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DEPARTMENT OF THE ARMY TECHNICAL BULLETIN

AIRFIELD PENETROMETER

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SECTION I

INTRODUCTION

1. Purpose. This bulletin contains infornna-tion on soils trafficability; the capacity of soils to support aircraft on forward landing strips, military vehicles on ground supply routes, and also aid in maintaining field control during constructions operations.

2. Scope. This bulletin includes information which will assist in solving specific trafficabil-ity problems. Procedures are presented for using the airfield penetrometer to measure soil strength and for correlating soil strength with the number of passes that can be made by aircraft having various wheel loads and tire pressures.

3. Terminology. Certain terms peculiar to this subject are defined as follows:

a. Airfield Index. A measure of soil strength obtained with the airfield cone penetrometer.

b. Aircraft Pa-w. One takeoff or one landing.

c. Coverage. One pass of a load wheel over each point within a traffic lane. In the case of large, multiple-wheel aircraft, as few as two passes may be required to apply one coverage; for smaller, single-wheel aircraft, as many as 10 to 20 passes may be required.

d. Equivalent Single-Wheel Load. The load on a single-wheel main gear which will produce effects equivalent to those produced by the total load on a multiple-wheel assembly.

e. KIP. A unit of weight equal to 1,000 pounds used to express deadweight load.

f. Nomograph. A graph that enables one by the aid of a straightedge to read off the value of a dependent variable when the value of the independent variable is given.

g. Penetrometer. Pen-e-trom-e-ter, an instrument for measuring the consistency of semi-solids.

h. Single-Wheel Load. The gross load supported by a single-wheel of a main landing gear.

4. References. *a.* TB ENG 37, Soils Trafficability.

b. TM 5–530, Materials Testing.

c. TM 5–541, Control of Soils in Military Construction.

d. U.S. Army Corps of Engineers Drawings MS–303–1, January 1965.

SECTION II

DESCRIPTION, USE AND MAINTENANCE

5. Description. *a.* The airfield penetrometer (fig. 1) is a probe-type instrument designed to measure soil strength. The overall length of the assembled penetrometer is approximately 36–1/8 inches, and weighs approximately 2.6 pounds (including the wrenches).

b. For ease in carrying, the penetrometer can be disassembled into three main pieces: two extension rods (5), each 12–5/8 inches long, and one piece 14-3/4 inches long, which includes removing the cone (6) from extension rod (5) and installing the cone (6) on the cone rod (4), removing cone cover and handle (2) from head (1) and securing cone cover (2) to bottom of housing (3).

c. The two wrenches (midget open end, double head, 15° and 75° heads, overall length 3–3/4 in., nominal openings 11/32 in. Military description: CCG-W-636A-1, Type VI, Style B), and an extra cone which accompany the penetrometer can be carried in the cone cover and handle.

d. The penetrometer's carrying case is constructed from heavy duck.

e. The extension rods (5) are graduated in two-inch increments and are provided with wrench flats to facilitate removal and installation. The cone (6) also has a wrench flat to permit removal and installation.

f. The handle (2) is a metal cylinder which fits into the head (1) at the top of the penetrometer.

g. The spring, consisting of two separate sets of interwound coils which act as a single unit, is stretched (tension) directly in proportion to the load applied to the handle.

h. The load-indicating device (7) is located in the housing (3) and moves up and down as the load on the handle (2) is varied. The penetrometer scale (8) has been factory calibrated at ten times the indicated load; hence, 100 lbs. reads 10 on the scale. The scale is marked 0-15 and reflects the load at any particular moment.

i. The airfield penetrometer is light enough and compact enough to be readily carried by an individual as supplemental equipment and is capable of withstanding rough handling during transport, or when used in reconnaissance or construction control work.

6. Use. *a.* Remove the penetrometer (fig. 1) from its carrying case and unscrew and remove cone cover and handle (2) from the housing (3), Remove extra cone and wrenches from the cone cover and insert handle (2) into head (1). Remove cone (6) from cone rod (4), then install extension rods (5) to cone rod (4) and install cone (6) to extension rod (5). Be sure that all joints are tight, and that the load indicator (7) registers "0" on the scale (8).

b. To use the penetrometer, place the cone (6) on the ground, grasp the handle (2), steady arms against the body and apply force to the handle until a slow, steady, downward movement occurs.

c. The load as indicated on the scale (8) is recorded at the moment the base of the cone (6) enters the ground (surface reading) and at desired depths at the moment the corresponding depth mark on the extension rod (5) reaches the soil surface.

d. A reading is made by shifting the line of vision from the soil surface to the scale (8) just before the desired depth is reached. Maximum efficiency is obtained with a two-man team in which one man operates the penetrometer, informing the other man when the desired depths are achieved. The second man reads the load as indicated on the scale and records the values. It is also possible for one man to use the penetrometer and record the measurements by stopping the penetration at any intermediate depth, recording the previous readings, and then resume the penetration.

Note. Observance of the following rules is important in obtaining accurate data—

(1) The load indicator (7) registers "0" on the Scalee (8) when suspended by the handle and 15 when a 150 pound load is applied,
Note.. *Do not exceed 150 pounds to handle.*

(2) Inspect and clean the cone (6), extension rod (5) and cone rod (4) prior to each use.

(3) The penetrometer must be kept in a vertical position while in use.

(4) The appropriate rate of penetration is 1/2 inch to 1 inch per second. However, slightly faster or slower rates will not materially affect the readings.

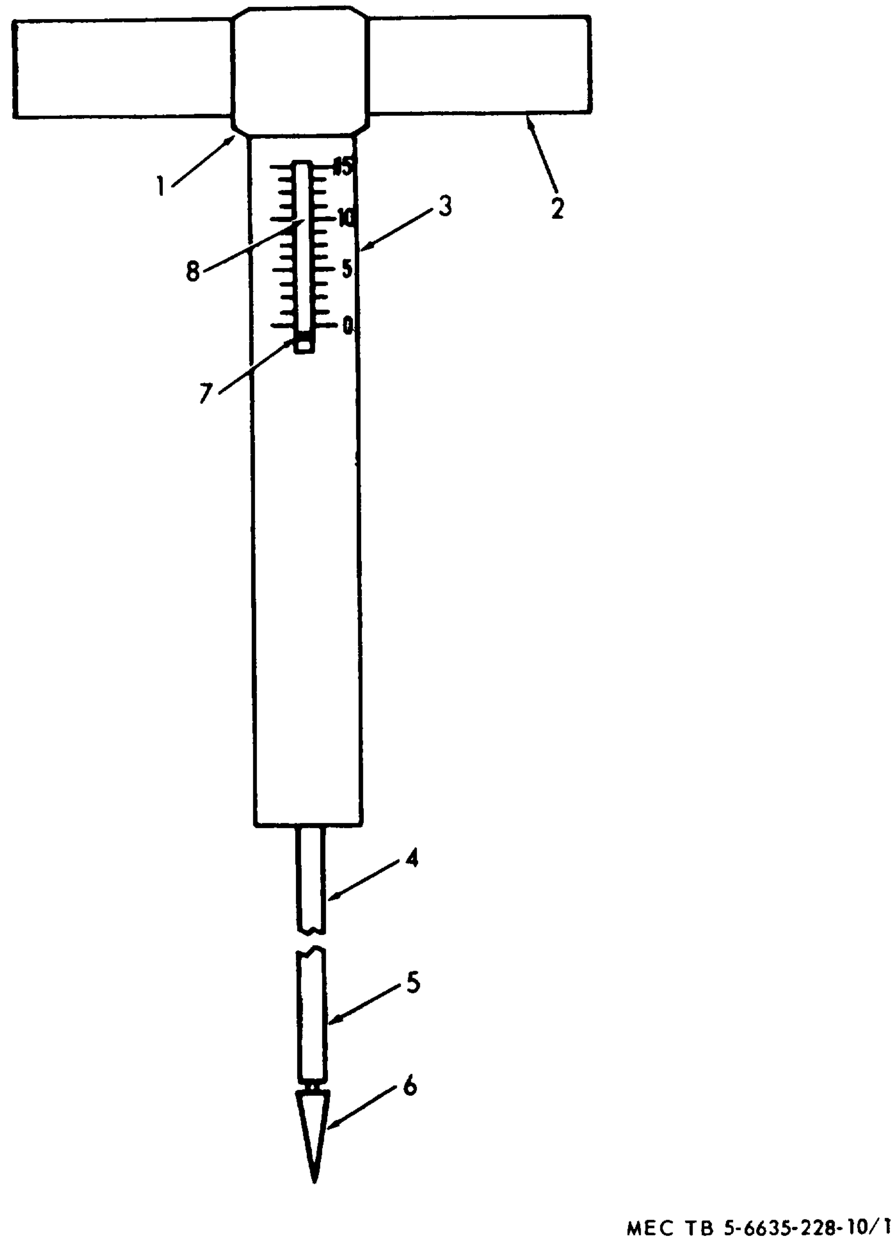
(5) If it is suspected that the cone is encountering a stone or other foreign matter at a depth where a reading is desired, make another penetration nearby.

(6) Readings must be taken at the proper depths. Carelessness in determining proper depth is one significant source of error in the use of the penetrometer.

7. Maintenance. *a. General.* The penetrometer is constructed of durable metals and needs little care other than cleaning and oiling.

b. Cleaning. Cleaning consists of removing dirt, grass and other foreign matter from the cone (6), the extension rod grooves and rods (4 and 5) as well as any accumulation of dirt around the lower spring cup and bushing housing at the bottom of the penetrometer housing (3).

c. Oiling. After cleaning and prior to storage, apply a light coat of engine oil (OE–10) to the surface of the cone (6), extension rods (5) and exposed portion of the cone rod (4), be sure to lubricate all threads.



1 Head
2 Cone cover and handle
3 Housing
4 Cone rod
5 Extension rod
6 Cone
7 Load-indicator
8 Scale

Figure 1. Airfield penetrometer front view

SECTION III

SOIL-STRENGTH EVALUATION

8. General. *a.* The number and location of measurements to be made with the airfield penetrometer vary with each area to be examined and the time available. For this reason, hard and fast rules for evaluating an airfield are not practicable, but the following instructions will be helpful.

b. The information in this section applies primarily to fine-grained soils (silts, clays, etc.) except for paragraph 11d which pertains to coarse-grained soils (sands).

9. Range of Readings. *a.* The airfield penetrometer has a range of 0 to 15.

b. A reading near 0 on the scale can occur in a very wet soil, which, of course, cannot support aircraft traffic.

c. A reading near 15 will occur in dry, compact clays or silts and in tightly packed sands or gravels.

d. Most aircraft that might be required to use an unpaved area could easily be supported for a substantial number of landings and takeoffs by a soil having an airfield index of 15.

10. Number of Measurements. *a.* Soil conditions are extremely variable; therefore, as many penetrometer readings will be taken in a given area as time and circumstances will permit.

b. The strength range and uniformity of the area will control the number of measurements required. Areas which are obviously too soft for emergency landing strips will be revealed after a few measurements, as will areas with strengths that are more than adequate to support aircraft traffic.

c. In all areas, it is advisable to test the softest-appearing spots first, since the softest condition controls the suitability of the area.

d. Soft spots are not always readily apparent, however, and if the first test results indicate barely adequate strength, the entire area will be examined. Penetrations in areas that appear to be firm and uniform may be few and widely spaced, e.g. approximately every 200 feet along the proposed center lime.

e. In areas of doubtful strength the penetrations will be more closely spaced, and areas on both sides of the center line will be measured. No less than three penetrations will be made at each location, and preferable five penetrations are desired.

f. If time permits or if inconsistencies are apparent, 10 penetrations will be made at each test location.

11. Penetrometer Readings. *a.* Soil strength usually increases with depth, but in some cases a thin, hard crust will overlie a deep, soft layer or the soil will contain thin layers of hard and soft material. For this reason, penetrations will be made to a depth of 24 inches unless prevented by a very firm condition at a lesser depth. When a penetration cannot be made to the full depth of 24 “inches, a hole will be dug or augered through the firm material and penetrometer readings will be taken in the bottom of the hole to ensure that no soft layer underlies the firm layer.

b. Readings will be taken every 2 inches from the surface to a depth of 24 inches. Generally, surface reading will not be used when readings are averaged to obtain a representative airfield index for common cargo aircraft (table 1).

c. In the normal soil condition, i.e. when strength increases with depth, the readings at the 2-inch to 8-inch depths (4 in. to 10 in. for dry sands and for soil that will be trafficked by larger aircraft) will be used to designate the soil strength for airfield evaluation. If readings in this critical layer at any one test location do not differ more than 3 or 4 units, the arithmetic average of these readings can be taken as the airfield index for the area represented by the readings. When the range between the highest and lowest readings is more than 4, the interpretation of the data in arriving at a rating figure will be the lower readings.

d. In an area in which a hard crust (less than 4 in. thick) overlies a much softer soil, the readings in the crust will not be used in evaluating the airfield. For example, if a 3 inch-thick crust results in an average reading of 10 at the 2 inch depth, while the average reading is 5 below the 3 inch depth, the area will be evaluated at 5. If the crust is more than 4 inches thick, it will in all probability aid in supporting aircraft, but the readings below the crust must be considered in the evaluation. If the crust in the example above is 5 inches thick, the rating of the field would then be approximately halfway between the 10 of the crust and the 5 of the underlying soil, or, conservatively, 7. Innumerable combinations of crust thickness and strength and underlying soil strength can occur. Therefore, sound reasoning and engineering judgment must be used in evaluating such areas.

e. In an area where the top layer of soil is very soft and thin with a firmer underlying layer of soil, the evaluation is also a matter of judgment. If, for example, 1 inch to 2 inches of soil with the airfield index averaging 5 overlies a soil with an index of 10, the field can be rated as 10. But if this soft layer is more than 4 inches thick, the field will be rated at 5. Areas of fine-grained soils with very low readings in the top 1 inch or more are likely to be slippery or sticky, especially if the soil is a clay.

12. Precautions for Sands. *a.* Many sands occur in a loose state. Such sands when relatively dry will show increasing airfield indexes with depth, but the 2-inch depth index will often be low, possibly 3 or 4. Such sands usually are capable of supporting aircraft whose requirements are much higher than an airfield index of 3 or 4, because the strength of the sand actually increases under the confining action of the aircraft tires.

b. Generally, any dry sand or gravel will be adequate for aircraft in the C–130 class (60- to 80-p.s.i. tire-inflation pressure), regardless of the penetrometer reading. This is also true for smaller aircraft with tire-inflation pressure 20- to 30-p.s.i. range.

c. All sands and gravels in a "quick" condition (water percolating through them) must be avoided. Evaluation of moist sands will be based on the penetrometer readings obtained as described in paragraphs 10 and 11.

Table 1. Required Airfield Index for Common Cargo Aircraft

Aircraft	Gross aircraft weight lb	Tire-inflation pressure p.s.i.	Normal load on single wheel of main gear lb	No. of passes	Airfield index required
C–47	31,000	50	14,000	1–3	3.2
				25	3.8
				250	4.9
				1000	5.8
C–119	66,000	70	15,000	1–3	3.9
				25	5.0
				250	6.5
				1000	7.5
C–123	58,100	85	26,100	1–3	4.9
				25	5.9
				250	7.5
				1000	8.6
C–124	175,000	65	39,400	1–3	6.2
				25	6.2
				250	9.7
				1000	11.2
C–130	116,000	60	26,100	1–3	3.9
				25	5.3
				250	7.0
				1000	7.9
C–130	135,000	80	30,000	1–3	5.2
				25	6.9
				250	8.7
				1000	10.1
C–133	275,000	95	31,000	1–3	7.0
				25	9.0
				250	11.4
				1000	13.2
C–135	276,000	125	31,000	1–3	7.2
				25	9.5
				250	12.0
				1000	13.9
C–141	317,000	185	35,700	1–3	9.4
				25	12.3
				250	—
				1000	—

SECTION IV

APPLICATION OF DATA

13. General Application. *a.* Once the airfield for a given landing strip is established, its relation to aircraft load, tire-inflation pressure, and anticipated number of coverages (a measure of load repetitions) must be determined. Relations of airfield index to these factors have been established from data gathered over many years.

b. Figure 2 is a nomograph relating single-wheel or equivalent single-wheel load, tire pressure, airfield index, and coverages. If the load and tire pressure of the aircraft and the airfield index are known, it is possible to determine the number of coverages that can safely be made by the aircraft by applying information to the nomograph (fig. 2).

c. Refer to figure 3 for procedure in determining the equivalent single-wheel load of aircraft having multiple-wheel assemblies (ESWL).

d. The required airfield index for 1 to 1,000 passes of some of the more common types of cargo aircraft is listed in table 1. In using the nomograph (fig. 2) directly, allowable coverages can be determined. However, this determination must be converted to aircraft passes for ultimate use. The relation of passes to coverages depends on the number, width, and spacing of wheels on an aircraft as well as the degree to which the aircraft can be expected to wander left and right of a central position. In nearly all cases, it is adequate to estimate the pass-per-coverage ratio from the following tabulation which shows the number of passes per coverage of four aircraft gear configurations.

Gear configuration	*Number of Passes--per-coverage*
Single wheel	5
Twin wheel	3-1/2
Single tandem	2
Twin tandem	2

Caution: Users of the information in this technical bulletin must be awars of its limitations. The curves and tabular information in figure 2 and table 1 are based on correlations of aircraft performance and airfield indexes. Unfortunately, these are not exact correlations uniquely relating aircraft performance to airfield index. As soils vary in type and condition from site to site, the relation of airfield index to aircraft performance also varies. For this reason, the curves in figure 2 and the data in table 1 will not in all cases accurately predict performance. These relations have been selected so that in nearly all cases aircraft performance will be at least that indicated. However, it should be recognized that on occasions performance may not be quite as good as that indicated.

14. Illustrative Problem. To assist the user of this technical bulletin, an illustrative prob lem and its solution are presented as follows:

a. Problem. Can 20 C–124 aircraft make three deliveries each to a site having an airfield index of 12?

b. Data, The gross weight of the aircraft is 175,000 lb; the tire pressure is 65 p.s.i. The twin-wheel assembly has 44-inch center-to-center (c-c) spacing.

c. solution.

20 aircraft x 3 deliveries x 2 passes/delivery = 120 passes

$$\frac{120 \text{ passes}}{\frac{3\text{-}1/2 \text{ passes}}{(\text{coverage}^*)}} = 34 \text{ coverages}$$

To determine equivalent single-wheel load (ESWL), the procedure described in figure 3 in used:

Tire-inflation pressure = 65 p.s.i.

Single-wheel load (SWL) = 39,400 lb (from table 1)

$$\text{Tire contact area (A)} = \frac{39{,}400}{65} = 606 \text{ sq in.}$$

Next, the radius of a circle having an area of 606 sq in. is determined:

$$\text{Equivalent radius (r)} = \left(\frac{A}{\pi}\right)^{1/2} = \left(\frac{606}{3.14}\right)^{1/2} = 13.9 \text{ in.}$$

Knowing the equivalent radius of 13.9 in. and the c-c wheel spacing of 44 in., it is possible to get the spacing in radii:

$$\text{c-c wheel spacing in radii} = \frac{44 \text{ in.}}{13.9 \text{ in/radius}} = 3.16 \text{ radii}$$

* From para 13d.

Next, determine the increase in SWL for adjacent wheel = 27 percent (from curve in figure 3)

Therefore: ESWL = 1.28 x SWL
= 1.28 X 39,400
ESWL = 50,400
Tire pressure = 65 p.s.i.

Airfield index required for 34 coverages = 9.0 (from figure 2)

d. Answer. Operations are safe, since required airfield index (9.0) is less than available airfield index (12).

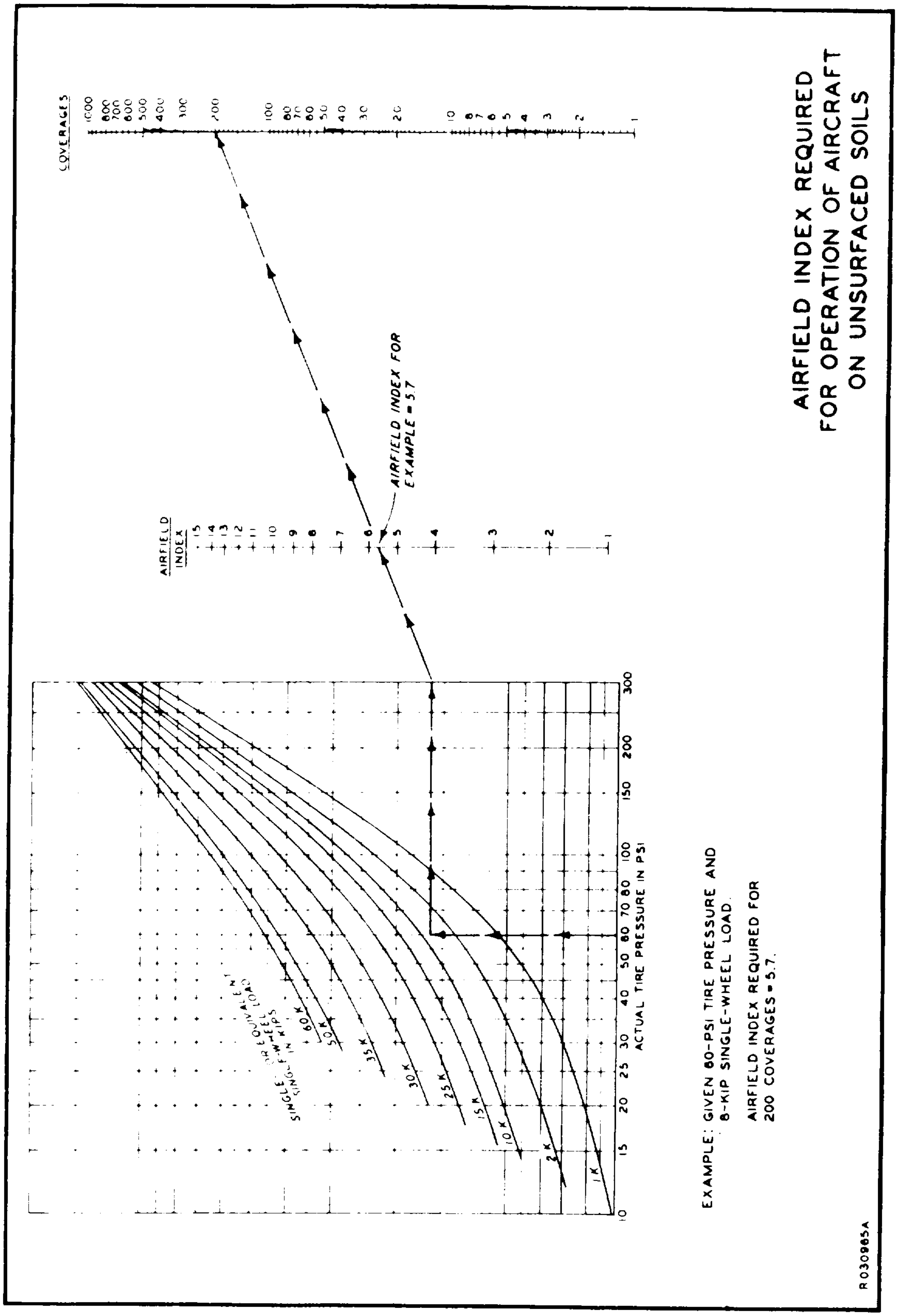


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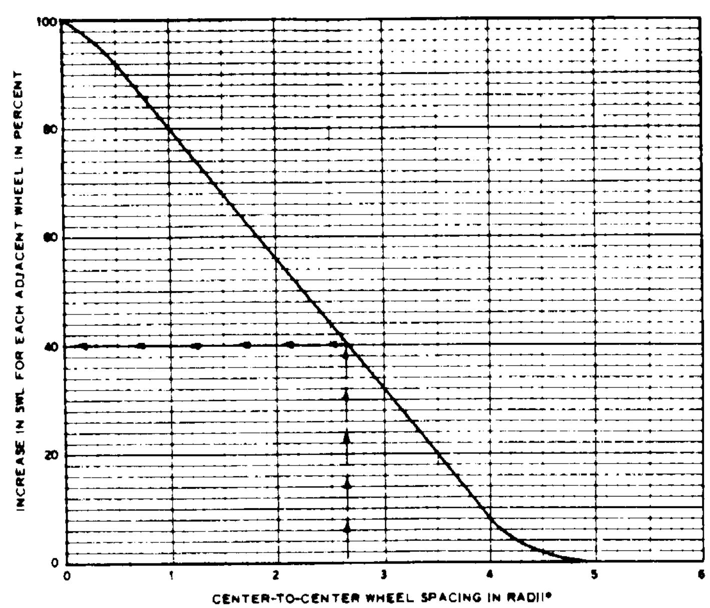
Figure 2. Nomograph



NOTE: * ANY WHEEL SPACED 4 RADII (CENTER TO CENTER) OR GREATER FROM A PARTICULAR WHEEL IS CONSIDERED TO HAVE NO EFFECT ON THE ESWL FOR THAT WHEEL.

** VALUES READ FROM CURVE AS INDICATED BY ARROWS.

PROCEDURE FOR DETERMINING THE ESWL FOR MULTIPLE-WHEEL ASSEMBLIES

ASSEMBLY LOAD = 100,000 LB

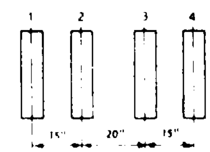
TIRE CONTACT AREA (A) = 100 IN ^{2}

SINGLE-WHEEL LOAD (SWL) = $\frac{\text{ASSEMBLY LOAD}}{\text{NO. OF WHEELS ON ASSEMBLY}}$

SWL = 25,000 LB

A = 100 IN ^{2} = πr^2

$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{100}{\pi}} = 5.65$ IN.



TWIN-TWIN ASSEMBLY

DETERMINE EQUIVALENT SINGLE-WHEEL LOAD (ESWL) FOR WHEEL NO. 2

WHEEL NUMBER	CENTER-TO-CENTER SPACING INCHES	CENTER-TO-CENTER SPACING RADII	INCREASE IN SWL PERCENT
1	15	2.65	40.2**
2			
3	20	3.54	19.0
4	35	6.19*	
		TOTAL	59.2

ESWL = 1.592 × SWL = 39,800 LB

UNLESS THE LOCATION OF THE MAXIMUM ESWL IS OBVIOUS, THE ESWL FOR EACH WHEEL OF THE ASSEMBLY AND AT THE CENTER OF THE ASSEMBLY WILL BE DETERMINED IN ORDER TO OBTAIN THE MAXIMUM ESWL FOR A GIVEN ASSEMBLY.

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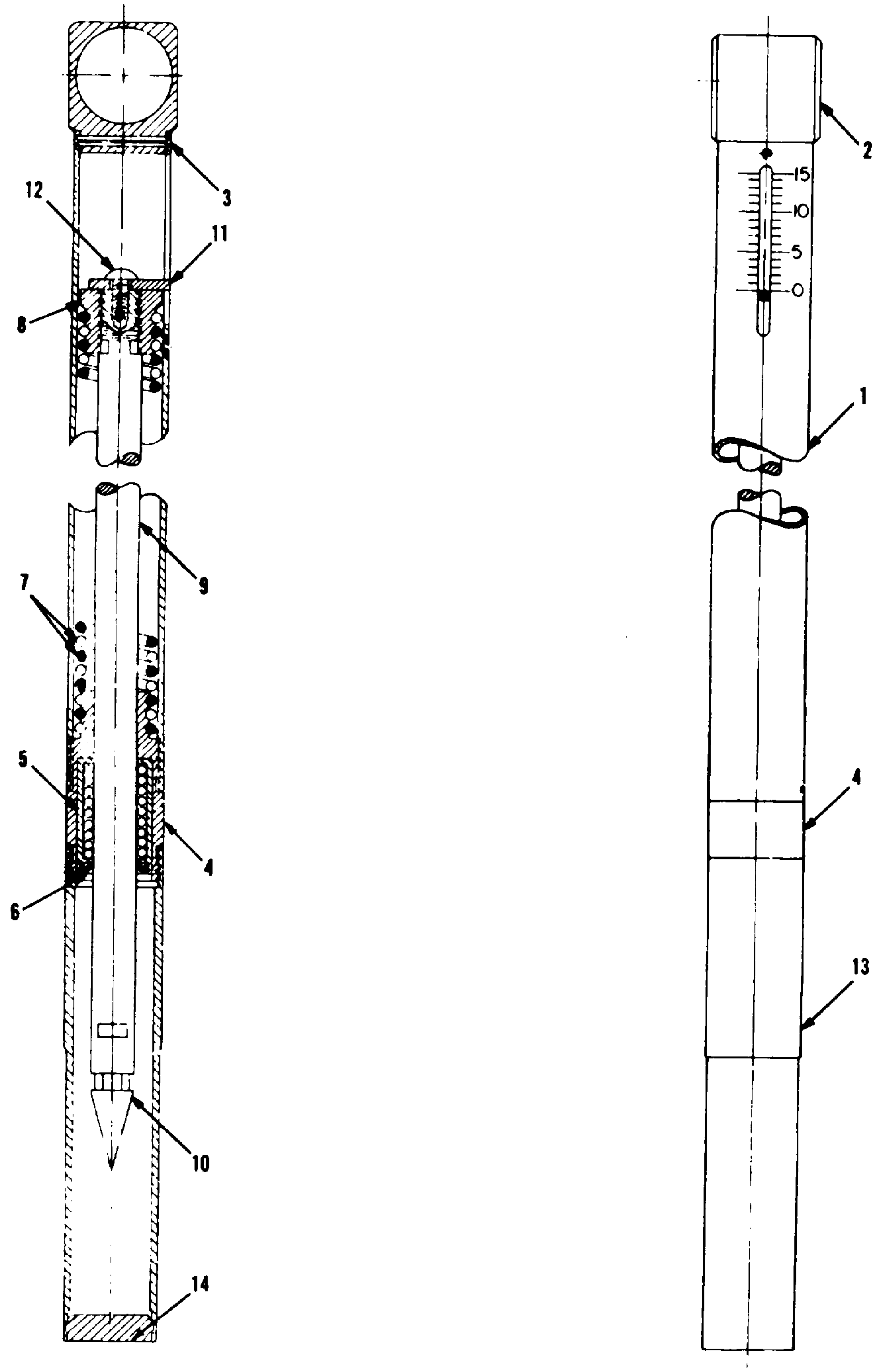
Figure 3. Curve for determining equivalent single-wheel load for multiple-wheel assemblies

APPENDIX A

PENETROMETER PARTS LIST

Description	Quantity incorporated per end item	Fig. No.	Item No.
Bushing, ball	1	4	5
Case, carrying	1		
Cone	2	4	10
Cup, lower spring & bushing housing	1	4	4
Cup, upper spring	1	4	8
Handle and cone cover	1	4	13
Head	1	4	2
Housing	1	4	1
Indicator, load	1	4	11
Pin, spring, cres, 0.94 in. dia. x 1.125 in. lg.	2	4	3
Plug	1	4	14
Rod, cone	1	4	9
Rod, extension	2	4	15
Screw, mach, pan hd, cross-recessed, carbon stl cad P1 #10-24 Unc-2A x 3/8 in. lg.	1	4	12
Seal	1	4	6
Spring, helical extension	2	4	7
Wrench, 11/32 in. x 3-3/4 in. lg.	2		



MEC TB 5-6635-228-10/Fig. 4

Figure 4. Penetrometer parts identification

1 Housing
2 Head
3 Pin, spring
4 Cup, lower spring and bushing housing
5 Bushing, ball
6 Seal
7 Spring, helical extension
8 Cup, upper spring
9 Rod, cone
10 Cone
11 Indicator, load
12 Screw
13 Handle and cone cover
14 Plug
15 Rod, extension

Figure 4. Continued

By Order of the Secretary of the Army:

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CofSptS (1)
USAMB (1)
USAARTYBD (2)
USAARENBD (2)
USAIB (2)
USAADBD (2)
USAAESWBD (2)
USAAVNTBD (2)
USCONARC (3)
OS Maj Comd (5)
USAMC (1)
MDW (1)
Armies (2)
Corps (2)
USAC (1)
Div (2)
Engr Bde (1)
USMA (2)
Svc Colleges (2)
Br Svc Sch (2)
Gen Dep (10)
Engr Dep (10)
Army Dep (2) except
TOAD (3)
USA Tml Comd (2)
Army Tml (1)
Div Engr (2)
Engr Dist (2)
USA Engr RD Lab (3)
USAMEC (46)
USACDCEC (10)
USAECFB (5)
USAREUR Engr Proc Cen (2)
USAREUR Engr Sup Con Agcy (10)
Engr FLDMS (2)
Ft Knox FLDMS (10)
Fld Comd, DASA (8)
AMS (3)
USAREURCOMZ (2)
MAAG (1)
JBUSMC (1)
Units org under fol TOE:
5-48 (2)
5-237 (5)
5-262 (5)
5-267 (1)
5-278 (5)
5-279 (2)

NG: State AG (3).

USAR: Same as Active Army except allowance is one copy to each unit.

For explanation of abbreviations used see AR 320-50.

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