Designation: D 6951 – 03

Standard Test Method for
Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications[1]

This standard is issued under the fixed designation D 6951; 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 hammer (8-kg DCP) through undisturbed soil and/or compacted materials. 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 sliding hammer when the use of the 8-kg sliding mass produces excessive penetration in soft ground conditions.

1.3 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *8-kg DCP dynamic cone penetrometer with an 8 kg hammer* (see Fig. 1)—a device used to assess the in situ strength of undisturbed soil and/or compacted materials.

2.1.2 *sliding attachment* (see Fig. 1)—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.

3. Summary of Test Method

3.1 The operator drives the DCP tip into soil by lifting the sliding hammer to the handle 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 charcharacteristics.

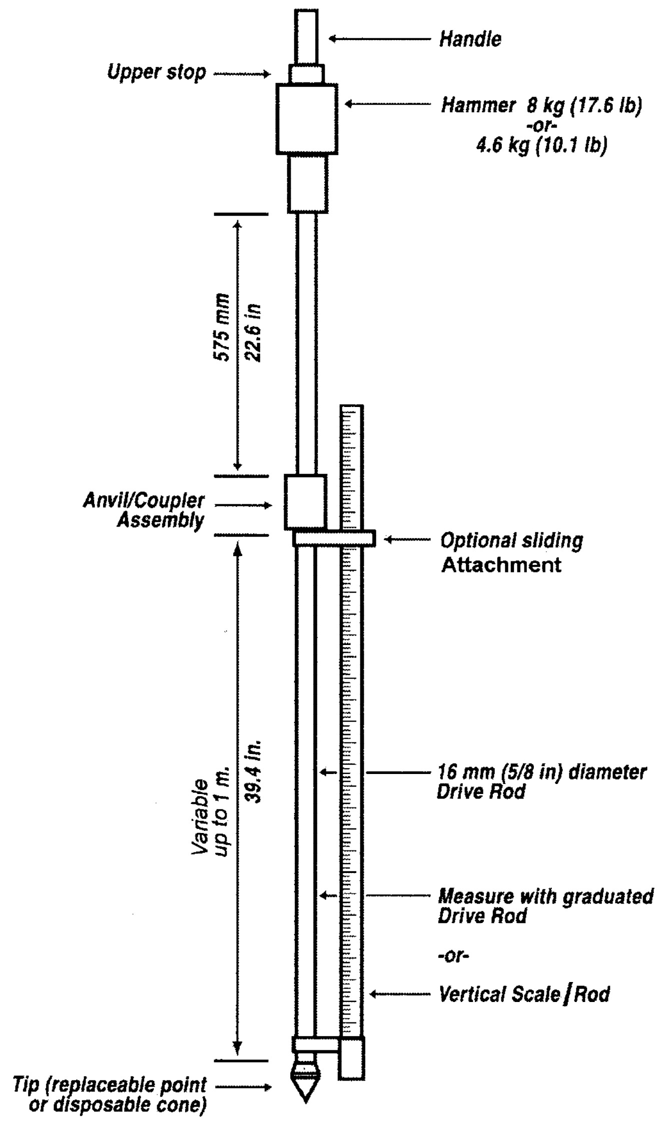

FIG. 1 Schematic of DCP Device

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.39 on Non-Destructive Testing of Pavements.

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4. Significance and Use

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

4.1.1 Other test methods exist for DCPs with different hammer weights and cone tip sizes, which have correlations that are unique to the instrument.

4.2 The 8-kg DCP is held vertically and therefore is typically used in horizontal construction applications, such as pavements and floor slabs.

4.3 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.

4.4 The 8-kg DCP can be used to estimate the strength characteristics of fine- and coarse-grained soils, granular construction materials and weak stabilized or modified materials. The 8-kg 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.).

4.5 The 8-kg 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.[2]

4.5.1 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.

5. Apparatus

5.1 The 8-kg DCP is shown schematically in Fig. 1. It consists of the following components: a 15.8-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 a fixed height of 575-mm (22.6-in.), a coupler assembly, and a handle. The tip has an included angle of 60 degrees and a diameter at the base of 20-mm (0.79-in.). (See Fig. 2.)

5.1.1 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.

5.2 The following tolerances are recommended:

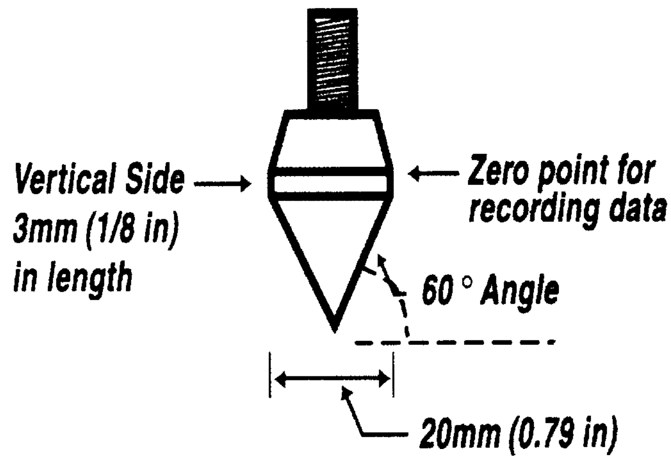

FIG. 2 Replaceable Point Tip

5.2.1 Hammer weight-measurement of 8.0-kg (17.6-lb); tolerance is 0.010-kg (0.022-lb),

5.2.2 Hammer weight-measurement of 4.6-kg (10.1-lb.); tolerance is 0.010-kg (0.022-lb),

5.2.3 Drop of hammer-measurement of 575-mm (22.6-in.); tolerance is 1.0-mm (0.039-in.),

5.2.4 Tip angle measurement of 60 degrees included angle; tolerance is 1 degree, and

5.2.5 Tip base diameter measurement of 20-mm (0.790-in.); tolerance is 0.25-mm (0.010-in.)

NOTE 2—A disposable cone tip may be used. The deposable 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.

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

5.3.1 Tools for assembling the DCP,

5.3.2 Lubricating Oil,

5.3.3 Thread Locking Compound, and

5.3.4 Data Recording form (see Table 1).

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

5.4.1 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,

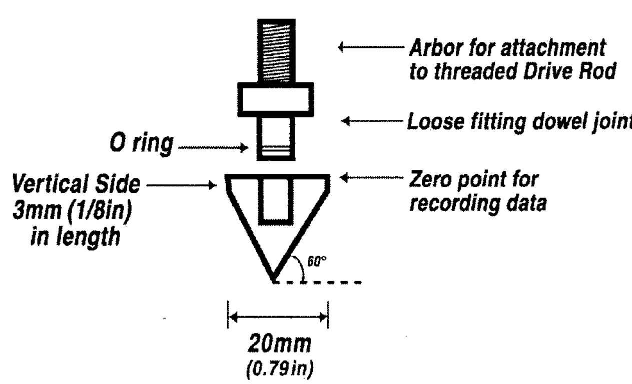

FIG. 3 Disposable Cone Tip

[2] "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.

TABLE 1 DCP Data Sheet[3]

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)[B]	Penetration Between Readings (mm)[C]	Penetration per Blow (mm)[D]	Hammer Factor[E]	DCP Index mm/blow[F]	CBR %[G]	Moisture %[H]
0	0	--	--	--	--	--	
5	25	25	5	1	5	50	
5	55	30	6	1	6	40	
15	125	70	5	1	5	50	
10	175	50	5	1	5	50	
5	205	30	6	1	6	40	
5	230	25	5	1	5	50	
10	280	50	5	1	5	50	
5	310	30	6	1	6	40	
5	340	30	6	1	6	40	
5	375	35	7	1	7	35	
5	435	60	12	1	12	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.

5.4.2 An optional sliding attachment for use with a separate scale or measuring rod,

5.4.3 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,

5.4.4 A wet/dry vacuum or suitable alternative to remove loose material and fluid if an access hole is made before testing,

5.4.5 Field power supply to power items in 5.4.3 and 5.4.4,

5.4.6 Disposable cone tips,

5.4.7 Dual mass hammer (see Fig. 4), and

5.4.8 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 devise.

6. Procedure

6.1 *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. 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.

6.2 *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.

6.3 *Initial Reading*:

6.3.1 *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 Fig. 2.

6.3.2 *Testing Below a Bound Layer*—When testing materials underlying a bound layer, a rotary hammer drill or coring apparatus meeting the requirements given in 5.4.3 above 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. 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.

6.3.3 *Testing Pavement With Thin Seals*—For pavements with thin seals, the tip is advanced through the seal until the zero point (see Fig. 4) of the tip is flush with the top of the layer to be tested.

6.3.4 Once the layer to be tested has been reached, a reference reading is taken with the zero point at the top of that

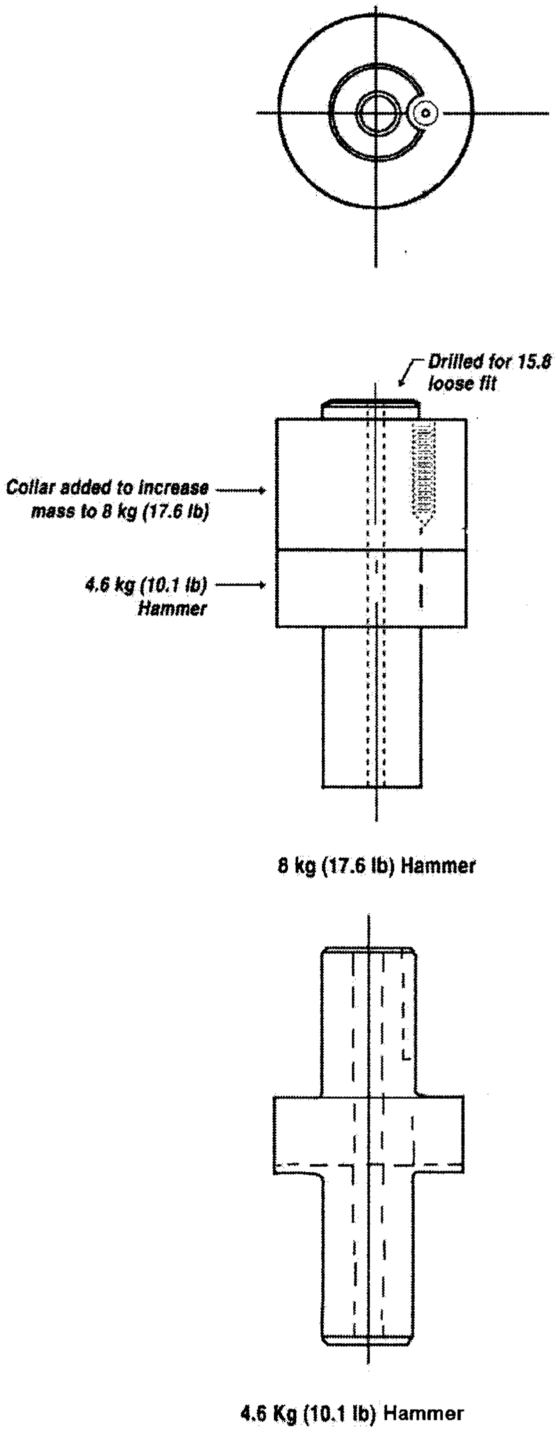

FIG. 4 Schematic of Dual-Mass Hammer

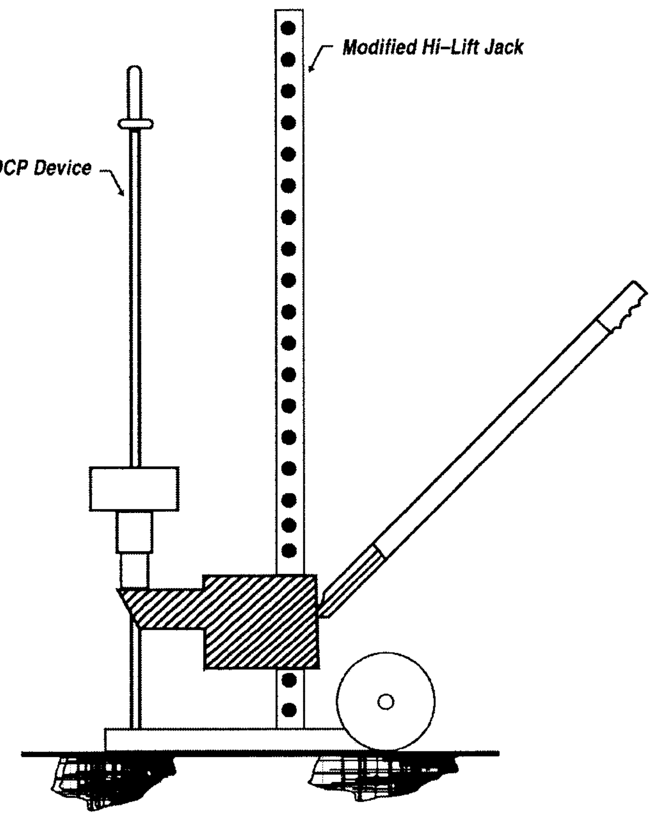

FIG. 5 Schematic of DCP Extraction Jack

layer and the thickness of the layer(s) cored through recorded. This reference reading is the point from which the subsequent penetration is measured.

6.4 *Testing Sequence*:

6.4.1 *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 6.5.

6.4.2 *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.

6.4.3 *Refusal*—The presence of large aggregates or rock strata will either stop further penetration or deflect the drive rod. If after 5 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.

6.4.4 *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.

6.5 *Data Recording*:

6.5.1 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 though a drilled or

TABLE 2 Tabulated Correlation of CBR versus DCP Index[3]

DCP Index mm/blow	CBR %	DCP Index mm/blow	CBR %	DCP Index mm/blow	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

cored access hole, the first reading corresponds to the referenced reading at the top of the layer to be tested as per 6.3.2. 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, 1 blow for soft material, 5 blows for "normal" materials and 10 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.

7. Calculations and Interpretation of Results

7.1 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 blow (DCP) in Table 2 is derived from the equation CBR = 292 / $DCP^{1.12}$ recommended by the US Army Corps of Engineers.[3] This 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 US Army Corps of Engineers:[4]

$$\text{CL soils CBR} < 10\text{: CBR} = 1 / (0.017019{*}\text{DCP})^2$$

$$\text{CH soils: CBR} = 1/0.002871{*}\text{DCP}$$

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

7.2 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.

8. Report

8.1 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.

9. Precision and Bias

9.1 *Precision*—The within-field-laboratory repeatability standard deviation has been determined to be less than 2 mm/blow.[5] 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 study[5] is on granular materials and would correspond to approximately 20 percent or less if expressed as a percentage.

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

10. Keywords

10.1 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

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