

A. History and Development

The Dynamic Cone Penetrometer 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. In 1999, the Penetration Index Method for compaction acceptance of base aggregate Classes 5, 6, and 7 was adapted by Mn/DOT, which requires the use of the DCP as the testing device.

B. Description of Device

The Dynamic Cone Penetrometer consists of two 16 mm (5/8-inch) diameter shafts coupled near the midpoint. The lower shaft contains an anvil and a pointed tip, which is driven into unbound materials by dropping a sliding hammer contained on the upper shaft onto the lower anvil. The strength is determined by measuring the penetration of the lower shaft into the unbound materials. This value is recorded in millimeters (inches) per blow and is known as the Penetration Index (PI).

C. Equipment

The DCP is comprised of the following elements. (See Fig. 1 5-692.255 mod)

1. 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.
2. Hammer: The 8 kg (17.61 lb.) 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. The upper shaft guides the hammer.
3. 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 575 mm (22.6 inches).
4. 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.
5. Lower Shaft: The lower shaft is a 16 mm (5/8-inch) diameter steel shaft, of variable length up to 1 m (39.4 inches) in length, marked in 5mm (0.2-inch) increments for recording the penetration after each hammer drop.
6. Cone: The cone measures 20 mm (0.787-inch) in diameter. The cone tip has a 60-degree angle. (See Fig. 2 5-692.255 mod)

D. Operation Points of Caution

1. Always use caution to avoid pinching fingers between the hammer and the 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 it to rest on the anvil for at least one second before raising it for another drop. Lifting and dropping too rapidly may affect results because the hammer's full energy may not be allowed to transfer to the lower shaft. This will cause incorrect test results.

E. Test Procedure - Base Aggregate (2211.3C3)

1. Record the gradation % passing values that represent the area to be tested by the DCP, on the attached Modified DCP Procedure 2005-06 form or spreadsheet. If using the form, calculate the Grading Number (GN) by using the formula on the form. If using the spreadsheet, the computer calculates this information. (See Fig. 3 5-692.255 mod)
2. Locate a level and undisturbed area (test site) that is representative of the material to be tested.
3. Record the Test #, Date, Station, Offset, and Test Layer Depth on the Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table. (See Fig. 3 5-692.255 mod)
4. Place the DCP device on the base aggregate test site. Record the initial reading using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inch). (Place this information on the attached Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table, under **Initial Reading** column.)
5. To properly seat the DCP (cone tip), two hammer blows are required. Therefore, carefully raise the sliding weighted hammer until it meets the handle, and then release the hammer under its own weight. Repeat this process one more time for a total of two complete blows.
6. Record the penetration measurement after seating using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inch). (Place this information on the attached Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table, under **Reading after seating (2 blows)** column.) (See Fig. 3 5-692.255 mod)

7. Carefully raise the hammer until it meets the handle, and then release the hammer under its own weight. Repeat this process two more times for a total of three times.
8. Record the final penetration measurement using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inches). (Place this information on the attached Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table, under **Reading after test (3 blows)** column.) (See Fig. 3 5-692.255 mod)
9. After using the DCP, obtain a sample of material and determine the moisture content of the aggregate base by using the pan drying method or a Super Speedy. Record the moisture content on the Modified DCP Procedure 2005-06 form or spread sheet, in the DCP Data table, under **MC (%)** column. (See Fig. 3 5-692.255 mod)
10. If using the Modified DCP Procedure 2005-06 form, fill in the **Maximum Allowable SEAT & Maximum Allowable DPI** columns; this information is in the Penetration Requirements table by using the recorded **GN & MC**. Next calculate the **SEAT** by using the following formula:

$$\text{SEAT} = \text{Reading after seating (2 blows)} - \text{Initial Reading}$$

Compare the calculated **SEAT** and compare it the **Maximum Allowable SEAT column**, if **SEAT** is larger than the **Maximum Allowable SEAT**, the **SEAT fails**. If the **SEAT** is smaller than the **Maximum Allowable SEAT**, the **SEAT passes**.

Next calculate the **DPI** by using the following formula:

$$\text{DPI} = \frac{\{\text{Reading after test (3 blows)} - \text{Reading after seating (2 blows)}\}}{3}$$

Compare the calculated **DPI** and compare it the **Maximum Allowable DPI column**, if the **DPI** is larger than the **Maximum Allowable DPI**, the **Ave. DPI fails**. If the **DPI** is smaller than the **Maximum Allowable DPI**, the **DPI passes**.

Next determine the **Adequate Layer?** by using the following formula:

$$\text{Adequate Layer?} = \{\text{Reading after test (3 blows)} - \text{Initial Reading}\} < \text{Test Layer Depth}$$

If the **{Reading after test (3 blows) – Initial Reading}** is larger than the **Test Layer Depth**, the answer is No. If the **{Reading after test (3 blows) – Initial Reading}** is less than the **Test Layer Depth**, the answer is Yes.

To determine whether the **Test Pass or Fail**, check the **Seat Pass or Fail**, **DPI Pass or Fail**, and **Adequate Layer?** columns, if any of the three columns has Fail or No, the **Test Fails**. If all three columns have Pass or Yes, the **Test Passes**.

If using the Modified DCP Procedure 2005-06 spreadsheet, all the above information is calculated by the computer and to determine if the test passes or fails look in the **Test Pass or Fail** column for the answer. (See Fig. 3 5-692.255 mod)

11. For test purposes, the approximate test layer in compacted thickness is located in the Penetration Index chart on Fig. 3 5-692.255 mod.

F. Test Procedure - Granular Subgrade Material (2105.3F3)

1. Record the gradation % passing values that represent the area to be tested by the DCP, on the attached Modified DCP Procedure 2005-06 form or spreadsheet. If using the form, calculate the Grading Number (GN) by using the formula on the form. If using the spreadsheet, the computer calculates this information. (See Fig. 3 5-692.255 mod)
2. Locate a level and undisturbed area (test site) that is representative of the material to be tested.
3. Record the Test #, Date, Station, Offset, and Test Layer Depth on the Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table. (See Fig. 3 5-692.255 mod)
4. Place the DCP device on the granular material test site. Record the initial reading using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inch). (Place this information on the attached Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table, under **Initial Reading** column.) (See Fig. 3 5-692.255 mod)
5. To properly seat the DCP (cone tip), two hammer blows are required. Therefore, carefully raise the sliding weighted hammer until it meets the handle, and then release the hammer under its own weight. Repeat this process one more time for a total of two complete blows.
6. Record the penetration measurement after seating using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inch). (Place this information on the attached Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table, under **Reading after seating (2 blows)** column.) (See Fig. 3 5-692.255 mod)

7. Carefully raise the hammer until it meets the handle, and then release the hammer under its own weight. Repeat this process two more times for a total of three times.
8. Record the final penetration measurement using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inches). (Place this information on the attached Modified DCP Procedure 2005-06 form or spreadsheet, in the DCP Data table, under **Reading after test (3 blows)** column.) (See Fig. 3 5-692.255mod)
9. After using the DCP, obtain a sample of material and determine the moisture content of the granular material by using the pan drying method or a Super Speedy. Record the moisture content on the Modified DCP Procedure 2005-06 form or spread sheet, in the DCP Data table, under **MC (%)** column. (See Fig. 3 5-692.255 mod)
10. If using the Modified DCP Procedure 2005-06 form, fill in the **Maximum Allowable SEAT & Maximum Allowable DPI** columns; this information is in the Penetration Requirements table by using the recorded **GN & MC**. Next calculate the **SEAT** by using the following formula:

$$\text{SEAT} = \text{Reading after seating (2 blows)} - \text{Initial Reading}$$

Compare the calculated **SEAT** and compare it the **Maximum Allowable SEAT column**, if **SEAT** is larger than the **Maximum Allowable SEAT**, the **SEAT fails**. If the **SEAT** is smaller than the **Maximum Allowable SEAT**, the **SEAT passes**.

Next calculate the **DPI** by using the following formula:

$$\text{DPI} = \frac{\{\text{Reading after test (3 blows)} - \text{Reading after seating (2 blows)}\}}{3}$$

Compare the calculated **DPI** and compare it the **Maximum Allowable DPI column**, if the **DPI** is larger than the **Maximum Allowable DPI**, the **Ave. DPI fails**. If the **DPI** is smaller than the **Maximum Allowable DPI**, the **DPI passes**.

Next determine the **Adequate Layer?** by using the following formula:

$$\text{Adequate Layer?} = \{\text{Reading after test (3 blows)} - \text{Initial Reading}\} < \text{Test Layer Depth}$$

If the **{Reading after test (3 blows) – Initial Reading}** is larger than the **Test Layer Depth**, the answer is No. If the **{Reading after test (3 blows) – Initial Reading}** is less than the **Test Layer Depth**, the answer is Yes.

To determine whether the **Test Pass or Fail**, check the **Seat Pass or Fail**, **DPI Pass or Fail**, and **Adequate Layer?** columns, if any of the three columns has Fail or No, the **Test Fails**. If all three columns have Pass or Yes, the **Test Passes**.

If using the Modified DCP Procedure 2005-06 spreadsheet, all the above information is calculated by the computer and to determine if the test passes or fails look in the **Test Pass or Fail** column for the answer. (See Fig. 3 5-692.255 mod)

12. For test purposes, a layer will be considered 300 mm (1-foot) in compacted thickness.

G. Test Procedure - Edge Drain Trench Filter Aggregate (2502)

1. After the compaction of the first 15 m (50 feet) of filter aggregate within the edge drain trench has been completed, determine the location of three test sites that are 3 m (10 feet) apart within that first 15 m (50 feet).
2. Calculate the number of hammer drops (blows) necessary to 'properly test the trench filter aggregate but not damage the edge drain pipe by subtracting 150 mm (6-inches) from the depth of the trench to be tested and dividing that total by 75 for metric measurements or 3 for English measurements. If necessary, round this number down to the next whole number. (See Fig. 4 5-692.225 mod)

Example: If the trench depth equals 650 mm (26-inches).

Then 650 mm (26-inches) minus 150mm (6 inches) equals 500 mm (20 inches).

Then 500 mm (20 inches) divided by 75 (for Metric) or 3 (for English) equals 6.7 or 6.

3. Place the DCP on test site #1 and seat the coned tip of the device by slightly tapping the lower anvil with the hammer until the coned tip is just out of sight.
4. After seating, record the penetration measurement using the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inch). [Use form TP-2170 -02(rev 11/05)] (See Fig. 5 5-692.255 mod)
5. Carefully raise the hammer until it meets the handle, and then release the hammer under its own weight. Repeat this process until the total number of hammer drops equals the required number of blows as calculated in step 2. Also, beware and avoid the chance of penetrating the edge drain pipe at the bottom of the trench when the compaction of the trench is less than passing.

6. Record the final penetration measurement from the graduated rule on the DCP. The measurement is taken to the nearest 2.5 mm (0.1 inch).
7. Subtract the measurement in step 4 from the measurement in, step 6 and then divide the difference of the measurements by the number of blows required for testing. The result is the penetration index. If necessary, follow the formula on the test form to convert from mm to inches.
8. Use the same procedures as outlined above for testing sites #2 and #3.
9. Add the three penetration index results from test site #1, #2, and #3 and divide that total by 3 in order to calculate the average of all three tests. Round off the average of the tests to the nearest 1 mm (0.1-inch). (See Grading and Base Manual 5-692.805)

H. Maintenance and Handling

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

1. Monitor the condition of the connections to the anvil and handle. When the connections uses bolts, pins, or set screws, extra bolts, pins, or set screws should be kept in the DCP carrying cases because they frequently become stripped or broken and may need to be replaced during testing.
2. Keep the upper shaft clean. Lubricate very lightly with oil if binding develops. Frequently wipe both shafts clean with a soft cloth during use.
3. 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.
4. The cone tip should be replaced when the diameter of its widest section is reduced by more than 10 percent (2 mm [0.08 inch]) or rocks gouge the cone's surface. Inspect the cone tip before and after each test. Nevertheless, the cone tip should be replaced at least once a year.
5. Never extract the DCP from the test hole by forcefully striking the hammer against the handle. Striking the handle causes accelerated wear and may lead to broken welds and connections. At least once a year, all welds on the DCP should be critically inspected for hairline or larger cracks.
6. Do not lay the device on the ground when not in use. The DCP should be kept in its carrying case to avoid bending the shafts. Straightness of the shafts is extremely important. The hammer cannot free fall if the shafts are bent. The

straightness of the shafts should be critically measured and reviewed each year prior to the start of construction season.



Estimated Optimum Moisture Content

SP _____ Highway _____ Inspector _____
 Material _____ Date _____ Notes _____

Procedure

- Perform a gradation test on AGGREGATE BASE or GRANULAR material.
- Electronic Version:
 - Enter the percent passing each sieve. The Estimated Optimum Moisture Content (**EOMC**) is reported on the bottom right corner of the sheet.
- Hard Copy:
 - Calculate the Coarse Grading Number (**CGN**) and the Fine Grading Number (**FGN**).
 - Round the **CGN** and the **FGN** to the nearest 0.2.
 - Find the rounded **CGN** and **FGN** values in the table and determine the **EOMC**.

NOTE: This relationship is based on empirical data and should ONLY be used as a guideline.

Gradation Data (use % passing in formulas)

$$CGN = \frac{1'' + \frac{3}{4}'' + \frac{3}{8}'' + \#4}{100}$$

$$FGN = \frac{\#10 + \#40 + \#200}{100}$$

CGN = Coarse Grading Number

- $CGN \leq 4.0$
- lower CGN indicates coarser material

Sieve	% Passing
1"	
3/4"	
3/8"	
#4	
Rounded CGN	
CGN =	

FGN = Fine Grading Number

- $FGN \leq 3.0$
- higher FGN indicates finer material

Sieve	% Passing
#10	
#40	
#200	
Rounded FGN	
FGN =	

Estimated Optimum Moisture Content

CGN	FGN	EOMC (% dry)
2.4	0.2	11
	0.4	9
2.6	0.4	9
	0.6	7
2.8	0.4	9
	0.6	8
	0.8	6
3.0	0.4	9
	0.6	8
	0.8	7
3.2	0.6	9
	0.8	8
	1.0	7
3.4	0.6	9
	0.8	9
	1.0	8
	1.2	7
3.6	0.8	9
	1.0	9
	1.2	9
	1.4	8
3.8	1.6	8
	0.8	10
	1.0	10
	1.2	10
	1.4	10
4.0	1.6	10
	1.8	10
	1.2	11
	1.4	12
	1.6	12
	1.8	12
4.0	2.0	13
	2.2	13

**Estimated Optimum
Moisture Content
(EOMC) =**

Questions? Contact Tim Andersen @ (651) 779-5609
 or Cary Efta @ (651) 779-5332

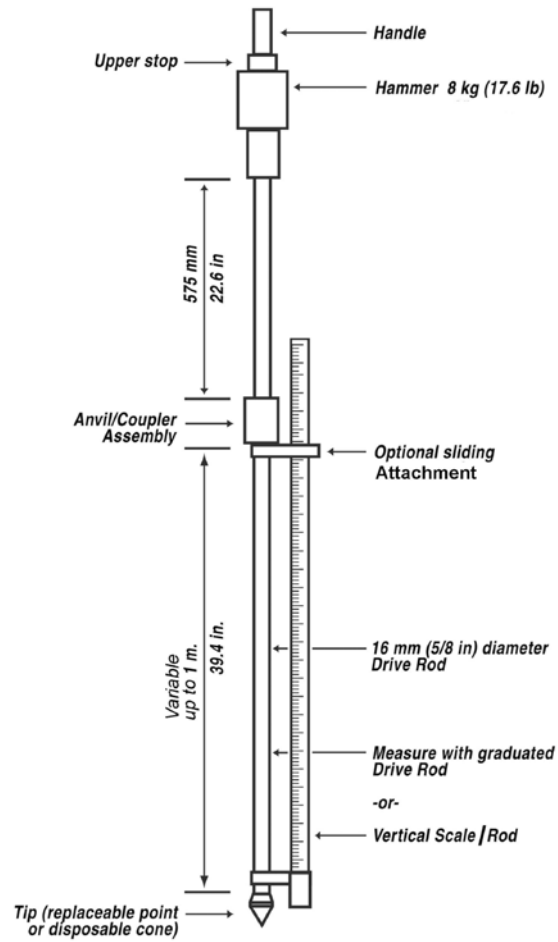


Figure 1 - Schematic of DCP Device

Fig. 1 5-692.255 mod

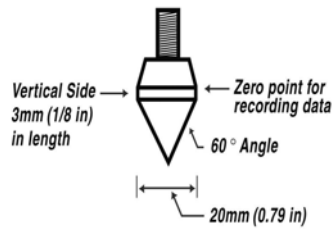


Figure 2 - Replaceable Point Tip

Fig. 2 5-692.255 mod

Modified DCP Procedure: 2005-06 (English)

SP Highway Engineer Inspector
 Material Date Notes

Procedure

- Enter Project info and Gradation Data. Calculate the Grading Number (**GN**) (electronic version calculated automatically)

$$SEAT = Pen_{2\text{ blows}} - Pen_{0\text{ blows}} \quad DPI = \frac{Pen_{5\text{ blows}} - Pen_{2\text{ blows}}}{3\text{ blows}}$$

Electronic Version

- Determine the test location and conduct the DCP test.
- Measure the moisture content (**MC**) at the DCP test location.
- Enter the Test Information and DCP Data in table.
- The test results will be determined automatically.

Hard Copy

- Determine the test location and conduct the DCP test.
- Measure the moisture content (**MC**) at the DCP test location.
- Enter the Test Information and DCP Data in table.
- Establish the allowable values for **SEAT** and **DPI** based on **GN** and **MC**.
- Compute **SEAT** and **DPI** test results.
- Compare **SEAT** and **DPI** to Maximum Requirements. *Both must pass to accept test.*

Gradation Data (use % passing in formulas)

$$GN = \frac{1" + \frac{3}{4}" + \frac{3}{8}" + \#4 + \#10 + \#40 + \#200}{100}$$

Sieve	% Passing
1"	
3/4"	
3/8"	
#4	
#10	
#40	
#200	
GN =	

Penetration Requirements

GN	MC (% dry)	Maximum Allowable SEAT (in)	Maximum Allowable DPI (in/blow)	Approximate Test Layer (in)
3.1-3.5	< 5.0	1.6	0.4	4.0 - 6.0
	5.0-8.0	1.6	0.5	
	> 8.0	1.6	0.6	
3.6-4.0	< 5.0	1.6	0.4	4.0 - 6.0
	5.0-8.0	1.7	0.6	
	> 8.0	2.1	0.7	
4.1-4.5	< 5.0	2.0	0.5	4.0 - 6.0
	5.0-8.0	2.4	0.7	
	> 8.0	2.8	0.8	

GN	MC (% dry)	Maximum Allowable SEAT (in)	Maximum Allowable DPI (in/blow)	Approximate Test Layer (in)
4.6-5.0	< 5.0	2.6	0.6	5.0 - 7.0
	5.0-8.0	3.0	0.7	
	> 8.0	3.4	0.9	
5.1-5.5	< 5.0	3.3	0.7	6.0 - 12.0
	5.0-8.0	3.7	0.8	
	> 8.0	4.1	1.0	
5.6-6.0	< 5.0	4.0	0.8	7.0 - 12.0
	5.0-8.0	4.5	0.9	
	> 8.0	4.9	1.1	

DCP Data

Metric DCP Measurements (check if Metric, un-check to return to English)

Test Information				Requirements		DCP Data (in)			Test Results								
Test #	Date	Station	Offset	Test Layer Depth (in)	GN	MC (%)	Maximum Allowable SEAT (in)	Maximum Allowable DPI (in/blow)	Initial Reading	Reading after seating (2 Blows)	Reading after test (3 Blows)	SEAT (in)	SEAT: Pass or Fail	DPI (in/blow)	DPI: Pass or Fail	(1) Adequate Layer?	TEST: Pass or Fail

(1) [Reading after test (3 Blows) - Initial Reading] < Test Layer Depth = Adequate Layer

Fig. 3 5-692.255 mod

Edge Drain Trench w/filter aggregate

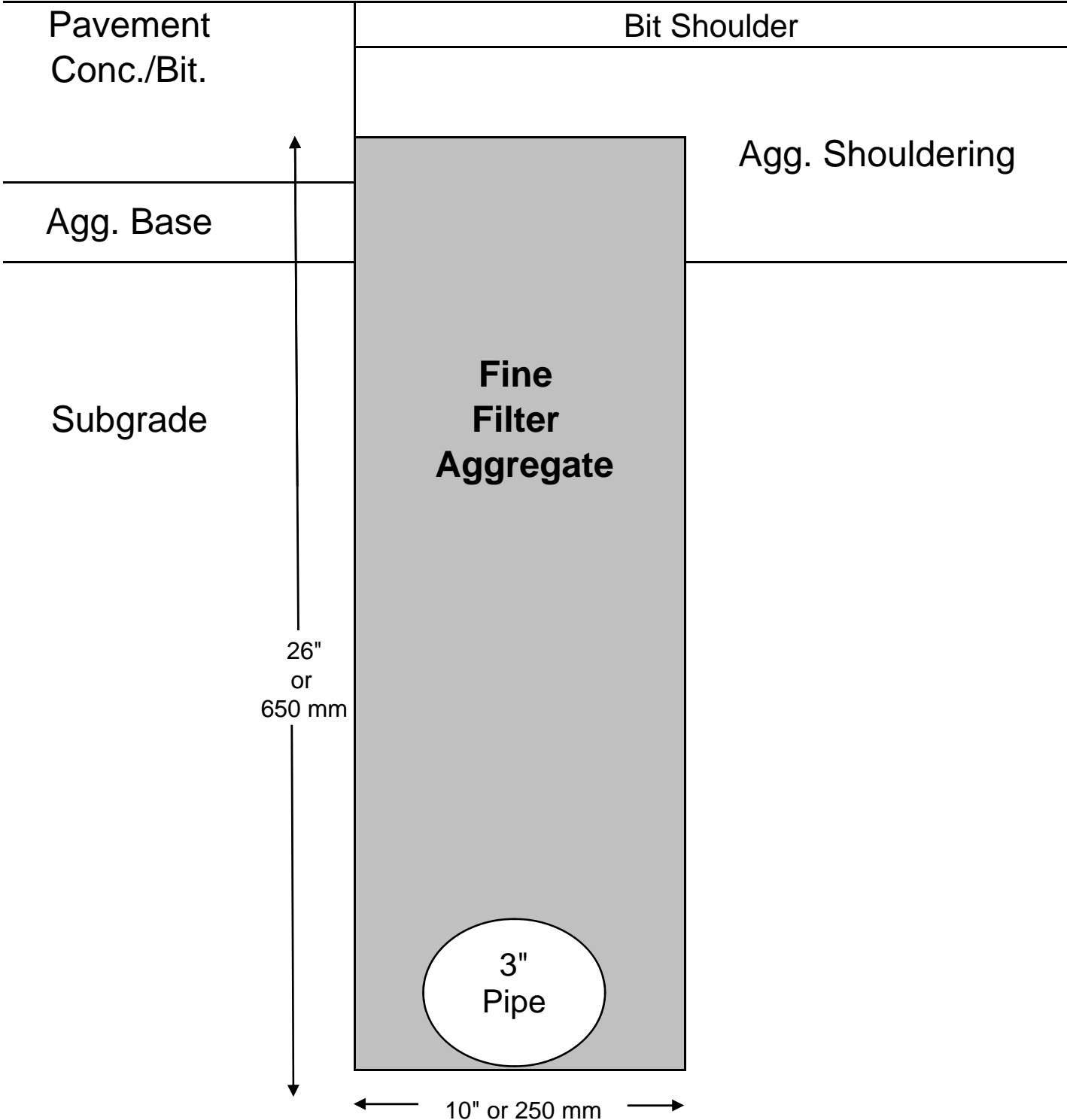


Fig. 4 5-692.255 mod



Penetration Index Method for Edge Drain Trench Filter Aggregate (English)

Grading & Base Manual 5-692.XXX

Project No:

Tester Name or Certification No.:

(A) Test #						
(B) Date						
(C) Station						
(D) Trench Depth [inches]						
(E) Number of Blows (D - 6 in) / 3 in (Round Down to Nearest Whole #)						
(F) Initial Reading (in)						
(G) Last Reading (in)						
(H) Difference (in) G - F						
(I) Penetration Index (PI) (in) H / E						
(J) Avg. Penetration Index (PI) (in) (I₁+I₂+I₃) / 3	X		X	X		X
(K) Average PI: Pass/Fail Passing Criteria: Average PI ≤ 3 in	X		X	X		X