




USER GUIDE TO THE DYNAMIC CONE PENETROMETER



MnROAD
Office of Minnesota Road Research

Building a Better Foundation for the Future



The Minnesota Department of Transportation (Mn/DOT) has traditionally provided information about pavement research findings in the form of reports to our colleagues and co-workers. These reports help influence changes in pavement design and construction not only in our state, but worldwide. In addition to the research reports, Mn/DOT is publishing user guides regarding the use of tools and equipment for the management of road systems.

Through the Office of Minnesota Road Research (Mn/ROAD), our researchers are finding new methods and tools to bring about better pavement research results. One such tool is the Dynamic Cone Penetrometer (DCP) which is used to determine the strength of subgrade and base layers. It is used by Mn/DOT and Mn/ROAD to conduct pavement research because it is easy to transport and inexpensive to operate.

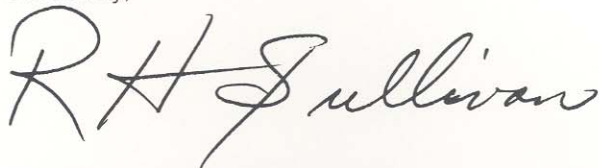
The DCP and its uses are fully illustrated and described in this *User Guide to the Dynamic Cone Penetrometer*. Information includes how to assemble the instrument, conduct a test, and determine test frequency and location. In addition, there are sections on DCP maintenance, correlation of data with pavement design parameters and a description of how construction operations are directly related to subgrade stability.

Included in the guide are several examples of DCP applications, along with illustrative charts and diagrams. A DCP test worksheet is also included that may be copied for your convenience.

Whether you conduct your own tests or are in partnership with others, the dynamic cone penetrometer is a valuable tool for identifying weak spots in embankments, measuring uniformity of material and locating boundaries of subcuts. The DCP can also be used to delineate between layers of frozen and unfrozen soils.

Please share the *User Guide to the Dynamic Cone Penetrometer* with your colleagues. If you would like more information or additional copies, see the back cover for contact information.

Sincerely,



Richard H. Sullivan, Director
Office of Minnesota Road Research

Measuring the strength of in situ soil and the thickness and location of underlying soil layers can be accomplished using a simple, hand-held device called the Dynamic Cone Penetrometer (DCP). Used worldwide, the DCP is an inexpensive and easily transportable tool. The DCP was first introduced to the Minnesota Department of Transportation (Mn/DOT) at the Minnesota Road Research Project (Mn/ROAD). Since 1993, the DCP has been used by Mn/DOT as an acceptance tool for the compaction of pavement edge drain trenches.

This user guide has been developed to highlight the use of the DCP by Mn/DOT. It provides complete fabrication and test procedure information, discusses the applications of DCP data, and outlines the many methods and correlations available for analyzing DCP results.

Description of Device

The Dynamic Cone Penetrometer (shown at right) consists of two 16-mm (5/8-inch) diameter shafts coupled near midpoint. The lower shaft contains an anvil and a pointed tip which is driven into the soil by dropping a sliding hammer contained on the upper shaft onto the anvil. The underlying soil strength is determined by measuring

the penetration of the lower shaft into the soil after each hammer drop. This value is recorded in millimeters (inches) per blow and is known as the DCP penetration index (DPI). The penetration index can be plotted versus depth to identify thicknesses and strengths of different pavement layers or can be correlated to other soil strength parameters such as the California Bearing Ratio (CBR).

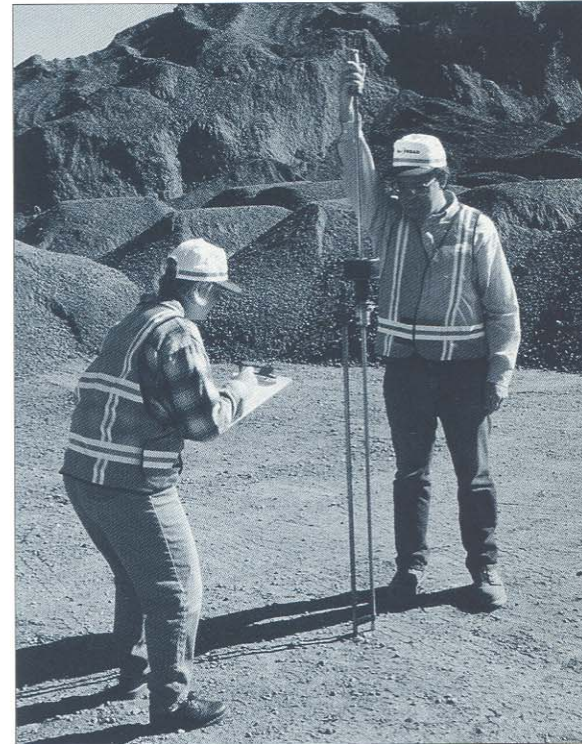
Hardware

Complete drawings of the DCP are given in Figures 1 through 6 at the back of this publication. The DCP is comprised of the following elements.

Handle: The handle is located at the top of the device. It is used to hold the DCP shafts plumb and to limit the upward movement of the hammer.

Hammer: The 8-kg (17.6-pound) hammer is manually raised to the bottom of the handle and then dropped (allowed to free fall) to transfer energy through the lower shaft to the cone tip. It is guided by the upper shaft.

Upper Shaft: The upper shaft is a 16-mm (5/8-inch) diameter steel shaft on which the hammer moves. The length of the upper shaft allows the hammer to drop a distance of 575 mm (22.6 inches).



The Dynamic Cone Penetrometer (DCP) is used to determine underlying soil strength by measuring the penetration of the device into the soil after each hammer blow.



A two-person crew operates the DCP and records data manually.

Anvil: The anvil serves as the lower stopping mechanism for the hammer. It also serves as a connector between the upper and lower shaft. This allows for disassembly which reduces the size of the instrument for transport.

Lower Shaft: The lower shaft is a 16-mm (5/8-inch) diameter steel shaft, 900-1200 mm (35-47 inches) long, marked in 5-mm (0.2-inch) increments for recording the penetration after each hammer drop.

Cone: The cone measures 20 mm (0.787 inch) in diameter. Dimensions of the cone are shown in Figure 4. The 60° cone is becoming the standard for DCPs, although a 30° cone can be used when measuring the penetration index in stiffer soils.

The combined weight of the upper shaft, anvil, lower shaft and cone should be approximately 3.1 kg (6-8 pounds.) The DCP (except for the hammer) is typically constructed of stainless steel to prevent corrosion. If stainless steel is not used, the instrument must be cleaned and dried after each use to prevent rusting.

Mn/DOT has incorporated a remote scale to ease the reading of the cone penetration. Figures 4, 5 and 6 provide the dimensions of the optional remote scale.

Test Procedure

Conducting a DCP test involves raising and dropping the hammer to drive the cone on the lower shaft through the underlying pavement layers. Typically, after each hammer blow, the penetration of the cone is measured and recorded. In stiffer soils, readings may be recorded after several hammer blows. The cone can be driven a total of 0.75 to 1 m (3-4 feet) at each test location.

Each test takes approximately 5 to 10 minutes, but may take up to 20 or 30 minutes if the bound pavement surface needs to be cored and then patched after testing.

DCP testing can be performed by a crew of one to three people. A person working alone must raise and drop the hammer, plus measure and record the penetration. The use of a video camera to record the cone penetration for each blow is possible. The video camera should be positioned at the pavement surface. When testing has been completed, the video should be reviewed and data recorded. When using this method it is critical that the calibration scale be legible on the shaft for the data to be accurate.

With a two-person crew, one person operates the hammer, and the other

person is positioned at the pavement surface to read and record the penetration for each blow (see photo at left). If the optional remote scale is used, readings can be taken from the top scale guide. A three-person crew enables one person to operate the hammer, one positioned at the pavement surface to read the penetration values, and the third to record the data. Having a second crew member will result in a significant increase in production, while a third crew member may increase production only a limited amount.

Common errors which may occur during testing include the operator not holding the DCP device plumb, and incorrect reading and recording of the test data.

Step-by-Step Procedure

The following procedure is used to conduct the test.

1. Obtain utility clearance prior to conducting any test.

2. Assemble the DCP. Begin by attaching the remote scale guide (if used) to the anvil area. Guide the top of the remote scale into the scale guide, while lowering the shaft through the bottom guide. Attach the cone tip, checking for damage or wear (see photo at upper right). Connect the upper and lower shafts. Use caution to avoid pinching fingers between the hammer and

anvil. Line up connecting hole, and insert connecting bolt, washer and clip pin (see photo at lower right).

3. When testing soil layers beneath a bound pavement surface, a hole must first be cut through the bound pavement layer. The DCP is not intended to be driven through concrete or thick bituminous pavements. The hole must be at least 50 mm (2 inches) in diameter, and the operator must be careful to not disturb the unbound layers beneath. If a water-cooled cutting device is used, the DCP test should be run immediately after cutting the hole to limit the saturation of the unbound layers. Excess water should be removed from the hole immediately.

4. Fill out test location and project information on data sheet. Figure 7 at the back of this publication is a standard data recording form.

5. Place the DCP on the test surface or insert the DCP into the center of the hole, holding the shafts plumb. The shaft should not touch the edge of the hole during the test because the friction between the shaft and the edge will affect the data.

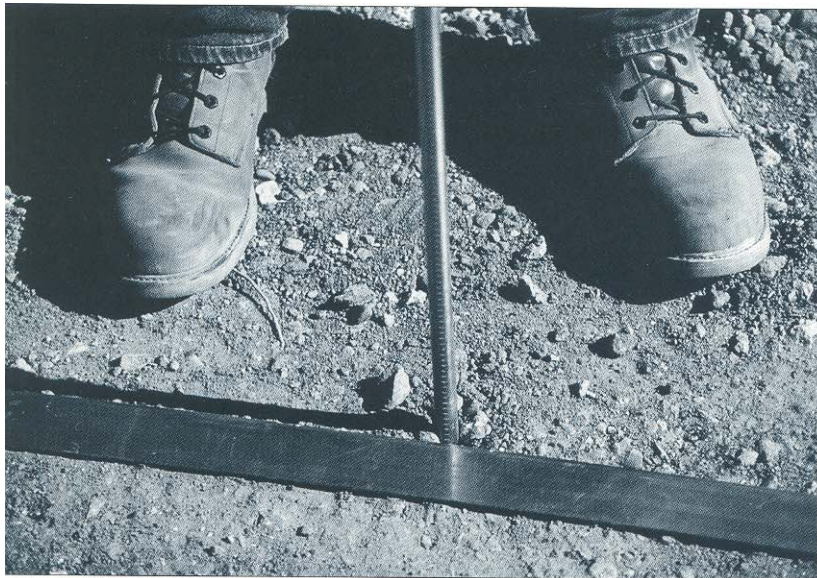
6. With one hand placed on the top handle, use other hand to seat the cone by dropping the hammer from a partial height until the widest part of the cone is below the reference



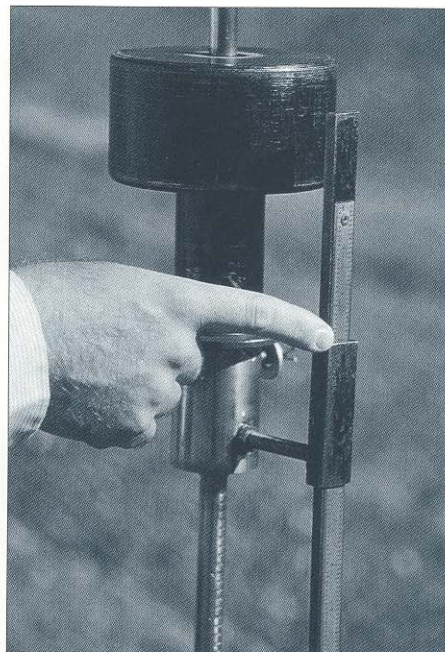
Before and after each test, examine the DCP cone tip for damage.



When assembling the DCP, line up connecting hole and insert connecting bolt, washer and clip pin.



Position a straightedge next to the DCP shaft to use as a reference point.



The top of the scale guide should be used as a reference point when the remote scale is used.

surface. Do not record penetration during the seating operation; data analysis is based on the full imprint area of the cone being in contact with the soil materials. Seating also positions the cone past any disturbed surface material.

7. Establish a reference for reading the penetration of the shaft after each blow. If a second crew member is reading the shaft, a straight-edge positioned next to the DCP shaft will make a good reference point. The straight-edge is a reference level that must remain constant for accurate depth readings (see photo at upper left).

If a remote scale is used, the top of the scale guide should serve as a reference point (see photo at lower left).

If a video camera is being used, position it to focus on the bottom 60-90 mm (2-3.5 inches) of the shaft above the pavement surface. Make sure the scale of the shaft is pointed toward the camera and is legible on the video monitor.

8. On the data sheet, record the current shaft reading as the starting point for blow number zero or start the video camera if using one.

9. Raise the hammer to its upper limit, using caution to not lift the shaft and break contact between the cone and the unbound material. Let the hammer fall freely to the anvil. Be careful to not influence the

drop by forcing the hammer down or gripping the upper handle too tightly (see photo at upper right).

10. Record the reading and blow count by reading the shaft to the nearest millimeter if using a metric scale or 0.1 inch if using an English scale. Record this as penetration for blow number 1.

11. Repeat steps 9 and 10 until the cone is driven the full depth of the lower shaft, the total penetration is less than 3 mm (0.1 inch)/blow for ten consecutive drops or the desired depth is reached.

12. If the lower shaft has penetrated full depth, remove the DCP from the hole with a specially equipped farm-purpose jack. Begin the extraction by placing the jack tongue under the handle of the device. Pump the jack until the tongue can be placed under the anvil. Then, lower the jack and finish extracting the DCP from the test hole (see photo at lower right).

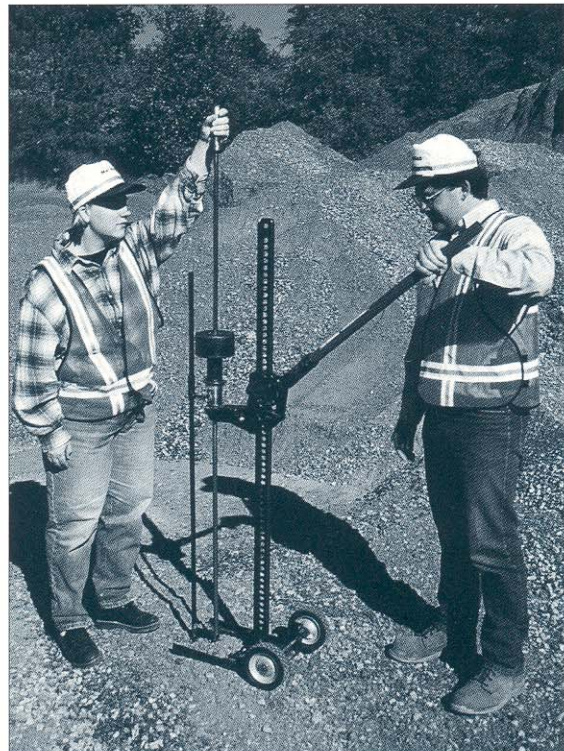
Wipe off the upper and lower shafts and inspect the cone for any damage.

Do not remove the DCP by forcefully striking the hammer against the handle. This will damage the DCP. For shallow tests or tests in softer material, the hammer may be lightly tapped against the handle to remove the instrument from the ground.

13. Fill and compact the test hole.



Raise the hammer to its upper limit and let it fall freely to strike the anvil. Record the penetration following each hammer drop. (Optional remote scale is shown.)



Use a jack to extract the DCP from the soil after testing. Never remove the DCP by striking the hammer against the handle.

Points of Caution

1. Always use caution to avoid pinching fingers between the hammer and anvil. During testing, use the handle to hold shafts plumb. Do not hold the DCP near the anvil area.
2. It is important to lift the hammer slowly and drop it cleanly, allowing at least two seconds to elapse between drops. Lifting and dropping too rapidly may affect results because the hammer's full energy may not be allowed to transfer to the lower shaft.
3. If testing in very fine-grained or cohesive soil, it may be necessary to rotate the device shaft every few drops to prevent sticking.

Test Location and Frequency Determination

To correctly profile the strength and thickness of soil layers in a given area, each site should be assessed individually to determine the proper frequency and location of the DCP tests.

Researchers at Mn/ROAD used DCP tests spaced at 30 m (100 feet) and offset from centerline left and right by 3 m (9.8 feet) (outer wheel-paths). The tests were conducted on both the tops of base and subgrade material to a maximum depth of approximately 1 m (42 inches).

The minimum distance between tests should be 300 mm (12 inches).

DCP Maintenance

Because the DCP is driven into the ground, sometimes into very hard soil layers, regular maintenance and care are required. To ensure that the device operates properly, the following guidelines must be followed.

1. Never extract the DCP from the test hole by forcefully striking the hammer against the handle; always use a jack unless it is not possible because of test location restrictions, shallow testing, or use in soft soils. Striking the handle causes accelerated wear and may lead to broken welds and connections.
2. Monitor the condition of the connection bolt. Extra bolts should be kept in the DCP carrying case because they frequently become stripped or broken and may need to be replaced during testing.
3. Keep the upper shaft clean. Lubricate very lightly with oil if binding develops. Do not lay the device on the ground. Frequently wipe both shafts clean with a soft cloth during use.
4. Monitor the DCP for excessive wear on any of the components and make repairs as needed. Because

the DCP is a standardized testing device, its overall weight and dimensions must not change from specifications.

5. The cone tip should be replaced when the diameter of its widest section is reduced by more than 10 percent (2 mm or 0.08 inch) or the cone's surface is gouged by rocks. Inspect the cone tip before and after each test.

Processing Test Results

DCP test results are expressed in terms of the DPI, defined as the vertical movement of the DCP cone produced by one drop of the hammer, expressed in mm/blow (inch/blow). Stiffer or stronger soils have a lower DPI. The DPI is used to identify pavement layer boundaries, determine material layer strengths and estimate overall strength of the unbound materials.

During or soon after testing, data should be recorded in spreadsheet form as shown in **Figure 8** (shown at upper right).

Data for the first two columns is taken from the field test form. The third column is the invert of the shaft reading. (The invert is used to aid in graphing.) The fourth column represents the penetration index which is calculated by subtracting the previous from the present DCP shaft

readings and dividing by the difference in the present and previous blow counts. The fifth column calculates the estimated CBR, based on a given equation. Correlations to other soil parameters are defined later in this publication.

To define layer boundaries in a pavement structure, a plot of the DPI versus depth should be developed. The graph will clearly show a profile of the depth and relative strength of the different subgrade or base layers (see Figure 9 at lower right).

It is possible that several layers may exist in the subgrade without a significant change in penetration rate per blow. This subgrade should be treated as one layer. In most layered conditions there is a DPI transition zone across both materials which will be recorded with testing.

Correlation of Data with Pavement Design Parameters

A great deal of work has been done to correlate the results of DCP testing with other soil or pavement design parameters. Note that general guidelines for those correlations are on the next page, but are not absolute. Engineering judgement must be used when analyzing DCP test results.

DCP Test Location

Blow Count	Rod Reading mm or inches	Invert Reading mm or inches	Penetration Index mm/blow or in/blow	Estimated CBR
0	4.2	-4.2	0	ERR
1	4.4	-4.4	0.2	60
2	4.6	-4.6	0.2	60
3	4.7	-4.7	0.1	104
4	4.8	-4.8	0.1	104
5	5.0	-5.0	0.2	60
6	5.1	-5.1	0.1	104
7	5.2	-5.2	0.1	104
8	5.3	-5.3	0.1	104
9	5.4	-5.4	0.1	104
10	5.6	-5.6	0.2	60
11	5.7	-5.7	0.1	104
12	5.8	-5.8	0.1	104
13	6.0	-6.0	0.2	60
14	6.1	-6.1	0.1	104
15	6.2	-6.2	0.1	104
16	6.4	-6.4	0.2	60
17	6.6	-6.6	0.2	60
18	7.0	-7.0	0.4	30
19	7.2	-7.2	0.2	60
20	7.6	-7.6	0.4	30
21	8.2	-8.2	0.6	19

Figure 8

Soil Profile from DCP Testing

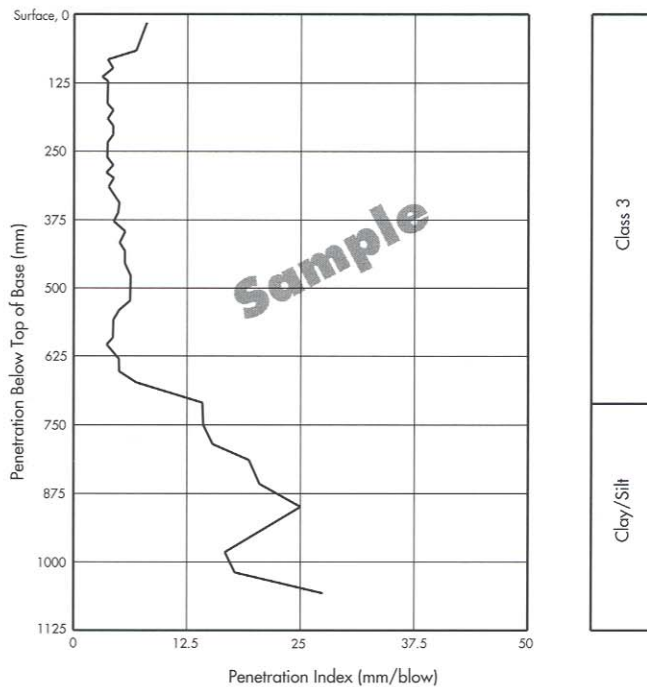


Figure 9

California Bearing Ratio

The most common correlation of DCP data is between the DPI and the California Bearing Ratio (CBR).

A graph of the correlation is given in **Figure 10** (at upper right) for a 60° cone. The relationship has been defined by the U.S. Army Engineers Waterways Experiment Station (1992) as:

$$\log \text{CBR} = 2.46 - 1.12 \log \text{DPI}$$

where DPI is the penetration index, expressed in mm/blow.

Research has shown that the effects of soil moisture content and dry density influence both CBR and DCP testing in a similar way and are typically considered negligible for this correlation.

The following is a table of typical CBR and DPI ranges for various soils. The CBR is expressed as a percentage and DPI is expressed in mm/blow.

Soil Type	CBR Range	DPI Range
Clay (CL)	2-17	127-15
Sand (S-W)	17-45	15-6
Gravel (G-W)	53-100	5-2.7

Loose sands and gravel will have higher DPI values.

Constructibility of Soils

Construction operations and pavement performance are directly related to subgrade stability. In most situations, construction-based stability considerations will control performance. The in situ subgrade CBR should be at least 6 to minimize rutting damage to the finished grade prior to paving, and to provide adequate subgrade support for proper compaction of the aggregate base and overlying pavement layers. Subgrade strength may be determined easily by conducting DCP tests. Soils with CBR values less than 8 may need remedial procedures, such as sub-cutting, drying and recompaction, backfilling with granular borrow or lime treatment.

CBR values of less than 8 correlate to DPI values greater than or equal to 25 mm (1 inch)/blow.

Relative Compaction Density

The correlation between DPI and relative compaction density can be useful. Mn/DOT has recently adopted an acceptance specification (Mn/DOT 2502) for compaction of pavement edge drain backfill material using the DPI. The specification was developed using an empirical relationship between sand cone density and DCP testing done at the same location.

During edge drain construction, contractors are required to construct a 15-m (50-foot) long test trench. Adequacy of compaction in the test trench is evaluated using the DCP. Penetration resistances of 75 mm (3 inches) or less per hammer blow indicate satisfactory compaction. Compliance is based on the average of three DCP readings for similar depths, in three tests taken 3 m (10 feet) apart. DCP testing when the drain is laid is recommended, but not required.

Work is under way toward a specification for acceptance of base material compaction using the DCP. A complete copy of the specifications may be obtained by calling Mn/ROAD at the numbers listed on the back of this publication.

Standard Penetration Resistance

Standard penetration test (SPT, ASTM D1586-64) data can be correlated to DPI using the following equation.

$$\log \text{DPI} = -1.05 + 2.03 \log \text{SPT}$$

where SPT represents the number of blows to obtain 305 mm (12 inches) of penetration

This equation is valid for SPT values greater than 30 blows/305 mm (30 blows/foot). **Figure 11** (at lower right) shows the relationship between DPI and SPT.

Correlation Plot of CBR vs. DPI

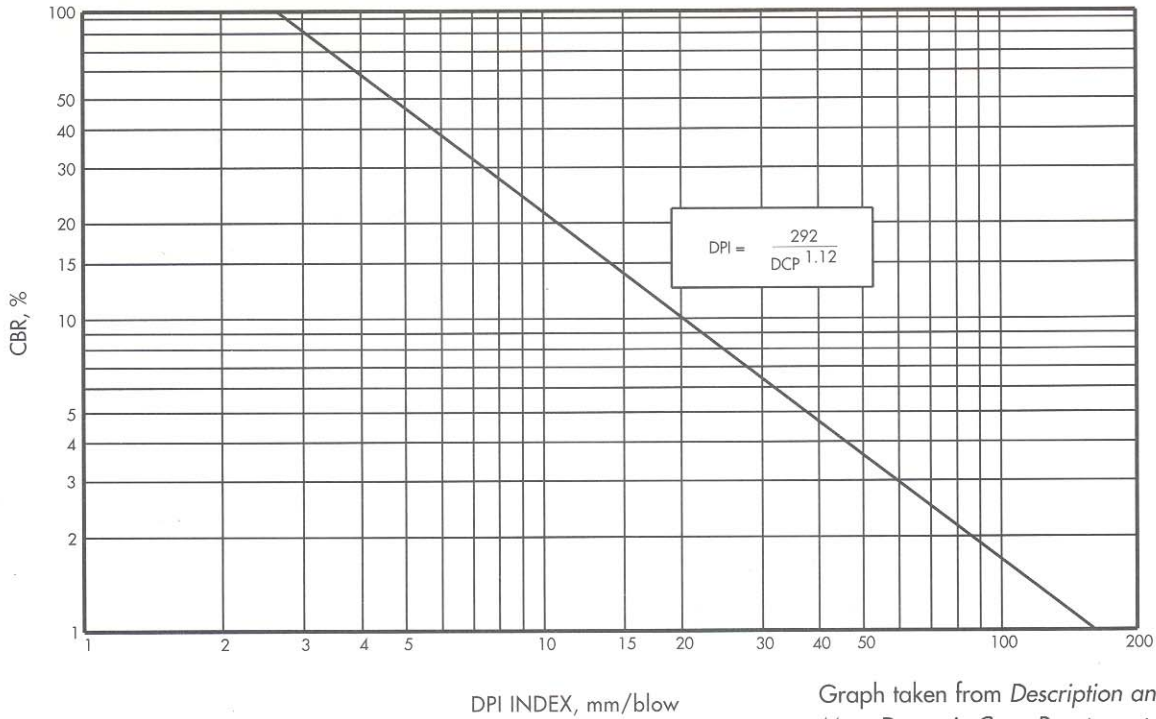


Figure 10

Graph taken from *Description and Application of Dual Mass Dynamic Cone Penetrometer*, R. Grau, S. Webster and T. Williams, Department of Army Waterways Equipment Station, GL-92-3, TA7 W34, May 1992.

Relationship between DCP Penetration Index (DPI) and Standard Penetration Test Results (SPT)

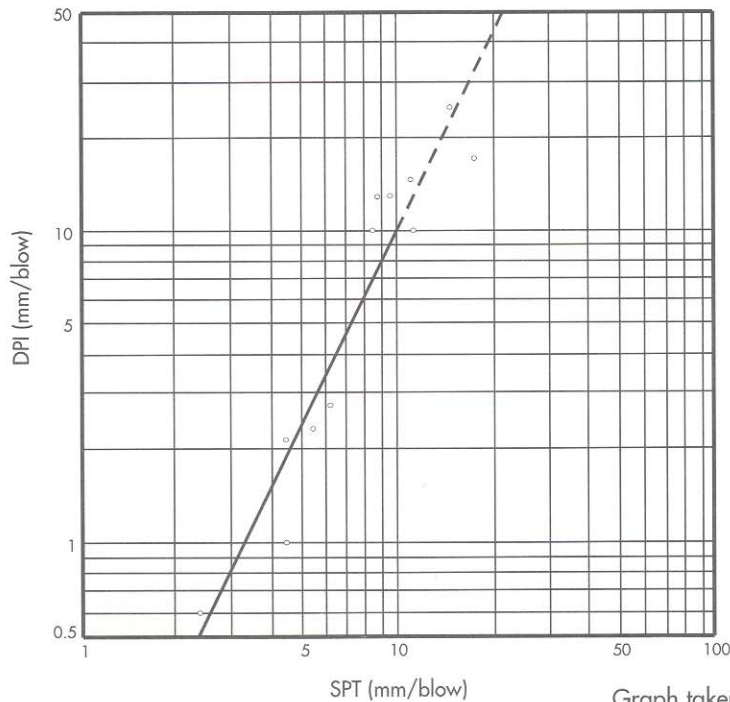


Figure 11

Graph taken from *The Relationship Between In Situ CBR Test and Various Penetration Tests*, Report Penetration Testing 1988, I. Ishai and M. Livneh, ISOPT-1, ISBN90 6191 801 4, 1988.

Limiting DPI Values Based on Soil Type

Over 700 DCP tests were conducted on the Mn/ROAD project during construction. These tests were analyzed and summarized to determine the limiting DPI value for each particular subgrade soil and base type. Test results were also analyzed to determine the effect of the base course application on underlying subgrade layers. The following general observations were made.

1. Identifiable DPI limits could be determined for the clay/silt subgrade, select granular subgrade, and Class 3 special base materials.
2. The effect of confinement from the base course layer could be seen clearly during the analysis of the select granular sections.

Based on the analysis, the following DPI limiting values are recommended when analyzing DCP test results.

Clay/Silt:
DPI < 25 mm (1 inch)/blow

Select Granular:
DPI < 7 mm (0.28 inch)/blow

Class 3 Special:
DPI < 5 mm (0.20 inch)/blow

These values were chosen assuming adequate confinement near the

testing surface. If these limits are exceeded during a rehabilitation study, additional soil testing methods are recommended.

Examples of DCP Applications

Since its introduction to Mn/DOT in 1991, the DCP has been evaluated by the Department for several different applications. The following examples outline successful uses of the DCP by Mn/DOT.

Locating layers in pavement structures and pavement rehabilitation strategy determination

As noted earlier, plots of DPI versus depth can be used to identify limits of underlying pavement layers, as well as the relative strength of those layers.

DCP testing has been used to measure the relative strengths of stabilized and unstabilized road layers. It has also been used to evaluate existing pavement base, subbase, and subgrade layer thicknesses and strength during rehabilitation evaluations.

Supplementing foundation testing for design

A DCP test can provide additional qualitative and quantitative in situ foundation information during normal soil survey sampling

operations. Conducting a DCP test through a drill hole or near a thinwall hole, gathers supplemental information for comparison with laboratory results. This additional information can lead to better design decisions.

To assist in developing a better understanding of the effects of soil type and moisture content on the penetration index, small soil samples should be obtained on a periodic basis. These samples should be tested for soil classification and gravimetric moisture content. Sand cone or nuclear density tests may also be taken near DCP test locations, and used for further investigation into compaction correlations.

Identifying weak spots in constructed embankments

DCP testing was used in October of 1991 to evaluate the embankment density on a TH-212 bridge. Measurements at the site demonstrated the ability of the DCP to map out weak spots and to highlight the variability of what was presumed to be uniformly compacted material.

Using as an acceptance testing tool

DCP testing is presently used as an acceptance tool for the compaction of pavement edge drain

trenches. Methods are being developed for its use in testing the compaction of roadway base layers. An attractive alternative to sand cone density testing, the DCP test is easier to perform and results are available much more quickly. The DCP is also an efficient construction acceptance tool because it may be operated by one person, is inexpensive, and is easy to operate and transport.

Locating boundaries of required subcuts

In areas where additional subcutting is required, the DCP can be used to locate the boundaries of soft soils. Several tests can be run in a short time to identify the location where subgrade soils make the transition from unacceptable to acceptable.

Determining thaw/freeze depth during spring

The DCP can be used to delineate between layers of frozen and unfrozen soils. This can be helpful when assessing whether a foundation or roadway subcut can be excavated.

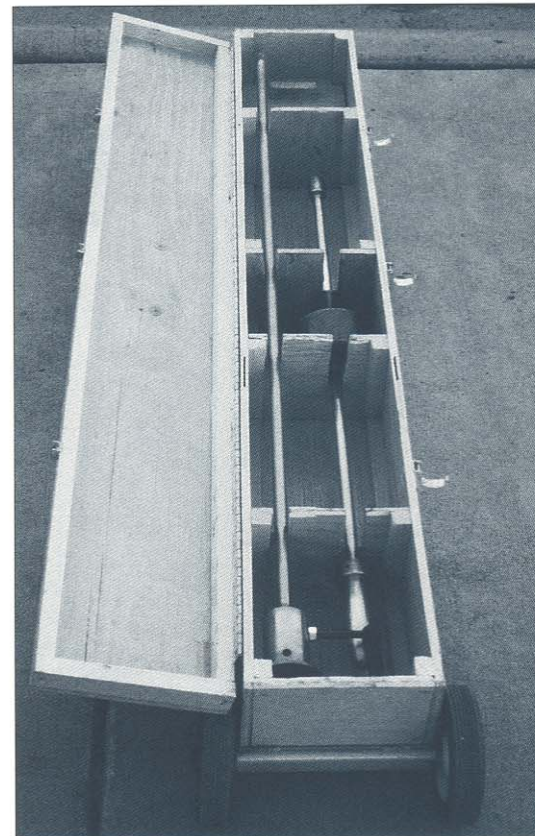
Costs

Typical fabrication costs for the DCP are approximately \$900 to \$1,000. Information about qualified machine shops and complete

material specifications may be obtained through the electronic mail address or the telephone number listed on the back of this publication. Plans for the DCP, modifications to a farm-purpose jack and plans for a full-sized carrying case (shown at right), can also be obtained from Mn/DOT.

Additional information

Mn/ROAD has developed and is using an automated DCP in which the hammer is automatically cycled and the penetration recorded by computer. It was developed because of the large volume of testing at Mn/ROAD. Further information on this device can be obtained from Mn/DOT through electronic mail or by calling the telephone number listed on the back of this publication.



The carrying case helps to make the DCP an easily transportable tool. Plans for the case can be obtained from Mn/DOT.

Mn/DOT DCP Design

(Scale 1 mm = 10 mm)

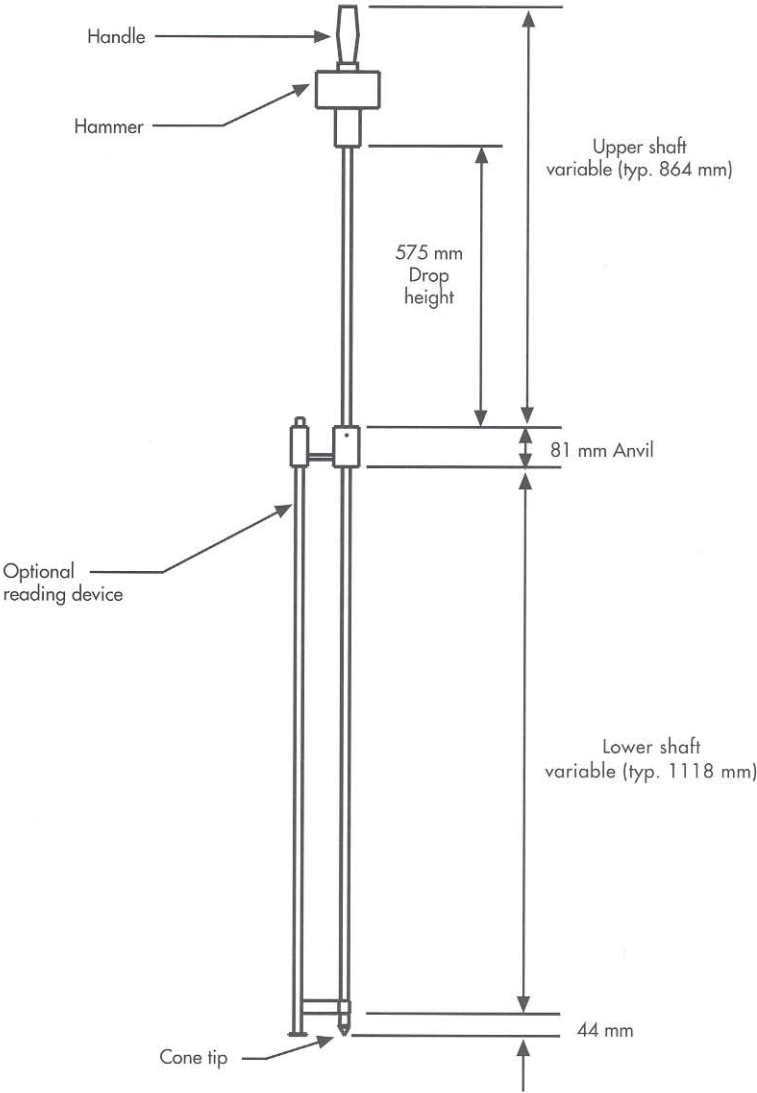
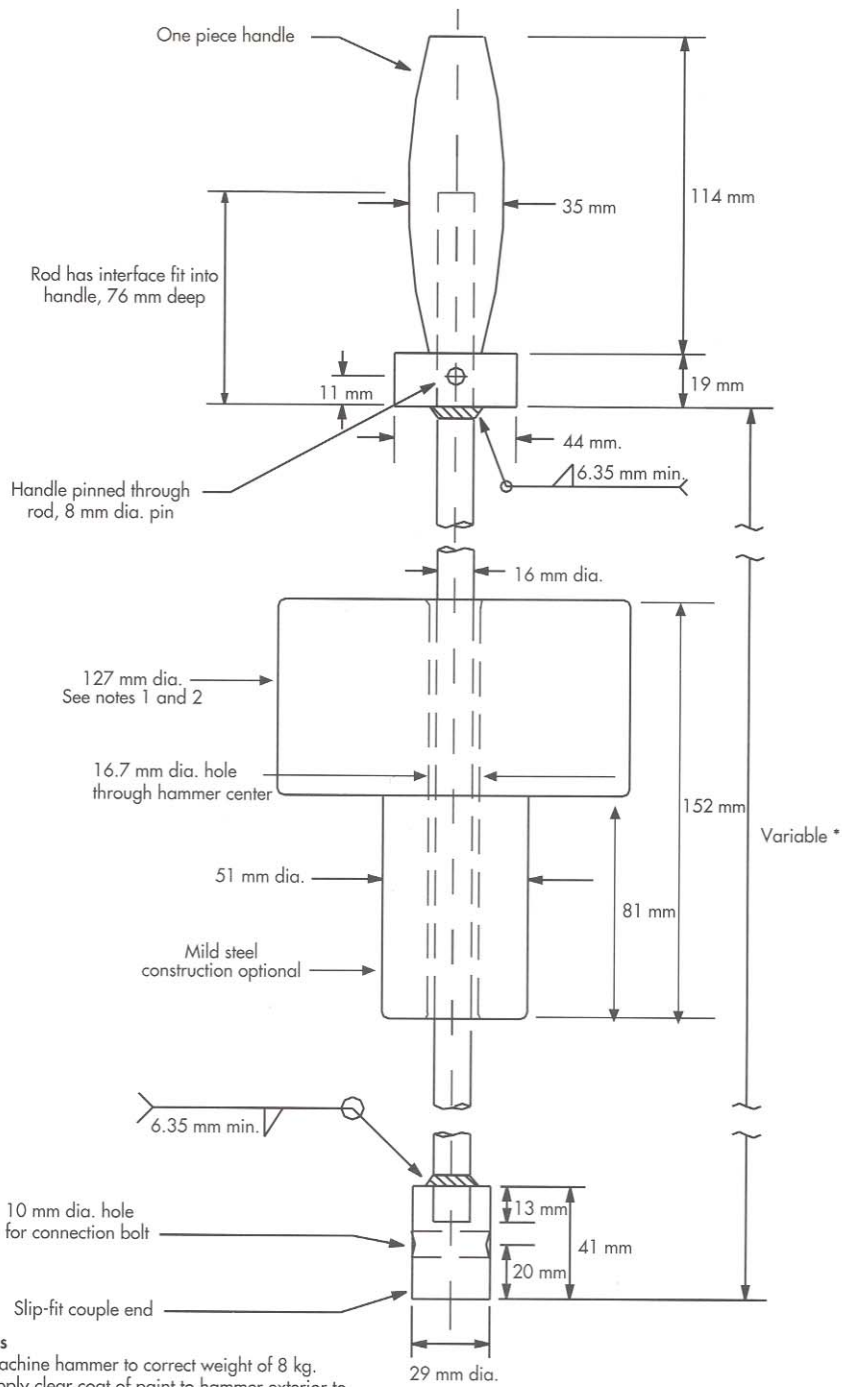


Figure 1

DCP Top Section (Not to Scale)



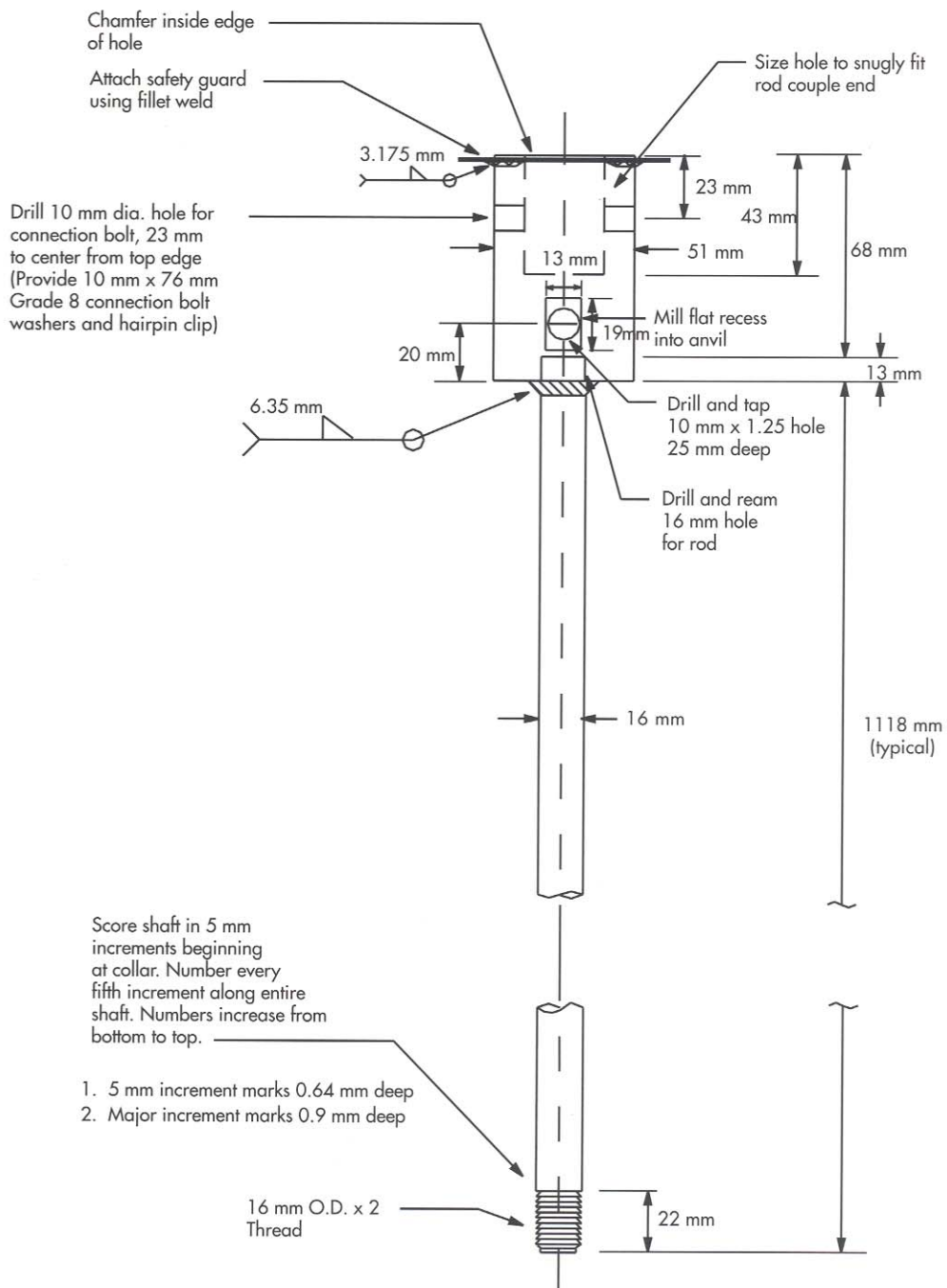
Notes

1. Machine hammer to correct weight of 8 kg.
 2. Apply clear coat of paint to hammer exterior to prevent rust (if not stainless steel).
 3. All materials 304 stainless steel unless noted.
- * 575 mm drop from bottom of hammer to top of anvil, when hammer is in top position, and top and bottom sections are assembled.

Figure 2

DCP Lower Shaft Detail

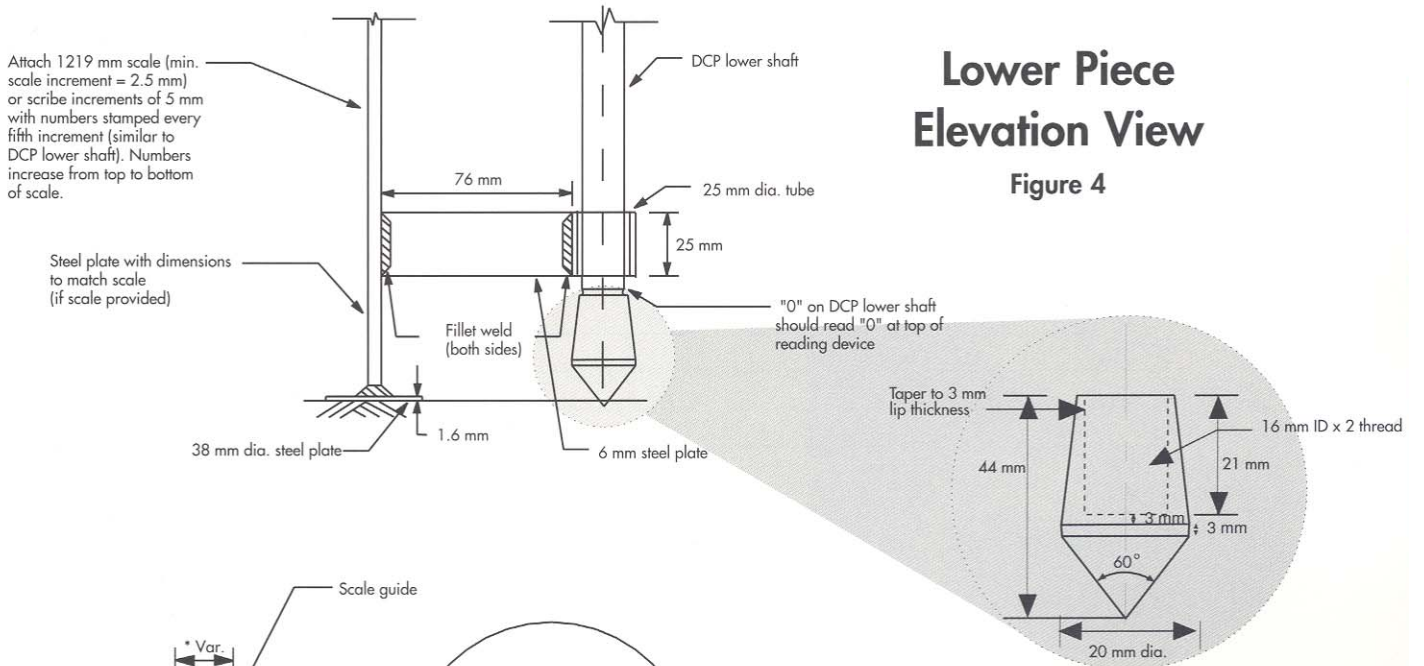
(Not to Scale)



Note: All material 304 Stainless Steel unless otherwise noted.

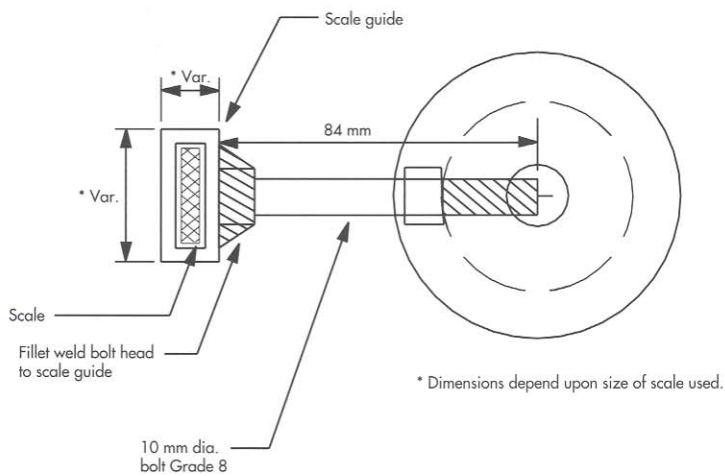
Figure 3

DCP Remote Scale and Cone Tip Details



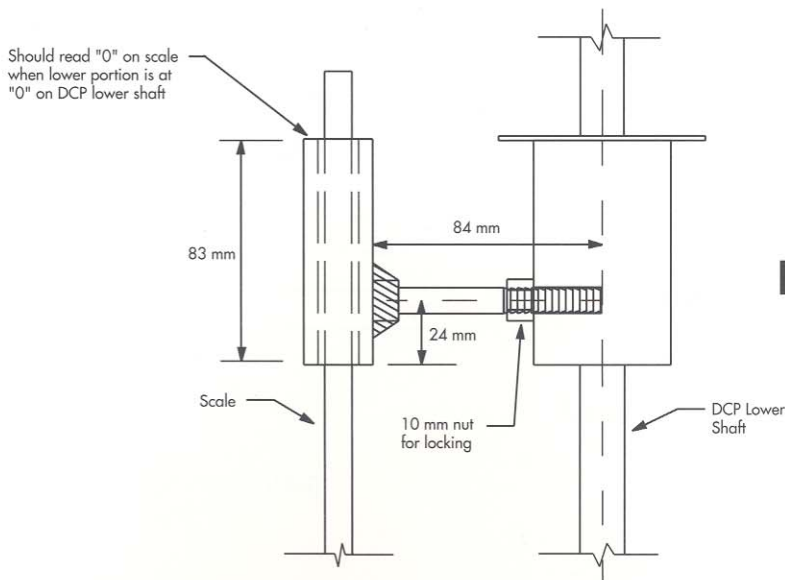
Lower Piece Elevation View

Figure 4



Top Piece Plan View

Figure 5



Top Piece Elevation View

Figure 6

Dynamic Cone Penetration Record

Client: _____

Location: _____

Pavement Condition: _____

Deflection Results: _____

Blow #	Reading	Blow #	Reading	Blow #	Reading	Blow #	Reading	Blow #	Reading
0ed		30		60		90		120	
1		31		61		91		121	
2		32		62		92		122	
3		33		63		93		123	
4		34		64		94		124	
5		35		65		95		125	
6		36		66		96		126	
7		37		67		97		127	
8		38		68		98		128	
9		39		69		99		129	
10		40		70		100		130	
11		41		71		101		131	
12		42		72		102		132	
13		43		73		103		133	
14		44		74		104		134	
15		45		75		105		135	
16		46		76		106		136	
17		47		77		107		137	
18		48		78		108		138	
19		49		79		109		139	
20		50		80		110		140	
21		51		81		111		141	
22		52		82		112		142	
23		53		83		113		143	
24		54		84		114		144	
25		55		85		115		145	
26		56		86		116		146	
27		57		87		117		147	
28		58		88		118		148	
29		59		89		119		149	

Figure 7

References

For those interested in fabricating or using the DCP, the following references are available from the Mn/ROAD library.

Application of the DCP to Mn/DOT's Pavement Assessment Procedures, Tom Burnham, Mn/ROAD, March 1996.

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User's Guide to the DCP, Office of Materials Research and Engineering, Mn/DOT, April 1993.

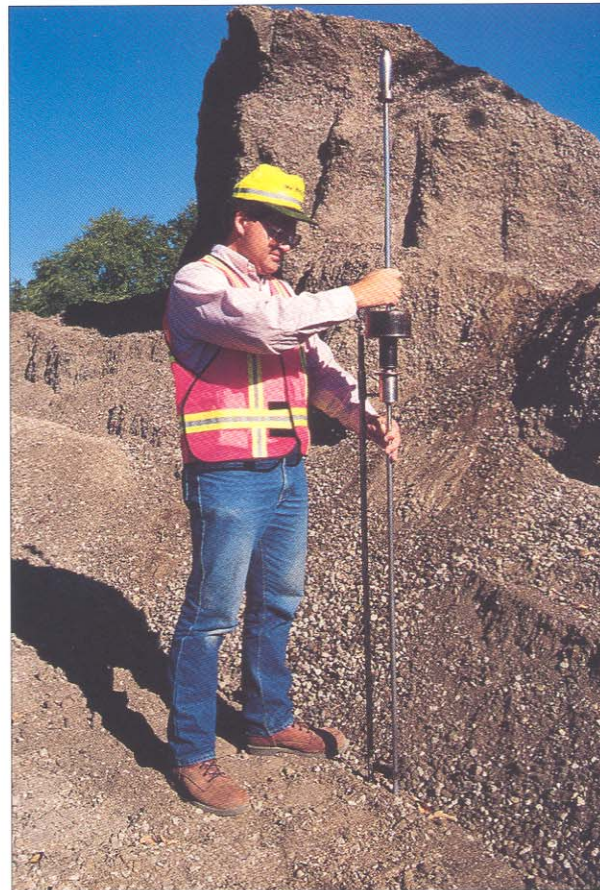
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Use of DCP for Finding the Strength of Unbound Paving Materials and Subgrade Soils for Pavement Design, Robert Van Sambeek, Braun Intertec, December 1991.

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Illinois DOT Highway Stability Manual, May 1982.





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