



TECHNICAL REPORT GL-81-7

C-5A OPERATIONAL UTILITY EVALUATION SOIL TESTS AND ANALYSIS

by

Robert W. Grau

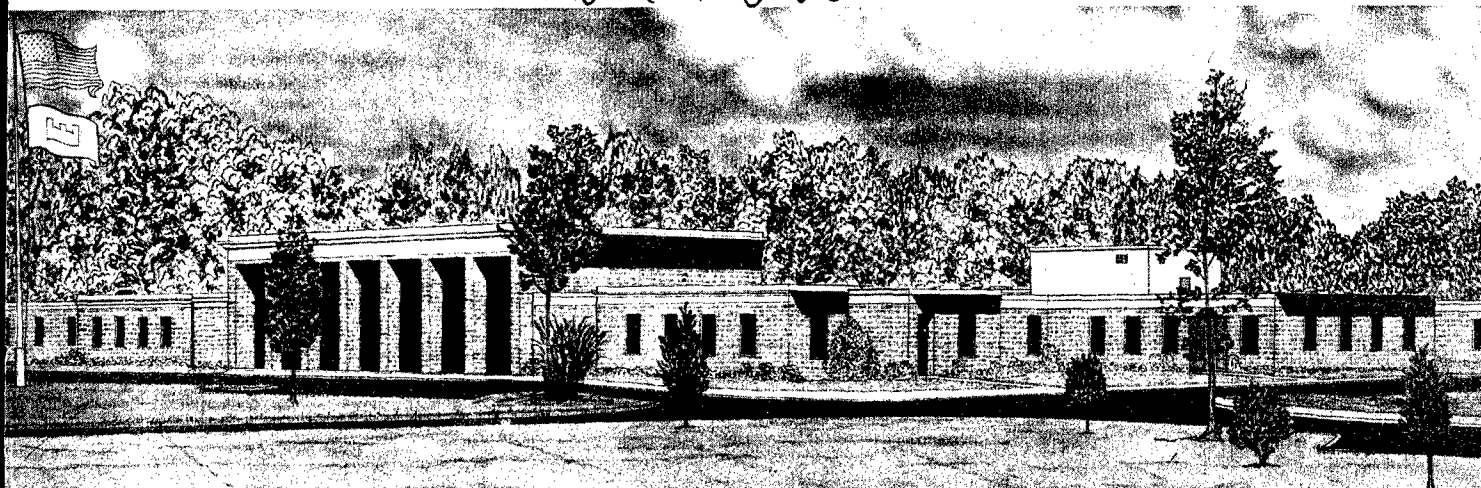
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August 1981

Final Report

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20061130 085



Prepared for Air Force Test and Evaluation Center
Kirtland Air Force Base
Albuquerque, N. Mex. 87117

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report GL-81-7	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) C-5A OPERATIONAL UTILITY EVALUATION SOIL TESTS AND ANALYSIS		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert W. Grau		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Mississippi 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Test and Evaluation Center Kirtland Air Force Base Albuquerque, New Mexico 87117		12. REPORT DATE August 1981
		13. NUMBER OF PAGES 65
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Cargo aircraft Ground flotation Soil analysis Soil-wheel interaction		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The purpose of this report is to present the data collected concerning the ground flotation characteristics of the C-5A aircraft during the C-5A operational utility evaluation test program. This report gives a description of the three test sites selected for this program, a summary of all soil and surface distress measurements taken at each site during aircraft operations, and an analysis of the data. (Continued)		

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20. ABSTRACT (Continued)

Results of this evaluation test program indicate that 3-in. ruts have little or no effect on the performance of the C-5A aircraft on unsurfaced areas.

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PREFACE

The U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, was requested by the Air Force Test and Evaluation Center (AFTEC), Kirtland AFB, New Mexico, to support them in conducting soil tests necessary to document C-5A aircraft performance during ground operations on unsurfaced and semiprepared natural areas. Funding was authorized by the AFTEC under MIPR Number F7B13001430001, dated 22 May 1980. This investigation, which was assigned to the Pavement Systems Division of the Geotechnical Laboratory at the WES, was conducted during June - August 1980.

Engineers of the Geotechnical Laboratory who were actively engaged in the planning, testing, analyzing, and reporting phases of the investigation were Messrs. A. H. Joseph, J. W. Hall, Jr., R. W. Grau, R. S. Rollings, D. R. Alexander, and D. M. Coleman. The investigation was under the general supervision of Dr. D. C. Banks and Mr. C. L. McAnear, alternately Acting Chief, and Dr. P. F. Hadala, Assistant Chief, Geotechnical Laboratory. This report was prepared by Mr. Grau. Commanders and Directors of the WES during the conduct of the study and preparation of the report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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

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

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
knots (international)	0.514444	metres per second
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square inches	6.4516	square centimetres
tons (2000 lb, mass)	907.1847	kilograms

C-5A OPERATIONAL UTILITY EVALUATION
SOIL TESTS AND ANALYSIS

PART I: INTRODUCTION

Background

1. The capabilities of the C-5A aircraft to operate from support area airfields in the theater of operations have not been conclusively demonstrated. The C-5A is a heavy cargo aircraft that was designed to operate from unsurfaced areas. Aircraft operations on unsurfaced areas require that adequate flotation be designed into the landing gear. Criteria for determining ground flotation requirements for the C-5A were determined during an investigation conducted by the U. S. Army Engineer Waterways Experiment Station (WES) during 1964 to 1966 (Ladd and Ulery, 1967). The C-5A has 24 main gear tires and 4 nose gear tires to provide the capability for operation on unsurfaced or temporary airfields. In early 1970, testing was initiated on the dry lake bed of Harper Lake, California, to demonstrate the flotation characteristics of the C-5A for operation on an unsurfaced area having a strength of 9 CBR. However, these tests were terminated because of engine damage due to ingested dirt during a maximum reverse thrust landing. Tests were also conducted at the Tri-Service Landing Mat Facility at Dyess AFB, Texas, during the early 1970's. These tests were terminated prior to the completion of testing because shear forces imparted by the braking of the aircraft resulted in failure of the mat and damage to the aircraft. Later, after serious deficiencies were discovered in the wing structure, aircraft restrictions were imposed that have limited C-5A operations to major airports with paved surfaces.

2. In response to Congressional requests, the Deputy Secretary of Defense has directed a C-5A Operational Utility Evaluation (OUE) to verify aircraft capability to operate from less than fully improved airfields. This evaluation, which was limited to ground operations only, was managed by the Air Force Test and Evaluation Center (AFTEC),

Kirtland AFB, New Mexico, and conducted by the Military Airlift Command (MAC), Scott AFB, Illinois.

3. At the request of AFTEC, the WES participated in the C-5A OUE project to the extent of providing technical assistance pertaining to site selection and in obtaining the necessary laboratory and field soil measurements to evaluate the soil strength and to determine the effects of aircraft ground operations at the test sites. At the conclusion of field testing, the data were analyzed and a report prepared.

Objective and Scope

4. The overall objective of the OUE was to evaluate C-5A operations on and between unprepared, semiprepared, matted, and paved airfield surfaces and determine the extent to which the C-5A payload capability at forward area airfields might be enhanced by limited airfield surface improvements. The operational evaluation will determine C-5A operational characteristics associated with forward area airfield operations, minimum airfield characteristics to accommodate C-5A operations, rapid cargo off-load capability, unique operational procedures, and the impact on maintainability and logistics support resulting from these operations. The specific objectives assigned to the WES were to provide technical assistance concerning the ground flotation characteristics of the aircraft during the test program and to provide laboratory and field soil testing necessary to document C-5A performance during ground operations at the test site. These objectives were accomplished by:

- a. Conducting field in-place water content, density, CBR, and airfield index (AI) measurements prior to and during aircraft operations.
- b. Performing laboratory compaction and CBR tests and tests required for soil classification on samples obtained from each of the test sites.
- c. Observing the general behavior of the test sites during ground operations and documenting the behavior with photographs and AI and rut depth measurements.

5. This report gives a description of each test site, a summary of all soil measurements taken, and an analysis of the data.

PART II: SITE SELECTION, TEST SITES,
TEST AIRCRAFT, AND TEST TRACKS

Criteria and Instruments Used in Site Selection

6. The criteria used in the selection of the unsurfaced test areas were as follows:

- a. The selected sites must provide a range of strengths and soil types representative of MAC's global operations.
- b. The selected sites must have a runway of sufficient length to accommodate the C-5A for arrival/departure associated with the ground maneuvers scheduled for evaluation, and an off-runway area sufficiently large to permit off-load cycles as required.
- c. The selected sites must be located in CONUS, accessible to adequate C-5A support, and restricted to a minimum number of locations to permit completion of site activities by late summer of 1980.

7. Based on the above criteria, three test sites were selected having soil types ranging from sand, clayey sand, and clay with soil strengths of 15 to 20 CBR, 20 to 25 CBR, and 9 CBR, respectively. The test sites were located at Tyndall AFB, Florida (sand), Shaw AFB, South Carolina (clayey sand), and Kelly AFB, Texas (clay). However, when testing was scheduled to begin at Tyndall AFB and Kelly AFB, the sub-grade strengths were unacceptable and alternate sites were used. These alternate sites were located at Eglin AFB, Florida (sand) and Altus AFB, Oklahoma (clay). Prior to the start of the C-5A ground operation, the soil strength at each test site was evaluated on the basis of CBR* and AI**. The test instruments and the reliability of results are discussed in the following paragraphs.

* CBR is a measure of the resistance of soils to penetration; it is determined by comparing the bearing value obtained from a penetration-type shear test with a standard bearing value obtained on crushed rock. The standard results are taken as 100 percent, and values obtained from other tests are expressed as percentages of the standard (U. S. Army Engineer Waterways Experiment Station, 1956).

** AI is the average of a number of airfield cone penetrometer readings in a given plane (Fenwick, 1965).

CBR measurements

8. The CBR values were determined from field in-place tests. Use of the CBR as a measure of soil bearing capacity has been well validated for indicating soil or pavement capability to sustain aircraft loadings and repetitions. All existing criteria on soil strength requirements for aircraft ground operations on unsurfaced soils are based on CBR or AI values.

Airfield index measurements

9. The airfield penetrometer was developed as an expedient means of measuring soil strength in relatively low-strength soils. It consists of a 30-degree right circular cone with a base diameter of 1/2 in.* (area equals 0.196 sq in.) mounted on a graduated staff. On the opposite end of the staff are a spring, a load indicator, and a handle. In use, the spring is stretched directly in proportion to the load applied to the handle, and the force required to move the cone through a layer of soil is an index of the shearing resistance of the soil, which is called the AI of that layer. The AI of a soil layer is read directly from the load indicator on the penetrometer. The penetrometer used during this investigation had a range of AI readings from 0 to 15.

Test Site Locations

Clayey sand test site

10. The clayey sand test site was located at Shaw AFB, Sumter, South Carolina. A 1000- by 1000-ft test area was positioned so that it was parallel to and 400 ft from the east edge of runway 4R and parallel to and 200 ft from the north edge of an abandoned taxiway. The abandoned taxiway was perpendicular to runway 4R and connected 4R to the west end of runway 8-26. A layout of the test area is shown in Figure 1. The subgrade soil was generally a clayey sand that supported medium to heavy vegetation (Photo 1) consisting of grass in the medium areas

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

and mostly weeds in the heavy areas. Thick weeds, approximately 2.5 to 3 ft in height, were located in an area bounded generally by grid points F-5, F-9, and K-5. See Figure 1 for grid point locations. The surface of the test area was relatively smooth except for two drainage depressions which ran diagonally across the test area. These drainage structures were 50 ft wide and 6 to 12 in. deep and were sodded very well with grass. The two drainage depressions crossed the test area lines connecting grid points G-4 to M-7 and C-13 to M-11. The maximum longitudinal and transverse grades were 1 percent or less.

Clay test site

11. Altus AFB, Altus, Oklahoma, was selected as the location for the clay test site. A 1000- by 600-ft test area was laid out within a right triangular, unsurfaced area which was located approximately 800 ft east of the main N-S runway. The test site was bound on two sides by abandoned asphaltic concrete (AC) airfield pavement and on the third side by an AC perimeter road. A layout of the test area is shown in Figure 2. As can be seen in Figure 2, a 200- by 200-ft area located in the west corner of the test site was overlaid with aluminum landing mat. The subgrade material was a silty clay and supported light vegetation as shown in Photo 2. The test area was relatively flat except for several localized depressions. In the areas where the depressions were 8 to 10 in. or more in depth, fill material was end-dumped, spread, and compacted for leveling purposes.

Sand test site

12. The sand test site was located in a triangular area approximately 700 ft east of the primary runway (01-19) at Eglin AFB, Florida. The site was bounded on the sides by taxiways 9, 10, and 21 (Figure 3). Aircraft ground operations were performed in a 1400- by 800- by 600-ft trapezoidal area within the triangular area. The subgrade soil was a silty sand and had a thick cover of vegetation consisting of grass and weeds (Photo 3). Surface irregularities consisted of shallow depressions and dunes (8 to 10 in. maximum in depth or height) caused mostly by sand mounds and gopher holes. The entire test area was relatively flat with the longitudinal and transverse grade not exceeding

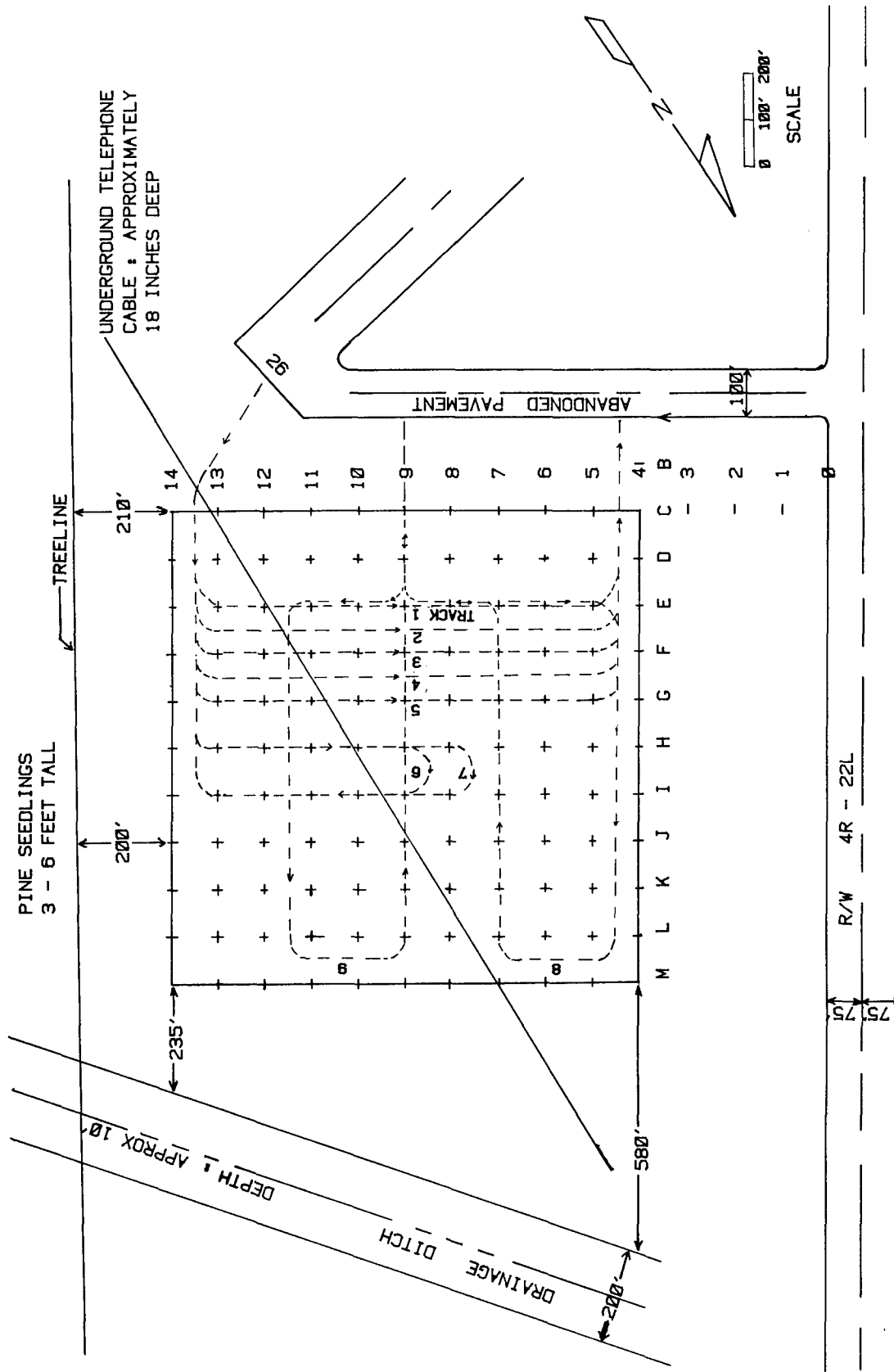


Figure 1. Layout of Shaw AFB test site, July 1980

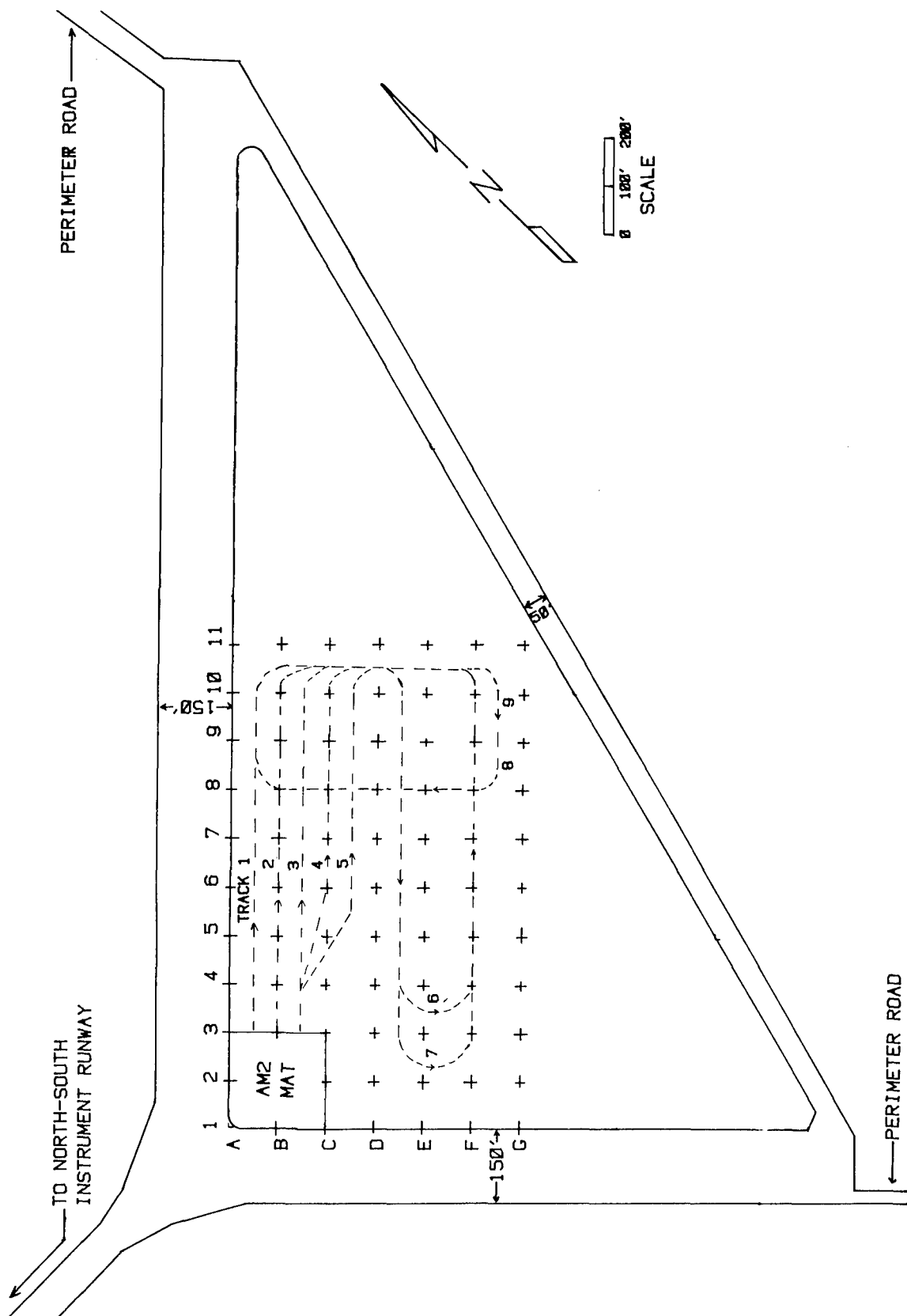


Figure 2. Layout of Altus AFB test site, July 1980

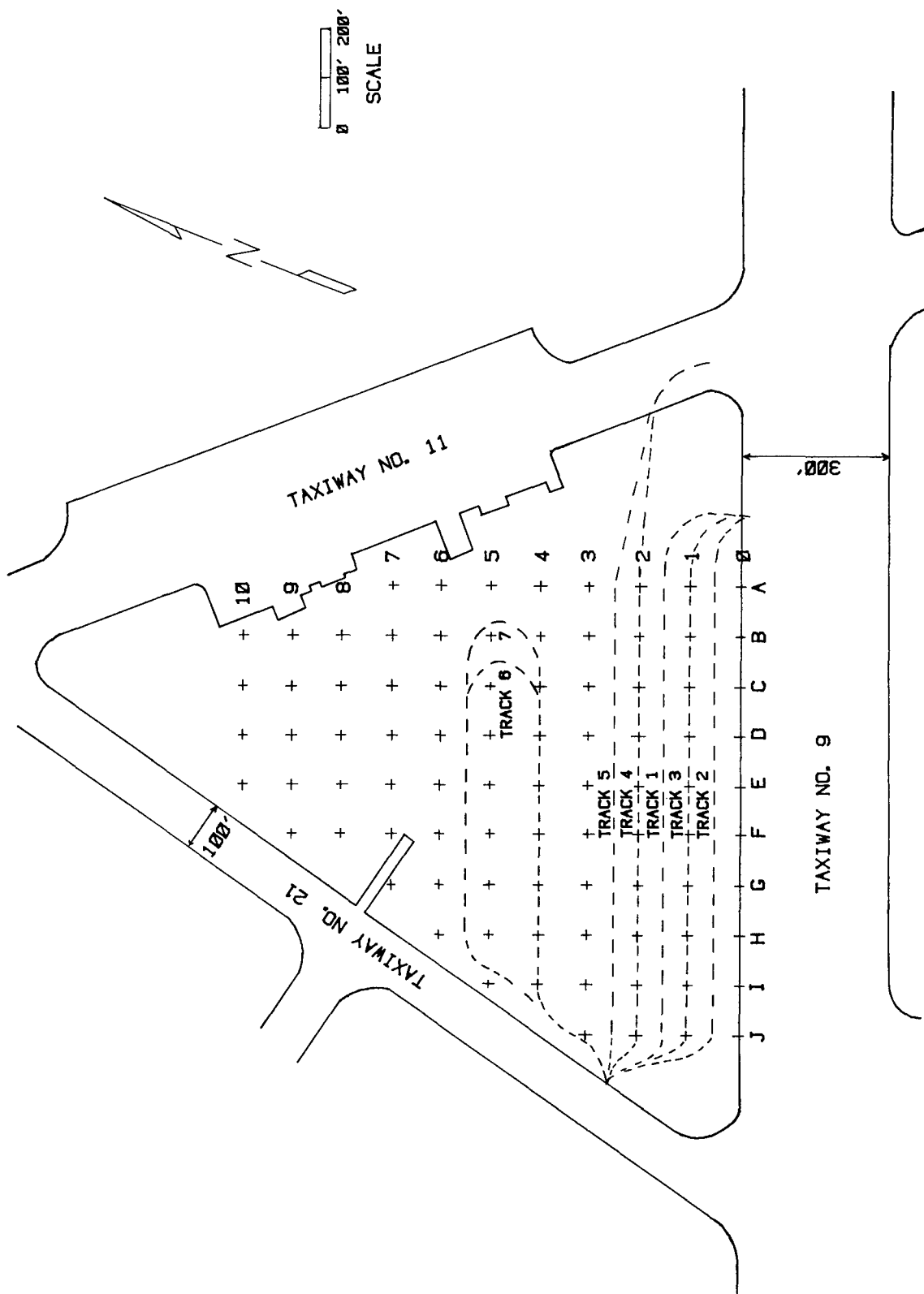


Figure 3. Layout of Eglin AFB test site, August 1980

one percent. The root structure was dense down to a depth of about 6 in.

Test Aircraft

13. The ground operations were conducted by MAC using a C-5A aircraft manufactured by the Lockheed-Georgia Company. The C-5A is a long-range, high-speed, high-altitude, swept-wing airplane designed for use as a heavy logistic transport. The airplane is designed to airlift a wide variety of combat support equipment and personnel. Four General Electric TF-39 turbofan engines equipped with thrust reverse power the airplane. Some unique design features of the airplane are a forward and aft cargo door system enabling straight-through loading and unloading and a landing gear kneeling system that enables the cargo deck to be tilted nose down or tail down or to be lowered in the level position. The airplane is equipped with retractable landing gear consisting of four six-wheel bogie-type main landing gears and a four-wheel, steerable nose gear. The gross weight (GW) of the aircraft varied from 425,000 to 665,000 lb during ground operations. During testing, the required weight was controlled by the amount of fuel on the aircraft and/or cargo, which consisted of representative Army loads of both wheeled and tracked vehicles and palletized equipment. At each of the test loads, the inflation pressure of the tires was adjusted to provide a contact area of 285 sq in.

Test Tracks

14. Aircraft ground maneuver events were performed on various test tracks that were laid out on the three test areas. Locations of the test tracks are shown in the layouts of the three test areas (Figures 1-3). A list of the ground maneuver events performed at each of the test sites and the respective tracks on which they were performed is shown in Table 1. Table 1 identifies the conditions for each taxi event such as run number, track number, aircraft gross weight, taxi speed, steering angle, number of replications, and whether cargo offload was accomplished.

15. Ground maneuvers were performed at aircraft gross weights of 425,000, 500,000, 560,000, 605,000, and 665,000 lb at each of the test sites in the following manner. Initially, ground maneuvers were commenced on track 1 at the lowest GW (425,000 lb) and the lowest risk maneuver (straight-line taxiing). After the straight-line taxiing was successfully completed, runs of increasing complexity were performed on track 6. Following the 425,000-lb GW track 6 traffic, the GW of the aircraft was increased to 500,000 lb and straight-line taxiing was applied to track 2. After completing the straight-line traffic on track 2, track 6 was again tracked at the 500,000-lb aircraft GW. This procedure was continued for the remaining three aircraft gross weights, which resulted in tracks 3, 4, and 5 receiving straight-line taxiing at aircraft gross weights of 560,000, 605,000, and 665,000 lb, respectively, and the more complex aircraft maneuvers at these weights being applied to track 6. After the completion of track 6 traffic, additional aircraft ground maneuvers (Table 1) were applied to tracks 7, 8, and 9. By applying test traffic in the above manner, test data were available from areas that had received only one pass of the aircraft loaded to each of its five gross weights and from areas that had received multiple passes of the aircraft operating at one or more of its gross weights. Tow tests were also performed at each test site in addition to the aircraft taxi maneuvers listed in Table 1.

PART III: TESTS AND RESULTS

Clayey Sand Test Site

Soil classification

16. Based on color changes of the soil layers observed during test pit excavation and auger sampling, there were predominantly two different soil types within the test area: a brownish material on the surface and a reddish-brown underlying material. The thickness of the surface material ranged from about 6 to 18 in. and was classified as a clayey sand (SC) with a liquid limit (LL) of 24 and plasticity index (PI) of 11 in accordance with the Unified Soil Classification System (USCS) (Department of Defense, 1968). Classification data for this material are shown by curve 1 in Figure 4 and laboratory compaction and CBR data are determined according to Method 100 (Department of Defense, 1964) for the surface SC as shown in Figure 5. The reddish-brown underlying soil (curve 4, Figure 4) also classified as a clayey sand (SC), and it had an LL of 30 and PI of 17. Laboratory compaction and CBR data for this underlying SC material are shown in Figure 6. Lenses of either dark brown sandy clay (CL) or red clayey sand (SC) were also observed in localized areas between the two predominant soils. Classification data for these materials are depicted by curves 2 and 3 in Figure 4 for the sandy clay and clayey sand, respectively.

Water content, density, CBR and penetrometer data

17. Approximately two weeks prior to aircraft ground operations, field in-place water content, density, CBR, and airfield penetrometer data on the clayey sand were obtained from six test pits located at various points throughout the test area. A summary of this data is shown in Table 2. It can be noted from the data in Table 2 (with the exception of pits M-11 and I-7) that the soil at the test site can generally be divided into two layers, a top 12- to 18-in.-thick layer and an underlying layer. The data for pits M-11 and I-7 are not in agreement with the data for the other pits because they were excavated

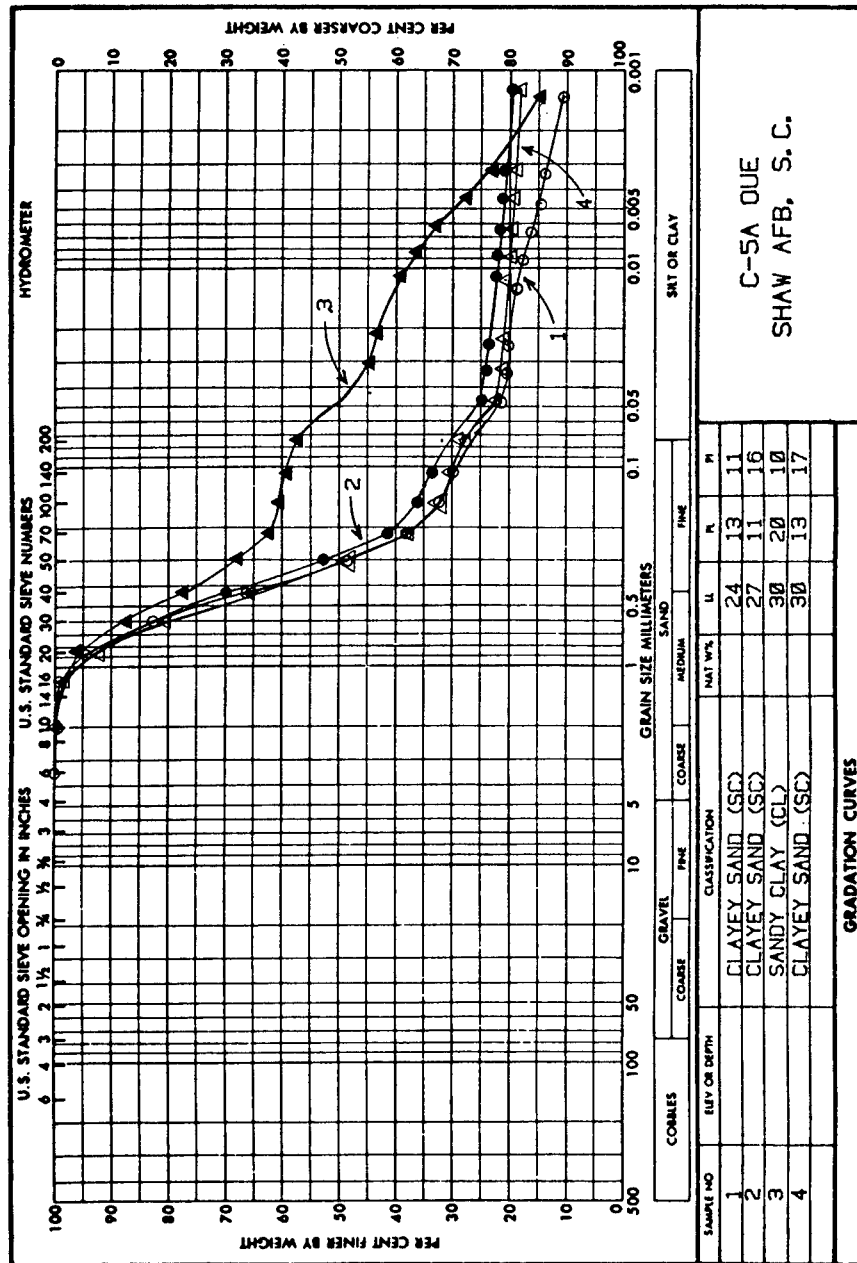


Figure 4. Grading curves for Shaw AFB test site subgrade materials

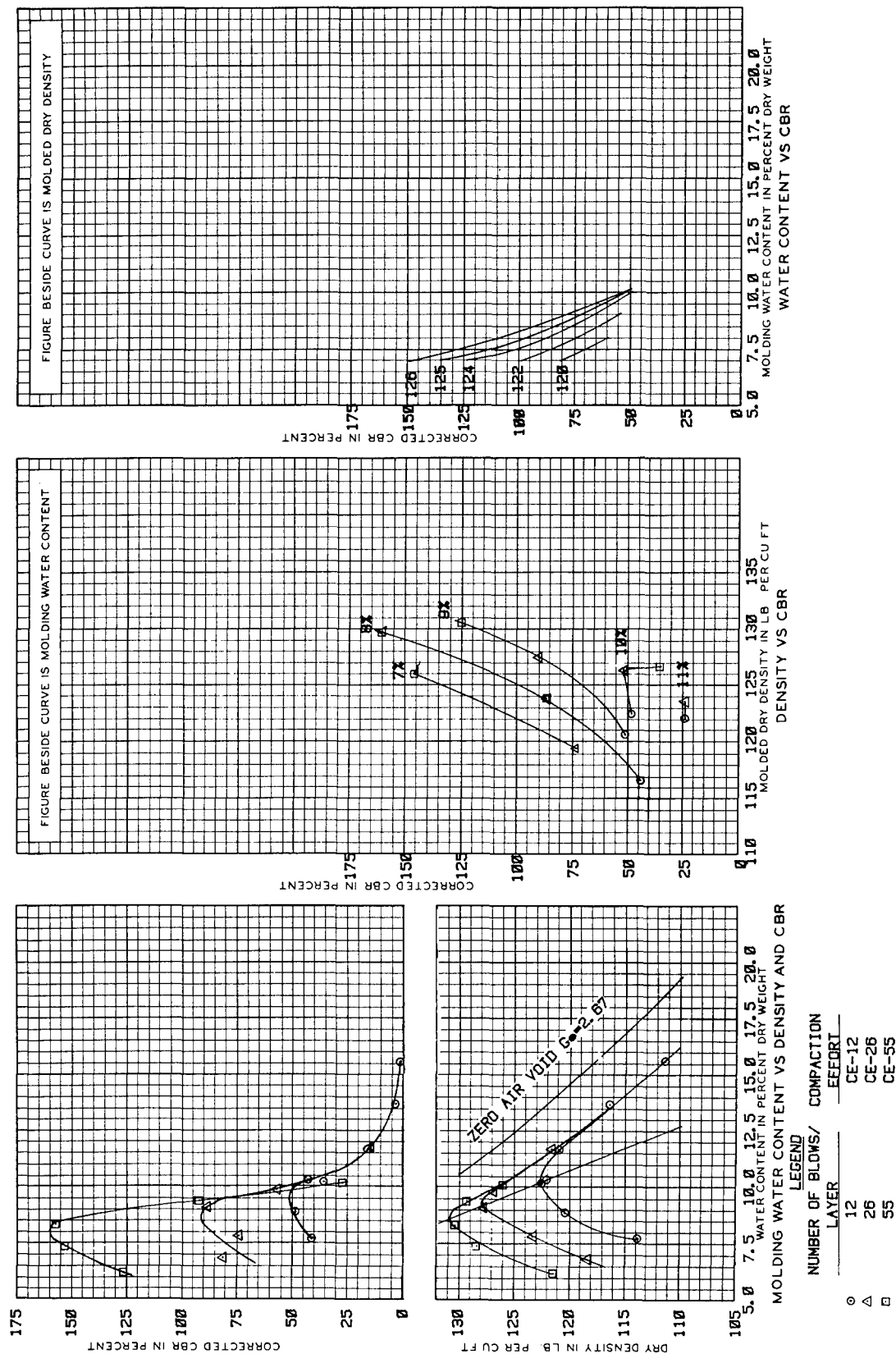


Figure 6. Water content, density, and CBR data for Shaw AFB subgrade material No. 4 (tested as molded)

in areas with lenses of either dark brown sandy clay or red clayey sand intermingled with the two predominant soil types. When only the data for pits E-6, G-12, C-11, and K-4 are considered, the upper layer has an average strength and density of about 12 CBR and 103.5 pcf, respectively, and the underlying layer has a strength of 5 CBR and a density of 94.9 pcf. These data also indicate that the average moisture content of the surface layer was 8.9 percent as compared to 9.7 percent for the underlying soil layer. Airfield penetrometer readings were made along with the CBR tests to establish a correlation between AI and CBR for the clayey sand soil. The AI measurements are tabulated in Table 2 and a plot of AI versus CBR is shown in Figure 7. In addition to the measurements taken at each of the test pits, airfield penetrometer readings were made at 100-ft intervals or each grid point (see Figure 1 for location of grid points). Averages of these measurements for 0-, 2-, 4-, 6-, 12-, 18-, 24-, and 30-in. depths are shown in Table 3.

18. Immediately prior to aircraft operations on 9 June 1980, a series of airfield penetrometer readings were made at selected grid coordinates within the test area. Results of these readings indicated that the average AI of the soil at a depth of 2 in.* was 15 or greater. Based on the readings and the AI versus CBR plot shown in Figure 7, the strength of the surface of the test area was an 11 CBR or greater. Although no CBR measurements were made at this time, the strength of the top 6-in. layer of soil was estimated to be between 15 and 20 CBR. This increase in strength of the surface layer between initial testing (see Tables 2 and 3) and pre-aircraft operations, 6 CBR versus 11 CBR, was attributed to the hot, dry weather experienced during this period.

Aircraft operation tests and resulting soil behavior

19. Ground operations were initiated on 9 July 1980 with the C-5A loaded to a GW of 425,000 lb and a main gear tire pressure that resulted in a contact area of 285 sq in. It should be noted that throughout the

* The upper limit of the airfield penetrometer is an AI of 15; therefore, no measurements were recorded at depths greater than those at which an AI of 15 was measured.

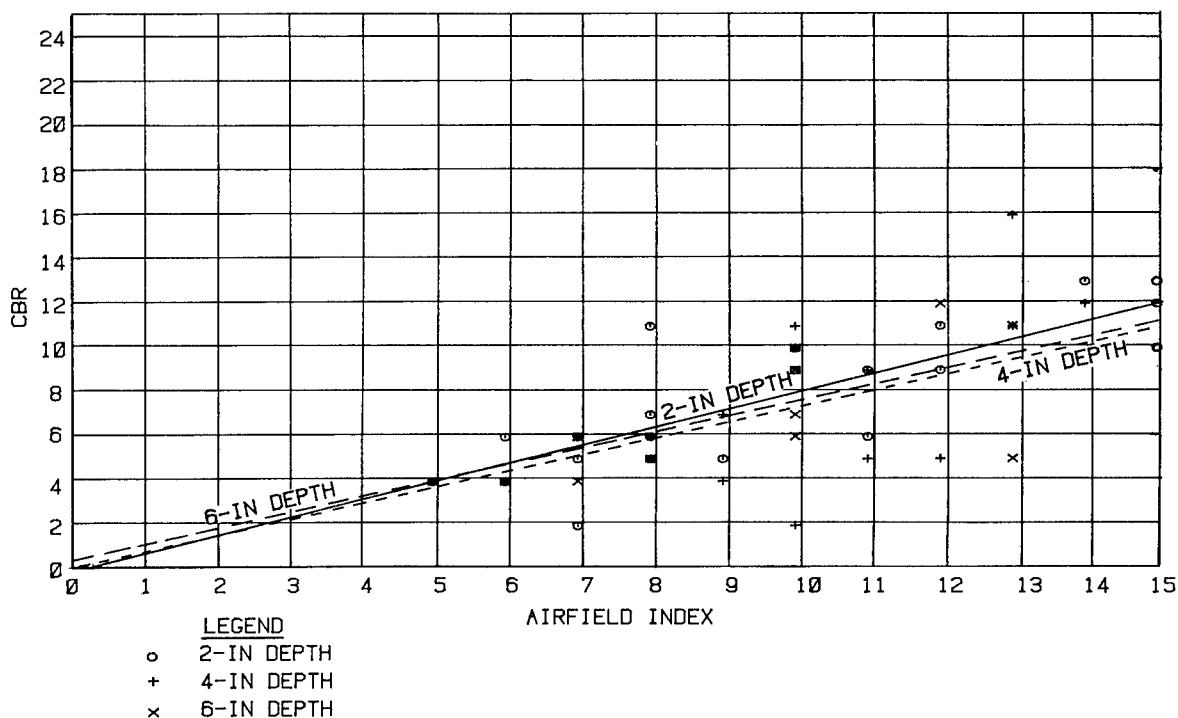


Figure 7. Correlation between the AI and the CBR for subgrade material at the Shaw AFB test site

entire test program the contact area of the main gear tires was maintained at 285 sq in. A summary of the rut depth and airfield penetrometer measurements and visual observations made after each aircraft operation on the clayey sand test site is shown in Table 4.

20. Generally, only minor surface deterioration, such as grass or vegetation abrasion and pulverization of the surface material, occurred during ground operations. Straight taxiing caused slight pulverization at the surface and turning maneuvers resulted in some additional surface pulverization as compared with the straight taxiing areas and slight upheaval of furrows of loose soil at the outside edges of the wheel paths. The first operation consisted of taxiing the aircraft over track 1 at a GW of 425,000 lb. After completion of this maneuver, the surface of track 1 was inspected and the aircraft traversed track 6 at the 425,000 GW. The only distress observed in either of these tracks after one pass was grass abrasion over the entire length of the tracks and slight pulverization and upheaval of the loose soil in the turn areas of both tracks. The soil beneath the loose pulverized material

was intact and remained at the same strength as that of the surrounding untracked area. As determined from the AI measurements shown in Table 4, an AI of 15 or greater was measured both in and out of the wheel paths at a depth of 2 to 4 in. After completion of the 425,000-lb GW operations, the aircraft GW was increased to 500,000 lb and tracks 2 and 6 were tracked. Again, the only distress observed was grass abrasion, slight pulverization of the surface, and upheaval of the loose material in the turn areas. Following the 500,000-lb GW taxi maneuvers, 605,000- and 665,000-lb aircraft GW taxi maneuvers were performed on tracks 4 and 6 and tracks 5 and 6, respectively. With the exception of the slight rutting, 1/4 to 1/2 in. deep, detected in track 5, there was very little difference in the performance of tracks 4 and 5 as compared to that of tracks 1 and 2 after one taxi operation. After the aircraft had maneuvered over track 5 and returned to the abandoned pavement, a rut approximately 1-1/2 in. deep was detected at about grid point D-4.5.* At this time, this area had received four passes of the aircraft, one at each of the four gross weights. Airfield penetrometer readings in this area indicated that a layer of low-strength (about 7 CBR) material was located approximately 6 to 8 in. below the surface. As ground operations continued throughout the schedule of maneuvers, the effect of increase in GW or number of passes on the subgrade was not very pronounced except in isolated, weak areas or in areas subjected to multiple turns of the aircraft. In these areas, H-7.5 and D-4.5, the maximum rut depth was only about 2 in. Grid point H-7.5 was located in a 90-degree turn area of track 6, and grid location D-4.5 in a localized soft area common to tracks 1-5 where the aircraft made multiple passes. After-traffic testing indicated that the rutting in the H-7.5 area was probably due to a layer of low-strength material located 6 to 8 in. below the surface. The underlying soil in this area had a soil strength of about 5 CBR.

21. The C-5A cargo handling system performed the off-load maneuver satisfactorily at the clayey-sand test site. During these maneuvers,

* The designation D-4.5, for example, indicates a location between grid numbers 4 and 5 on line D.

the maximum rutting was only about 1-1/2 in. which caused no problems during off-loading. The surface roughness conditions encountered had little or no effect on operation of the aircraft kneeling and cargo door systems, and shoring requirements for the ramp and ramp extension were not significantly different from those on paved surfaces.

22. Tow testing at the site indicated that the 10K Adverse Terrain (AT) forklifts will perform satisfactorily for towing the C-5A and that if M-35 2-1/2-ton trucks are to be used, the trucks should be loaded. The unloaded M-35 trucks that were initially used for towing performed unsatisfactorily due to loss of traction. However, these trucks performed satisfactorily as tow vehicles after they were loaded with palletized cargo.

Post-aircraft operation subgrade tests

23. When all ground maneuvers were completed, airfield penetrometer readings were taken at each of the grid points within the test section. Results of these tests indicated that the average strength of the subgrade was a 12 CBR or greater at a depth of 2 to 4 in. Although no AI measurements were recorded at depths below where an AI of 15 was measured, it is assumed that the layer of 5-CBR material still existed 12 to 18 in. below the estimated 15- to 20-CBR surface layer.

Clay Test Site

Soil classification

24. The soil at the clay test site had an LL of 46 and a PI of 30 and was classified as a sandy clay (CL). Classification data for this material are shown in Figure 8. Based on the specimens removed and observations made while excavating test pits within the test area, the sandy clay was consistent throughout the test area down to a depth of at least 30 in. Laboratory compaction and CBR data for this subgrade material are shown in Figure 9. From these data it can be determined that for this soil, the maximum CE 12 density is 104.6 pcf at an optimum water content of 19.5 percent.

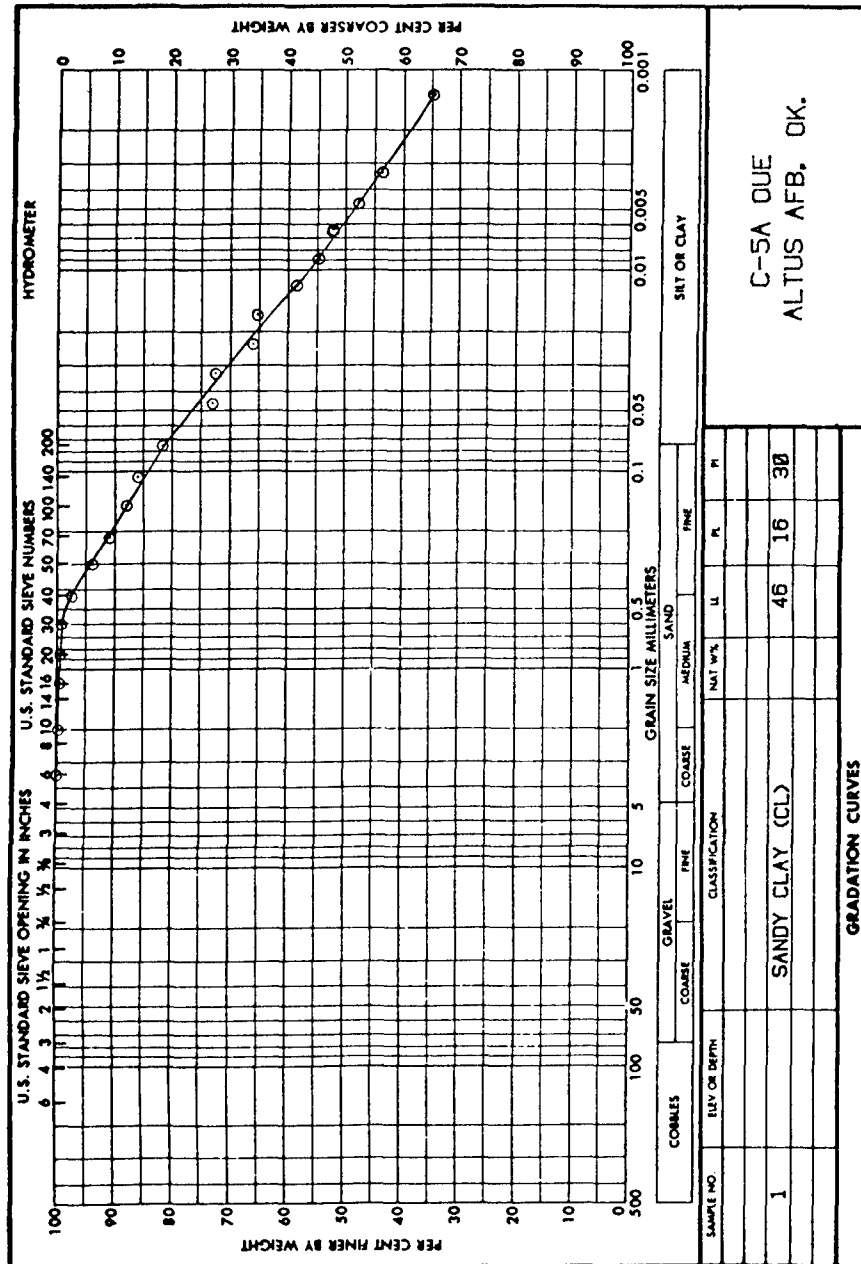


Figure 8. Grading curve for Altus AFB test site subgrade material

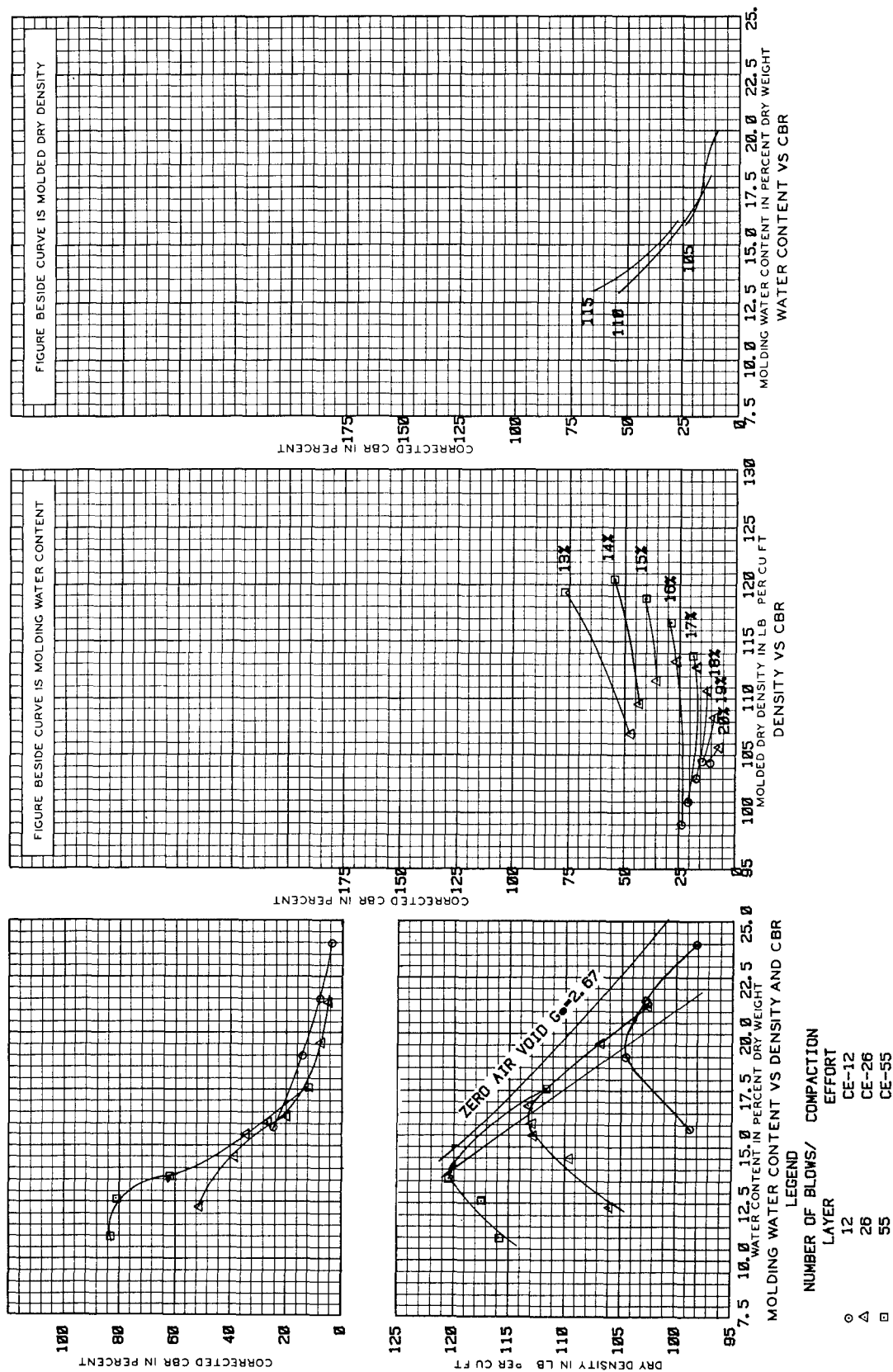


Figure 9. Water content, density, and CBR data for Altus AFB test site subgrade material (tested as molded)

Water content, density, CBR,
and penetrometer data

25. The strength of the subgrade material was erratic due to variations in moisture content. This variation was due to the watering of the test area prior to testing which was required to reduce the existing subgrade strength. At the time Altus AFB was chosen as a test site, the strength of the in situ material was about 9 CBR, which was the desired strength. However, approximately two weeks before ground operations were to begin, the strength of the upper 12 in. or so had increased to a 15 CBR or more due to the hot, dry weather this portion of the United States was experiencing. To lower the subgrade strength to the desired 9 CBR, an irrigation system was set up and the entire test area shown in Figure 2 was watered. On 21 July 1980, two days after watering, in-place soil testing was begun to determine the strength of the subgrade. Six test pits were excavated to a depth of 24 in. at grid points B-2, B-9, D-2, D-7, F-9, and G-4. See Figure 2 for grid point locations. CBR, water content, dry density, and airfield penetrometer measurements were recorded at depths of 0, 6, 12, and 24 in. in each of these pits. A summary of this data is shown in Table 5. The airfield penetrometer readings that were made along with the CBR tests were used to establish the correlation between AI and CBR shown in Figure 10 for this sandy clay soil. In addition to these CBR pit data, airfield penetrometer readings were taken at each of the 100-ft grid points. Results of these tests are shown in Table 6. As can be determined from these test results (Tables 5 and 6), the subgrade strength was somewhat erratic and considerably lower than the desired 9 CBR. Excluding the higher strength (13 CBR or greater) data shown in Table 5, the average strength of the top 12 in. of the subgrade after watering was 3.4 CBR and the average strength at the 24-in. depth was 6 CBR. It should also be pointed out that only one test pit (B-2) was excavated within the area that was overlaid with AM2 mat and that the data from this pit indicate that the strength of the top 6 in. of the subgrade was 4.5 CBR as compared to an average strength of 23 CBR for the layer of soil between the 6- and 24-in. depth. Although no additional CBR pits were excavated

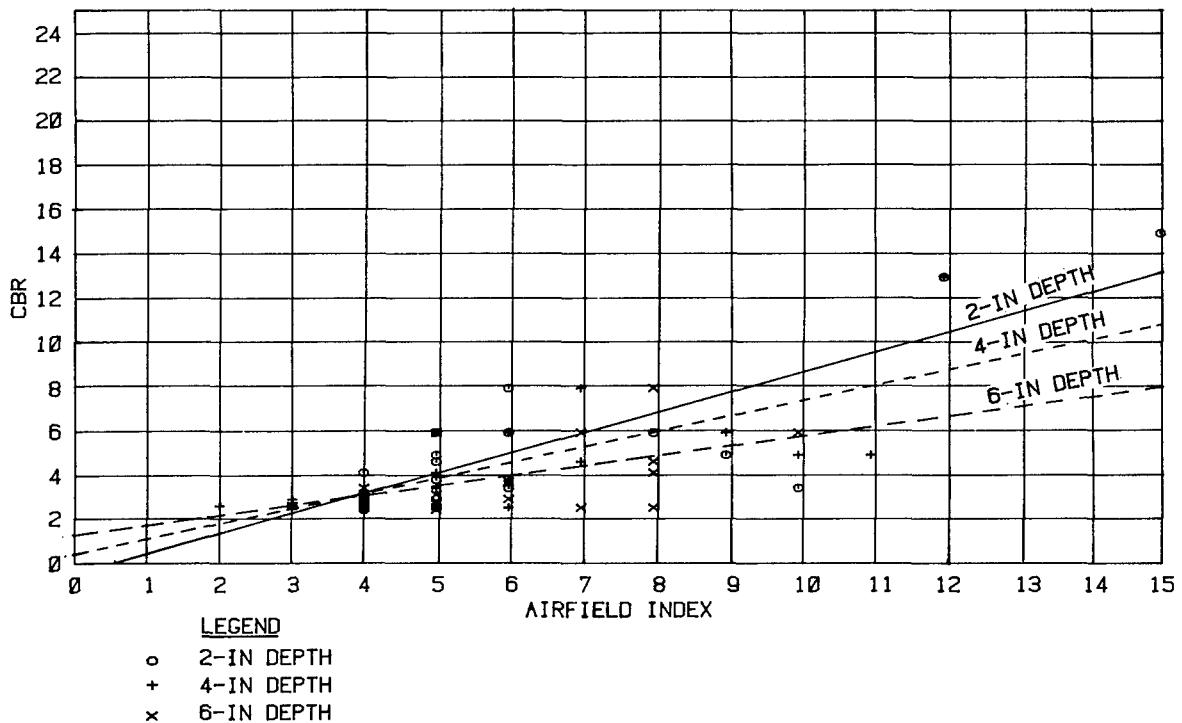


Figure 10. Correlation between the AI and the CBR for subgrade material at the Altus AFB test site

within the 200- by 200-ft mat area because the mat was being placed at this time, AI measurements taken at random within the area indicated that the subgrade strength was very erratic. At several locations within the AM2 area AI's of 15 would be measured at depths of 0 or 2 in. and then at about 10 ft from these locations, AI's of 5 to 8 would be measured from the surface down to a depth of 24 in.

26. This sandy clay site was used as a test area even though initial measurements indicated that the strength of the subgrade was erratic and lower at many locations than the desired 9 CBR (Tables 5 and 6). However, aircraft operations did not commence until the average strength of the subgrade increased to a 9 CBR. Airfield penetrometer readings taken daily at each of the grid points within the test area during the test pit excavation period indicated a gradual increase in strength due to drying of the subgrade. Based on this, it was decided to monitor the increase in soil strength and begin aircraft operations when the average strength of the top 24 in. of the subgrade reached

9 CBR. Monitoring the increase in soil strength was accomplished by taking penetrometer readings daily along grid lines 3, 5, 7, and 9, and then converting these data to CBR by using the correlation shown in Figure 10. Results of these tests are shown in Figure 11. The soil strengths (CBR's) plotted in Figure 11 are an average for the entire test area and were calculated from the AI measurements taken along grid lines 3, 5, 7, and 9. Aircraft operations were begun on 2 August 1980 when the average subgrade strength was a 9 CBR.

Aircraft operation tests
and resulting soil behavior

27. C-5A ground maneuver operations were performed on the clay test site during the period 2-5 August 1980. The aircraft maneuvers consisted of straight and turning taxi operations at aircraft GW's of 425,000, 500,000, 560,000, 605,000, and 665,000 lb, cargo off-load operations at the four highest gross weights, and towing maneuvers at the 425,000-lb GW. Straight and turning taxi maneuvers were also performed on the AM2 matting at these five gross aircraft weights. Generally, the effects of these maneuvers on the 9-CBR-strength subgrade were abrasion of the vegetation, pulverization of the surface, slight densification of the soil, and light to moderate rutting. The effect of an increase in gross aircraft weight on the subgrade was not very pronounced. Straight taxiing over the 9-CBR subgrade strength areas of the test tracks produced maximum ruts of 1.25, 1.50, 1.50, 2.00, and 2.00 in. in the 425,000-, 500,000-, 560,000-, 605,000-, and 665,000-lb test tracks, respectively. In the turn areas of these test tracks, the degree of rutting increased slightly. However, the maximum amount of rutting that occurred as expected in the 665,000-lb test track was only 2-1/2 to 3-1/4 in. deep. Also associated with the ruts in the turn areas was upheaval of the loose pulverized soil due to the skidding of the tires in the turns. The maximum amount of upheaval measured during these tests was about 2 in. Due to the wander of the aircraft while traversing the test tracks, the ruts that were made during the previous run were sometimes smoothed out to a degree by an additional pass of the aircraft. Therefore, the degree of rutting was not necessarily a function of the

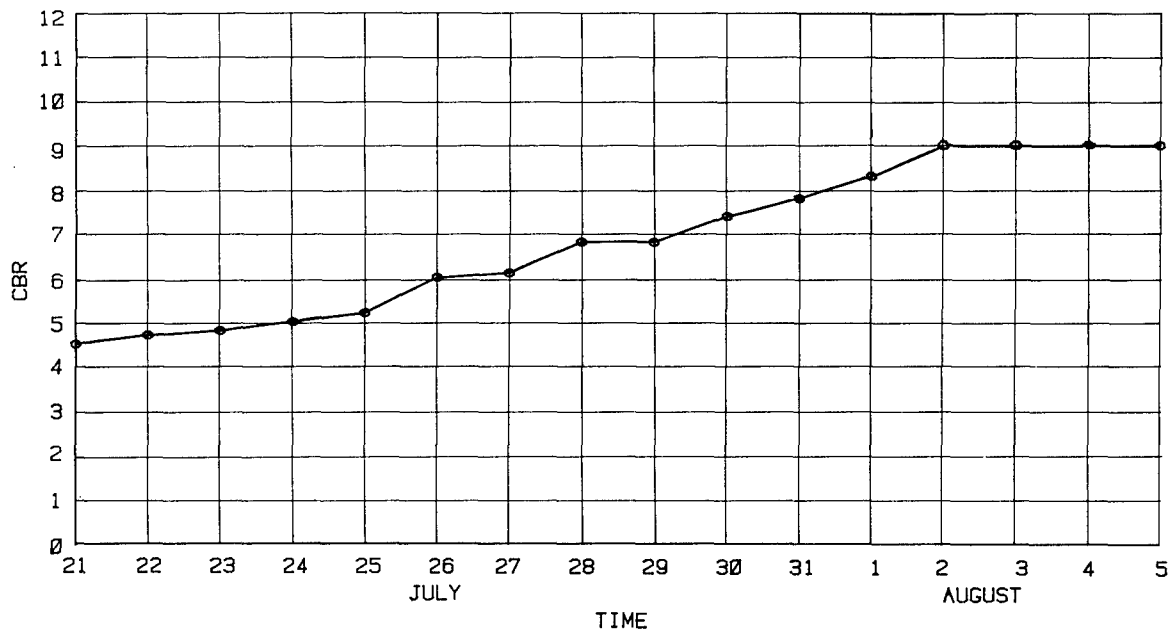


Figure 11. Time versus CBR for the Altus AFB test site subgrade material

number of passes. This can be determined from the data shown in Table 7 for run number 10. Also by comparing the AI values (in versus out) shown in Table 7, it can be determined that some densification of the subgrade occurred within the wheel paths of the aircraft.

28. Maximum rutting (4 in. deep) occurred in two areas (B.5-3* and C.2-6) of track 4 during the 605,000-lb GW taxi maneuvers. The 4-in. ruts in the area of grid location B.5-3 were attributed to 6 to 8 in. of loose fill material that had been placed in a depression prior to aircraft operations. AI measurements in this area indicate that the strength of the fill material was between 4 and 5 CBR and that the strength of the underlying natural subgrade was 8 CBR. The 4-in. ruts that occurred at grid point C.2-6 were located in a turn area of track 4 which was slightly weaker than 9 CBR. AI measurements in this area indicated that the strength of the natural subgrade was about 7 CBR. Upheavals of 3 to 4 in. were associated with these 4-in. ruts; however,

* The designation B.5-3, for example, indicates a location between grid points B and C on line 3.

at no time were aircraft operations impeded. Additional traffic in these lower strength areas tended to some extent to smooth out the ruts.

29. Cargo off-load and towing operations were performed at the test site without difficulty. The shoring requirements for the ramp and ramp extension for cargo off-loads at the test site were approximately the same as those for paved surfaces. Each of the three types of vehicles (two 5-ton trucks, two 10K AT forklifts, and an OSHKOSH tow) used to tow the 425,000-lb aircraft performed satisfactorily. Only slight pulverization of the surface was noticed in the turn areas after the tow maneuvers.

30. The straight and turn taxi maneuvers which were performed on the AM2 matting at the five aircraft gross weights resulted in only several anchors becoming loose. During the turn maneuvers, skidding of the tires was evident. Although the amount of skidding did not cause any problems, in the future it could be minimized by either applying new antiskid paint on used mat or by operating on new mat. The AM2 mat that was laid for these tests was used and most of the antiskid surfacing was worn off.

Postaircraft operation subgrade tests

31. After aircraft operations, test pits were excavated at grid points D.5-4 and D-10.5. The total amount of traffic and maximum rut depths measured during aircraft maneuvers at these pit locations were 22 passes and 3-1/4-in. ruts at D.5-4 and 63 passes and 1/2-in. ruts at D-10.5. In-place CBR, water content, and density determinations were measured down to a depth of 24 in. in the pit excavated at D.5-4 and to a depth of 12 in. in the pit excavated at D-10.5. Results of these tests are shown in Table 8. The average strength of the subgrade at D.5-4 was 10 CBR while the strength at D-10.5 was 16 CBR. In addition to the test pit data, penetrometer readings were taken along grid lines 3, 5, 7, and 9. Based on the AI's recorded at depths of 2, 6, 12, and 18 in. along these four grid lines, the average strength for the entire test area immediately after aircraft maneuvers was 9 CBR.

Sand Test Site

Soil classification

32. The soil at the sand test site was nonplastic and classified as a silty sand (SP-SM) according to the USCS. A grading curve for this material is shown in Figure 12. Laboratory compaction and CBR tests were performed on specimens in the as-molded, unsoaked condition. Results of these tests are shown in Figure 13. These data indicate that the maximum CE 12 density of 109.7 pcf was obtained at a water content of about 12 percent and resulted in an as-molded strength of approximately 21 CBR.

Water content, density, CBR, and penetrometer data

33. Prior to aircraft operations, water content, density, CBR, and airfield penetrometer data were obtained from test pits located at grid points B-2, F-4, D-8, and H-2. See Figure 3 for location of grid points. A summary of the test results is shown in Table 9. Also included in Table 9 are the airfield penetrometer readings that were obtained along with the CBR data in order to develop a correlation between AI and CBR for the silty sand. As can be noted from the data shown in Table 9, the average water content of the top 12 in. was 2.6 percent as compared to 4.2 percent for the sand between the 12- and 48-in. depths. The average CBR's of the upper foot of sand and of the sand between the 12- and 48-in. depths were 9 and 2.6, respectively. The in-place dry density ranged from 82 to 91 percent of standard AASHO maximum density. From the plot of AI versus CBR shown in Figure 14, it can be determined that the relation between AI and CBR varies with depth. In previous tests of this type, the ability of an aircraft to operate on unsurfaced sands has correlated closely with the average soil strength in the 6- to 12-in. depth. Therefore, during these tests the average of the 6- and 12-in. plots shown in Figure 14 was used in converting AI measurements to CBR values. In addition to the test pit data, AI measurements were taken at each of the grid points. Results of these tests are shown in Table 10.

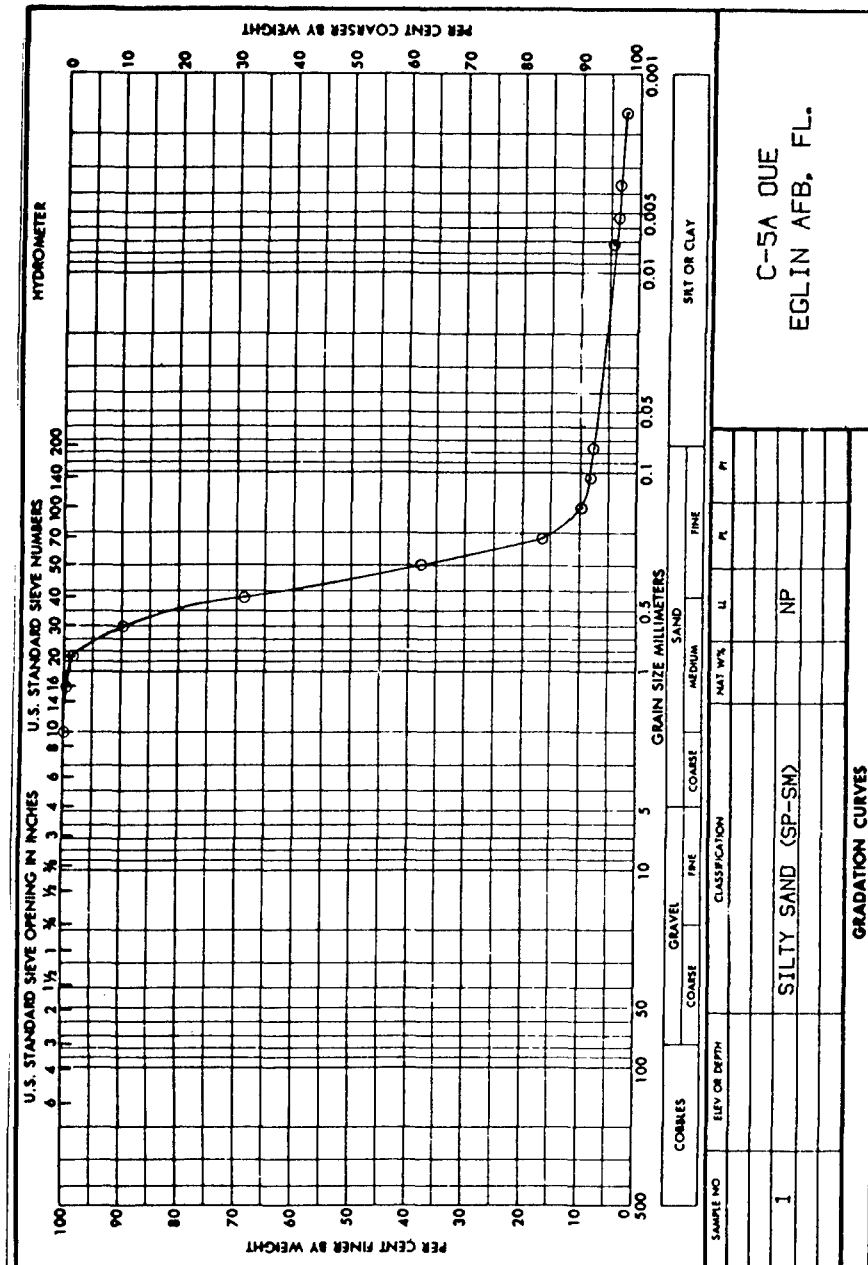
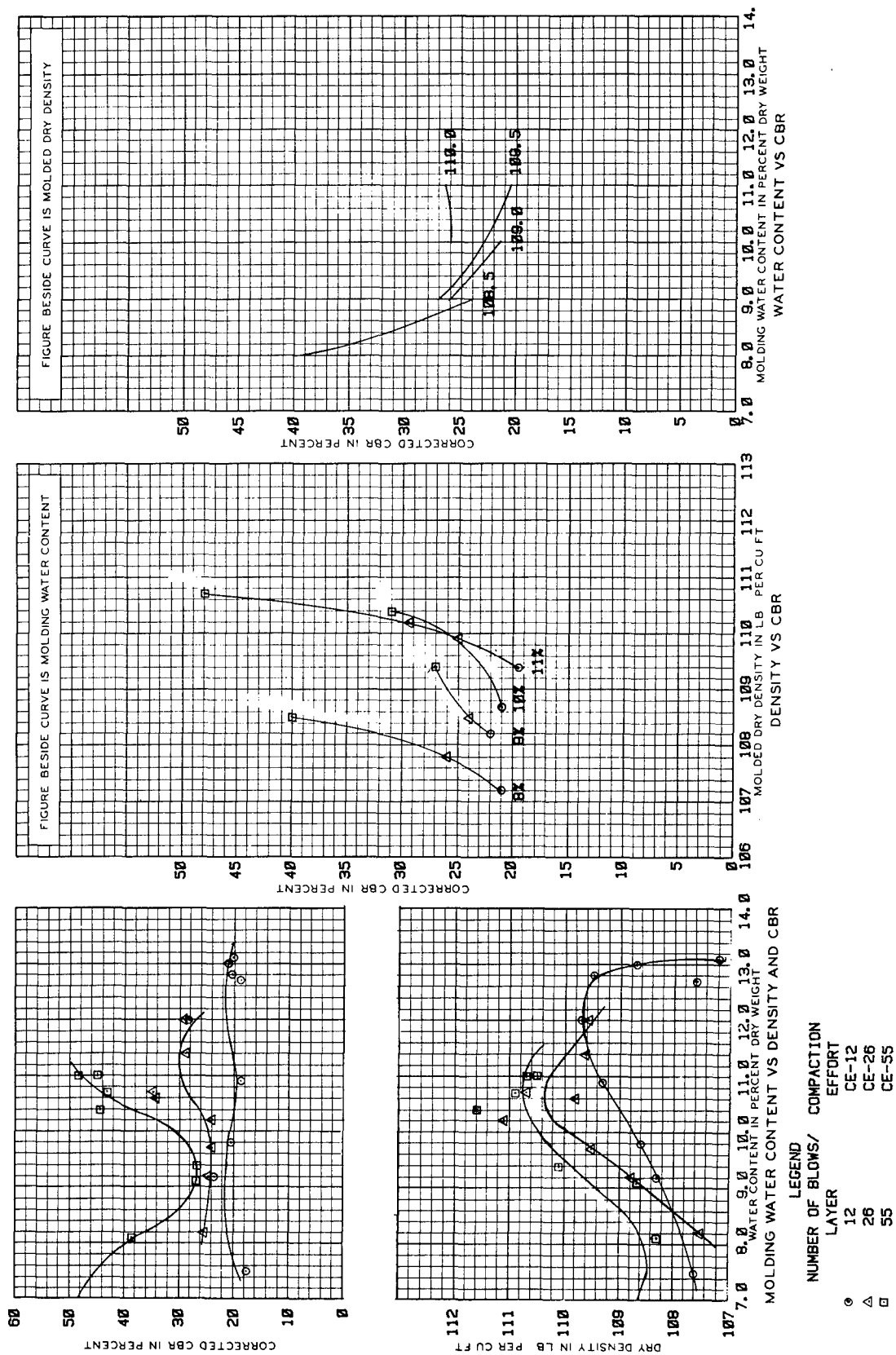


Figure 12. Grading curve for Eglin AFB test site subgrade material



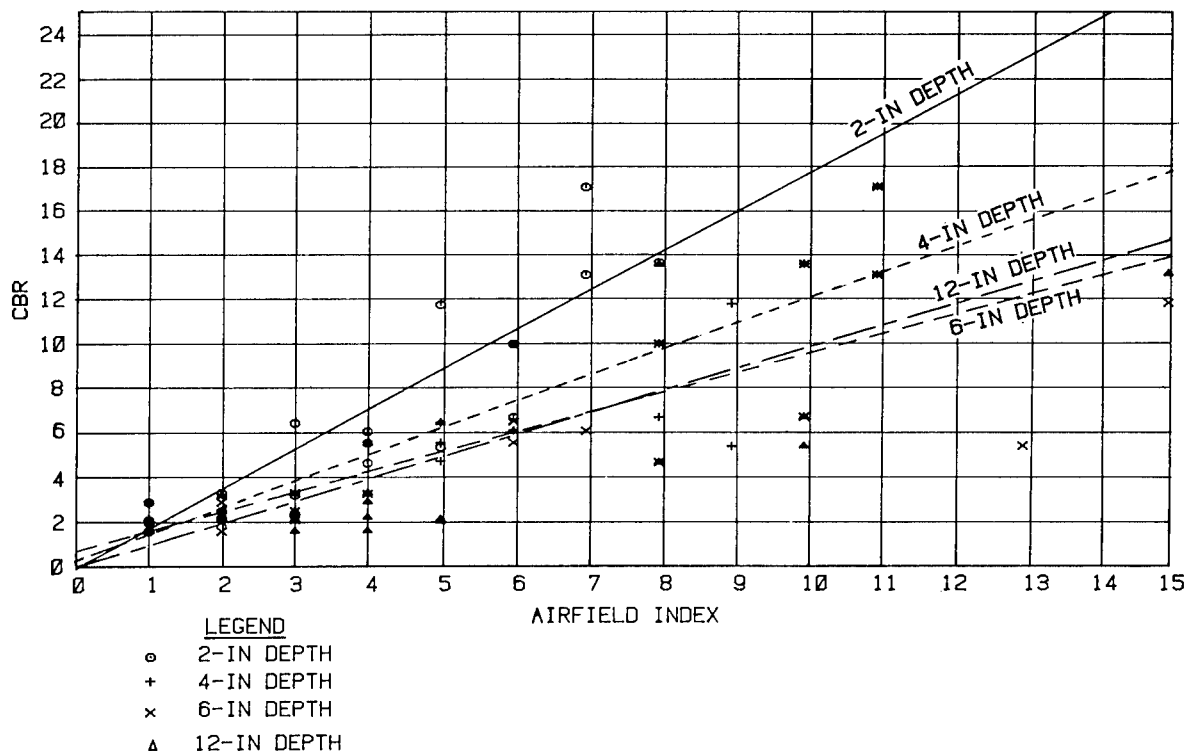


Figure 14. Correlation between the AI and the CBR for subgrade material at the Eglin AFB test site

Aircraft operation tests and resulting soil behavior

34. C-5A ground maneuver operations were initiated at the sand test site on 11 August 1980 and continued through 15 August 1980. "S" type taxi turns were performed on the sand in addition to maneuvers similar to those performed at the Shaw and Altus AFB test sites. In general, the sand loosened (became less dense and decreased in strength) rapidly under traffic. A single pass of the aircraft over the sand destroyed the sod cover as shown in Photo 4 and produced ruts of at least 2 to 4 in. After an additional pass or two, the sod cover was completely destroyed, and the sand was in a loose, plowed or furrowed condition to a depth of approximately 12 in. as shown in Photo 5. An increase in aircraft GW resulted in more rapid surface deterioration and deeper ruts; however, after several passes of the aircraft at any of its operating GW's, the surface distress seemed to stabilize when the ruts

reached a depth of about 8 in. In each of the test tracks, the greatest surface deterioration occurred either in the turn areas due to the skidding or plowing action of the tires or between grid locations E and F due to low strength. Photos 6 and 7 depict results of the tires skidding through turn areas causing ruts up to about 8 in. in depth with 5 in. of associated upheaval. A summary of the soil measurements taken during these tests is shown in Table 11. More detailed descriptions of the aircraft operations and soil behavior are given in the following paragraphs.

35. The subgrade distress observed during the 425,000- and 500,000-lb GW maneuvers was about the same. Rutting from a trace up to 5.5 in. was produced during these maneuvers. In some areas of the straight taxi portions of tracks 1, 2, and 6, only a trace of rutting was detected after one pass; however, the average depth of rutting over the entire straight portions of these tracks after one pass was estimated to be about 2 in. After four straight taxiing operations over track 1, the average rut depth increased to about 3 in. Turning maneuvers at these GW's resulted in the sod cover being destroyed and maximum rutting occurring earlier as compared to the straight portions of the tracks. However, after multiple turns in these tracks, the maximum amount of rutting and upheaval was only about 5.5 and 4.5 in., respectively. Based on the airfield penetrometer readings taken in and out of the wheel paths (Table 11), it can be determined that the test traffic loosened the soil to a depth of at least 24 in. Generally, a 15+ AI was measured at the 12-in. depth prior to traffic as compared to 8 AI at the 24-in. depth after traffic. An AI of 8 correlates to a CBR of 8 at the 24-in. depth.

36. The 560,000-lb GW maneuvers consisted of two runs on tracks 3 and 6 and one off-load maneuver on track 7. The initial run over track 3 produced average rutting of about 2 in. in the straight portion of the track and 4-in.-deep ruts in the turn areas of the track. After two passes over F.5-1, which was in the soft area, 8-in. ruts and 4-in. upheaval were measured. The CBR in this severely rutted area based on AI measurements was about 5 down to a depth of 6 to 12 in. and 8 to 9

between the 12- and 24-in. depths. AI measurements taken in this area indicate that the soil was disturbed to a depth of at least 24 in. after two passes of the aircraft. Eight-inch ruts were also measured in tracks 6 and 7 after three passes of the aircraft. Including the previous traffic, a total of six passes had been applied to tracks 6 and 7 at this time. After off-loading the aircraft on track 7, the C-5A was temporarily immobilized due to the nose gear's being turned at an angle and the buildup of loose sand in front of the gear. However, after the nose gear was straightened, the aircraft began moving without difficulty.

37. The 605,000-lb GW test traffic consisted of eight passes over track 4 and two passes including an off-load maneuver over track 6. As can be seen from the data presented in Table 11, the severity of rutting and upheaval increased with repetition up to four or five passes after which additional traffic resulted in little or no effect to surface deterioration. During these maneuvers, the maximum depth of rutting, 10.7 in., was measured at D-2 after four passes of the aircraft. However, after eight passes of the C-5A over this same point rutting was only 6.6 in. deep. This decrease in rutting after additional traffic was attributed to loose sand flowing into the ruts. After approximately four passes of the aircraft over an area, the sod cover was completely destroyed and the loose, upheaved sand was free to flow back into the wheel paths. AI measurements taken in track 4 indicate that after the first pass, the soil was disturbed or loosened down to a depth of at least 24 in. At grid points D-2 and F-2, an AI of 15+ was measured out of the trafficked area at a depth of about 6 in. as compared to a maximum AI of 10 measured at a depth of 24 in. within the rutted area. Excluding the segment of track 4 between D-2 and F-2, the average depth of the furrows (rutting plus upheaval) over the remainder of the track after eight passes was about 12 in. The average rut depth and upheaval in these furrows was 5 to 6 in. and 4 to 6 in., respectively, and the AI was 11 at a depth of 12 in. and 15 at 24 in. As in the previous tracks, surface distress was more pronounced in the turn areas of track 4 than in the straight portion due to the skidding of the tires. After the first few taxi turns, the severity of distress leveled out to an average

rut depth and upheaval of approximately 8 and 5 in., respectively.

38. The towing maneuvers that were attempted at only the 425,000-lb GW with the OSHKOSH, M-54 5-ton trucks, and 10K AT forklifts were rated as marginal to unsuccessful. Both the OSHKOSH tow vehicle and the M-54 trucks failed to generate sufficient traction to successfully tow the aircraft. The 10K AT forklifts performed satisfactorily on undisturbed areas on which the vegetation was intact, but lost traction in the sand when traversing areas previously tracked by the aircraft.

39. The C-5A cargo handling system performed the off-loading maneuvers satisfactorily at the 605,000-lb GW. However, the severe rutting in the sand impaired the capability of the aircraft to turn sharply and depart from the Air Transportable Dock (ATD). This maneuver is required of the C-5A in departing from the off-load position at the ATD.

40. Track 5 was tracked at an aircraft GW of 665,000 lb, and the soil behavior during the first four passes was similar to that during the taxi maneuvers over tracks 1-4. Based on AI measurements taken before traffic, the subgrade strength of track 5 was about 12 CBR at the surface and 14 CBR below the 6-in. depth. One pass of the C-5A over the track produced ruts of about 4-in. depth and upheavals of 5 in. This initial pass loosened the soil down to a depth of at least 2 ft. After this first pass, the strength of the top 6 in. was reduced to a 5 CBR, and below the 6-in. depth the soil strength was 8 to 9 CBR. The sod cover was broken into large pieces after one pass and completely destroyed after three passes. Also, after three passes, the surface deterioration became stabilized, and the average rut depth was about 5 in. Upheaval at this time measured approximately 6 in. AI measurements taken after three passes (see Table 11) indicated that subgrade strength was about the same as it was after the initial taxi maneuver.

41. Thundershowers occurring between the fourth and fifth passes over track 5 caused a significant difference in soil behavior under traffic due to change in moisture content. Prior to the thunderstorms, the moisture content of the top 1 ft of subgrade material averaged 2.6 percent and the moisture content of the sand between 12 and 48 in. deep

was 4.2 percent. After the rain, the water content of the upper 1 ft of subgrade material and that of the material between the 12- and 48-in. depths had increased to 4.0 and 4.9 percent, respectively. Immediately after the C-5A began the fifth taxi maneuver, sod and sand began to build up in front of the nose gear. After the aircraft had traversed approximately half of the track, it became immobilized due to a mound of material (Photos 8 and 9) that had built up in front of the nose gear. This mound of sod and sand measured about 22 in. above the axle. As this material was removed, sand and sod was found packed between the nose wheels. During the previous four passes when the loose upper layer of material was relatively drier, it tended to flow through the nose wheel openings; however, after the thunderstorms, the material tended to stick together and compact between the nose wheels, thus blocking the flow of sand. After the material was removed from in front of and between the nose wheels, the aircraft was off-loaded; then it taxied out of the area without difficulty. Straightedge measurements taken in this area indicate that the nose gear produced ruts up to 11.5 in. deep and that the maximum rutting caused by the main gears was only about 8 in. Airfield penetrometer readings obtained within and out of the area where the aircraft became immobilized indicate that traffic over the moist sand tended to strengthen the subgrade at the 18- and 24-in. depths. As can be determined from the data presented in Table 11, an AI of 15 plus which correlates to a 14 or greater CBR was measured at the 18- and 24-in. depths within the ruts as compared to an AI or CBR of about 7 at these same depths outside of the rutted area. Test traffic was discontinued at this time because there was no instrumentation on the landing gears and additional testing in the moist sand could possibly overstress the gears.

Postaircraft operation subgrade tests

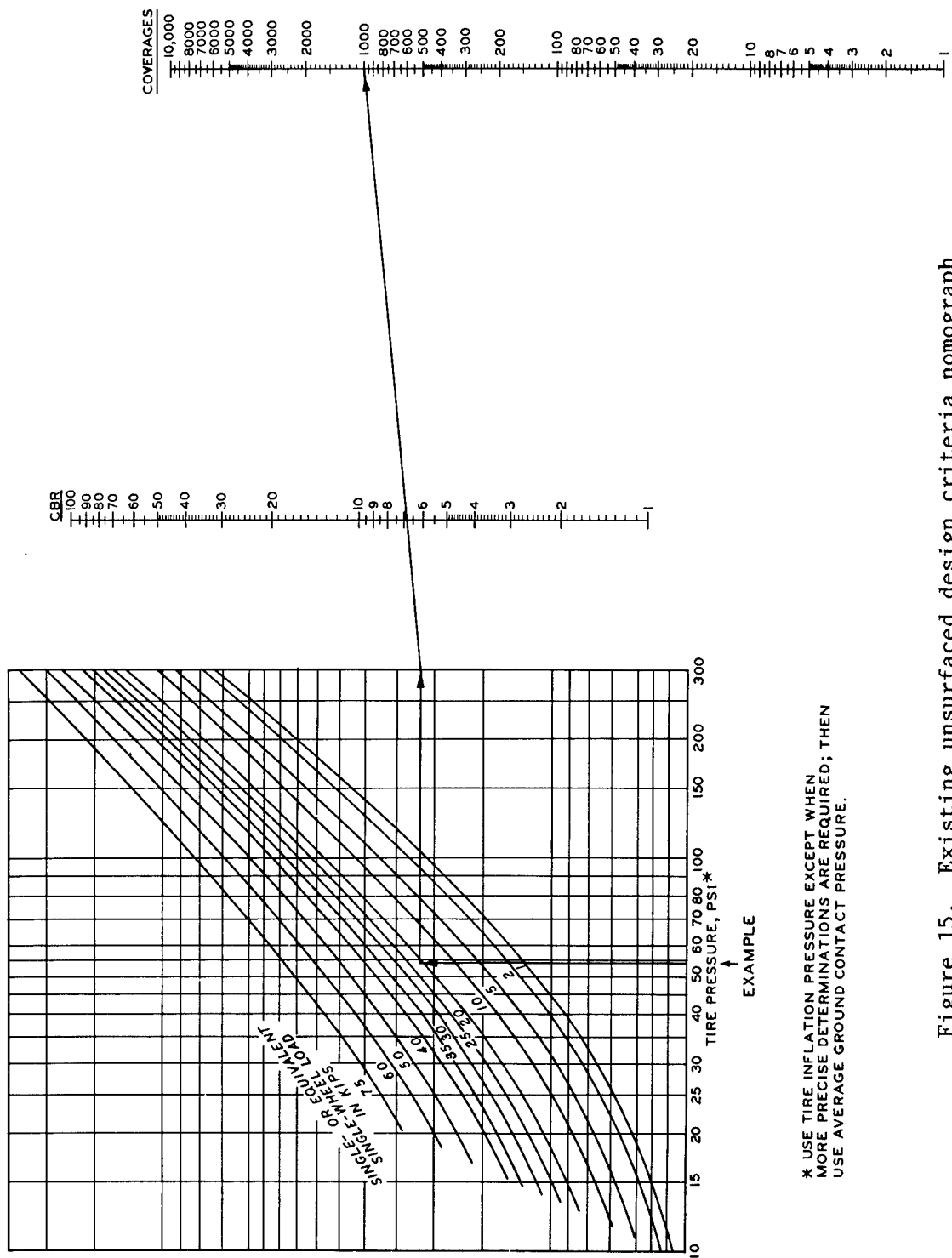
42. Test pits were excavated at grid points F-2.5, H-4.5, and F-3. In-place CBR, water content, and dry density determinations were made at predetermined depths as these pits were excavated. Results of these tests are presented in Table 8. It should be noted that the subgrade material in pit H-4.5 at the 12-, 18-, and 24-in. depths contained

pieces of sand asphalt. Therefore, the data obtained at these depths were disregarded in evaluating the subgrade. The remainder of the test pit data revealed that when compared with the data taken prior to aircraft maneuvers (Table 10) the strength of the upper portion (top 1 ft) of the subgrade decreased while the strength of the underlying layer increased slightly and that the moisture content and dry density increased. The average CBR, water content, and density of the top 12 in. of the subgrade prior to traffic were 9, 2.6 percent, and 95.4 pcf, respectively, as compared with after-traffic values of 4.4 CBR, 4.0 percent water content, and 98.9 pcf dry density. The average CBR, water content, and density of the layer of sand between the 12- and 48-in. depths before and after traffic were 2.6 CBR, 4.2 percent, and 97.0 pcf and 3.4 CBR, 4.9 percent, and 98.8 pcf, respectively. The increase in moisture content is attributed to the thundershowers that occurred during the final day of taxi maneuvers. Indications are also that the thundershowers were the contributing factor to the increase in density. This is believed to be true because visual observations and AI measurements taken prior to the rain indicated traffic tended to loosen the sand and density determinations taken after traffic indicate an increase in density. Although in-place CBR values measured in the sand are presented, it should be noted that the effective soil strength under the large low-pressure C-5A tires was probably greater than that indicated by the CBR test. The strength of a sand is primarily a function of internal friction and will increase as the degree of confinement increases. Due to the in-place CBR test procedure of excavating the material above the level to be tested, the degree of sand confinement is decreased resulting in lower measured CBR values. Based on the AI readings and the AI versus CBR correlation, it is estimated that the average strength of the top 1 ft of sand was about 5 to 6 CBR and the CBR of the underlying layer was between 9 and 14.

Analysis of Data

43. The approach selected for the analysis of data resulting

from this investigation was to compare data measured during these tests with existing unsurfaced criteria. Two separate criteria are used in this analysis. The first of these criteria is for determining the soil surface strength necessary for supporting operations of an aircraft, and the second is for determining the thickness of material that must be placed over the natural subgrade in order to support operations of an aircraft. Both of these criteria were developed from the results of simulated aircraft traffic performed on fine-grained cohesive soil test beds, and failure was arbitrarily defined as (a) ruts more than 3 in. deep as measured from a 10-ft straightedge, (b) elastic deflection greater than 1.5 in., or (c) overall subsidence in excess of 4 in. measured from a 10-ft straightedge. The criteria for determining the soil surface strength necessary for supporting operations of an aircraft are represented by the nomograph shown in Figure 15 (Ladd and Ulery, 1967). 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; and the term coverages refers to the amount of traffic for which the airfield is being designed or evaluated. The ESWL's were determined by use of Figure 16 (Hall, 1978) where the effect of multiple-wheel aircraft is accounted for through relationships of ESWL to the gear load. The curves shown in Figure 16 relate the ESWL, expressed as a percent of the load on the number of wheels used to establish the ESWL, to depth from the surface. Twenty-four wheels were the controlling number of wheels used to establish the curve for the C-5A aircraft. To determine the ESWL for the C-5A by use of Figure 16, the gross load on the controlling number of wheels is determined first by multiplying the load on each main gear wheel by 24 and then multiplying this gross load by the ESWL in percent at the depth being considered. Traffic which is in terms of coverages can be converted to aircraft passes by using the pass-to-coverage ratio of 0.81 for the C-5A (Brown and Thompson, 1973). The unsurfaced soil



* USE TIRE INFLATION PRESSURE EXCEPT WHEN MORE PRECISE DETERMINATIONS ARE REQUIRED; THEN USE AVERAGE GROUND CONTACT PRESSURE.

Figure 15. Existing unsurfaced design criteria nomograph

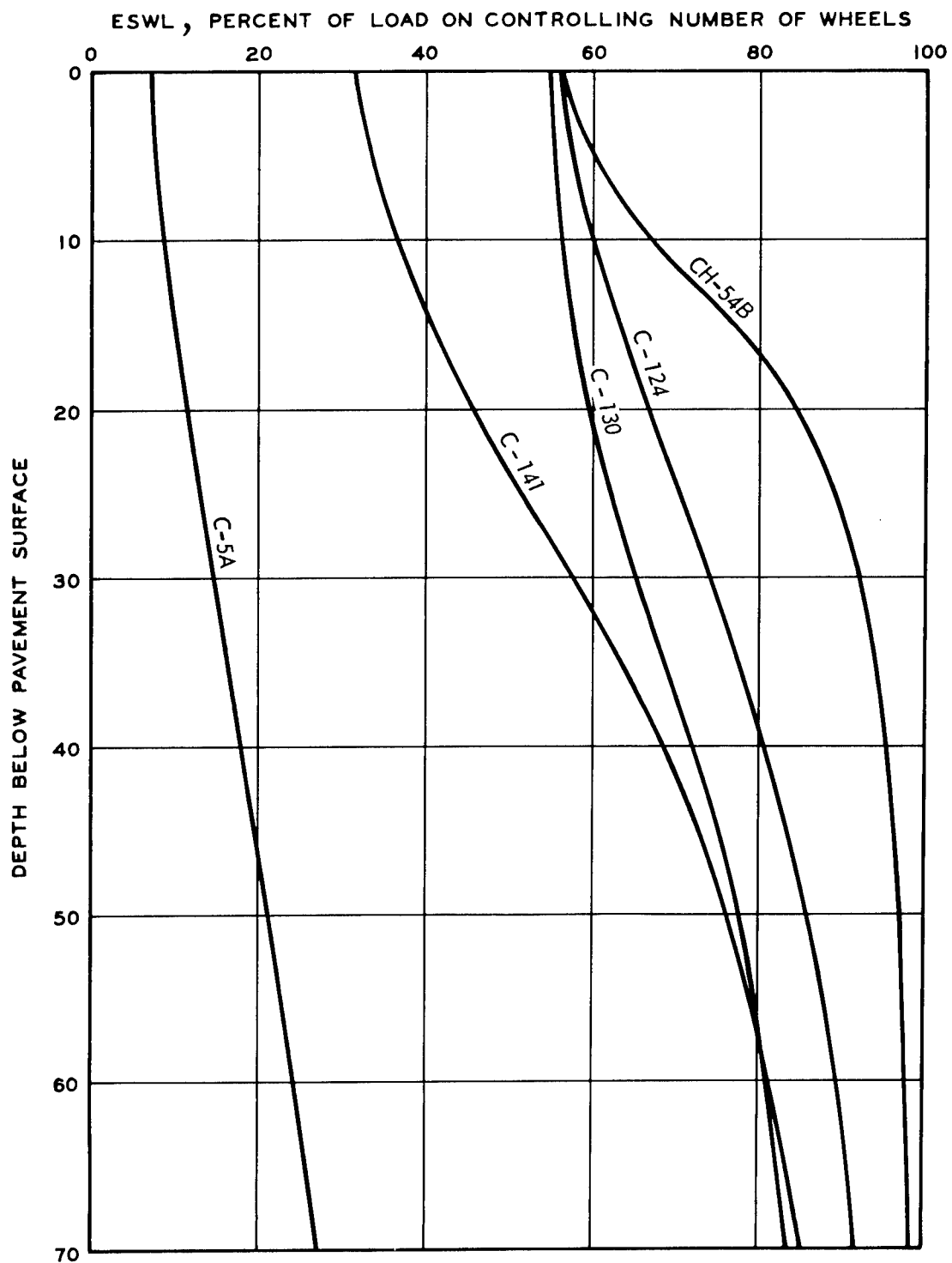


Figure 16. Percent ESWL versus depth below pavement surface

thickness criteria (Ladd and Barber, 1971) are expressed by the following equation:

$$\begin{aligned}\log t = & -1.02165 + 0.63624 (\log p) + 0.21484 (\log P) \\ & + 0.23937 (\log C) - 0.40281 (\log \text{CBR}_s) - 0.31404 (\log \text{CBR}_c)\end{aligned}$$

where

t = thickness of soil placed above subgrade, in.

p = average tire contact pressure, psi

P = ESWL, lb

C = number of coverages

CBR_s = strength of subgrade soil

CBR_c = strength of soil layer placed over the subgrade

In using this equation, the ESWL must be determined at the depth equal to the thickness calculated.

44. Two sets of data measured in track 4 at the Altus AFB test site were measured at grid points C.2-6 and D.5-4 and were selected because the soil strength at these sites was relatively uniform down to a depth of 24 in. The average AI of the soil at grid points C.2-6 and D.5-4 was 8 and 10.5, respectively. Based on the AI versus CBR correlation shown in Figure 10, an AI of 8 is equivalent to 5 CBR and an AI of 10.5 is equivalent to a CBR of 6. By use of the nomograph (Figure 15) and an aircraft gross weight of 605,000 lb, failure (or 3-in. rutting) is predicted after about three passes on a 5-CBR material and after nine passes on a 6-CBR subgrade. Actual traffic of the 605,000-lb aircraft produced rutting of about 4 in. in the 5-CBR material after two passes and 3-in. ruts in the 6-CBR material after 14 passes. The nomograph shown in Figure 15 was also used in predicting the number of C-5A passes before failure for each of the operating GW's at each test site. These predictions are shown in Table 12. The rated CBR's shown in Table 12 are an estimated average strength for each test site. Due to the limited amount of traffic and/or relatively high subgrade strengths at the Shaw AFB and Altus AFB test sites, the predictions shown in Table 12 could not be evaluated during the taxi maneuvers. Although 3-in.-deep ruts generally occurred after three passes of the

C-5A over a test track at the Eglin AFB test site, these data are not and should not be in accordance with the predictions shown in Table 12 because the nomograph was developed based on tests performed on fine-grained cohesive soils.

45. The unsurfaced soil thickness design criteria were used to evaluate a set of test data measured at the Shaw AFB test site. These data were taken at grid location D-4.5 where a 1.5-in. rut was measured after two passes of the C-5A loaded to a GW of 665,000 lb. The surface strength was estimated to be approximately 20 CBR based on AI measurements. An underlying layer of 7-CBR material was about 6 in. below the stronger surface material. By use of the thickness design equation and solving for coverages, the 20-CBR material over the 7-CBR subgrade should withstand about five passes of the 665,000-lb C-5A before rutting of about 3 in. occurs. Field measurements indicate that 1.5-in. ruts occurred after two passes of the aircraft.

PART IV: CONCLUSIONS

46. The C-5A operated on the clayey sand and sandy clay test sites with gross loads ranging from 425,000 to 665,000 lb without difficulty. During aircraft operations, the soil strength of the clayey sand test site was between 15 and 20 CBR, and the average strength of the sandy clay test site was about 9 CBR. The first distress observed at these test sites was abrasion of the vegetation and pulverization of the surface material. Rutting during maneuvers at these test sites was rated as slight to moderate. Generally, maximum rutting occurred in the turn areas. The maximum amounts of rutting measured at the clayey sand and sandy clay sites were 2 and 4 in., respectively. The 4-in.-deep ruts occurred in a soft (5 CBR) area of the sandy clay test site; whereas, only about 3-in. ruts were measured in the areas where the subgrade strength was a 9 CBR. Towing and offloading were performed at these sites without difficulty.

47. The maximum depth of rutting measured during the taxi maneuvers on the sand test site was between 8 and 12 in. During the taxi maneuvers, the sand became loose after about three passes of the aircraft and then additional traffic had little effect on the subgrade. Although the rutting was severe, it had little effect on the capability of the aircraft to maneuver on the sandy subgrade. The C-5A was immobilized once during these tests. However, this occurred after a rain and was due to wet sod and sand packed between the nose wheels. After this material was removed and the aircraft unloaded, the C-5A taxied out of the rutted area without difficulty. Offloading was performed on the severely rutted sand satisfactorily; however, towing of the aircraft was rated as marginal to unsuccessful. All of the tow vehicles either failed initially to generate sufficient traction to tow the aircraft or were unable to get sufficient traction after the sod cover was destroyed.

48. Although a limited amount of traffic was applied to these test sections resulting in a limited amount of data, an analysis of selected data from the Shaw AFB and Altus AFB test sites shows that the performance of the C-5A at these sites compares to the predicted performance.

The predicted performance was calculated using the existing unsurfaced design criteria. An analysis of the performance of the C-5A on the Eglin AFB test site was not made because the existing criteria were developed for fine-grained cohesive soils and not for sands.

49. It should be noted that although the C-5A performed satisfactorily on the three test sites, an increase in moisture content at the Shaw and Altus sites would greatly affect the performance. The strength of the subgrade at these test sites is greatly dependent upon the moisture content due to the clay particles in the subgrade materials. An appreciable increase in moisture content at either site will result in a decrease in CBR.

50. Results of this OUE test program indicate that 3-in. ruts have little or no effect on the performance of the C-5A aircraft on unsurfaced areas.

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Table 1
Schedule of Aircraft Taxi Maneuvers

Track No.	Gross Weight lb	Taxi Speed Knots	Nose Wheel Steering Angles, deg	Site* and Number of Replications			Remarks
				1	2	3	
1	425,000	5-10	20-40	1	1	1	
2	500,000	5-10	20-40	1	1	1	
3	560,000	5-10	20-40	1	1	1	
4	605,000	5-10	20-40	1	1	1	
5	665,000	5-10	20-40	1	1	1	
6	425,000	5-10	40-60	1	1	1	
6	500,000	5-10	40-60	2	2	2	CO** (1) (1) (1)
6	560,000	5-10	40-60	2	4	2	CO (1) (2) (1)
6	605,000	5-10	40-60	4	6	4	CO (2) (3) (2)
6	665,000	5-10	40-60	4	6	4	CO (2) (3) (2)
7	560,000	5-10	40-60	1	1	1	ATD† Undock
							CO (1) (1) (1)
7	605,000	5-10	40-60	1	2	1	ATD Undock
							CO (1) (2) (1)
7	665,000	5-10	40-60	1	2	1	ATD Undock
							CO (1) (2) (2)
8	560,000	5-10	40-60	2	3	2	CO (1) (2) (1)
8	605,000	5-10	40-60	2	3	2	CO (1) (2) (1)
9	665,000	5-10	40-60	3	4	3	CO (2) (2) (2)
	425,000	5-10	Variable		1		AM2 Mat
	500,000	5-10	Variable		1		AM2 Mat
	560,000	5-10	Variable		4		AM2 Mat
	605,000	5-10	Variable		6		AM2 Mat
	665,000	5-10	Variable		8		AM2 Mat

*Site 1 - Shaw AFB

Site 2 - Altus AFB

Site 3 - Eglin AFB

**CO = Cargo offload () per site.

†ATD = Air transportable dock.

Table 2
Summary of Subgrade Field Test Data
Shaw AFB Test Site

Test Pit Location	Depth in.	CBR	Water Content %	Dry Density pcf	Airfield Index at Depth Shown, in.			
					0	2	4	6
E-6	Surf.	5	9.8	102.1	2	8	12	15+
	6	11	8.8	103.9	3	9	10	15+
	12	9	8.7	106.6	3	11	15+	
	18	11	10.9	100.8	4	12	13	13
	24	6	9.8	95.6	3	6	7	7
	36	5	9.8	94.4	4	7	8	8
	48	6	9.8	95.9	3	7	8	10
G-12	Surf.	6	7.9	100.7	3	8	15+	
	6	13	9.0	104.1	5	14	15+	
	12	9	9.5	101.8	4	10	11	10
	18	4	10.2	95.8	4	6	6	5
	24	4	11.3	92.3	3	5	5	5
M-11	Surf.	9	9.7	106.4	3	12	15+	
	6	40	8.6	114.8	6	15+		
	12	29	10.5	114.7	6	15+		
	18	18	12.2	107.4	5	15+		
	24	13	12.0	103.8	4	15	15+	
I-7	Surf.	2	12.0	86.3	3	7	10	15+
	6	12	7.8	109.6	7	15+		
	12	12	11.2	111.7	6	15	14	12
	18	10	13.7	93.0	5	15	15+	
	24	13	9.3	102.0	5	15+		
	36	6	7.4	87.3	5	11	15	15+
	48	5	7.7	89.5	4	9	11	13
C-11	Surf.	4	8.6	95.0	2	6	9	15
	6	19	9.3	105.8	6	15+		
	12	16	8.8	106.0	15+	15+	13	
	18	7	8.4	99.3	4	8	9	10
	24	6	7.7	94.1	4	8	8	7
K-4	Surf.	10	7.1	104.6	6	15+		
	6	28	7.9	111.8	5	15+		
	12	10	8.7	101.8	5	10	10	10
	18	4	9.9	94.9	4	5	6	7
	24	4	10.8	91.9	3	5	6	6

NOTES:

- (1) Airfield penetrometer readings were made along with the CBR tests. The "0" airfield index depth shown is located at the surface of the depth being tested for CBR, water content, and density.
- (2) All CBR, water content, and density values shown are an average of three measurements.
- (3) All airfield index values shown are an average of three to five measurements.

Table 3
Summary of Airfield Index Measurements
Obtained at the Shaw AFB Test Site

Test Site*	Airfield Index at Depth Indicated, in.**							
	0	2	4	6	12	18	24	30
C-4	1	3	7	8	12	17		
C-5	1	3	7	12	11	9	11	11
C-6	1	3	9	15+	15	13	15	13
C-7	1	2	9	13	14	11	12	9
C-8	1	6	8	15+				
C-9	2	7	12	16				
C-10	1	4	9	13				
C-11	1	4	10	16				
C-12	2	6	16	16+				
C-13	4	15						
C-14	4							
D-4	2	6	12	15+				
D-5	2	7	15					
D-6	3	7	16	17	16	13	14	
D-7	2	4	13					
D-8	2	5	12					
D-9	2	4	15					
D-10	2	7	13					
D-11	2	5	12					
D-12	3	7	14	14	15+			
D-13	4	9						
D-14	3	16						
D-4	3	6	10	15				
E-5	2	5	15					
E-6	2	8	14	15				
E-7	2	5	11	16				
E-8	2	6	16					
E-9	2	4	10	16	13	13		
E-10	3	9	16	17				
E-11	3	6	11	16				
E-12	2	5	12	15				
E-13	4	10	13	15+				
E-14	2	8	17					

(Continued)

* See Figure 1 for layout of test site.

** All airfield index values are an average of 3 to 5 measurements.

Table 3 (Continued)

Test Site	Airfield Index at Depth Indicated, in.**							
	0	2	4	6	12	18	24	30
F-4	2	5	14					
F-5	3	7	16					
F-6	4	14						
F-7	3	9	14					
F-8	2	7	10	16				
F-9	3	7	9	16				
F-10	4	7	14	16	15	10	6	5
F-11	3	9	17	15+				
F-12	3	13	16					
F-13	4	13						
F-14	3	6	13	15	16	15+		
G-4	3	10	15+					
G-5	3	8	12	15+				
G-6	2	7	15	15+				
G-7	2	5	11	14	15+			
G-8	2	4	8	15+				
G-9	3	7	14	15+				
G-10	4	9	15	15+				
G-11	3	10	15+					
G-12	4	13	15+					
G-13	3	11	15+					
G-14	3	14	15+					
H-4	4	12	15+					
H-5	2	7	13	15+				
H-6	2	5	13	15+				
H-7	2	4	8	13				
H-8	2	4	7	15+				
H-9	2	4	11	15+				
H-10	2	13	15+					
H-11	2	8	15+					
H-12	3	9	15+					
H-13	3	9	15+					
H-14	3	13						
I-4	2	5	10	12	15+			
I-5	3	8	15+					
I-6	2	5	10	15+				
I-7	2	5	10	15+				
I-8	2	5	9	15+				
I-9	3	9	15+					

(Continued)

Table 3 (Continued)

Test Site*	Airfield Index at Depth Indicated, in.**							
	0	2	4	6	12	18	24	30
I-10	2	8	15+					
I-11	3	14						
I-12	6	11						
I-13	3	14						
I-14	2	7	15+					
J-4	3	7	12					
J-5	2	7	15					
J-6	2	4	8	15+				
J-7	2	4	8					
J-8	2	5	10					
J-9	2	7	13	15+				
J-10	3	8	15+					
J-11	2	7	12					
J-12	3	7	10					
J-13	4	15+						
J-14	3	9	15					
K-4	3	8						
K-5	3	9	14					
K-6	3	7						
K-7	2	5	10	14				
K-8	3	10	6					
K-9	3	12						
K-10	3	9	15					
K-11	3	12						
K-12	3	13						
K-13	4	16						
K-14	3	11						
L-4	3	9	12	14				
L-4	3	8						
L-6	3	7	13	15				
L-7	3	9	14					
L-8	4	9	15					
L-9	3	10	13					
L-10	4	14						
L-11	3	11						
L-12	2	12						
L-13	3	13	15+					
L-14	3	8	12					
M-4	3	10						
M-5	3	11	14					

(Continued)

Table 3 (Concluded)

Test Site*	Airfield Index at Depth Indicated, in.**							
	<u>0</u>	<u>2</u>	<u>4</u>	<u>6</u>	<u>12</u>	<u>18</u>	<u>24</u>	<u>30</u>
M-6	3	13						
M-7	3	12						
M-8	2	10						
M-9	4	11	14					
M-10	4	12						
M-11	3							
M-12	3	9	13					
M-13	3	11	14					
M-14	3	8	12	15				

Table 4
Summary of Aircraft Operations and Subgrade Evaluation
Shaw AFB Test Site

Event No.	Test Track No.	Data Location	Type of Operation	Gross Aircraft Load lb	Total Passes Over Data Point	Maximum Rut Depth in.	Upheaval in.	Subgrade Evaluation												Remarks
								Airfield Index at Depth Shown, in.*												
								0		2		4		6		12		18		
In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out					
1	1	C - 13.5	Taxi	425,000	1	0	0	12	8	15+	12	--	15+	--	--	--				
1	1	E - 13	90° turn	425,000	1	0	1.0	6	5	15+	15+	--	--	--	--	--				
1	6	C - 13.5	Taxi	425,000	1	0	0	2	8	15+	12	--	15+	--	--	--				
1	6	H - 13.5	90° turn	425,000	1	0	1.0	2	7	15+	15+	--	--	--	--	--				
1	6	H.5 - 7.5	180° turn	425,000	1	0	1.0	1	6	9	13	15+	15+	--	--	--	Slight pulverization			
2	2	E.5 - 4.5	90° turn	500,000	1	0.3	1.0	1	4	13	11	15+	15+	--	--	--	Slight pulverization			
2	6	H.5 - 8	180° turn	500,000	3	0.3	1.0	0	6	11	13	15+	15+	--	--	--	Slight pulverization			
4	4	F.5 - 13.5	Taxi	605,000	1	0.3	1.0	1	5	15+	14	--	15+	--	--	--	Slight pulverization in turns			
4	6	H.5 - 7.5	180° turn	605,000	5	1.0	1.0	0	6	15+	13	--	15+	--	--	--	Slight pulverization			
6	6	H - 9	180° turn	605,000	6	0	4.0	0	1	4	4	12	15+	15+	--	--	Upheaval of loose surface material			
6	6	I.5 - 10	Offload	605,000	7	1.5	2.0	2	3	6	9	11	15+	15+	--	--	Rutting due to nose gear			
7	2	E.5 - 9	Tow	425,000	1	Trace	0	1	1	7	7	12	9	15+	15+	--	M-35 trucks required additional weight			
8	5	--	Taxi	665,000	1	Trace	0	--	--	--	--	--	--	--	--	--	Trace of ruts over entire track			
8	5	D - 4.5	Taxi	665,000	2	1.5	1	1	1	6	6	13	12	14	15	9	9	Weak area in test area		
8	6	I.5 - 10.2	Offload	665,000	9	1.5	1.5	9	6	15+	13	--	15+	--	--	--				
8	7	I - 8	180° turn	665,000	9	1.5	3	4	1	12	4	15+	8	--	15+	--	Upheaval of pulverized material			
9	6	--	Taxi	665,000	11	Trace	0	10	7	15+	12	--	15+	--	--	--	Upheaval of 4-in. in 180° turn			
11	7	H - 7.5	180° turn	560,000	12	2	4	2	1	11	6	15+	13	--	15+	--	Upheaval of pulverized material			
12	6	--	Docking	665,000	14	Trace	1	3	3	15+	15+	--	--	--	--	--				
13	6	H - 8.5	180° turn	665,000	14	2	4	3	1	5	6	13	14	15+	15+	--	Maximum upheaval in outside wheel path			
16	8	I - 7	Offload	560,000	2	Trace	0	0	1	7	9	15+	15+	--	--	--				
18	8	--	Offload	605,000	4	Trace	0	0	1	7	9	15+	15+	--	--	--				
20	9	--	Offload	665,000	3	Trace	1	2	2	15+	15+	--	--	--	--	--				

* Measurements taken in the ruts and outside the ruts.

Table 5
Summary of Subgrade Field Test Data
Altus AFB Test Site

Test Pit Location	Depth in.	CBR	Water Content %	Dry Density pcf	Airfield Index at Depth Indicated, in.			
					0	2	4	6
B-2	0	4	18.6	100.0	3	4	5	8
	6	5	15.1	104.6	4	5	11	15+
	12	19	11.0	107.3	14+	-	-	-
	24	27	8.4	105.7	15+	-	-	-
B-9	0	2.9	12.8	88.4	4	4	4	5
	6	2.8	22.3	93.6	3	4	4	5
	12	3.5	19.0	98.7	6	10	15+	-
	24	6	17.8	101.5	5	6	6	5
D-2	0	3.0	19.5	96.2	3	4	3	6
	6	3.8	15.4	103.2	3	5	6	6
	12	5.0	21.1	99.1	4	5	7	8
	24	5.0	15.2	103.0	6	9	10	15+
D-7	0	13.0	10.3	95.0	5	12	12	15+
	6	22.0	11.3	101.9	11	15+	-	-
	12	15.0	11.9	102.9	11	15	15+	-
	24	8.0	17.3	101.3	7	6	7	8
F-9	0	3.5	17.0	89.9	3	6	5	4
	6	3.2	18.3	97.0	5	4	4	5
	12	2.6	21.7	97.2	3	4	5	7
	24	6.0	22.0	96.5	5	5	6	7
G-4	0	2.7	21.3	96.9	2	3	2	3
	6	2.5	18.0	103.4	3	4	4	5
	12	2.6	16.6	106.1	4	5	6	8
	24	6.0	16.6	107.3	5	8	9	10

Notes: 1. All CBR, water content, density, and AI values shown are an average of three measurements.

2. The 0-, 2-, 4-, and 6-in. depths shown for AI measurements are 0, 2, 4, and 6 in., respectively, below the depth being tested for CBR, water content, and density.

Table 6
Summary of Airfield Index Measurements
Obtained at the Altus AFB Test Site

Test Site*	Airfield Index at Depth Indicated, in.,**						
	0	2	4	6	12	18	24
A-1							
A-2							
A-3	3	7	6	9	15		
A-4	3	8	6	7	15		
A-5	2	5	5	6	10	10	15
A-6	2	4	4	4	5	5	9
A-7	2	4	6	7	10	15	
A-8	2	13	12	12	15		
A-9	5	8	7	7	6	7	15
A-10	3	8	11	6	6	5	11
A-11	3	6	8	10	10	15	
B-1							
B-2							
B-3	4	4	5	5	9	15	
B-4	1	3	3	3	7	14	15
B-5	1	2	3	4	5	8	15
B-6	1	3	4	4	5	4	10
B-7	2	3	3	4	4	10	15
B-8	2	2	3	2	3	5	11
B-9	3	4	4	5	10	12	15
B-10	3	4	4	4	4	5	7
B-11	3	4	5	6	5	5	7
C-1	13	15					
C-2	4	3	4	5	8	15	
C-3	1	3	3	3	5	7	15
C-4	1	2	3	3	7	10	15
C-5	1	2	2	3	6	6	13
C-6	1	2	2	3	6	6	13
C-7	2	3	4	4	4	9	15
C-8	1	2	3	4	4	6	9
C-9	1	2	3	3	3	9	15
C-10	1	2	3	3	4	5	8
C-11	2	3	3	3	4	5	6
D-1	8	15					
D-2	2	3	4	5	7	10	11

(Continued)

* See Figure 2 for layout of test site.

** All airfield index values are an average of 3 to 5 measurements.

Table 6 (Concluded)

Test Site*	Airfield Index at Depth Indicated, in.,**						
	0	2	4	6	12	18	24
D-3	3	4	4	5	9	10	15
D-4	3	4	5	5	7	15	
D-5	1	2	3	4	5	8	8
D-6	2	4	5	7	15		
D-7	3	6	6	6	7	15	
D-8	3	5	6	7	9	14	15
D-9	2	4	4	4	5	15	
D-10	3	6	6	5	10	14	15
D-11	3	4	4	3	7	10	11
E-1	5	14	15				
E-2	2	4	5	6	9	10	15
E-3	3	4	4	4	7	15	
E-4	2	4	4	5	7	13	15
E-5	2	3	3	3	6	8	8
E-6	3	4	4	5	7	10	15
E-7	2	4	4	5	6	15	
E-8	2	5	6	7	7	15	
E-9	2	4	4	4	5	8	9
E-10	3	6	7	7	7	11	13
E-11	3	6	7	7	7	8	9
F-1	3	10	13	15			
F-2	4	6	7	15			
F-3	1	2	4	5	6	7	15
F-4	3	4	4	6	10	10	14
F-5	3	3	3	4	8	10	13
F-6	3	5	5	5	7	10	15
F-7	2	4	4	4	6	11	15
F-8	2	4	4	4	6	15	
F-9	2	4	4	4	6	8	9
F-10	2	5	6	5	6	10	11
F-11	2	3	6	7	7	8	9
G-1	5	14	15				
G-2	5	15					
G-3	2	3	4	4	8	10	10
G-4	2	3	4	4	7	9	13
G-5	2	3	3	4	7	9	15
G-6	2	11	15				
G-7	1	4	4	5	6	13	15
G-8	2	9	15				
G-9	1	4	4	4	5	7	12
G-10	3	6	6	5	7	11	12
G-11	3	7	8	10	10	12	14

Table 7

Summary of Aircraft Operations and Subgrade Evaluation
Altus AFB Test Site

Run No.	Test Track No.	Data Point Location	Type of Operation	Gross Aircraft Load lb	Total Passes Over Data Point	Maximum Rut Depth in.	Upheaval in.	Subgrade Evaluation												Remarks
								Airfield Index at Depth Shown, in.*												
								0		2		6		12		18		24		
In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out					
1	1	A.5 - 5	Taxi	425,000	1	0	0	5	6	8	10	9	11	10	15+	13	--	15+	--	Slight pulverization
6	6	F - 5	Taxi	425,000	1	1.3	0.5	6	2	15+	6	--	9	--	8	--	9	--	12	Slight pulverization
6	6	E - 3.5	180° turn	425,000	1	0	0.5	5	5	15+	15+	--	--	--	--	--	--	--	--	Slight plowing in turns
6	6	E.5 - 1.3	Tow	425,000	1	0	0	13	7	15+	15+	--	--	--	--	--	--	--	--	Tow with Oshkosh
		G - 5	Tow	425,000	1	0	1	3	5	15+	10	--	13	--	14	15+	15+	--	--	Plowing in turns
		--	Tow	425,000	1	0	1	6	3	15+	7	--	9	--	7	--	9	--	9	Forward circle tow
2	2	B - 5	Taxi	500,000	1	0.5	Trace	5	5	14	10	13	14	14	15+	15+	--	--	--	Plowing in outside wheel paths
7	6	D.6 - 4	Taxi	500,000	3	1.5	1	7	6	5	8	7	7	13	7	15+	7	--	10	Loose fill in this area
7	6	E - 3	180° turn	500,000	3	0	1	6	6	15+	15+	--	--	--	--	--	--	--	--	Plowing in outside wheel paths
3	3	B.5 - 5.5	Taxi	560,000	1	1.3	0.5	11	10	14	11	15+	15+	--	--	--	--	--	--	Loose fill in this area
3	3	B.5 - 3	Taxi	560,000	1	3.5	2.0	14	4	6	5	13	8	14	15	14	15+	15+	--	Loose fill in this area
8	6	E - 3	Offload	560,000	7	0	0	7	5	15+	8	--	10	--	14	--	15+	--	--	Left main gear ruts in loose fill
11	7	F - 5	Offload	560,000	8	0	0	14	8	15	15+	9	--	13	--	15+	--	--	--	Right main gear ruts in loose fill
14	8	F - 8	Taxi	560,000	3	0	0	5	4	14	8	15+	14	--	15	--	9	--	4	Trace of rutting over entire track
4	4	B.5 - 3	Taxi	605,000	2	4.0	2	5	10	7	11	11	12	15+	12	--	15+	--	--	Right main gear ruts
4	4	B.5 - 3	Taxi	605,000	2	3.0	2	9	10	13	11	14	12	15	12	15+	15+	--	--	Trace of rutting over entire track
4	4	C.2 - 6	Taxi	605,000	2	4.0	2	5	4	15+	10	--	9	--	6	--	9	--	10	Right main gear ruts
4	4	Track	Taxi	605,000	2	1.5	0.5	6	5	15+	13	--	15+	--	--	--	--	--	--	Measurements prior to taxi
9	6	D.5 - 4	Offload	605,000	14	3.0	1.5	6	11	15	8	14	14	11	10	12	9	12	11	Measurements prior to taxi
12	7	D.5 - 4	Taxi	605,000	16	3.0	1.5	--	--	--	--	--	--	--	--	--	--	--	--	Measurements prior to taxi
15	8	Track	Taxi	605,000	6	Trace	Trace	--	--	--	--	--	--	--	--	--	--	--	--	Measurements prior to taxi
5	5	C.2 - 6	--	665,000	1	2.0	0.5	15+	9	--	12	--	15+	--	--	--	--	--	--	Measurements prior to taxi
10	6	D.5 - 4	Taxi	665,000	16	1.5	1.0	--	--	--	--	--	--	--	--	--	--	--	--	Measurements prior to taxi
10	6	D.5 - 4	Taxi	665,000	17	2.0	1.5	12	8	6	15+	12	--	15+	--	--	--	--	--	Measurements prior to taxi
10	6	D.5 - 4	Taxi	665,000	19	2.8	2.0	13	8	15+	15+	--	--	--	--	--	--	--	--	Measurements prior to taxi
10	6	D.5 - 4	Taxi	665,000	20	2.3	2.0	15+	14	--	15+	--	--	--	--	--	--	--	--	Measurements prior to taxi
10	6	D.5 - 4	Taxi	665,000	21	2.6	1.2	--	--	--	--	--	--	--	--	--	--	--	--	Measurements prior to taxi
10	6	D.5 - 4	Taxi	665,000	22	3.3	0.8	13	12	15+	15	--	10	--	15+	--	--	--	--	Measurements prior to taxi
10	6	Track	Offload	665,000	22	Trace	Trace	--	--	--	--	--	--	--	--	--	--	--	--	Measurements prior to taxi
13	7	Track	Taxi	425,000	--	0	0	--	--	--	--	--	--	--	--	--	--	--	--	Trace of rutting over entire track
16	9	D - 10.5	Taxi	665,000	63	Trace	0	11	7	15+	15+	--	--	--	--	--	--	--	--	Average of entire track
																				Area of maximum traffic

* Measurements taken in and outside of ruts.

Table 8
Summary of After-Traffic Field Test Data

<u>Test Pit Location</u>	<u>Depth in.*</u>	<u>CBR</u>	<u>Water Content %</u>	<u>Dry Density pcf</u>	<u>Remarks</u>
<u>Altus AFB Test Site</u>					
D.5-4	Surf.	12	15.3	110.4	Rutted area
	6	9	19.0	104.0	
	12	9	18.9	103.1	
	18	8	16.6	101.2	
	24	11	17.3	101.5	
D-10.5	Surf.	24	9.6	109.7	
	6	12	15.3	99.4	
	12	11	13.9	103.6	
<u>Eglin AFB Test Site</u>					
F-2.5	Surf.	2	3.2	92.6	Track 5, rutted area
	6	3	4.3	106.7	
	12	6	4.3	108.7	
	24	5	4.4	103.6	
	36	4	4.3	101.0	
	48	4	4.4	97.6	
H-4.5	Surf.	4	3.6	97.6	Track 6, outside of traffic area
	6	9	3.8	100.7	
	12	13	4.1	104.9	
	18	12	5.3	105.2	
	24	10	6.2	101.3	
F-3	Surf.	5	4.3	94.2	Track 6, outside of traffic area
	6	4	4.1	96.6	
	12	2	4.7	93.6	
	18	2	4.2	94.4	
	24	2	5.3	97.2	

* Pieces of sand asphalt were encountered at these depths.

Table 9
Summary of Subgrade Field Test Data
Eglin AFB Test Site

Test Pit Location	Depth in.	CBR	Water Content %	Dry Density pcf	Airfield Index at Depth Shown, in.				
					0	2	4	6	12
B-2	Surf.	5.6	2.0	93.5	2	5	9	13	10
	6	14.7	2.7	98.8	2	8	10	10	8
	12	7.3	3.7	97.9	3	4	5	6	4
	24	2.2	4.1	97.8	0	1	1	2	3
	36	2.2	4.8	98.9	1	1	1	2	4
	48	2.7	4.7	98.4	0	1	1	2	5
F-4	Surf.	4.9	3.4	89.5	1	4	5	8	8
	6	7.2	3.0	96.5	1	4	6	7	6
	12	3.8	3.4	95.0	1	3	4	4	2
	18	3.0	3.5	95.1	1	2	2	3	4
	24	2.8	3.8	95.8	0	1	2	3	5
D-8	Surf.	6.9	1.6	90.3	2	6	8	10	10
	6	10.2	2.5	95.8	2	6	8	8	6
	12	6.7	3.0	95.3	1	3	5	6	5
	24	2.8	3.8	94.1	1	2	2	3	3
H-2	Surf.	10.3	1.2	95.8	2	7	11	11	15
	6	13.3	1.3	96.4	2	5	9	15	--
	12	17.3	3.2	100.1	2	7	11	11	11
	24	3.6	4.4	97.3	1	2	3	3	4
	36	3.2	4.4	98.4	0	1	1	2	4
	48	--	4.6	97.1	0	1	1	2	5

Notes: 1. Airfield penetrometer readings were made along with the CBR tests. The "0" airfield index depth shown is located at the surface of the depth being tested for CBR, water content, and density.

2. All CBR, water content, and density values shown are an average of three measurements.

Table 10
Summary of Airfield Index Measurements
Obtained at the Eglin AFB Test Site

Test Site*	Airfield Index at Depth indicated, in.**					
	0	2	4	6	12	18
A-0	2	7	6	9	15+	13
A-1	2	5	8	13	15+	13
A-2	2	5	9	13	15+	12
A-3	3	4	9	13	14	11
A-4	2	4	7	9	9	7
A-5	2	5	10	14	13	9
A-6	3	6	10	13	14	12
A-7	2	9	12	15+	15+	11
B-0	3	5	6	8	14	
B-1	2	6	9	12	13	11
B-2	2	5	8	11	11	9
B-3	2	6	8	10	12	12
B-4	2	4	6	6	9	7
B-5	2	5	7	8	7	8
B-6	2	4	7	8	10	7
B-7	2	4	8	9	8	6
B-8	2	7	10	15	13	12
	2	7	9	11	10	11
B-9	3	10	12	15+		12
B-10	2	7	12	15+		
C-0	2	5	10	11		
C-1	1	5	9	13	15	12
C-2	2	4	10	12	12	7
C-3	1	5	9	11	13	9
C-4	2	4	7	10	11	10
C-5	2	3	8	12	14	8
C-6	2	4	12	15	15+	10
C-7	2	4	8	13	13	11
C-8	2	3	8	10	8	6
C-9	1	4	6	9	11	8
C-10	2	8	11	13		

(Continued)

* See Figure 3 for layout of test site.

** All airfield index values are an average of
3 to 5 measurements.

Table 10 (Continued)

Test Site*	Airfield Index at Depth indicated, in.**					
	0	2	4	6	12	18
D-0	2	3	8	13	15+	
D-1	1	5	11	13	11	9
D-2	1	4	8	9	9	6
D-3	2	7	8	10	11	10
D-4	2	4	8	9	9	7
D-5	2	4	7	10	9	4
D-6	2	4	8	11	13	9
D-7	2	5	8	10	11	8
D-8	2	4	7	9	10	9
D-9	2	4	9	11	15+	
D-10	1	5	8	10	15+	13
E-0	3	5	7	10		
E-1	1	4	7	9	11	9
E-2	2	6	9	13	15+	12
E-3	2	6	9	13	13	8
E-4	2	5	7	8	8	6
E-5	2	3	6	6	9	6
E-6	2	7	8	9	9	7
E-7	2	4	6	8	11	8
E-8	1	4	10	13	13	
E-9	2	5	8	10	11	
E-10	3	7	7	9	15	
F-0	1	7	11	14		
F-1	2	4	8	11	13	10
F-2	2	4	6	7	11	10
F-3	2	3	5	7	7	6
F-4	1	4	6	7	8	6
F-5	2	5	6	10	10	4
F-6	1	3	8	9	15	14
F-7	1	6	9	13		
F-8	2	7	9	11		
F-9	3	6	8	13		
F-10						
G-0	3	5	10	14		
G-1	1	3	8	9	10	8
G-2	1	5	7	10	12	9
G-3	2	3	6	9	15+	13
G-4	2	4	9	11	15	13
G-5	2	6	10	13	14	
G-6	2	5	7	8	15	
G-7	2	8	10	15		

Table 10 (Concluded)

Test Site*	Airfield Index at Depth indicated, in.**					
	0	2	4	6	12	18
G-8						
G-9						
G-10						
H-0	1	3	7	12		
H-1	1	3	5	7	11	
H-2	1	7	9	8	15	10
H-3	2	5	9	11		12
H-4	1	6	8	11		
H-5	2	5	9	12		
H-6	1	7	10	12		
I-0	1	3	7	10		
I-1	1	3	7	8	12	
I-2	1	4	5	9	15+	
I-3	2	6	8	12		
I-4	2	5	11	14		
I-5	1	8	12	15		
J-0	1	3	8	14	15+	
J-1	3	4	8	12	12	
J-2	2	4	6	9		
J-3	2	6	9	13		
J-4	2	5	8	11		

Table 11
Summary of Aircraft Operations and Subgrade Evaluation
Eglin AFB Test Site

Test Track No.	Data Point Location	Type of Operation	Gross Aircraft Load lb	Total Passes Over Data Point	Maximum Rut Depth in.	Upheaval in.	Subgrade Evaluation Airfield Index at Depth Shown, in.*												Remarks		
							0		2		4		6		12		18			24	
							In	Out	In	Out	In	Out	In	Out	In	Out	In	Out		In	Out
1	Track	Taxi	425,000	1	Trace	--	1	2	3	7	4	13	5	15+	7	--	10	--	15+	--	"S" turns in this area Start of turn Straight taxi Hose gear sliding in turn Average for entire track Nose gear sliding in "S" turn Start of turn
1	F - 1.5	Taxi	425,000	2	3.0	2.0	0	1	3	6	4	9	6	13	9	15+	12	--	8	--	
1	F - 1.5	Taxi	425,000	4	5.5	5.0	0	1	3	6	4	9	5	13	9	15+	11	--	8	--	
6	C.7 - 4	180° turn	425,000	1	4.0	5.0	1	2	3	8	4	15+	5	--	7	--	8	--	6	--	
6	E.5 - 5	Taxi	425,000	1	2.0	1.0	1	3	3	8	6	14	6	15+	8	--	8	--	8	--	Right main gear ruts
6	I - 4.5	90° turn	425,000	1	0	4.5	--	2	--	5	--	8	--	11	--	15+	--	--	--	--	
2	Track	Taxi	500,000	1	Trace	0	2	2	5	8	7	12	9	14	13	15+	14	--	15+	--	
2	Track	Taxi	500,000	2	1.5	4.5	--	--	--	--	--	--	--	--	--	--	--	--	15+	15+	
6	C - 4	180° turn	500,000	3	2.5	4.5	0	1	2	5	4	9	6	15+	6	--	8	--	10	--	Area smoothed with tow vehicles
3	F.5 - 1	Taxi	560,000	2	8.0	4.0	2	3	5	11	5	15+	5	--	8	--	10	--	9	--	
6	D - 5.5	Taxi	560,000	6	8.0	6.0	1	1	2	8	3	12	4	14	10	15+	12	--	14	--	
6	F - 4	Offload	560,000	6	4.5	8.0	1	1	2	4	4	6	5	7	8	8	10	6	12	5	
4	D - 2	Taxi	605,000	1	3.6	0.4	1	3	4	11	4	14	5	15+	7	--	9	--	10	--	Area smoothed with tow vehicles
4	D - 2	Taxi	605,000	2	5.8	1.1	3	3	3	11	4	14	4	15+	8	--	12	--	13	--	
4	D - 2	Taxi	605,000	4	10.7	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
4	D - 2	Taxi	605,000	5	7.1	1.3	1	3	3	11	5	14	6	15+	9	--	13	--	10	--	
4	D - 2	Taxi	605,000	6	8.4	2.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Area smoothed with tow vehicles
4	D - 2	Taxi	605,000	8	6.6	2.6	1	3	3	11	4	14	6	15+	10	--	14	--	--	15+	
4	F - 2	Taxi	605,000	1	1.7	0.6	1	3	3	11	5	14	8	15+	15+	--	--	--	--	--	
4	F - 2	Taxi	605,000	2	4.1	1.2	3	3	6	11	6	15+	6	--	8	--	9	--	10	--	
4	F - 2	Taxi	605,000	4	6.1	2.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Area smoothed with tow vehicles
4	F - 2	Taxi	605,000	5	7.2	4.3	3	3	5	11	5	15+	6	--	9	--	15+	--	--	--	
4	F - 2	Taxi	605,000	6	6.6	3.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
4	F - 2	Taxi	605,000	8	7.8	1.8	2	3	6	11	7	15+	8	--	12	--	15+	--	--	--	
4	F - 2	---	--	8	--	--	1	3	4	11	7	15+	9	--	15+	--	--	--	--	--	Average prior to traffic Nose gear immobilized Left main gear Right main gear
6	F - 4	Taxi	605,000	8	8.0	4.0	1	1	2	4	4	6	5	7	9	8	12	6	15	15	
5	Track	---	--	0	0	0	--	1	--	7	--	12	--	15	--	15+	--	--	--	--	
5	F.5 - 2.5	Taxi	665,000	1	4.0	5.0	2	2	3	8	4	12	5	14	8	15+	10	--	10	--	
5	D - 2.5	Taxi	665,000	3	5.0	6.0	1	1	3	3	4	5	5	8	8	15+	11	--	12	--	
5	F.3 - 2.5	Taxi	665,000	5	11.5	8.0	1	1	4	5	5	7	6	8	10	9	15+	7	--	6	
5	F.8 - 2.5	Taxi	665,000	5	6.0	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
5	F.8 - 2.5	Taxi	665,000	5	8.0	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	

* Measurements taken in and outside of ruts.

Table 12
Predicted Performance of C-5A Before Failure
at Shaw, Altus and Eglin AFB Sites

<u>Test Site</u>	<u>Rated CBR</u>	<u>Gross Aircraft Load kips</u>	<u>Predicted Number of Aircraft Passes Before Failure*</u>	<u>Remarks</u>
Shaw AFB	15	425	10,000+	
	15	500	10,000+	
	15	560	4,250+	
	15	605	2,230+	
	15	665	900+	
Altus AFB	9	425	2,100	
	9	500	560	
	9	560	190	
	9	605	100	
	9	665	40	
Eglin AFB	14	425	10,000+	Predictions not appropriate because of soil type
	14	500	7,700	
	14	560	2,800	
	14	605	1,500	
	14	665	590	

* Predicted using the nomograph for operation of aircraft on unsurfaced soils.



Photo 1. Typical vegetation at the Shaw AFB test site



Photo 2. Typical vegetation at the Altus AFB test site

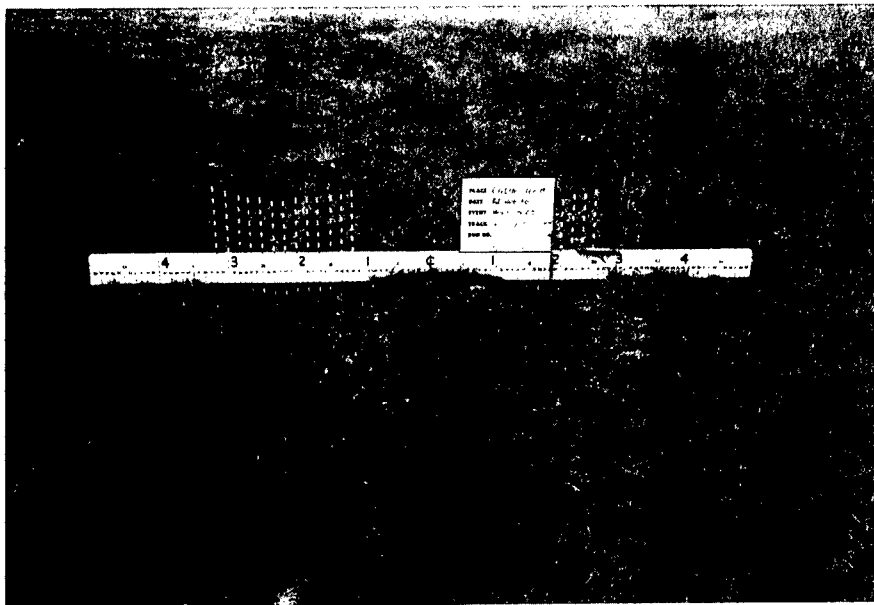


Photo 3. Typical vegetation at the Eglin AFB test site



Photo 4. Sand test site after one pass of the C-5A

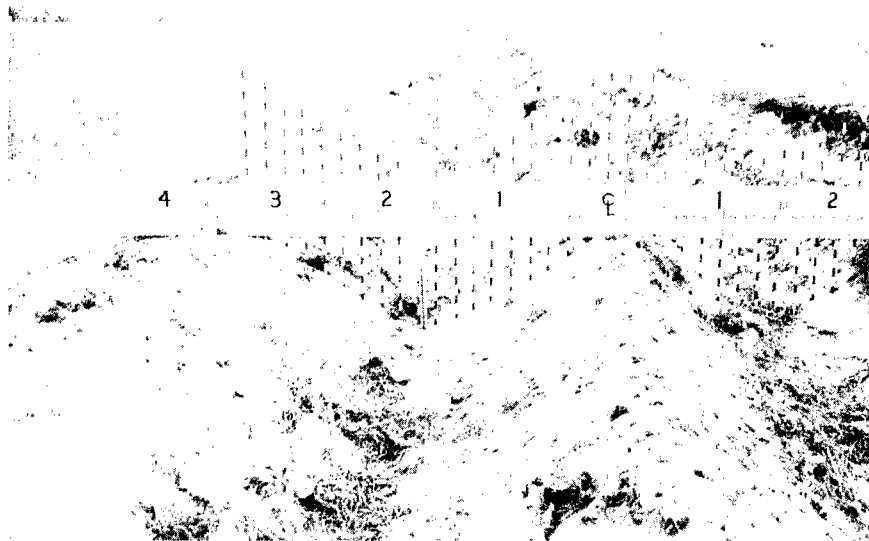


Photo 5. Typical rutting in the sand
after three passes of the C-5A

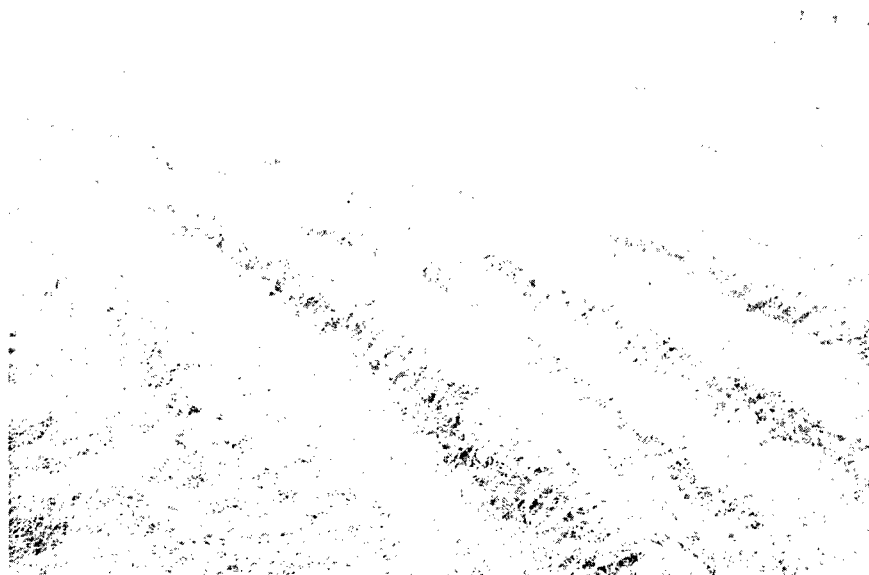


Photo 6. Typical rutting in the turn areas
at the sand test site

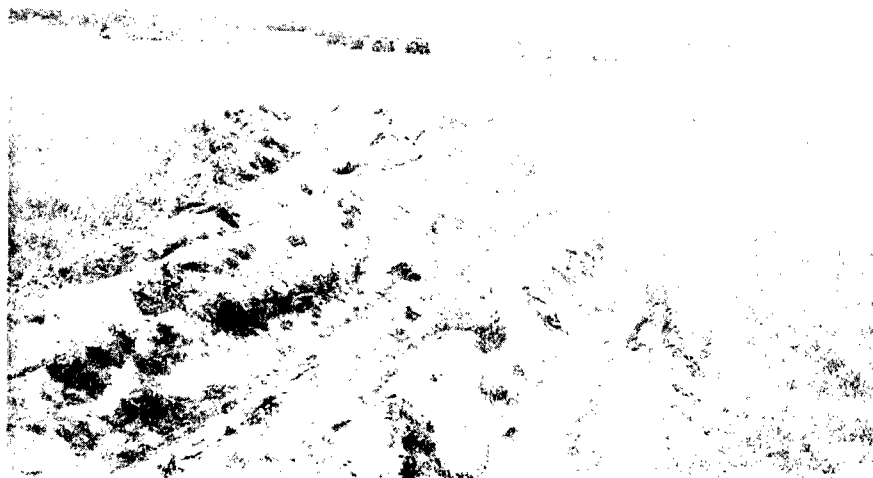


Photo 7. Closeup view of rutting in the turn areas at the sand test site



Photo 8. Sod and sand buildup in front of nose gear



Photo 9. Rear view of nose gear after C-5A
became immobilized in sand

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Grau, Robert W.

C-5A operational utility evaluation soil tests and analysis : final report / by Robert W. Grau (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, [1981].

45, [23] p. : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; GL-81-7)

Cover title.

"August 1981."

"Prepared for Air Force Test and Evaluation Center, Kirtland Air Force Base, Albuquerque, New Mexico 87117."

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4. Soils--Testing. I. Air Force Test and Evaluation Center (U.S.) II. U.S. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; GL-81-7.
TA7.W34 no.GL-81-7