

Application of the Dynamic Cone  
Penetrometer to Minnesota  
Department of Transportation  
Pavement Assessment Procedures



Local Road Research Board



Implementation

## Technical Report Documentation Page

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16. Abstract (Limit: 200 words)  The Minnesota Department of Transportation (Mn/DOT) began testing the dynamic cone penetrometer (DCP) in 1991, finding the DCP an effective tool in the assessment of subsurface pavement conditions and strength. Researchers conducted extensive DCP testing and research on both the Minnesota Road Research Project (Mn/ROAD) and several pilot project sites in an effort to understand its useful applications in Minnesota.  Mn/DOT currently specifies two applications of DCP testing in its pavement assessment procedure. One application involves using the DCP as a quality control device during the backfill compaction of pavement edge drain trenches. The second application involves its use in quality control of granular base layer compaction. This report details these applications and includes a copy of both specifications in the appendices. Other nonspecified applications of the DCP have included investigations of soft subcut areas, determination of the condition of base and subgrade materials under full depth bituminous cracks, and monitoring of the effectiveness of subgrade flyash stabilization.  Researchers recently analyzed Mn/ROAD project DCP test results to determine the limiting DPI value for each particular subgrade soil and base type. The report presents recommended DPI limits.			
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**APPLICATION OF THE  
DYNAMIC CONE PENETROMETER TO  
MINNESOTA DEPARTMENT OF TRANSPORTATION  
PAVEMENT ASSESSMENT PROCEDURES**

**Final Report**

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## EXECUTIVE SUMMARY

Since its introduction to the Minnesota Department of Transportation (Mn/DOT) in 1991, the dynamic cone penetrometer (DCP) has been found to be an effective tool in the assessment of subsurface pavement conditions and strength. Extensive DCP testing and research was conducted on both the Minnesota Road Research Project (Mn/ROAD) and several pilot project sites in an effort to understand its useful applications in Minnesota.

Mn/DOT conducted many studies attempting to determine whether there is a reasonable correlation between the DCP's penetration index (DPI) and in-place compaction density. Most results of DCP testing on cohesive and select granular materials showed too much variability to practically apply a correlation. Research demonstrated, however, that properly compacted granular base materials exhibit very uniform DPI values.

Over 700 DCP tests were conducted on the Mn/ROAD project during its construction. Test results were recently analyzed to determine the limiting DPI value for each particular subgrade soil and base type. Recommended DPI limits are presented.

Mn/DOT currently specifies two different applications of DCP testing in its pavement assessment procedures. One application involves using the DCP as a quality control device during the backfill compaction of pavement edge drain trenches. Reports to date have indicated this testing to be reliable and effective in improving the compaction levels of these trenches. The second specified application of DCP testing involves its use in quality control of granular base layer compaction. A copy of both specifications are included in the appendices.

Other nonspecified applications of the DCP by Mn/DOT have included investigations of soft subcut areas, determination of the condition of the base and subgrade materials under full depth bituminous cracks, and monitoring the effectiveness of subgrade flyash stabilization. The DCP has also been used to measure the foundation strength of footing pads for a maintenance building.

Through extensive research, several pavement assessment applications have been discovered for the DCP. The utilization of this simple and inexpensive tool should provide long lasting benefits to newly constructed and rehabilitated pavements throughout Minnesota.

## Introduction

Since its introduction to the Minnesota Department of Transportation (Mn/DOT) in 1991, the dynamic cone penetrometer (DCP) has been found to be an effective tool in the assessment of subsurface pavement conditions and strength. Extensive DCP testing and research was conducted on both the Minnesota Road Research Project (Mn/ROAD) and several pilot project sites in an effort to understand its useful applications in Minnesota.

An important part of any research is the implementation of its successful aspects. As recommended by the Mn/DOT DCP Research and Implementation Committee, this report was put together to summarize the implemented aspects of the DCP in Mn/DOT pavement assessment procedures. A DCP research history and a summary of recent research findings is also presented.

## Recent Mn/DOT DCP Research

Historically, Mn/DOT has monitored the compaction levels of pavement subgrade and base layers by means of in-place density testing. As a result of this, many studies were conducted to determine whether there is a reasonable correlation between the DCP's penetration index (DPI) and in-place compaction density. Most results of DCP testing on cohesive and select granular materials showed too much variability to practically apply a correlation. Research demonstrated, however, that properly compacted granular base materials exhibit very uniform DPI values.

The most recent research focused on whether a limiting DPI value, one that will ensure adequate compaction levels during construction, can be determined for some of the standard Mn/DOT granular base (manufactured) materials. Through statewide field testing on granular base layers deemed adequately compacted by existing test methods, it was discovered that a limiting DPI could be determined. The results of that study allowed the creation of a granular base layer compaction DCP test procedure (to be described later in this report). The long term implementation goal of that procedure is the reduction or elimination of the time consuming sand cone density testing method.

During past DCP testing research on select granular materials, it was found that due to lack of confinement near the surface, DPI values were not valid until several inches below the testing surface. To assess whether this same behavior occurred in granular base materials, an



experimental steel plate was fabricated to test whether imposed confinement would provide more accurate DPI values closer to the surface. The plate (300 mm diameter, 20 mm thick, 28.6 mm dia. center hole) was used at several projects during the 1996 construction season, and showed little effect on the confinement level near the surface. Based on results from that testing, it was shown that the granular base materials used in Minnesota do not experience much loss of confinement near the surface when properly compacted. This information provided confidence that the granular base layer compaction specification could be developed without requiring imposed surface confinement during DCP testing.

The DCP was originally designed to be used as a tool for the assessment of pavement conditions and layer thicknesses in rehabilitation studies. This application of the tool has, up until this point, been underutilized by Mn/DOT. The main reason for this has been the lack of DPI values which can be used for strength comparison. On recommendation of the DCP committee, DCP test results from the Mn/ROAD project were assembled and analyzed to determine the presence of reasonable limiting DPI values. The results of this analysis are outlined in the next section.

For further information, a chronology of Mn/DOT DCP research can be found in Appendix C.

#### Limiting DPI values based on soil type

Over 700 DCP tests were conducted on the Mn/ROAD project during its construction. Tests were conducted on subgrade, subbase, and base layers as they were constructed. Those test results were recently analyzed to determine the limiting DPI value for each particular subgrade soil and base type. The test results were also analyzed to determine the effect base course application had on previously tested subgrade layers (confinement effects).

The following general observations were made during the analysis:

- 1) Identifiable DPI limits could be determined for the Mn/ROAD silty/clay subgrade, select granular subgrade, and class 3 special gradation granular base material
- 2) The effect of confinement from an overlying granular base layer could clearly be seen during the analysis of pavement sections with select granular subgrade

3) The layer thicknesses of Mn/ROAD class 4 special, class 5 special, and class 6 special gradation materials were inadequate to establish a reliable DPI limit value.

Table 1 summarizes the Mn/ROAD DCP results from tests conducted just prior to paving the various surfaces. Each soil and base type was divided into test cell type (5 year design life, 10 year design life, low volume road design), then into 300 mm (12") layers, and finally analyzed for its average DPI. Figures 1-7 depict the analysis results with the recommended DPI limit indicated by the bold horizontal line. Appendix D contains figures generated from DCP tests conducted before the granular base layers were constructed.

Based on the analysis of Mn/ROAD DCP testing, the following DPI limit values are recommended for use by a soils engineer when analyzing DCP test results conducted during a rehabilitation study:

$$\text{Silty/clay material} \rightarrow \text{DPI} < 25 \frac{\text{mm}}{\text{blow}} \left( 1.0 \frac{\text{inches}}{\text{blow}} \right)$$

$$\text{Select granular material} \rightarrow \text{DPI} < 7 \frac{\text{mm}}{\text{blow}} \left( 0.28 \frac{\text{inches}}{\text{blow}} \right)$$

$$\text{Mn/ROAD Class 3 Special gradation materials} \rightarrow \text{DPI} < 5 \frac{\text{mm}}{\text{blow}} \left( 0.20 \frac{\text{inches}}{\text{blow}} \right)$$

These recommended values assume adequate confinement near the testing surface. If these recommended limits are exceeded during a rehabilitation study, additional soil testing methods are recommended.

Special notice should be given in that the above values were determined independent of moisture content effects. Moisture effects are many times responsible for the great variability in DCP test results. However, as the figures show, a limiting value for each soil type is recognized. To further test whether the recommended limiting DPI values for subgrade soils are reasonable, the values were correlated to CBR (California Bearing Ratio) and compared to the constructibility limits as recommended by the Illinois Department of Transportation (IDOT). Figure 8 shows a graph presented in IDOT's *Subgrade Stability Manual* [2] which indicates minimum subgrade CBR values below which subgrade treatment is recommended. Using the DPI-CBR correlation

as suggested by the U.S. Army Corps of Engineers (Waterways Experiment Station) [3] :

$$\text{CBR} = \frac{292}{\text{DPI}^{1.12}}$$

the silty/clay recommended DPI limit of 25mm/blow correlates to a CBR of 8. A field (unsoaked) CBR value of 8 corresponds to the subgrade correction cutoff point on Figure 8. For CBR values above 8, subgrade improvement is usually not necessary. This simple exercise provides confidence in the recommended DPI limit for silty/clay subgrade soils.

#### Current application of the DCP by Mn/DOT

Mn/DOT currently specifies two different applications of DCP testing in its pavement assessment procedures. One application involves using the DCP as a quality control device during the backfill compaction of pavement edge drain trenches[1]. This application was devised to reduce settlements of bituminous shoulders near the pavement edge.

The specific test procedure for edge drain trench testing is described in Mn/DOT's Special Provisions SP5-128. A copy of this special provision can be found in Appendix A. The procedure is essentially as follows: shortly after installation of the pavement edge drain pipe and fine filter aggregate backfill material, DCP testing is conducted to insure the penetration index (DPI) is less than 75 mm per blow (3 inches per blow). Each 150 mm (6 inches) of compacted backfill material is tested for compliance. Reports to this date have indicated this testing to be reliable and effective in improving the compaction levels of these trenches.

The second specified application of DCP testing involves its use in quality control of granular base layer compaction. This application was devised to reduce testing time and effort, while providing more consistent quality control of base layer compaction.

The specific test procedure for granular base layer compaction is described in the Mn/DOT (trial) specification 2211.3.C4. A copy of this trial specification can be found in Appendix B. The procedure for this type of testing is as follows: following the compaction of each layer of granular base material, DCP tests are conducted to insure the penetration index (DPI) is less than 19 mm per blow (0.75 inches per blow). This DPI limit value is valid for all freshly compacted

granular base materials. Numerous field tests have shown the DPI dramatically decreases as the base materials “set up” over time and under loading from traffic.

At this time, the trial specification only allows DCP testing to “pass” adequately compacted granular base layers. Test failures must be confirmed by testing using the standard Mn/DOT sand cone density test method (modified AASHTO T 191).

Other nonspecified applications of the DCP by Mn/DOT have included investigations of soft subcut areas, determination of the condition of the base and subgrade materials under full depth bituminous cracks, and monitoring the effectiveness of subgrade flyash stabilization. The DCP has also been used to measure the foundation strength of footing pads being constructed for a maintenance building.

### Summary

Through extensive research conducted by the Office of Minnesota Road Research, several pavement assessment applications have been discovered for the dynamic cone penetrometer. Simple and inexpensive in design and operation, the DCP proves to be a versatile tool in pavement condition analysis and design. The application of DCP testing in the quality control of edge drain trench and granular base layer compaction should provide long lasting benefits to newly constructed and rehabilitated pavements in Minnesota.

## REFERENCES

1. Ford, R.G. and Eliason, B.E.. "Comparison of Compaction Methods in Narrow Subsurface Drainage Trenches," Paper presented at TRB 72nd Annual Meeting, January 1993, Washington, D.C.
2. "Subgrade Stability Manual," Illinois Department of Transportation, Policy Mat-10, 1982.
3. Webster, S.L., Grau, R.H., and Williams, T.P., "Description and Application of Dual Mass Dynamic Cone Penetrometer," USAE Waterways Experiment Station, Vicksburg, MS, May 1992.

**Table 1**  
**DCP testing results after base course placement**

Material Type	Cell Type	DPI Average (Std Dev) 0-300 mm depth	DPI Average (Std Dev) 300-600 mm depth	DPI Average (Std Dev) 600-900 mm depth
Clay/silt	5 year	10.8 (3.36)	21.4 (6.95)	21.3 (7.24)
Clay/silt	10 year	14.0 (5.57)	18.0 (5.24)	16.0 (4.97)
Clay/silt	South Low Volume	12.0 (5.48)	20.0 (6.95)	15.0 (6.87)
Clay/silt	North Low Volume	15.0 (6.71)	19.0 (6.95)	25.0 (11.44)
Sand	Low Volume	5 (1.61)	5 (1.30)	6 (2.02)
Class 3 Special	5 & 10 year	4.0 (1.62)	3.2 (0.50)	3.1 (0.31)
Class 3 Special	Low Volume	4.2 (0.93)		

**Mn/ROAD SUBGRADE SOILS**  
5 YEAR CELLS AVERAGE DPI  
VALUES AFTER BASE COURSE APPLIED

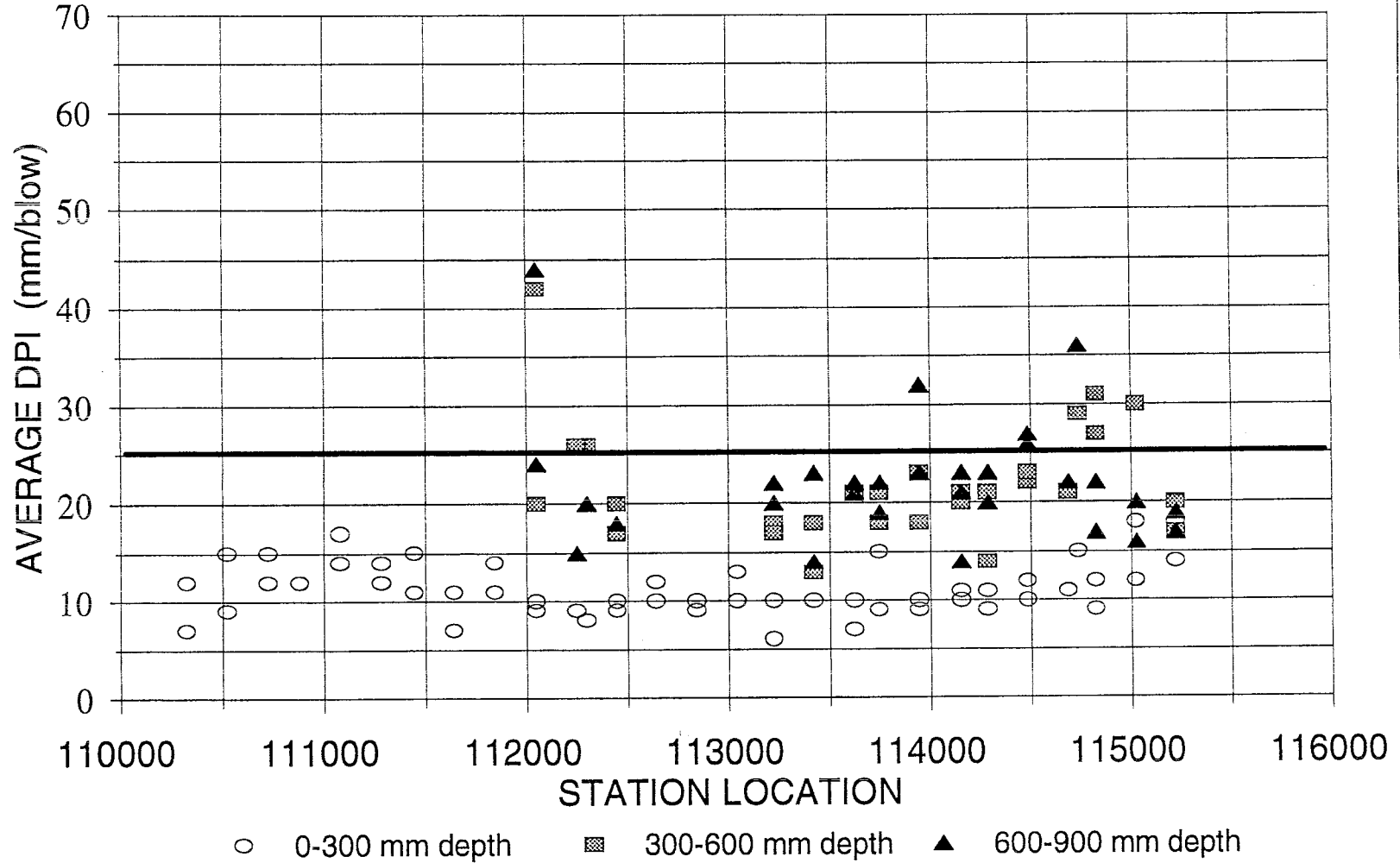


Figure 1

**Mn/ROAD SUBGRADE SOILS**  
10-YEAR CELL AVERAGE DPI  
VALUES AFTER BASE COURSE APPLIED

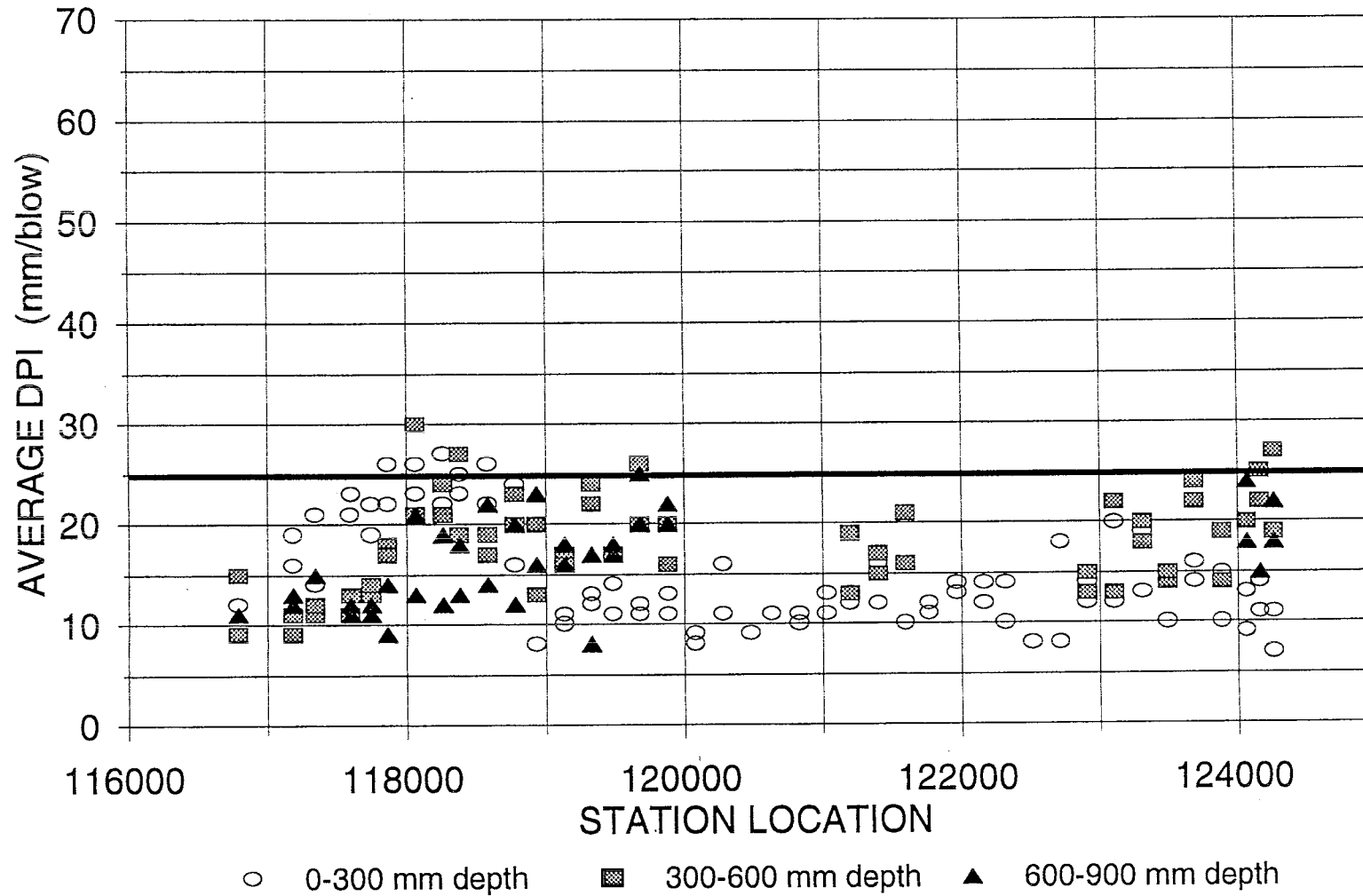


Figure 2



# Mn/ROAD SELECT GRANULAR SUBGRADE SOILS

## AVERAGE DPI

VALUES AFTER BASE COURSE APPLIED

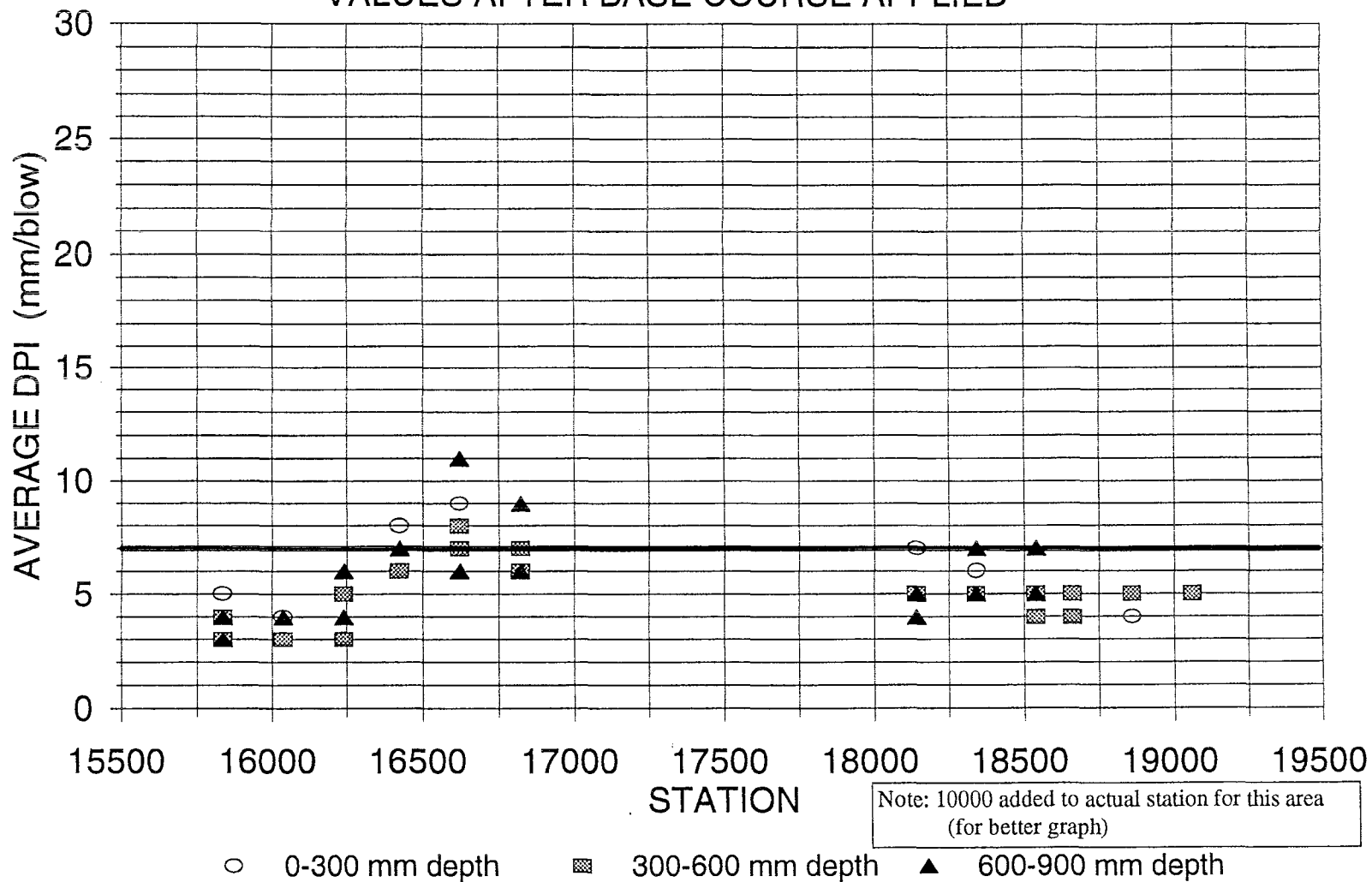


Figure 3

Mn/ROAD R=12 SUBGRADE SOILS  
SOLVR CELL AVERAGE DPI  
VALUES AFTER BASE COURSE APPLIED

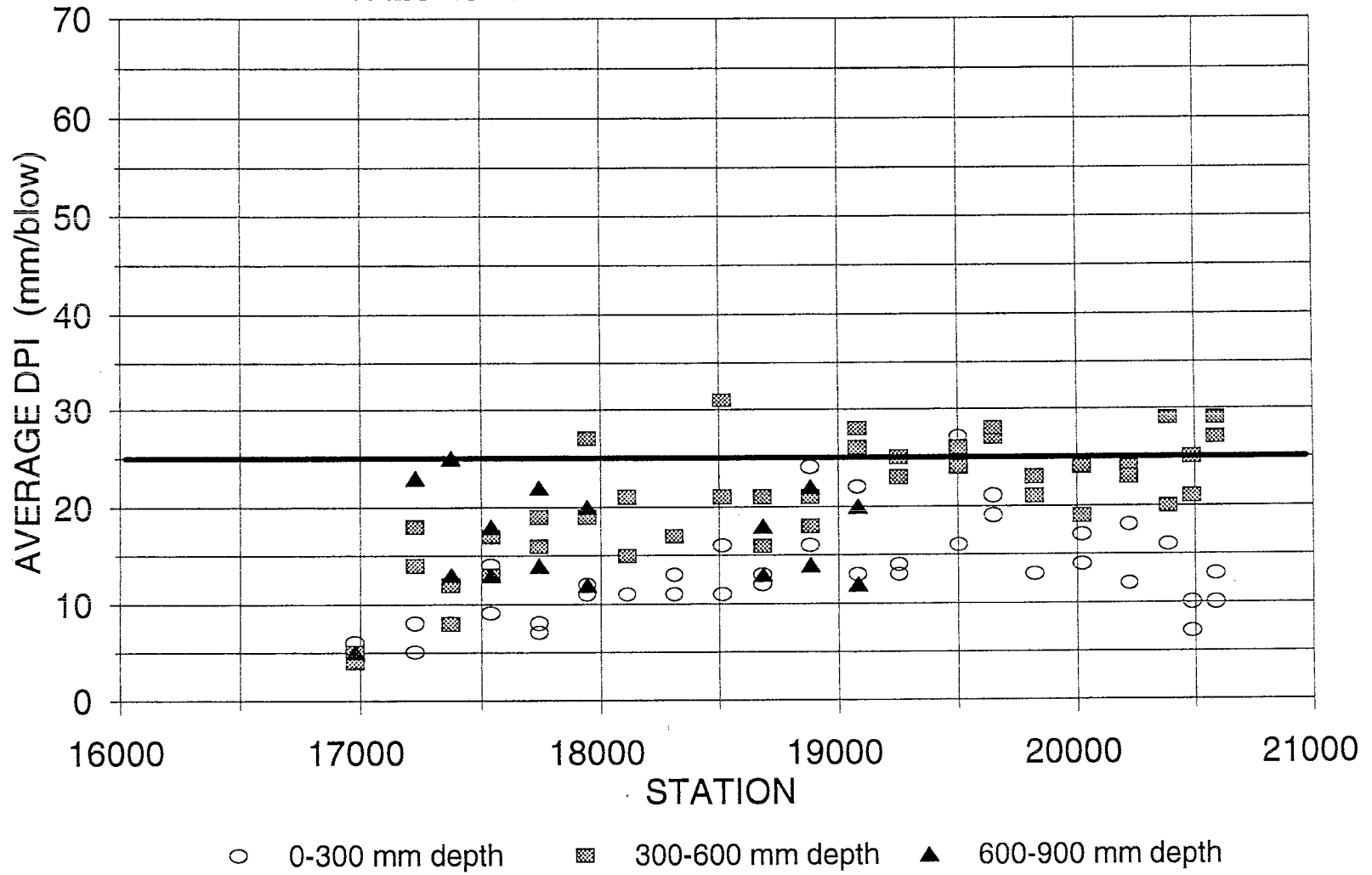
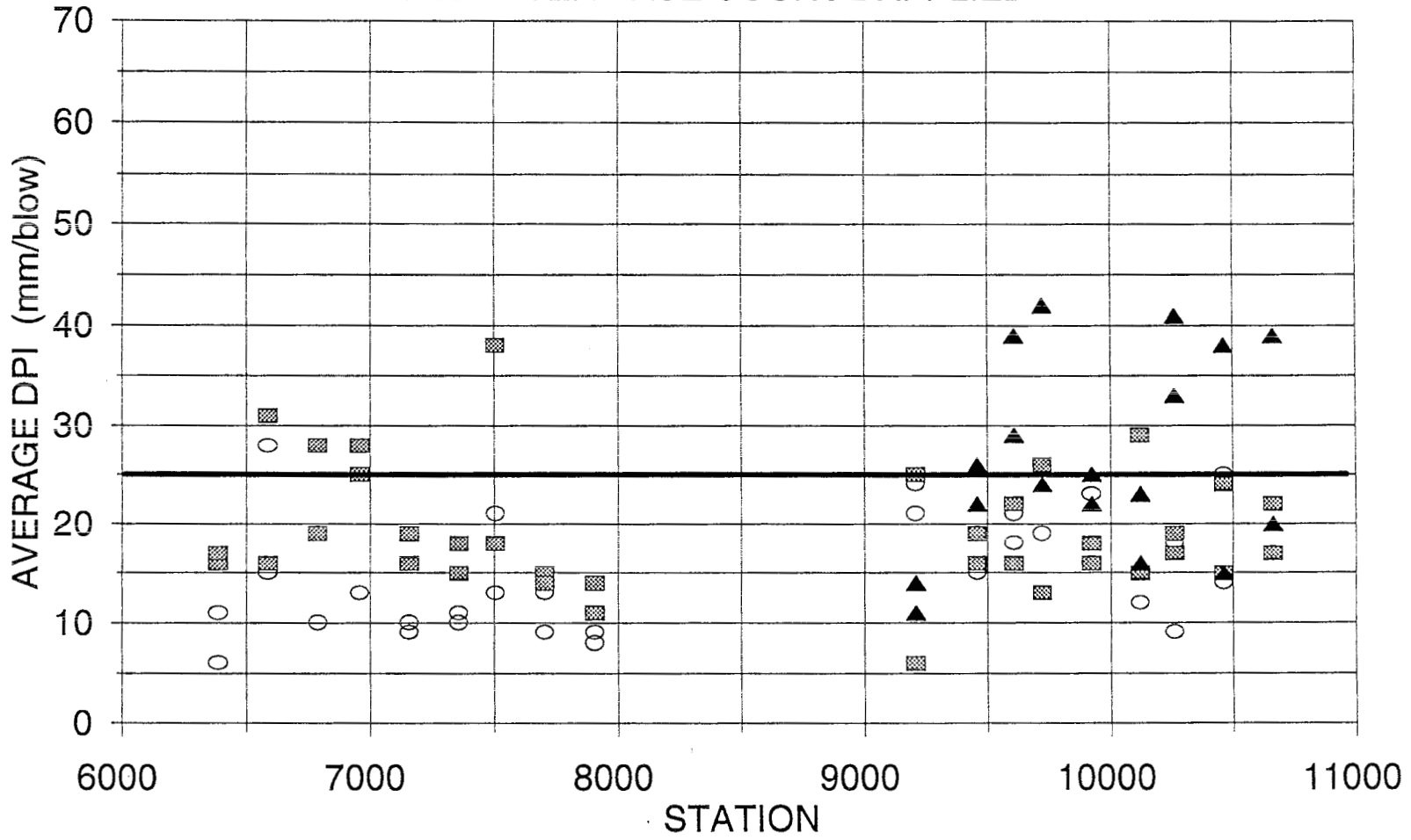


Figure 4

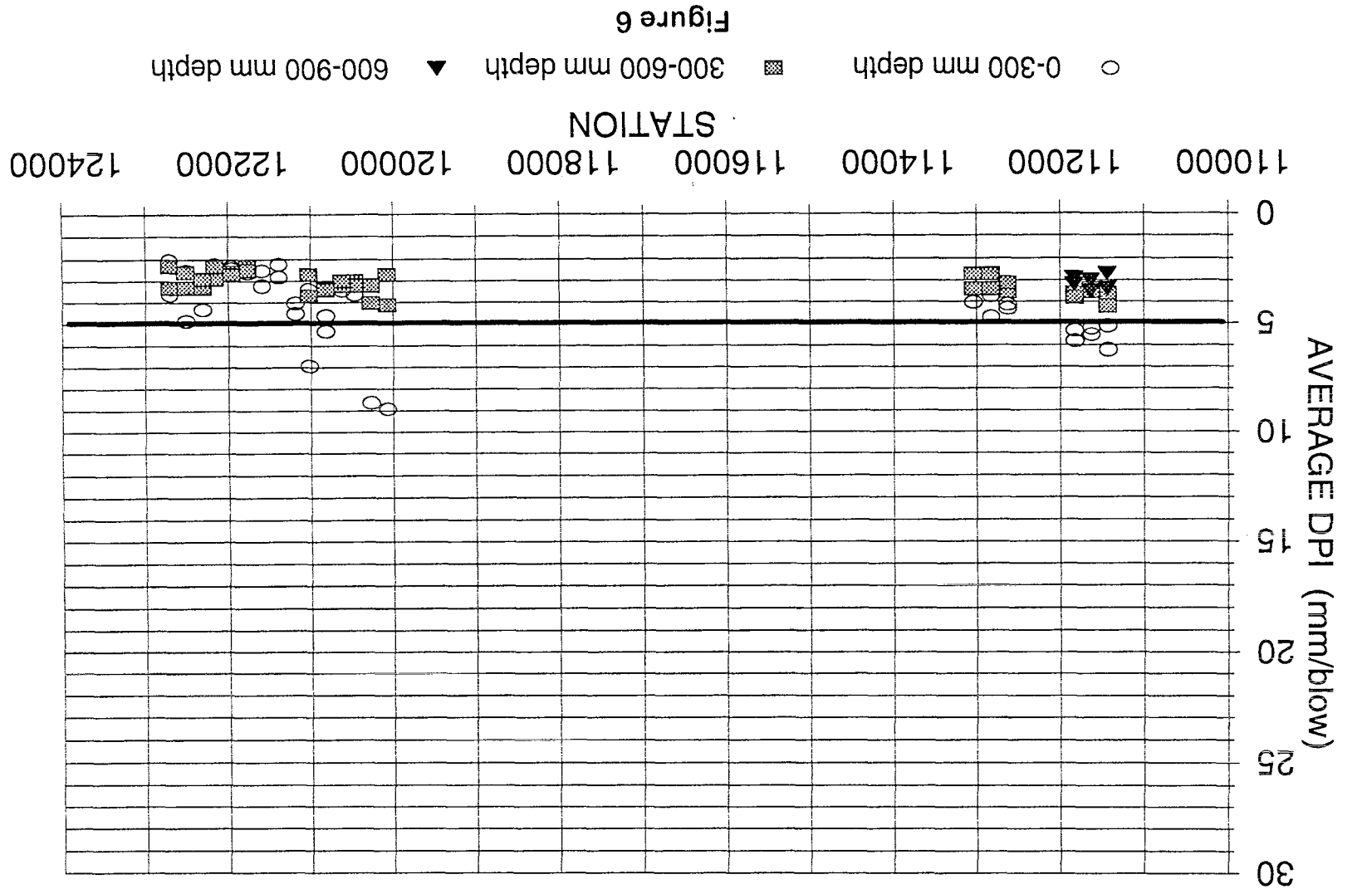
**Mn/ROAD R=12 SUBGRADE SOILS**  
NOLVR CELL AVERAGE DPI  
VALUES AFTER BASE COURSE APPLIED



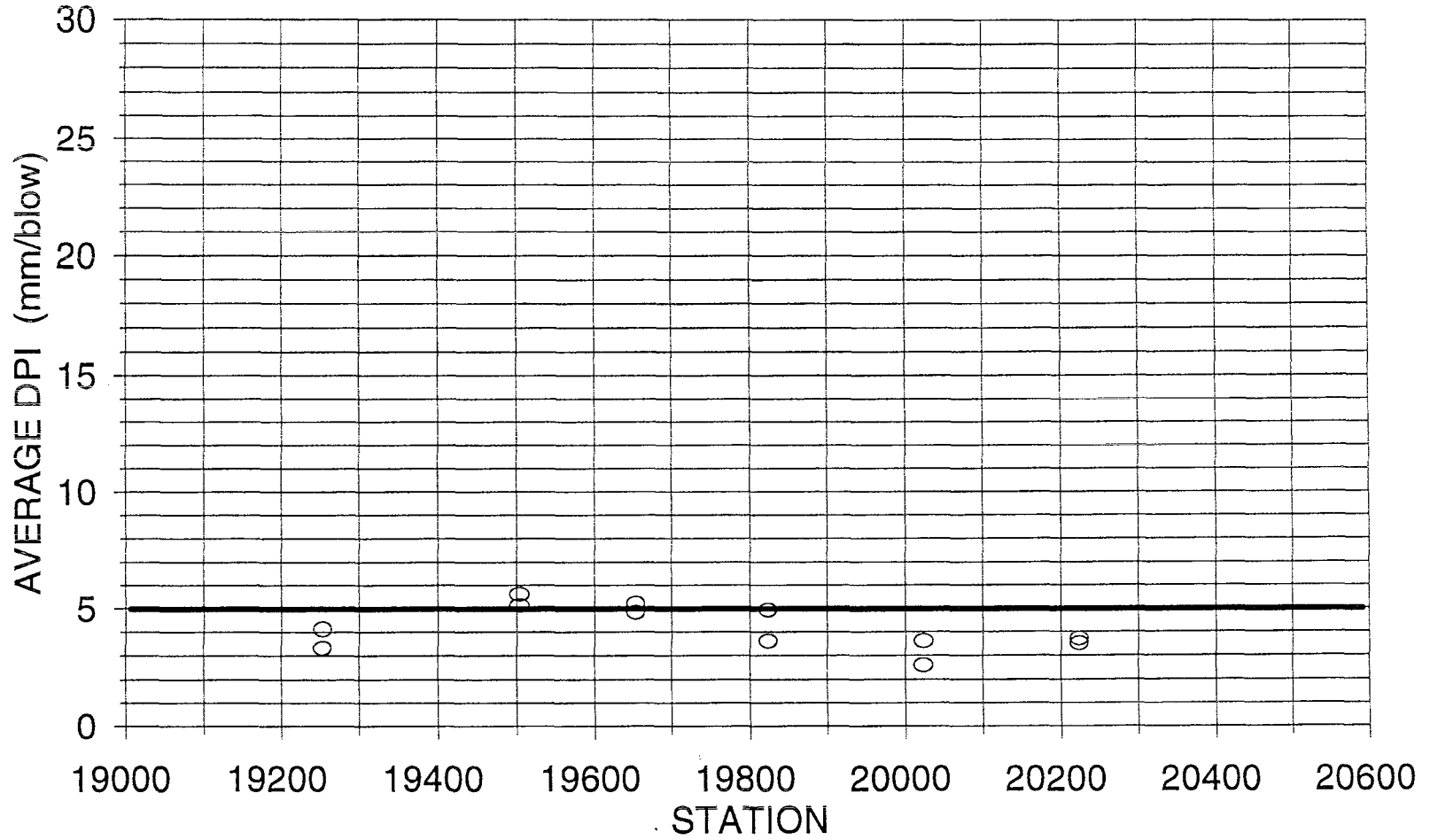
○ 0-300 mm depth    ■ 300-600 mm depth    ▲ 600-900 mm depth

Figure 5

**Mn/ROAD BASE MATERIALS  
CLASS 3 SPECIAL AVERAGE DPI  
5 & 10 YEAR MAINLINE CELLS**



**Mn/ROAD BASE MATERIALS**  
**CLASS 3 SPECIAL AVERAGE DPI**  
**LOW VOLUME ROAD CELLS**



○ 0-300 mm depth

Figure 7

RELATIONSHIP BETWEEN THE SOIL STRENGTH AND REMEDIAL THICKNESS OF GRANULAR BACKFILL / LIME MODIFICATION [2]

15

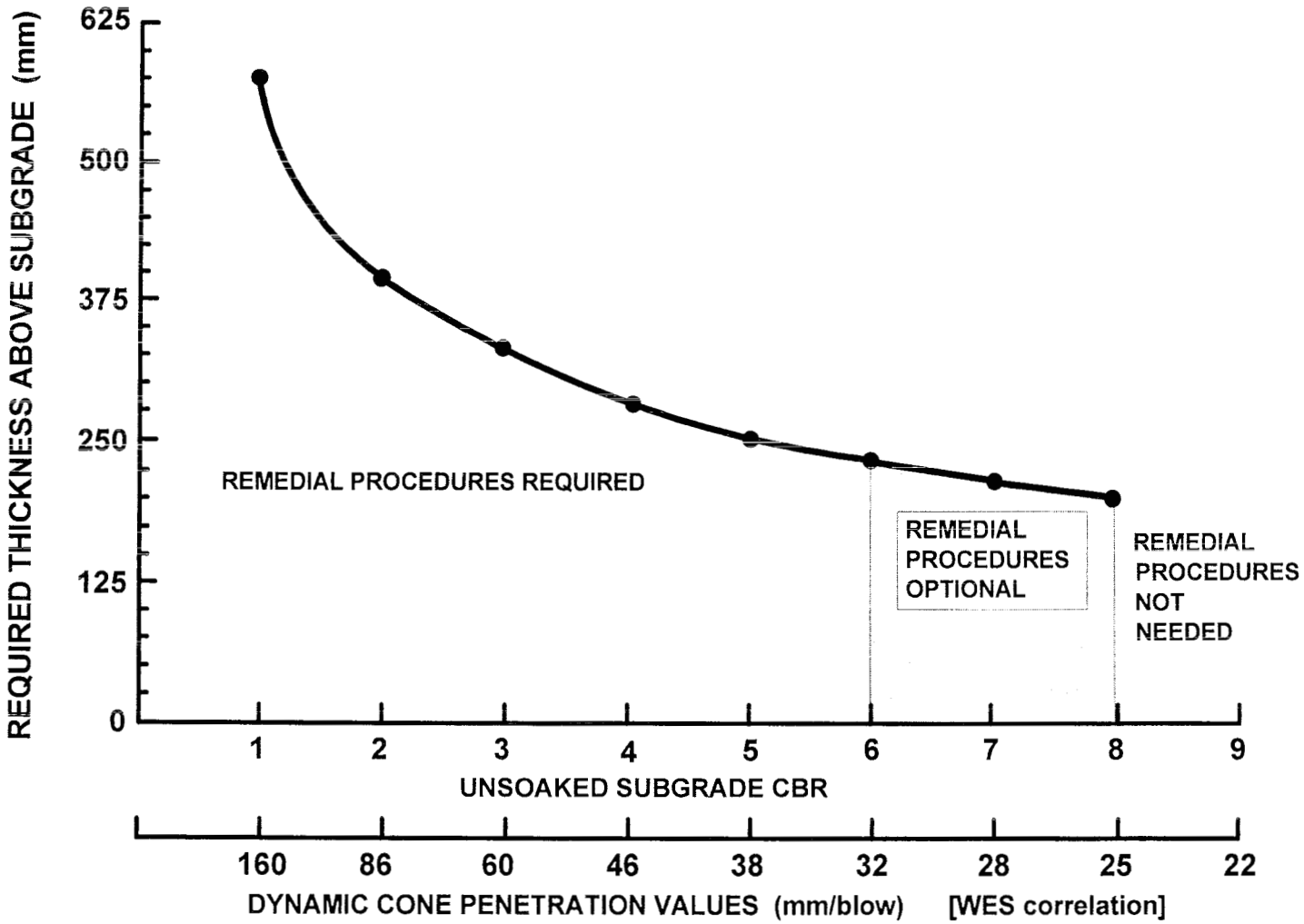


Figure 8

**APPENDIX A**

**Mn/DOT SUBSURFACE DRAIN INSTALLATION SPECIFICATIONS**

SP5-128

S- (2502) SUBSURFACE DRAINS, PAVEMENT EDGE DRAIN TYPE

This work shall consist of constructing 3-inch diameter edge drains in accordance with the applicable provisions of Mn/DOT 2502, the Plan and these Special Provisions. This drain is intended to collect and discharge water infiltrating into the pavement system from rain or snow melt, and spring-thaw seepage.

S-.1 Material Requirements

Edge drain pipe shall be perforated Corrugated Polyethylene (PE) Tubing, Mn/DOT 3278. To prevent infiltration of fine filter aggregate into the perforated pipe, it shall be wrapped with geotextile, Mn/DOT 3733, Type I. Trench backfill shall be Fine Filter Aggregate, Mn/DOT 3149.2J, which is modified so that the percent passing the No. 40 sieve will be 5-35.

S-.2 Construction Requirements

A. Drains adjacent to new pavements shall be placed after the pavement has been constructed to prevent damage to the drain and/or discharge pipe by truck hauling. (See paragraph B.4. below.) Drains shall be placed by machine trencher capable of cutting the trench and laying the pipe in a continuous operation. Plowing will not be permitted. The trenching equipment shall be so designed and operated that excavated material does not fall back into the trench. A self-leveling trenching machine shall be used if the off-set between tracks/tires of the trencher is greater than 6 inches. Trench width shall be 6-inch minimum, 10-inch maximum. Bottom of the trench shall be shaped to cradle lower one-third of the pipe. Laser grade control will be required whenever pipe grades do not follow pavement grades at a constant depth.

B. Unless otherwise specified:

1. Where in place PCC pavement is to be cracked prior to overlay, the edge drain shall be installed prior to pavement cracking.

2. Drains placed in conjunction with pavement widening shall be placed prior to excavating the widening-trench. A "feeler gage" on the trenching machine shall be used to insure that the pipe is accurately located at the design distance from the edge of the in place pavement. After compaction, the filter aggregate in the drain shall extend at least 4 inches above the bottom of the trench to be cut for widening.



3. When the drain is being placed next to a PCC pavement, the trenching head shall run tight against the pavement so as to completely excavate all adjacent soil. The Engineer may direct that any soil not so excavated, be removed prior to placing any filter aggregate, or repaired if discovered later, and, all at the Contractor's expense.
  4. When the drain is being placed next to a new bituminous pavement, it shall be constructed after all the base/leveling courses are in place, but before the wearing course is placed, to avoid damage to the finished pavement. For both new and retrofit construction, the trenching head shall continuously intercept and cut-off the roll-over portion of at least the lower bituminous course. This will provide a positive connection for water flow from thermal cracks into the drain. The trenching spoils shall always show evidence of bituminous materials. Any spoils on the pavement shall be totally cleaned-off prior to placing the wearing course for new pavements or the first bituminous lift for overlays, and to the satisfaction of the Engineer.
  5. When a bituminous shoulder is to remain in place after drain placement, the bituminous shall be coultured, sawed, milled, (or other approved method), to leave a smooth edge and prevent disturbance to the bituminous to remain in place.
  6. For new construction, the shoulder aggregate/base must be in place prior to trenching, except that for bituminous pavements, aggregate need only be in place to the height of the adjacent lift at the time of trenching.
  7. Unless otherwise specified, drain grades shall not be less than 0.2% and outlets to the ditch shall be at a maximum spacing of 500 feet and at low points as shown in the Plan.
- C. The filter aggregate backfill may be placed simultaneously with the pipe or in a separate operation which will immediately follow the trenching activity. If the pipe and filter aggregate are not placed simultaneously by the trenching machine, the Contractor shall insure that the pipe is properly aligned in the shaped cradle before placing the enclosing filter aggregate. No shield will be required on the trenching head unless the soil type or Contractor's operations lead to sloughing or caving from either side of the trench, in which case the Engineer will direct that a shield be used and that the filter aggregate be placed within the shield. All excavated trench material shall be disposed of off the Right of Way unless other uses are approved by the Engineer.

D. Filter aggregate shall be free-flowing, but with adequate moisture to permit satisfactory compaction. (Typically 3-5 percent by weight.) Filter aggregate shall be compacted by equipment which can achieve a minimum compacted density of 95 percent of maximum standard Proctor for the full depth of the trench. (Maximum standard Proctor density is approximately 110-120 pounds per cubic foot for Fine Filter Aggregate.)

Prior to beginning of the routine trenching and backfilling operation, the Contractor shall construct at least a 50 foot long test trench on the project using the same compaction depths, trench backfill, compactor, etc. as will be used for the project work. Adequacy of compaction in the test trench will be evaluated using a Mn/DOT- supplied Dynamic Cone Penetrometer (DCP), details for which are on file in the Research Section, Office of Materials Research and Engineering. Arrangements for DCP testing must be done through the Engineer, and at least two days of lead-time must be provided.

Penetration resistances of three (3) inches or less per DCP hammer blow will indicate satisfactory compaction. Compliance will be based on the average of three DCP readings for similar depths in three tests taken 10 feet apart. Unless otherwise directed by the Engineer, penetration readings will be started from the point where the DCP equipment stabilizes after being carefully set in the trench.

No more than 24 inches of filter aggregate may be compacted in any one lift. Unless approved by the Engineer, depending on equipment type, smaller lifts or more than one pass of the compactor may be required to achieve satisfactory density throughout the compacted depth. Unless otherwise approved by the Engineer based on DCP testing, the compactor shall not travel at a rate greater than 60 feet per minute. If the compaction method or source of trench backfill changes, or for any reason the Engineer is not satisfied with the compaction provided, the trenching operation will be stopped until additional DCP testing is performed and any necessary corrections have been made. (Up to two days lead-time may be required for DCP re-testing.) Additional compaction will be required when DCP testing indicates insufficient density. After compaction and any necessary leveling, the filter aggregate shall extend up onto the adjacent pavement to the extent shown in the Plan typical section.

E. Where the filter aggregate trench, as required by the Plan, is to be capped by another type of granular material or bituminous mixture, these materials shall be placed and compacted separately from the filter aggregate and not as part of any similar material to be placed in a future operation. Bituminous caps shall be heaped at least one-inch and rolled; granular caps

*SPECIAL PROVISIONS SP5-128: REV. 11/21/96*

shall be placed at least one-inch high and receive vibratory compaction to the satisfaction of the Engineer. Placement of these caps will provide support for overlying materials and also incorporate a second compaction effort in the trench.

F. Contamination of the filter aggregate will not be permitted. Aggregates and/or other soils shall not be deposited or mixed on the adjoining concrete or bituminous pavement. Any material spilled on the pavement surface shall be removed by sweeping.

Once the drain and discharge pipe are in place, no construction equipment will be allowed to traverse the drain or discharge pipe until the system is properly protected (covered) to the satisfaction of the Engineer. The drain shall remain open and operative after installation so that water does not collect in the pipe.

S-3            Measurement and Payment

Measurement will be made by the length of furnished and satisfactorily installed Subsurface Drain, Pavement Edge Drain Type, approved by the Engineer. Payment will be made under Item 2502.541 (3" Perforated PE Pipe Drain) at the Contract bid price per linear foot, which shall be full compensation for trenching, fabric wrapped PE pipe and installation, aggregate backfill, cap, compaction, and all other associated work.

**APPENDIX B**

**Mn/DOT BASE COMPACTION SPECIFICATION  
BASED ON DCP TESTING  
(TRIAL VERSION)**

The following information outlines the Mn/DOT granular base material compaction specifications based on DCP testing. This method of compaction quality control testing was first made available for the 1997 construction season.

#### 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 19mm per blow, as determined by a Mn/DOT standard dynamic cone penetrometer (DCP) device. For test purposes, a layer will be considered to be 75mm in compacted thickness but a testing layer can be increased in thickness to a maximum of 150mm 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(CV) of constructed base course.

Compacted areas with a penetration index greater than 19mm per 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.

#### 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*.

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

1. Locate a level, undisturbed area.
2. Place DCP device on the base aggregate and lightly seat the cone tip by tapping the anvil with the hammer. If seating process or self weight of device causes initial penetration exceeding 20mm, relocate test to a site at least 300mm from previous test location and reseat cone. If second site fails the above criteria, compaction is not acceptable and the area being tested must be recompacted.
3. Record penetration measurement from 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 the process three more times for a total of four drops of the hammer.
5. Record final penetration measurement from the graduated rule on the DCP.
6. Subtract measurement in step 3 from measurement in step 5 and then divide the difference of the measurements by four. If the resulting value is 19mm or less, the test passes.

**APPENDIX C**

**Mn/DOT DYNAMIC CONE PENETROMETER RESEARCH HISTORY**

## Mn/DOT DCP Research History

The following is a brief history of dynamic cone penetrometer (DCP) research conducted by the Minnesota Department of Transportation (Mn/DOT).

- 1991: - Idea of using DCP on Mn/ROAD project introduced by Matt Witzak.  
- Prototype DCP fabricated by Maplewood shop, based on plans obtained from Illinois DOT.  
- DCP testing begins on Mn/ROAD mainline subgrade layer.  
- DCP research pilot projects conducted in Becker, Sacred Heart, and Faribault, Minnesota.
- 1992: - Mn/DOT Geotechnical section performs research and analysis on using the DCP for monitoring edge drain trench compaction levels.  
- New edge drain compaction specification based on DCP testing is formulated.  
- DCP testing continues at Mn/ROAD on subgrade and base layers. Large subgrade void in test cell 23 found during DCP testing.  
- Design and development of an automated dynamic cone penetrometer (ADCP) begins.  
- Laboratory experiments begin in effort to determine correlation of penetration index (DPI) to compaction density for subgrade materials.
- 1993: - Edge drain trench compaction specification based on DCP is adopted.  
- 15 DCPs are fabricated by machine shop in Illinois for distribution throughout Mn/DOT districts.  
- DCP training course developed and conducted for district personnel.  
- Users Guide for the Dynamic Cone Penetrometer developed and distributed.  
- ADCP delivered, tested, and accepted by Mn/DOT.  
- Comprehensive literature search and investigation conducted to research current DPI correlations utilized worldwide.
- 1994: - Extensive subgrade ADCP testing on Highway 59 near Marshall, Minnesota conducted in continued effort to develop correlation of DPI to compaction density. Project construction inspector also conducted side by side DCP and sand cone density tests throughout season.
- 1995: - Highway 59 data analyzed. Conclusion that there is not a reasonable correlation of DPI to compaction density for fine grained soils. Empirical DPI limits are developed based on general soil types.  
- DCP used in Mn/ROAD test cell 33 rutting investigation.  
- DCP used to evaluate flyash subgrade stabilization.

- 1996: - DCP research conducted towards developing empirical DPI limits for base layer compaction during construction. Specification developed based on results of testing several sites throughout the state.
- Problems with edge drain trench compaction specifications noticed. Introduced proposed changes to testing procedure to insure intended results.
  - Comprehensive *User Guide to the Dynamic Cone Penetrometer* brochure developed for widespread distribution. Contains test procedure, correlations, and plans for fabrication of a DCP.
- 1997: - DCP brochure is highlighted in several national publications. DCP information inquiry has increased significantly.
- Base layer compaction specification based on DCP testing is adopted and will be utilized on several projects during 1997 construction season.
  - DCP training video to be produced.

Several reports and articles have been written throughout the research process.

Published reports:

- May 1993: 93-05 *In Situ Foundation Characterization Using the Dynamic Cone Penetrometer* (Burnham and Johnson)
- Fall 1996: *User Guide to the Dynamic Cone Penetrometer* (Mn/ROAD brochure)

Unpublished reports:

- July 1991: The Dynamic Cone Penetrometer, A Summary Outlining Its Characteristics and Uses As They May Relate to the Mn/ROAD Research Project
- November 1991: Use of the Dynamic Cone Penetrometer in Evaluating Subgrade and Base Material at the Becker Pilot Project
- December 1991: Use of the Dynamic Cone Penetrometer in the Subgrade Evaluation of TH-212 Near Sacred Heart, Minnesota
- January 1992: Use of the Dynamic Cone Penetrometer in the Subgrade Evaluation of I-35 Near Faribault, Minnesota
- April 1993: Users Guide for the Dynamic Cone Penetrometer



Spring 1995: Mn/ROAD Test Cell 33 Rut Investigation

July 1995: Hwy 59 DCP Correlation Study

August 1996: Application of the Dynamic Cone Penetrometer to Mn/DOT's Pavement Assessment Procedures (Revised Draft)

**APPENDIX D**

**AVERAGE DPI VALUES FOR TESTS CONDUCTED BEFORE BASE PLACEMENT**

**Mn/ROAD SUBGRADE SOILS**  
5-YEAR CELL AVERAGE DPI  
VALUES BEFORE BASE COURSE APPLIED

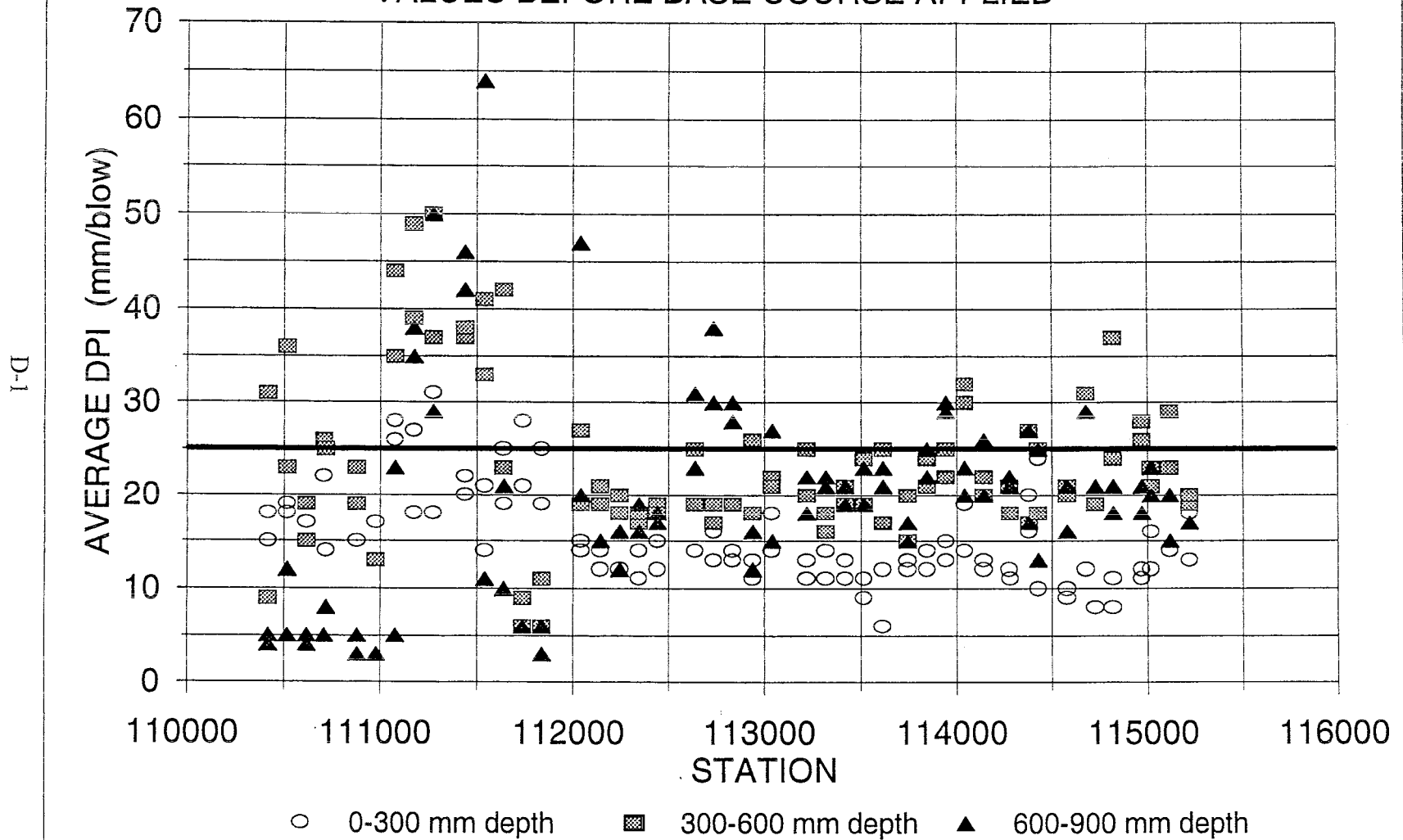


Figure D-1

**Mn/ROAD SUBGRADE SOILS**  
10-YEAR CELL AVERAGE DPI  
VALUES BEFORE BASE COURSE APPLIED

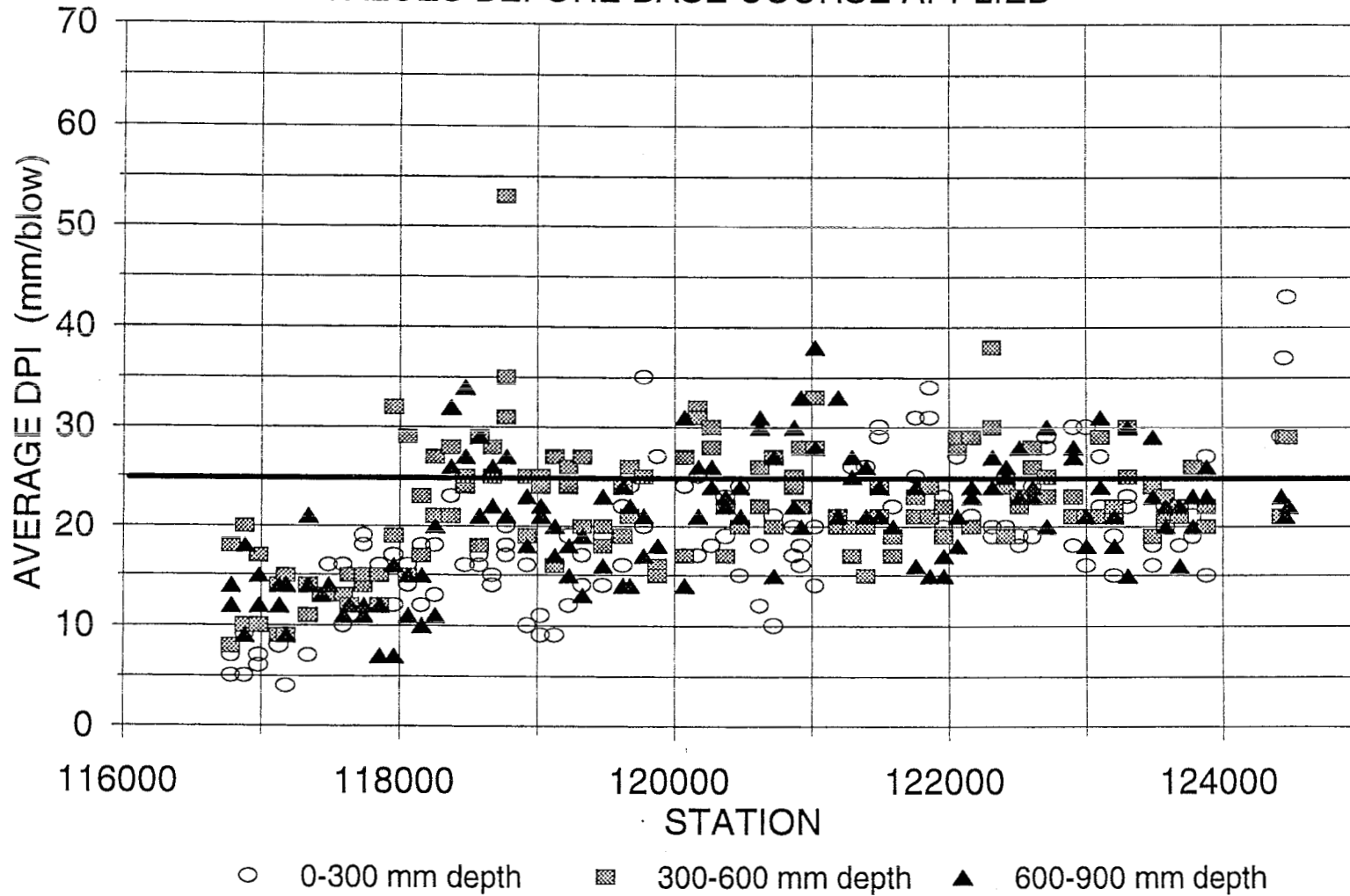


Figure D-2

D-2

# Mn/ROAD SELECT GRANULAR SUBGRADE SOILS

AVERAGE DPI

VALUES BEFORE BASE COURSE APPLIED

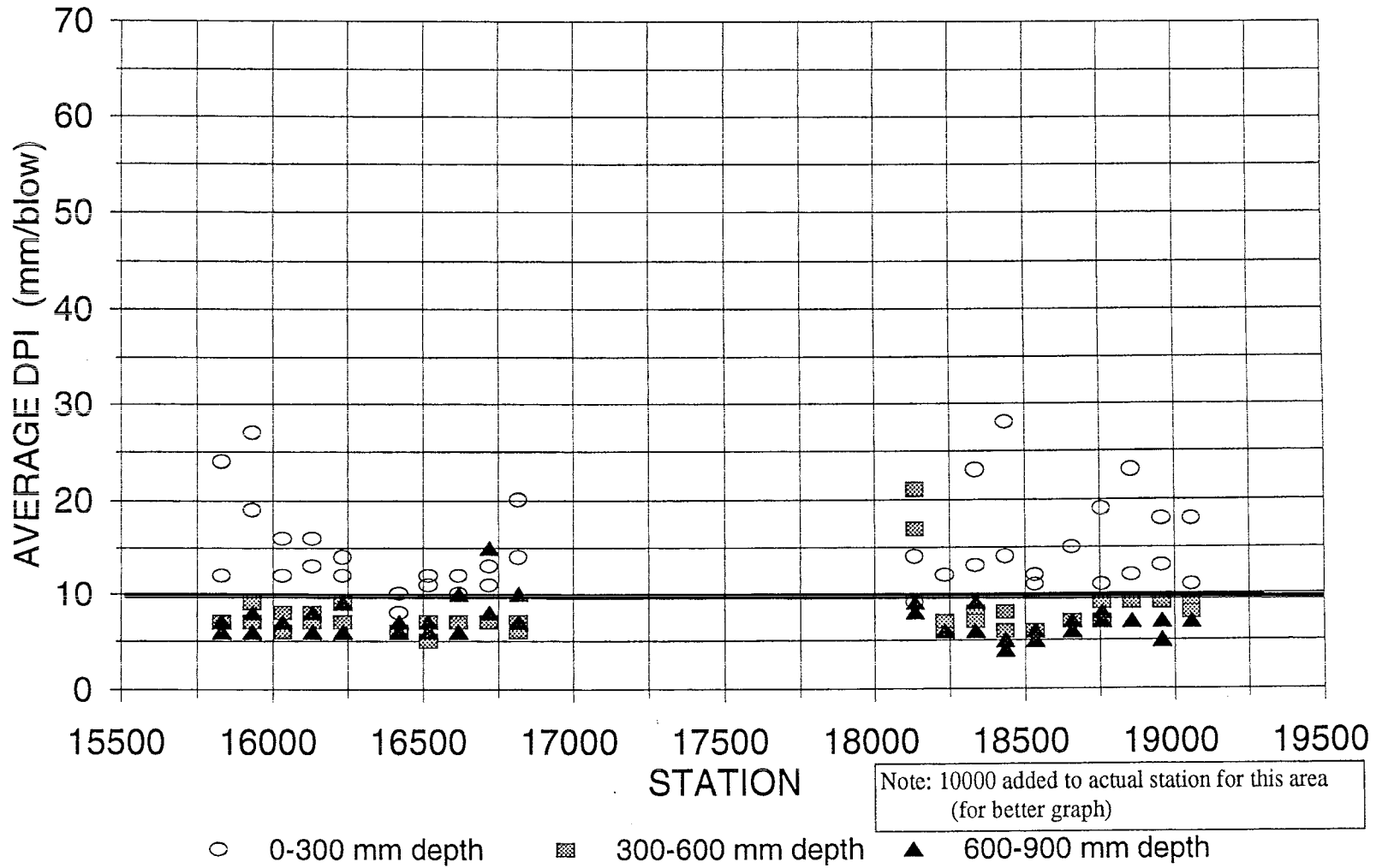


Figure D-3

D-3

**Mn/ROAD SUBGRADE SOILS**  
SOLVR CELL AVERAGE DPI  
VALUES BEFORE BASE COURSE APPLIED

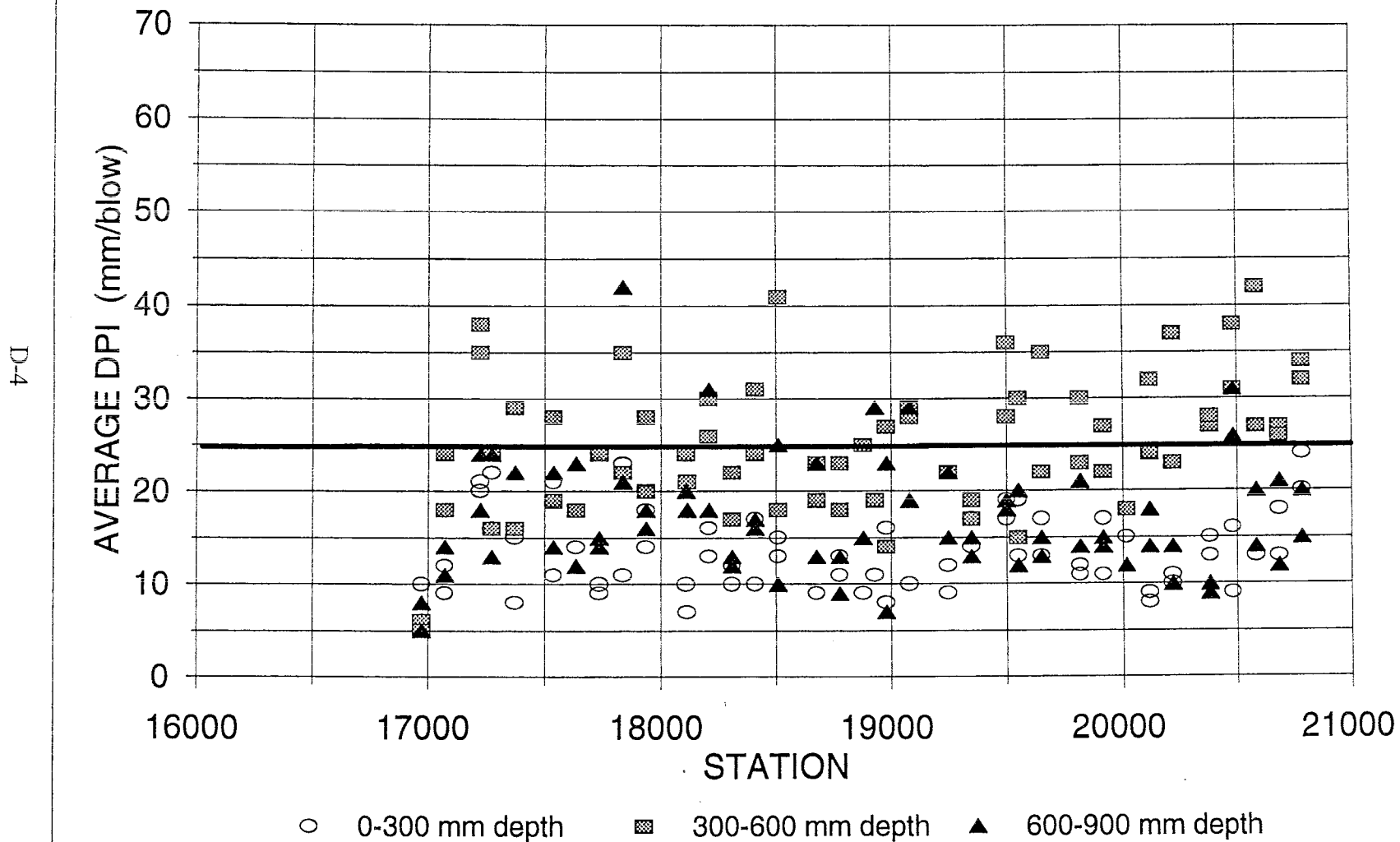
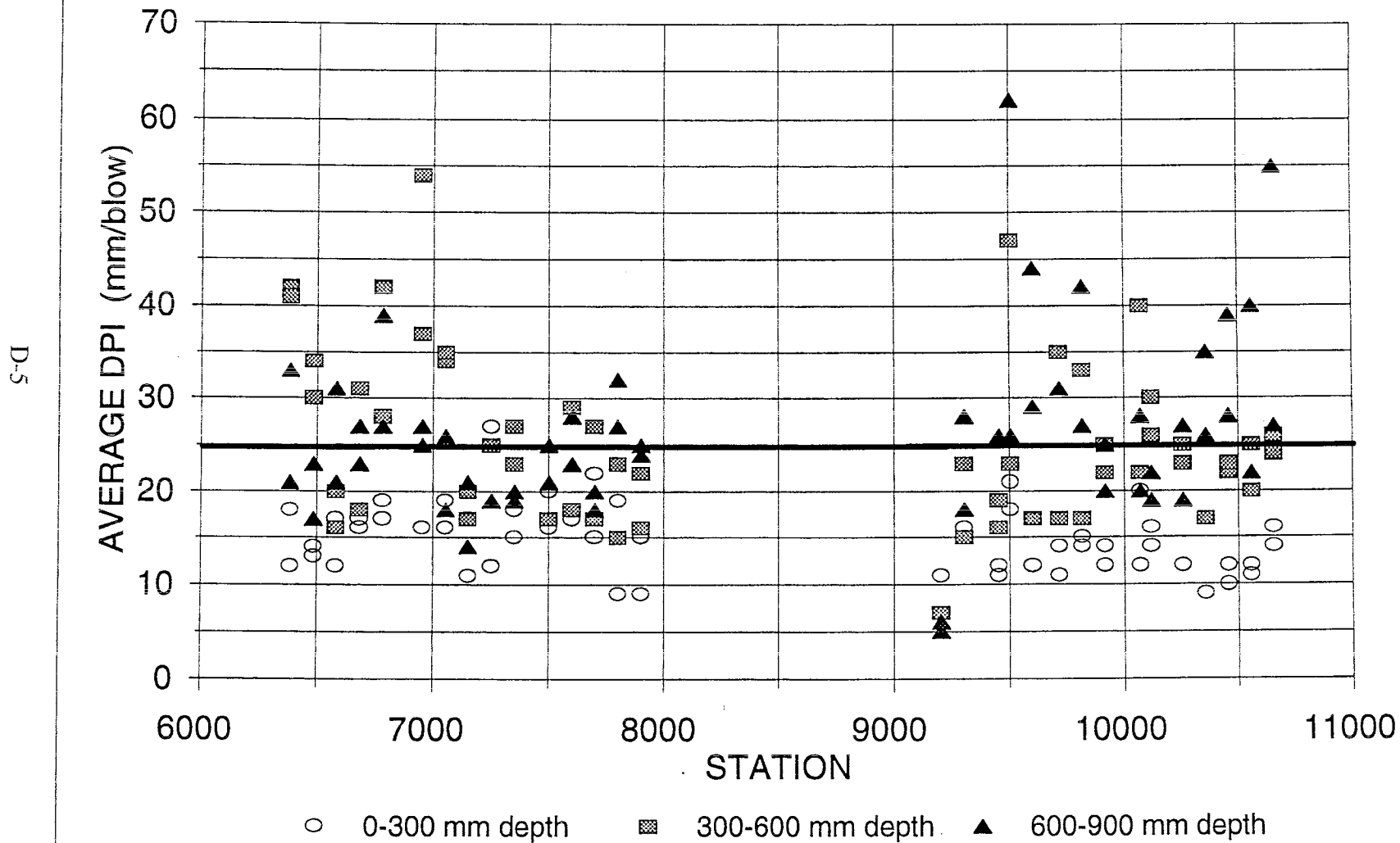


Figure D-4

**Mn/ROAD SUBGRADE SOILS**  
NOLVR CELL AVERAGE DPI  
VALUES BEFORE BASE COURSE APPLIED



**Figure D-5**



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