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AFFDL-TR-66-43
PART XVII

AIRCRAFT GROUND-FLOTATION INVESTIGATION

PART XVII – DATA REPORT ON TEST SECTION 16

J. WATKINS and G. HAMMITT II

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

TECHNICAL REPORT AFFDL-TR-66-43, PART XVII

SEPTEMBER 1966

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

AIRCRAFT GROUND-FLOTATION INVESTIGATION

PART XVII — DATA REPORT ON TEST SECTION 16

J. WATKINS and G. HAMMITT II

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FOREWORD

The investigation described herein constitutes one phase of studies conducted during 1964 and 1965 at the U. S. Army Engineer Waterways Experiment Station (WES) under U. S. Air Force Project No. 410-A, MIPR No. AS-4-177, "Development of Landing Gear Design Criteria for the CX-HLS Aircraft." (The CX-HLS is now designated C-5A.) This project was sponsored and directed by the Landing Gear Group, Air Force Flight Dynamics Laboratory, Research and Technology Division, Mr. R. J. Parker, Project Engineer.

These tests were conducted by personnel of the WES Flexible Pavement Branch, Soils Division, under the general supervision of Messrs. W. J. Turnbull, A. A. Maxwell, and R. G. Ahlvin, and the direct supervision of Mr. D. N. Brown. Other personnel actively engaged in this study were Messrs. C. D. Burns, D. M. Ladd, H. H. Ulery, Jr., W. J. Hill, Jr., J. E. Watkins, and G. M. Hammitt II. This report was prepared by Messrs. Watkins and Hammitt.

Directors of WES during the conduct of this investigation and preparation of this report were Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

K N Digges

KENNERLY H. DIGGES
Chief, Mechanical Branch
Vehicle Equipment Division
AF Flight Dynamics Laboratory

ABSTRACT

This data report describes work undertaken as part of an overall program to develop ground-flotation criteria for the C-5A aircraft. A test section was constructed to a width adequate for one test lane. The lane was divided into three items, each having different subgrade CBR values. Item 1 was surfaced with modified T11 aluminum landing mat, item 2 was surfaced with M8 steel landing mat, and item 3 remained unsurfaced. Traffic was applied to the lane using a 12-wheel (four abreast in three rows) tracking assembly with 100-psi tire inflation pressure and 273,000-lb loading. The wheel assembly consisted of twelve 20.00-20, 22-ply aircraft tires.

The information reported herein includes layout of the test lanes, characteristics and print dimensions of the load assembly tires, and data collected on soil strengths, surface deformations and deflections, and drawbar pull. The traffic coverage level at which each test item was considered failed is given.

CONTENTS

ILLUSTRATIONS AND TABLES

SUMMARY

Tests on Section 16 are one phase of a comprehensive research program to develop ground-flotation criteria for heavy cargo-type aircraft. Section 16 consisted of one traffic lane, lane 35, which was divided into three items having different subgrade CBR values (figure 9).

Traffic was applied to the test lane using a 12-wheel (four abreast in three rows) tracking assembly with 100-psi tire inflation pressure and 273,000-lb loading. The wheel assembly consisted of twelve 20.00-20, 22-ply aircraft tires. The tire spacings were 34-44-34 in. abreast and 123 in. between tandems. Figure 11 gives pertinent tire-print dimensions and tire characteristics.

The test lane was trafficked in accordance with the criteria designated in Part I of this report. Data were recorded throughout testing to give a behavior history of each item. Using the test criteria mentioned above, it was possible to determine the effect of trafficking with a simulated C-5A load. Basic performance data are summarized in the following paragraphs.

Item 1

Item 1 was considered failed due to roughness at 210 coverages. The rated CBR of the item was 2.2.

Item 2

Traffic on this item was discontinued at 1300 coverages, with no failure. The rated CBR was 5.7.

Item 3

Item 3 was considered failed due to roughness at 455 coverages. The rated CBR was 9.0.

AIRCRAFT GROUND-FLOTATION INVESTIGATION

PART XVII DATA REPORT ON TEST SECTION 16

SECTION I: INTRODUCTION

The investigation reported herein is one phase of a comprehensive research program being conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., as part of U. S. Air Force Project No. 410-A, MIPR No. AS-4-177, to develop ground-flotation criteria for the C-5A, a heavy cargo-type aircraft. Specifically, the tests reported herein are part of a series of tests to determine the degree of interaction of the wheels of multiple-wheel landing gear assemblies on landing mat and unsurfaced soils under various conditions of loading.

Prosecution of this investigation consisted of constructing one traffic lane and subjecting it to traffic of a 12-wheel (four abreast in three rows) assembly. This report presents a description of the test section and wheel assembly and gives results of trafficking. Equipment used, types of data and methods of recording them, and general test criteria are summarized in this part with more complete explanations and illustrations appearing in Part I of this report.

SECTION II: DESCRIPTION OF TEST SECTION AND LOAD VEHICLE

Description of Test Section

Test Section 16 (figure 9) was constructed within a roofed area to allow control of the subgrade CBR (California Bearing Ratio) in the test items. Section 16 was located on the same site as prior Test Sections 13 and 15 of this series. The construction of Test Section 15 is described in Part XVI of this report. The underlying subgrade was undisturbed by prior tests on the site so that in construction of Section 16 only the upper 24 in. of soil was excavated. The surface exposed by excavation was scarified and recompacted before backfilling the area in four compacted lifts with a heavy clay soil (buckshot; classified as CH according to the Unified Soil Classification System, MIL-STD-619). The fill material used was a local clay with a plastic limit of 27, liquid limit of 58, and plasticity index of 31. Gradation and classification data for the subgrade material are given in Part I.

One traffic lane divided into three items was constructed in the test section. Item 1 was surfaced with modified T11 aluminum mat, and item 2 was surfaced with M8 steel mat (figure 10). Item 3 remained unsurfaced. Different subgrade strengths were obtained in the items by controlling the water content and compaction effort.

Load Vehicle

The multiwheel load vehicle used in trafficking lane 35 is shown in figure 2. This vehicle consists of an electrically powered prime mover with three load carts. The load carts are attached to the prime mover through a torsion bar, and to each other by use of parallel bars that maintain horizontal stability while allowing the load carts to oscillate vertically. The test load was 22,750 lb per wheel for a total load of 273,000 lb. The wheel assembly consisted of twelve 20.00-20, 22-ply tires inflated to a pressure of 100 psi, spaced 34-44-34 in. abreast and 123 in. between tandems. Typical tire contact area dimensions, overall assembly dimensions, and pertinent tire characteristics are shown in figure 11.

SECTION III: APPLICATION OF TRAFFIC, FAILURE CRITERIA, AND DATA COLLECTED

Application of Traffic

Traffic was applied to the test lane in a nonuniform pattern with intensity of traffic being varied to approximate the bell-shaped traffic distribution curve which results from the wander of aircraft from a runway center line. The multiwheel traffic was distributed across the lane width in four zones of about 100, 80, 60, and 20 percent traffic coverage (figure 1). The coverage levels referred to in the tables and text of this data report are the total number of coverages applied to the 100 percent coverage zone. The corresponding number of coverages applied to the outer traffic zones is proportional to the percentage factor for the respective zones as shown in figure 1.

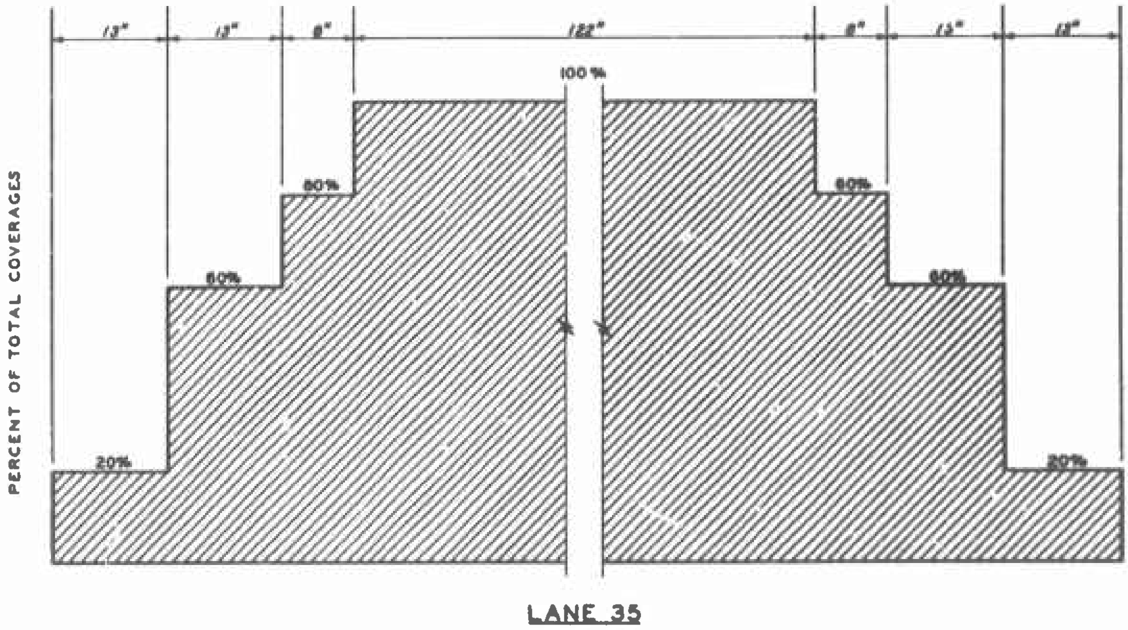

Figure 1. Traffic distribution pattern for Test Section 16

Failure Criteria and Data Collected

Failure criteria used in this investigation and descriptive terms used in presentation and discussion of data in all reports in this series are presented in Part I. A general outline of types of data collected is given in the following paragraphs.

CBR, water content, and dry density

CBR, water content, and dry density of the subgrade soil were measured for each test item prior to application of traffic, at intermediate coverage levels, and at failure or suspension of traffic if no failure condition was reached. After traffic was concluded on an item, a measure of subgrade strength termed "rated CBR" was determined. Rated CBR is generally the average CBR value obtained from all the determinations made in the top 12 in. of soil during the test life of an item. In certain instances, extreme or irregular values may be ignored if the analyst decides that they are not properly representative.

Surface roughness, or
differential deformation

Surface roughness, or differential deformation, measurements were made using a 10-ft straightedge at various traffic coverage levels on all items. Rut depths were measured for unsurfaced items, and dishing effects of individual mat panels in the mat-surfaced items were recorded.

Deformations

Deformations, defined as permanent surface changes in cross section or profile of an item, were charted by means of level readings at pertinent traffic coverage levels.

Deflection

Deflection of the test surface under static load of the tracking assembly was measured at various traffic coverage levels on both surfaced and unsurfaced items. Level readings on the item surface on each side of the load wheels and on a pin and cap device directly beneath a load wheel provided deflection data. Both total and elastic (recoverable) deflections were measured on unsurfaced items. All mat deflection was for practical purposes recoverable, i.e. total deflection equaled elastic deflection. The pin and cap device for measuring deflection directly beneath load wheels was installed in the subgrade of surfaced items through a hole (existing or cut) in the mat.

Rolling resistance

Rolling resistance, or drawbar pull, measurements were performed with the load vehicle over each test item at designated coverage levels. Apparatus and procedures for determining drawbar pull values are illustrated and explained in Part I.

Mat breaks

Mat breaks on the surfaced items were inspected, classified by type, and recorded on the data sheet at various coverage levels. Illustrations and descriptions of each type of break in the T11 and M8 mats are given in Part I.

SECTION IV: BEHAVIOR OF ITEMS UNDER TRAFFIC AND TEST RESULTS

Behavior of Items Under Traffic

Item 1

Figure 3 shows item 1 after 1 pass. After 210 coverages the item was considered failed due to roughness (figure 4). The rated CBR was 2.2.

Item 2

Figure 5 shows item 2 after 1 pass. Traffic was continued to 1300 coverages, at which time traffic was terminated even though the item was not considered failed (figure 6). The rated CBR was 5.7.

Item 3

Figure 7 shows item 3 after 1 pass. After 455 coverages the item was considered failed due to excessive roughness (figure 8). The rated CBR was 9.0.

Test Results

Test results are summarized in table 1. Soil test data are presented in table 2.

Item 1

Item 1 was considered failed at 210 coverages of the load vehicle. The following information was obtained from traffic tests on item 1.

Roughness. At failure the maximum and average transverse differential deformations measured 1.88 and 1.47 in., respectively. The maximum and average diagonal differential deformations measured 2.50 and 2.10 in., respectively (see table 1).

Deformation. Permanent mat and soil cross-section deformation plots at failure are shown in figure 12. It should be pointed out that the mat was fully embedded in the subgrade at the start of traffic. However, as traffic was applied, the soft clay soil was displaced laterally from under the load wheels, which caused the mat to raise up and actually bridge over or stand off from the subgrade in the traffic lane. Note the difference between mat and subgrade elevations at the end of traffic. Figure 13 shows a permanent deformation profile along the center line of the traffic lane. The maximum mat deformation measured at failure was 1.9 in. The maximum permanent soil deformation at failure measured 4.5 in.

Deflections. Deflection plots are shown in figure 14. All deflection measurements showed an increase with the application of traffic. At failure, the maximum quarter point, center point, and joint deflections measured 6.2, 5.7, and 5.2 in., respectively (see table 1). Elastic soil deflection at failure measured 2.6 in.

Rolling resistance. Rolling resistance increased with the application of traffic (see table 1). Initial drawbar pull (DBP) increased from 29.0 kips at 0 coverages to 30.4 kips at failure. Peak DBP increased from 16.7 kips at 0 coverages to 23.7 kips at failure. Rolling DBP increased from 14.5 kips at 0 coverages to 21.0 kips at failure.

Item 2

Item 2 did not fail. The following information was obtained from traffic tests on item 2.

Roughness. When traffic was terminated at 1300 coverages, item 2 was still in good condition. The maximum and average transverse differential deformations measured 1.87 and 1.59 in., respectively (see table 1).

Deformation. Mat deformation plots are shown in figure 12, and a profile deformation 4 ft west of the traffic lane center line is shown in figure 13. Although some subgrade consolidation occurred, there was very little mat deformation. When traffic was terminated, the maximum mat deformation measured was 1.6 in. (4 ft west of the traffic lane center line).

Deflections. Deflection plots are shown in figure 14. All deflection measurements generally showed a slight increase with the application of traffic. When traffic was halted, the maximum quarter point, center point, and joint deflections measured 1.5, 1.6, and 1.5 in., respectively. Elastic soil deflection at 1300 coverages measured 1.8 in.

Rolling resistance. Rolling resistance values are shown in table 1. Initial, peak, and rolling DBP increased with the application of traffic from 0 to 130 coverages and then remained relatively the same until traffic was discontinued at 1300 coverages.

Item 3

Item 3 was considered failed at 455 coverages. The following information was obtained from traffic tests on item 3.

Roughness. At failure, maximum and average transverse differential deformations measured 4.60 and 3.93 in., respectively. Maximum and average rut depths measured 2.25 and 1.53 in., respectively (see table 1).

Deformation. Permanent soil deformation plots are shown in figure 12. Figure 13 shows a profile along the traffic lane center line. The maximum permanent soil deformation at failure measured 2.1 in.

Deflection. Only cap and pin deflections were measured in item 3. The maximum total deflection at failure measured 0.6 in. The elastic soil deflection at failure measured 0.5 in. (see table 1).

Rolling resistance. Rolling resistance generally increased with the application of traffic (see table 1). Initial DBP increased from 14.2 kips at 0 coverages to 17.5 kips at failure. Peak DBP increased from 10.0 kips at 0 coverages to 17.7 kips at failure. Rolling DBP increased from 6.6 kips at 0 coverages to 11.0 kips at failure.

SECTION V: PRINCIPAL FINDINGS

From the foregoing discussion, the principal findings relating test load, wheel assembly, tire inflation pressure, subgrade CBR, and traffic coverages are as follows:

Load, Wheel Assembly, and Tire Pressure	Type of Surface	Rated Subgrade CBR	Coverages at Failure
273,000-lb load, 12-wheel assembly; 20.00-20, 22-ply tires at 100-psi inflation pressure	Modified T11 aluminum landing mat	2.2	210
	M8 steel landing mat	5.7	1300 (no failure)
	Unsurfaced	9.0	455

TABLE 1

SUMMARY OF TRAFFIC DATA, TEST SECTION 16

Test Item	Traffic Coverages	Rated CBR	No. of Mat Breaks* A	B	C	D	E	F	Differential Deformation (in.) Longitudinal Max	Longitudinal Avg	Transverse Max	Transverse Avg	Diagonal Max	Diagonal Avg	Dishing or Rutting (in.) Max	Avg	Drawbar Pull (kips) Initial	Peak	Rolling	Total Deflection (in.) with Center Line of Assembly Located on: Unsurfaced Subgrade Max	Unsurfaced Subgrade Center Line of Assembly	Quarter Point of Plank Max	Quarter Point of Plank Center Line of Assembly	Center Point of Plank Max	Center Point of Plank Center Line of Assembly	Joint of Plank Max	Joint of Plank Center Line of Assembly	Elastic Subgrade Deflection (in.)	Remarks
1 Modified T11 aluminum landing mat	0		--	--	--	--	--	--	--	--	--	--	--	--	--	--	29.0	16.7	14.5	--	--	2.50	2.00	2.10	1.80	2.5	1.50	--	Failure at 210 coverages due to roughness
	130	2.2	0	15	0	6	0	0	2.25	1.62	1.50	1.31	2.00	1.68	0.50	0.38	29.9	23.4	20.2	--	--	5.10	4.10	4.80	4.60	4.4	3.90	--	
	210		9	46	0	30	0	0	2.25	1.68	1.88	1.47	2.50	2.10	0.50	0.41	30.4	23.7	21.0	--	--	6.20	5.00	5.70	5.60	5.2	4.50	2.6	
2 M8 steel landing mat	10		--	--	--	--	--	--	--	--	--	--	--	--	--	--	15.0	11.1	7.0	--	--	1.20	0.70	1.25	0.75	1.1	0.35	0.6	No failure; 1300 coverages
	130		0	0	0	0	0	0	0.75	0.56	1.25	0.66	1.00	0.63	--	--	19.0	14.7	8.2	--	--	1.50	0.90	1.30	0.90	1.5	0.50	0.6	
	210		0	0	0	0	0	0	0.50	0.40	0.75	0.53	0.75	0.56	--	--	19.0	14.2	9.5	--	--	1.70	1.00	1.40	1.00	1.5	0.50	1.7	
	455	5.7	--	--	--	--	--	--	0.50	0.41	1.10	0.99	1.10	0.99	--	--	16.9	14.3	10.7	--	--	--	--	--	--	--	--	1.8	
	690		--	--	--	--	--	--	0.88	0.82	1.25	1.10	1.25	1.16	--	--	--	--	--	--	--	--	--	--	--	--	--	0.8	
	952		0	0	0	0	0	0	0.88	0.69	1.25	1.09	1.13	0.90	--	--	--	--	--	--	--	--	--	--	--	--	--	0.5	
	1300		5	0	0	0	0	0	1.00	0.82	1.87	1.59	1.63	1.57	--	--	18.8	14.5	9.9	--	--	1.50	1.30	1.60	1.00	1.5	0.50	1.8	
3 Unsurfaced	0		--	--	--	--	--	--	--	--	--	--	--	--	--	--	14.2	10.0	6.6	--	--	--	--	--	--	--	--	--	Failure at 455 coverages due to roughness
	130		--	--	--	--	--	--	0.50	0.40	1.75	1.75	1.75	1.56	1.25	1.06	16.4	13.5	9.5	0.60	--	--	--	--	--	--	--	0.4	
	210	9.0	--	--	--	--	--	--	0.88	0.59	2.00	1.72	1.88	1.78	1.63	1.44	16.5	13.5	9.5	0.70	--	--	--	--	--	--	--	0.5	
	325		--	--	--	--	--	--	0.38	0.31	2.75	2.46	2.70	2.32	2.00	1.73	--	--	--	--	--	--	--	--	--	--	--	--	
	455		--	--	--	--	--	--	2.25	1.03	4.60	3.93	4.38	4.00	2.25	1.53	17.5	17.7	11.0	0.60	--	--	--	--	--	--	--	0.5	

Note: A 273-kip load on a 12-wheel assembly was used in all tests. Tires were 20.00-20, 22-ply, inflated to 100 psi.
* Break types are defined and illustrated in Part I.

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TABLE 2

SUMMARY OF CBR, DENSITY, AND WATER CONTENT DATA,
TEST SECTION 16, LANE 35

Test Item*	Type of Surface	No. of Traffic Coverages	Depth (in.)	CBR	Water Content (%)	Dry Density (lb/cu ft)
1	Modified T11 aluminum landing mat	0	0	2.2	28.9	91.0
			6	1.8	31.4	87.3
			12	2.6	29.8	88.9
		210	0	2.6	28.8	92.1
			6	2.0	28.8	91.2
			12	2.0	29.8	91.1
2	M8 steel landing mat	0	0	4.1	26.7	94.9
			6	3.3	28.2	92.3
			12	5.7	25.4	97.3
		1300	0	5.7	25.5	97.0
			6	7.2	24.0	99.1
			12	8.3	23.8	99.2
3	Unsurfaced	0	0	9.0	23.0	98.4
			6	11.0	22.2	97.8
			12	9.0	24.1	99.0
		455	0	10.0	22.0	101.9
			6	7.0	21.9	102.2
			12	6.0	22.2	100.9

Note: For coverage-failure information, see remarks column in table 1.
* Subgrade material was a heavy clay (buckshot; classified as CH) in all test items.

Figure 2. Test load cart

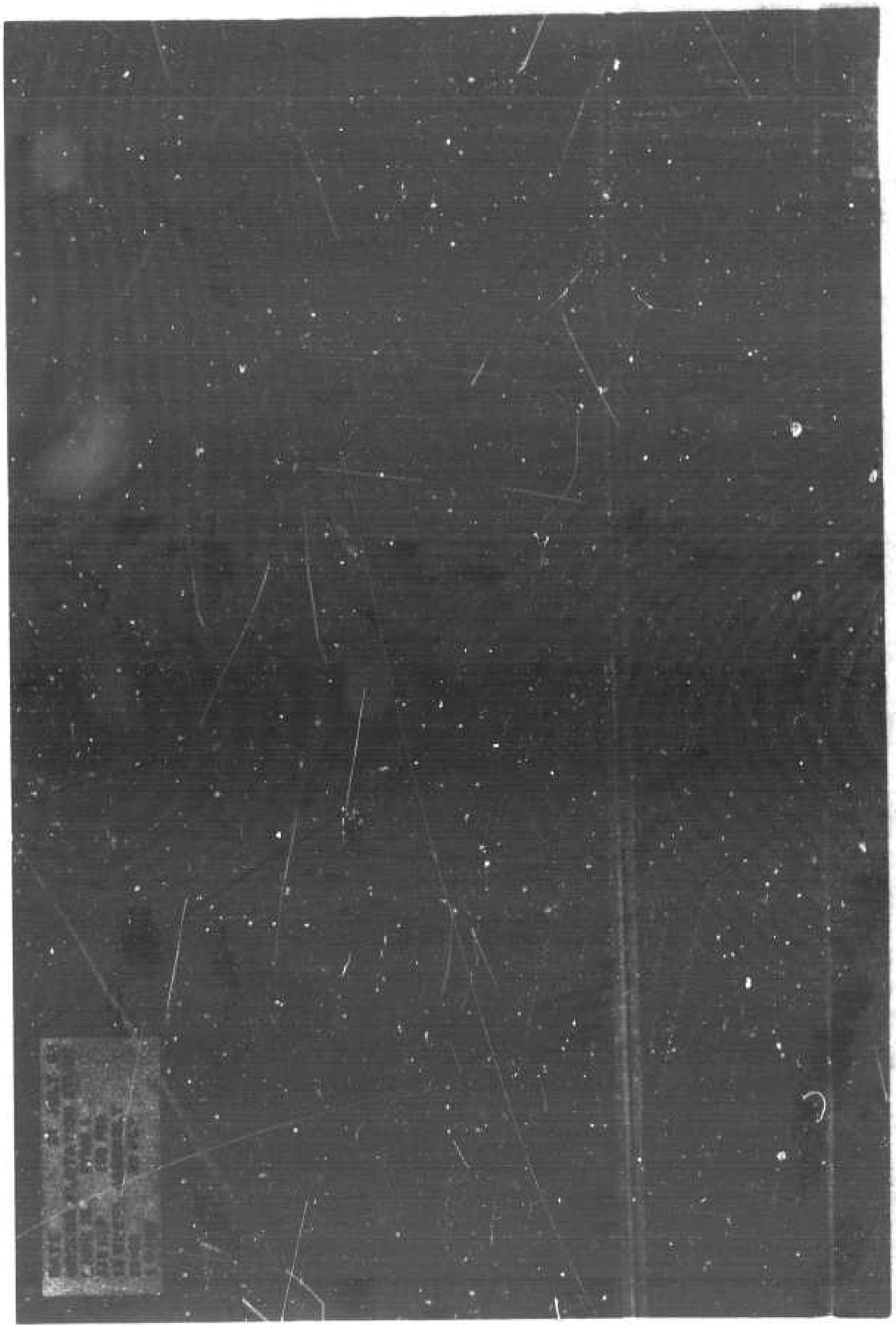


Figure 3. Lane 35, item 1, after 1 pass

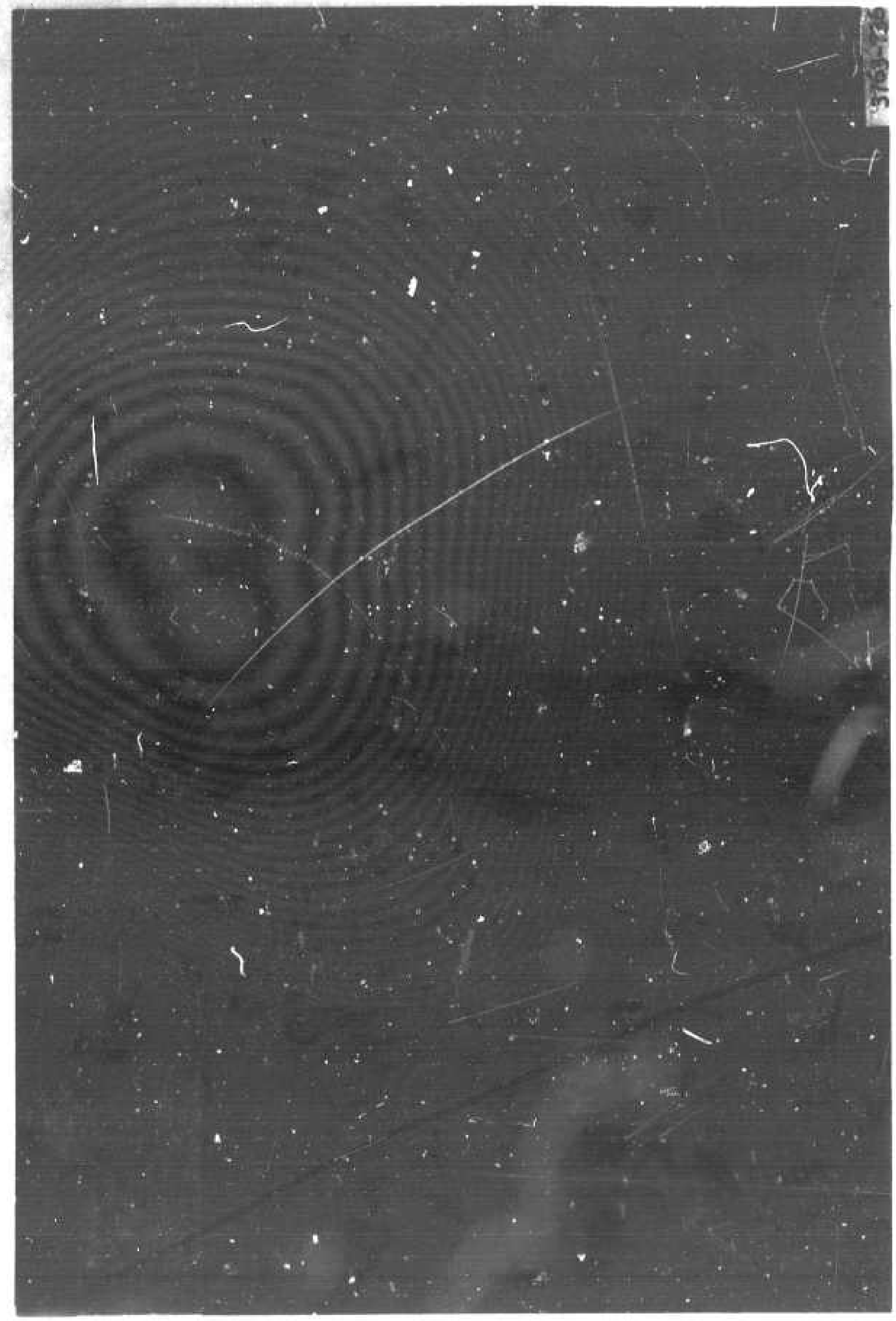


Figure 4. Lane 35, item 1, failure at 210 coverages

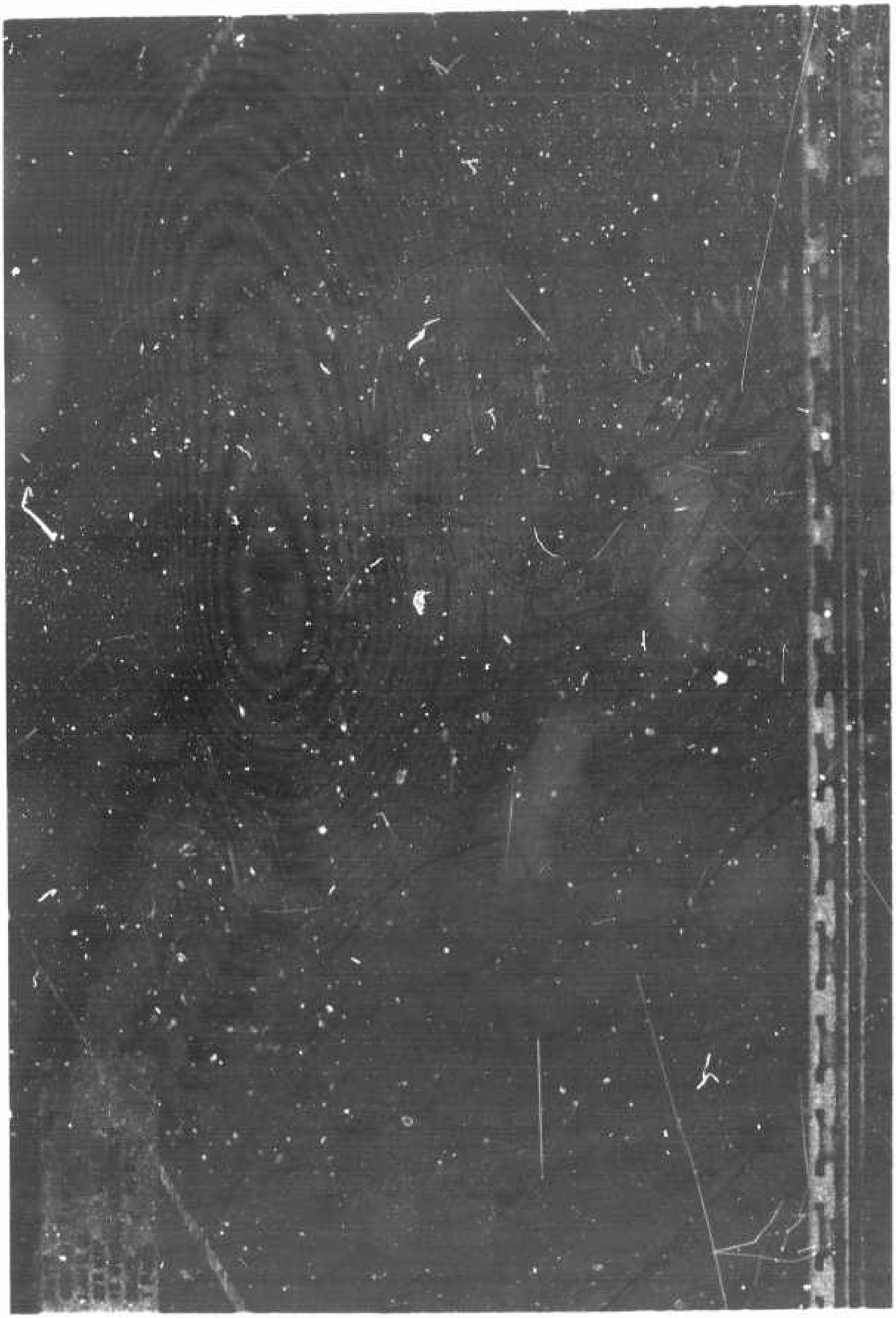


Figure 5. Lane 35, item 2, after 1 pass

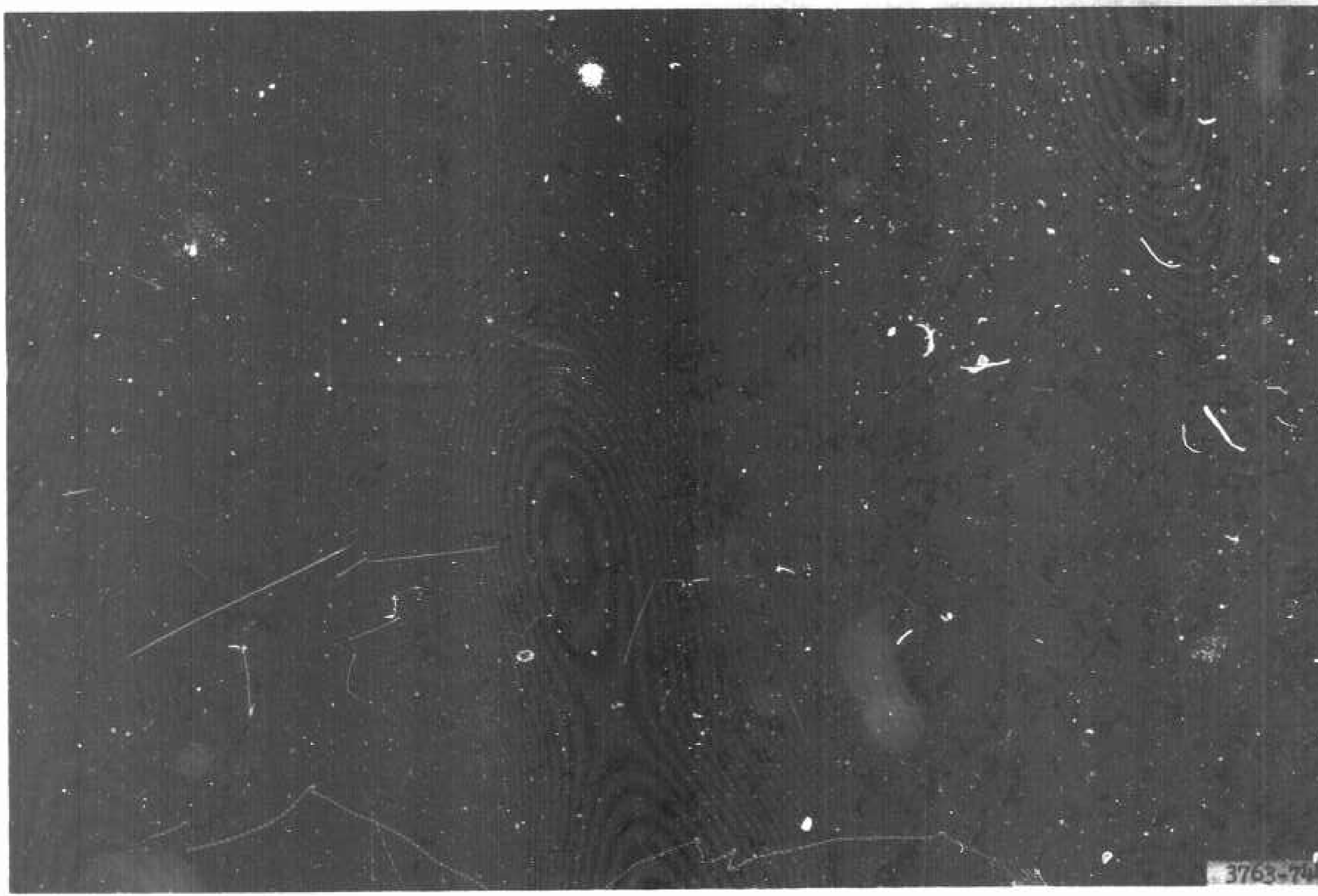


Figure 6. Lane 35, item 2, after 1300 coverages (no failure)

Figure 7. Lane 35, item 3, after 1 pass

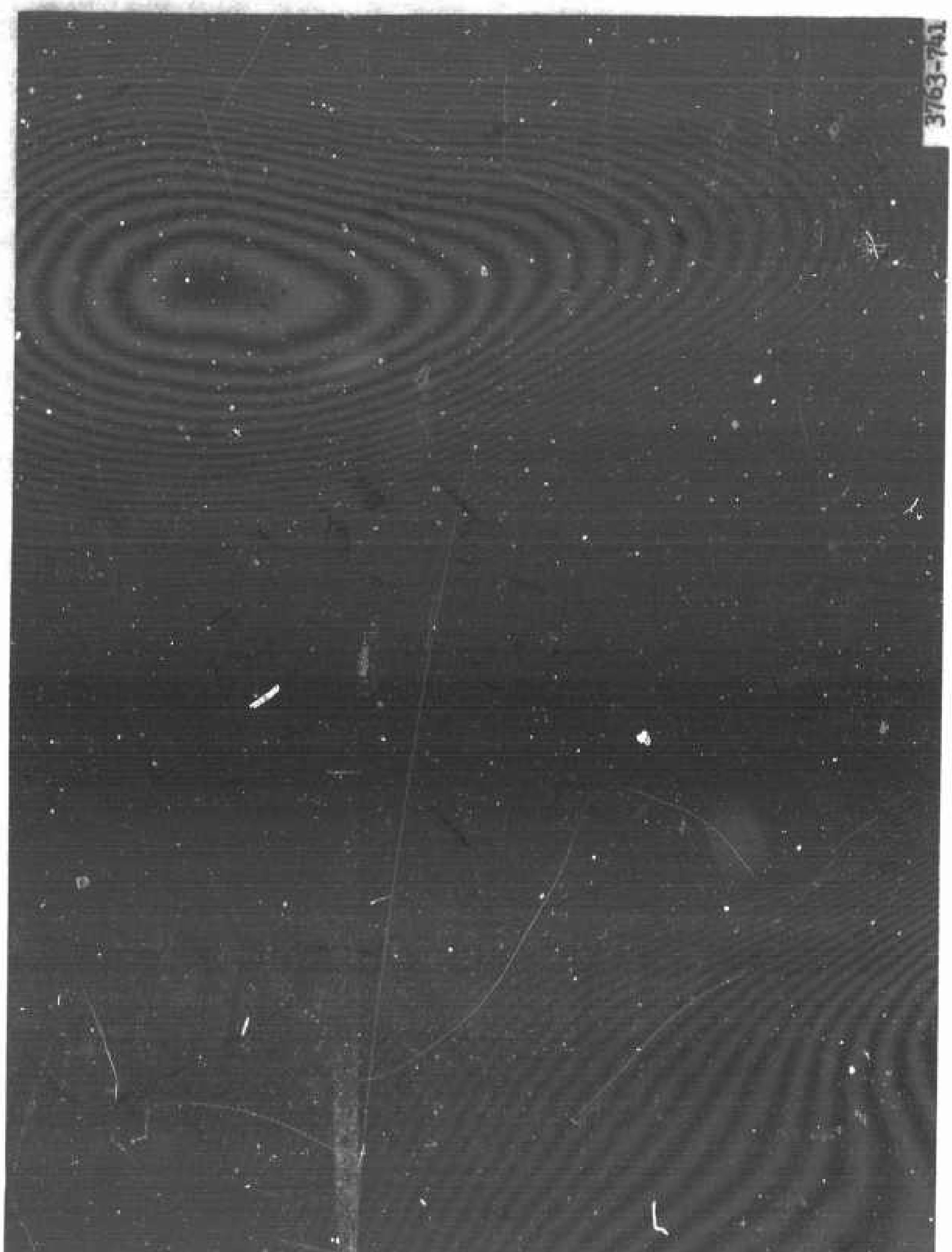


Figure 8. Lane 35, item 3, failure at 455 coverages

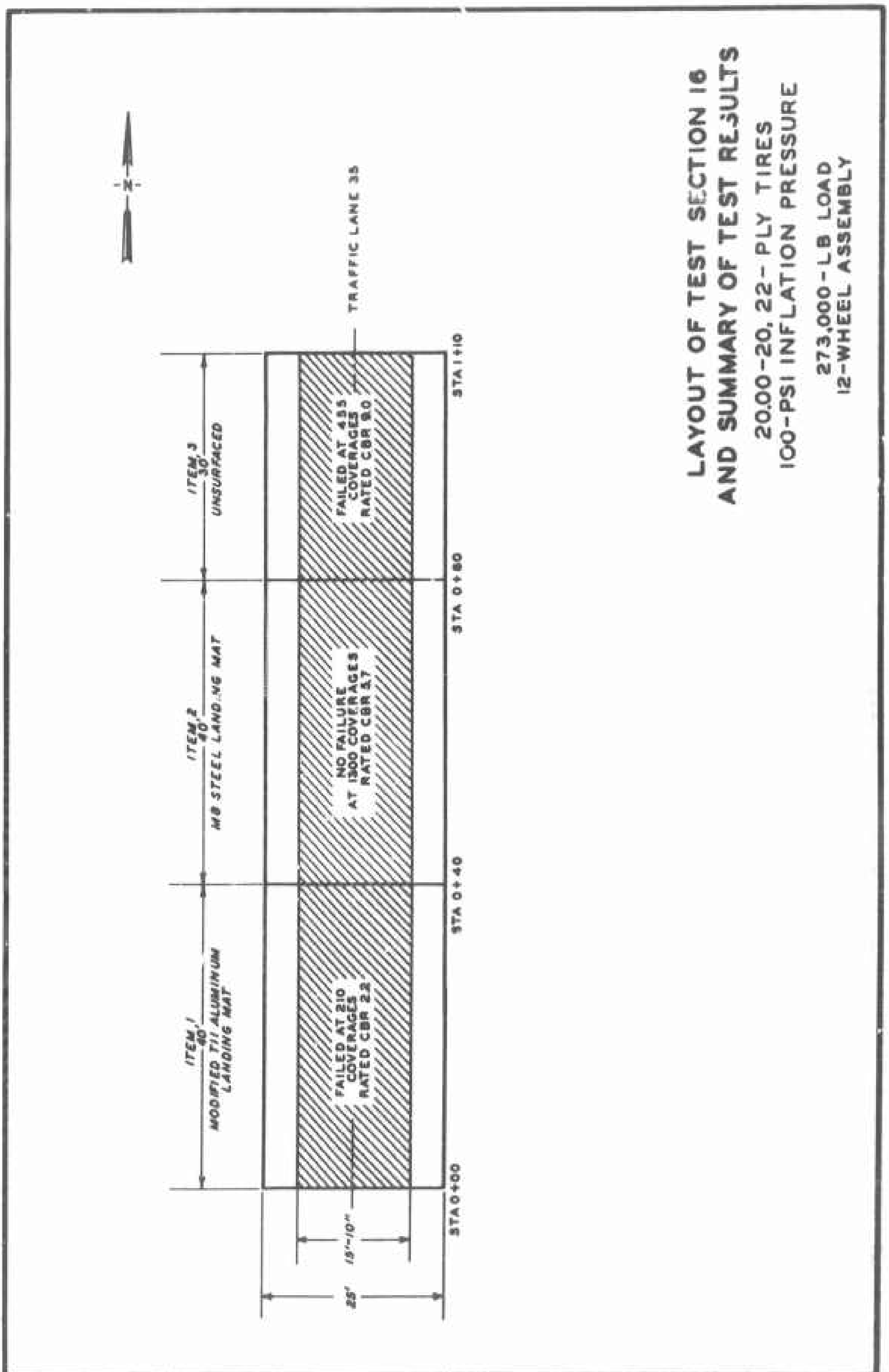

LAYOUT OF TEST SECTION 16
AND SUMMARY OF TEST RESULTS
20.00-20, 22-PLY TIRES
100-PSI INFLATION PRESSURE
273,000-LB LOAD
12-WHEEL ASSEMBLY
N
TRAFFIC LANE 35
ITEM 1
40'
MODIFIED T11 ALUMINUM LANDING MAT
ITEM 2
40'
M8 STEEL LANDING MAT
ITEM 3
30'
UNSURFACED
FAILED AT 210 COVERAGES RATED CBR 2.2
NO FAILURE AT 1300 COVERAGES RATED CBR 5.7
FAILED AT 455 COVERAGES RATED CBR 9.0
STA 0+00
STA 0+40
STA 0+80
STA 1+10
25'
15'-10"

Figure 9

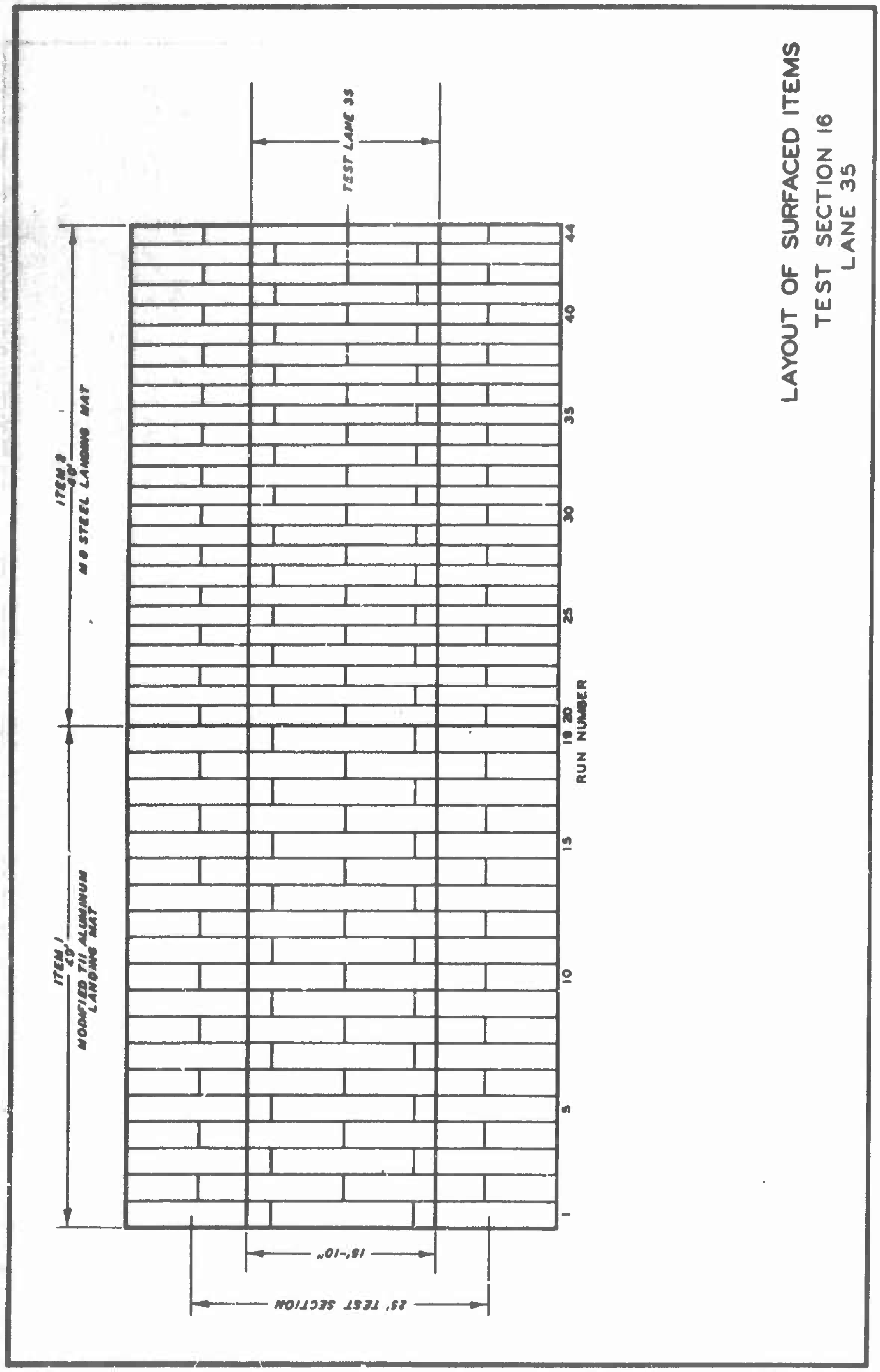
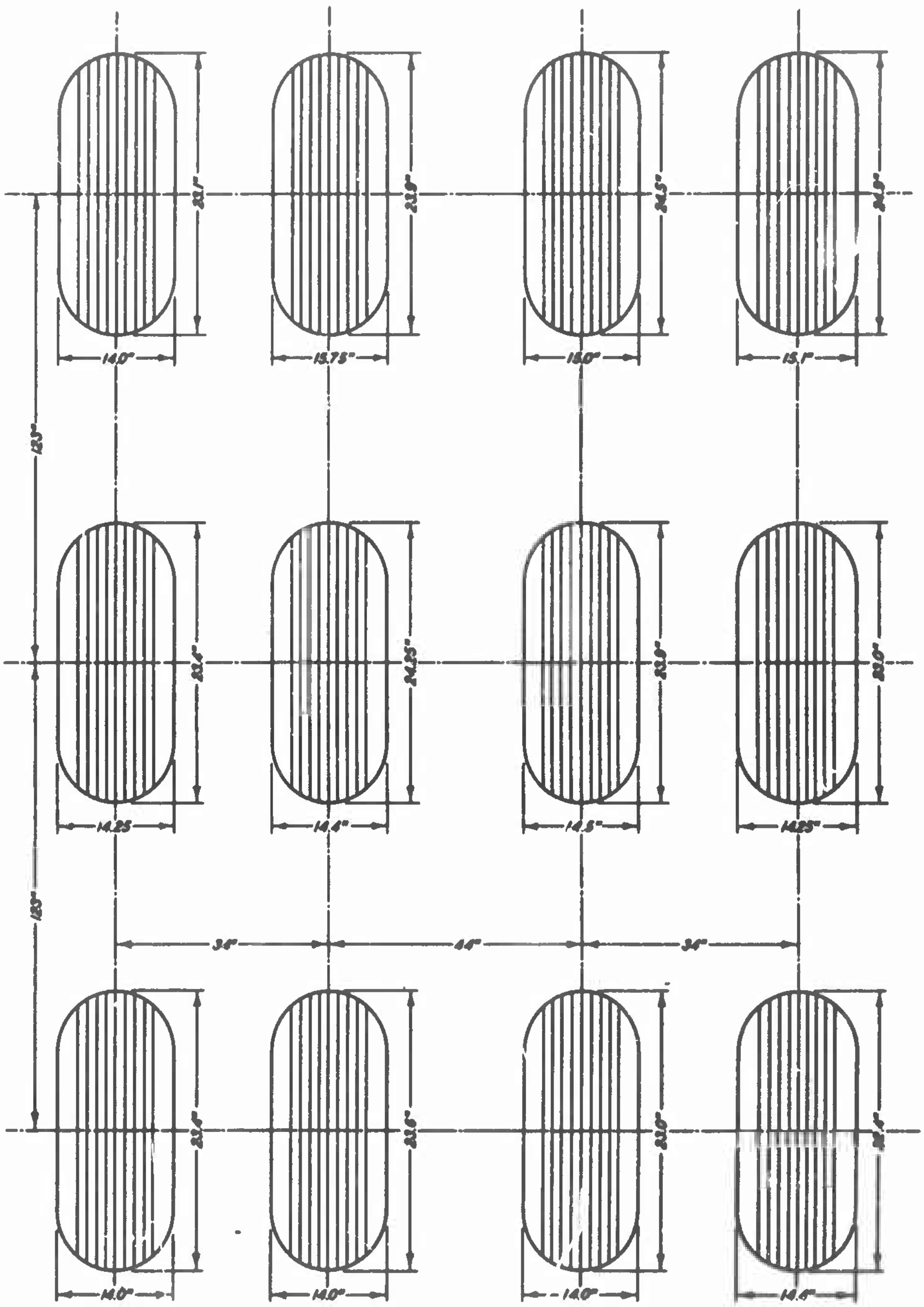

LAYOUT OF SURFACED ITEMS
TEST SECTION 16
LANE 35
TEST LANE 35
ITEM 2
40'
M 8 STEEL LANDING MAT
ITEM 1
40'
MODIFIED T11 ALUMINUM LANDING MAT
1
5
10
15
19 20
25
30
35
40
44
RUN NUMBER
18'-10"
25' TEST SECTION

Figure 10



TIRE SIZE	20.00-20
NO. OF PLYS	22
AVERAGE CONTACT AREA, SQ IN.	280
AVERAGE CONTACT PRESSURE, PSI	88
INFLATION PRESSURE, PSI	100
AVERAGE DEFLECTION, %	33
GROSS ASSEMBLY LOAD = 273,000 LB	

TIRE-PRINT DIMENSIONS AND TIRE CHARACTERISTICS

TEST SECTION 16

LANE 35

Figure 11

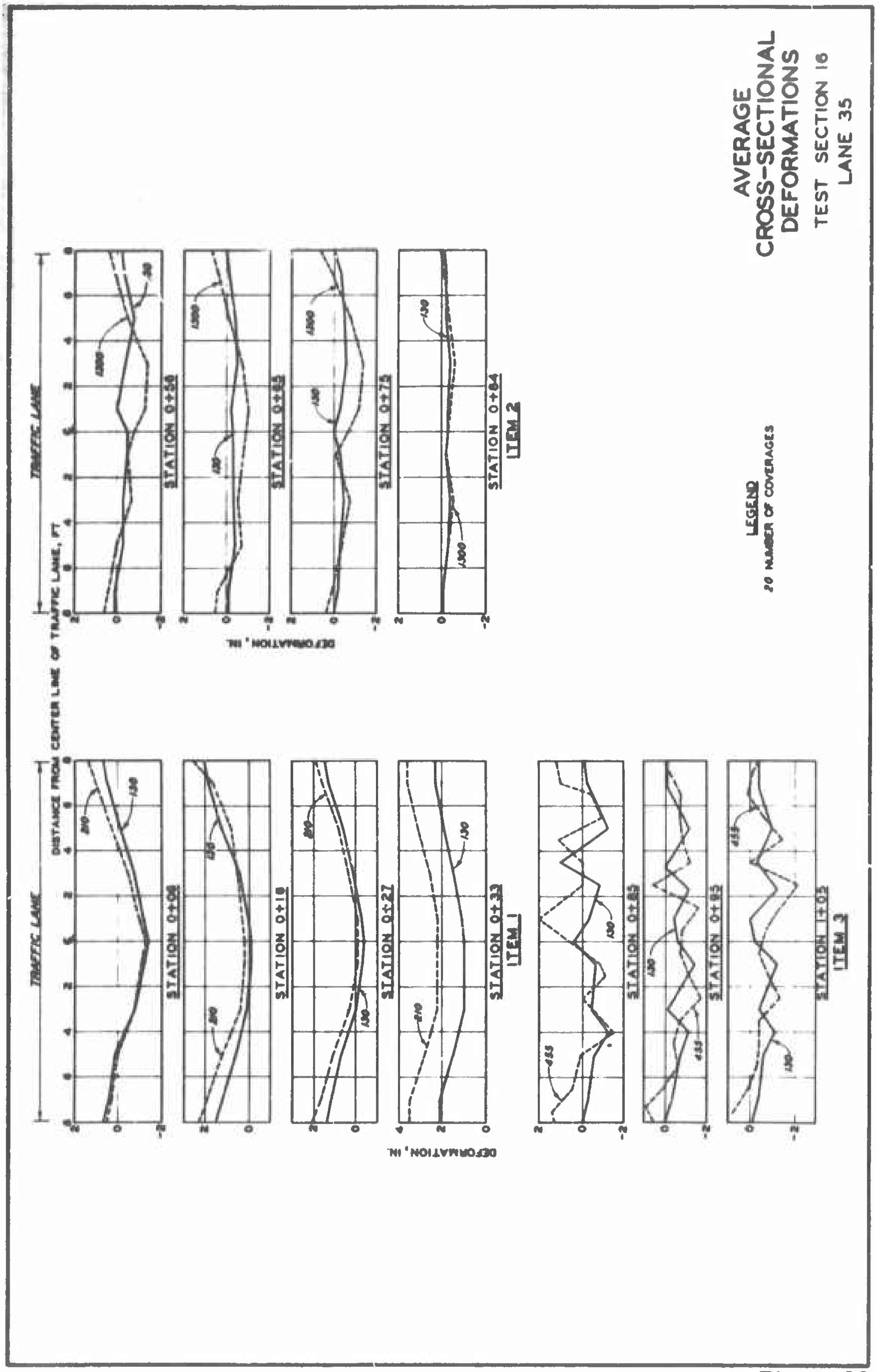
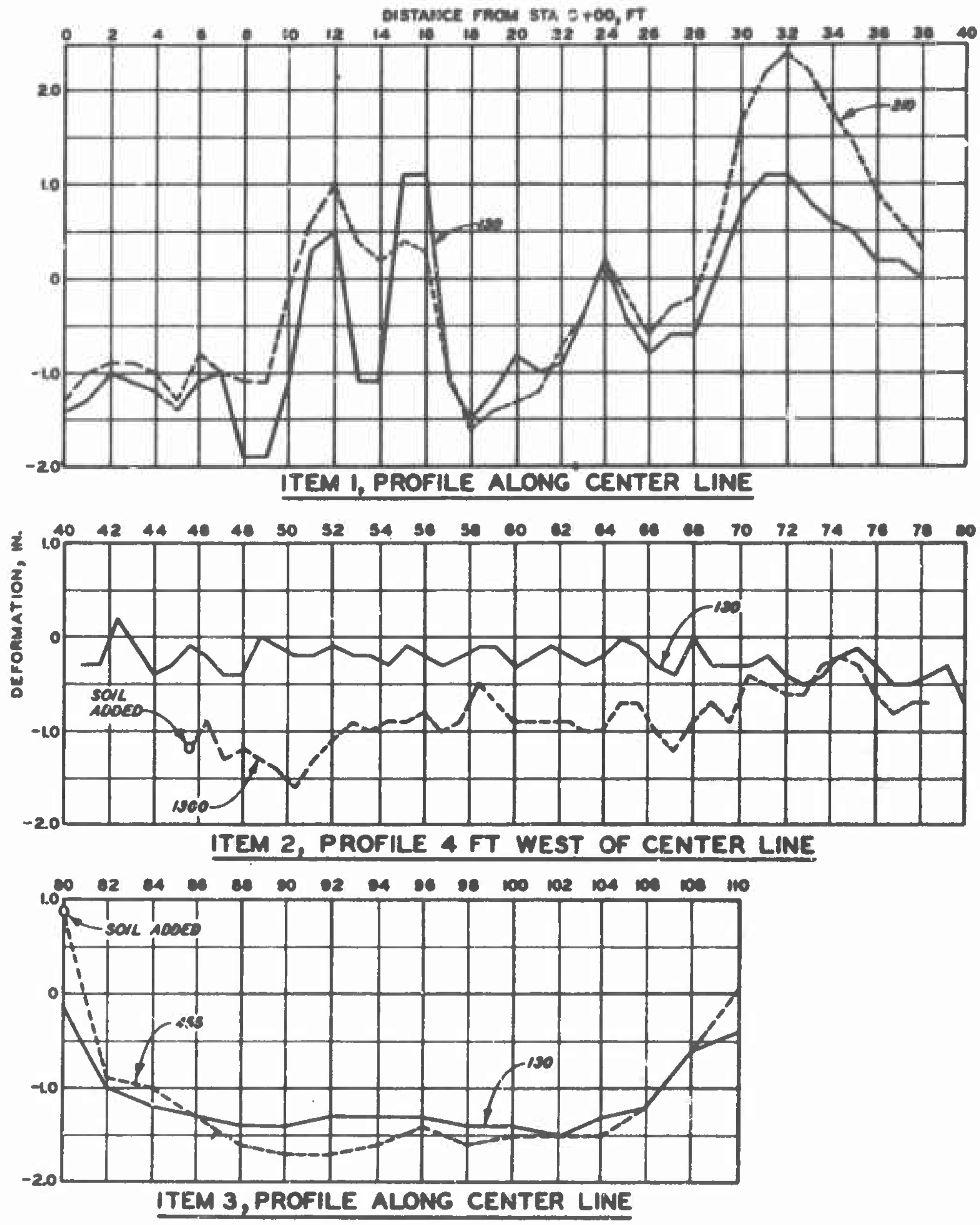

AVERAGE
CROSS-SECTIONAL
DEFORMATIONS
TEST SECTION 16
LANE 35
LEGEND
20 NUMBER OF COVERAGES
TRAFFIC LANE
DISTANCE FROM CENTER LINE OF TRAFFIC LANE, FT
DEFORMATION, IN.
STATION 0+08
STATION 0+18
STATION 0+27
STATION 0+33
ITEM 1
STATION 0+85
STATION 0+93
STATION 1+03
ITEM 3
STATION 0+56
STATION 0+65
STATION 0+75
STATION 0+84
ITEM 2

Figure 12



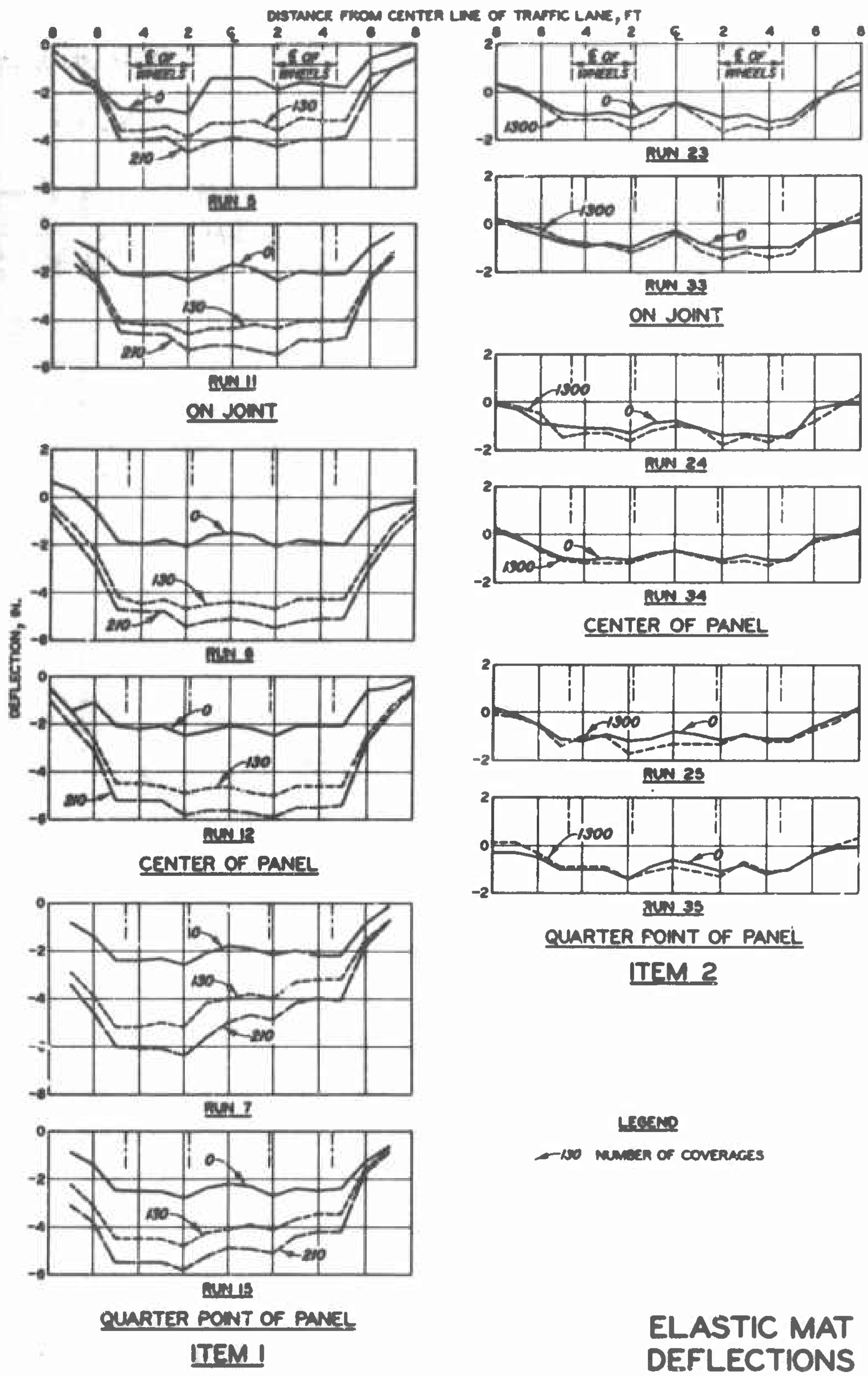
LEGEND

20 NUMBER OF COVERAGES

PERMANENT PROFILE
DEFORMATIONS

TEST SECTION 16
LANE 35

Figure 13



ELASTIC MAT DEFLECTIONS
TEST SECTION 16
LANE 35

Figure 14

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D (Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
	2b. GROUP	
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13. ABSTRACT

This data report describes the results of work undertaken as part of an overall program to develop ground-flotation criteria for the C-5A aircraft.

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