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IMPROVED SURFACING MATERIALS FOR TRACKED VEHICULAR TRAFFIC

by

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Durable surfacings	Tracked vehicles
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to determine whether thinner plain or reinforced portland cement concrete (PCC) sections could be utilized for pavement subjected to tracked vehicular traffic for new construction or whether other types of surfacings could be utilized for tank traffic. Test pavement items of 2-in. plain PCC, 2-in. reinforced PCC, 2-in. fibrous PCC, 4-in. plain PCC, 4-in. reinforced PCC, and 2-in. PCC placed in aluminum grids were

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20. ABSTRACT (Continued).

constructed. Pea gravel (3/8 in.) was used in the PCC mix to facilitate the placement in the 2- by 4-in. welded wire fabric that was used for reinforcing. The pavement was placed on a foundation with an average modulus of subgrade reaction value of 856 lb/sq in./in. Traffic was applied with an M-48 tank that was loaded to 114,000 lb, which was the approximate combat weight of an M-1 Abrams tank. Results indicate that sections of reinforced PCC slabs possibly thinner than the minimum used presently can support M-48 tank traffic on high-strength base courses and that fibrous concrete may also be satisfactory.

PREFACE

The investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, under Project No. 4A762719AT40, "Design and Construction of Fixed Military Facilities," Task Area EO, Work Unit 009.

The investigation was conducted by personnel of the Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), and the report written under the general supervision of Messrs. J. P. Sale, former Chief, GL, Dr. W. F. Marcuson III, Chief, GL, and Dr. T. D. White, Chief, Pavement Systems Division (PSD), and under the direct supervision of Messrs. D. M. Ladd and S. G. Tucker, PSD, GL. Personnel actively engaged in planning and conducting the investigation were Messrs. R. L. Hutchinson, A. H. Joseph, P. J. Vedros, S. L. Webster, R. D. Jackson, and S. J. Alford, all of PSD, GL, and Mr. K. L. Saucier, Structures Laboratory, WES. This report was prepared by Mr. Jackson.

The Commanders and Directors of the WES during the conduct of this investigation were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

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

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

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	2.54	centimetres
kips (force) per inch	1.751	kilonewtons per centimetre
pounds (force) per cubic inch	271.448	kilonewtons per cubic metre
pounds (force) per square inch	6894.757	pascals
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.

IMPROVED SURFACING MATERIALS FOR TRACKED VEHICULAR TRAFFIC

PART I: INTRODUCTION

Background

1. The current manual (TM 5-822-6)* for the design of rigid pavements for roads, streets, and open storage areas contains criteria for plain portland cement concrete (PCC) and reinforced concrete. Other types of concrete pavements are not included. In addition, the manual specifies a minimum thickness of 6 in.** for rigid pavements. The use of a thickness less than the minimum specified or another type of rigid pavement surfacing would be advantageous especially if cost of construction would be less and a more durable surfacing could be provided.

Objective

2. Since the current design manual sets minimum requirements for thickness and provides criteria for plain PCC and reinforced PCC only, it was the objective of this study to investigate the performance of pavements constructed at thicknesses less than the minimum and to investigate other types of rigid pavements.

Scope

3. This investigation involved construction and trafficking of a test section containing 11 test items. These test items consisted of plain PCC, reinforced concrete, fibrous concrete, and grid-reinforced concrete. The thicknesses of the test items were 2 or 4 in. In addition, the slab sizes of test items were varied. The test items were trafficked with an M-48 tank,

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* Department of the Army. 1977. "Rigid Pavements for Roads, Streets, Walks, and Open Storage Areas," Technical Manual TM 5-822-6, Washington, D. C.

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

which was loaded with an additional 10,000 lb to simulate the combat weight of the M-1 Abrams tank at 114,000 lb.

PART II: TEST SECTION

Description

4. The test section was constructed over a strong foundation consisting of at least 6 in. of crushed limestone over various materials and thicknesses. These foundation layers consisted of 9 in. of cement-stabilized gravelly sand, 15 in. of lime-stabilized lean clay, 15 in. of cement-stabilized lean clay, 15 in. of crushed limestone, and 15 in. of cement-stabilized clayey gravelly sand. A layout and cross section of the test section are shown in Figure 1. Items 1 and 2 of the test section were reinforced with 2- by 4-in. 14-gage welded wire fabric. Items 4 and 5 were reinforced with two layers of the welded wire fabric that was placed on chairs at the neutral axis of the slabs. The percent steel for all reinforced slabs was 0.188. The concrete in item 11 was placed in hexagonal aluminum grids with cell sizes of approximately 2 in. The grids had been purchased from commercial sources and were available from a previous project. Photos 1-10 show construction of the test items, and Table 1 gives the characteristics of the individual test items including item number, type of surfacing material, thickness of slabs, and slab size.

Table 1

Characteristics of Test Items

Item	Thickness, in.	Type	Slab Size, ft
1	2	Reinforced	12.5 × 12.5
2	2	Reinforced	8.33 × 8.33
3	2	Fibrous	12.5 × 20.0
4	4	Reinforced	8.33 × 8.33
5	4	Reinforced	12.5 × 12.5
6	2	Plain	12.5 × 12.5
7	2	Plain	8.33 × 8.33
8	2	Fibrous	10.0 × 12.5
9	4	Plain	8.33 × 8.33
10	4	Plain	12.5 × 12.5
11	2	Aluminum grids	8.0 × 20.0

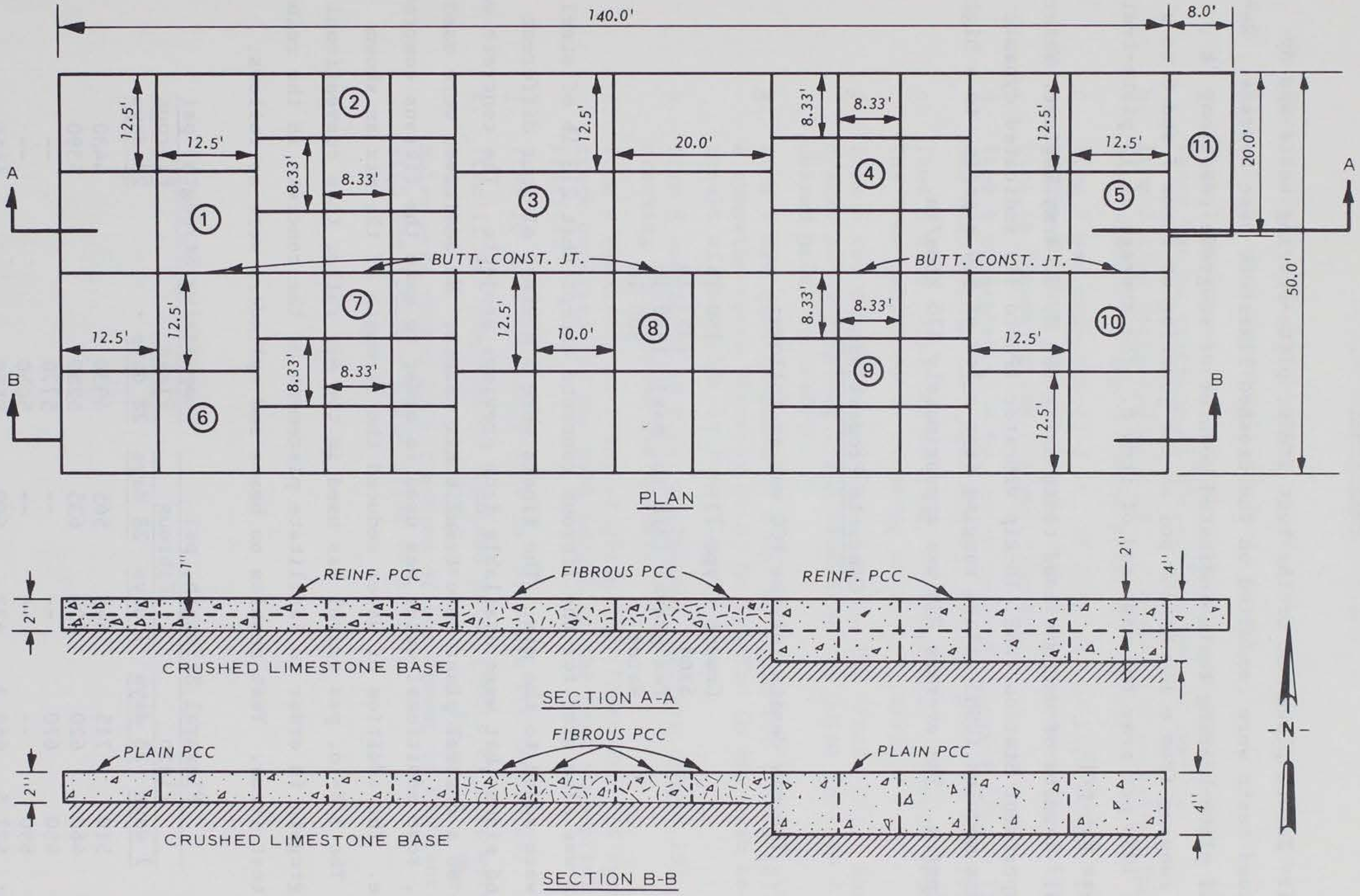

Figure 1. Plan and layout of test section

Soil Tests

5. Before placement of the test items, plate-bearing tests and dynamic load tests were conducted on the crushed limestone base courses. Results of plate-bearing tests indicated modulus of subgrade reaction, k , values ranging from a low of 680 pci at the junction of items 7 and 8 to a high of 1050 pci near the east end of item 8. The average of 15 plate-bearing tests was 856 pci.

6. Results of dynamic load tests using the U. S. Army Engineer Waterways Experiment Station (WES) 16-kip vibrator (Photo 11) indicated dynamic stiffness modulus (DSM) values ranging from a low of 560 kips/in. to a high of 1020 kips/in. The average DSM was approximately 870 kips/in.

Concrete Properties

7. The mix design for the PCC was as follows:

Cement (Type I)	750 lb
Sand	1357 lb
Pea gravel (3/8 in. max)	1589 lb
Water	300 lb

This mix was also used for the fibrous concrete except that 213 lb of steel fibers were added to the mix. The fibers were a mixture of four different types and sizes that were available from previous projects. The concrete was batched at a central plant into transit mix trucks. No additives were used; however, some additional water was used in order to make the fibrous concrete workable. The addition of water reduced the strength of the mix as shown below. The 3/8-in. pea gravel was used in the mix rather than conventional size aggregate in order to facilitate placement of the concrete in the reinforced test items. Test results on beams and cylinders were as follows:

	Flexural Strength, psi				Compressive Strength, psi	
	Plain		Fibrous		Plain	Fibrous
	7 days	28 days	7 days	28 days	28 days	28 days
	510	715	445	565	4930	4430
	460	620	420	635	5250	4390
	450	670	--	--	5770	--
	690	--	--	--	5050	--
Avg:	527.5	668.3	432	600	5500	4416

Condition Prior to Traffic

8. Photos 12-22 show the 11 test items after construction but before traffic. Each of the test items is described below:

a. Item 1 consisted of 2 in. of reinforced concrete (Photo 12). There was no cracking of the slabs prior to traffic.

b. Item 2 also consisted of 2 in. of reinforced concrete (Photo 13). Some minor cracking occurred prior to traffic.

c. Item 3 was composed of 2 in. of fibrous concrete (Photo 14). Slight surface irregularities can be seen because of difficulties in finishing the fibrous concrete.

d. Item 4 consisted of 4 in. of reinforced concrete (Photo 15). One slab within the test item had cracked prior to traffic.

e. Item 5 also consisted of 4 in. of reinforced concrete (Photo 16). The item exhibited no cracking prior to traffic.

f. Item 6 was composed of 2 in. of plain PCC (Photo 17). Shrinkage cracks and a sympathy crack caused by the joint in item 7 occurred prior to traffic.

g. Item 7 was also composed of 2 in. of plain PCC (Photo 18). A sympathy crack occurred prior to traffic in one slab as a result of the joint in item 6.

h. Item 8 consisted of 2 in. of fibrous concrete (Photo 19). No cracking occurred before traffic.

i. Item 9 consisted of 4 in. of plain PCC (Photo 20). A sympathy crack occurred for the full length of the test item prior to traffic.

j. Item 10 also consisted of 4 in. of plain PCC (Photo 21).

k. Item 11 was composed of aluminum grids (Photo 8) that were 2 in. deep and filled with plain PCC as shown in Photo 22. The small holes were caused by a reaction of the cement in the concrete with the aluminum grids prior to traffic.

PART III: TRAFFIC TESTS AND RESULTS

9. Traffic consisting of 5,000 passes and 1,000 turns was applied to each item with an M-48 tank that was loaded with extra weights to a total load of 114,000 lb which is the approximate combat weight of an M-1 Abrams tank (Photo 23). The test section consisted of north and south traffic lanes. The north lane consisted of six test items and the south lane had five test items. Traffic was applied so that one pass was applied to the north lane and then one pass to the south lane. During each pass on a traffic lane, a locked track turn of 90 deg was accomplished on one of the test items so that when five passes of the tracked vehicle were completed, each item had been subjected to a locked track turn. These turns consisted of locking one track, turning 90 deg, and then returning to the original position in the reverse order.

10. To determine what effect temperature had on the slabs, level readings were taken on each corner of each slab; however, it was not possible to detect any curling or buckling of the slabs. Traffic was applied during periods of both hot and cold temperatures. The pavement temperature during cold weather traffic ranged from 25° to 39° F and during hot weather traffic it ranged from 76° to 113° F. No differences in the performance of the pavements were observed during traffic tests when varying cold and hot temperatures occurred.

11. The results of the traffic tests are presented in Table 2. This table shows the average number of pieces that each slab had broken into at the indicated number of passes. Initial failure is generally considered to occur when a slab is broken into three or more pieces. The data from Table 2 were interpolated to estimate the traffic level at which initial failure occurred. These estimates are also shown in Table 2. The condition of the items is shown in Photos 24-45 at various passes and turns of the tank, and the performance of each test item is discussed below:

a. Item 1. Cracks occurred in two slabs prior to the start of traffic. During traffic, cracking occurred rapidly and the slabs had broken into an average of 11.5 pieces per slab at 1250 passes and 250 turns of the tank. There was very little additional cracking at 2500 passes and 500 turns (Photo 24), but the average number of pieces per slab increased to 28 after 5000 passes and 1000 turns (Photo 35).

Table 2

Test Results

Item	Type of PCC	Thickness in.	Slab Size ft	Average Number of Pieces per Slab: Before Traffic	1250 Passes 250 Turns	2500 Passes 500 Turns	5000 Passes 1000 Turns	Estimated Number of Passes at Initial Failure*
1	Reinforced	2	12.5 × 12.5	1.0	11.5	12.0	28	70
2	Reinforced	2	8.33 × 8.33	1.0	5.6	8.2	11.4	200
3	Fibrous	2	12.5 × 20.0	1.0	2.5	3.5	3.5	1750
4	Reinforced	4	8.33 × 8.33	1.0	1.6	1.7	1.8	NF**
5	Reinforced	4	12.5 × 12.5	1.0	2.75	3.5	3.5	1750
6	Plain	2	12.5 × 12.5	1.25	33.0	95.0	†	100
7	Plain	2	8.33 × 8.33	1.11	17.6	42.0	92.0	225
8	Fibrous	2	10.0 × 12.5	1.0	1.75	1.75	2.5	NF**
9	Plain	4	8.33 × 8.33	1.33	2.0	2.2	3.6	3750
10	Plain	4	12.5 × 12.5	1.0	2.25	3.0	7.0	2500
11	Grid reinforced	2	8.0 × 20.0	--	--	--	--	--

* Defined as three or more pieces.

** NF = item did not reach initial failure.

† Too numerous to count.

b. Item 2. Two slabs of item 2 had cracked prior to traffic. Cracking increased in the slabs with traffic (Photo 25), and the average number of pieces per slab was 11.4 after 5000 passes and 1000 turns (Photo 36).

c. Item 3. Item 3 performed well under the applied traffic. There was no cracking prior to traffic, but the item had broken into 3.5 pieces per slab when traffic was completed. The slabs had an average of 3.5 pieces per slab at 2500 passes and 500 turns (Photo 26) and showed no increase in cracking after 5000 passes and 1000 turns (Photo 37).

d. Item 4. The reinforced concrete in item 4 performed well. One slab had cracked prior to traffic. The other slabs contained a minimum number of cracks after 2,500 passes and 500 turns but soon broke into an average of 1.8 pieces per slab after 5000 passes and 1000 turns (Photo 38). The item therefore did not reach initial failure.

e. Item 5. There was no cracking prior to traffic. This item reached the initial failure condition (35 pieces per slab) after 2500 passes and 250 turns of the tank (Photo 28) and remained in this same condition with no significant increase in cracking after 5000 passes and 500 turns (Photo 39).

f. Item 6. This item contained some cracking prior to traffic and broke up rapidly under traffic. It contained an average of 33 pieces per slab by 1250 passes and 250 turns of the tank. As the passes and turns increased, the cracking increased (Photos 29 and 40).

g. Item 7. Item 7 contained a sympathy crack prior to traffic, broke up rapidly, and had an average of 17.6 pieces per slab at 1250 passes and 250 turns. Cracking continued as the passes and turns increased (Photos 30 and 41).

h. Item 8. This fibrous concrete test item contained no cracks prior to traffic, but had broken into an average of 2.5 pieces per slab and was therefore approaching initial failure as the traffic reached 5000 passes and 1000 turns (Photos 31 and 42).

i. Item 9. The center slabs of this test item developed sympathy cracks for the full length of the test item prior to traffic. As the traffic increased from 2500 passes and 500 turns to 5000 passes and 1000 turns, two slabs showed no cracking although the average number of pieces per slab increased from 2.2 to 3.6 which was slightly past initial failure (Photos 32 and 43).

j. Item 10. All four slabs of item 10 had at least one crack after 1250 passes and 250 turns of the tank. The slabs were broken into an average of three pieces per slab at 2500 passes and 500 turns which indicated that initial failure had occurred (Photo 33). There was an average of 7.0 pieces after 5000 passes and 1000 turns (Photo 44).

k. Item 11. The performance of this test item could not be judged according to regular criteria since it consisted of concrete-filled aluminum grids. The item appeared to perform well although the concrete in each cell had loosened to some degree, and there was some degradation along the edge of the item (Photos 34 and 45).

PART IV: DISCUSSION OF RESULTS

12. All test items sustained 5000 passes and 1000 turning movements of the tank with various results. A discussion of each pavement type follows.

Plain Concrete

13. The 2-in. plain PCC test items (items 6 and 7) were very unsatisfactory because they broke into numerous pieces after only a few passes. Better performance was demonstrated by the 4-in. plain PCC items (items 9 and 10), although they cracked in excess of the criteria for initial failure. Based upon these results, neither the 4- nor the 2-in. PCC test items were considered to be satisfactory for regular use by tank traffic.

Reinforced PCC

14. Addition of reinforcement contributed to better performance of both the 2- and 4-in. thick sections, although the 2-in. test items (items 1 and 2) reached initial failure early in the traffic. The 4-in. test items (items 4 and 5) performed reasonably well in that item 4 did not reach initial failure and item 5 exceeded initial failure only slightly. If the 5000 passes and 1000 turning movements represent a reasonable amount of traffic to expect in the pavement's life, then the 4-in. reinforced PCC may be a candidate for future use.

Fibrous Concrete

15. The two fibrous concrete test items (items 3 and 8) performed in a manner similar to the 4-in. reinforced PCC items in that item 8 did not reach initial failure, but item 3 slightly exceeded the initial failure criterion. This performance indicates that the 2-in. fibrous concrete may be a satisfactory surface for the traffic applied when the surface is placed on a strong base.

Grid-Reinforced Concrete

16. Test item 11 that consisted of a grid-reinforced concrete was not

considered to be a satisfactory surfacing because the concrete in each grid loosened and could have been removed by additional traffic, although this removal did not occur in the test. The loose nature of the concrete in the grids would also allow moisture to enter the base which would contribute to a reduction in foundation strength.

17. It should be pointed out, that although considerable cracking occurred in the test items, no displacement of the slab pieces occurred; thus, traffic was allowed to continue to 5000 passes and 1000 turning movements on each item. This performance occurred because of the strong foundation on which the items were constructed. A somewhat weaker foundation would have allowed movement of the slab pieces and subsequent displacement of broken pieces.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

18. Based on the results of traffic tests, it is believed that the following conclusions are warranted:

a. The 4-in. reinforced PCC and 2-in. fibrous concrete test items on a strong foundation provided reasonably satisfactory performance under the applied traffic.

b. Thicknesses of plain concrete less than the 6-in. minimum in the design manual are not satisfactory for tank traffic.

c. Grid-reinforced concrete should not be used as surfacing for pavements subjected to tank traffic.

d. The high-strength foundation contributed to the lack of displacement of all test items.

e. Two inches of reinforced PCC was not adequate to sustain tank traffic.

Recommendations

19. The following recommendations are made:

a. Fibrous concrete 2 in. in thickness should be considered for use over high-strength foundations when the anticipated traffic would be equal to or less than 5000 passes and 1000 turning movements of tank traffic.

b. The minimum thickness shown in TM 5-822-6 for plain PCC should not be reduced.

c. Reduction of minimum thicknesses for reinforced PCC should be considered for use over high-strength bases.

d. Additional tests of 2-in. fibrous concrete and 4-in. reinforced concrete over foundation strengths less than a k of 500 pci and at higher percent steel for reinforced PCC should be conducted.

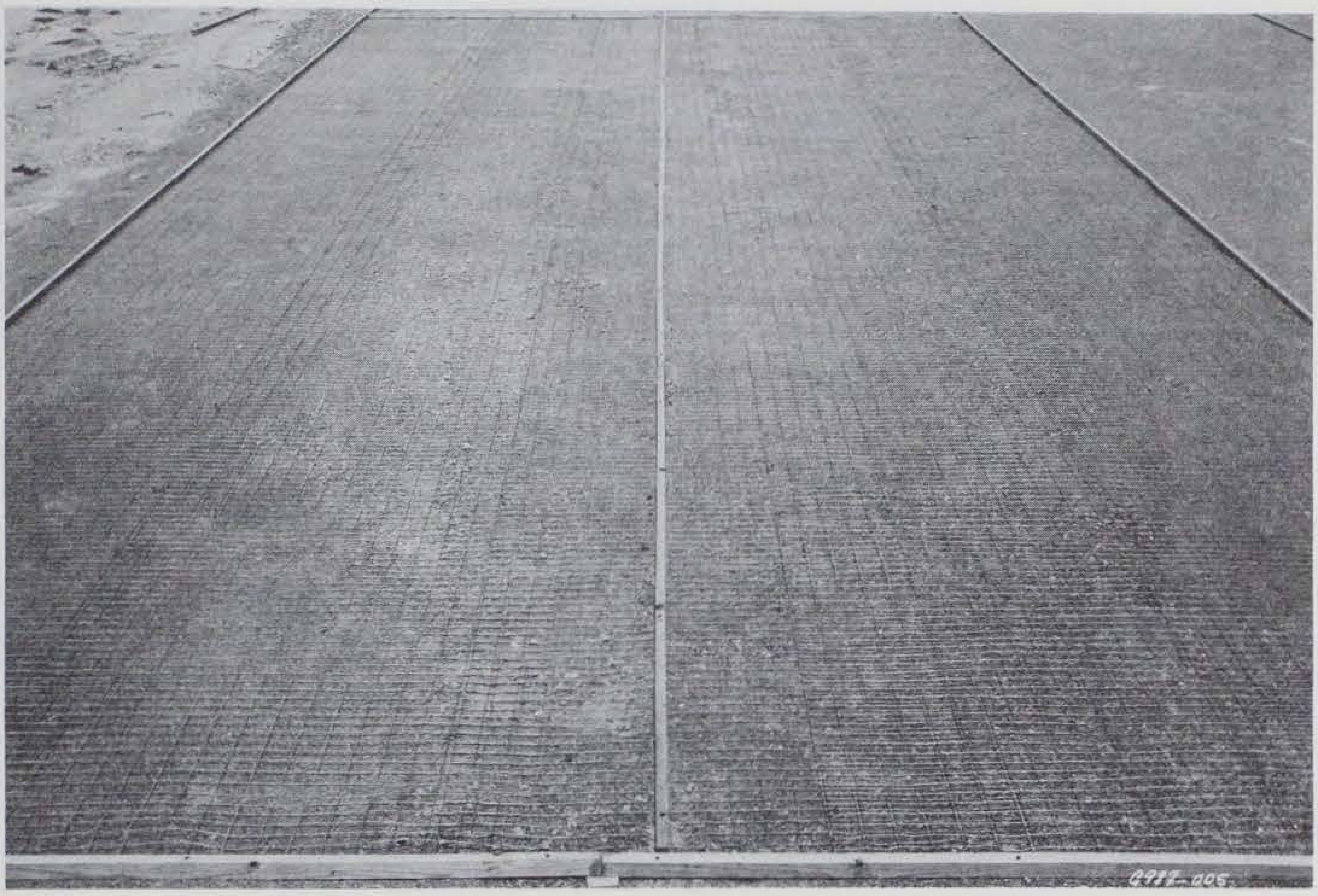

Photo 1. Items 1 and 2 after placement of welded wire fabric

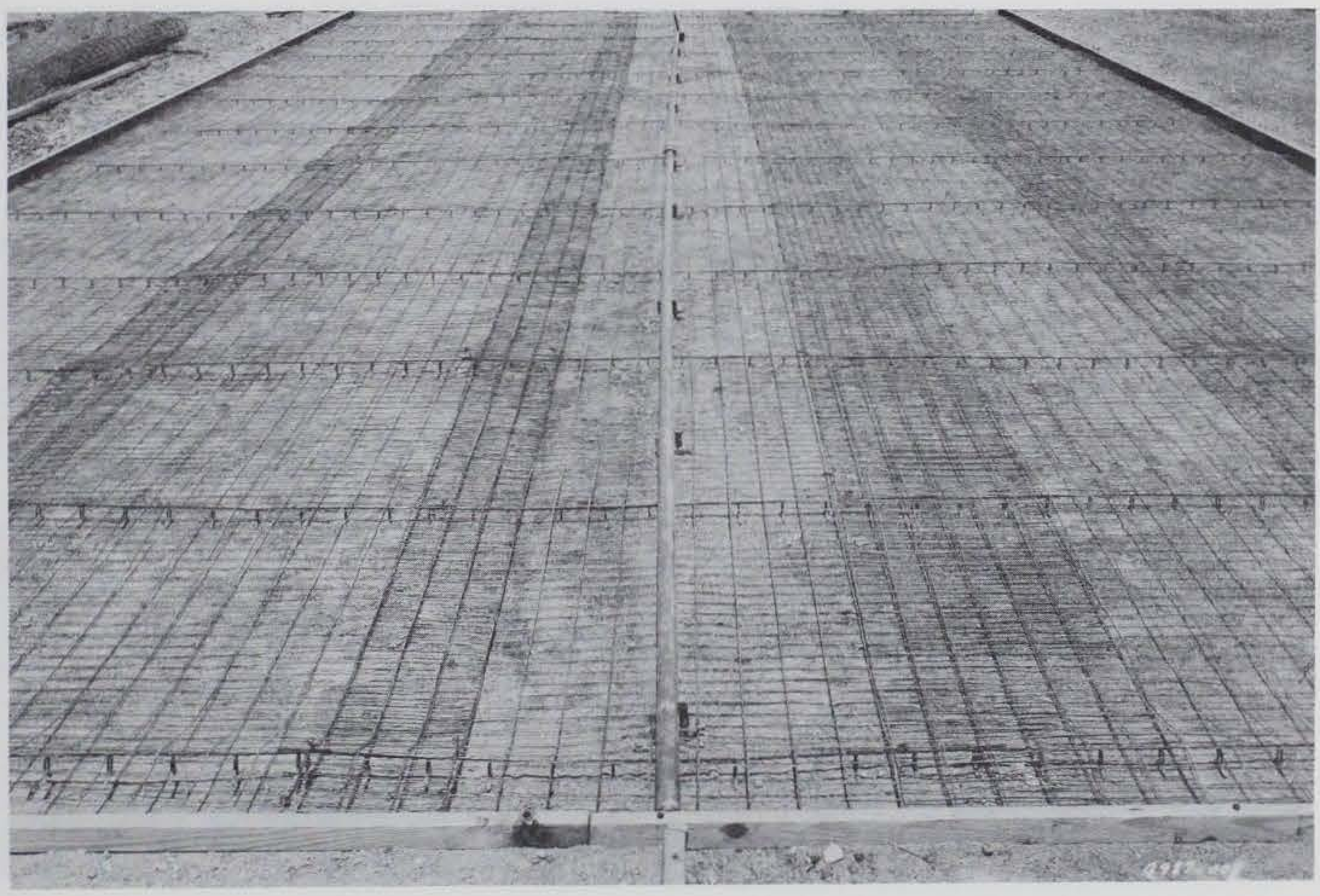

Photo 2. Items 4 and 5 after placement of two layers of welded wire fabric on chairs

Photo 3. Placing concrete in item 1

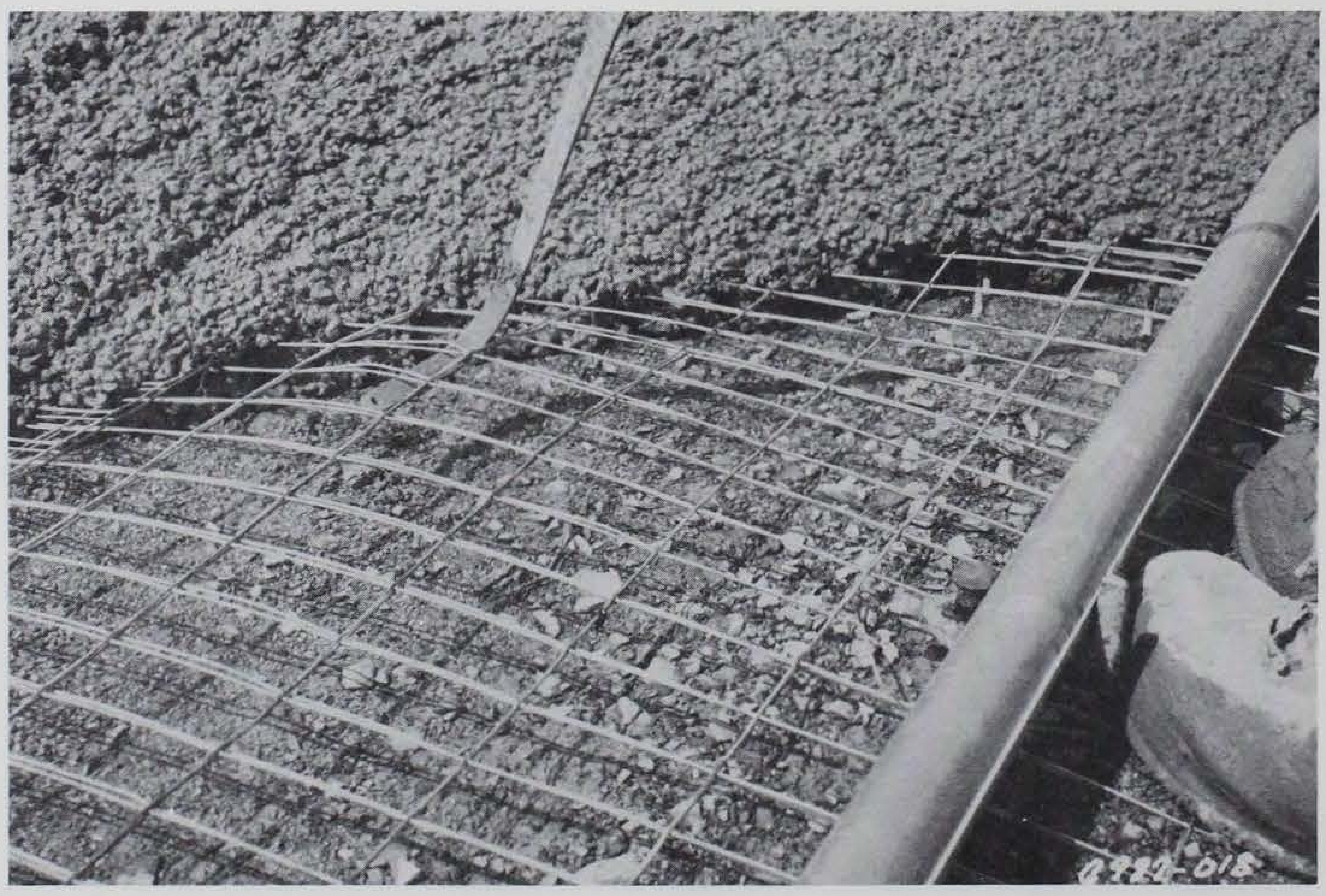

Photo 4. Placing concrete in item 4

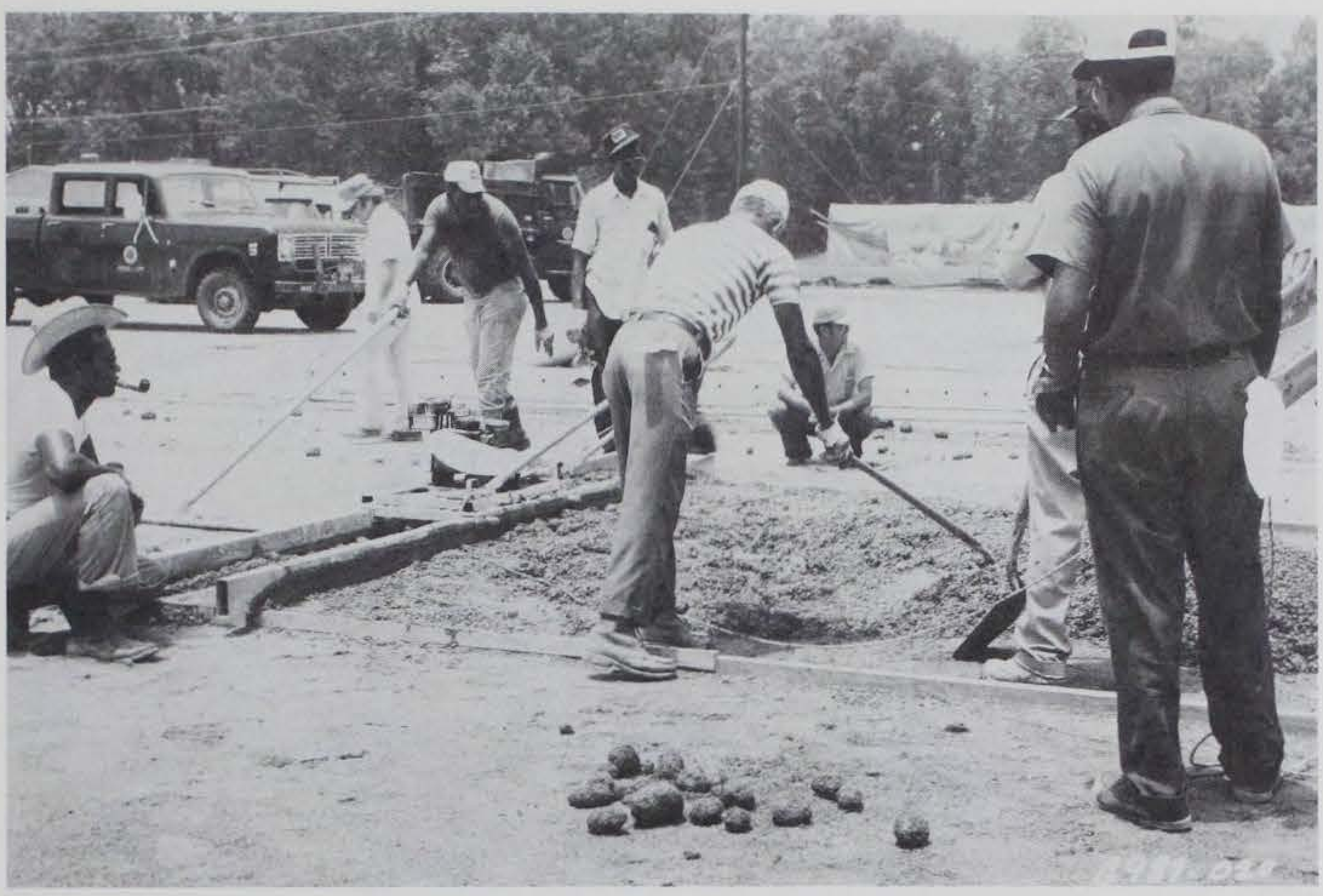

Photo 5. Placing fibrous concrete in item 3

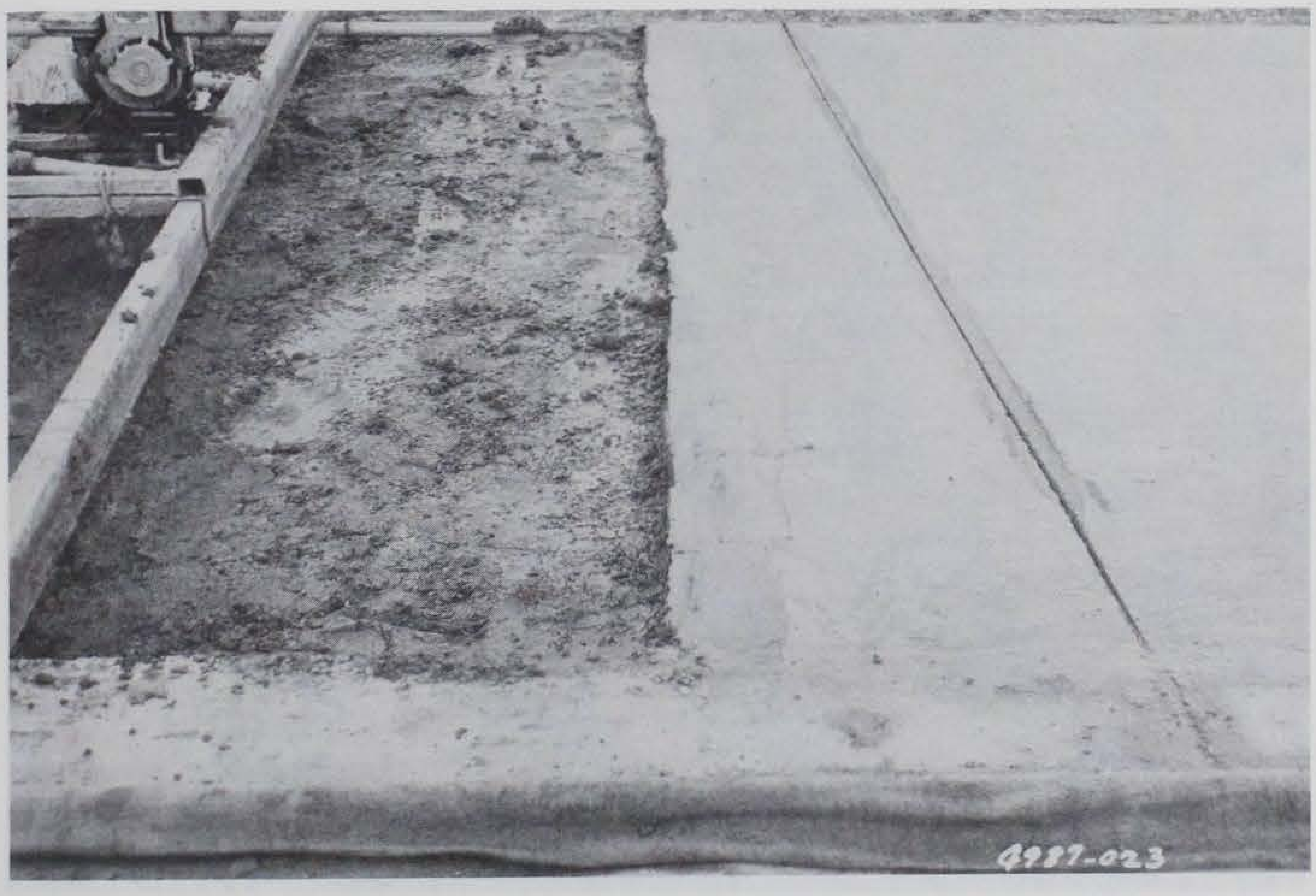

Photo 6. Construction joint in item 10

Photo 7. Forming weakened plane joints in items 1-10

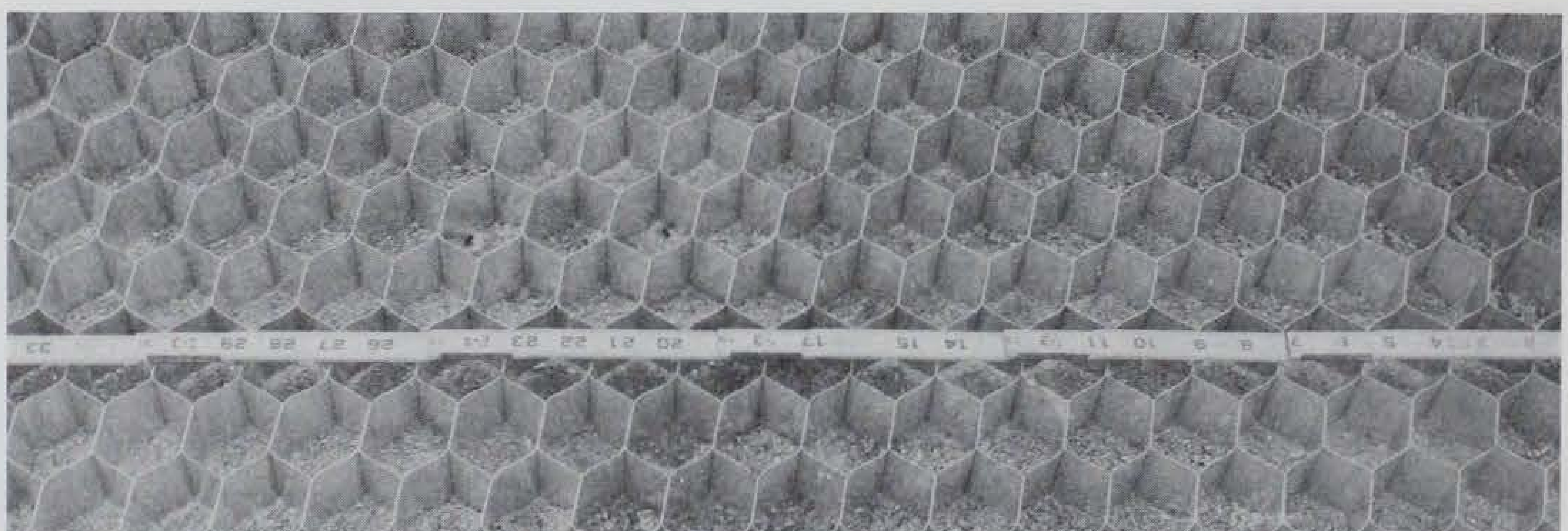

Photo 8. Item 11, aluminum grids

Photo 9. Placing concrete in grids by chute

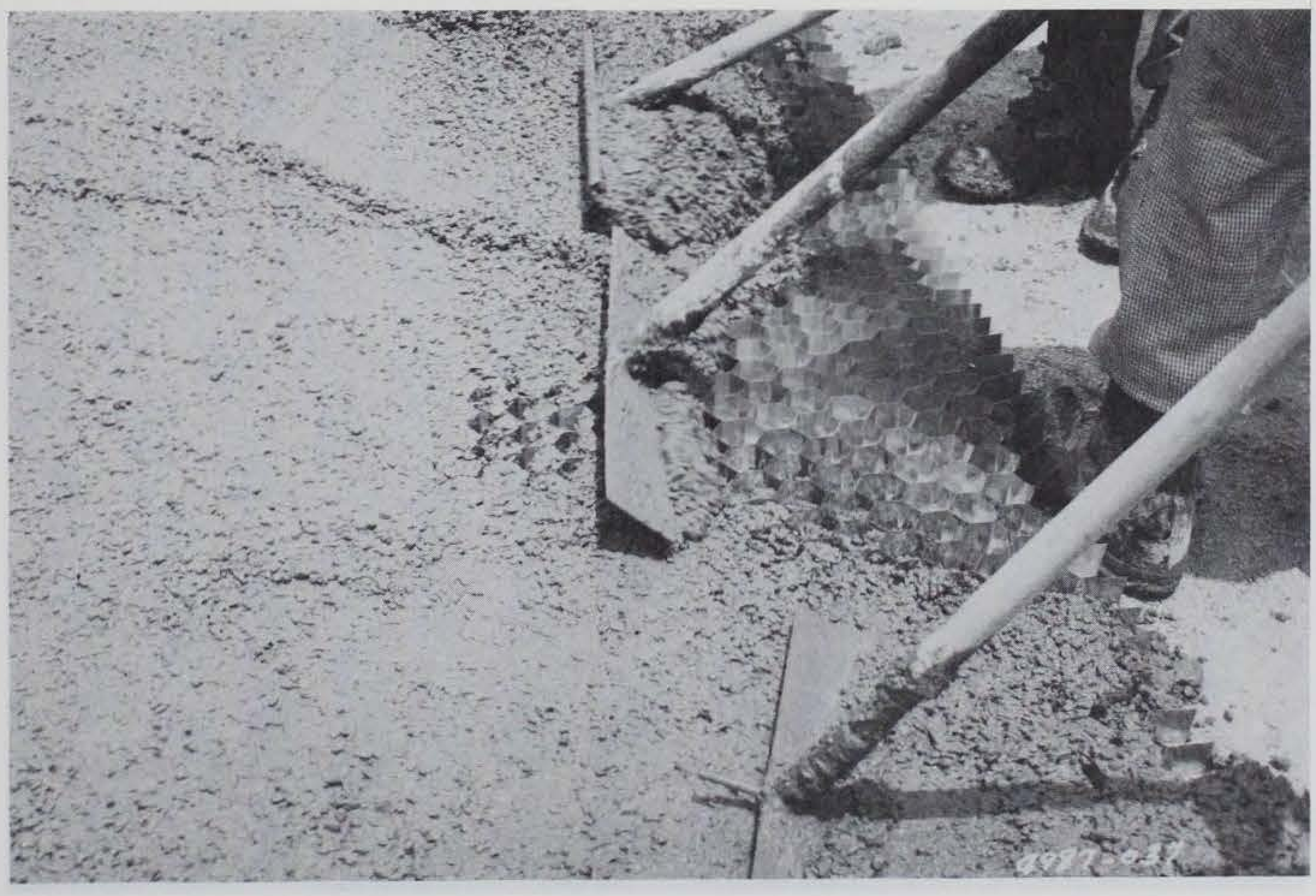

Photo 10. Spreading and working concrete into grids

Photo 11. WES 16-kip vibrator

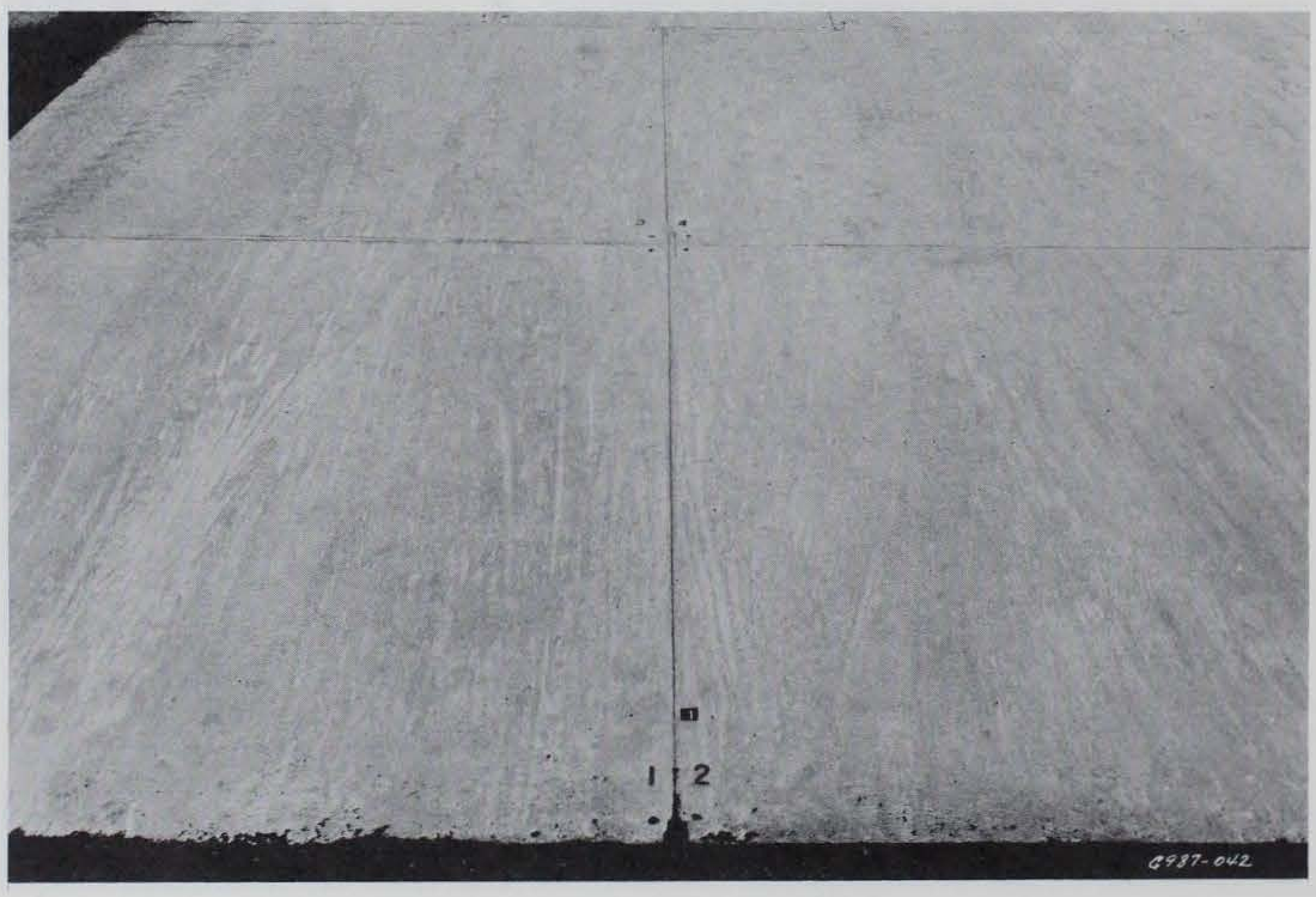

Photo 12. Item 1 before traffic

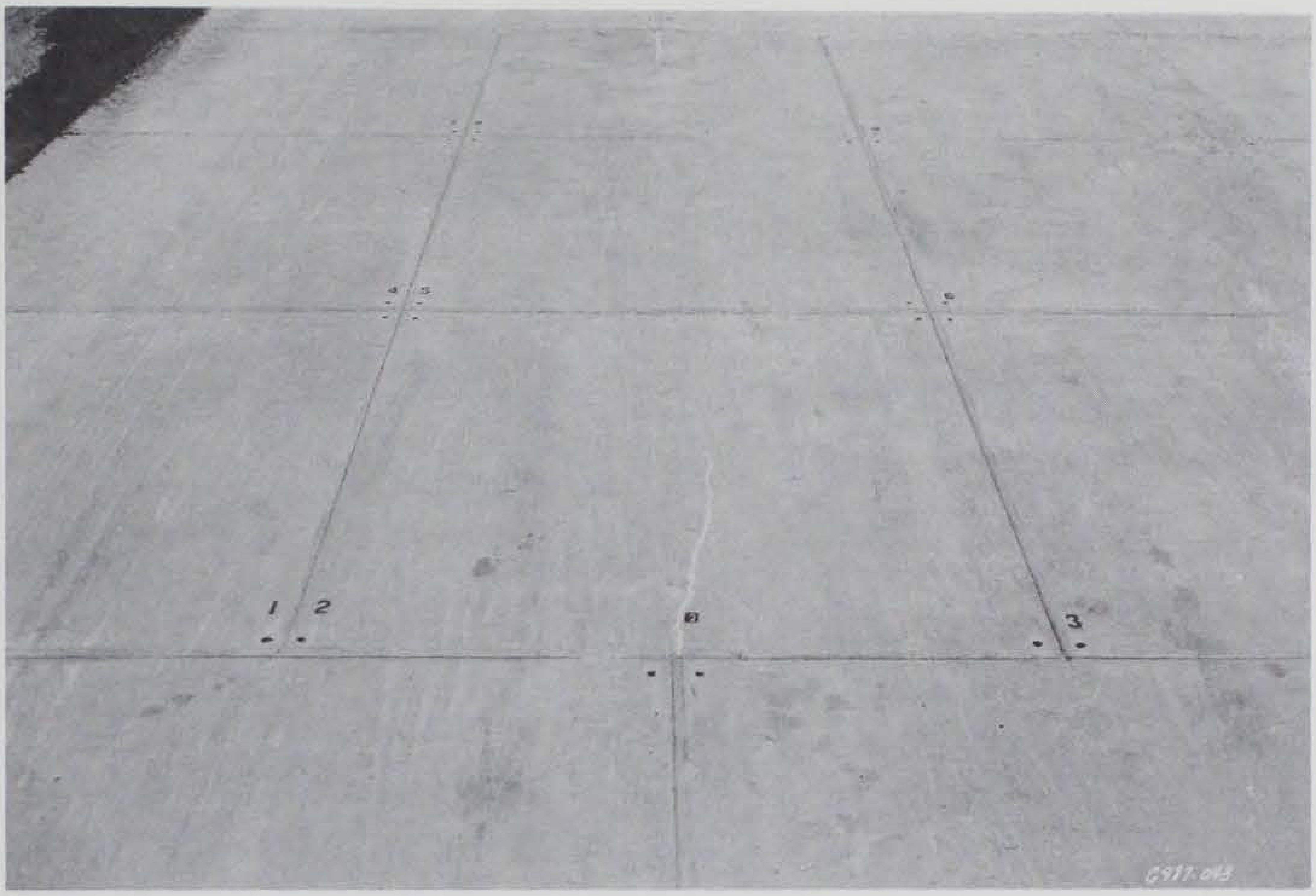

Photo 13. Item 2 showing weakened plane progressing from items 1 and 3

Photo 14. Item 3 showing irregularities in surface due to finishing

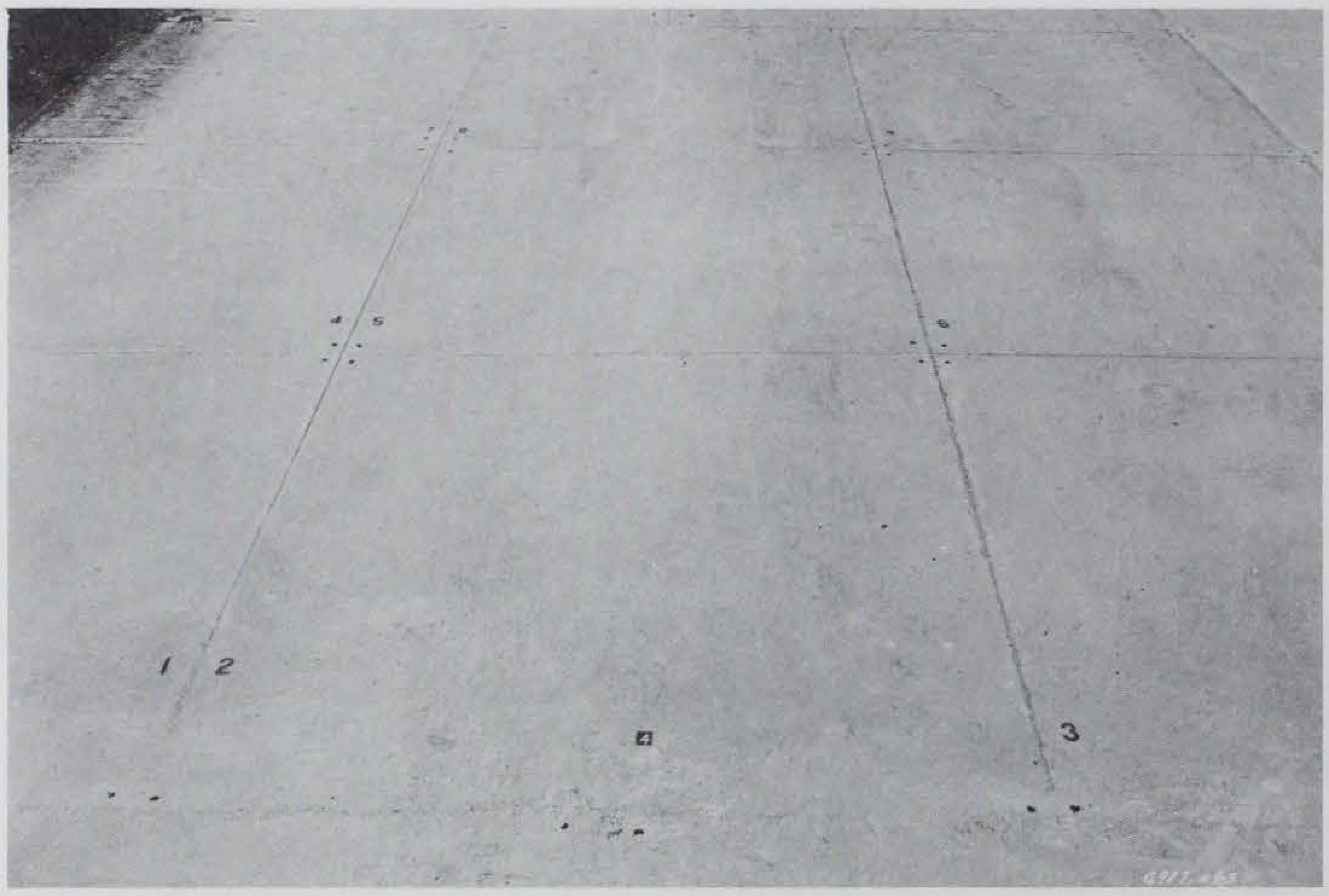

Photo 15. Item 4 before traffic

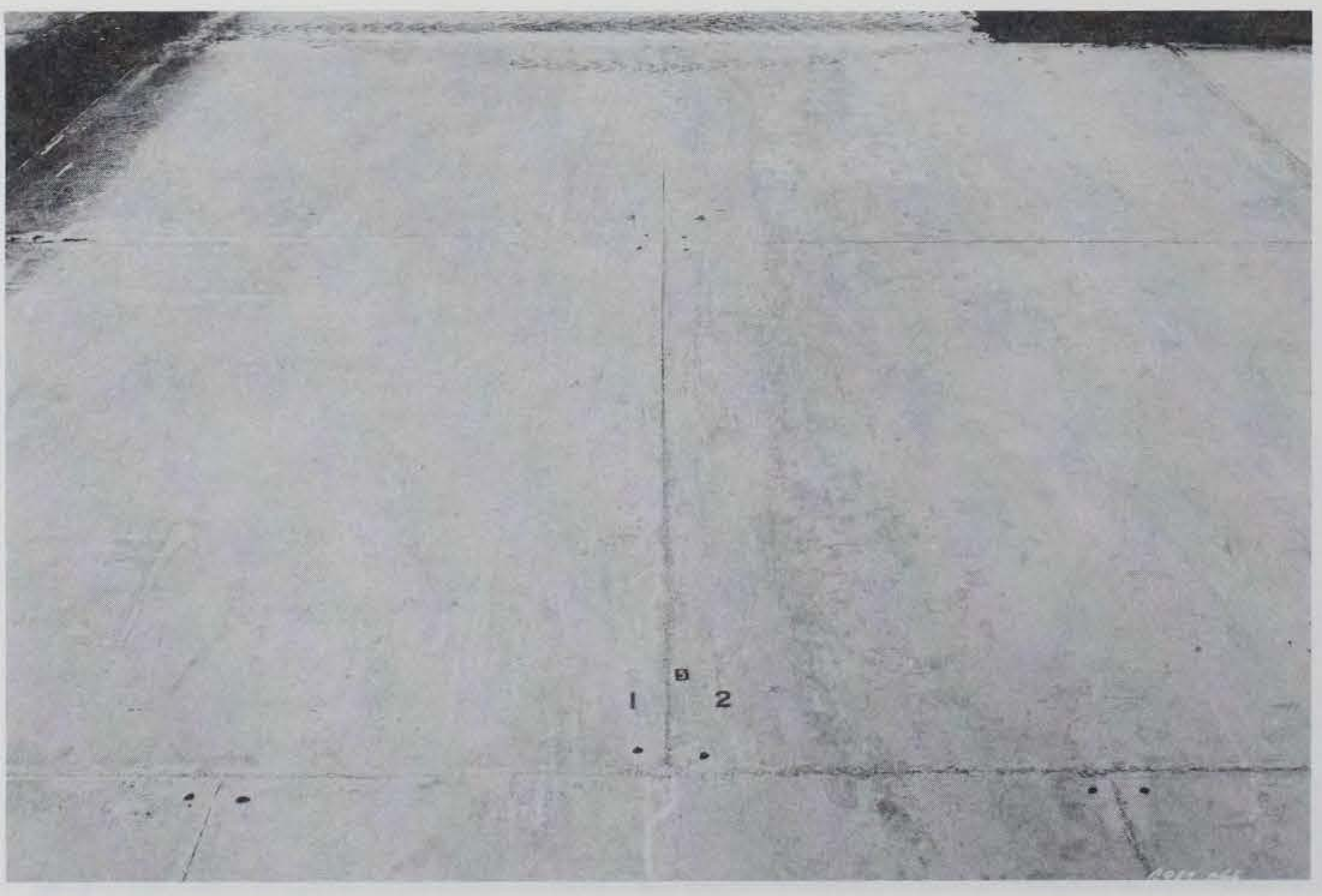

Photo 16. Item 5 before traffic

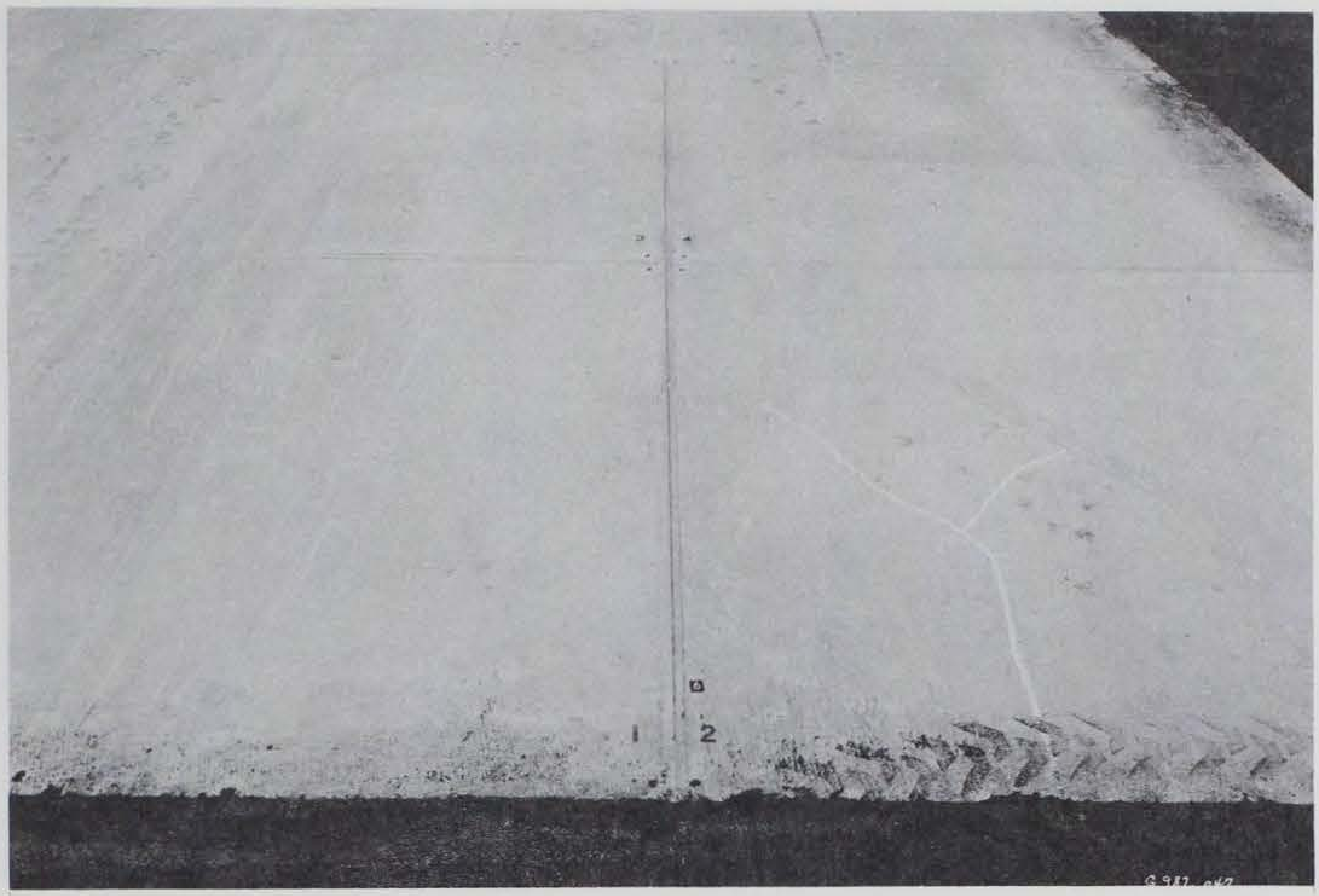

Photo 17. Shrinkage cracks in item 6

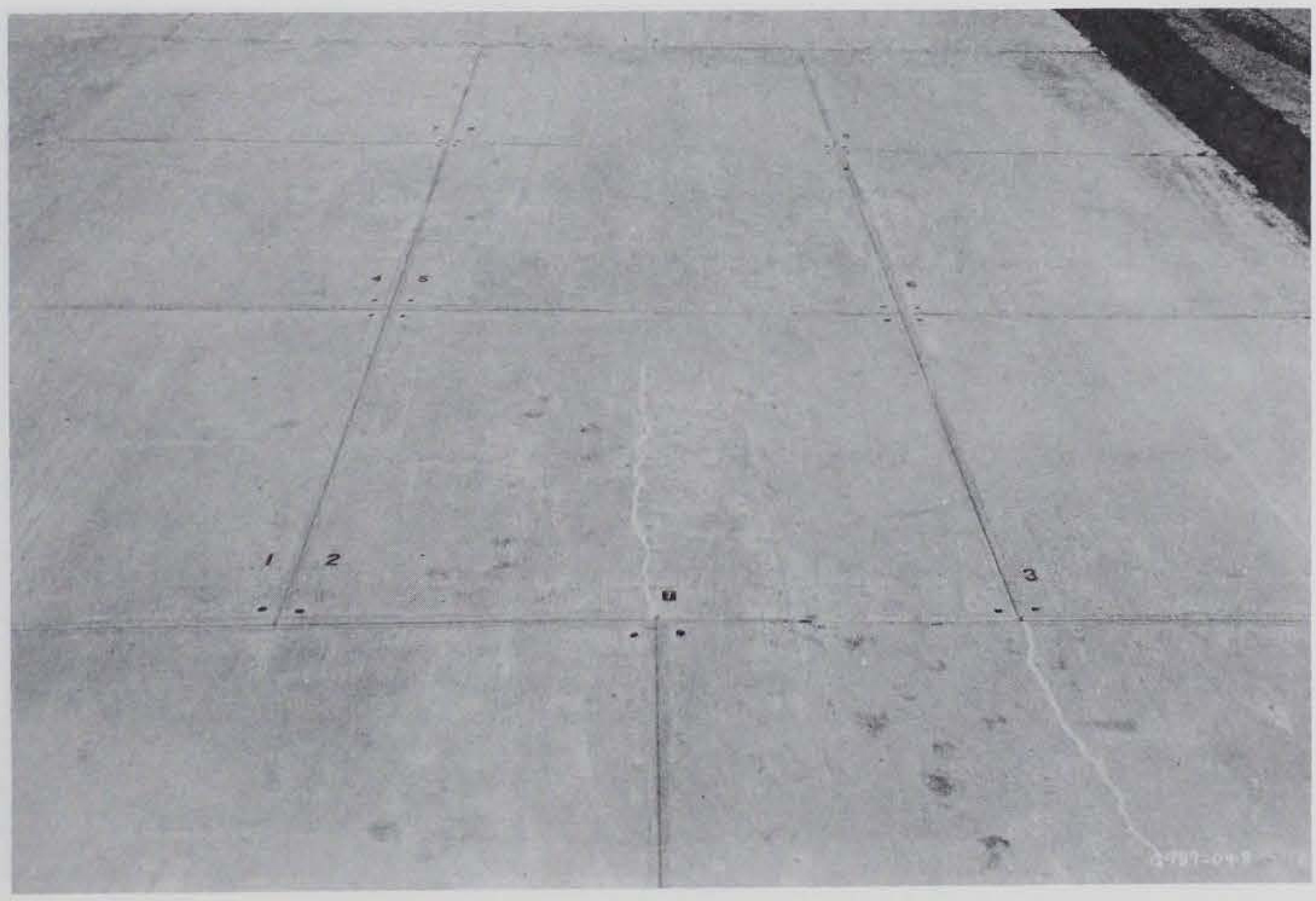

Photo 18. Item 7 showing weakened plane crack progression from item 6

Photo 19. Item 8 before traffic

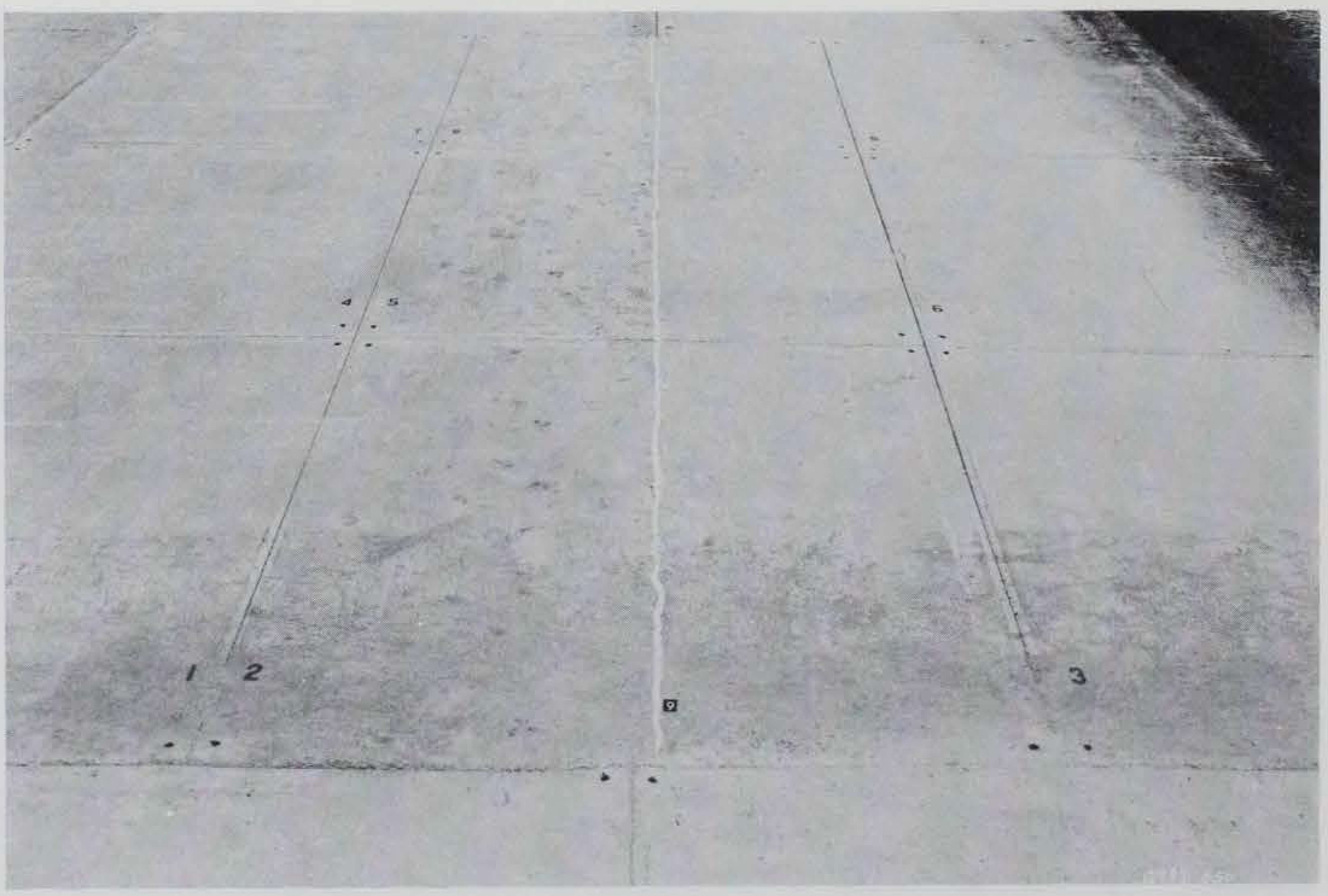

Photo 20. Item 9 showing a weakened plane progression crack from item 10

Photo 21. Item 10 before traffic

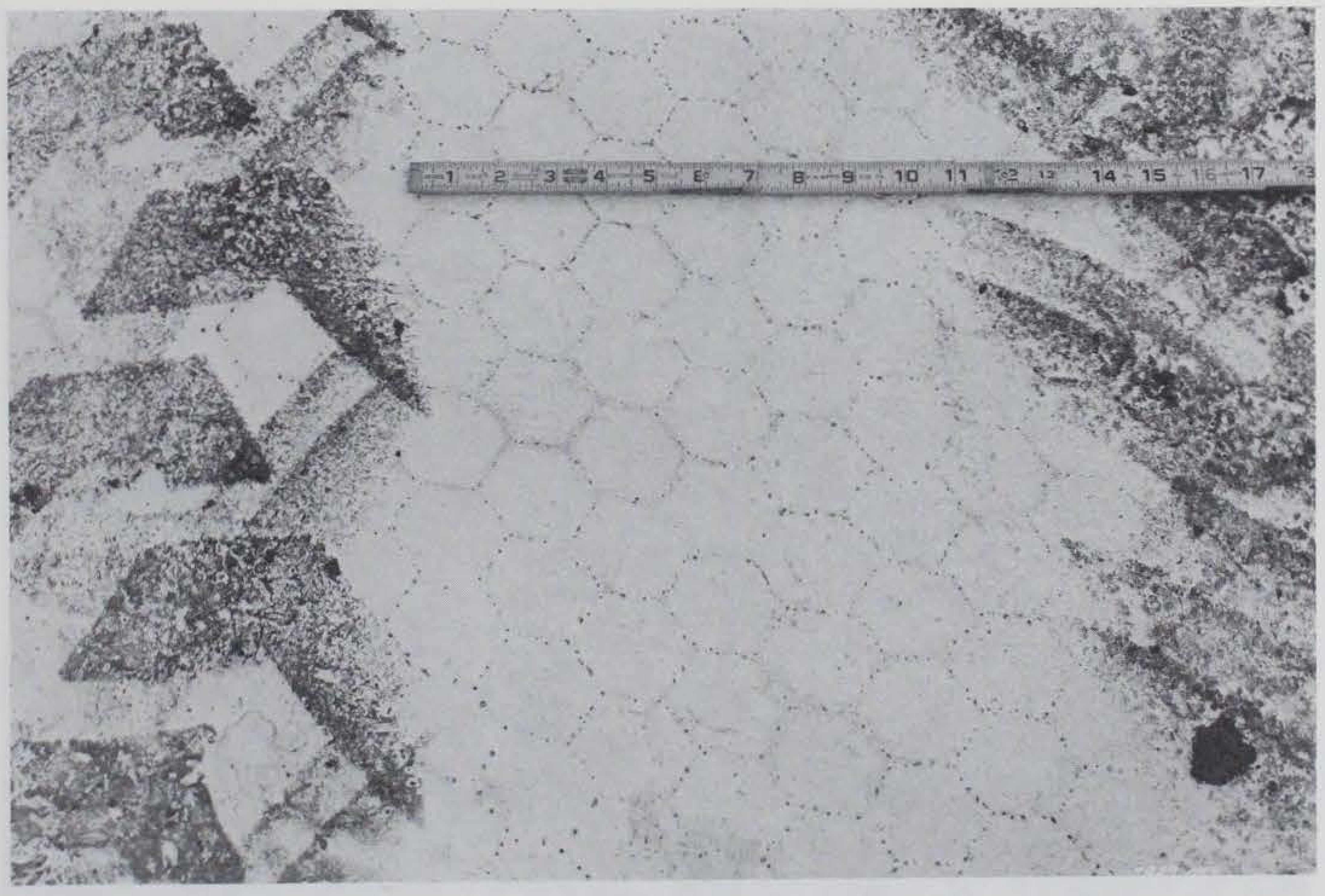

Photo 22. A closeup view of item 11

Photo 23. View of M-48 tank loaded with blocks to simulate combat weight

Photo 24. Item 1 after 2500 passes and 500 turning movements

Photo 25. Item 2 after 2500 passes and 500 turning movements

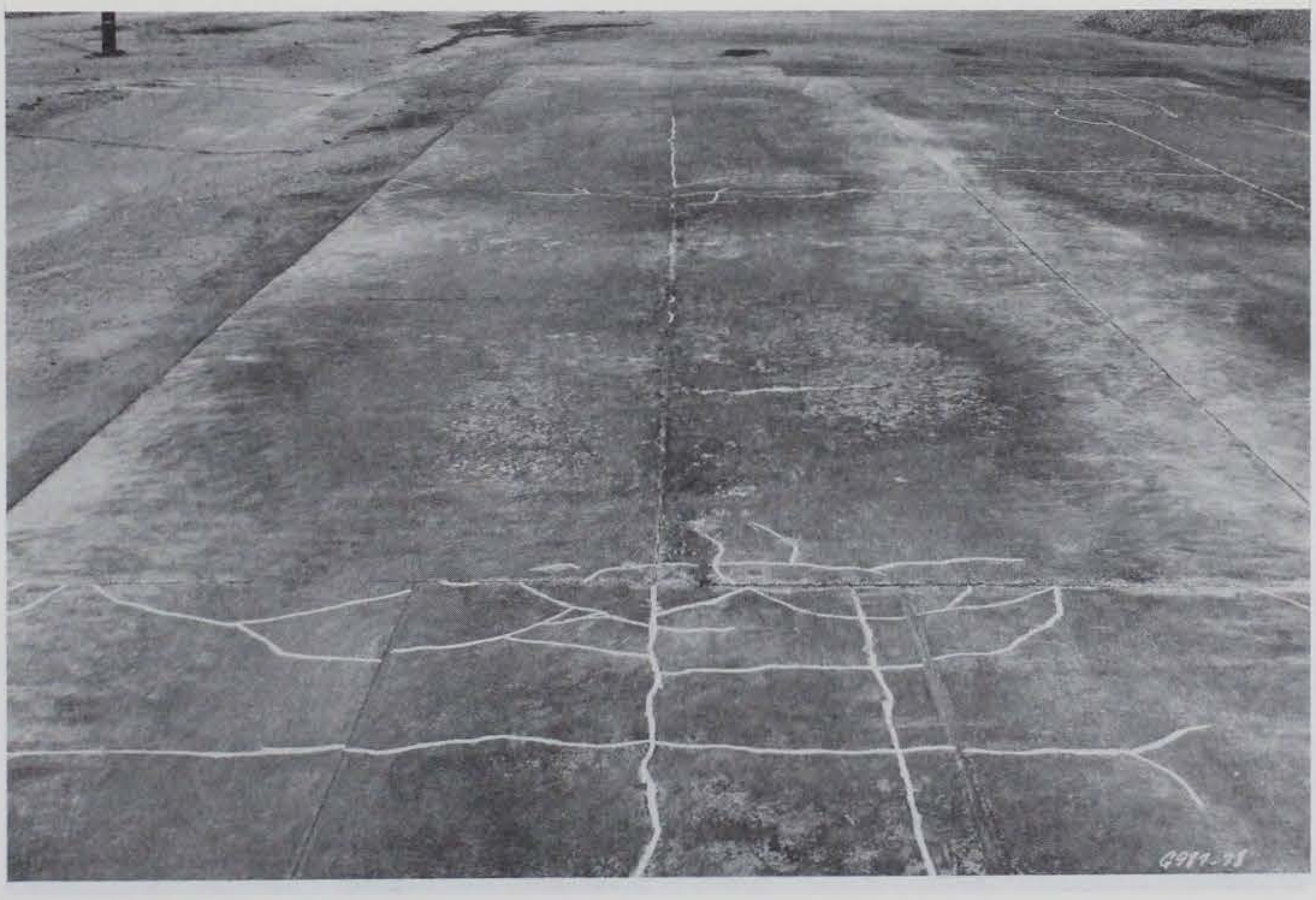

Photo 26. Item 3 after 2500 passes and 500 turning movements

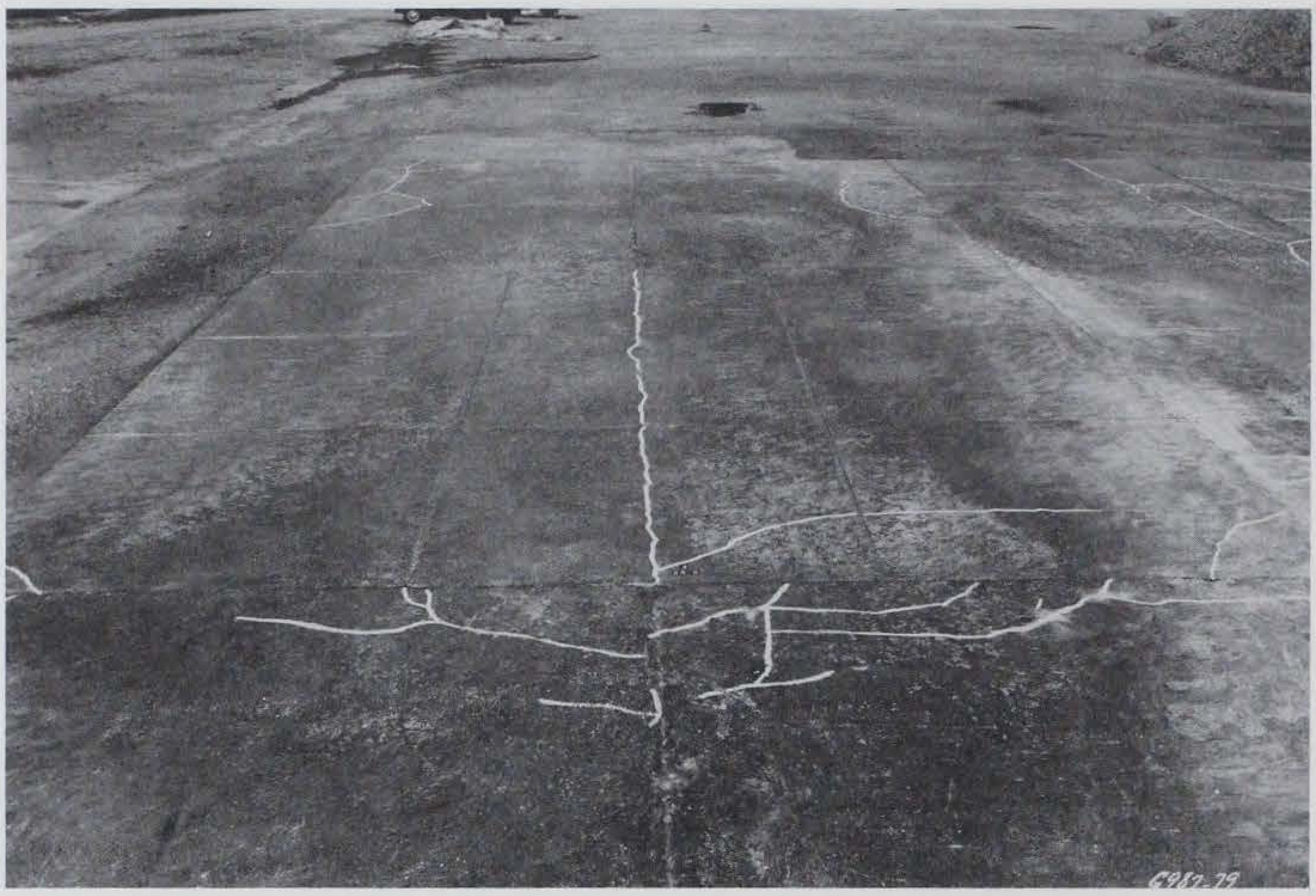

Photo 27. Item 4 after 2500 passes and 500 turning movements

Photo 28. Item 5 after 2500 passes and 500 turning movements

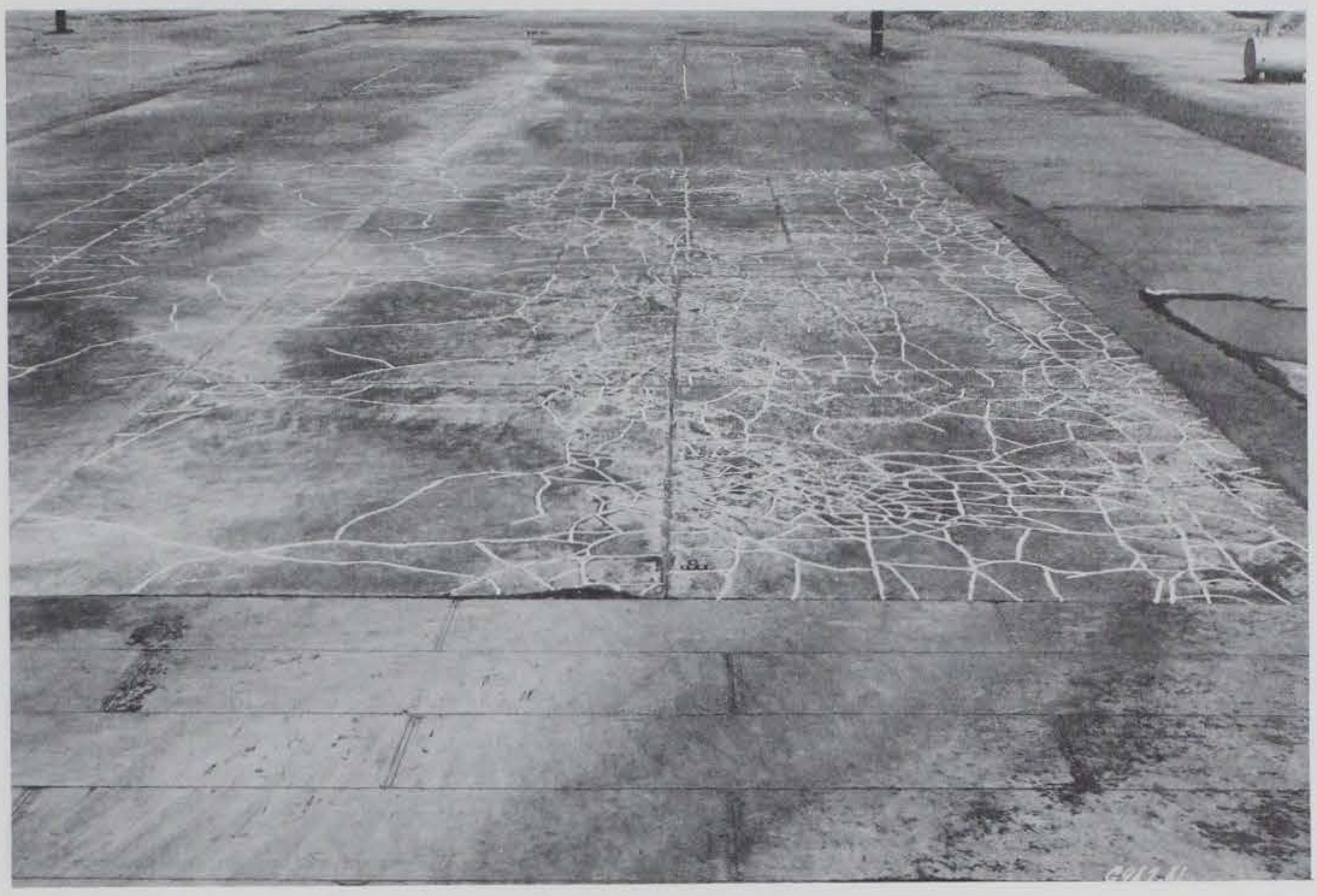

Photo 29. Item 6 after 2500 passes and 500 turning movements

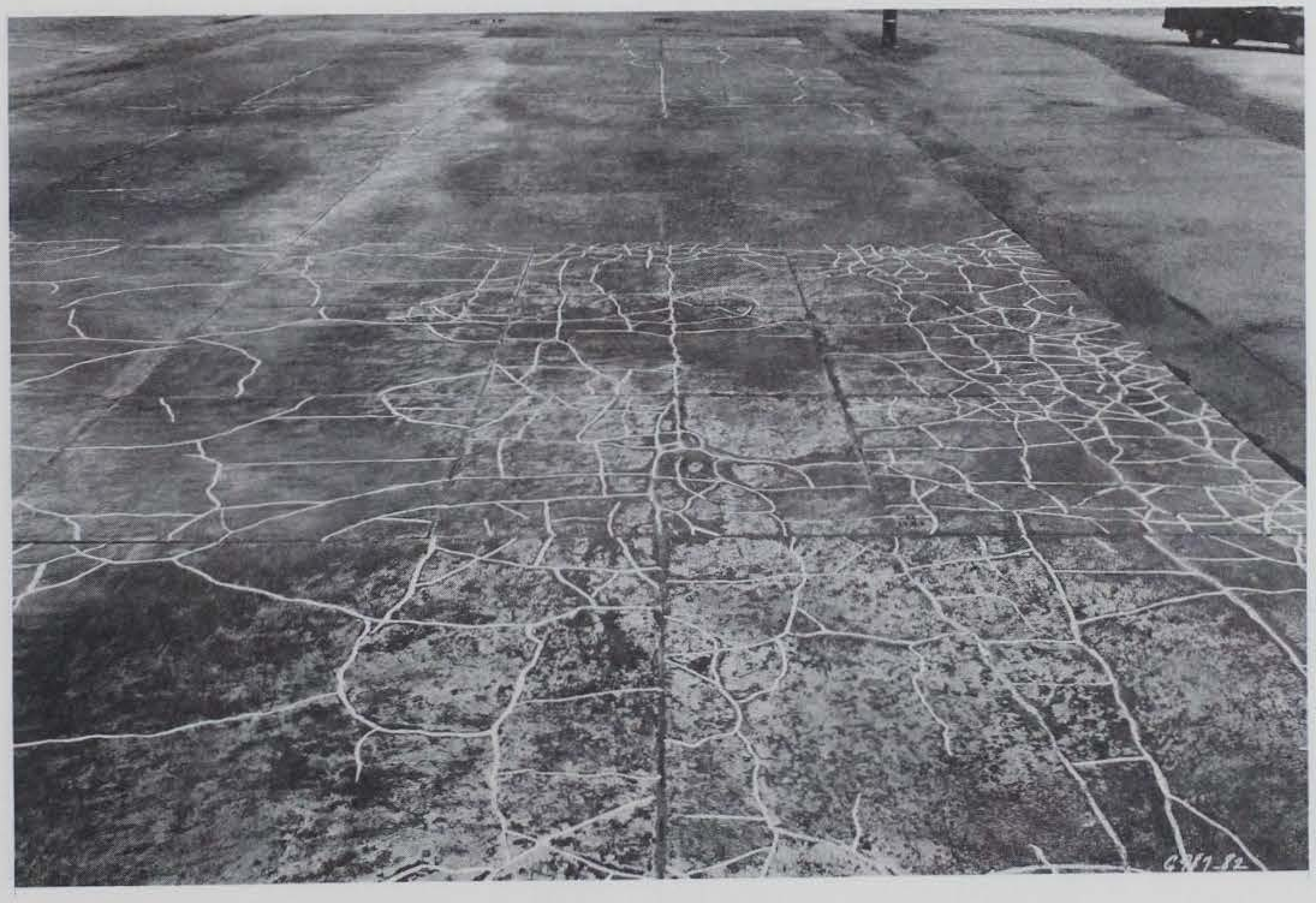

Photo 30. Item 7 after 2500 passes and 500 turning movements

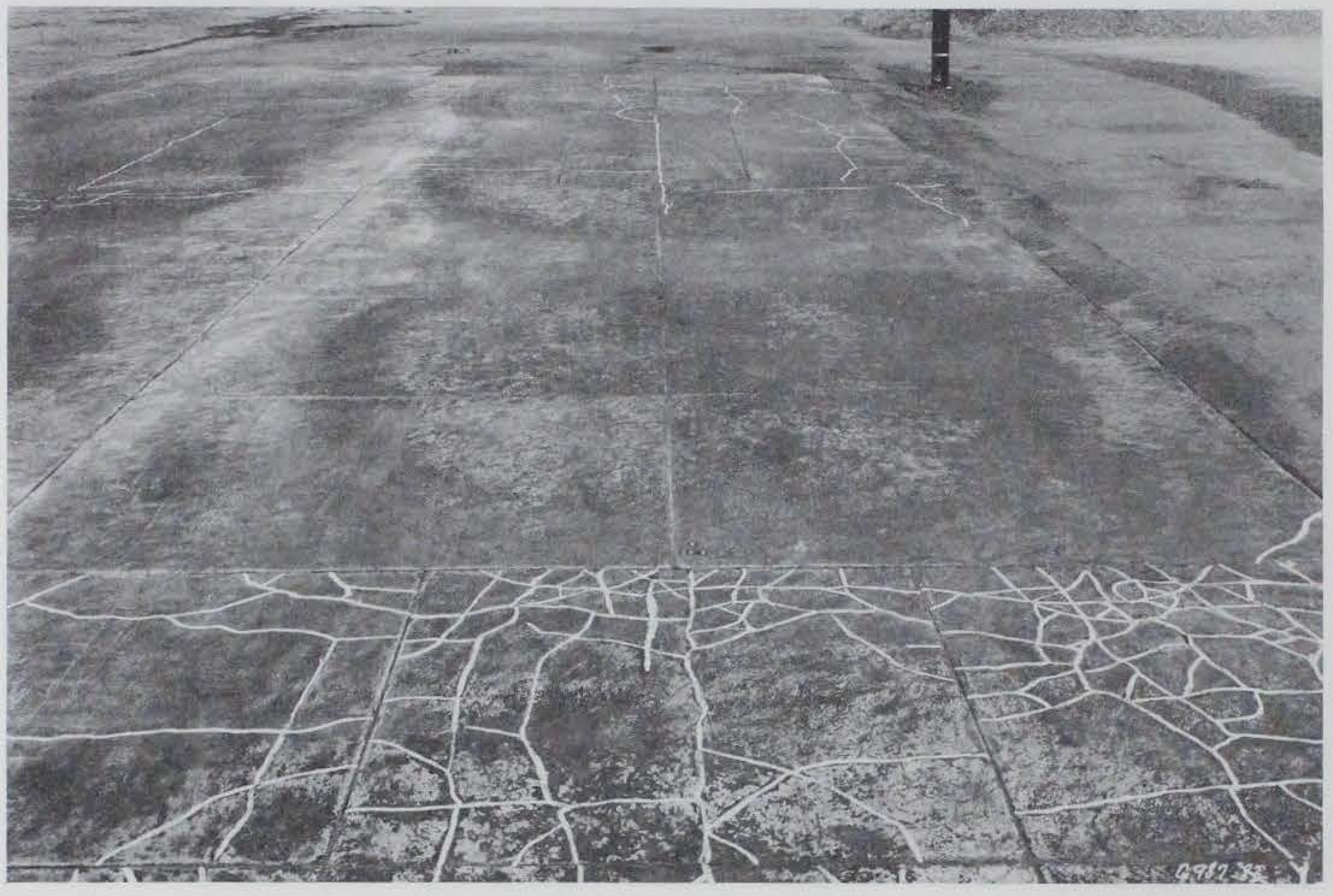

Photo 31. Item 8 after 2500 passes and 500 turning movements

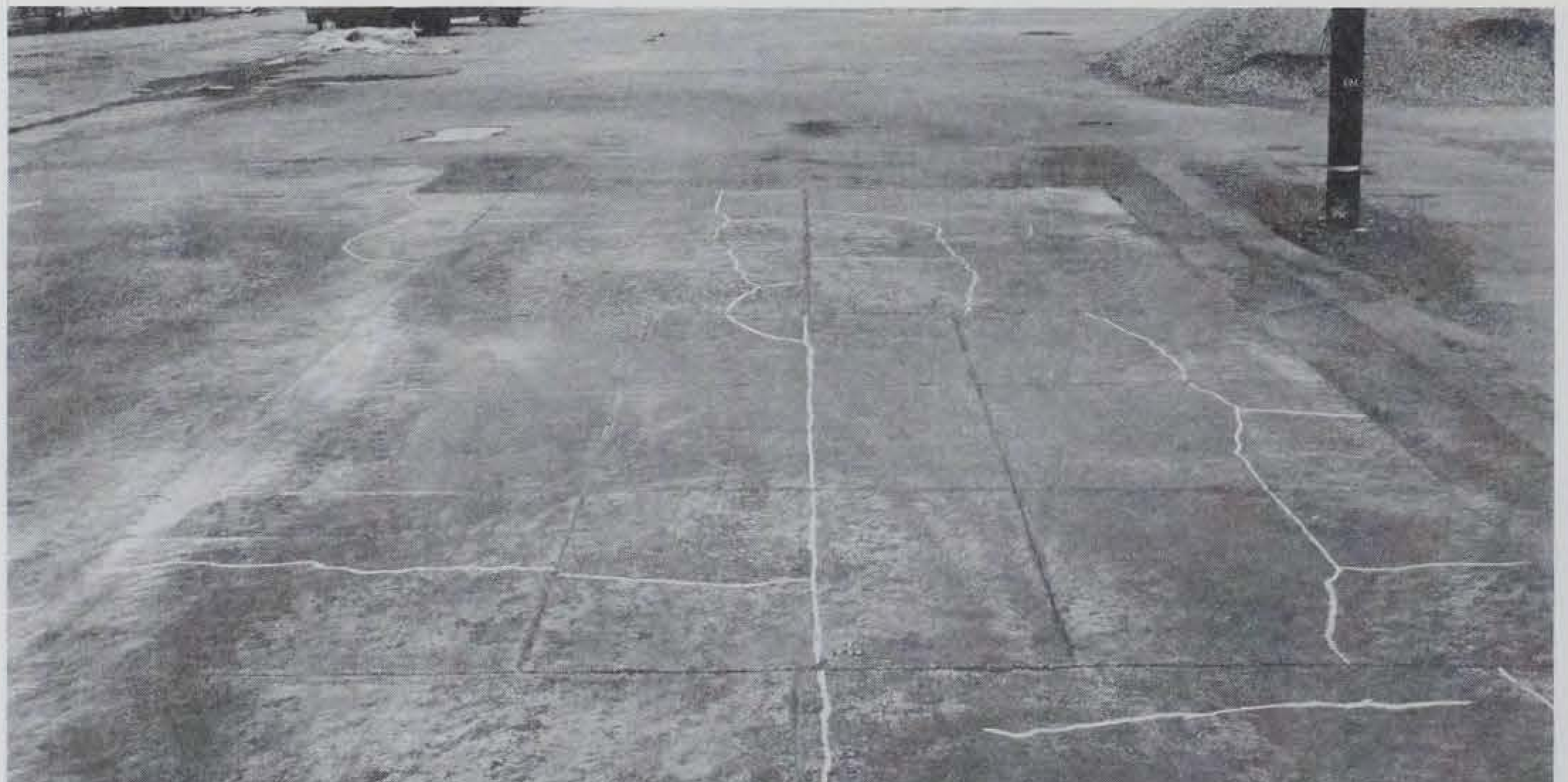

Photo 32. Item 9 after 2500 passes and 500 turning movements

Photo 33. Item 10 after 2500 passes and
500 turning movements

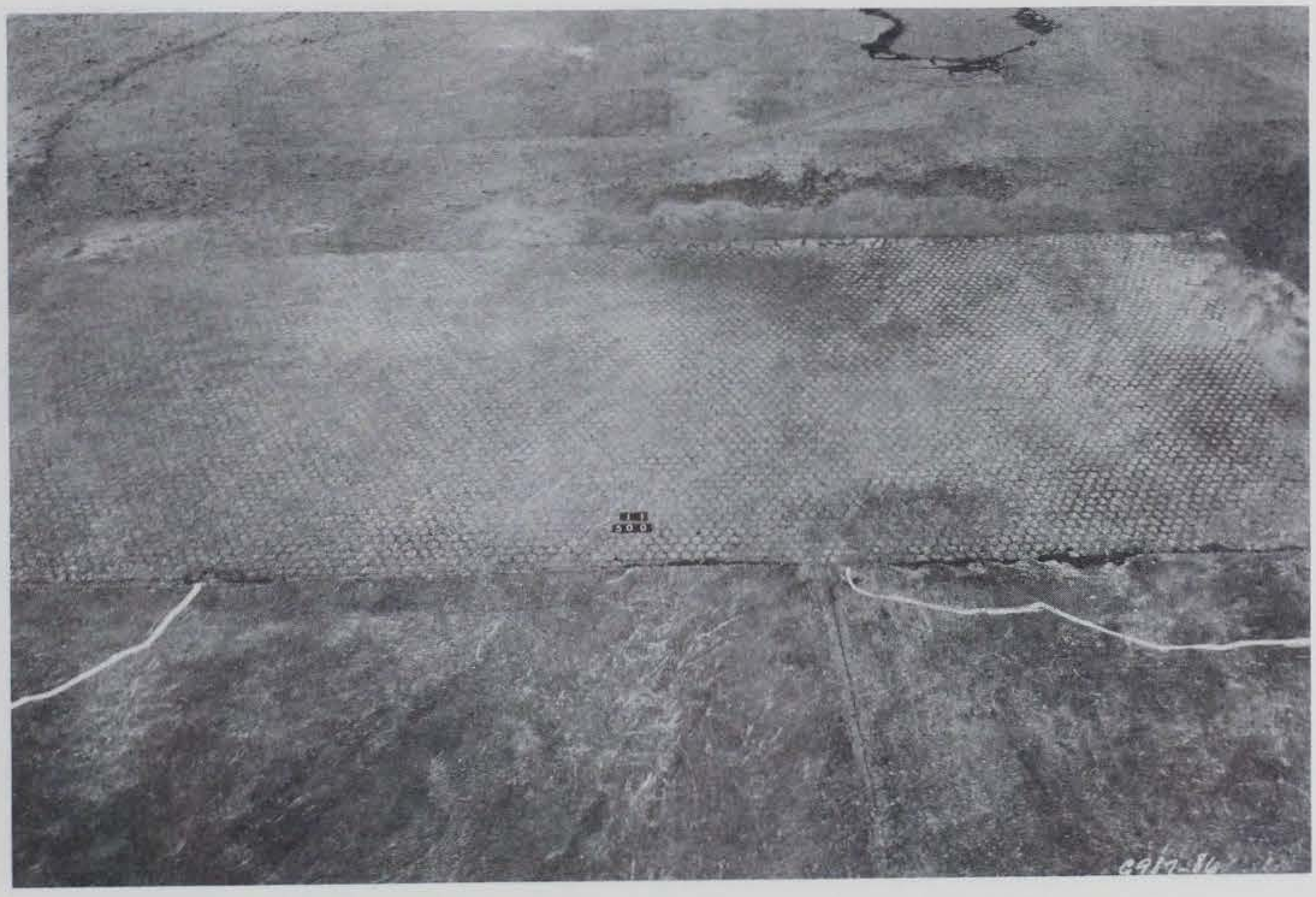

Photo 34. Item 11 after 2500 passes and
500 turning movements

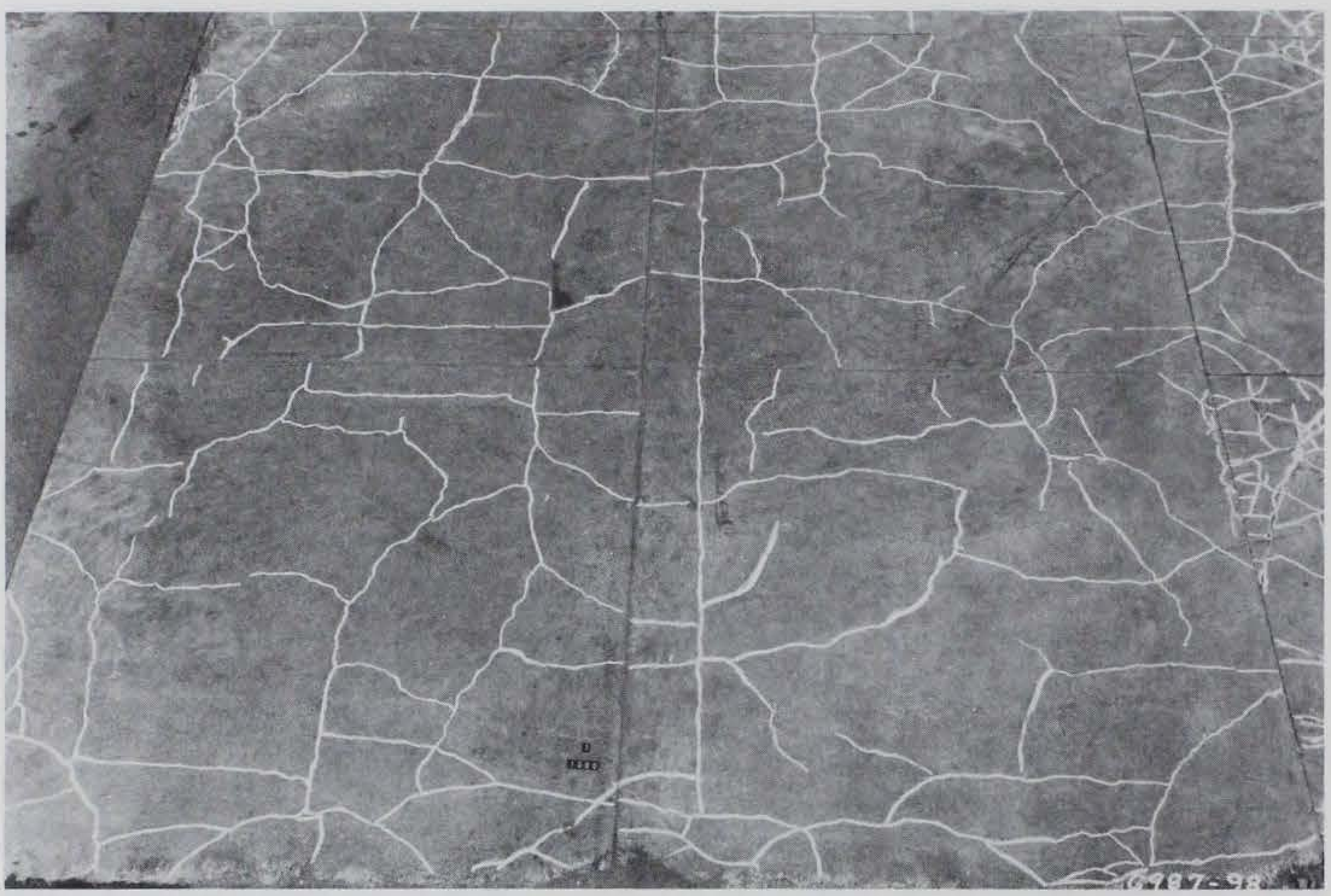

Photo 35. Item 1 after traffic tests were completed (5000 passes and 1000 turns)

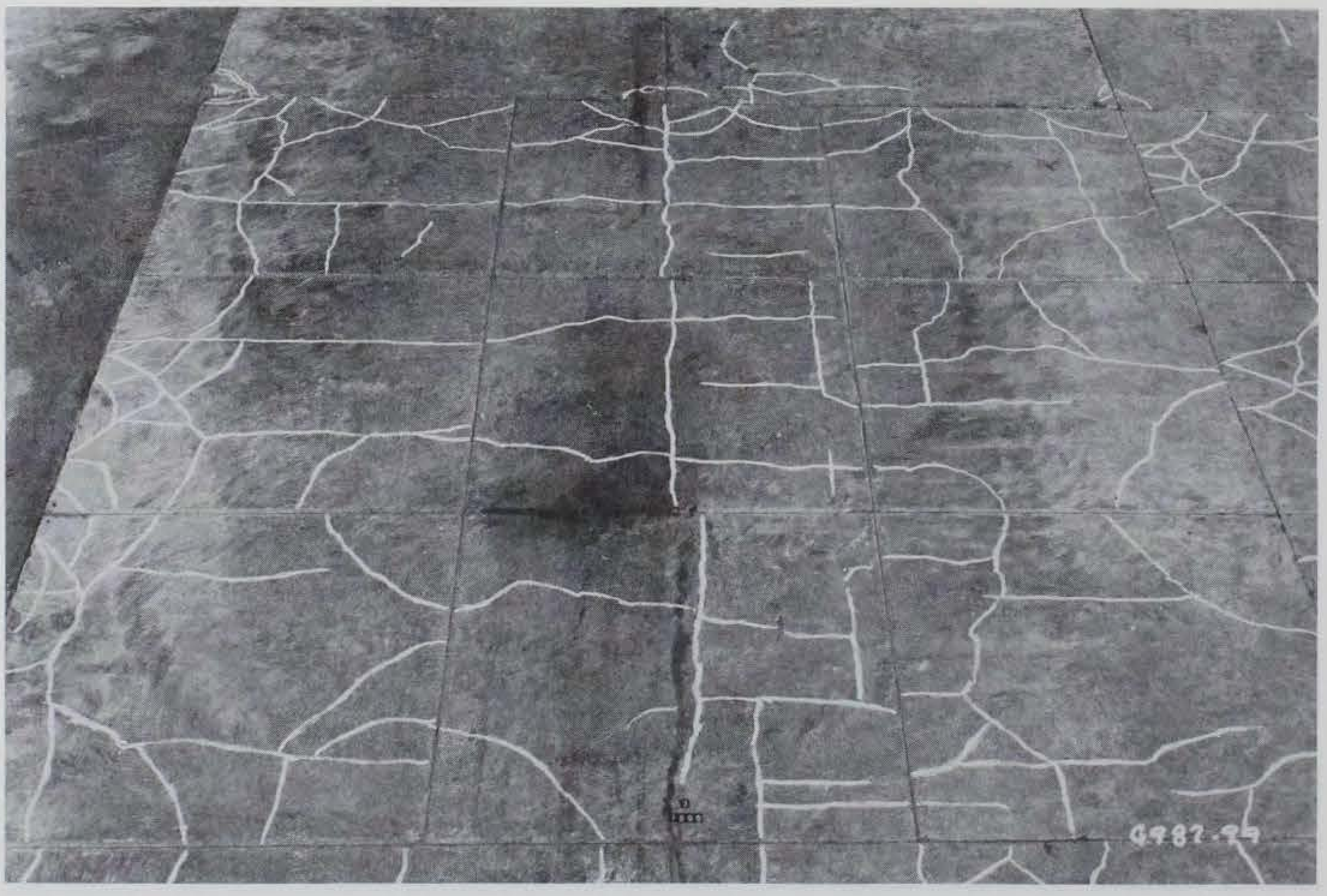

Photo 36. Item 2 after traffic tests were completed

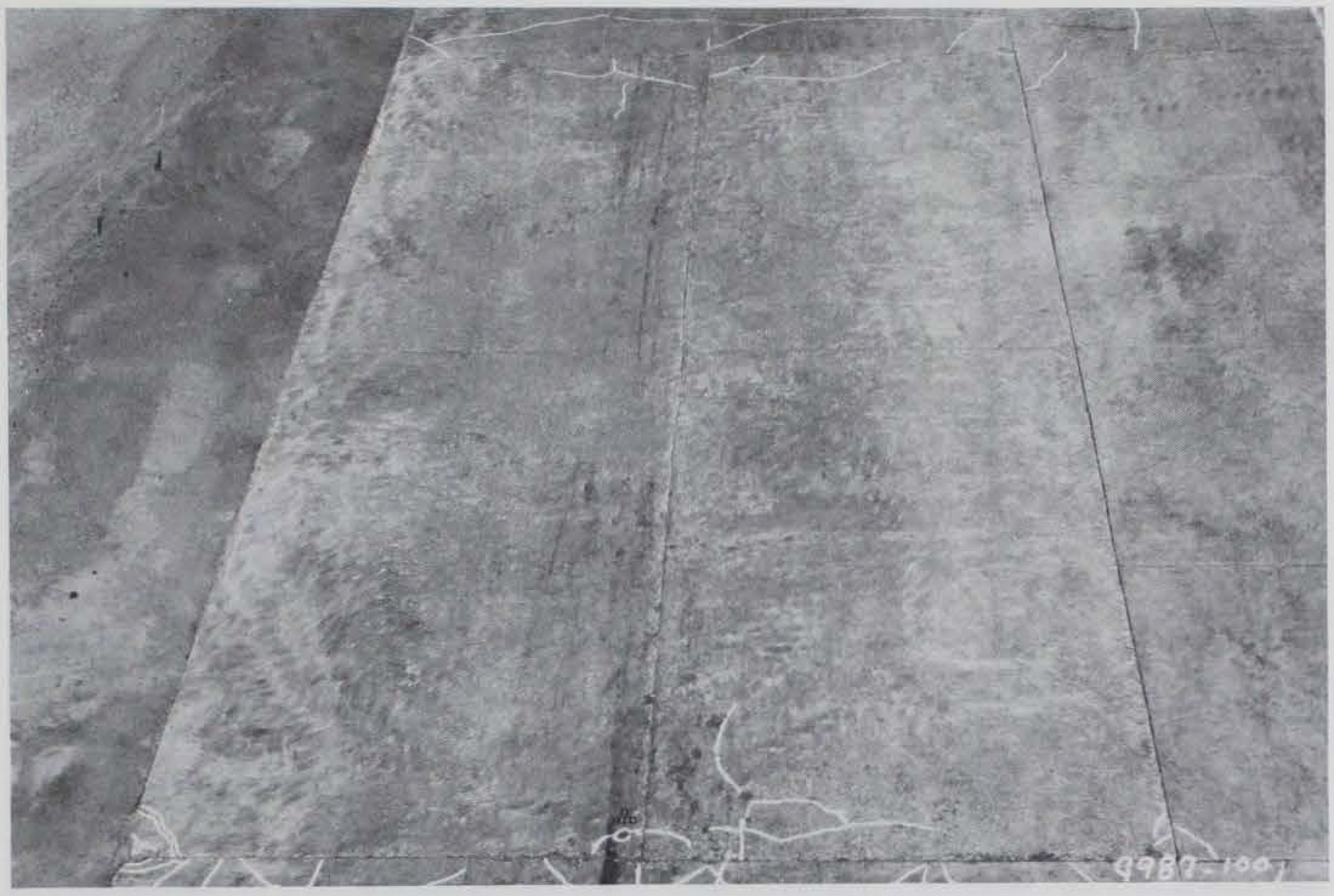

Photo 37. Item 3 after traffic tests were completed

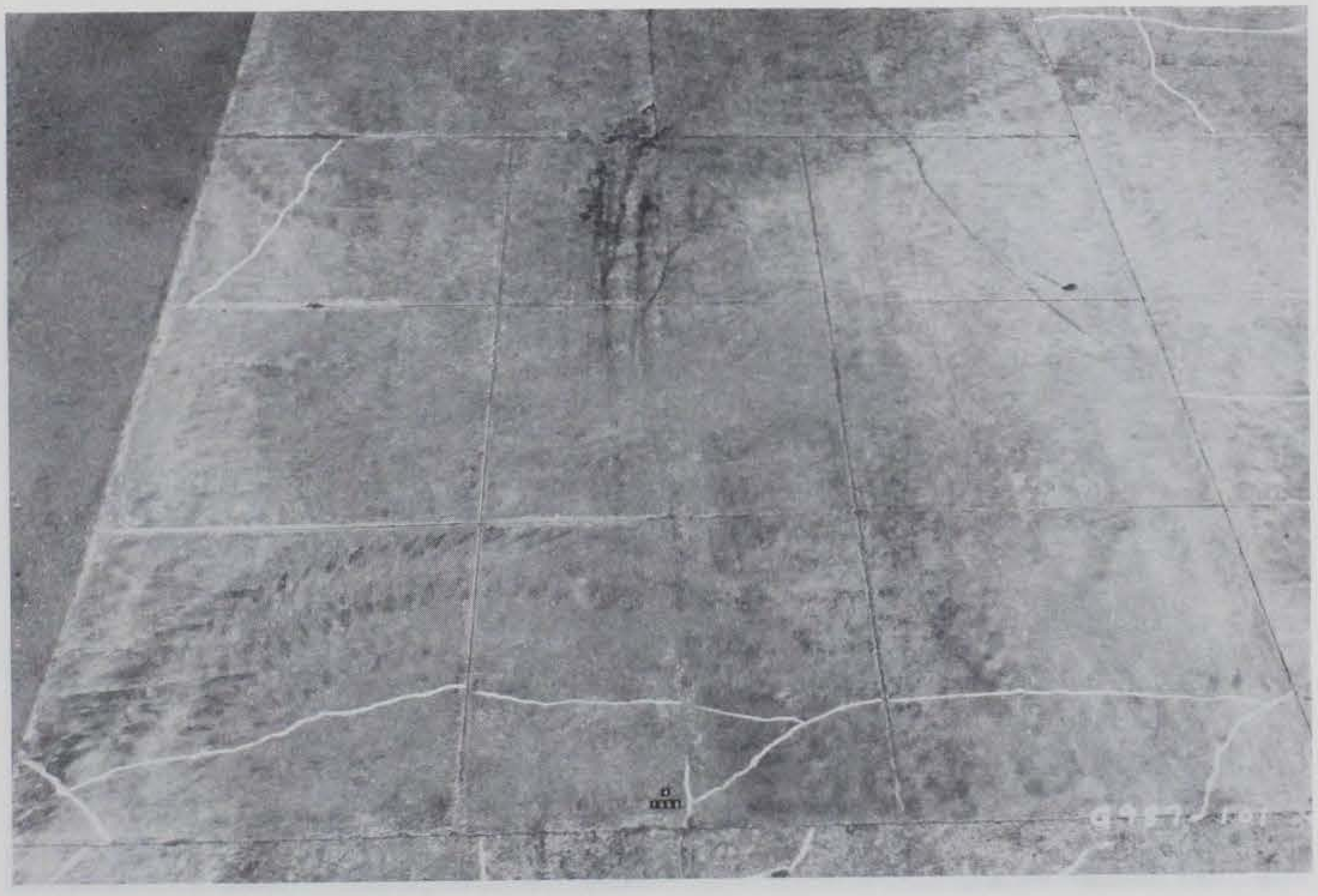

Photo 38. Item 4 after traffic tests were completed

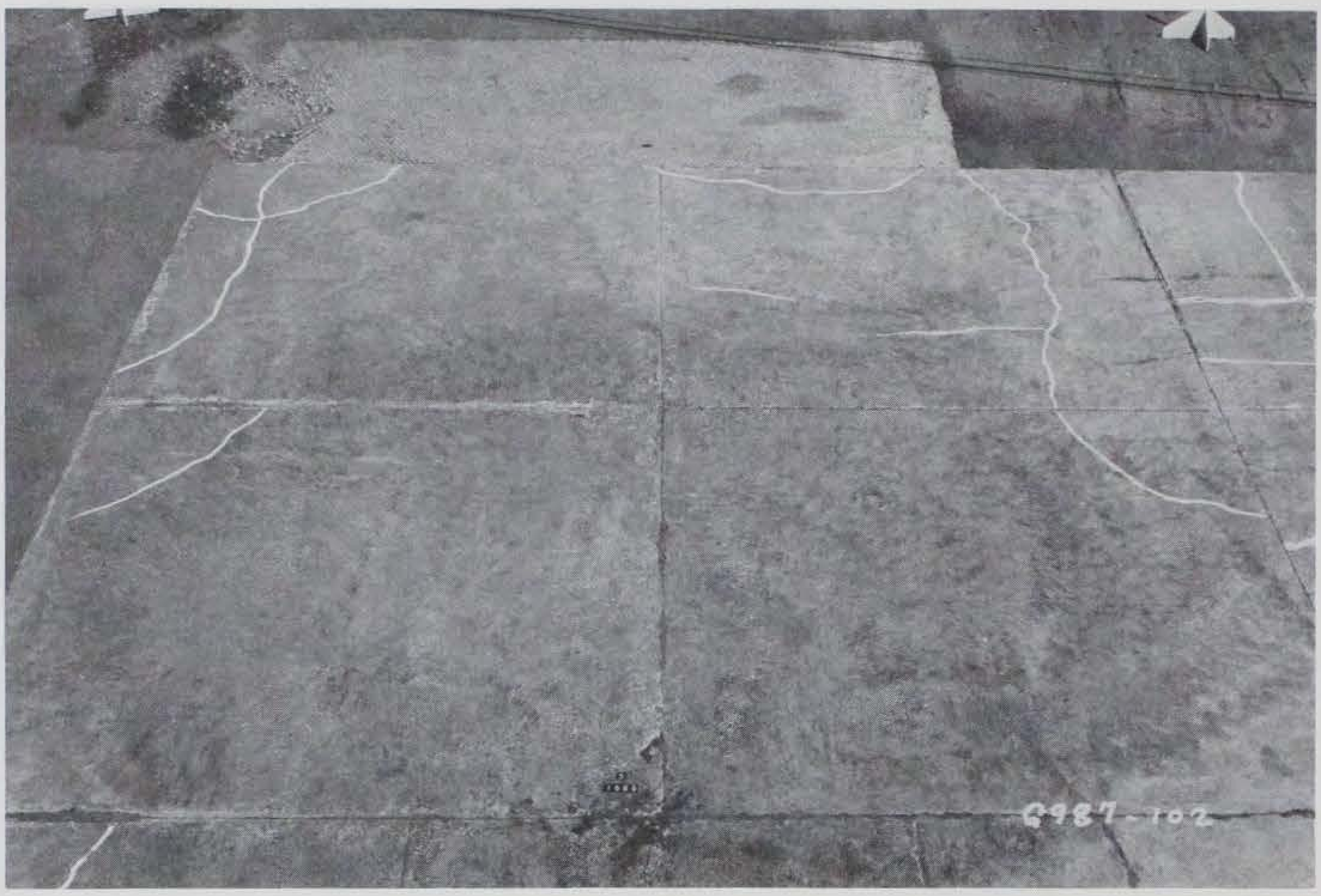

Photo 39. Item 5 after traffic tests were completed

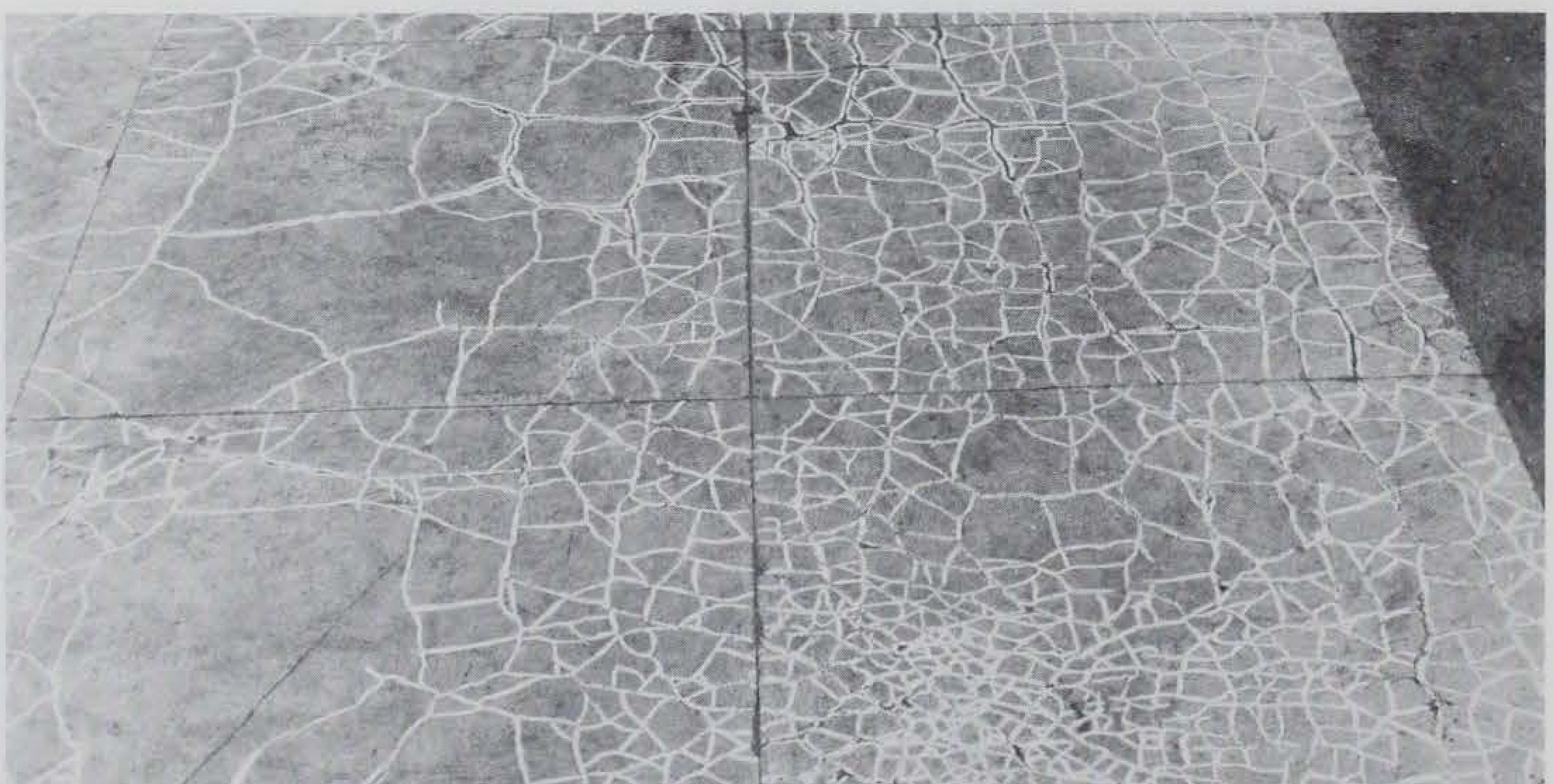

Photo 40. Item 6 after traffic tests were completed

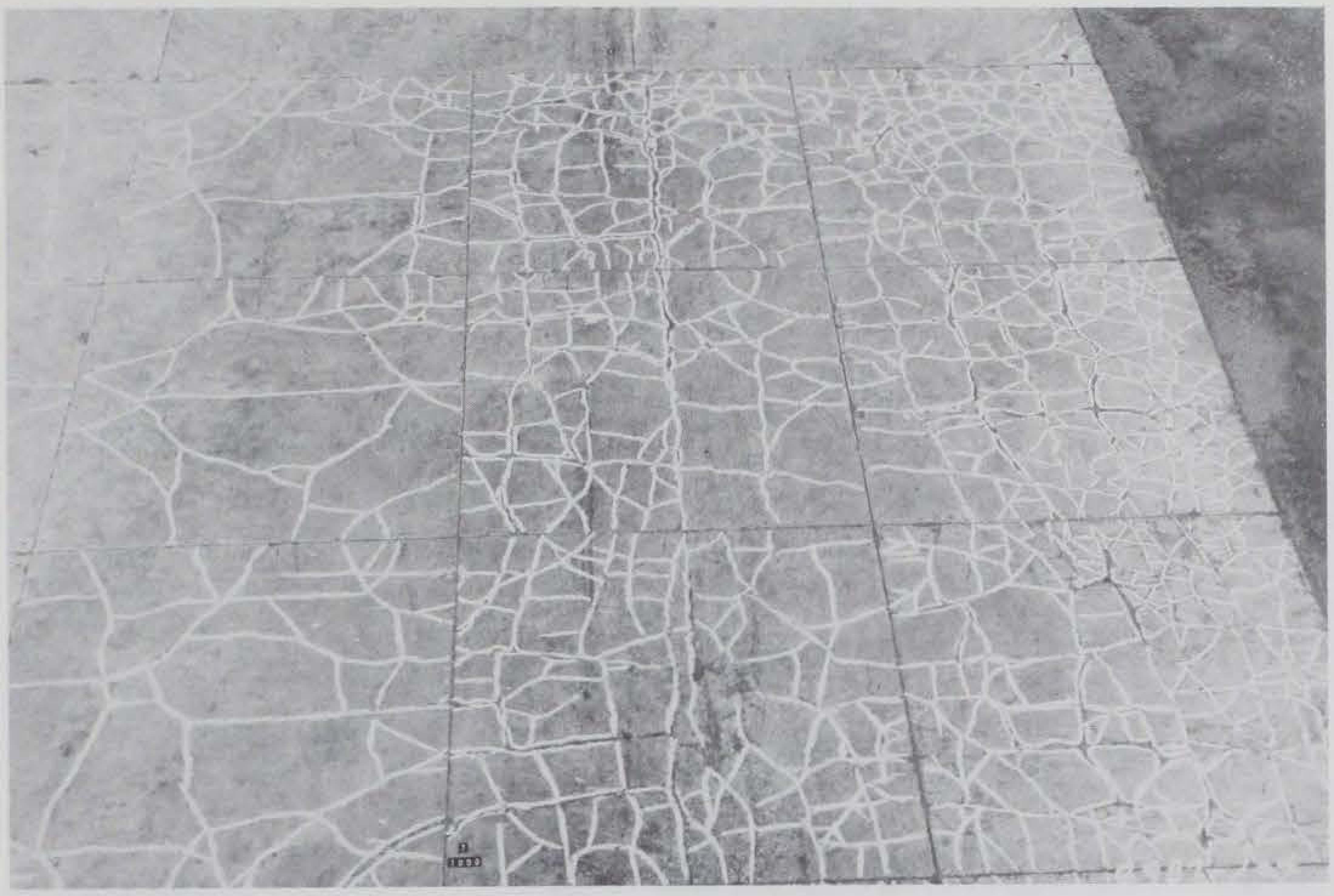

Photo 41. Item 7 after traffic tests were completed

Photo 42. Item 8 after traffic tests were completed

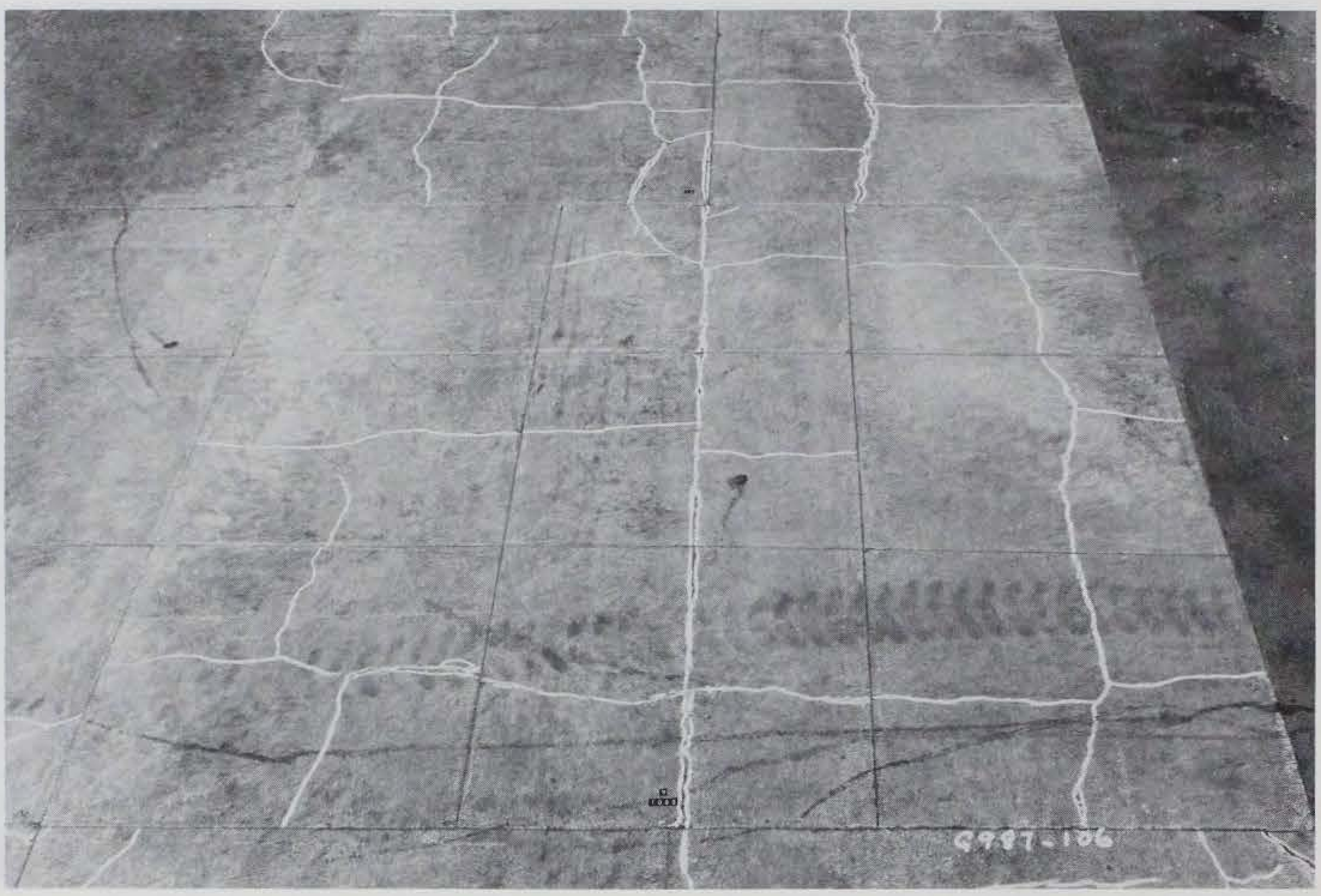

Photo 43. Item 9 after traffic tests were completed

Photo 44. Item 10 after traffic tests were completed

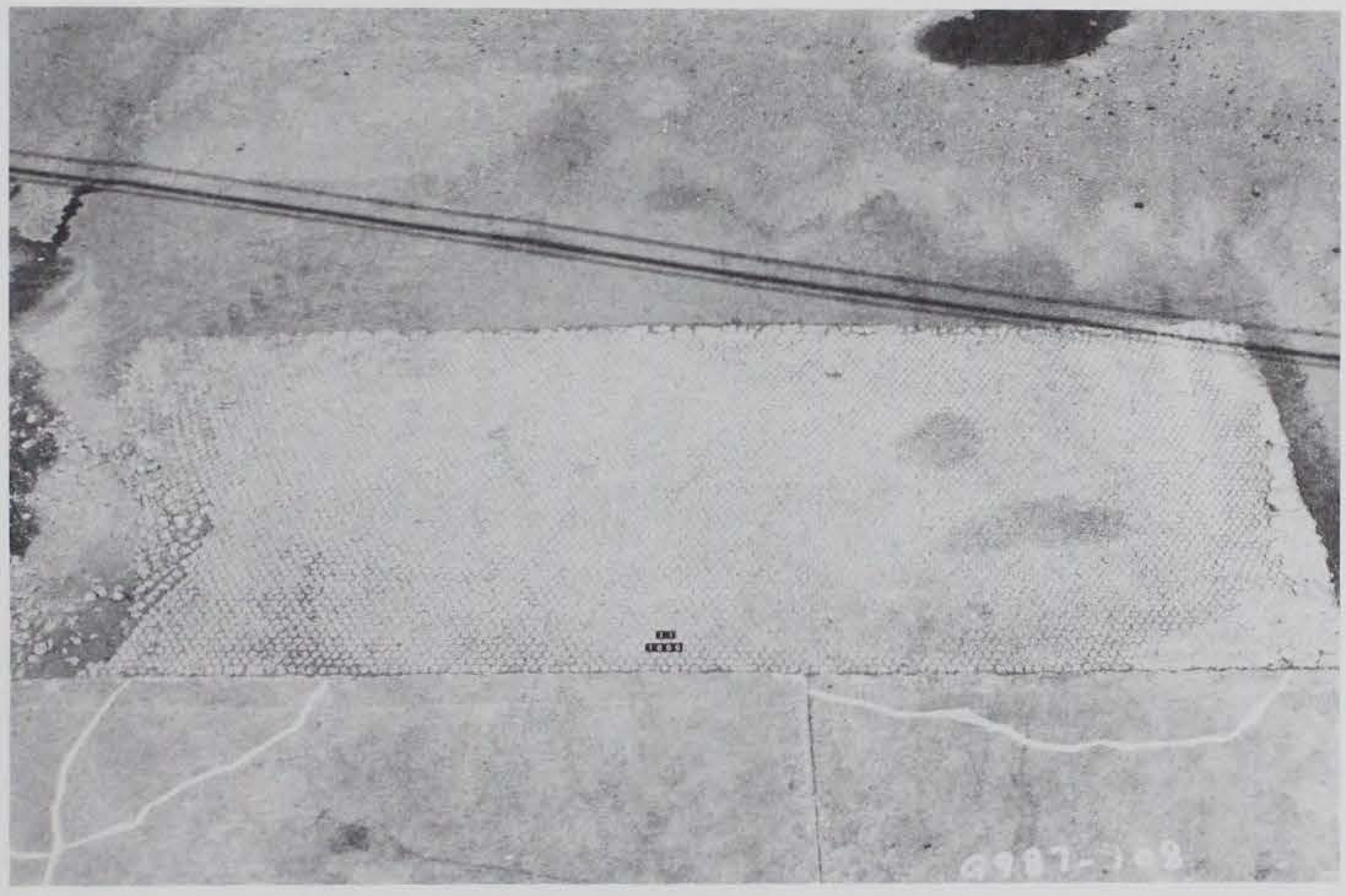

Photo 45. Item 11 after traffic tests were completed