Mn/DOT's New Base Compaction Specification Based on the Dynamic Cone Penetrometer

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Abstract

The Minnesota Department of Transportation (Mn/DOT) has traditionally utilized three methods of aggregate base layer compaction testing during pavement construction. These methods are the specified density method, quality compaction method, and nuclear control strip method.

While these methods have served the Mn/DOT well in the past, improved efficiency and quality in the inspection process are always desired. Proposed improvements included increased visual inspections and increased test frequency. However, to increase test frequency within a limited time budget requires testing to be done faster while maintaining accuracy. An alternative to the three existing methods was desired.

In 1991, Mn/DOT began investigating the potential application of the dynamic cone penetrometer (DCP). The DCP is a quick and inexpensive testing device that provides a measure of the in-situ shear strength of soils and aggregate base materials. Research and experience using the device pointed to the possibility of its application for base compaction quality assurance.

Utilizing data collected in 1996 from several construction projects, limiting DCP penetration index values were determined for several base materials used in Minnesota. Using this data, a

new base compaction specification, which included the DCP method, was developed for the 1997 construction season. The DCP testing procedure was defined and the recommended testing frequency determined. Compaction failures, as determined by the DCP method, were verified by the specified density method.

During the 1997 construction season about six projects utilized the DCP method described in the new specification. The results were positive and with some refinement the DCP method will remain part of Mn/DOT's standard specification. It is expected that the DCP will become more common at pavement construction sites throughout the state as more public and private organizations learn of its utility. To facilitate the learning process, Mn/DOT has begun the "DCP Loan Program," which allows interested organizations to "sign-out" a DCP for one-month periods to become familiar with the device.

1.0 Introduction

The capacity of pavement subgrade soil to support load is most often estimated using the Hveem Stabilometer R-Value (R-value), California Bearing Ratio (CBR), unconfined compression, or triaxial compression test. Mn/DOT has traditionally used the R-value of the subgrade determined in the laboratory to design pavements, but has not routinely utilized a field test to measure the in-situ shear strength during construction. Indirect measures, such as field density and moisture tests, are generally used. Visual assessments, which are dependent on the experience of the observer, are also common. However, because everyone's level of experience is different this often means variability in the assessment, which sometimes results in the acceptance of substandard areas or the unnecessary reconstruction of adequate areas. To help improve the assessment of field conditions the dynamic cone penetrometer (DCP) is being used because it provides a quick, quantitative, and repeatable measure of the in-situ shear strength during construction.

A variety of DCPs have been manufactured in the past by other organizations. Mn/DOT has adopted the most commonly used standard to facilitate communication and cooperation between other state and national transportation departments. The standard DCP consists of an 8-kg hammer that falls 575 mm and drives a 60-degree 20-mm-diameter cone into the soil or aggregate base (figure 1). The DCP produces shear failure in the material similar to the bearing capacity failure of a foundation (Sowers, G.F. and Hedges, C.S., 1966). Sowers comments that a cone-shaped tip yields more consistent results than a flat tip or thick-walled sampler and that the dynamic, as opposed to static, loading allows a wider variety of materials to be tested. He also cautions that like any test, the DCP should not be used as the sole measure of conditions and does not replace the need for good judgement. The DCP is most useful for verifying consistency and uniformity at specific construction sites. It also supports more accurate communication between the field observer and the office.

DCP use by other transportation departments is becoming more common as research and field experience increase. DCP development, applications, and published correlations to other measures of strength and stiffness have been summarized (Burnham, T. and Johnson, D., 1993) (Livneh, M., 1989). The DCP has also been recommended as a subgrade evaluation tool by the National Cooperative Highway Research Program of the Transportation Research Board, National Research Council (Laguros, J.G. and Miller, G.A., 1997).

The U.S. Army Corps of Engineers has published results from an extensive series of field tests in a variety of soil types (Webster, S.L., et al., 1994). The report compares the Corps' results to prior studies and concludes that a reliable correlation exists between the DCP and the CBR, which is a commonly used measure of subgrade mechanical properties. A reliable DCP/CBR correlation was expected since both tests use large strain penetration to measure bearing capacity. In fact, others have shown that the DCP produces more repeatable results than the CBR as measured by lower coefficients of variation (Livneh, M., 1989).

The Illinois DOT has compared field moisture-density measurements to DCP measurements and concluded that DCP tests can be successfully substituted for moisture-density tests when monitoring embankment and subgrade construction for final product acceptance (Bratt, T. et al., 1995). In fact, Bratt found that the DCP provided a better indication of stability for silty soils with high moisture. These soils would pass the moisture-density specification, yet fail to provide adequate stability during construction. The DCP was found to identify problem areas more reliably than density tests and allow correction prior to additional fill placement.

For granular base materials, the correlation between the DCP and the CBR has been studied by The Foundation for Industrial and Scientific Research at the Norwegian Institute of Technology (SINTEF) with funding from the Norwegian Road Research Laboratory (NRRL) (Ese, D., et al., 1994). This study also concluded that the mechanical properties of granular base materials, as measured by the CBR, correlated well to the DCP (figure 2).

The DCP technique is finding acceptance within Mn/DOT because it is both accurate and quick. The DCP allows more consistent identification of problem areas, more expeditious decision making in the field, and more accurate communication between field and office personnel. All of which result in fewer delays during construction.

Mn/DOT specifications currently address two applications for DCP testing. These are compaction control of the granular base layer and edge drain trench backfill. Non-specified uses include investigating soft subcut areas, evaluating base and subgrade materials below full-depth cracks in bituminous pavements, measuring the effectiveness of stabilizing subgrades with flyash, and estimating the soil shear strength beneath shallow spread footings (Burnham, T.R., 1997).

2.0 Field Testing

Mn/DOT personnel performed field tests at several projects around Minnesota during 1996 in order to develop the specification used in 1997. Additional field tests were performed during July of 1997 at the T.H. 23 project near St. Cloud, Minnesota. The base material at the T.H. 23 project was a blend of sand, gravel, and crushed granite that conformed to the Mn/DOT class 6 specification (figure 3). This figure shows that the base material was quite uniform and tended to only vary through about half of the acceptable range for each sieve size. DCP testing was performed in general accordance with the procedure defined in section 5.0 of this report, Penetration Index Method (Trial Mn/DOT Specification 2211.3C4). The percent compaction was determined using the Specified Density Method (Mn/DOT Specification 2211.3C1) in which the sand cone density is compared to the standard Proctor density.

3.0 Results

The results of the DCP tests are shown in figure 4. This figure shows that the penetration per blow, which is defined as the DCP penetration index (DPI), ranges from 5 to 23 mm/blow with most DPIs less than 15 mm/blow. Percent compaction results are shown in figure 5. Note that some of these compaction results are somewhat greater than what is considered reasonable. This was due to several factors, such as sand cone procedures and Proctor material variations, which were addressed and corrected later in the project. Figure 5 shows that the percent compaction meets or exceeds 100 percent, which is the percent compaction required in the specification. Figures 4 and 5 together show general agreement between these two methods of aggregate base assessment.

In addition to the general agreement between the DPI and percent compaction is the ability of the DCP to measure the variation in strength with depth (figure 6). Note that near the surface, the amount of penetration per blow decreases rapidly as depth increases because of the confinement provided by the surrounding material. This indicates that it is important to seat the cone tip properly and begin the test consistently.

The penetration per blow is also affected by the moisture content, set-up time, and construction traffic (figures 7 through 10). Figures 7 through 9 show that as the post-compaction time increases and the base material dries, the strength increases due to an apparent cohesion. Figure 10 shows that the base becomes significantly stronger in the wheel path due to the additional compaction caused by construction traffic.

4.0 Conclusions and Recommendations

Several conclusions and recommendations can be drawn from the results of this study.

1. The DCP method is an appropriate substitute for the specified density method when assessing aggregate base materials. It is recommended that the DCP method remain an option for determining acceptable aggregate base condition and that its use be increased.
2. A penetration of 19 mm/blow, which was allowed in 1997, may be too high based on the new data that shows less penetration per blow is generally achieved. It is recommended that the criteria be changed to 15 mm/blow in the upper 75 mm. It is also suggested that inspectors use the DCP in other ways to further assess questionable areas and gain greater experience with the DCP. Optional testing could be done to assess the condition of the completed aggregate base course just prior to paving. Possible criteria would be 10 mm/blow at depths between 75 and 150 mm and 5 mm/blow at depths below 150 mm.
3. Accurate and repeatable DCP tests depend on seating the cone tip properly and beginning the test consistently. It is recommended that the cone tip be seated by one full drop of the hammer.
4. Set-up time and moisture content affect the DPI. The criteria of 15 mm/blow recommended above is based on the test being performed not more than one day after compaction while the base material is still damp.
5. Compaction caused by construction traffic increased the strength of the base in the wheel

path. Though this increase in strength with traffic may be expected it may not be desirable because of its non-uniform nature. Since the increase in strength is likely due to more closely packed particles and fewer voids, the potential exists for slightly different water contents during wet conditions. Varying water contents result in differential frost heave and increased strain in the pavement. It is recommended that construction traffic be distributed more uniformly by requiring haul trucks to vary their path.

5.0 Specification

The 1997 specification was revised based on the above recommendations. The following is the 1998 Mn/DOT granular base material compaction specification that pertains to DCP testing.

5.1 Penetration Index Method (Trial Mn/DOT Specification 2211.3C4)

The full thickness of each layer shall be compacted to achieve a penetration index value less than or equal to 15 mm/blow, as determined by a Mn/DOT standard dynamic cone penetrometer (DCP) device. For test purposes, a layer will be considered to be 75 mm in compacted thickness but a testing layer can be increased in thickness to a maximum of 150 mm if compacted in one lift by a vibratory roller. At least two dynamic cone penetrometer tests shall be conducted at selected sites within each 800 cubic meters of constructed base course.

Compacted areas with a penetration index greater than 15 mm/blow may be alternatively retested and accepted if meeting the criteria of the Specified Density Method 2211.3C1.

Water shall be applied to the base material during the mixing, spreading and compacting operations when and in quantities the Engineer considers necessary for proper compaction.

5.2 Determination of Penetration Index Value

The penetration index value will be determined using a Mn/DOT standard dynamic cone penetrometer (DCP) device. The basic test method and detailed test procedure can be found in the Mn/DOT *User Guide to the Dynamic Cone Penetrometer*.

5.3 DCP Test Procedure for Compaction Quality Control of Granular Base Materials

Figure 11 is a sample of the field test data sheet used by Mn/DOT.

1. Locate a level, undisturbed area.
2. Place the DCP device on the base aggregate test site. To seat the DCP cone tip properly, carefully raise the sliding weighted hammer until it meets the handle, then release the hammer under its own weight. If the seating process causes initial penetration exceeding 20 mm, relocate the test to a site at least 300 mm from the previous test location and reseat the cone. If the second test site fails the above criteria, compaction is not acceptable and the area being tested must be recompacted.
3. Record the penetration measurement after seating using the graduated rule on the DCP.
4. Carefully raise the hammer until it meets the handle, then release the hammer under its own weight. Repeat this process two more times for a total of three times when testing a lift of 75 mm or less. Repeat this process four more times for a total of five times when testing a lift of between 75 and 150 mm.
5. Record the final penetration measurement from the graduated rule on the DCP.
6. Subtract the measurement in step 3 from the measurement in step 5 and then divide the difference of the measurements by the number of blows required for testing. If the resulting value is 15 mm/blow or less, the test passes.

6.0 Dynamic Cone Penetrometer Loan Program

The DCP is currently being implemented within Mn/DOT, but the benefits of the technique have not yet been transferred to the broader engineering community. Mn/DOT has developed a user's guide, an instructional video, and has also manufactured 9 additional DCPs, which are available for loan to participating public and private organizations.

The loan program is intended to overcome the cost of manufacturing the DCP device, which is an obstacle that deters interested organizations from trying the DCP. It is anticipated that once an organization has had the opportunity to use the loaned DCP and become familiar with the device that they would be willing to purchase their own DCP for future use.

6.1 Mn/DOT's Responsibilities

The principle author listed above is responsible for the following tasks.

1. Inform county highway departments, city public works departments, engineering societies, and consulting engineers of the DCP Loan Program and answer questions about the program and the operation of the DCP.
2. Loan the DCPs to participating organizations for one-month periods during the 1998 construction season. The participating organization would "sign-out" the DCP from the Mn/DOT project engineer and ship the DCP back to the project engineer upon completion of the loan period.
3. Provide an instructional package that would contain the "User Guide to the Dynamic Cone Penetrometer" and the instructional video.
4. Maintain and repair the DCPs as needed.
5. Measure the outcomes using the surveys described below.
6. Prepare a preliminary report in the fall of 1998 and a final report in the fall of 1999, upon receipt of the one-year surveys. The final report will be sent to all participants in the program.

6.2 Receiving Organization's Responsibilities

As a condition of the DCP loan program, the receiving organization agrees to share the DCP data and interpretations with Mn/DOT. The organization also agrees to complete an initial survey at the end of the loan period and a second follow-up survey one-year after the loan period.

Survey #1 (completed by the receiving organization after the one-month loan period)

1. Number of projects on which the loaned DCP was used.
2. Number of miles of road on which the loaned DCP was used.
3. Number of problem areas on road right-of-way identified.
4. Number of square feet of problem areas on road right-of-way identified.
5. Number of square feet of parking lots on which loaned DCP was used.
6. How did the DCP allow you to make a more informed analysis of the conditions?
7. How did the DCP results affect the outcome of the project with regard to cost, time, etc.?
8. Did contractors believe the DCP results?
9. Were contractors cooperative in correcting areas identified as deficient?
10. What other uses did you find for the DCP?
11. What correlations did you develop between the DCP and other tests?
12. Do you plan to have a DCP manufactured for future use?
13. Do you plan to require specific DCP results in your specifications?

Survey #2 (completed by the receiving organization one year later)

1. Number of DCPs built by the receiving organization.

Repeat many of the questions asked in Survey #1

6.3 Agreement

I have borrowed a DCP from Mn/DOT and will return the DCP in one month. I agree to share the DCP data and interpretations with Mn/DOT, complete an initial survey at the end of the loan period and a second follow-up survey one-year after the loan period.

Organization: ____ Phone: __________________

Address: ____

Name: _______________________Signature: _______________________Date: _______________

If you are interested in participating in this program, please contact the project engineer listed above. Thank you.

7.0 Acknowledgements

This report was made possible by Mn/DOT's construction inspectors who used the DCP and reported their experiences. The authors are particularly indebted to Tim Voigt who went well beyond his regular duties to perform the additional tests necessary to make refinement of the specification possible.

8.0 References

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Standard Mn/DOT DCP

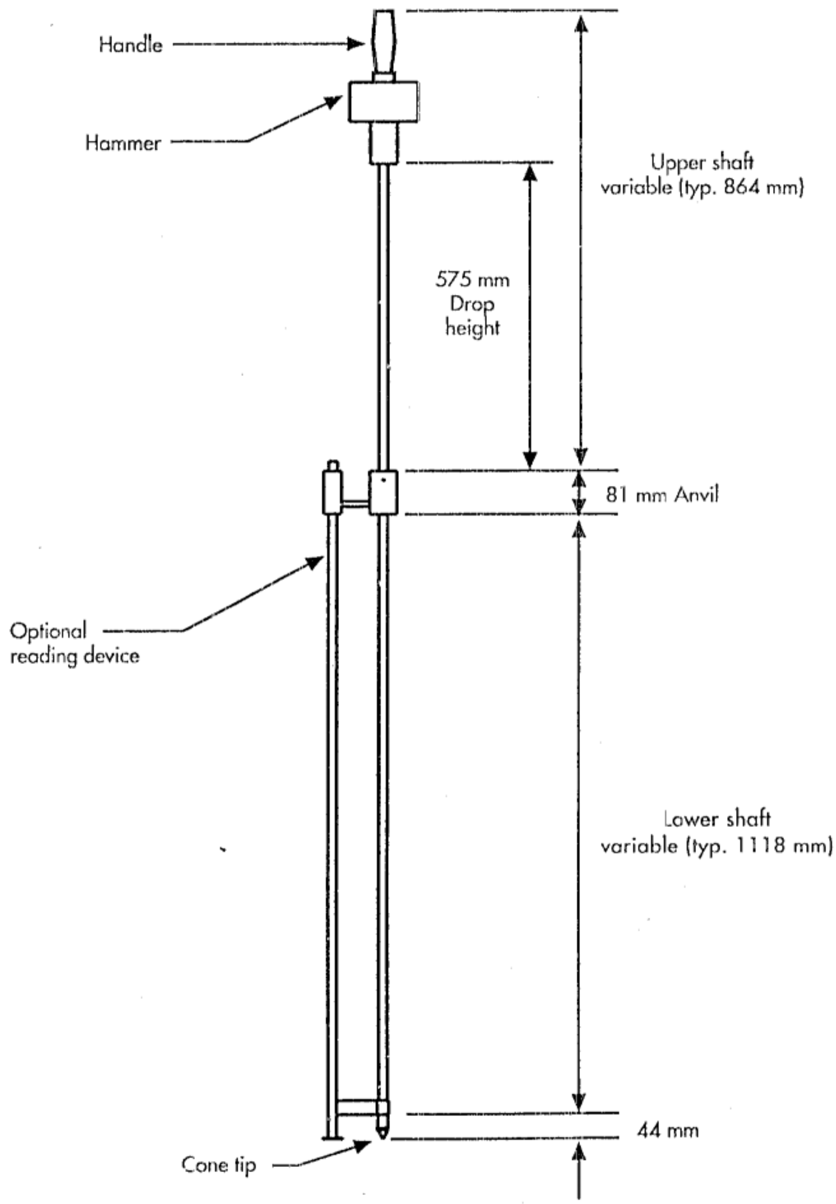


figure 1

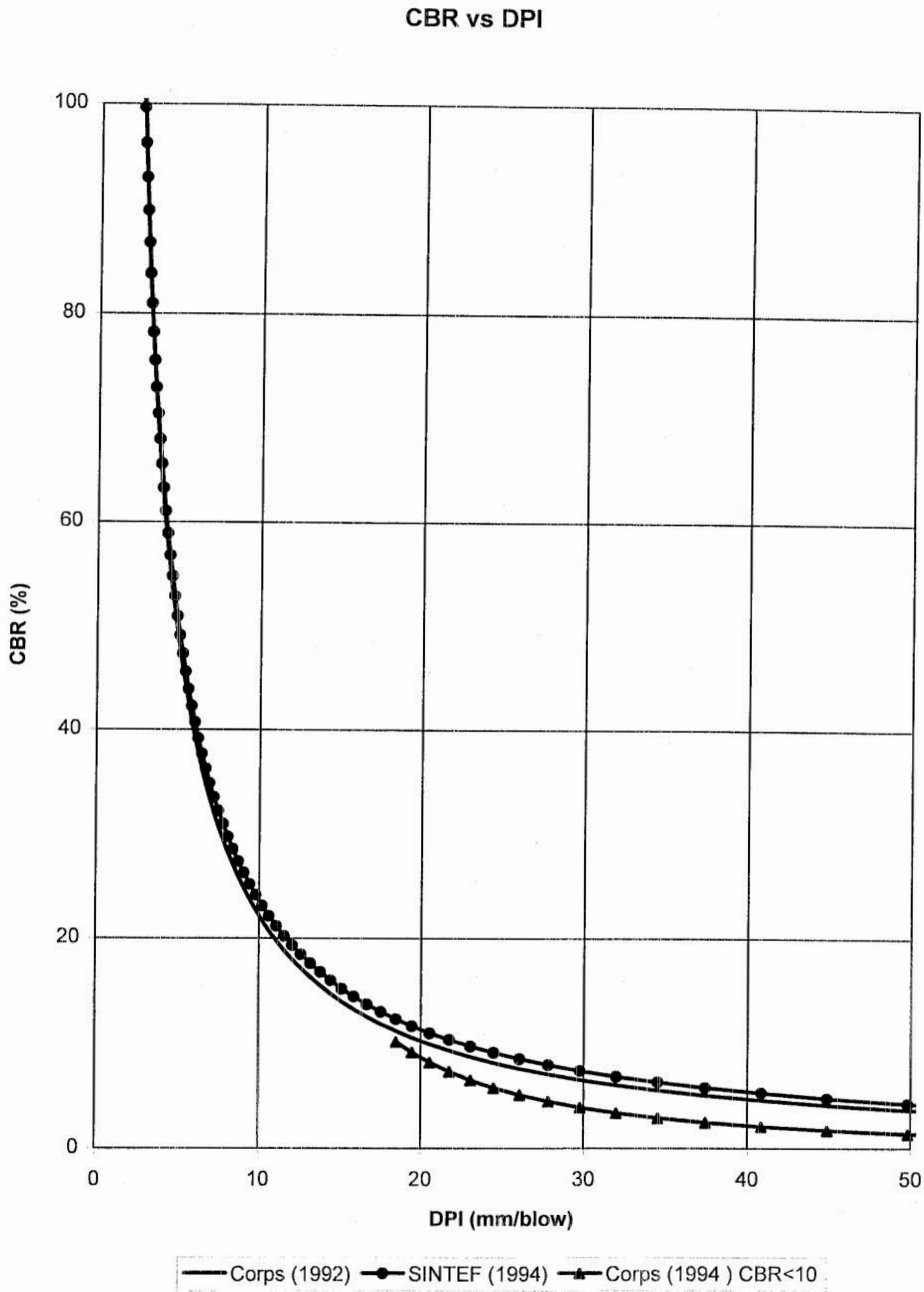

CBR vs DPI
100
80
60
40
20
0
CBR (%)
0
10
20
30
40
50
DPI (mm/blow)
Corps (1992)
SINTEF (1994)
Corps (1994) CBR<10

figure 2

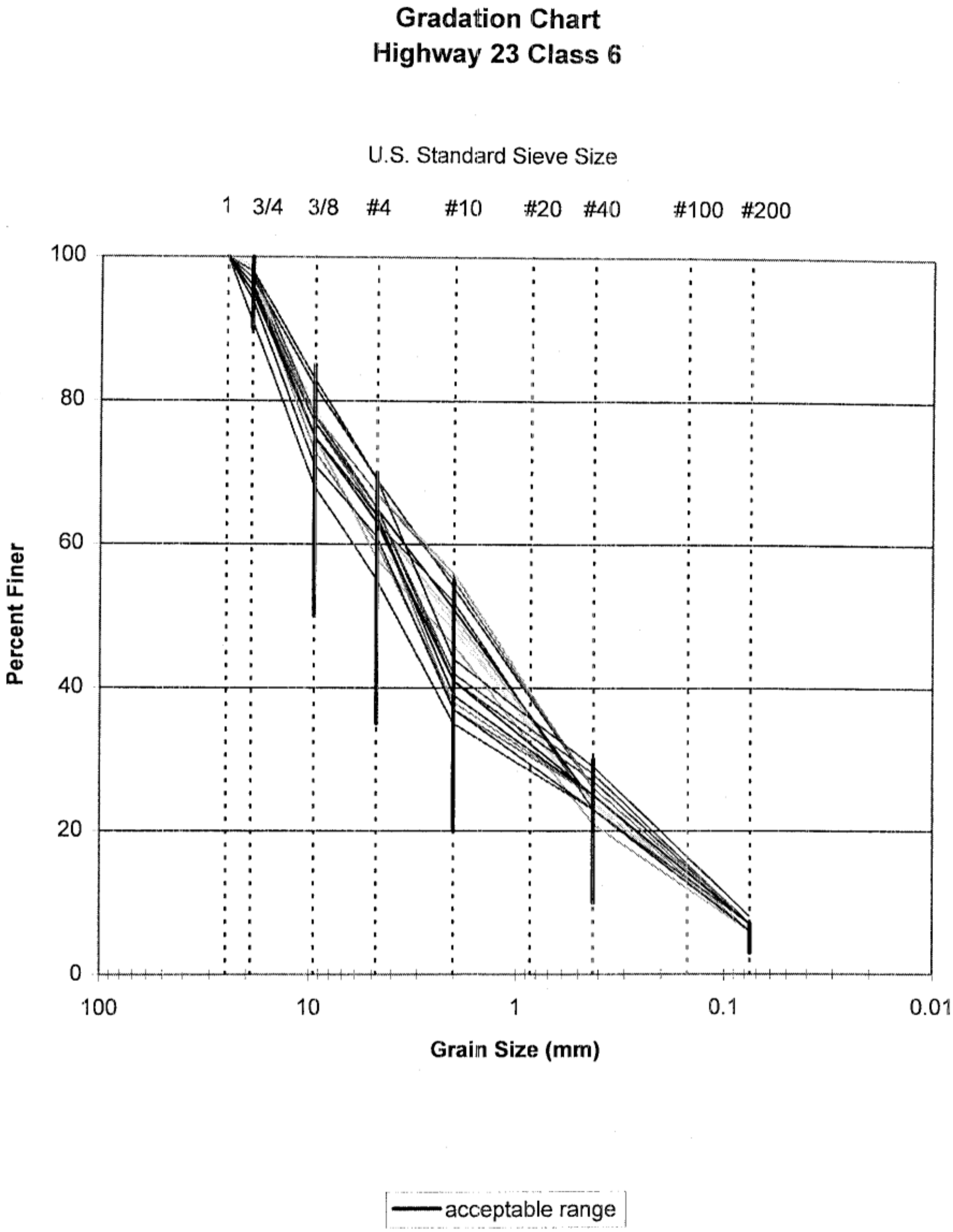

Gradation Chart
Highway 23 Class 6
U.S. Standard Sieve Size
1
3/4
3/8
#4
#10
#20
#40
#100
#200
100
80
60
40
20
0
Percent Finer
100
10
1
0.1
0.01
Grain Size (mm)
acceptable range

figure 3

DPI by Location

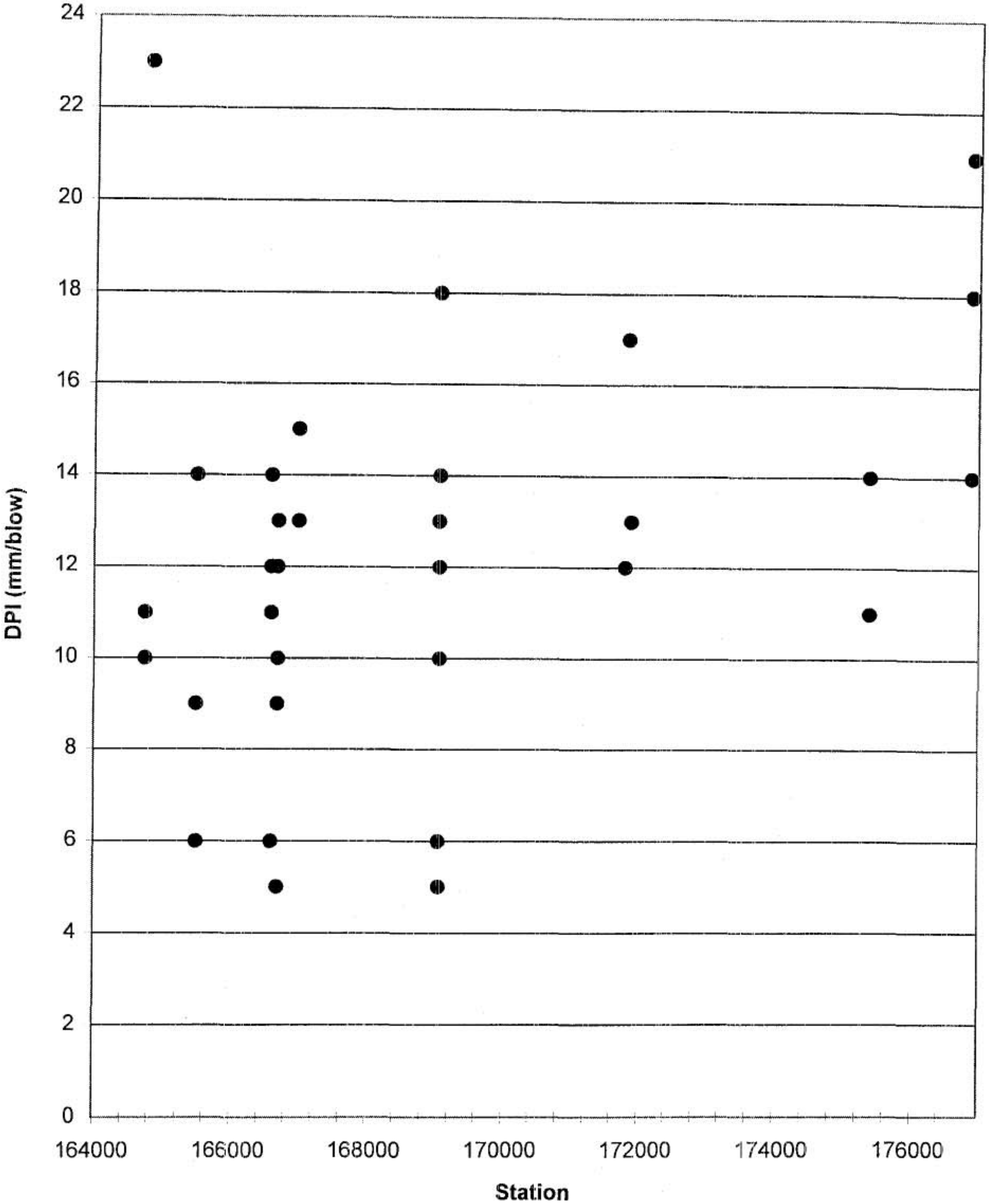


figure 4

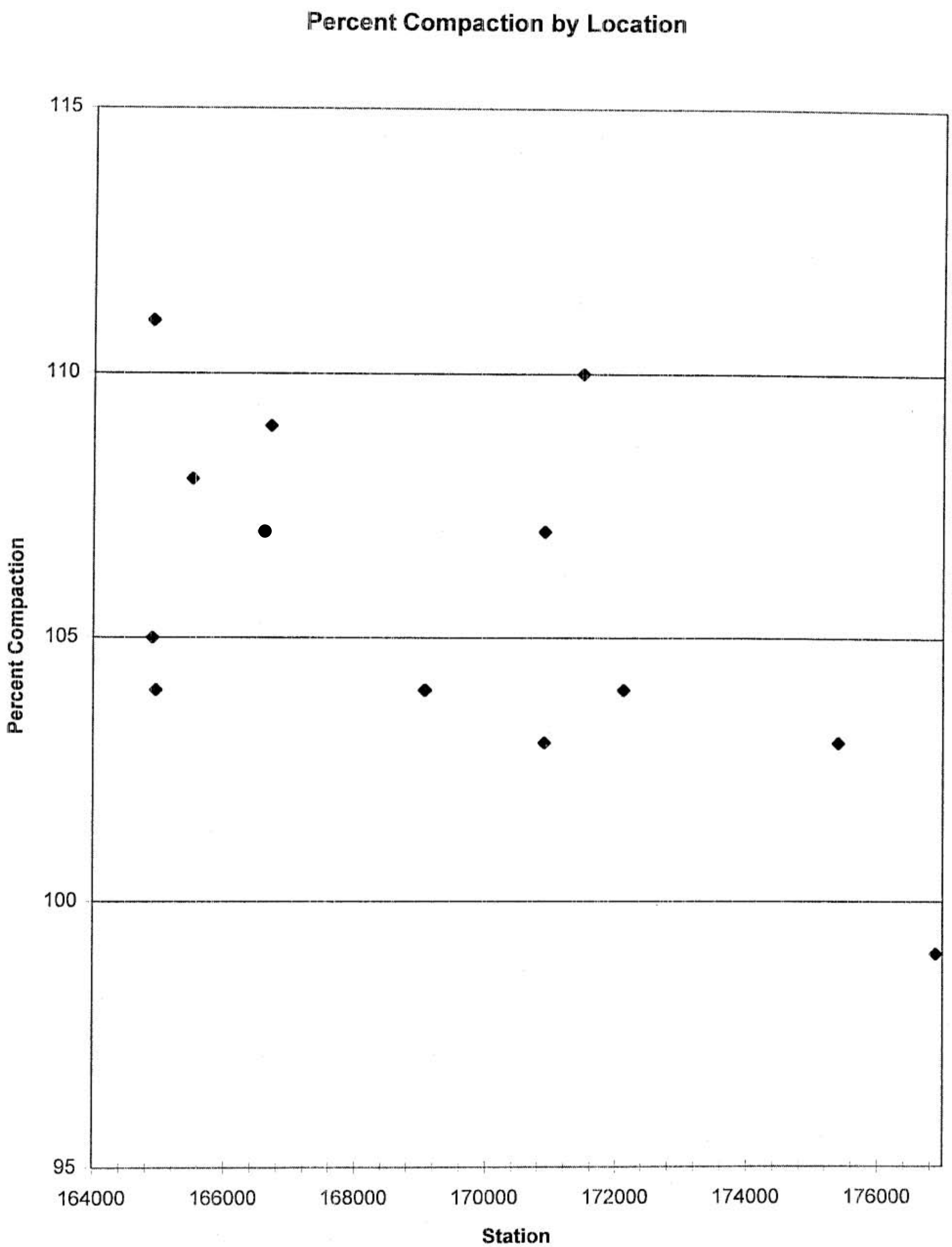

Percent Compaction by Location
115
110
105
100
95
Percent Compaction
164000
166000
168000
170000
172000
174000
176000
Station

figure 5

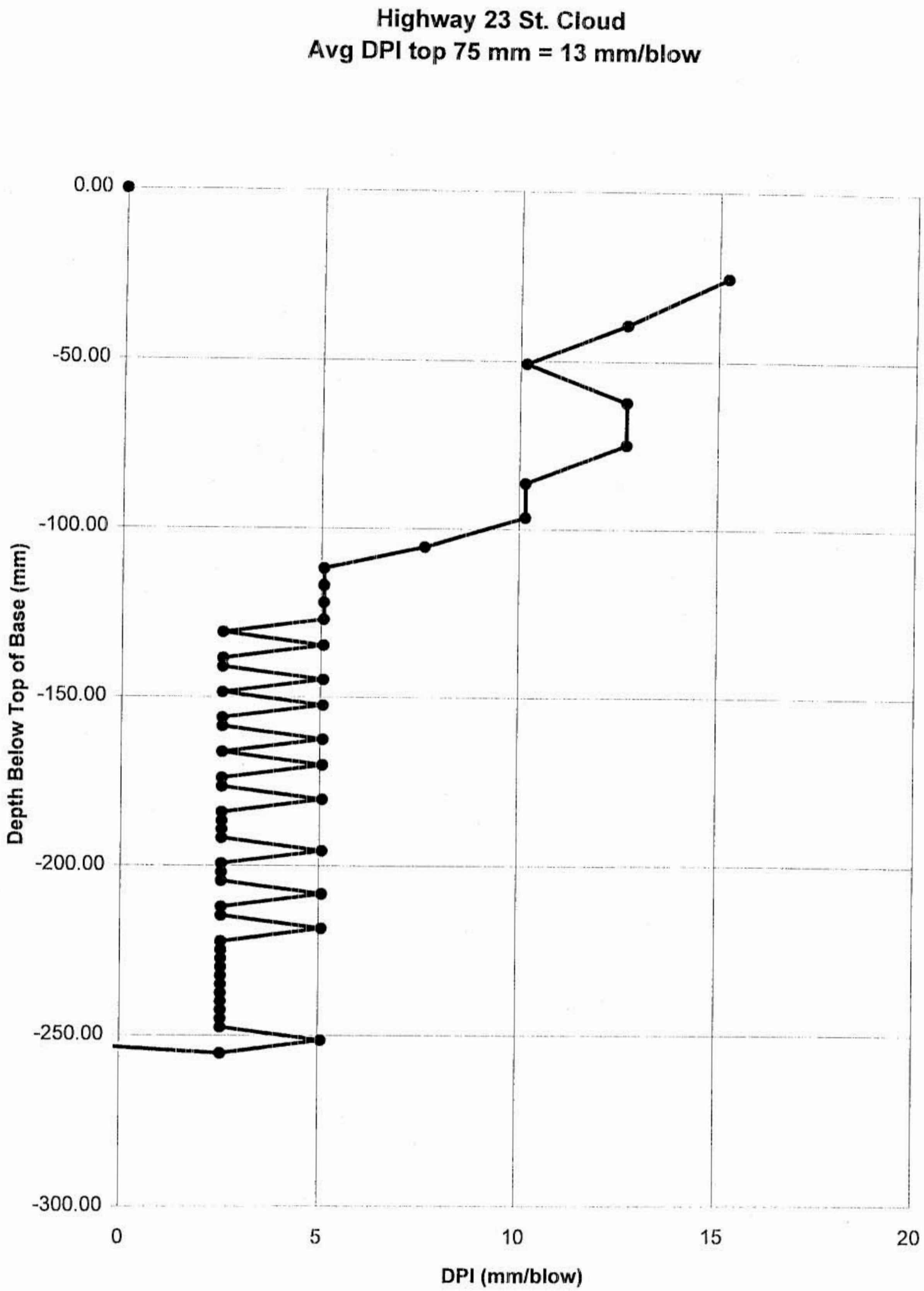
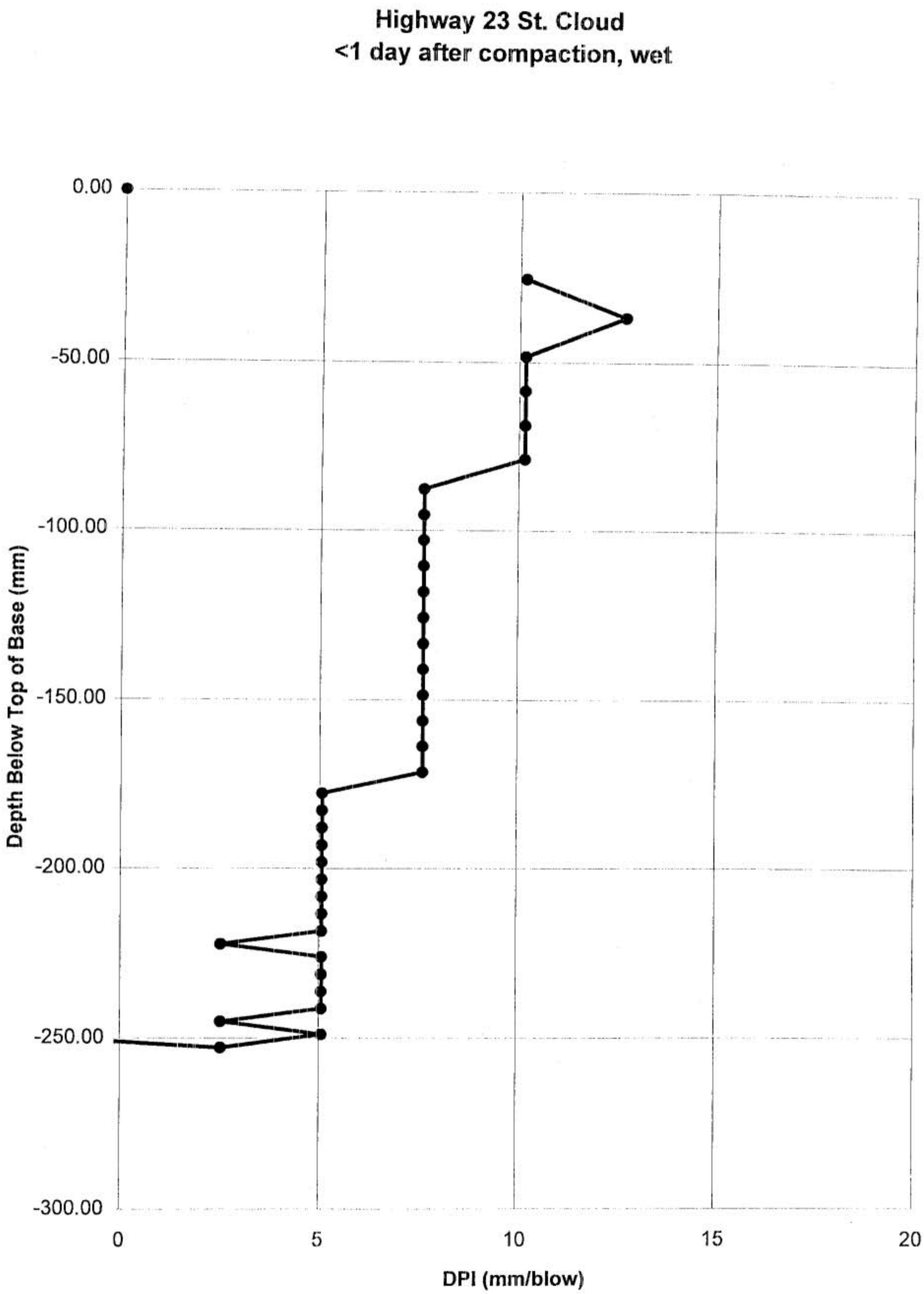

Highway 23 St. Cloud
Avg DPI top 75 mm = 13 mm/blow
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
Depth Below Top of Base (mm)
0
5
10
15
20
DPI (mm/blow)

figure 6



Highway 23 St. Cloud
<1 day after compaction, wet
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
Depth Below Top of Base (mm)
0
5
10
15
20
DPI (mm/blow)

figure 7

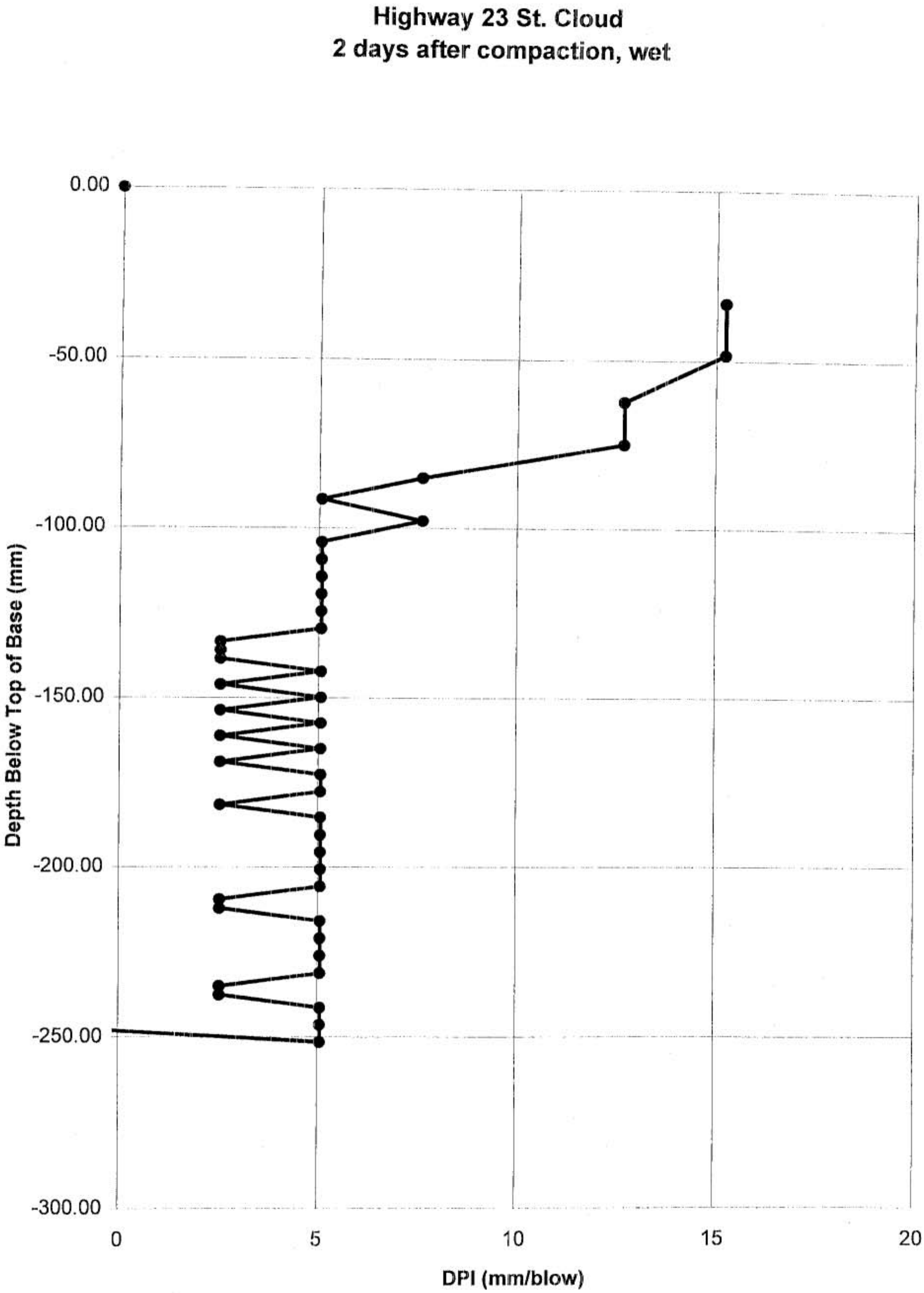

Highway 23 St. Cloud
2 days after compaction, wet
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
Depth Below Top of Base (mm)
0
5
10
15
20
DPI (mm/blow)

figure 8

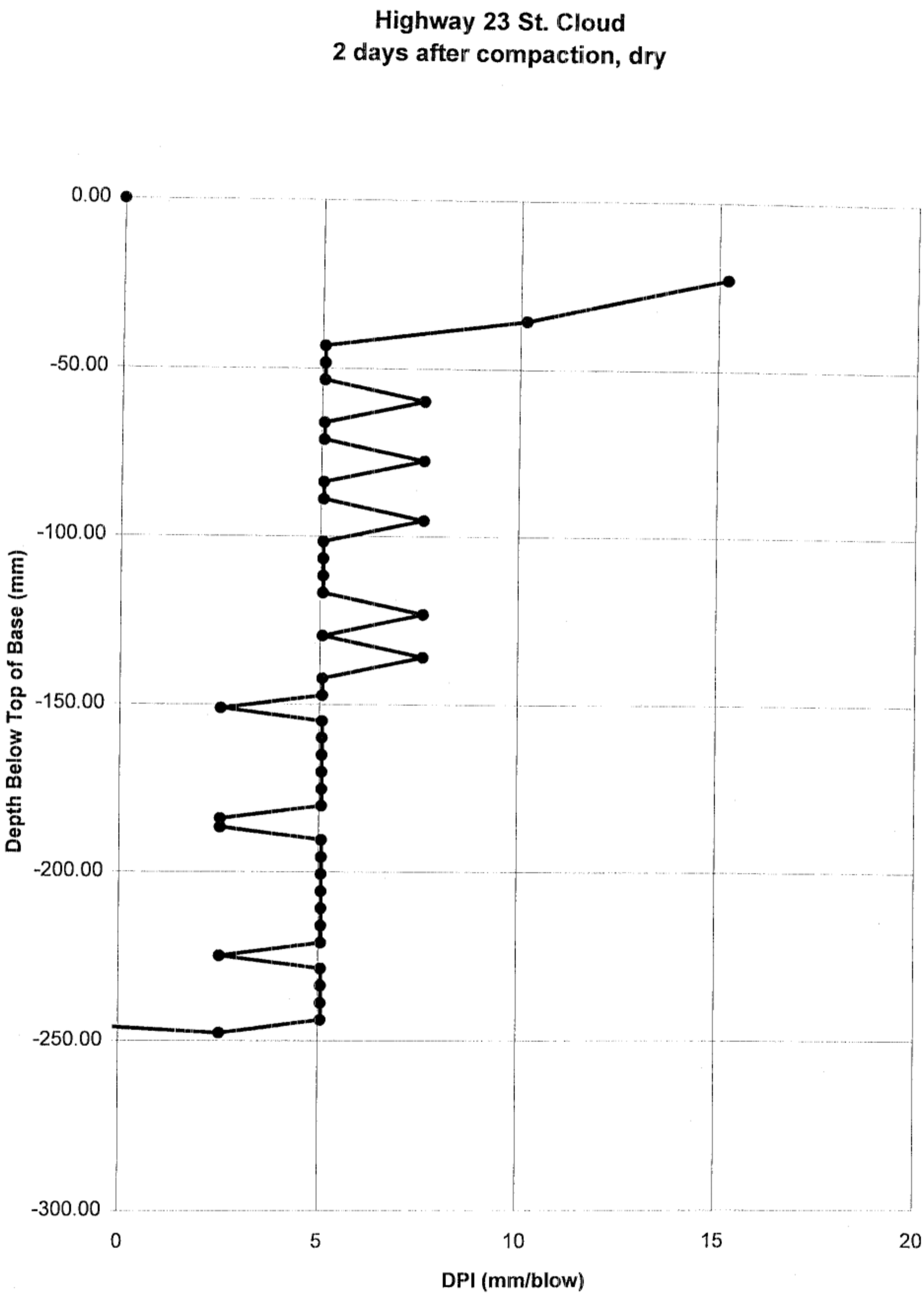

Highway 23 St. Cloud
2 days after compaction, dry
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
Depth Below Top of Base (mm)
0
5
10
15
20
DPI (mm/blow)

figure 9

Highway 23 St. Cloud
wheel path

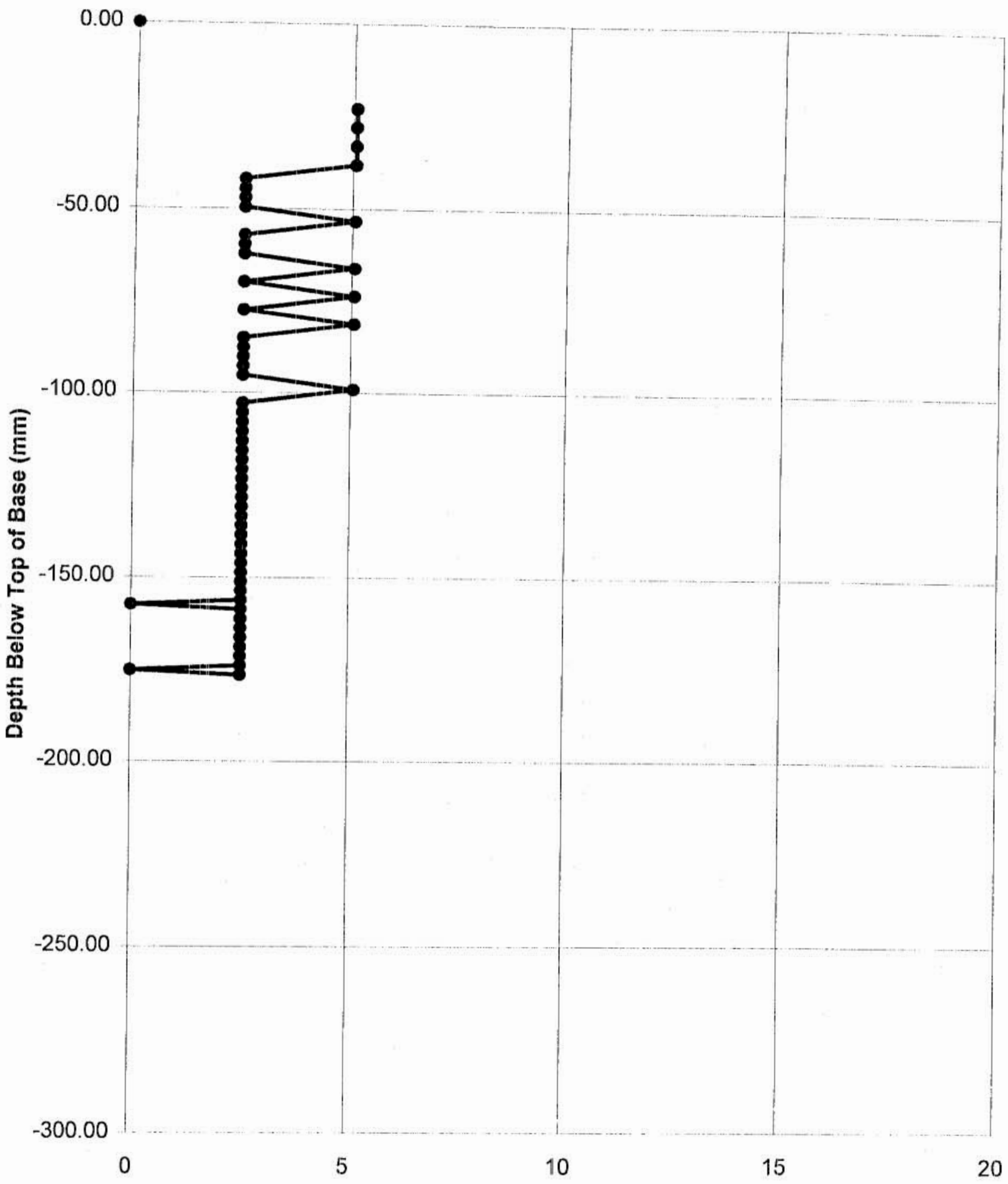


figure 10

Minnesota Department of Transportation

Density Test for Base Aggregate and Edge Drain Trench Filter Aggregate

(Penetration Index Method by DCP*)

SP ____________________ TH ____________________ Tester(s) ____________________

Test No.	Aggregate Class or Filter Aggregate	Station	Lift Thickness or Trench Depth	(A) 2nd Reading	(B) 1st Reading	(C) Difference	(D) Blows	(E) Penetration Index	Pass or Fail	Date

*Dynamic Cone Penetrometer

For Base Aggregate

C = A – B

E = C ÷ D

(Conversion from inches to mm = E x 25)

Penetration Index (E) = 15 mm or less = Passing

For Filter Aggregate

C = A – B

E = C ÷ D

(Conversion from inches to mm = E x 25)

Penetration Index (E) = 75 mm or less = Passing