

**AIRCRAFT GROUND-FLOTATION INVESTIGATION
PART VIII DATA REPORT ON TEST SECTION 7**

*W. BRABSTON and W. HILL, JR.
U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION*

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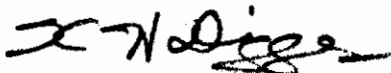
FOREWORD

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 program 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, W. N. Brabston, A. H. Rutledge, H. H. Ulery, Jr., A. J. Smith, Jr., and W. J. Hill, Jr. This report was prepared by Messrs. Brabston and Hill.

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. Oswald, 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.



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 four unsurfaced test lanes having approximately the same subgrade CBR values. Single-wheel traffic was applied to each lane using one of the following tire size and test load combinations: (a) a 56x16, 32-ply aircraft tire with 25,000-lb load; (b) a 25.00-28, 30-ply aircraft tire with 25,000-lb load; (c) a 17.00-16, 12-ply aircraft tire with 25,000-lb load; and (d) a 34x9.9, 14-ply aircraft tire with 19,000-lb load. Tire inflation pressure was 100 psi for all 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 is given at which each test lane was considered failed.

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SUMMARY

Tests on Section 7 are one phase of a comprehensive research program to develop ground-flotation criteria for heavy cargo-type aircraft. Test Section 7 consisted of four similar traffic lanes (lanes 13, 14, 15, and 16), all of which were unsurfaced and constructed to approximately the same CBR value (figure 11). The four test lanes were subjected to traffic by single-wheel tracking assemblies using a different tire size and test load combination on each lane. The following combinations of tire size and test load were used on lanes 13, 14, 15, and 16, respectively: (a) a 56x16, 32-ply aircraft tire with 25,000-lb load; (b) a 25.00-28, 30-ply aircraft tire with 25,000-lb load; (c) a 17.00-16, 12-ply aircraft tire with 25,000-lb load; and (d) a 34x9.9, 14-ply aircraft tire with 19,000-lb load. Inflation pressure for all tires was 100 psi.

The test lanes were trafficked to failure in accordance with the criteria designated in Part I of this report. Data were recorded throughout testing to give a behavior history of each lane. Using the test criteria mentioned above, it was possible to directly compare the effects of trafficking with the four assemblies. Basic performance data are summarized in the following paragraphs.

Lane 13

The lane was considered failed due to rutting at 70 coverages. The rated CBR of the lane was 9.2.

Lane 14

The lane was considered failed due to excessive transverse differential deformations at 200 coverages. The rated CBR of the lane was 7.8.

Lane 15

The lane was considered failed due to excessive transverse

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differential deformations at 100 coverages. The rated CBR of the lane was 7.8.

Lane 16

The lane was considered failed due to rutting at 32 coverages. The rated CBR of the lane was 8.4.

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AIRCRAFT GROUND-FLOTATION INVESTIGATION

PART VIII DATA REPORT ON TEST SECTION 7

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 were conducted to determine the effect of wheel size of single-wheel landing-gear assemblies on unsurfaced soils under similar conditions of loading.

Prosecution of this investigation consisted of constructing four similar test lanes and subjecting them to traffic of four single-wheel tracking assemblies, each consisting of a different size aircraft tire. Three of the lanes were trafficked with 25,000-lb loads and one was trafficked with a 19,000-lb load. Tire inflation pressure was 100 psi for all assemblies.

This report presents a description of the test section and wheel assemblies, and gives results of traffic. Equipment used, types of data and method of recording them, and general test criteria are explained and illustrated in Part I of this report.

SECTION II: DESCRIPTION OF TEST SECTION AND LOAD VEHICLE

Description of Test Section

Test Section 7 was constructed within a roofed area in order to allow control of the subgrade CBR (California Bearing Ratio) in the test lanes. Section 7 was located on the same site as Test Sections 3 and 5. The construction of Test Section 3 is described in Part IV of this report. The underlying subgrade was undisturbed by the two prior tests on the site so that in construction of Section 7 only the upper 18 in. of soil was excavated. The excavated area was backfilled to the original grade level 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.

Four traffic lanes were constructed in the test section, having approximately the same subgrade CBR values. All lanes were unsurfaced.

Load Vehicle

The load vehicle used for trafficking lanes 13 and 14 is shown in figure 1. Load cart construction, details of linkage between the load compartment and prime mover, and method of applying load are explained in Part I. For both lanes, a single-wheel assembly was used with a load of 25,000 lb and tire inflation pressure of 100 psi. The assemblies consisted of a 56x16, 32-ply aircraft tire and a 25.00-28, 30-ply aircraft tire for lanes 13 and 14, respectively.

For trafficking lanes 15 and 16, the load vehicle shown in figure 2 was used with loads of 25,000 lb and 19,000 lb, respectively. For both lanes, a single-wheel assembly was used with tire inflation pressure of 100 psi. The assemblies consisted of a 17.00-16, 12-ply aircraft tire and a 34x9.9, 14-ply aircraft tire for lanes 15 and 16, respectively.

Tire-print data and pertinent tire characteristics for the wheel assemblies used on Section 7 are given in figure 12.

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

Application of Traffic

Traffic was applied to the test lanes in a nonuniform pattern with intensity of traffic being varied within each lane to produce three zones of approximately 100, 80, and 20 percent traffic coverage. Traffic so distributed within a traffic lane simulates as nearly as possible the bell-shaped traffic distribution curve which results from the wander of aircraft from the lane center line. The coverage levels referred to in the tables and text herein 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 13.

Failure Criteria and Data Collected

Failure criteria used in this investigation and descriptive terms used in presentation and discussion of data are presented in Part I. A general outline of types of data collected is given in the following paragraphs. Details on apparatus and procedure for obtaining specific measurements are given in Part I.

CBR, water content, and dry density

CBR, water content, and dry density of the subgrade were measured for each test lane prior to application of traffic, at intermediate coverage levels, and at failure. After traffic was concluded on a lane, 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 a lane. 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 lanes. Rut depths were also measured on test lanes.

Deformations

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

Deflection

Deflection of the test surface under an individual static load of the tracking assembly was measured at various traffic-coverage levels on each lane. Level readings on the lane surface on each side of the load wheel and on a pin and cap device directly beneath the load wheel provided deflection data. Both total (for a single loading) and elastic (recoverable) deflections were measured.

Rolling resistance

Rolling resistance, or drawbar pull, measurements were performed with the load vehicle over each test lane at designated coverage levels. Three types of drawbar measurements were taken: (a) maximum force required to overcome static inertia and commence forward movement of the load cart, termed "initial DBP"; (b) average force required to maintain a constant speed once the load vehicle is in motion, termed "rolling DBP"; and (c) maximum force obtained during the constant speed run, termed "peak DBP."

SECTION IV: BEHAVIOR OF LANES UNDER TRAFFIC AND TEST RESULTS

Lane 13

Behavior of lane under traffic

Figure 3 shows lane 13 prior to traffic. The surface was moderately rutted at 20 coverages with rut depths averaging 1.5 in. Traffic was continued until the lane was considered failed due to rutting at 70 coverages (figure 4). The rated CBR of the lane was 9.2.

Test results

Results of trafficking lane 13 are summarized in table 1. Soil test data are given in table 2. Table 1 contains drawbar pull values for the load vehicle operated over an asphalt-paved strip for comparison with drawbar values recorded on the test lane. The following information was obtained from traffic tests on lane 13.

- a. Roughness. Table 1 shows the progressive development of differential deformations and rut depths with traffic. At failure, both transverse and diagonal differential deformations averaged 3.69 in. Longitudinal deformations were relatively small, averaging 0.69 in. Rut depths averaged 3.31 in. at failure.
- b. Deformation. Figure 14 shows the average cross-section deformations at 20 and 70 coverages. Center-line profiles at 20 and 70 coverages are plotted in figure 15.
- c. Deflection. Average total soil deflections measured at 0, 20, and 70 coverages are plotted in figure 16. Total soil deflection at 70 coverages was about twice as great as in prior measurements. Elastic soil deflections increased similarly, as indicated in table 1.
- d. Rolling resistance. Drawbar pull values measured at several coverage levels are shown in table 1. Drawbar values were small at all levels and increased only slightly with traffic. Minimum initial and peak drawbar values occurred at 20 coverages.

Lane 14

Behavior of lane under traffic

Figure 5 shows lane 14 prior to traffic. The test surface held up well under testing and traffic was continued to 200 coverages at which time the lane was considered failed due to excessive transverse differential

deformations (figure 6). The rated CBR of the lane was 7.8.

Test results

Results of trafficking lane 14 are summarized in table 1. Soil test data are given in table 2. The following information was obtained from traffic tests on lane 14.

- a. Roughness. Table 1 shows the differential deformations and rut depths measured at intervals during testing. Transverse and diagonal differential deformations exceeded in magnitude other deformation measurements and averaged 3.50 and 3.56 in., respectively, at failure. Due to the uniform subsidence in the lane cross section, rut depths were not great and averaged only 1.16 in. at failure.
- b. Deformation. Average cross-section deformations at 20 and 200 coverages are plotted in figure 14. Center-line profiles are plotted in figure 15. Both figures illustrate the extensive subsidence that developed along the lane center line.
- c. Deflection. Average total soil deflections measured at 0, 20, and 200 coverages are plotted in figure 16. Greatest total deflections occurred at 200 coverages. Elastic soil deflections, shown in table 1, registered no significant change with traffic.
- d. Rolling resistance. Drawbar pull values measured at 0, 20, and 200 coverages are shown in table 1. All drawbar values decreased slightly between 20 and 200 coverages.

Lane 15

Behavior of lane under traffic

Figure 7 shows lane 15 prior to traffic. The lane was considered failed at 100 coverages primarily due to excessive transverse differential deformations (figure 8). The rated CBR of the lane was 7.8.

Test results

Results of trafficking lane 15 are summarized in table 1. Soil test data are given in table 2. The following information was obtained from traffic tests on lane 15.

- a. Roughness. Table 1 shows differential deformations and rut depths measured at 20 and 100 coverages. Transverse and diagonal differential deformations were largest and averaged 3.62 and

3.83 in., respectively, at failure. Rutting was less severe, averaging 2.15 in. at failure.

- b. Deformation. Average cross-section deformations are plotted in figure 14 for 20 and 100 coverages. The same coverage levels are represented in the center-line plot in figure 15.
- c. Deflection. Average total soil deflections measured at 0, 20, and 100 coverages are plotted in figure 16. Only small increases in total deflection resulted from traffic. Elastic soil deflections, shown in table 1, increased slightly.
- d. Rolling resistance. Drawbar pull values, shown in table 1, increased progressively during testing with maximum values occurring at 100 coverages.

Lane 16

Behavior of lane under traffic

Figure 9 shows lane 16 prior to traffic. Severe ruts developed early in testing with high ridges forming between the ruts. It became impossible beyond 14 coverages to track the ridged strips, as the load wheel continually slipped sideways into an adjacent rut. The relative heights of the ridges increased with continued trafficking due to soil upheaval from the rutted areas. To obtain more representative roughness data, the influence of the ridge areas was de-emphasized by cutting access notches across the ridges so that for differential deformation measurements the ends of the 10-ft straightedge rested on the undisturbed surfaces outside the tracking lane. Figure 10 shows the lane after it was judged failed at 32 coverages. The rated CBR of the lane was 8.4.

Test results

Results of trafficking lane 16 are summarized in table 1. Soil test data are given in table 2. Table 1 contains drawbar pull values for the load vehicle operated over an asphalt strip for comparison with drawbar values recorded on the test lane. The following information was obtained from traffic tests on lane 16.

- a. Roughness. Table 1 shows differential deformations and rut depths at 20 and 32 coverages. Transverse and diagonal differential deformations exceeded rut depth measurements, averaging 3.22 and 3.16 in., respectively, at failure. Rut depths averaged 2.07 in.
- b. Deformation. Average cross-section deformations measured at 20 and 32 coverages are plotted in figure 14. The extremely rough cross section at 32 coverages reflects the combination

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of ridges and ruts developed in the lane. Profile plots in figure 15 show the irregular grade that developed from uneven longitudinal settlement.

- c. Deflection. Average total soil deflections measured at 0, 20, and 32 coverages are plotted in figure 16. Measurements at 0 and 20 coverages were identical and exceeded those at 32 coverages. Elastic soil deflections, shown in table 1, did not change with traffic.
- d. Rolling resistance. Drawbar pull values, shown in table 1, increased steadily with traffic and reached a maximum at 32 coverages.

SECTION V: PRINCIPAL FINDINGS

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

<u>Load, Wheel Assembly, and Tire Pressure</u>	<u>Rated Subgrade CBR*</u>	<u>Coverages at Failure</u>
25,000-lb load; single-wheel assembly; 56x16, 32-ply tire at 100-psi inflation pressure	9.2	70
25,000-lb load; single-wheel assembly; 25.00-28, 30-ply tire at 100-psi inflation pressure	7.8	200
25,000-lb load; single-wheel assembly; 17.00-16, 12-ply tire at 100-psi inflation pressure	7.8	100
19,000-lb load; single-wheel assembly; 34x9.9, 14-ply tire at 100-psi inflation pressure	8.4	32

* All test lanes were unsurfaced.

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TABLE 1
SUMMARY OF TRAFFIC DATA, TEST SECTION 7

Test Lane No.	Load (kips)	Tire Size and Ply	Coverages	Rated CBR	Differential Deformations (in.)						Rutting (in.)		Drawbar Pull (kips)		Subgrade Deflection at Approximate Center Line of Assembly (in.)		Remarks		
					Longitudinal		Transverse		Diagonal		Max	Avg	Max	Avg	Initial	Peak		Total	Elastic
					Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg					
13 Unsurfaced	25	56x16, 32 ply	0	↑	--	--	--	--	--	--	--	3.9	2.9	0.8	1.0	0.3	Lane 13 failed due to rutting at 70 coverages		
			20	9.2	0.25	0.25	2.50	2.07	2.25	1.82	2.00	1.50	3.0	2.5	1.3	1.2		0.4	
			70	↓	1.00	0.69	4.75	3.69	4.50	3.69	4.55	3.31	5.3	3.2	1.6	2.1		1.2	
Asphalt strip 14 Unsurfaced	25	56x16, 32 ply	--	--	--	--	--	--	--	--	2.6	Negligible	Negligible	--	--	--	Lane 14 failed due to excessive transverse differential deformations at 200 coverages		
			0	↑	--	--	--	--	--	--	--	--	2.8	1.3	0.7	1.1		0.2	
			20	7.8	0.50	0.35	1.63	1.50	1.50	1.35	1.25	0.88	4.0	1.5	0.8	1.0		0.3	
15 Unsurfaced	25	17.00-16, 12 ply	100	↓	0.75	0.50	2.75	2.38	2.50	2.13	1.00	0.88	--	--	--	--	--	Lane 15 failed due to excessive transverse differential deformations at 200 coverages	
			170	↓	0.50	0.38	3.50	2.91	3.13	2.66	0.88	0.72	--	--	--	--	--		
			200	↓	1.25	0.81	4.00	3.50	4.25	3.56	1.38	1.16	3.6	1.4	0.5	1.4	0.4		
16 Unsurfaced	19	34x9.9, 14 ply	0	↑	--	--	--	--	--	--	--	3.1	2.3	1.5	0.8	0.2	Lane 16 failed due to excessive transverse differential deformations at 100 coverages		
			20	8.4	0.88	0.60	3.00	2.35	3.00	2.56	2.13	1.41	5.1	5.3	2.3	1.0		0.4	
			32	↓	2.50	1.88	4.50	3.22	4.38	3.16	2.63	2.07	5.8	5.8	2.5	0.8		0.4	
Asphalt strip	19	34x9.9, 14 ply	--	--	--	--	--	--	--	--	4.1	1.3	0.8	--	--	--			
			0	↑	--	--	--	--	--	--	--	--	3.3	2.4	1.4	1.0		0.4	
			20	8.4	0.88	0.60	3.00	2.35	3.00	2.56	2.13	1.41	5.1	5.3	2.3	1.0		0.4	
Asphalt strip	19	34x9.9, 14 ply	32	↓	2.50	1.88	4.50	3.22	4.38	3.16	2.63	2.07	5.8	5.8	2.5	0.8	0.4		
			--	--	--	--	--	--	--	--	--	--	4.1	1.3	0.8	--	--		
			--	--	--	--	--	--	--	--	--	--	4.1	1.3	0.8	--	--		

Note: Single-wheel loading and 100-psi tire inflation pressure were used in all tests.

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TABLE 2

SUMMARY OF CBR, DENSITY, AND WATER CONTENT DATA, TEST SECTION 7

Test Lane No.*	Cover-ages	Depth (in.)	CBR	Water Content %	Dry Density (lb/cu ft)	Remarks	
13	0	0	6	26.3	94.1	Lane failed due to rutting at 70 coverages	
		6	9	25.6	91.6		
		12	9	25.1	96.7		
		18	6	27.5	94.4		
	70	0	7	26.4	95.8		
		6	9	23.9	95.5		
		12	15	23.8	97.2		
		18	11	25.5	94.6		
14	0	0	6	26.3	94.1	Lane failed due to excessive differential deformations at 200 coverages	
		6	9	25.6	91.6		
		12	9	25.1	96.7		
		18	6	27.5	94.4		
	200	0	6	26.9	96.5		
		6	8	25.8	96.1		
		12	9	26.4	95.0		
		18	10	26.0	95.6		
	15	0	0	7	25.8	93.4	Lane failed due to excessive differential deformations at 100 coverages
			6	9	23.5	90.0	
			12	8	25.7	94.8	
			18	8	25.9	92.1	
100		0	7	25.8	96.9		
		6	9	25.0	99.4		
		12	7	27.3	94.1		
		18	8	26.7	92.8		
16	0	0	7	25.8	93.4	Lane failed due to rutting at 32 coverages	
		6	9	23.5	90.0		
		12	8	25.7	94.8		
		18	8	25.9	92.1		
	32	0	8	25.3	96.4		
		6	10	25.5	96.4		
		12	15**	24.0	94.7		
		18	12	26.1	95.0		

Note: Subgrade material was heavy clay (buckshot; classified as CH) in all lanes.

* All lanes were unsurfaced.

** Excessively high value; disregarded in computing rated CBR.

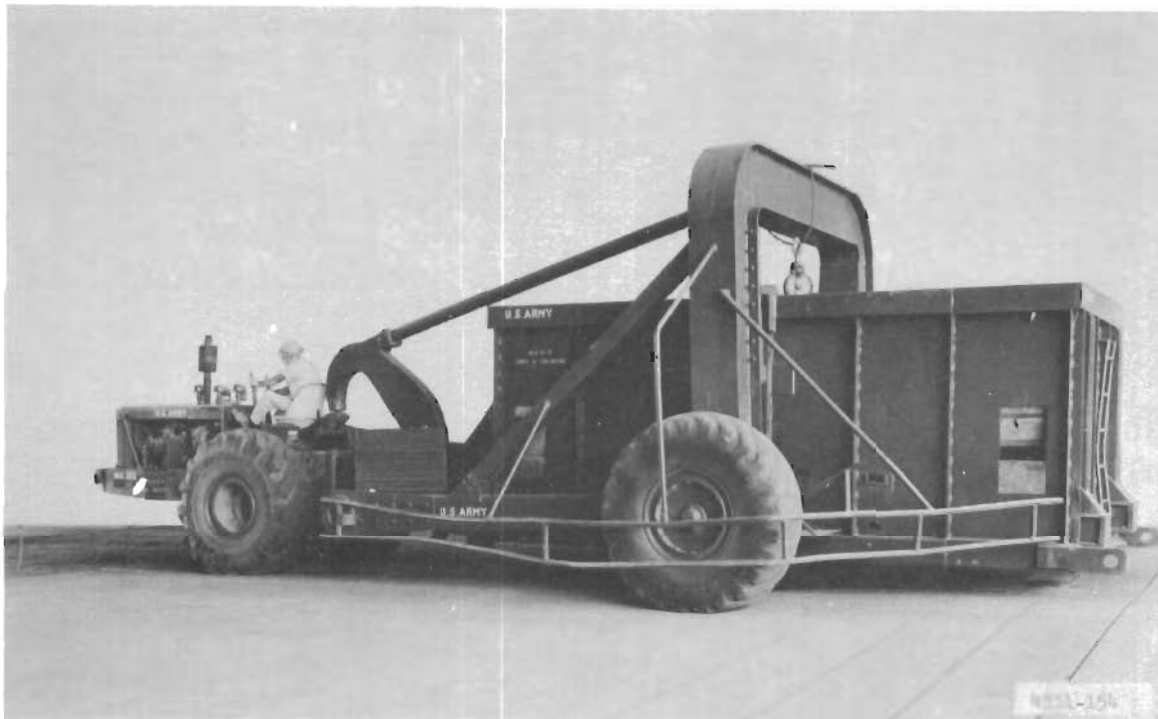


Figure 1. Load vehicle used on lanes 13 and 14



Figure 2. Load vehicle used on lanes 15 and 16

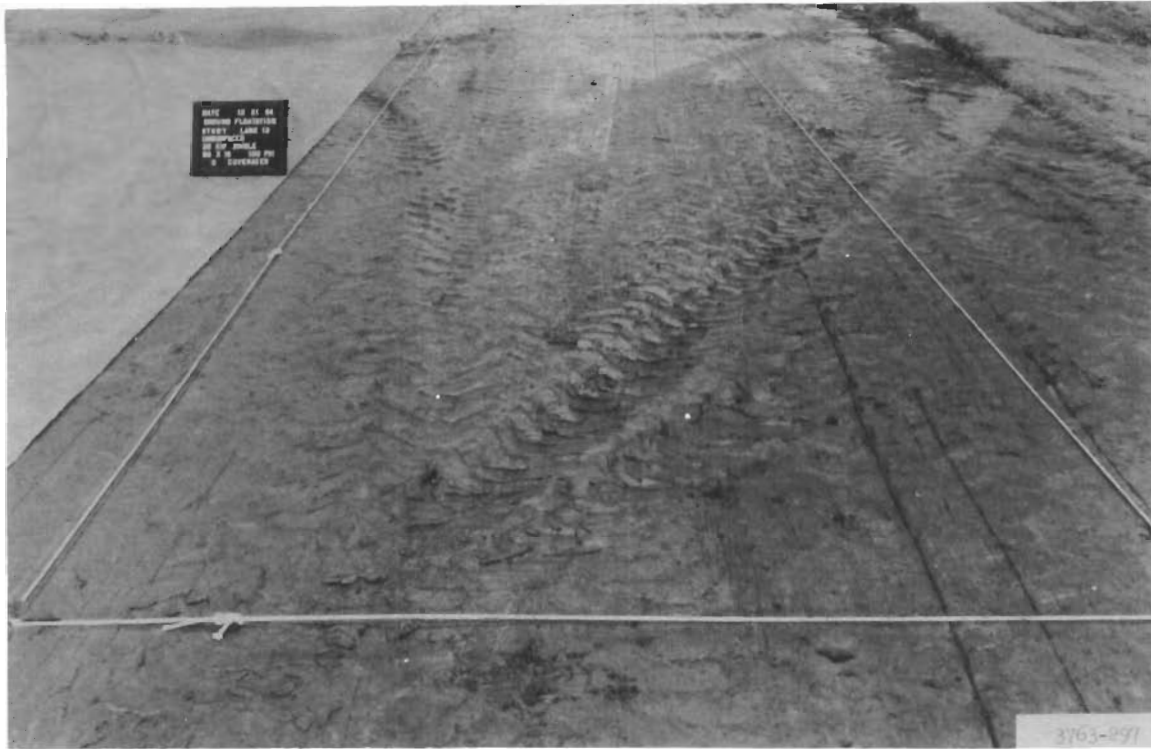


Figure 3. Lane 13 prior to traffic

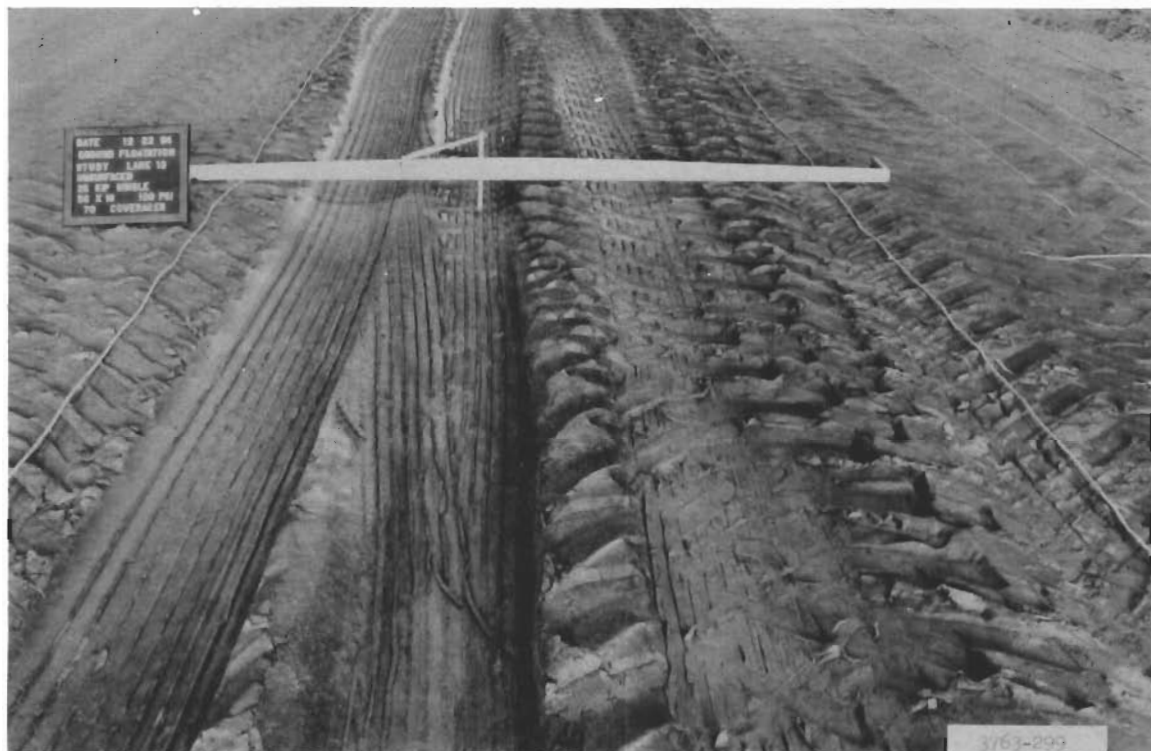


Figure 4. Lane 13; general view showing transverse straightedge measurement at 70 coverages (failure)

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Figure 5. Lane 14 prior to traffic

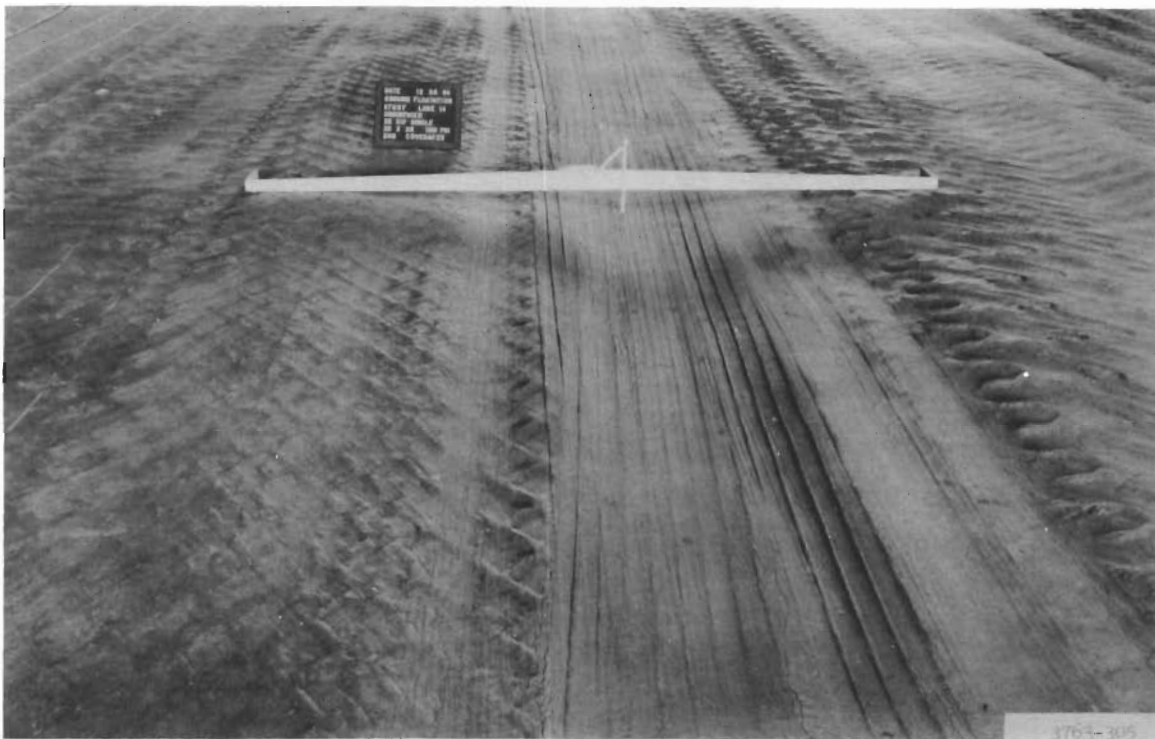


Figure 6. Lane 14; general view showing transverse straightedge measurement at 200 coverages (failure)

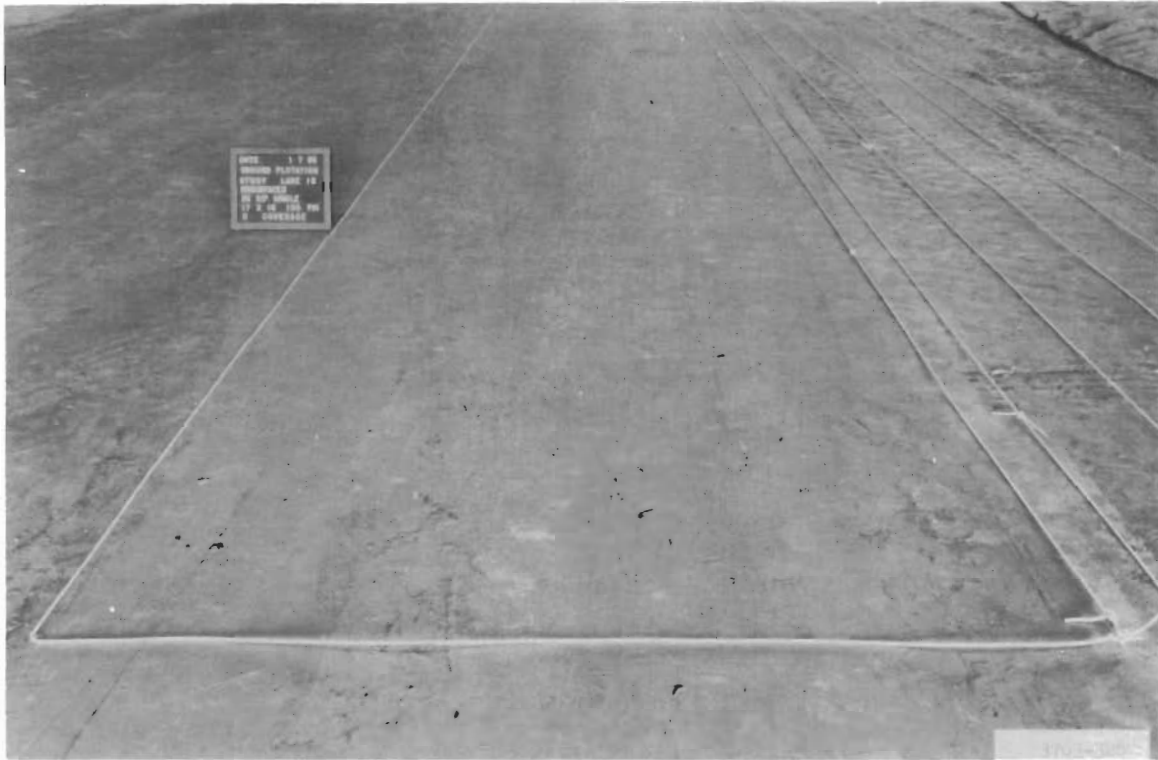


Figure 7. Lane 15 prior to traffic



Figure 8. Lane 15; general view showing transverse straightedge measurement at 100 coverages (failure)

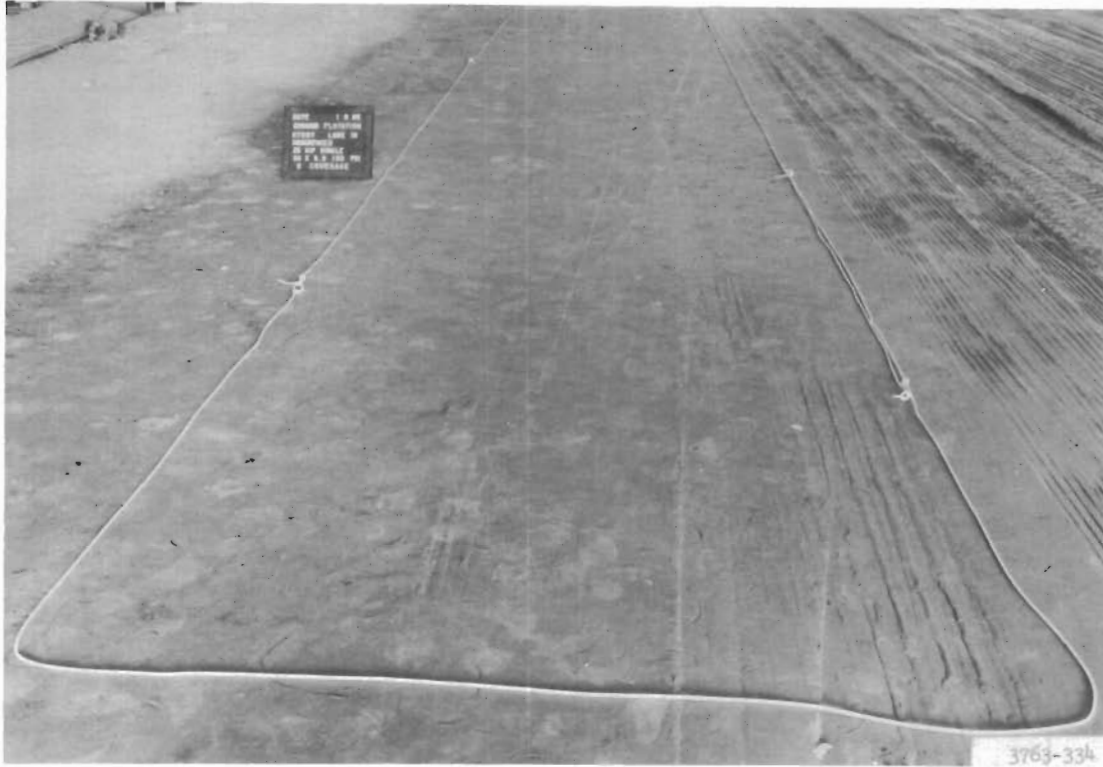


Figure 9. Lane 16 prior to traffic

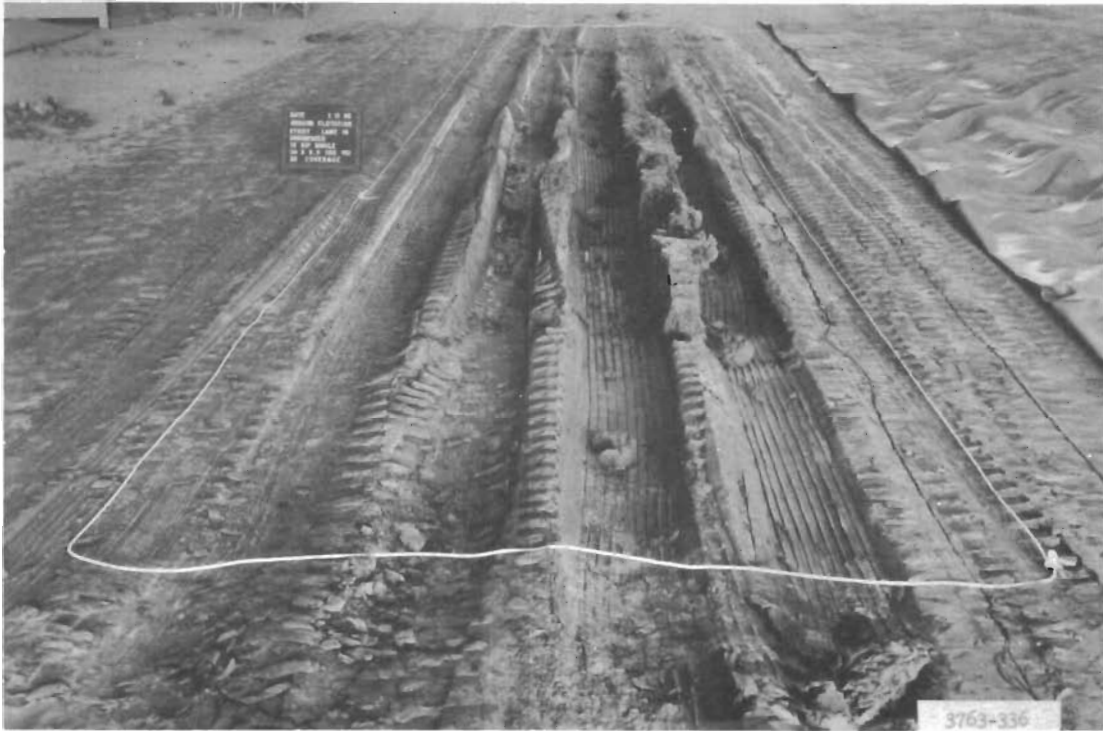


Figure 10. General view of lane 16 after 32 coverages (failure)

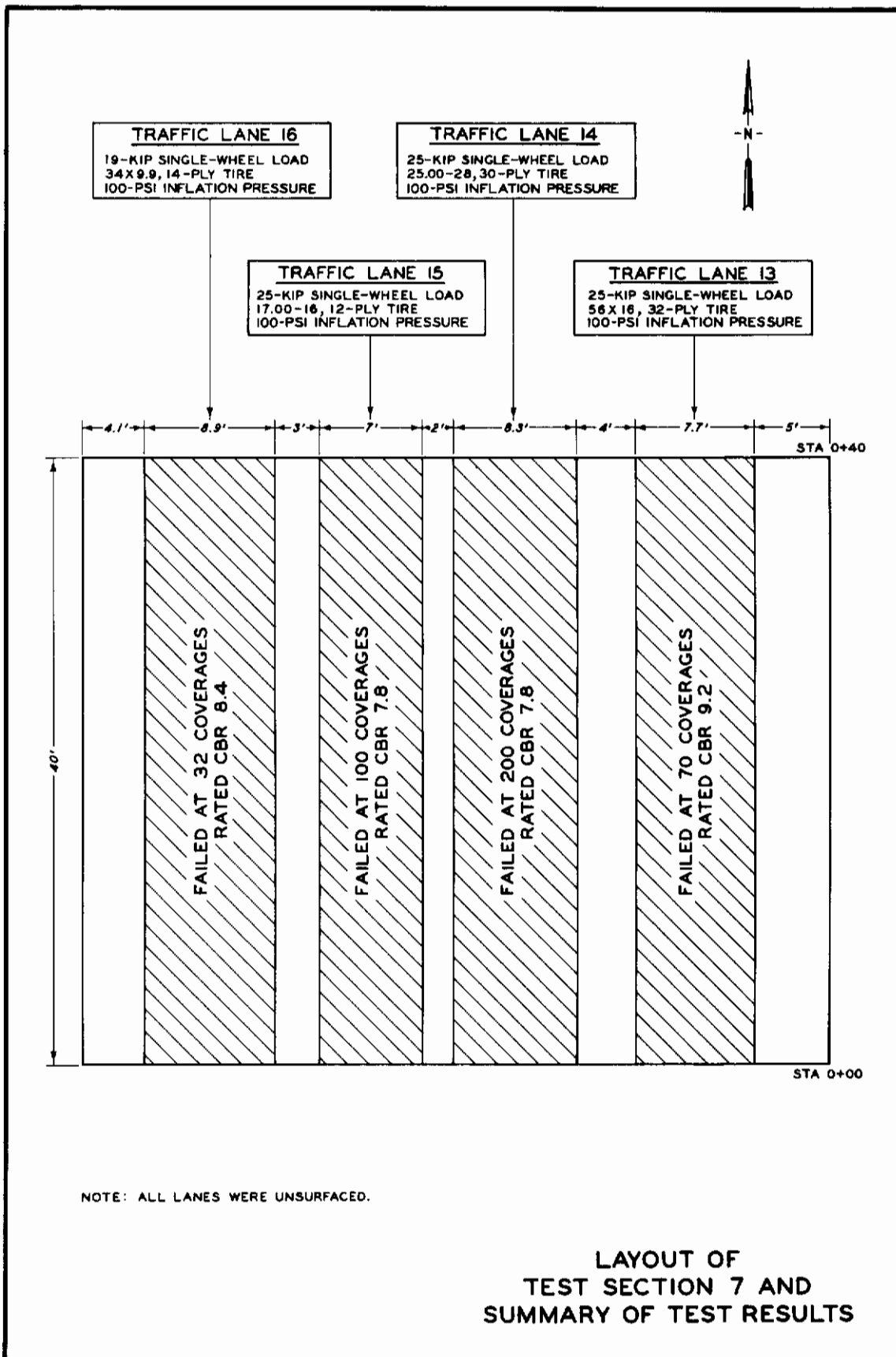
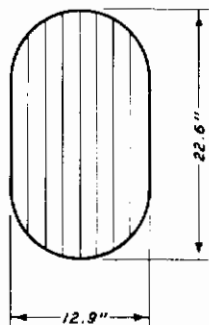
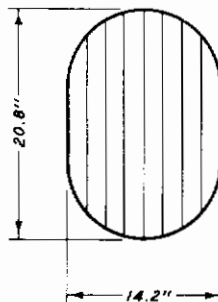


Figure 11



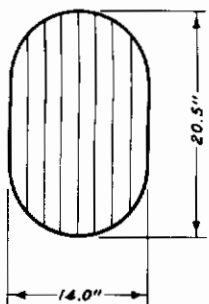
TIRE SIZE	56X16
NO. OF PLYS	32
CONTACT AREA, SQ IN.	242
CONTACT PRESSURE, PSI	103
INFLATION PRESSURE, PSI	100
DEFLECTION, %	29
GROSS ASSEMBLY LOAD, KIPS	25

LANE 13



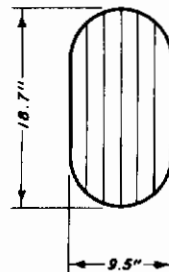
TIRE SIZE	25.00-28
NO. OF PLYS	30
CONTACT AREA, SQ IN.	227
CONTACT PRESSURE, PSI	110
INFLATION PRESSURE, PSI	100
DEFLECTION, %	17
GROSS ASSEMBLY LOAD, KIPS	25

LANE 14



TIRE SIZE	17.00-16
NO. OF PLYS	12
CONTACT AREA, SQ IN.	251
CONTACT PRESSURE, PSI	100
INFLATION PRESSURE, PSI	100
DEFLECTION, %	35
GROSS ASSEMBLY LOAD, KIPS	25

LANE 15



TIRE SIZE	34X9.9
NO. OF PLYS	14
CONTACT AREA, SQ IN.	164
CONTACT PRESSURE, PSI	116
INFLATION PRESSURE, PSI	100
DEFLECTION, %	59
GROSS ASSEMBLY LOAD, KIPS	19

LANE 16

**TIRE-PRINT DIMENSIONS AND
TIRE CHARACTERISTICS
TEST SECTION 7
LANES 13, 14, 15, AND 16**

Figure 12

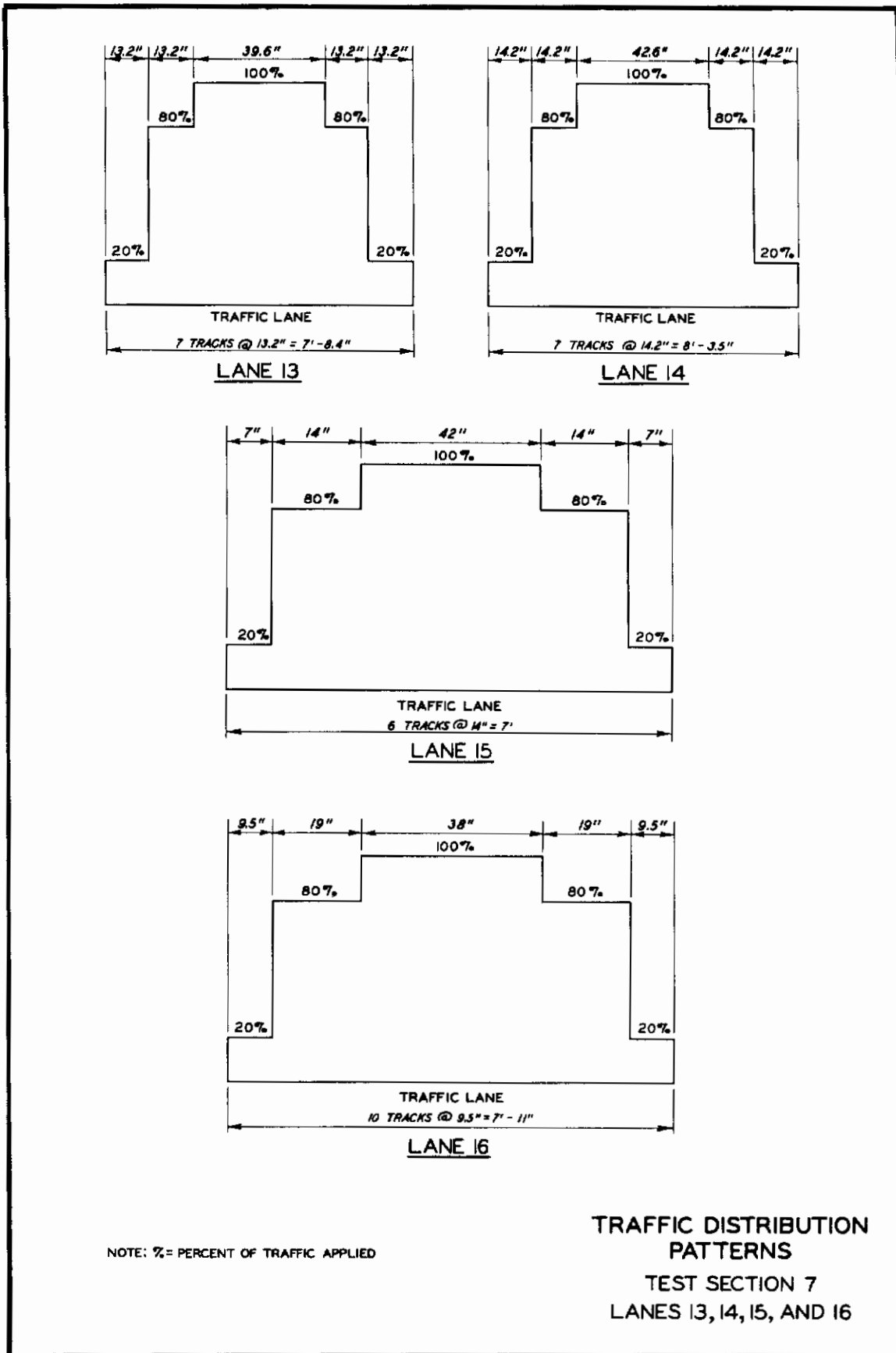


Figure 13

Contrails

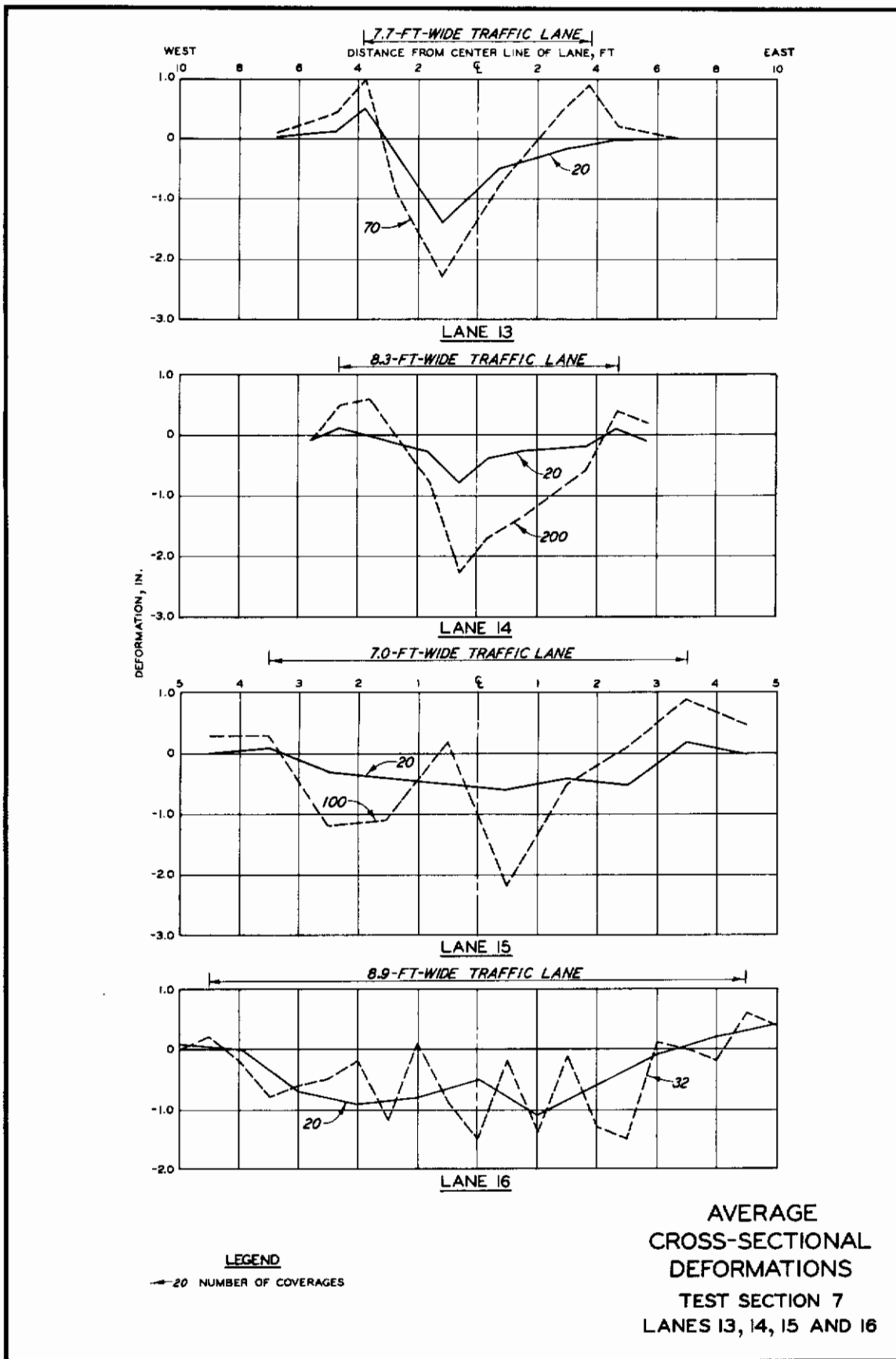


Figure 14

Contrails

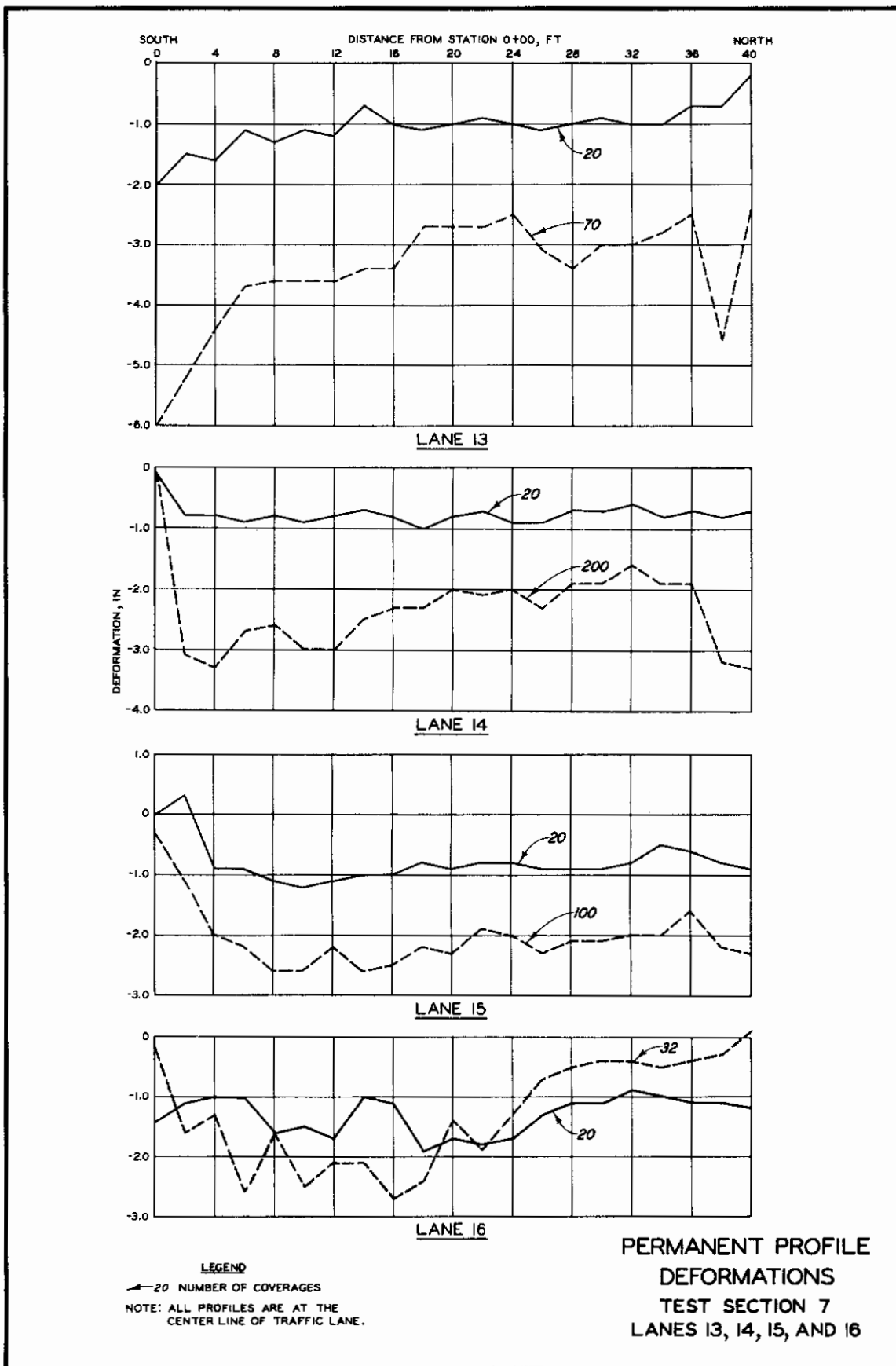


Figure 15

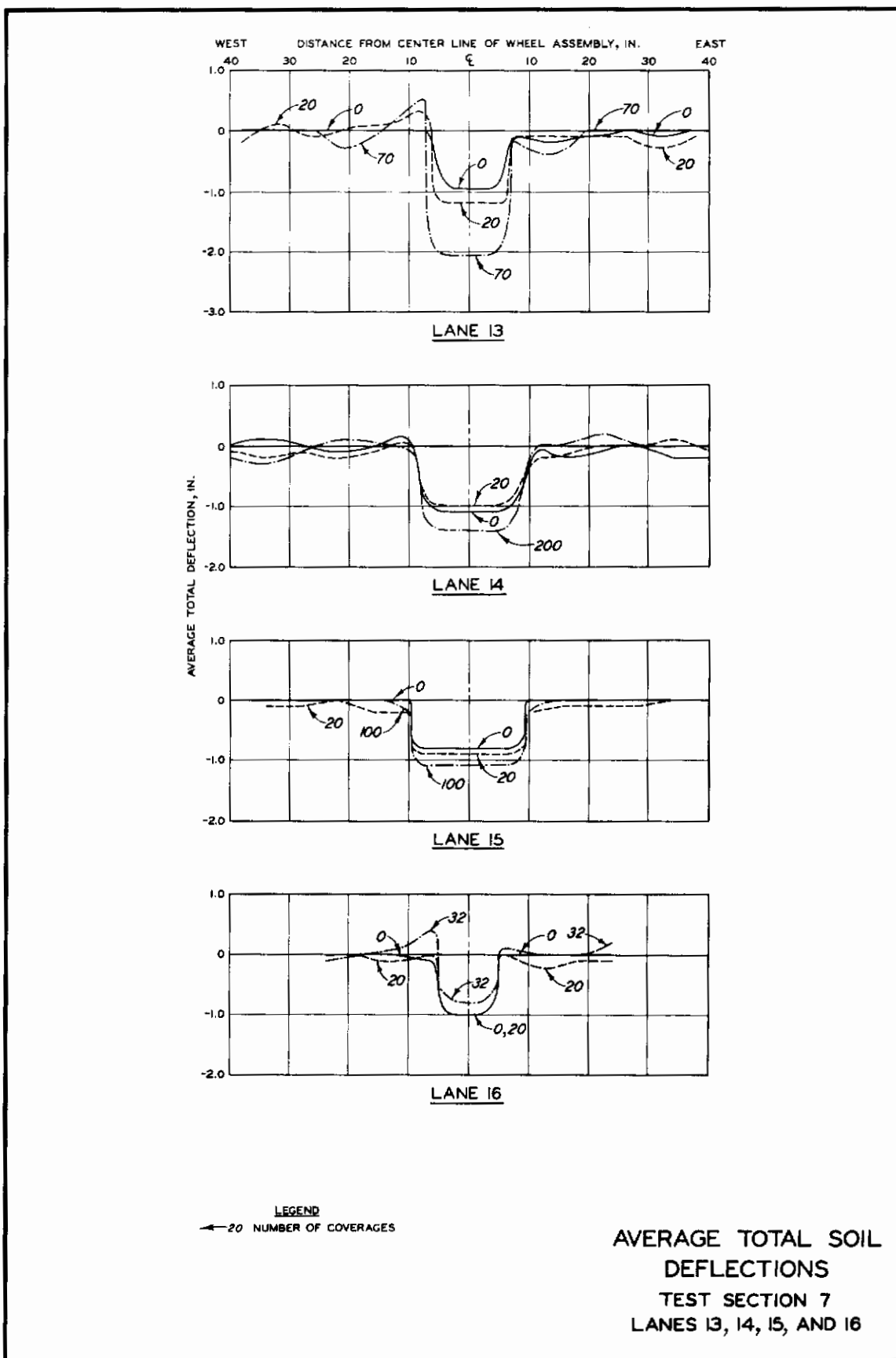


Figure 16

Contrails

Contrails

Contrails

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		2b. GROUP	
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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Air Force Flight Dynamics Laboratory Research and Technology Division AF Systems Command, WPAFB, Ohio	
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.			

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Ground Flotation Rolling Resistance Rear Area Airfields Support Area Airfields Forward Area Airfields Vehicle Mobility						

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