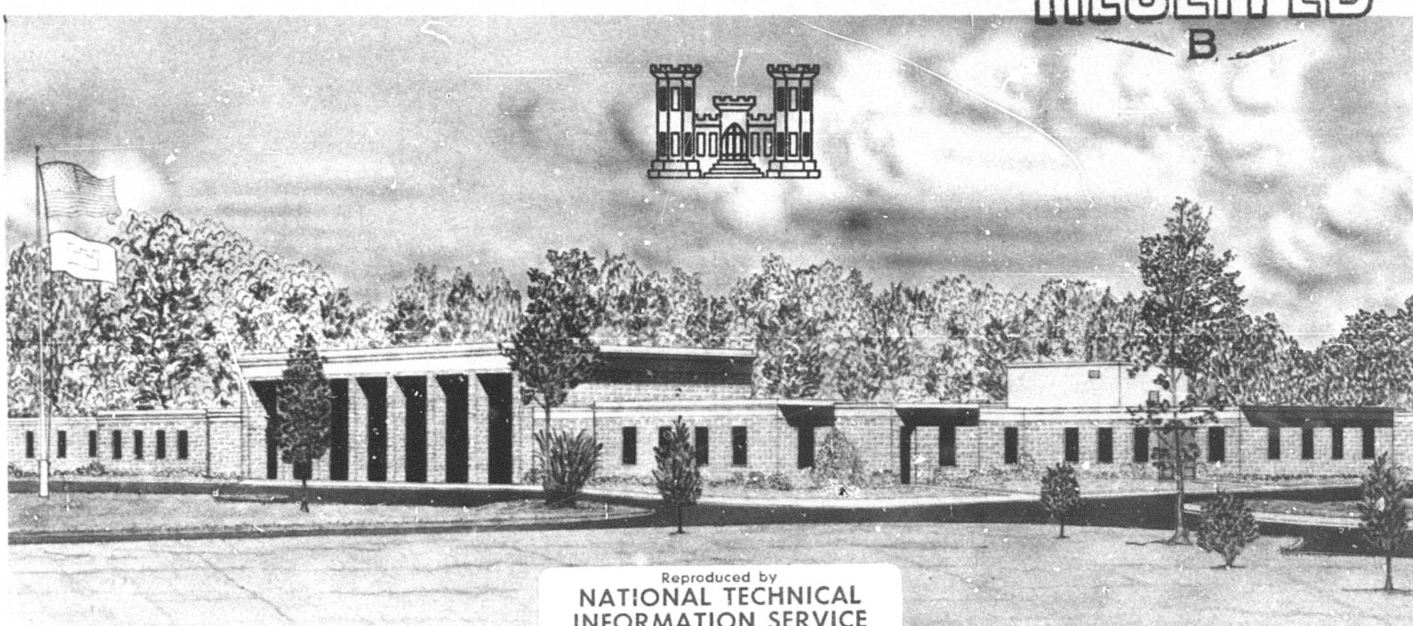
MISCELLANEOUS PAPER S-71-27

DESIGN OF UNSURFACED SOIL FACILITIES FOR OPERATIONS OF C-5A AIRCRAFT

by

D. M. Ladd, V. C. Barber



December 1971

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

R

56

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
Vicksburg, Mississippi

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
DESIGN OF UNSURFACED SOIL FACILITIES FOR OPERATIONS OF C-5A AIRCRAFT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (First name, middle initial, last name)
Donald M. Ladd
Victor C. Barber

6. REPORT DATE
December 1971

7a. TOTAL NO. OF PAGES
50

7b. NO. OF REFS
6

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Miscellaneous Paper S-71-27

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Office, Chief of Engineers, U. S. Army
Washington, D. C.

13. ABSTRACT
The purpose of the study reported herein was to obtain data to validate or modify, if necessary, existing criteria for the operation of the C-5A aircraft on unsurfaced airfields. Two specially prepared test sections were constructed and trafficked. Test section 1 consisted of a three-item test lane designed for evaluation of surface strength requirements and was trafficked with a 12-wheel C-5A gear arrangement loaded to 252,000 lb. Test section 2 consisted of two traffic lanes (lanes 1 and 2) of four items each designed for evaluation of thickness requirements. Lane 1 was trafficked with a 35,000-lb single-wheel load, and lane 2 was trafficked with the 12-wheel C-5A gear arrangement. An analysis of the test data showed that existing criteria could be used to design unsurfaced airfields for operations of C-5A aircraft.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
C-5A aircraft						
Traffic tests						
Unsurfaced airfields						

Unclassified

Security Classification

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

This report presents results of a series of tests conducted during the period 1970-71 by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Chief of Engineers, using Military Engineering Design and Expedient Construction Criteria funds under Task 10, Work Unit 001, entitled "C-5A Prototype Landing Gear Controlled Ground Flotation Tests."

Engineers of the WES Soils Division who were actively engaged in the planning, testing, analyzing, and reporting phases of this study were Messrs. J. P. Sale, Chief, R. G. Ahlvin, R. L. Hutchinson, C. D. Burns, D. N. Brown, D. M. Ladd, and V. C. Barber. This report was prepared by Messrs. Ladd and Barber.

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

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square inches	6.4516	square centimeters
pounds	0.45359237	kilograms
kips	453.59237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter

SUMMARY

The purpose of the study reported herein was to obtain data to validate or modify, if necessary, existing criteria for the operation of the C-5A aircraft on unsurfaced airfields. Two specially prepared test sections were constructed and trafficked. Test section 1 consisted of a three-item test lane designed for evaluation of surface strength requirements and was trafficked with a 12-wheel C-5A gear arrangement loaded to 252,000 lb. Test section 2 consisted of two traffic lanes (lanes 1 and 2) of four items each designed for evaluation of thickness requirements. Lane 1 was trafficked with a 35,000-lb single-wheel load, and lane 2 was trafficked with the 12-wheel C-5A gear arrangement. An analysis of the test data showed that existing criteria could be used to design unsurfaced airfields for operations of C-5A aircraft.

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DESIGN OF UNSURFACED SOIL FACILITIES FOR OPERATIONS OF C-5A AIRCRAFT

PART I: INTRODUCTION

Background

1. The C-5A aircraft is the world's largest aircraft constructed to date. It has a maximum gross weight of 769,000 lb* for operation on permanent (paved) airfields and a limited gross weight of 571,000 lb for operation on temporary airfields (landing-mat-surfaced and unsurfaced soils). The C-5A has 24 main tires and 4 nose tires to provide the capability for operation on temporary airfields.

2. A series of tests on landing-mat-surfaced and unsurfaced soils was conducted in 1965-1967 to develop criteria by which an aircraft designer could design a landing gear that would allow operation of the C-5A on temporary airfields.[1] Included in this study were several tests using a 12-wheel arrangement to simulate one main gear of the C-5A. The gear for the C-5A had not been selected at the time of these tests; therefore, the tests were conducted using an arrangement that was considered fairly well representative of the C-5A landing gear. When the C-5A design was completed, the landing gear arrangement was significantly different from that previously tested. Therefore, it was deemed necessary to test the final gear arrangement on landing-mat-surfaced and unsurfaced soils. This report presents the results of the tests on unsurfaced soils.

Purpose and Scope

3. The purpose of this investigation was to evaluate the applicability of existing design criteria to operation of the C-5A aircraft on unsurfaced soil airfields. This included evaluating surface strength

* A table of factors for converting British units of measurement to metric units is presented on page vii.

requirements and thickness requirements. Therefore, two test sections were constructed, one for the evaluation of surface strength requirements and one for the evaluation of thickness requirements.

PART II: TEST EQUIPMENT AND MATERIALS

Test Sections

4. The test sections were constructed under a roofed area in order that the subgrade strength of the test items could be controlled. Layouts of the test sections are shown in plates 1 and 2. Test section 1 was constructed with one traffic lane consisting of three test items. Test section 2 was constructed with two lanes of four items each. To construct the test sections, the natural soil was excavated to a depth of 2 ft for test section 1 and 3 ft for test section 2, and the area was backfilled with a local heavy clay. The fill material was processed and compacted to provide the design strength. For test section 1, test items 1, 2, and 3 had design strengths of 10, 8, and 6 CBR, respectively. For test section 2, item 1 had 12 in. of 14-CBR material over an 8-CBR subgrade; item 2 had 9 in. of a 14-CBR material over an 8-CBR subgrade; item 3 had 15 in. of a 12-CBR material over a 4-CBR subgrade; and item 4 had 10 in. of a 12-CBR material over a 4-CBR subgrade.

Soil

5. The soil used to construct these test sections was a heavy buckshot clay that is classified CH according to the Unified Soil Classification System presented in Military Standard MIL-STD-619B[2] and has a liquid limit of 68, a plastic limit of 28, and a plasticity index of 40. This soil was used primarily because its strength can be easily controlled and maintained.

Load Carts and Tire

Load carts

6. The load cart used to apply traffic to test section 1 and to lane 2 of test section 2 is shown in fig. 1. This load cart is driven by electric motors in each wheel and consists of a power unit and frame

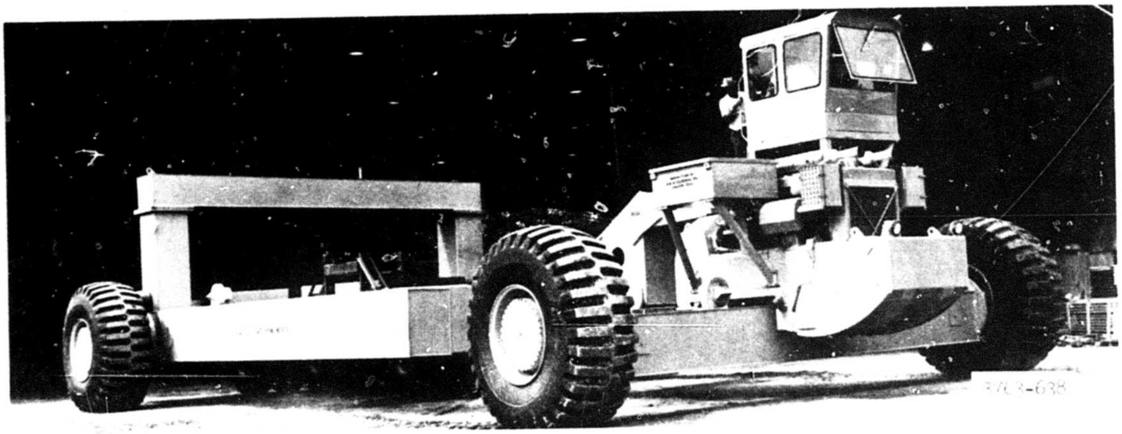

Fig. 1. Load cart used for C-5A tests

and two interior load compartments with the tracking wheels. Weights were placed in the load compartments to provide the desired test load of 252,000 lb, which is the load on 12 main gear tires of the C-5A at a gross load of 571,000 lb. The configuration and tire size of the tracking wheels were the same as one main landing gear of the C-5A aircraft. The load boxes are interconnected, and the forward box is connected to the frame by two draw pins. The boxes are free to move in a vertical direction independent of the frame. This load cart was operated in such a manner that the wheels of the frame did not traffic the test lanes.

7. The load cart used to apply traffic to lane 1 of test section 2 is shown in fig. 2. The cart is drawn by a commercial-type tractor

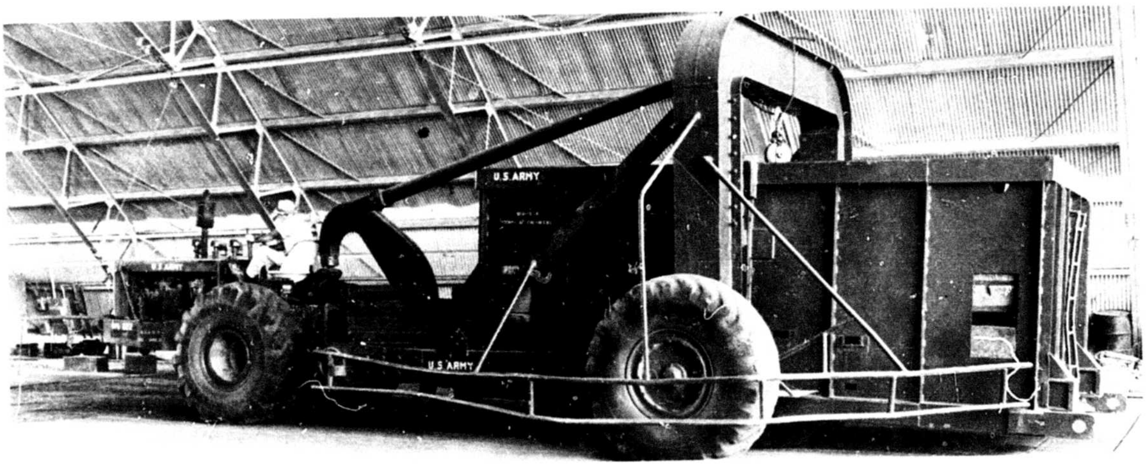

Fig. 2. Load cart used for single-wheel tests

and consists of an interior load compartment with loaded tracking wheels and an outer support frame. The load compartment is connected to the frame by a single draw pin in the front, providing free vertical movement independent of the frame. The wheels of the tractor trafficked the test lane, but the weight and tire pressures were small and this traffic was considered negligible.

Tire

8. The loaded characteristics of the type of tire used in these tests are as follows:

Size	Load kips	Inflation Pressure psi	Average Contact Area sq in.	Average Contact Pressure psi
49x17	35	100	341	103
	21	100	195	108

PART III: TESTS, DATA COLLECTION, AND FAILURE CRITERIA

Traffic Tests

9. Traffic tests were conducted on each test item to simulate actual aircraft traffic, thereby producing the same effect on the unsurfaced soil that would be produced on an unsurfaced soil airfield. The traffic was applied in a nearly normal distribution pattern. To apply test traffic, the load cart was driven forward along the test lane and then backward in the same path. The load vehicle was then shifted laterally a distance equal to one tire print width, and the process was repeated. Guidelines placed on the test section for the load cart to follow while applying traffic were spaced to allow control of the distribution of traffic across the traffic lanes. The distribution patterns for application of traffic on the test lanes are shown in plate 3. One distribution pattern could be produced by eleven passes of the forward six wheels of the C-5A landing gear. However, since the rear six wheels track the forward six wheels and since the cart moves forward and backward in the same path before shifting to another traffic path, four distribution patterns are being produced simultaneously. These four patterns result in 32 coverages at the center line by 22 passes of the load cart. (The item "coverages," as opposed to "passes," is defined in paragraph 11.) Similarly, the forward and backward movement of the single wheel in the same path before shifting to another path produces two traffic patterns simultaneously. These two patterns result in 10 coverages at the center line of the test lane by 50 passes of the load cart.

Data Collection

Soils data

10. Water content, density, and CBR determinations were made prior to traffic and at time of failure in all test items. Soils tests were made at the surface of the soil and at depths of 6 and 12 in. Three tests were made at each depth. The averages from these tests are

shown in tables 1 and 2. The rated strength of each test item was based on combined effects of the CBR values measured. Test procedures and techniques for these soil tests are presented in Military Standard MIL-STD-621A.[3]

Coverages

11. A coverage is defined as a sufficient number of passes of load tires in adjacent tire paths to just cover a width of pavement one time. For example, a coverage over a traffic lane represents the loading of the entire lane one time, or a coverage over a point is the loading of that point one time. For the purpose of this test, the number of failure coverages is represented by that section of the traffic lane that received the maximum number of coverages, normally the center line of the traffic lane. The number of coverages was recorded at any time that significant measurements or observations were accomplished and at failure of a test item.

Tire contact area

12. The tire contact area is an average contact area determined by obtaining a tire print and measuring its gross area by use of a planimeter. The tire print was obtained by rolling the loaded tire onto a piece of paper lying on a hard surface and spraying paint around that part of the tire in contact with the paper. The paint was then allowed to dry and the tire was rolled away, leaving a tire print outline on the paper.

Tire inflation pressure

13. The tire inflation pressure is the gage pressure to which a tire is inflated prior to a given test. Tire inflation pressure was checked prior to and periodically throughout each test and was maintained as close as possible to the specified value.

Tire contact pressure

14. The tire contact pressure was determined by dividing the load on a tire by the measured tire contact area.

Deformation

15. The two types of deformation measurements obtained during these tests were permanent and differential deformation. The permanent

deformation measurements were used to plot cross sections and profiles for the various items. Differential deformation measurements were used to gage the roughness of an item. Two types of differential deformation measurements were made in these tests, i.e. the amount of general subsidence and the rut depth. Procedures for measuring deformations are presented in reference 1.

Deflections

16. Total and elastic deflection measurements, which represent the amount that the soil surface deflects under a static load, were also obtained and used to assist in judging failure. Procedures for measuring deflections by use of a pin and cap are presented in reference 1.

Failure Criteria

17. Failure of an unsurfaced item was based primarily on general subsidence or rutting, but elastic deflection was also taken into consideration. An item was considered failed when the average rut depth exceeded 3 in., when the soil surface deviated by at least 4 in. from the bottom of a 10-ft straightedge laid transversely across the item, or when the elastic deflection exceeded 1.5 in.

PART IV: BEHAVIOR OF ITEMS UNDER TRAFFIC

Test Section 1

18. Test section 1 consisted of one traffic lane with three test items. The design CBR's of items 1, 2, and 3 were 10, 8, and 6, respectively. These items were trafficked with a 252,000-lb 12-wheel assembly using 49x17 tires inflated to 100 psi.

Item 1

19. Item 1 prior to traffic is shown in photo 1. After two passes with the test vehicle, rutting was negligible. After 96 coverages, the maximum rut depth measured was 2.6 in. (photo 2). Traffic was continued to 128 coverages, at which time severe rutting had developed and item 1 was considered failed (photo 3).

Item 2

20. Item 2 prior to traffic is shown in photo 4. Moderate rutting developed in item 2 at two passes of the load vehicle, and at 16 coverages, the item was considered failed (photo 5).

Item 3

21. Item 3 prior to traffic is shown in photo 6. Severe rutting developed immediately with the application of test traffic, and the item was considered failed after one forward and one backward pass of the load cart in the same path. Failure in terms of coverages may then be considered to be between 4 and 8 coverages. For this study, failure was considered to be at 8 coverages (photo 7).

Surface deformation and rutting

22. Typical cross-sectional elevations of items 1, 2, and 3 are shown in plate 4. The cross section for item 3 was taken at 16 coverages rather than at 8 coverages when failure occurred. These plots indicate the severe deformation that occurred in each item at failure. Rut depth measurements taken at failure in each item are shown in table 3. Average rut depths in items 1, 2, and 3 were 3.1, 3.2, and 3.0 in., respectively. Maximum rut depths at failure in items 1, 2, and 3 were 5.0, 5.5, and 3.3 in., respectively. Profile elevations taken

along the center line of each item at various coverage levels in items 1-3 are shown in plate 5. The profile for item 3 is for 16 coverages, although failure occurred at 8 coverages.

Deflection

23. Elastic and total soil deflection measurements, obtained by the pin-and-cap method[1] using 18- and 36-in. pins in items 1-3, are also shown in table 3. The values obtained using the 18-in. pin are different from those obtained using the 36-in. pin. The reason that these values differ is not known. However, the values measured are reported as a matter of record. Due to the short duration of traffic on test section 1, no posttraffic deflection measurements were made.

Test Section 2

24. Test section 2 was constructed with two traffic lanes consisting of four items each. A brief description of the test section is presented in the tabulation below, and a plan and cross section of the test section are shown in plate 2.

Item No.	Surface Thickness in.	Surface CBR	Subgrade Thickness in.	Subgrade CBR
1	12	14	24	8
2	9	14	27	8
3	15	12	21	4
4	10	12	26	4

Lane 1

25. Lane 1 was trafficked with a 35,000-lb single-wheel load on a tire inflated to 100 psi, and lane 2 was trafficked with a 252,000-lb load on the 12-wheel C-5A gear with tires inflated to 100 psi. Lane 1 of test section 2 prior to traffic is shown in photo 8.

26. Item 1. Item 1 held up well under traffic, with only minor rutting and gradual subsidence. The deformation increased slowly until at 550 coverages the item was considered failed based on a differential deformation exceeding 4 in. Photo 9 shows item 1 at 550 coverages.

27. Item 2. Rutting developed at a moderate rate in item 2 until the item was considered failed at 110 coverages. At this time, the average rut depth was 3 in., and the maximum rut depth was greater than 4 in. (photo 10).

28. Item 3. Severe rutting developed in the early stages of traffic, and item 3 was considered failed at 50 coverages. Photo 11 shows item 3 at failure.

29. Item 4. The initial passes caused very severe rutting, and at 10 coverages, item 4 was considered failed. Photo 12 shows item 4 at failure.

30. Surface deformation and rutting (items 1-4). Typical cross-sectional elevations of items 1-4 of lane 1 are shown in plate 6. These data indicate the severe surface deformation that had occurred in each item at failure. Rut depth measurements taken in each item at failure are shown in table 4. These values indicate that the average rut depths of the items at failure were each at least 3 in. and that the maximum rut depths were at least 4 in. Profile elevations taken along the center line of each item at 0 coverages and after failure are shown in plate 7.

31. Subgrade deformation (items 1-4). Typical cross sections of the interface of the two soil layers in each item are shown in plate 8. These data indicate that the failures noted in the surface of each item were contributed to by deformation in the soil subgrade. Photo 13 shows typical subgrade deformation upon failure of an item.

32. Deflection (items 1-4). Total and elastic soil deflection measurements obtained with the 18- and 36-in. pins in items 1-4 are shown in table 4.

Lane 2

33. Test lane 2 (see plate 2 and tabulation in paragraph 24) prior to traffic is shown in photo 14.

34. Item 1. Rutting remained negligible in item 1 for about 100 coverages of traffic; however, at this point, rutting began to increase significantly, and at 228 coverages the item was judged failed. Photo 15 shows item 1 at failure.

35. Item 2. Very slight rutting occurred in item 2 upon application of traffic and increased until failure occurred at 76 coverages. Photo 16 shows item 2 at failure.

36. Item 3. Significant rutting took place in item 3 upon application of the initial pass of traffic, and at 40 coverages the item was considered failed. Photo 17 shows item 3 after failure.

37. Item 4. Severe rutting in item 4 resulted from the first pass of the tracking vehicle, and after 20 coverages the item was judged failed. Photo 18 shows item 4 after failure.

38. Surface deformation and rutting (items 1-4). Typical cross sections of items 1-4 are shown in plate 9. These data show the deformation that occurred in each item at failure. Rut depth measurements taken at failure in each item are shown in table 4 and indicate that the average depths were at least 3 in. and that maximum depths all exceeded 4 in. Profile elevations taken along the center line of each item prior to traffic and upon failure are shown in plate 10.

39. Subgrade deformation (items 1-4). Typical cross sections of the interface of the two soil layers in each item are shown in plate 11. These data indicate that the failures noted in the surface of each item were contributed to by deformation in the soil below the interface of the two layers.

40. Deflection (items 1-4). Total and elastic soil deflection measurements obtained with the 18- and 36-in. pins in items 1-4 are shown in table 4. Due to the short duration of traffic in item 4, no posttraffic deflection measurements were made.

PART V: ANALYSIS OF DATA

Discussion of Procedure

41. The purpose of the tests reported herein was to determine if current criteria for the design of unsurfaced airfields were satisfactory for the design of unsurfaced airfields for operations of C-5A aircraft. Two separate criteria had to be validated. One of these was the criterion for determining the soil surface strength necessary for supporting operations of an aircraft, and the other was the criterion for determining the thickness of material that must be placed over the natural subgrade in order to support operations of an aircraft. The analysis procedure, therefore, was simply to compare the test results with the current design criteria.

Analysis of Soil Surface Strength Data

42. Traffic and soils test data collected for the purpose of validating the unsurfaced soil strength criteria are shown in table 1. The analysis of these data was directed toward validating the existing design criteria as represented by the nomograph shown in plate 12. This nomograph involves the parameters of load, tire pressure, soil strength (CBR), and coverages. The load used with the nomograph is the single or equivalent single-wheel load (ESWL) in kips; the tire pressure is the inflation pressure in pounds per square inch; the soil strength is the strength of the surface of the soil measured in terms of CBR; and the term coverages refers to the amount of traffic for which the airfield is being designed or evaluated.

43. The ESWL's were determined by use of plate 13. This plate shows wheel spacing versus the percent influence that one wheel has on another. The wheel spacing is expressed in radii and is determined by dividing the wheel spacing in inches by the radius of a circle having the same area as the contact area of one tire. The percent influence that one wheel has on another represents the amount that one wheel load

must be increased to determine the ESWL. For the C-5A, the least spacing between two wheels is 34 in. Since the contact area of one tire is 195 sq in., the radius of this area is $\sqrt{195/\pi}$, or 7.89 in. The spacing between the tires is, therefore, 34/7.89 = 4.31-in. radii. From plate 13, the influence of one wheel on the other is found to be 10 percent. The ESWL is, therefore, 21,000 lb × 1.10 = 23,100 lb. The other wheels of the assembly are spaced so that they have no influence on the ESWL.

44. A plot of the actual test results is shown in plate 14. This is a plot of coverages versus CBR for the load and tire pressure used in the test. In order to see how these test results compared with the existing criteria, the nomograph was used to estimate the number of coverages that the test items should have sustained. These data were then plotted as a curve in plate 14. As can be seen, the test points fall reasonably close to the curve. The differences that exist between the test points and the criteria can perhaps be attributed to the inability to accurately measure the CBR. Since a change in the rated CBR by as little as 1/2 CBR would place the test points almost on top of the criteria curve, it is considered that the test results correlate reasonably well with the existing criteria and that the nomograph can be used in the design of unsurfaced airfields to accommodate C-5A aircraft.

45. Specific design curves for determining the soil surface strength required to support operations of C-5A are shown in plate 15. These curves relate traffic cycles to CBR and airfield index. The nomograph, plate 12, presents traffic in terms of coverages. However, traffic cycle, as used in plate 15, is a more common term and is related to coverages by a cycles per coverage factor of 0.69. Also, soil strength, in a military situation, is normally measured in terms of airfield index, not CBR; therefore, the airfield index is shown along with CBR in plate 15.

Analysis of Unsurfaced Thickness Requirements Data

46. Traffic test data collected for the purpose of validating the unsurfaced thickness requirements are shown in table 2. The analysis of

these data was directed toward validating existing design criteria. Methods for designing unsurfaced soil layers to be placed over the subgrade are presented in references 4 and 5. Because the method presented in reference 5 best fitted the data accumulated during these tests, it was used to make the data analysis. Reference 5 presents the following relationship for determining unsurfaced soil thickness requirements:

$$\text{Log } t = -1.02165 + 0.63624 (\log p) + 0.21484 (\log P) + 0.23937 (\log C) - 0.40281 (\log CBR_s) - 0.31404 (\log CBR_c)$$

where

t = thickness of soil placed above subgrade, in.
p = average tire contact pressure, psi
P = single- or equivalent single-wheel load (ESWL), lb
C = number of coverages
CBR_s = strength of subgrade soil
CBR_c = strength of soil layer placed over the subgrade

Use of this equation for design is a trial and error procedure for multiple-wheel landing gears because the ESWL must be determined at a depth equal to the thickness calculated. The ESWL to use in the equation above is determined in the same manner as the ESWL for flexible pavement design. This procedure is presented in reference 6. For the purpose of evaluating the test results reported herein, the ESWL is taken at a depth equal to the thickness of the cover layer used in the tests. The data for the single-wheel test and the C-5A test were substituted in the equation, and the following comparisons were made.

Item No.	Thickness of Cover Layer in.	Computed Thickness in. Single Wheel	Computed Thickness in. C-5A
1	12	14.2	11.5
2	9	10.0	8.6
3	15	10.9	10.7
4	10	7.8	9.2

47. The single-wheel computed thickness values, except that for

item 3, are reasonably close to the actual test thickness values. In items 1 and 2, the computed values were greater than the thicknesses tested, which results in some conservatism. In item 4, the computed value was less than the thickness tested, which produces some unconservatism. The greatest deviation between computed values and actual test thickness occurred for item 3; the reason for this is not known.

48. The C-5A computed thicknesses for items 1, 2, and 4 are all slightly less than the actual test thicknesses. However, if the values computed for items 1 and 2 were rounded off, they would be the same as the test values, and item 4 would be the only item in which the computed thickness was less than the test thickness. Again, a much greater deviation of computed thickness from test thickness occurred for item 3.

49. Considering the results for test items 1, 2, and 4 for the single-wheel and C-5A tests, the existing criteria seem to produce results reasonably close to the test results. Significant differences exist between the computed and the test values for item 3 for both the single-wheel and C-5A tests, but no explanation has been found. Therefore, based on the results in items 1, 2, and 4, it is believed that existing criteria can be used to determine the required thickness of unsurfaced soils for the operation of C-5A aircraft.

50. Specific unsurfaced soil thicknesses for the C-5A can best be determined by using the equation presented in paragraph 46 rather than by developing a series of curves, since the number of parameters involved would require one set of curves for every subgrade CBR.

PART VI: SUMMARY AND CONCLUSIONS

51. Several tests were conducted for the purpose of validating existing design criteria for aircraft (specifically the C-5A) operating on unsurfaced soils. This required validation of the surface strength and thickness requirements. The analysis of data indicated that the existing criteria could be used to design unsurfaced airfields to accommodate C-5A aircraft. It is concluded, therefore, that the nomograph shown in plate 12 should be used for determining surface strength requirements and that the equation presented in paragraph 46 should be used for determining unsurfaced soil thickness requirements.

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Table 1

Traffic and Soils Test Data, Test Section 1

Item No.	Coverages	Depth from Surface in.	Water Content %	Density pcf	CBR	Rated CBR*	Remarks
1	0	0	27.6	93.2	10	9.7	Item failed at 128 coverages
		6	27.3	90.6	9		
		12	27.6	90.7	9		
	0	0	27.1	93.3	10		
		6	27.1	93.9	12		
		12	26.2	92.8	11		
	128	0	27.2	93.0	7		
		6	27.0	93.1	8		
		12	26.3	94.8	12		
	128	0	26.8	93.0	10		
		6	27.1	93.4	8		
		12	25.9	94.5	10		
2	0	0	27.9	92.0	7	7.3	Item failed at 16 coverages
		6	26.8	92.9	7		
		12	26.8	93.1	9		
	0	0	27.6	92.8	7		
		6	27.3	92.2	8		
		12	28.6	91.3	8		
	16	0	26.5	93.7	8**		
	16	0	27.6	92.1	7		
		6	26.8	92.8	8		
		12	29.0	90.4	6		
3	0	0	27.2	92.3	6	5.4	Item considered failed at 8 coverages
		6	30.3	87.1	4.5		
		12	28.8	89.7	5		
	0	0	27.2	92.2	7		
		6	28.2	91.4	7		
		12	29.5	89.2	6		
	8	0	28.5	91.6	6**		
	8	0	26.7	93.8	6		
		6	30.1	89.1	5		
		12	30.4	88.0	3.4		

* The rated CBR is generally an average of the average CBR at zero coverages and the average CBR at failure.

** Not considered in rating CBR since only surface strength was measured.

Table 2

Traffic and Soils Test Data, Test Section 2

Item No.	Soil Layer	Depth from Surface, in.	Coverages	Water Content, %	Density, pcf	CBR	Rated CBR
			Lanes 1 and 2 Pretest Data				
1	Cover	0	0	23.3	97.0	15	
		6		24.2	96.4	14	
	Subgrade	12		26.2	93.5	9	
		18		27.8	92.0	8	
		24		27.9	92.8	8	
2	Cover	0	0	24.3	96.6	14	
		6		24.6	95.3	14	
	Subgrade	9		28.9	93.1	9	
		15		28.0	92.1	8	
		21		28.6	91.1	7	
3	Cover	0	0	25.9	94.9	11	
		6		24.9	95.6	12	
	Subgrade	15		29.7	90.3	4.7	
		21		30.8	88.6	4.5	
		27		30.9	88.0	4.1	
4	Cover	0	0	25.1	94.4	12	
		6		26.3	94.1	9	
	Subgrade	10		29.2	90.1	4.3	
		16		29.7	89.5	4.3	
		22		30.9	88.1	4.5	
			Lane 1 Failure Data				
1	Cover	0	550	22.7	100.7	12	13.3
		6		23.7	98.6	12	
	Subgrade	12		25.5	93.4	8	8.7
		18		25.1	95.2	10	
		24		26.7	94.1	9	
2	Cover	0	110	23.2	99.3	12	12.0
		6		23.3	98.6	8	
	Subgrade	9		27.0	92.9	8	8.0
		15		26.2	93.5	8	
		21		28.0	93.0	8	
3	Cover	0	50	24.8	98.7	11	11.0
		6		24.9	97.8	10	
	Subgrade	15		28.7	91.0	5	4.6
		21		31.0	87.6	4.4	
		27		30.8	88.0	4.9	
4	Cover	0	10	24.9	97.4	11	10.0
		6		24.7	95.8	8	
	Subgrade	10		29.8	90.4	4.5	4.5
		16		28.8	91.8	4.9	
		22		30.9	88.0	4.6	
			Lane 2 Failure Data				
1	Cover	0	228	23.5	98.9	13	13.5
		6		24.3	97.5	12	
	Subgrade	12		25.1	94.8	11	9.2
		18		26.3	94.5	10	
		24		26.5	93.9	9	
2	Cover	0	76	24.0	98.7	12	13.5
		6		24.3	97.7	14	
	Subgrade	9		27.0	93.5	8	8.7
		15		27.0	94.0	12	
		21		28.3	91.4	8	
3	Cover	0	40	25.1	97.3	9	10.2
		6		25.3	96.6	9	
	Subgrade	15		29.3	90.5	6	5.0
		21		30.6	89.1	5	
		27		30.4	88.6	6	
4	Cover	0	20	25.5	96.9	11	9.8
		6		25.2	94.9	7	
	Subgrade	10		29.3	90.9	6	4.8
		16		30.6	88.6	5	
		22		30.6	89.2	5	

Table 3

Summary of Rut Depth and Soil Deflection Data, Test Section 1

Item No.	Coverages*	Rut Depth, in. Avg	Rut Depth, in. Max	Soil Deflection, in. Obtained Using 18-in. Pin** Elastic	Soil Deflection, in. Obtained Using 18-in. Pin** Total	Soil Deflection, in. Obtained Using 36-in. Pin** Elastic	Soil Deflection, in. Obtained Using 36-in. Pin** Total
1	0	--	--	0.3	0.4	0.9	1.1
	2†	0.75	0.75	--	--	--	--
	32	--	1.1	--	--	--	--
	96	--	2.6	1.9	2.8	1.6	2.7
	128	3.1	5.0	--	--	--	--
2	0	--	--	0.7	1.3	0.5	1.0
	2†	--	2.4	--	--	--	--
	16	3.2	5.5	--	--	--	--
3	0	--	--	2.0	2.8	1.6	2.5
	2†	3.0	3.3	--	--	--	--

* C-5A 12-wheel main gear assembly loaded with 252,000 lb.
** The pin and cap method for measuring deflections is presented in reference 1.
† Passes of the test cart.

Table 4

Summary of Rut Depth and Soil Deflection Data, Test Section 2

Lane No.	Item No.	Coverages*	Rut Depth, in. Avg	Rut Depth, in. Max	Soil Deflection, in. Obtained Using 18-in. Pin** Elastic	Soil Deflection, in. Obtained Using 18-in. Pin** Total	Soil Deflection, in. Obtained Using 36-in. Pin** Elastic	Soil Deflection, in. Obtained Using 36-in. Pin** Total
1	1	0	--	--	0.4	0.6	0.4	0.7
		550	--	4.0†	0.5	1.0	0.4	0.9
	2	0	--	--	0.4	0.6	0.4	0.5
		110	3.0	4.4	0.5	0.6	0.7	1.2
	3	0	--	--	0.5	0.9	0.6	1.0
		50	3.0	4.0	0.7	0.9	0.6	0.8
	4	0	--	--	0.8	1.7	0.9	1.6
		10	3.5	4.7	1.0	1.6	0.9	1.3
2	1	0	--	--	0.4	0.7	0.3	0.6
		228	3.0	4.4	0.3	0.4	0.3	0.5
	2	0	--	--	0.5	1.1	0.3	1.1
		76	3.1	4.1	0.5	0.7	0.5	0.7
	3	0	--	--	0.7	1.2	0.6	1.1
		40	3.0	4.1	1.6	2.7	1.4	1.8
	4	0	--	--	1.2	2.0	1.0	1.6
		20	3.3	5.3	--	--	--	--

* Lane 1 was trafficked with 35,000-lb single-wheel load. Lane 2 was trafficked with 252,000-lb 12-wheel assembly.
** The pin and cap method of measuring deflections is presented in reference 1.
† Subsidence.

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Photo 1. Test section 1, item 1, prior to traffic

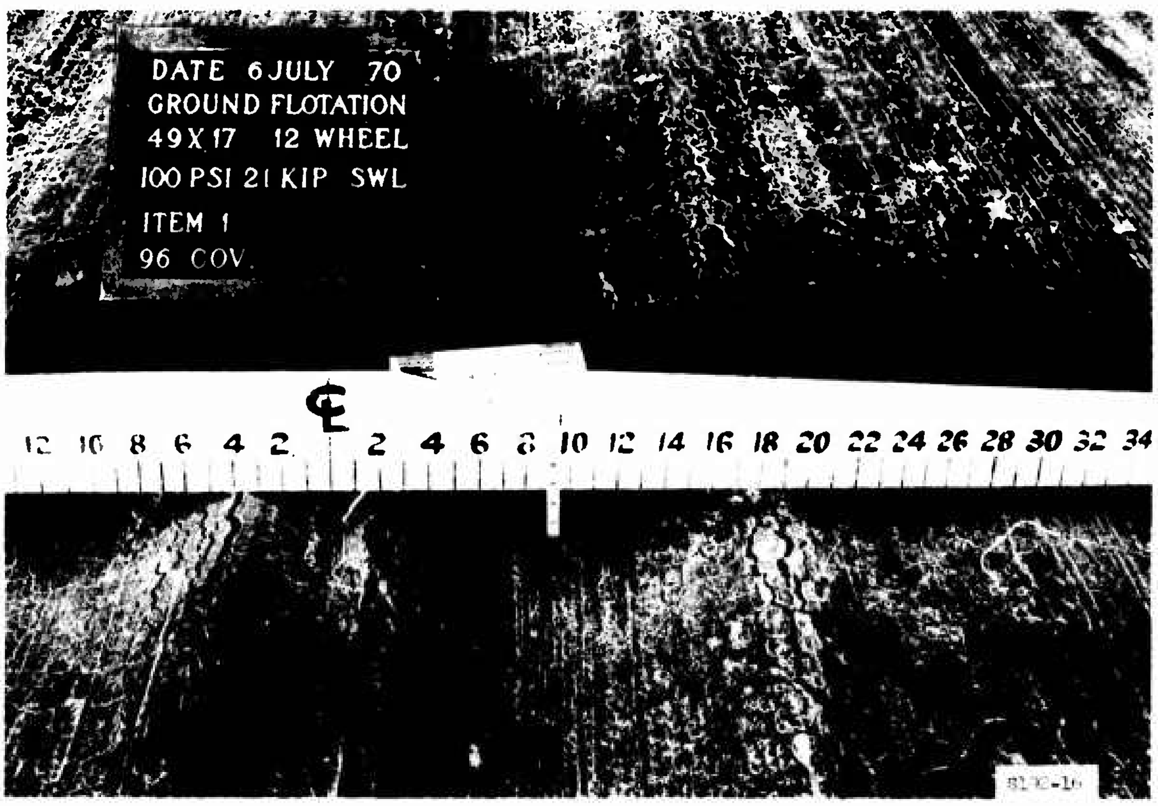

Photo 2. Test section 1, item 1, at 96 coverages

Photo 3. Test section 1, item 1, after failure at 128 coverages

Photo 4. Test section 1, item 2, prior to traffic

Photo 5. Test section 1, item 2, after failure at 16 coverages

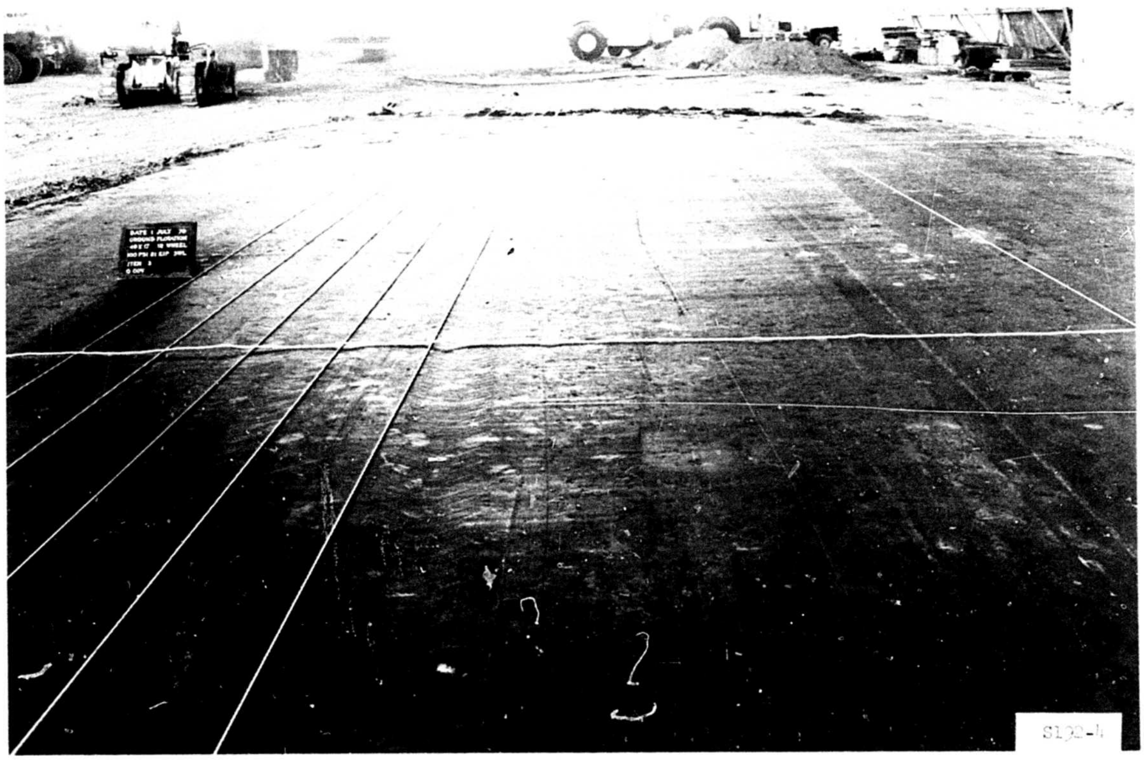

Photo 6. Test section 1, item 3, prior to traffic

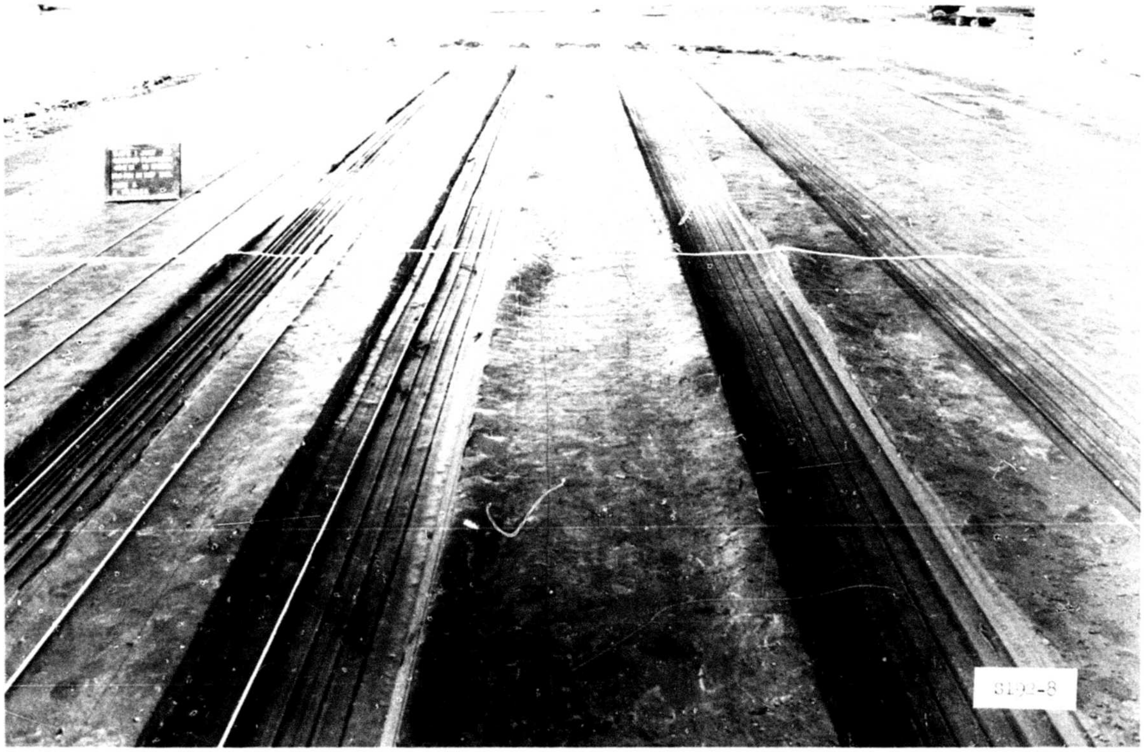

Photo 7. Test section 1, item 3, at failure

Photo 8. Test section 2, lane 1, prior to traffic

Photo 9. Test section 2, lane 1, item 1, after failure at 550 coverages

Photo 10. Test section 2, lane 1, item 2, after failure at 110 coverages

Photo 11. Test section 2, lane 1, item 3, after failure at 50 coverages

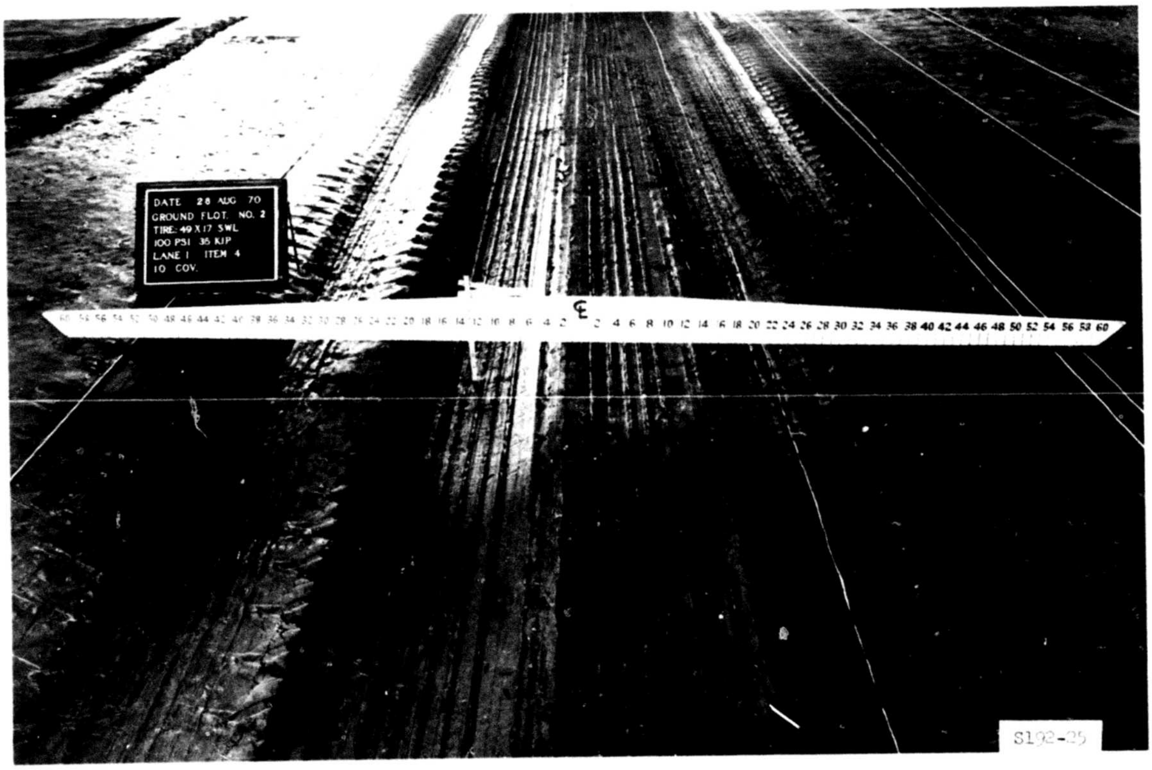

Photo 12. Test section 2, lane 1, item 4, after failure at 10 coverages

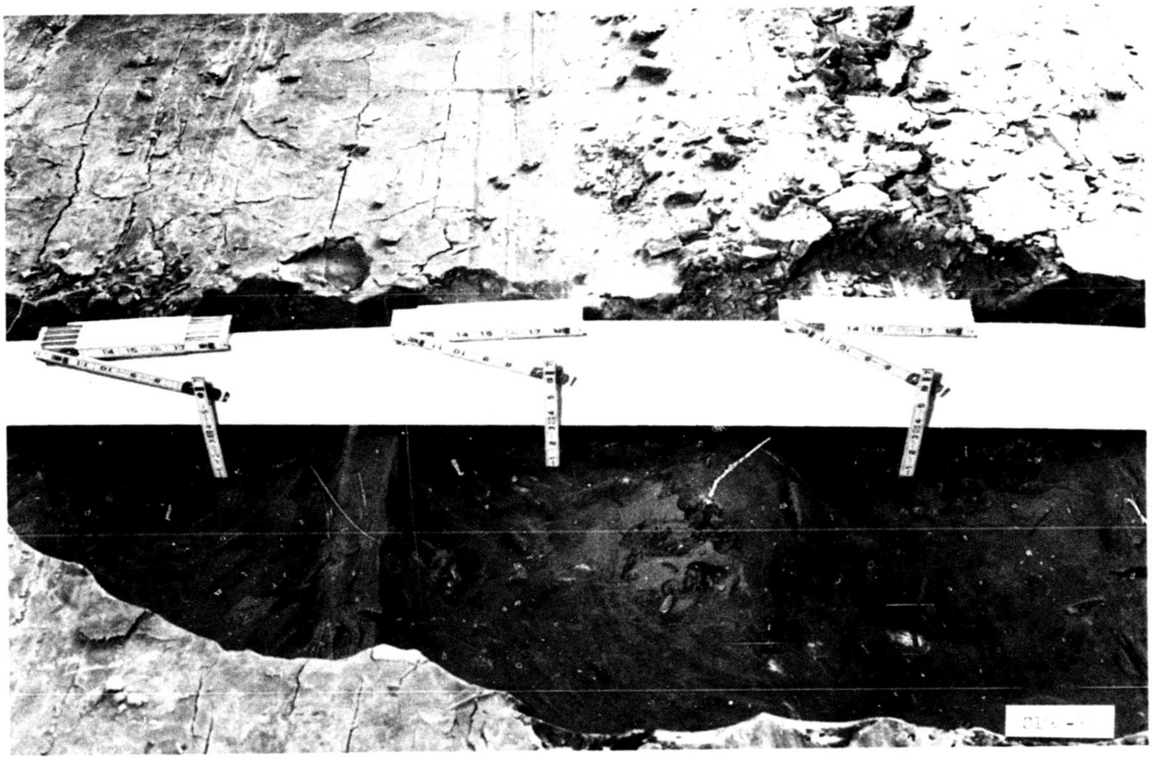

Photo 13. Typical subgrade deformation at failure in test section 2, lane 1

Photo 14. Test section 2, lane 2, prior to traffic

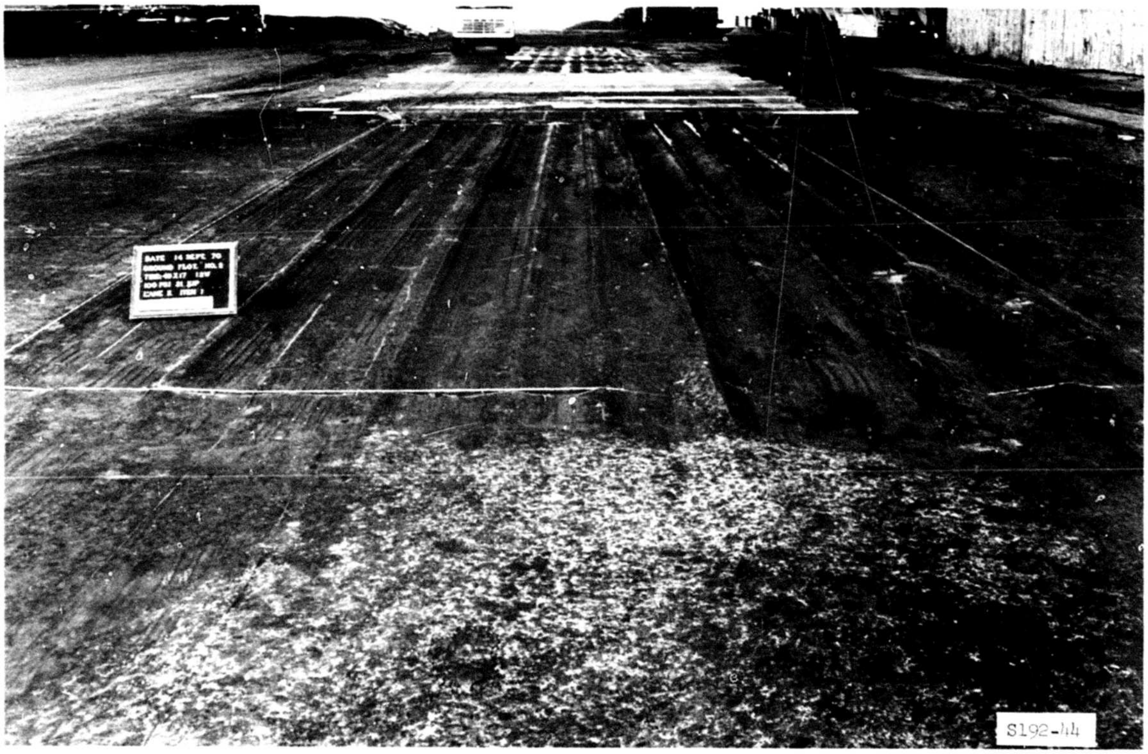

Photo 15. Test section 2, lane 2, item 1, at failure after 228 coverages

Photo 16. Test section 2, lane 2, item 2, at failure after 76 coverages

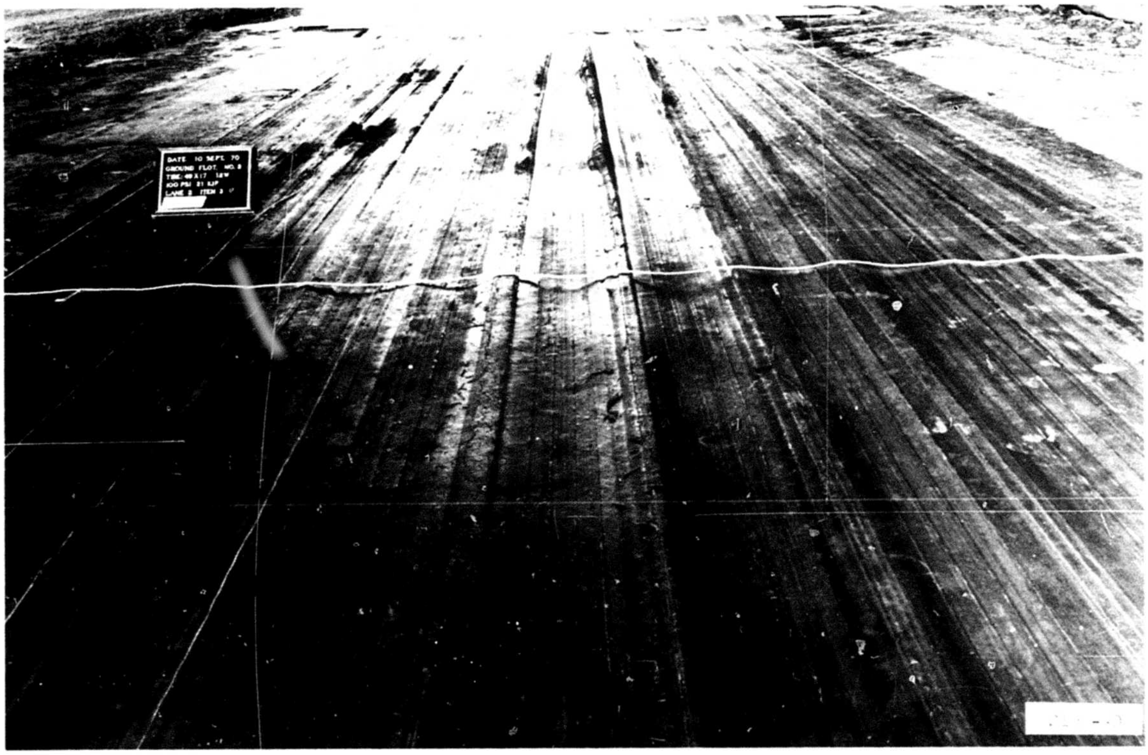

Photo 17. Test section 2, lane 2, item 3, at failure after 40 coverages

Photo 18. Test section 2, lane 2, item 4, at failure after 20 coverages

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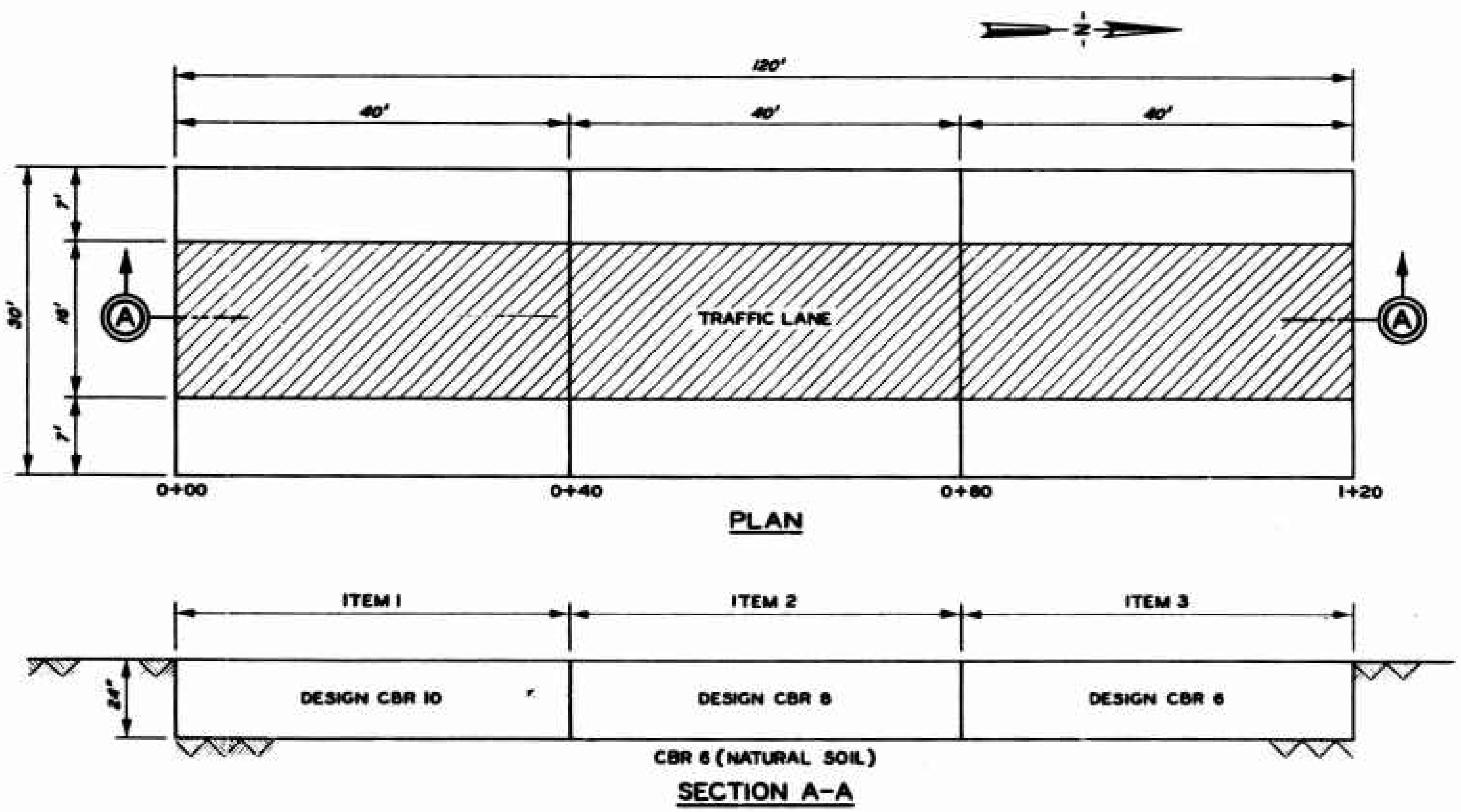
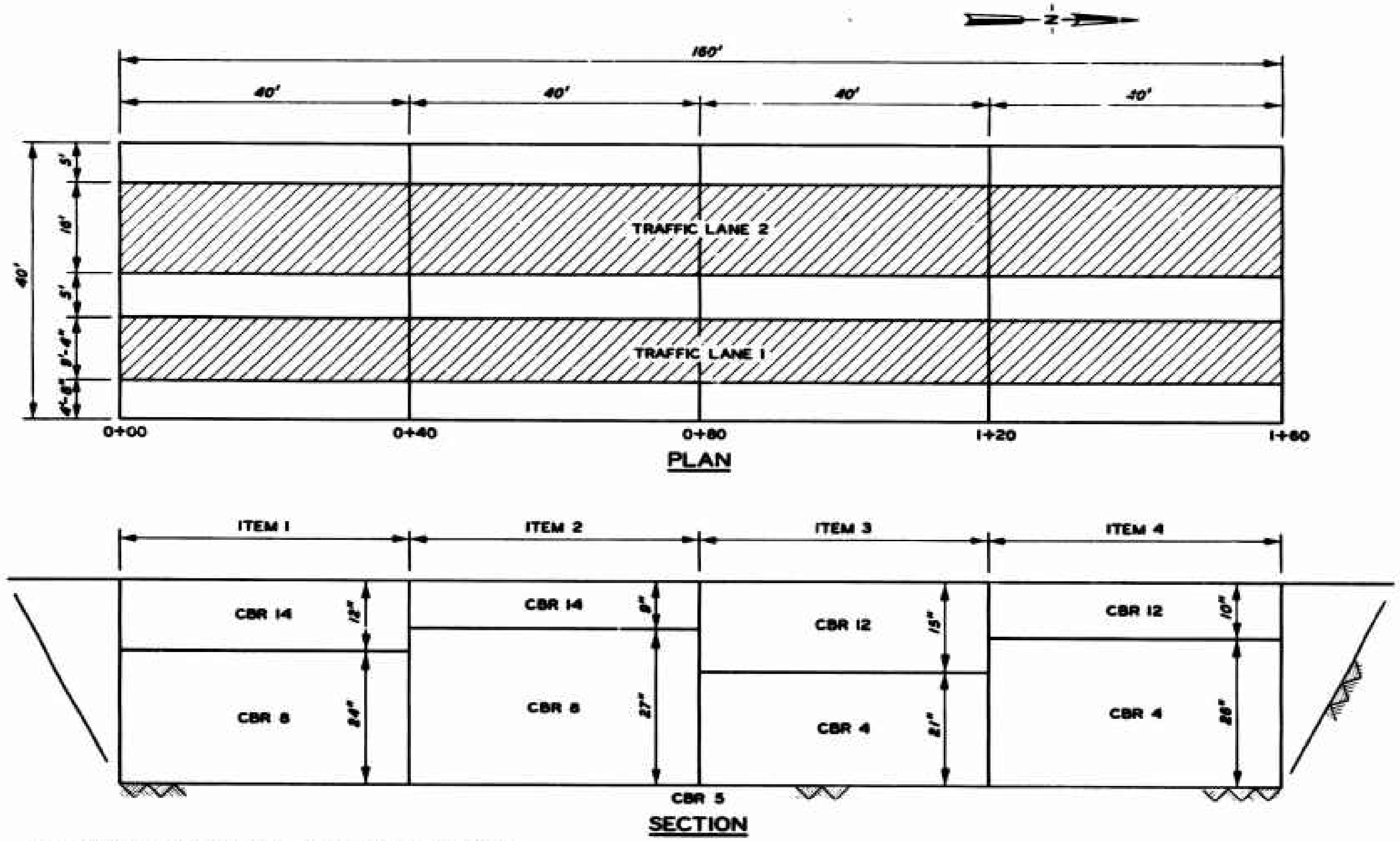


NOTE: TEST SECTION TRAFFICKED WITH C-5A GEAR AT 252,000 LB AND WITH TIRES AT 100-PSI TIRE PRESSURE.

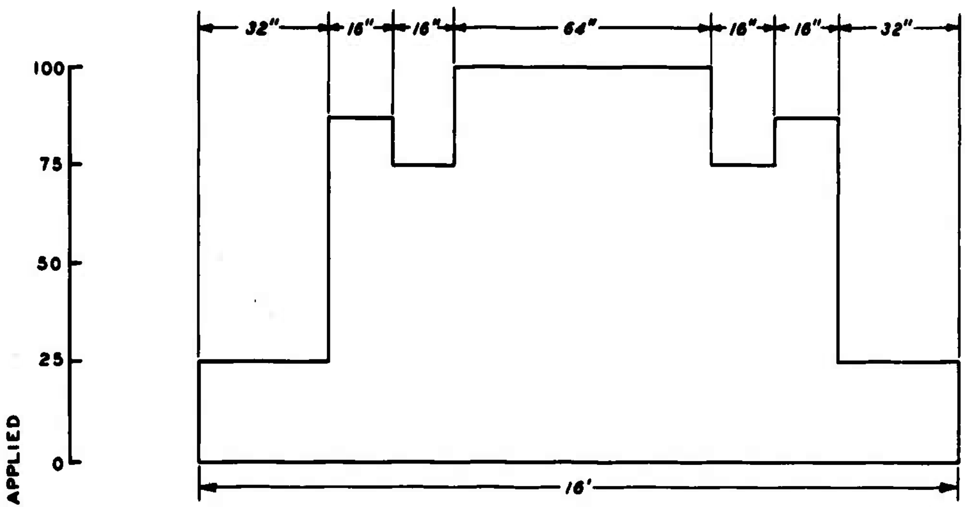
PLAN AND CROSS SECTION
TEST SECTION 1



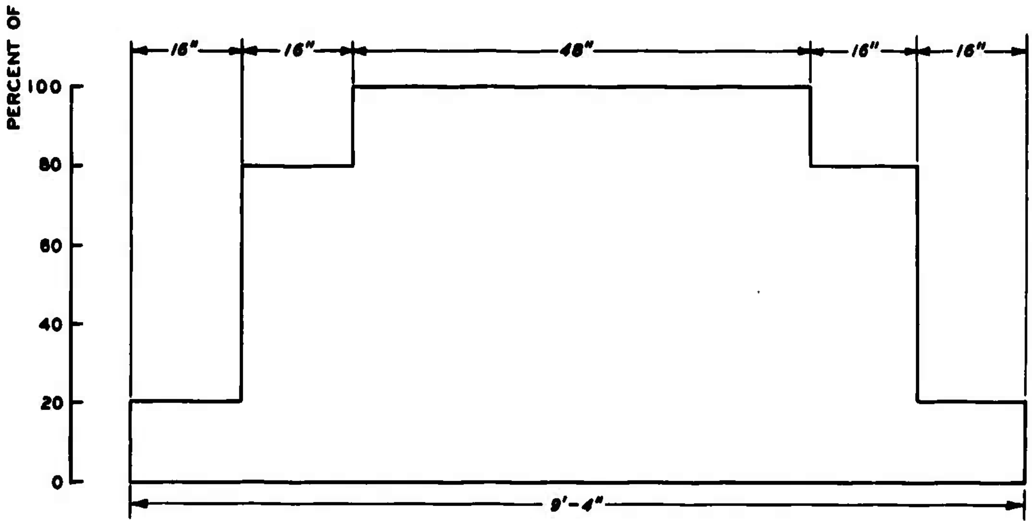
NOTE: LANE 1 TRAFFICKED WITH 35,000-LB SINGLE-WHEEL LOAD AT 100-PSI TIRE PRESSURE.
LANE 2 TRAFFICKED WITH 252,000-LB C-5A 12-WHEEL GEAR AT 100-PSI TIRE PRESSURE.
CBR VALUES ARE THE DESIGN VALUES.

PLAN AND CROSS SECTION
TEST SECTION 2

PLATE 2

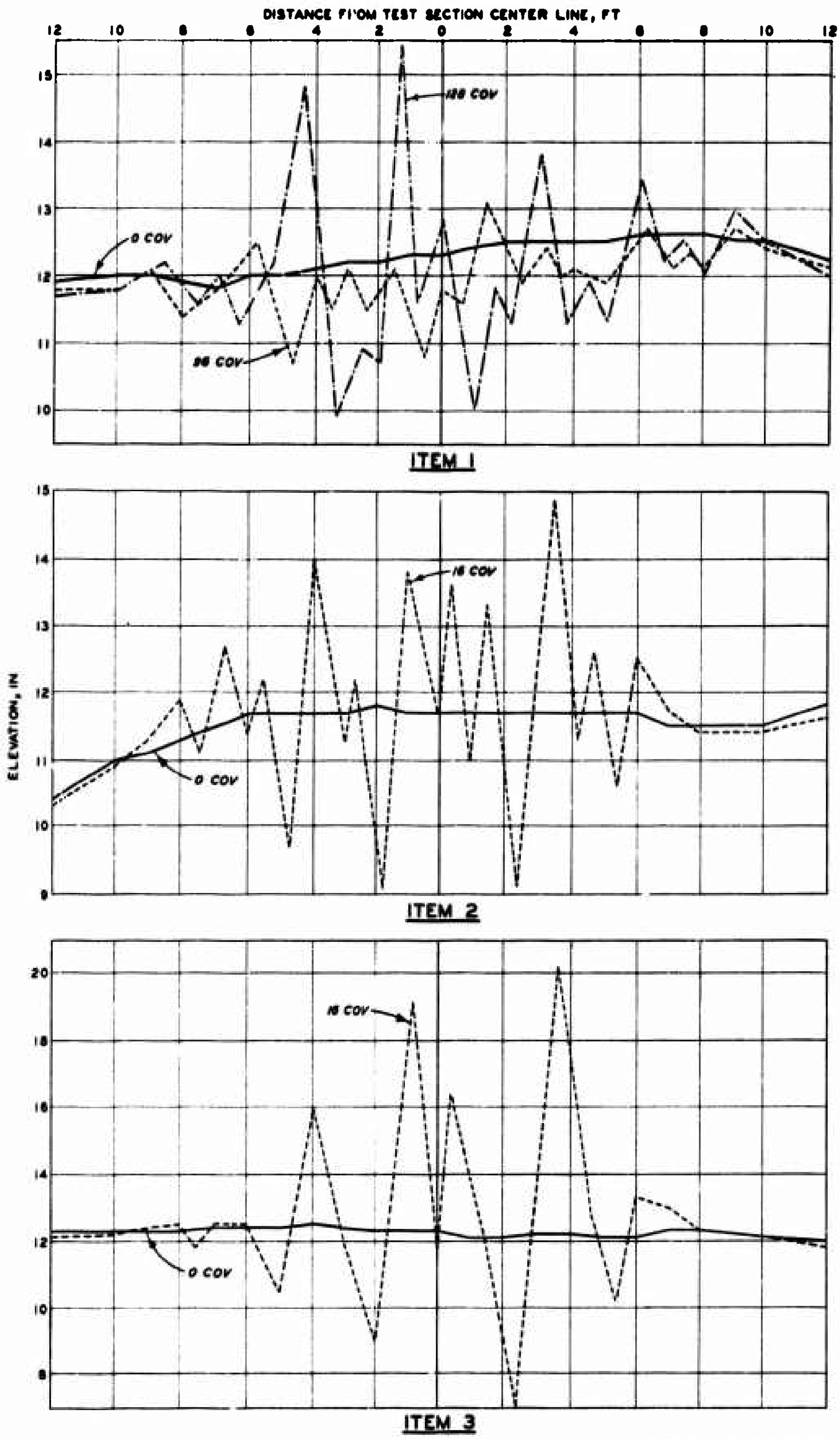


a. TEST SECTION 1 AND LANE 2 OF TEST SECTION 2



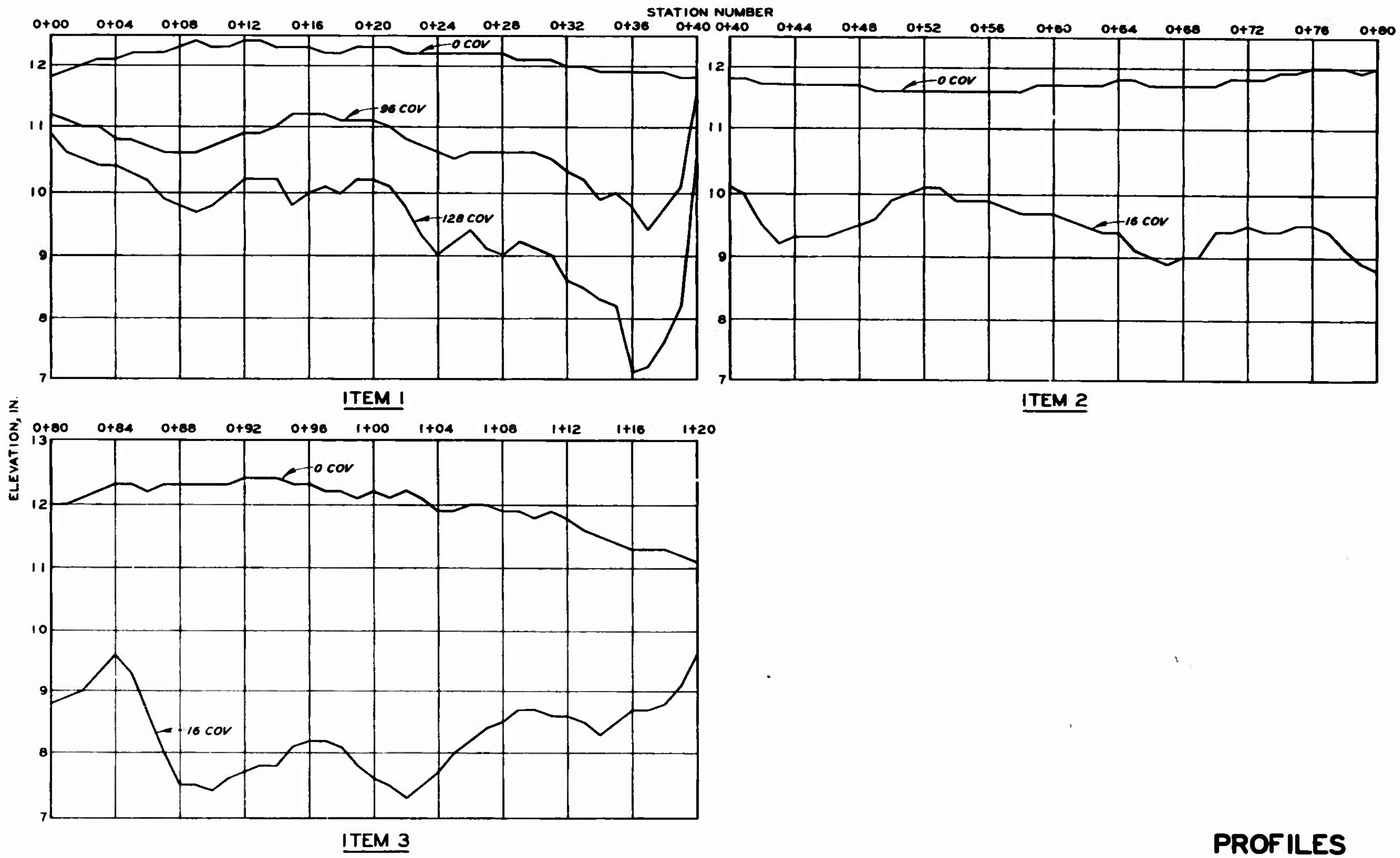
b. LANE 1 OF TEST SECTION 2

TRAFFIC DISTRIBUTION PATTERNS



CROSS SECTIONS
TEST SECTION 1

PLATE 4



PROFILES
TEST SECTION I

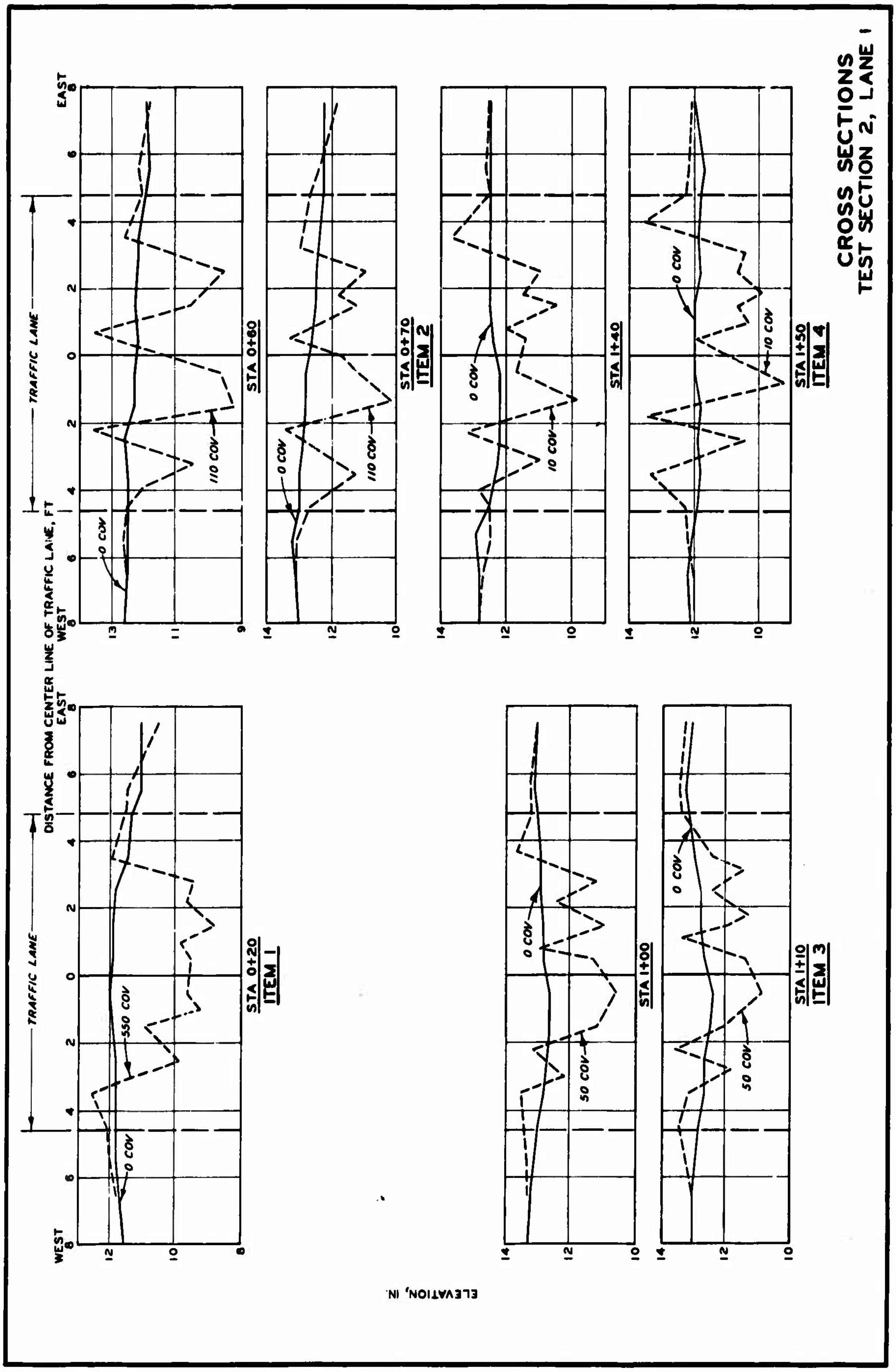
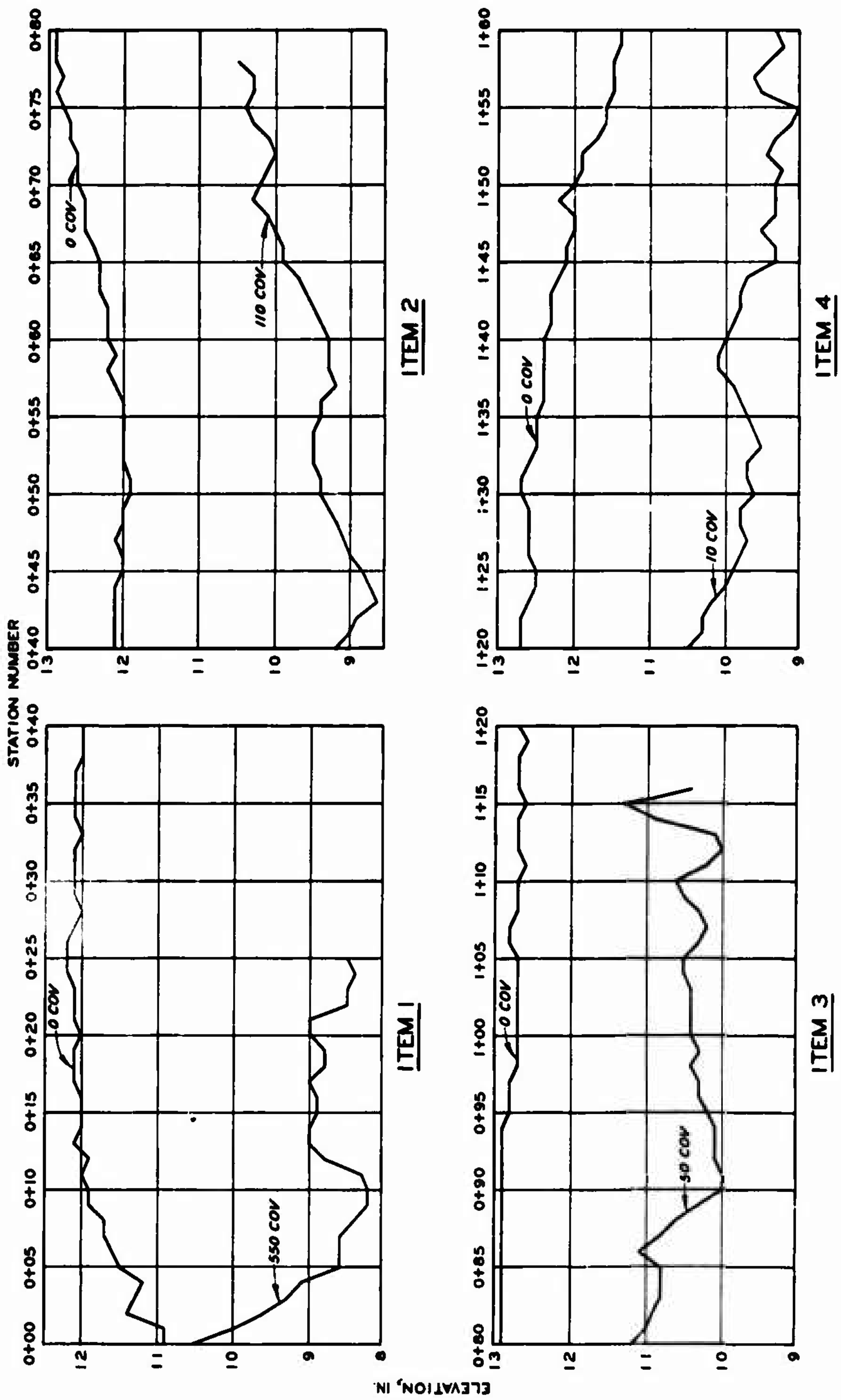

CROSS SECTIONS
TEST SECTION 2, LANE 1
DISTANCE FROM CENTER LINE OF TRAFFIC LANE, FT
ELEVATION, IN.
TRAFFIC LANE
WEST
EAST
STA 0+20
ITEM 1
STA 0+60
STA 0+70
ITEM 2
STA 1+00
STA 1+10
ITEM 3
STA 1+40
STA 1+50
ITEM 4
0 COV
550 COV
110 COV
50 COV
10 COV

PLATE 6



PROFILES
TEST SECTION 2, LANE 1

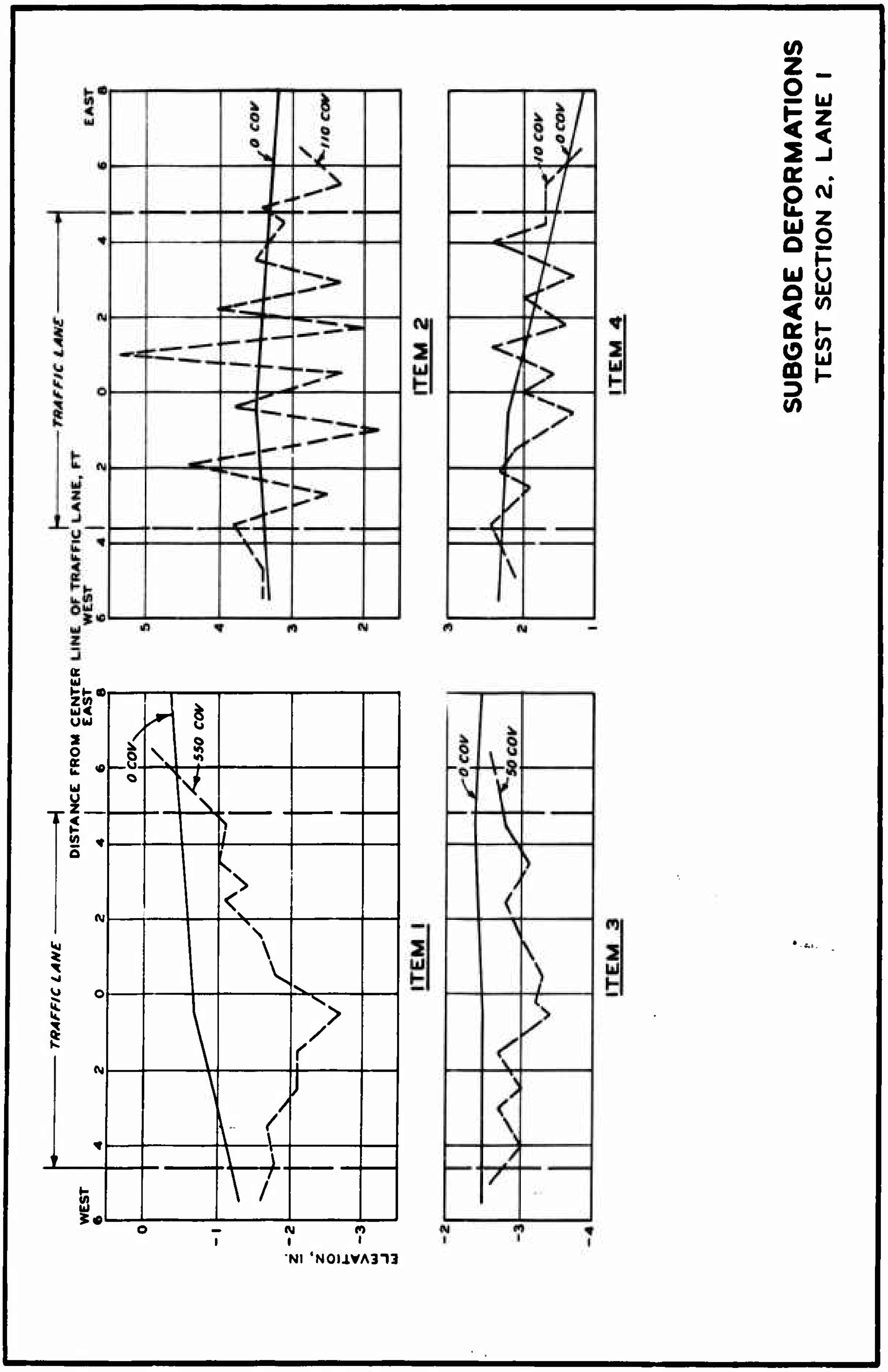
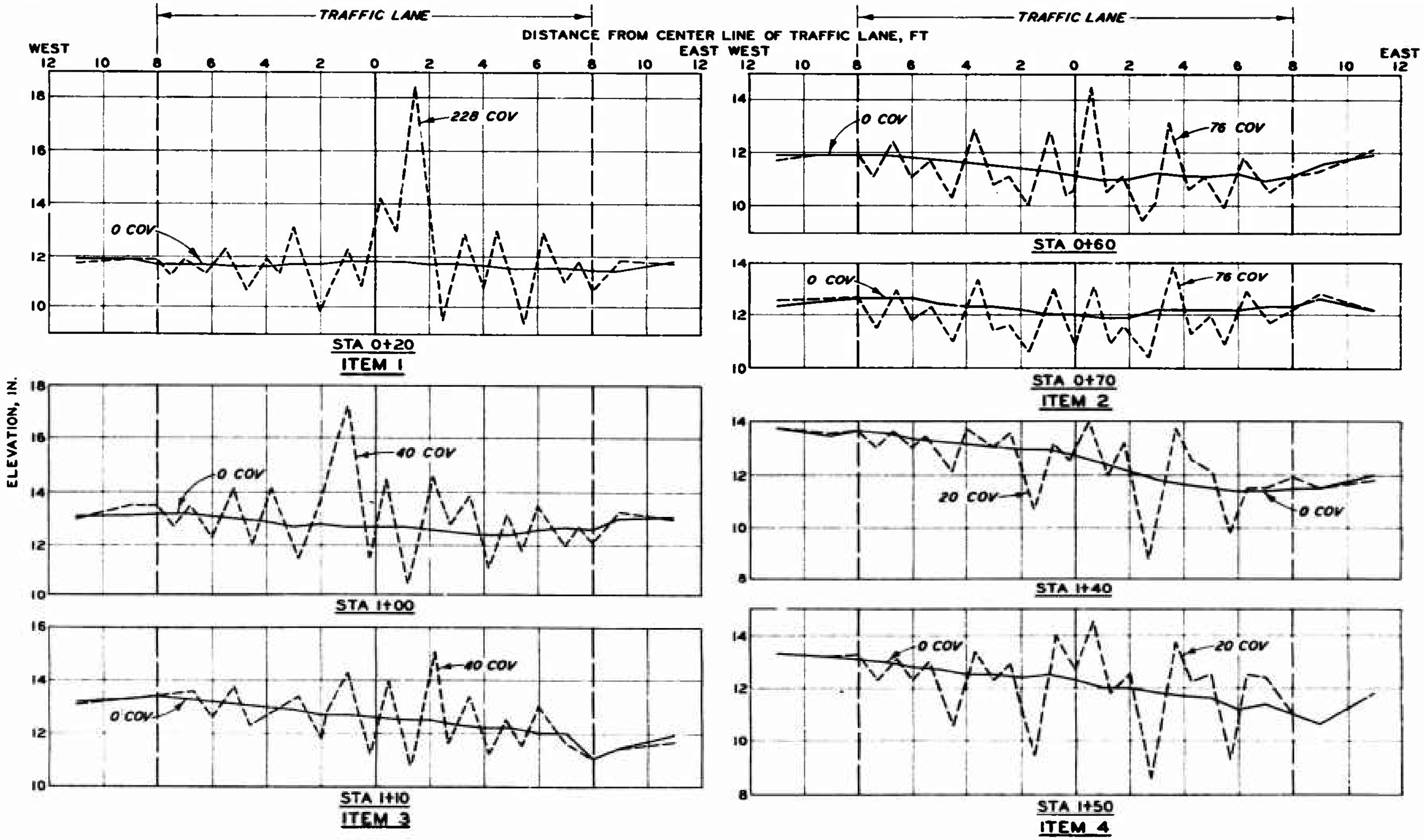
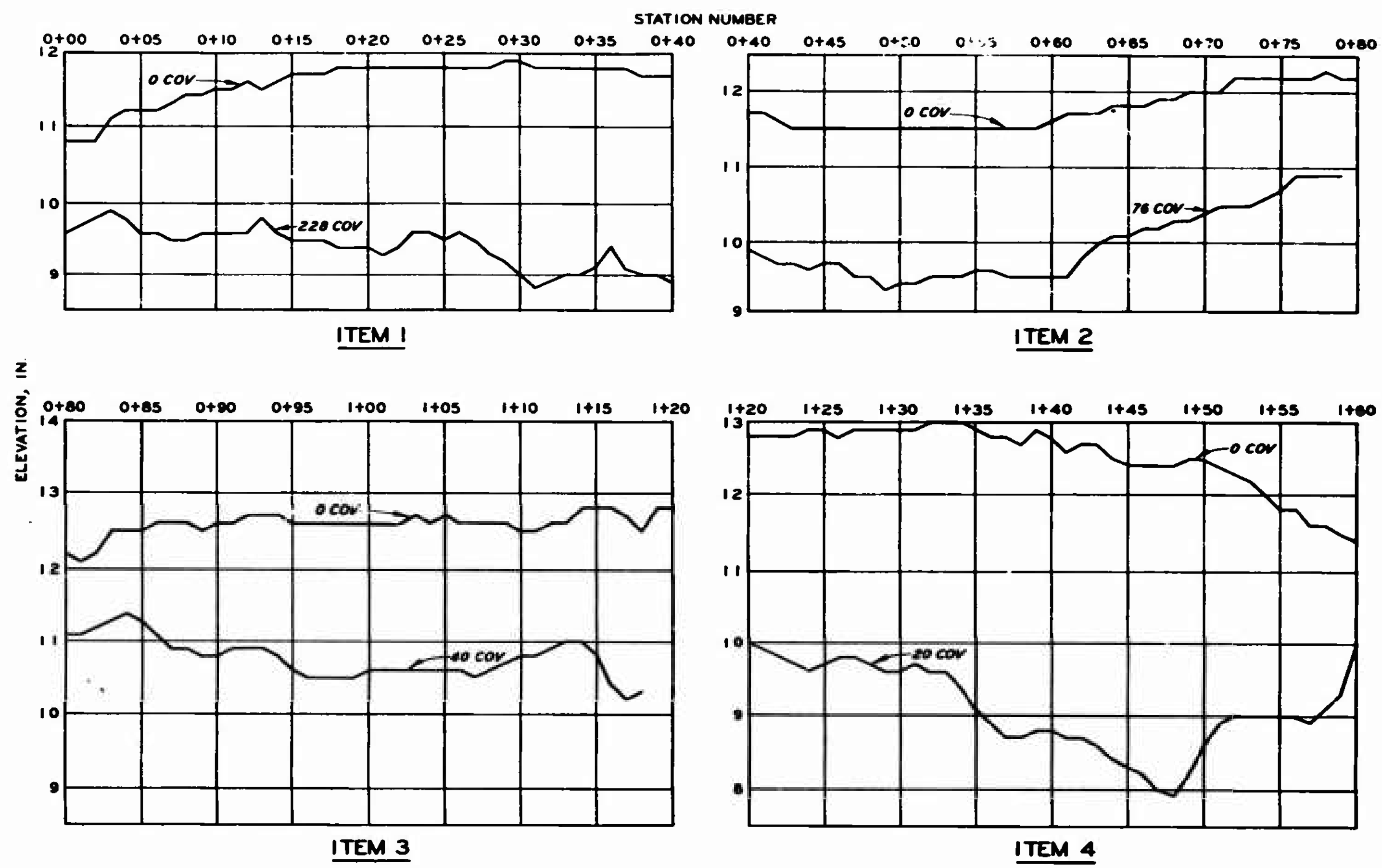

SUBGRADE DEFORMATIONS
TEST SECTION 2, LANE 1
ITEM 1
ITEM 2
ITEM 3
ITEM 4
TRAFFIC LANE
DISTANCE FROM CENTER LINE OF TRAFFIC LANE, FT
WEST
EAST
ELEVATION, IN.
0 COV
550 COV
110 COV
50 COV
10 COV

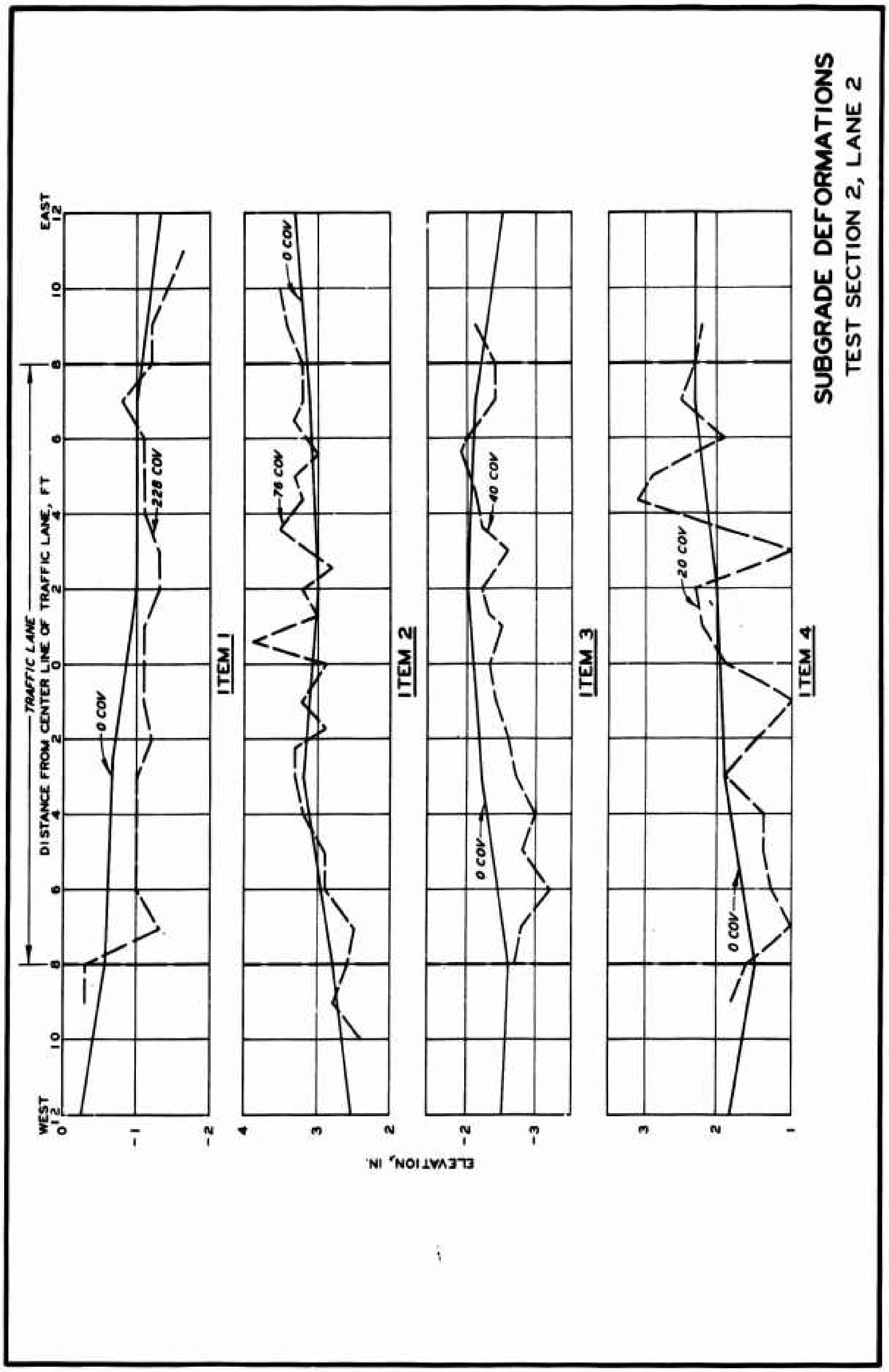
PLATE 8



CROSS SECTIONS
TEST SECTION 2, LANE 2



PROFILES
TEST SECTION 2, LANE 2



SUBGRADE DEFORMATIONS
TEST SECTION 2, LANE 2

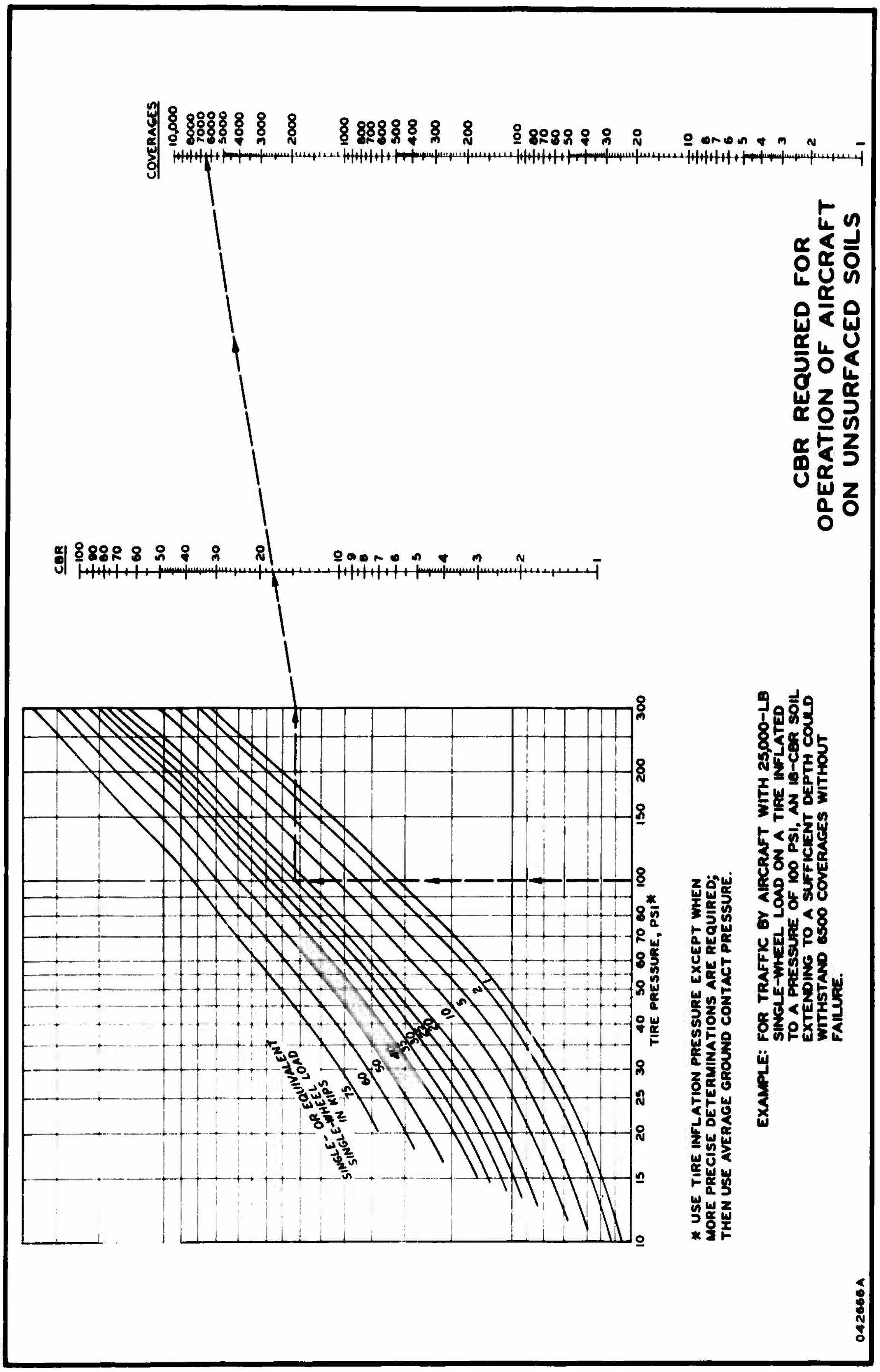
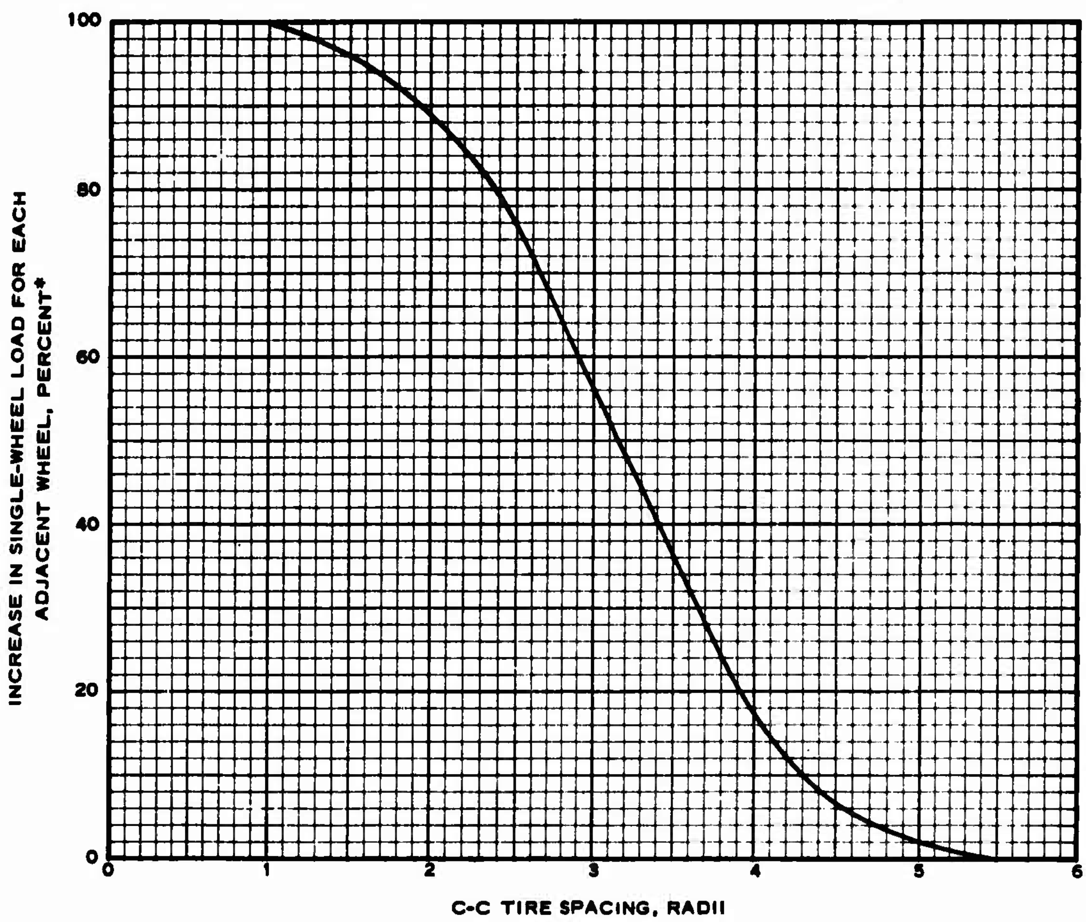

CBR REQUIRED FOR
OPERATION OF AIRCRAFT
ON UNSURFACED SOILS
COVERAGES
10,000
8000
7000
6000
5000
4000
3000
2000
1000
800
700
600
500
400
300
200
100
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
CBR
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
SINGLE-WHEEL LOAD
OR EQUIVALENT
SINGLE-WHEEL LOAD
IN KIPS
75
60
50
10
5
2
10 15 20 25 30 40 50 60 70 80 100 150 200 300
TIRE PRESSURE, PSI*
* USE TIRE INFLATION PRESSURE EXCEPT WHEN
MORE PRECISE DETERMINATIONS ARE REQUIRED;
THEN USE AVERAGE GROUND CONTACT PRESSURE.
EXAMPLE: FOR TRAFFIC BY AIRCRAFT WITH 25,000-LB
SINGLE-WHEEL LOAD ON A TIRE INFLATED
TO A PRESSURE OF 100 PSI, AN 18-CBR SOIL
EXTENDING TO A SUFFICIENT DEPTH COULD
WITHSTAND 6500 COVERAGES WITHOUT
FAILURE.
042668A

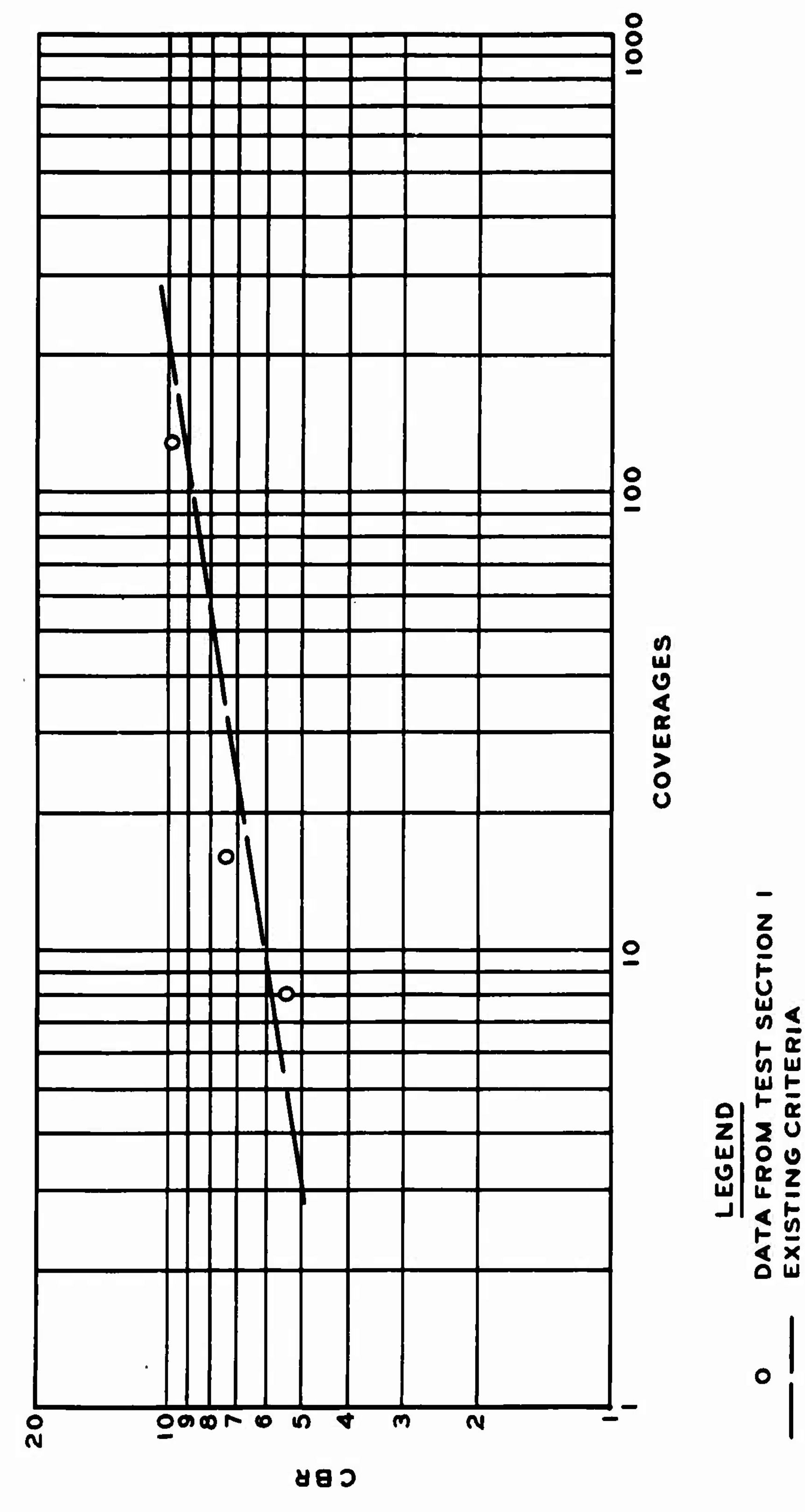
PLATE 12



* INCREASE IN LOAD ON A SINGLE WHEEL OF A MULTIPLE-WHEEL GEAR TO ACCOUNT FOR EFFECTS OF ADJACENT WHEELS OF THE MULTIPLE-WHEEL GEAR IN ARRIVING AT AN EQUIVALENT SINGLE-WHEEL LOAD.

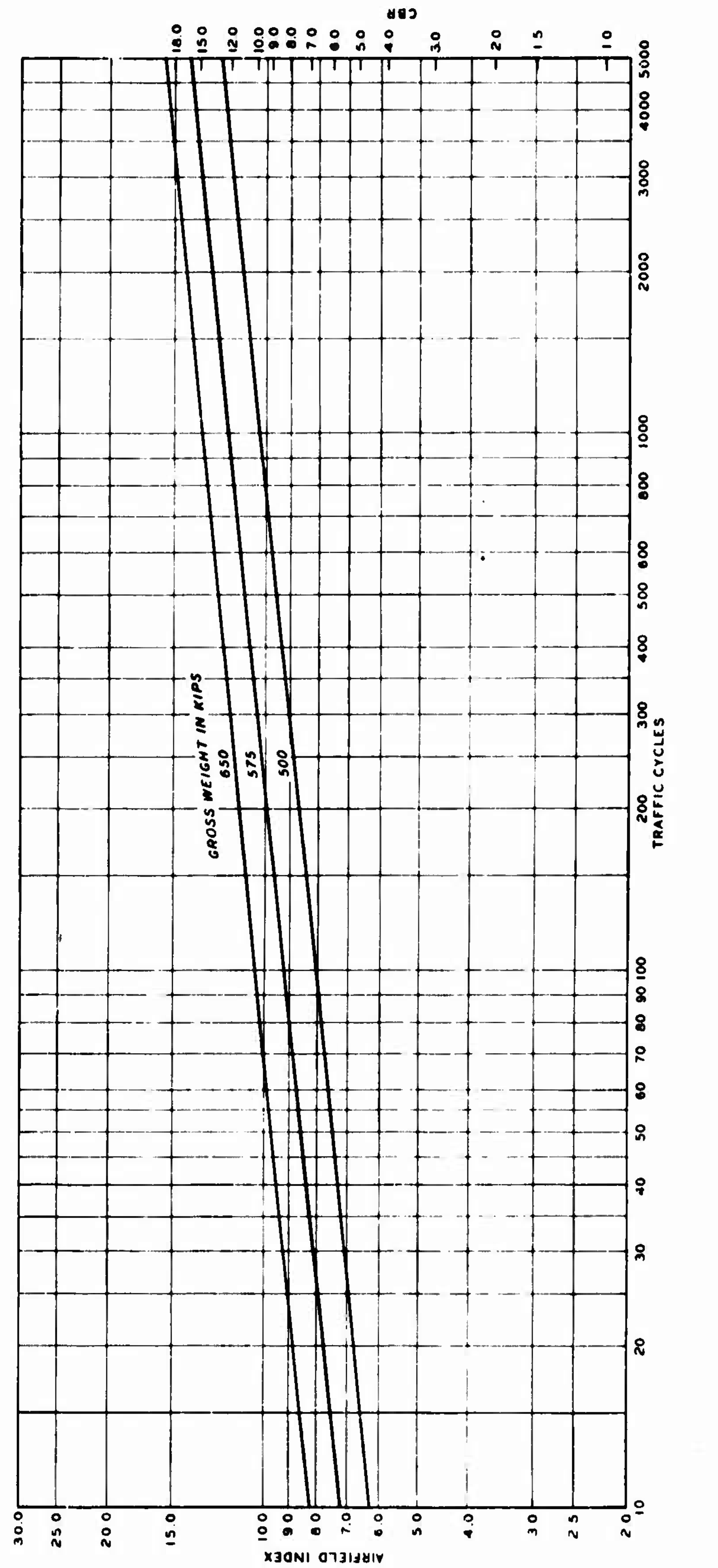
EQUIVALENT SINGLE-WHEEL LOAD-ADJUSTMENT CURVE FOR UNSURFACED SOILS

042666 B



COMPARISON OF EXISTING CRITERIA WITH ACTUAL DATA

PLATE 14



UNSURFACED SOIL STRENGTH REQUIREMENTS FOR OPERATIONS OF C-5A AIRCRAFT