



Designation: D6951/D6951M – 18

Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications¹

This standard is issued under the fixed designation D6951/D6951M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of the penetration rate of the dynamic cone penetrometer with an 8-kg [17.6-lb] hammer (8-kg [17.6-lb] DCP) through undisturbed soil or compacted materials, or both. The penetration rate may be related to *in situ* strength such as an estimated *in situ* CBR (California Bearing Ratio). A soil density may be estimated (Note 1) if the soil type and moisture content are known. The DCP described in this test method is typically used for pavement applications.

1.2 The test method provides for an optional 4.6-kg [10.1-lb] sliding hammer when the use of the 8-kg [17.6-lb] sliding mass produces excessive penetration in soft ground conditions.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Testing and Evaluation.

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2. Referenced Documents

2.1 *ASTM Standards*:²

D7380 Test Method for Soil Compaction Determination at Shallow Depths Using 5-lb (2.3 kg) Dynamic Cone Penetrometer

3. Terminology

3.1 *Definitions*:

3.1.1 *8-kg [17.6-lb] DCP dynamic cone penetrometer, n*—a device with an 8-kg [17.6-lb] hammer used to assess the *in situ* strength of undisturbed soil or compacted materials, or both, by dropping the hammer from a set height and measuring the depth of penetration and counting hammer drops (blows). (See Fig. 1.)

3.1.2 *sliding attachment, n*—an optional device used in reading the distance the DCP tip has penetrated. It may be fastened to the anvil or lower rod to hold/slide along a separate measuring rod, or it may be fastened to the separate rod and slide along a graduated drive rod. (See Fig. 1.)

4. Summary of Test Method

4.1 The operator drives the DCP tip into soil by lifting the sliding hammer to the handle and then releasing it. The total penetration for a given number of blows is measured and recorded in mm/blow, which is then used to describe stiffness, estimate an *in situ* CBR strength from an appropriate correlation chart, or other material characteristics.

5. Significance and Use

5.1 This test method is used to assess *in situ* strength of undisturbed soil and compacted materials (or both). The penetration rate of the 8-kg [17.6-lb] DCP can be used to estimate *in situ* CBR (California Bearing Ratio), to identify strata thickness, shear strength of strata, and other material characteristics.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

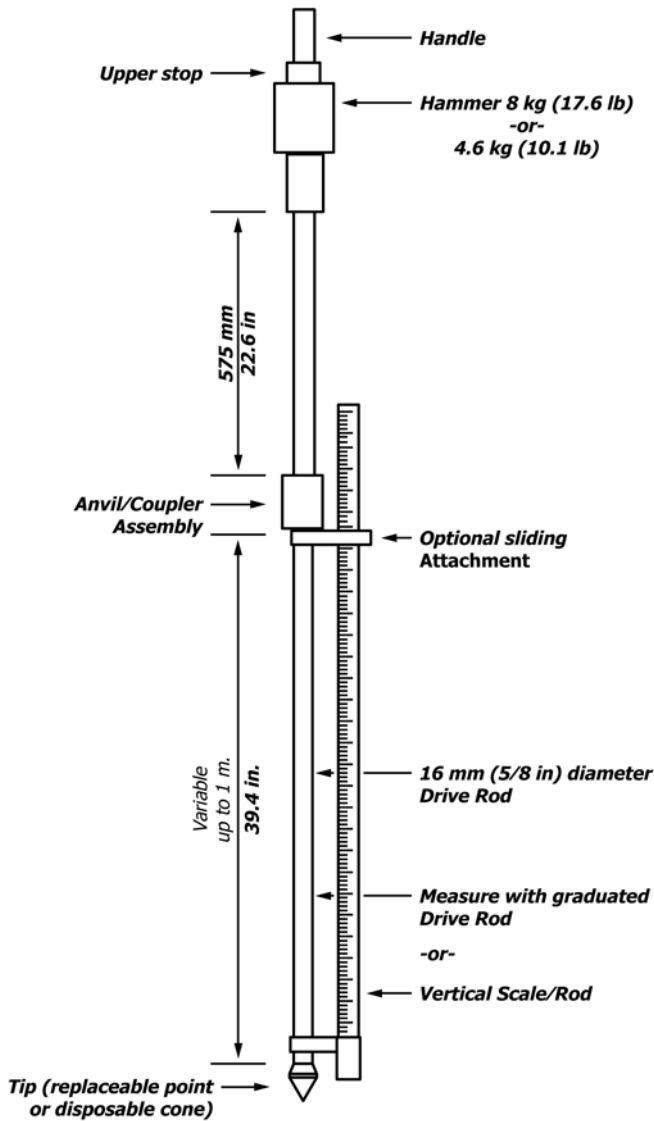


FIG. 1 Schematic of DCP Device

materials. The 8-kg [17.6-lb] DCP cannot be used in highly stabilized or cemented materials or for granular materials containing a large percentage of aggregates greater than 50 mm [2 in.].

5.5 The 8-kg [17.6-lb] DCP can be used to estimate the strength of *in situ* materials underlying a bound or highly stabilized layer by first drilling or coring an access hole.

NOTE 1—The DCP may be used to assess the density of a fairly uniform material by relating density to penetration rate on the same material. In this way, undercompacted or “soft” spots can be identified, even though the DCP does not measure density directly.³

5.6 A field DCP measurement results in a field or *in situ* CBR and will not normally correlate with the laboratory or soaked CBR of the same material. The test is thus intended to evaluate the *in situ* strength of a material under existing field conditions.

6. Apparatus

6.1 The 8-kg [17.6-lb] DCP is shown schematically in Fig. 1. It consists of the following components: a 16-mm [5/8-in.] diameter steel drive rod with a replaceable point or disposable cone tip, an 8-kg [17.6-lb] hammer which is dropped from a fixed height of 575 mm [22.6 in.], a coupler assembly, and a handle. The tip has an included angle of 60° and a diameter at the base of 20 mm [0.79 in.]. (See Fig. 2.)

6.1.1 The apparatus is typically constructed of stainless steel, with the exception of the replacement point tip, which may be constructed from hardened tool steel or a similar material resistant to wear.

6.2 The following tolerances are required:

6.2.1 Hammer weight measurement of 8.0 kg [17.6 lb]; tolerance is 0.01 kg [0.02 lb],

6.2.2 Hammer weight measurement of 4.6 kg [10.1 lb.]; tolerance is 0.01 kg [0.02 lb],

6.2.3 Drop of hammer measurement of 575 mm [22.6 in.]; tolerance is 1.0 mm [0.04 in.],

³ “METHOD ST6: Measurement of the In Situ Strength of Soils by the Dynamic Cone Penetrometer (DCP), Special Methods for Testing Roads,” Draft TMH6, Technical Methods for Highways (TMH), Pretoria, South Africa, ISBN 0 7988 2289 9, 1984, p. 20.

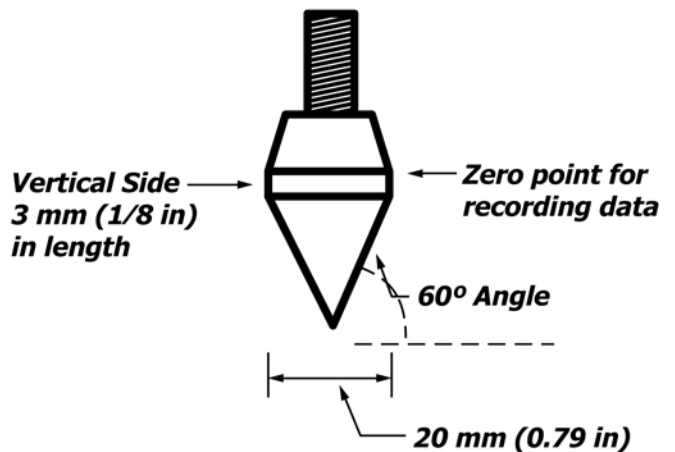


FIG. 2 Replaceable Point Tip

5.1.1 Other test methods exist for DCPs with different hammer weights and cone tip sizes, which have correlations that are unique to the instrument, such as Test Method D7380.

5.2 The 8-kg [17.6-lb] DCP is held vertically, and therefore is typically used in horizontal construction applications, such as pavements and floor slabs.

5.3 This instrument is typically used to assess material properties down to a depth of 1000 mm [39 in.] below the surface. The penetration depth can be increased using drive rod extensions. However, if drive rod extensions are used, care should be taken when using correlations to estimate other parameters, since these correlations are only appropriate for specific DCP configurations. The mass and inertia of the device will change and skin friction along drive rod extensions will occur.

5.4 The 8-kg [17.6-lb] DCP can be used to estimate the strength characteristics of fine- and coarse-grained soils, granular construction materials, and weak stabilized or modified

6.2.4 Tip angle measurement of 60° included angle; tolerance is 1°, and

6.2.5 Tip base diameter measurement of 20 mm [0.79 in.]; tolerance is 0.25 mm [0.01 in.].

NOTE 2—A disposable cone tip may be used. The disposable cone tip is held in place with an O-ring, which allows the cone tip to be easily detached when the drive rod is pulled upward after completion of the test. The disposable cone tip is shown schematically in Fig. 3.

6.3 In addition to the DCP, the following equipment is needed:

- 6.3.1 Tools for assembling the DCP,
- 6.3.2 Lubricating oil,
- 6.3.3 Thread locking compound, and
- 6.3.4 Data recording form (see Table 1).

6.4 Depending on the circumstances, the following equipment may also be needed or is recommended:

- 6.4.1 A vertical scale, graduated, using increments of 1.0 mm [0.04 in.], or measuring rod longer than the longest drive rod if the drive rod(s) are not graduated,
- 6.4.2 An optional sliding attachment for use with a separate scale or measuring rod,
- 6.4.3 A rotary hammer drill or coring apparatus capable of drilling a minimum diameter hole of 25 mm [1 in.]. A larger hole may be required, depending on the underlying material or the need for addition tests or sampling,
- 6.4.4 A wet/dry vacuum or suitable alternative to remove loose material and fluid if an access hole is made before testing,
- 6.4.5 Field power supply to power items in 6.4.3 and 6.4.4,
- 6.4.6 Disposable cone tips,
- 6.4.7 Dual-mass hammer (see Fig. 4), and
- 6.4.8 Extraction jack, recommended if disposable cone tips are not used (see Fig. 5).

NOTE 3—A 4.6-kg [10.1-lb] hammer (see Fig. 4) may be used in place of the 8-kg [17.6-lb] hammer, provided that the standard drop height is maintained. The 4.6-kg [10.1-lb] hammer is used in weaker materials where the 8-kg [17.6-lb] hammer would produce excessive penetration.

NOTE 4—An automated version of the DCP (ADCP) may be used, provided all requirements of this standard with respect to the apparatus and procedure are met.

NOTE 5—An automated data collection system may be used, provided it measures and records to the nearest 1 mm [0.04 in.] and does not interfere with the operation/results of the device.

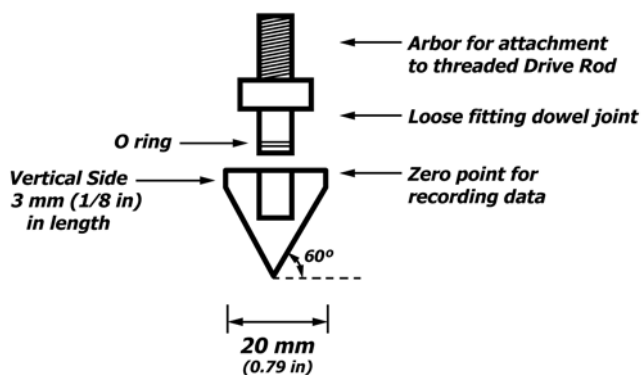


FIG. 3 Disposable Cone Tip

7. Hazards

7.1 Be aware and maintain control of the hammer during movement of the device prior to and after testing to prevent pinch point injuries.

7.2 Always secure the hammer or the assembled DCP device, or both, when placing it on a flat, elevated surface to prevent it from rolling off and causing personal injury or damage to the instrument.

7.3 Do not put hands near the anvil when the hammer is raised. Keep one hand on the handle while operating the DCP.

8. Preparation of Apparatus

8.1 *Equipment Check*—Before beginning a test, the DCP device is inspected for fatigue-damaged parts, in particular the coupler and handle, and excessive wear of the drive rod and replaceable point tip. Drive rods should be visually inspected for straightness; rolling it on a flat surface can aid in detecting a bent rod.

8.2 All joints must be securely tightened, including the coupler assembly and the replaceable point tip (or the adapter for the disposable cone tip) to drive rod. It is recommended using wrenches to tighten all joints to prevent damage to the threads in the joints. Channel lock or similar pliers are not recommended.

9. Procedure

9.1 *Basic Operation*—The operator holds the device by the handle in a vertical or plumb position and lifts and releases the hammer from the standard drop height. The recorder measures and records the total penetration for a given number of blows or the penetration per blow.

9.2 Initial Reading:

9.2.1 *Testing a Surface Layer*—The DCP is held vertically and the tip seated such that the top of the widest part of the tip is flush with the surface of the material to be tested. An initial reading is obtained from the graduated drive rod or a separate vertical scale/measuring rod. The distance is measured to the nearest 1 mm [0.04 in.]. Some sliding reference attachments allow the scale/measuring rod to be set/marked at zero when the tip is at the zero point shown in Figs. 2 and 3.

9.2.2 *Testing Below a Bound Layer*—When testing materials underlying a bound layer, a rotary hammer drill or coring apparatus meeting the requirements given in 6.4.3 is used to provide an access hole to the layer to be tested. Wet coring requires that coring fluid be removed immediately and the DCP test be performed as soon as possible, but not longer than 10 min following completion of the coring operation. The coring fluid must not be allowed to soak into or penetrate the material to be tested. A wet/dry vacuum or suitable alternative is used after completion of drilling or coring to remove loose materials and fluid from the access hole before testing. To minimize the extent of the disturbance from the rotary hammer, drilling should not be taken completely through the bound layer, but stopped short by about 10 to 20 mm [0.4 to 0.8 in.]. The DCP is then used to penetrate the bottom portion of the bound layer. This can be a repetitive process between drilling and doing DCP tests to determine the thickness of the layer.

TABLE 1 DCP Data Sheet⁴

Project: Forest Service Road				Date: 7 July 2001			
Location: STA 30+50, 1 M RT of C/L				Personnel: JLS & SDT			
Depth of zero point below Surface: 0				Hammer Weight: 8 kg [17.6 lb]			
Material Classification: GW/CL				Weather: Overcast, 25 °C, [72 °F]			
Pavement conditions: Not applicable				Water Table Depth: Unknown			
Number of Blows ^A	Cumulative Penetration mm [in.] ^B	Penetration Between Readings mm [in.] ^C	Penetration per Blow mm [in.] ^D	Hammer Factor ^E	DCP Index mm/blow [in./blow] ^F	CBR % ^G	Moisture % ^H
0	0 [0]
5	25 [0.98]	25 [0.98]	5 [0.196]	1	5 [0.196]	50	
5	55 [2.17]	30 [1.19]	6 [0.238]	1	6 [0.238]	40	
15	125 [4.92]	70 [2.75]	5 [0.183]	1	5 [0.183]	50	
10	175 [6.89]	50 [1.97]	5 [0.197]	1	5 [0.197]	50	
5	205 [8.07]	30 [1.18]	6 [0.236]	1	6 [0.236]	40	
5	230 [9.06]	25 [0.99]	5 [0.198]	1	5 [0.198]	50	
10	280 [11.02]	50 [1.96]	5 [0.196]	1	5 [0.196]	50	
5	310 [12.20]	30 [1.18]	6 [0.236]	1	6 [0.236]	40	
5	340 [13.39]	30 [1.19]	6 [0.238]	1	6 [0.238]	40	
5	375 [14.76]	35 [1.37]	7 [0.274]	1	7 [0.274]	35	
5	435 [17.13]	60 [2.37]	12 [0.474]	1	12 [0.474]	18	

^A Number of hammer blows between test readings.

^B Cumulative penetration after each set of hammer blows.

^C Difference in cumulative penetration (Footnote B) between readings.

^D Footnote C divided by Footnote A.

^E Enter 1 for 8-kg [17.6-lb] hammer; 2 for 4.6-kg [10.1-lb] hammer.

^F Footnote D × Footnote E.

^G From CBR versus DCP index correlation.

^H % Moisture content when available.

9.2.3 *Testing Pavement with Thin Seals*—For pavements with thin seals, the tip is advanced through the seal until the zero point (see Figs. 2 and 3) of the tip is flush with the top of the layer to be tested.

9.2.4 Once the layer to be tested has been reached, a reference reading is taken with the zero point at the top of that layer and the thickness of the layer(s) cored through recorded. This reference reading is the point from which the subsequent penetration is measured.

9.3 Testing Sequence:

9.3.1 *Dropping the Hammer*—The DCP device is held in a vertical or plumb position. The operator raises the hammer until it makes only light contact with the handle. The hammer shall not impact the handle when being raised. The hammer is then allowed to free fall and impact the anvil coupler assembly. The number of blows and corresponding penetrations are recorded as described in 9.4.

9.3.2 *Depth of Penetration*—The depth of penetration will vary with application. For typical highway applications, a penetration less than 900 mm [35 in.] will generally be adequate.

9.3.3 *Refusal*—The presence of large aggregates or rock strata will either stop further penetration or deflect the drive rod. If after five blows the device has not advanced more than 2 mm [0.08 in.] or the handle has deflected more than 75 mm [3 in.] from the vertical position, the test shall be stopped, and the device moved to another test location. The new test location should be a minimum of 300 mm [12 in.] from the prior location to minimize test error caused by disturbance of the material.

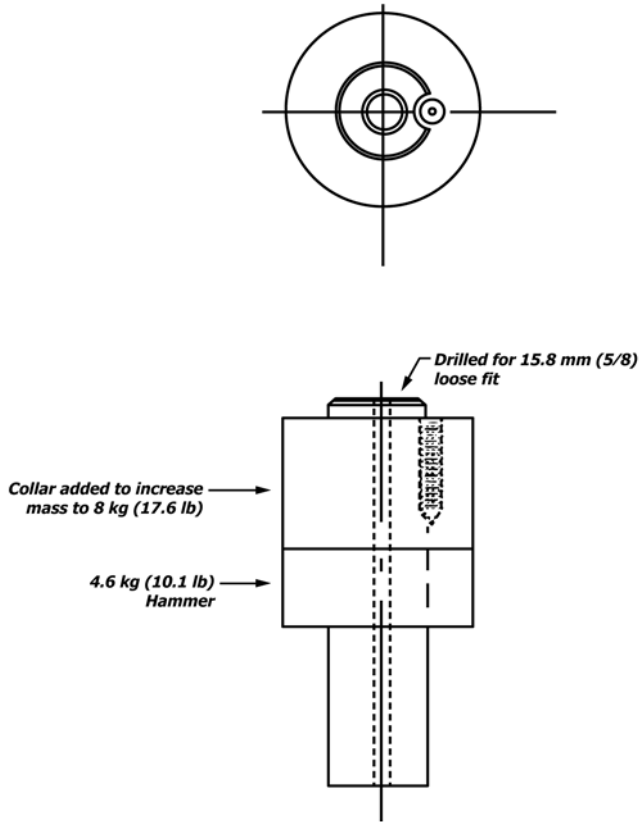
9.3.4 *Extraction*—Following completion of the test, the device should be extracted using the extraction jack when using a replaceable point tip. When using a disposable cone, the device is extracted by driving the hammer upward against the handle.

9.4 Data Recording:

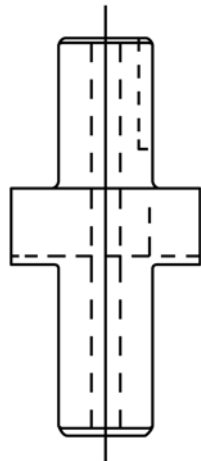
9.4.1 A form like the one shown in Table 1 is suggested for data recording. The recorder enters the header information before the test. The actual test data are recorded in Column 1 (Number of Blows) and Column 2 (Cumulative Penetration in mm); if the moisture content is available, it is entered in Column 8. When testing a subsurface layer through a drilled or cored access hole, the first reading corresponds to the referenced reading at the top of the layer to be tested as per 9.2.2. The number of blows between readings may be varied depending on the resistance of the material. Normally, readings will be taken after a fixed number of blows, that is, one blow for soft material, five blows for “normal” materials, and ten blows for very resistive materials. The penetration to the nearest 1 mm [0.04 in.] corresponding to a specific number of blows is recorded. A reading is taken immediately when the material properties or penetration rate change significantly.

10. Calculation and Interpretation of Results

10.1 The estimated *in situ* CBR is computed using the DCP index (Column 6, Table 1) and Table 2 for each set of readings. The penetration per blow may then be plotted against scale reading or total depth. The penetration per blow is then used to estimate *in situ* CBR or shear strength using the appropriate correlation. For example, the correlation of penetration per



8 kg (17.6 lb) Hammer



4.6 kg (10.1 lb) Hammer

FIG. 4 Schematic of Dual-Mass Hammer

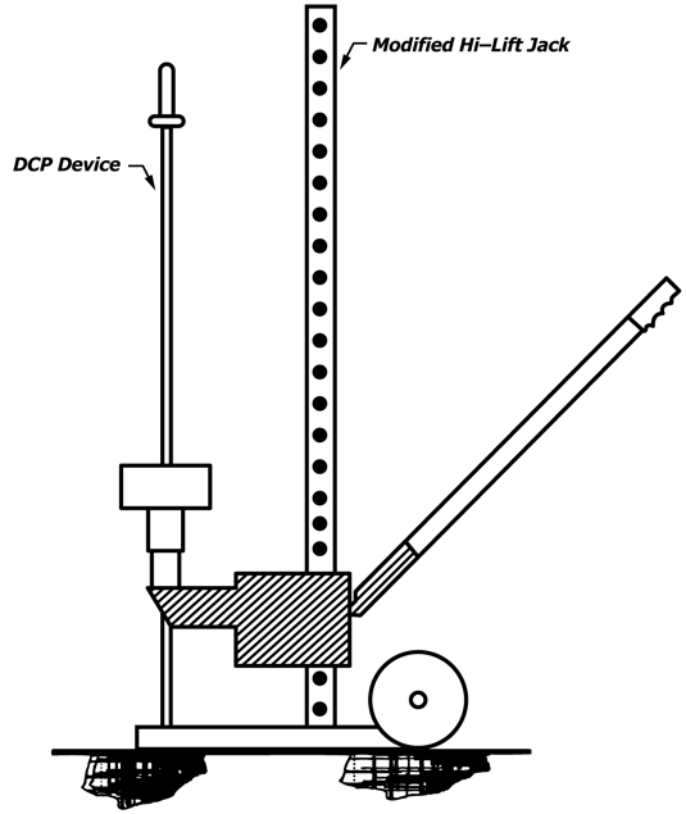


FIG. 5 Schematic of DCP Extraction Jack

TABLE 2 Tabulated Correlation of CBR versus DCP Index⁴

DCP Index mm/blow ^A	CBR %	DCP Index mm/blow ^A	CBR %	DCP Index mm/blow ^A	CBR %
<3	100	39	4.8	69 - 71	2.5
3	80	40	4.7	72 - 74	2.4
4	60	41	4.6	75 - 77	2.3
5	50	42	4.4	78 - 80	2.2
6	40	43	4.3	81 - 83	2.1
7	35	44	4.2	84 - 87	2.0
8	30	45	4.1	88 - 91	1.9
9	25	46	4.0	92 - 96	1.8
10 - 11	20	47	3.9	97 - 101	1.7
12	18	48	3.8	102 - 107	1.6
13	16	49 - 50	3.7	108 - 114	1.5
14	15	51	3.6	115 - 121	1.4
15	14	52	3.5	122 - 130	1.3
16	13	53 - 54	3.4	131 - 140	1.2
17	12	55	3.3	141 - 152	1.1
18 - 19	11	56 - 57	3.2	153 - 166	1.0
20 - 21	10	58	3.1	166 - 183	0.9
22 - 23	9	59 - 60	3.0	184 - 205	0.8
24 - 26	8	61 - 62	2.9	206 - 233	0.7
27 - 29	7	63 - 64	2.8	234 - 271	0.6
30 - 34	6	65 - 66	2.7	272 - 324	0.5
35 - 38	5	67 - 68	2.6	>324	<0.5

⁴ For DCP Index in units of in./blow, divide by 25.4.

blow (DCP) in Table 2 is derived from the following equation recommended by the U.S. Army Corps of Engineers:⁴

⁴ Webster, S. L., Grau, R. H., and Williams, T. P., "Description and Application of Dual Mass Dynamic Cone Penetrometer," Report GL-92-3, Department of the Army, Washington, DC, May 1992, p. 19.

$$CBR = 292/DCP^{1.12} \text{ for DCP in mm/blow} \quad (1)$$

$$CBR = 292/(DCP \times 25.4)^{1.12} \text{ for DCP in in./blow} \quad (2)$$

The above equation is used for all soils except for CL soils

below CBR 10 and CH soils. For these soils, the following equations are recommended by the U.S. Army Corps of Engineers.⁵

$$\text{CBR} = 1/(0.017019 \times \text{DCP})^2 \text{ for DCP in mm/blow} \quad (3)$$

$$\text{CBR} = 1/(0.432283 \times \text{DCP})^2 \text{ for DCP in in./blow} \quad (4)$$

for CL soils with CBR <10 and

$$\text{CBR} = 1/(0.002871 \times \text{DCP}) \text{ for DCP in mm/blow} \quad (5)$$

$$\text{CBR} = 1/(0.072923 \times \text{DCP}) \text{ in in./blow} \quad (6)$$

for CH soils.

10.1.1 Selection of the appropriate correlation is a matter of professional judgment.

10.2 If a distinct layering exists within the material tested, a change of slope on a graph of cumulative penetration blows versus depth will be observed for each layer. The exact interface is difficult to define because, in general, a transition zone exists between layers. The layer thickness can be defined by the intersection of the lines representing the average slope of adjacent layers. Once the layer thicknesses have been defined, the average penetration rate per layer is calculated.

⁵ Webster, S. L., Brown, R. W., and Porter, J. R., "Force Projection Site Evaluation Using the Electric Cone Penetrometer (ECP) and the Dynamic Cone Penetrometer (DCP)," *Technical Report No. GL-94-17*, Air Force Civil Engineering Support Agency, U.S. Air Force, Tyndall Air Force Base, FL, April 1994.

11. Report

11.1 The report should include all the information as shown in **Table 1**. The relationship used to estimate the *in situ* CBR values should also be included.

12. Precision and Bias

12.1 *Precision*—The within-field laboratory repeatability standard deviation has been determined to be less than 2 mm/blow [0.08 in./blow].⁶ It is not possible to determine reproducibility limits for this field test, which is destructive in nature, and the sample is not homogeneous and cannot be replicated in moisture and density in another laboratory.

NOTE 6—The repeatability study⁶ is on granular materials and would correspond to approximately 20 % or less if expressed as a percentage.

12.2 *Bias*—No statement is being made as to the bias of the test method at the present time.

13. Keywords

13.1 ADCP; aggregate base testing; California Bearing Ratio; CBR; DCP; disposable cones; dual-mass hammer; dynamic cone penetrometer; *in situ* testing; paving material testing; shear strength; subgrade testing

⁶ Burnham, T. R., "Application of Dynamic Cone Penetrometer to Minnesota Department of Transportation Pavement Assessment Procedures," *MN/RC-97/19*, Minnesota Department of Transportation, Saint Paul, MN, 1997, p. 37.

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