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STRENGTHENING OF KEYED LONGITUDINAL CONSTRUCTION JOINTS IN RIGID PAVEMENTS

ARMY ENGINEER WATERWAYS EXPERIMENT STATION

PREPARED FOR

FEDERAL AVIATION ADMINISTRATION

AUGUST 1972

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STRENGTHENING OF KEYED LONGITUDINAL CONSTRUCTION JOINTS IN RIGID PAVEMENTS

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Soils and Pavements Laboratory
Vicksburg, Mississippi 39180

AUGUST 1972

FINAL REPORT

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15. Supplementary Notes

16. Abstract The rigid pavement test section was constructed of portland cement concrete (PCC) and trafficked with a 360-kip 12-wheel assembly and a 166-kip twin-tandem assembly to evaluate the performance of keyed and doweled longitudinal construction joints in rigid airfield pavement under multiple-wheel heavy gear loadings (MWHGL) and to investigate the feasibility of strengthening existing keyed longitudinal joints. The findings from this investigation are as follows: (1) The performance of keyed joints of rigid pavements on medium-strength (k = 200 - 400 pci) foundations was marginal; (2) it is feasible to strengthen the keyed joints in existing rigid pavements that are founded on low- to medium-strength (k < 400 pci) materials and are in good condition if the airfield is scheduled for MWHGL aircraft traffic; (3) keyed longitudinal construction joints in existing rigid pavements constructed on high-strength (k > 400 pci) or stabilized soil foundations will probably perform satisfactorily under MWHGL aircraft traffic; (4) a sand-filter course beneath a pavement structure will be effective in minimizing subgrade pumping; (5) a 6-in.-thick stabilized base course placed over a low-strength (k < 200 pci) subgrade is very effective in increasing the load-carrying capacity of a 10-in.-thick nonreinforced PCC pavement; and (6) doweled longitudinal construction joints in rigid pavements constructed on low-, medium-, and high-strength subgrades (k < 200 to > 400 pci) performed satisfactorily under MWHGL traffic.

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PREFACE

The investigation reported herein was jointly sponsored by the Federal Aviation Administration (FAA), Inter-Agency Agreement No. DOT FA71WAI-218 and the Air Force Weapons Laboratory (AFWL), Air Force Project Order No. F29601-71-X-0007, "Strengthening of Keyed Longitudinal Construction Joints in Rigid Pavements."

Responsibility for conducting the investigation was assigned to the Soils and Pavements Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES). The investigation reported herein was conducted from April 1971 to May 1972.

The investigation was conducted under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, Soils and Pavements Laboratory. Engineers of the Soils and Pavements Laboratory actively engaged with the planning, testing, analyzing, and reporting phases of this study were Messrs. R. L. Hutchinson, A. H. Joseph, C. D. Burns, W. N. Brabston, R. W. Grau, and R. H. Ledbetter. Engineering technicians responsible for the conduct of the tests were Messrs. J. E. Watkins, R. W. Patrick, and H. G. Brown. This report was written by Mr. Grau.

COL Ernest D. Peixotto, CE, was the Director of WES during the conduct of this study and preparation of this report. Mr. F. R. Brown was Technical Director.

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EVALUATION OF STRENGTHENING OF KEYED LONGITUDINAL CONSTRUCTION JOINTS IN RIGID PAVEMENTS

I INTRODUCTION

A. Background

The multiple-wheel gears of large, new aircraft (such as the C-5A and Boeing 747) impose loads on pavements that are radically different from those previously encountered. Results of recently completed MWHGL traffic on the rigid pavement test section at the WES indicated that pavement thickness requirements for the MWHGL traffic, as determined from extrapolations to current design procedures, were valid (reference 1). However, these same tests demonstrated that conventional keyed longitudinal construction joints were inadequate for pavements constructed on low-strength subgrade and that pumping of fine-grained subgrade materials through the pavement joints could become serious and result in failure of the pavement and pavement joints. Other unanswered questions included such things as:

(1) Would the conventional keyed longitudinal joint have performed adequately over subgrades with greater strengths;

(2) Would a doweled longitudinal joint have performed adequately under the MWHGL traffic on the low-strength subgrade;

(3) Would the normally required sand-filter course have prevented the severe subgrade pumping problem;

(4) Would a stabilized base course prevent the subgrade pumping and result in improved performance of rigid pavements including the keyed construction joint; and

(5) Can existing keyed joints be strengthened?

The inadequacy of the keyed joints in the rigid pavement in weak subgrades and the unanswered question regarding the adequacy of keyed joints in rigid pavements on medium- to high-strength subgrades* pose rather

* The descriptors of subgrade strength used in this report are related to the modulus of soil reaction k as follows:

	Modulus of Soil Reaction k, pci
Low strength	< 200
Medium strength	200-400
High strength	> 400

serious problems to airport operators faced with the future traffic of the new MWHGL aircraft inasmuch as many of the existing rigid airport pavements have been constructed using the keyed longitudinal construction joint. These pavements may be adequate from a thickness standpoint, but they may experience early failures of the keyed joint, which would then lead to structural failures of the paving slab. The study reported herein was conducted to obtain answers to the questions enumerated above.

B. Objectives

The objectives of this study were:

(1) Determine the adequacy of conventional longitudinal keyed joints in rigid pavements constructed over medium- and high-strength subgrades when subjected to MWHGL traffic;

(2) Determine the feasibility of strengthening keyed construction joints in existing rigid pavements that are to be subjected to MWHGL traffic;

(3) Determine the effectiveness of a sand-filter course in preventing subgrade pumping in rigid pavements under MWHGL traffic;

(4) Investigate the use of doweled longitudinal joints in rigid pavements that are to be subjected to MWHGL traffic;

(5) Determine the effectiveness of a stabilized base course to provide additional stiffness and protection to joints in rigid pavements when subjected to MWHGL traffic.

C. Scope

The objectives of this study were accomplished by removing the original rigid pavement from the four test items of the MWHGL test section at the U. S. Army Engineer Waterways Experiment Station (WES), constructing four new test items, conducting MWHGL traffic tests, collecting and analyzing data, and reporting results.

II DESIGN

A. General

The multiple-wheel gear configurations selected for the traffic testing of the test section were the C-5A and Boeing 747: the same as was used in the original MWHGL test (reference 1). The thicknesses of portland cement concrete (PCC) for each item were selected based on the results of the original MWHGL rigid pavement tests. First the PCC in item 2, which was to be placed over a low-strength subgrade, was designed to withstand from 500 to 1000 coverages of the C-5A test traffic and then the design thicknesses of the PCC for the remaining three test items were adjusted, depending on the strengths of their underlying layers, to withstand this same amount of traffic.

The entire area of the original MWHGL rigid pavement test section at the WES was utilized for this study. A layout of the new test items is shown in figure 1. The pavement thicknesses, foundation materials, and types of longitudinal construction joint were varied in the four test items. The pavement thicknesses of items 1 and 2 were 8 and 11 in., respectively; while items 3 and 4 were both 10-in. thick. The foundation of each item was designed to be as follows: item 1, a 24-in.-thick, medium-strength base course over a low-strength subgrade; item 2, a low-strength subgrade; item 3, a 4-in.-thick sand-filter course over a low-strength subgrade; and item 4, a 6-in.-thick, high-strength stabilized base course over a low-strength subgrade. Both keyed and doweled longitudinal joints were constructed in items 1 and 4; a keyed joint was used for the entire length of item 2; and a doweled joint was employed for the entire length of item 3. The three methods used to strengthen the keyed longitudinal joint of item 2 are shown in figure 1. The test items were separated by 25-ft-long by 50-ft-wide transition slabs: sections of original MWHGL rigid pavement test section that were heavily reinforced and would prevent the migration of cracks from one test item to another.

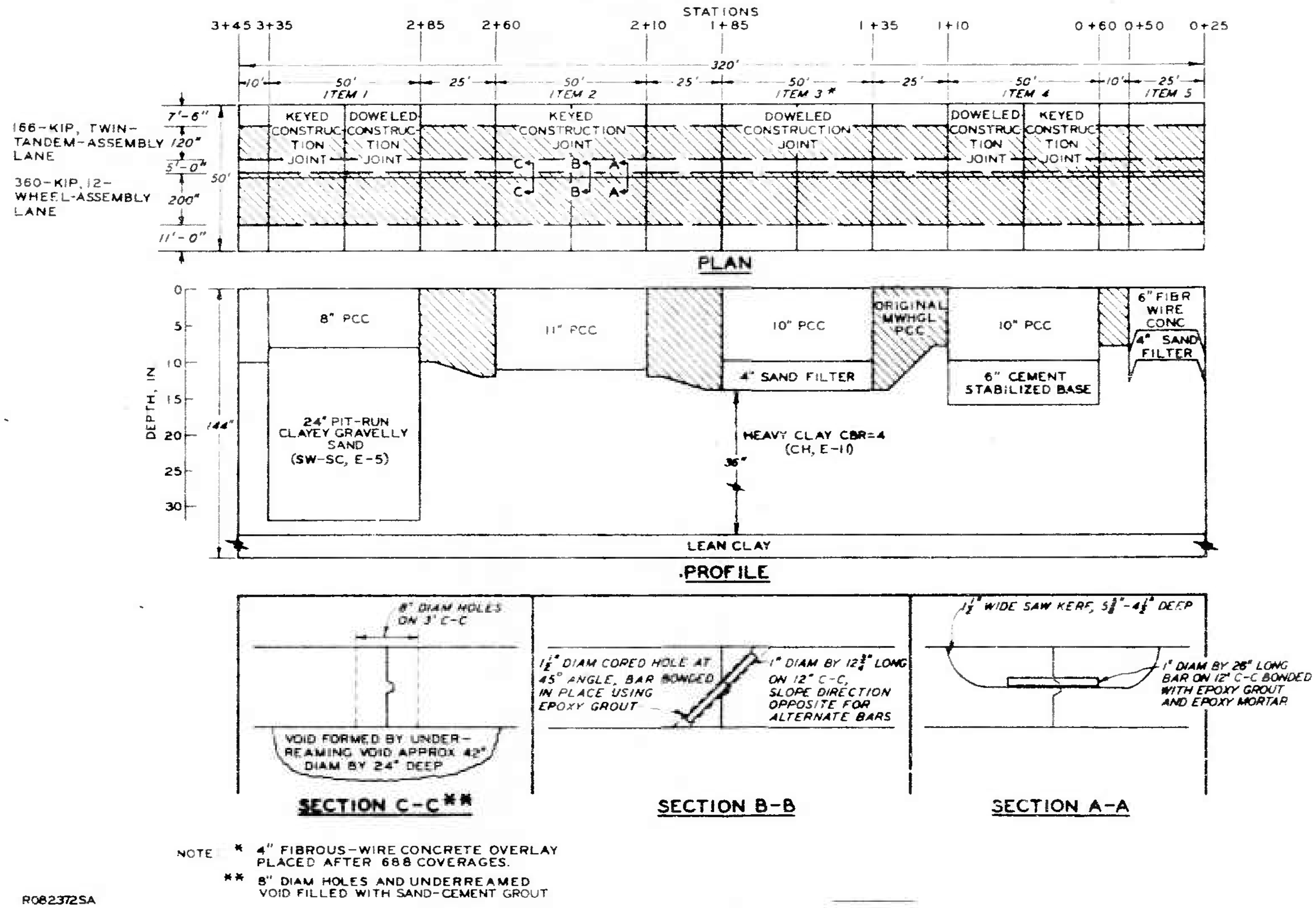

Figure 1. Plan and profile of test section showing three methods used to strengthen keyed longitudinal construction joints.

The existing PCC slabs in the locations of new test items and necessary subgrade material were removed from four 50- by 50-ft areas.* Items 1-4 were then built in their respective locations. The test section was laid out to tie in with the existing grades of the transition slabs: a transverse grade of 0.75 percent from north to south and a longitudinal grade of 0.50 percent from west to east.

B. Foundation

1. Heavy clay subgrade

The subgrade of the original MWHGL rigid pavement test section was used for this test section. It consisted of a heavy clay (CH, E-11)** that had a liquid limit (LL) of 73, plastic limit (PL) of 25, and a plasticity index (PI) of 48. Classification data for this soil are shown in figure 2. Laboratory compaction and CBR data for the as-molded and soaked conditions are shown in figures 3 and 4. These data, determined according to MIL-STD-621A (reference 4), indicate a CBR of about 4 to 5 at molding water contents of from 30 to 32 percent for both the as-molded and soaked conditions.

2. Base courses

A medium-strength 24-in.-thick clayey gravelly sand base course was constructed over the heavy clay subgrade in item 1. The relationship shown by figure 5 was used to arrive at the thickness of granular base needed to produce the k of 300 pci. The relations expressed by figure 5 have been established by plate bearing tests performed on various thicknesses of base courses on a range of subgrade strengths. It is used to establish the thickness of material necessary

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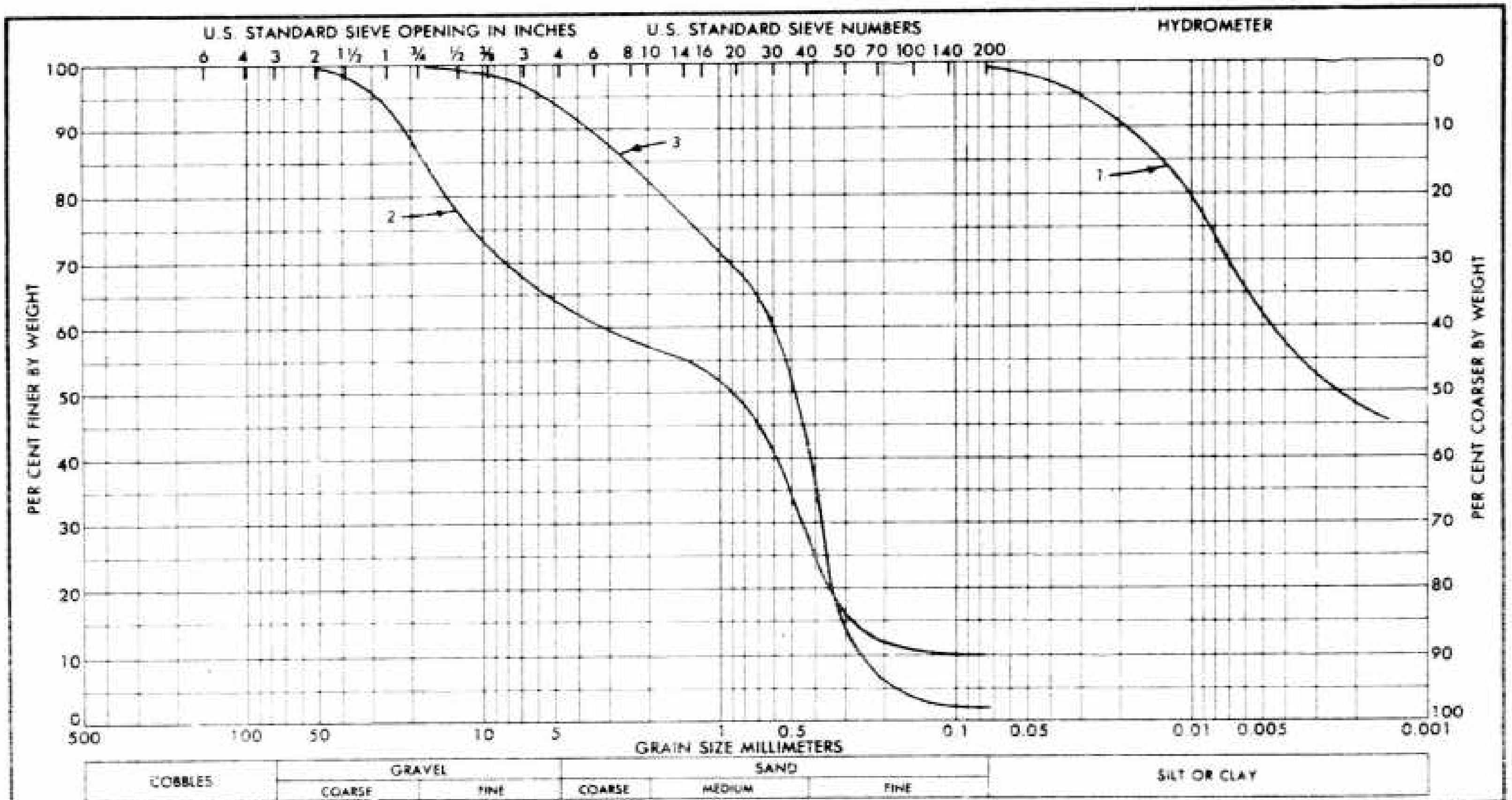
* In conjunction with this investigation, item 5, which was paved with a fibrous-wire concrete, was constructed. Later, item 3 was overlaid with a 4-in.-thick, fibrous-wire concrete. The performance and evaluation of the fibrous-wire concrete will be reported by Construction Engineering Research Laboratory.

** All soils were classified according to both the Unified Soil Classification System (reference 2) and the Federal Aviation Agency (FAA) Soil Classification System (reference 3). In this report, double entries, e.g., (CH, E-11), represent the Unified and the FAA Classifications, respectively.



SAMPLE NO	MATERIAL	CLASSIFICATION	NAT W%	LL	PL	PI
1	SUBGRADE	HEAVY CLAY (CH, E-11)		73	25	48
2	BASE	CLAYEY GRAVELLY SAND (SW-SC, E-5)		25	11	14
3	SAND FILTER	SAND (SP, E-2)		NONPLASTIC		
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Figure 2. Classification data for subgrade, base, and sand-filter course materials.

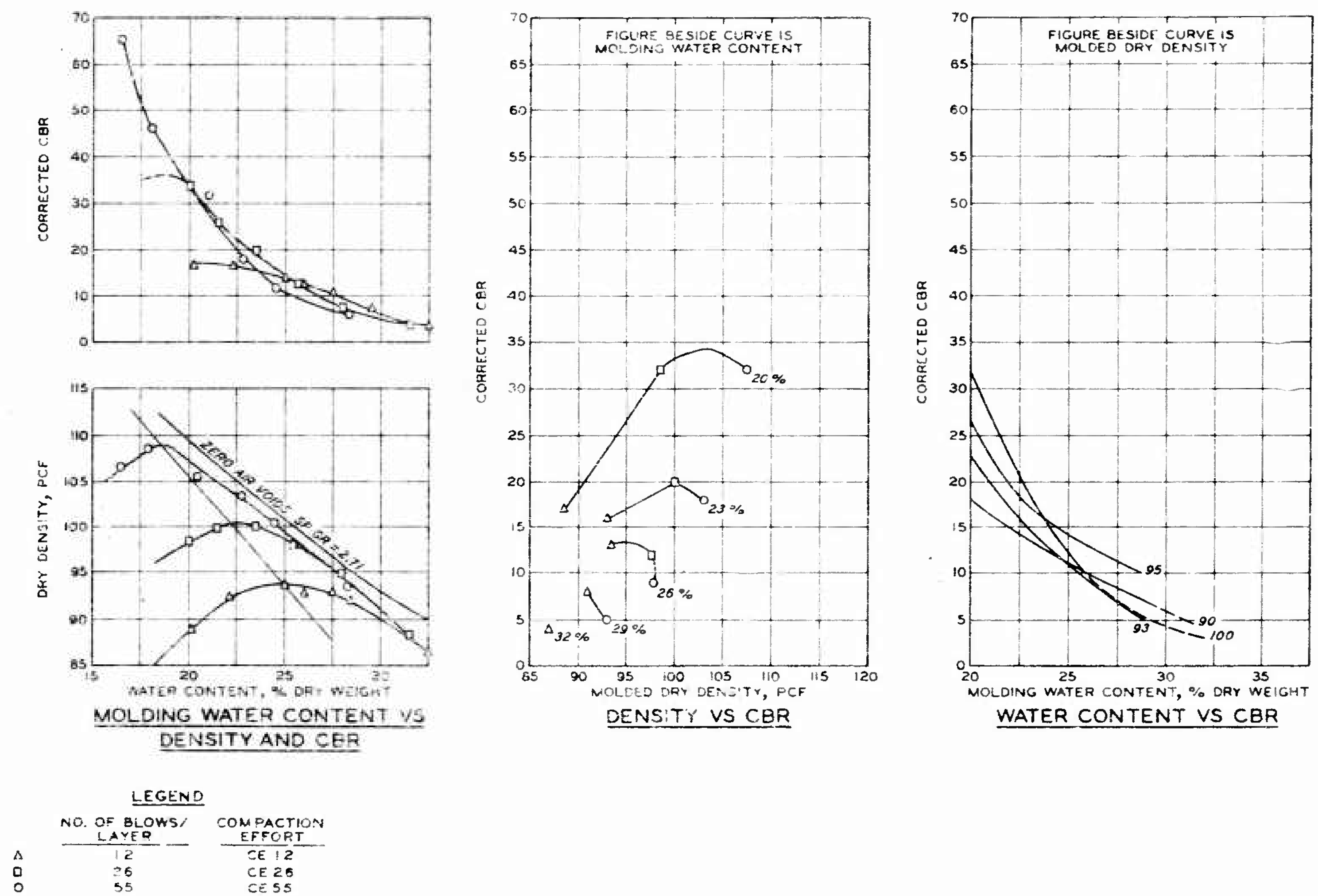

Figure 3. CBR, density, and water-content data for heavy clay subgrade material tested as molded.

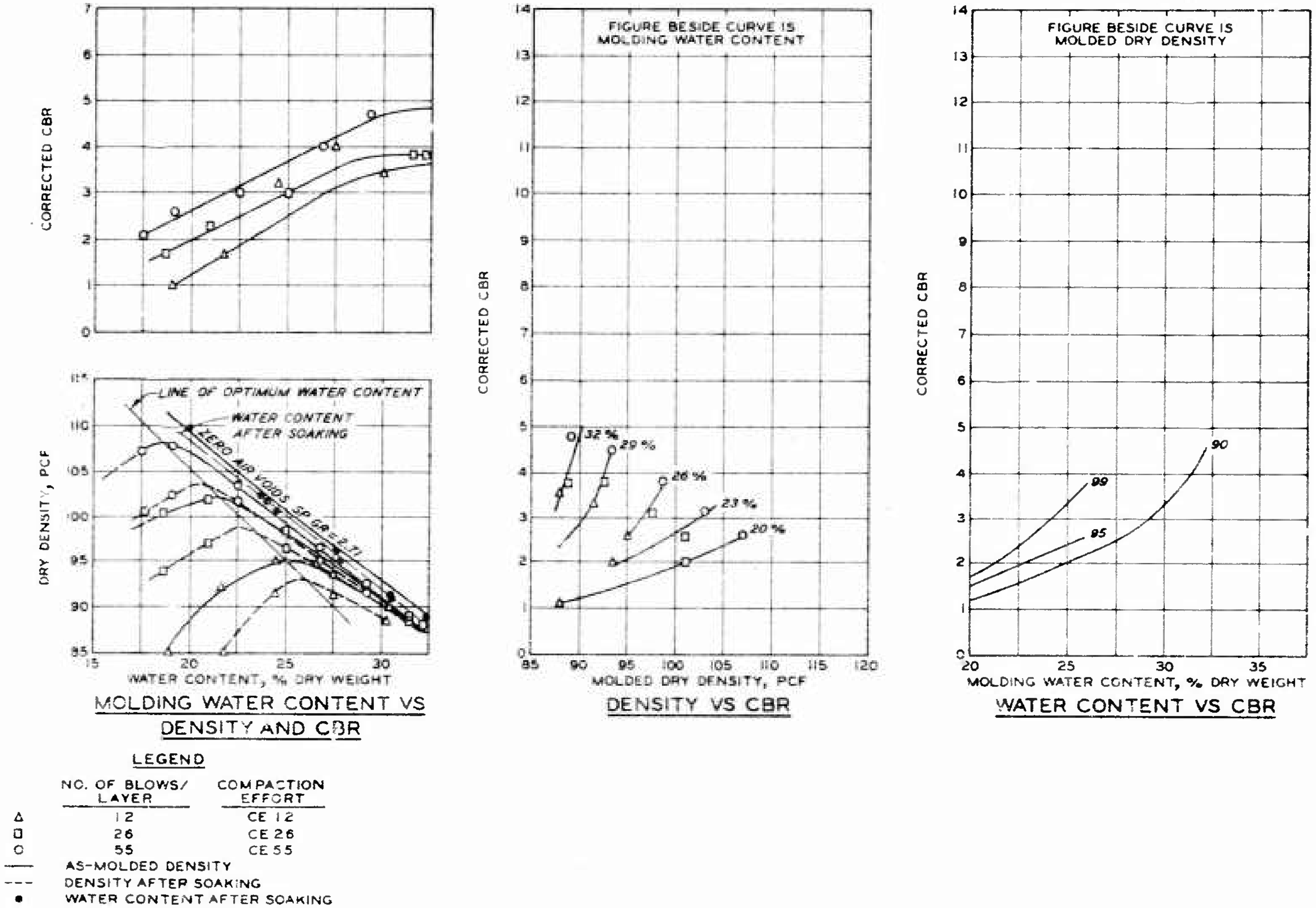

Figure 4. CBR, density, and water-content data for heavy clay subgrade material tested after soaking.

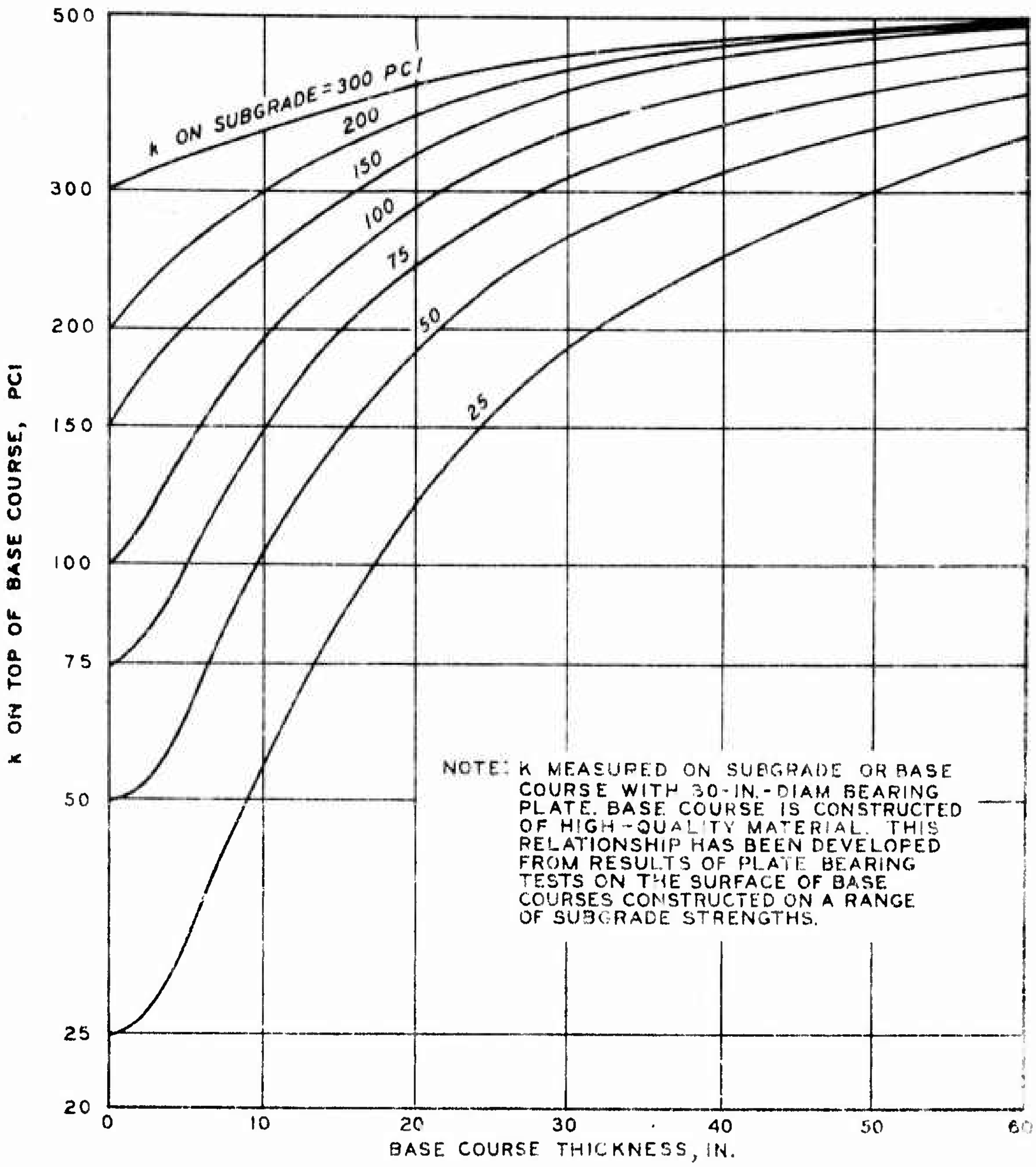

Figure 5. Soil strength k versus base course thickness.

to increase the k-value to the desired amount; however, the k-value on the surface of the base course for either design or evaluation is determined by plate bearing test after the base course has been constructed. This material was classified as an SW-SC (E-5) with a LL of 25 and PI of 14 (figure 2). Laboratory compaction data for this soil determined according to reference 4, and Item T-611 of AC/5370-1A, Standard Specifications for Construction of Airports, reference 5 are shown in figure 6. These data show that the maximum density for the CE 55 (T-611)* compaction effort was obtained at 6.6 percent water content. Only the CE 55 (T-611) compaction effort was used because compaction requirements for an SW-SC (E-5) soil when used as a base material in airfield construction would normally be related to the maximum density-optimum moisture determined by the CE 55 (T-611) compaction effort.

The stabilized base material in item 4 was the same SW-SC (E-5) soil used for the base course of item 1. A cement content of 6 percent was selected to stabilize the clayey gravelly sand. This cement content was determined by the procedure for cement requirement for expedient base course construction described in reference 6.

3. Sand-filter course

A 4-in.-thick sand-filter course meeting the requirements stated in reference 7 (TM 5-824-3) was placed over the heavy clay subgrade of item 3. The gradation of this material, which was classified as an SP (E-2), is shown in figure 2.

C. Pavement

The mix design for the PCC was the same as that used for the original MWHGL rigid pavement test section. The aggregate consisted of a mixture of natural sand and 1-in. maximum-size chert gravel, which was obtained locally. Type I normal portland cement conforming to Federal Specifications SS-C-192b was used in the mix at a cement factor of 6.5 bags (611 lb) per cu yd. The mix was designed to yield a 28-day flexural strength of about 650 psi. Thicknesses were selected using the

* CE 55 compaction effort is the equivalent of the compaction effort identified as T-611 by the FAA.

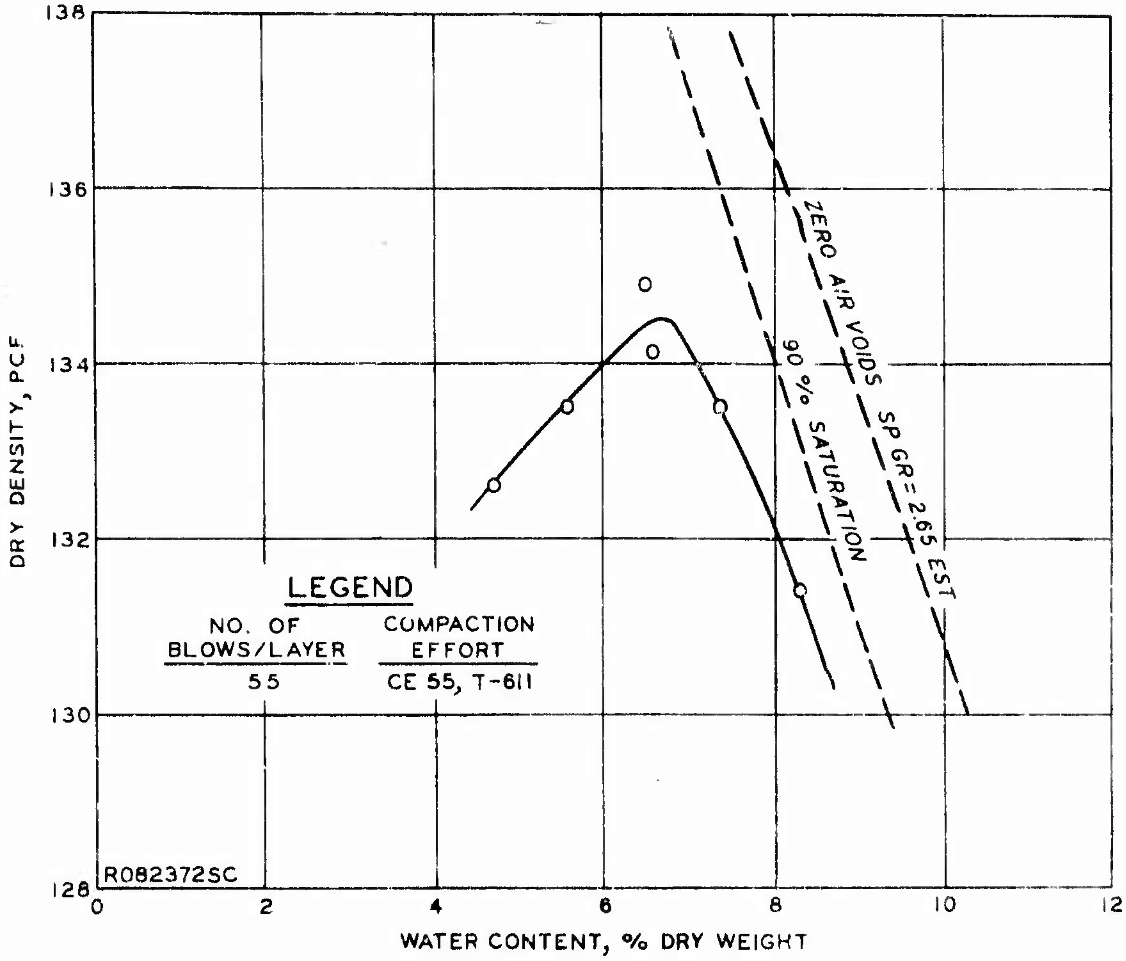

Figure 6. Water-content and density data for clayey gravelly sand base course material tested as molded.

Westergaard solution for stress due to edge loading and assuming that 25 percent of the edge loading would be transferred to the adjoining slab through the load-transfer mechanism in the joint. The PCC in items 1 and 2 was 8- and 11-in. thick, respectively; items 3 and 4 were constructed to a PCC thickness of 10 in.

Two 25-ft-wide paving lanes separated by a longitudinal construction joint were used. Each test item contained four 25-ft-square nonreinforced concrete slabs of uniform thickness, two in the north lane and two in the south lane. The test items were separated by 25-ft-long reinforced concrete transition slabs. For reasons of economy, the transition slabs constructed for the MWHGL were left in place. Each transition slab was reinforced with 0.5 percent steel placed just above the neutral axis of the slab to prevent cracking from migrating from one test item to another. The 10-ft-long reinforced concrete ramp slabs constructed for the MWHGL tests were also left in place at the west end of the test track and between item 4 and the fibrous-wire concrete item, item 5. Ordinarily these reinforced transition and ramp slabs would have been constructed at the same time as the test sections and the joint between would be a weakened-plane transverse joint with aggregate interlock providing load transfer across the joint. As stated above, for reasons of economy, the new test slabs were cast against the fractured face of the in place concrete, thus depending upon the resulting interlock between the existing concrete and new concrete to provide the required load transfer to guard against a free edge condition. As will be pointed out later, adequate load transfer was not obtained by this procedure and premature cracking occurred at the ends of some test items because of excessive edge stresses.

Sawed weakened-plane transverse contraction joints were used on 25-ft spacings within the test sections. The 25-ft spacing exceeds that recommended for 8- and 10-in. pavements in references 3 and 7 (AC 150/5320-6A and TM 5-824-3/AFM 88-6, Chapter 3). The greater slab size was desirable because of the dimensions of the multiple-wheel gear. Special curing procedures were used which minimized the possibility of cracking in the large slabs early during the curing period. The curing procedure consisted of overlaying the slabs with saturated burlap for a period of seven days after pouring and then removing the burlap and covering the slab with polyethylene for an additional twenty-one days. In general, this procedure prevented excessive uncontrolled contraction-type cracking; however, a few cracks of this type did occur before traffic was applied. All joints were sealed with a hot-poured joint-sealer material.

III CONSTRUCTION

A. General

Excavation, construction of the foundation materials, and final paving phases of the test section occurred during the period April-May 1971. The longitudinal construction joint in item 2 was strengthened by the three methods shown in figure 1 during May-August 1971. All work was accomplished by WES personnel, except the mixing and delivering of the concrete. The Vicksburg Concrete Co., Inc., Vicksburg, Miss., mixed and delivered the concrete under contract.

B. Foundations

1. Removal of old concrete

The PCC in items 1-4 of the original MWHGL rigid pavement test section was removed by breaking the pavement into small pieces by use of a dragline and a 2000-lb headache ball and wasting it in a disposal area.

2. Subgrade

The existing heavy clay subgrade at the test site was originally constructed for the MWHGL Rigid Pavement test section. After removal of the concrete, the heavy clay was brought to grade, either by excavation or fill depending on the item involved. The soil strength was checked prior to fine blading. If needed, the upper 6 in. of soil was reprocessed to produce a strength of about a 4 CBR and then fine bladed. CBR, water-content, dry density, and modulus of soil reaction tests were performed on the surface of the subgrade in each test item. The results of these tests are summarized in table 1. Figure 7 shows a view typical of the surface of the subgrade; figure 8 shows the test setup for a plate bearing test.

3. Base courses

The 24-in.-thick clayey gravelly sand base of item 1 was placed in four equal lifts. Prior to hauling this material to the test site, it was processed to approximately the water content that would result in the desired strength after compaction. Sufficient material to produce a 6-in.-thick compacted lift was placed in the item, and each lift

TABLE 1.--SUMMARY OF CBR, WATER CONTENT, DRY DENSITY, AND MODULUS OF SOIL REACTION

Item	Material	Station	Elevation ft	CBR	Water Content %	Dry Density pcf (A)	CE 55 (T-611) Density pcf (B)	Percent CE 55 (T-611) Density (A/B)	Modulus of Soil Reaction, k, pci	Degree of Saturation %	Date Tested
						As Constructed					
1	Base (SW-SC, E-5)	3+05	192.54	21	5.1	137.9	133	103	--	68	14 April 1971
	Subgrade (CH, E-11)		190.54	4.1	31.4	85.4	89	96	175	86	8 April 1971
2	Subgrade (CH, E-11)	2+30	191.94	4.5	28.2	91.7	94	98	111	91	4 May 1971
3	Sand-Filter Course (SP, E-2)	1+55	191.65	--	--	--	--	--	81	--	3 May 1971
	Subgrade (CH, E-11)		191.32	3.2	33.4	84.0	85	99	---	89	28 April 1971
4	Cement-Stabilized Base	0+75	191.30	--	--	--	--	--	344	--	21 April 1971
	Subgrade (CH, E-11)		190.80	3.3	30.5	86.5	91	95	47	86	16 April 1971
						After Traffic					
1	Base (SW-SC, E-5)	2+84	192.51	22	6.7	137.4	134	103	138	86	15 October 1971
	(SW-SC, E-5)		191.51	11	6.4	135.6	134	101	--	76	15 October 1971
	Subgrade (CH, E-11)		190.51	6	33.1	85.4	86	99	--	91	15 October 1971
2	Subgrade (CH, E-11)	2+37	191.91	--	35.6	80.9	86	94	81	89	20 March 1972
3	Sand Filter (SP, E-2)	1+63	191.63	--	--	--	--	--	129	--	15 March 1972
	Subgrade (CH, E-11)		191.30	--	32.1	85.4	88	97	--	88	20 March 1972
4	Cement-Stabilized Base	0+87	191.29	--	6.1	138.3	131	106	395	96	14 March 1972
	Subgrade (CH, E-11)		190.79	3.5	33.7	85.5	86	99	--	93	20 March 1972

Figure 7. Surface of finished subgrade in item 2.

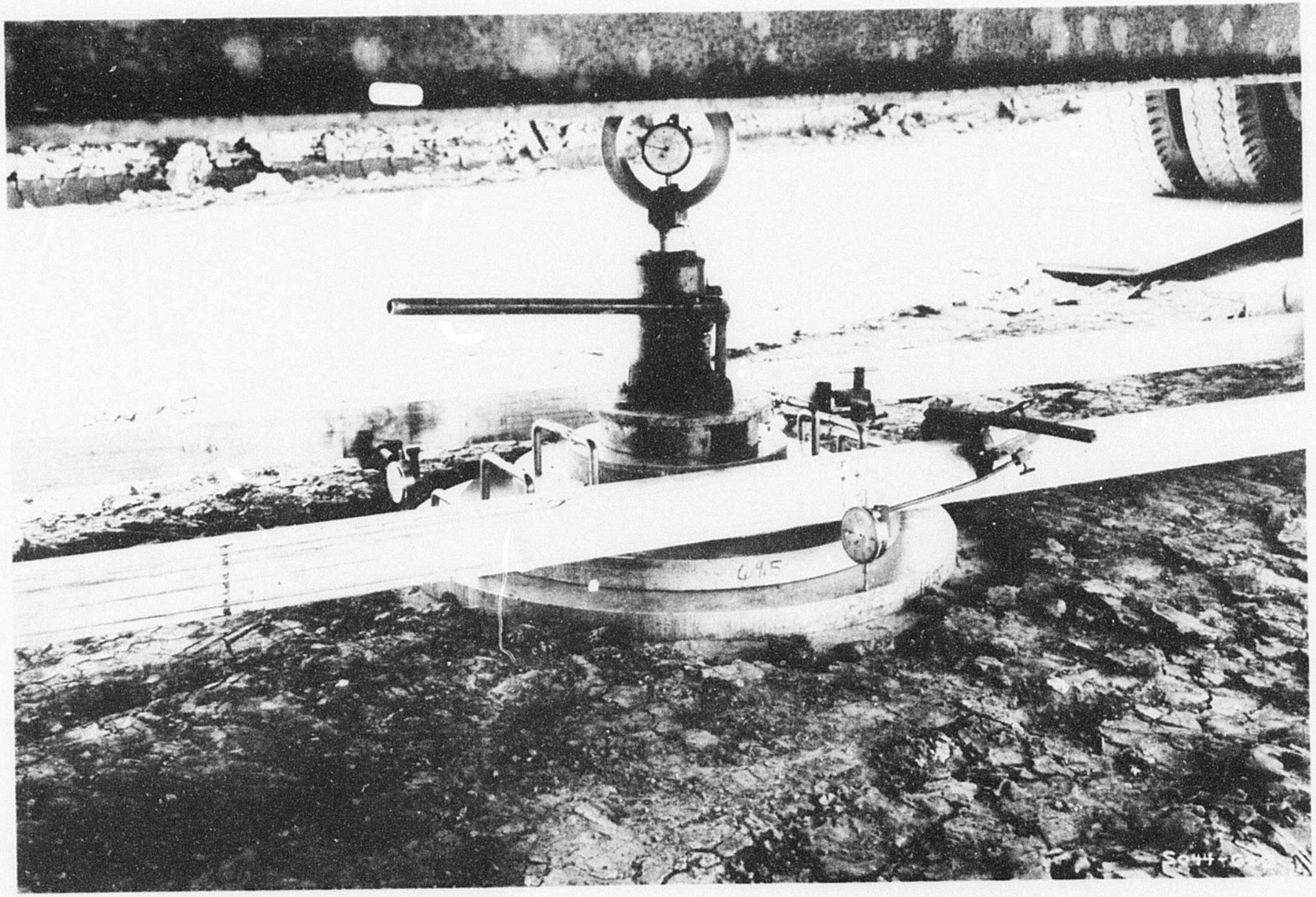

Figure 8. Test setup for plate bearing test.

was compacted with 8 coverages of a self-propelled, 7-wheel, rubber-tired roller weighing approximately 40,000 lb with a tire pressure of 90 psi. The final lift was given additional compaction of 8 coverages with a 50-ton, four-wheel, rubber-tired, towed roller with tire inflation pressure of 90 psi. After compaction of the final lift, the section was fine bladed with a motor grader. Figure 9 shows a general view of the base course of item 1 prior to paving. A summary of the CBR, water content, dry density, and k determinations performed on the surface of the base course is shown in table 1.

The 6-in.-thick cement-stabilized clayey gravelly sand base course of item 4 was placed in one lift. Prior to applying the cement, the soil was processed to approximately the desired water content (7.5 percent) and then placed on the subgrade in an 8-in.-thick loose lift. After placement of the loose material, bags of cement were placed at predetermined intervals to give a uniform 6 percent cement by weight for the 8-in. loose lift. The cement was spread by hand over the surface of the loose material and then thoroughly mixed to a depth of about 8 in. with a pulvimixer (figure 10). During the mixing procedure, a light sprinkling of water was added to maintain the desired water content. The stabilized material was then compacted with 8 coverages of a 30,000-lb, self-propelled, rubber-tired roller. After compaction, the surface was fine bladed to finish grade. A k-value of 344 pci was measured on the surface of the stabilized base 24 hours after construction. A view of the surface of the finished cement-stabilized base is shown in figure 11.

4. Sand-filter course

A 4-in. sand-filter course (SP, E-2) was placed on the finished subgrade in item 3. The sand was initially spread with a D-4 dozer and finished to final grade by hand. The surface of the sand-filter course is shown in figure 12. After construction, a k-value of 81 pci was measured on the surface of the sand-filter course.

5. Instrumentation

During construction, strain (deflection) sensors and stress cells were installed in items 2 and 3. Description of the installation and test results will be reported later.

Figure 9. View of completed clayey gravelly sand base in item 1.

Figure 10. Mixing soil and cement for stabilized base in item 4.

Figure 11. Cement-stabilized base in item 4 after compaction.

Figure 12. Finished sand-filter course in item 3.

C. Pavement

1. Concrete placement

The concrete in each item was first placed in the north paving lane. The placement dates for the north and south lanes are tabulated in table 2. The concrete was dry batched at the plant of the Vicksburg Concrete Co., Inc. It was transit-mixed and delivered to the construction site, a distance of about 2-1/2 miles, in ready-mix trucks. During the paving operation, the concrete was spread by use of shovels and then vibrated with a stinger-type hand vibrator. The surface of the concrete was screeded off with a straightedge and was finished by hand with bull floats and burlap drags. Figure 13 shows a typical placement-and-spreading operation of the concrete. Slump tests were performed on samples from the material delivered by each ready-mix truck. Beam and cylinder specimens were taken from concrete placed in each slab. These specimens were subjected to unconfined compression tests, third-point loading tests, and indirect tension tests to develop the compressive, flexural, and tensile strength of the concrete. Results of these tests, which were performed by the WES Concrete Laboratory, are summarized in table 2.

2. Joints and joint sealing

(a) General

Keyed construction joints were used between the north and south paving lanes in the west 25 ft of item 1, the entire length of item 2, and the east 25 ft of item 4. Doweled longitudinal construction joints were installed between the north and south paving lanes in the east 25 ft of item 1, the entire length of item 3, and the west 25 ft of item 4. The keyway and dowel bar dimensions, locations, and spacing met the requirements contained in reference 7. These dimensions are only slightly different than those specified by reference 3. Figure 14 shows a view of the doweled and keyed longitudinal joint of item 1.

The weakened-plane transverse joints were provided on 25-ft spacing in both paving lanes. These joints were constructed as required by the specifications stated in references 3 and 7. A gasoline-

TABLE 2.--PHYSICAL PROPERTIES OF IN-PLACED CONCRETE[a]

Item	Sample Location	Slump in.	Entrained Air %	Compressive Strength, psi		Flexural Strength, psi		28-day Tensile Strength[b] psi	Dynamic Properties 28-day			Placement Date
				7-day	28-day	7-day	28-day		E x 10^6 psi	G x 10^6 psi	ν	
1	N 1/2	6	-	5390	6710	690	930	580	-	-	-	19 April 1971
	N 1/2	6	2.0	5360	6870	695	895	645	-	-	-	19 April 1971
	N 1/2	6	-	5380	6790	740	910	610	-	-	-	19 April 1971
	S 1/2	2 1/2	2.3	5790	6490	775	850	520	7.84	3.27	0.20	26 April 1971
	S 1/2	4	1.6	5480	6960	775	805	490	7.35	3.10	0.19	26 April 1971
2	N 1/2	4	5.4	4360	5430	560	600	530	6.05	2.59	0.17	17 May 1971
	N 1/2	5 1/2	5.8	3750	4640	540	650	480	5.41	2.41	0.12	17 May 1971
	S 1/2	3 3/4	5.7	3950	4810	490	620	430	6.23	2.63	0.18	18 May 1971
	S 1/2	3 1/2	5.0	3700	4780	455	605	420	6.41	2.63	0.22	18 May 1971
3	N 1/2	4	3.6	5130	6070	560	720	535	7.52	3.19	0.18	6 May 1971
	N 1/2	3 1/2	2.6	5000	6120	650	690	490	7.48	3.17	0.18	6 May 1971
	S 1/2	3	3.3	4880	6280	610	740	560	7.00	2.69	0.30	14 May 1971
	S 1/2	6	7.0	3770	4810	565	625	450	6.00	2.49	0.20	14 May 1971
4	N 1/2	2 1/2	1.4	5520	6450	695	780	490	7.40	3.11	0.19	3 May 1971
	N 1/2	4 1/2	2.6	5710	6490	630	750	570	7.21	3.13	0.15	3 May 1971
	S 1/2	4 1/2	3.4	5250	6480	640	710	550	6.72	3.01	0.12	4 May 1971
	S 1/2	6 1/2	2.8	5210	6240	620	680	600	6.48	2.90	0.12	4 May 1971

[a] Cement factor = 6.5 bags/cu yd

[b] Determined from indirect tension tests on cylinders

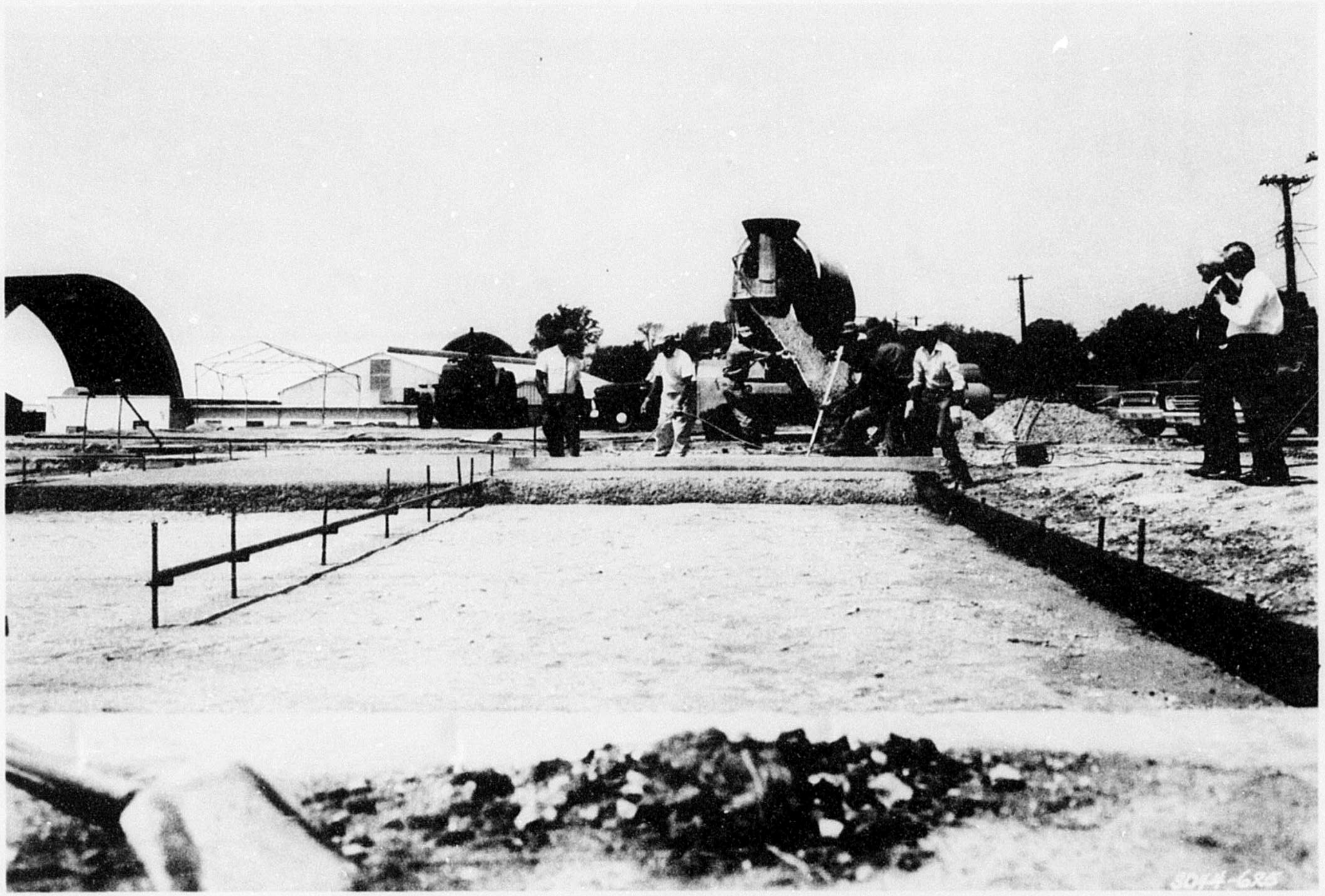

Figure 13. Concrete placement in north lane.

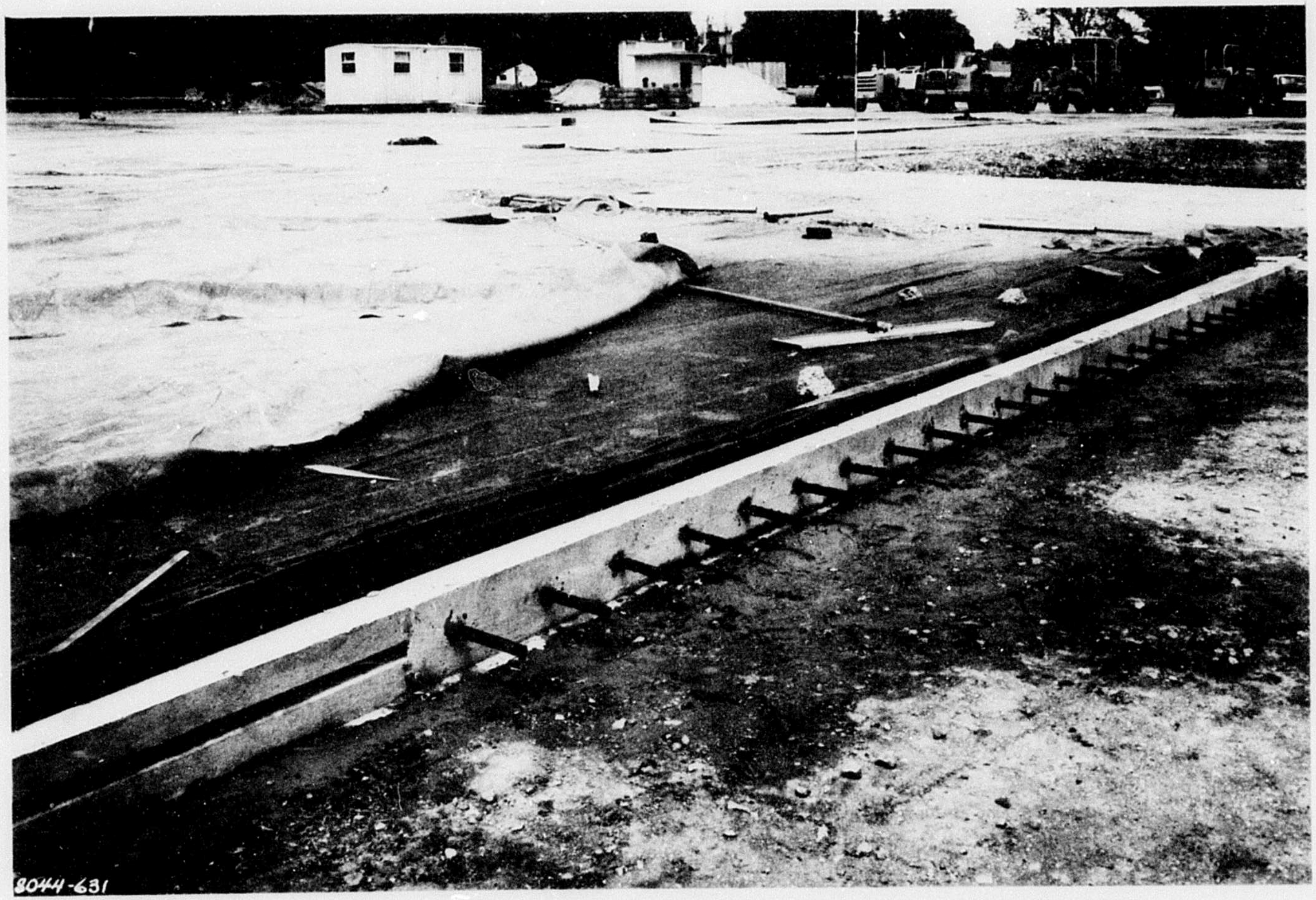

Figure 14. View of keyed and doweled longitudinal construction joint in item 1.

operated concrete saw was used to cut these joints to the required dimensions. The sawed grooves were thoroughly cleaned with compressed air and sealed with a hot-poured joint-sealing compound meeting Federal Specification SS-S-164.

(b) Strengthening of the keyed longitudinal construction joint in item 2

A plan of each of the three methods used to strengthen the longitudinal joint in item 2 and the locations where each method was used are shown in figure 1. A concrete saw, figure 15, was used to cut the 1-1/2-in.-wide kerfs, which were spaced 12 in. c-c. The depth of these kerfs ranged between 4-1/2 to 5-5/8 in., and the lengths were approximately 28 in. at the surface of the pavement and 12 to 13 in. at the bottom of the kerfs. Figure 16 depicts the kerfs after sawing. Any loose material was removed from the kerfs. Dowel bars, 1 in. in diam by 12 in. long, were bonded to the slab in the bottom of the kerf with epoxy mortar. One end of the dowel was greased to prevent bonding. After the epoxy grout had cured, the remainder of the void was filled with an epoxy mortar (figure 17).

A small truck-mounted drill rig was used to core 1-1/2-in.-diam holes at a 45° angle on 12-in. centers (figure 18). These holes were located through the center of the keyed construction joint and were sloped in opposite directions for alternate holes. A 1-in.-diam by 12-3/4-in.-long dowel bar was grouted into each of these holes with an epoxy grout.

The third strengthening method of keyed longitudinal joints consisted of coring 8-in.-diam holes through the pavement at the longitudinal joint on 3-ft centers, underreaming a void approximately 42 in. in diam by 24 in. deep in the subgrade through the 8-in. holes, and then filling the 8-in.-diam holes and underreamed void with sand-cement grout. A specially designed underreaming attachment connected to the drill stem was used to underream the void in the subgrade. Figures 19-21 show the underreaming procedure. After completion of the underreaming, the sand-cement grout was pumped into the void as shown in figure 22. The

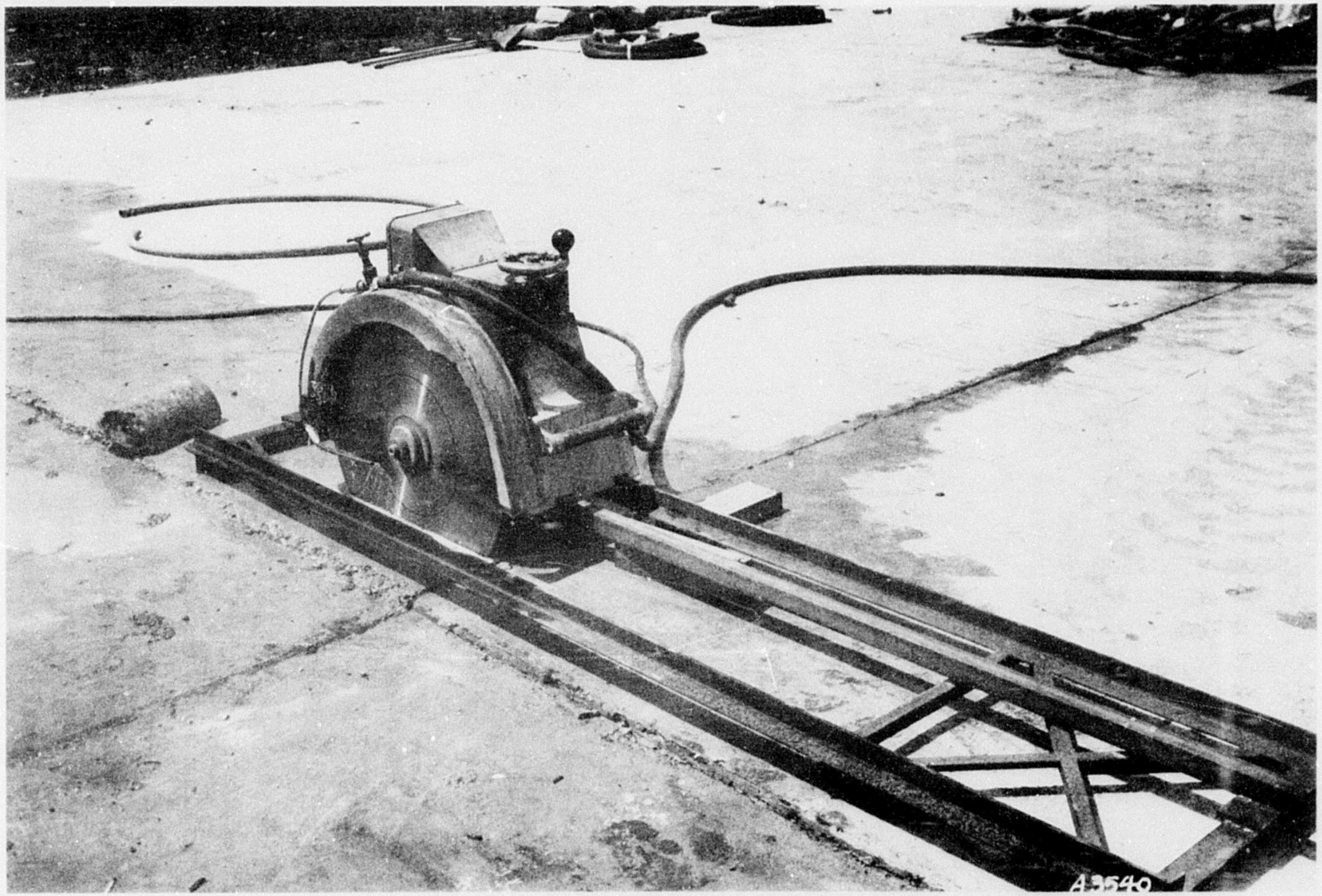

Figure 15. Sawing kerfs across longitudinal construction joint in item 2.

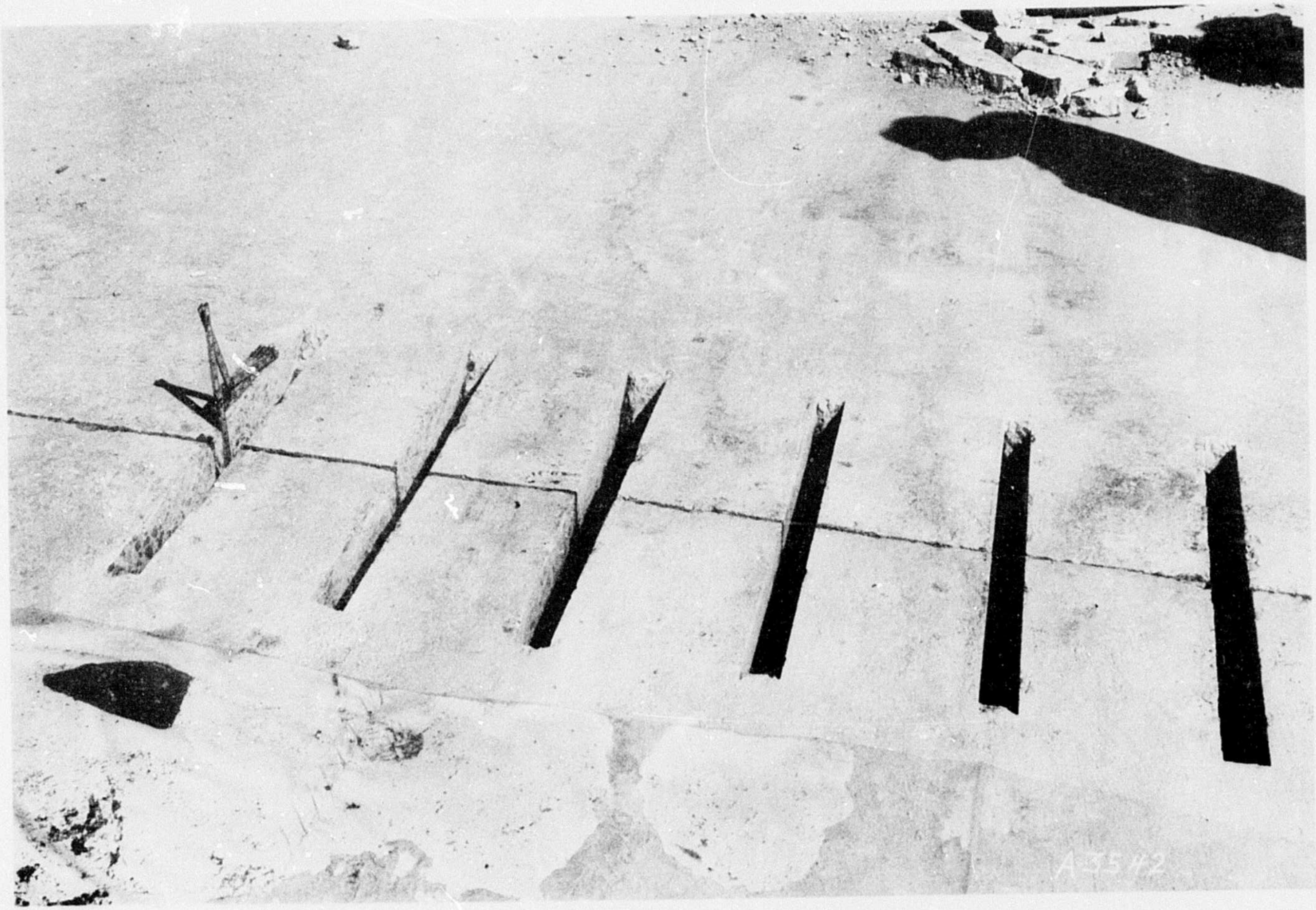

Figure 16. 1-1/2-in.-wide sawed kerfs in item 2.

Figure 17. Filling sawed kerfs with epoxy mortar after tie bar has been bonded in bottom of kerf with epoxy grout.

Figure 18. Coring 1-1/2-in.-diam hole at a 45° angle through the longitudinal joint in item 2.

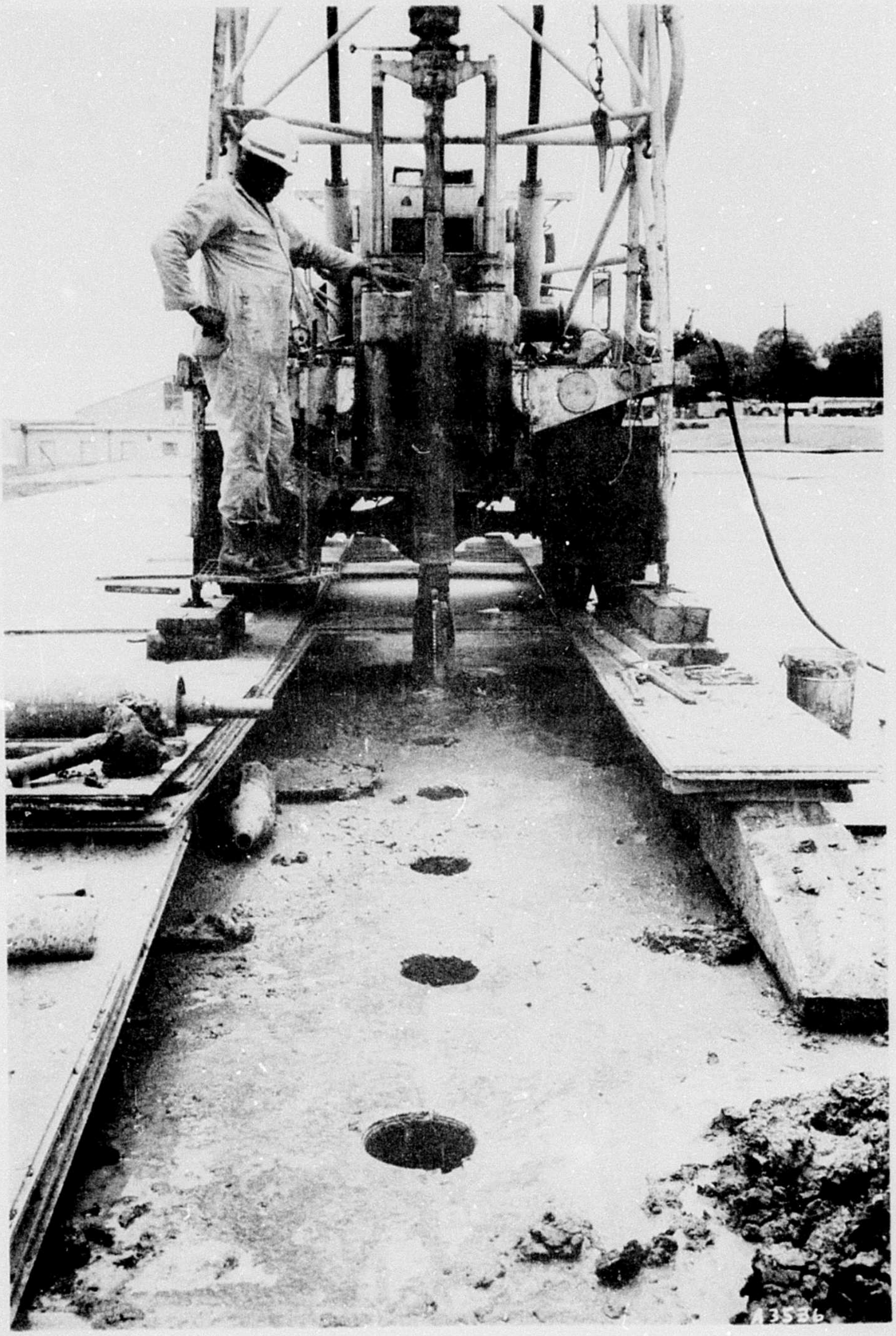

Figure 19. Underreaming device being lowered into position above 8-in.-diam hole.

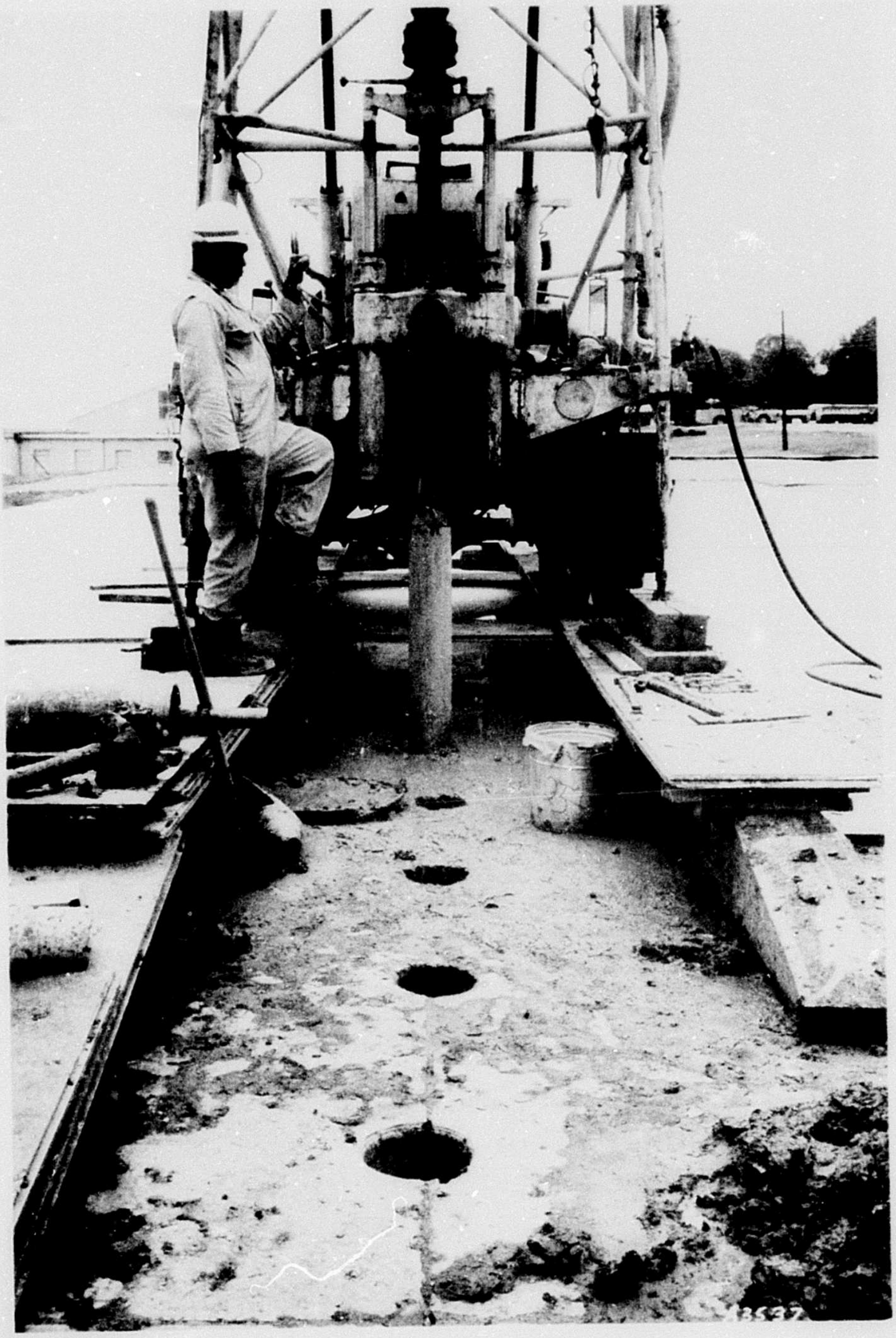

Figure 20. Underreaming device being lowered into hole.

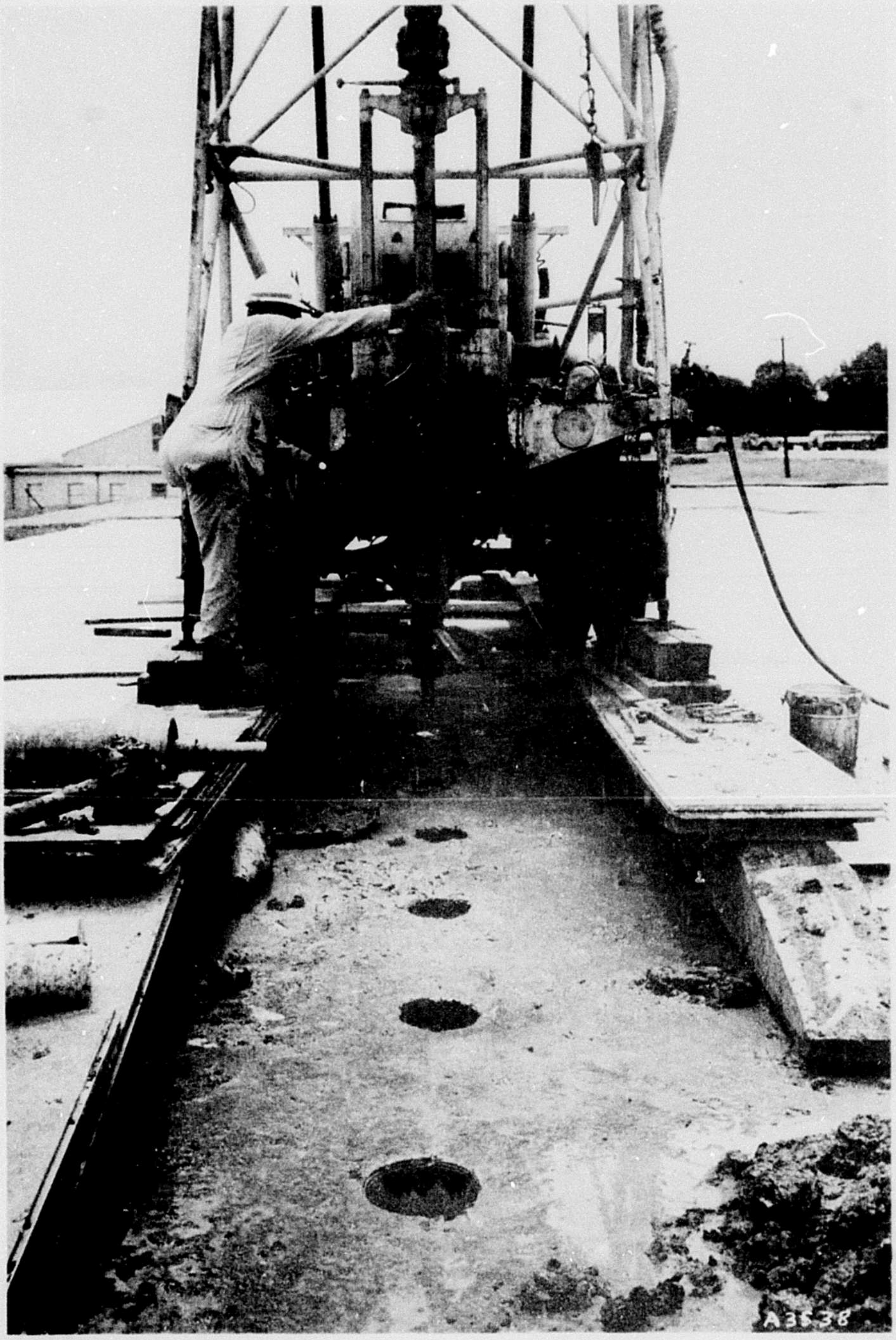

Figure 21. Open position of underreaming device as it would appear underneath the concrete slab.

Figure 22. Filling underreamed void under the longitudinal joint in item 2 with sand-cement grout.

28-day compressive strengths of the sand-cement grout placed in the underreamed holes and the 8-in.-diam access holes were 3000 and 4000 psi, respectively.

IV TRAFFIC TESTING AND RESULTS

A. Test Conditions and Procedures

1. General

Before beginning traffic testing, dynamic (slowly moving) and static loading tests using single-wheel, 4-wheel, and 12-wheel assemblies were performed for instrumentation purposes. The data from the pretraffic load tests will be reported later. After intial instrumentation data were recorded, traffic tests were performed by applying simulated C-5A aircraft traffic (one main gear) over the four test items in lane 1 and simulated 747 aircraft traffic in lane 2. The test carts, test lane, traffic pattern, pavement conditions, and failure criteria are discussed in the following paragraphs. The results of an after-traffic test program and a summary of traffic test data are also presented.

2. Test carts

Test traffic was applied with the 12-wheel and twin-tandem assemblies. All test wheel assemblies were equipped with 49x17, 26-ply rating tires. The tire pressure was checked and adjusted if needed each morning prior to testing.

Twelve-wheel-assembly traffic was applied with the test cart shown in figure 23. This assembly and test-wheel configuration represented one main gear of the C-5A aircraft. The test cart was powered by a prime mover with drive wheels that straddled the test lane. The 12-wheel assembly consisted of two load boxes, each of which was carried by 6 load wheels, resulting in the wheel arrangement shown in figure 24. The boxes were loaded to result in a net weight of 360 kips distributed equally over the 12 wheels. Each tire was inflated to 100 psi, which resulted in a tire contact area of 285 sq in. per tire and a contact pressure of about 106 psi.

The twin-tandem-assembly test traffic was applied with the test cart shown in figure 25. The wheel spacing, which is shown in figure 24, duplicated one twin-tandem component of the 747 assembly. The test cart consisted of a load box supported by an A-frame and was

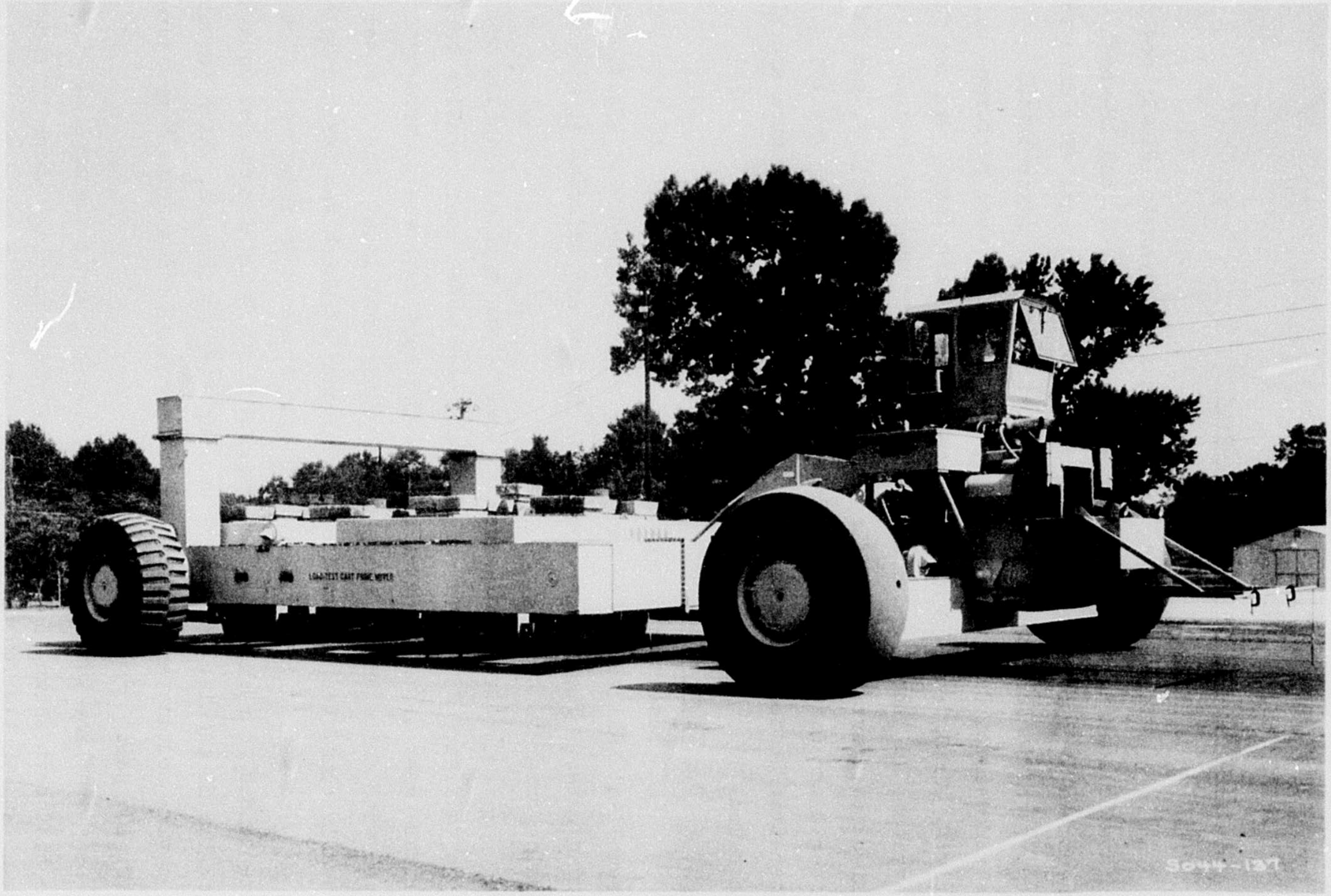

Figure 23. 360-kip, 12-wheel-assembly test cart.

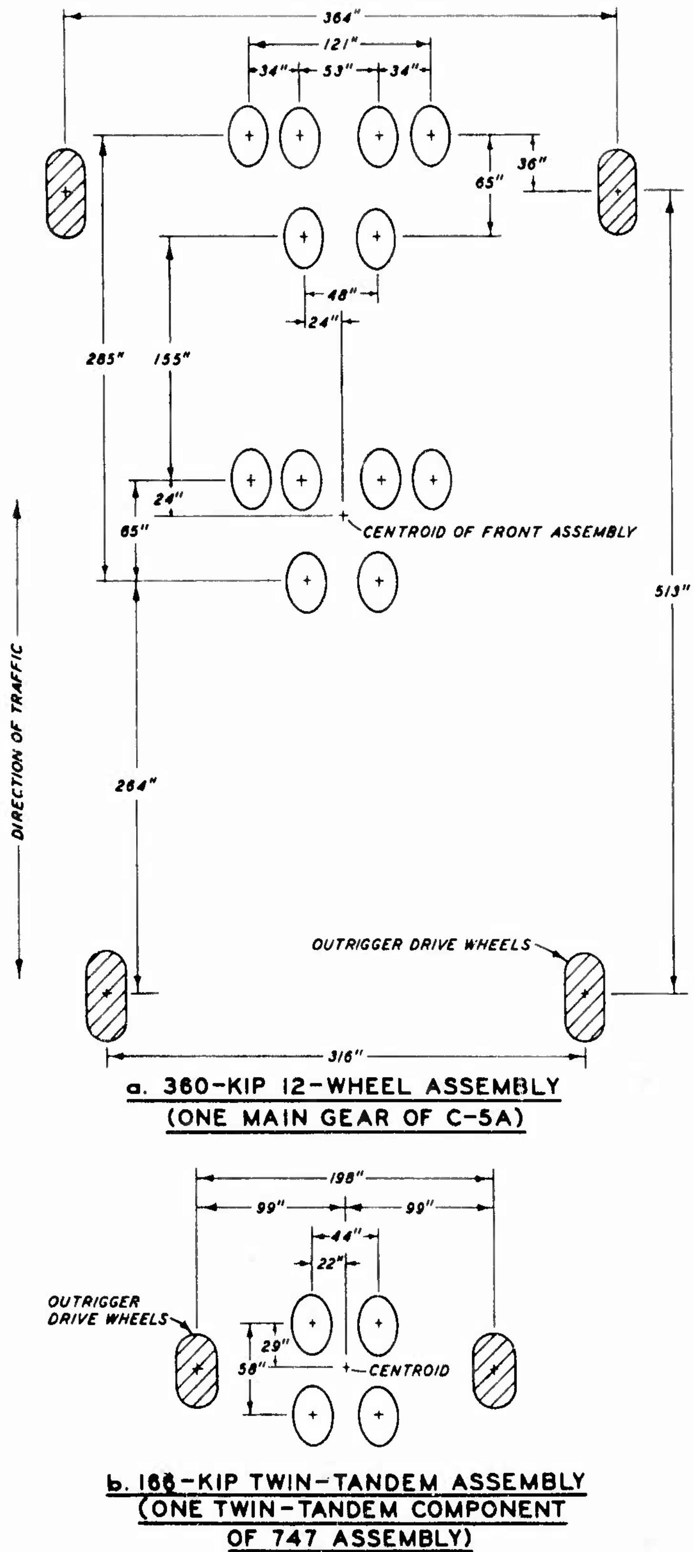

Figure 24. Wheel arrangements for 12-wheel and twin-tandem assemblies.

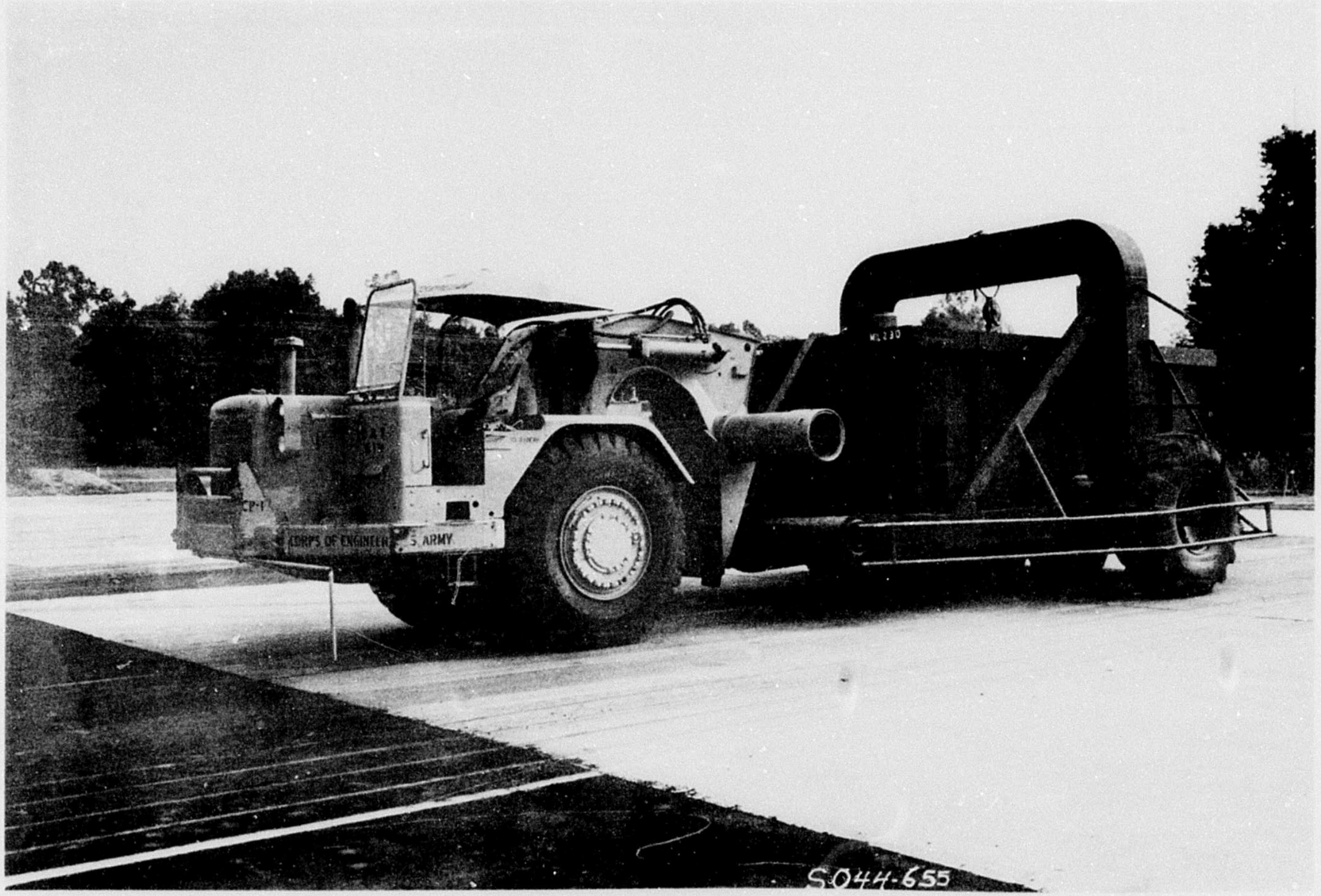

Figure 25. 166-kip, twin-tandem-assembly test cart.

towed by a Catapillar Model 619 tractor. Test traffic was applied in a 120-in.-wide lane (lane 2) with the twin-tandem assembly test cart after completion of the 12-wheel assembly test traffic. The twin-tandem assembly was loaded to a net weight of 166 kips (41.5 kips per wheel) and was equipped with four 49x17, 26-ply rating tires, which were inflated to a tire pressure of 200 psi, giving a contact area of about 207 sq in.

3. Test lanes

The layout shown in figure 1 indicates the location, width, and length of the test lanes, which were the same as those for the MWHGL pavement tests (reference 1). Test lane 1 was 200-in. wide through all five test items and was subjected to the 12-wheel-assembly traffic. The south edge of the test lane was located 11 ft north of the south edge of the south paving lane and the north edge of the 200-in.-wide test lane was positioned 32 in. north of the keyed longitudinal construction joint.

The test lane for the twin-tandem-assembly traffic (lane 2) was located in the middle of the north paving lane (figure 1) to minimize the effects that the 12-wheel-assembly traffic might have had on the structural condition of pavement in the north lane. Theoretical and model studies (reference 8) showed that the difference in concrete stress is small (±5 percent) with the twin-tandem gear oriented parallel to or normal to the slab edge. Therefore, the location of the test lane for the twin-tandem assembly was not an important factor on the pavement slab behavior.

4. Traffic patterns

The traffic patterns, the distribution of traffic applied over the width of the test lanes, are shown in figure 26. The coverage levels* referred to in this report are the total number of coverages applied in the central portion of the traffic pattern.

* For rigid pavements, coverages is a measure of the number of maximum stress repetitions that occur in the pavement due to the applied traffic. A coverage occurs when each point of the pavement within the test lane has been subjected to a maximum stress, assuming that the stress is equal under the full tire print width. For the 12-wheel assembly, separate and distinct maximum stresses occur under front and rear 6-wheel array. For the twin-tandem gear, the front and rear twin wheels are sufficiently far apart that two maximum stress repetitions occur for each pass of the gear.

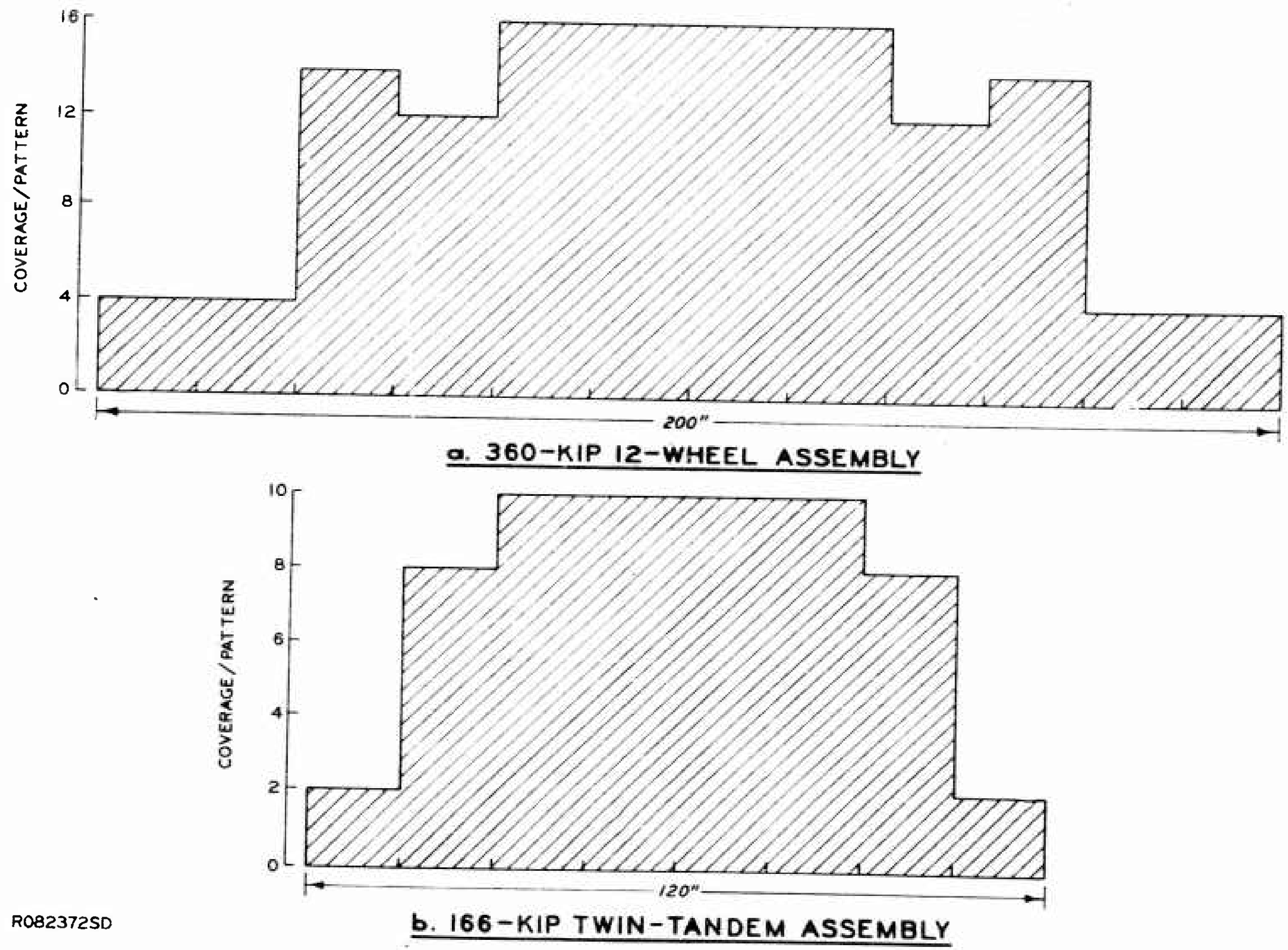

Figure 26. Traffic patterns for 12-wheel and twin-tandem assemblies.

Traffic was applied in the 12-wheel-assembly test lane by repetition of the traffic pattern shown in figure 26a. A traffic pattern consisted of 22 passes of the test cart distributed in the test lane by following five guidelines painted on the pavement surface on 16-in. centers (approximately one tire print width). The 22 passes resulted in 16 coverages* in the center 60 in. of the test lane with a lesser number along the edges of the test lane. The distribution of passes and coverages in the test lane is shown in figure 26. To apply the traffic shown by this, the test cart traveled for the full length of the test lane along guideline 1 (south edge of the test lane) and back along the same line; then the cart was shifted laterally to lines 2, 3, 4, and 5 in succession with a pass in each direction on each line. After tracking line 5 (north edge of the test lane), the guidelines were run in reverse order commencing with line 5. A pass in each direction was made on each of the 5 guidelines except for guideline 3, where two passes were made in each direction to produce a uniform traffic pattern in the center of the test lane.

Traffic with the twin-tandem-assembly test cart was in the pattern shown in figure 26b using five guidelines each 15 in. apart. The test cart was operated forward and backward along guideline 1 and then was shifted laterally to guidelines 2, 3, 4, and 5 in succession with a pass in each direction on each line. The cart then made a pass in each direction along guidelines 4, 3, 2, 3, 4, 4, 3, 2, and 3 (in that order) to produce the pattern shown in figure 26b. A traffic pattern required 30 passes and resulted in 10 coverages in the center (figure 26b). All traffic patterns were started from the east maneuver area and the forward direction of traffic was with the test cart moving from east to west.

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* See footnote on preceeding page.

5. Failure criteria

(a) Pavement

For plain nonreinforced rigid pavements, there are three structural failure conditions, which are defined below. It must be emphasized that these failure conditions define the structural integrity of the concrete slabs and do not necessarily indicate the operational or functional condition of the pavement. Roughness is normally considered to be the primary measure of the operational condition of a pavement and must be coupled with the structural condition for an accurate definition of failure. It is possible for a rigid pavement to be cracked but smooth or to be structurally intact but rough. Nevertheless, experience indicates that the degree of cracking is a good indicator of the operational as well as the structural condition of the pavement.

Initial-crack failure. A crack that is visible at the surface of the pavement, extends through the depth of the concrete slab, and is the result of traffic loading constitutes the initial-crack failure condition. This should not be confused with surface cracks resulting from such minor defects as spalls, popouts, shrinkage, etc. It must also be recognized that concrete may crack during its early life due to causes other than traffic loading and any such cracks should not be construed as denoting the initial-crack failure condition.

Shattered-slab failure. Cracking that is visible on the pavement surface and subdivides a pavement slab into six pieces consitutes the shattered-slab failure condition. The cracking must be that associated with traffic loading rather than the result of some minor defect or early-life cracking prior to application of traffic.

Complete failure. Cracking that is visible on the pavement surface and subdivides the pavement slab into individual pieces having an area of less than about 15 to 20 sq ft each and that is characterized by relatively large permanent deflections and faulted cracks or joints constitutes complete failure.

(b) Joints

The primary purpose of this study was to evaluate the performance of the longitudinal construction joint under traffic;

Traffic was applied in the 12-wheel-assembly test lane by repetition of the traffic pattern shown in figure 26a. A traffic pattern consisted of 22 passes of the test cart distributed in the test lane by following five guidelines painted on the pavement surface on 16-in. centers (approximately one tire print width). The 22 passes resulted in 16 coverages* in the center 60 in. of the test lane with a lesser number along the edges of the test lane. The distribution of passes and coverages in the test lane is shown in figure 26. To apply the traffic shown by this, the test cart traveled for the full length of the test lane along guideline 1 (south edge of the test lane) and back along the same line; then the cart was shifted laterally to lines 2, 3, 4, and 5 in succession with a pass in each direction on each line. After tracking line 5 (north edge of the test lane), the guidelines were run in reverse order commencing with line 5. A pass in each direction was made on each of the 5 guidelines except for guideline 3, where two passes were made in each direction to produce a uniform traffic pattern in the center of the test lane.

Traffic with the twin-tandem-assembly test cart was in the pattern shown in figure 26b using five guidelines each 15 in. apart. The test cart was operated forward and backward along guideline 1 and then was shifted laterally to guidelines 2, 3, 4, and 5 in succession with a pass in each direction on each line. The cart then made a pass in each direction along guidelines 4, 3, 2, 3, 4, 4, 3, 2, and 3 (in that order) to produce the pattern shown in figure 26b. A traffic pattern required 30 passes and resulted in 10 coverages in the center (figure 26b). All traffic patterns were started from the east maneuver area and the forward direction of traffic was with the test cart moving from east to west.

* See footnote on preceeding page.

therefore, particular attention was given to signs of distress along the joints as well as in the slabs. The two forms of joint distress noted during the MWHGL tests (reference 1) were spalling of the concrete and faulting across the joint. Periodic inspections of the joint were made during and following each traffic pattern and straightedge measurements were made across the joint to detect faulting. If severe spalling and faulting at the longitudinal joint occurred before the slab reached the shattered-slab failure condition described above, the joint was considered inadequate. When this occurred, a portion of the slab adjacent to the joint was removed to inspect and document the failure condition. The test item was then eliminated from the test. Traffic was continued on the remaining items until either all joints had failed or the slabs had reached the shattered-slab failure condition; whereupon, traffic was halted and the after-traffic test program was conducted.

6. Data obtained during traffic testing

A visual inspection of the slabs and longitudinal construction joints in each test item was made after the completion of each traffic pattern. The occurrence and location of cracks and other defects were noted and plotted. Periodically, the cracks were painted white to improve contrast, and the test items were photographed. Cross-section measurements were also taken periodically during traffic testing.

Pavement deflection measurements were made in the twin-tandem traffic lane at about the midpoint of each item of the test section prior to the start of traffic. The term deflection as used in this report indicates the total vertical movement that occurred under the static weight of the load wheels. The measurements were obtained with level instruments by reading rods (engineer scales) at prearranged positions on lines transverse to the direction of traffic. Rod readings were first taken with the load off the pavement; then the test cart was moved forward until the back axle of the assembly was over the prearranged position, and a second series of readings were taken with the load on. The difference in rod readings with load on and load off indicates the vertical movement or total deflection of the pavement under load.

B. Behavior of Pavement Under 12-Wheel-Assembly Traffic

1. General

The behavior of each test item under the 12-wheel-assembly traffic, as determined from the visual observations and measurements made during traffic, is discussed in the following paragraphs.

2. Item 1

A general view of test item 1 prior to traffic is shown in figure 27. As can be seen in this photograph, both the southwest and northwest slabs contained longitudinal cracks prior to traffic. The crack in the southwest slab began at the west end of the item about 9 ft from the south free edge and ran approximately 13 ft longitudinally into the slab. The crack in the northwest slab began at the west edge of the item and ran 21 ft longitudinally through the center of the slab. Neither of these cracks was located inside the 200-in.-wide traffic lane.

After one pattern of test traffic (16 coverages), flaking and spalling were evident along the edges of the existing cracks. Initial cracking due to test traffic occurred in the southwest slab at about 54 coverages. This cracking consisted of a 25-ft-long longitudinal crack about 10 ft south of the longitudinal construction joint and a transverse crack in about the center of the slab extending from the construction joint to the longitudinal crack. Between 54 and 144 coverages, cracks developed very rapidly in the two south slabs of the item. After 144 coverages, the surfaces of the southwest and southeast slabs were subdivided into 7 and 4 pieces, respectively, as shown in figure 28. Although the southwest slab met the shattered-slab failure criterion after 144 coverages, traffic was continued because the longitudinal construction joint was performing satisfactory.

A small, 5-ft-long, diagonal crack in the southeast slab was the only additional distress observed after 216 coverages. At the 344-coverage level, the transverse cracks detected at 144 coverages running approximately through the centers of the southeast and southwest slabs had extended to the south free edge of the pavement. Also at this time, there was a large half-moon-shaped crack located in the east end

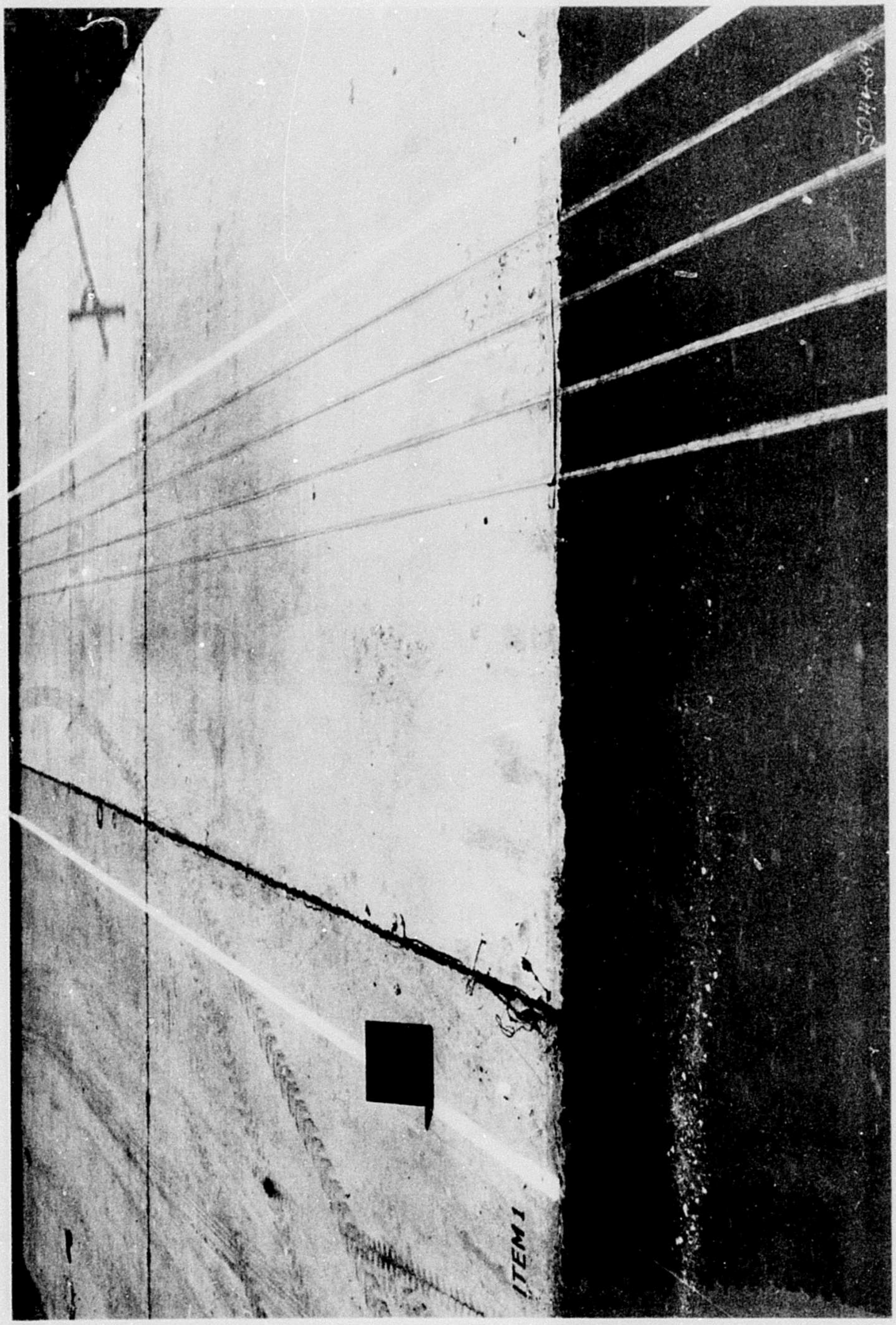


Figure 27. General view of item 1 prior to test traffic.

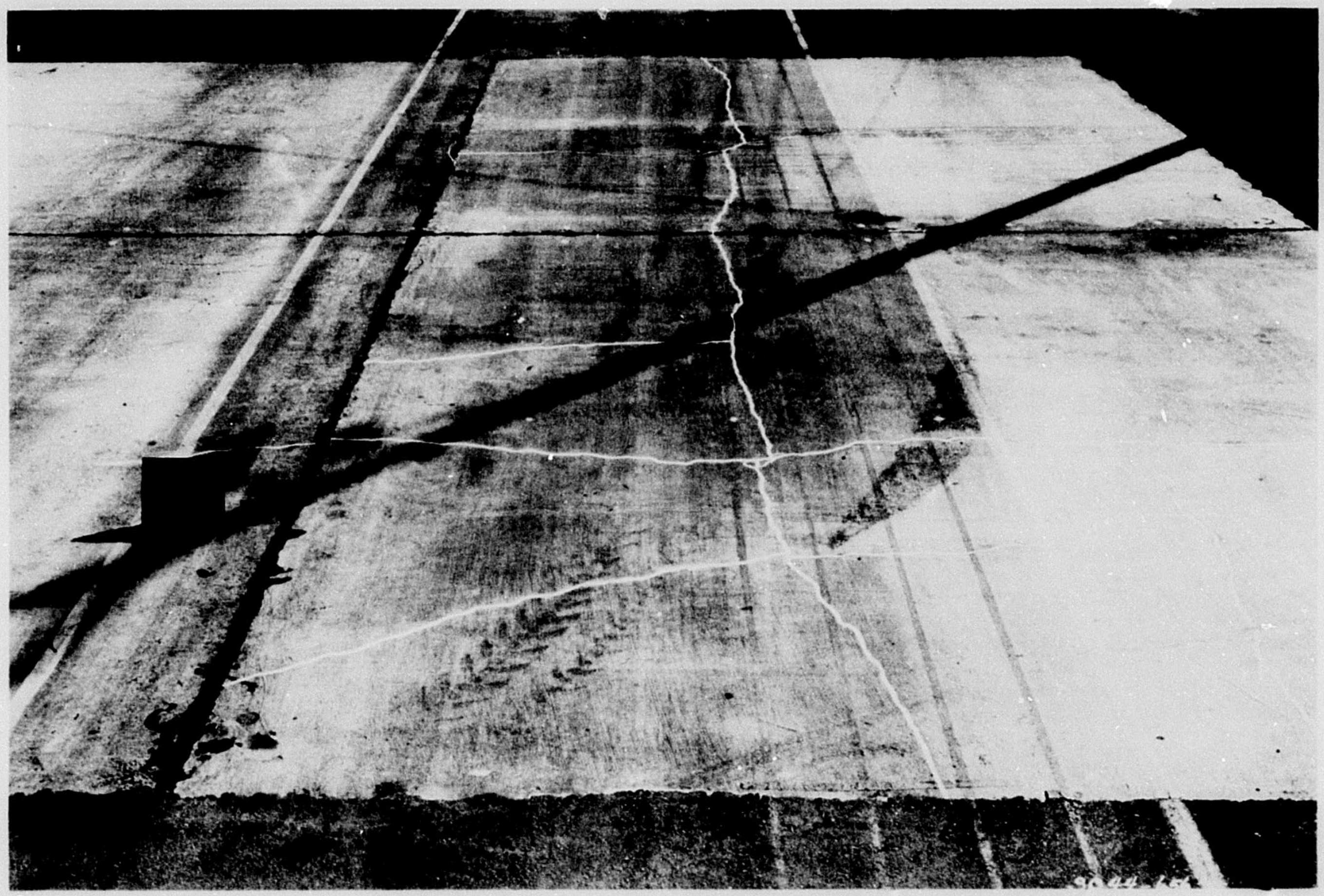


Figure 28. Item 1, 360-kip, 12-wheel-assembly lane after 144 coverages.

of the item. Additional surface cracking had developed in both of the north slabs and in the southwest slab after 504 coverages. Figure 29 depicts the crack pattern in this item after 504 coverages. Several of the cracks in the southwest slab were severely spalled and raveled. Traffic was stopped after 43 traffic patterns (688 coverages) due to the severe faulting of the keyed longitudinal construction joint, as well as the shattered-slab failures of both south slabs and the item was rated as failed. Figure 30 indicates faulting of 3/8 to 1/2 in. after 688 coverages at the construction joint between the southwest and northwest slabs. An overall view of the item after 688 coverages is shown in figure 31; the progression and extent of cracking due to test traffic is shown in figure 32. After traffic was discontinued, a portion of the southwest slab adjacent to the keyed construction joint was removed to confirm the joint failure. As can be seen in figure 33, the bottom half of the keyway of the keyed longitudinal construction joint was failed. The longitudinal construction joint containing the dowel bars on 12-in. centers in the eastern half of the item was in satisfactory condition at the end of traffic.

Minor pumping was noted after 8 coverages at the transition of item 1 and the west maneuver area. As traffic was applied, pumping at the edge of the slab decreased; near the end of traffic, clear water was being pumped through the cracks in the southeast and southwest slabs. The pumping was not considered to be severe and probably did not materially affect the pavement performance during traffic.

Some permanent deformation occurred across the slabs with the application of test traffic, as shown in figure 34. (Typical cross sections were measured at the center of each slab). After 43 traffic patterns (688 coverages), the permanent deformation averages 0.24 in. with a maximum deformation of 0.48 in. occurring adjacent to the longitudinal construction joint at station 3+10.5.

3. Item 2

There were no structural cracks in the slabs in item 2 before traffic was commenced (figure 35). The only defect noticed prior to traffic

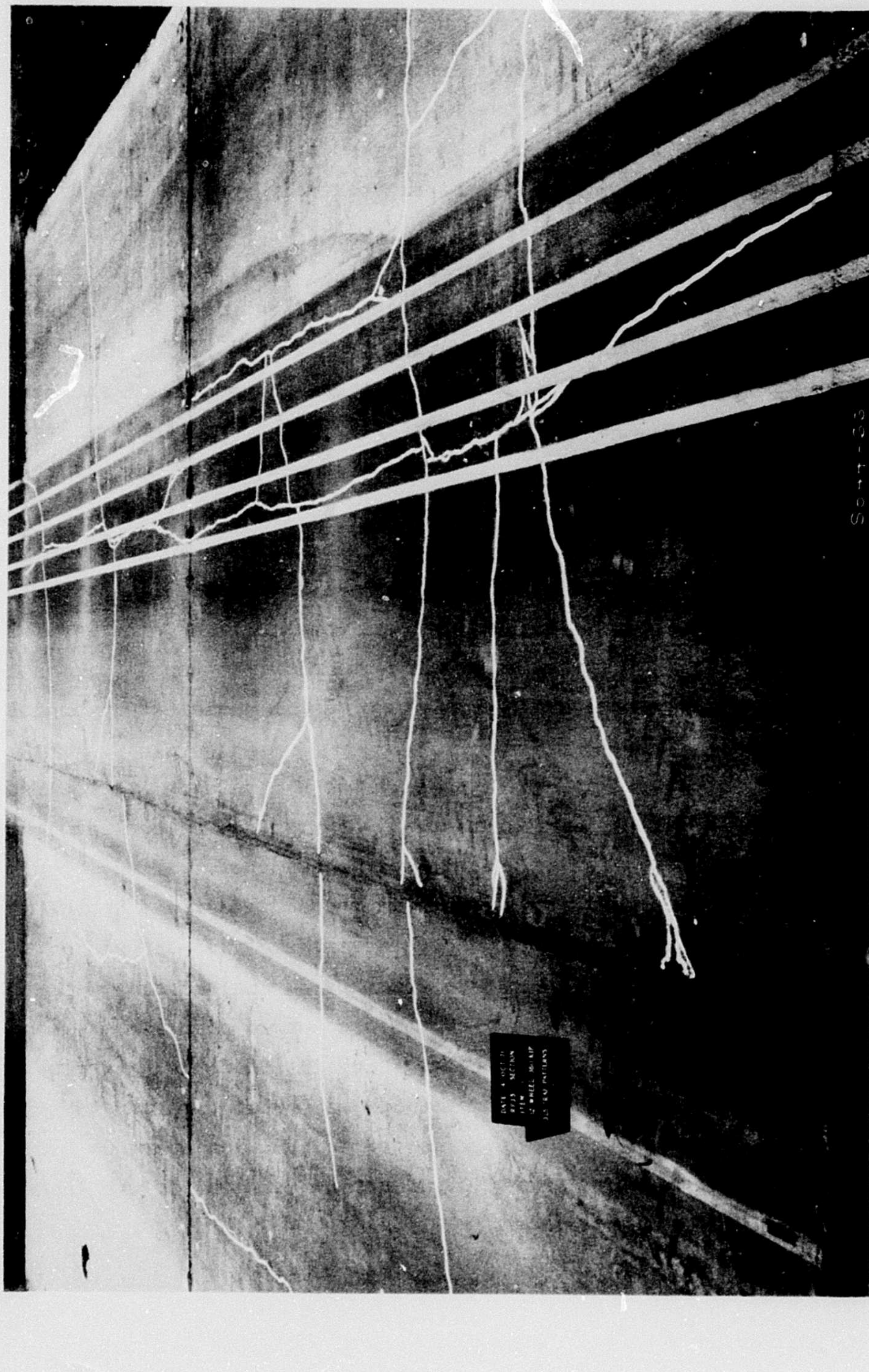


Figure 29. Item 1, 360-kip, 12-wheel-assembly lane after 504 coverages.

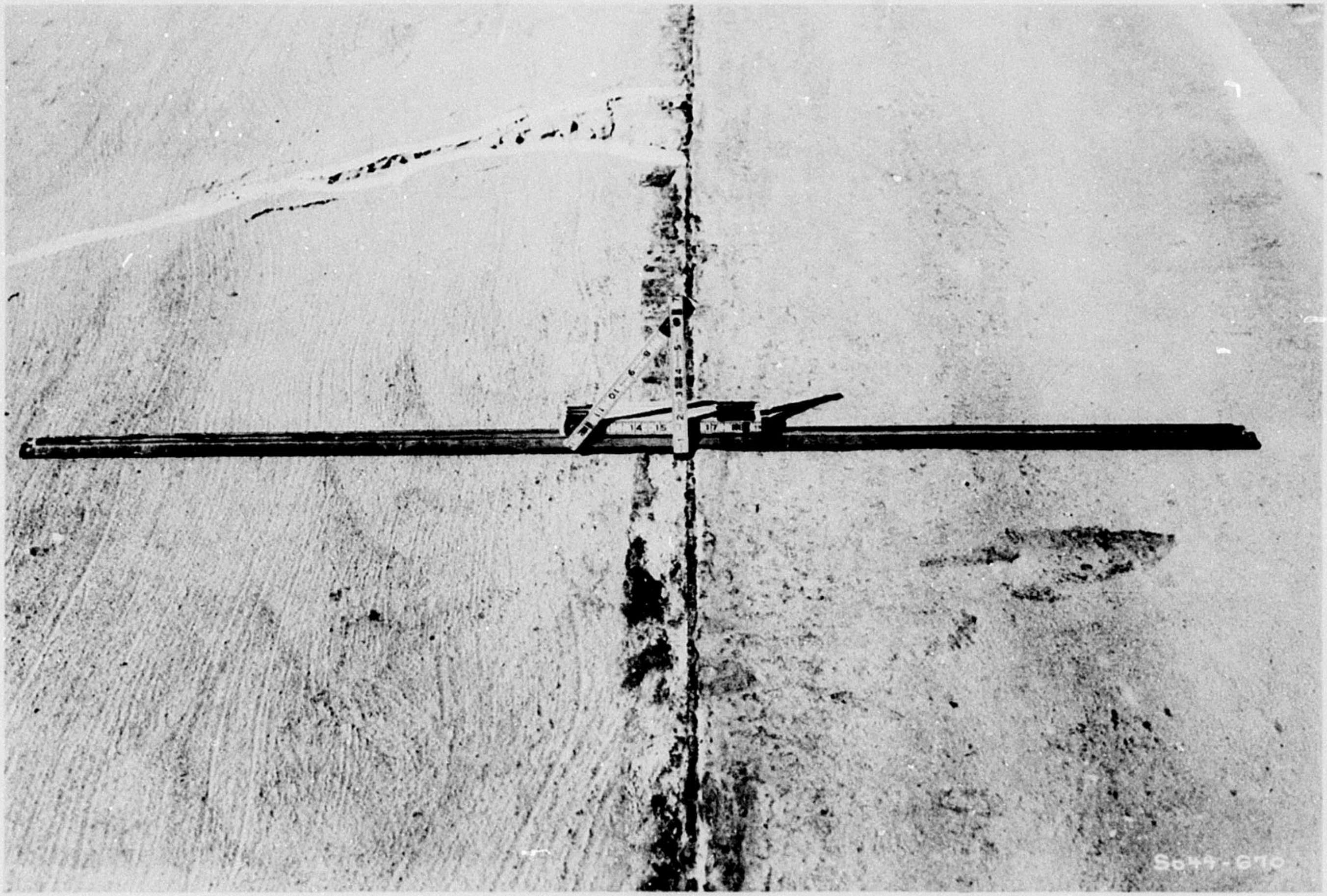


Figure 30. Faulting of longitudinal construction joint in item 1 after 688 coverages.

Figure 31. General view of item 1, 360-kip, 12-wheel-assembly lane after 688 coverages.

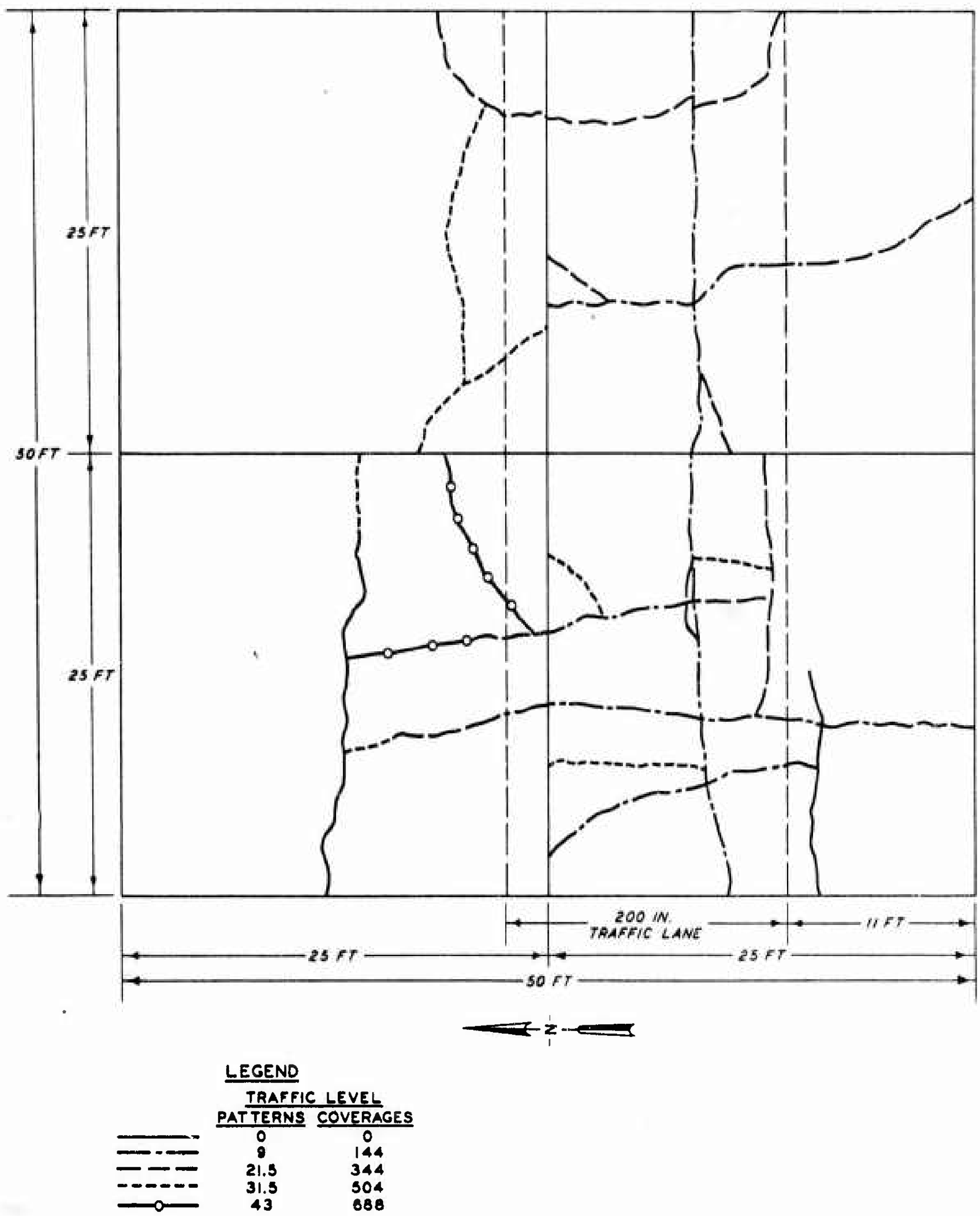


Figure 32. Crack development in item 1 under 360-kip, 12-wheel-assembly traffic.

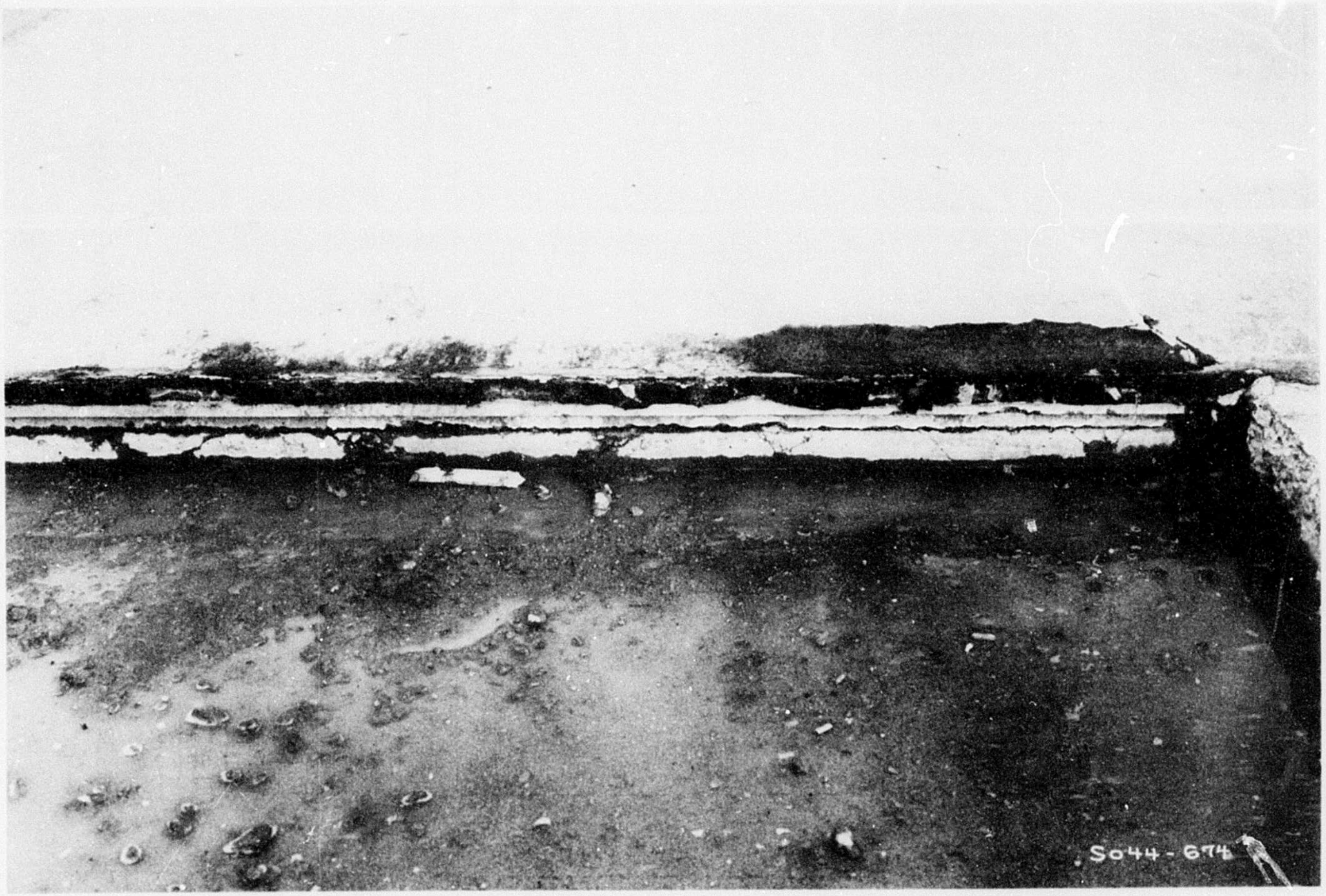


Figure 33. View of failed keyed longitudinal joint in item 1 after 688 coverages of the 360-kip, 12-wheel assembly.

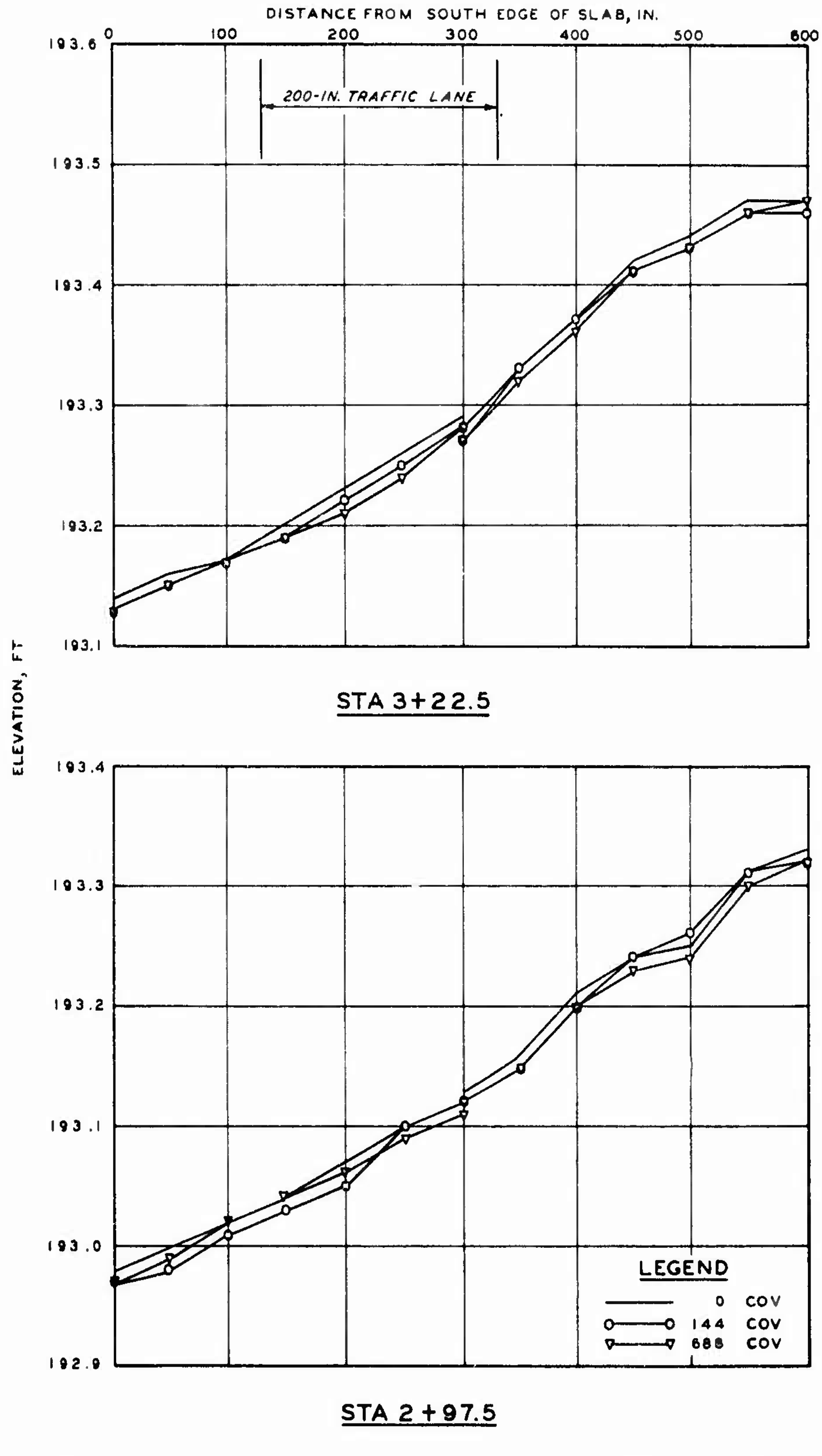


Figure 34. Typical cross sections of item 1, 360-kip, 12-wheel-assembly lane.

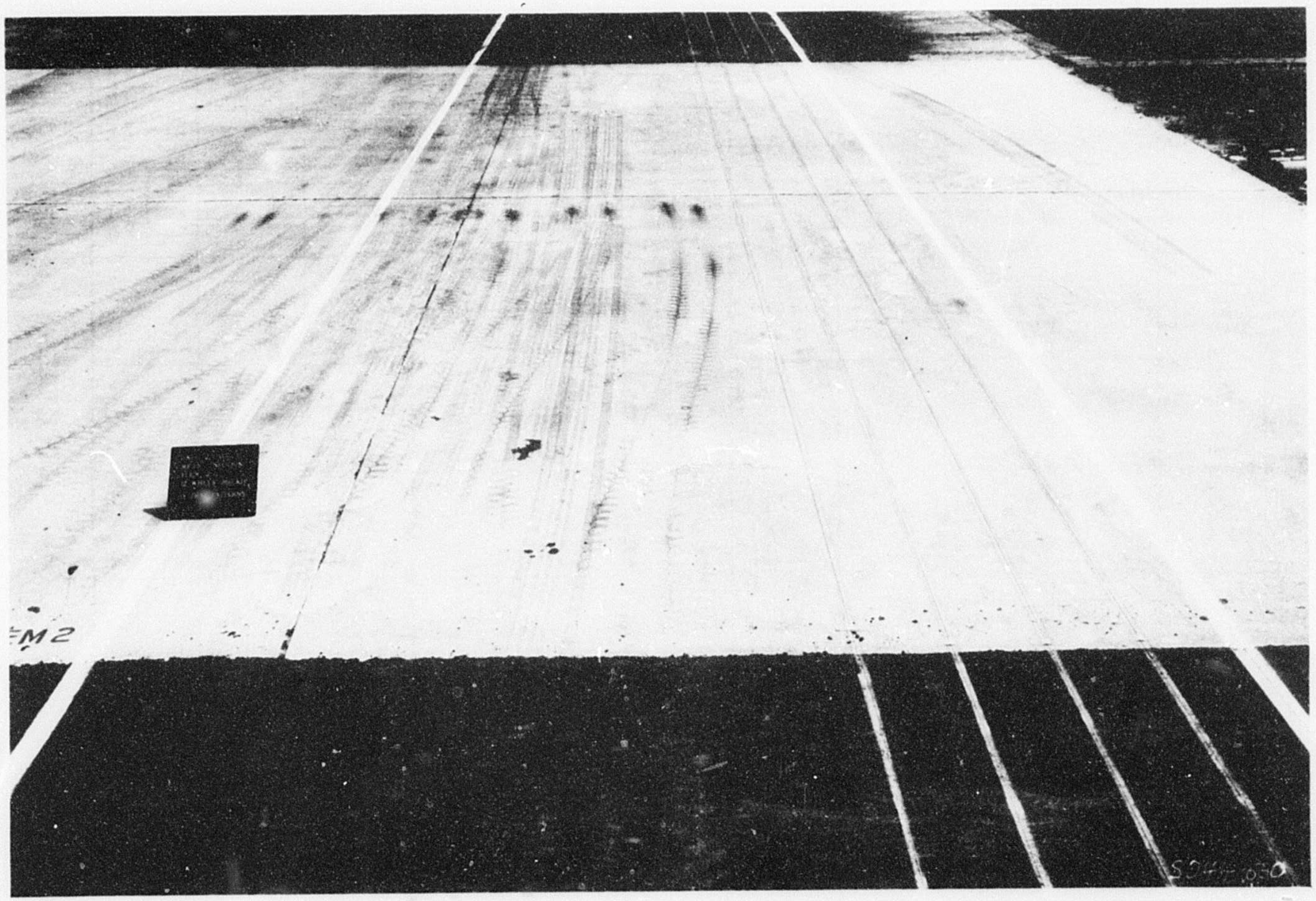


Figure 35. General view of item 2, 360-kip, 12-wheel-assembly lane prior to traffic.

on the surface of the pavement was a spall along the transverse joint between the northeast and northwest slabs. Pumping at the transverse joint between the east edge of the item and the transition section was noted after 8 coverages. After 16 coverages, passage of the test cart caused a small amount of clear water to squirt out around the edges of two of the 8-in.-diam holes located at the longitudinal construction joint in the western half of the item. This indicated that there was a very poor, if any, bond between the slab and the sand-cement grout used to fill the underreamed void and 8-in.-diam access holes. The lack of bond did not appear to have any effect on the strengthening characteristics. Slight spalling and flaking were also observed around the edges of the access holes after 16 coverages of traffic.

Initial cracking occurred during the ninth traffic pattern (144 coverages). This consisted of a transverse crack, which began at the longitudinal construction joint and ran about 15 ft across the southwest slab, as shown in figure 36. After 21.5 traffic patterns (344 coverages), the transverse crack in the southwest slab had progressed across the slab and a transverse crack was also detected going across the southeast slab. Both south slabs in this item were essentially halved by these cracks. Each of the three types of longitudinal construction joint strengthening seemed to be performing satisfactory at this time. After 10 more patterns of traffic or a total of 31.5 patterns, a slight amount of flaking occurred along the edges of the transverse cracks in the two south slabs. Two additional cracks were observed in the southeast slab at the 504 coverage level (31.5 patterns). One of these cracks was a corner break and the other was a longitudinal crack connecting the transverse crack that occurred at 344 coverages to the transverse weakened-plane contraction joint. The general condition of this item after 504 coverages is depicted in figure 37. The strengthened longitudinal construction joint was performing satisfactorily at this time; however, flaking and spalling such as that shown in figure 38 had occurred around all of the 8-in.-diam cored holes filled with sanded grout.

Figure 36. Initial crack in item 2, 360-kip, 12-wheel-assembly lane after 144 coverages.

Figure 37. Item 2, 360-kip-assembly lane after 504 coverages.

Figure 38. Flaking and spalling around the 8-in.-diam access holes filled with sand-cement grout (after 504 coverages).

Traffic was temporarily stopped on item 2 after 43 traffic patterns (688 coverages) while item 3 was cleaned and overlaid. Several new surface cracks were observed in item 2 at this time. A general view of the item after 688 coverages showing the extent of cracking is shown in figure 39. The new cracks detected consisted of a longitudinal crack in the southwest slab that essentially halved the eastern half of this slab, two large corner cracks in the northeast slab, and one large corner crack in the northeast slab.

Traffic was continued on item 2 after the overlay on item 3 had cured. After 51 patterns (816 coverages), traffic was discontinued on the western half of this item, that portion of the item where the keyed joint was strengthened by undergrouting. Faulting of 3/8 to 1/2 in. was present at several locations along the longitudinal joint. This faulting usually occurred where transverse cracks extended from the longitudinal joint into the slab (figure 40). Therefore, it is believed that this type of strengthening method will perform satisfactory as long as the pavement remains in serviceable condition.

Although failure had occurred, test traffic was continued to determine the effectiveness of the other two methods of strengthening keyed joints employed in this test item. After 106 patterns (1696 coverages), traffic was discontinued on the entire item because of the severe spalling and raveling along cracks. Other than the spalling and raveling along cracks, the only additional distress observed on the pavement surface occurring between 816 and 1696 coverages were corner cracks located in the northeast and southeast slabs. These are shown in figures 41 and 42. At the conclusion of traffic, sections of the keyed construction joint strengthened by both horizontal and slanted dowel bars were performing satisfactorily.

Typical cross sections at the center of each slab show the permanent deformation in the test lane due to traffic (figure 43). The average permanent deformation was about 0.24 in. with maximum deformation of 0.48 in.

Figure 39. General view of item 2, 360-kip, 12-wheel-assembly lane after 688 coverages.

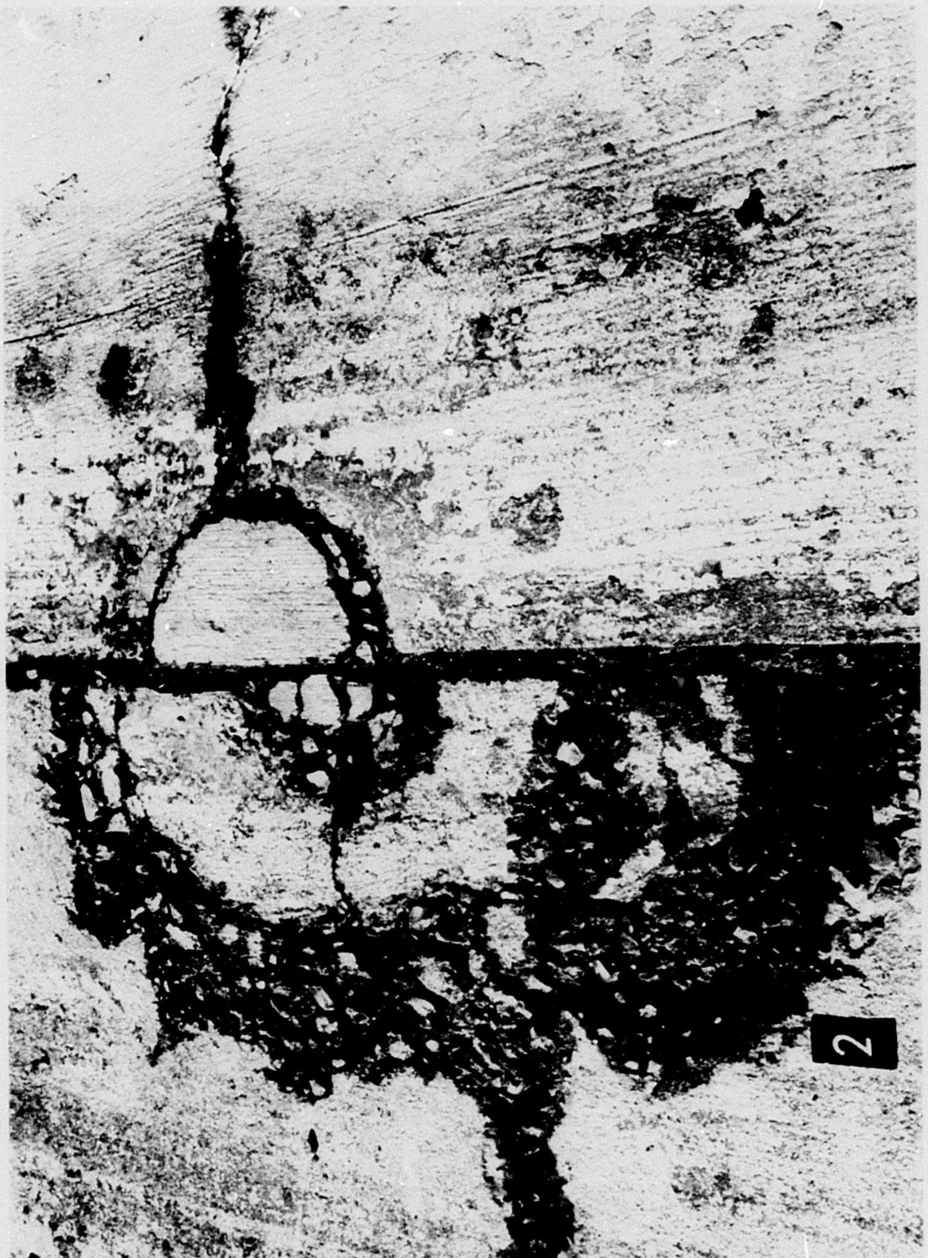


Figure 40. View of under-grouted joint in item 2, 360-kip, 12-wheel-assembly lane after 816 coverages.

Figure 41. Item 2, 360-kip, 12-wheel-assembly lane after 1696 coverages.

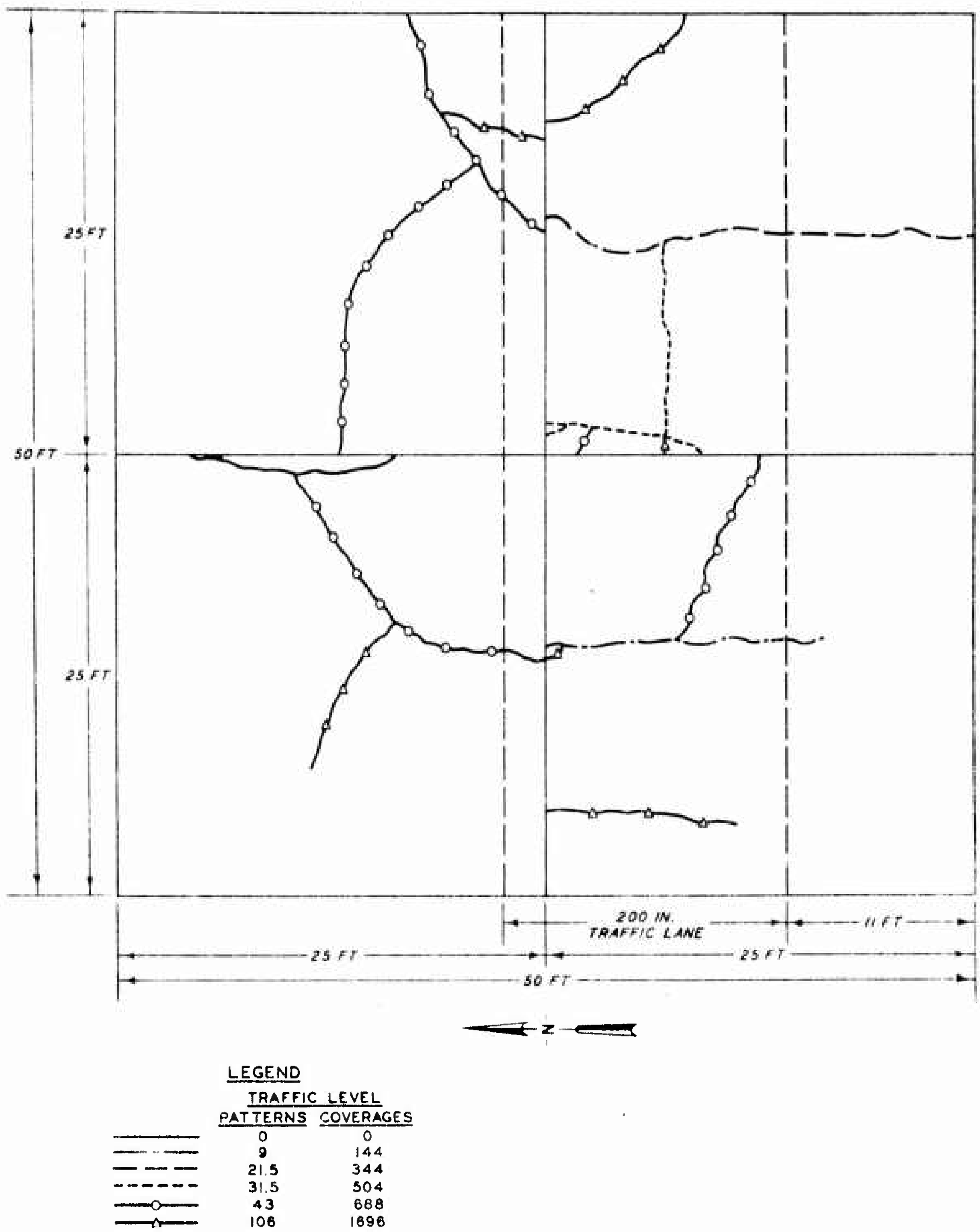


Figure 42. Crack development in item 2 under 360-kip, 12-wheel-assembly traffic.

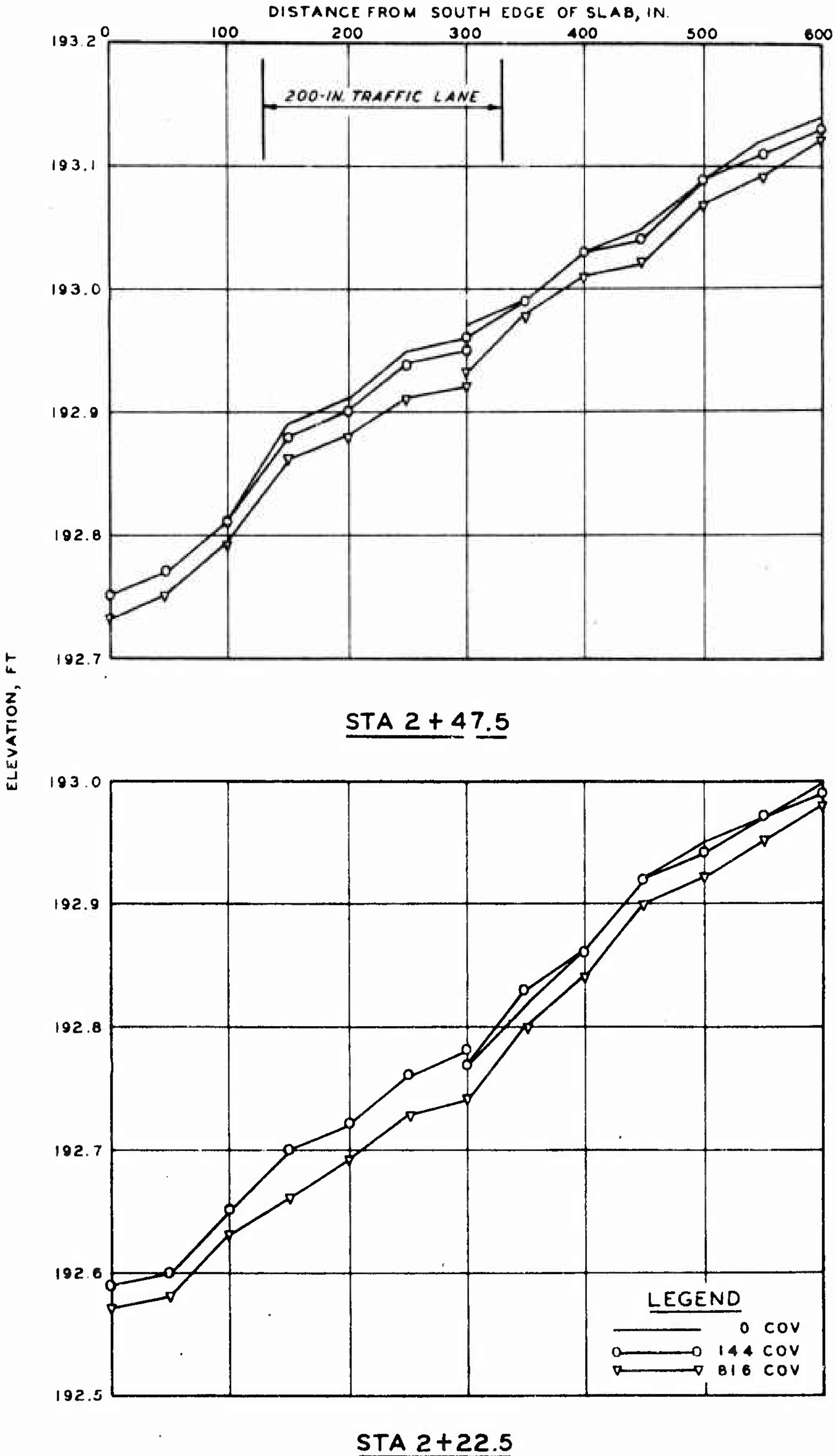


Figure 43. Typical cross sections of item 2, 360-kip, 12-wheel-assembly lane.

At the completion of traffic, a 6- by 6-ft concrete specimen was removed from the northwest corner of the southeast slab. After removing the slab, inspection of the exposed longitudinal joint indicated that the bars placed at a 45° angle through the keyed joint were intact and performing satisfactory at the end of traffic. Although the horizontal bars were not exposed after removing the concrete specimen, their performance during traffic indicated that they were intact at the end of traffic. Figure 44 shows a view of this joint after removing the specimen.

4. Item 3

A general view of item 3 prior to test traffic is shown in figure 45. As can be seen in this photograph, several cracks developed during the curing of the slab. An epoxy cement was placed under pressure (10 psi) into the longitudinal cracks located in the southeast slab running from the south free edge of the slab to the longitudinal joint. Epoxy cement was first applied of the surface of the pavement and allowed to cure before the epoxy cement was forced under 10-psi pressure into the cracks. There was also a transverse crack between the southwest and southeast slabs parallel to the weakened-plane construction joint. However, since this crack developed prior to the construction of the weakened-plane joint, it was decided to consider the crack as the joint between the two slabs.

Prior to the application of continuous test traffic, 22 coverages of traffic were accumulated while recording instrumentation data. During this time two transverse cracks developed in the southeast and southwest slabs, and a longitudinal and a transverse crack appeared in the northwest slab. The length and location of these cracks can be determined from the data plotted in figure 46.

The initial crack attributed to uniformly applied test traffic was detected after 6 patterns (96 coverages*). This was an extension of a transverse crack in the southeast slab, which began at

* This does not include the 22 coverages applied during instrumentation traffic.

Figure 44. View of the longitudinal construction joint in item 2 strengthened by bonding bars at 45° angles (after 1676 coverages).

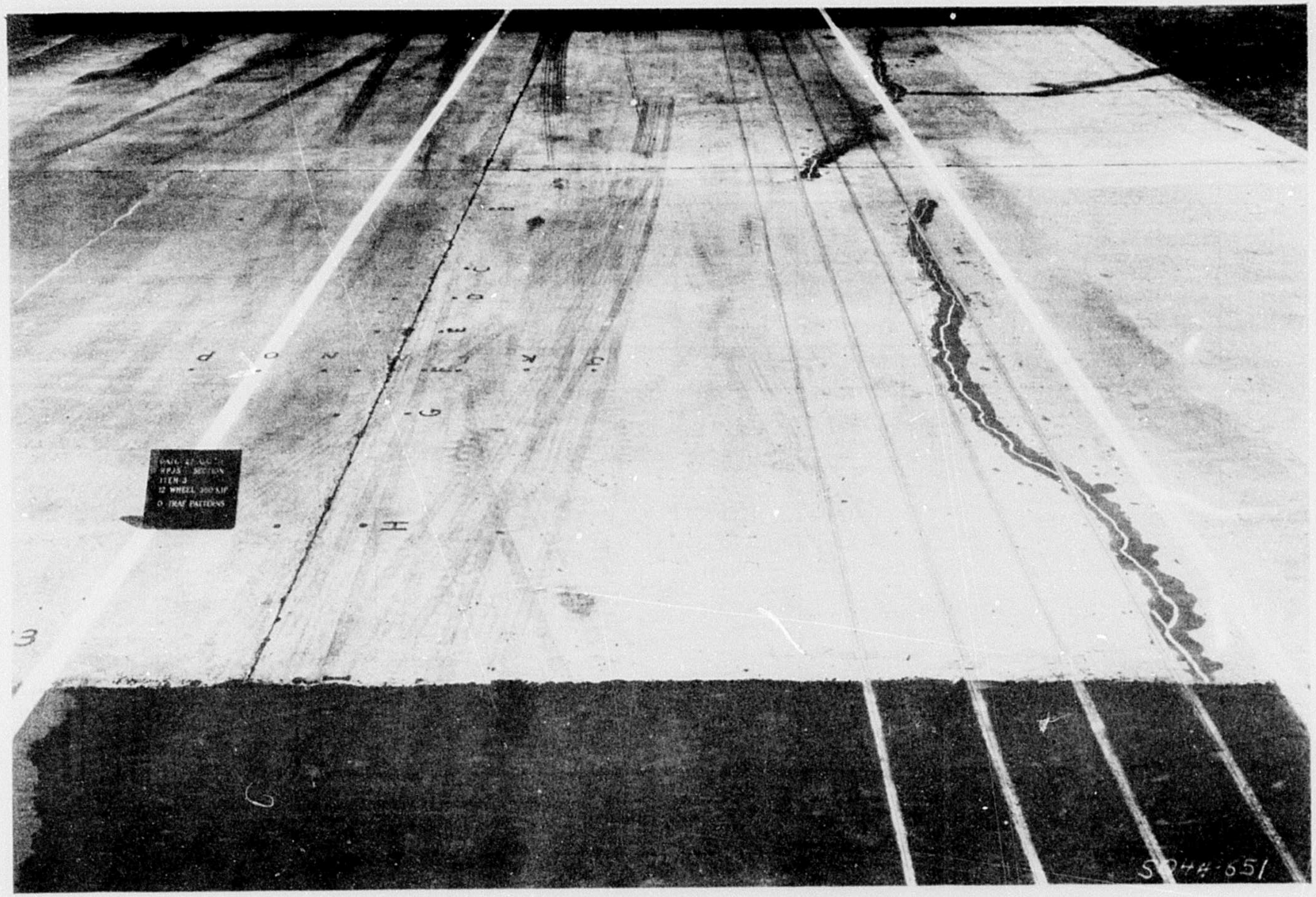


Figure 45. Item 3, 360-kip, 12-wheel-assembly lane prior to traffic.

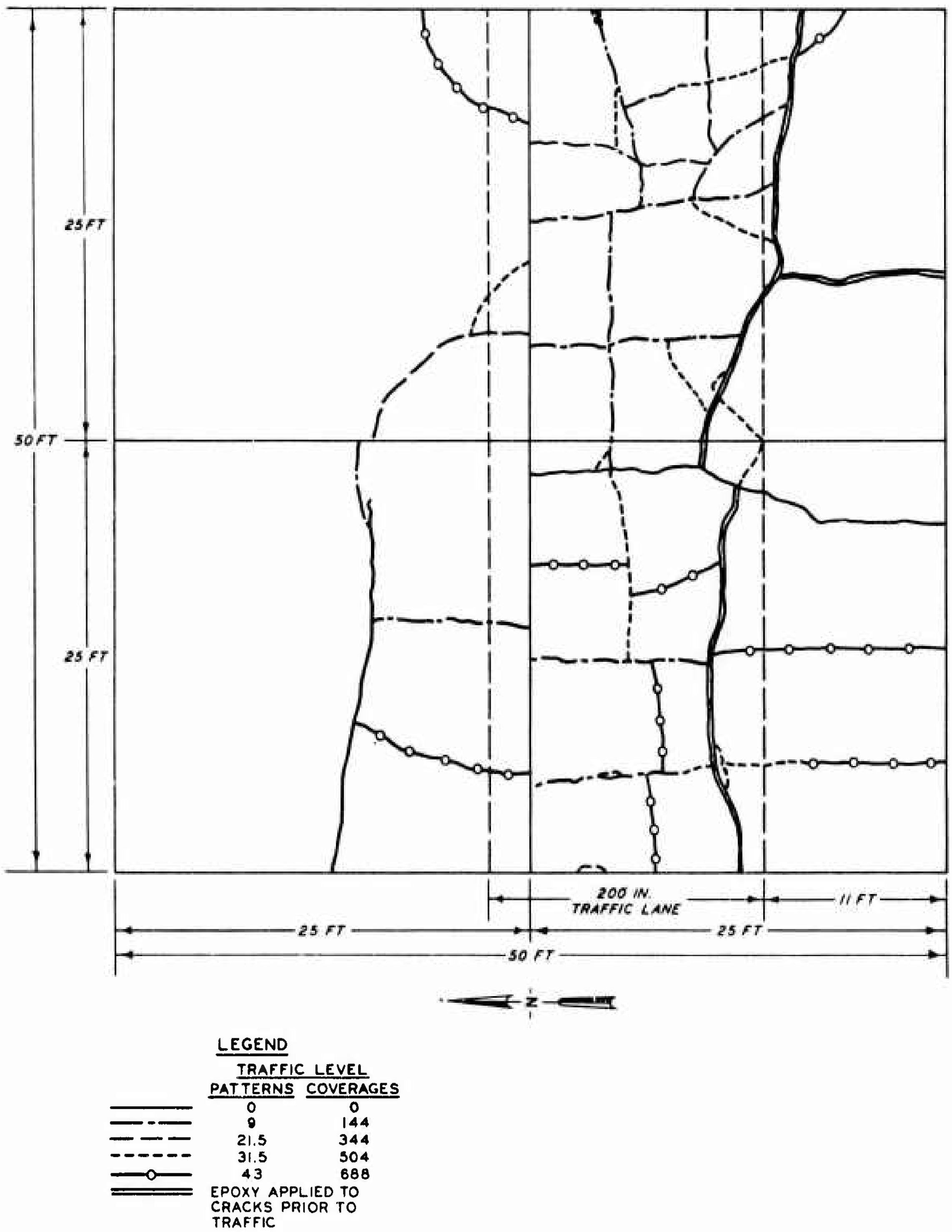


Figure 46. Crack development in item 3 under 360-kip, 12-wheel-assembly traffic.

the doweled longitudinal construction joint. After 96 coverages, the crack had progressed approximately 14 ft across the slab to a longitudinal crack that had been epoxied prior to traffic. After 9 patterns of traffic (144 coverages), the surfaces of the southwest and southeast slabs had subdivided into 4 and 8 pieces, respectively, as indicated in figures 46 and 47. Although the southeast slab met the shattered-slab failure criterion at this time, traffic was continued because the longitudinal construction joint was performing satisfactory.

As traffic was continued, several transverse and longitudinal cracks developed in the southeast and southwest slabs and the existing cracks, mainly transverse, were working. After 31.5 patterns (504 coverages), the east slab in the south lane was broken into 19 pieces and the west slab in the lane was subdivided into 5 pieces. The general condition of this item after 31.5 patterns is shown in figure 48. Figure 49 depicts the extent of flaking and spalling that had developed at the crack between the two south slabs at the 31.5 traffic pattern level. Only slight working of the other cracks was noticed at this time. During the next 12.5 patterns of traffic, two longitudinal and four transverse cracks developed in the southwest slab; 11-ft-long transverse crack running from the longitudinal construction joint in an existing longitudinal crack in the northwest slab was detected; and a corner break occurred in the northeast slab. An overall view of item 3 after 43 patterns (688 coverages) is shown in figure 50. As can be seen, severe spalling had occurred in several of the transverse cracks located in the two south slabs. A close-up of a typical spalled area after loose material was removed is shown in figure 51. Due to the severe spalling of several of the transverse cracks and the number of pieces into which the two south slabs had subdivided, test traffic was stopped after 43 patterns of traffic (688 coverages). At the end of traffic, both slabs in the south lane were subdivided into more pieces than that constituting shattered-slab failure. The progression of cracking with traffic is shown in figure 46. The doweled longitudinal construction joint performed very well during test traffic; it was rated as in satisfactory condition at the end of traffic.

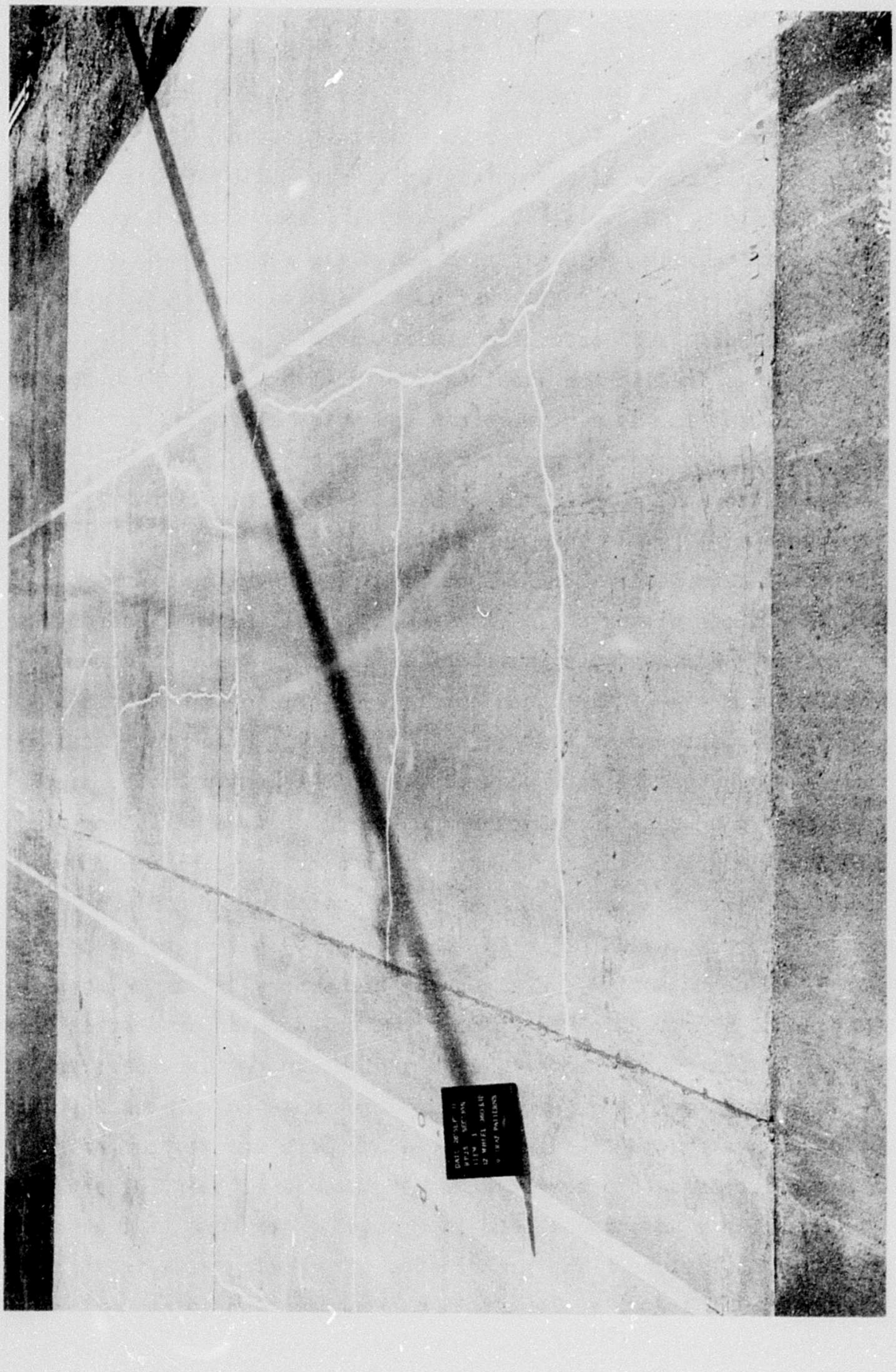


Figure 47. Item 3, 360-kip, 12-wheel-assembly lane after 144 coverages.

Figure 48. Item 3, 360-kip, 12-wheel-assembly lane after 504 coverages.

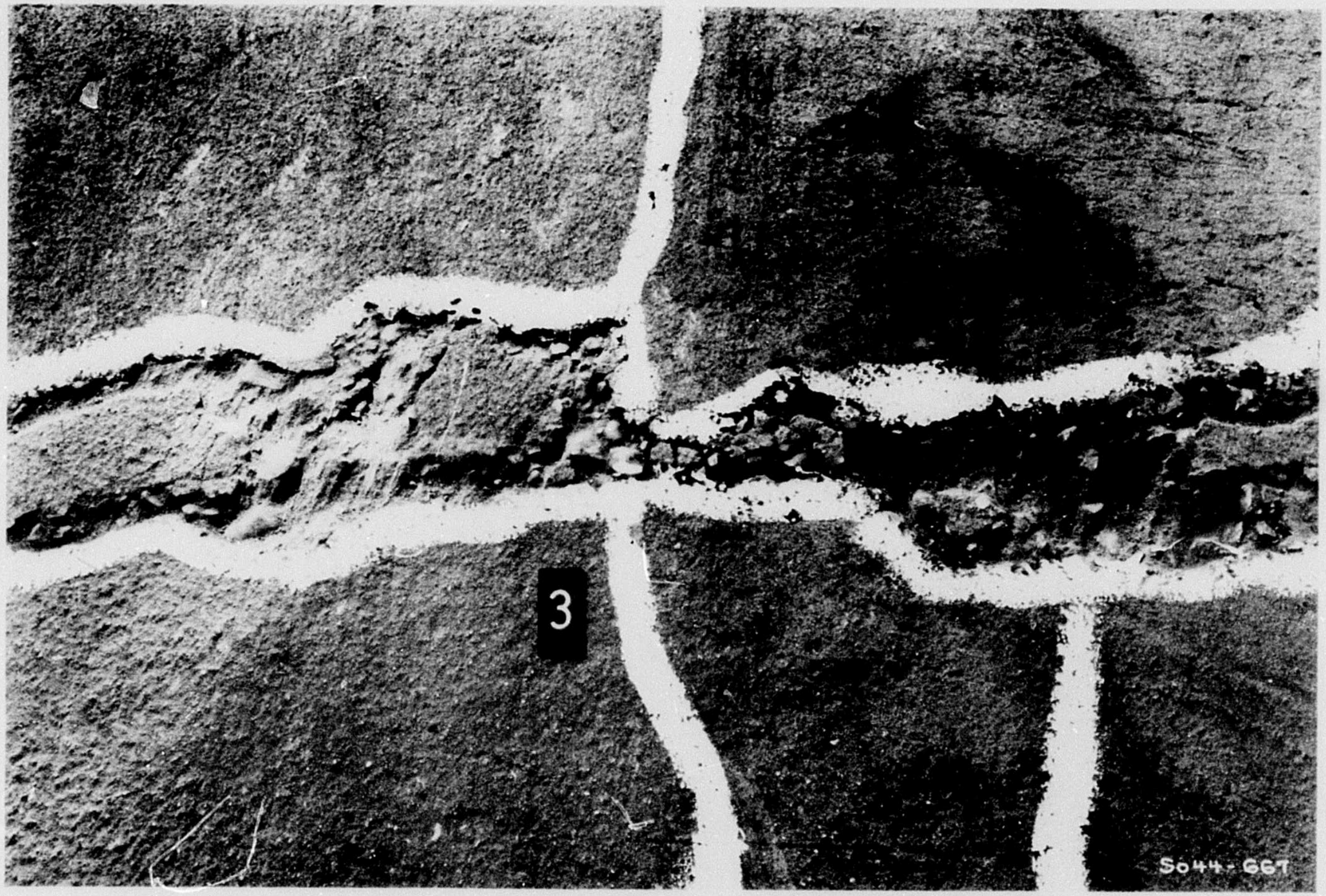


Figure 49. Spalling and flaking along cracks in item 3, 360-kip, 12-wheel-assembly lane after 504 coverages.

Figure 50. Item 3, 360-kip, 12-wheel-assembly lane after 688 coverages.

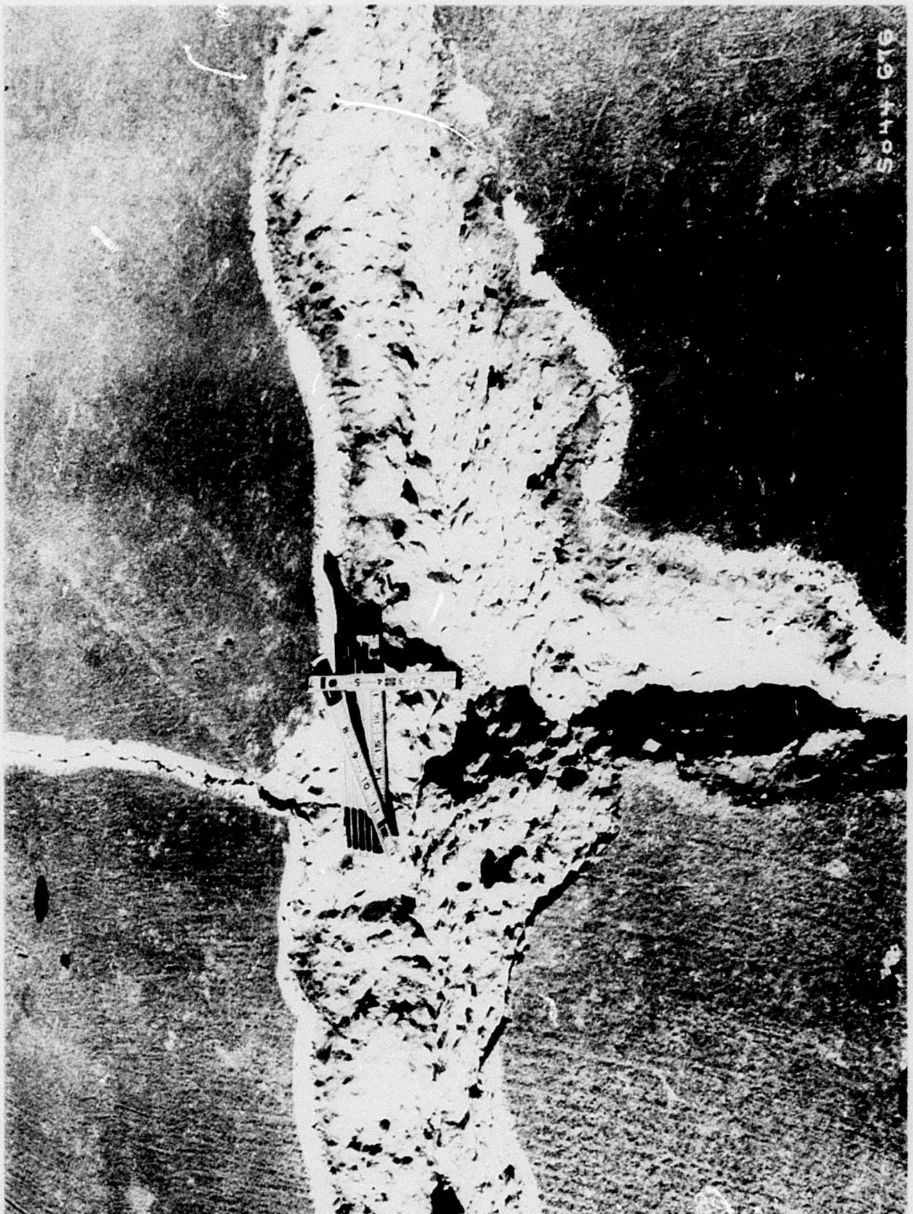


Figure 51. Typical spalled area in item 3, 360-kip, 12-wheel-assembly lane after 688 coverages.

Slight pumping was observed at either end of the item when test traffic began and pumping was also observed during or the day after a rain. In the interior portion of the item, only clear water was seen squirting through the cracks during the trafficking of this item.

The typical cross-section plot of item 3 shown in figure 52 indicate that the average permanent deformation after 688 coverages (prior to overlaying) was about 0.18 in., and the maximum deformation measured was 0.24 in.

A specimen was removed from the northwest corner of the southeast slab after applying 688 coverages on the original test item and 5008 coverages on the 4-in.-thick overlay. Figure 53 shows the satisfactory condition of the doweled longitudinal construction joint, which was exposed after removing the specimen. Therefore, it can be assumed that the doweled construction joint was in satisfactory condition when the original item was considered a shattered-slab failure.

5. Item 4

There were no defects in item 4 prior to traffic, as shown in figure 54. Pumping at the joints between the transition areas and the east and west ends of the item was noted after only 1.5 traffic patterns (24 coverages) and became progressively worse as traffic continued. The first crack was observed during the 54th traffic pattern (864 coverages). This was a half-moon-shaped crack located at the west end of the item. The pumping is believed to have contributed to this break and to the large corner breaks detected in the southeast and northeast slabs after 83 patterns of traffic (1328 coverages). These two corner breaks were the only additional distress observed at the 1328-coverage level. A general view of this item showing the crack pattern after 83 traffic patterns is shown in figure 55. After 146 traffic patterns (2336 coverages), the western edge of the half-moon-shaped crack in the southwest slab was approximately 1/2-in. below its original elevation due to the pumping of the subgrade material beneath the slab, and a 4-ft longitudinal crack was observed running from the west edge of the slab to the existing half-moon-shaped crack. These moon-shaped cracks at each end of the test item were

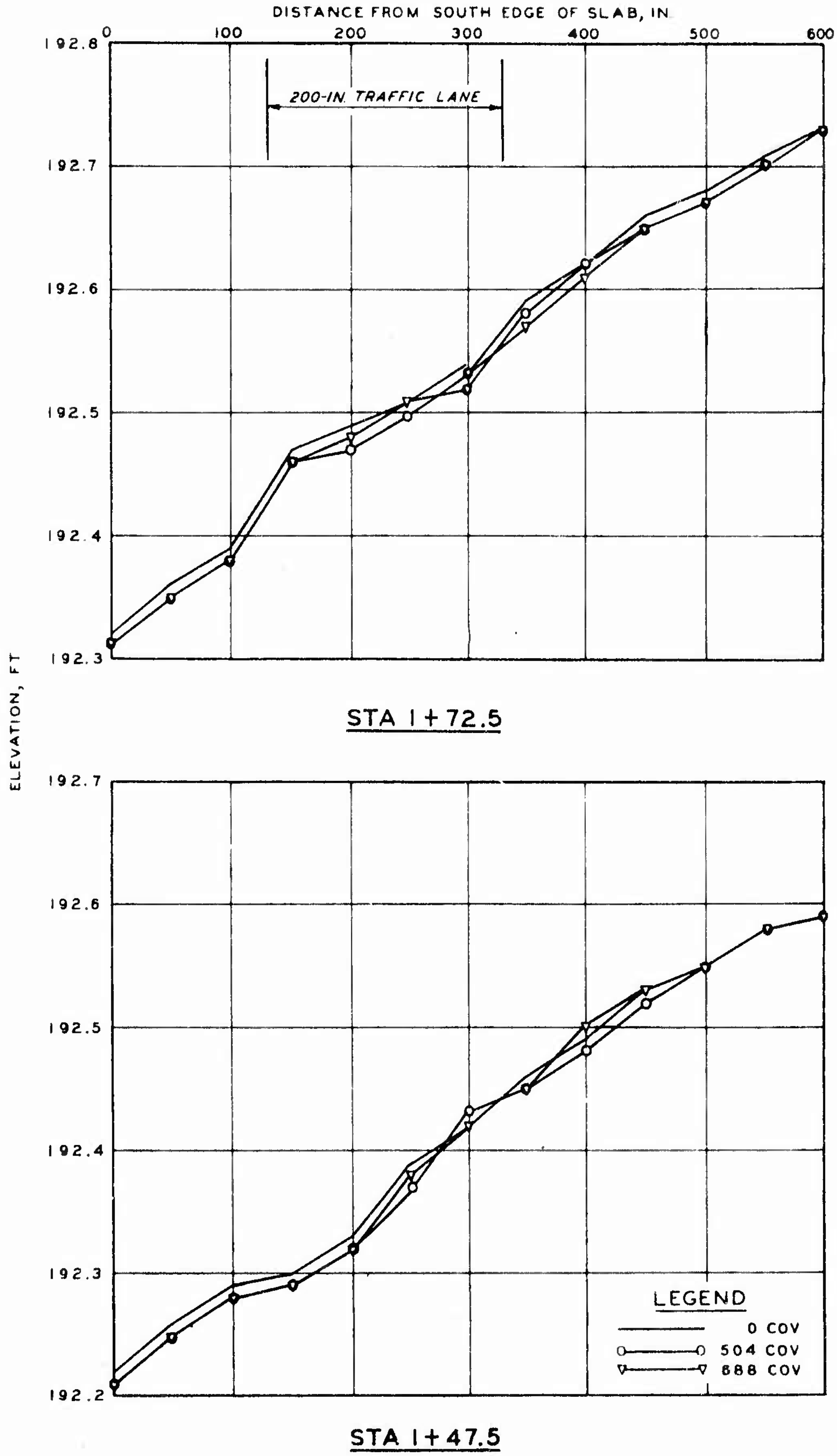


Figure 52. Typical cross sections of item 3, 360-kip, 12-wheel-assembly lane.

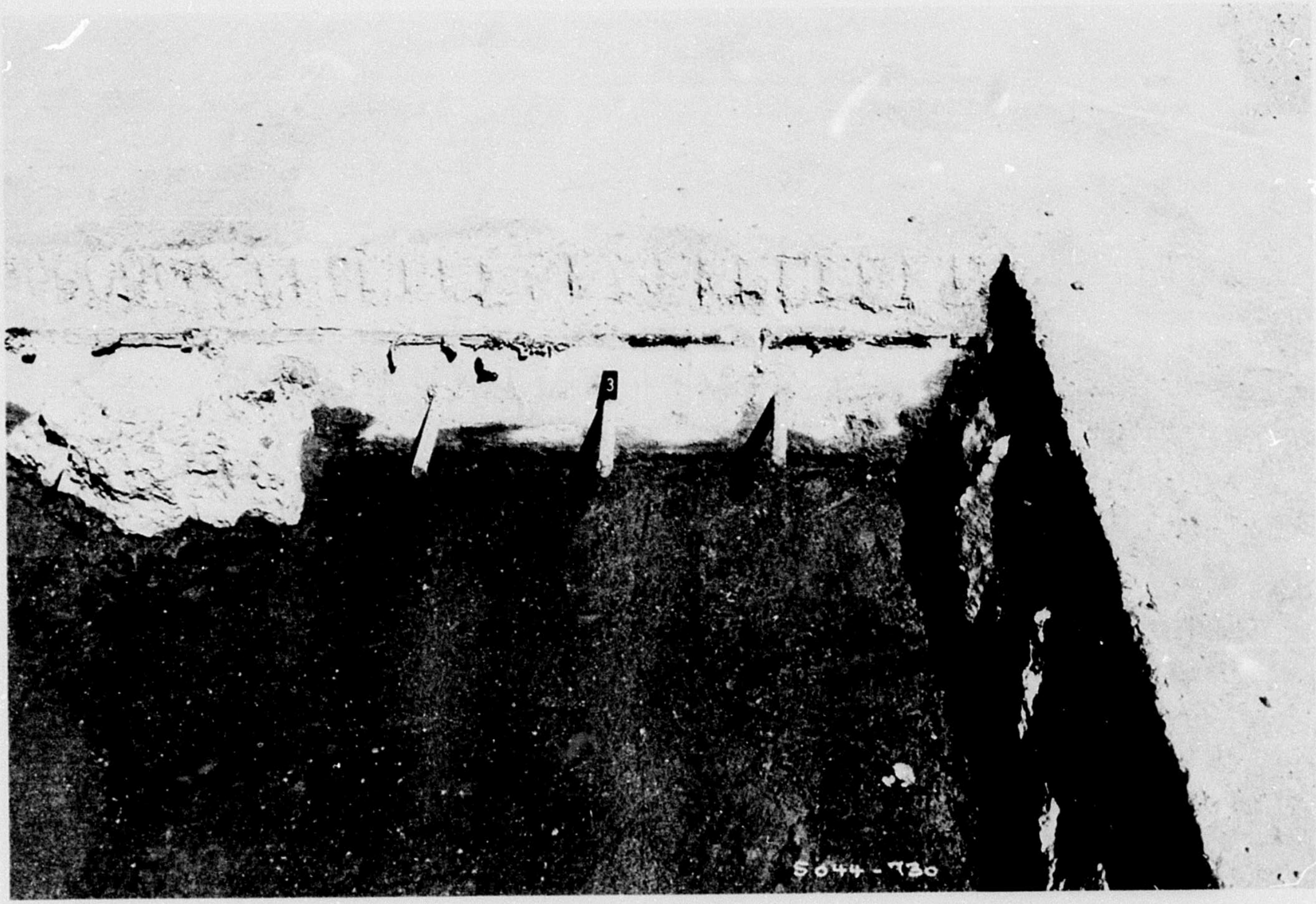


Figure 53. View of doweled longitudinal construction joint in item 3, 360-kip, 12-wheel-assembly lane after 688 coverages prior to overlaying and 5008 coverages after overlaying.

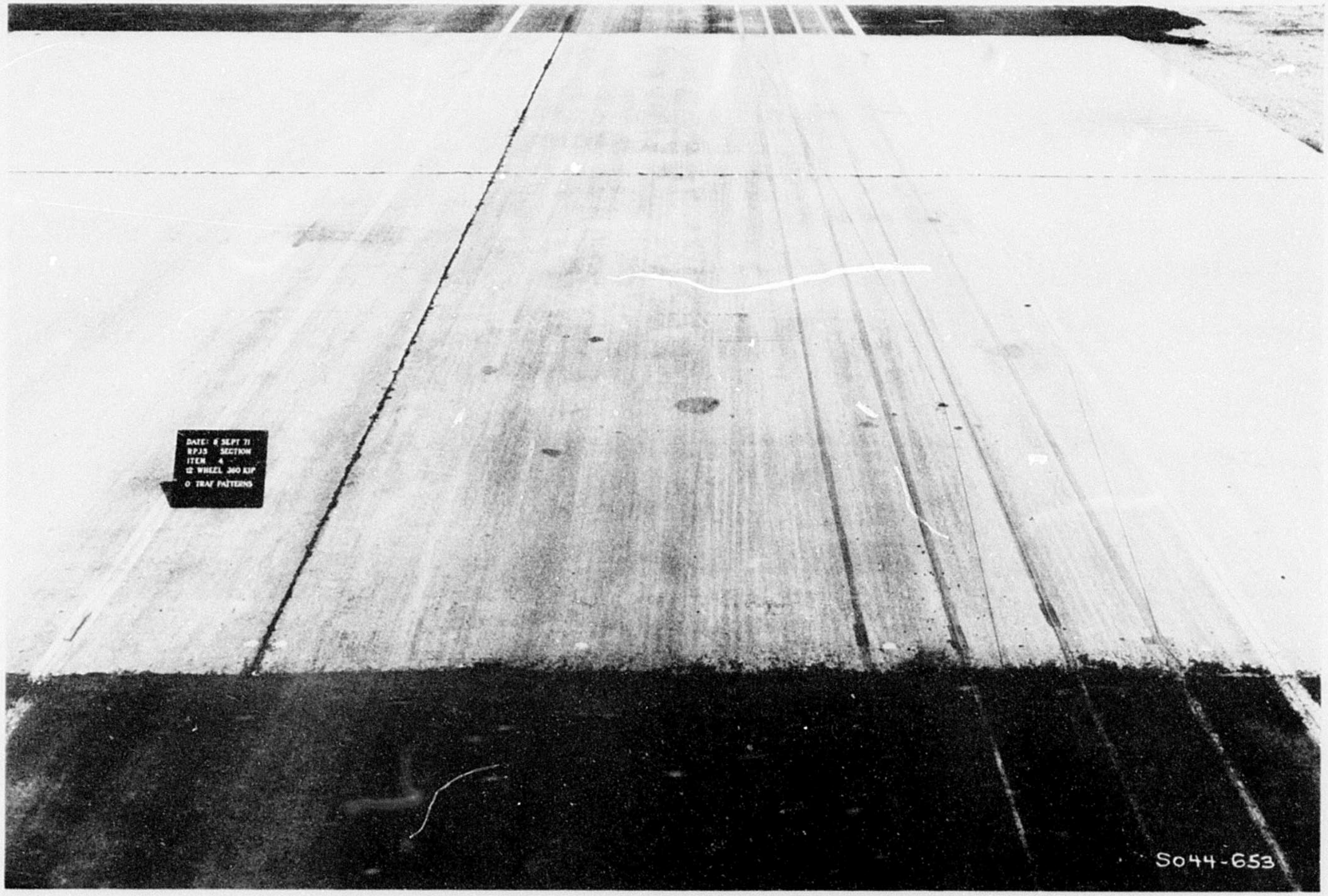


Figure 54. Item 4, 360-kip, 12-wheel-assembly lane prior to traffic.

Figure 55. Item 4, 360-kip, 12-wheel-assembly lane after 1328 coverages.

undoubtedly the result of low load transfer across the transverse joint between the test item and transition slab, which in turn aggravated the pumping problem and loss of subgrade support at the joint. These type cracks would normally not occur when load transfer at the joints is adequate.

After 200 patterns (3200 coverages), approximately 6 ft of the western end of the item was overlaid with landing mat to provide a smooth transition between the test item and transition area because the test slab had sunk about 2 in. due to severe pumping. A longitudinal crack located in the southeast slab was the only other crack observed during test traffic. This crack was detected at the end of traffic, 396 patterns (6336 coverages); however, it could have occurred prior to this and not detected due to the mud and muddy water covering the slab during the last 197 traffic patterns. The mud and muddy water covering the slab was the result of a combination of rain and of pumping at both ends of this test item. The progression of cracking is shown in figure 56; a general view of the item after traffic is shown in figure 57.

At the end of traffic (6336 coverages), the entire item was rated as in satisfactory condition, and the longitudinal construction joint was in excellent condition. Very little spalling was observed during the trafficking of this item. Traffic was discontinued because indications were that a large number of coverages would be required to produce a shattered-slab failure condition in the interior portion of the test item. It should be pointed out that the transition slabs were constructed directly on the clay subgrade during the initial construction of the MWHGL test section and were left in place for this test. This resulted in the pumping problem as discussed above. There was no evidence of subgrade pumping through the stabilized base course at any location in the test item.

A typical cross section for this item indicating the permanent deformation due to traffic is shown in figure 58. The average permanent deformation was about 0.48 in. and the maximum deformation was 0.60 in. This plot indicates that about 75 percent of the average

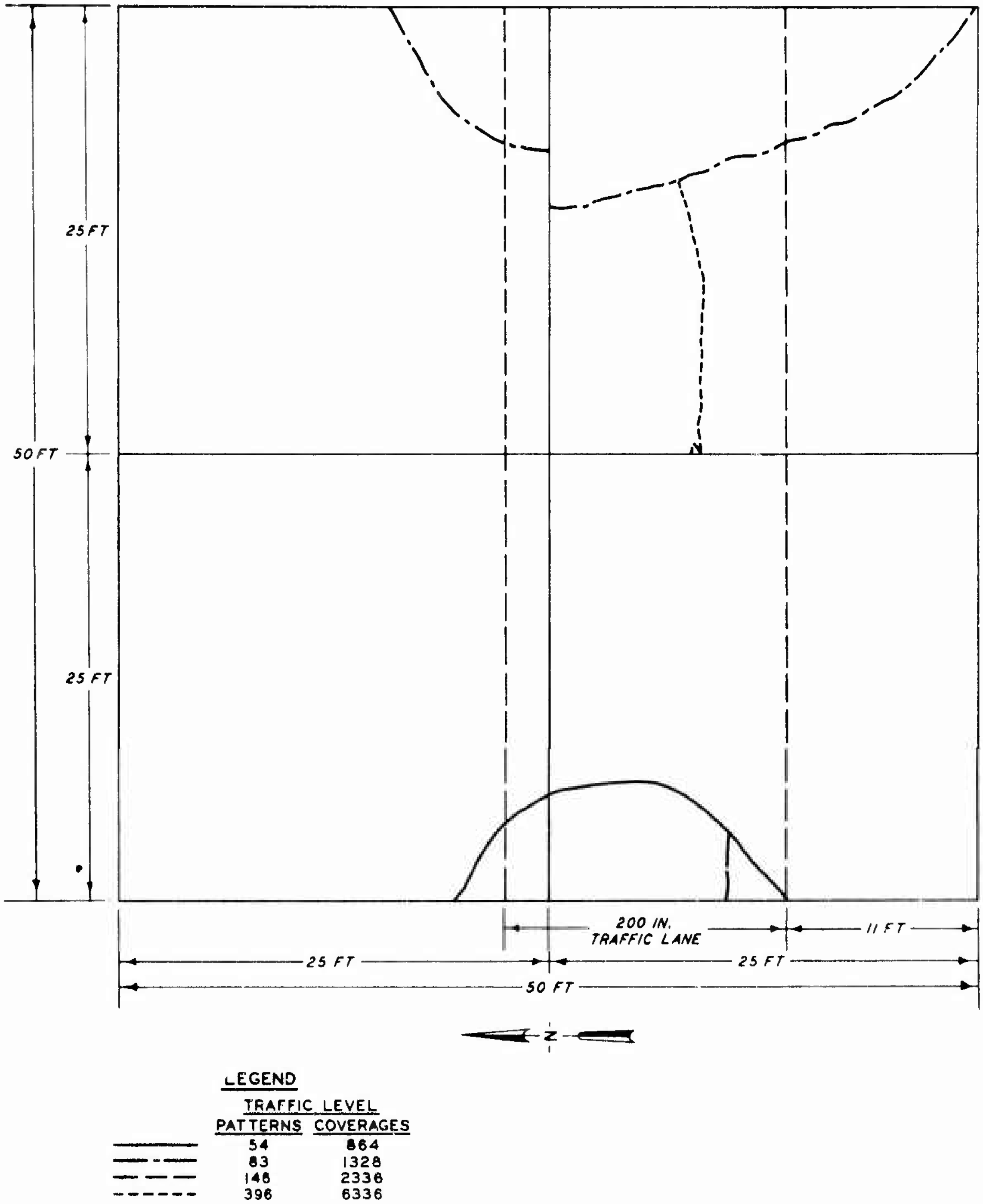


Figure 56. Crack development in item 4 under 360-kip, 12-wheel-assembly traffic.

Figure 57. Item 4, 360-kip, 12-wheel-assembly lane after 6336 coverages.

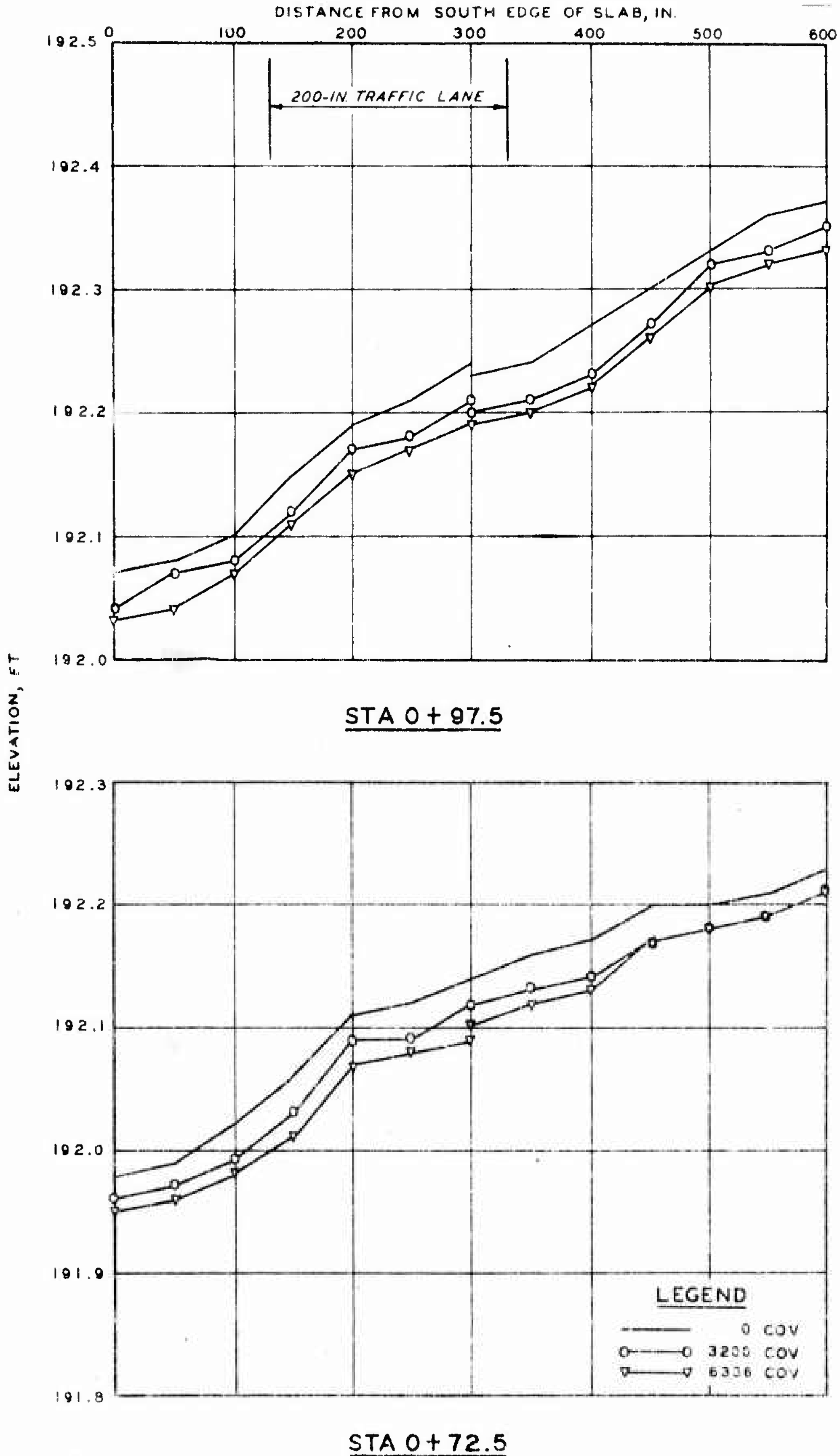


Figure 58. Typical cross sections of item 4, 360-kip, 12-wheel-assembly lane.

permanent deformation occurred between 0 and 3200 coverages with the remaining 25 percent occurring between 3200 and 6336 coverages.

The keyed longitudinal construction joint was inspected after a concrete specimen was removed from the northwest corner of the southeast slab. Both the key and keyway of this joint were in good condition when the specimen was removed. A view of the keyway is shown in figure 59.

C. Behavior of Pavement Under Twin-Tandem-Assembly Traffic

1. General

The behavior of each test item subjected to the 166-kip, twin-tandem-assembly traffic as determined from visual observations and measurements made during the traffic is discussed in the following paragraphs. The performance of item 3 which was overlaid with 4 in. of fibrous-wire concrete prior to the twin-tandem traffic will be reported by the CERL.

2. Item 1

A general view of the item prior to traffic is shown in figure 60. As can be seen, both slabs contained cracks prior to traffic. The longitudinal crack in about the center of the traffic lane of the northwest slab was detected prior to the 12-wheel-assembly traffic; the remaining cracks developed during the 12-wheel-assembly traffic. When the twin-tandem traffic was commenced, pumping was observed at the existing longitudinal crack in the northwest slab. The initial crack due to traffic, a 6-ft-long longitudinal crack in the northeast slab, was detected after 4 coverages of traffic and continued to progress and extended the length of the slab after 35 coverages. After 35 coverages, several diagonal cracks and another longitudinal crack had developed in the northeast slab, and a longitudinal and several transverse cracks were observed in the northwest slab. Traffic was discontinued after 35 coverages when the item was considered to be a shattered-slab failure. A general view of the item at failure is shown in figure 61. The progression and extent of cracking during the traffic period is shown in figure 62.

Figure 59. View of keyed longitudinal construction joint in item 4, 360-kip, 12-wheel-assembly lane after 6336 coverages.

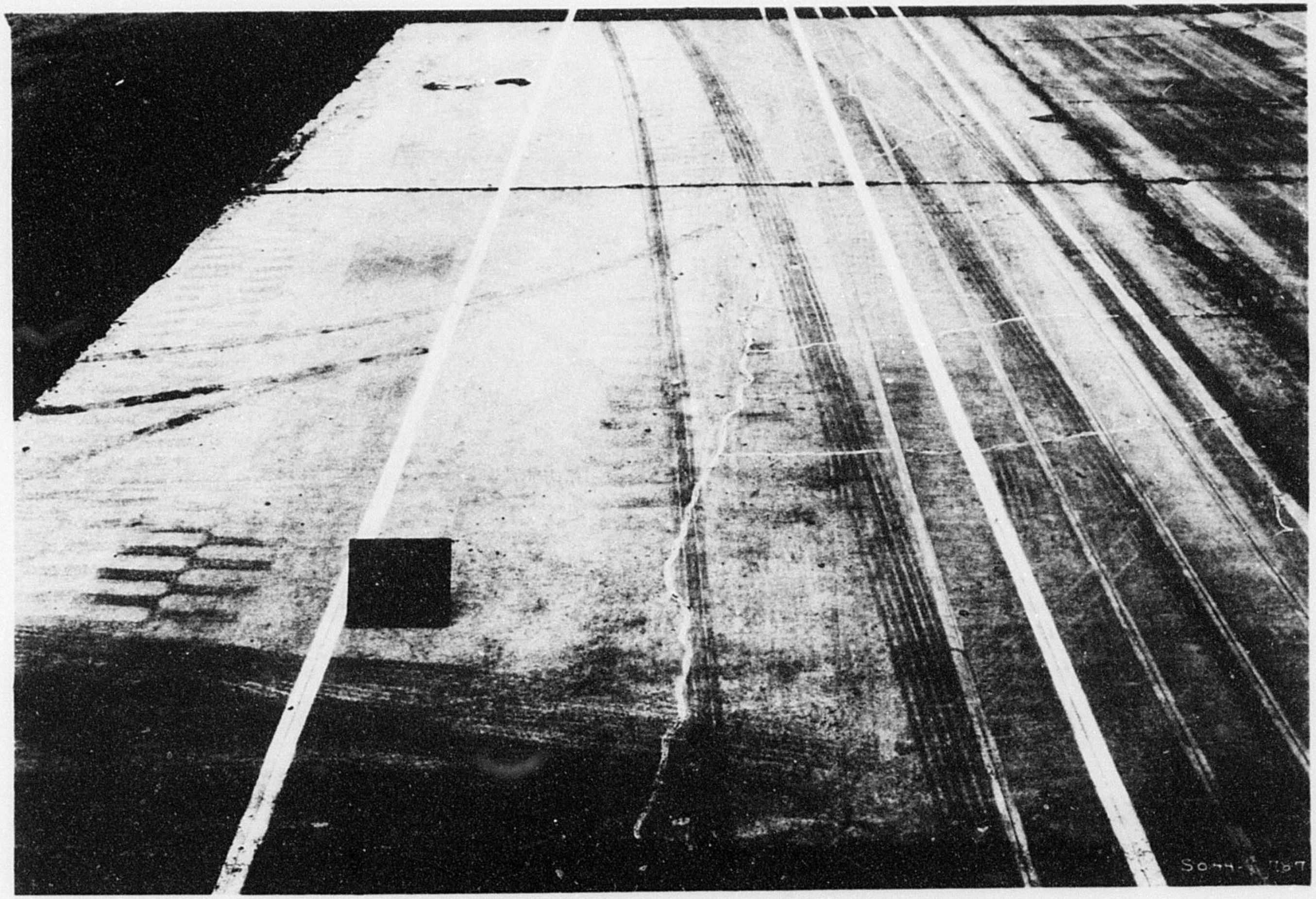


Figure 60. Item 1, 166-kip, twin-tandem-assembly lane prior to traffic.

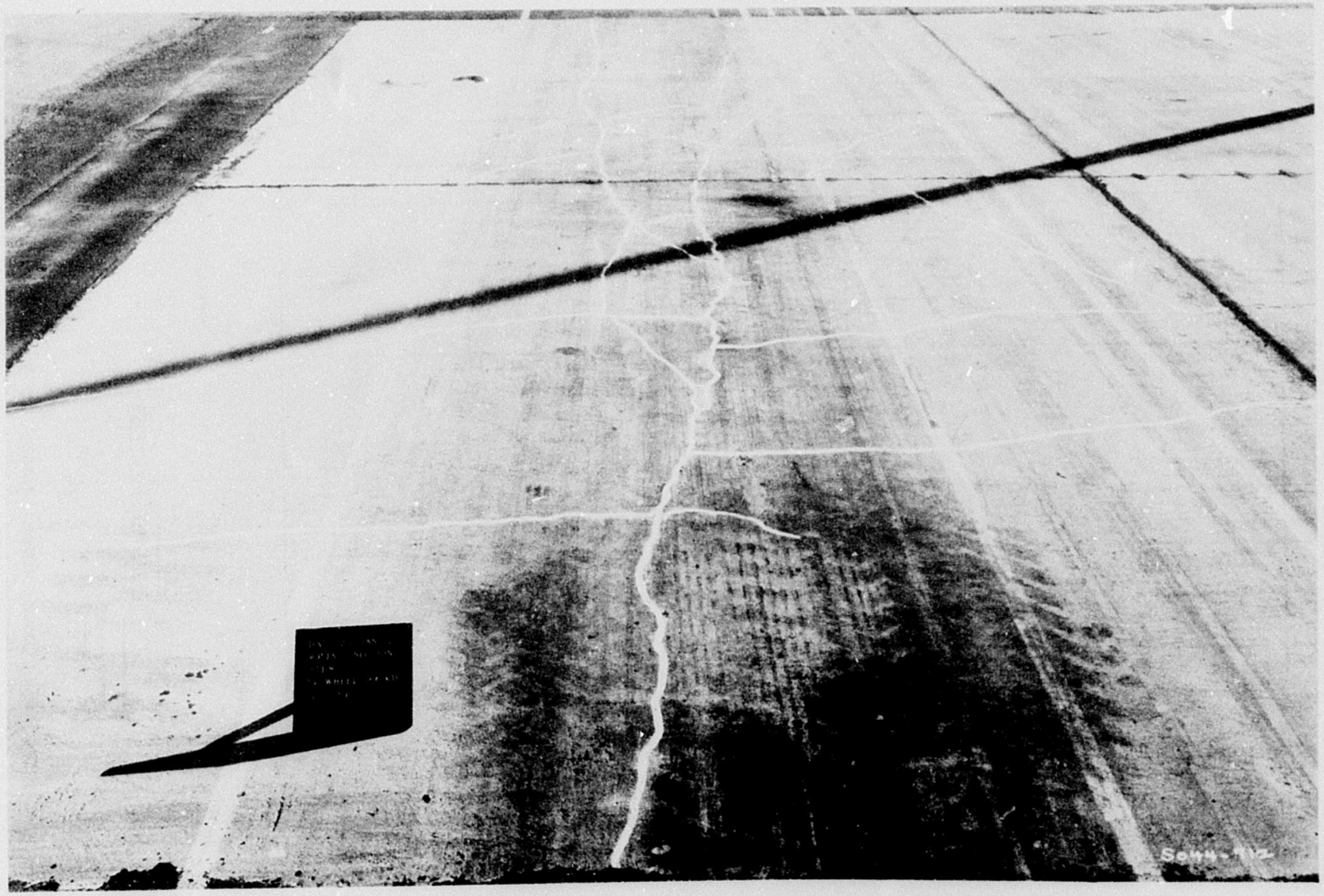


Figure 61. Item 1. 166-kip. twin-tandem-assembly lane after 35 coverages.

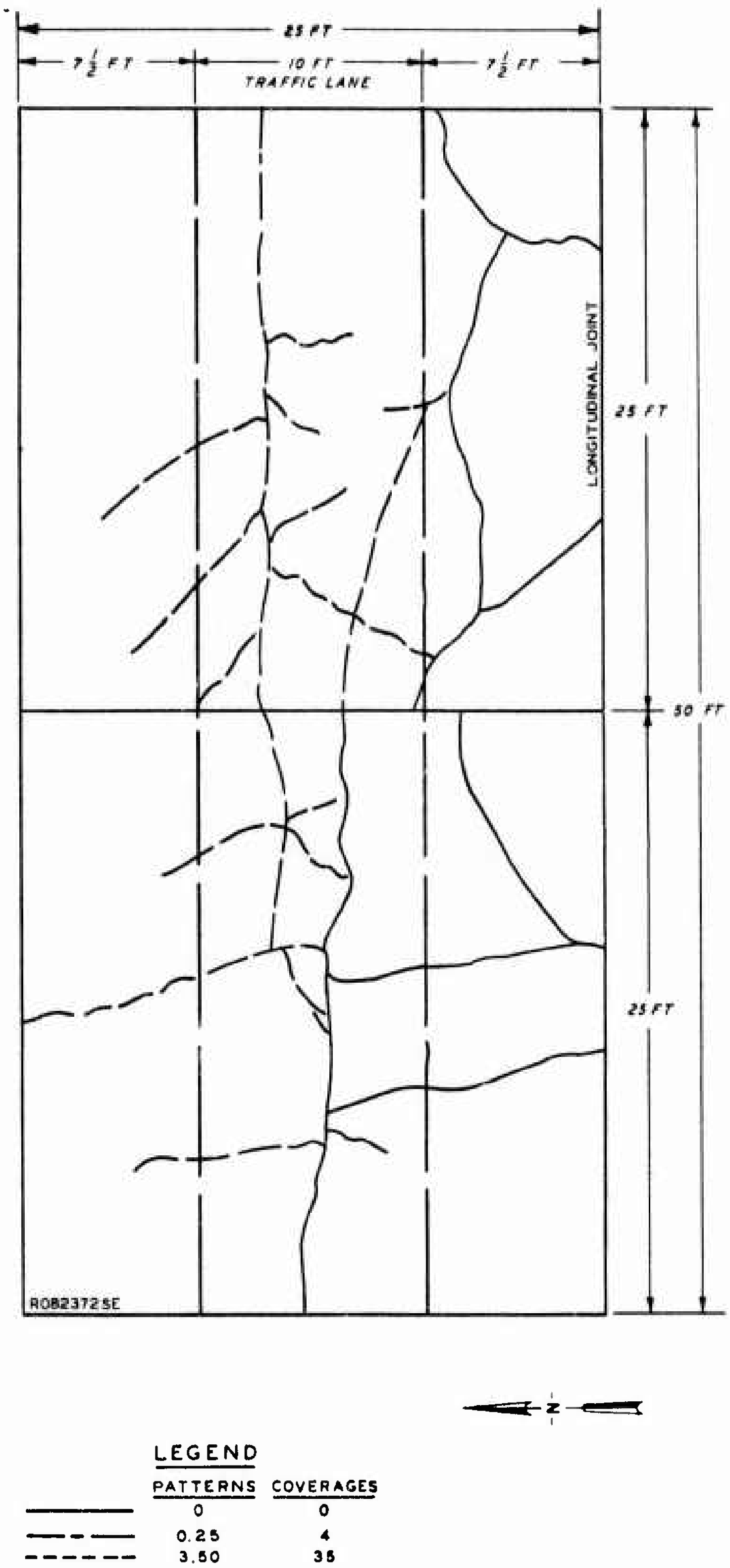


Figure 62. Crack development in item 1 under 166-kip, twin-tandem-assembly traffic.

Typical permanent deformations, which occurred as a result of traffic, are shown by the typical cross-sections taken at the center of each slab (figure 63). An average deformation of about 0.15 in. and a maximum of 0.36 in. were recorded. The maximum total deflection measured prior to traffic was about 0.12 in. Plots of deflection measurements taken prior to traffic are shown in figure 64.

3. Item 2

The condition of item 2 prior to traffic is shown in figure 65. Corner cracks were present in both slabs before traffic commenced. The first distress observed under traffic occurred at 120 coverages and consisted of longitudinal cracks commencing at either end of the item and running about 6 ft into the item. As traffic was continued, pavement cracking progressed rather rapidly. After 170 coverages, traffic was stopped and the item was considered to be a shattered-slab failure. At the end of traffic, both slabs contained several diagonal cracks, spalling and flaking were present at the existing cracks, and each slab was subdivided into six or more pieces. A general view of the item at failure is depicted in figure 66; a plot indicating the extent and progression of cracking during traffic is shown in figure 67.

Typical cross-section plot showing the permanent deformation that occurred during traffic is shown in figure 68. The maximum deformation measured at the conclusion of traffic was 0.24 in. As shown in figure 69, a maximum total deflection of about 0.13 in. was measured prior to traffic.

4. Item 4

Prior to test traffic, there were corner cracks located at the southeast corner of the northeast slab and at the southwest corner of the northwest slab of item 4. Figure 70 is a general view of the item prior to traffic. The first crack observed during traffic was a hairline longitudinal crack in approximately the center of the traffic lane and extending the length of the item. This crack was detected after 320 coverages. Slight spalling of the existing longitudinal crack at the east end of the item was noticed after about 360 coverages. After 630

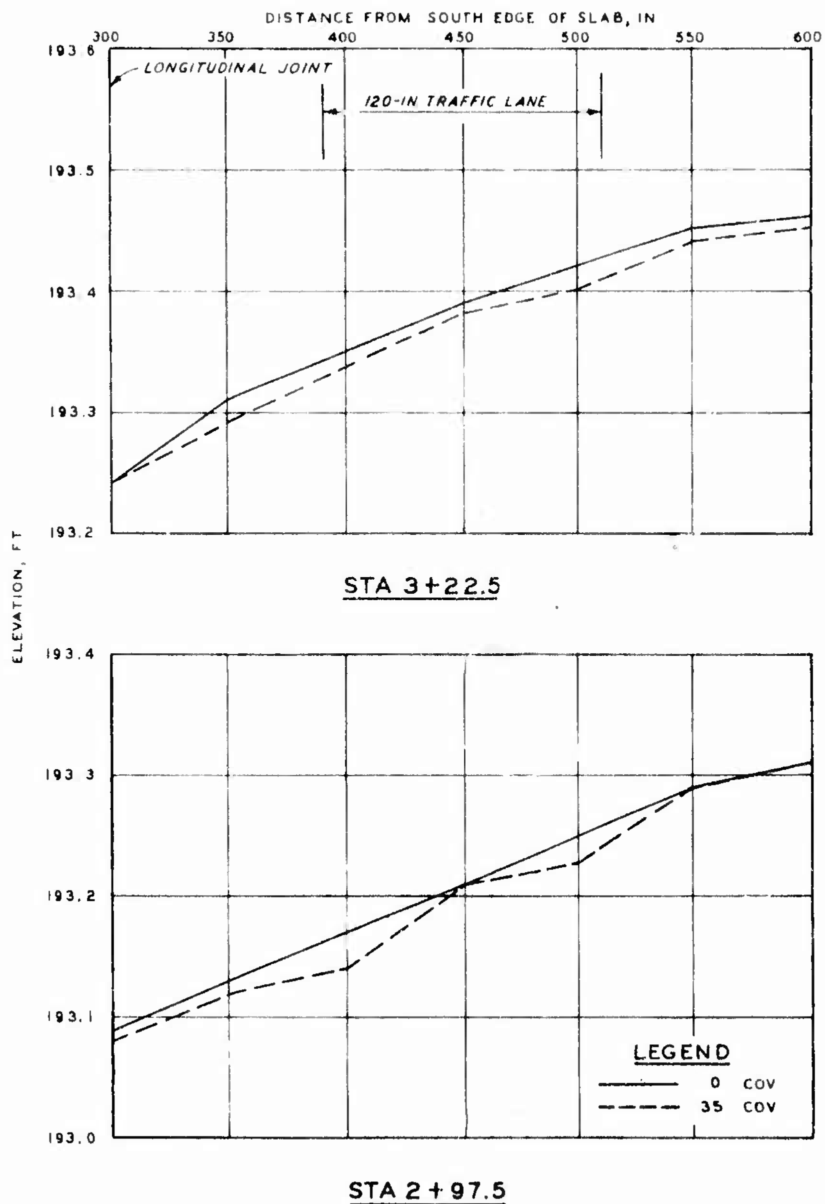


Figure 63. Typical cross sections of item 1, twin-tandem-assembly lane.

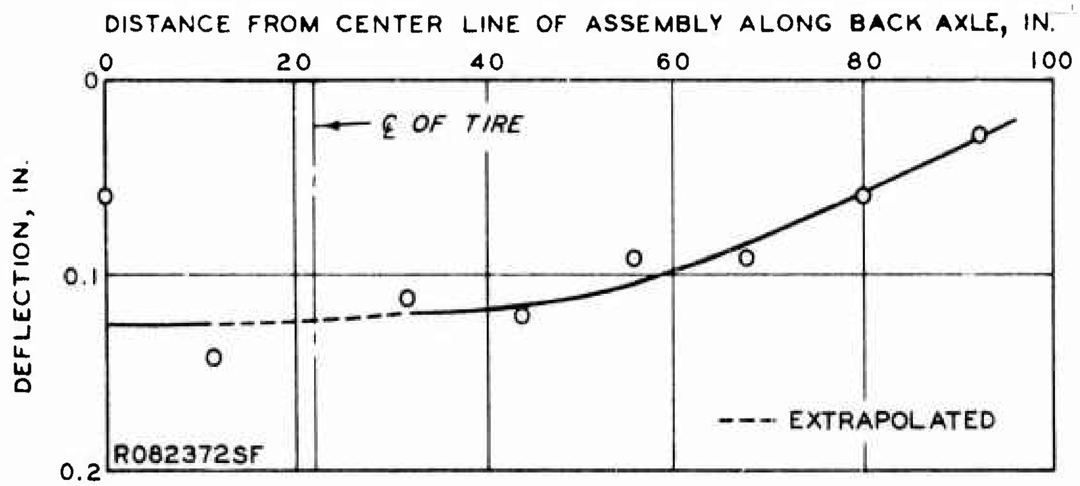


Figure 64. Total deflection in item 1, 166-kip, twin-tandem-assembly lane measured prior to traffic.

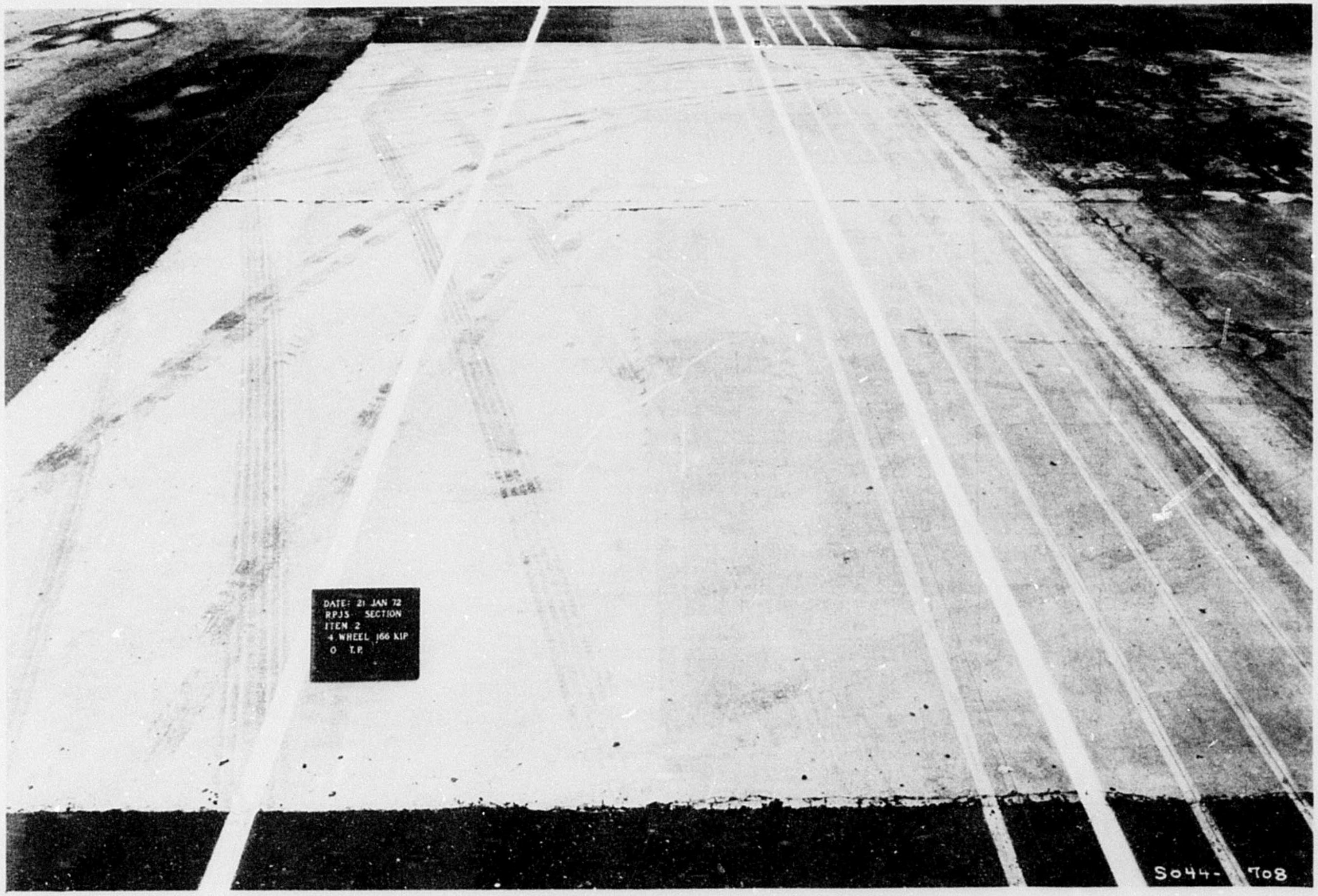


Figure 65. Item 2, 166-kip, twin-tandem-assembly lane prior to traffic.

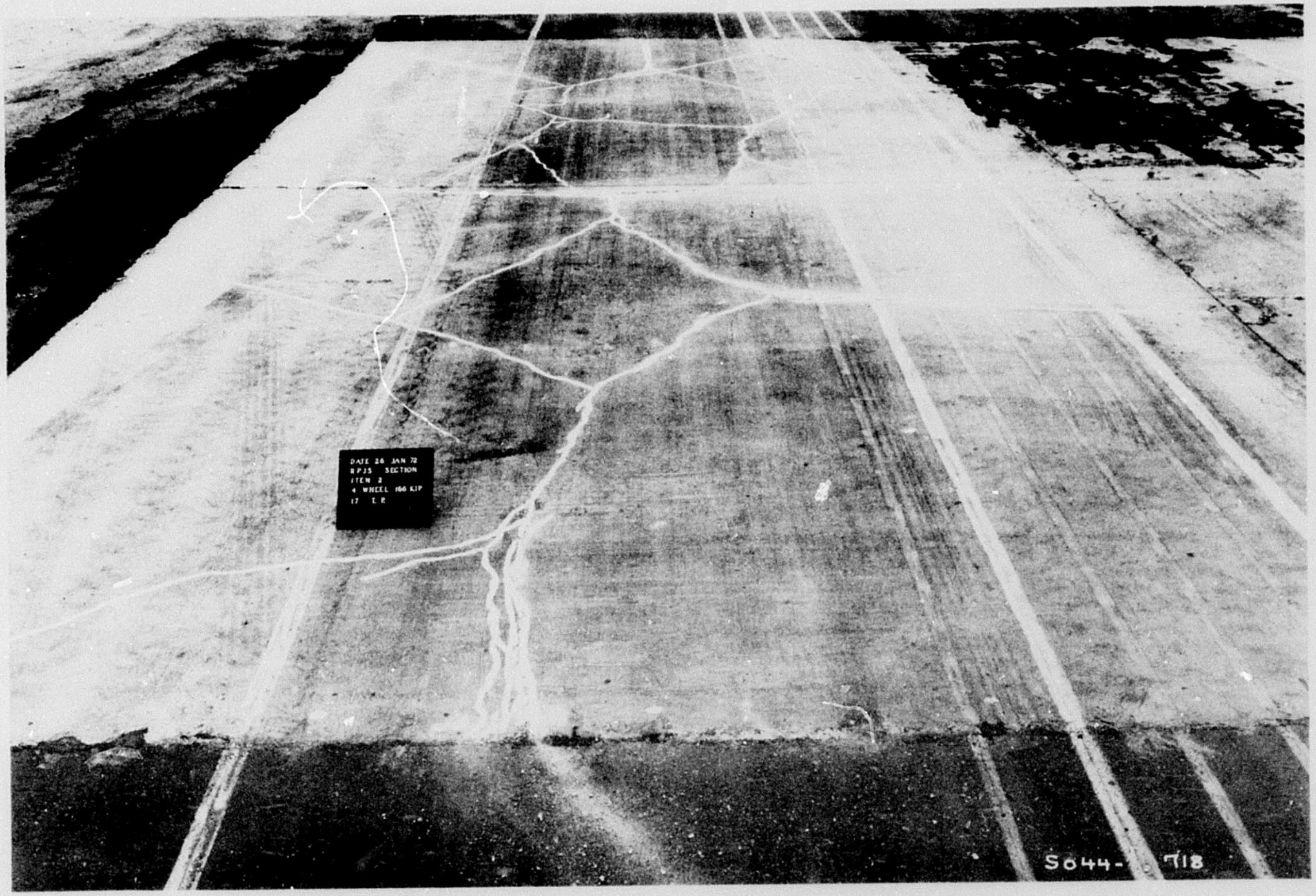
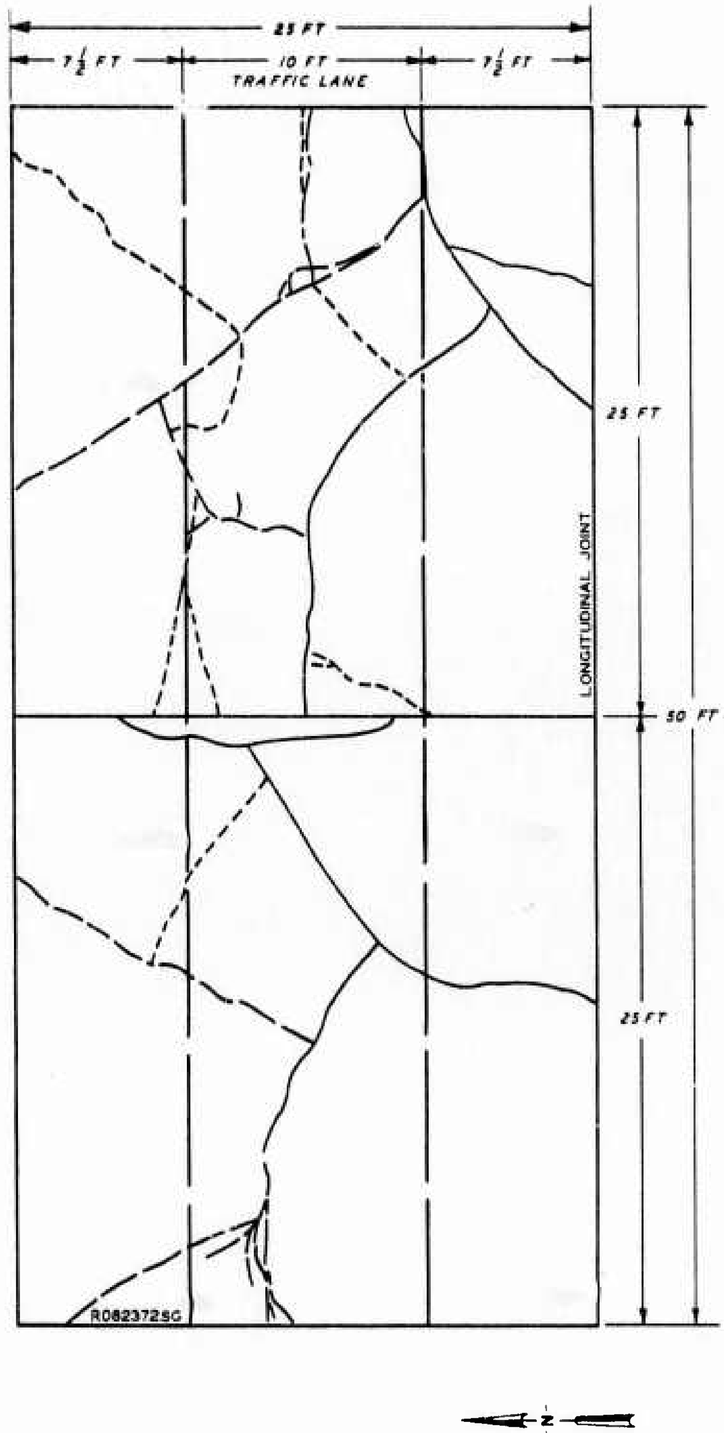


Figure 66. Item 2, 166-kip, twin-tandem-assembly lane after 170 coverages.



	PATTERNS	COVERAGES
———	0	0
— - - —	12	120
— — —	13	130
- - - - - -	17	170

LEGEND

Figure 67. Crack development in item 2 under 166-kip, twin-tandem-assembly traffic.

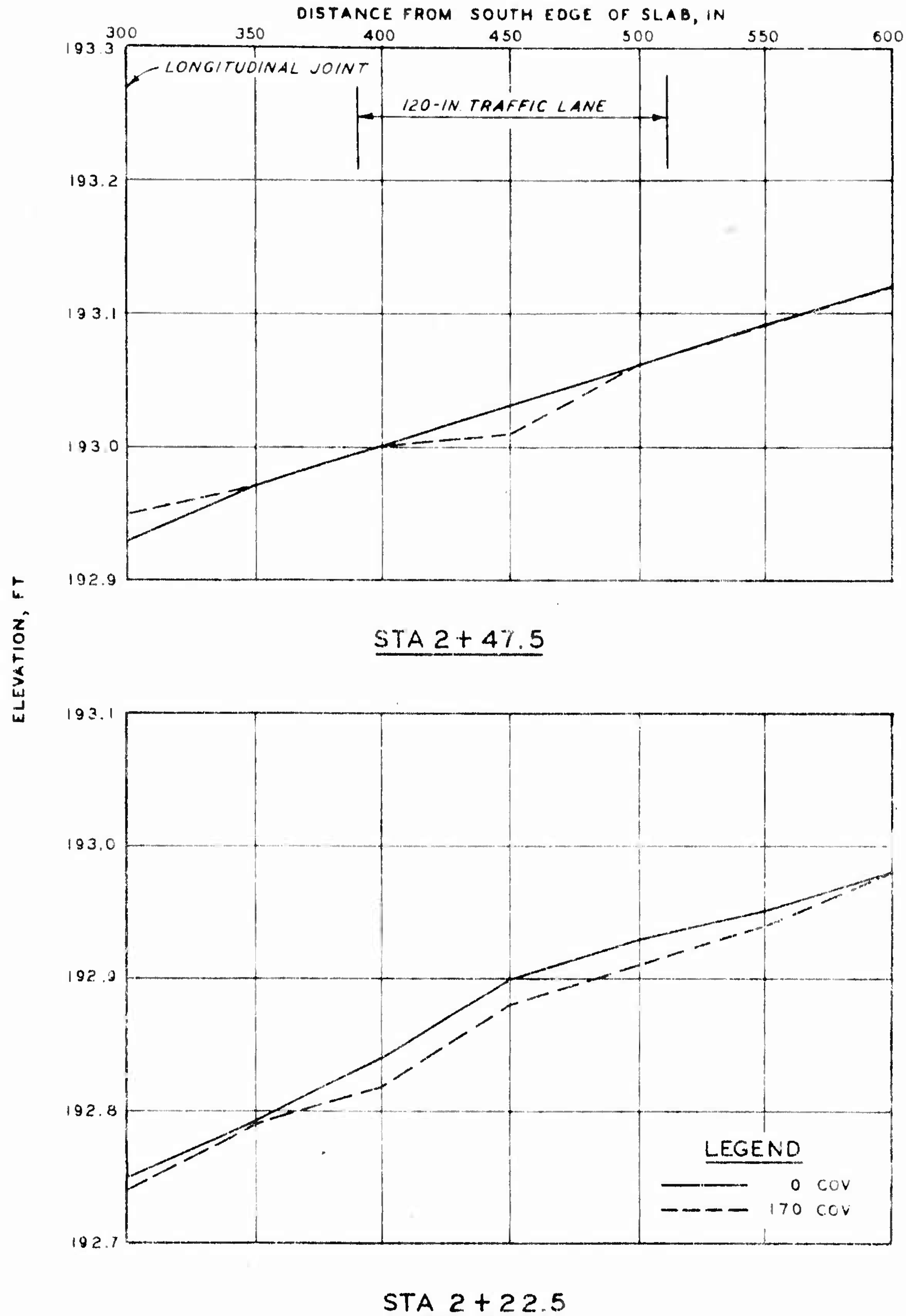


Figure 68. Typical cross sections of item 2, 166-kip, twin-tandem-assembly lane.

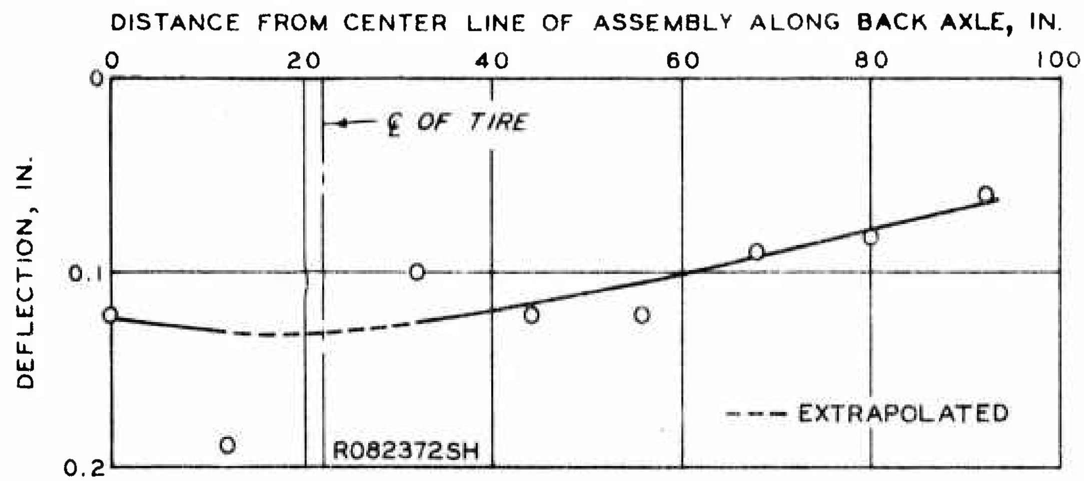


Figure 69. Total deflection in item 2, 166-kip, twin-tandem-assembly lane measured prior to traffic.

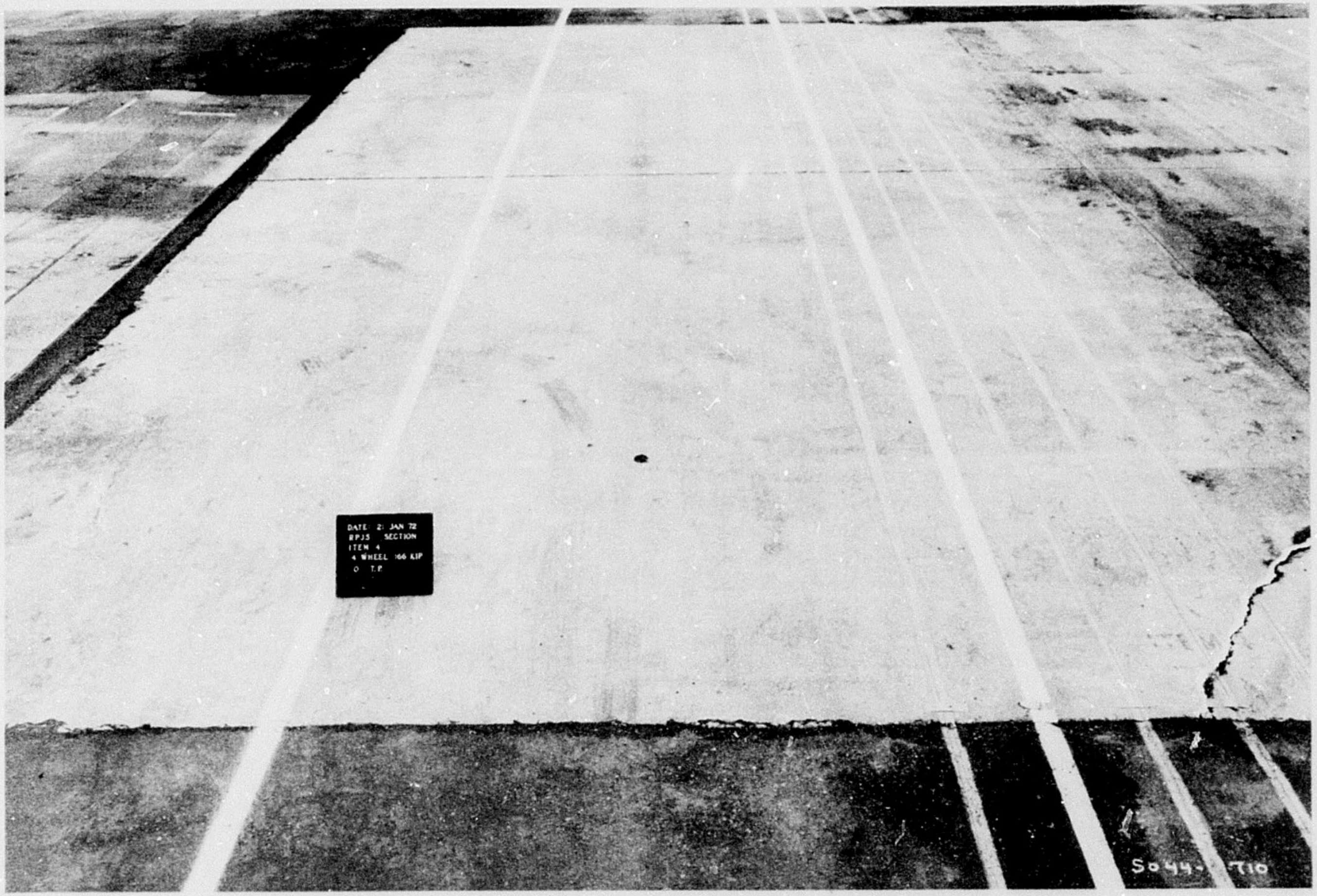


Figure 70. Item 4, 166-kip, twin-tandem-assembly lane prior to traffic.

coverages, a crack was observed running diagonally from the north edge of the pavement to the longitudinal crack in the middle of the traffic lane. Small hairline cracks extending transversely out from the longitudinal crack in the northwest slab were observed between 710 and 880 coverages. At the 950-coverage level, the transverse cracks in the northwest slab had progressed to the edges of the slab, which resulted in subdividing the slab into the shattered-slab condition, and traffic was stopped. Spalling and flaking, such as that shown in figure 71, were evident along most of the cracks at the end of traffic. The progression of cracking is shown by the crack pattern plot in figure 72, and the final condition of the item is shown in figure 73.

The maximum total deflection measured prior to traffic was about 0.09 in. A plot of the deflection basin measured before applying test traffic is shown in figure 74. As can be seen from the typical cross-section plots shown in figure 75, the average permanent deformation after failure was about 0.18 in., and the maximum permanent deformation was 0.24 in.

D. After-Traffic Test Program

1. General

An after-traffic test program was conducted in both paving lanes to establish the physical properties of the pavement and foundation materials, which was needed for the final evaluation of the pavement and longitudinal joint behavior. Table 3 contains a summary of these physical properties and results of the traffic testing. Nominal 6-in.-diam core samples were removed from each quarter of the four test items and tensile splitting tests were conducted on the samples. Flexural tests were conducted on two beams sawed from a slab sample that was removed from the south paving lane of item 4. Plate bearing tests, and CBR, density, and water-content determinations were used to evaluate the foundation materials. The test program utilized both laboratory and field tests.

2. Test program and results

A test pit was located in the south paving lane of each item. A 5- by 6-ft concrete specimen was removed from the northeast

Figure 71. Spalling and flaking along the cracks in item 4, 166-kip, twin-tandem-assembly lane after 950 coverages.

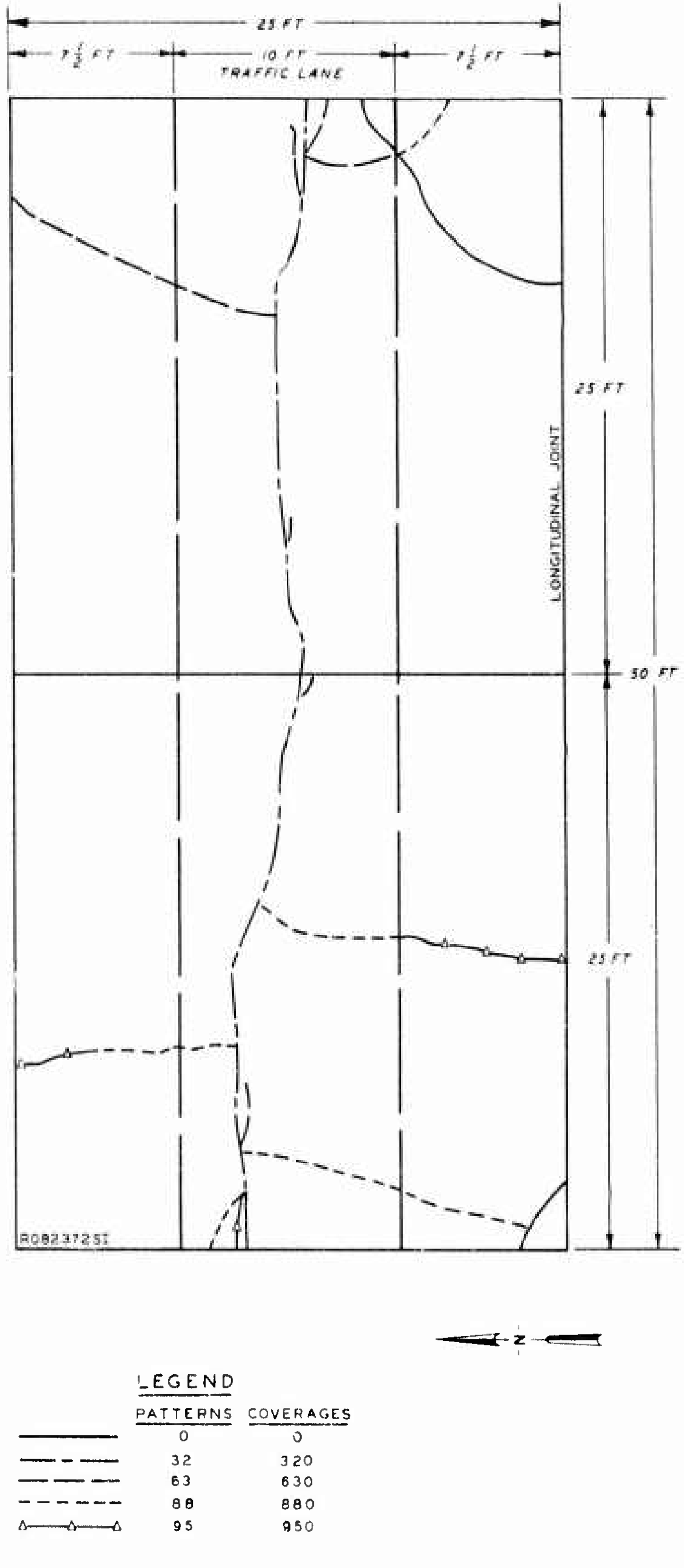


Figure 72. Crack development in item 4 under 166-kip, twin-tandem-assembly traffic.

Figure 73. Item 4, 166-kip, twin-tandem-assembly lane after 950 coverages.

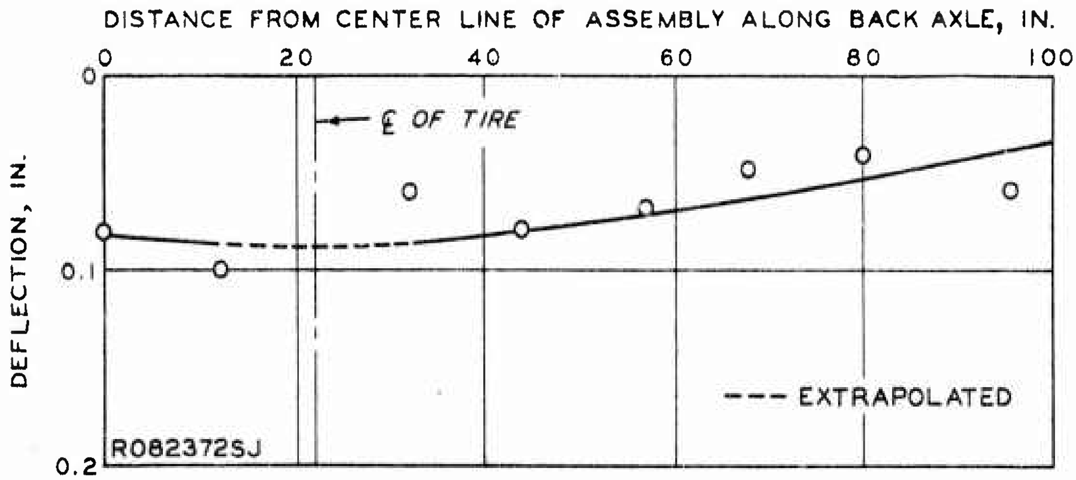


Figure 74. Total deflection in item 4, 166-kip, twin-tandem-assembly lane measured prior to traffic.

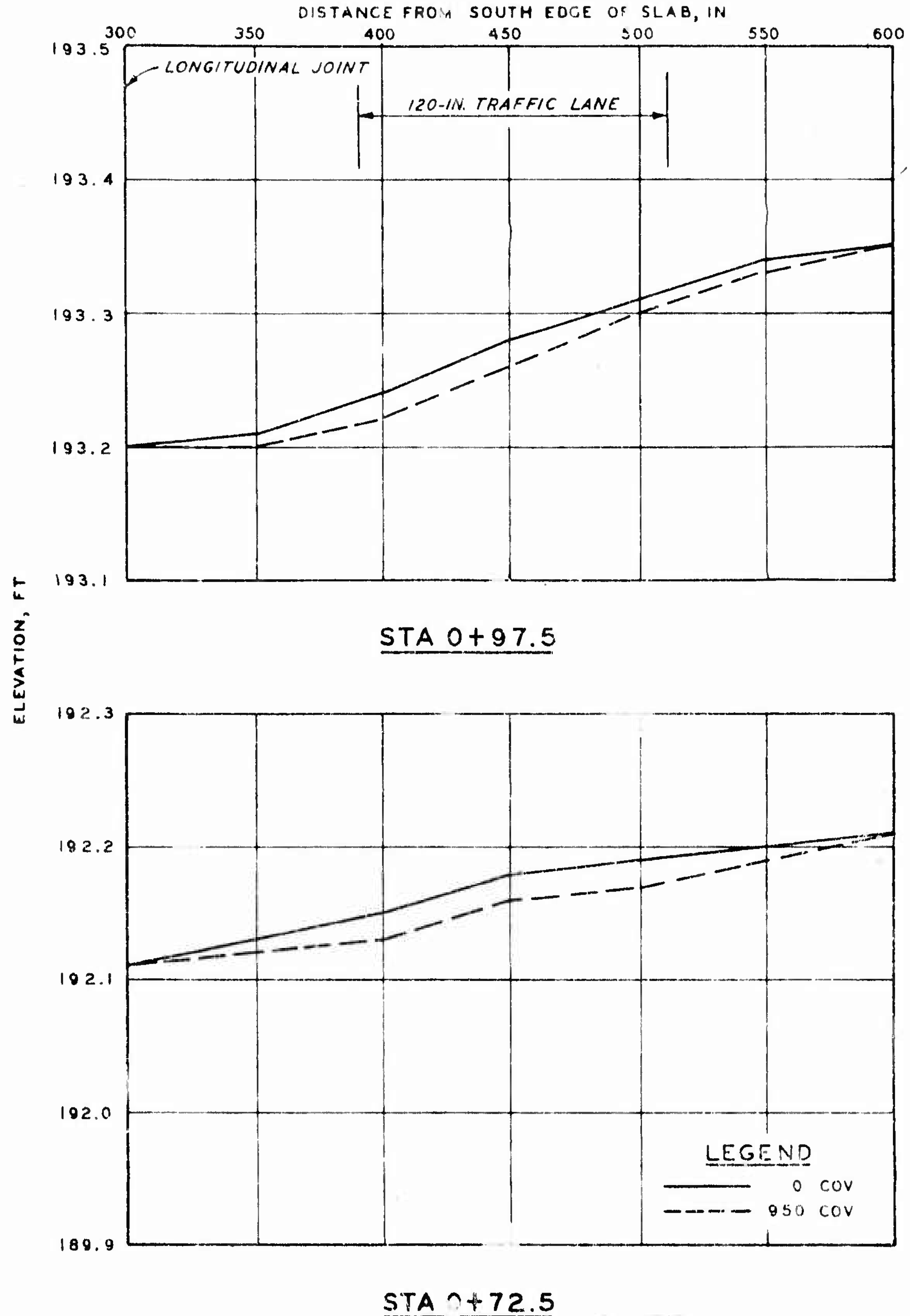


Figure 75. Typical cross sections of item 4, 166-kip, twin-tandem-assembly lane.

Test Item	Lane	Assembly Used For Traffic	Load Per Tire lb	Tire Inflation Pressure psi	Tire Contact Area sq in.	Subgrade				Thicknes in.
						CBR		Modulus of Soil Reaction, k		
						As-Constructed	After Traffic	As-Constructed pci	After Traffic pci	
1	S	12-wheel	30,000	100	285	4.1	6	175	--	24
	N	Twin-tandem	41,500	250	200	4.1	6	175	--	24
2	S	12-wheel	30,000	100	285	4.5	-	111	81	--
	N	Twin-tandem	41,500	250	200	4.5	-	111	81	--
3	S	12-wheel	30,000	100	285	3.2	-	--	--	4
	N	Twin-tandem	41,500	250	200	3.2	-	--	--	4
4	S	12-wheel	30,000	100	285	3.3	3.5	47	--	6
	N	Twin-tandem	41,500	250	200	3.3	3.5	47	--	6

* Determined by correlation with tensile strengths

** Pavement condition in south lane after 12-wheel traffic:

Item 1 - Keyed longitudinal joint was failed, the doweled longitudinal joint was performing satisfactory.

Item 2 - After 816 coverages the longitudinal joint strengthened by the undergrouting method was considered fa
After 1696 coverages traffic was stopped in the eastern half of the lane because of spalling and rave
along the cracks. All three strengthening methods performed satisfactory as long as the pavement rem

Item 3 - The doweled longitudinal joints were performing satisfactory at the end of traffic. The sand-filter
effective in preventing pumping of the clay subgrade up through the cracks during traffic.

Item 4 - No failure, the longitudinal joints and slabs were performing satisfactory after 6336 coverages.

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TABLE 3.--SUMMARY OF TRAFFIC TEST DATA

Base Course					Portland Cement Concrete					
	CBR		Modulus of Soil Reaction, k			28-Day Strengths			After-Traf[fic] Strength[s]	
[Thi]ckness in.	As-Constructed	After Traffic	As-Constructed pci	After Traffic pci	Thickness in.	Compressive psi	Flexural psi	Tensile psi	Flexural psi*	Te[nsile]
24	21	22	--	138	8	6725	828	540	730	
24	21	22	--	138	8	6790	912	613	705	
--	--	--	--	--	11	4795	613	425	510	
--	--	--	--	--	11	5035	625	505	550	
4	--	--	81	129	10	5545	683	505	598	
4	--	--	81	129	10	6095	705	513	730	
6	--	--	344	395	10	6360	695	575	753	
6	--	--	344	395	10	6470	765	530	790	

[a]d failed.
[-]raveling
[-]t remained serviceable.
[fi]lter course was

...s of ...ction, k After Traffic pci	Portland Cement Concrete Thickness in.	28-Day Strengths Compressive psi	28-Day Strengths Flexural psi	28-Day Strengths Tensile psi	After-Traffic Strengths Flexural psi*	After-Traffic Strengths Tensile psi	Coverages for Failure Condition** Joint	Coverages for Failure Condition** Initial Crack	Coverages for Failure Condition** Shattered Slab
138	8	6725	828	540	730	670	688	54	688
138	8	6790	912	613	705	645	--	4	35
--	11	4795	613	425	610	558	816	144	--
--	11	5035	625	505	550	503	--	120	170
129	10	5545	683	505	598	548	--	96	688
129	10	6095	705	513	730	670	--	--	--
395	10	6360	695	575	753	690	--	6336	6336+
395	10	6470	765	530	790	723	--	320	950

corner of the southwest slab in item 1 and from the northwest corner of the southeast slabs in test items 2-4. The test pits were deliberately located in the corners of the slabs to minimize the cutting needed to remove the specimen and to expose a portion of the strengthened longitudinal and weakened-plane transverse joints for examination. The concrete specimens were cut with air hammers and removed with a hoist. The specimen removed from item 4 was taken to the WES Concrete Laboratory for sawing into test specimens and testing.

Originally, it had been planned to cut two beams from each specimen for flexural strength determinations. However, due to the high cost, only two beams were cut from the specimen removed from item 4. Each of these beams had a depth and width equal to the pavement thickness and a length of three times the pavement thickness. The beams were tested for flexural strength according to CRD-C 16 (reference 9). Each beam was tested in the direction they were cast. The flexural strengths of these beams were 830 and 675 psi. Flexural strength determinations made on these two beams were then correlated to the tensile strengths of the cores cut from the same specimen. The flexural strength of the remaining slabs were calculated from this correlation and are tabulated in table 3. Although these beams were tested about 11 months after placement of the concrete, the strengths were about the same when compared to the 28-day flexural strengths of the concrete in item 4 (see table 2). As can be seen in table 2, an increase of 10 to 19 percent in flexural strength occurred between the 7- and 28-day strengths for the pavement in item 4. The flexural strength for the concrete placed in items 1-3 increased from 4 to 33 percent between the 7- and 28-day strengths. Since there was very little change in flexural strength between the after-traffic tests on the concrete in item 4 and the 28-day strengths and the increase in strengths between the 7- and 28-day strengths was about the same for all items, it is assumed that most of the increase in strength occurred by the time traffic was commenced.

Nominal 6-in.-diam cores were drilled from each slab of each test item for thickness determinations and were then subjected to tensile splitting tests according to CRD-C 77 (reference 9). The results of thickness measurements and tensile splitting tests on the concrete cores are shown in table 4. These after-traffic tensile strengths show an increase of 14 to 28 percent when compared to the 28-day tensile strengths shown in table 2. The cores were tested 90 degrees from the direction they were cast.

A summary of the soil strength, water-content, and density determinations performed during construction and after traffic is shown in table 1. These data show that there was a slight increase in the base course modulus of soil reaction k during the traffic period and that the CBR of the subgrade increased in item 1, decreased in items 2 and 3, and remained about the same in item 4 during traffic.

TABLE 4.--RESULTS OF TENSILE SPLITTING TESTS ON CONCRETE CORES

Item No.	Core Location	Length in.	Diameter in.	Tensile Strength psi
1	NE 1/4	8.0	5.91	650
	SE 1/4	7.5	5.91	670
	SW 1/4	8.1	5.91	670
	NW 1/4	8.1	5.91	640
2	NE 1/4	11.0	5.91	525
	SE 1/4	10.0	5.91	585
	SW 1/4	11.0	5.91	530
	NW 1/4	11.0	5.91	480
3	NE 1/4	10.4	5.91	695
	SE 1/4	9.0	5.91	545
	SW 1/4	8.5	5.91	550
	NW 1/4	10.1	5.91	645
4	NE 1/4	10.2	5.91	695
	SE 1/4	10.5	5.91	695
	SW 1/4	10.2	5.91	685
	NW 1/4	9.8	5.91	750

V SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. Summary

Item 1 consisted of an 8-in.-thick plain concrete slab constructed on a medium-strength (k = 300) base composed of 24 in. of clayey gravelly sand (SW-SC, E-5). The subgrade was a low-strength (k = 175) clay (CH, E-11). A keyed longitudinal joint was used for one half (25 ft) of the item, and a doweled joint was used for the other half. After 688 coverages of the 360-kip 12-wheel assembly, the keyed joint was considered failed as were the two south slabs (shattered slab). The doweled joint performed satisfactorily for the full life of the pavement. During the 166-kip, twin-tandem-assembly traffic, the north lane was considered a shattered slab after 35 coverages.

Item 2 consisted of an 11-in.-thick plain concrete slab constructed on a low-strength (k = 111) clay (CH, E-11) subgrade. A keyed construction joint was employed for the full length (50 ft) of the test section. Prior to test traffic, the keyed joint was strengthened by the three methods shown in figure 1. Each of these three types of strengthening methods performed satisfactorily during the life of the pavement. After 816 coverages of the 360-kip 12-wheel assembly, traffic was discontinued on the west half of the item, and traffic was stopped on the east half of the item after 1696 coverages. The north lane of this item withstood 170 coverages of the 166-kip twin-tandem assembly before it was considered failed (shattered slab).

In item 3, a 10-in.-thick plain concrete slab was constructed on a 4-in.-thick sand (SP, E-2) filter course, which was over a low-strength (k = 81) clay (CH, E-11) subgrade. A doweled longitudinal construction joint was constructed through the entire length (50 ft) of the item. This joint performed satisfactorily for the full life of the pavement. After 688 coverages of the 360-kip 12-wheel assembly, the two south slabs were in a shattered-slab condition. No pumping of the subgrade material was observed during the traffic period in the interior portion of this item.

Item 4 consisted of a 10-in.-thick plain concrete slab, constructed on a 6-in.-thick cement-stabilized clayey gravelly sand (SW-SC, E-5), which was placed over a low-strength (k = 47) clay (CH, E-11) subgrade. Half of the longitudinal construction joint was keyed while the other half was doweled. Both types of joints performed satisfactorily during the 360-kip 12-wheel-assembly traffic. After 6336 coverages, the 12-wheel assembly traffic was discontinued. The two south slabs were also in good condition at the end of traffic. The north lane of this item withstood 950 coverages of the 166-kip twin-tandem assembly before it was considered a shattered-slab failure. The high-strength stabilized base course prevented the subgrade from pumping in the interior portion of this item, which resulted in increasing the service life of the 10-in.-thick plain-concrete slab and an excellent performance of the doweled and keyed longitudinal construction joints during traffic.

The deflection measurements recorded prior to test traffic in the twin-tandem traffic lane indicate that the largest deflection was measured in item 1 which was rated as failed after 35 coverages, and the least deflection was measured in item 4 which was considered failed after 950 coverages.

Each of the three items trafficked by the twin-tandem assembly failed at a much lower coverage level than did the similar item trafficked by the 12-wheel assembly, which is consistent with the results of the previous pavement tests at WES (reference 1).

	Coverages to Shattered-Slab Failure	
Item	12-Wheel Assembly	Twin-Tandem Assembly
1	688	35
2	1696+*	170
4	6336+*	950

* Although joint failure occurred at 816 coverages in item 2, shattered-slab failure had not been reached when traffic was stopped at 1696 coverages. In item 4, traffic was stopped at 6336 coverages because it was evident that both the pavement and the joint could survive many more coverages.

B. Conclusions

Based on the results of tests reported herein, the following conclusions are believed warranted:

1. The service life of keyed joints in rigid pavements placed on medium-strength foundations is about the same as that of the slab itself.

2. Keyed longitudinal joints in existing pavements to be subjected to MWHGL traffic can be strengthened to prevent early failure by (a) sawing grooves across the joint and bonding dowel bars with an epoxy mortar; (b) angled holes drilled through the joint keyway and bonding dowel bars using epoxy grout; or (c) underreaming a large void beneath the joint and then filling the void with sanded grout. Although each of these types of strengthening methods performed satisfactorily, they are very time consuming to install. Although cost data were not maintained, based upon the labor required it is believed that the most economical and practical strengthening method of these three was method b.

3. Use of either a sand-filter course or a cement-stabilized clayey gravelly sand base course will prevent pumping of the fine-grained subgrade material when subjected to MWHGL traffic.

4. Conventional keyed longitudinal joints will perform adequately if this type of construction is placed over high-strength (stabilized) foundations.

5. A 6-in.-thick stabilized base course placed over a low-strength subgrade is a very effective means of increasing the load-carrying capacity of a nonreinforced PCC pavement.

6. A 166-kip twin-tandem assembly imposes a much more severe loading to a pavement structure than does a 360-kip 12-wheel assembly.

7. A doweled longitudinal construction joint will perform satisfactorily in pavement constructed on low-, medium-, and high-strength foundations.

C. Recommendations

The following recommendations are offered regarding the design of longitudinal construction joints in rigid pavements to be trafficked by MWHGL aircraft:

1. Consideration should be given to strengthening the keyed construction joints in existing rigid pavements that are founded on low- to medium-strength materials, are in good structural condition, and are scheduled for MWHGL aircraft traffic.

2. Keyed longitudinal construction joints in existing rigid pavements constructed on high-strength or stabilized soil foundations will probably perform satisfactorily under MWHGL aircraft traffic. However, it is recommended that these pavements be periodically observed (or tested) and if distress is noted, consideration be given to strengthening the keyed joint.

3. For new construction, the use of keyed longitudinal construction joints is discouraged for pavements on unbound (nonstabilized) foundations except on the very low-usage paved areas, such as outer lanes of runways and aprons. As an alternate, thickened-edge keyed, thickened-edge butt, or doweled joints may be satisfactory. The doweled longitudinal construction joint proved to be satisfactory in the test program described herein and is recommended for use.

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