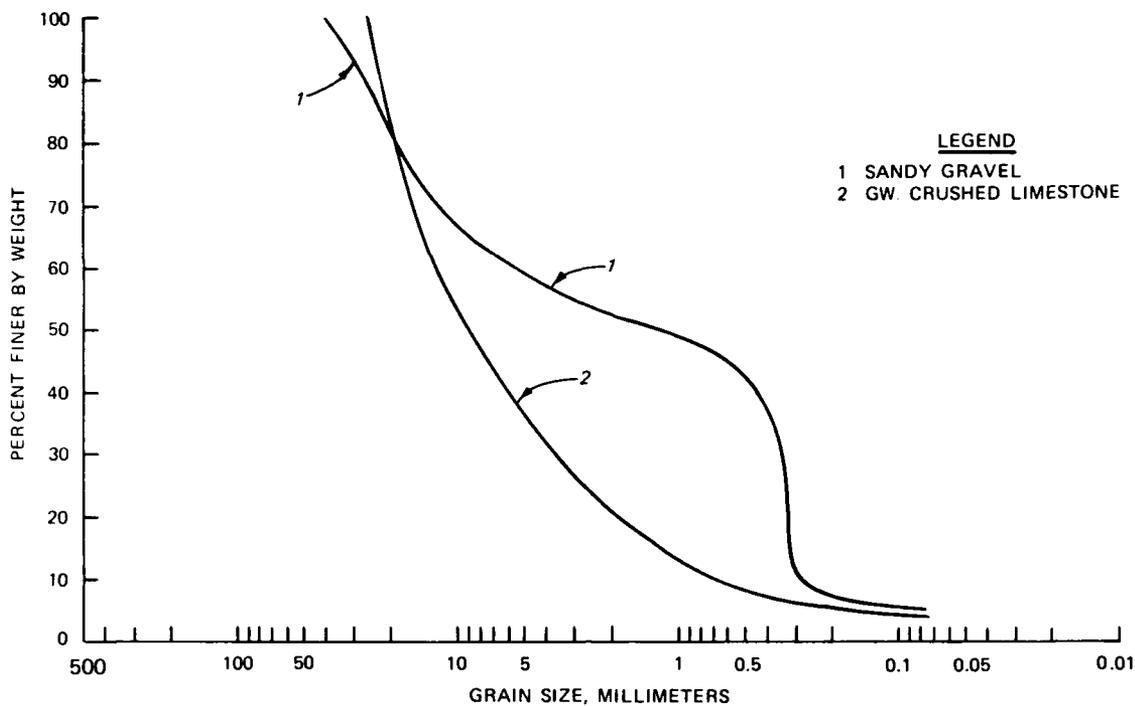


Figure 3. Gradation of materials used in craters 3, 4, and 5.

cement. The sandy gravel was spread out approximately 1 ft thick on a processing area, and water was added to bring the water content of the sandy gravel to 8 percent. After achieving the desired water content, bags of portland cement were placed at predetermined intervals to give the desired 8 percent rate of stabilization. The cement was then spread over the surface of the loose material and pulvimixed (Photo 5). After mixing, the material was stockpiled and then loaded by front-end loaders into dump trucks and hauled to the crater as needed.

14. The stabilized material was placed into the crater in three lifts. As the material was dumped into the crater, it was spread in 6-in. lifts using a D-4 bulldozer (Photo 6). Each lift was compacted with 4 passes* with the vibratory roller at 36-kip dynamic force. Compaction of the final lift was accomplished with 4 passes of the

* A pass as used herein is defined as the movement of load tires past any given point one time.

vibratory roller and 4 coverages* by 50,000-lb four-wheel pneumatic tired roller with a tire inflation pressure of 90 psi (Photo 7). The surface of the crater repair was then fine-bladed with a motor grader (Photo 8) and compacted with one pass with the vibratory roller.

15. After final compaction an AC-20 seal coat was applied to bind any loose surface aggregate to the compacted surface and to prevent surface aggregate particles from becoming dislodged during traffic. Dislodged aggregate particles are potential FOD problems to aircraft. The AC-20 was heated to 350°F and hand sprayed (Photo 9) at a rate of 0.5 gal/sq yd on the surface of the stabilized material. AC-20 was used for the seal coat because of its indefinite storage life and its fast curing time after application. The ambient temperature ranged from 65° to 70°F during spraying. Because of this cool temperature the AC-20 cured too quickly and there was not adequate penetration into the stabilized material. A thin layer of sand was spread by hand over the AC-20 and then rolled with a seven-wheel pneumatic roller having a gross weight of 50,000 lb and 90-psi tire pressure (Photo 10). This was done to avoid a slick surface and to prevent pickup of the AC-20 under traffic.

Crater 4

16. Crater 4 was repaired with a 2-in. neat-grout cap placed over 14 in. of well-graded crushed limestone (Figure 3). The crushed limestone was placed in three 5-in. lifts. The limestone was spread using a D-4 bulldozer; the first two lifts were rolled with 8 passes each with a vibratory roller set at 36-kip dynamic force (Photo 11). The final lift was rolled 32 coverages with a four-wheel pneumatic roller having a gross weight of 100,000 lb and 90-psi tire pressure. The average as-constructed CBR, density, and water content data are shown in Table 1. A motor grader was used to shape the surface of the limestone to a final elevation 2 in. below the adjoining AC/PCC pavement (Photo 12).

* A coverage as used herein is defined as sufficient passes of load tires in adjacent tire paths to cover a given width of surface area one time.

17. A 2-in. neat-grout cap was placed over the limestone for FOD cover. The grout mixture was the same as that used in craters 1 and 2. The grout was placed directly on the limestone from a ready-mix concrete truck (Photo 13). The grout was moved into place and leveled using a 30-ft aluminum straightedge (Photo 14) and then the surface was bull-floated (Photo 15).

Crater 5

18. The crater 5 repair consisted of a 12-in.-thick layer of well-graded crushed limestone (see gradation in Figure 3) overlaid with a double surface treatment (DBST) for FOD cover. The limestone was placed in two 6-in. lifts. The first lift was compacted with 8 passes with the vibratory roller at 36-kip dynamic force. The second and final lift was compacted with the vibratory roller plus 32 coverages with the four-wheel pneumatic roller having a gross weight of 100,000 lb and 90-psi tire pressure. After final compaction, the crater repair surface was shaped and leveled with the motor grader and then primed with MC-70 at a rate of 0.3 gal/sq yd (Photo 16). After the MC-70 cured, the DBST was applied. The DBST consisted of two courses of crushed limestone with AC-20 used for the binder. Gradation curves for the crushed limestone are shown in Figure 2; curve 2 shows the first course and curve 3 the second. AC-20 was used because of its indefinite storage life and because heating is the only requirement before its use. The AC-20 was heated to 350°F and sprayed at a rate of 0.3 gal/sq yd; the first course of limestone was immediately spread by hand as the AC-20 was being sprayed (Photo 17). After approximately one-half of the crater repair was covered, it was rolled with a seven-wheel pneumatic roller having a gross weight of 50,000 lb and 90-psi tire pressure to embed the limestone into the AC-20 before it cooled (Photo 18). The other one-half of the crater repair was finished in the same manner. The second course was applied immediately after the first in the same manner as the first except approximately one-third of the crater repair was finished at a time, enabling the roller to roll the DBST while the AC-20 was at a

higher temperature, ensuring a better embedment of the limestone. The ambient temperature ranged from 65^o to 70^oF during the construction of the DBST.

PART III: TRAFFICKING ON TEST CRATERS

19. F-4 and C-141 traffic was applied to the test craters. A total of 550 passes or 72 coverages of F-4 traffic was applied to lane 1 only, and C-141 traffic was applied to both lanes. Figure 4 shows the traffic distribution pattern used for the traffic and Figure 1 shows the locations of the traffic lanes.

20. Traffic was started and applied to craters 1, 2, 3, and 4 in a time frame to allow for a minimum curing time and to simulate the volume and type of traffic that would be expected after a repair had been made to an airfield. Table 2 shows the time, in hours, after repairs were completed in craters 1 and 2 that traffic was applied and the total number of coverages or passes at the end of each traffic period. For the time of traffic application after placement of the grout cap on crater 3 add 28 hr and on crater 4 add 2.5 hr. Upon completion of traffic on lane 1, 340 passes or 100 coverages of C-141 traffic were applied in order to place some early C-141 traffic on an area that had already received F-4 traffic. After the 340 passes or 100 coverages, traffic was continued on lane 2 to 3400 passes or 1000 coverages. At the termination of F-4 traffic, C-141 traffic was once again applied on lane 1.

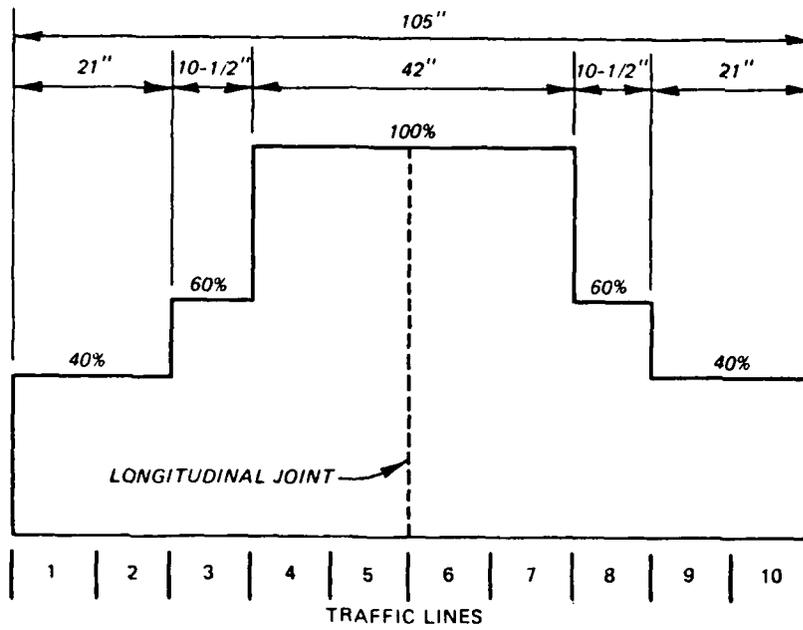
Crater 1

21. A small number of shrinkage cracks appeared in the crater repair 1 hr after placement. Once formed, these cracks did not increase in number or size before traffic was applied.

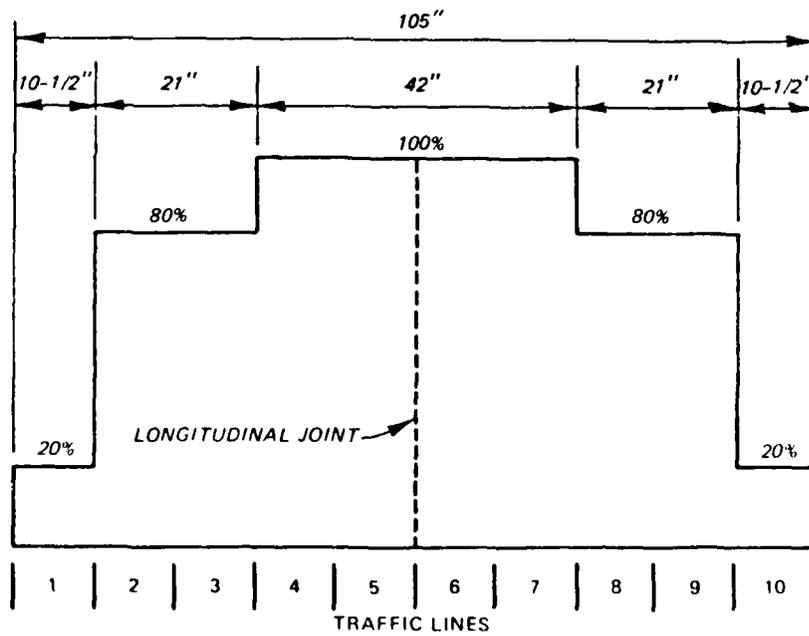
22. Test methods CRD-C 16-76 and CRD-C 14-73 (WES 1949) were used to determine flexural and compressive strengths for beams and cylinders cast for craters 1 and 2. The flexural strength was 80 psi 8 hr after placement, and 270 psi after 7 days. The compressive strength was 590 psi after 8 hr, 1970 psi after 7 days, and 2210 psi after 21 days (Figure 5).

Lane 1

23. Photo 19 shows the traffic lane before traffic. F-4 traffic



C-141 TRAFFIC PATTERN



F-4 TRAFFIC PATTERN

Figure 4. Traffic distribution patterns used in Series 4 crater testing

Table 2
Traffic Applied to Craters 1 and 2 After
Placement of Grout

Hours After Placement	Lane 1		Lane 2
	F-4 Traffic Coverages (Passes)	C-141 Traffic Coverages (Passes)	C-141 Traffic Coverages (Passes)
8- 11	26(197)		
18- 20	40(304)		20(68)
25- 27	50(380)		40(136)
33- 35	72(550)		60(204)
42- 44			100(340)
90-100		50(170)	
114-120		100(340)	
120-124			140(476)
138-150			350(1190)
162-174			560(1904)
186-198			820(2788)
260-268			910(3094)
284-290			1000(3400)
308-315		150(510)	
332-336		180(612)	
428-435		340(1156)	
451-461		460(1564)	
476-480		500(1700)	
500-510		600(2040)	
524-525		610(2070)	
547-557		780(2652)	
594-604		920(3128)	
620-628		1000(3400)	

NOTE: At 8 hr, compressive strength and flexural strength of the grout were 590 and 80 psi, respectively. At 7 days, compressive strength and flexural strength were 1970 and 270 psi, respectively. Compressive strength at 21 days was 2210 psi.

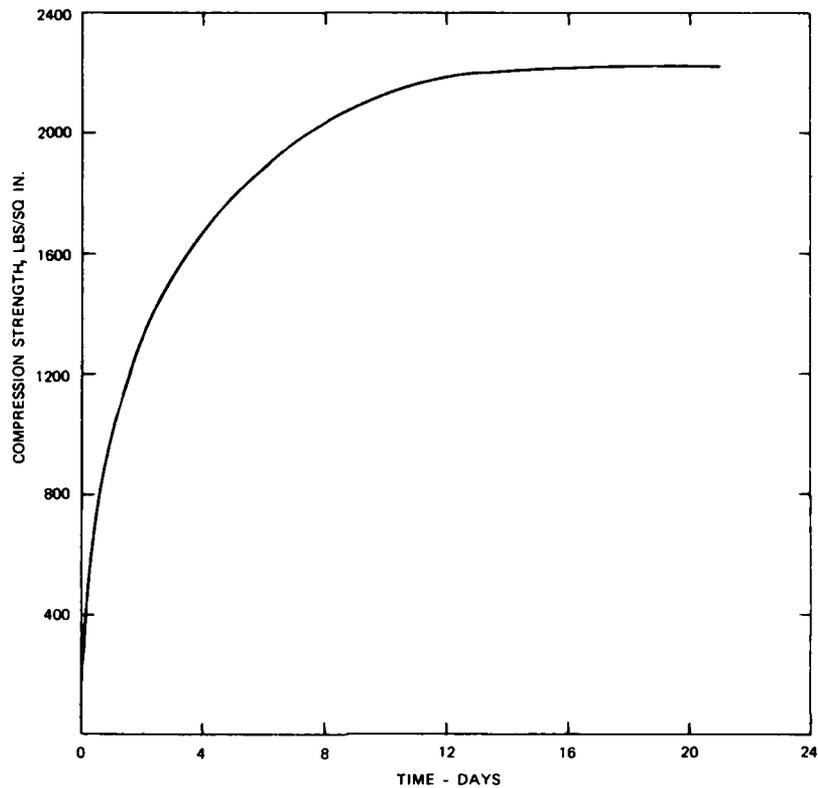


Figure 5. Compressive strength for craters 1 and 2 was started 8 hr after placement of the grout and crushed limestone repair and continued for 3 hr. A total of 197 passes or 26 coverages were applied during this time period (Table 2) with no apparent damage. Eighteen hours after placement of the grout, with no additional traffic, there were a number of cracks in the south half of the crater where the traffic lane is located. These cracks stopped at the center of the crater. Photo 20 shows these cracks and surface conditions after 228 passes or 30 coverages. Traffic was continued at different intervals through the day until 550 passes or 72 coverages were applied, with only a slight increase in the number of cracks. C-141 traffic was started 90 hr after placement of the grout and continued to 120 hr, at which time 340 passes or 100 coverages had been completed. During this traffic period there was a large increase in cracks in the south half of the crater repair (Photo 21) all of which appeared to be shrinkage cracks.

After 340 passes or 100 coverages, traffic was stopped in lane 1 in order to allow for the continuation of traffic in lane 2. However, C-141 traffic was resumed in lane 1 308 hr after placement of the crater repair. After 2754 passes or 810 coverages, a longitudinal crack became visible on the edge of the traffic lane and there was minor spalling in the southeast corner of the crater repair. Photo 22 shows surface conditions after 3400 passes or 1000 coverages with the longitudinal crack outlined but not the shrinkage cracks as in Photo 21. The longitudinal crack appeared to be the only structural damage with very minor spalling along the edge of the crack. Figure 6 shows typical cross-section data for this lane.

Lane 2

24. Photo 23 is a general view of the traffic lane before traffic. C-141 traffic was started 18 hr after the crater repair was finished. After 68 passes or 20 coverages, there were 3 shrinkage cracks in the traffic lane. After 340 passes or 100 coverages, there had been an increase in the shrinkage cracks and there was one longitudinal crack located outside the traffic lane (Photo 24). After 2788 passes or 820 coverages, there were two corner breaks plus the longitudinal crack. One thousand coverages or 3400 passes were applied to the traffic lane within 290 hr (12 days) after placement, and at this time there was one longitudinal crack and three corner breaks, with very minor spalling (Photo 25). Figure 7 shows typical cross-section data for the traffic lane.

Crater 2

25. As in crater 1, shrinkage cracks developed in the crater repair in limited numbers, approximately 1 hr after placement. Photo 26 is a close-up of the most severe cracks.

Lane 1

26. Photo 27 shows the surface conditions of the traffic lane before traffic. F-4 traffic was started 8 hr after placement and continued at different time intervals (Table 2) during the next 35 hr for a

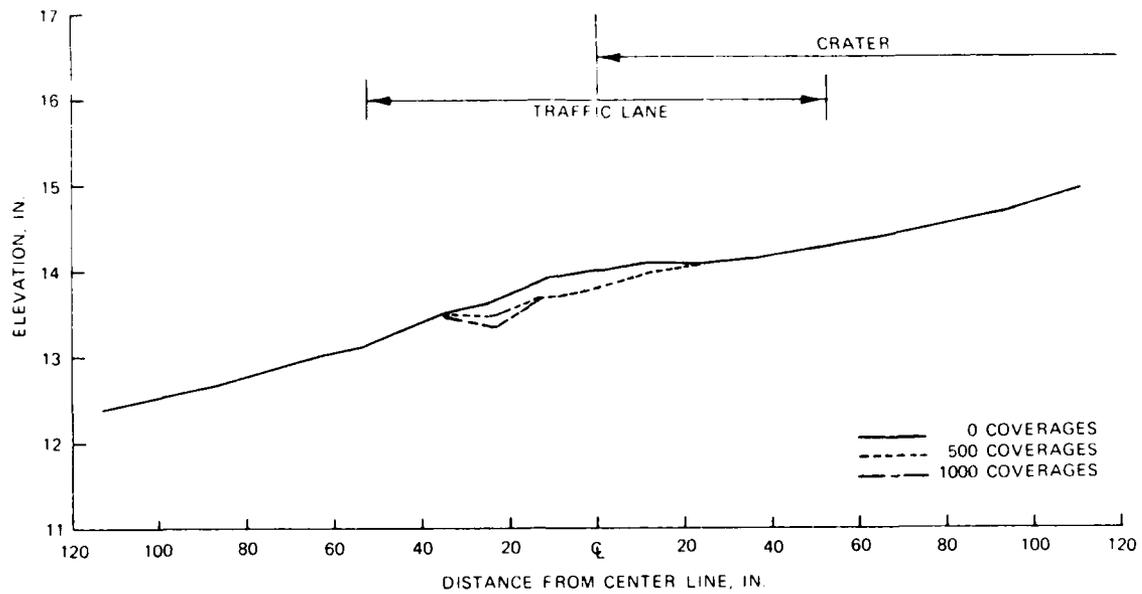


Figure 6. Cross-section data for crater 1, lane 1

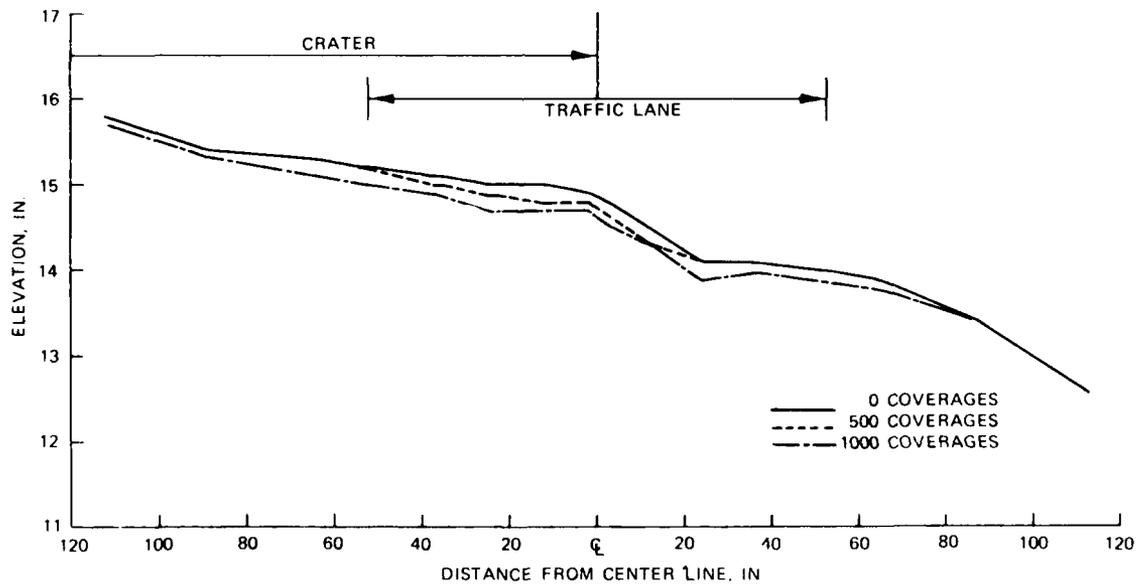


Figure 7. Cross-section data for crater 1, lane 2

total of 550 passes or 72 coverages. The defect noted was numerous shrinkage cracks (Photo 28). C-141 traffic was started 90 hr after placement of grout and 340 passes or 100 coverages were applied before traffic was shifted back to lane 2. Photo 29 shows the increase in

shrinkage cracks that occurred during this traffic. There was no increase in shrinkage cracks when traffic was resumed and continued to 3400 passes or 1000 coverages. Only very minor spalling at one location along the edge of the crater was noted (Photo 30). Figure 8 shows typical cross-section data for the traffic lane.

Lane 2

27. Photo 31 is a general view of the traffic lane before C-141 traffic. As in crater 1, lane 2, traffic was applied at different time intervals. Shrinkage cracks developed with time and traffic as in the previous traffic lanes. After 204 passes or 60 coverages, the lane contained one corner break in the northeast corner. Photo 32 shows the shrinkage cracks and corner break after 340 passes or 100 coverages. After 2788 passes or 820 coverages, there were two corner breaks and very minor spalling along the edge of the crater. There were no additional defects when traffic was stopped at 3400 passes or 1000 coverages (Photo 33). Figure 9 shows cross-section data for this lane.

Crater 3

Lane 1

28. Photo 34 shows the traffic lane before traffic. F-4 traffic was started 36 hr (Table 2) after construction of the crater repair. After 20 passes or 4 coverages the stabilized sandy gravel was starting to rut in the southeast corner of the crater and the bond between the asphalt (AC-20) and the stabilized sandy gravel was broken in this area. After 76 passes or 10 coverages the rutted area was approximately 2 ft square and 2.5 in. deep, and the sandy gravel was starting to work up through the asphalt. The AC-20 had formed an asphalt membrane over the crater repair with very little or no penetration into the stabilized sandy gravel. The stabilized sandy gravel began to break down after 106 passes or 14 coverages, and the degree of rutting had increased. The depth of the rutted area was 3 in. at this time. As traffic continued, the size of the rutted area and depths of the ruts increased. After 456 passes or 60 coverages the rutted area was 5.5 ft long and

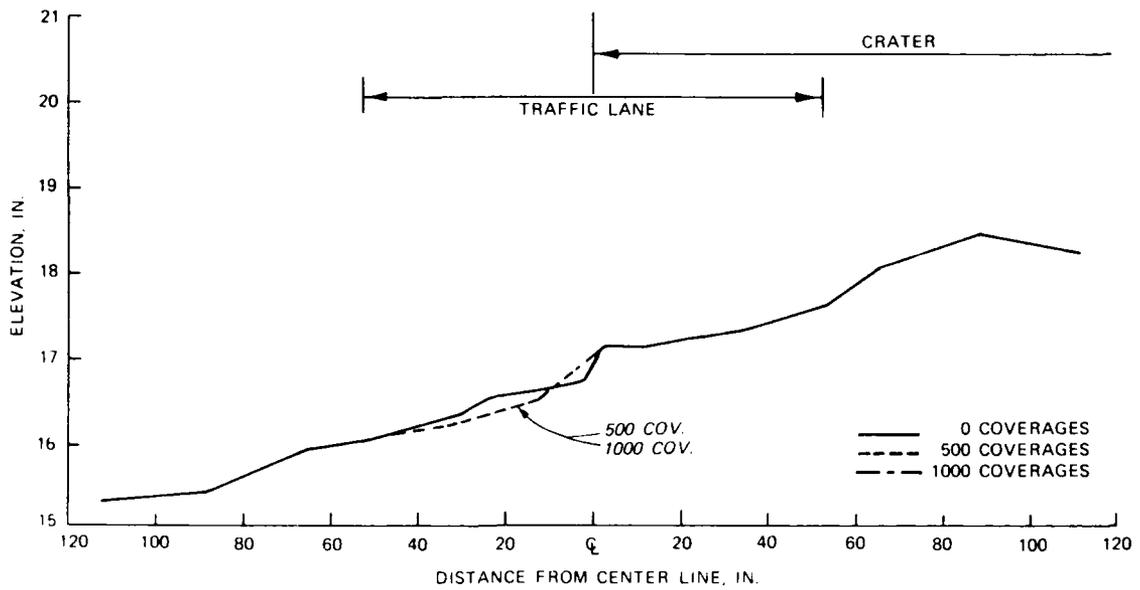


Figure 8. Cross-section data for crater 2, lane 1

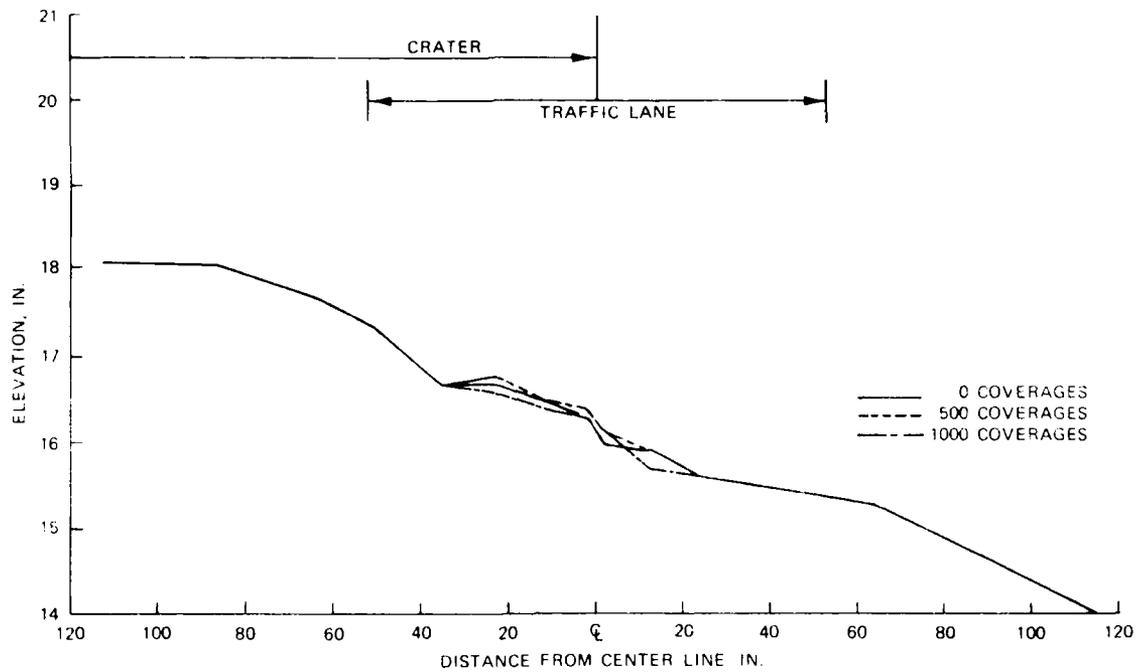


Figure 9. Cross-section data for crater 2, lane 2

6 ft wide, and the maximum rut depth measured was about 4.5 in. Between 456 passes or 60 coverages and 550 passes or 72 coverages the rutted area became almost impassable. There was no increase in the maximum rut depth, but there was an additional breakdown of the stabilized sand.

gravel in the rutted area. This material became unstable and shifted under the wheel. Photo 35 shows the surface condition after 550 passes or 72 coverages of the F-4. Figure 10 shows typical cross-section data of the rutted area. The loose material was removed from the rutted area and replaced with a well-graded crushed limestone and rolled 4 passes with the vibratory roller at 36-kip dynamic force. In repairing the rutted area it was found that the loose material was confined to the top 5 in., which was the last lift placed in the section. The stabilized sandy gravel under the rutted area was in excellent condition; this was the second lift placed in the repair. The rutted area was repaired to see if it was possible to patch a small area such as this with crushed limestone and continue traffic on craters 2 and 4. Photo 36 shows the traffic lane after 340 passes or 100 coverages of C-141 traffic, with no apparent damage. Note that the limestone repair is in the background. At 952 passes or 280 coverages a 1-in. rut had developed in the stabilized material at the edge of the patched area. This rut did not increase in depth as traffic continued. However, a 1-in. rut developed in the southwest corner and along the south edge of the crater repair after 1700 passes or 500 coverages. This rut increased in depth to 2 in. with the continuation of traffic to 3400 passes or 1000 coverages (Photo 37). Figure 11 shows cross-section data for the west end of the traffic lane.

Lane 2

29. Photo 38 is a general view of the traffic lane before traffic. C-141 traffic was started 46 hr after construction of the crater repair and continued at different time intervals until 3400 passes or 1000 coverages had been applied. After 170 passes or 50 coverages, a slight amount of consolidation of the repair materials (approximately 0.5 in.) was noted in each corner of the traffic lane. Photo 39 shows that after 340 passes or 100 coverages the asphalt seal (AC-20) had started to deteriorate in the corners of the crater. Between 340 passes or 100 coverages and 1020 passes or 300 coverages deterioration of the stabilized sandy gravel started in the northeast corner of the crater repair. The area was approximately 10 ft long and 1.5 ft wide with rutting 2.25 in. deep. There was no noticeable increase in the deterioration

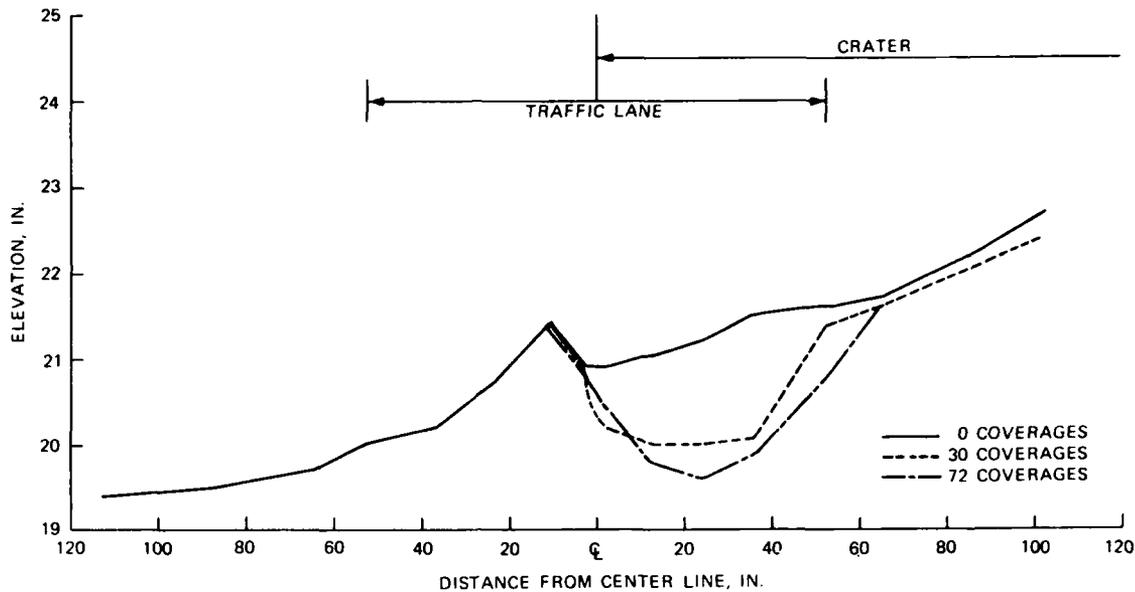


Figure 10. Cross-section data of the rutted area, crater 3, lane 1, after F-4 traffic

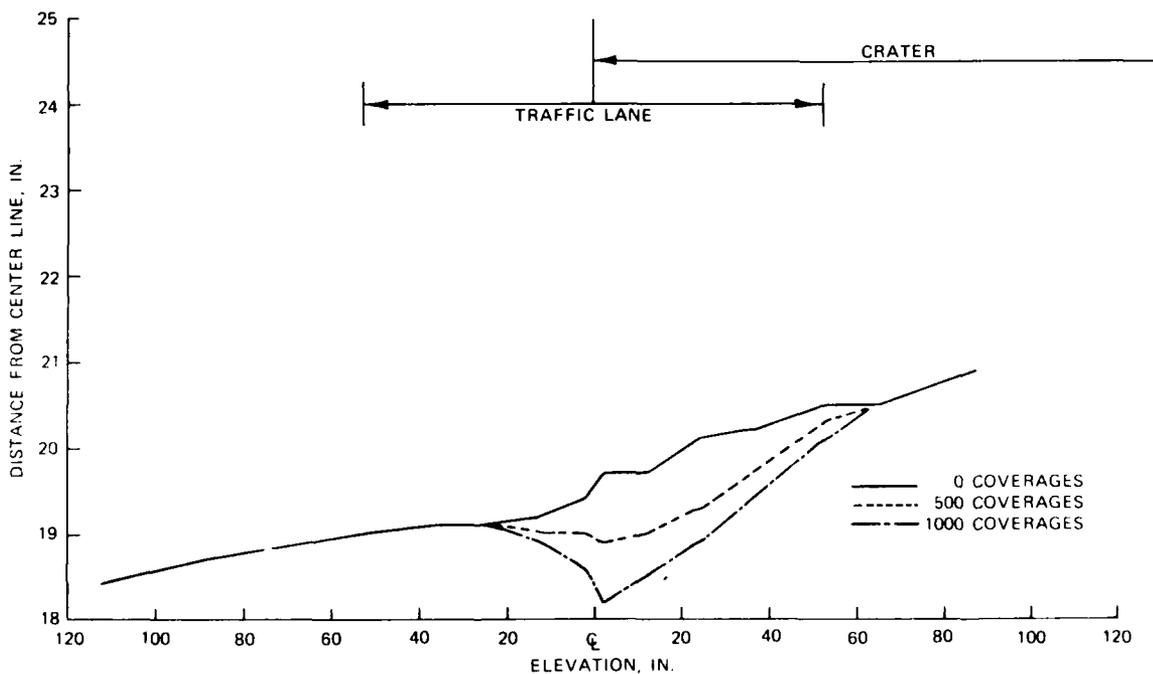


Figure 11. Cross-section data for west end of crater 3, lane 1

until after 2040 passes or 600 coverages, at which time the rut depth was 2.5 in. The deteriorated area increased in length and rut depth between 2040 passes or 600 coverages and 3400 passes or 1000 coverages.

The length was approximately 15 ft and the rut depth was 3.5 in. Raveling of the surface gravel was starting in the northwest corner of the crater at this time (Photo 40). Figure 12 shows typical cross-section data for this traffic lane.

Crater 4

Lane 1

30. Photo 41 shows the traffic lane before traffic. F-4 traffic was started 10.5 hr after placement of the grout cap over the well-graded crushed limestone. Hairline cracks started in the grout cap after 15 passes or 2 coverages, and they ran the length and width of the traffic lane. After 45 passes or 6 coverages, minor spalling was noted along the edge of the crater repair. After 228 passes or 30 coverages a large number of cracks developed in a semicircular pattern (Photo 42). As the traffic continued, the number of cracks inside and outside of the traffic lane increased along with the spalling at the edges of the crater. Photo 43 shows the severity of the cracking and spalling after 550 passes or 72 coverages. C-141 traffic caused additional cracks and spalling after 340 passes or 100 coverages. Some of the cracks were 2 in. apart and the spalling had reached a depth of 1.5 in. along the edge of the crater (Photo 44). Traffic was continued to 3400 passes or 1000 coverages and there was no noticeable increase in the number of cracks; however, the spalling continued along the edges of the crater repair and some minor spalling was noted on the cracks inside the crater (Photo 45). Figure 13 shows that there was consolidation of the repair materials under C-141 traffic, with the maximum being 0.5 in. after 100 coverages, 1.5 in. after 500 coverages, and 2.0 in. after 1000 coverages.

Lane 2

31. Photo 46 shows the traffic lane before C-141 traffic which was applied 20.5 hr after placement of the grout cap. With the start of traffic, hairline cracks developed in the grout. After 34 passes or 10 coverages the cracks were visible throughout the traffic lane with

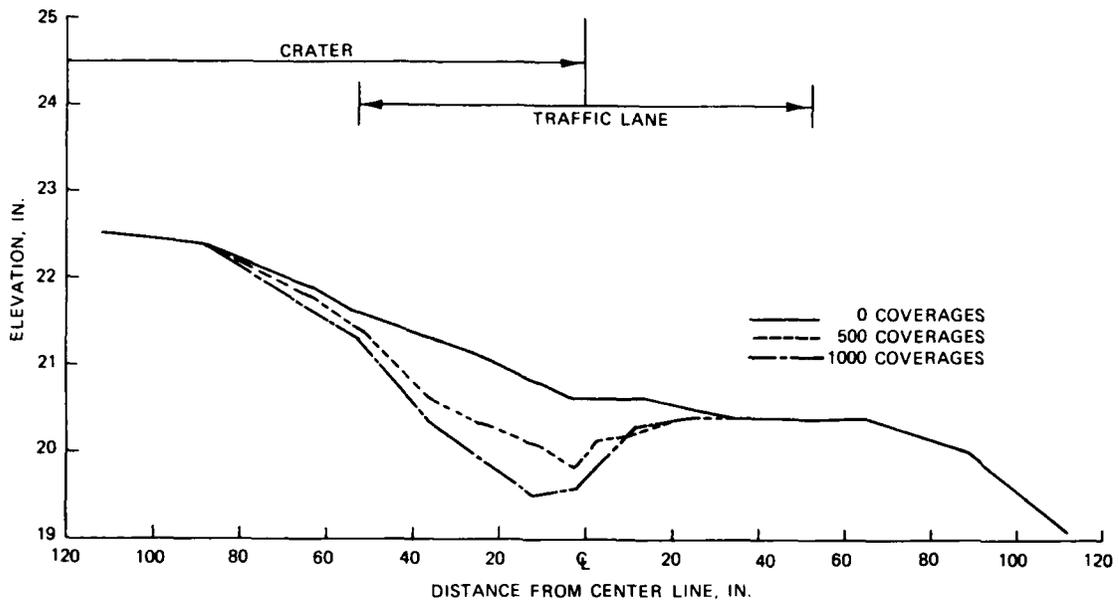


Figure 12. Cross-section data for crater 3, lane 2

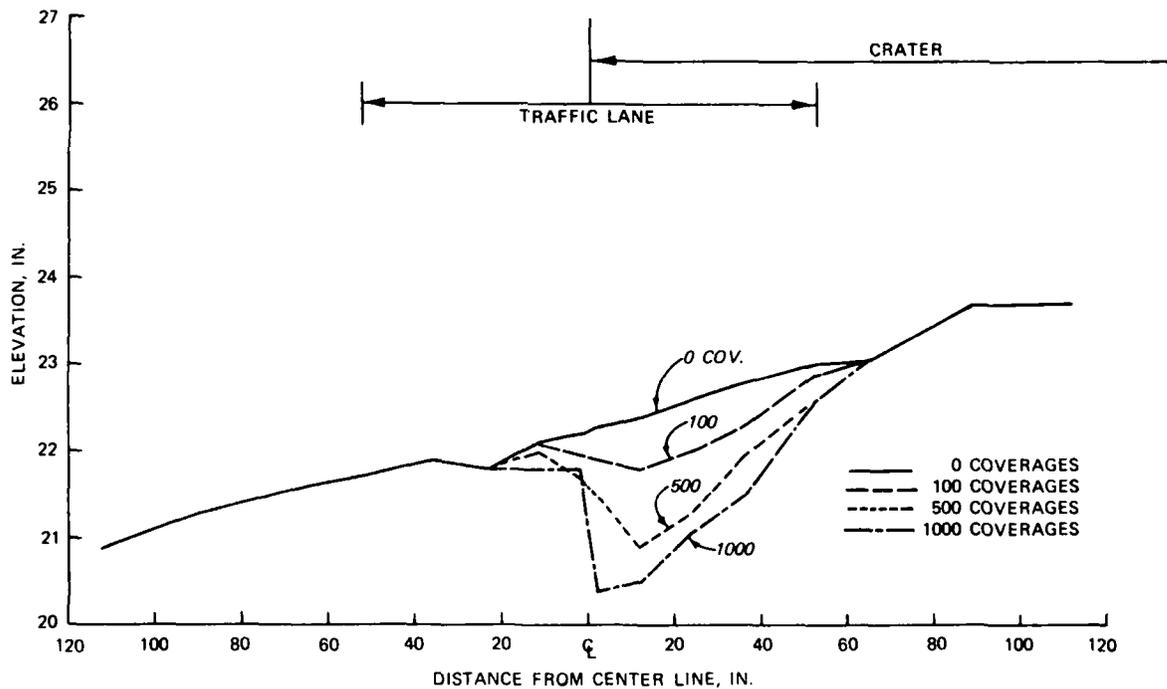


Figure 13. Cross-section data for crater 4, lane 1

minor spalling along the edges of the crater repair. As in lane 1 the cracks and spalling increased with traffic. After 340 passes or 100 coverages the traffic lane was completely covered with cracks, and major spalling occurred along the edges of the crater repair, with some pieces

of the loose grout measuring 1 in.³ (Photo 47). After 1020 passes or 300 coverages, the spalling along the edges of the crater had progressed 13 in. back into the crater repair and there was spalling on some of the cracks inside the traffic lane. From 340 passes or 100 coverages to 3400 passes or 1000 coverages there was no noticeable increase in the number of cracks, only the continuation of the spalling. Photo 48 shows the surface conditions after 3400 passes or 1000 coverages. As in lane 1 there was consolidation of about 2 in. of the repair materials under traffic (Figure 14).

Crater 5

Lane 1

32. Photo 49 shows the traffic lane before F-4 traffic. After 152 passes or 20 coverages, the top course of the DBST was embedded further into the AC-20 with approximately 10 percent completely embedded into the asphalt on the traffic lane. After 304 passes or 40 coverages, there was minor bleeding of the asphalt along the edge of the crater, but there was no pickup of the asphalt by traffic. After 380 passes or 50 coverages the grooves in the tire were leaving a slight impression in the DBST in the area of the traffic lane where bleeding of the asphalt was present. Photo 50 shows the surface conditions after 550 passes or 72 coverages, with complete embedment of the top course of DBST in approximately 75 percent of the traffic lane at this time. There was a very slight amount of consolidation (less than 0.3 in.) in the materials along the edge of the crater. After 170 passes or 50 coverages of the C-141, the top course of the DBST was completely embedded into the asphalt and there was bleeding of the asphalt. C-141 traffic caused the material in the crater repair to consolidate at a faster rate. The maximum deformation was 2.0 in. after 340 passes or 100 coverages (Photo 51). The asphalt continued to bleed under traffic and at 510 passes or 150 coverages two areas of the surface treatment adhered to the tires. These areas were approximately 9 in. square (Photo 52). The surface of the traffic lane was covered with limestone fines to blot

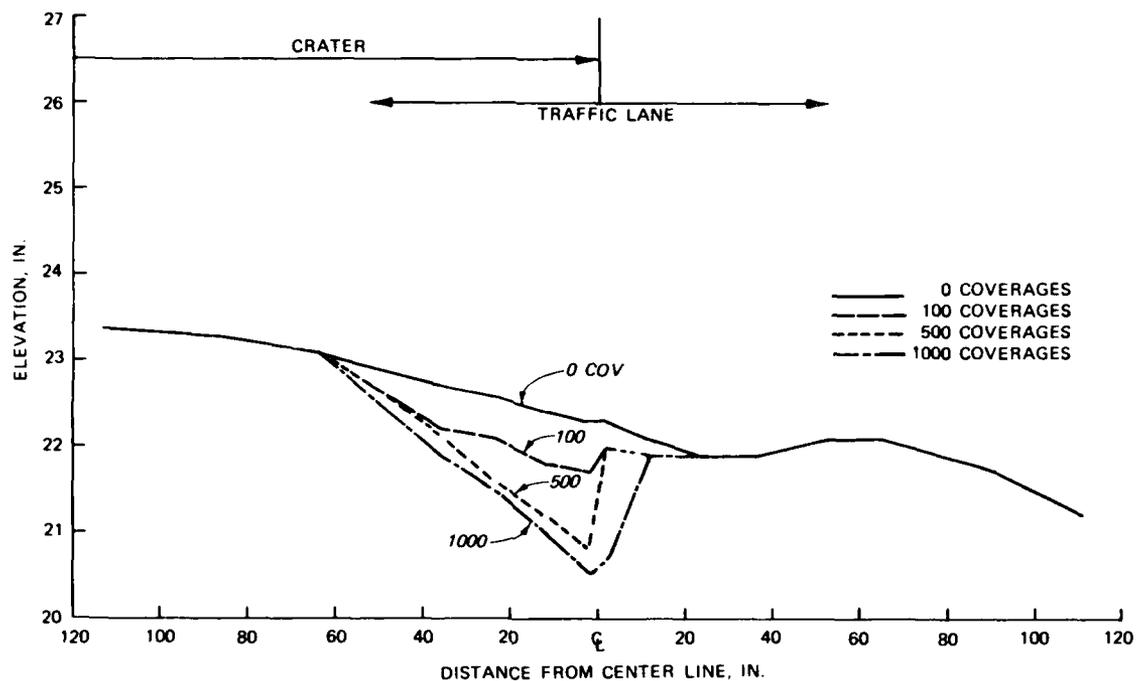


Figure 14. Cross-section data for crater 4, lane 2

the bleeding asphalt and prevent further removal of the DBST. After 1156 passes or 340 coverages there was minor rutting in the DBST and the bond between the DBST and crushed limestone was broken at the edge of the crater in the east half of the traffic lane. Settlement of the AC over PCC pavement was noted in the southeast corner of the traffic lane outside the crater repair. This area contained two breaks from a previous series of tests. After 1700 passes or 500 coverages the rutting continued in the DBST, with some displacement of the DBST outside of the crater repair (Photo 53). Along with consolidation of repair materials at the edge of the crater and additional settlement of the AC over PCC pavement, the maximum deformation was 3.5 in. at the east end of the traffic lane. Between 1700 passes or 500 coverages and 2074 passes or 610 coverages the DBST stopped the rutting and displacement and rebonded itself to the crushed limestone (Photo 54). However, because the displaced DBST bonded to the AC over PCC pavement, the crater repair materials consolidated, and the AC over PCC pavement settled additionally, a tire hazard developed at the east end of the traffic lane and traffic was stopped. Figure 15 shows cross-section data for the east end of the traffic lane, crater 5, lane 1.

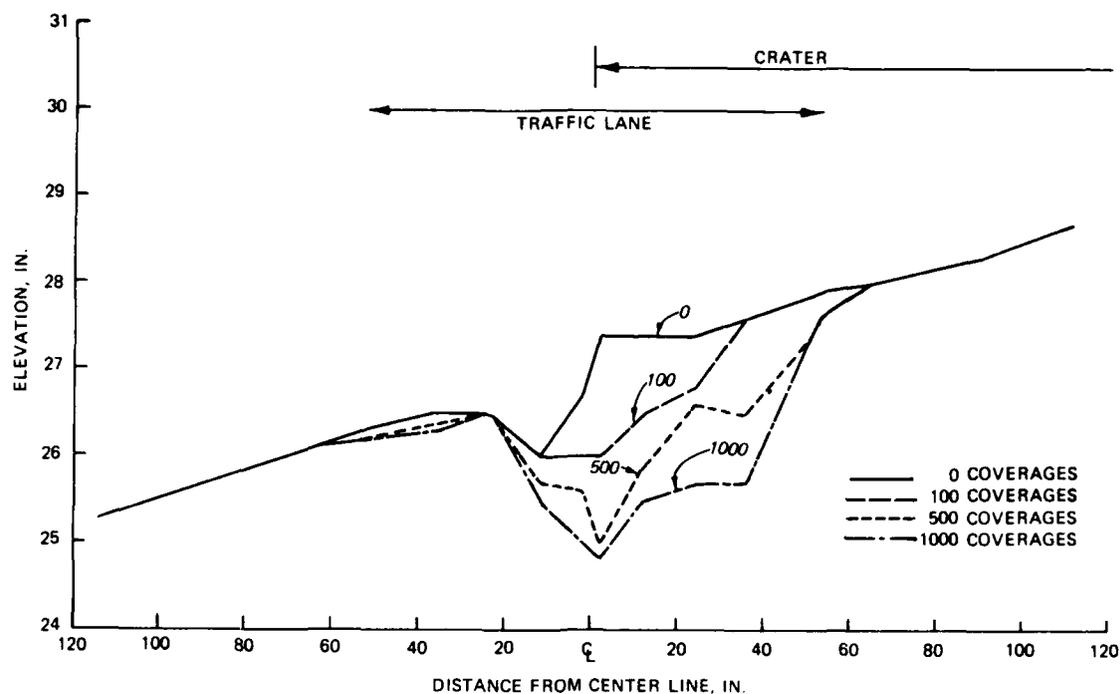


Figure 15. Cross-section data for the east end of crater 5, lane 1

Lane 2

33. Photo 55 shows a general view of the traffic lane before traffic. There was some minor raveling and embedment of the surface aggregate into the asphalt with the start of C-141 traffic. After 136 passes or 40 coverages there was very minor bleeding of the asphalt along the edge of the crater. After 170 passes or 50 coverages there was some minor consolidation of the repair materials in the northeast corner of the crater. Photo 56 shows the surface condition of the traffic lane after 340 passes or 100 coverages, with the raveling and embedment of the surface aggregate and the consolidation in the northwest corner continuing. After 1020 passes or 300 coverages the average deformation was 1 in. and the maximum was 1.75 in. at the west end of the crater. Settlement in the AC over PCC pavement outside the crater in the northeast corner of the traffic lane had started at this coverage level. This was due to a longitudinal crack located along the north edge of the traffic lane. This crack was from a previous series of tests. At 1700 passes or 500 coverages the surface aggregate was completely embedded into the asphalt, with the tire grooves making slight

impressions in the DBST. The average deformation was 2.0 in. and the maximum was 3.0 in. The consolidation of the repair materials and the settlement of the AC over PCC pavement continued and after 3400 passes or 1000 coverages the average deformation was 2.4 in. and the maximum was 3.25 in. (Photo 57). There also was minor bleeding of the asphalt in the DBST. Figure 16 shows cross-section data for crater 5, lane 2.

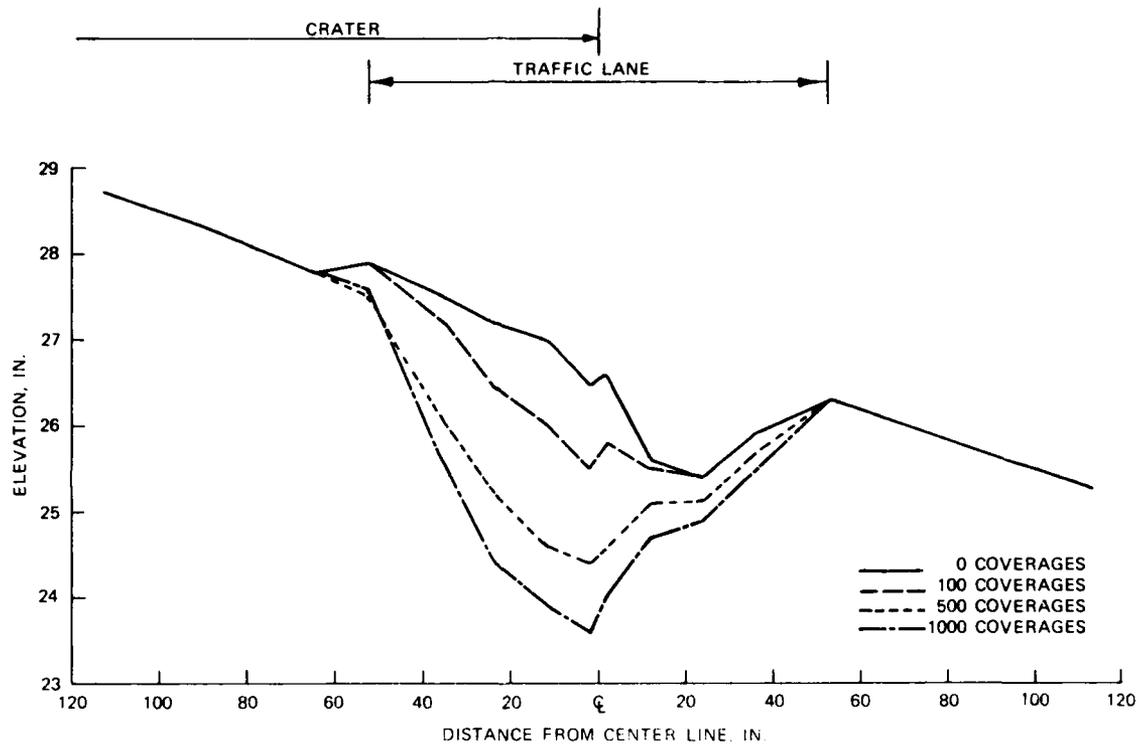


Figure 16. Cross-section data for crater 5, lane 1

PART IV: CONCLUSIONS AND RECOMMENDATIONS

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

- a. The performance of the 14-in. grout-limestone repair was very good in lane 1 and fair in lane 2. The numerous shrinkage cracks in the crater repair were minor defects and would not impair aircraft operations. There was no damage to the crater repair from the F-4 traffic. The delay in placing the C-141 traffic on lane 1 showed that major defects or damage would be significantly less if the volume of traffic is spread over a longer time period than that used for lane 2. The grout-limestone will support C-141 traffic 18 hr after placement, but no more than 204 passes or 60 coverages could be applied within 48 hr after placement without damage to the crater repair (Series 4, crater 1).
- b. The performance of the 18-in. grout-limestone repair was excellent in lane 1 and good in lane 2, with the exception of the shrinkage cracks. This repair as tested is adequate to support C-141 traffic (with minor damage) 18 hr after placement and applied in the time frame used for lane 2 traffic (Series 4, crater 2).
- c. Because of the rutting and the breakup of the stabilized sandy gravel under traffic, this type of repair would be unsatisfactory for the repair of a runway or taxiway (Series 4, crater 3).
- d. The spalling of the grout cap caused a FOD problem of its own, while trying to eliminate the loose stone (FOD) problem encountered with the well-graded crushed limestone. The amount of spalling that occurred under traffic makes this crater repair method unacceptable (Series 4, crater 4).
- e. Because of the ambient temperature of 65° to 70°F, the AC-20 cooled too quickly for proper seating of the aggregate into the binder. Also, the amount of asphalt used was somewhat higher than necessary--0.6 percent was used as compared to a design amount of 0.5 percent. As traffic was begun and the ambient temperature increased, the aggregate became embedde into the asphalt, resulting in a bleeding condition. If an AC is used for the binder in a DBST, it should be applied at the design amount or slightly less. Also, the DBST should not be placed if the ambient temperature is below 80°F or the surface to be treated is below 100°F. Even if these weather conditions are met, the aggregate may require preheating to ensure a good

coating of AC and binding of the aggregate in the AC. It is essential that the asphalt be covered within 1 min or the increase in viscosity that takes place within that time may prevent good embedding for placement and binding of the aggregate (Series 4, crater 5).

- f. The consolidation of the crushed limestone in craters 4 and 5 showed that additional compaction, other than with a roller, is required along the edges on material placed below the surface of the crater repair. This could be accomplished with a gasoline-powered hand impactor compactor or vibratory plate compactor attached to a backhoe boom (Series 4, craters 4 and 5).
- g. The 18 in. of neat grout-large stone repair is recommended for the semipermanent crater repair where concrete transit mix trucks are not available.
- h. The asphalt caps are not recommended due to the difficulty in placement of correct temperatures and the question of availability of asphalt during wartime.

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Photo 1. Placement of grout in crater



Photo 2. Dumping limestone in crater



Photo 3. Rolling the limestone and grout



Photo 4. Spreading and leveling the grout



Photo 5. Pulvimixer mixing portland cement and sandy gravel



Photo 6. Spreading stabilized material in crater 3

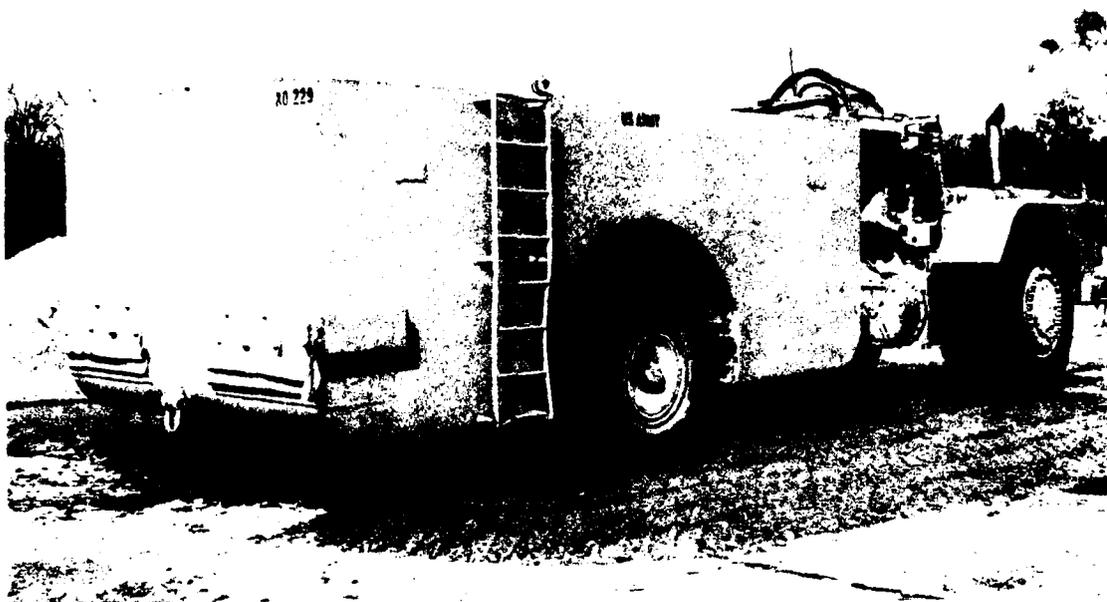


Photo 7. Rolling final lift in crater 3



Photo 8. Leveling the surface of crater 3



Photo 9. Bituminous seal being applied to crater 3



Photo 10. Rolling the sand placed over the AC-20

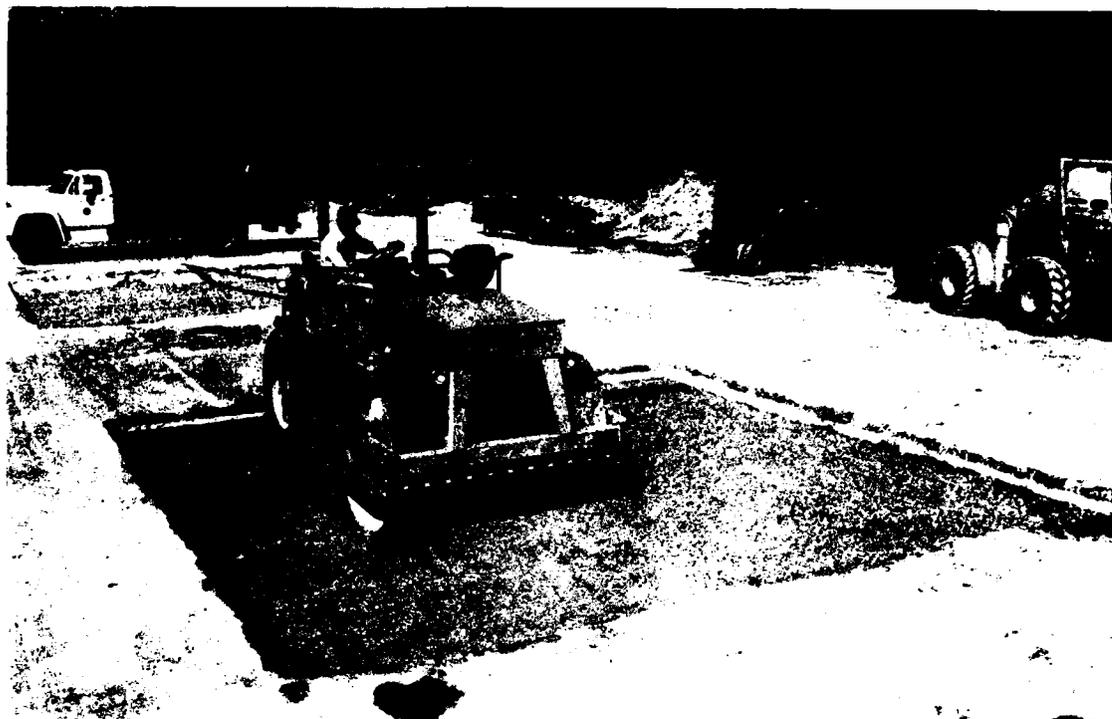


Photo 11. Rolling limestone with vibratory roller

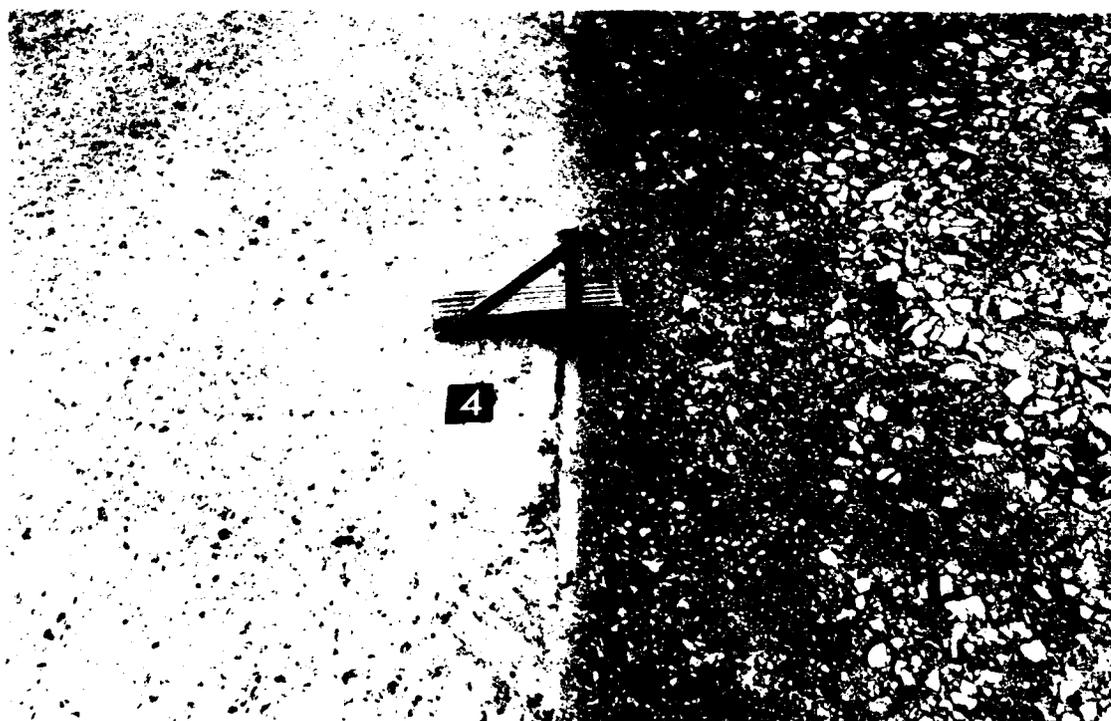


Photo 12. Final elevation of the limestone in crater 4



Photo 13. Placing grout cap on limestone



Photo 14. Moving and leveling grout in crater 4



Photo 15. Bullfloating grout in crater 4



Photo 16. Priming the surface of crater 5



Photo 17. Spraying AC-20 and spreading limestone



Photo 18. Embedding the limestone into the AC-20

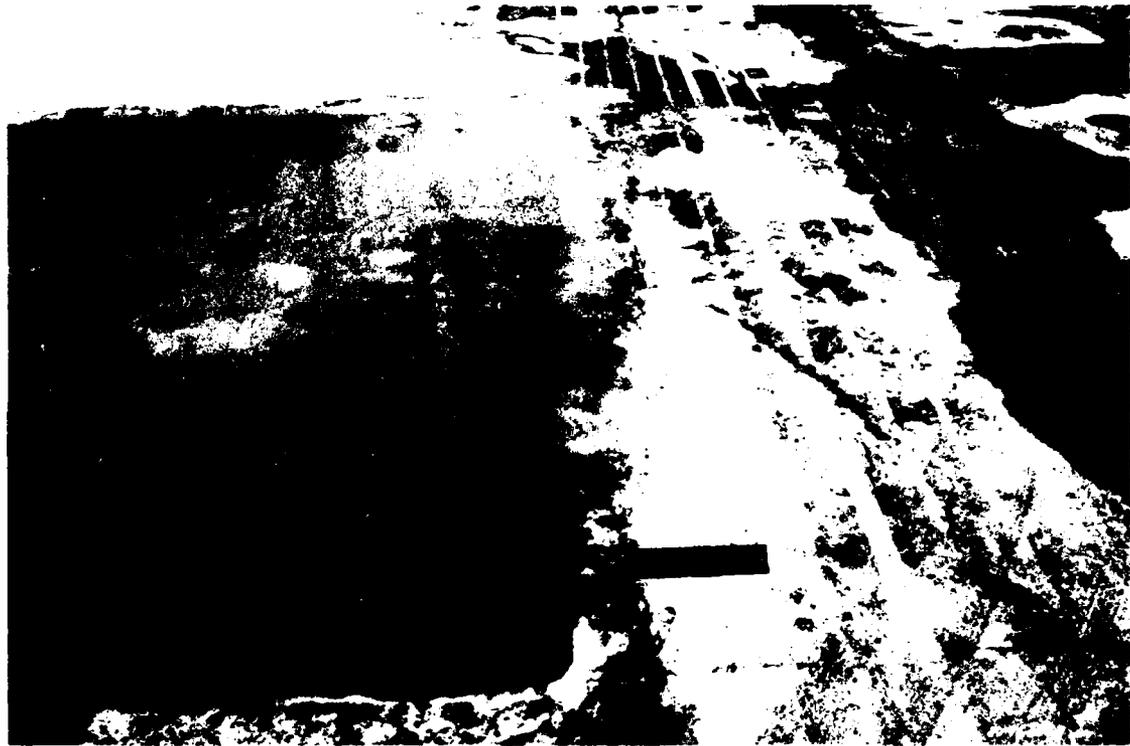


Photo 19. Crater 1, lane 1, before traffic

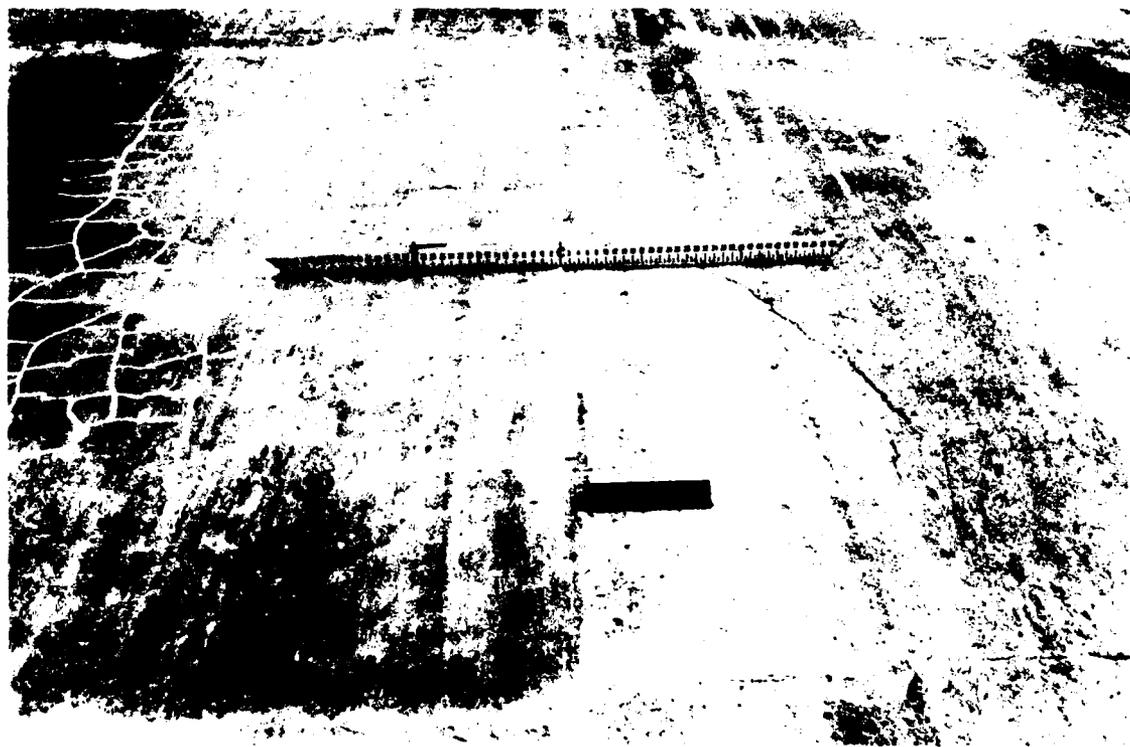


Photo 20. Crater 1, lane 1, after 30 coverages of F-4 traffic

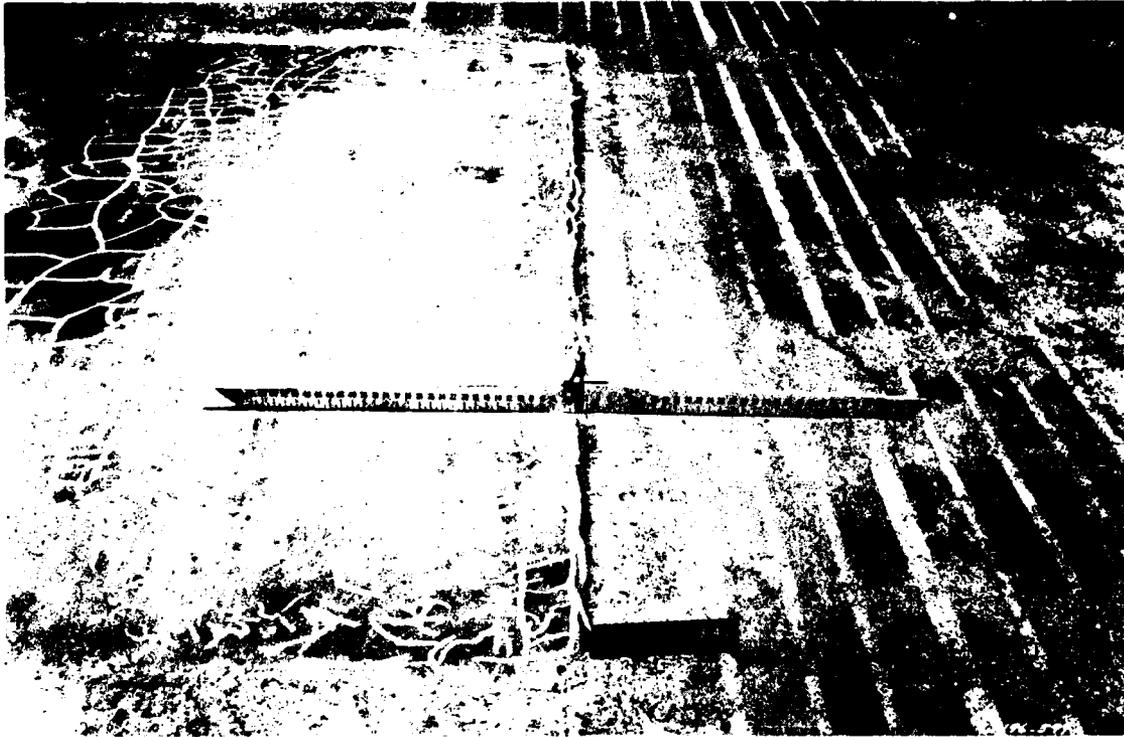


Photo 21. Crater 1, lane 1, after 100 coverages of C-141 traffic

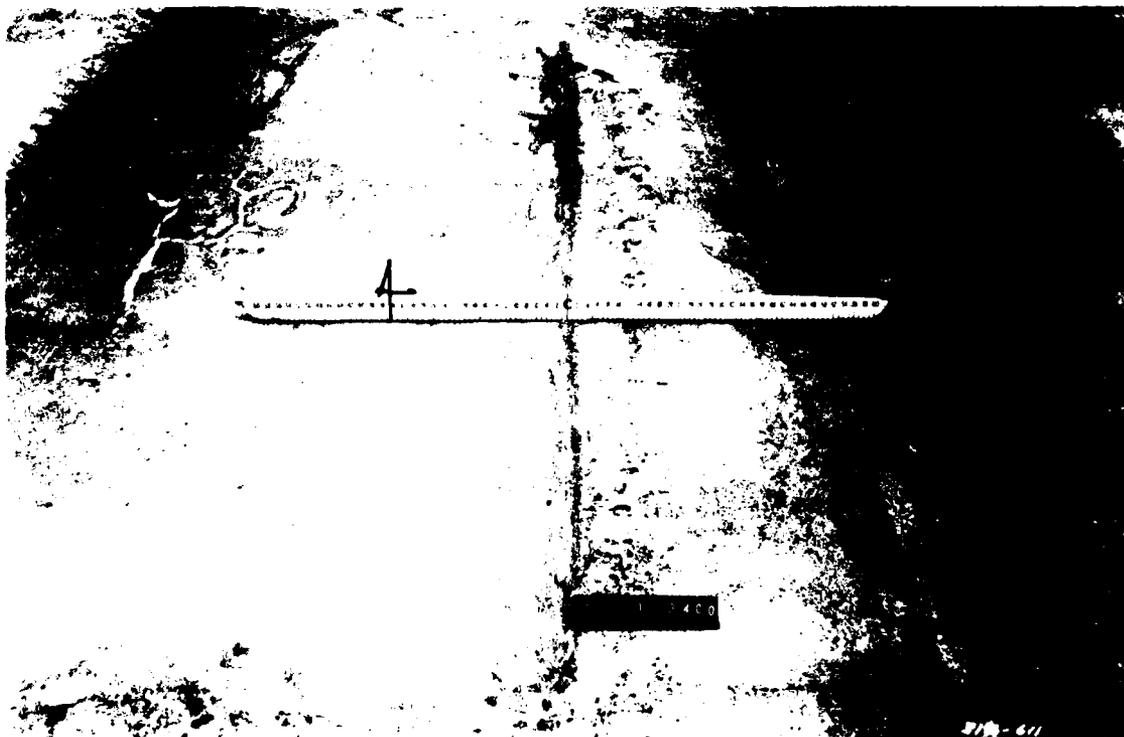


Photo 22. Crater 1, lane 1, after 1000 coverages of C-141 traffic



Photo 23. Crater 1, lane 2, before traffic



Photo 24. Crater 1, lane 2, after 100 coverages of C-141 traffic



Photo 25. Crater 1, lane 2, after 1000 coverages of C-141 traffic



Photo 26. Close-up of the shrinkage cracks in crater 2



Photo 27. Crater 2, lane 1, before traffic

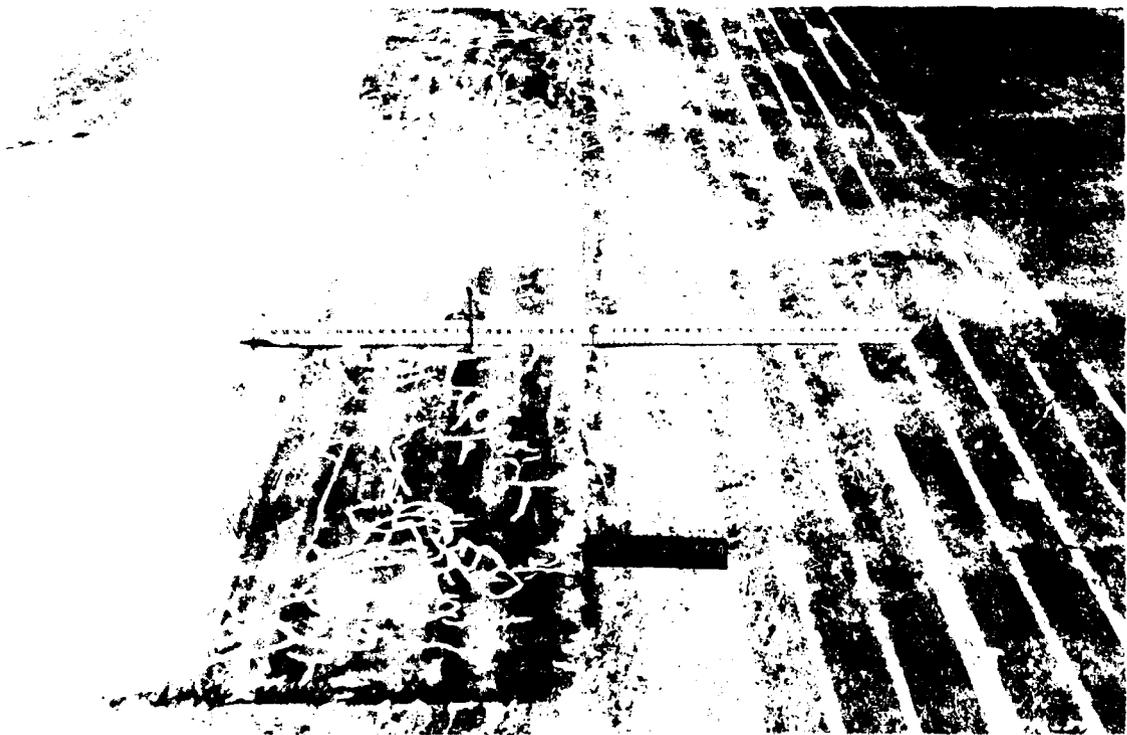


Photo 28. Crater 2, lane 1, after 72 coverages of F-4 traffic

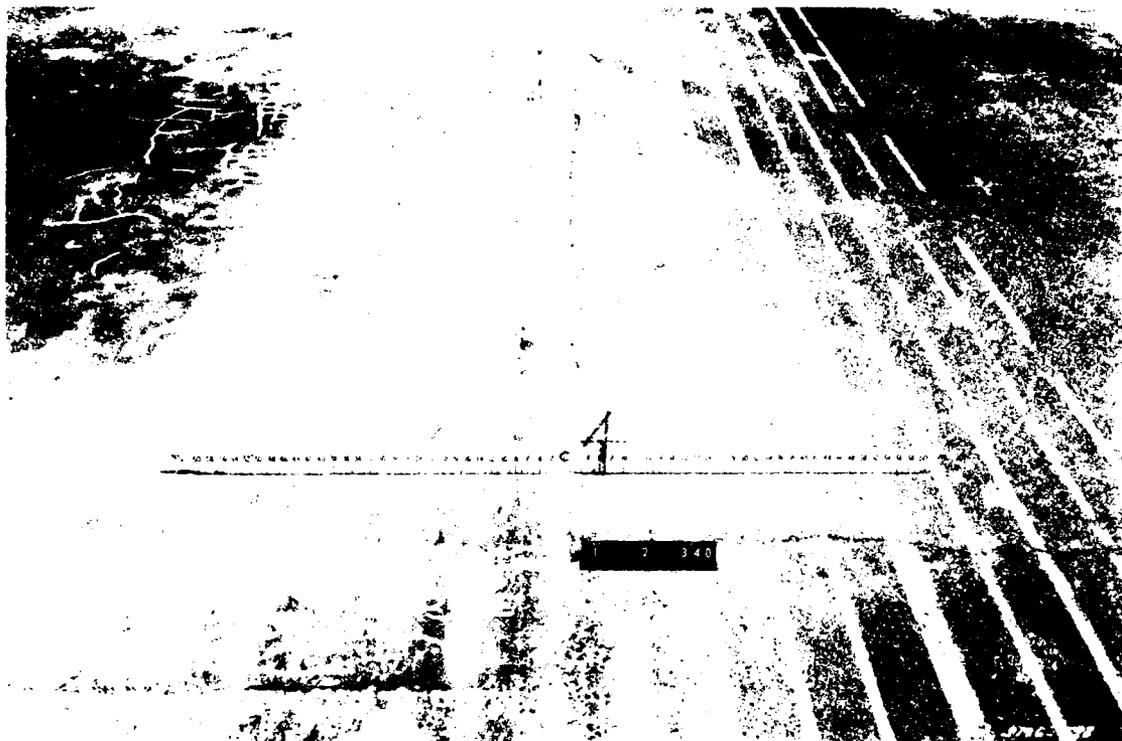


Photo 29. Crater 2, lane 1, after 100 coverages of C-141 traffic

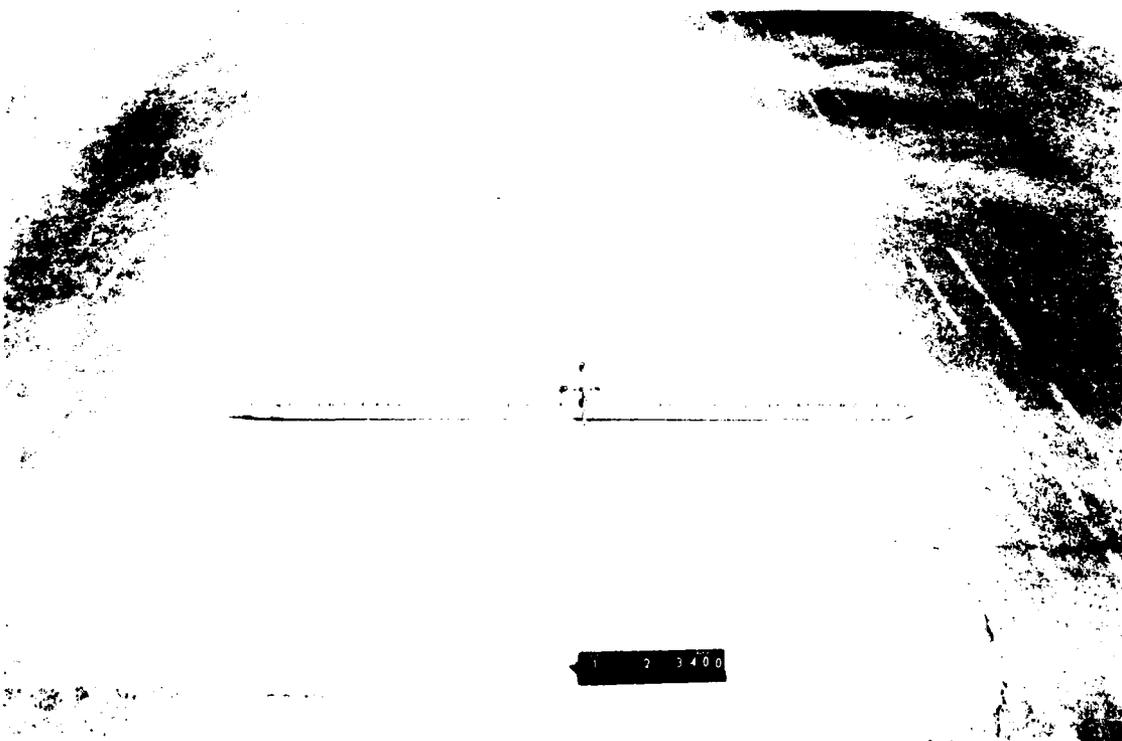


Photo 30. Crater 2, lane 1, after 1000 coverages of C-141 traffic



Photo 31. Crater 2, lane 2, before traffic

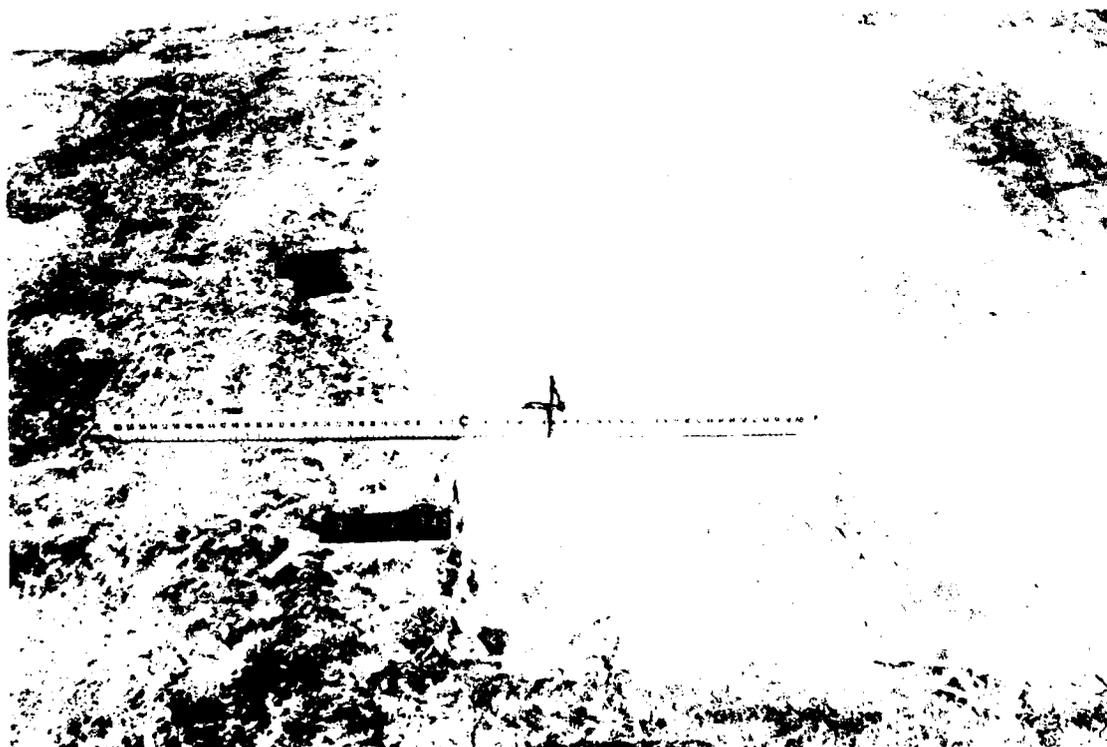


Photo 32. Crater 2, lane 2, after 100 coverages of C-141 traffic

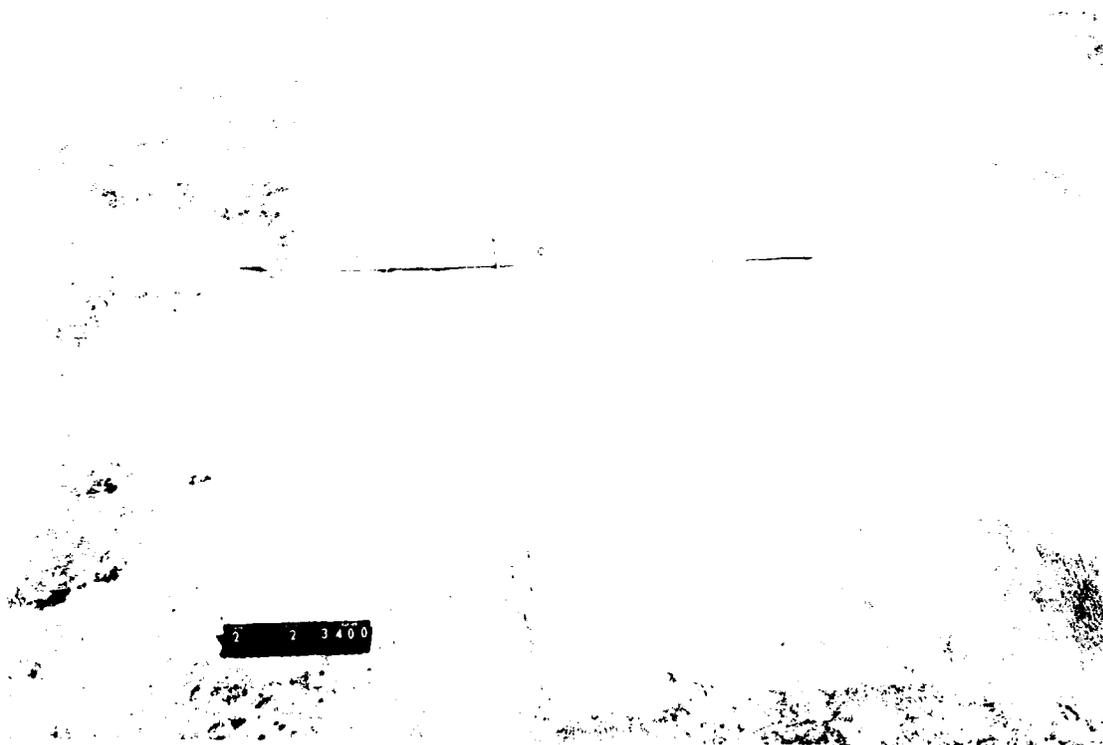


Photo 33. Crater 2, lane 2, after 1000 coverages of C-141 traffic

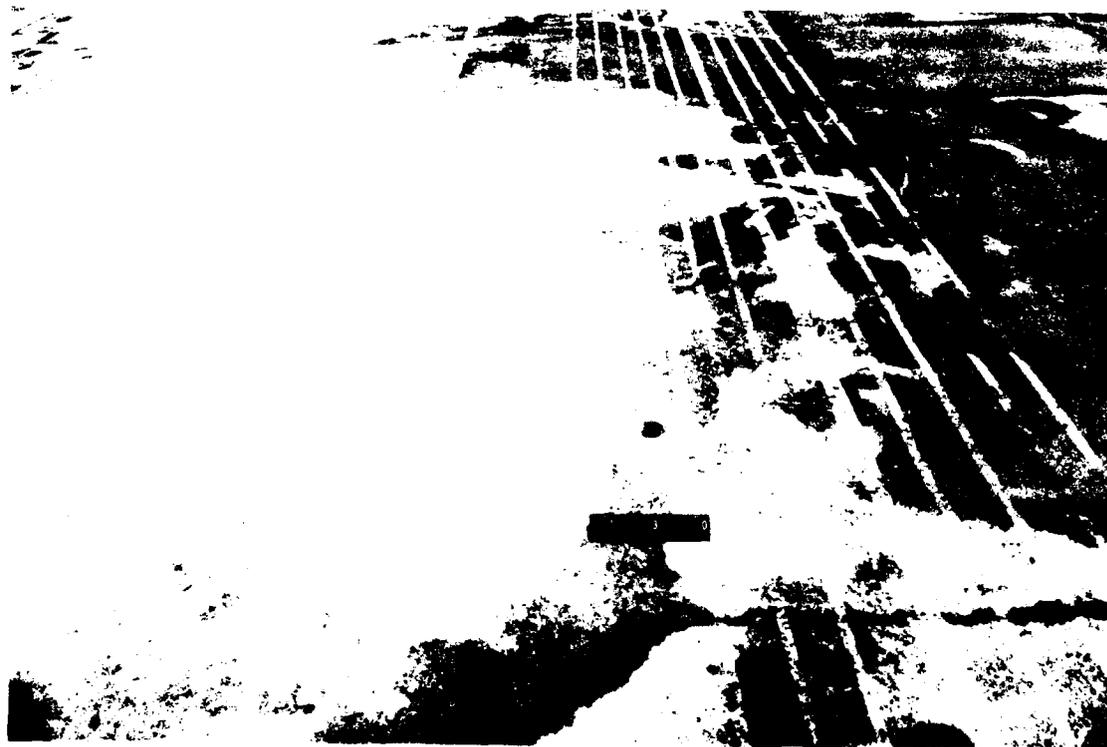


Photo 34. Crater 3, lane 1, before traffic



Photo 35. Crater 3, lane 1, after 72 coverages of F-4 traffic

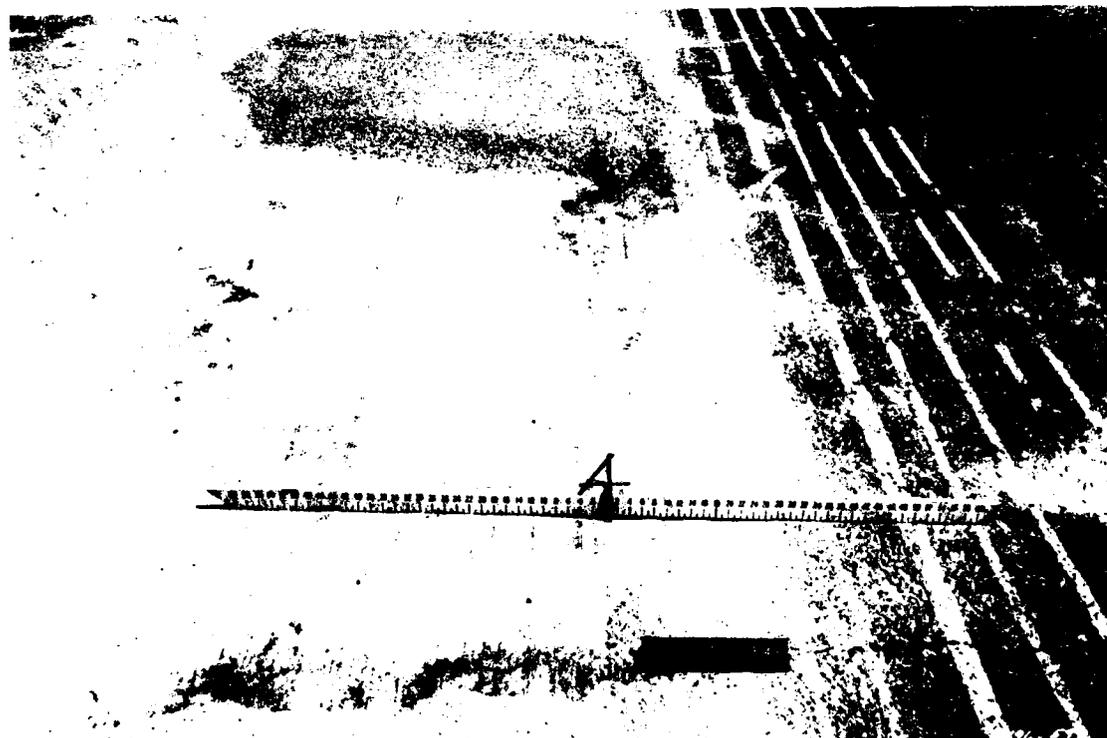


Photo 36. Crater 3, lane 1, after 100 coverages of C-141 traffic;
note limestone repair

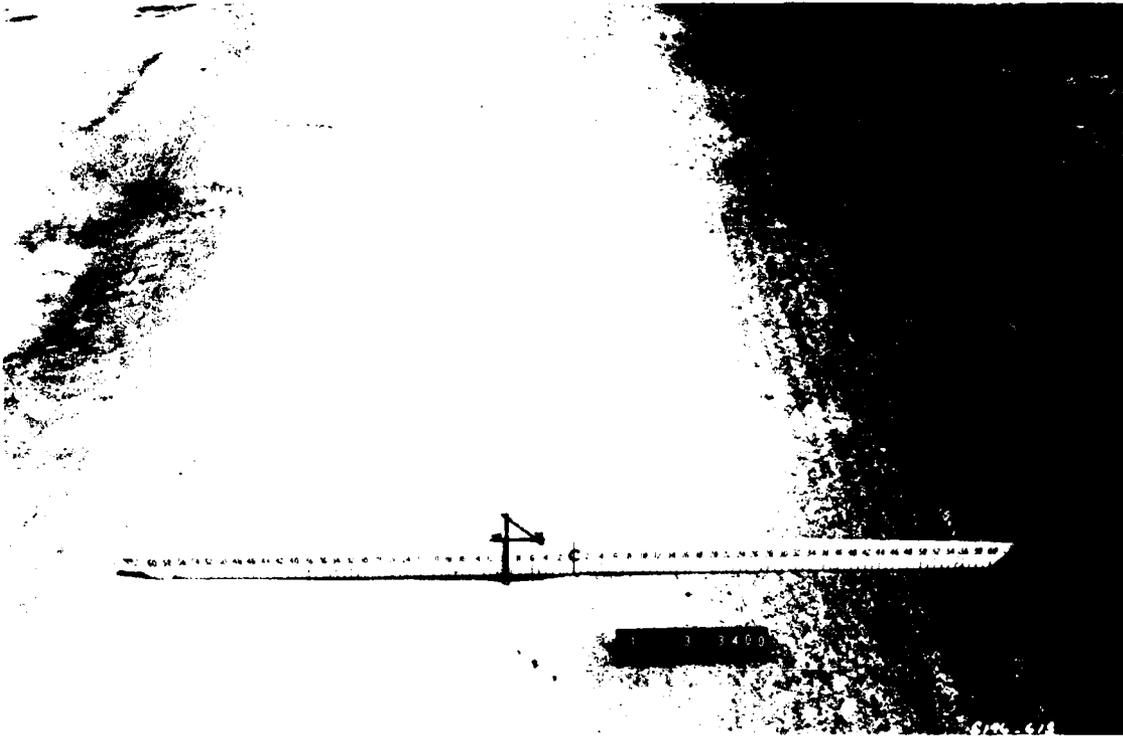


Photo 37. Crater 3, lane 1, after 1000 coverages of C-141 traffic



Photo 38. Crater 3, lane 2, before traffic

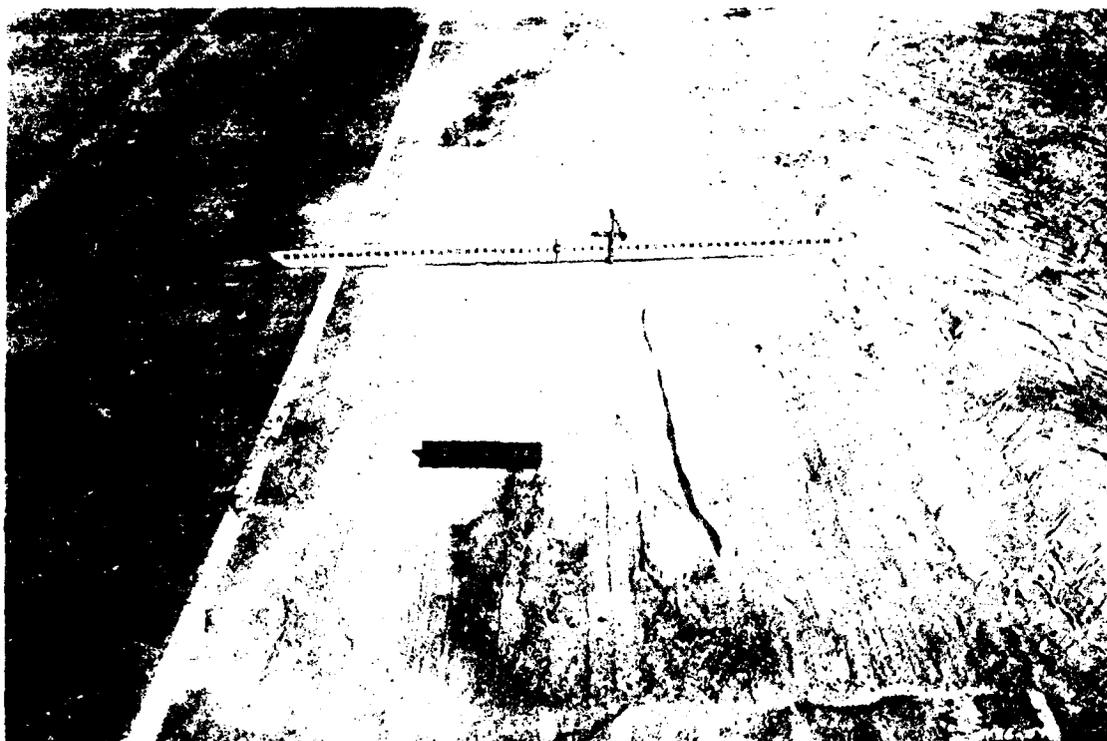


Photo 39. Crater 3, lane 2, after 100 coverages of C-141 traffic



Photo 40. Crater 3, lane 2, after 1000 coverages of C-141 traffic



Photo 41. Crater 4, lane 1, before traffic

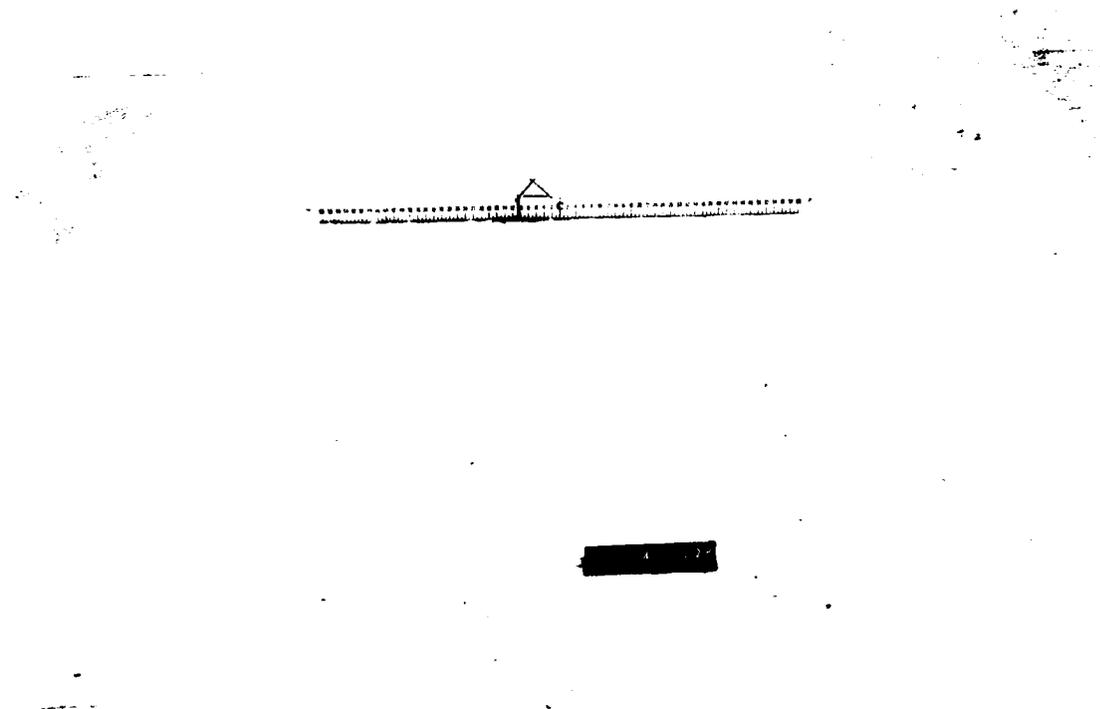


Photo 42. Crater 4, lane 1, after 30 coverages of F-4 traffic

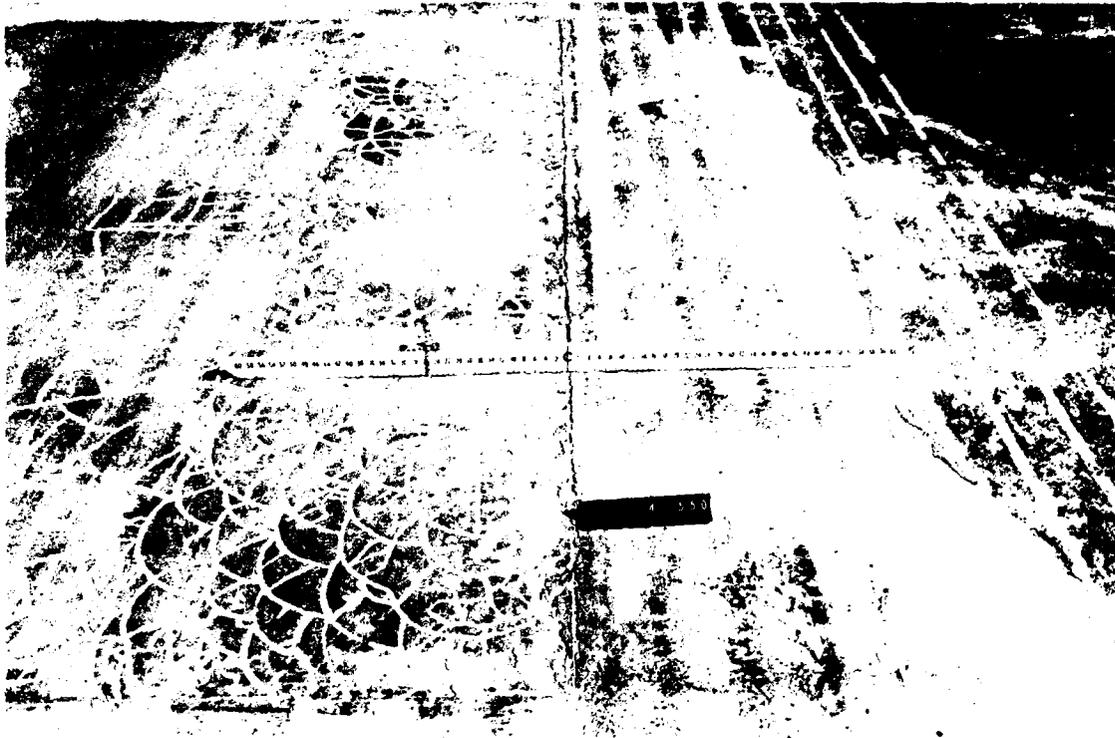


Photo 43. Crater 4, lane 1, after 72 coverages of F-4 traffic

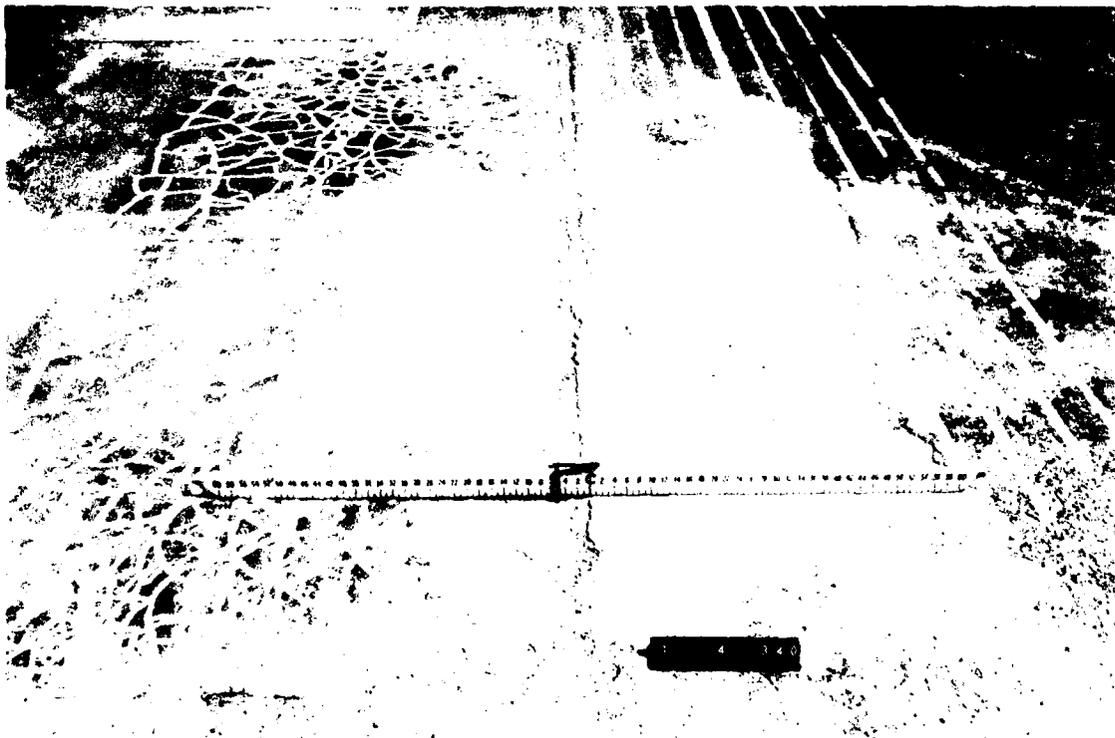


Photo 44. Crater 4, lane 1, after 100 coverages of C-141 traffic

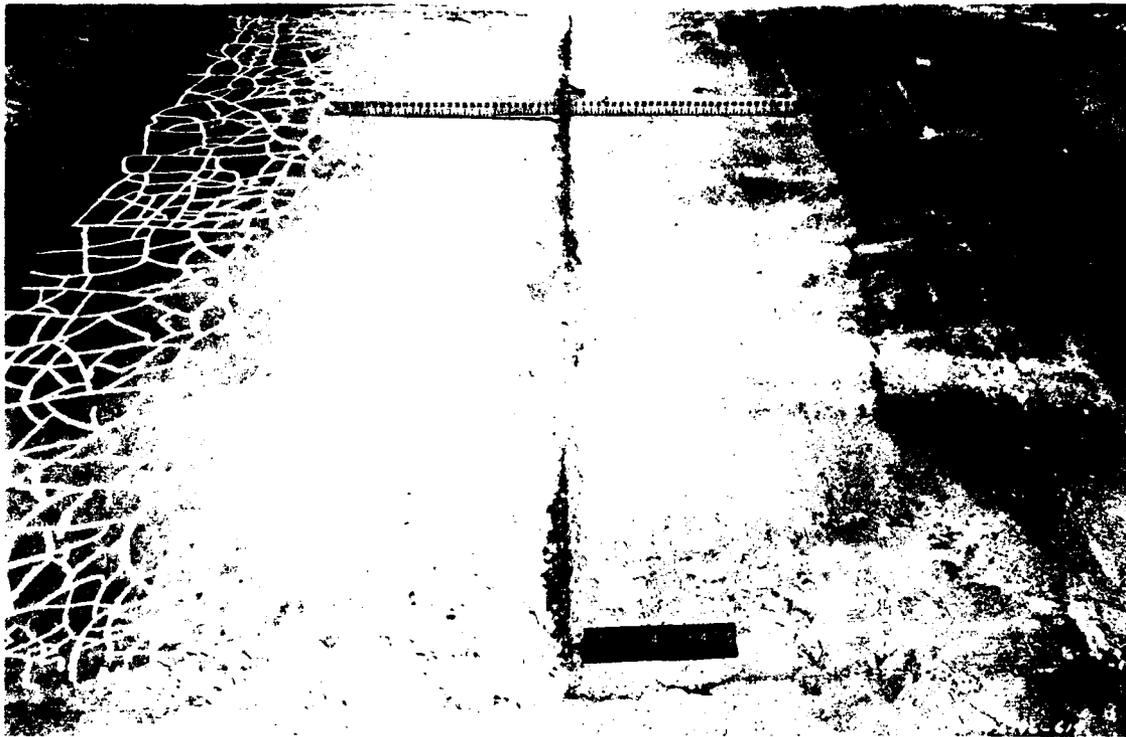


Photo 45. Crater 4, lane 1, after 1000 coverages of C-141 traffic



Photo 46. Crater 4, lane 2, before traffic

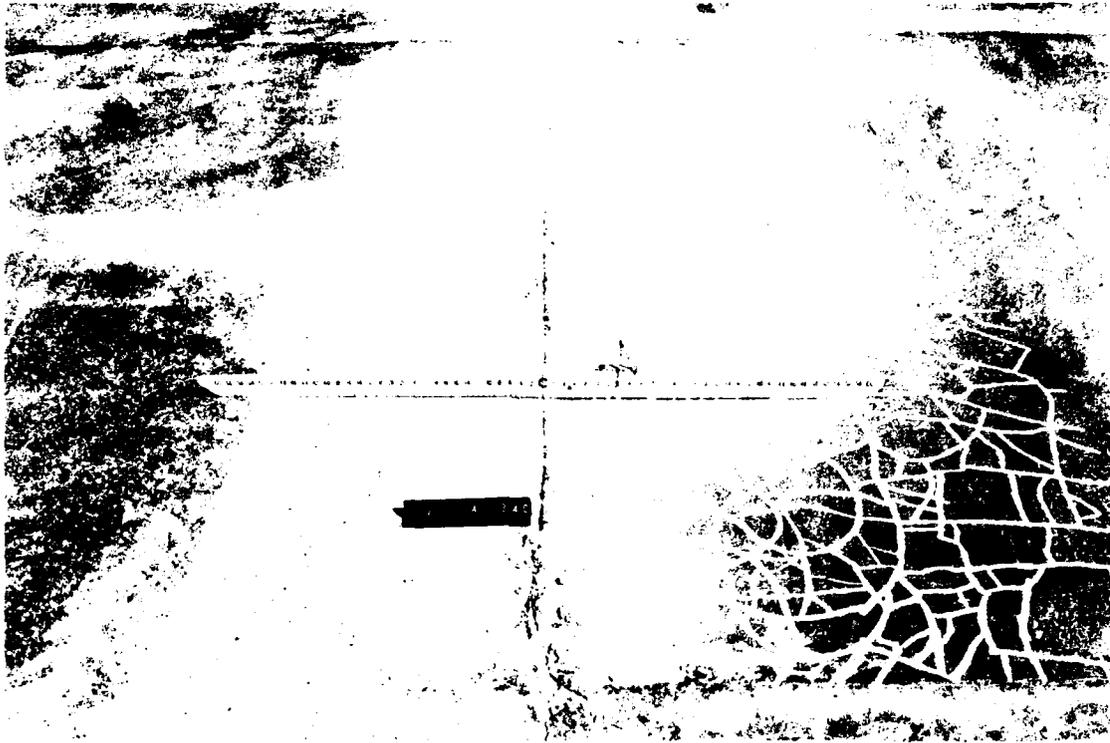


Photo 47. Crater 4, lane 2, after 100 coverages of C-141 traffic



Photo 48. Crater 4, lane 2, after 1000 coverages of C-141 traffic

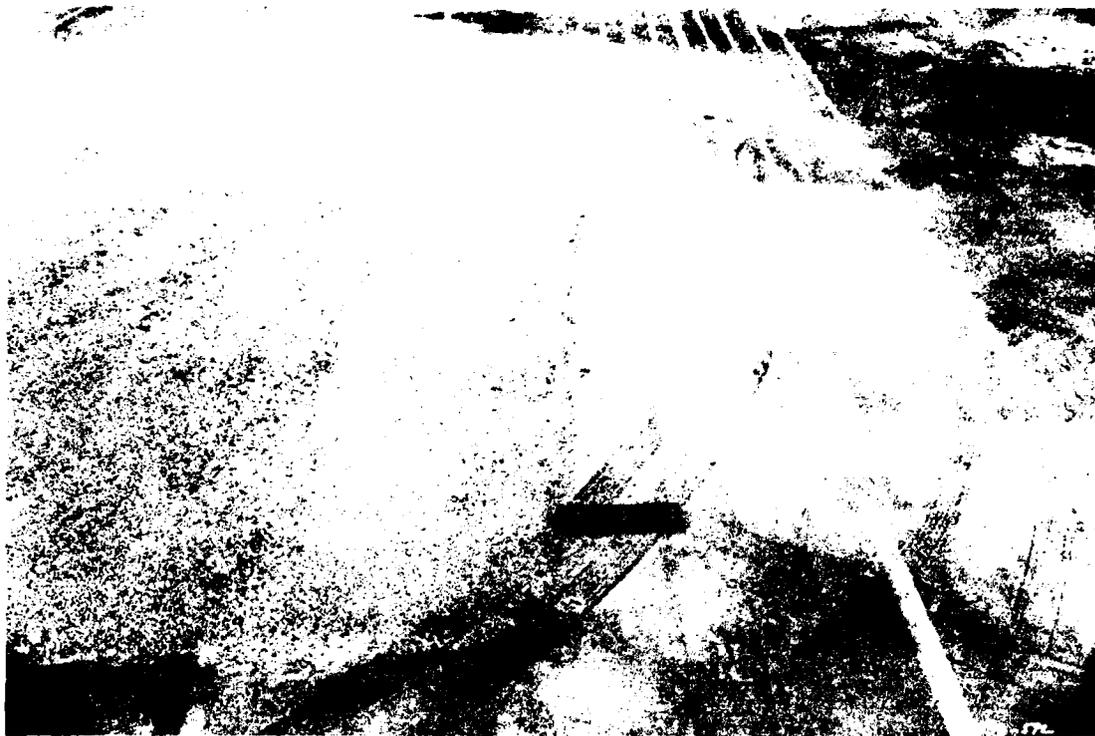


Photo 49. Crater 5, lane 1, before traffic

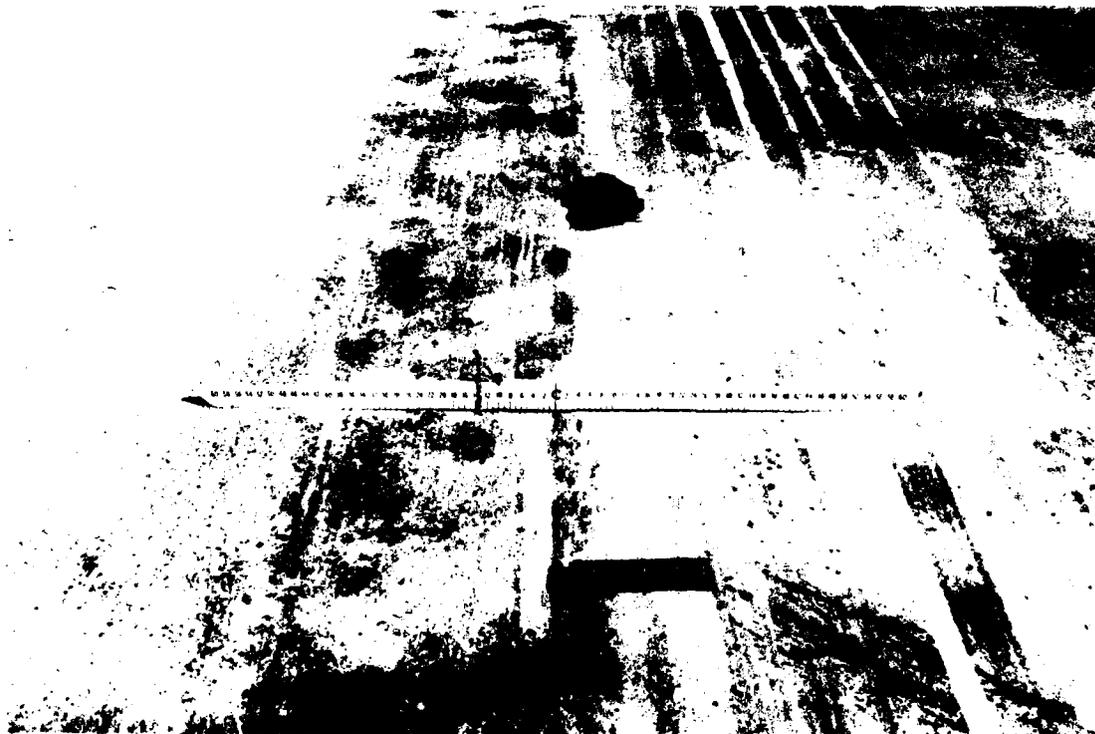


Photo 50. Crater 5, lane 1, after 72 coverages of F-4 traffic

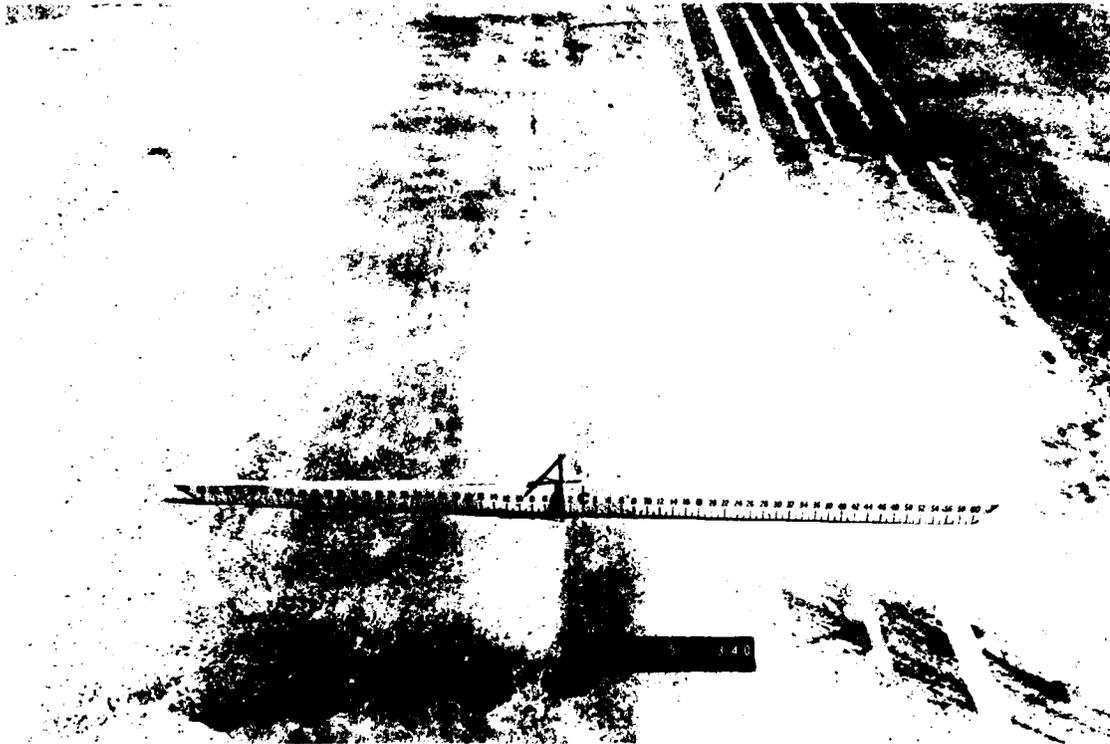


Photo 51. Crater 5, lane 1, after 100 coverages of C-141 traffic

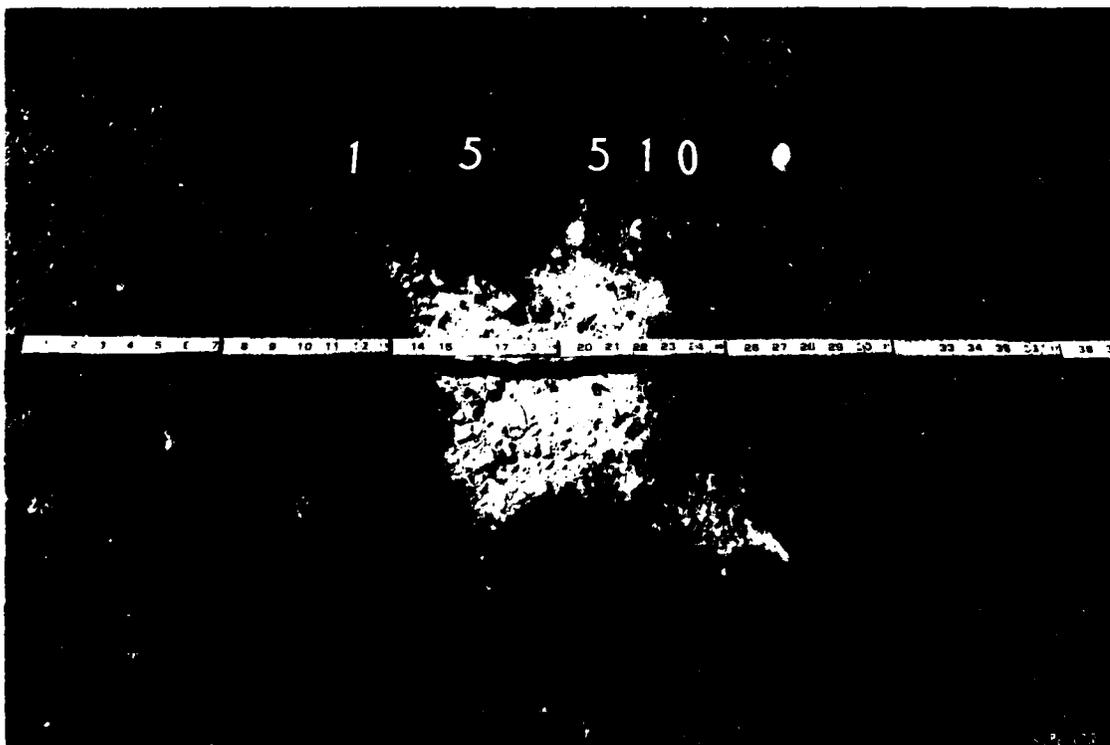


Photo 52. Crater 5, lane 1, one area of DBST which adhered to the tires of C-141 after 150 coverages

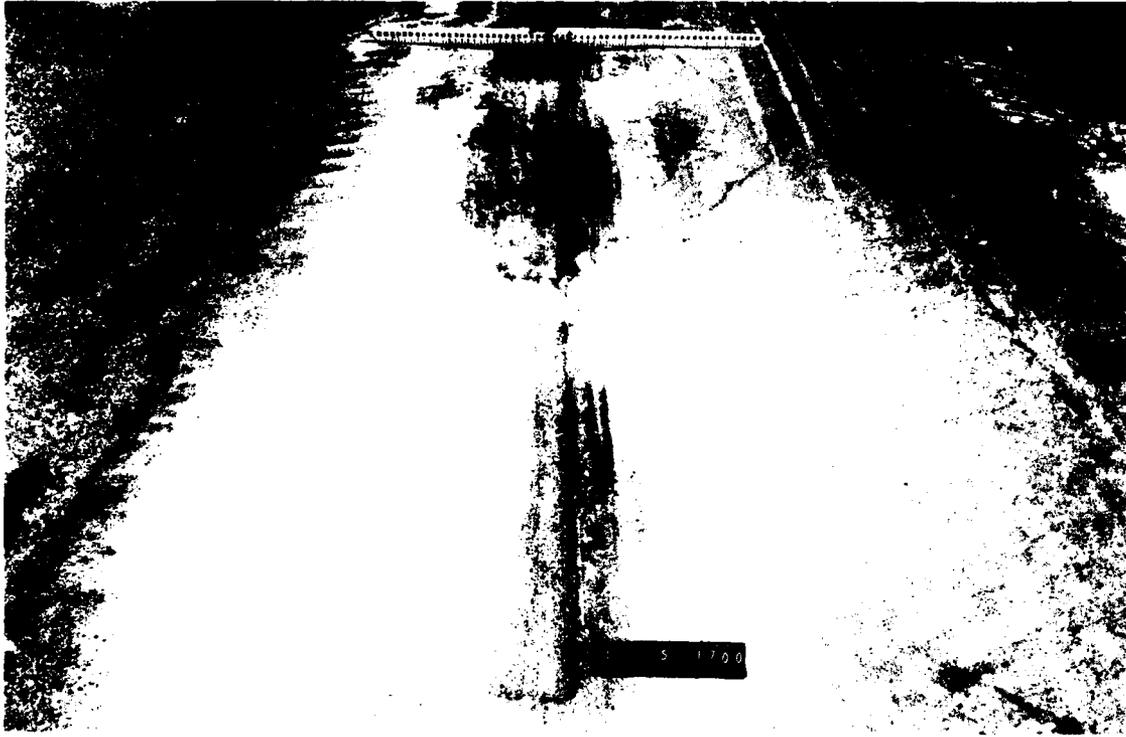


Photo 53. Crater 5, lane 1, after 500 coverages of C-141 traffic

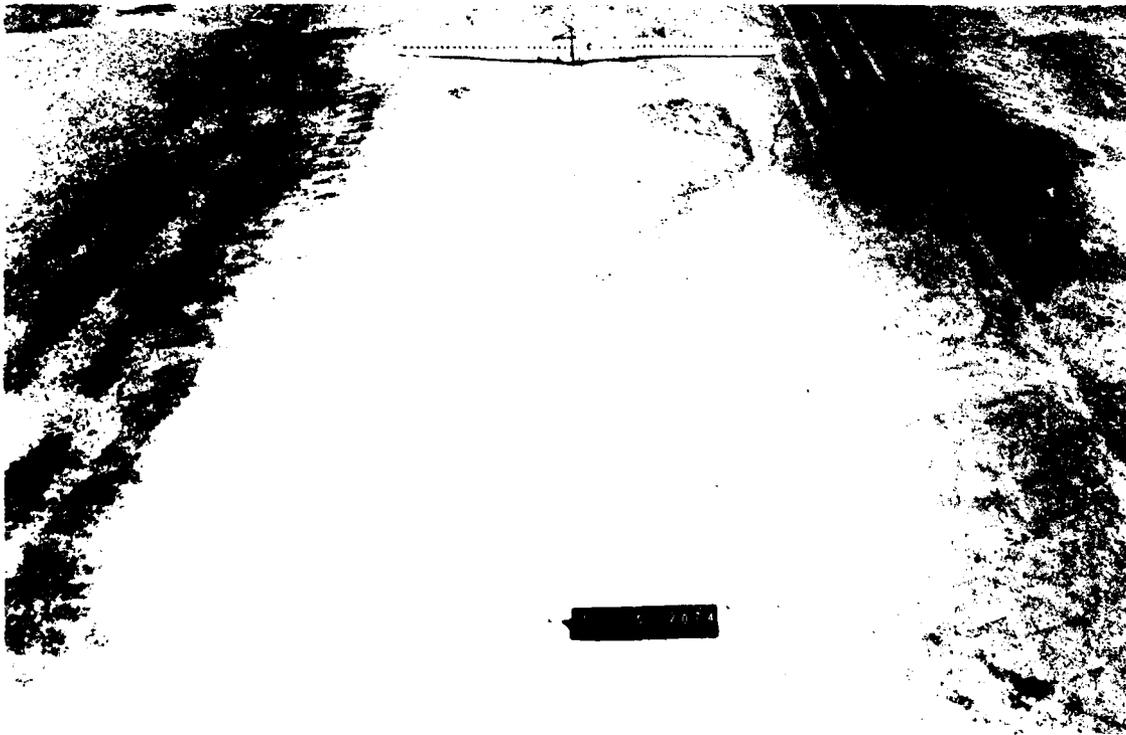


Photo 54. Crater 5, lane 1, after 610 coverages of C-141 traffic

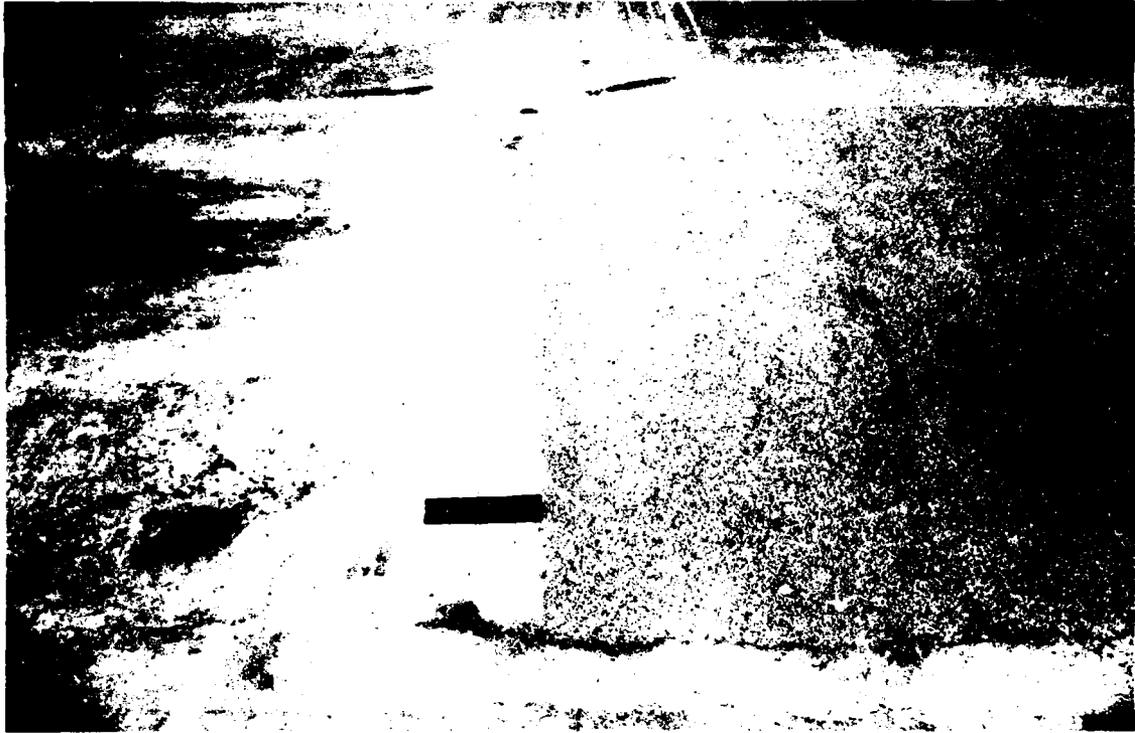


Photo 55. Crater 5, lane 2, before traffic

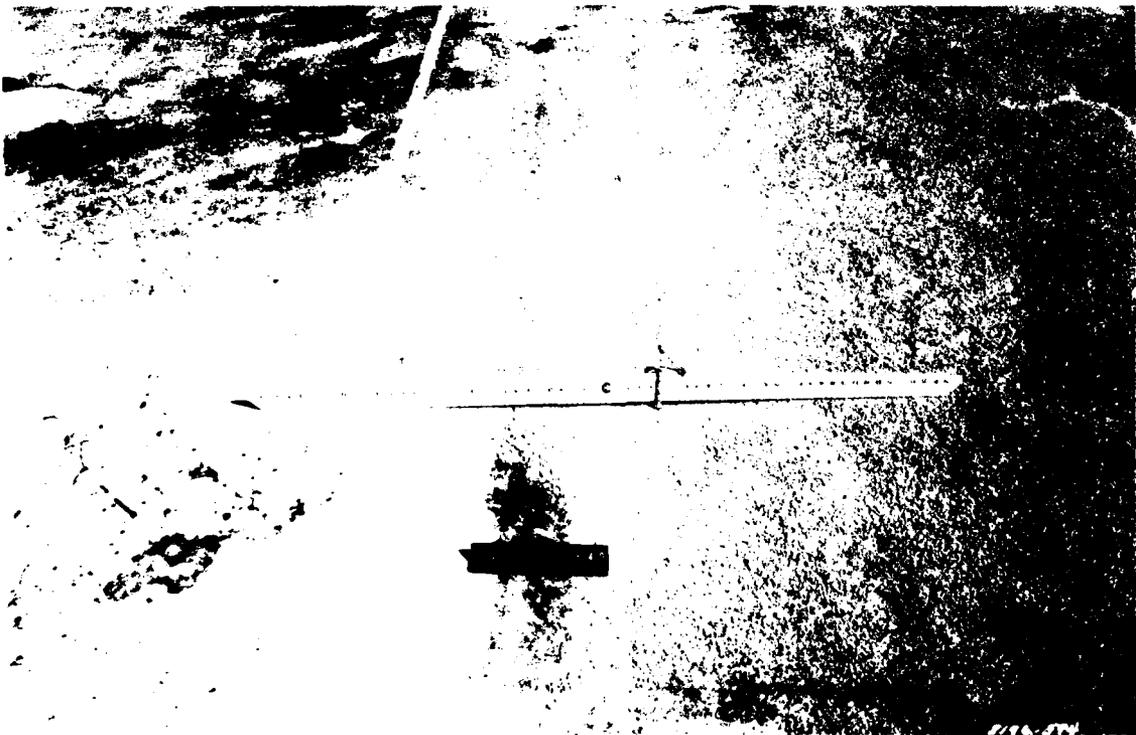


Photo 56. Crater 5, lane 2, after 100 coverages of C-141 traffic

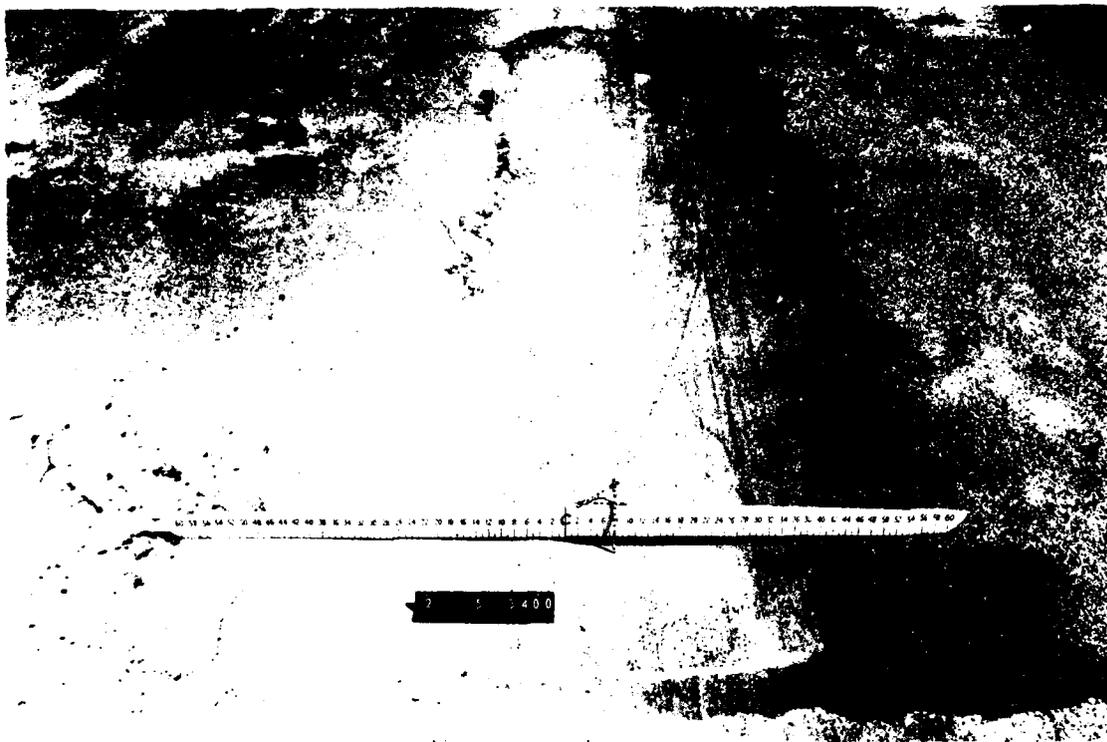


Photo 57. Crater 5, lane 2, after 1000 coverages of C-141 traffic

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