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SCHOOL OF ENGINEERING
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SOIL ANALYSES AND EVALUATIONS AT THE IMPACT DYNAMICS RESEARCH FACILITY FOR TWO FULL-SCALE AIRCRAFT CRASH TESTS

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By

Robert Y. K. Cheng

Final Report
For the period May 24-August 31, 1977

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Master Contract Agreement NAS1-14193
Task Authorization No. 36
Robert G. Thomson, Technical Monitor
Structures and Dynamics Division

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SOIL ANALYSES AND EVALUATIONS AT THE IMPACT DYNAMICS RESEARCH FACILITY FOR TWO FULL-SCALE AIRCRAFT CRASH TESTS

By

Robert Y. K. Cheng[1]

SUMMARY

An investigation to determine the aircraft structural crash behavior and occupant survivability for aircraft crashes on a soil surface was conducted at the Impact Dynamics and Research Facility at NASA Langley Research Center. This report contains the results of placement, compaction, and maintenance of two soil test beds, and a description of the crators formed by the aircraft after each test.

INTRODUCTION

Currently, the Impact Dynamics and Research Facility at NASA Langley Research Center is conducting a series of aircraft free-flight-crash test programs. Under controlled flight conditions, real aircraft are crashed on concrete surfaces to study the crash characteristics of the aircraft. Descriptions of the test facility and the crash safety program are given in references 1 and 2.

In furthering the knowledge of structural crash behavior and occupant survivability, two real aircraft were crashed on a soil surface. This is the first attempt in the test program to crash aircraft on a yielding surface such as soils. A high-winged and a low-winged single-engine aircraft were crashed on a soil surface at a velocity of 13.4 m/s with a pitch angle of -30°.

[1] Professor, Department of Civil Engineering, School of Engineering, Old Dominion University, Norfolk, Virginia 23508.

The purpose of this study is to identify and classify the soils used in the two crash tests and to develop criteria for placement, compaction, and maintenance of the soil bed.

LIST OF SYMBOLS

G = specific gravity of soil-solid particles

S = degree of saturation

w = moisture content

W_d = weight of dry soils

W_w = weight of water

γ = wet unit weight of soils

γ_d = dry unit weight of soils

SOIL TEST BED

Figure 1 shows the test facility with the soil test bed. The test bed was approximately 12.1 m (40 ft) wide, 24.4 m (80 ft) long and 1.2 m (4 ft) high and was built on top of a concrete pad. With a depth of 1.2 m, the test bed would simulate an actual field condition. As the soils were purchased in advance, the selection of an appropriate soil strength was of prime importance. Using the criteria of crash tests on a ploughed field, the test bed was prepared for a CBR (California Bearing Ratio) strength of four. The CBR number is used to rate the performance of soils primarily for use as bases beneath pavements of roads and airfields. A soil strength of CBR 4 is rated as poor to fair by the Unified Soil Classification System. The soils would be sufficiently firm to support the load of a light pneumatic-tired tractor and soft enough for the aircraft to sink into the soils during the crash.

LABORATORY AND FIELD MEASUREMENT METHODS

Laboratory tests were performed to provide necessary information for construction of the test bed. Field tests were performed to monitor construction of the test bed to satisfy the specified conditions and to establish the soil bed properties. Whenever possible, similar testing procedures were used for tests in the laboratory and in the field.

Soil Classification Using Grain Size Analysis

The soils acquired by NASA are typical top soils commonly classified for agricultural purposes as loam. The soils contain a significant amount of organic matter consisting of roots and decayed vegetation. The organic content of soils is expressed as a percentage of the total dry weight of soils. Since organic matter can absorb moisture and is so much lighter than the mineral soil particles, a small amount of organic matter will decrease the density and increase the moisture content of soils. To perform the tests effectively, the soil sample used in the laboratory was processed to remove all visible forms of twigs and roots. The organic content of the soils used for the laboratory tests was one percent, whereas the organic content of soils in the field was nine percent. The substantial variation in organic content between the soils would influence the guidelines for construction of the test bed.

The gradation curve was determined by sieve analysis. The curve presented in figure 2 shows the range of particle size for three samples taken at various locations. The maximum size particle is less than 2 mm (passing No. 10-sieve size), and less than 6 percent (by weight) of the particles are smaller than 0.074 mm (passing No. 200-sieve size). The No. 200-sieve size is about the smallest particle visible to the naked eye. Using the Unified Soil Classification System, the soil is classified as a nonplastic sand-silt mixture (SM soils).

Moisture Content Determination

The moisture content was determined in the laboratory by the standard oven-dry method. The moisture content expressed as a percentage is determined by

$$w = \frac{W_w - W_d}{W_d} \times 100 \qquad (1)$$

The oven-dry procedure is time consuming and will not be expedient for field measurements where rapid determination of moisture content is desired. The moisture content was also determined on the same soil sample by the speedy moisture tester. The tester measures the moisture content by gauging the pressure of acetylene gas generated when calcium carbide reacts with the moisture in a small soil sample. The maximum variation of moisture content between the oven-dry method and the speedy moisture tester method is 0.5 percent. The speedy moisture method was adopted for monitoring the proper moisture content for construction just prior to the aircraft crash-test.

Moisture Density Determination

The moisture-density tests were performed in accordance with ASTM specification D698-70, Method B. The soils were thoroughly mixed in a mixer and were compacted in a mold 15.2 cm (6 in.) in diameter by 11.6 cm (4.584 in.) high in 3 equal layers. Each layer was compacted by 56 uniformly distributed blows with a 2.5 kg (5.5 lb) hammer free-falling 30.5 cm (12 in.). The 15.2 cm diameter will permit both CBR and Airfield Index (AI) penetration resistance tests on the same specimen. The main emphasis for conducting the moisture-density tests is to establish the relationship between the CBR number and the moisture content, whereas the normal objective for the moisture-density test is to establish the maximum dry density for a given compaction effort. The maximum dry density usually becomes the compaction job standard for the soils. Figure 3 shows the results of the test.

Field Density Determination

The density at the surface of the test bed was measured by the Field Density Sampler designed by the Corps of Engineers. It consists of a 7.6 cm (3 in.) diameter by 7.1 cm (2 13/16 in.) long cylinder which is driven into the ground with a 4.5 kg (10 lb) driving hammer. The cylinder is then removed carefully from the ground to prevent disturbing the soil sample within the cylinder. Excess soils are trimmed off the cylinder, and the cylinder is then immediately weighed; the wet density can be readily computed. Some of the soils in the cylinder are also used to determine the moisture content. The dry density of the soil sample is determined by

$$\gamma_d = \frac{1}{1 + w} \gamma \tag{2}$$

The California Bearing Ratio (CBR) Test For Soil Strength

The CBR test measures the relative quality of subgrade, subbase, and base soils for pavements of roads and airfields. The CBR number was used as a measure of soil strength for studies of aircraft operation on soil runways as given in reference 3. The test is a plate bearing test intended to measure the soil's resistance to small indentation prior to reaching the ultimate shear strength. The bearing plate is a cylindrical piston 4.95 cm (1.95 in.) in diameter. Annular weights 4.5 kg (10 lb) or more are placed around the piston. The test can be performed on any flat surface.

In the laboratory, the piston was driven into the soils previously compacted in a compaction mold by a compression machine geared to a strain-rate of 0.127 cm/min (0.05 in./min). For all field tests the piston was driven into the soils by a screwjack reacting against a counterweight supported by a crane, and the loads were measured by a proving ring (see figure 4). The deflections were measured by a dial gage referenced to the soils from a fixed steel beam. Readings of load versus penetration were taken at each 0.063 cm (0.025 in.) of penetration to include the penetration value of 0.508 cm (0.200 in.) and then at each

0.254 cm (0.1 in.) thereafter until the penetration reached 1.27 cm (0.5 in.). The pressure-deflection curve was plotted to reflect errors due to improper seating of the piston on the soils. The pressure at 0.254 cm (0.1 in.) deflection is compared to that supported by a typical well-graded crushed gravel which is assigned a CBR number of 100 (equivalent to supporting a pressure of 6895 kN/m^2 or 1000 psi). The CBR number is expressed as a percentage. All the CBR tests were performed in accordance with ASTM specification D1883-67.

Airfield Cone Penetrometer Measurement for Soil Strength

The cone penetrometer measures the penetration resistance of soils as it is gradually forced into the soils. The penetration resistance is a measure of the shear strength of the soils. As the penetration resistance will vary according to the size and shape of the penetrometer and the type of soils, the penetrometer measures the relative shear strength of soils, and it is necessary to correlate the penetrometer measurements with other types of strength measurements. However, the cone penetrometer provides an efficient and rapid method for measuring the relative soil strength and, more importantly, the variation of soil strength with depth. Penetrometer measurements were used to monitor the uniformity of soil strength of the test bed.

The airfield cone penetrometer is a hand-operated device with a 30° cone having a 1.29 cm^2 (0.2 in^2) base area as shown in figure 5. The penetration resistance is measured by a spring which is calibrated in terms of the Airfield Index (AI) number. One AI number equals a force of 44 N (10 lb). The AI readings are made at 5.08 cm (2 in.) intervals up to a depth of 45.7 cm (18 in.). However, if the AI readings at any depth exceeded AI of 15 (660N or 150 lb), the test was discontinued and the penetrometer was considered to have been driven to refusal. For field measurements, the operator forced the penetrometer into the soil at a slow uniform rate calling out each 5.08 cm (2 in.) of penetration. An observer would then record the AI number at each command. Because of the large quantity of roots present in the soils, the penetration tests required repetition on many occasions. In the laboratory, the AI number of the first 5.08 cm

(2 in.) was determined on the soils in the compaction mold, since the height of the sample was 11.4 cm (4.5 in.). Two tests were performed on each compacted sample immediately following the CBR test.

SOIL ANALYSES AND RECOMMENDATIONS

Figure 3 represents the data for all tests for the moisture content-density relationship. The data also include a modified compaction effort using 25 blows for each layer instead of the standard 56 blows for each layer of compaction. The degree of saturation is larger than 95 percent at a moisture content of 12 percent. Consequently, at moisture contents greater than 12 percent the compaction effort has a small influence on the moisture-density relationship, whereas at moisture contents less than 12 percent the compaction effort has a larger influence.

Figure 6 presents the data for all tests for CBR versus moisture content. As in the case for the moisture content-density relationship, the compaction effort has a small influence on the CBR number when the moisture content is greater than 12 percent. Furthermore, a significant amount of scatter is apparent in the data when the moisture content is less than 12 percent. These tests indicate that to obtain a soil test bed of CBR4 the moisture content of the soils should be 12 percent or higher.

The correlation between the airfield cone penetration resistance from 0 to 5.08 cm (2 in.) depth and the CBR strength tests in the laboratory is shown in figure 7 using AI and CBR numbers. For CBR of eight or less, the data showed good correlation between the AI and CBR numbers. The relationship may be approximated to be linear. A significant amount of scatter is apparent in the data at higher values of CBR.

Based on the laboratory investigations, the following guidelines were established for the construction and maintenance of the soil test bed:

1. That the moisture content of the soils be maintained at 12 percent or higher during compaction in order to obtain a soil strength CBR of 4;

2. That light pneumatic-tired tractors be used for compacting the soils. Good uniformity of density can be obtained since the degree of saturation would be greater than 95 percent so that a moderate variation in compaction effort would not significantly change the CBR number of the soils; and

3. That airfield cone penetrometer measurements be used to provide a rapid method for monitoring the uniformity of soil strength at various locations of the test bed and depth.

CONSTRUCTION OF TEST BEDS

Test Bed 1

No special effort could be made to monitor and control the moisture content of the soils for construction of test bed 1. The soils were placed on the concrete slab by dump trucks and then spread by a light bulldozer and a pneumatic-tired grader. Wherever possible large roots and twigs were removed by combing the surface with rakes towed by light pneumatic tractors. The soils were spread to less than 15.2 cm (6 in.) and compacted in place by a box-grader towed by a light pneumatic tractor. The combination of the pressure of the box-grader and tire-pressure of the tractor served to compact the soils. Special effort was made to avoid loading the soil bed with heavy dump trucks. Rakes and box-graders were also used to dress the soil bed to the proper elevation.

Once constructed the test bed was protected from exposure to the sun and rain by covering it with plastic sheets. The plastic sheets prevented the loss of moisture in the soils by evaporation. Where additional moisture was required, water was sprayed on the surface with hoses. This procedure served to prevent the surface from drying without appreciably changing the moisture content of soils below the surface.

Prior to the crash test, elevation readings at the top of the soil bed were made by surveyors. Elevations at one-meter square grids are given in figure 8. The planned impact target was located at grid point G1. The depth of soil at the center is approximately 1.3 m (4.4 ft). A gentle slop of 1:30 (transversely from the flight path) permitted adequate surface runoff.

Test Bed 2

A major portion of the test bed was left intact after the first crash test. A strip about 4.9 m (16 ft) wide and 46 cm (18 in.) deep across the width of the test bed at the aircraft impact point was removed. The excavated soils were raked again to remove additional roots and twigs. Field measurements of moisture content by the speedy method indicated moisture contents varying between 14 and 16 percent. The moisture content was acceptable, and no addition of water nor further drying of the soils was necessary. As mentioned earlier in the report, a higher organic content in the field sample would increase the moisture content in the soil.

The soils were compacted and leveled by the box-grader. Plastic sheets were placed over the impact area whenever possible until the time of the crash test. The elevations at one-meter square grids are given in figure 8. The depth of soils at the center was approximately 1.2 m (4.1 ft).

FIELD MEASUREMENTS

All field measurements for establishing the soil properties were made one day before the crash at the grid points in the vicinity of the target area. The target point is located at grid point G1. The field measurement program included the following tests:

1. CBR measurement,
2. Airfield cone penetrometer measurement after crash test at the impact area,
3. Density measurement by field density sampler, and
4. Moisture content measurement by speedy moisture tester.

Table 1 shows the CBR, moisture content, and dry density at various grid points. For crash test 1, because of obstructions at the target area, 11 CBR tests were performed only at the southern half of the test bed. Although there was substantial variation of CBR from 0.9 to 10 percent in the target area, the postcrash test indicated that the zone of soils significant to the crash test was along the flight path, which is along line G shown in figure 8. Taking the average of the CBR along line G, the average CBR for the test bed is 3.5 for crash test 1 as shown in figure 9.

With no obstructions at the target area, 18 CBR tests were performed. The grid pattern for the CBR tests was based on the low winged aircraft used in crash test 2. The average CBR along the flight path (line G) for crash test 2 is 3.4 (see figure 9), which indicated that the CBR strength were similar for both test beds.

Tables 2 and 3 show the AI numbers of the airfield cone penetrometer measurements for crash tests 1 and 2 respectively. The average value of the AI number is the mean average of the AI readings from 0 to 40.7 cm (16 in.) depth. Variation of the AI number along the flight path (line G) is shown in figure 10. Variation between the 2 AI test bed averages is 10 percent.

The density and moisture measurements for test bed 2 were taken essentially along the flight path line, and the results are given in table 1. The measurements were taken from samples at 2.5 cm (1 in.) below the surface. The moisture content varied from 13.3 to 16.3 percent with an average value of 14.5 percent. The dry density varied from 1474 kg/m^3 (92 lb/ft^3) to 1586 kg/m^3 (99 lb/ft^3) with an average value of 1586 kg/m^3 (96 lb/ft^3) as shown in figure 11. The moisture contents from the field measurements were higher than those predicted by laboratory studies for the corresponding CBR of 3.5 (see figure 6) because the field soil samples contained more organic contents.

In summary, the results of the field measurements indicated that the desired soil properties were attained and that the soil properties for both test beds were similar and relatively uniform along the flight path.

CRASH TEST RESULTS

Test 1

A high-winged single-engine aircraft was used in the crash test. During the crash, the front part of the fuselage, which contained the engine, penetrated into the soils, heaving and splashing soils in the direction of the flight path. In comparison with other high-speed photographs taken during the crash, the crater formed by the fuselage was considerably shallower, indicating that a substantial amount of loose soils had fallen back into the crater. Due to rainy weather, the postcrash test soil measurements were made two days after the test. Although the crashed area was protected by plastic sheets, seepage of water had damaged the contours of the crater and altered the moisture content. Figure 12 shows the plan view of the crater and the soil profile along the flight path at the center of the crater. The crater was about 1 m (3.3 ft) wide by 3.5 m (11.5 ft) long. The length of the crater indicated the approximate distances travelled by the aircraft upon impact with the soils. The AI number at the center of the area contacted by the nose gear varied from 1 to 1.5 for the first 10 cm (4 in.) of penetration. It appeared that the failure zone of the soil extended 10 cm (4 in.) below the surface. A number of AI measurements were made at the crater, but the results were too scattered to permit any interpretation to establish the depth of penetration of the fuselage.

Test 2

A low-winged single-engine aircraft was used in the crash test. Soil measurements were carried out immediately following the crash test. Figure 13 shows the plan view of the crater and the soil profile along the flight path at the center of the crater. As in the case with test 1, a certain amount of loose soils fell back into the crater. The crater was about 1 m (3.3 ft) wide by 1.5 m (5 ft) long.

The actual flight path occurred between lines G and H. Airfield penetration resistances were made along the centerline of the crater. The average AI number varied from 1.5 to 2.0 for the first 15 cm (6 in.) of penetration. The AI number increased to three or higher below this depth. The low AI number indicated that loose soils which were formed by either the accumulation of the loose soils fallen into the crater or the highly disturbed soils caused by shear failure. Penetration resistance measurements were also made at the grid points surrounding the crater. The results did not show any significant changes from those taken prior to the tests.

In an attempt to trace the soil displacement in the impact zone, thirty 2.5 cm (1 in.) diameter steel balls were placed at depths 15 cm (6 in.) and 30 cm (12 in.) in a cross pattern. The balls were painted white and numbered. After the crash test, these balls were located by a metal detector. The displacement of each ball was determined from the initial and final positions of the ball. Unfortunately, the actual flight path occurred about 50 cm (20 in.) south of the planned flight path. Only two of the steel balls were displaced, as shown in figure 13.

CONCLUSIONS

The following conclusions were made on the basis of soil tests and studies for the two crash tests:

1. Laboratory tests of the sand-silt soils (SM) established the CBR-moisture content relationship and the AI-CBR relationship. These relationships provided sufficient guidelines for constructing the test bed.

2. The soil properties along the flight path for both test beds were similar. The CBR's for test beds 1 and 2 are 3.5 and 3.4 respectively for surface field readings. The average AI number for test beds 1 and 2 are 5.3 and 4.8 respectively for a depth of 40.6 cm (16 in.). The average moisture content for test bed 2 taken at 2.5 cm

(1 in.) below the surface varied from 13.3 to 16.3 percent with an average of 14.5 percent. The dry density varied between 1474 kg/m^3 (92 lb/ft^3) and 1586 kg/m^3 (99 lb/ft^3) with an average of 1538 kg/m^3 (96 lb/ft^3).

3. Based on the length of the crater formed after the crash, the fuselage was stopped by the soils after it had travelled 3.5 m (11.5 ft) and 1.5 m (5 ft), respectively, from the point of impact for tests 1 and 2. No conclusive observations could be made on the depth of penetration by the fuselage due to insufficient information.

4. Based on penetration measurements, the crater was formed mostly by shearing and removal of the soils as the fuselage ploughed through the soils. Any compaction of the soil within the crater and its immediate vicinity would be indicated by high penetration resistance.

5. Buried steel balls can be used to trace the soil displacement between the initial and final positions for the crash test. However, a significant number of balls must be used over a wide area if one desires a detailed plot of the displacement field.

REFERENCES

1. Vaughan, V.L.; and Alfaro-Bou, E.: Impact Dynamics Research Facility for Full-Scale Aircraft Crash Testing. NASA TN D-8179, April 1976.
2. Thomson, R.G.: General Aviation Crash Safety Program at Langley Research Center, the Proceedings of Aircraft Safety and Operating Problems. NASA SP-416, October 1976.
3. Crenshaw, B.M.; Butterworth, C.K.; and Truesdale, W.B.: Aircraft Landing Gear Dynamic Loads from Operation on Clay and Sandy Soil. AFFDL-TR-69-51, U.S. Air Force, February 1971.

Table 1. CBR, moisture content, and dry density measurements.

Test Bed Location	Test Bed 1 CBR %	Test Bed 2 CBR %	Test Bed 2 Moisture Content %	Test Bed 2 Dry Density kg/m^3
C4	-	3.3	-	-
D4	-	4.8	-	-
E4	-	1.8	-	-
F3	-	4.9	-	-
F4	-	2.5	13.8	1570
F5	-	4.5	-	-
G1	4.0	2.2	-	-
G2	6.2	3.2	14.4	1474
G3	2.9	4.6	16.3	1522
G4	-	2.9	13.9	1585
G5	0.9	3.9	13.3	1570
H1	3.5	-	-	-
H2	5.0	-	-	-
H3	5.0	2.9	-	-
H4	-	3.1	15.5	1538
H5	-	3.0	-	-
I1	10.0	3.9	-	-
I3	3.6	-	-	-
I4	-	3.9	-	-
I5	0.8	-	-	-
I7	2.7	-	-	-
J4	-	2.4	-	-
K4	-	3.4	-	-

Table 2. Measured Airfield Index (AI) values for test bed 1.

Test Bed Location	AI Readings at Depth Shown								Average
	5.1 cm 2 in.	10.2 cm 4 in.	15.2 cm 6 in.	20.3 cm 8 in.	25.4 cm 10 in.	30.5 cm 12 in.	35.6 cm 14 in.	40.7 cm 16 in.	
E1	3	5	4	4	4	5	2	3	4.2
E2	1	5	5	3	3	4	4	10	4.4
E3	4	6	5	6	7	8	8	-	6.3
E5	2	7	6	6	7	9	7	6	6.2
E7	1	5	5	5	5	3	6	7	6.0
E9	5	5	4	6	5	5	8	8	5.8
F1	9	10	9	8	7	6	5	4	7.2
F2	4	10	9	11	10	15	7	8	9.2
F3	4	7	9	9	8	5	5	5	6.5
G0	2	2	6	6	8	7	5	5	5.2
G1	5	4	5	6	7	6	7	7	5.9
G2	2	6	8	7	9	6	7	5	6.2
G3	2	5	7	7	7	6	4	4	5.2
G5	4	4	4	3	3	3	3	9	4.1
G6	5	6	4	4	4	2	6	7	4.8
G7	2	3	3	5	7	6	8	10	5.5

(cont'd.)

Table 2. Measured Airfield Index (AI) values for test bed 1 (concluded).

Test Bed Location	AI Readings at Depth Shown								
	5.1 cm 2 in.	10.2 cm 4 in.	15.2 cm 6 in.	20.3 cm 8 in.	25.4 cm 10 in.	30.5 cm 12 in.	35.6 cm 14 in.	40.7 cm 16 in.	Average
G8	5	8	7	4	5	6	8	8	6.4
G9	5	5	7	6	4	5	8	9	6.1
H1	2	4	4	5	6	6	6	5	5.7
H2	4	4	8	7	7	8	9	3	6.2
H3	4	5	7	8	8	8	7	6	6.6
I1	8	9	10	10	8	6	6	5	7.2
I2	5	6	8	10	7	6	7	8	7.1
I3	4	5	5	4	6	9	10	11	6.8
I5	3	9	9	7	6	7	6	6	6.6
I7	3	3	3	6	4	6	7	8	5.0

Table 3. Measured Airfield Index (AI) values for test bed 2.

Test Bed Location	AI Readings at Depth Shown								
	5.1 cm 2 in.	10.2 cm 4 in.	15.2 cm 6 in.	20.3 cm 8 in.	25.4 cm 10 in.	30.5 cm 12 in.	35.6 cm 14 in.	40.7 cm 16 in.	Average
D4	5	7	6	7	7	7	8	9	7.0
D5	3	5	6	7	6	6	6	5	5.5
E4	2	5	7	6	6	7	8	11	6.5
E5	4	4	5	6	5	7	9	10	6.2
F2	2	3	4	5	5	6	4	3	4.0
F3	3	4	4	5	5	7	7	4	6.2
F4	3	4	6	7	7	8	8	8	6.4
F5	3	6	6	7	7	6	7	8	6.2
G1	2	4	5	5	4	3	3	5	3.9
G2	2	3	4	5	5	4	5	5	4.1
G3	4	6	6	6	8	5	8	6	6.1
G4	2	5	5	5	6	5	9	8	5.6
G5	4	3	4	4	4	5	5	7	4.5
G6	3	4	5	3	4	5	7	9	5.0
H2	3	4	4	4	6	6	5	7	4.9
H3	3	4	4	7	7	8	6	9	6.0

(cont'd.)

Table 3. Measured Airfield Index (AI) values for test bed 2 (concluded).

Test Bed Location	AI Readings at Depth Shown								Average
	5.1 cm 2 in.	10.2 cm 4 in.	15.2 cm 6 in.	20.3 cm 8 in.	25.4 cm 10 in.	30.5 cm 12 in.	35.6 cm 14 in.	40.7 cm 16 in.	
H4	2	5	6	7	6	6	7	8	5.9
H5	2	5	6	7	8	4	5	5	5.2
I4	3	5	5	5	5	5	7	9	5.5
I5	3	5	4	4	4	4	5	6	4.4
J4	2	4	6	6	6	7	6	8	5.6
J5	3	4	6	5	6	6	6	5	5.1

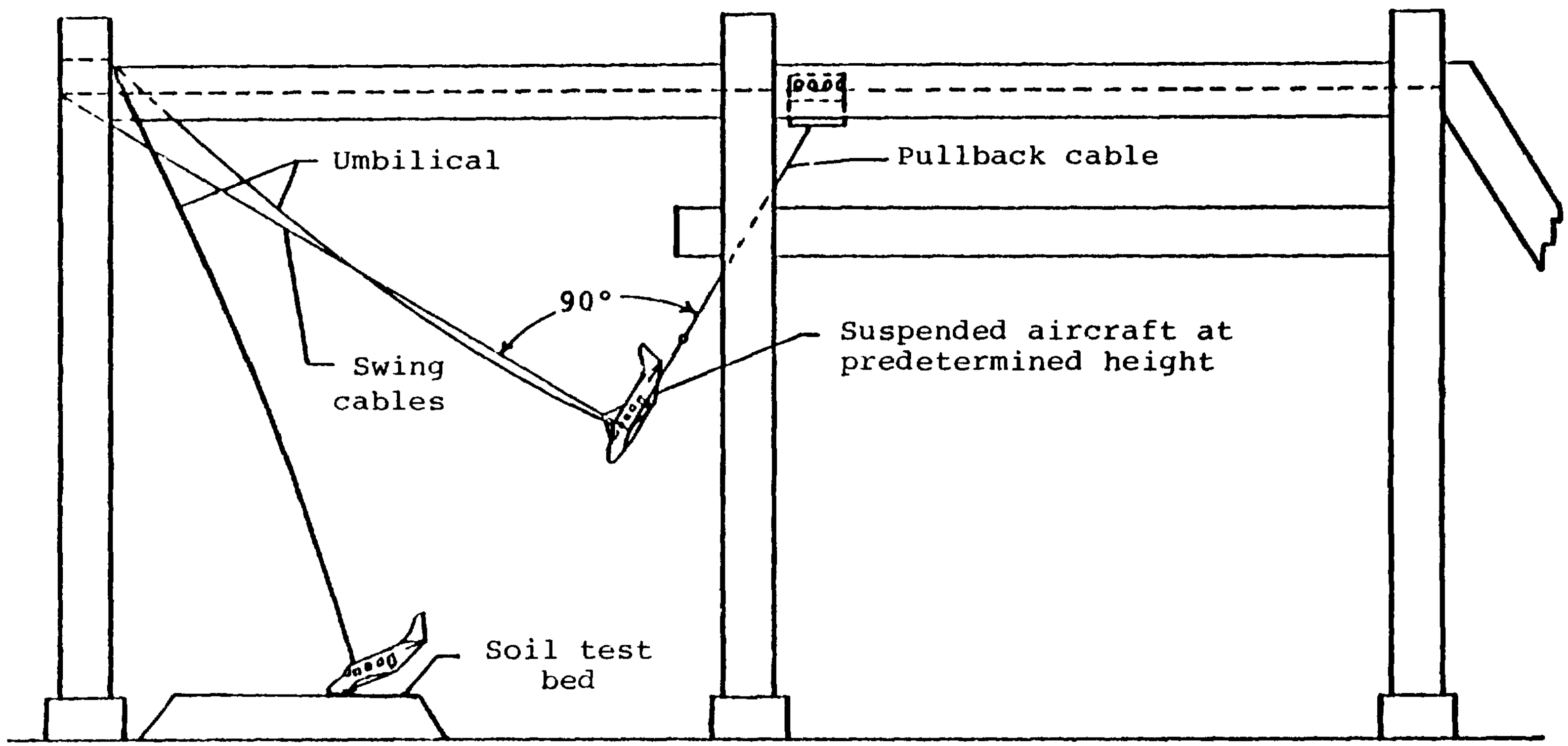


Figure 1. Full-scale aircraft crash-test technique.

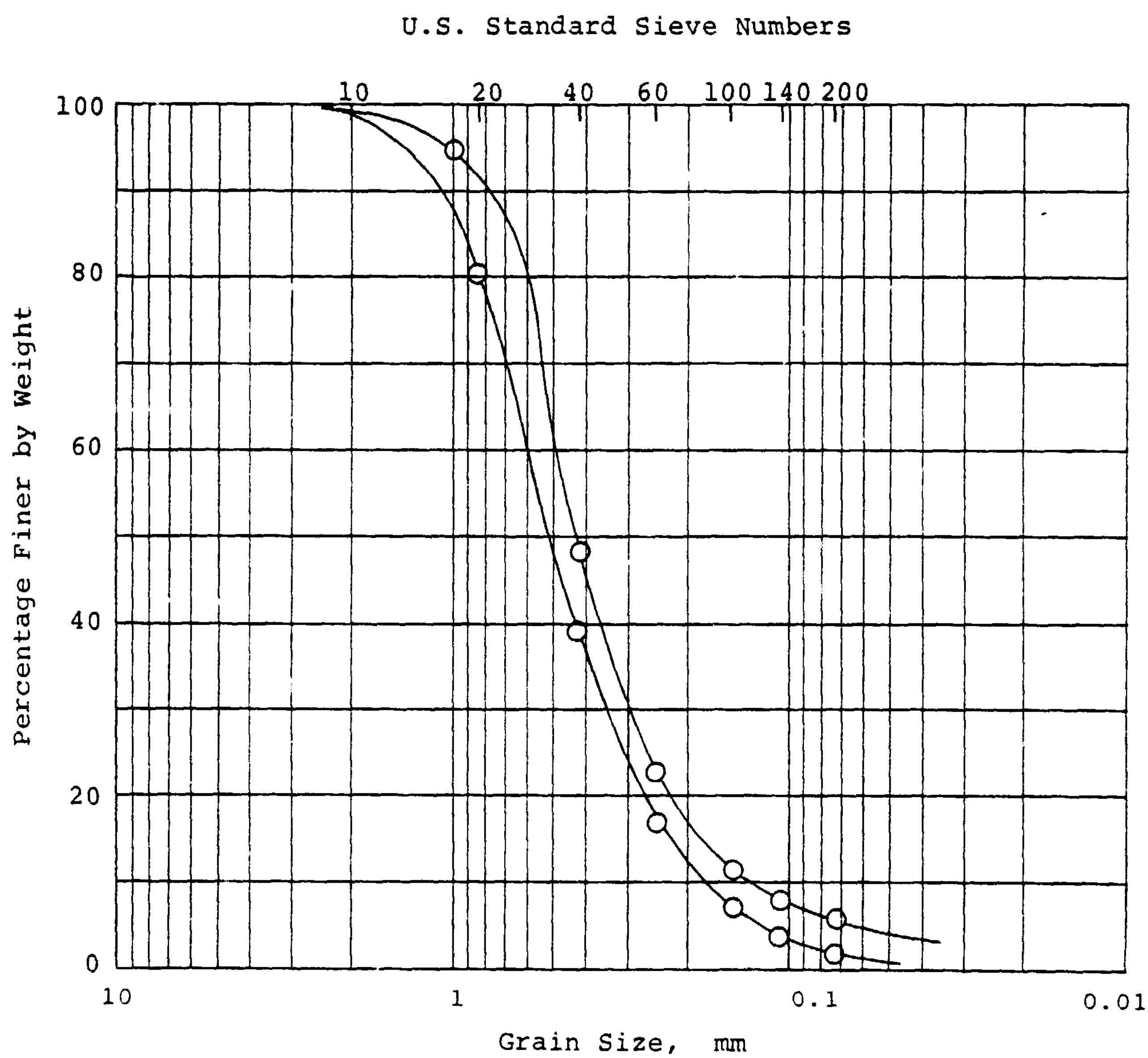


Figure 2. Grain size distribution curve.

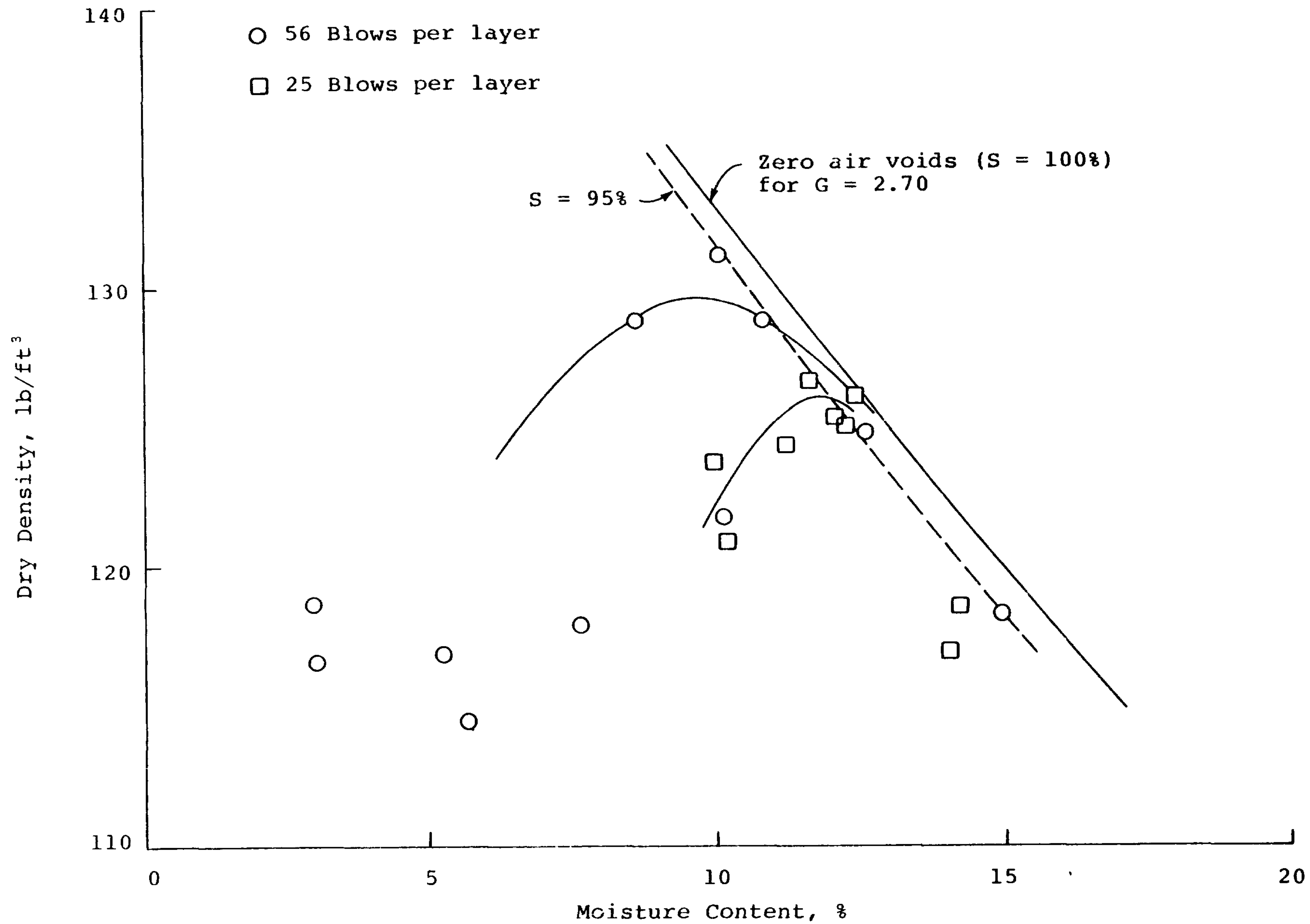


Figure 3. Moisture density relationship.

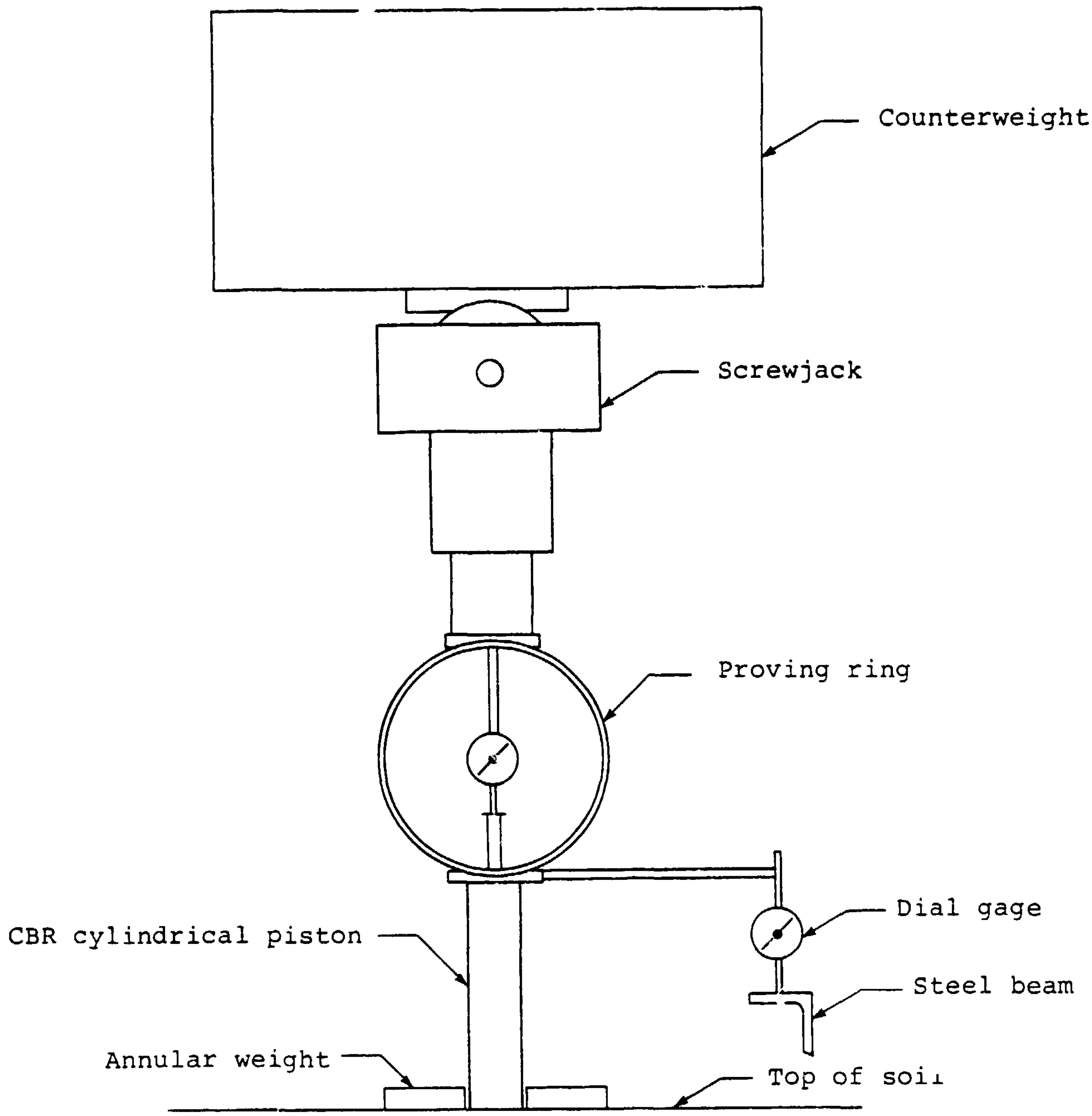


Figure 4. Schematic of CBR field test.

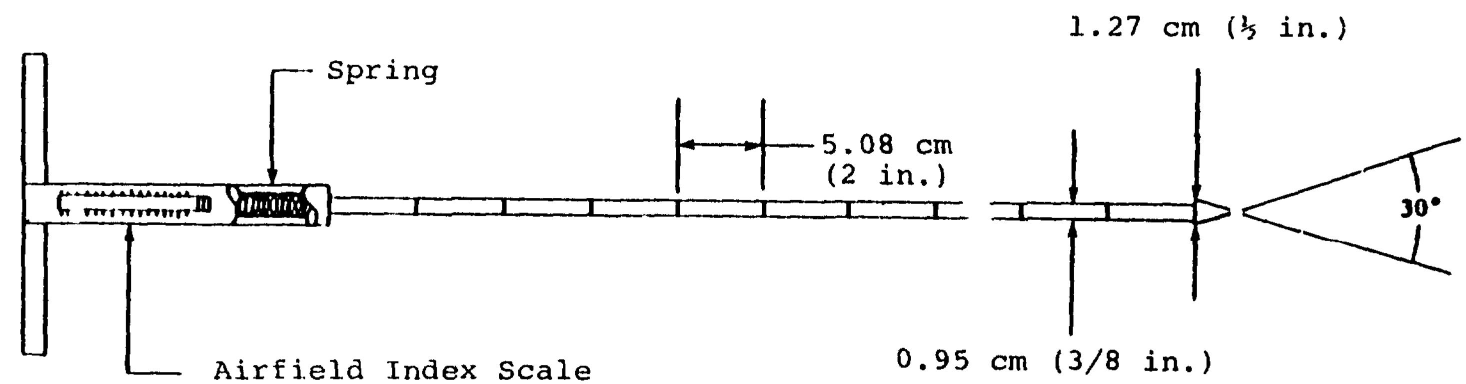


Figure 5. Schematic of airfield cone penetrometer.

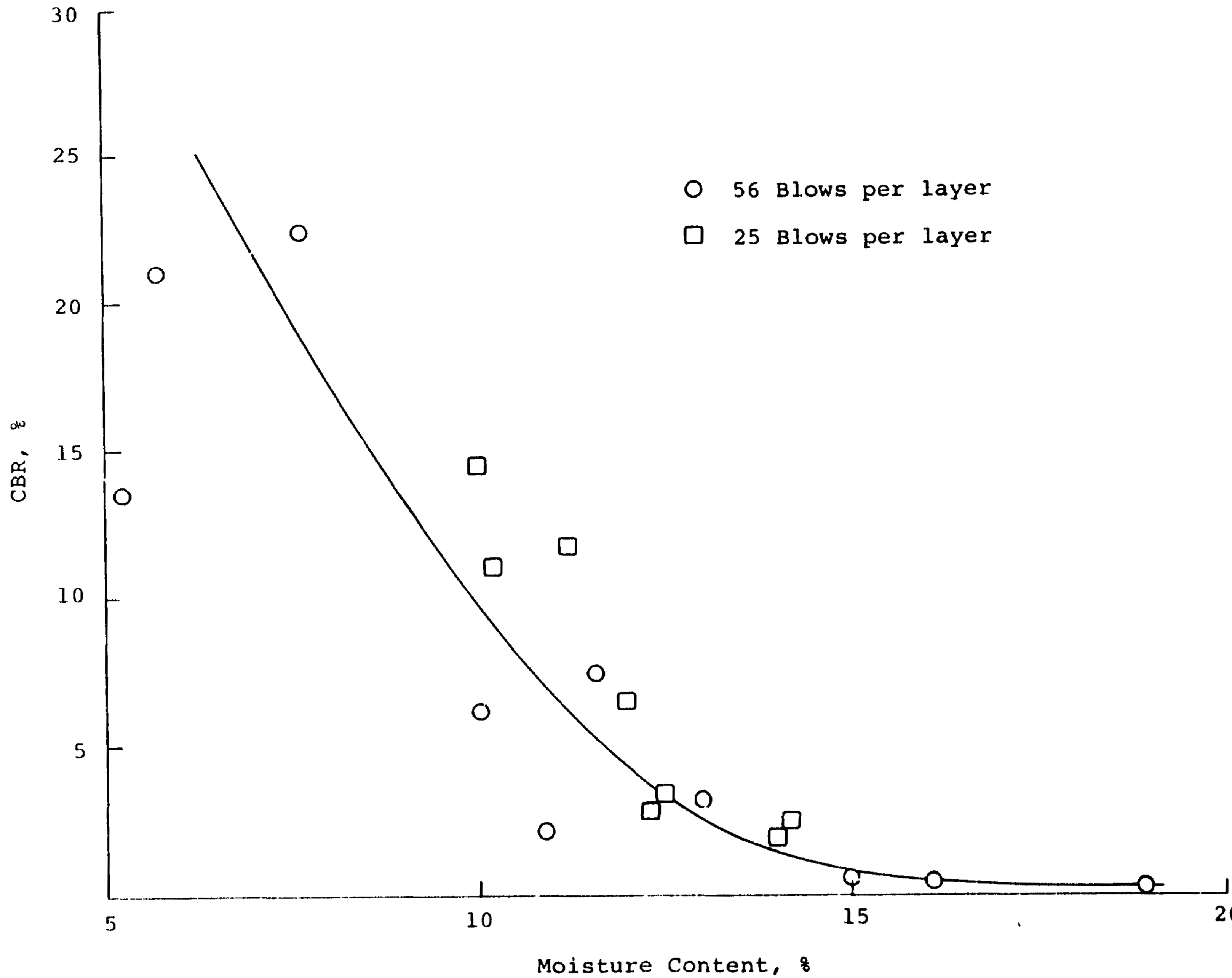


Figure 6. CBR and moisture content relationship.

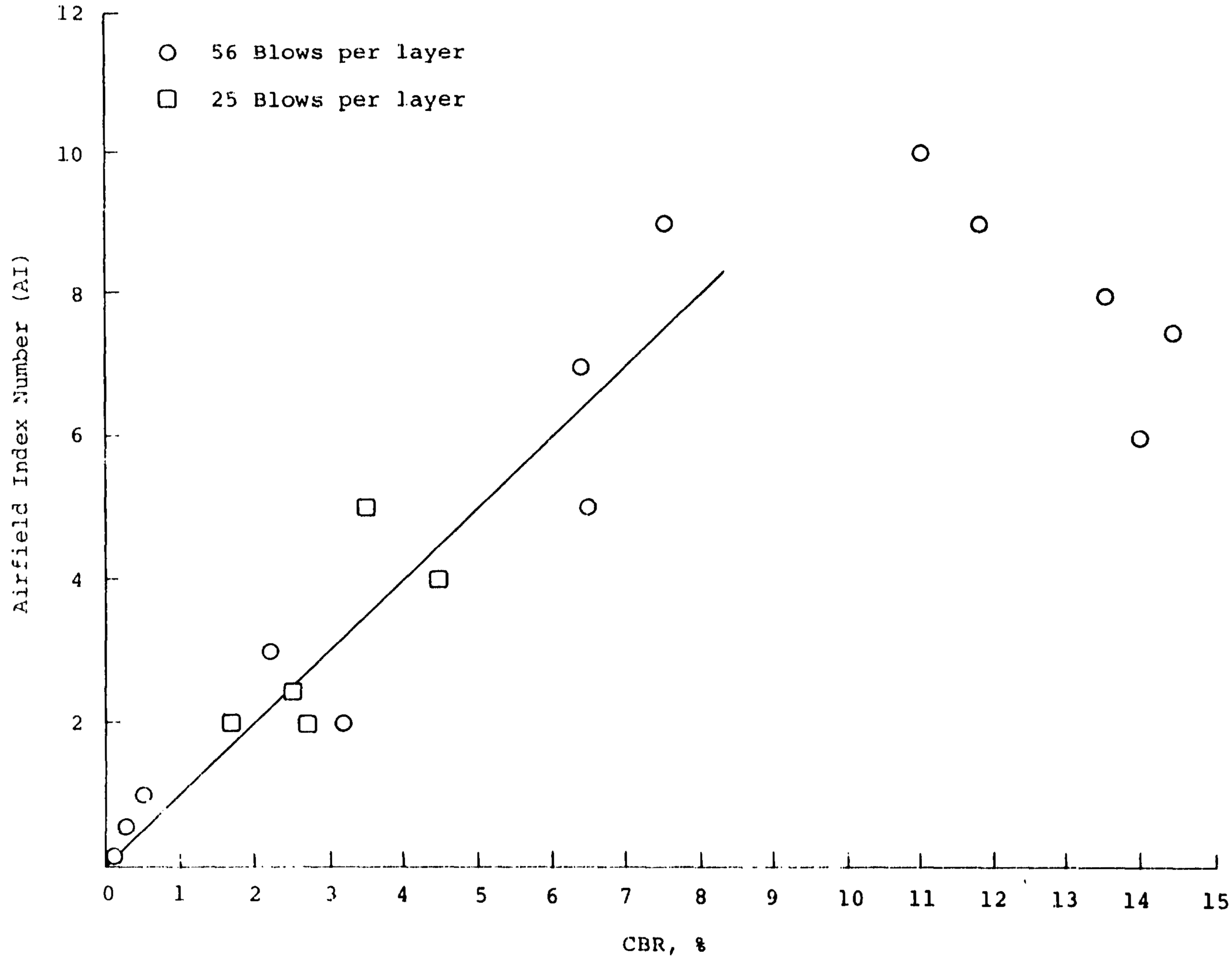


Figure 7. Airfield Index and CBR relationship.

Test Bed 1

Grid Line Identification	6	5	4	3	2	1	0
C	4.10	4.05	4.00	4.05	4.00	3.93	3.79
D	4.10	4.09	4.08	4.05	3.99	3.98	3.91
E	4.10	4.16	4.14	4.10	4.07	4.04	4.01
F	4.19	4.24	4.21	4.19	4.21	4.14	4.13
G	4.28	4.46	4.41	4.23	4.37	4.32	4.31
H	4.38	4.34	4.30	4.38	4.35	4.35	4.29
I	4.29	4.24	4.34	4.28	4.26	4.18	4.14
J	4.34	4.34	4.33	4.20	4.19	4.11	4.08
K	4.20	4.14	4.16	4.14	4.12	4.04	4.04

Grid Line Identification (7 6 5 4 3 2 1 0)
Test Bed 1

N

Test Bed 2

Grid Line Identification	6	5	4	3	2	1	0
C	4.05	4.10	4.11	4.09	3.98	3.95	3.81
D	4.18	4.20	4.17	4.10	4.02	3.97	3.93
E	4.22	4.23	4.17	4.13	4.07	4.04	4.03
F	4.24	4.24	4.20	4.15	4.10	4.09	4.08
G	4.24	4.24	4.22	4.17	4.12	4.07	4.09
H	4.24	4.25	4.24	4.22	4.15	4.11	4.09
I	4.26	4.24	4.25	4.24	4.17	4.09	4.04
J	4.23	4.24	4.24	4.27	4.14	4.04	3.96
K	4.17	4.19	4.23	4.21	4.12	4.01	3.93

Grid Line Identification (7 6 5 4 3 2 1 0)
Test Bed 2

flight path

Scale (m): 0 — 1

Figure 8. Relative soil levation of test beds. Elevations in feet indicate the thickness of the test bed. The decimal point of each number is located at the grid point.

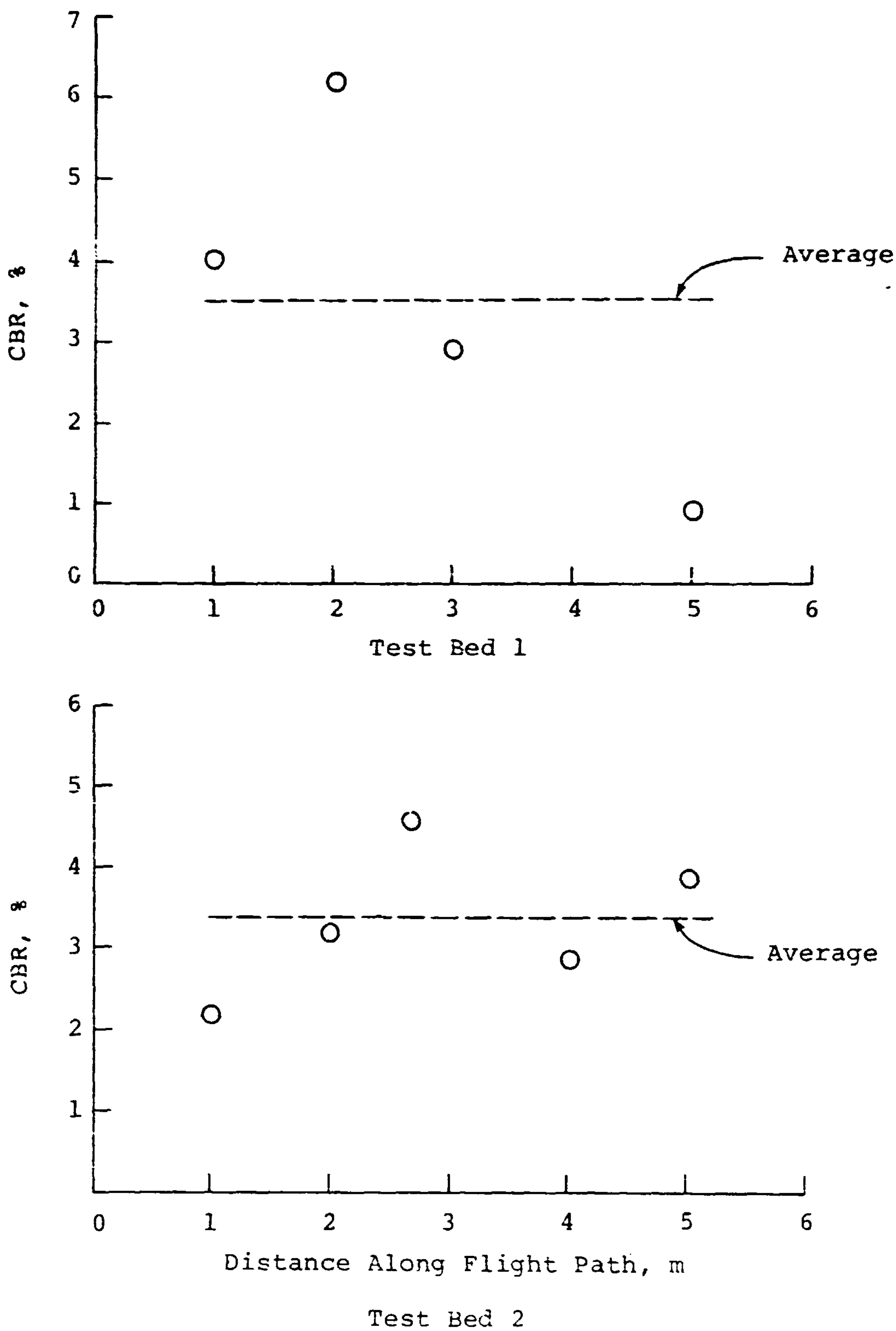
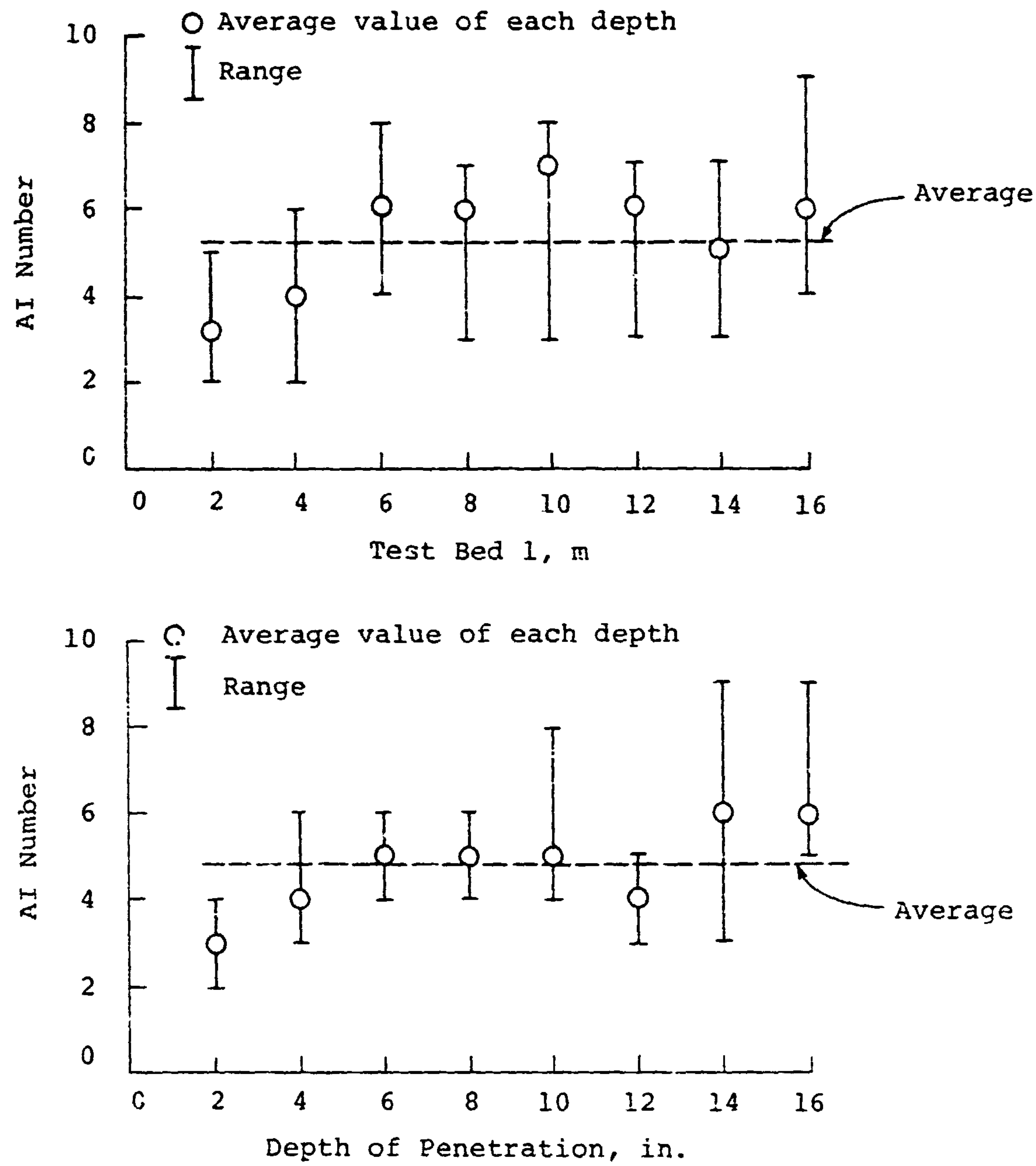


Figure 9. CBR along the flight path.



Test Bed 2

Figure 10. Variation of Airfield Index number with depth along the flight path between grid points G1 and G6.

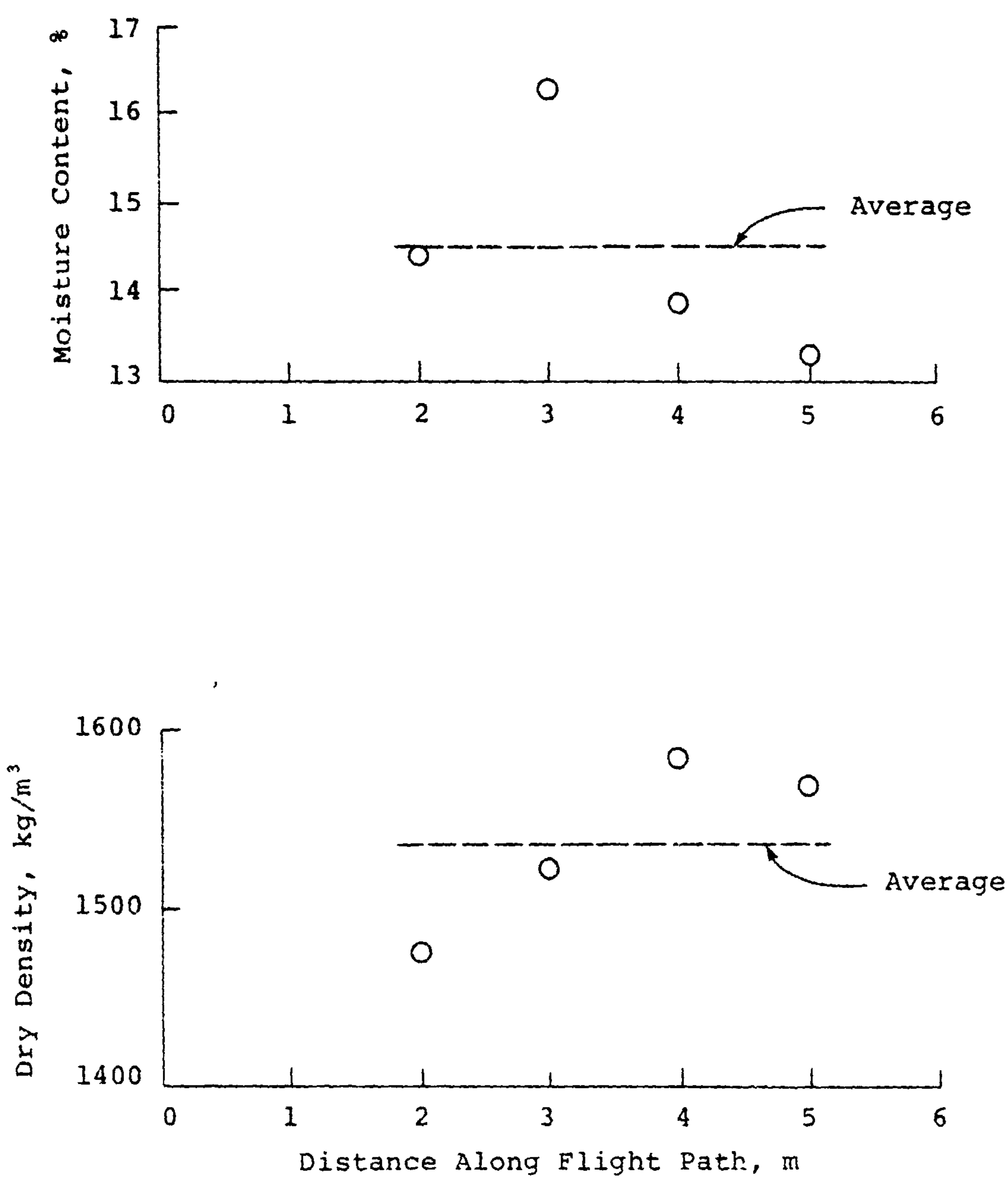


Figure 11. Variation of moisture content and dry density along the flight path between grid points G2 and G5.

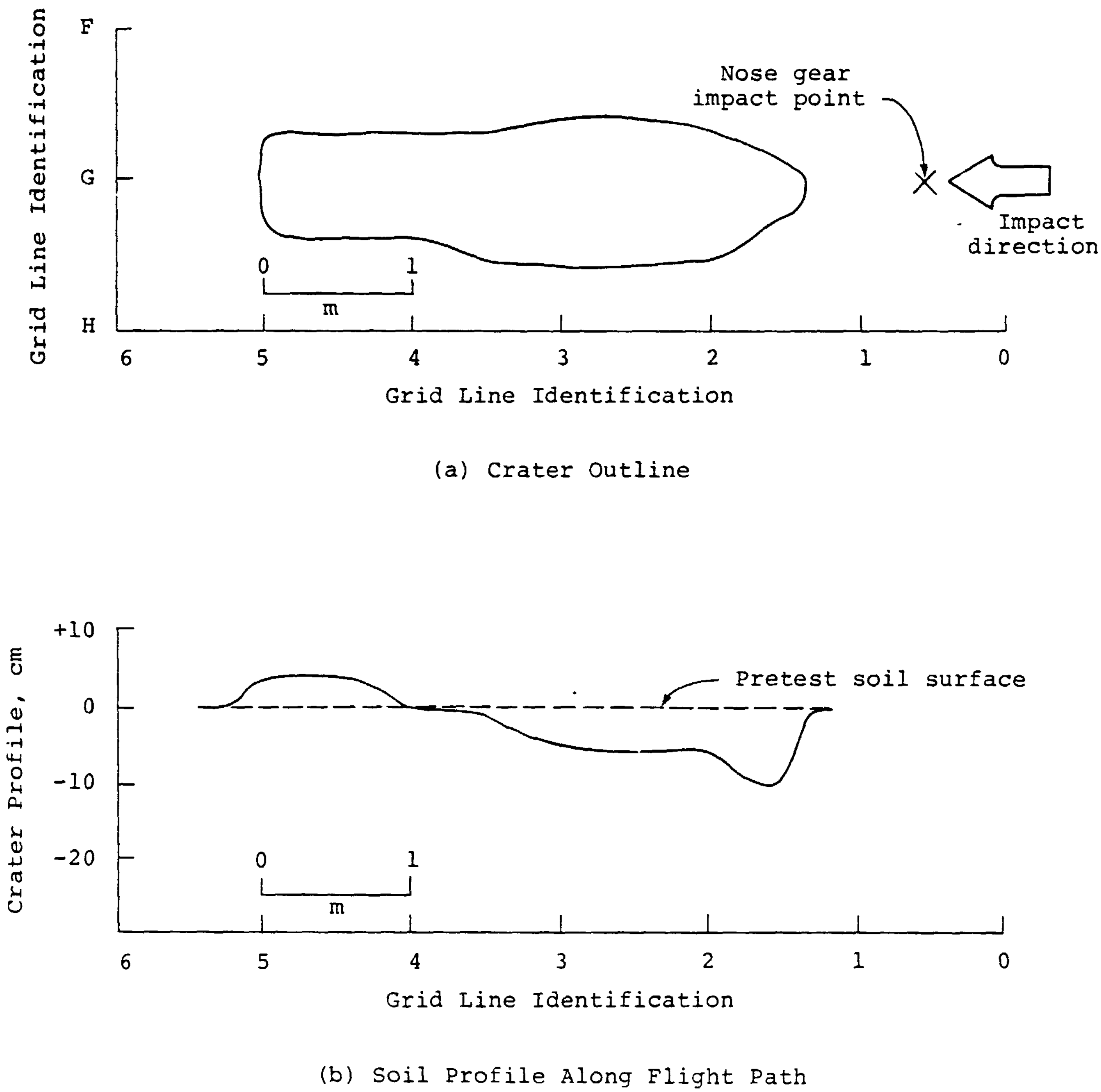


Figure 12. Crater and soil profile along flight path created by crash test 1.

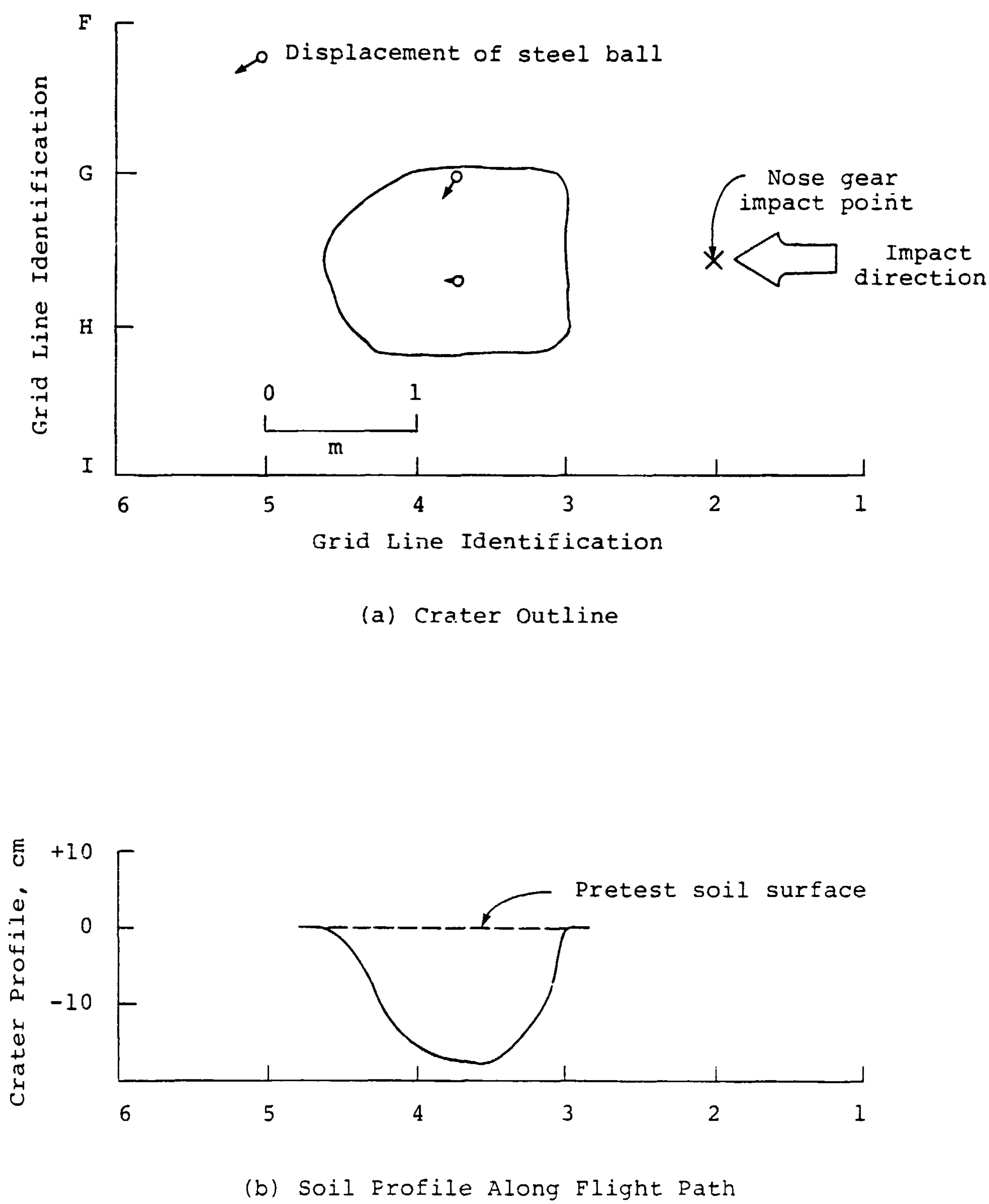


Figure 13. Crater and soil profile along flight path created by crash test 2.