EVALUATION OF PAVEMENT PERFORMANCE ON DEL-23 – INTERIM REPORT – FORENSIC STUDY FOR SECTIONS 390103, 390108, 390109, AND 390110 OF OHIO SHRP U.S. RT. 23 TEST PAVEMENT

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PREPARED IN COOPERATION WITH THE OHIO DEPARTMENT OF TRANSPORTATION AND THE U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

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Ohio University
Ohio Research Institute for Transportation and the Environment
Civil Engineering Department

January 2006

SI* (MODERN METRIC) CONVERSION FACTORS

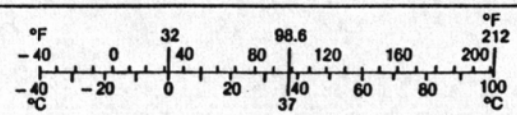
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

NOTE: Volumes greater than 1000 L shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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ABSTRACT

The Ohio SHRP Test Road, constructed on U.S. 23 about 25 miles (40 km) north of Columbus, Ohio, contained forty test sections in the SHRP SPS-1, SPS-2, SPS-8, and SPS-9 experiments. During the summer of 2002, a forensic study of Sections 390103, 390108, 390109, and 390110 in the SPS-1 experiment was completed through a series of non-destructive and destructive tests to determine the cause of rutting and localized distresses that had developed in these four pavement sections.

Distress surveys were conducted on the four sections in accordance with SHRP-P-338 "Distress Identification Manual for the Long-Term Pavement Performance Project." The sections were categorized in terms of low, moderate, or high distress. Non-destructive testing conducted on each section included Falling Weight Deflectometer, transverse profiling, and Dynamic Cone Penetration tests. Trenches were excavated at locations with various levels of distress to measure transverse layer profiles, to determine the thickness of individual material layers, and to obtain material samples for laboratory testing. Analysis of all the collected data was utilized to determine the causes of the localized distresses.

1.0 INTRODUCTION

The Ohio SHRP Test Road, located about 25 miles (40 km) north of Columbus Ohio, encompasses forty test sections in the SHRP SPS-1, SPS-2, SPS-8 and SPS-9 experiments. The SPS-1 experiment was a strategic study of the effectiveness of various structural factors on the performance of flexible pavement. During the summer of 2002, localized distresses were observed in Section 390103 of the SPS-1 experiment. Deflection analysis indicated distress was imminent in Sections 390108, 390109, and 390110. A forensic investigation consisting of destructive and non-destructive testing was designed to determine the possible causes of rutting and other distresses observed in these sections. The pavement designs for these four SPS-1 sections are outlined in Table 1.1. Environmental instrumentation was installed in Section 390110 at the time of construction to monitor temperature, moisture, and frost penetration in the pavement structure.

Table 1.1 Pavement Structure.

Section	Thickness (in (cm))		Base Type	Drainage
	AC	Base		
390103	4 (10.1)	8 (20.3)	Asphalt Treated Base	No
390108	7 (17.8)	12 (30.4)	4” Permeable Asphalt Treated Base 8” Dense Graded Aggregate Base	Yes
390109	7 (17.8)	16 (40.6)	4” Permeable Asphalt Treated Base 12” Dense Graded Aggregate Base	Yes
390110	7 (17.8)	8 (20.3)	4” Asphalt Treated Base 4” Permeable Asphalt Treated Base	Yes

1.1 LOAD HISTORY

The SPS-1 sections were opened to traffic on August 14, 1996. The highway was closed from September 3-11, 1996 to overlay Sections 390102 and 390107 which became rutted. Rutting began to develop in Section 390101 and the highway was closed from December 3, 1996 until November 1997. During this time, these three sections in the SPS-1 experiment were replaced with stiffer sections, and Sections 390803 and 390804 in the SPS-8 experiment were replaced with the same basic designs, except that the subgrade was stabilized with lime. Severe localized distress occurred on Section 390105 in May 1998, and the test road was closed again for repairs. Section 390103 developed localized distress on March 8, 2002. After a review of the remaining SPS-1 sections, it was determined that distresses were imminent in Sections 390108, 390109 and 390110. On April 24, 2002 the SPS-1 sections were again closed to traffic and a forensic study was conducted on the four distressed SPS-1 sections. A load cell based weigh-in-motion (WIM) system was used to continuously monitor traffic flow on the Ohio SHRP Test Road.

1.2 PAVEMENT ANALYSIS

The service lives were predicted to be 1.3, 1.8, 4.3, and 2.8 years for sections 390103, 390108, 390109, and 390110 respectively using the AASHTO Guide for Design of Pavement Structures [(2)] with the following structural parameters:

Structural Coefficients:

AC	0.35
PATB	0.14
ATB	0.35
DGAB	0.14

Other Parameters:

$P_0 = 4.5$

$P_t = 2.5$

$$R = 50\%$$

$$S_0 = 0.49$$

Estimated 20 year design ESAL = 19,650,000

$$M_R\ (390103) = 2500\ \text{psi} = 17240\ \text{kPa}$$

$$M_R\ (390108) = 3000\ \text{psi} = 20680\ \text{kPa}$$

$$M_R\ (390109) = 3000\ \text{psi} = 20680\ \text{kPa}$$

$$M_R\ (390110) = 3000\ \text{psi} = 20680\ \text{kPa}$$

Values for resilient modulus were obtained from a correlation between moisture and resilient modulus developed for specific soil types according to Laboratory Characterization of Materials & Data Management for Ohio- SHRP Project U.S. 23. [(3)] The average subgrade moisture for each section was determined from the collected soil samples.

1.3 WATER TABLE

Figures 1.3.1 and 1.3.2 are the water table elevations for Sections 390103 and 390108. The charts begin in December of 1996 and continue through April of 2003. The wells are located at SHRP station 3+73 and 2+75 for Section 390103 and 390108 respectively. The data shows strong seasonal variation in water elevation. The peak water elevations occur mainly in the spring months of April and May each year, and the low point elevations mainly in the late fall months each year. The peak elevations and date recorded are listed in Table 1.3.1. The average high point elevation is 948.21 feet (289 m) above sea level, and the average low point elevation is 943.79 feet (287.7 m) above sea level.

The highest water table elevation recorded at SHRP station 3+73 was in March of 1997 at 948.93 feet (289.2 m) above sea level. This was 5.37 feet (1.64 m) below the surface of the subgrade. Similarly at SHRP station 2+75, the highest water table elevation was just 3.42 feet (1.04 m) below the subgrade elevation (on 7/2/01). With the water table being so close to the surface of the subgrade in this area, good drainage systems are crucial to the endurance of the pavement.

Table 1.3.1 Peak Water Table Elevations.

	High Peak			Low Trough		
		Water elevation above sea level			Water elevation above sea level	
Location	Date	(ft)	(m)	Date	(ft)	(m)
SHRP Station 3+73	3/25/1997	948.93	289.23	11/25/1997	943.19	287.48
	5/13/1998	948.09	288.98	11/23/1998	943.34	287.53
	4/13/1999	947.99	288.95	12/3/1999	941.69	287.03
	5/24/2000	948.09	288.98	9/27/2000	944.79	287.97
	7/2/2001	948.29	289.04	10/30/2001	945.29	288.12
	4/26/2002	948.59	289.13	11/18/2002	942.64	287.32
SHRP Station 2+75	6/17/1997	948.2	289.01	11/25/1997	944.0	287.73
	5/13/1998	948.1	288.98	10/?/1998	944.0	287.73
	4/13/1999	947.7	288.86	12/3/1999	943.0	287.43
	5/24/2000	948.1	288.98	1/21/2000	944.9	288.01
	7/2/2001	948.4	289.07	10/30/2001	945.3	288.13
	4/26/2002	948.0	288.95	10/30/2002	943.4	287.55
Average:		948.21	289.01		943.80	287.67

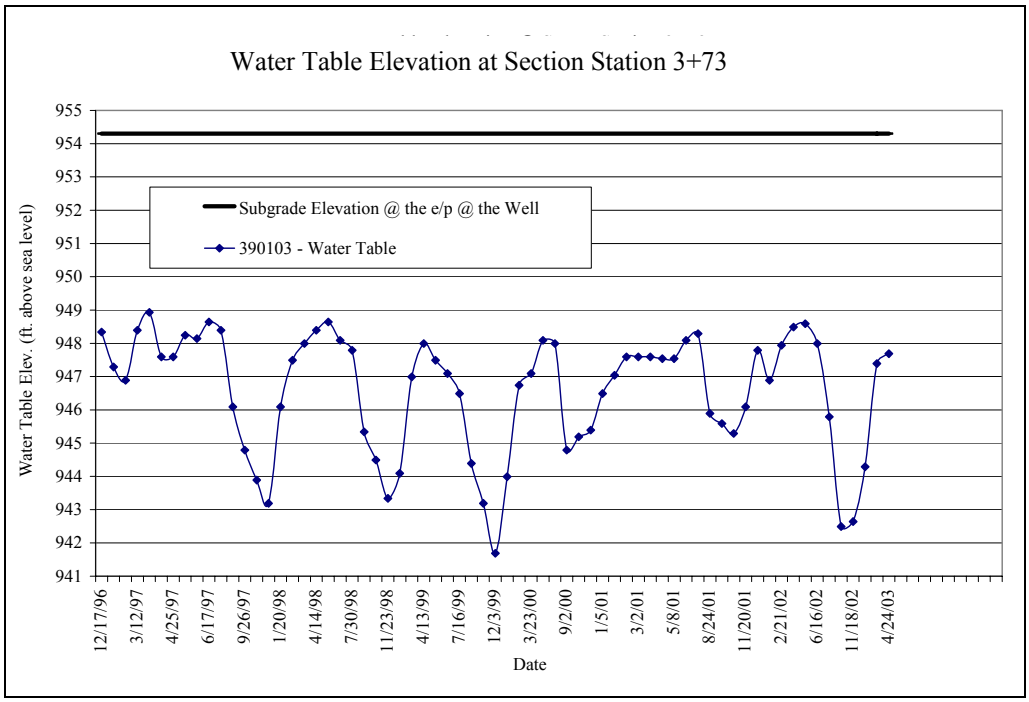


Figure 1.3.1 Water Table Elevations at Section Station 3+73 (1 ft = 0.3048 m)

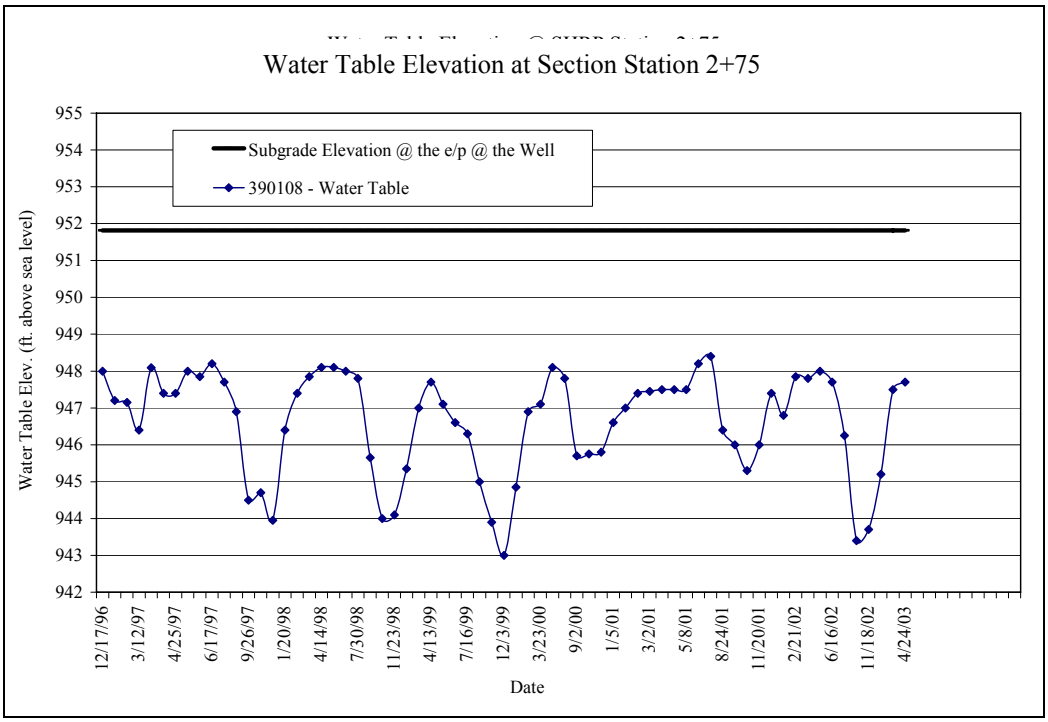


Figure 1.3.2 Water Table Elevations at Section Station 2+75 (1 ft = 0.3048 m)

1.4 FORENSIC PROCEDURE

To complete the forensic investigation of Sections 390103, 390108, 390109 and 390110, several tests and procedures were performed in each of the four test sections. The testing was subdivided into non-destructive and destructive testing. Non-destructive testing included photographs of selected areas and referenced by station, distress surveys conducted according to SHRP-P-338 Distress Identification Manual for Long-Term Pavement Performance Project,[1] falling weight deflectometer (FWD) tests, and transverse profiles were taken to measure rutting.

Destructive testing included dynamic cone penetration (DCP) tests, trenching, and recovering cores and sections of AC for laboratory testing. During the excavation of trenches material sampling, moisture testing, and stiffness testing was also completed.

2.0 MATERIAL PROPERTIES

During the trenching process several cores of AC were recovered and sent to ODOT laboratories for testing. Data from the time of construction was obtained from the ORITE database and are summarized in Table 2.1. Properties at the time of the forensic study are discussed in section 4.7.

Table 2.1 Properties of materials used in the test pavements.

	AC Surface	**AC Intermediate**
Material Type	ODOT 446	ODOT 446
Design Thickness	1.75 in (4.44 cm)	2.25 in (5.71 cm)
Bulk Specific Gravity	2.155	2.185
Max Specific Gravity	2.460	2.474
% Air Voids	7.1	6.6
% Water Absorption	2.5	2.0
% Asphalt Content	6.4	5.3
Kinetic Viscosity @ 275° F	20.9 ft^2/hr (5.40x10^{-4} m^2/s)	21.2 ft^2/hr (5.46x10^{-4} m^2/s)
Absolute Viscosity @ 140° F	12.00 lb·s/ft^2 (574.6 Pa·s)	10.00 lb·s/ft^2 (478.8 Pa·s)
Bulk Sp Gravity of Coarse Agg	2.50	2.50
Absorption of Coarse Agg	1.52%	1.7%
Bulk Sp Gravity of Fine Agg	2.53	2.56
Uncompacted Void Content	47.08%	47.28%
Ash Content of Bitumen	0.4%	0.9%
Sp Gravity of Extracted AC	1.044	1.052
Penetration @ 77° F (25°C)	38	44
Penetration @ 115° F (46°C)	179	250
Penetration Index	1.5	1.6
Permeable Asphalt Treated Base		
Mix Type	ODOT Special Item	
Aggregate	#57 stone	
Asphalt Binder Content	2 to 2.5% by weight	
Design Thickness	4 in (10 cm)	
Asphalt Treated Base		
Mix Type	ODOT Item 301	
Aggregate	ODOT Item 703.04	
Bituminous Material	ODOT Item 702.01	
Mineral Filler	ODOT Item 703.07	
Bituminous Content	3 to 8 %	
Air Voids	3 to 8 %	
Voids in Mineral Aggregates	11.5 %	
Design Thickness	8.0 in (20.3 cm)	
Unit Weight (Wet)	137.1 pcf (2196 kg/m^3)	

3.0 NON-DESTRUCTIVE TESTING

3.1 PAVEMENT DISTRESS

Visual observations of distresses were observed in accordance with SHRP-P-338 Distress Identification Manual for the Long-Term Pavement Performance Project[1] and are summarized in Table 3.1.1. Complete distress surveys are documented in Appendix A. Three different types of cracking were present in the four sections; fatigue cracking, wheel path longitudinal cracking and non-wheel path longitudinal cracking. Severity levels are low, moderate, and high for each type of crack.

Low level fatigue cracking is an area of cracks with none or few connecting cracks and no pumping is present. Moderate severity fatigue cracking is an area of interconnected cracks forming a complete pattern and still no pumping present. High level fatigue cracking is an area of highly concentrated interconnected cracks, pumping may be present, and the pieces of cracked AC may move subject to traffic or pop out.

Low severity level longitudinal cracking indicates a long crack, not interconnected to others, with a mean crack width of less than ¼ inch (0.64 cm). Moderate level cracking indicates a crack with a mean width greater than ¼ inch (0.64 cm) and less than ¾ inch (1.92 cm). High severity level longitudinal cracking are cracks greater than ¾ inch (1.92 cm). The crack widths were measured with a standard tape measure and measured as accurately as possible (Figure 3.1.1).

Section 390103 showed the worst overall distress. High levels of rutting and longitudinal cracking were the most prevalent in this section. The longitudinal cracking was present in the center of the lane for the entire length of section 390103, with a mean crack width of about ½ inch (1.27 cm). Also, longitudinal cracking of the same magnitude was noted along the inside edge of both wheel paths. The most severe rutting in 390103 occurred between section station 0+50 and 1+00. Cold patch had been used to repair some of this area (Figure 3.1.2). The patching was classified as high severity patch. Extreme distress was indicated at this location. Fatigue cracking was present in approximately 25% of the right and left wheel paths, mostly concentrated between section stations 0+00 and 1+50. This fatigue cracking was classified as

moderate in severity and can be seen in Figure 3.1.3. Some alligator cracking was also noticed in the wheel path and on the shoulder.

Section 390108 generally displayed minor rutting, though in one section the deepest ruts were as much as $^{4}/_{5}$ inch (2.03 cm) deep. This section also had longitudinal cracking over approximately 50% of the length of the center lane and along the inside edges of the wheel paths; the average crack width of the longitudinal cracking was approximately $^{3}/_{8}$ inch (0.95 cm). This section was classified as having moderate overall distresses, see Figure 3.1.4.

Section 390109 experienced moderate overall rutting of less than ¾ inch (1.92 cm) deformation, and fatigue cracking over less than 10% of the total area of the section. Longitudinal cracks less than ¼ inch (0.64 cm) wide were very apparent in both wheel paths and in the center of the lane for the entire section length (Figure 3.1.5). This section was classified as having low overall distresses.

Section 390110 contained environmental instrumentation, and was categorized as having mild rutting and moderate longitudinal cracking. The maximum rut depth for this section was approximately ½ inch (1.27 cm) and the average longitudinal crack width was about ¼ inch (0.64 cm). Overall this section was also classified as having low level distresses. More pictures of the distress surveys can be found in Appendices B, C, and D.

Table 3.1.1 Distress Summary of Sections. Percentages are of section length.

Section	Average Distress Classification	Maximum rut depth (in)	Maximum rut depth (cm)	Longitudinal Cracking in Center of Lane	Longitudinal Cracking in Wheel Path	Average Crack Width (in)	Average Crack Width (cm)
390103	High	2.75	6.985	100%	90%	0.5	1.27
390108	Moderate	0.8	2.032	50%	50%	0.375	0.9525
390109	Low	0.75	1.905	10%	10%	0.25	0.635
390110	Low	0.5	1.27	15%	10%	0.25	0.635

Figure 3.1.1 Measurement of Crack Width.

Figure 3.1.2 Distress Photograph of Section 390103.

Figure 3.1.3. Alligator cracking in Section 390103.

Figure 3.1.4 Fatigue Cracking in Section 390103.

Figure 3.1.5 Distress Photograph of Section 390108.

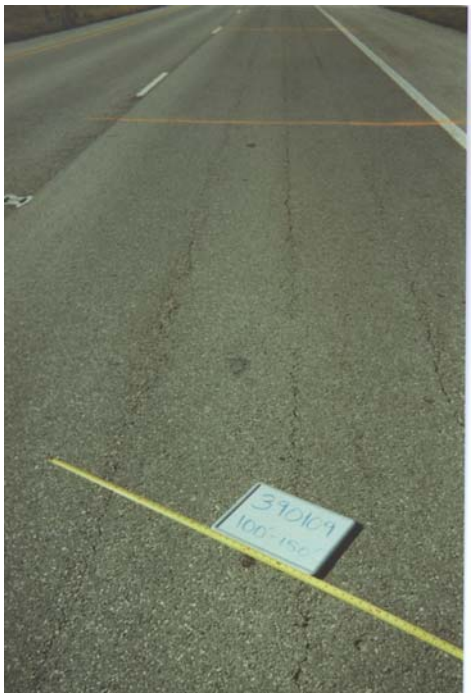


Figure 3.1.6 Distress Photograph of Section 390109.

Figure 3.1.7 Distress Photograph of Section 390110.

3.2 LONGITUDINAL CRACKING

Longitudinal cracking observed in all four sections during trench excavation, was initiated on the pavement surface and was considered to be top-down with low to moderate severity. See Figures 3.2.1 and 3.2.2. The longitudinal crack consistently occurred in the center of the lane in all four sections and did not stray from a straight line path. The longitudinal wheel path cracking occurred on the edge of the wheel path and also was consistent in forming a straight line. The wheel path cracks were shallower than the center line cracks. None of the longitudinal cracks extended all the way to the base, most were within the first four inches of the surface.

Very similar observations were made during the recent Colorado top-down crack study[7]. Of twenty-five longitudinal crack sites in Colorado, 72% were top-down cracking and 67% of the top-down cracking associated with visual segregation at the bottom of the surface layer. Figure 3.2.3 shows the segregation, i.e., a relatively large portion of coarse aggregates is distributed in the bottom half of the surface layer. The Colorado study further identified the source of the segregation. Certain models of pavers caused the early longitudinal cracking at the pavement locations corresponding to the edges of the slat conveyors and the center point of the paver. This explains the straight line longitudinal cracks shown in Figure 3.1.6.

More pictures of the longitudinal cracking were taken at different locations during trench excavation and can be found in Appendix E.

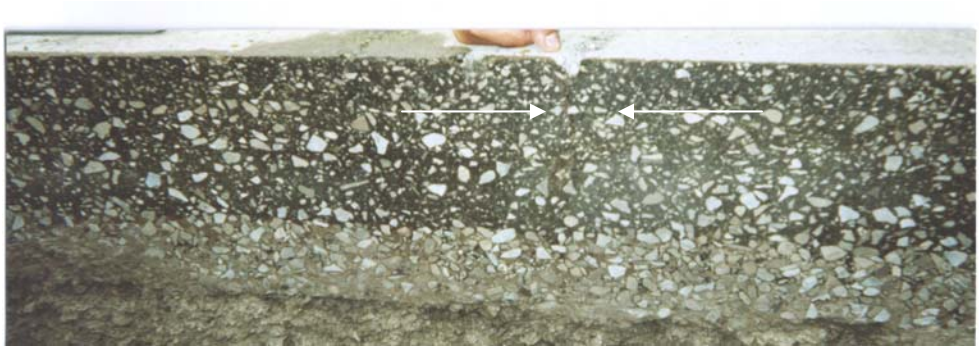


Figure 3.2.1. Longitudinal Cracking.

Figure 3.2.2. Longitudinal Crack Close-up.

Figure 3.2.3. Top-down longitudinal crack of Figure 3.2.2 with segregation of surface layer indicated white line.

3.3 RUTTING

Two methods were used to determine the profiles of the pavement; the profilometer and dipstick, see Figure 3.3.1 and 3.3.2. Thirteen profiles were taken for each section approximately forty feet apart. The profiles were plotted and compared.

Transverse profiles from Section 390103 for the profilometer and dipstick, shown in Figures 3.3.3 and 3.3.4, illustrate significant variations in profile from the proposed design. The greatest rutting present of all sections are at these particular locations in Section 390103 (Figure 3.3.5). Rutting is defined as a longitudinal surface depression located in the wheel path. It is not classified according to severity levels, but by the rut depth. The maximum rut depths for each section are outlined in Table 3.1.1. It should be noted that the profiles measured with the dipstick and profilometer were very similar and differences between the two can be attributed to each instrument starting at a slightly different reference point on the pavement. The remaining profiles for each section can be found in Appendices F, G, H, and I.

Figure 3.3.1 Profilometer Operation.

Figure 3.3 2 Dipstick Operation.

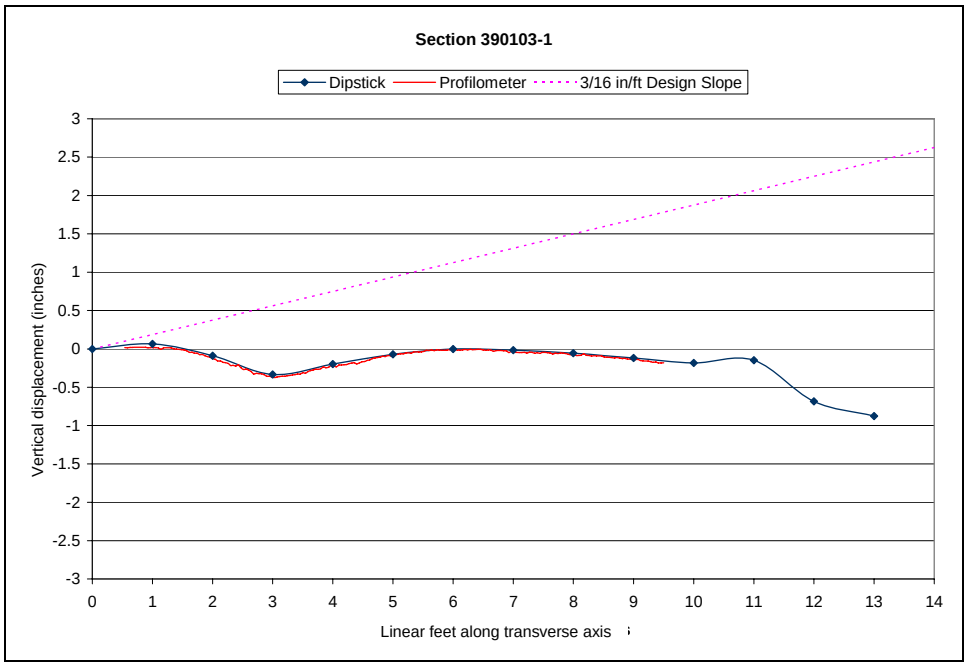


Figure 3.3 3 Transverse Profile 1 of Section 390103. (1 in = 2.54 cm, 1 ft = 0.3048 m)

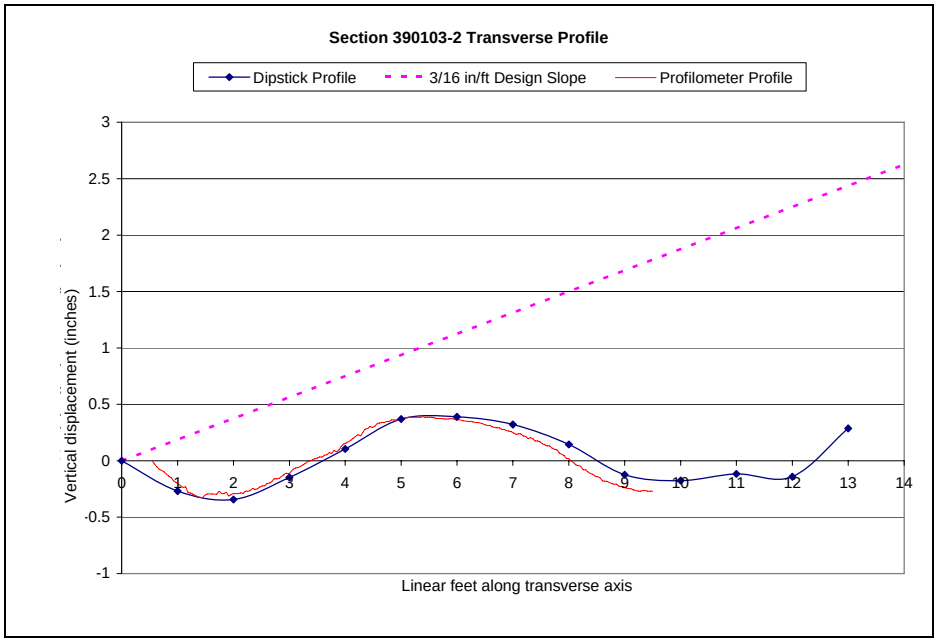


Figure 3.3.4 Transverse Profile 2 of Section 390103. (1 in = 2.54 cm, 1 ft = 0.3048 m)

Figure 3.3.5 Severe Rutting in section 390103.

3.4 FALLING WEIGHT DEFLECTOMETER

During the first week of August 2002, Falling Weight Deflectometer (FWD) tests were conducted every fifty feet along the centerline and right wheel path on the surface of the AC pavement. The tests were staggered to provide better coverage. Plots of the FWD tests for Section 390103 are shown in Figure 3.4.1 and 3.4.2. They indicate that stiffness varied along the section length in the center of the lane and wheel path. Along the centerline in Section 390103 at stations 1+50, and 4+00, there was a significant increase in vertical deflection relative to the other deflections seen. Along the right wheel path, there was one large deflection spike occurring at station 1+25. This location was the same as that where cold patch was needed to repair the rutting damage.

Similarly the highest deflections occurred in the centerline and right wheel paths of Sections 390108, 390109, and 390110, where there appeared to be maximum distress (Appendix J). Comparing the transverse profiles with the FWD plots, the greatest rutting is located in the same general location as the higher deflection points.

FWD tests were also conducted during construction (Figure 3.4.4). In order to compare the two sets of data, the FWD data taken at the time of the forensic study was normalized to a load of one kip. Looking at the normalized FWD plot at the time of the forensic study for Section 390103 (Figure 3.4.3) there is one large deflection spike. Comparing it to the FWD plot taken at the time of construction, there are no spikes present in the AC or ATB layers. Therefore the distress occurring in the pavement at that location can not be attributed to any flaw in the layers of the pavement during construction. Similarly, the subgrade does not show any significant deflection variation, which may indicate a weak spot in the subgrade during construction.

The normalized plots for the remaining three sections at the time of the forensic study (Appendix K) were constant in the AC surface layer. No considerable spikes in deflection were present; consequently the occurring distress in each section could not be contributed to any problems within the pavement layers. The normalized FWD plots performed at the time of construction for section 390108, 390109, and 390110 are located in Appendix L.

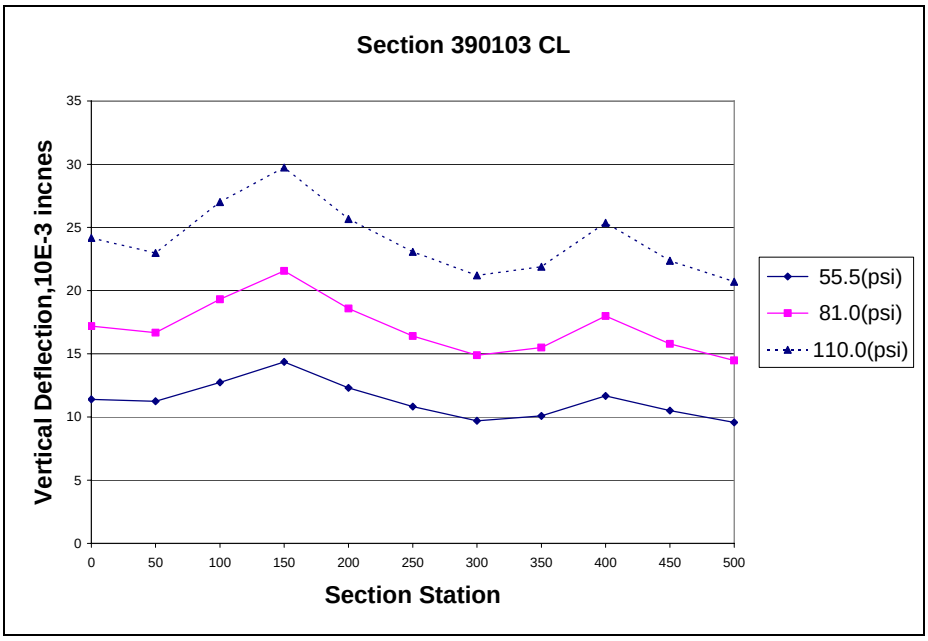


Figure 3.4.1 FWD Plot of Section 390103 Centerline. (1 in =2.54 cm; 55.5 psi = 383 kPa, 81.0 psi=558 kPa, 110.0 psi = 758 kPa)

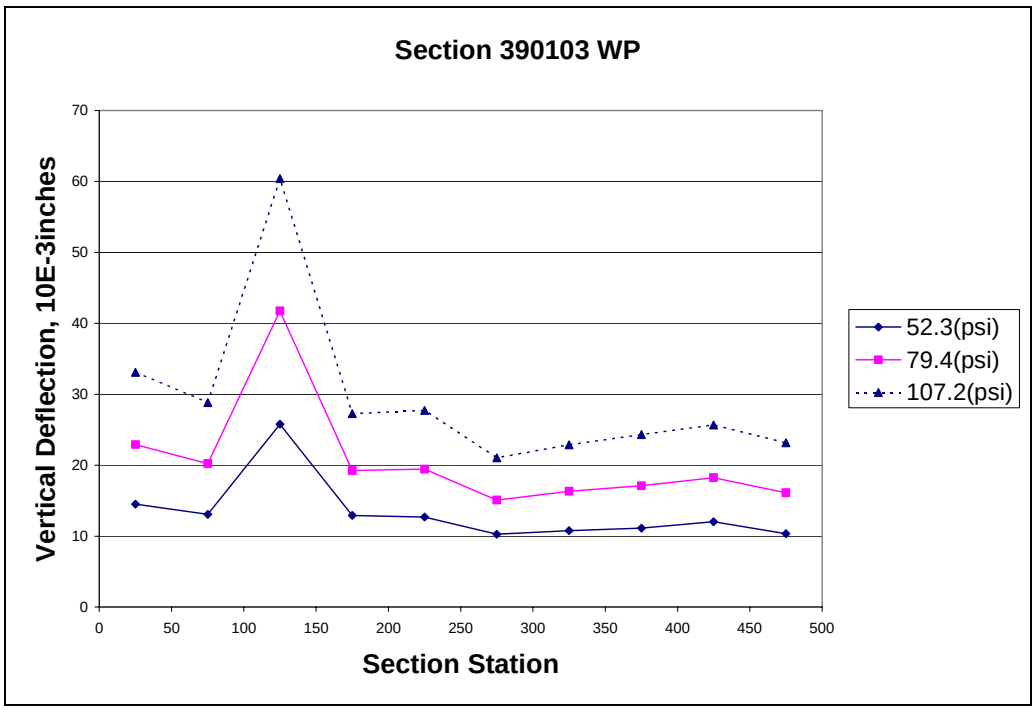


Figure 3.4.2 FWD Plot of Section 390109 Wheel Path. (1 in =2.54 cm; 52.3 psi = 361 kPa, 79.4 psi = 547 kPa, 107.2 psi = 739 kPa)

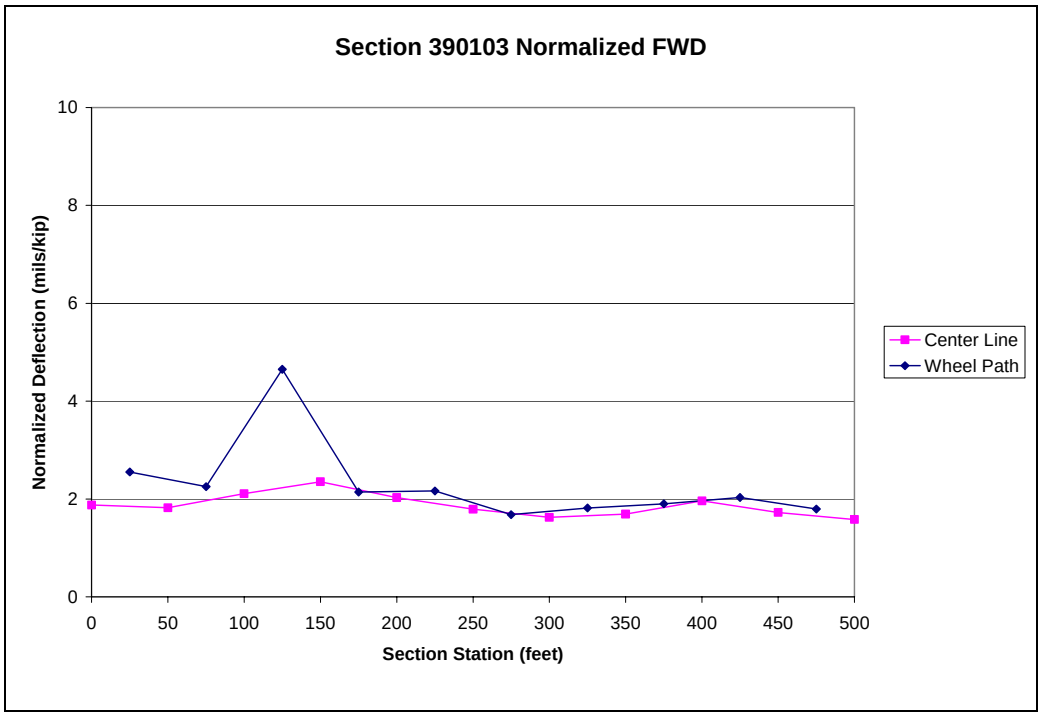


Figure 3.4.3 Normalized FWD Plot of Section 390103. (1 ft = 0.305 m; 1 mil/kip = 5.71×10^{-9} m/N = 5.71 nm/N)

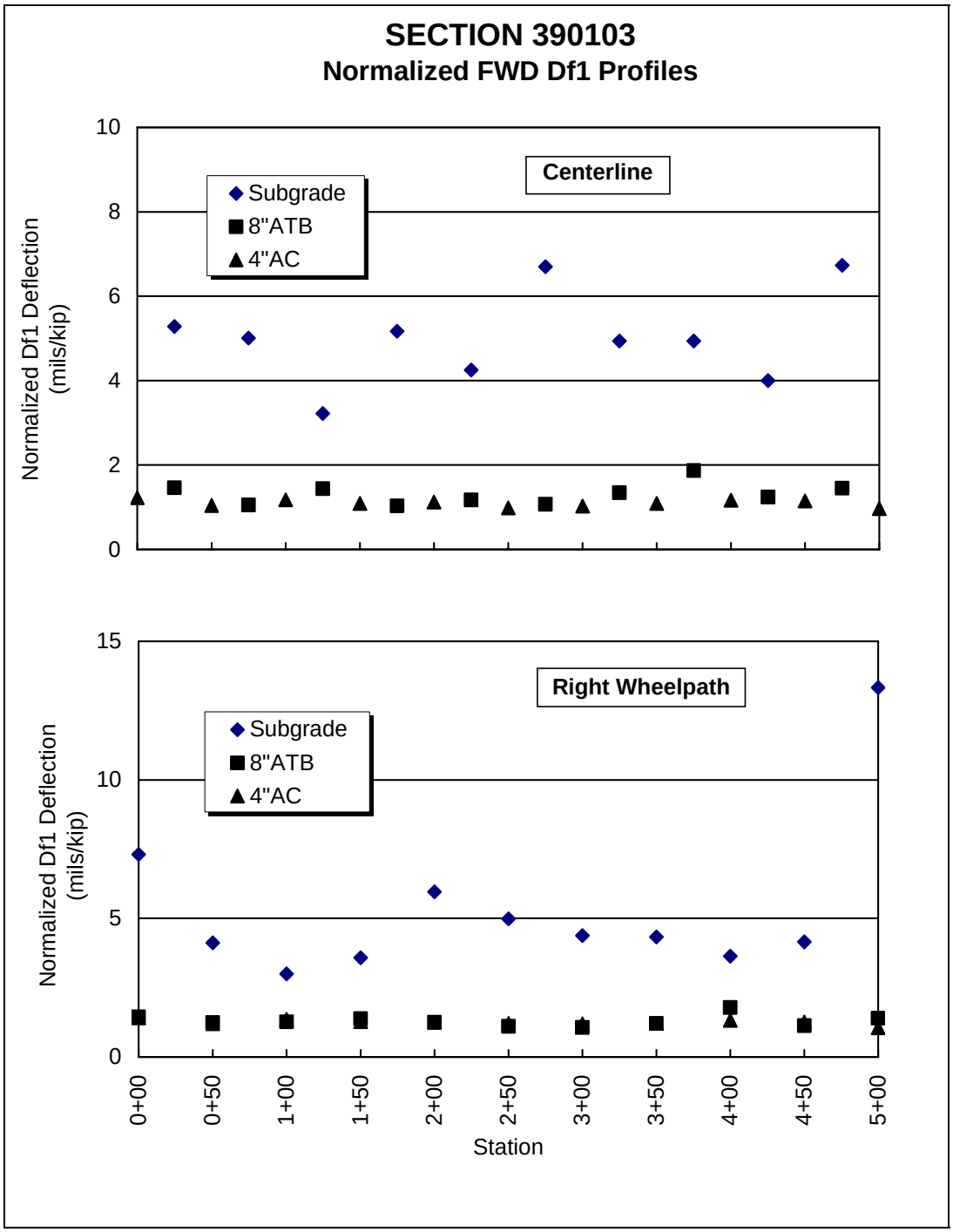


Figure 3.4.4 Normalized FWD at Time of Construction for Section 390103. (1 mil/kip = 5.71×10^{-9} m/N = 5.71 nm/N; 4" = 10.2 cm; 8" = 20.3 cm)

4.0 DESTRUCTIVE TESTING

4.1 TRENCHES

Lateral trenches roughly five feet (1.5 m) wide and four feet (1.2 m) deep were excavated (Figure 4.1) at locations in each section representing various levels of distress. Three trenches were excavated in Sections 390103 and 390110, and two trenches in Sections 390108 and 390109. Approximate section stations and levels of distress noted at the trench locations are shown in Table 4.1.

Table 4.1.1 Trench Distress Classification and Locations.

Section	Trench	Section Station	Indicated Distress Classification
390103	#1	1+27	High
	#2	3+00	Low
	#3	4+05	Moderate
390108	#1	3+32	Moderate
	#2	5+00	Low
390109	#1	2+00	Moderate
	#2	3+27	Moderate
390110	#1	1+10	Low
	#2	2+52	Moderate
	#3	5+63	Environmental Trench

Figure 4.1.1 Trench Excavation.

4.2 LAYER AND LIFT THICKNESS

The thickness of individual pavement and base lifts were measured at three foot intervals with a standard tape measure along the length of each trench and estimated to the nearest ¼ inch (0.64 cm) (Figure 4.2.1). The results of all the measurements are presented in Tables 4.2.1, 4.2.2, 4.2.3, and 4.2.4. While the extent of rutting was very apparent in some sections, as shown in the transverse profiles, the thickness of the pavement layers remained consistent with their design thickness throughout the transverse length of all the trenches, indicating minimal, if any rutting in the AC material. Some consolidation of the base layers was noted. Pictures of each trench are located in Appendix M.

In some locations it was difficult to see the layer interfaces, and as a result some layer thicknesses could not be determined and some entries in Tables 4.2.2 through 4.2.4 are blank. For Section 390103 it was relatively easy to see where each layer began and ended, see Figure 4.2.2. For Section 390110 it was much more difficult to tell where the surface AC layer ended. This difficulty is reflected in the AC surface and intermediate layers observed in the trenching differing from those at the time of construction, as seen in Table 4.2.4. A second lift in the intermediate AC layer was very notable; also it was very difficult to accurately measure the ATB layer, see Figure 4.2.3. There seemed to be some consolidation in the base layers, especially evident in the third trench. The condition of the PATB layers in sections 390108, 390109, and 390110 were not explicitly noted, however the condition was often poor, as evidenced by the core samples falling apart. The trenching operation made it impossible to tell if the presence of fines were clogging the PATB. PATB cores were sent to ODOT for analysis to determine M_R, density and percentage of fines, but results were not obtained by publication date of this report.

Table 4.2.1 Layer/Lift Thickness for Section 390103.

Section 390103 layer thicknesses in inches											
	Trench 2			Trench 3						At time of construction	
Layer	0+00	0+03	0+06	0+09	0+00	0+03	0+06	0+09	0+12	Design	Actual
AC Surface	1.75	1.75	1.75	1.75	1.75	2	1.75	1.5	2.25	1.75	1.71
AC intermediate	2	2	2	2	2.5	1.75	2.5	2	2	2.25	2.16
ATB	3	3.75	3.5	3.75	3.5	2.5	2	2.5	2.75	8	8.04
	5	5	4.75	5	4.5	4.75	4.25	4.75	4		

Section 390103 layer thicknesses in cm											
	Trench 2			Trench 3						At time of construction	
Layer	0+00	0+03	0+06	0+09	0+00	0+03	0+06	0+09	0+12	Design	Actual
AC Surface	4.45	4.45	4.45	4.45	4.45	5.08	4.45	3.81	5.72	4.45	4.34
AC intermediate	5.08	5.08	5.08	5.08	6.35	4.45	6.35	5.08	5.08	5.72	5.49
ATB	7.62	9.53	8.89	9.53	8.89	6.35	5.08	6.35	6.99	20.32	20.42
	12.70	12.70	12.07	12.70	11.43	12.07	10.80	12.07	10.16		

Table 4.2 2 Layer/Lift Thickness for Section 390108.

Section 390108 layer thicknesses in inches									
	Trench 1				Trench 2			At time of construction	
Layer	0+03	0+06	0+09	0+12	0+03	0+06	0+09	Design	Actual
AC surface	3.5	1.75	1.75	2	2	2	2	1.75	1.7
AC intermediate	3	2.25	2.25	2	2	2	2	5.25	4.85
		3		2.5	2.5	3	3		
PATB	5.5	4		4.25	4.5	3.5	4	4	4.03
DGAB								8	8.04

Section 390108 layer thicknesses in cm									
	Trench 1				Trench 2			At time of construction	
Layer	0+03	0+06	0+09	0+12	0+03	0+06	0+09	Design	Actual
AC surface	8.89	4.45	4.45	5.08	5.08	5.08	5.08	4.45	4.32
AC intermediate	7.62	5.72	5.72	5.08	5.08	5.08	5.08	13.34	12.32
		7.62		6.35	6.35	7.62	7.62		
PATB	13.97	10.16		10.80	11.43	8.89	10.16	10.16	10.24
DGAB								20.32	20.42

Table 4.2.3 Layer/Lift Thickness for Section 390109.

Section 390109 layer thicknesses in inches										
	Trench 1			Trench 2					At time of construction	
Layer	0+03	0+06	0+09	0+00	0+03	0+06	0+09	0+12	Design	Actual
AC surface	2	2	2	2	2	2	2	2	1.75	1.8
AC intermediate	2	2	2	2	2	2	2	2	5.25	5.17
	3.25	3.5	3.25	3	3	3	3	3		
PATB	3.25	3.5	3.75	4	4	4	4	4	4	3.95
DGAB				12	12	12	12	12	12	11.98

Section 390109 layer thicknesses in cm										
	Trench 1			Trench 2					At time of construction	
Layer	0+03	0+06	0+09	0+00	0+03	0+06	0+09	0+12	Design	Actual
AC surface	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	4.45	4.57
AC intermediate	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	13.34	13.13
	8.26	8.89	8.26	7.62	7.62	7.62	7.62	7.62		
PATB	8.26	8.89	9.53	10.16	10.16	10.16	10.16	10.16	10.16	10.03
DGAB				30.48	30.48	30.48	30.48	30.48	30.48	30.43

Table 4.2.4 Layer/Lift Thickness for Section 390110.

Section 390110 layer thicknesses in inches													
	Trench 1			Trench 2 (moderate)			Trench 3					At time of construction	
Layer	0+03	0+06	0+09	0+00	0+09	0+12	0+00	0+03	0+06	0+09	0+12	Design	Actual
AC Surface	4	3.5	4	3.25	4.25	4	4	4	4	4	4	1.75	1.83
AC Intermediate	3	3.5		4.75	3.25	3.5	3.75	3.75	3.75	3.75	3.75	5.25	5.51
ATB	4.5	4.5		3.75	2.5	2.5						4	3.71
PATB	3.5	3		3.25	4	4	7	7	7	7	7	4	3.88

Section 390110 layer thicknesses in cm													
	Trench 1			Trench 2 (moderate)			Trench 3					At time of construction	
Layer	0+03	0+06	0+09	0+00	0+09	0+12	0+00	0+03	0+06	0+09	0+12	Design	Actual
AC Surface	10.16	8.89	10.16	8.26	10.80	10.16	10.16	10.16	10.16	10.16	10.16	4.45	4.65
AC Intermediate	7.62	8.89		12.07	8.26	8.89	9.53	9.53	9.53	9.53	9.53	13.34	14.00
ATB	11.43	11.43		9.53	6.35	6.35						10.16	9.42
PATB	8.89	7.62		8.26	10.16	10.16	17.78	17.78	17.78	17.78	17.78	10.16	9.86

Figure 4.2.1 Measurement of Lift Layers.

Figure 4.2.2 Section 390103 Layers.

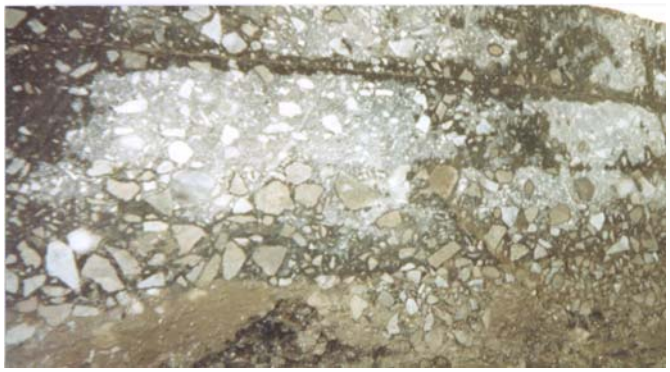


Figure 4.2.3 Section 390110 Layers.

4.3 STIFFNESS VARIABILITY

In-situ subgrade stiffness was measured at different depths in the trenches with a Humboldt Stiffness Gauge. The resulting data is shown in Figures 4.3.1, 4.3.2, 4.3.3, and 4.3.4. Measurements were taken at six and twelve inch depths at the same transverse location as the trenches were excavated. Overall the data revealed considerable variability in stiffness with depth in each section.

In Section 390103 a strong trend in the data showed the stiffness escalating at a location of twenty-four inches below the surface. This trend was present in all sections in at least one trench. In Section 390108 the trend was present in trench #1 in the wheel path location, and in Section 390110 in trench #1 for the wheel path and center line locations. Section 390109 seems to also follow the same pattern, with the higher stiffness measurement being at the same depth in the subgrade.

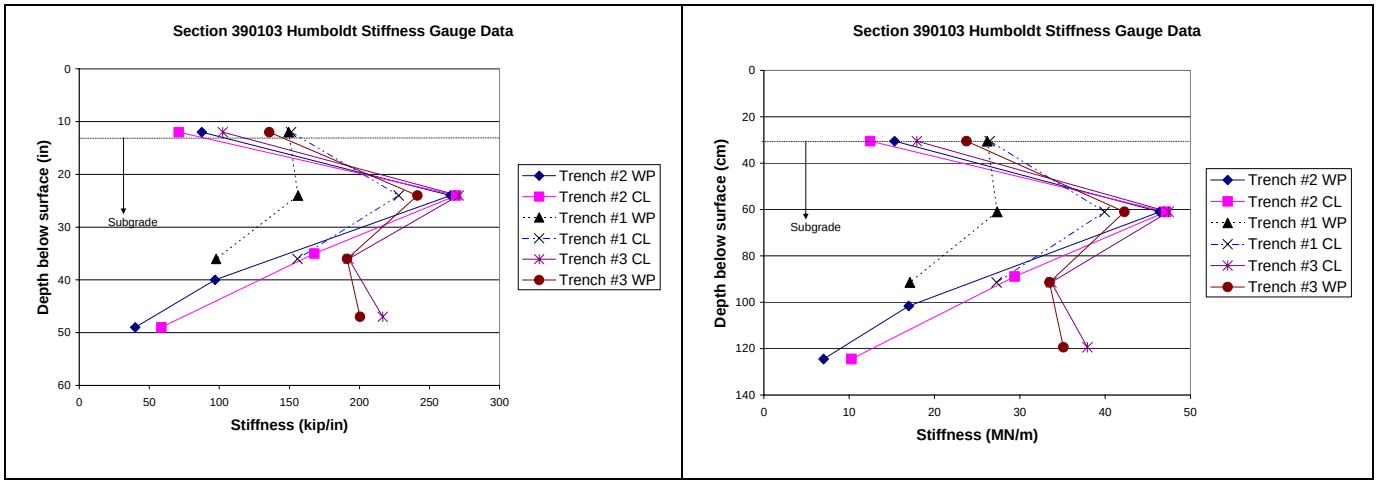


Figure 4.3.1 Humboldt Stiffness Gauge Plot of Section 390103. Left in English units, right in metric units.

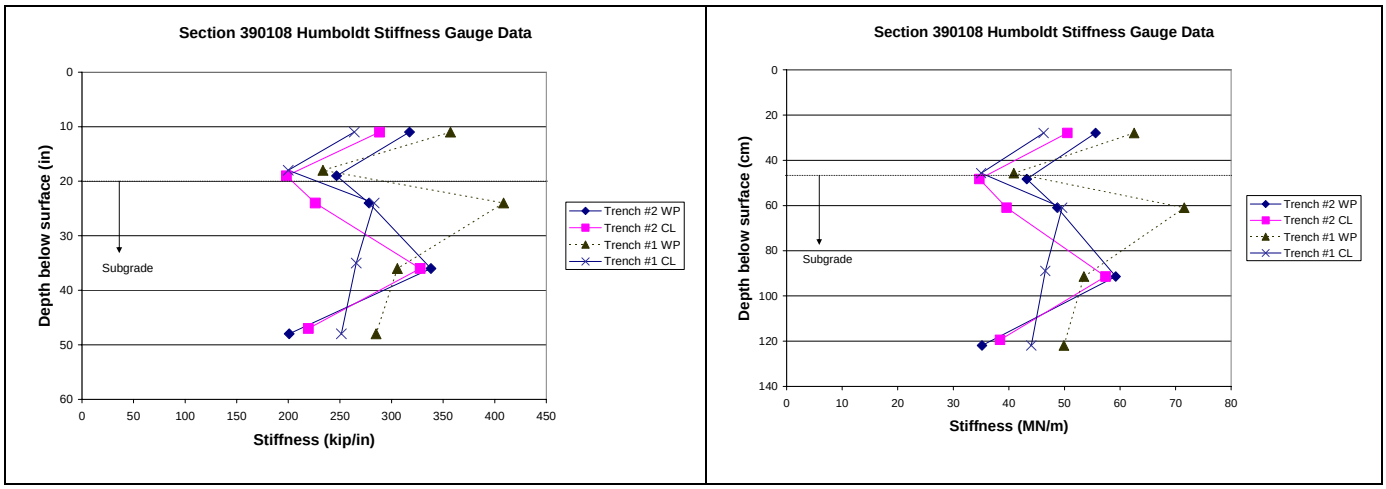


Figure 4.3.2 Humboldt Stiffness Gauge Plot of Section 390108. Left in English units, right in metric units.

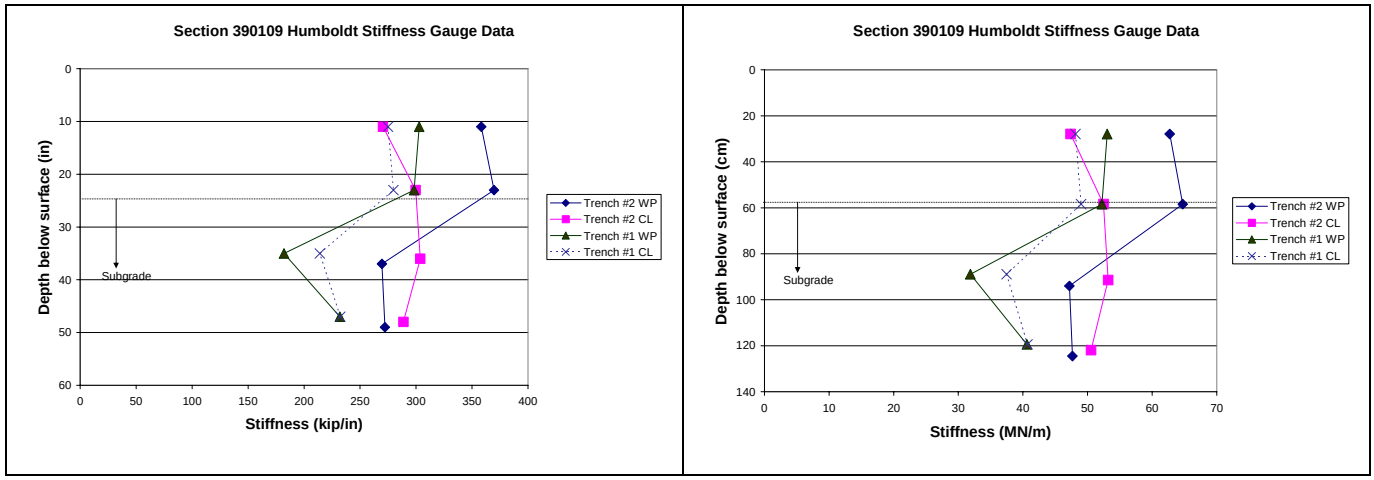


Figure 4.3.3 Humboldt Stiffness Gauge Plot of Section 390109. Left in English units, right in metric units.

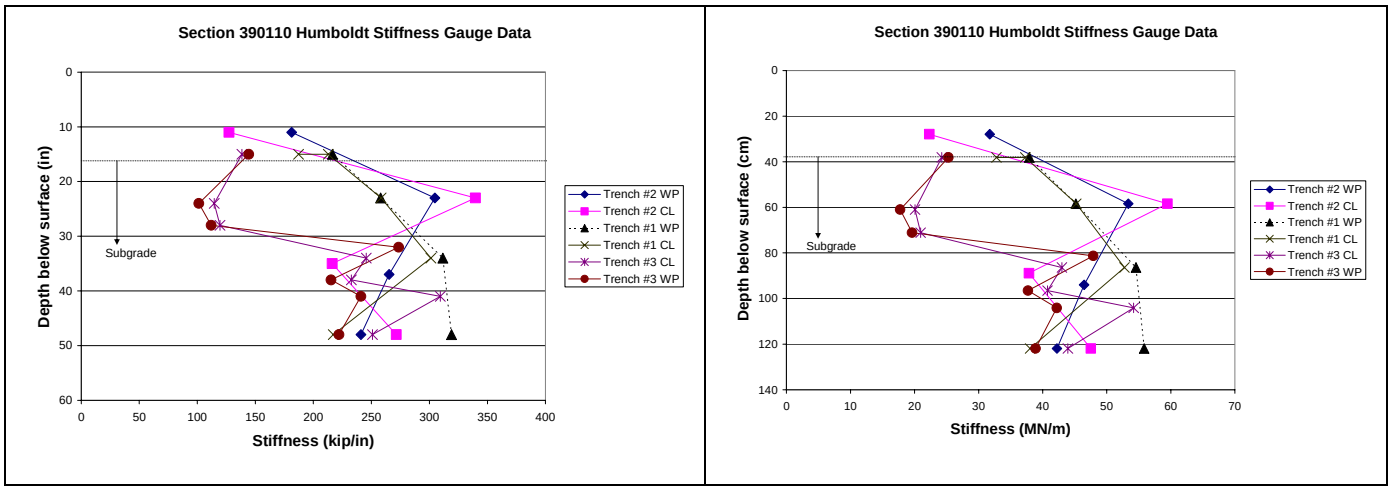


Figure 4.3.4 Humboldt Stiffness Gauge Plot of Section 390110. Left in English units, right in metric units.

4.4 MOISTURE CONTENT

Moisture content of the subgrade was determined by three methods; traditional laboratory methods, a nuclear gauge, and TDR probes. Soil samples and nuclear gauge readings were taken at approximately six and twelve inch (15 and 30 cm) depths during excavation of the trenches. The soil samples were then transferred to the Ohio Research Institute for Transportation and the Environment (ORITE) laboratory in sealed containers, and tested for moisture.

The data from the soil samples taken generally showed moisture content to increase up to a depth of 25-40 inches (63.5-101.6 cm), then decrease at further depths in all four sections (Appendix N). The highest and lowest moisture content readings are shown in table 4.4.1 for each section. Also an inverse relationship between stiffness and moisture content was noted. When the moisture content was higher, the stiffness of the subgrade was low, and vice versa. Further examination of the stiffness moisture relationship may suggest that moisture was seeping up through the subgrade, and also down through the pavement structure. The increase in stiffness indicated by the Humboldt readings and lower moisture content at a depth of twenty-four inches may indicate the moisture had not gotten to this point from either direction.

Figure 4.4.4 illustrates a significant increase in TDR moisture readings between January and later in the summer, again indicating strong seasonal variation in moisture as previously indicated in the water table data.

From the nuclear gauge data, it was determined that the subgrade soil was very close to being fully saturated (Appendix O) in all four sections undergoing the forensic investigation, assuming the specific gravity of the soil was 2.7. Plots of the data taken with the nuclear gauge are in Appendix O. The nuclear gauge readings were taken at six and twelve inch (15 and 30 cm) intervals. Nuclear gauge data was not able to be taken in all trenches. Agreement between the nuclear gauge readings and the in-situ moisture samples collected in the field validates the accuracy of the gauge.

Free water was observed between layers in the subgrade, between the asphalt pavement and base layers (Figure 4.4.1), and also water could be seen "seeping" from the subgrade (Figure 4.4.2 and 4.4.3). This indicated a lack of adequate drainage in the four pavement structures, even though Sections 39108, 390109, and 390110 were constructed with edge drains.

Table 4.4.1 Moisture Content Range.

	Gravemetric %	
Section	Highest Moisture Content	Lowest Moisture Content
390103	30.2%	14.7%
390108	25.6%	5.8%
390109	23.3%	5.6%
390110	27.0%	12.9%

Figure 4.4.1 Free Water Between Base and AC.

Figure 4.4.2 Water Seeping From Interface Layer.

Figure 4.4.3 Water Seeping From Subgrade.

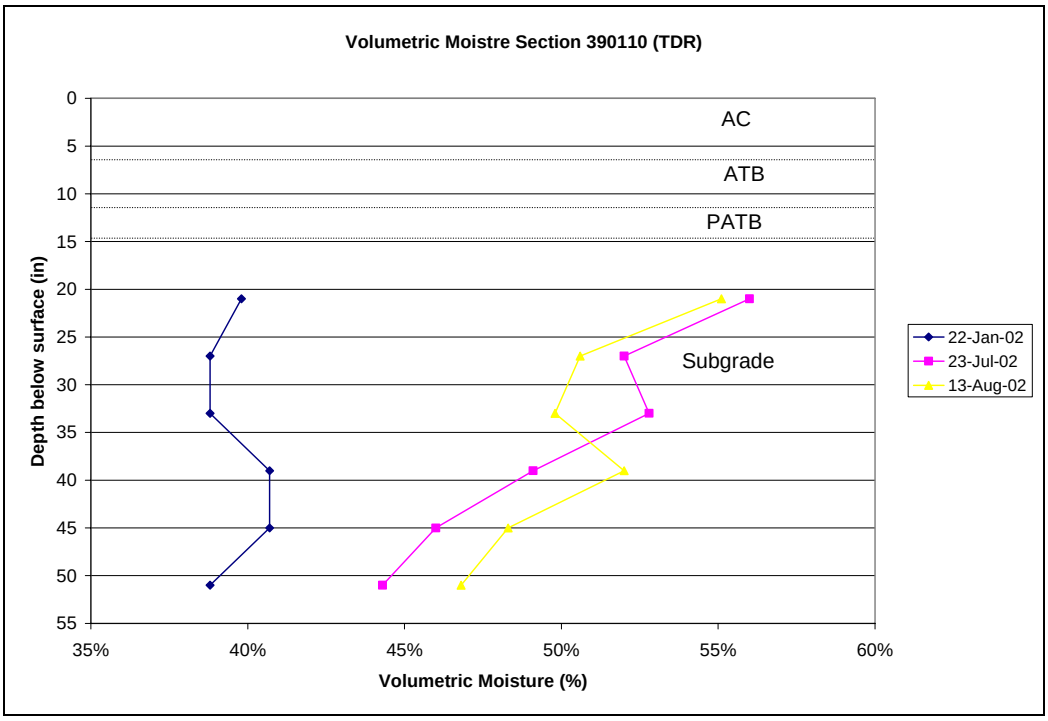


Figure 4.4.4 Moisture Content by TDR. (1 in = 2.54 cm)

4.5 DYNAMIC CONE PENOTROMETER

Dynamic Cone Penetration (DCP) tests also showed non-uniform subgrade stiffness with depth in each test section. The resulting data yielded Penetration Index versus depth plots shown in Appendix Q, and blows per depth plots also in Appendix Q. The tests were conducted every 100 feet (30.5 m) in both the centerline and wheel path, and also at trench locations. These data were used to calculate the resilient modulus of the subgrade in the following section.

4.6 RESILIENT MODULUS OF SUBGRADE

The resilient modulus M_R of the subgrade was calculated and plotted for each section from the DCP tests (Appendix K). The M_R was determined from DCP data using the following equation:

M_R = 1200*CBR (units are in kip per square inch (ksi))

where Log (CBR) = 2.20 - 0.71 Log (PI)1.5 ± 0.075

and PI is the DCP penetration index (mm/blow).

The average resilient modulus of the upper level of subgrade in Sections 390103, 390108, 390109, and 390110 was calculated to be 12.58 ksi (86.74 MPa), 24.42 ksi (168.4 MPa), 21.09 ksi (145.4 MPa), and 22.50 ksi (155.1 MPa), respectively. According to the report Characterization of Materials & Data Management for Ohio SHRP Projects, U.S. 23 [(3)] the AASHTO soil classifications are A-6 for section 390103 and A-4 for sections 390109 and 390110. Section 390108 did not have a soil class identified in the report.

The resilient modulus for each structural layer was also estimated by a back calculation technique using FWD data. The back calculation program selected for this analysis was MODULUS 4.2. [(5)] This program, which was developed by the Texas Transportation Institute, is based on the multilayer linear elasto-static theory.

The input parameters for this analysis include sensor locations, layer thickness, initial modulus ranges, and Poisson's ratio. The initial values used for the analysis based on the FHWA/OH-2002/031 report [(4)] are shown in Table 4.6.1. It should be noted that the subgrade

layer was assumed to be semi-infinite. The analysis results are summarized for each section in Table 4.6.2. The deflection matching errors per sensor for all of the back calculation runs fell within acceptable limits. The station-by-station resilient modulus results were plotted and can be found in Appendix T.

Just after completion of construction, FWD tests were run and this same technique was used to estimate layer resilient modulus [4]. Those results are compared with the results from this forensic investigation and shown in Table 4.6.3. It is clearly seen from the comparison that all the layers in the four sections suffered decreases in resilient modulus. This indicates that the pavement structure was weakened by increased moisture and various distresses. The back calculated resilient modulus for the subgrade was also compared with the resilient modulus calculated from DCP test data. Comparison showed a fair agreement in modulus values between two methods as shown in Table 4.6.4. Resilient modulus values were also determined from measured moisture content and interpolation from curves determined during the laboratory characterization of materials[3], assuming σ_d=2 psi (13.8 kPa). While the average M_R from moisture values is smaller than the other values, this may be due to additional moisture from water used during the asphalt cutting process. These moisture derived values are closer to the values reported in the materials database from the same report, and all measured values are in the range of values recorded during the original laboratory tests. Table 4.6.6 shows the soil type and dry unit weight of the subgrade soil in each section taken from the "Laboratory Characterization of Ohio-SHRP Test Road Pavement Material" database[3].

Table 4.6.1 Back Calculation Input Parameters.

	Initial modulus range				
Material type	low (ksi)	high (ksi)	low (MPa)	high (MPa)	Poisson's ratio
AC	200	2500	1400	17000	0.35
DGAB	10	150	70	1000	0.35
PATB	50	1000	350	7000	0.25
ATB	150	4000	1000	28000	0.25
Subgrade	3	30	20	200	0.40

Table 4.6.2 Summary of Back Calculated Modulus.

		Thickness		Backcalculated Modulus (ksi)			Backcalculated Modulus (MPa)			Absolute Error/Sensor
Section	Layer	(in)	(cm)	CL	WP	Average	CL	WP	Average	
390103	AC	4	10.16	2127	1978	2052.5	14665.1	13637.8	14151.5	1.30%
	ATB	8	20.32	42.1	24.4	33.25	290.3	168.2	229.3	
	Subgrade	-	-	11.2	10.9	11.05	77.2	75.2	76.2	
390108	AC	7	17.78	283	346	314.5	1951.2	2385.6	2168.4	0.60%
	PATB	4	10.16	57.8	56	56.9	398.5	386.1	392.3	
	DGAB	8	20.32	13.7	10.5	12.1	94.5	72.4	83.4	
	Subgrade	-	-	21.9	23.4	22.65	151.0	161.3	156.2	
390109	AC	7	17.78	342	396	369	2358.0	2730.3	2544.2	0.60%
	PATB	4	10.16	140.5	96.5	118.5	968.7	665.3	817.0	
	DGAB	12	30.48	18	16.1	17.05	124.1	111.0	117.6	
	Subgrade	-	-	25	26.5	25.75	172.4	182.7	177.5	
390110	AC	7	17.78	523	524	523.5	3606.0	3612.9	3609.4	0.70%
	ATB	4	10.16	214.4	167	190.7	1478.2	1151.4	1314.8	
	PATB	4	10.16	33	28	30.5	227.5	193.1	210.3	
	Subgrade	-	-	20.9	22.3	21.6	144.1	153.8	148.9	

Note: Absolute Error/Sensor is the difference between deflection actually recorded by FWD at one of the sensors and the backcalculated value of the same deflection, expressed as a percentage.

Table 4.6.3 Comparison of Back Calculated Modulus.

		Thickness		M_R (ksi)		M_R (MPa)		
Section	Layer	(in)	(cm)	After Construction	After Distress	After Construction	After Distress	Change
390103	AC	4	10.16	2762	2053	19043.3	14154.9	-25.7%
	ATB	8	20.32	83	33.3	572.3	229.6	-59.9%
	Subgrade	-	-	16	11.1	110.3	76.5	-30.6%
390108	AC	7	17.78	781	315	5384.8	2171.8	-59.7%
	PATB	4	10.16	83	56.9	572.3	392.3	-31.4%
	DGAB	8	20.32	41	12.1	282.7	83.4	-70.5%
	Subgrade	-	-	24	22.7	165.5	156.5	-5.4%
390109	AC	7	17.78	843	369	5812.3	2544.2	-56.2%
	PATB	4	10.16	124	118.5	854.9	817.0	-4.4%
	DGAB	12	30.48	24	17	165.5	117.2	-29.2%
	Subgrade	-	-	23	25.8	158.6	177.9	12.2%
390110	AC	7	17.78	708	524	4881.5	3612.9	-26.0%
	ATB	4	10.16	163	190.7	1123.8	1314.8	17.0%
	PATB	4	10.16	51	30.5	351.6	210.3	-40.2%
	Subgrade	-	-	19	21.6	131.0	148.9	13.7%

Table 4.6.4 Comparison of Subgrade Modulus between DCP and Backcalculation.

	Average M_R (ksi)		Average M_R (MPa)		
Section	DCP based	Backcalculated	DCP based	Backcalculated	Difference
390103	12.6	11.1	86.9	76.5	11.90%
390108	24.4	22.7	168.2	156.5	6.97%
390109	21.2	25.8	146.2	177.9	-21.70%
390110	22.5	21.6	155.1	148.9	4.00%

Table 4.6.5 Comparison of all Subgrade Modulus Values

	Average M_R (ksi)			
Section	DCP based	Backcalculated	Moisture based	Original Lab value
390103	12.6	11.1	10.1	15.7
390108	24.4	22.7	12.9	19
390109	21.1	25.8	12	11.5
390110	22.5	21.6	13.5	13

	Average M_R (MPa)			
Section	DCP based	Backcalculated	Moisture based	Original Lab value
390103	86.9	76.5	69.6	108.2
390108	168.2	156.5	88.9	131.0
390109	145.5	177.9	82.7	79.3
390110	155.1	148.9	93.1	89.6

Table 4.6.6 Dry Unit Weight and Soil Class for Subgrade Soils

	In-Situ Average Dry Unit Weight		
Section	(pcf)	(kg/m^3)	Soil Class
390103	119.8	1919	A-6b
390108	117.8	1887	-
390109	119.7	1917	A-4a
390110	118.6	1900	A-4a

4.7 CORE DENSITY AND AIR VOID

One of the common detection methods for segregation is comparison of mix volumetrics between segregated and non-segregated areas. When the air void difference between segregated and non-segregated areas is larger than 2 to 6%, it is considered medium to high level segregation[6]. The segregation of surface course in the vertical direction observed in this study would also cause high air void levels. Table 4.7.1 shows air voids of cores taken from the test pavements. As expected, cores taken from wheel-pass were further compacted by traffic and had generally lower air voids than cores taken from the center-lane. Overall, air voids of most cores were significantly higher than normal range of new pavements, which might have been caused by the vertical segregation discussed in section 3.2. Mix properties typically affected by segregation are lowered modulus, lowered strength, and increased moisture sensitivity. Top-down cracks observed on the test pavements might be explained by the segregation.

Density determination of cores taken from the sites showed much higher air voids than usual. This is believed to be caused by the segregation of asphalt mixes and to contribute to the top-down cracking.

It should be noted that the average percentage of air voids in the surface layers ranges from 9.45% for section 390108 to 11.25% for 390110, and over all four sections the average is 10.1%. These values are much higher than the 7.1% recorded at the time of construction and shown in Table 2.1. For intermediate layers, a similar story holds: the averages range from 10.9% in section 390108 to 12.95% in section 390110, for an overall average of 11.9% compared to 6.6% recorded at the time of construction.

Table 4.7.1. Density of cores taken from test pavements.

Pavement Layer	Location	AC %	Bulk Sp. Gravity	Max Sp. Gravity	% AIR VOIDS
Section 390103					
Surface	CL	6.7	2.193	2.450	10.5
	WP	6.8	2.238	2.453	8.8
Intermediate	CL	6.0	2.192	2.468	11.2
	WP	6.0	2.208	2.476	10.8
Base	CL	4.6	2.242	2.486	9.8
	WP	4.6	2.28	2.521	9.6
Section 390108					
Surface	CL	6.7	2.225	2.461	9.6
	WP	6.4	2.241	2.470	9.3
Intermediate	CL	6.1	2.172	2.465	11.9
	WP	6.1	2.222	2.467	9.9
Section 390109					
Surface	WP	6.5	2.222	2.460	9.7
	WP	7.0	2.202	2.454	10.3
Intermediate	CL	5.9	2.143	2.469	13.2
	WP	5.7	2.165	2.465	12.2
Section 390110					
Surface	CL	6.2	2.178	2.465	11.6
	WP	6.6	2.186	2.453	10.9
Intermediate	CL	5.6	2.153	2.469	12.8
	CL	5.7	2.147	2.472	13.1
Base	CL	5.3	2.24	2.461	9.0
	WP	5.3	2.285	2.454	6.9

5.0 CONCLUSIONS

An in-depth forensic study of Sections 390103, 390108, 390109, and 390110 on the Ohio SHRP Test Road was performed to determine the causes of localized distresses occurring in these sections. Various degrees of distress were present in the four sections. Section 390103 exhibited the highest distress with extreme rutting, fatigue cracking in the wheel paths, and longitudinal cracking extending the length of the section. Low to moderate distresses of a similar nature were present in the other three sections.

The service lives of 1.3, 1.8, 4.3, and 2.8 years predicted by the AASHTO equations for sections 390103, 390108, 390109, and 390110 respectively, agreed with performance observed in the field, assuming actual ESALs equal the design ESALs. The sections were opened to traffic on August 14, 1996 and closed for replacement on April 24, 2002. During that period, the sections were closed at various times totaling about one year, resulting in an actual service life of about 4½ years.

The investigation revealed substantial variability in stiffness and high levels of moisture in the subgrade of all four pavement sections. According to the stiffness test results from the FWD, the distresses observed were not due to any flaws in the pavement at the time of construction. A correlation between stiffness and moisture was evident. These trends indicate that the severity of distress in Sections 390108, 390109, and 390110 would soon be similar to those in Section 390103 if the sections were left open to traffic.

Despite the use of various base materials and the presence of edge drains in Sections 390108, 390109 and 390110, higher than anticipated levels of subgrade moisture were present in all four pavement sections. The subgrade in these sections was saturated. This moisture was the underlying cause of rutting and cracking. While edge drains probably removed some moisture infiltrating down from the pavement surface, they provided little benefit for moisture migrating up through the subgrade.

Laboratory measurements and field tests showed the subgrade soil in Sections 390108, 390109, and 390110 to have similar values of resilient modulus, stiffness, and moisture content regardless of the type of base used. Section 390103 also had similar subgrade soil characteristics with the exception of the average resilient modulus being significantly less than the other three sections.

The thickness of the AC pavement layers remained constant along the transverse axis, and consistent with their design specifications in all test sections. Some consolidation of the base material was noted. This would indicate that rutting observed in the pavement surface had reflected up from the base and subgrade.

The longitudinal cracking observed in all test sections was the result of the segregation of aggregates in the asphalt mix at the time of construction, the augers or spreaders in the paving machine are the most likely cause of the segregation of aggregates. This segregation is reflected in the much higher percentage of air voids seen in the core samples taken for the forensic study compared to those recorded at the time of construction.

In comparison of the resilient modulus, there was good agreement between the back calculation technique and the DCP test results. The decrease of the layer modulus between time of construction and the forensic investigation is attributed to distress upon the pavement.

6.0 REFERENCES

1.) SHRP-P-338 Distress Identification Manual for the Long-Term Pavement Performance Project, © 1993 National Academy of Sciences, Washington, D.C.

2.) AASHTO Guide for Design of Pavement Structures, © 1986 American Association of State Highway and Transportation Officials, Washington, D.C.

3.) FHWA/OH-2001/07 Laboratory Characterization of Materials & Data Management for Ohio-SHRP Projects U.S. 23, © 2002 Ohio Department of Transportation, Columbus, Ohio.

4.) FHWA/OH-2002/031 Determination of Pavement Layer Stiffness on the Ohio SHRP Test Road Using Non-Destructive Testing Techniques, © 2002 Ohio Department of Transportation, Columbus, Ohio.

5.) Michalak, C.H. and Scullion, T., "Modulus 5.0: User's Manual", Texas Transportation Institute, College Station, Texas, 1995.

6.) Stroup-Gardiner, M., "Influence of Segregation on Pavement Performance" AAPT vol 69, 2000, pp 424-454.

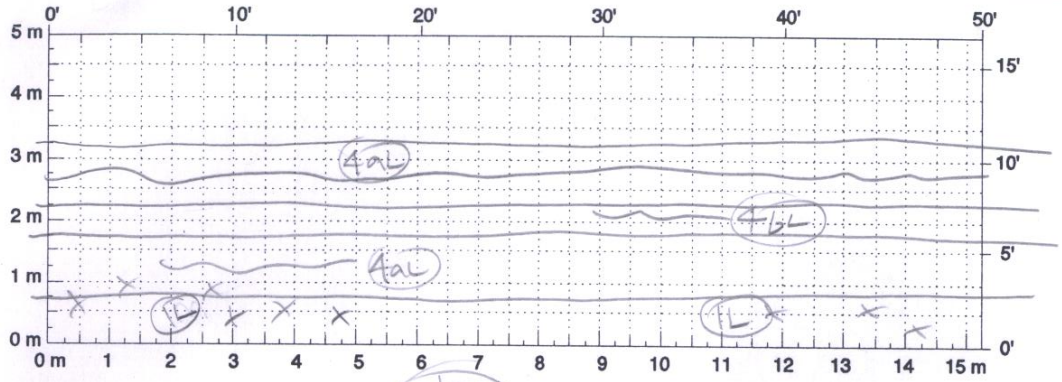
7.) Donna Harmelink, Tim Aschenbrener, "Extent of Top-Down Cracking In Colorado", Rpt CDOT-DTD-R-200-7, 2003.

Appendix A Distress Surveys

State Assigned ID 39

State Code 61

SHRP Section ID 08



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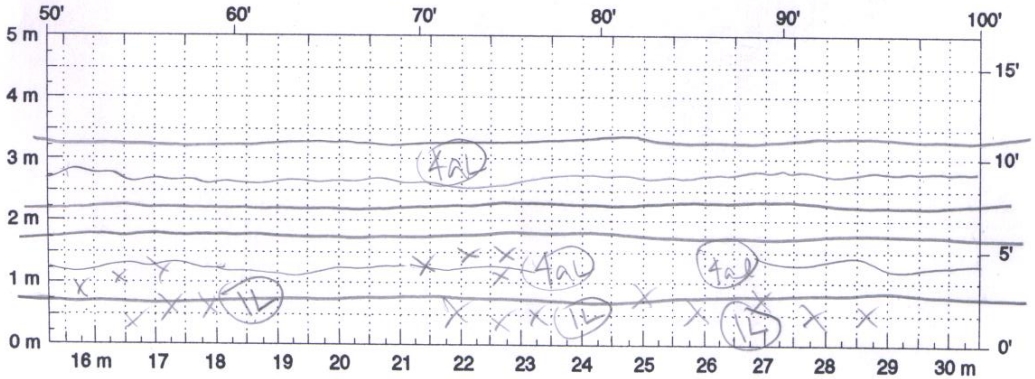

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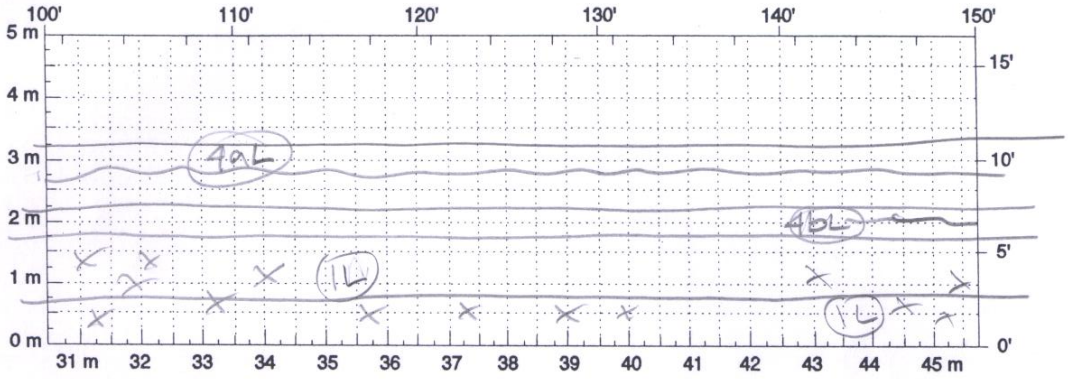

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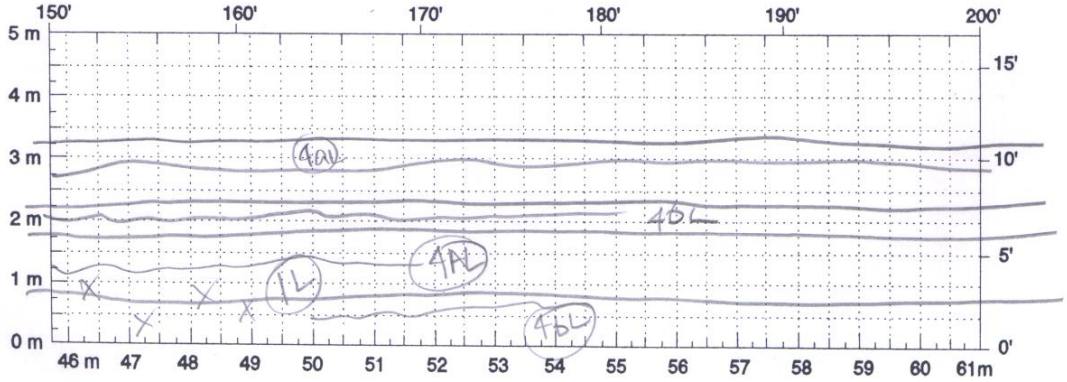

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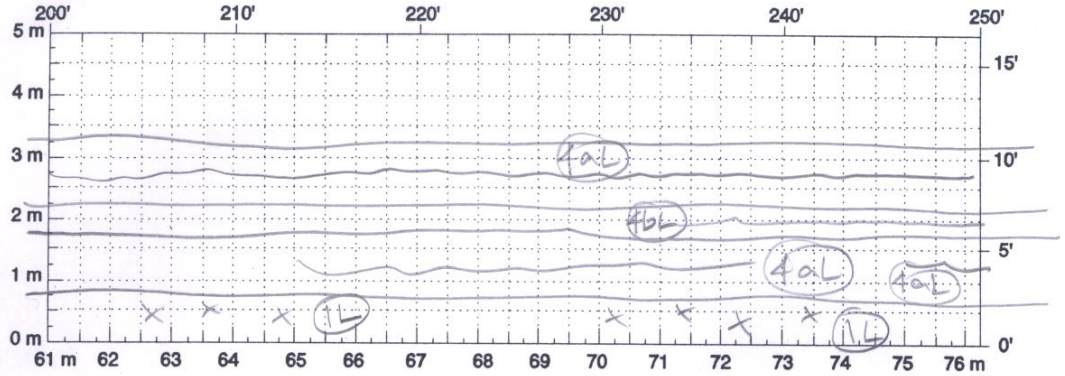

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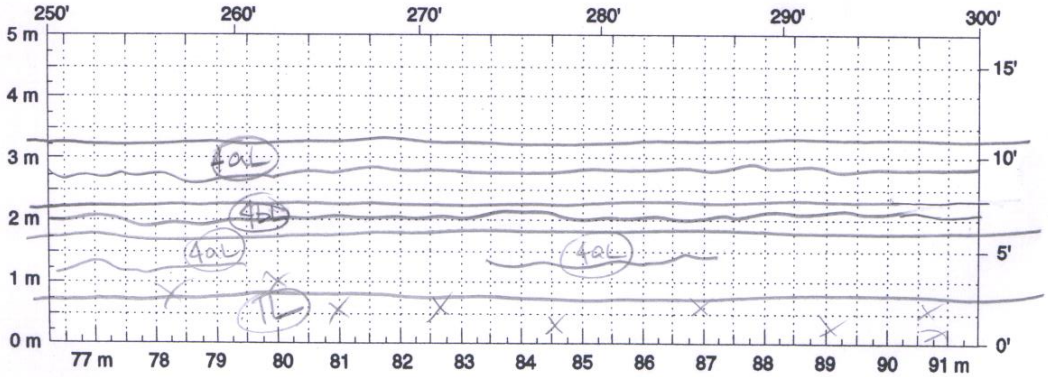

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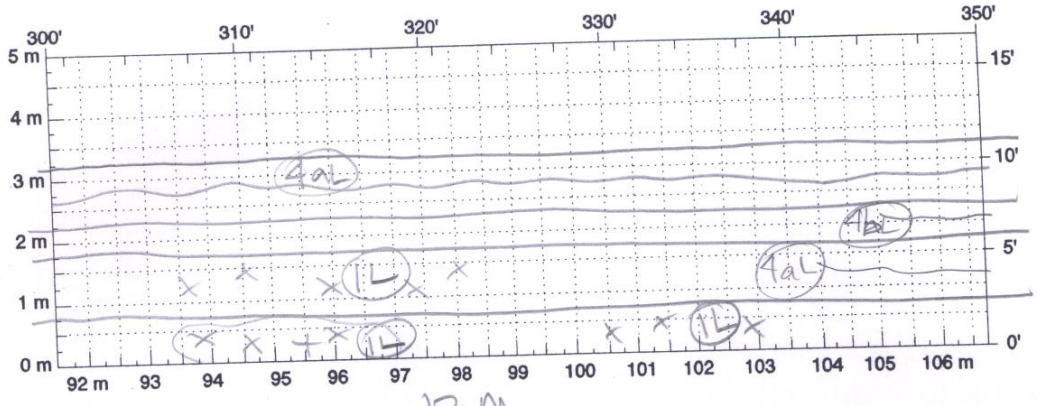

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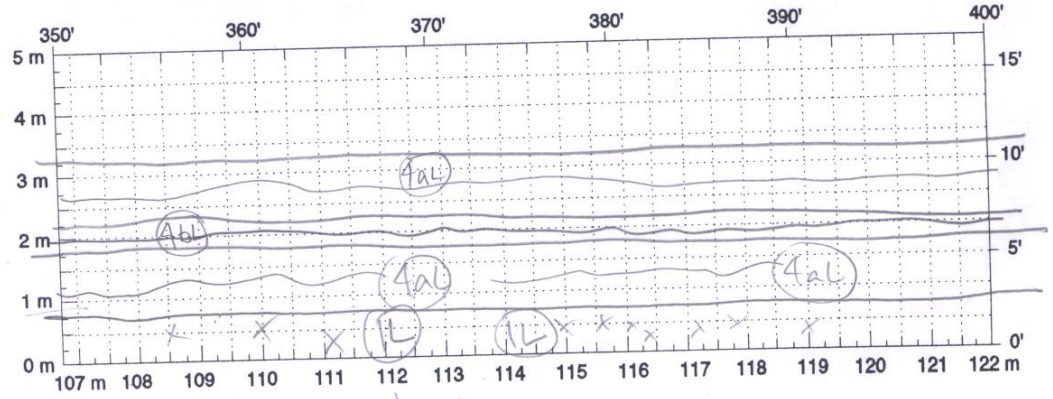

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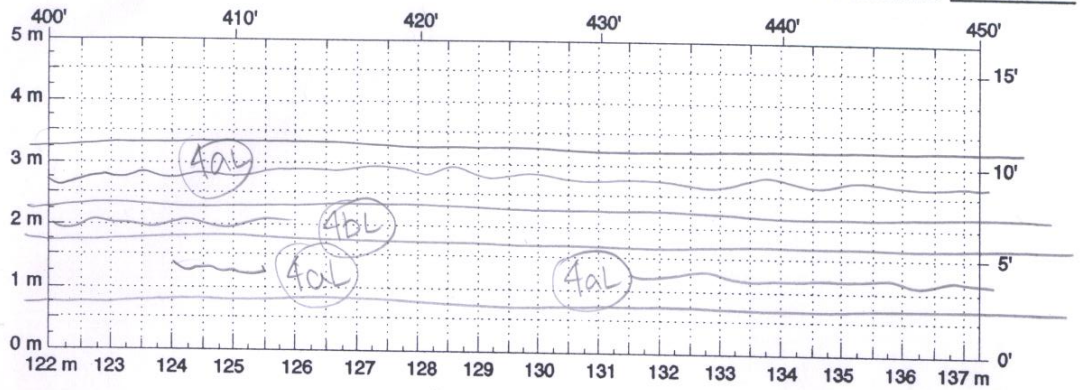

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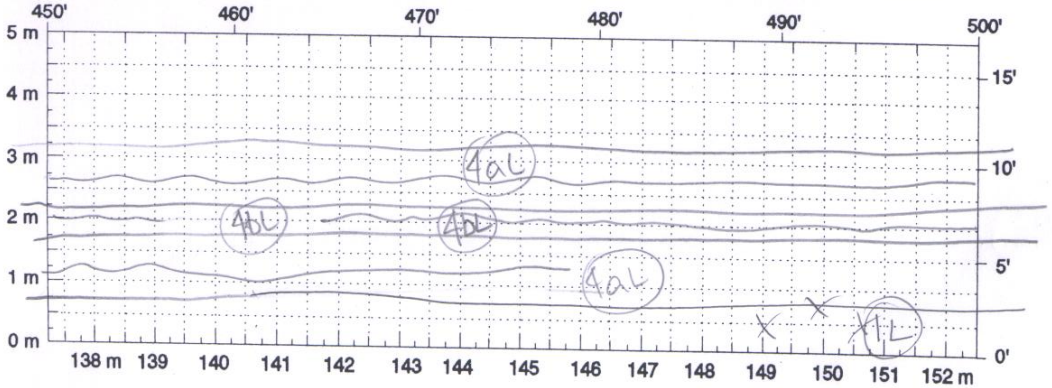

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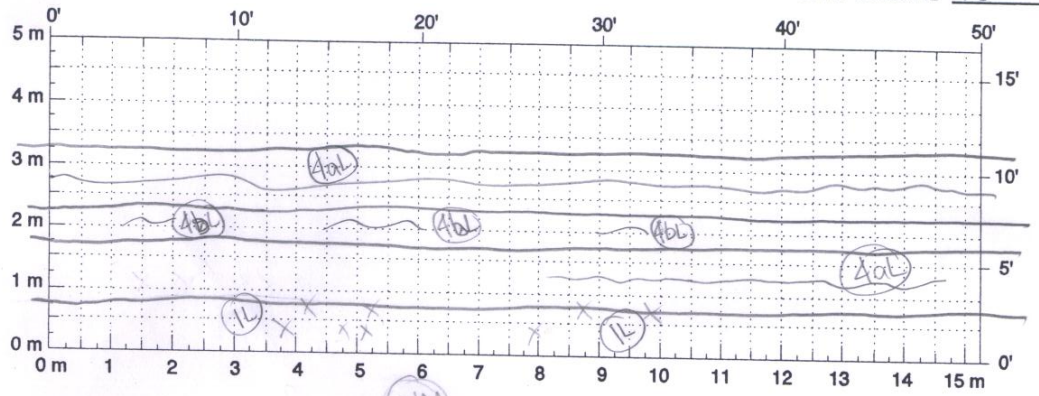

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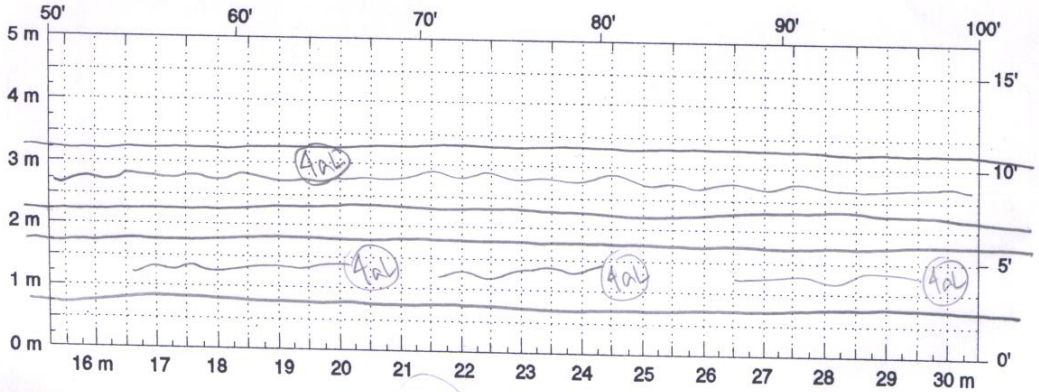

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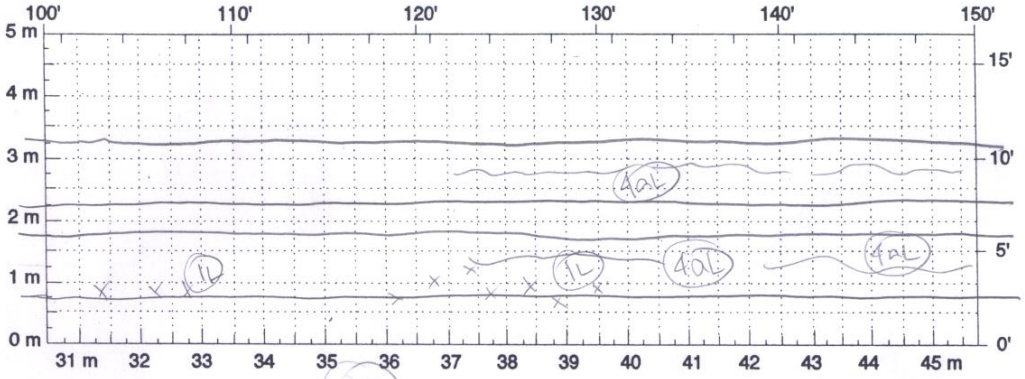

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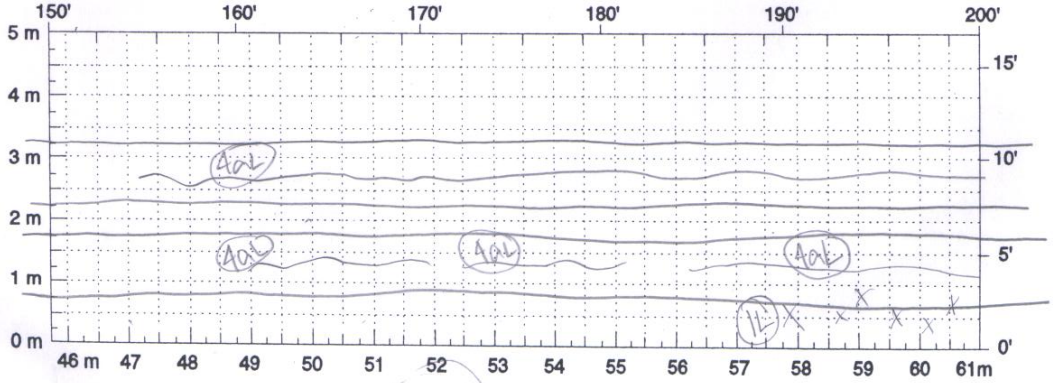

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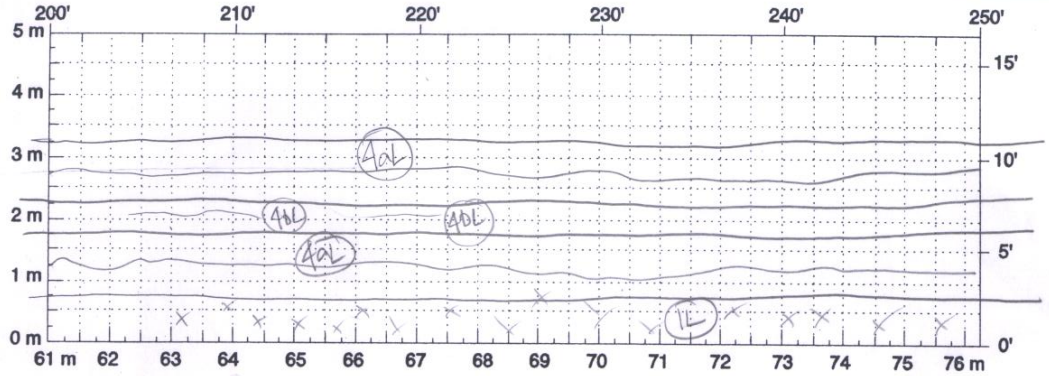

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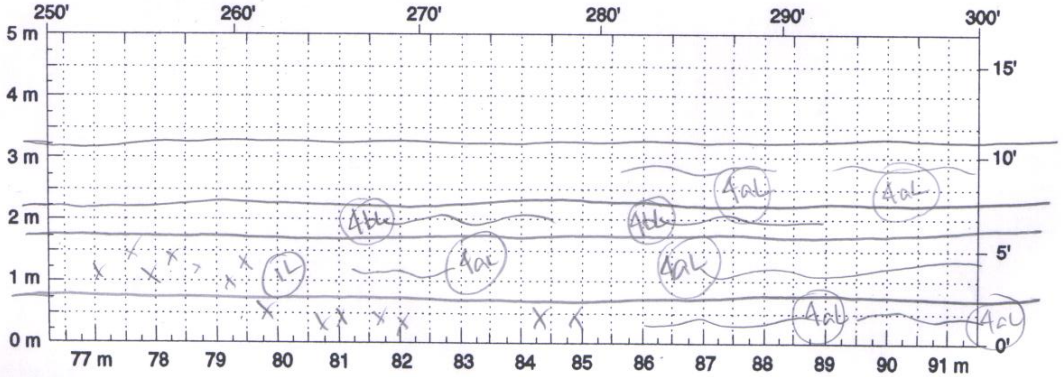

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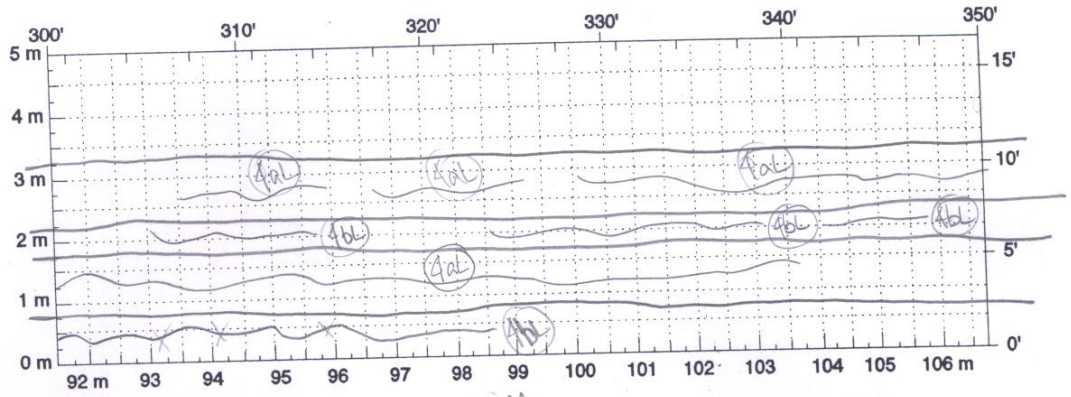

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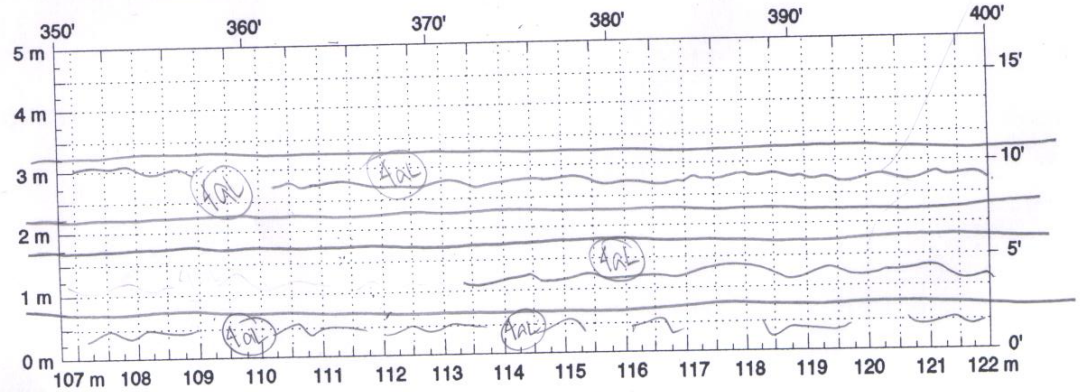

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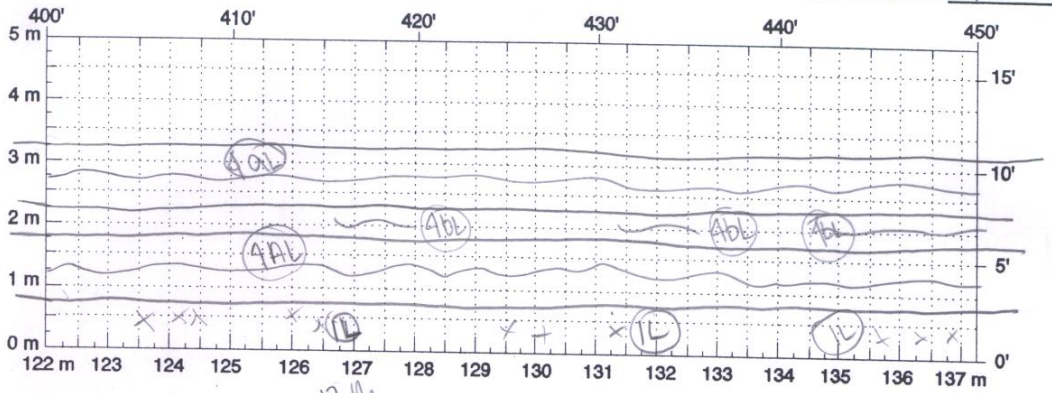

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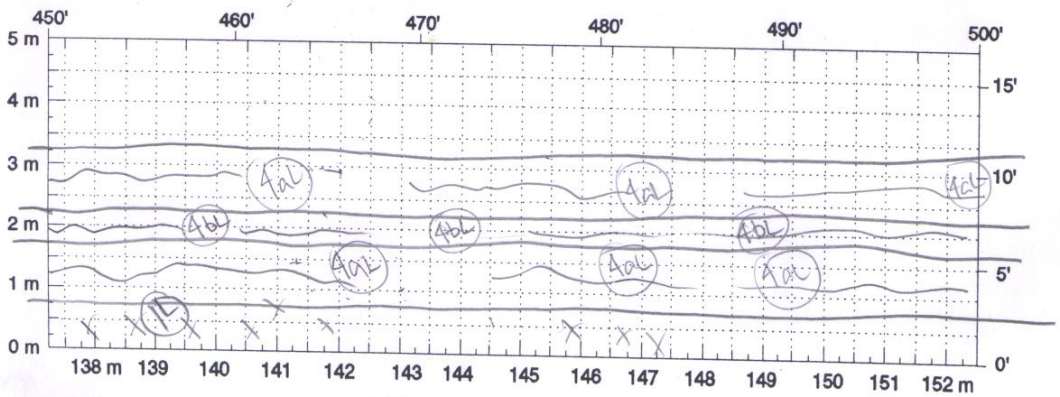

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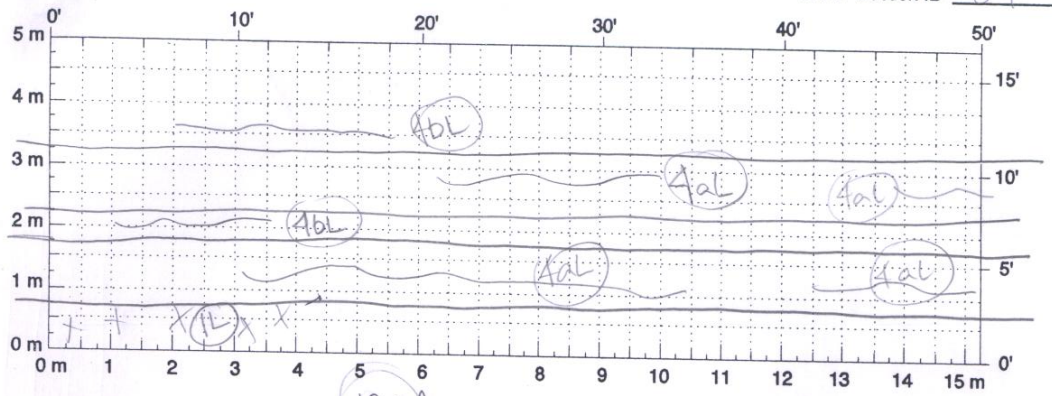

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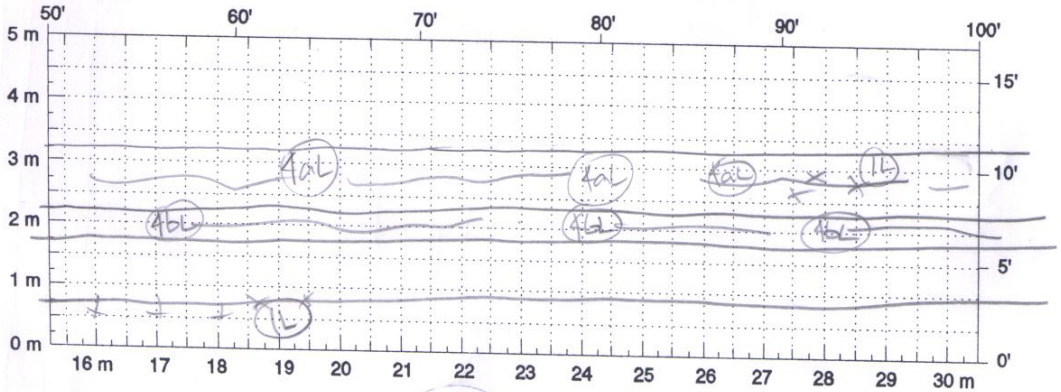

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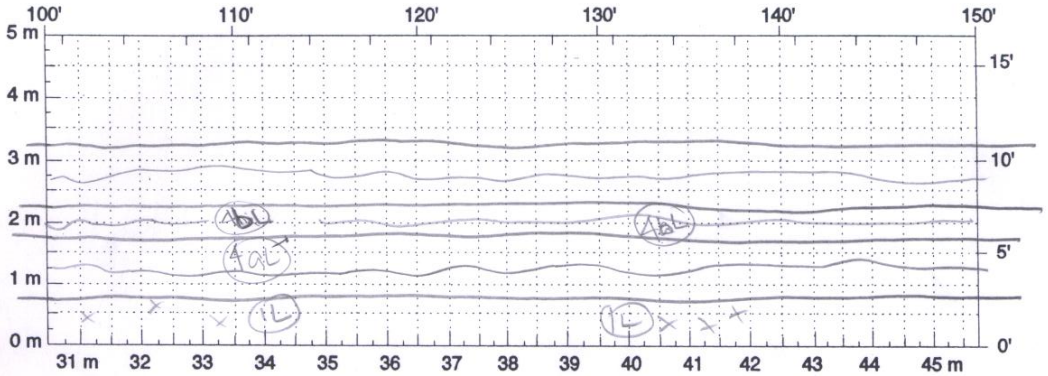

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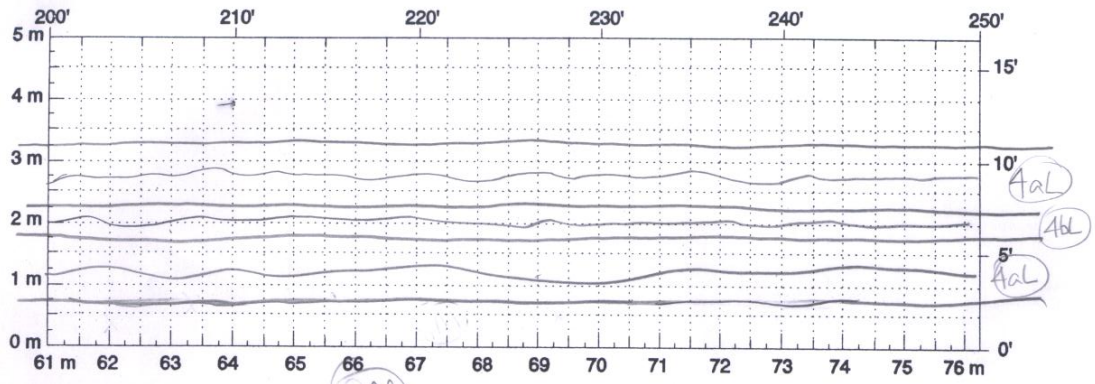

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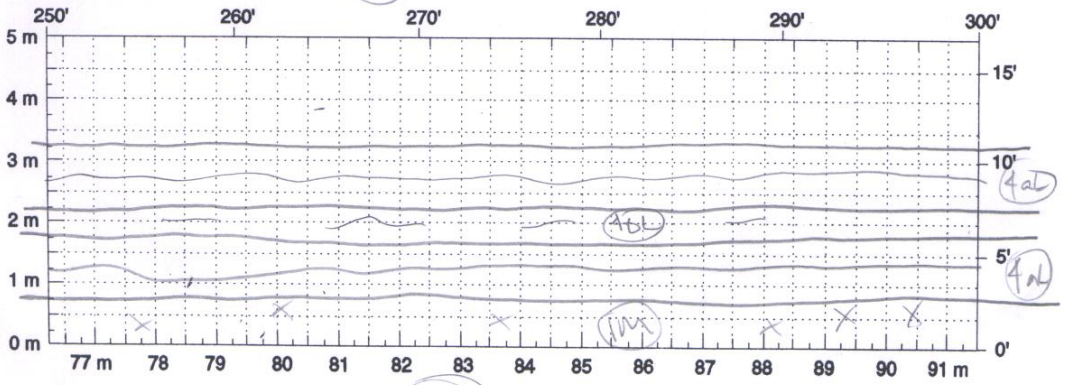

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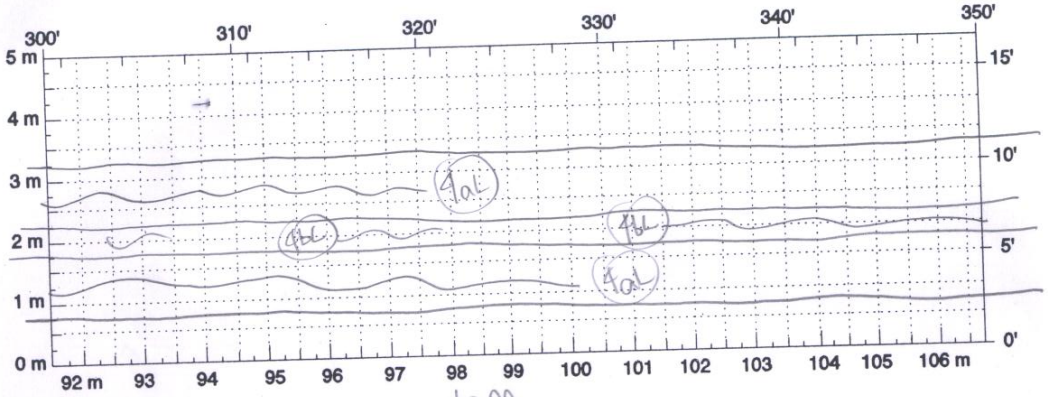

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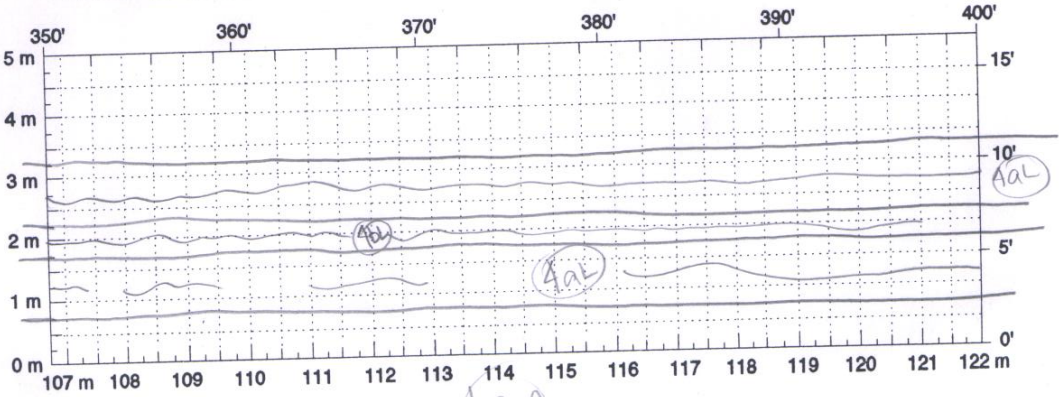

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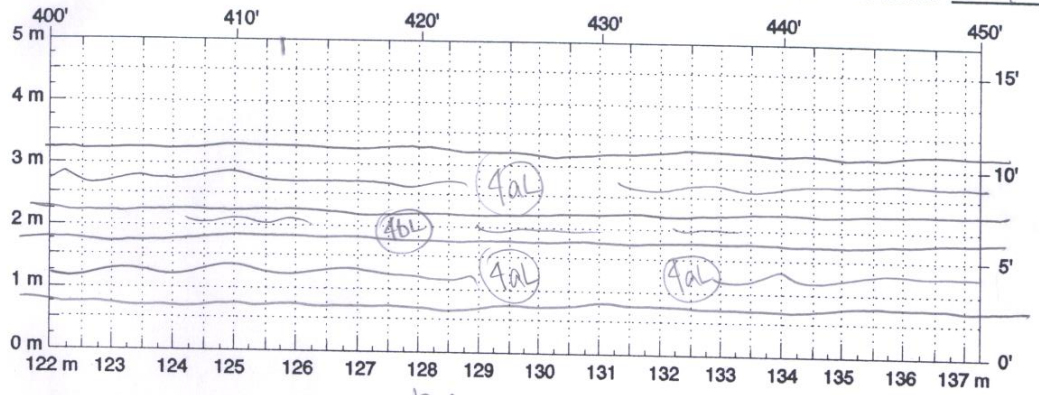

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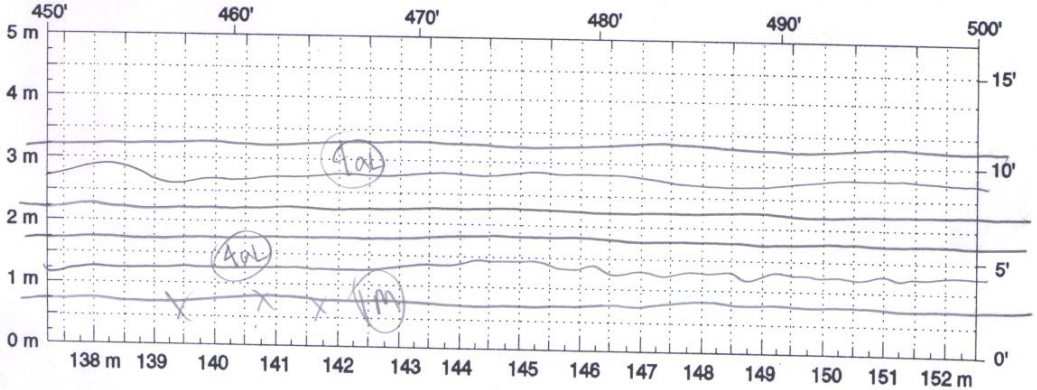

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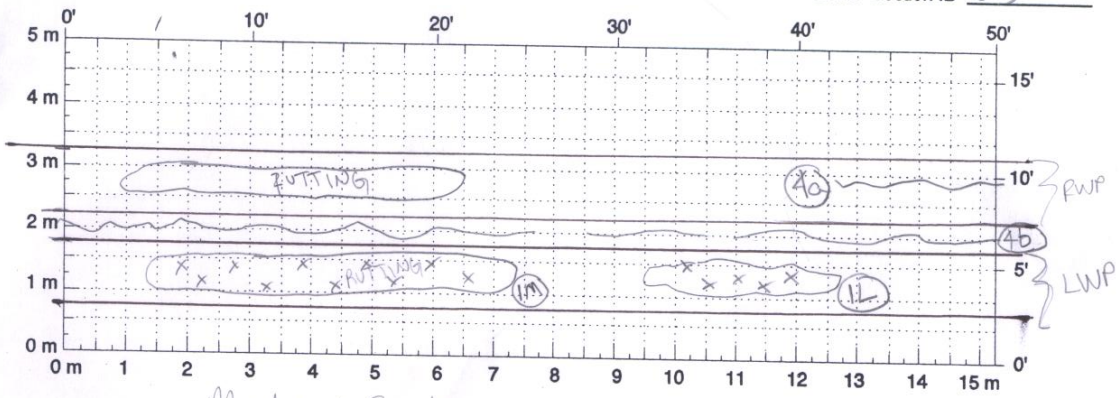

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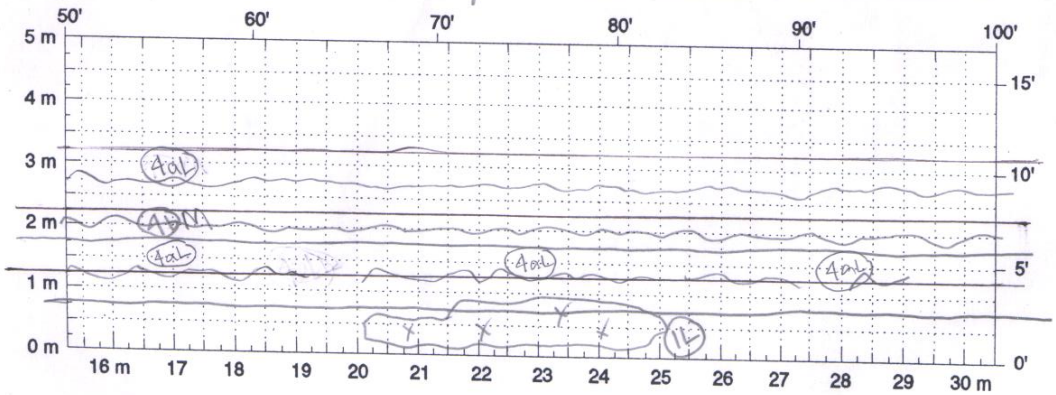

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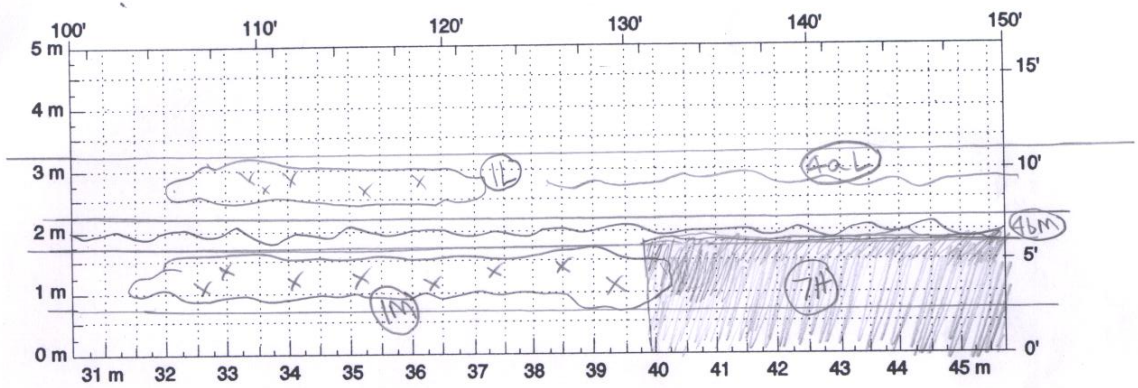

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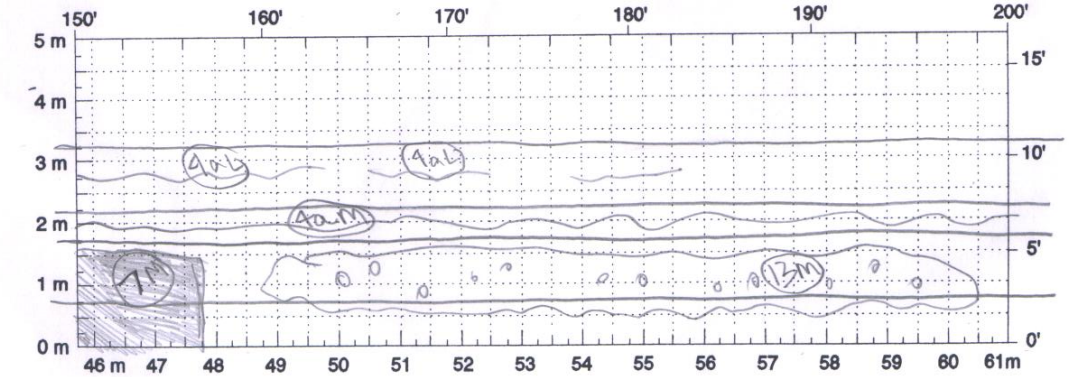

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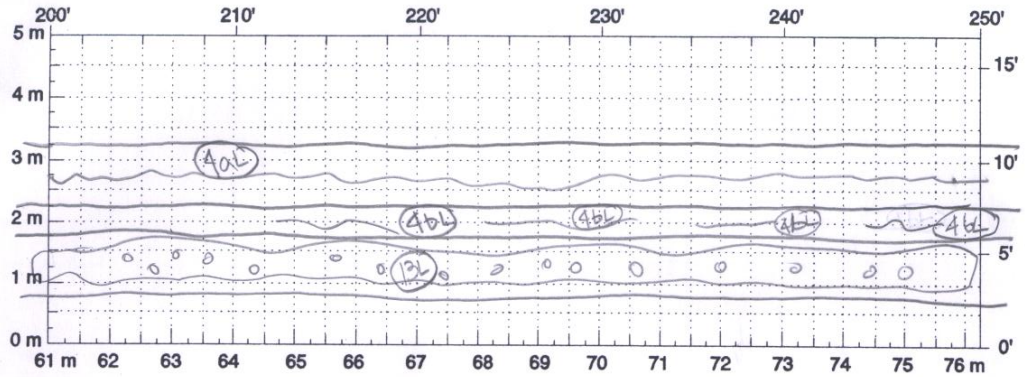

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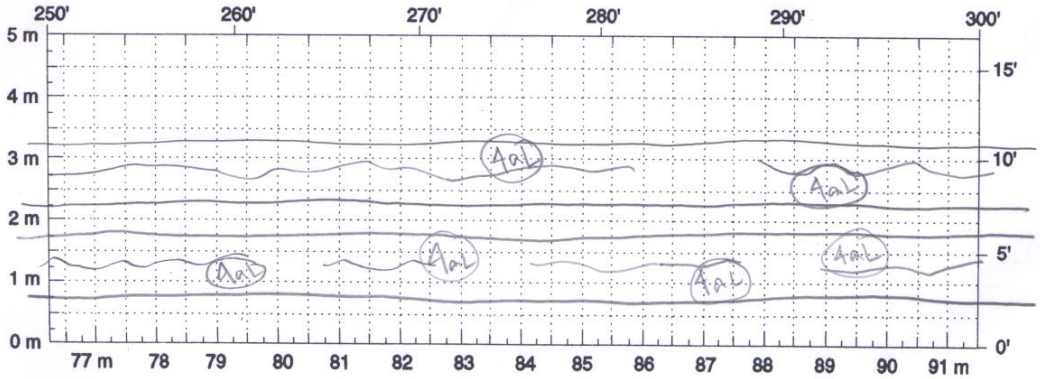

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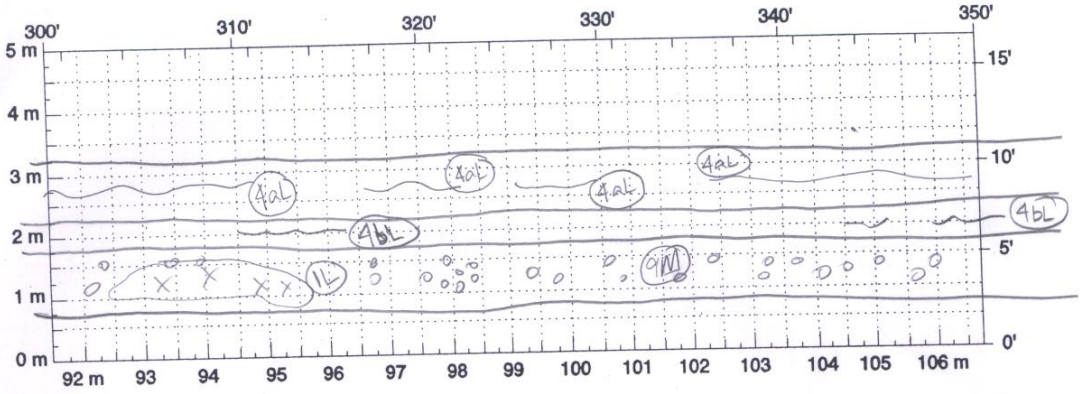

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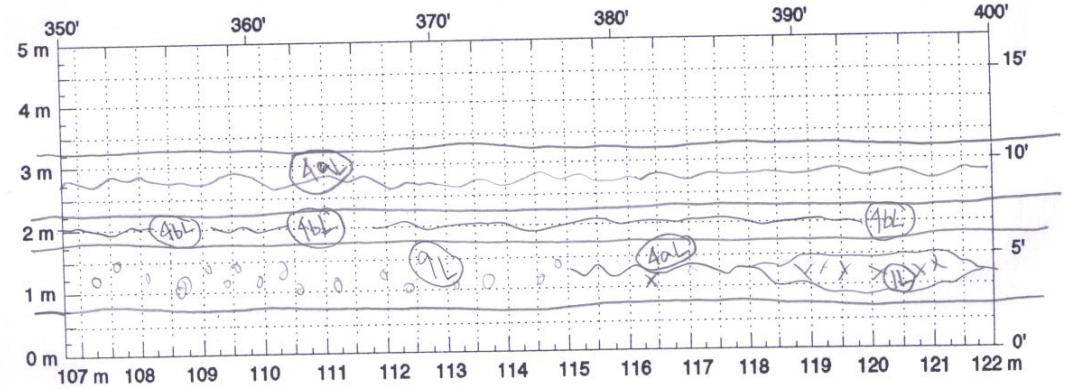

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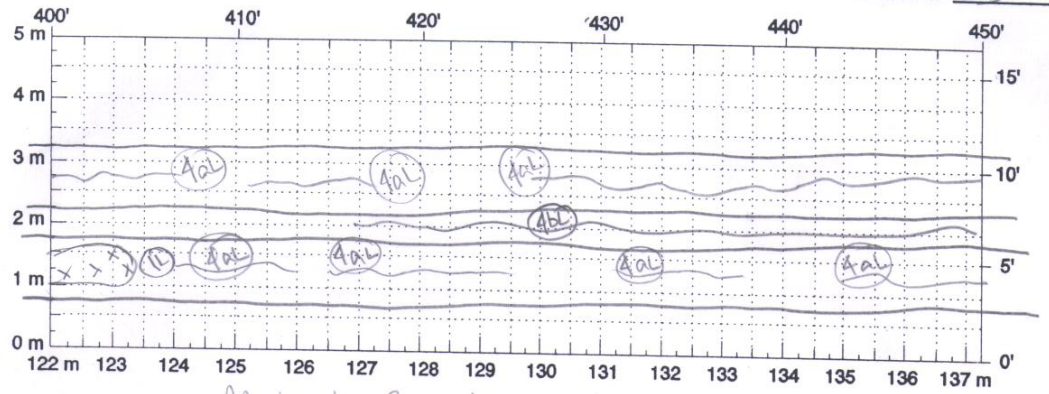

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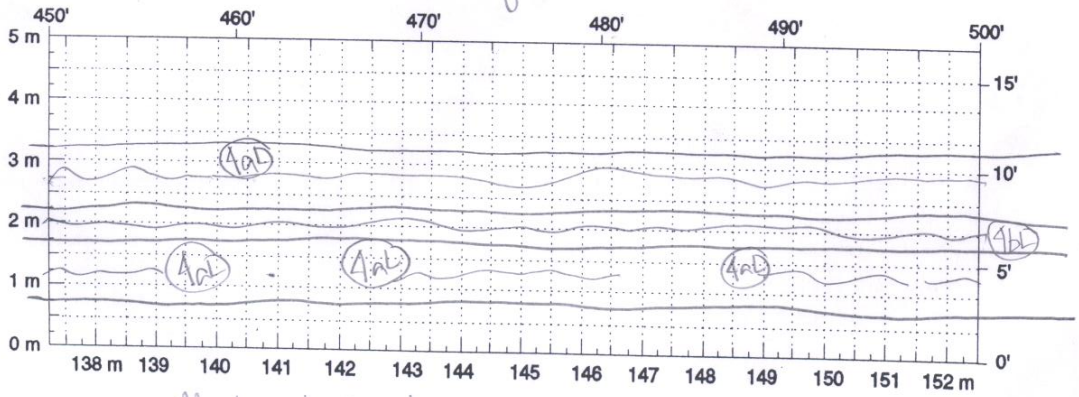

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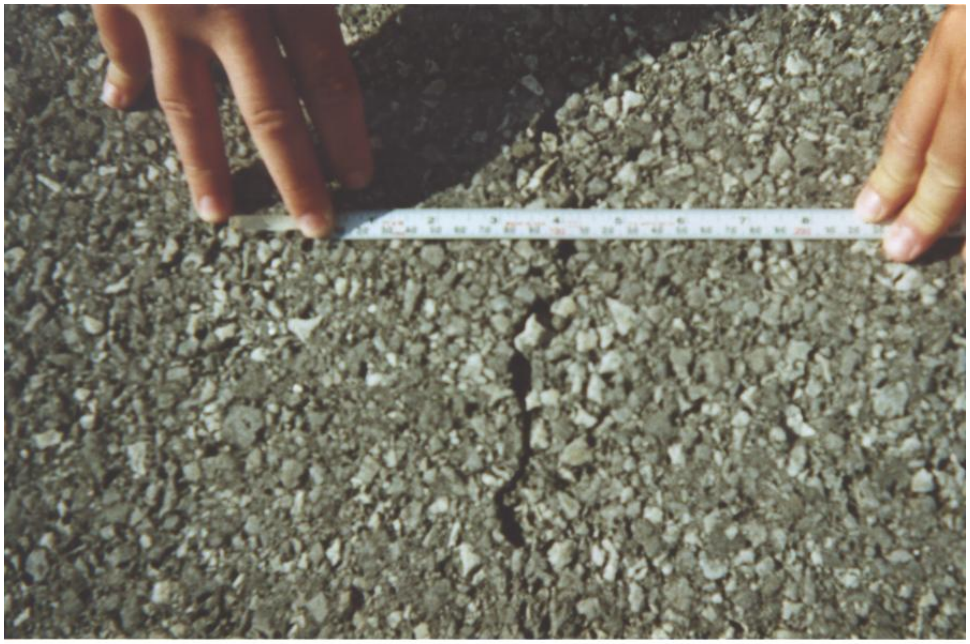
390103
300'-350'

390103
450' - 500'



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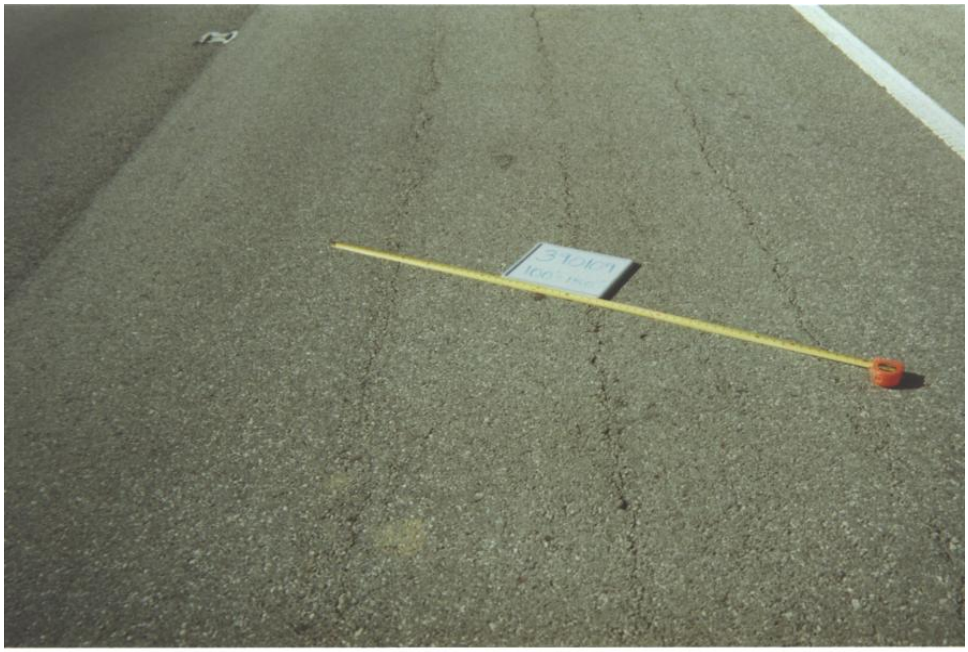
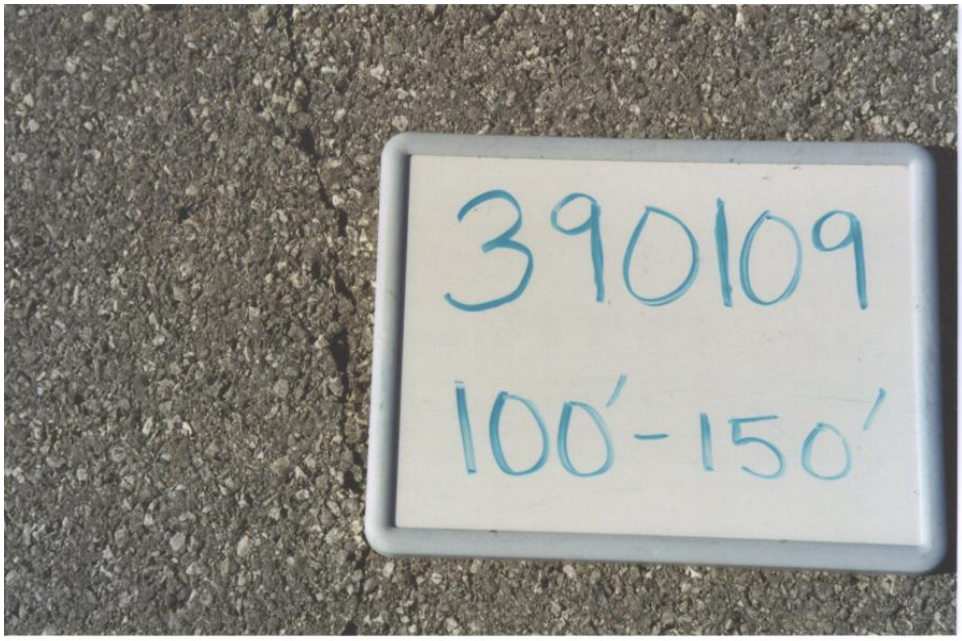


390109
100'-150'
EXPO 64


390109
100'-150'

390109
200'-250'

Appendix D Distress Survey Photographs of Section 390110

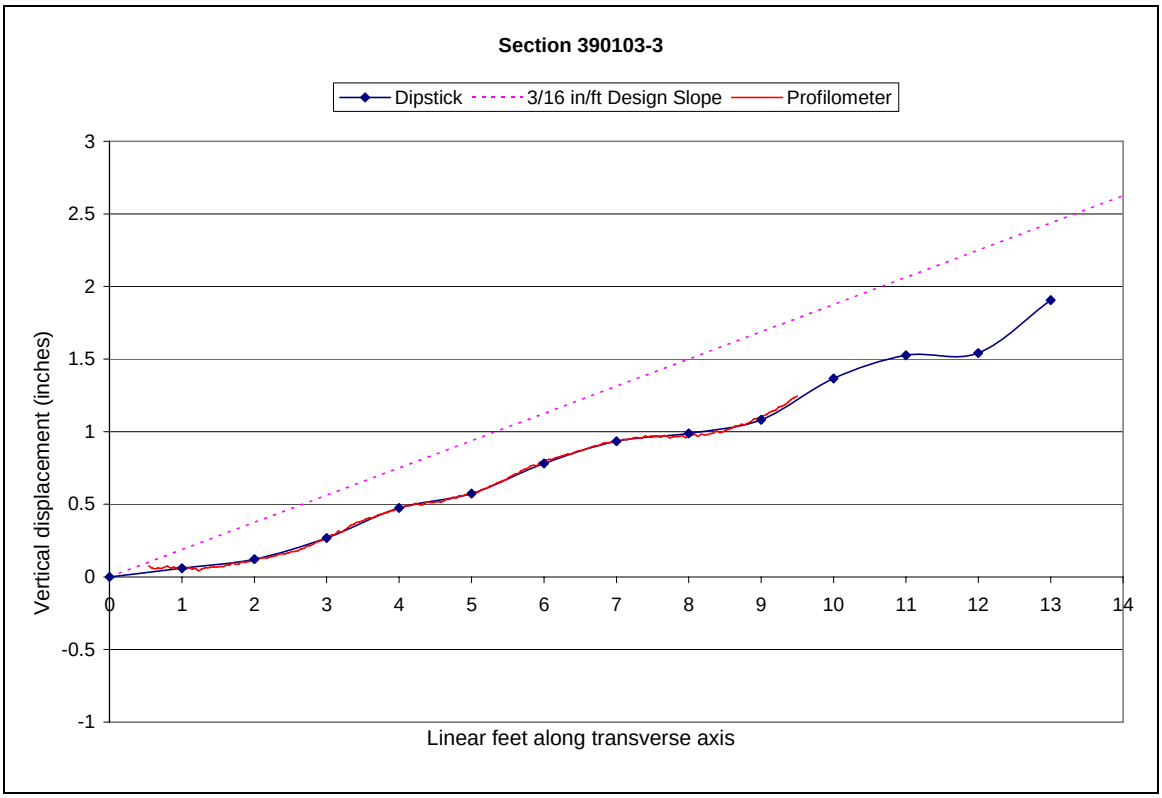
390110
200'-250'

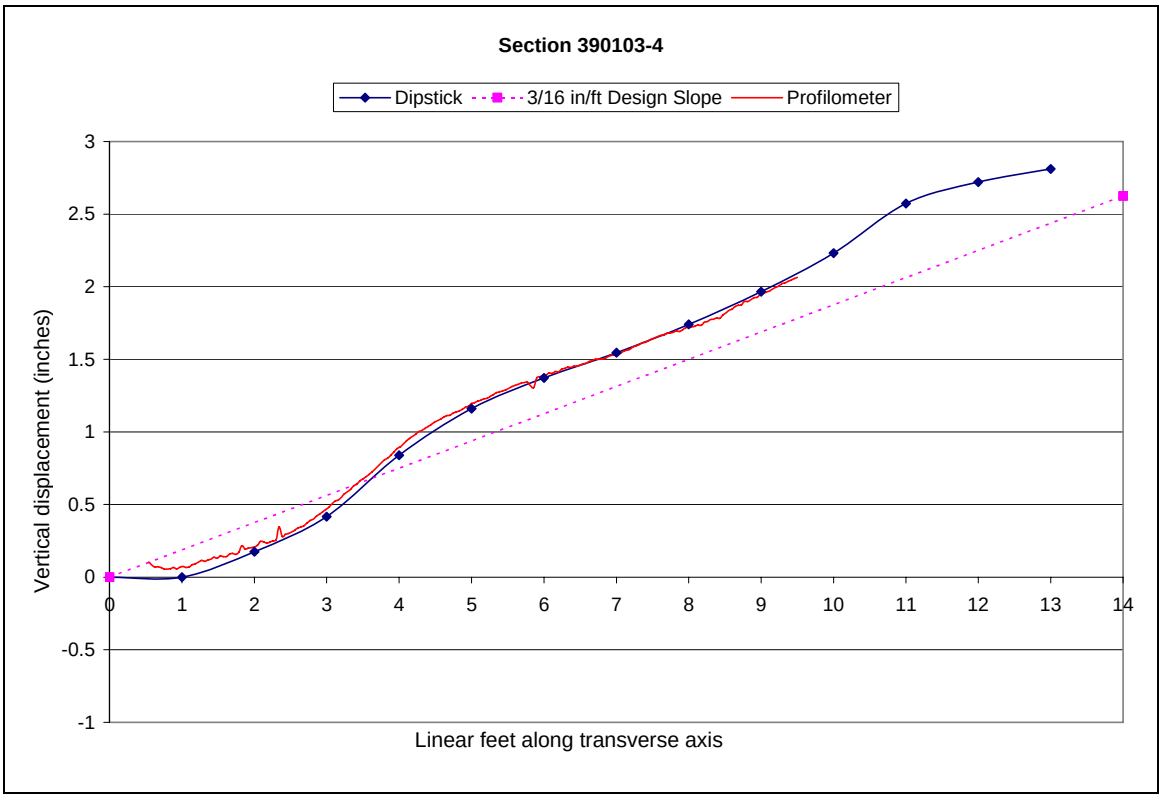
Appendix E Longitudinal Cracking Pictures

Lufkin

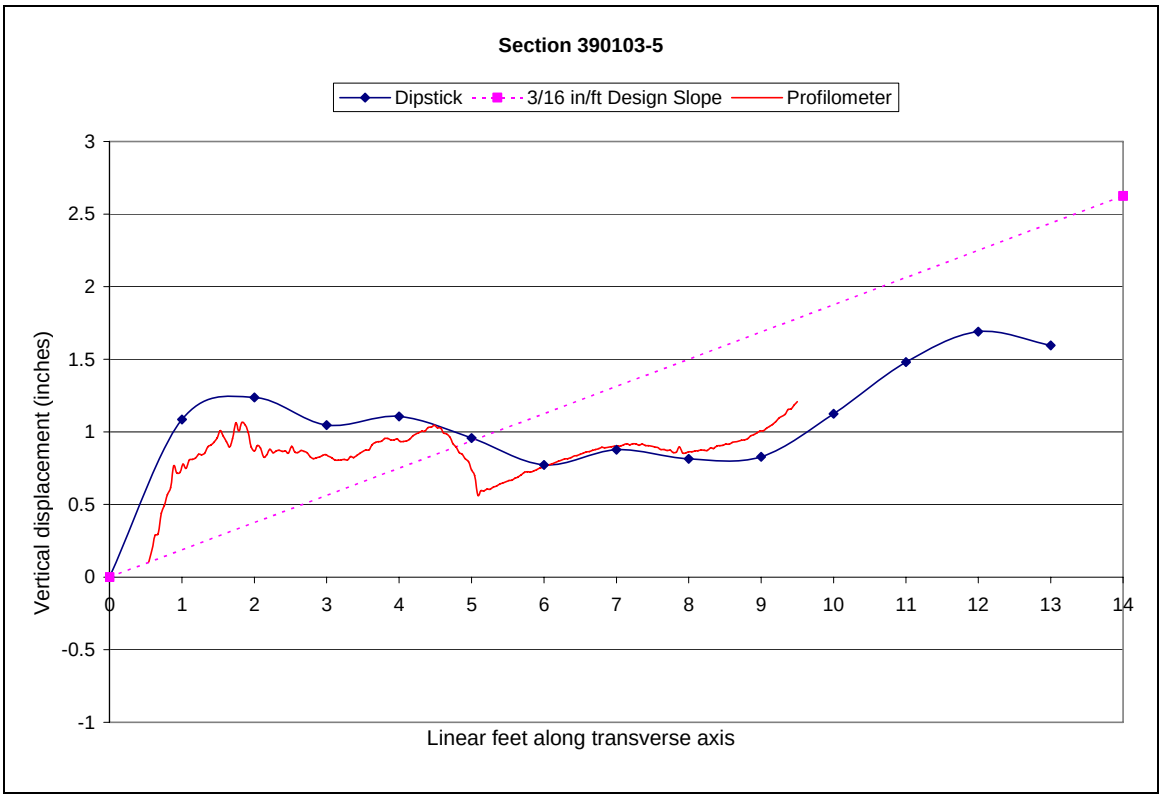
BROWN
SEC 109
TRENCH#1
08/15/02

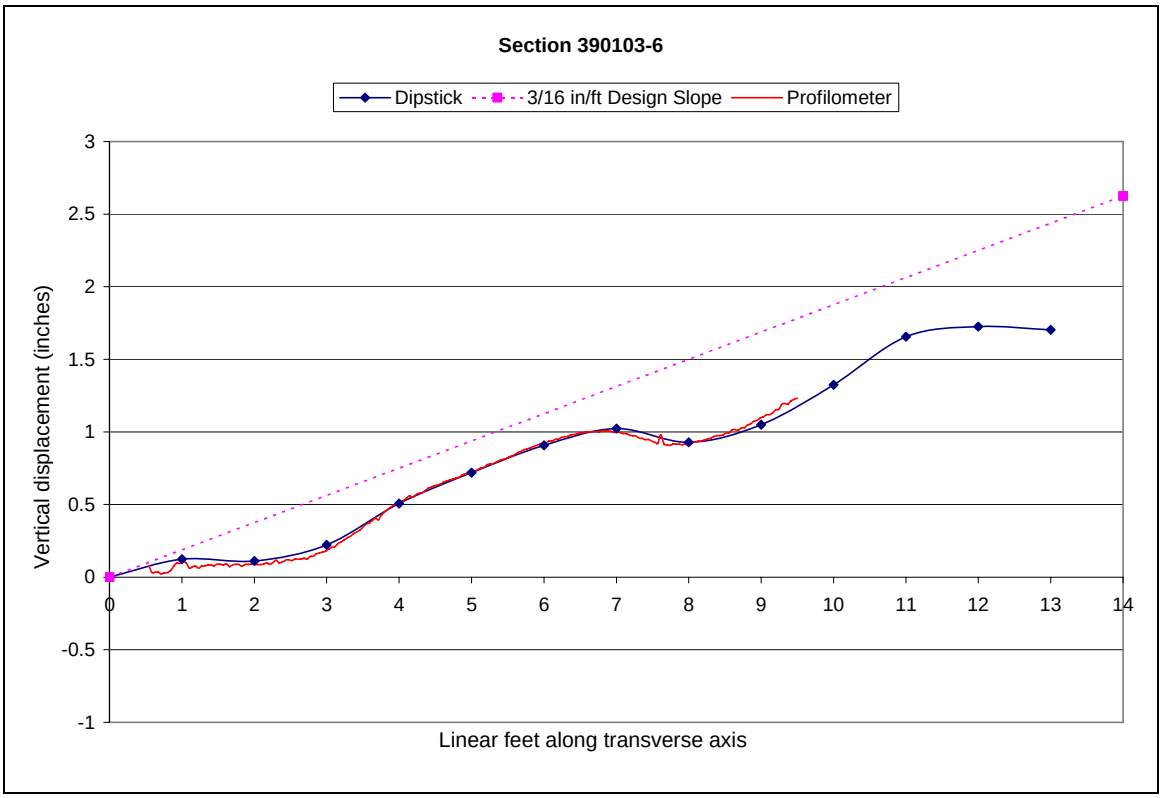
Appendix F Transverse Profiles Section 390103



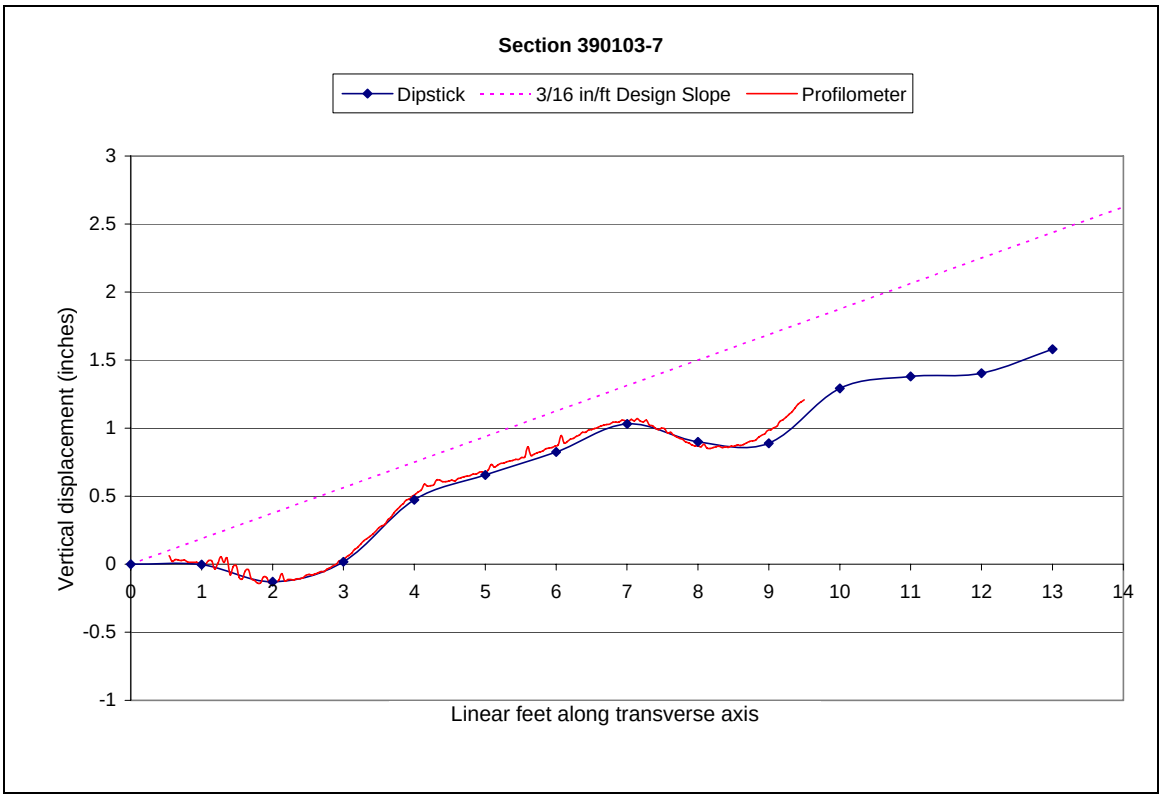


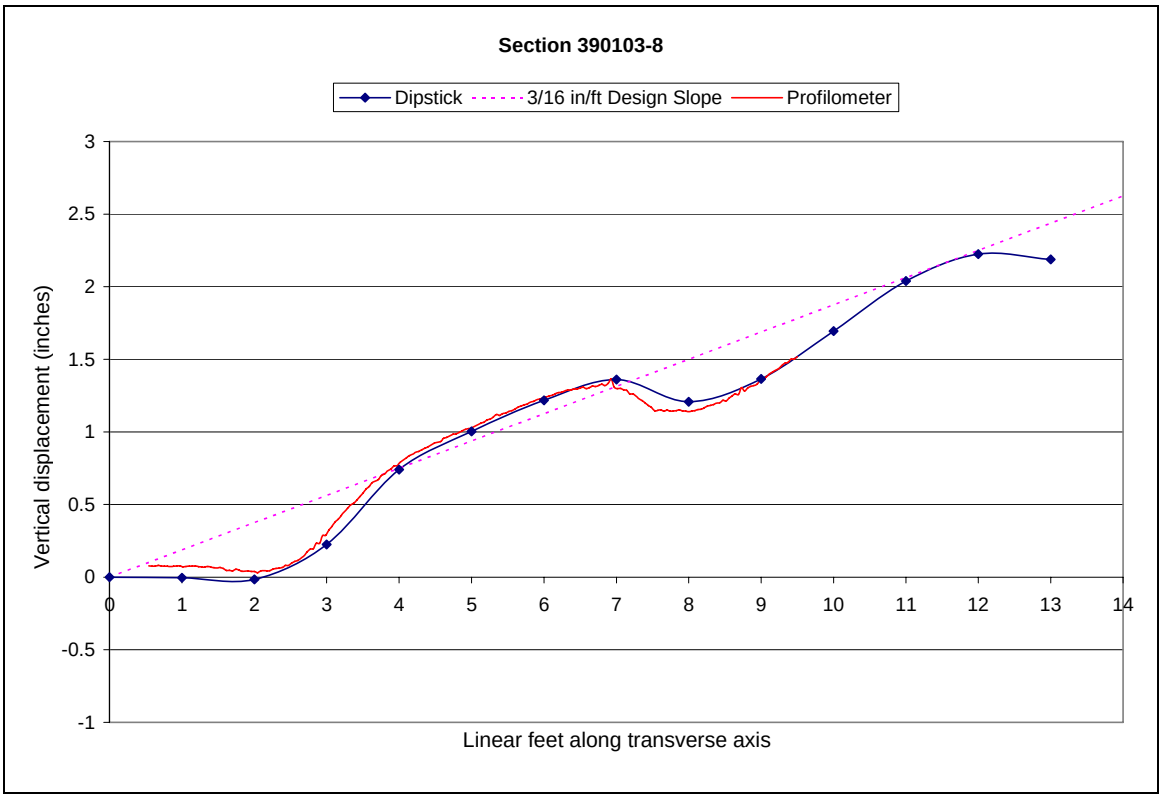
(1 in = 2.54 cm; 1 ft = 30.48 cm)



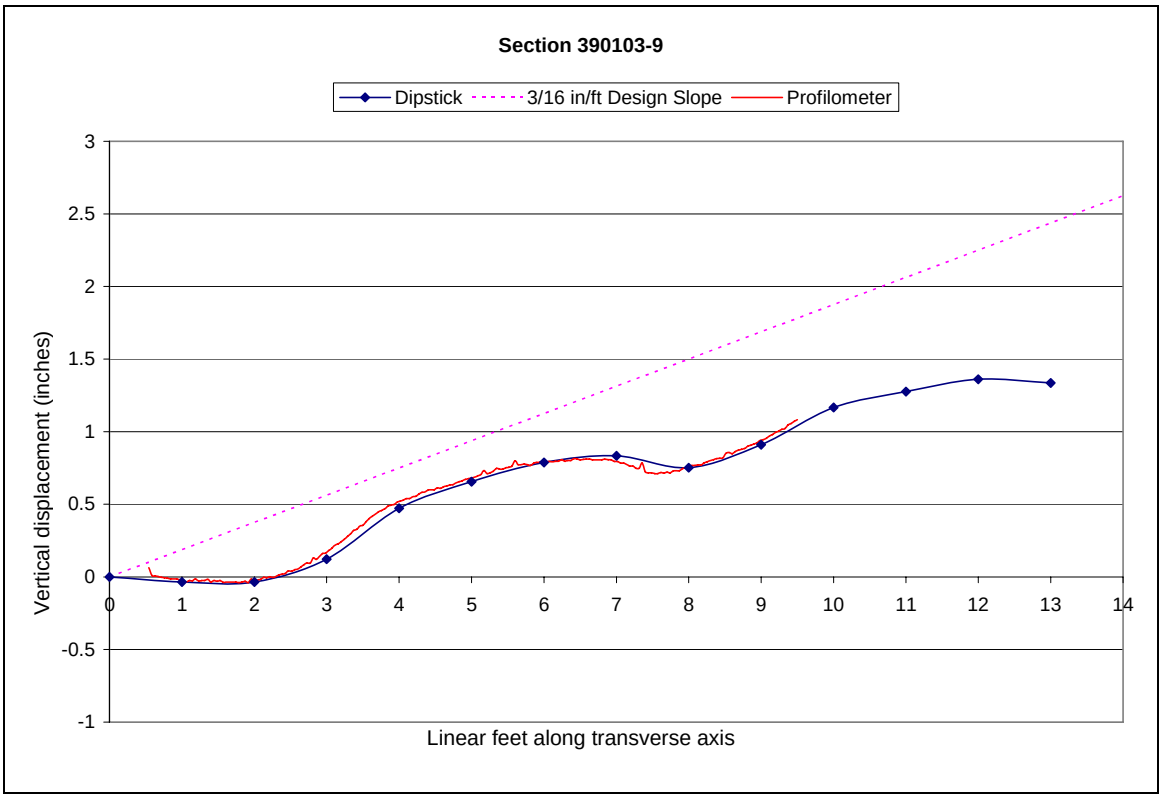


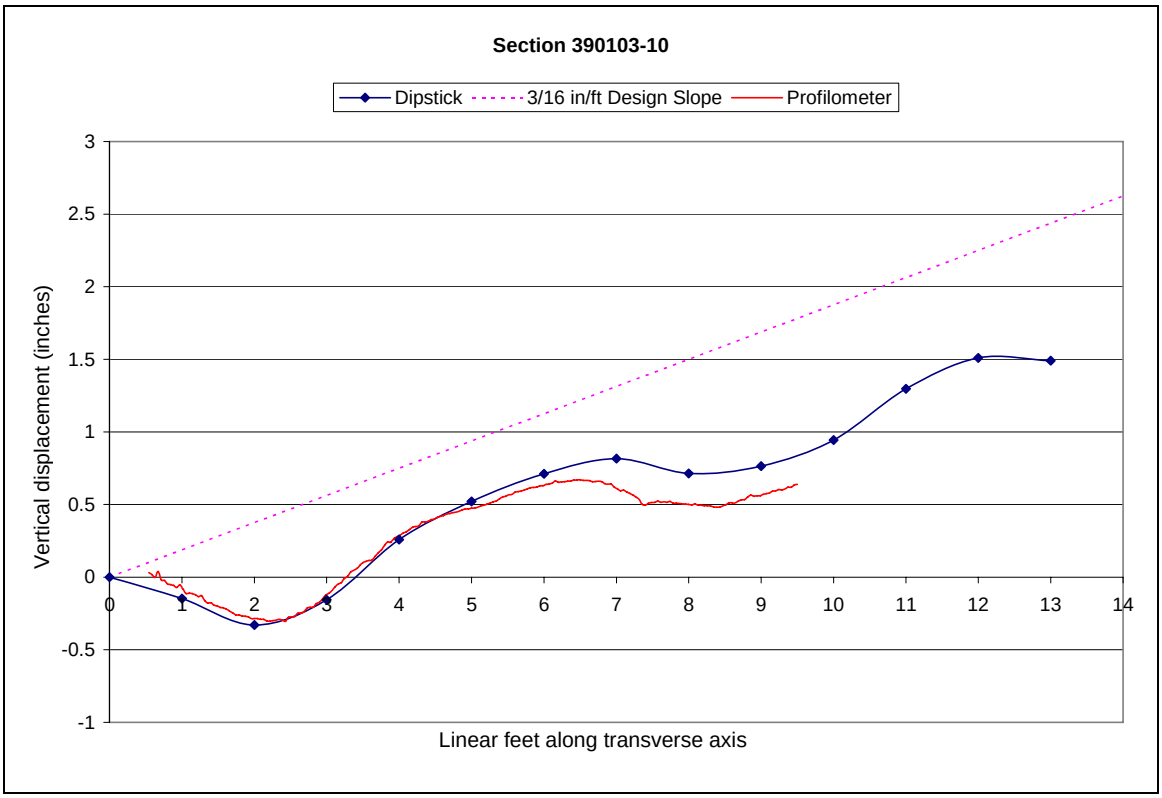
(1 in = 2.54 cm; 1 ft = 30.48 cm)



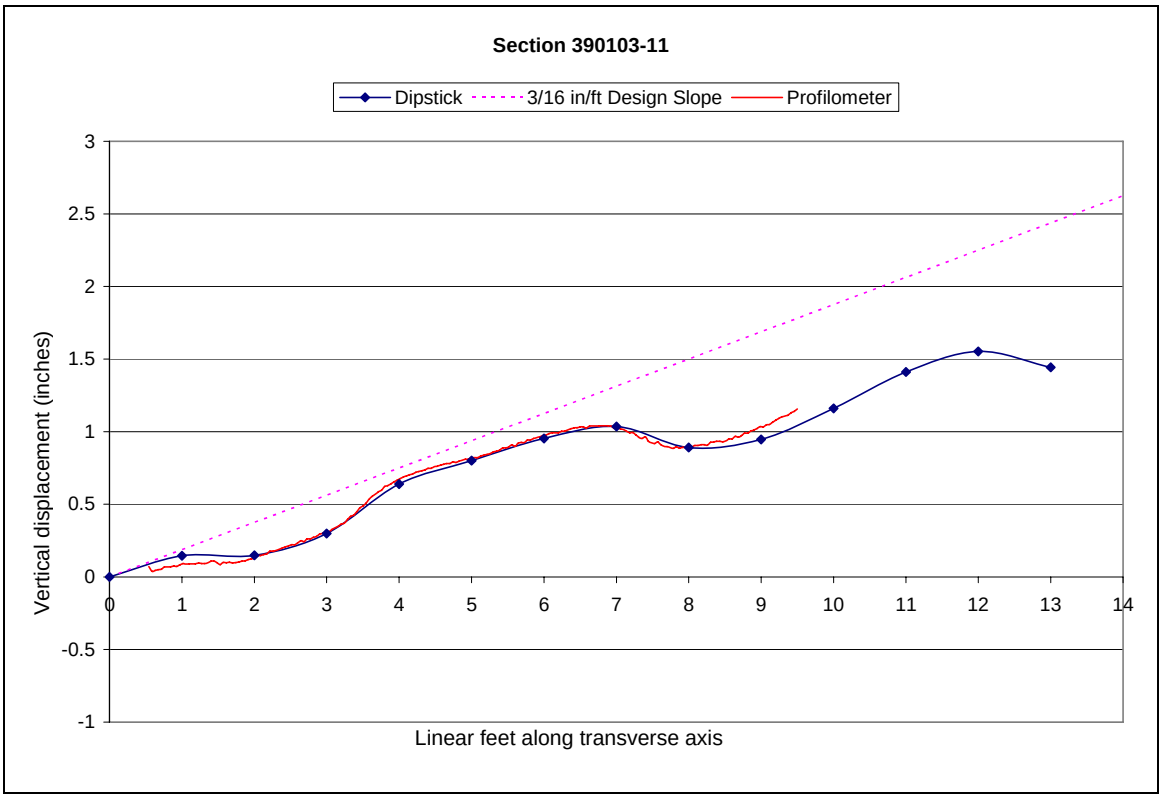


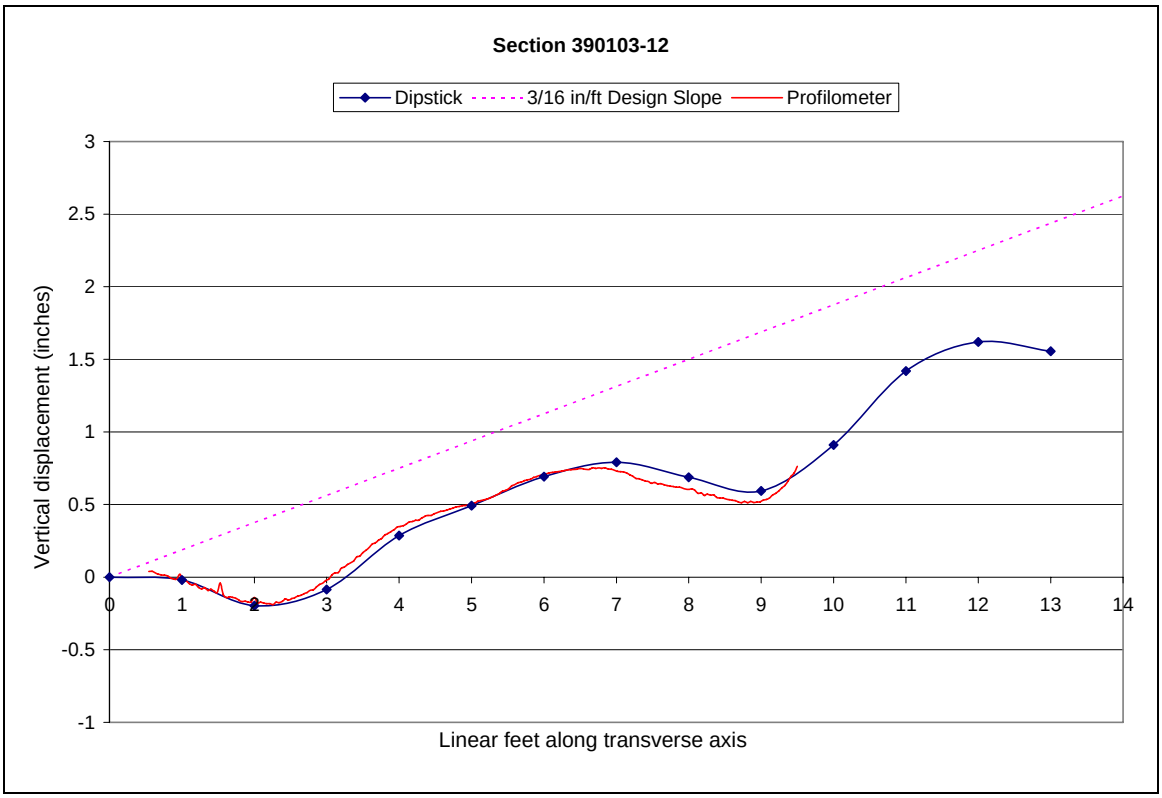
(1 in = 2.54 cm; 1 ft = 30.48 cm)



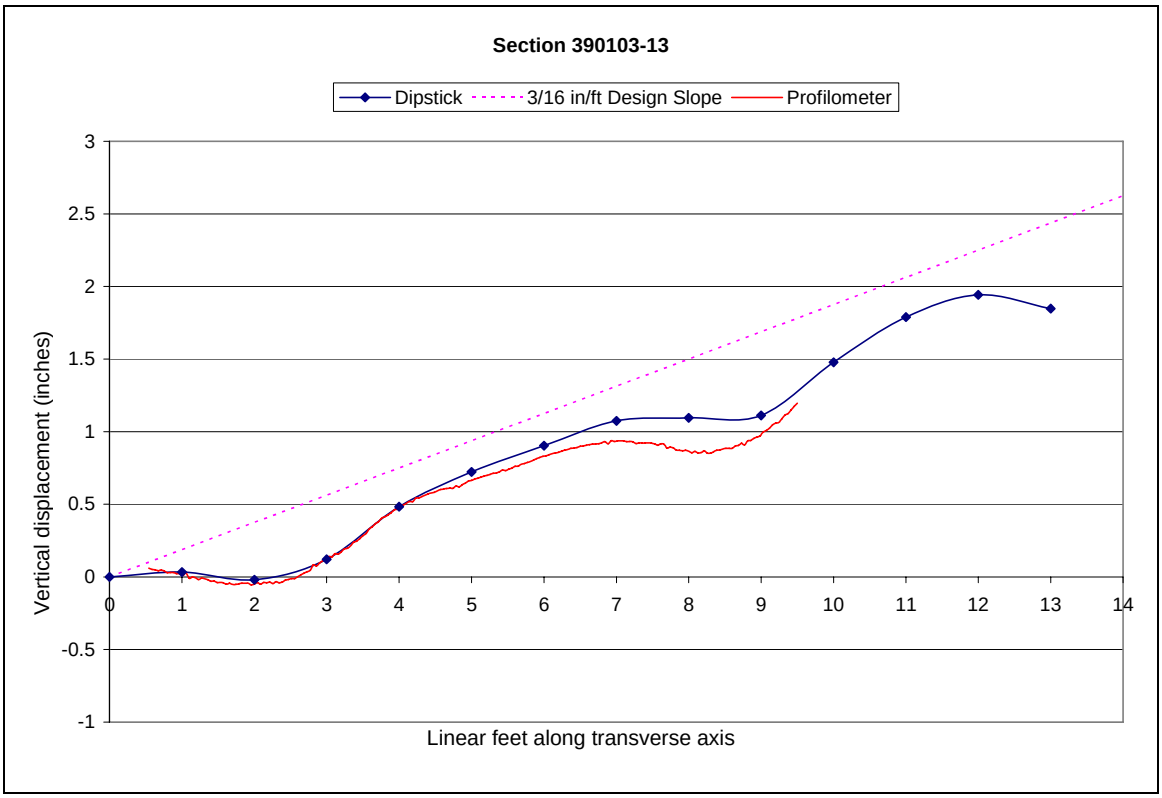


(1 in = 2.54 cm; 1 ft = 30.48 cm)



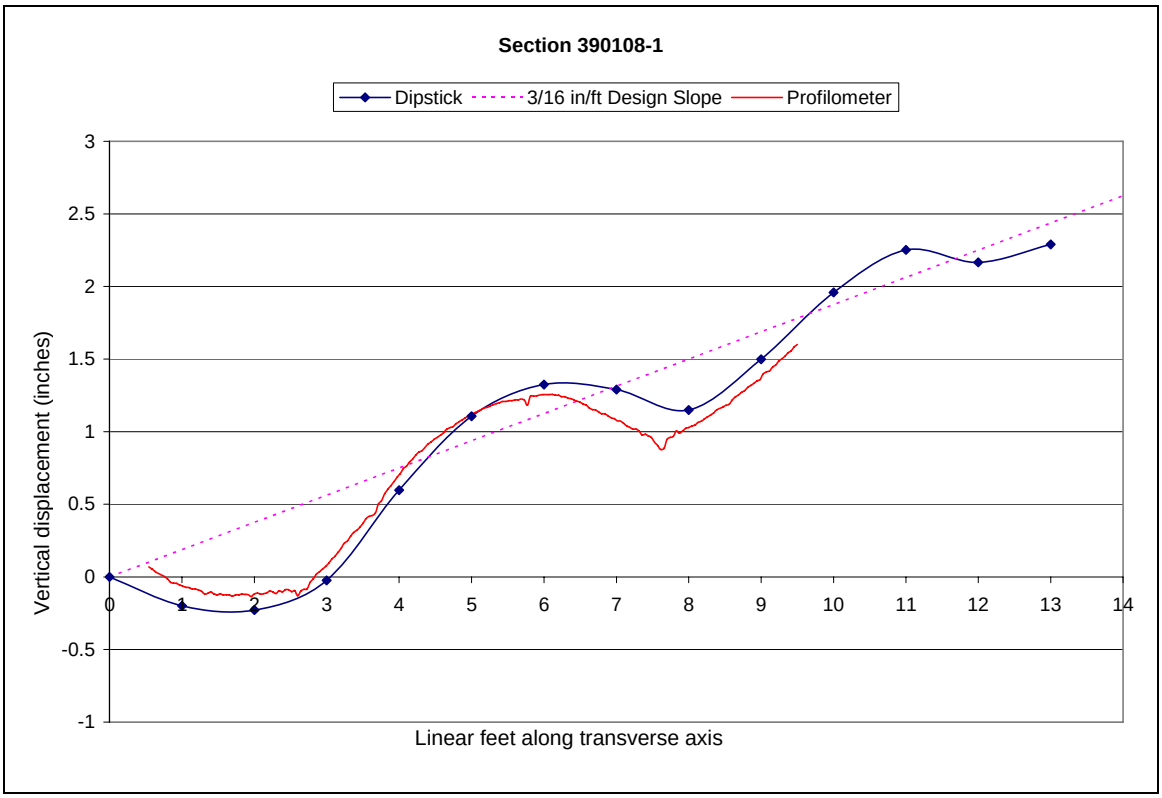


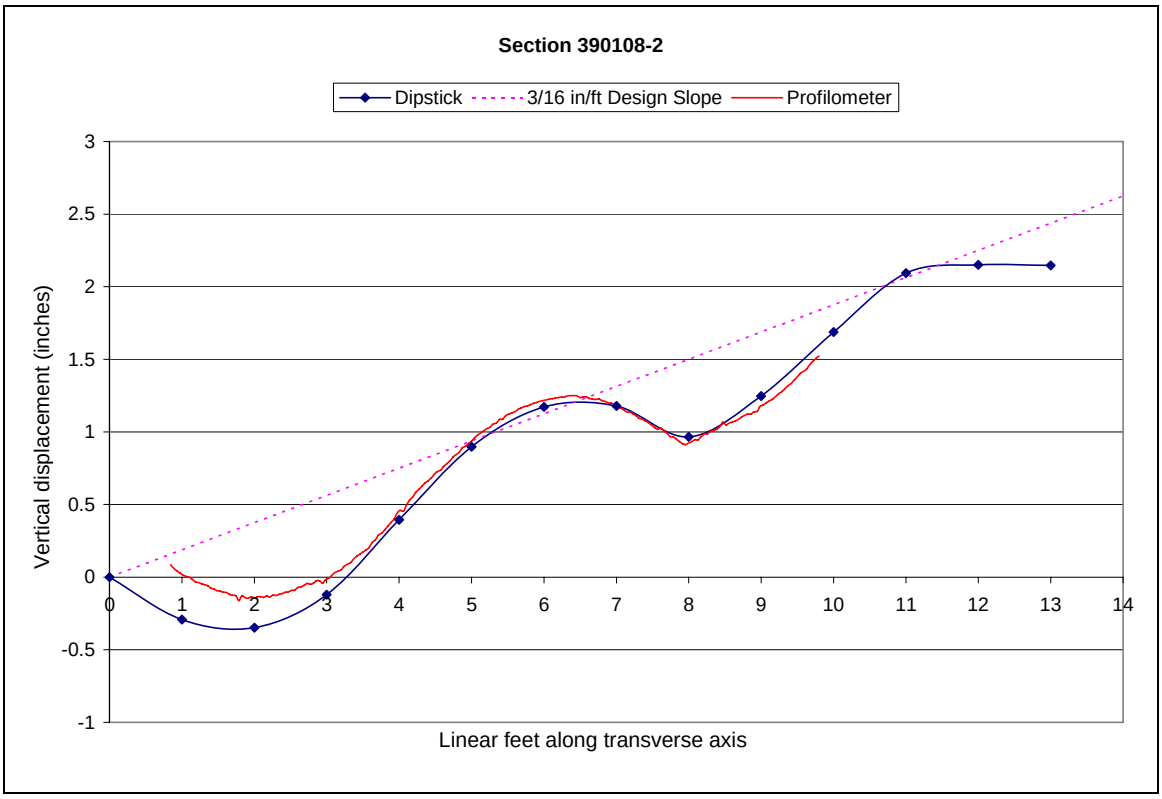
(1 in = 2.54 cm; 1 ft = 30.48 cm)



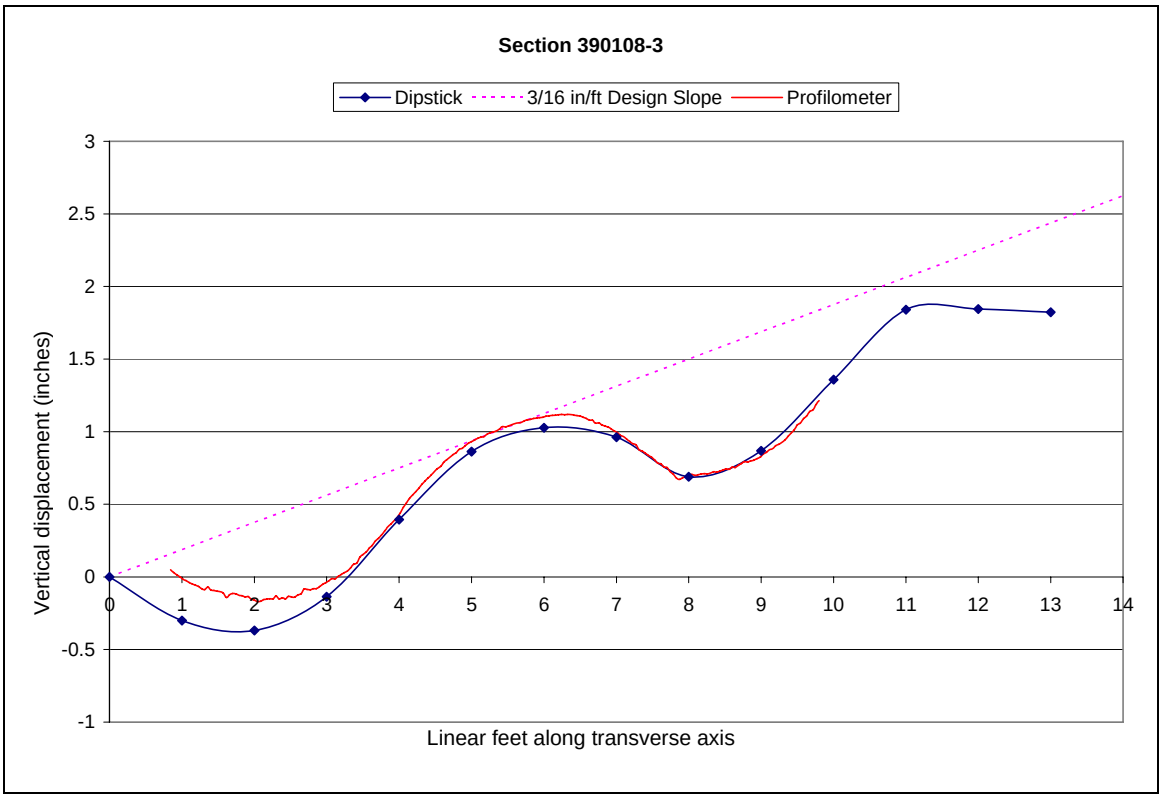
(1 in = 2.54 cm; 1 ft = 30.48 cm)

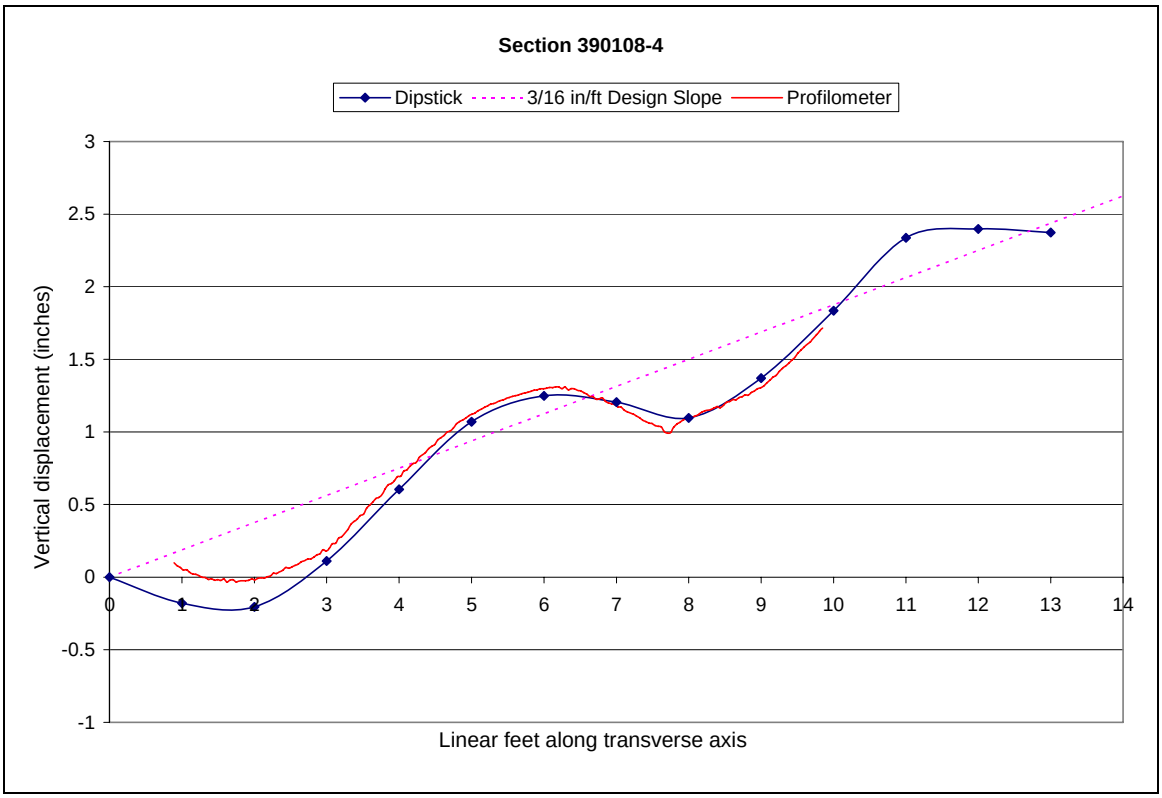
Appendix G Transverse Profiles for Section 390108



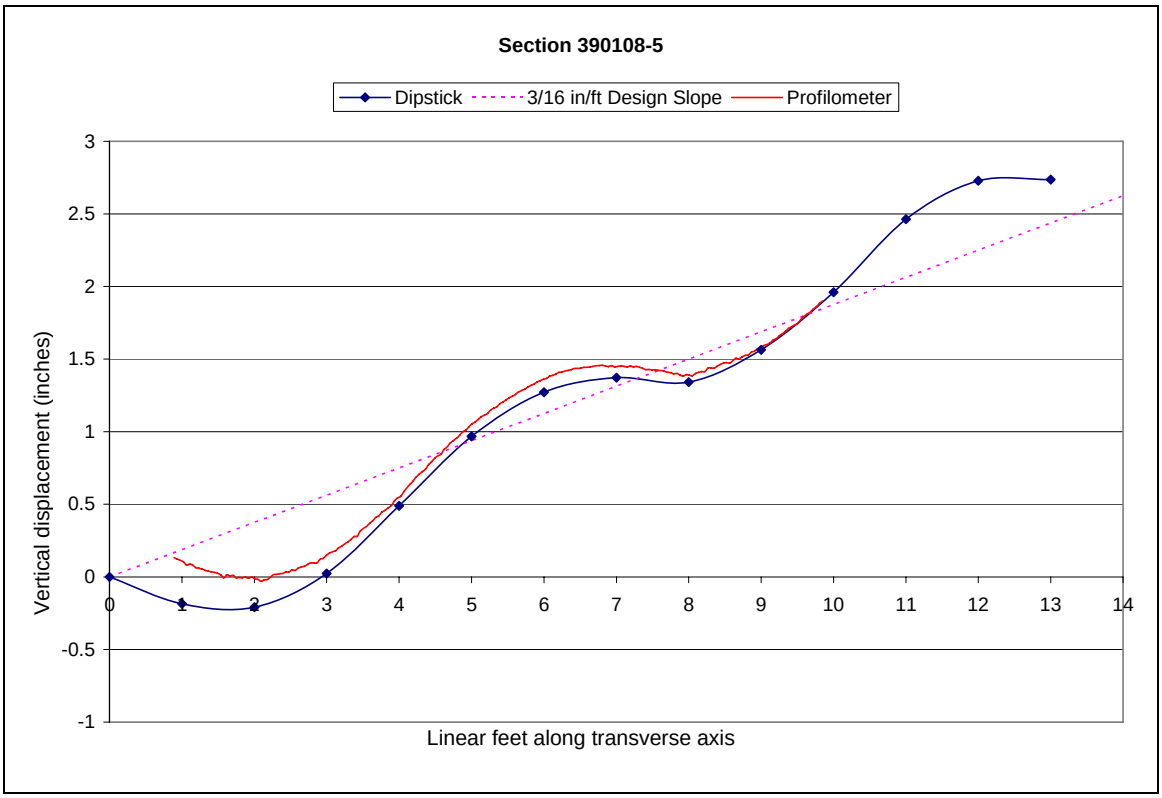


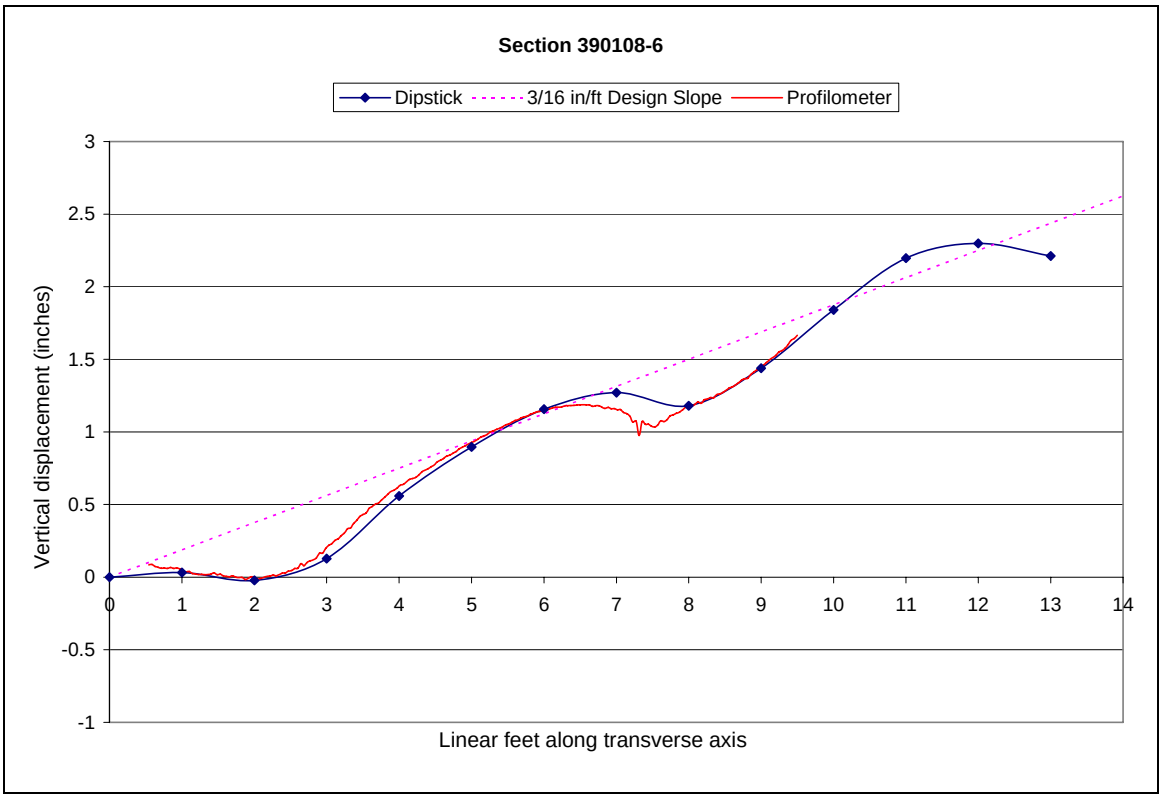
(1 in = 2.54 cm; 1 ft = 30.48 cm)



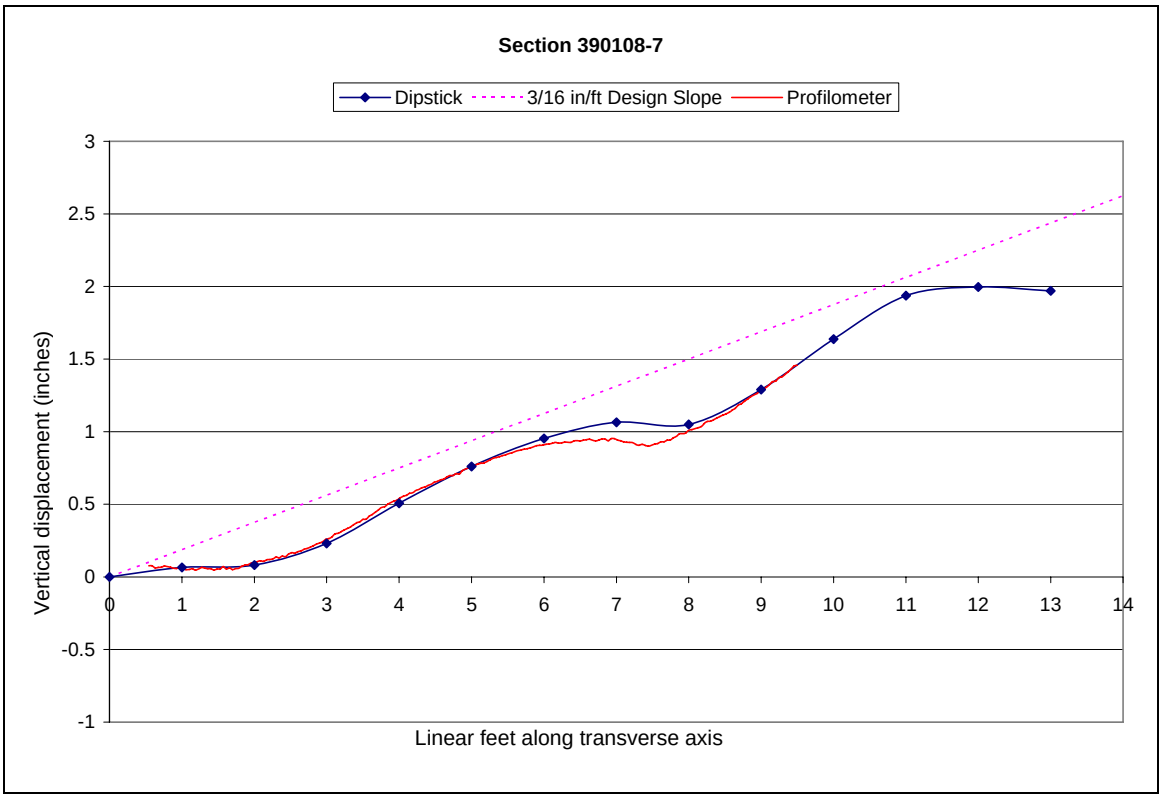


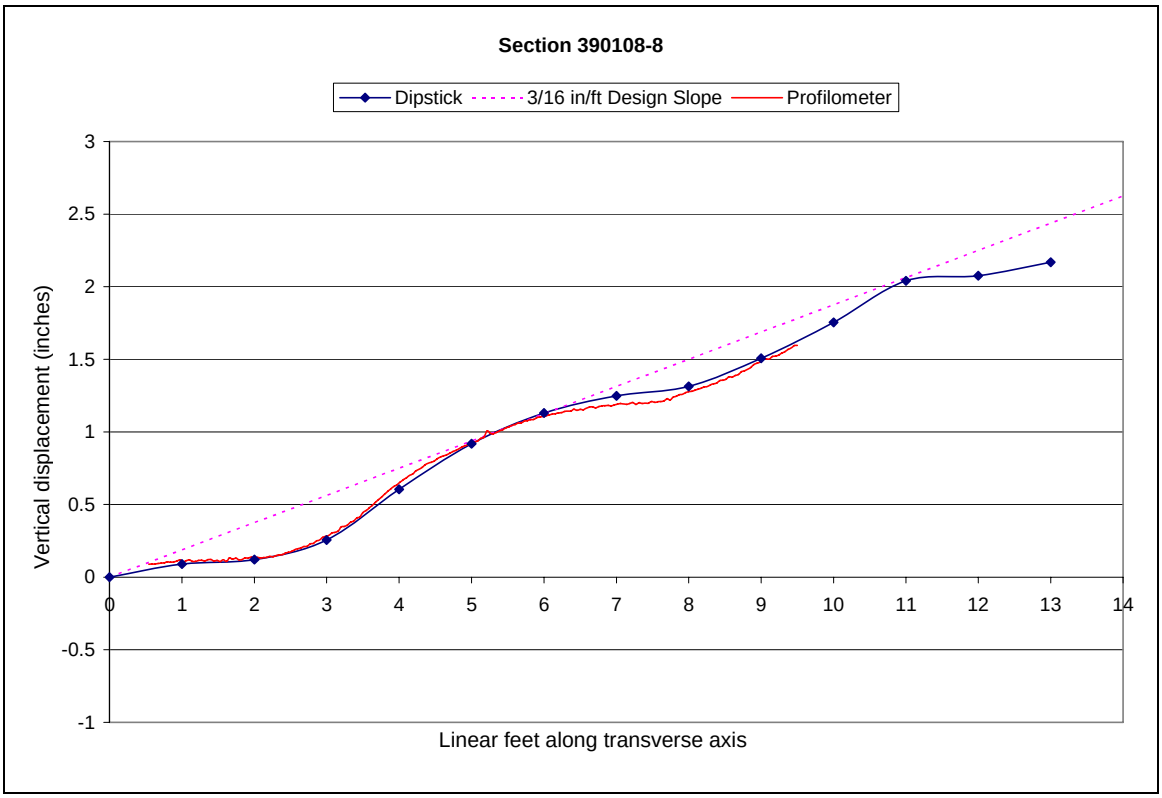
(1 in = 2.54 cm; 1 ft = 30.48 cm)



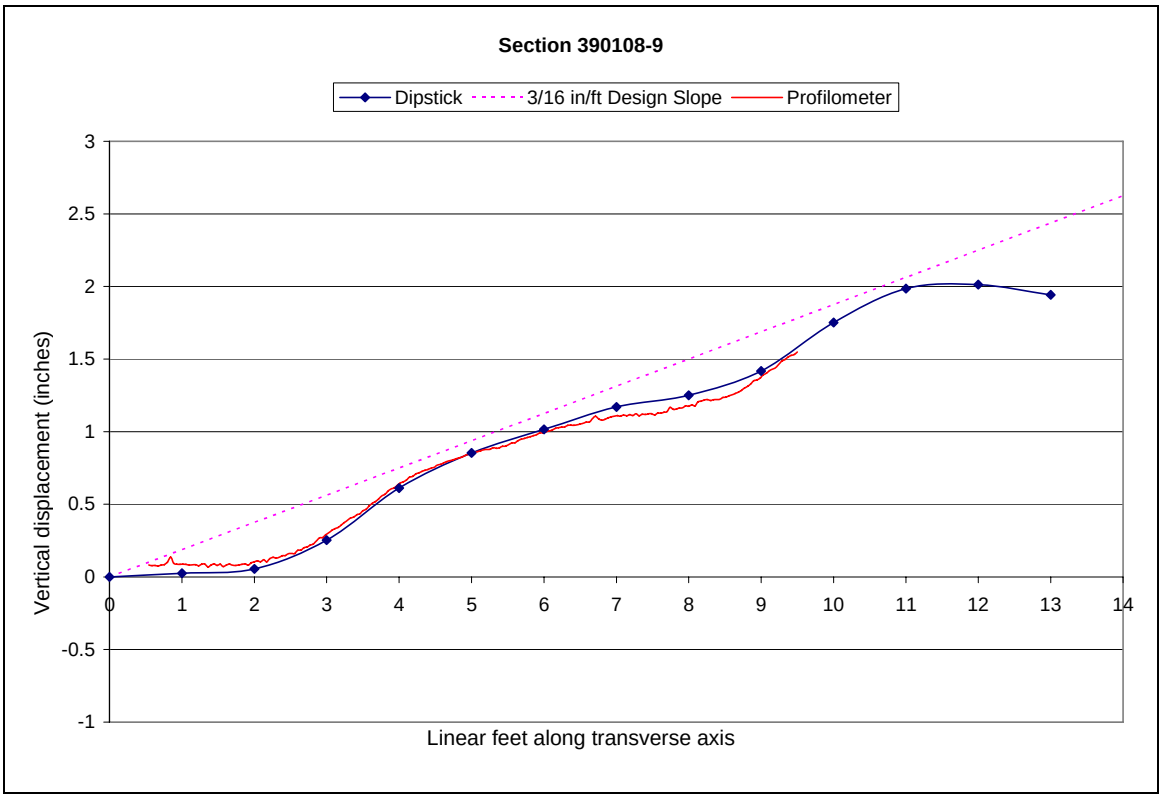


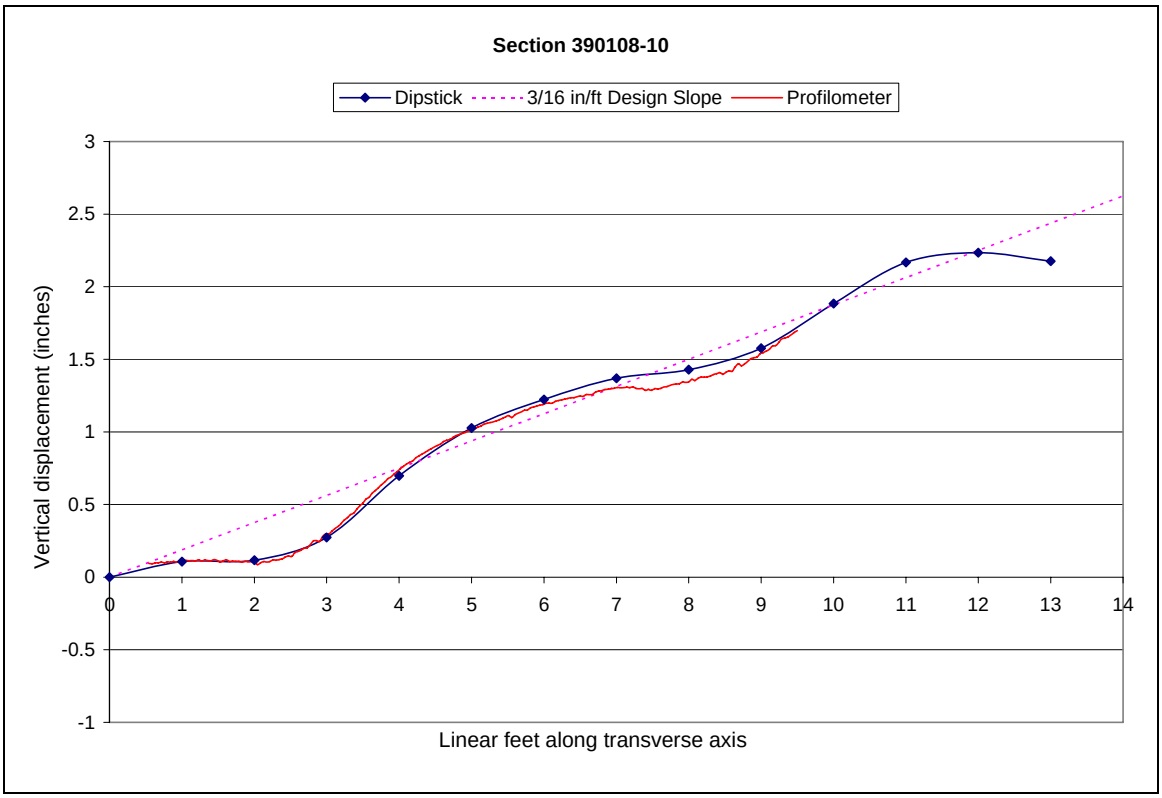
(1 in = 2.54 cm; 1 ft = 30.48 cm)



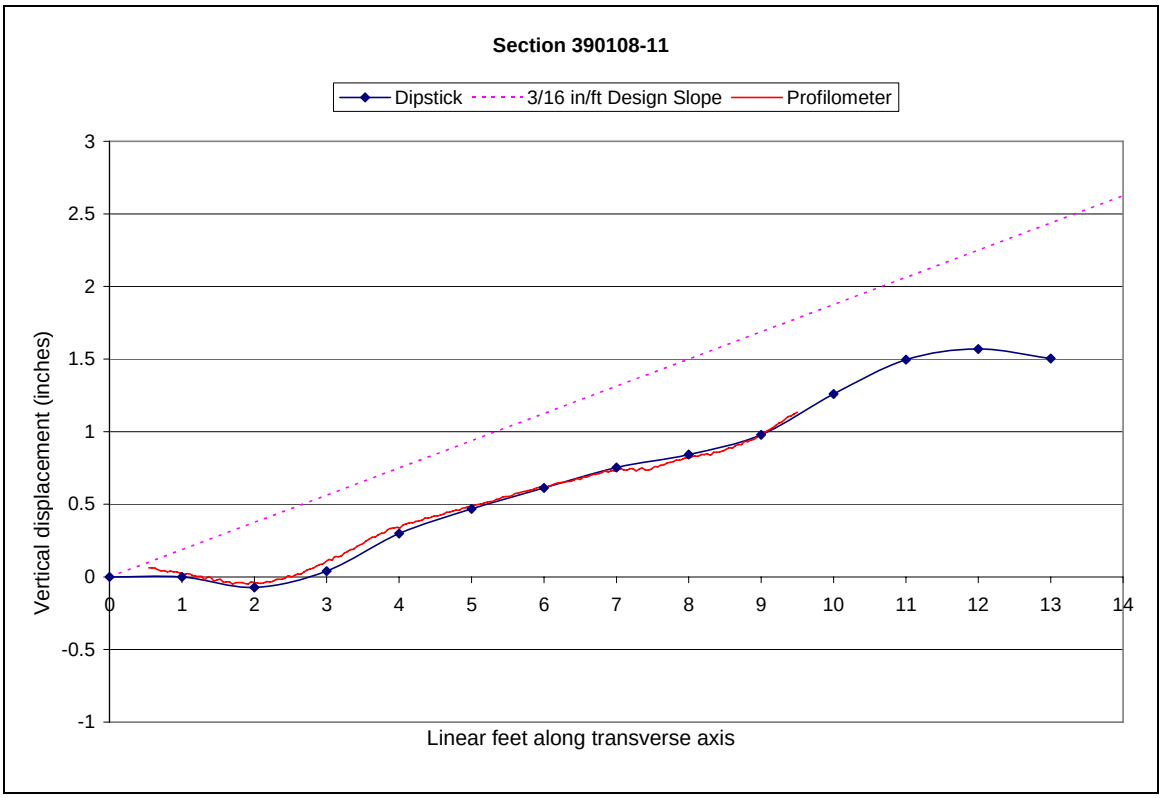


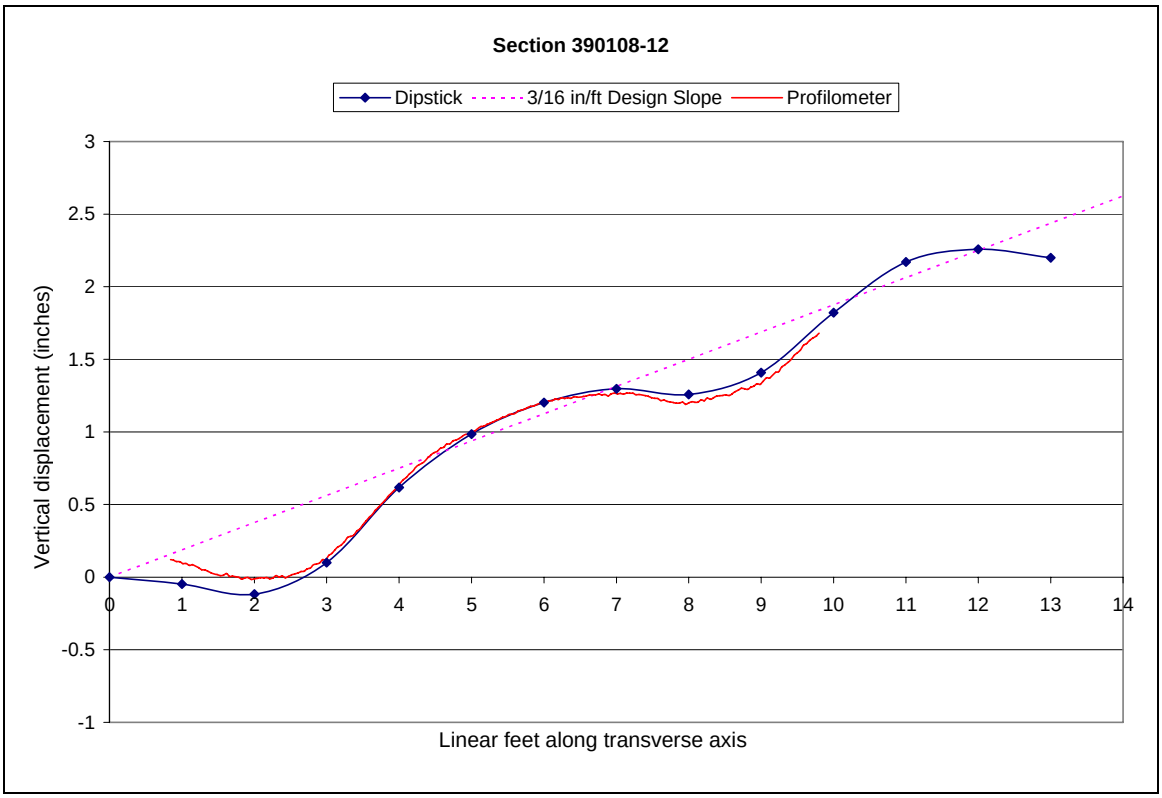
(1 in = 2.54 cm; 1 ft = 30.48 cm)



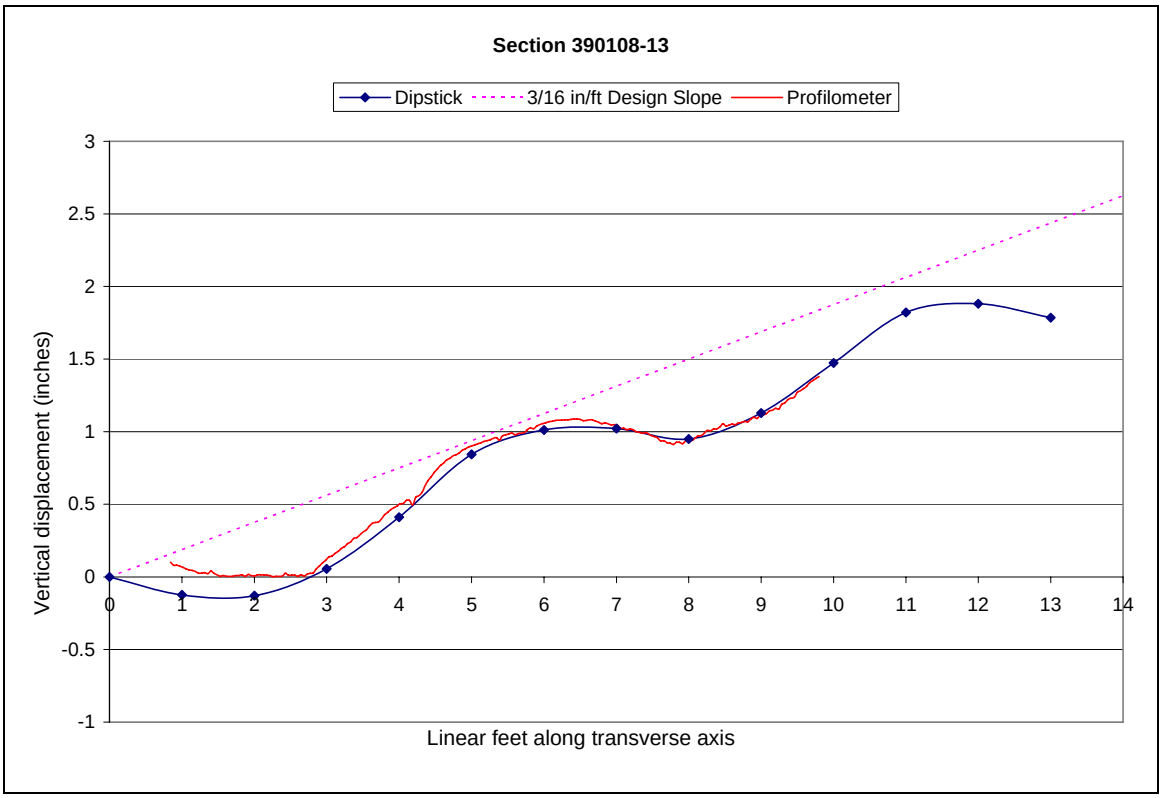


(1 in = 2.54 cm; 1 ft = 30.48 cm)



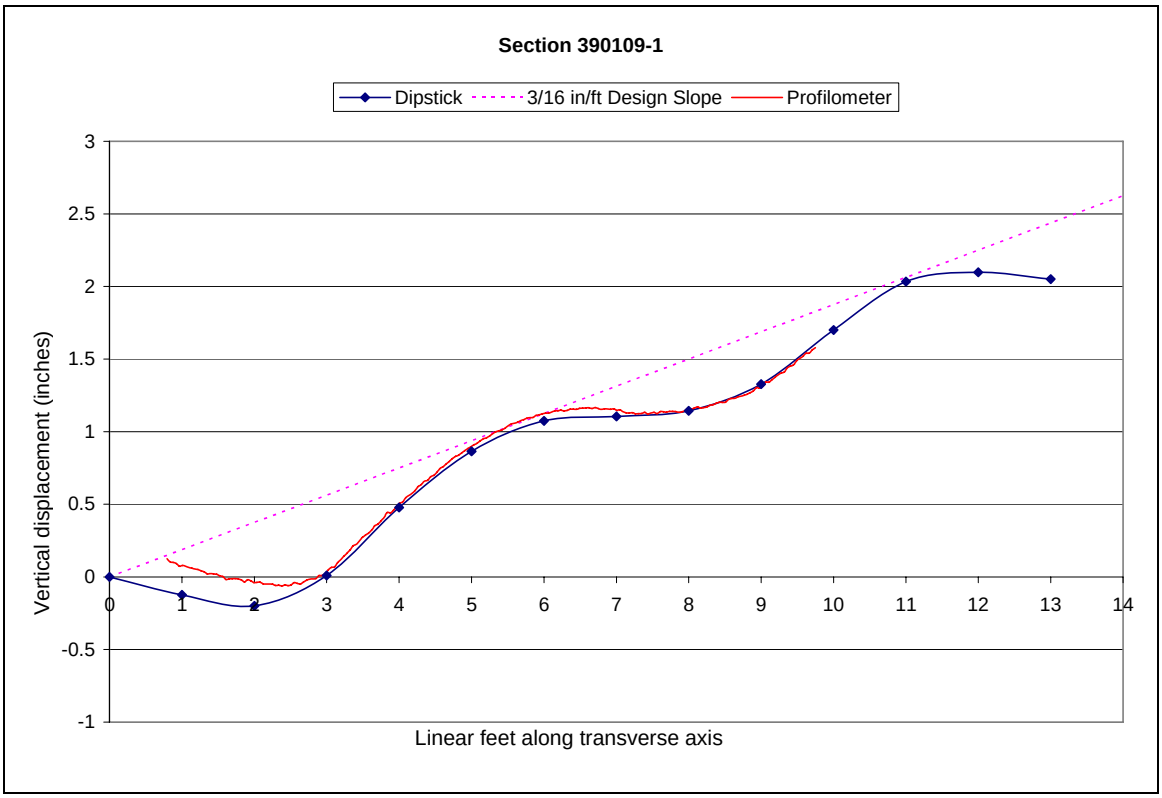


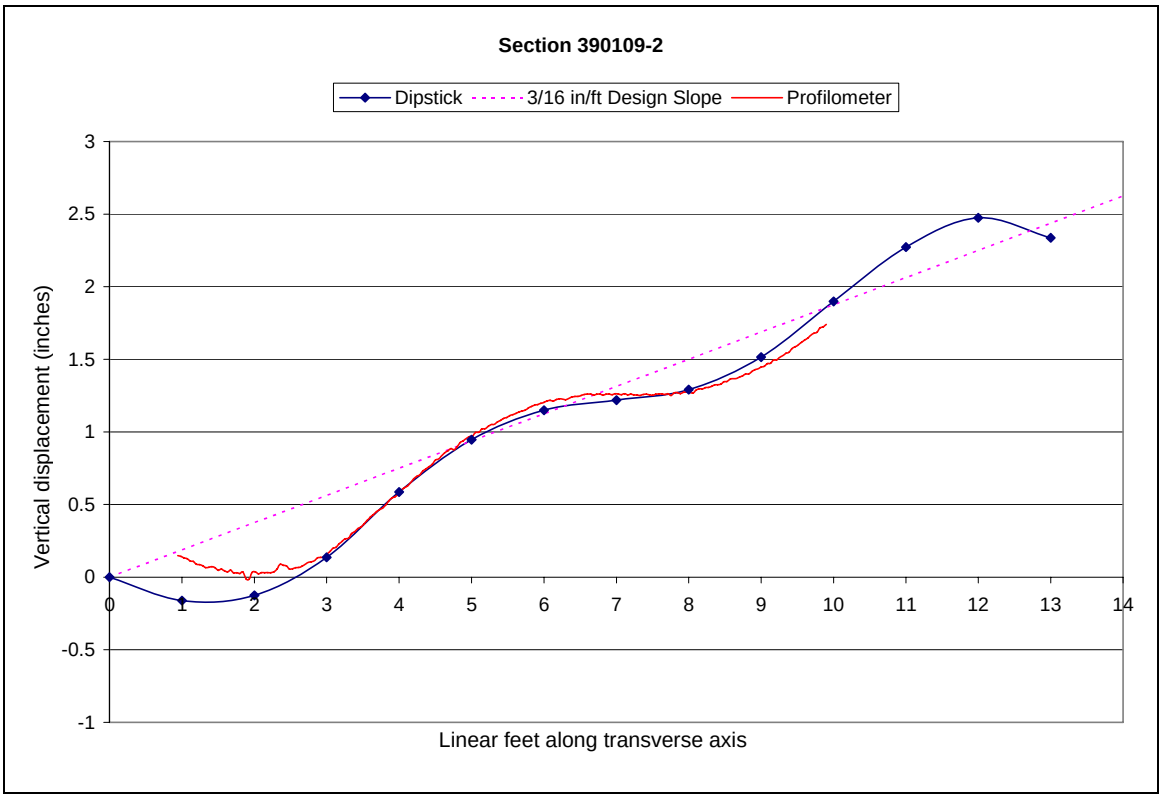
(1 in = 2.54 cm; 1 ft = 30.48 cm)



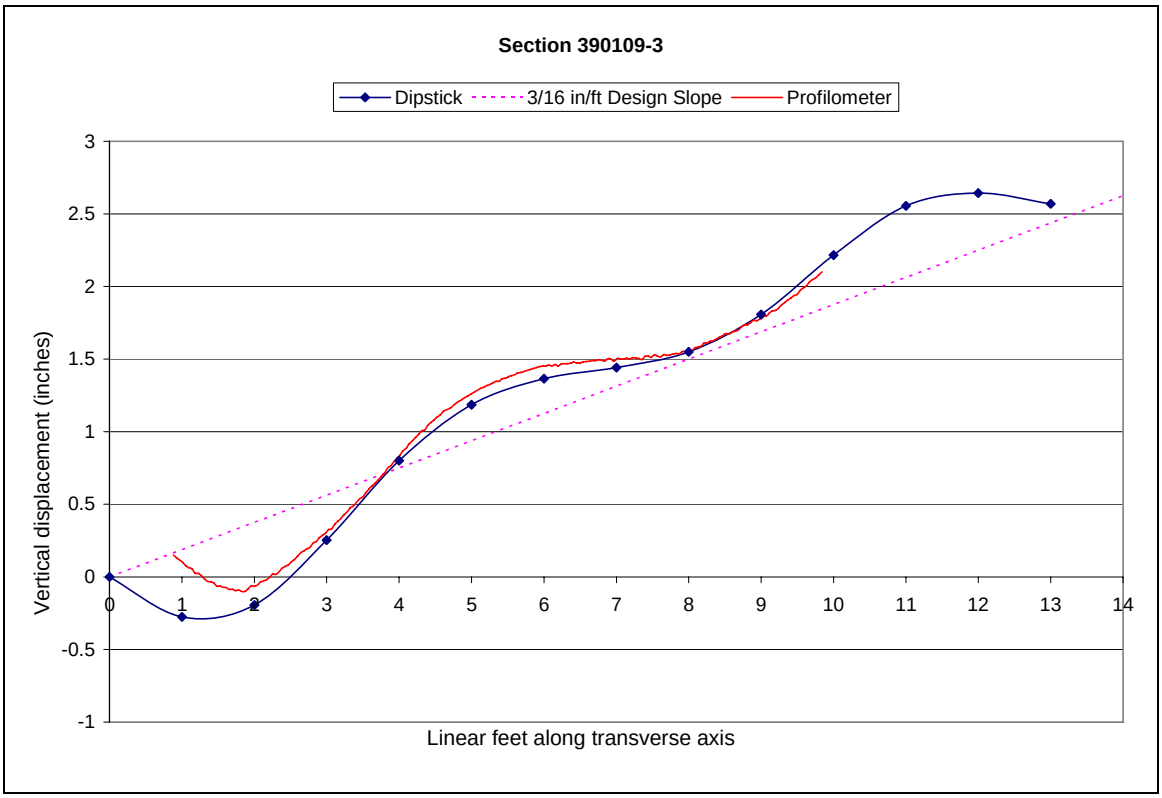
(1 in = 2.54 cm; 1 ft = 30.48 cm)

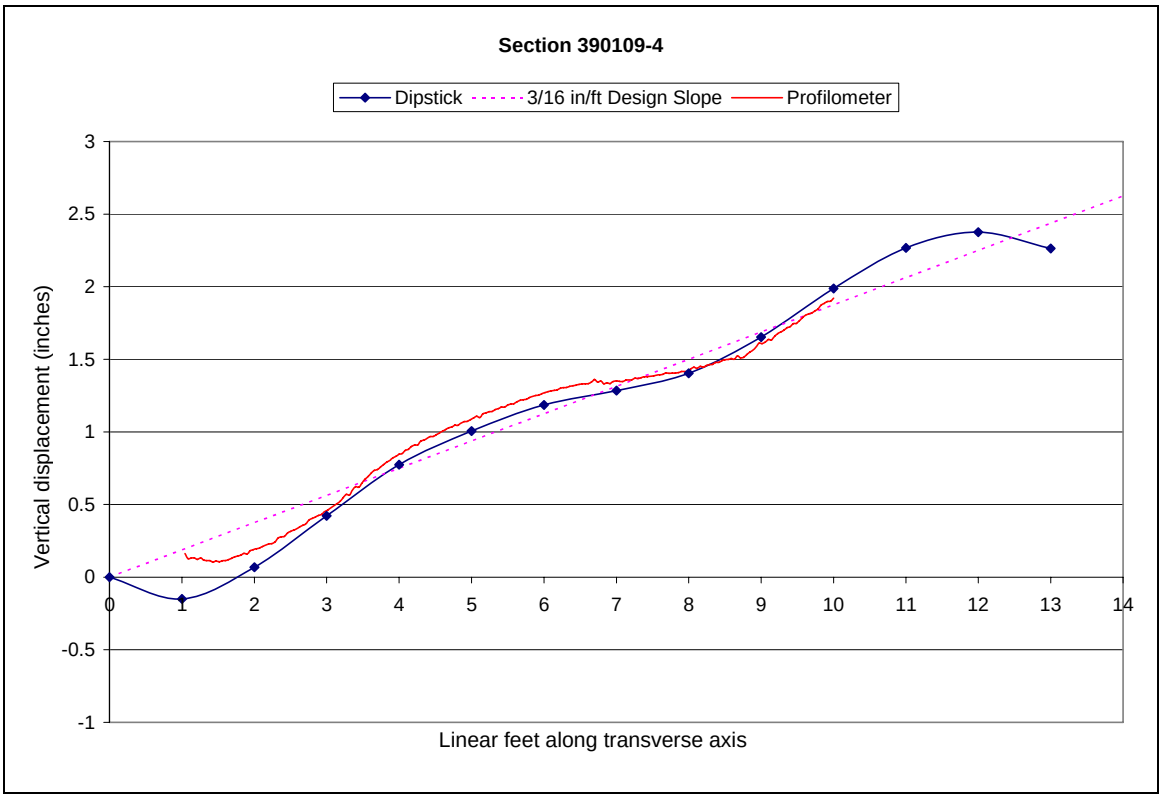
Appendix H Transverse Profiles for Section 390109



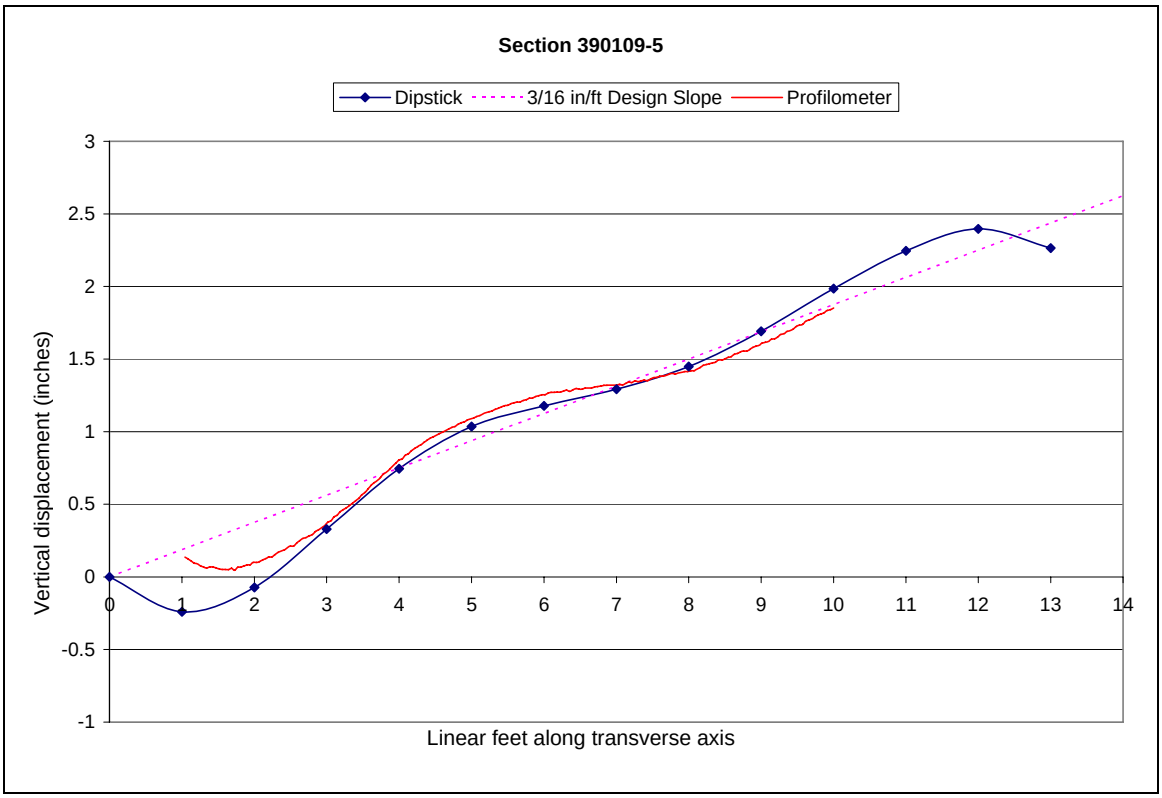


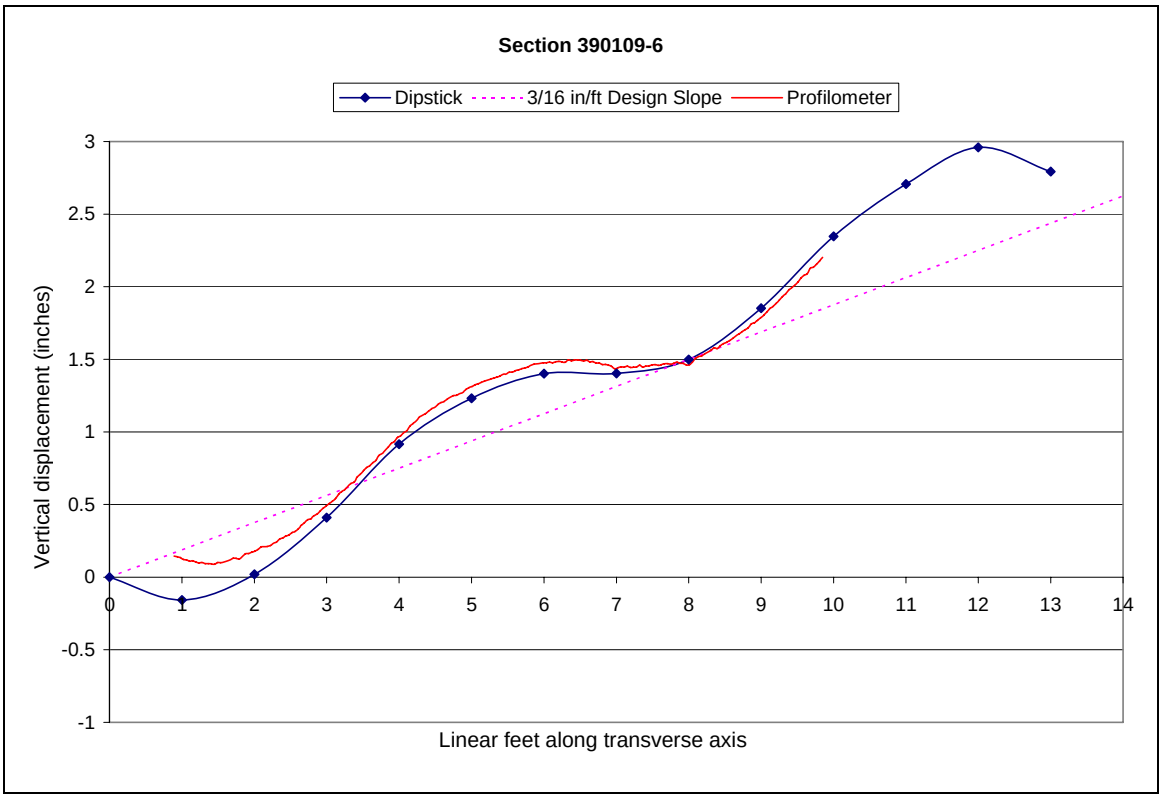
(1 in = 2.54 cm; 1 ft = 30.48 cm)



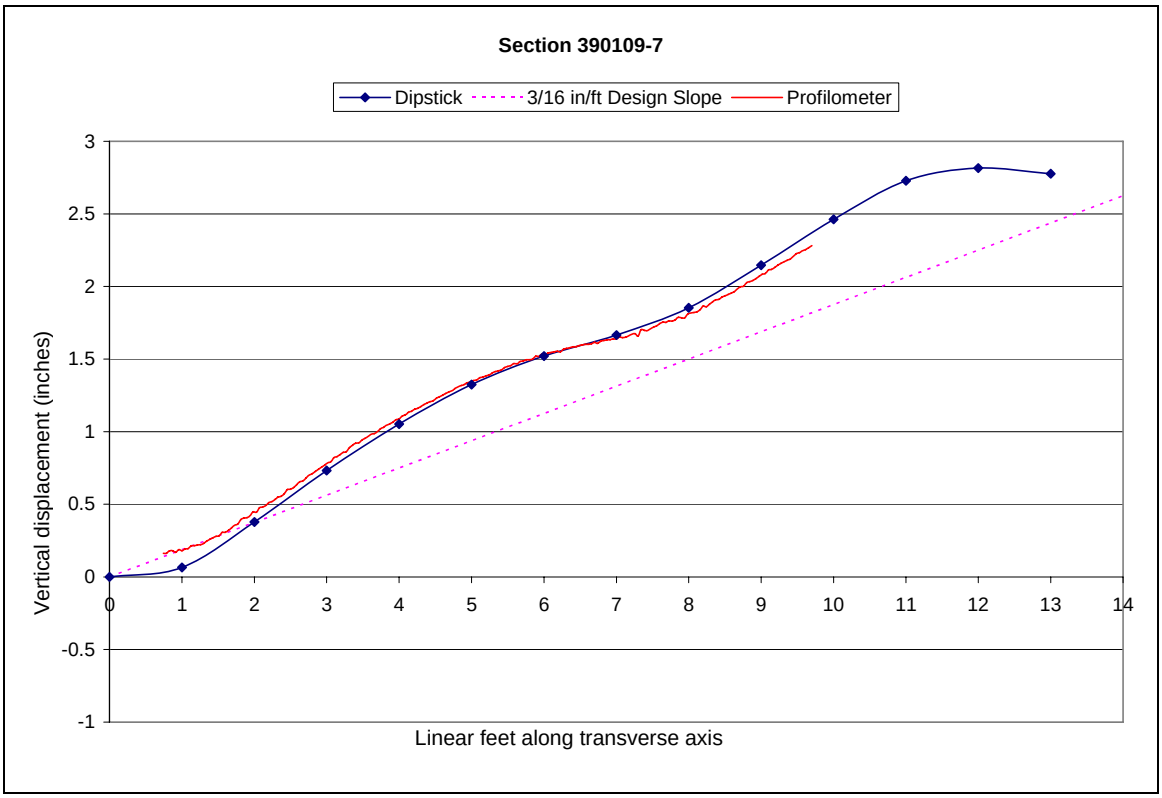


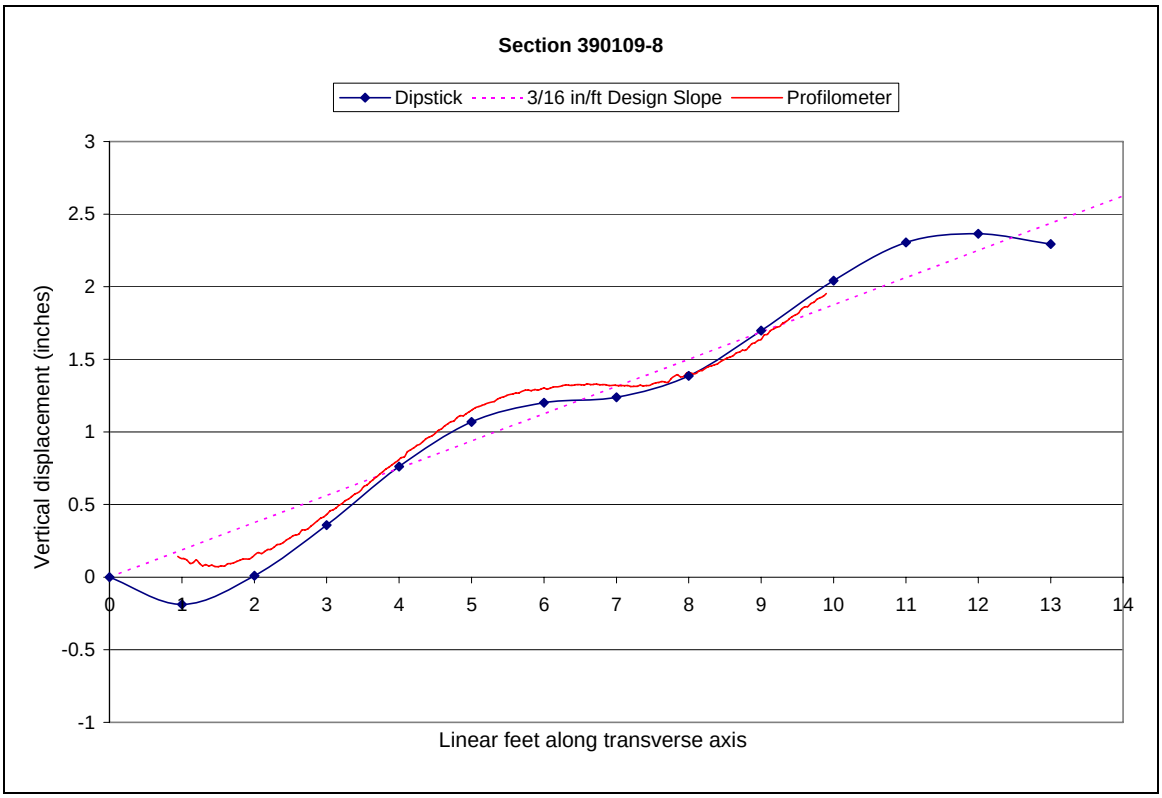
(1 in = 2.54 cm; 1 ft = 30.48 cm)



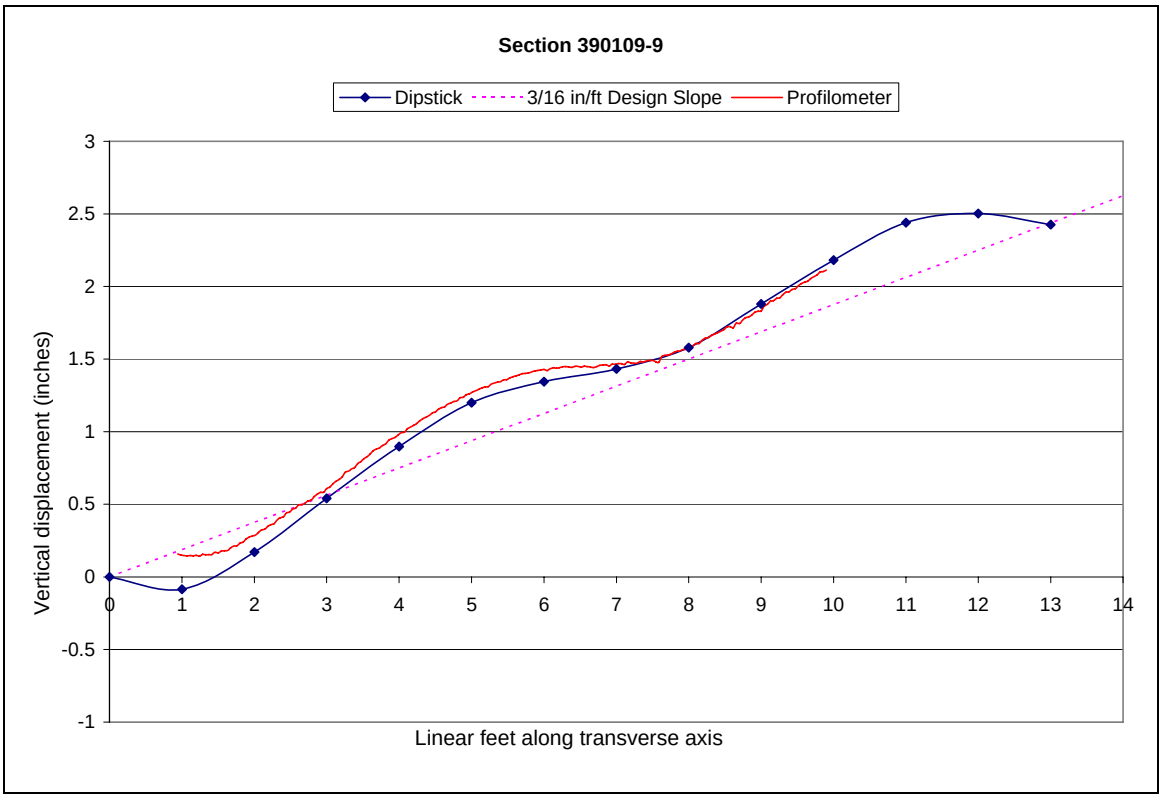


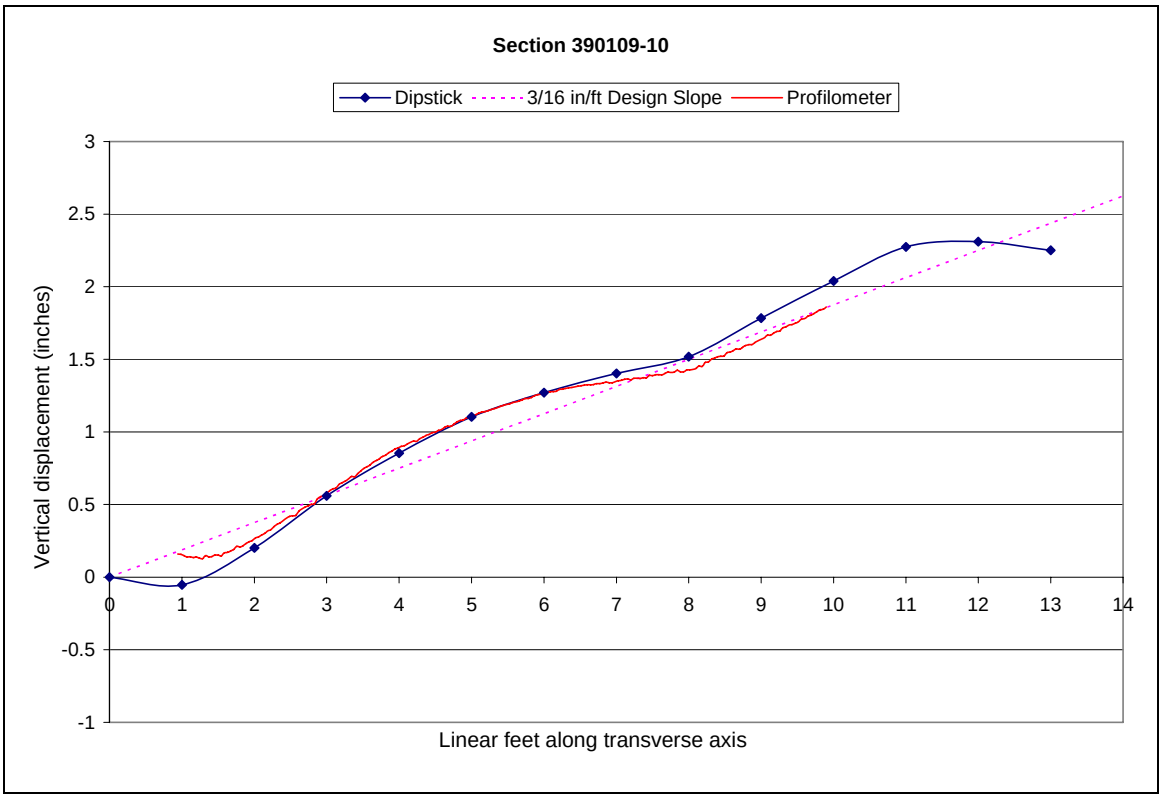
(1 in = 2.54 cm; 1 ft = 30.48 cm)



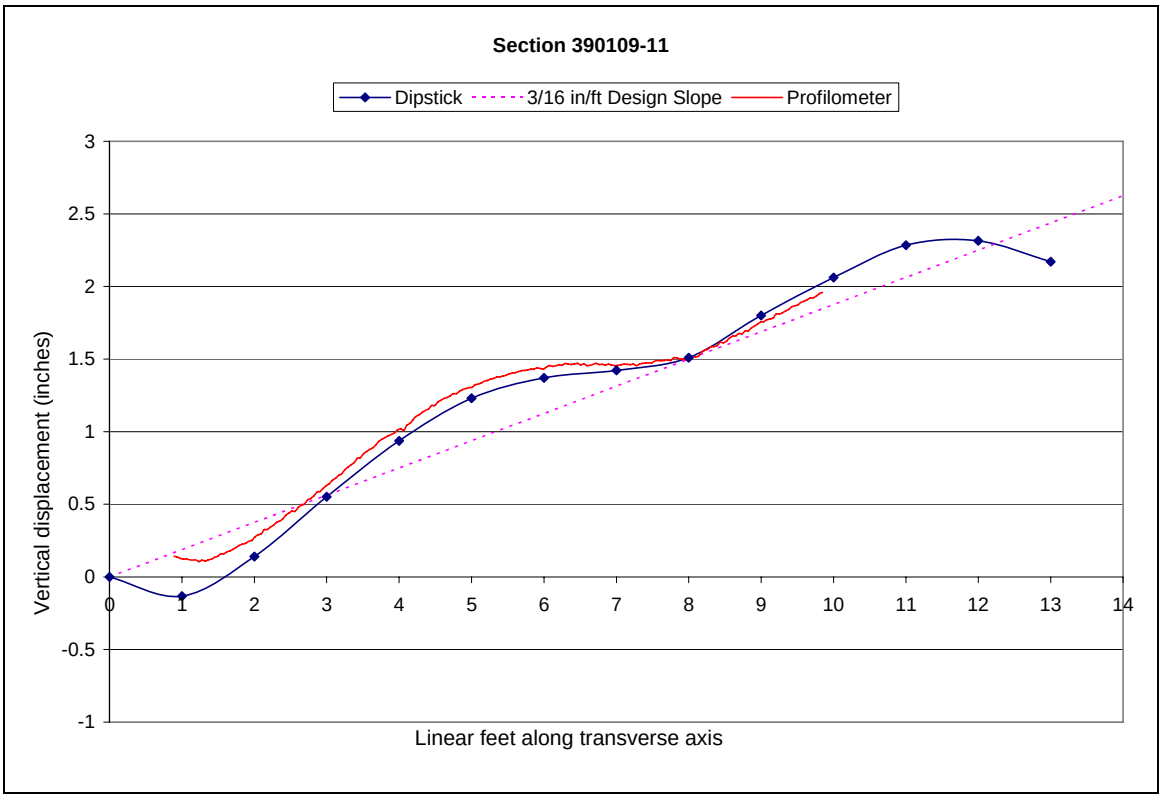


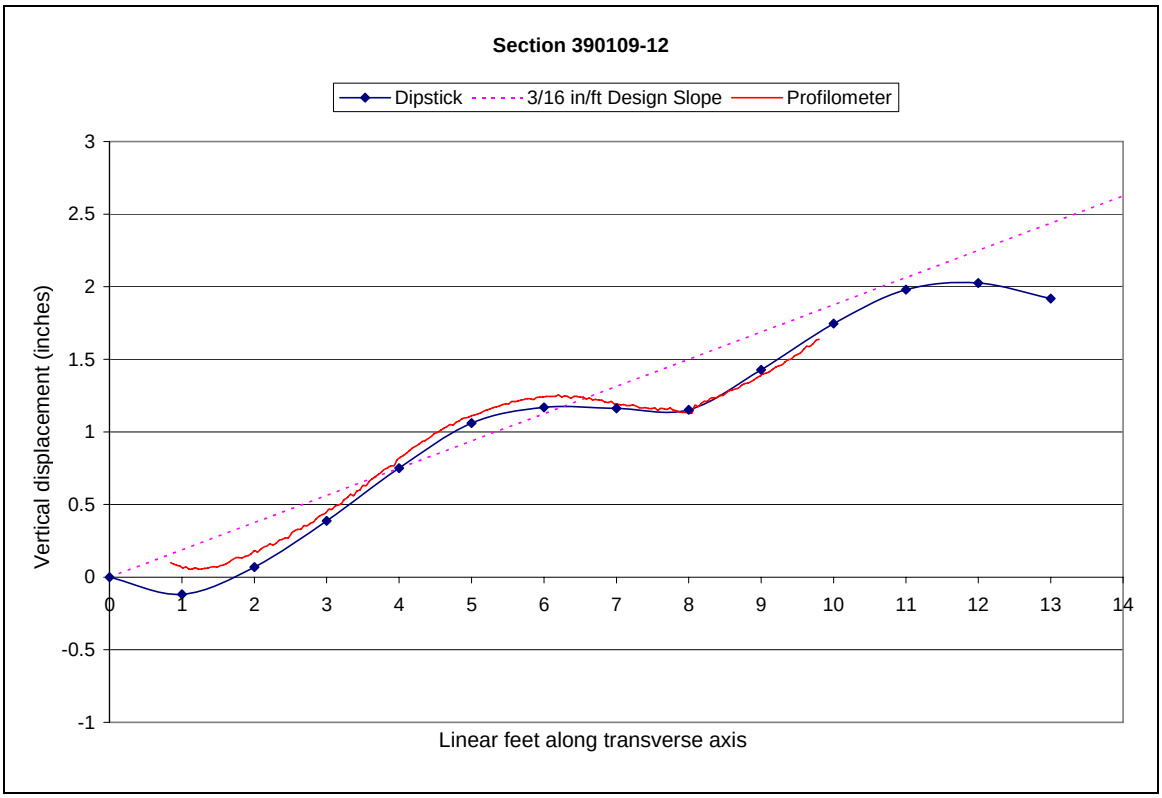
(1 in = 2.54 cm; 1 ft = 30.48 cm)



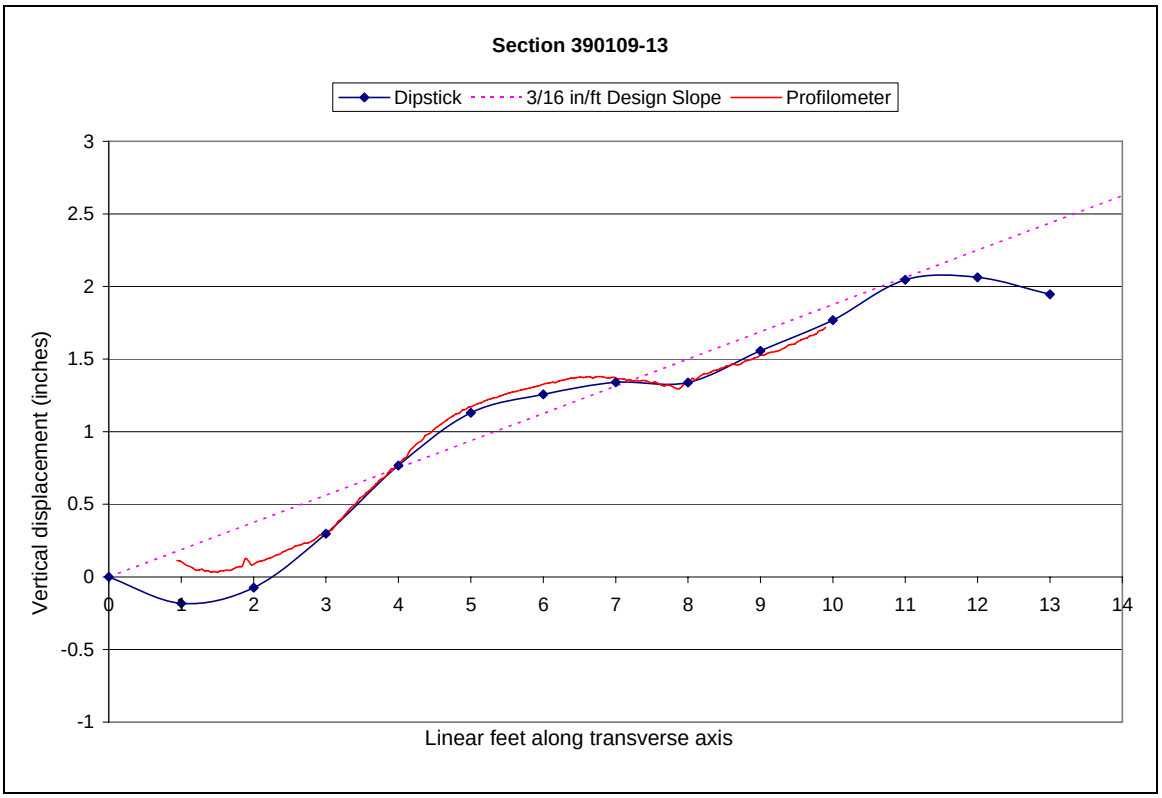


(1 in = 2.54 cm; 1 ft = 30.48 cm)



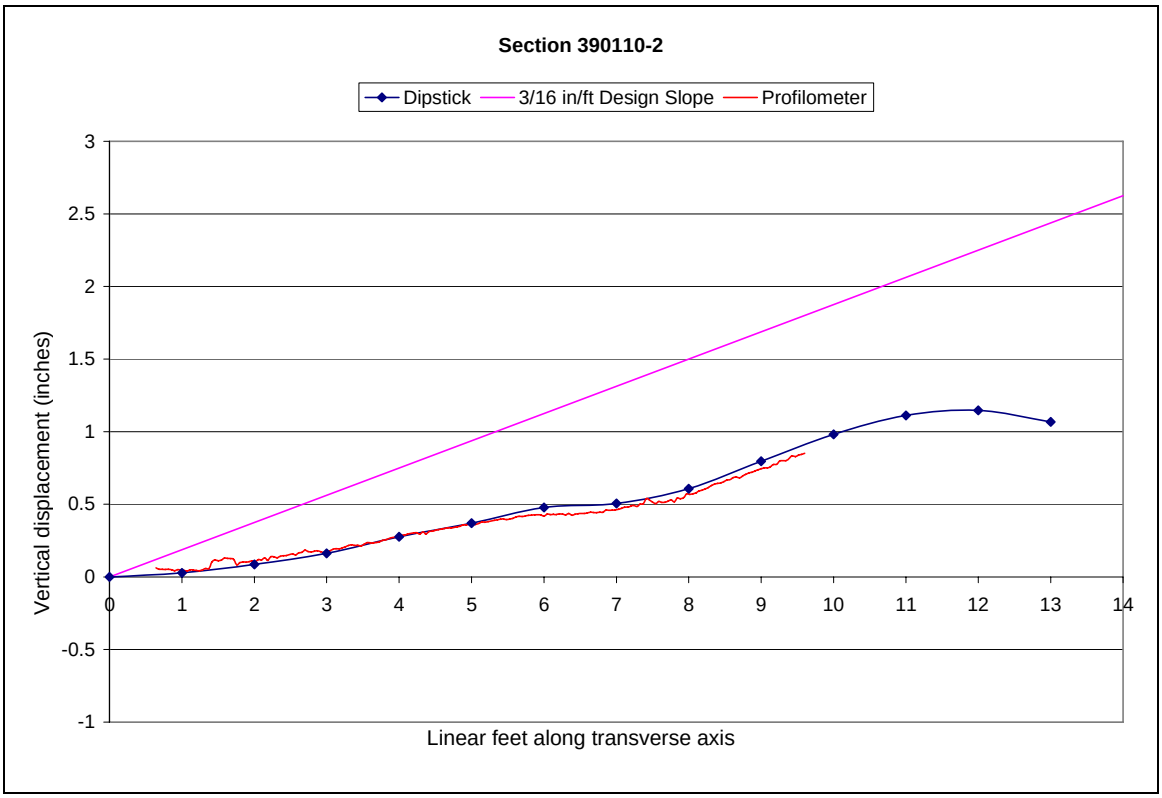


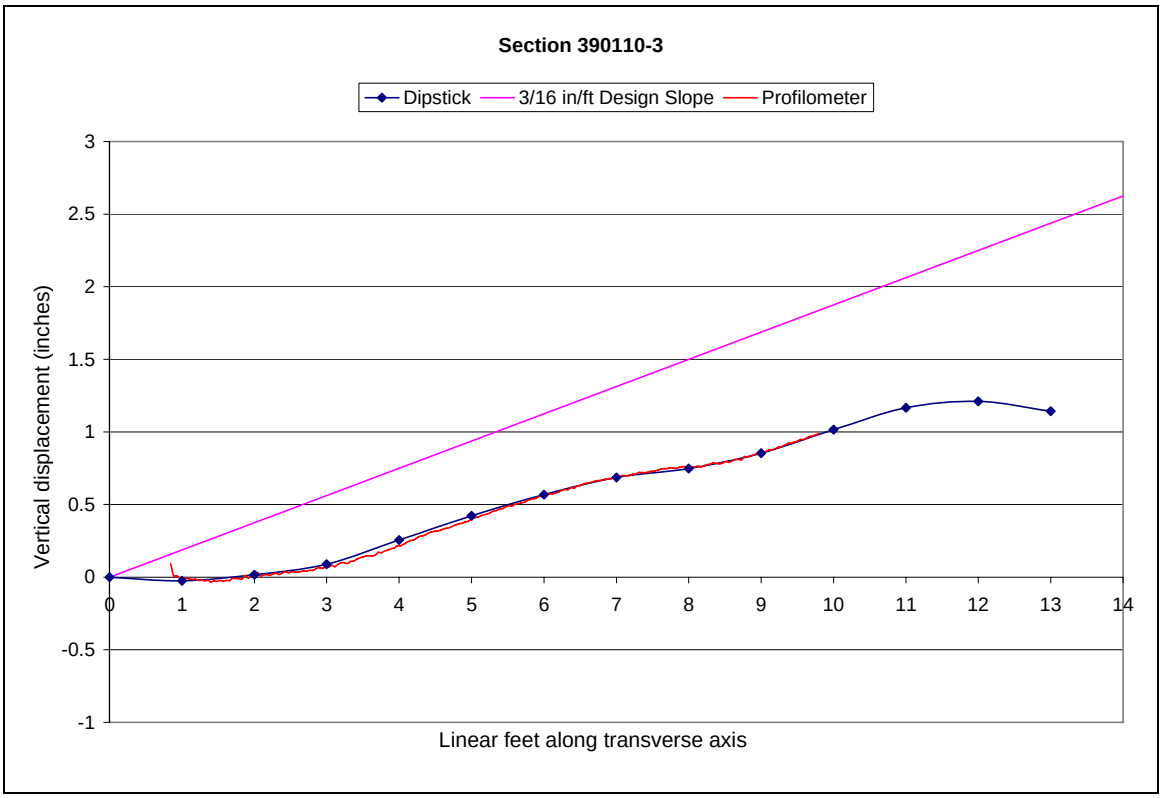
(1 in = 2.54 cm; 1 ft = 30.48 cm)



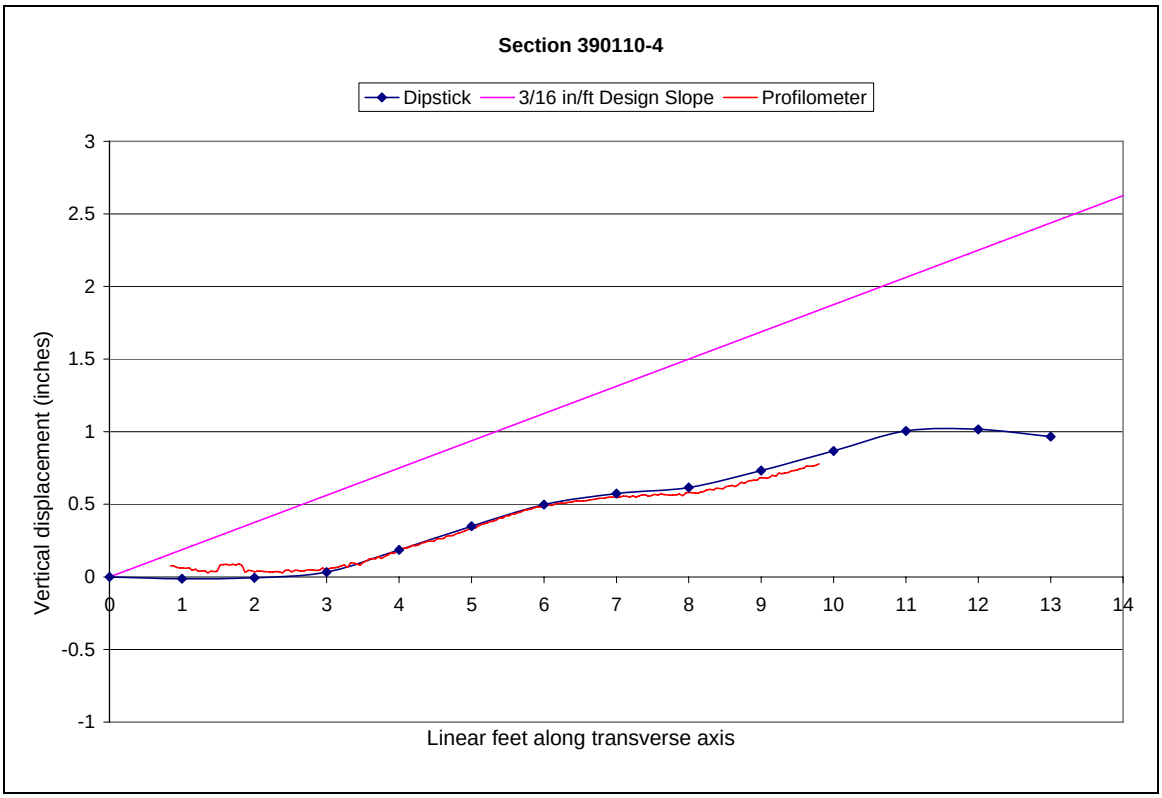
(1 in = 2.54 cm; 1 ft = 30.48 cm)

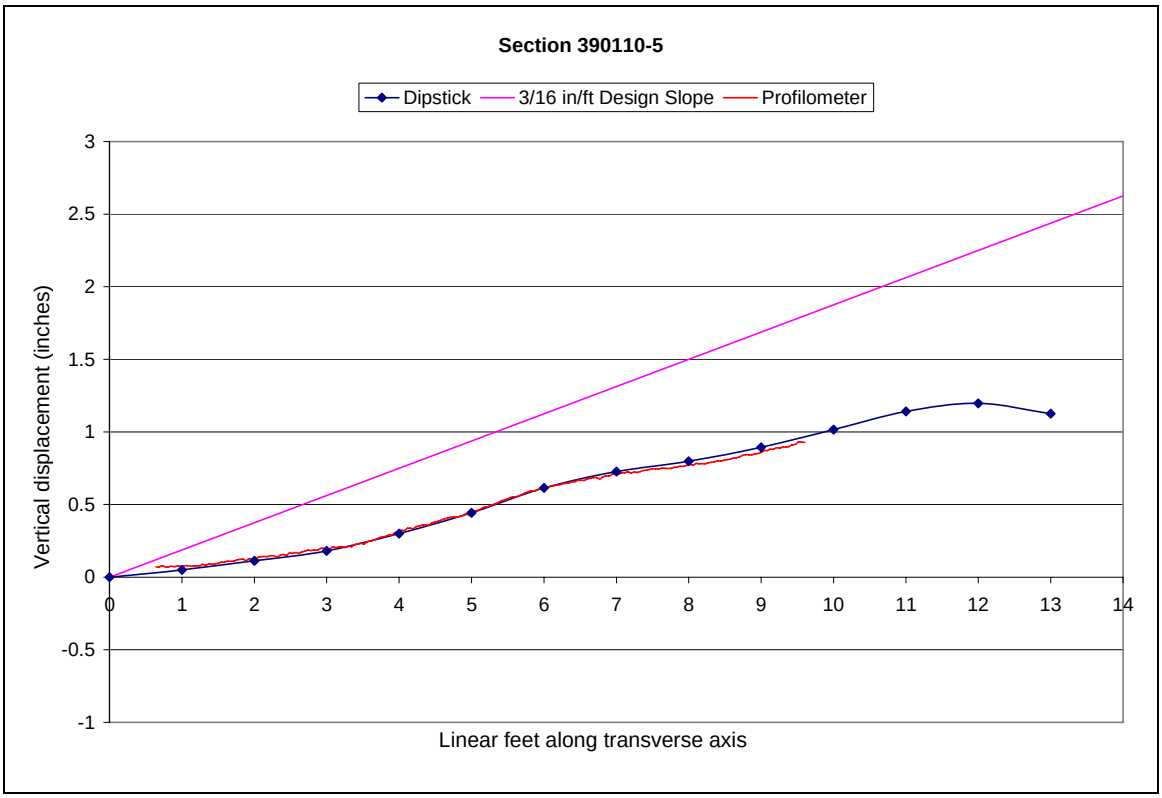
Appendix I Transverse Profiles for Section 390110



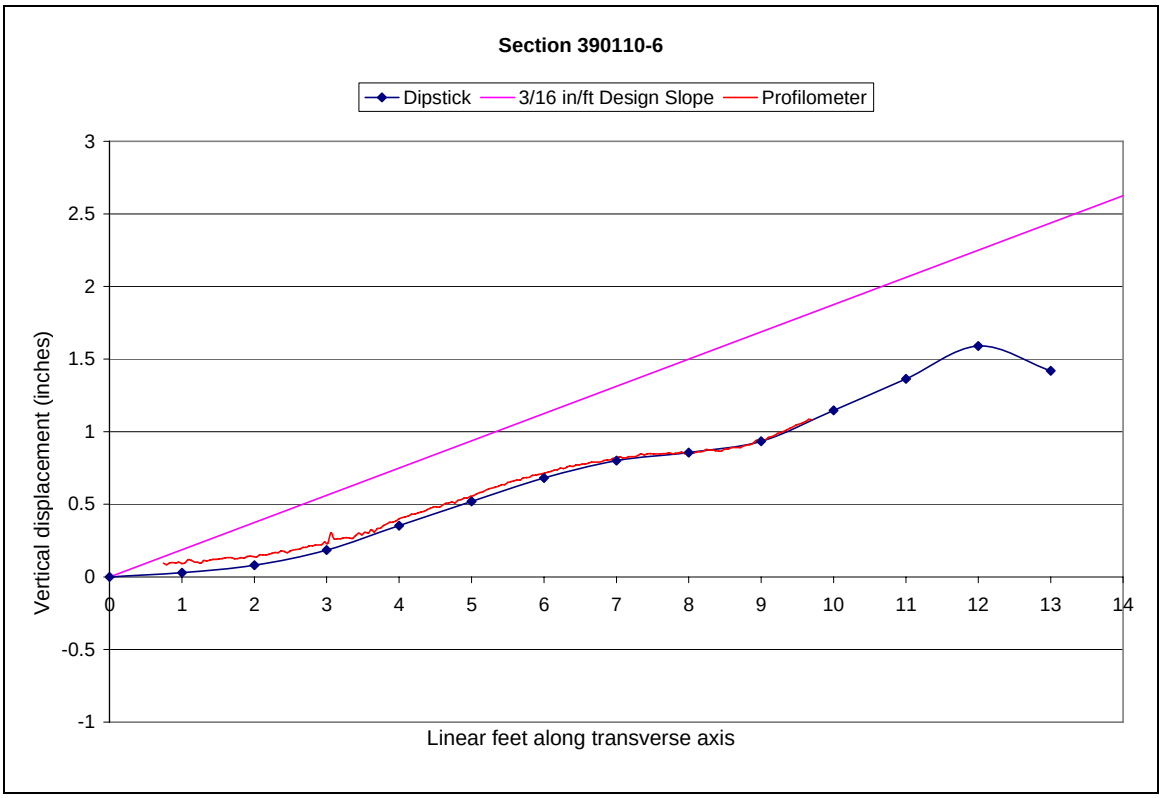


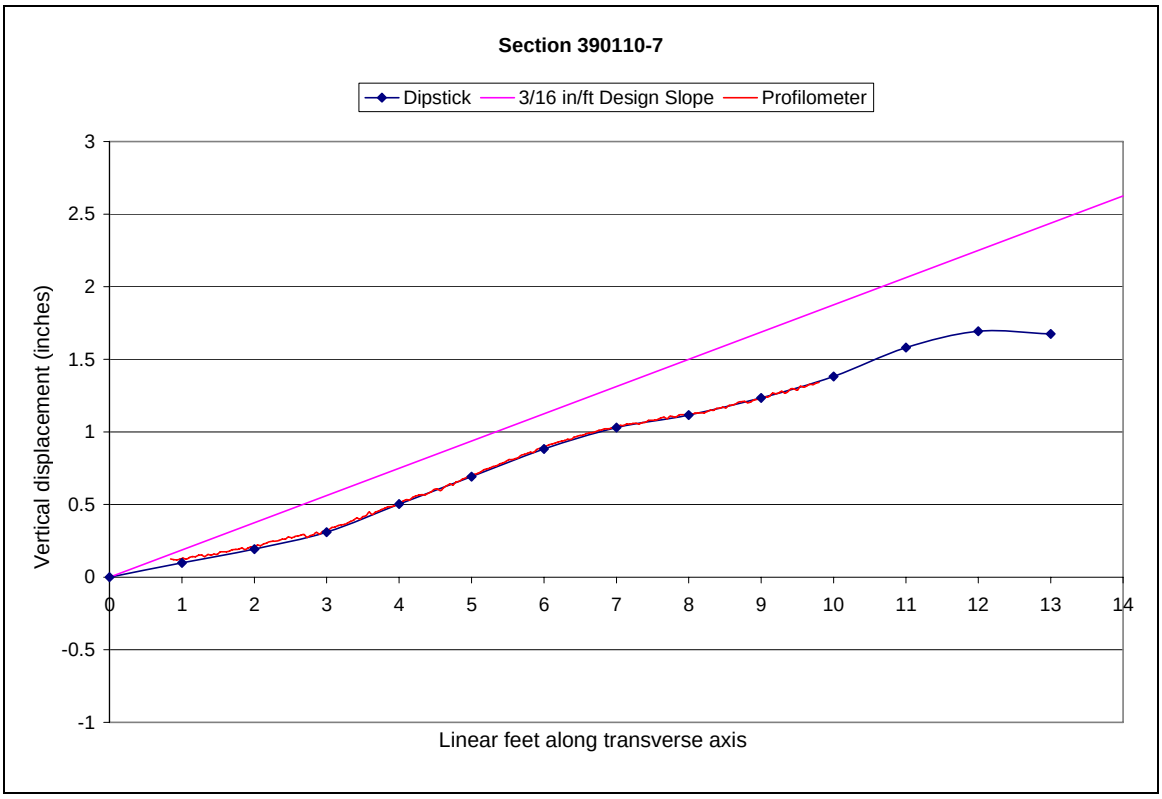
(1 in = 2.54 cm; 1 ft = 30.48 cm)



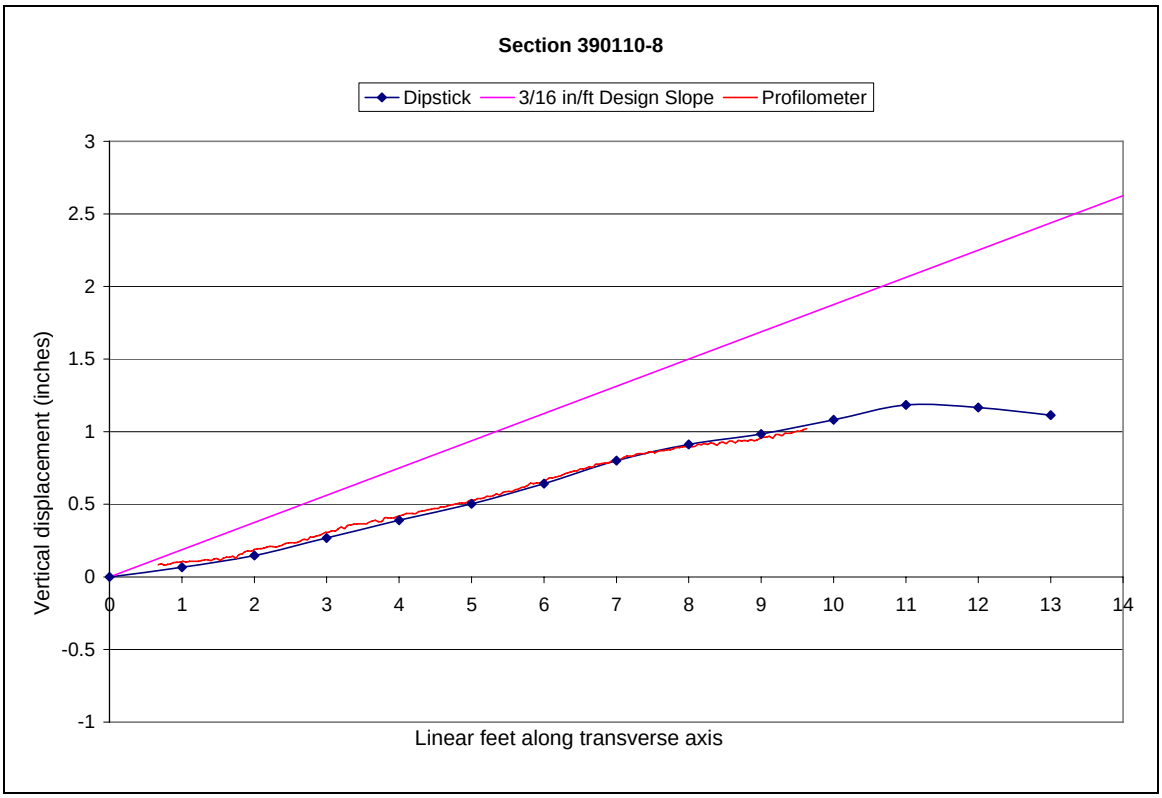


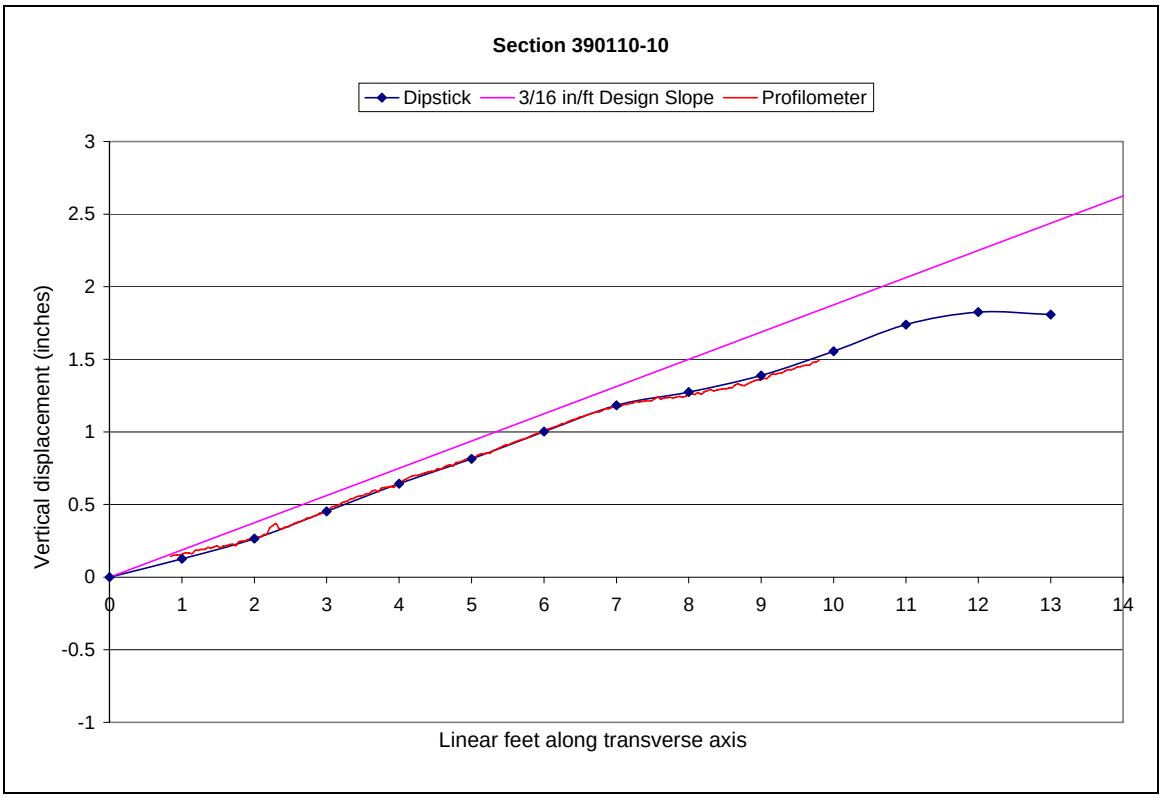
(1 in = 2.54 cm; 1 ft = 30.48 cm)



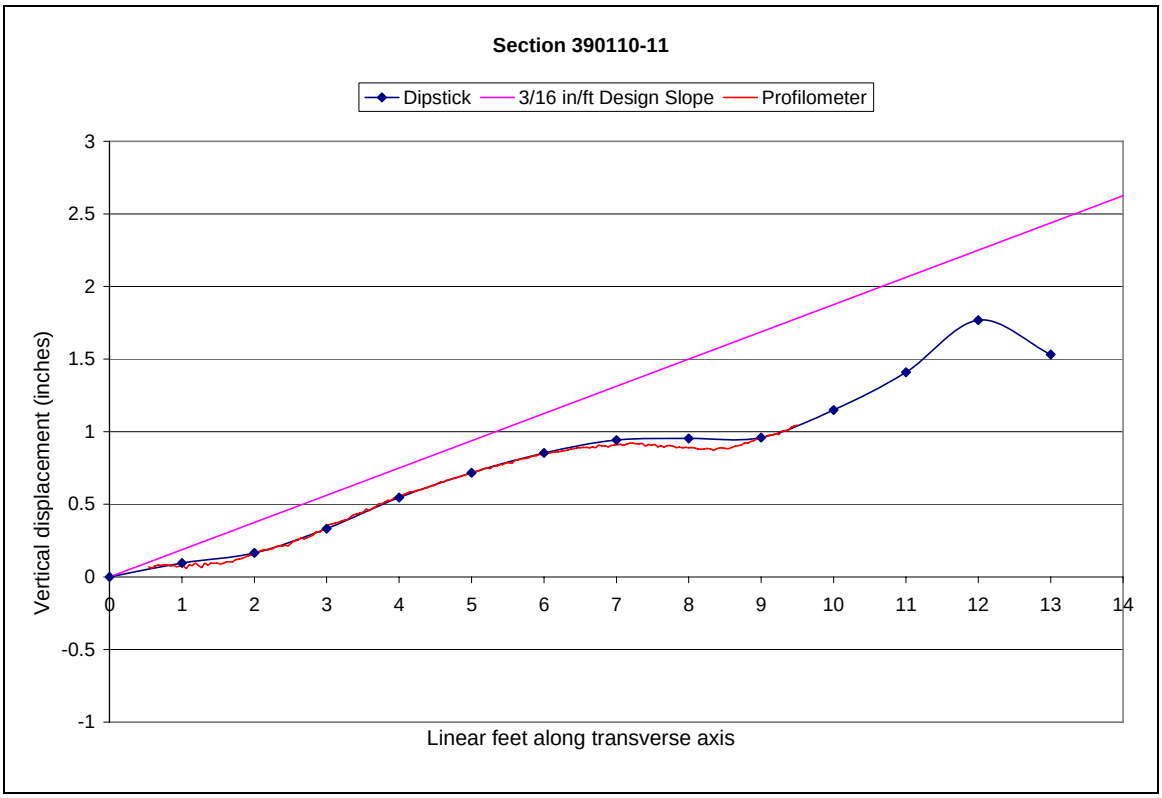


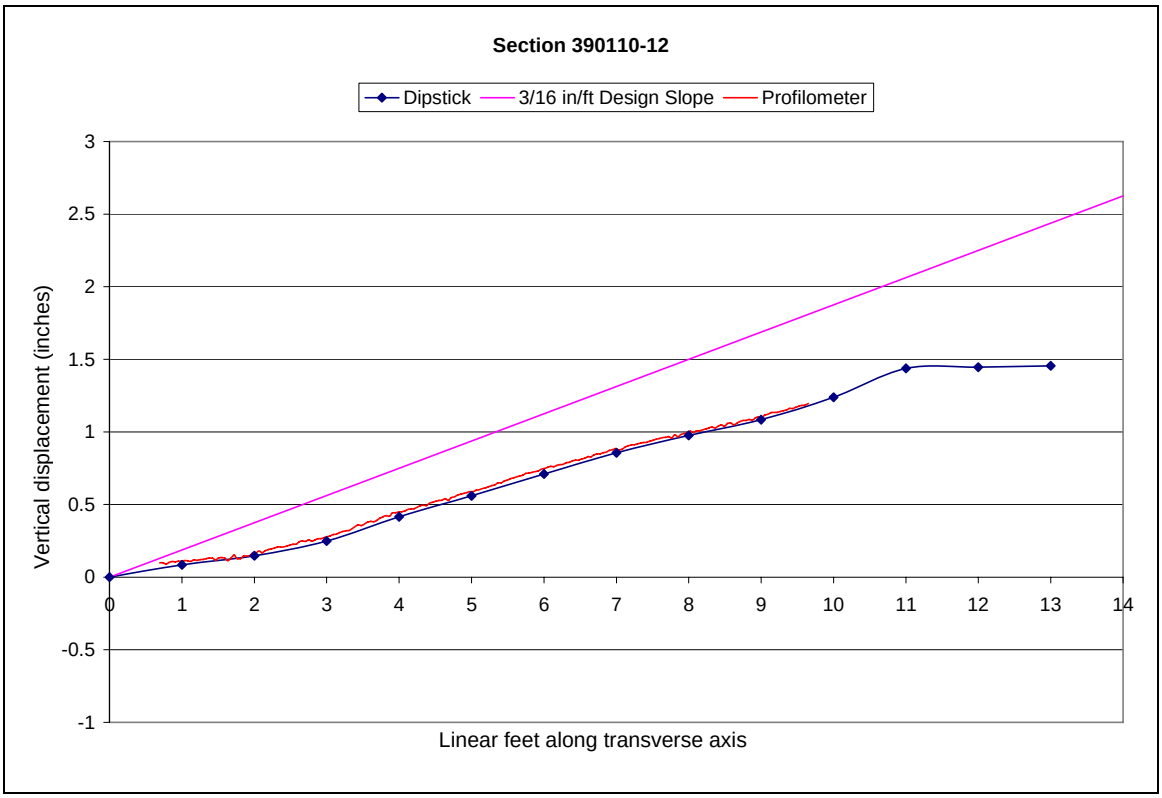
(1 in = 2.54 cm; 1 ft = 30.48 cm)



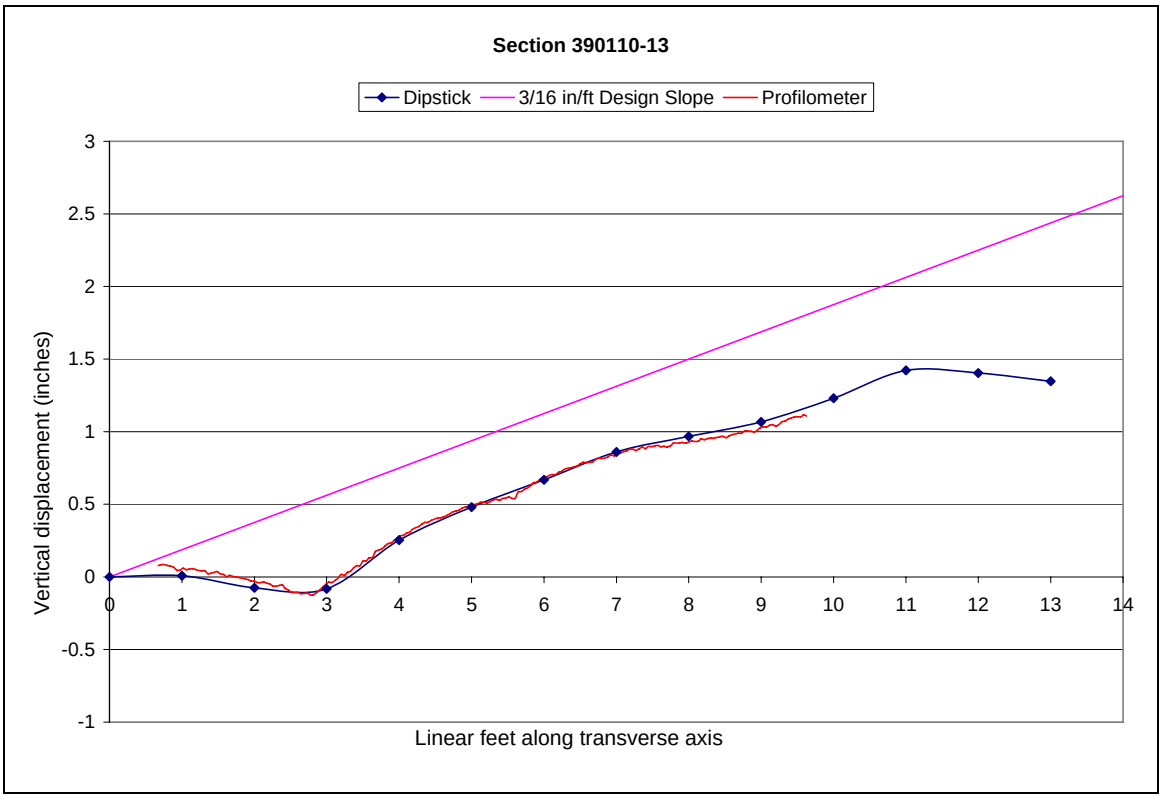


(1 in = 2.54 cm; 1 ft = 30.48 cm)



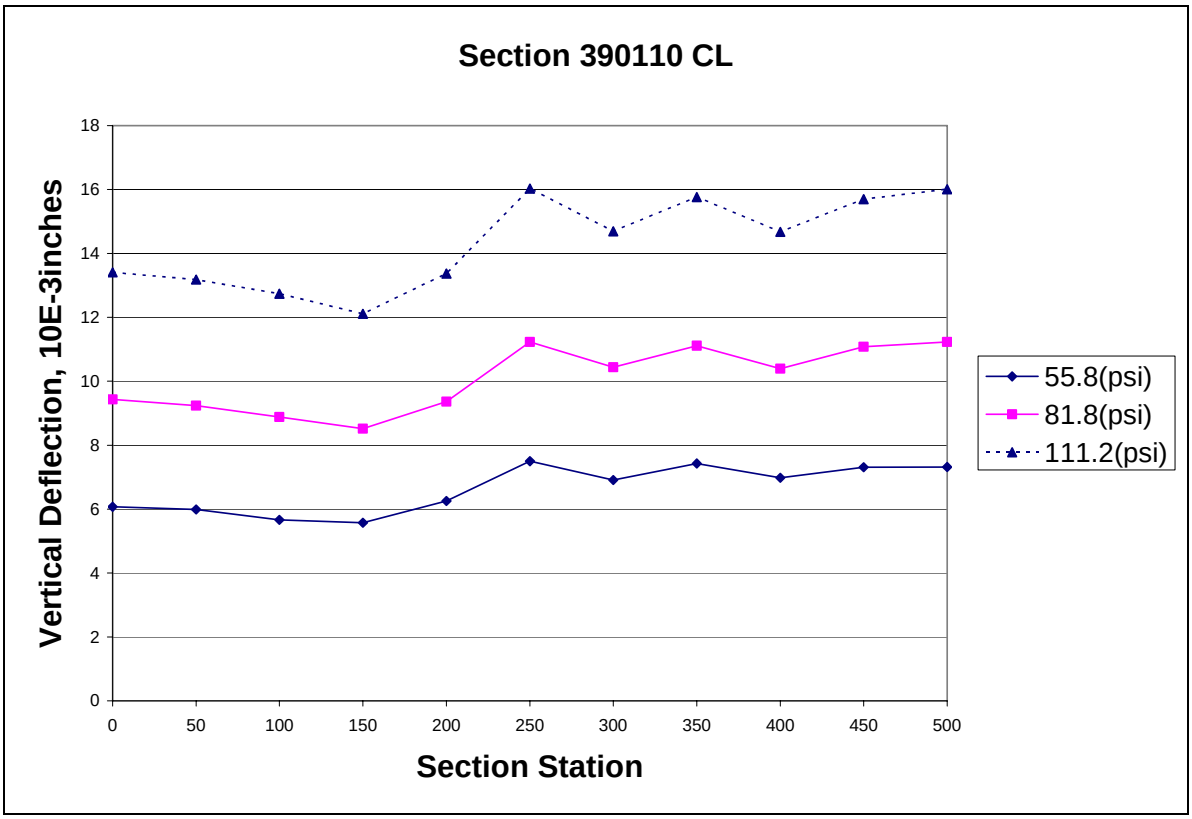


(1 in = 2.54 cm; 1 ft = 30.48 cm)

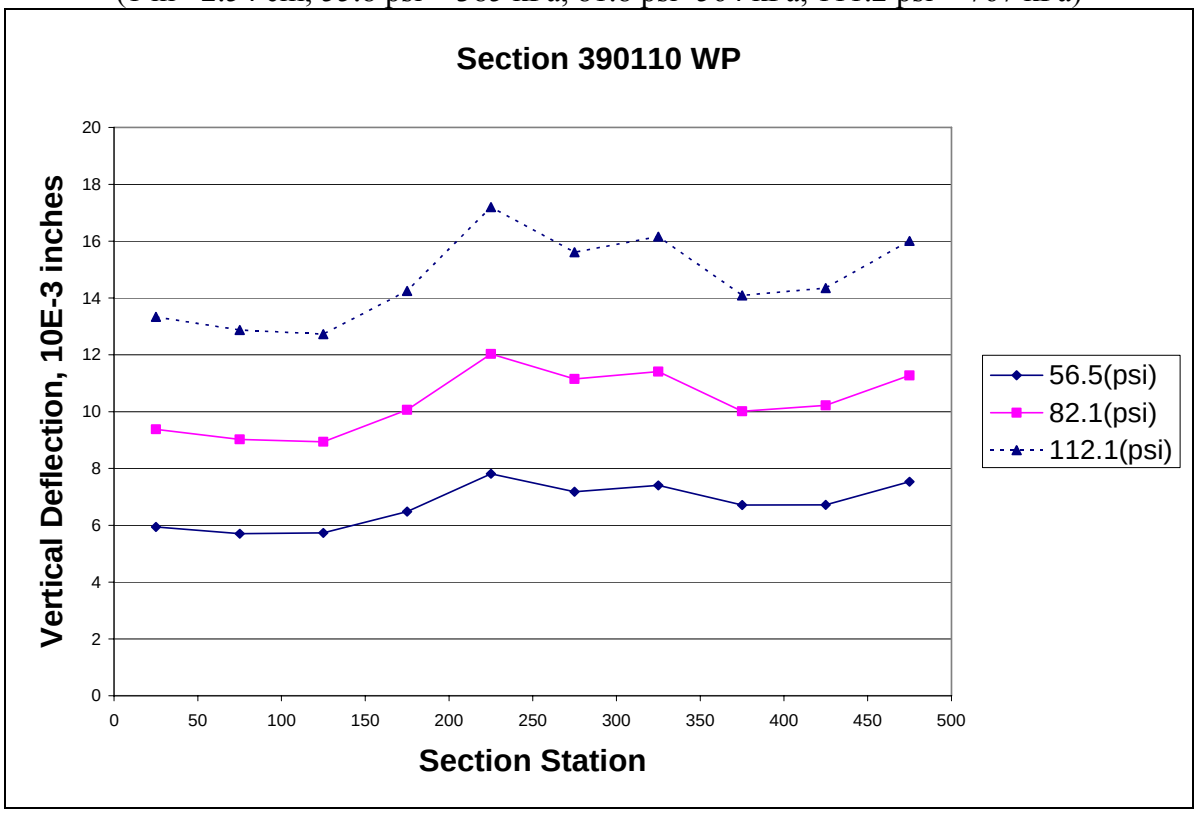


(1 in = 2.54 cm; 1 ft = 30.48 cm)

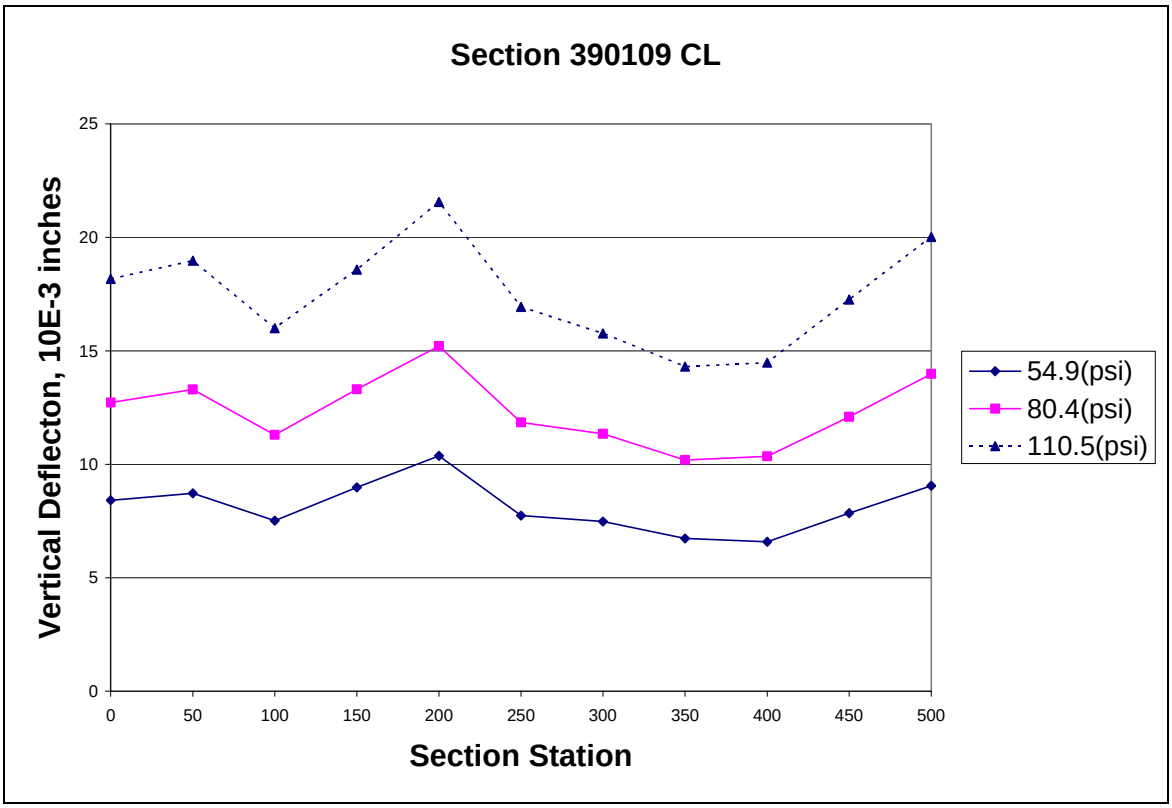
Appendix J FWD Plots (At time of forensic study)



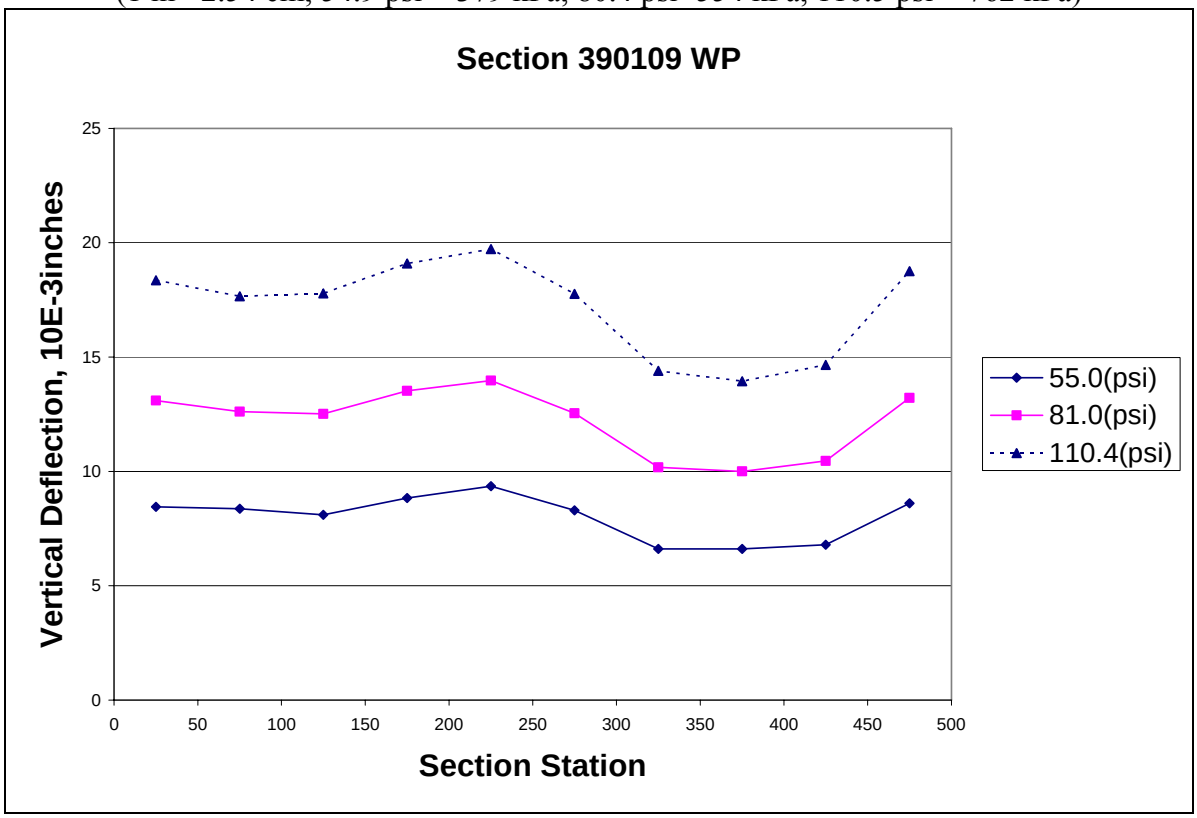
(1 in =2.54 cm; 55.8 psi = 385 kPa, 81.8 psi=564 kPa, 111.2 psi = 767 kPa)



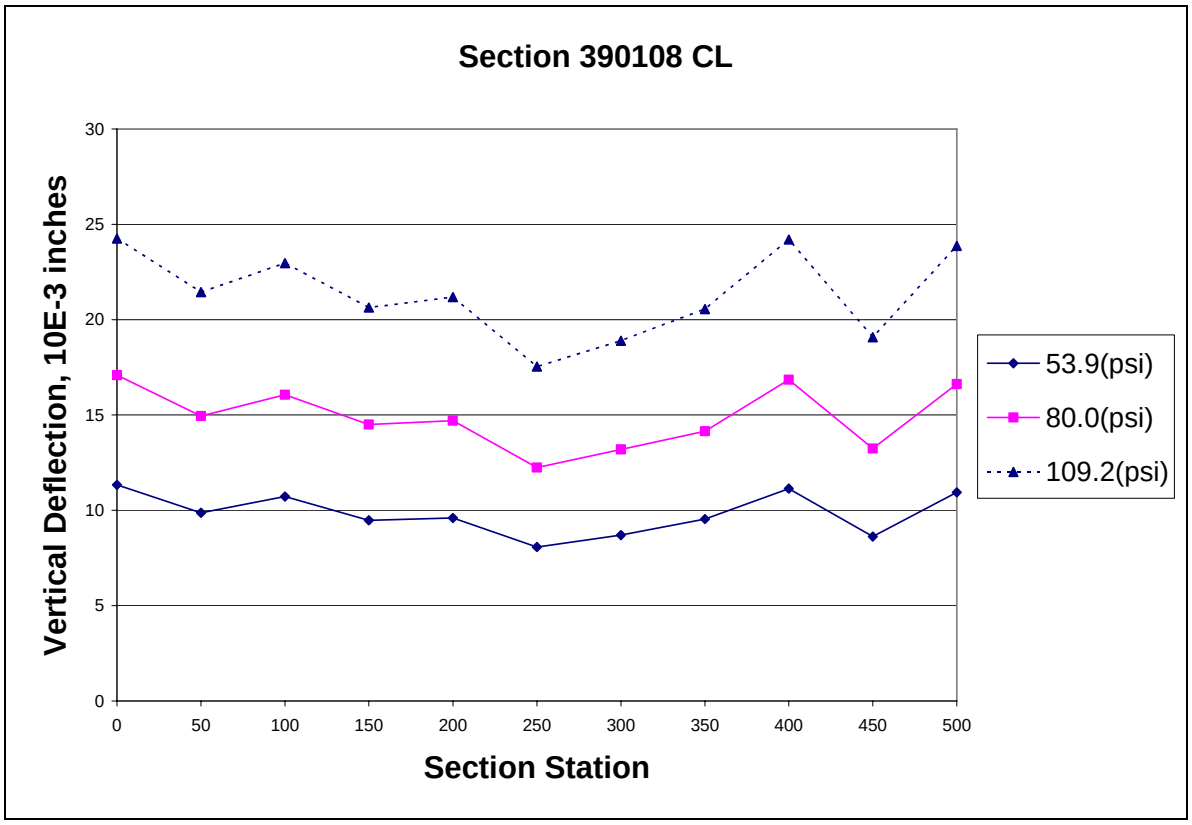
(1 in =2.54 cm; 56.5 psi = 390 kPa, 82.1 psi=566 kPa, 112.1 psi = 773 kPa)



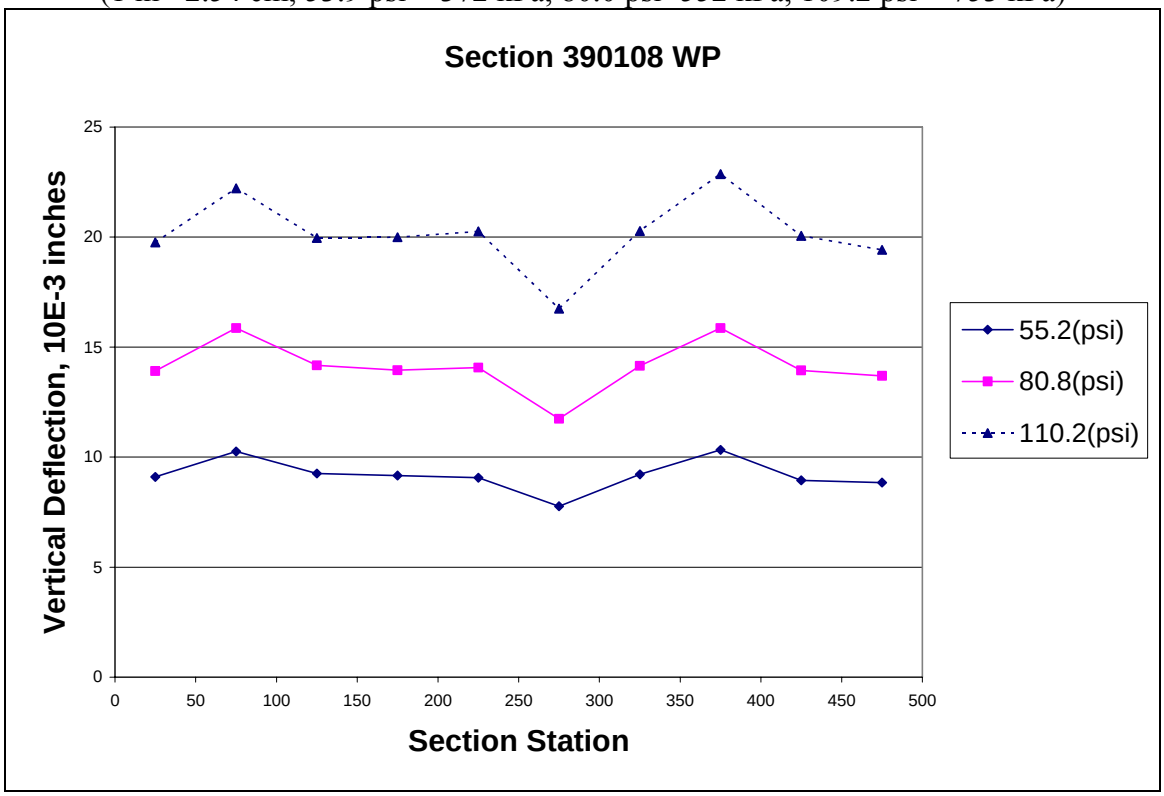
(1 in =2.54 cm; 54.9 psi = 379 kPa, 80.4 psi=554 kPa, 110.5 psi = 762 kPa)



(1 in =2.54 cm; 55.0 psi = 379 kPa, 81.0 psi=558 kPa, 110.4 psi = 761 kPa)

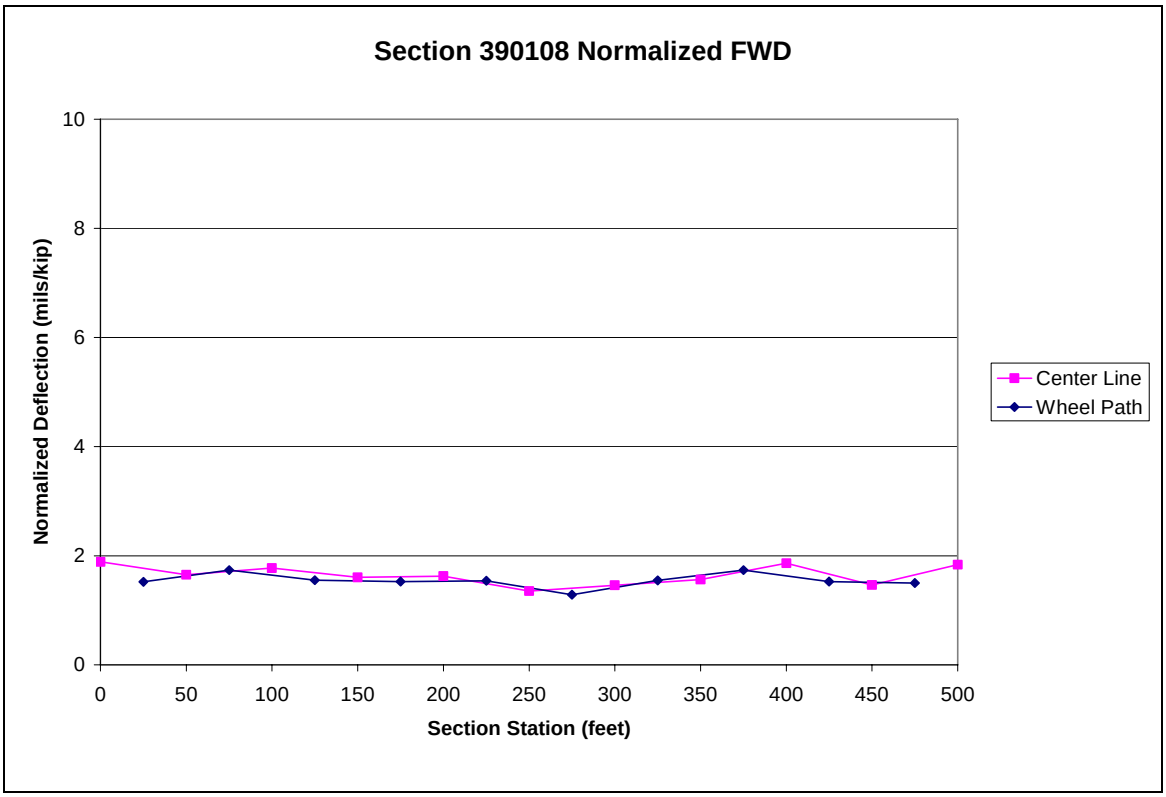


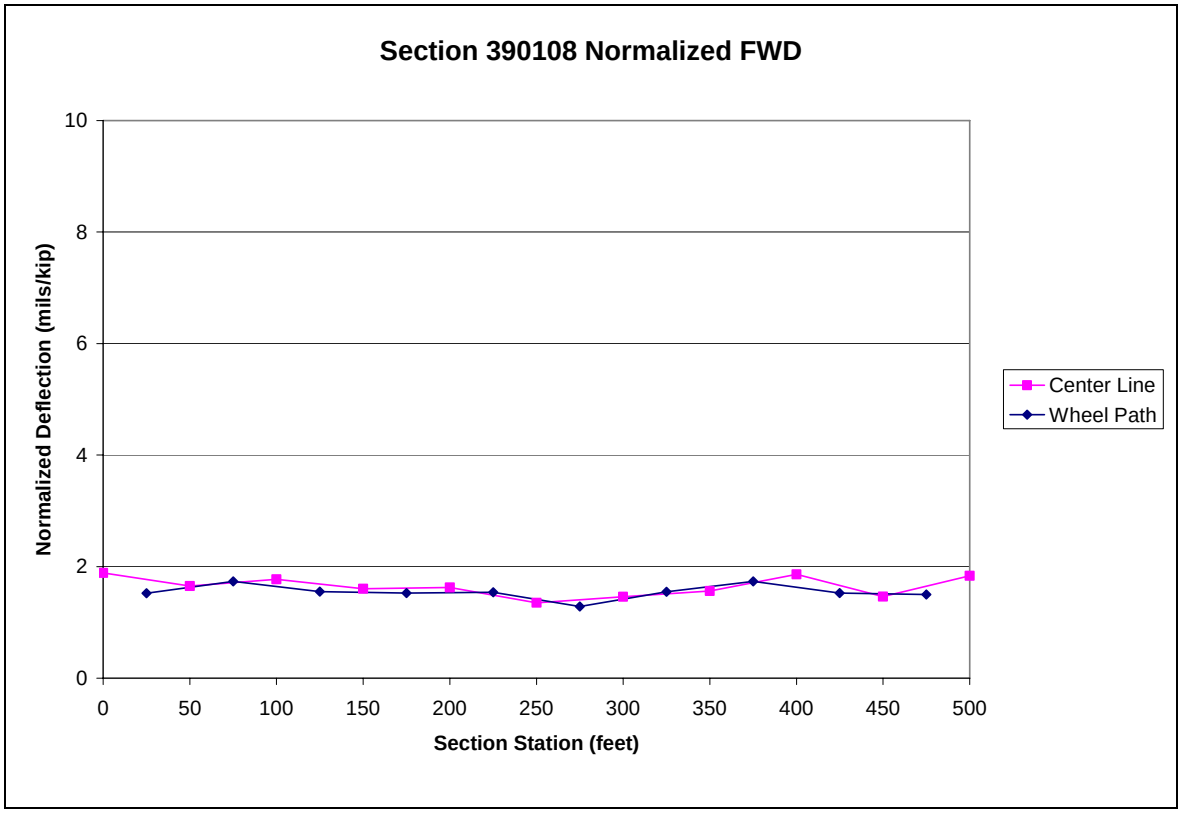
(1 in =2.54 cm; 53.9 psi = 372 kPa, 80.0 psi=552 kPa, 109.2 psi = 753 kPa)



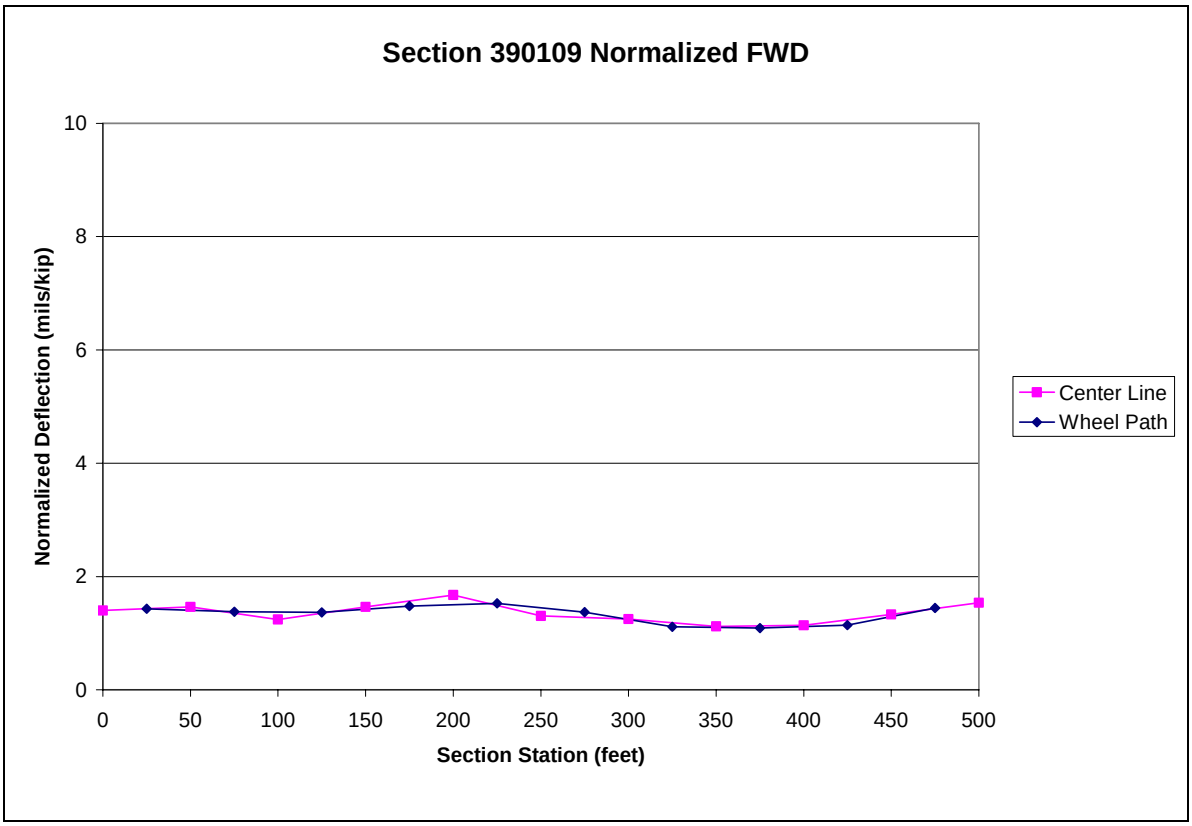
(1 in =2.54 cm; 55.2 psi = 381 kPa, 80.8 psi=557 kPa, 110.2 psi = 760 kPa)

Appendix K Normalized FWD Plots (At time of forensic study)

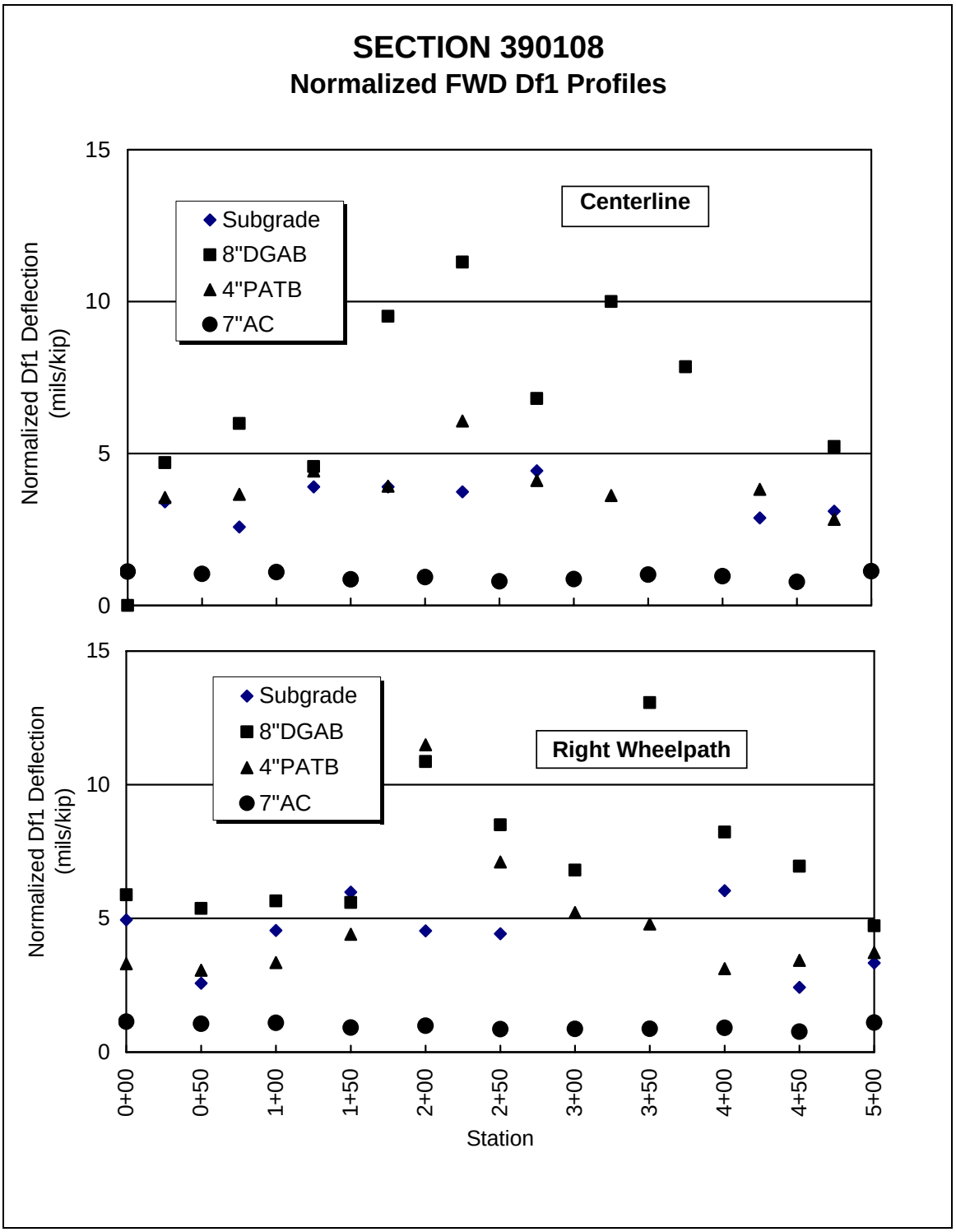

Section 390108 Normalized FWD
Normalized Deflection (mils/kip)
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
450
500
Section Station (feet)
Center Line
Wheel Path


Section 390108 Normalized FWD
Normalized Deflection (mils/kip)
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
450
500
Section Station (feet)
Center Line
Wheel Path

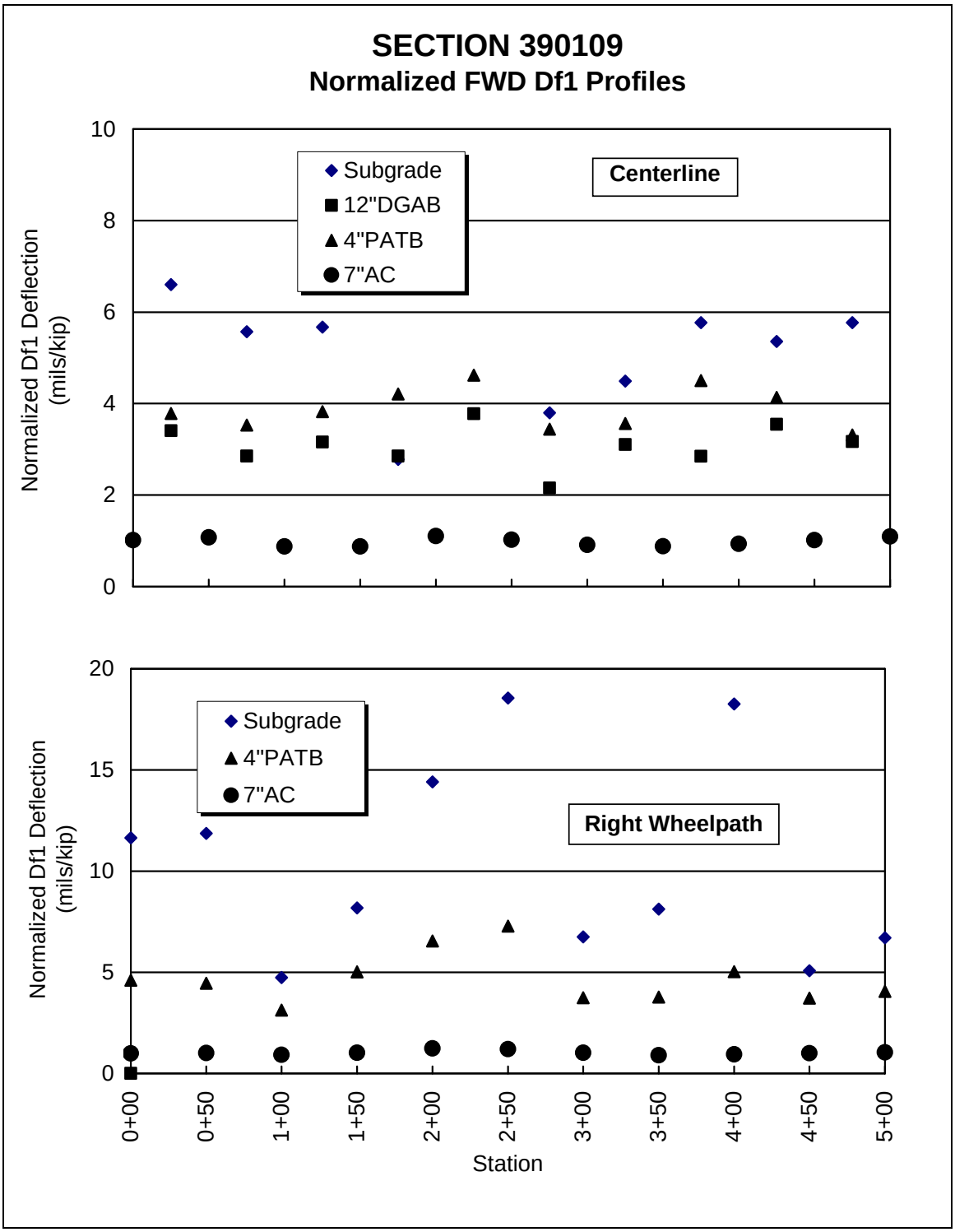
(


Section 390109 Normalized FWD
Normalized Deflection (mils/kip)
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
450
500
Section Station (feet)
Center Line
Wheel Path

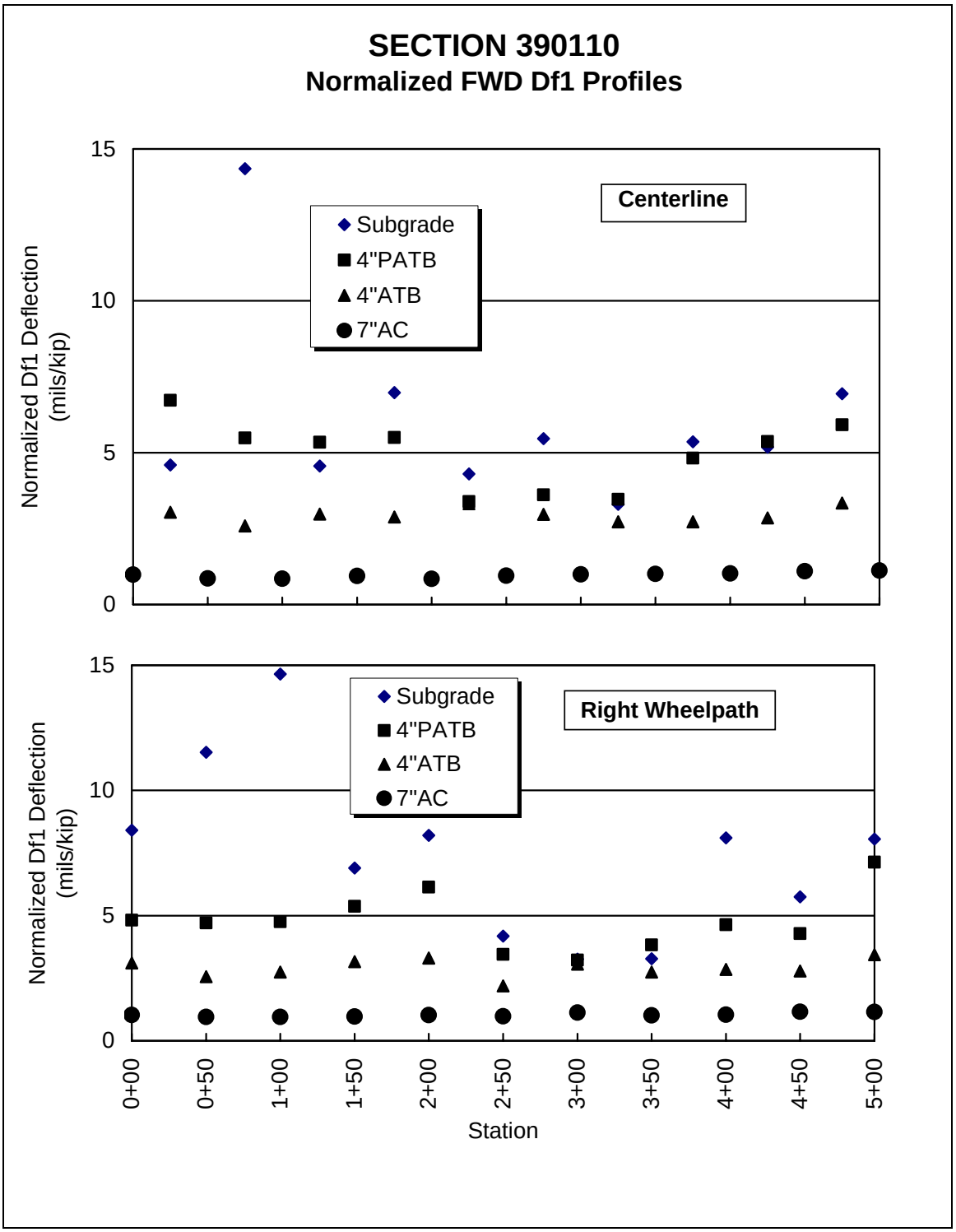
Appendix L Normalized FWD Plots (At time of construction)



(1 mil/kip = 5.71×10^{-9} m/N = 5.71 nm/N; 8" = 20.3 cm, 4" = 10.2 cm, 7" = 17.8 cm)



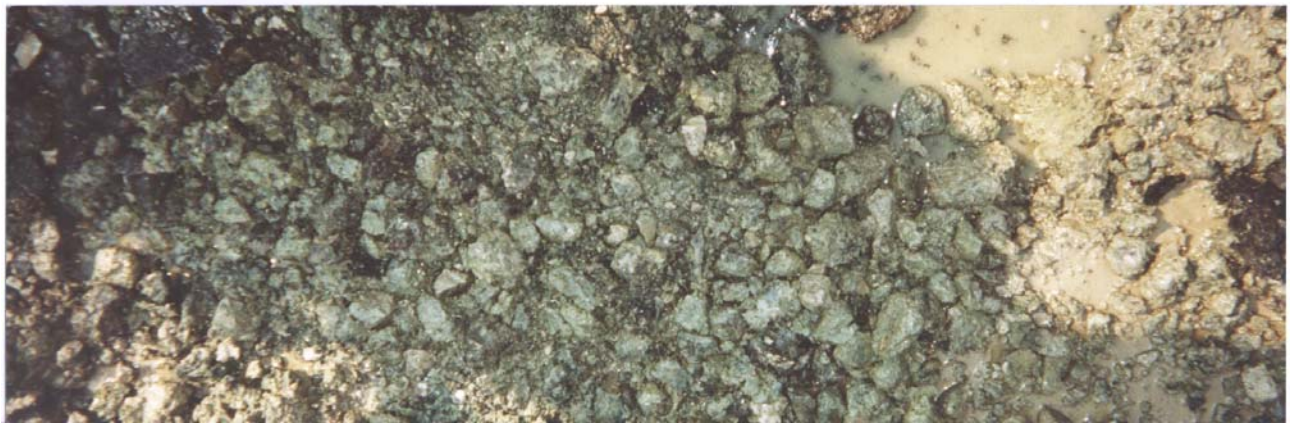
(1 mil/kip = 5.71×10^{-9} m/N = 5.71 nm/N; 12” = 30.5 cm, 4” = 10.2 cm, 7” = 17.8 cm)



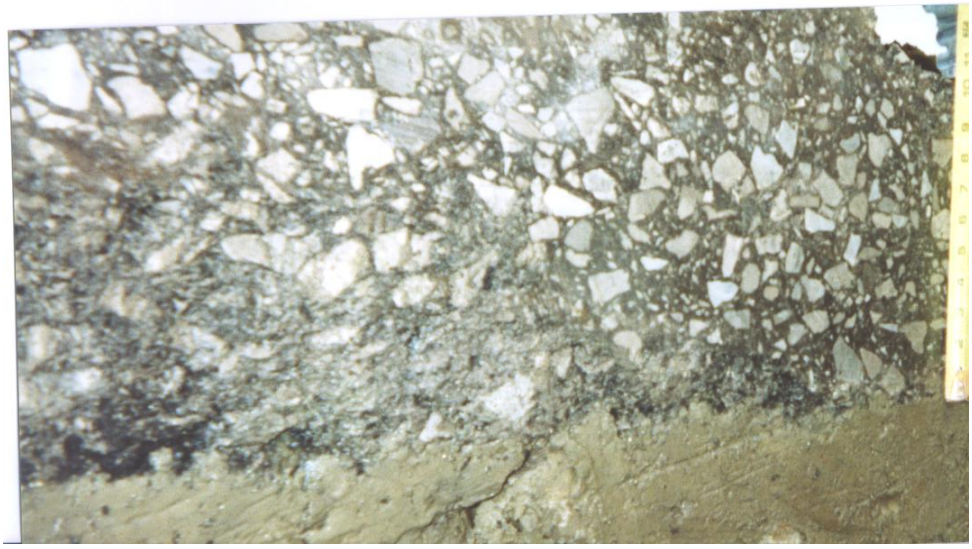
(1 mil/kip = 5.71×10^{-9} m/N = 5.71 nm/N; 4" = 10.2 cm, 7" = 17.8 cm)

Appendix M Trench Pictures

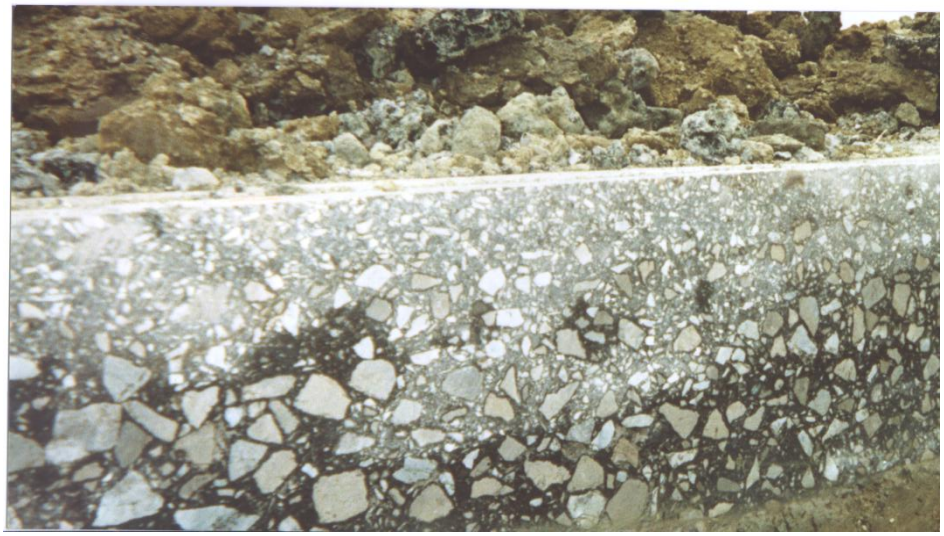
SECTION 390103 Trench #1



SECTION 390103 Trench # 2

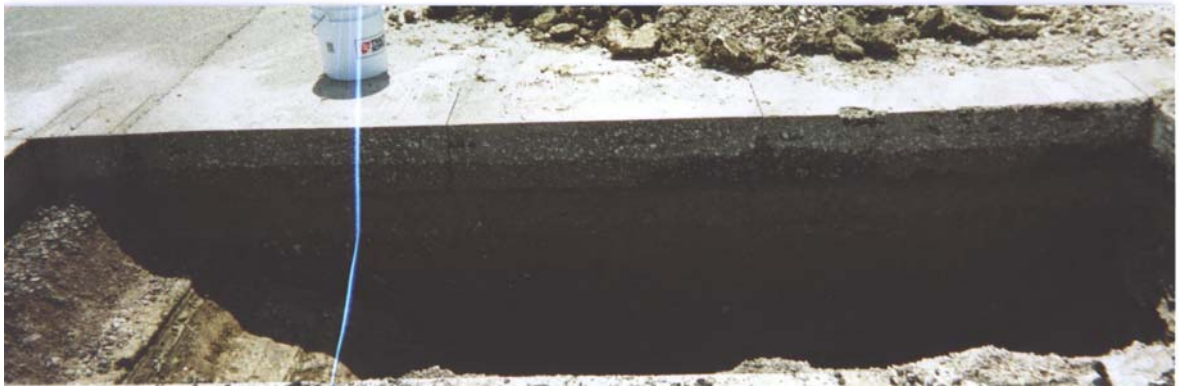


SECTION 390103 Trench # 3



SECTION 390108 Trench # 1

SEC 108
TRENCH 1
08/20/02



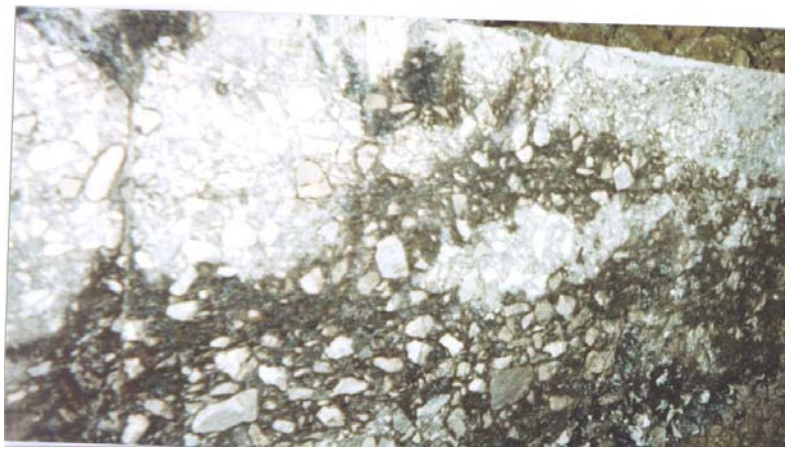
SECTION 390108 Trench # 2

SECTION 390109 Trench # 1

SEC. 109
TRENCH#1
08/15/02

SECTION 390109 Trench # 2

SECTION 390110 Trench # 1



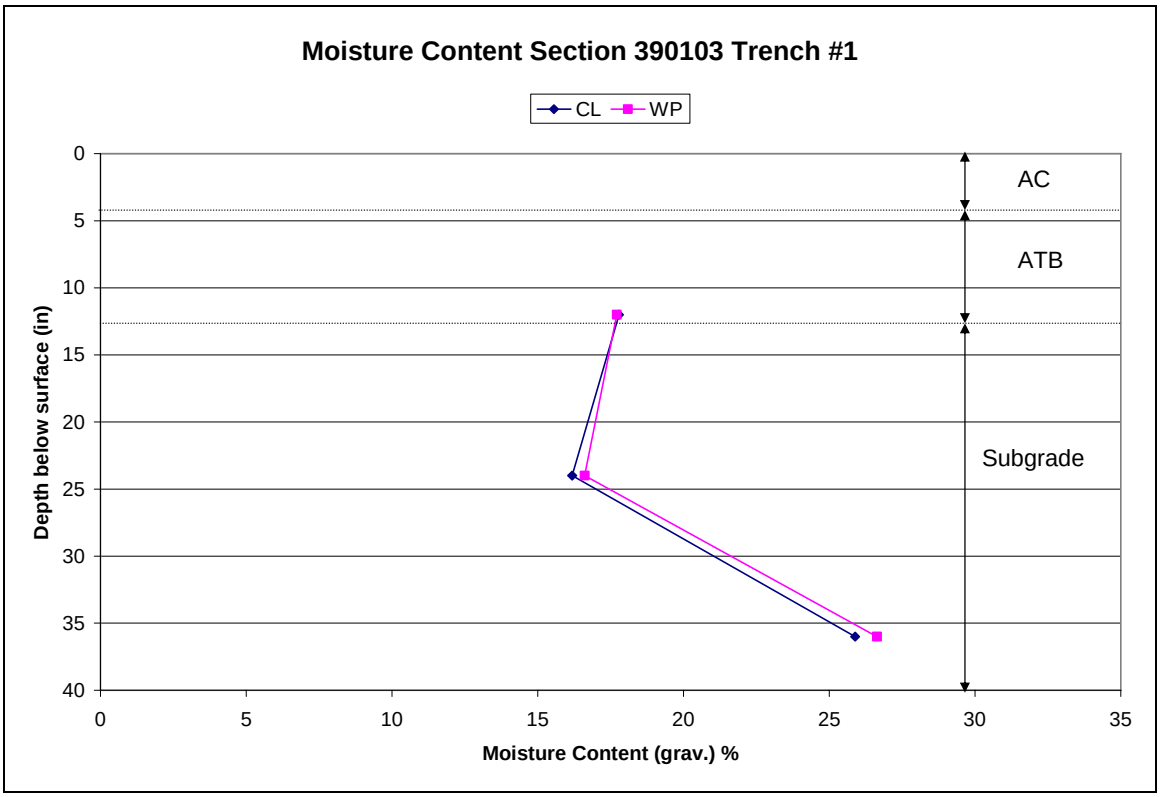
SECTION 390110 Trench #2

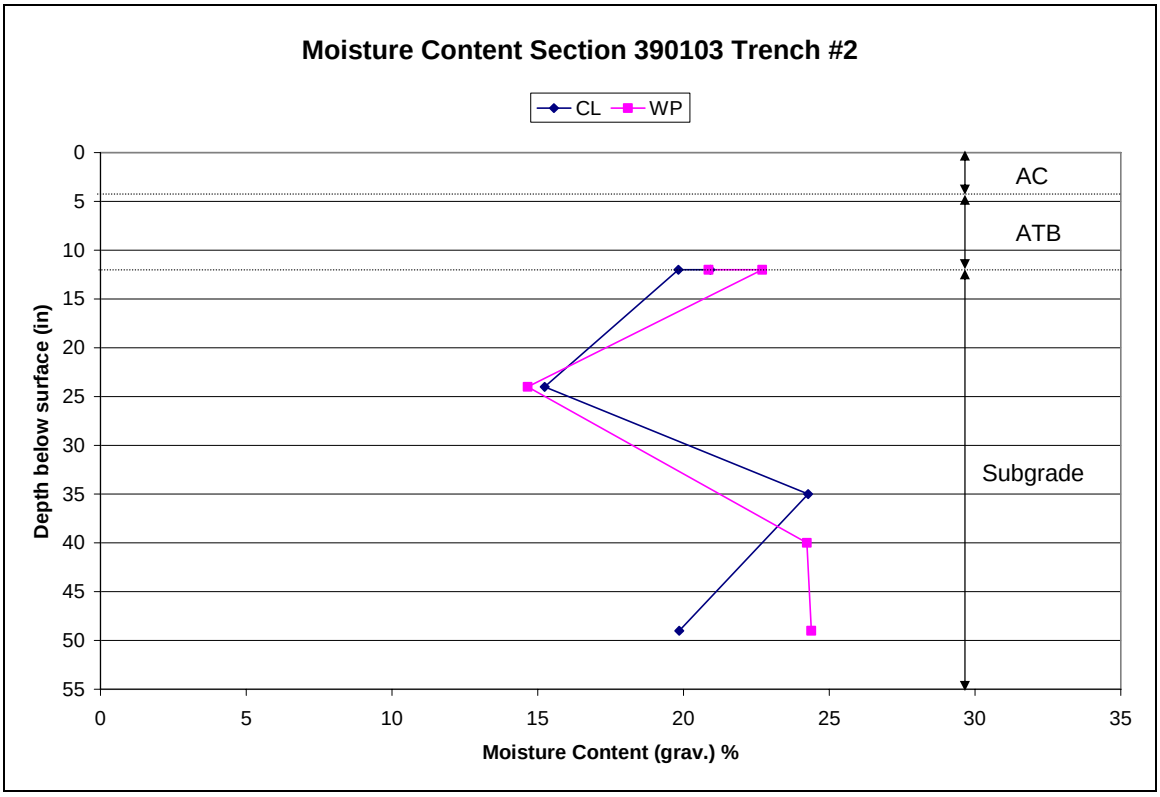
SEC. 110
TRENCH #2
08/15/02

SEC. 110
TRENCH #2
08/15/02

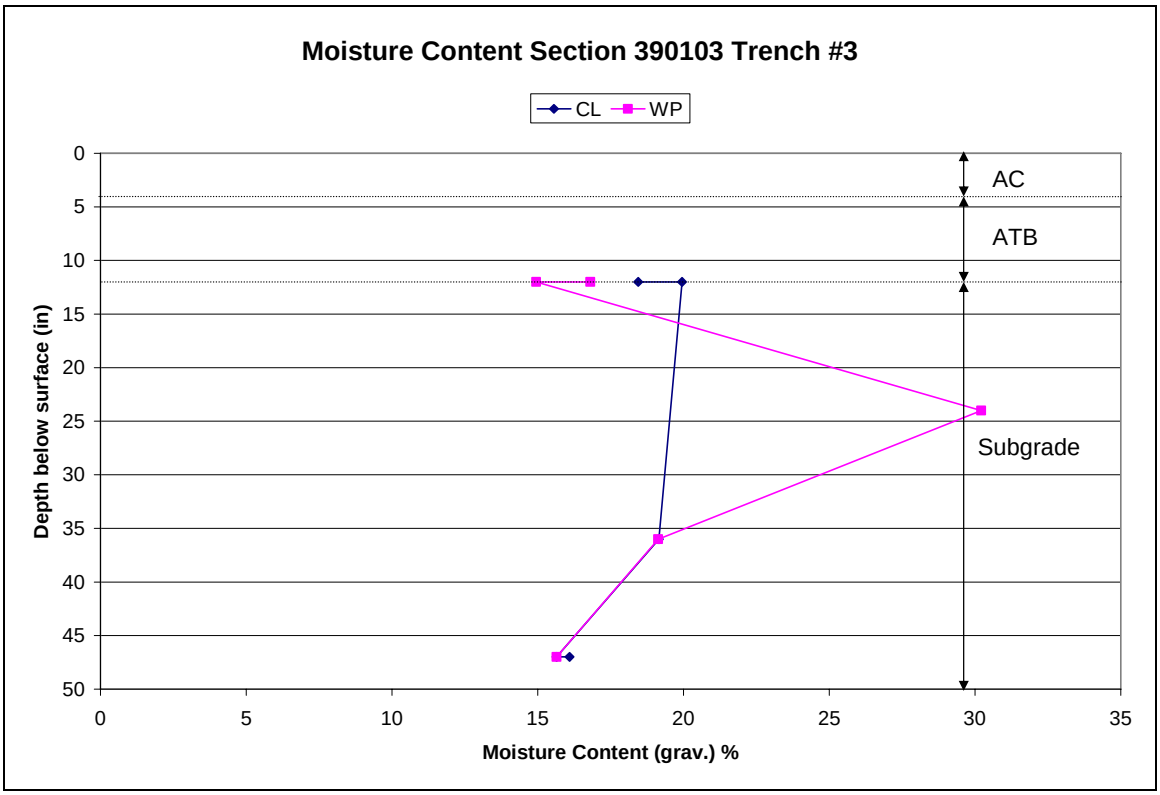
SECTION 390110 Trench # 3

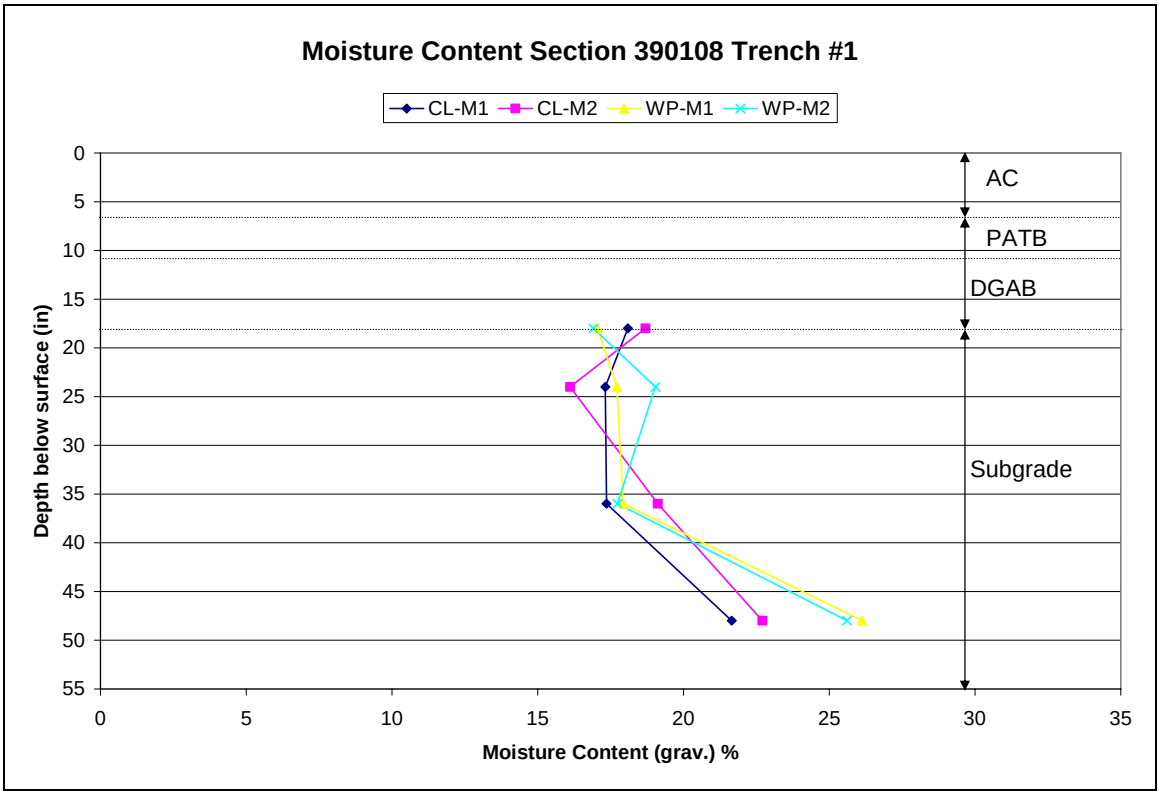
Appendix N Moisture Content (from collected soil samples)


Moisture Content Section 390103 Trench #1
CL
WP
AC
ATB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40

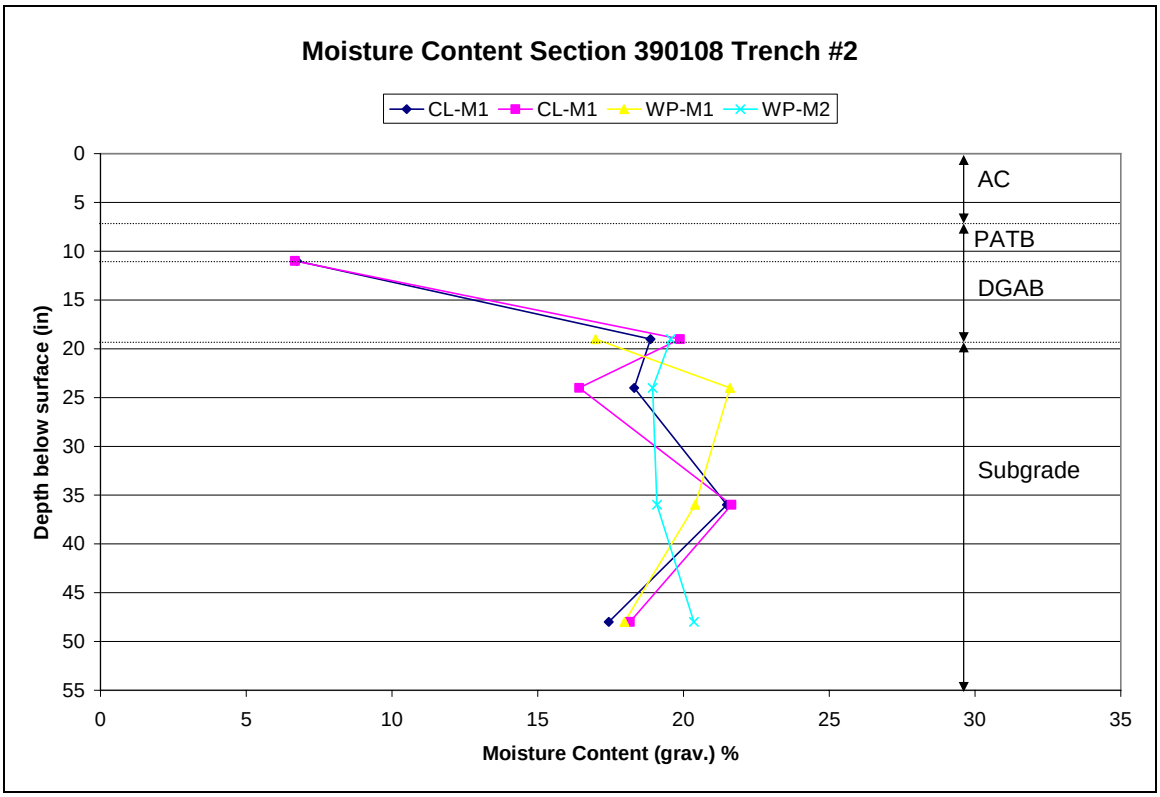

Moisture Content Section 390103 Trench #2
CL
WP
AC
ATB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50
55

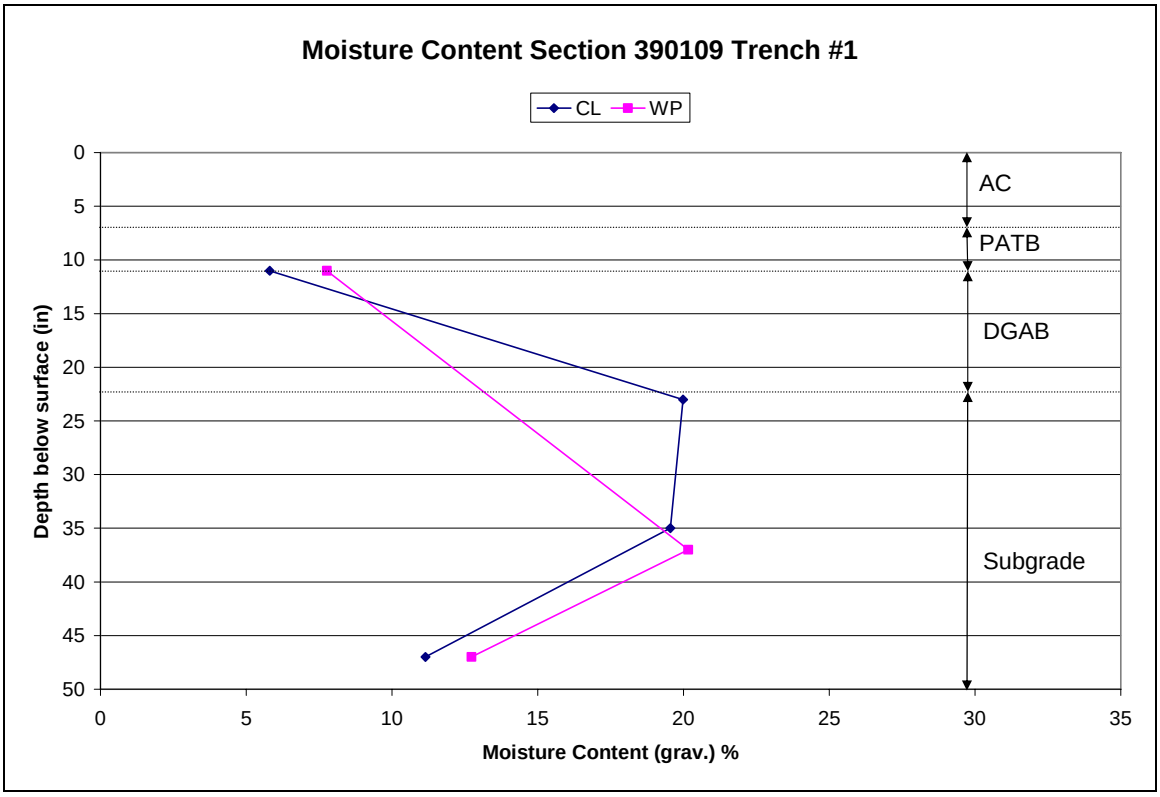
(1 in = 2.54 cm)


Moisture Content Section 390103 Trench #3
CL
WP
AC
ATB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50

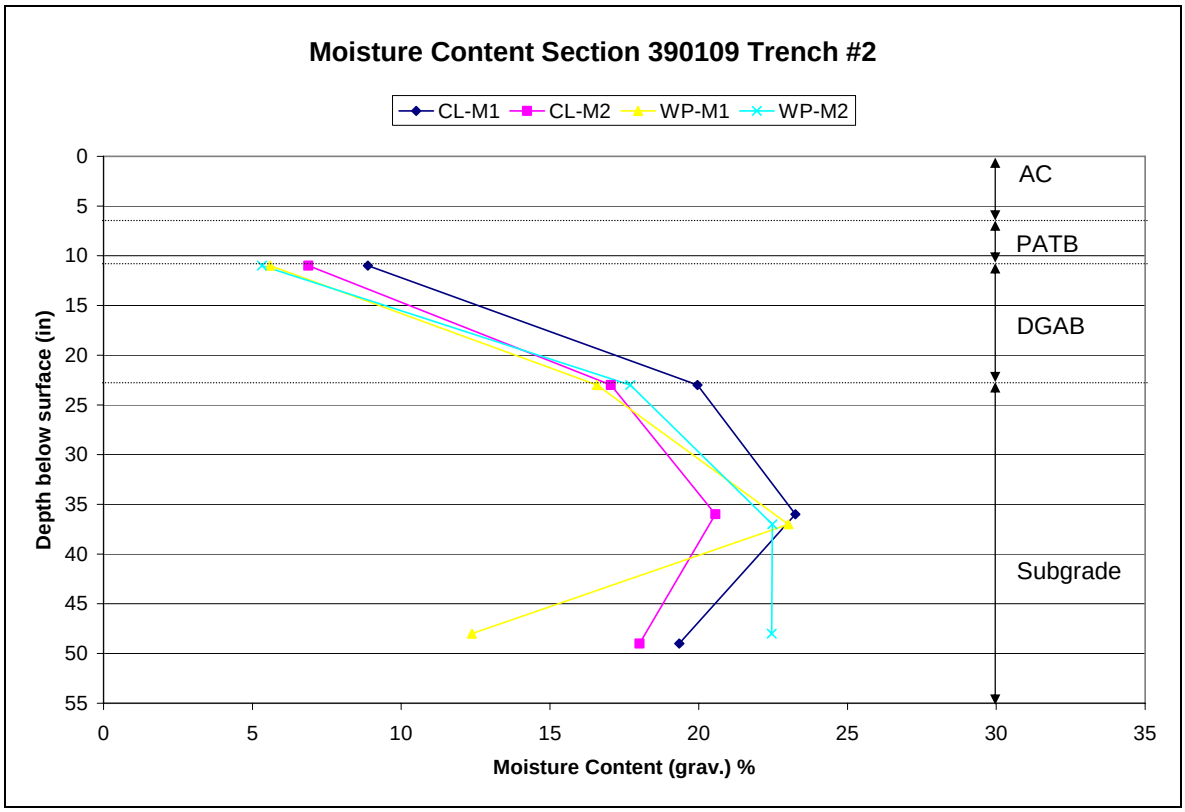

Moisture Content Section 390108 Trench #1
CL-M1
CL-M2
WP-M1
WP-M2
AC
PATB
DGAB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50
55

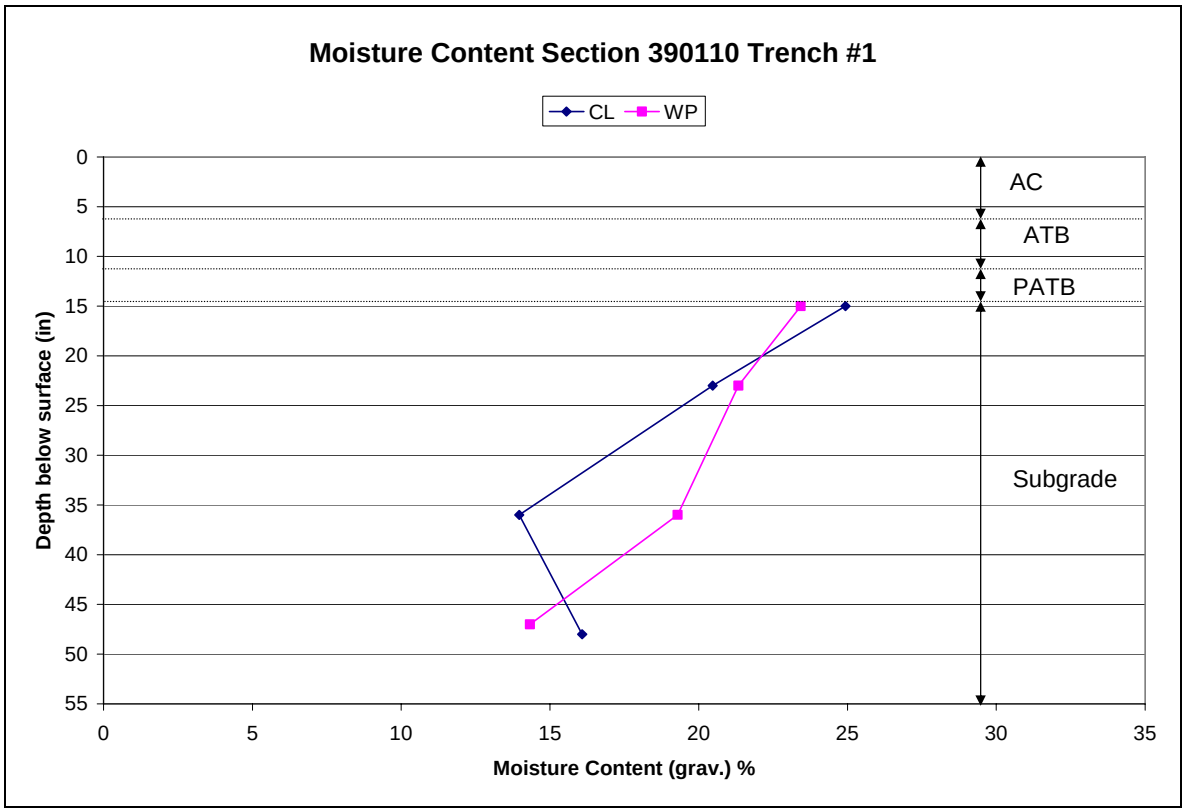
(1 in = 2.54 cm)


Moisture Content Section 390108 Trench #2
CL-M1
CL-M1
WP-M1
WP-M2
Depth below surface (in)
Moisture Content (grav.) %
AC
PATB
DGAB
Subgrade
0
5
10
15
20
25
30
35
40
45
50
55
0
5
10
15
20
25
30
35

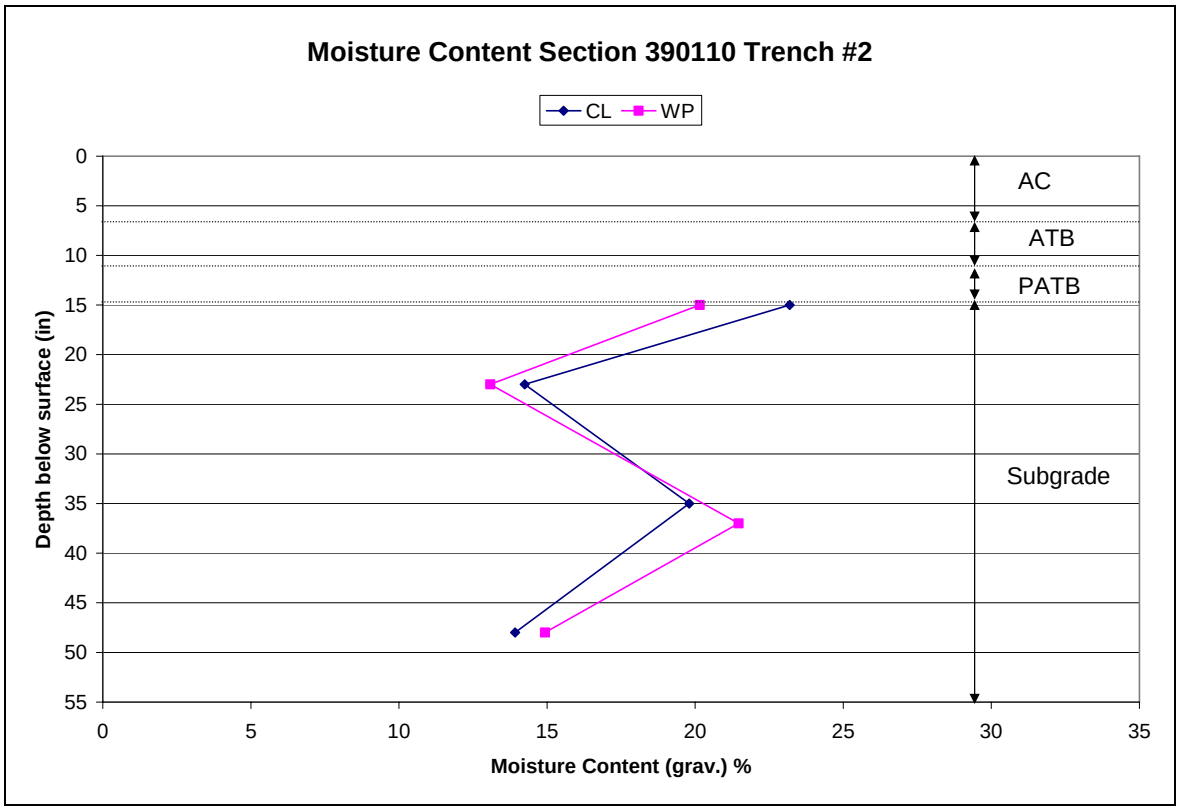

Moisture Content Section 390109 Trench #1
CL
WP
Depth below surface (in)
Moisture Content (grav.) %
AC
PATB
DGAB
Subgrade
0
5
10
15
20
25
30
35
40
45
50
0
5
10
15
20
25
30
35

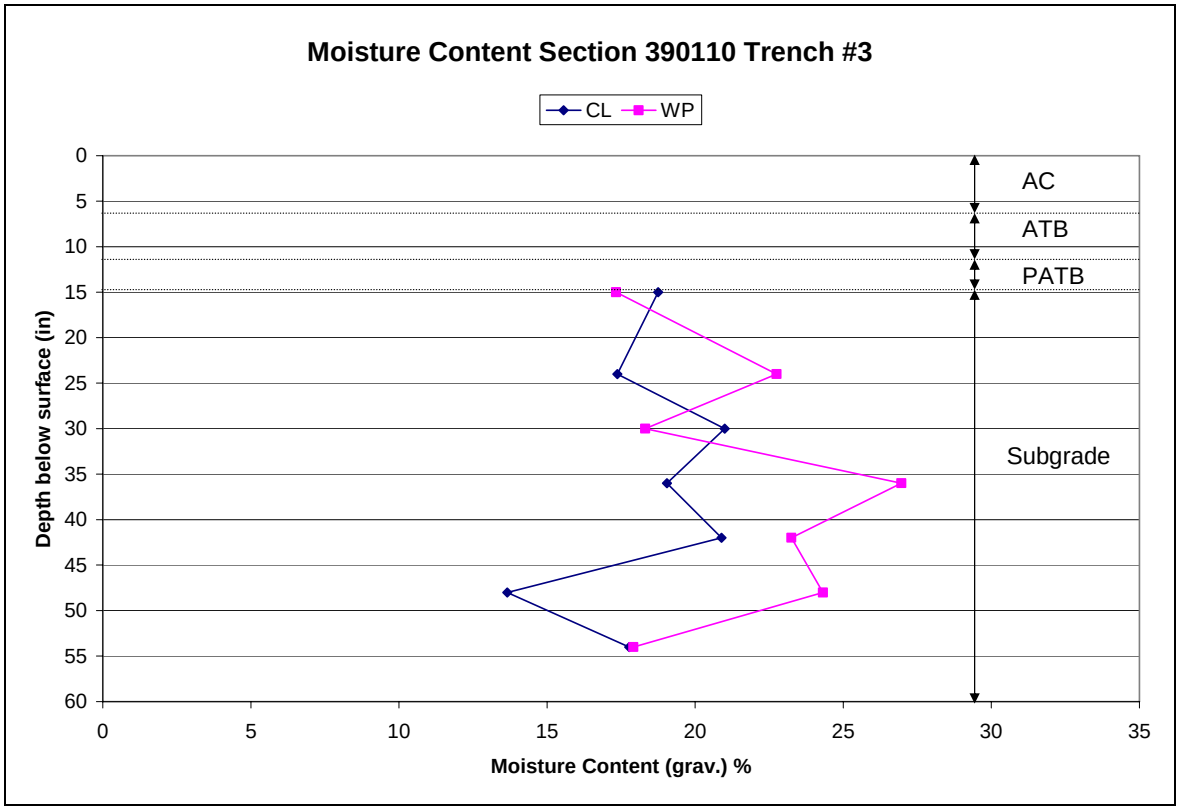
(1 in = 2.54 cm)


Moisture Content Section 390109 Trench #2
CL-M1
CL-M2
WP-M1
WP-M2
AC
PATB
DGAB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50
55


Moisture Content Section 390110 Trench #1
CL
WP
AC
ATB
PATB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50
55

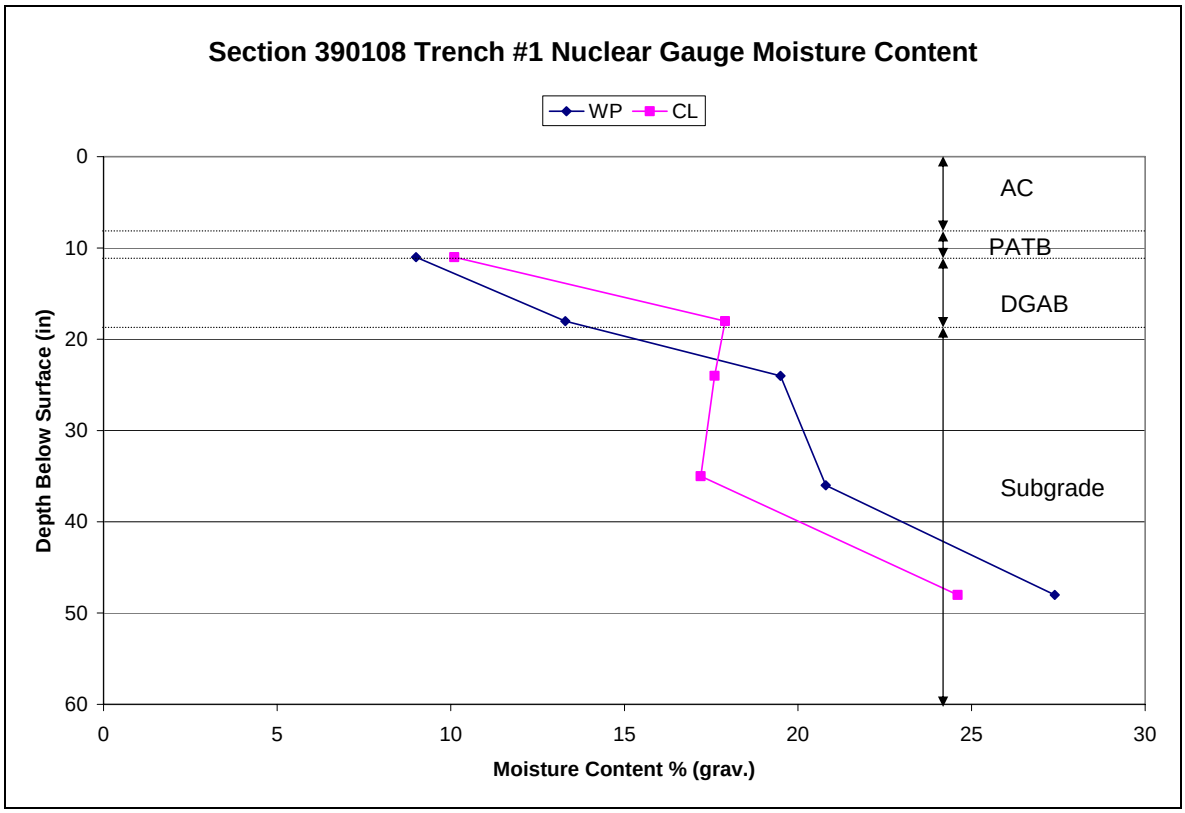
(1 in = 2.54 cm)

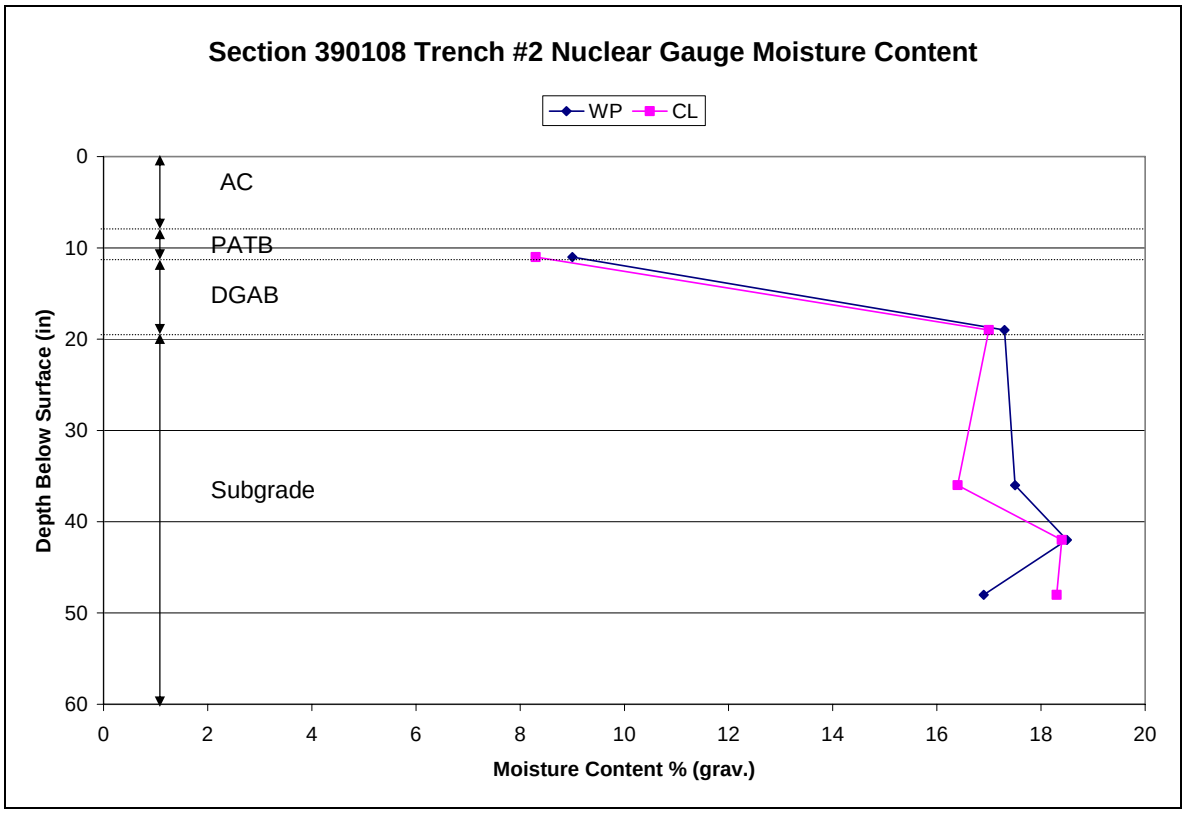

Moisture Content Section 390110 Trench #2
CL
WP
AC
ATB
PATB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50
55


Moisture Content Section 390110 Trench #3
CL
WP
AC
ATB
PATB
Subgrade
Depth below surface (in)
Moisture Content (grav.) %
0
5
10
15
20
25
30
35
40
45
50
55
60

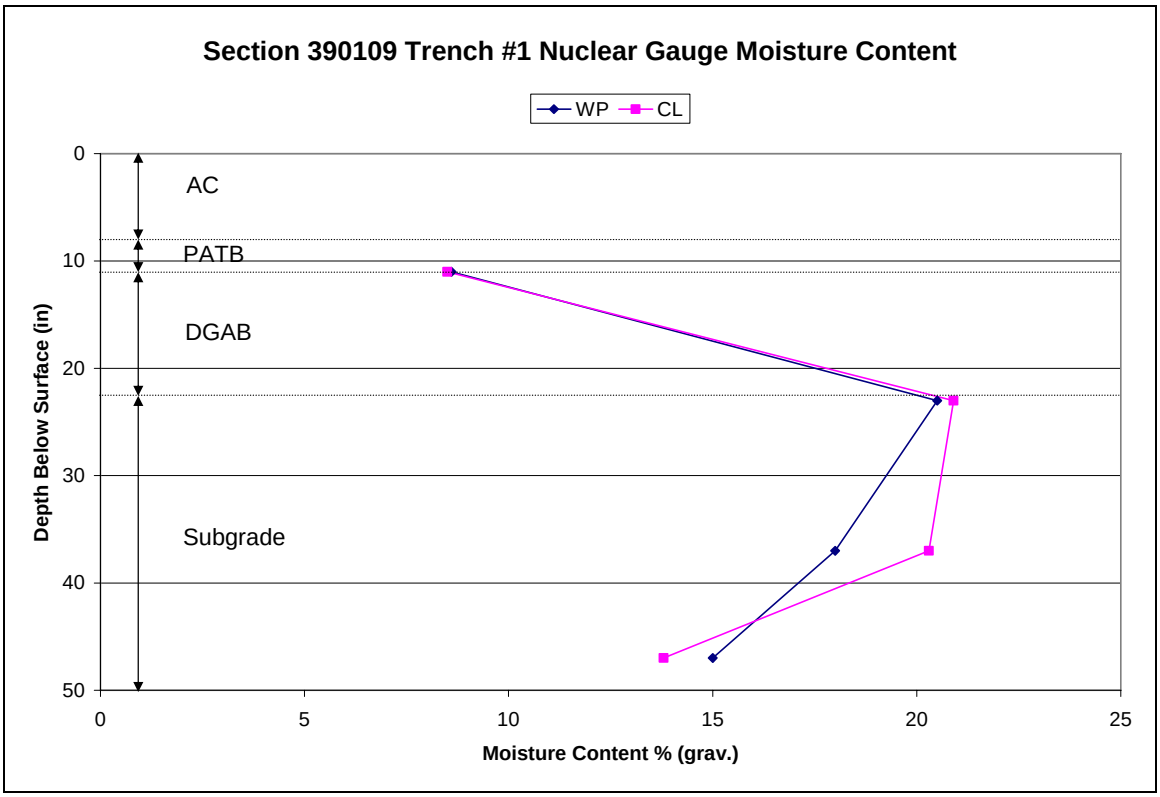
(1 in = 2.54 cm)

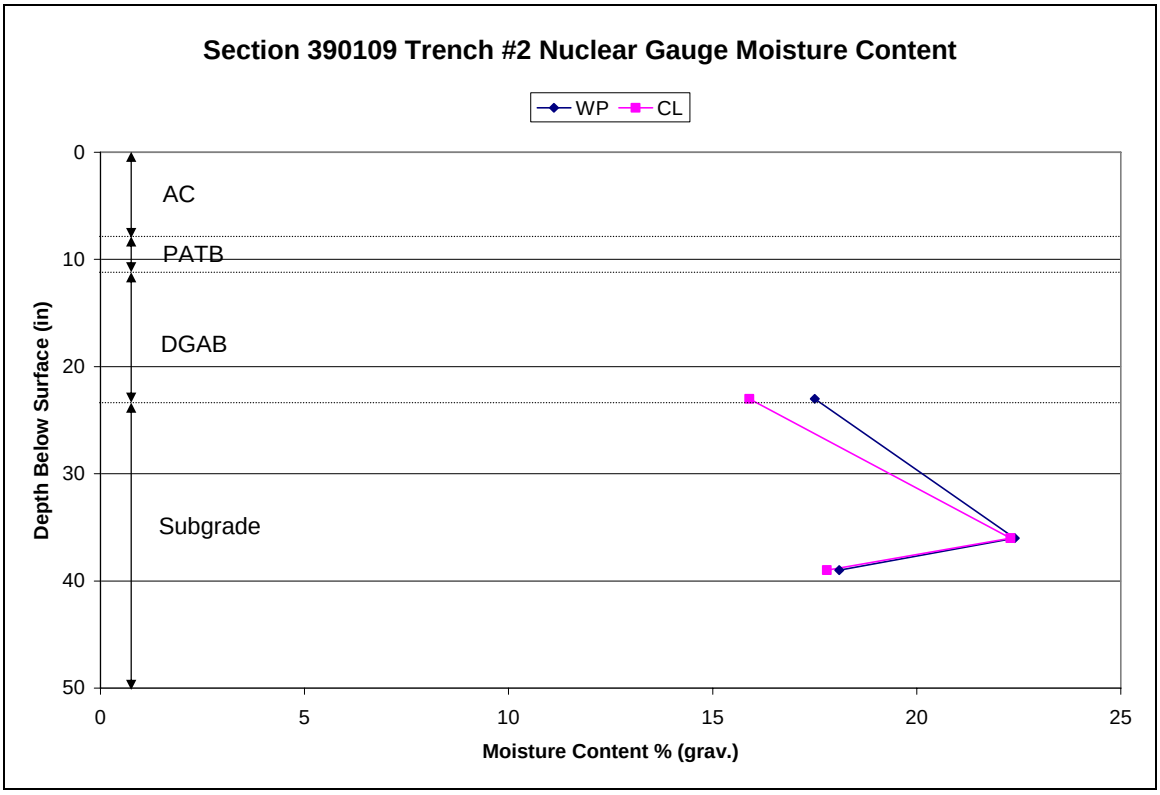
Appendix O: Nuclear Gauge Moisture Content Plots


Section 390108 Trench #1 Nuclear Gauge Moisture Content
WP
CL
AC
PATB
DGAB
Subgrade
Depth Below Surface (in)
Moisture Content % (grav.)
0
10
20
30
40
50
60
0
5
10
15
20
25
30

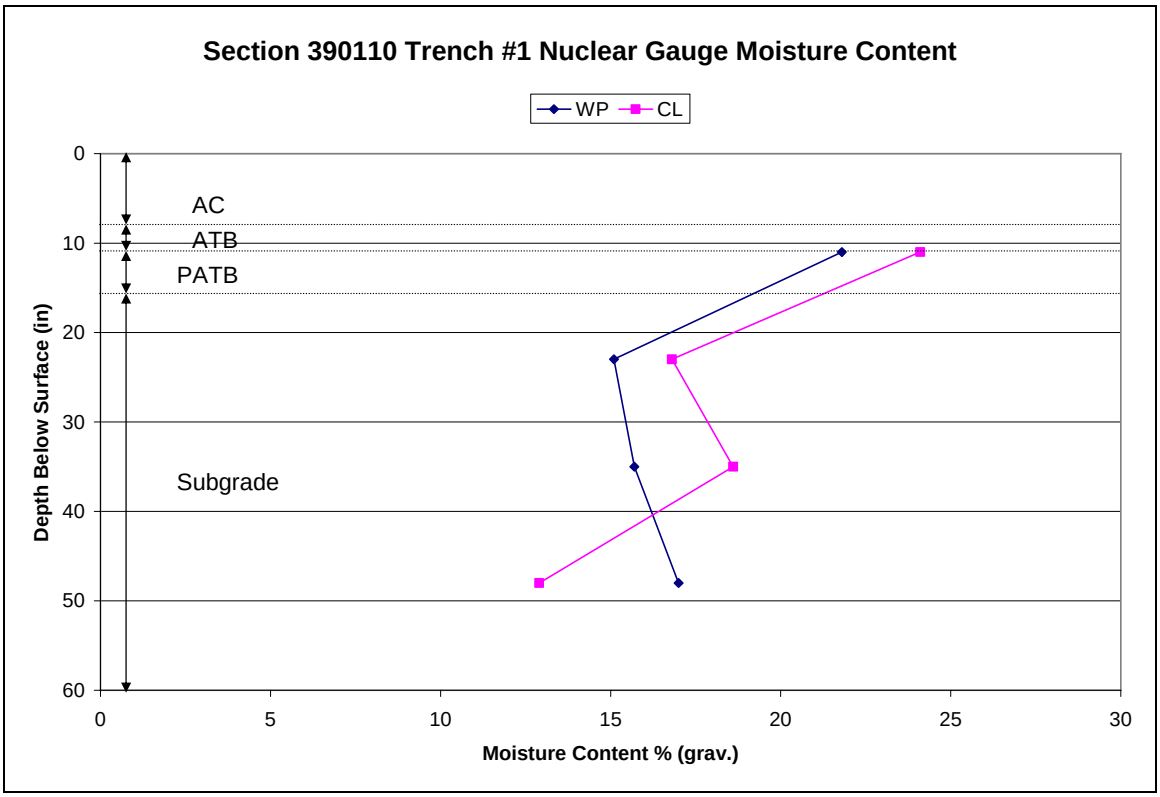

Section 390108 Trench #2 Nuclear Gauge Moisture Content
WP
CL
AC
PATB
DGAB
Subgrade
Depth Below Surface (in)
Moisture Content % (grav.)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
18
20

(1 in = 2.54 cm)


Section 390109 Trench #1 Nuclear Gauge Moisture Content
WP
CL
AC
PATB
DGAB
Subgrade
Depth Below Surface (in)
0
10
20
30
40
50
0
5
10
15
20
25
Moisture Content % (grav.)


Section 390109 Trench #2 Nuclear Gauge Moisture Content
WP
CL
AC
PATB
DGAB
Subgrade
Depth Below Surface (in)
0
10
20
30
40
50
0
5
10
15
20
25
Moisture Content % (grav.)

(1 in = 2.54 cm)


Section 390110 Trench #1 Nuclear Gauge Moisture Content
WP
CL
AC
ATB
PATB
Subgrade
Depth Below Surface (in)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
Moisture Content % (grav.)

(1 in = 2.54 cm)

Appendix P Nuclear Gauge Data

	108-1-11"		108-1-18"		108-1-24"		108-1-35" (CL-35", WP-36")		108-1-48"	
	CL	WP	CL	WP	CL	WP	CL	WP	CL	WP
ρ_{wet} (lb/cf)	138.8	145.9	133.3	132.9	131.4	131.1	128.1	126.4	123.4	122.7
ρ_{wet} (g/cc)	2.22	2.34	2.14	2.13	2.10	2.10	2.05	2.02	1.98	1.97
ρ_{dry}(lb/cf)	126.0	133.9	113.1	112.4	111.7	110.0	109.3	104.6	99.1	96.3
ρ_{dry}(g/cc)	2.02	2.14	1.81	1.80	1.79	1.76	1.75	1.68	1.59	1.54
Moisture content %	10.1	9.0	17.9	13.3	17.6	19.5	17.2	20.8	24.6	27.4
Volumetric MC %	20.4	19.3	32.4	23.9	31.5	34.4	30.1	34.9	39.0	42.3
e	0.338	0.259	0.490	0.500	0.509	0.532	0.542	0.611	0.701	0.750
S (%)	80.7	93.9	98.6	71.9	93.4	98.9	85.7	91.8	94.8	98.6

	108-2-11"		108-2-19"		108-2-42"		108-2-36"		108-2-48"	
	CL	WP	CL	WP	CL	WP	CL	WP	CL	WP
ρ_{wet} (lb/cf)	137.8	144.7	130.9	134.9	131.5	131.6	132.2	131.6	126.7	125.6
ρ_{wet} (g/cc)	2.21	2.32	2.10	2.16	2.11	2.11	2.12	2.11	2.03	2.01
ρ_{dry}(lb/cf)	127.2	132.7	111.8	115.0	111.0	111.9	111.7	111.0	107.0	104.0
ρ_{dry}(g/cc)	2.04	2.13	1.79	1.84	1.78	1.79	1.79	1.78	1.71	1.67
Moisture content %	8.3	9.0	17.0	17.3	16.4	17.5	18.4	18.5	18.3	20.7
Volumetric MC %	16.9	19.1	30.4	31.9	29.2	31.4	32.9	32.9	31.4	34.5
e	0.325	0.270	0.508	0.466	0.519	0.506	0.509	0.519	0.575	0.621
S (%)	68.9	89.9	90.4	100.3	85.4	93.3	97.6	96.3	85.9	90.0

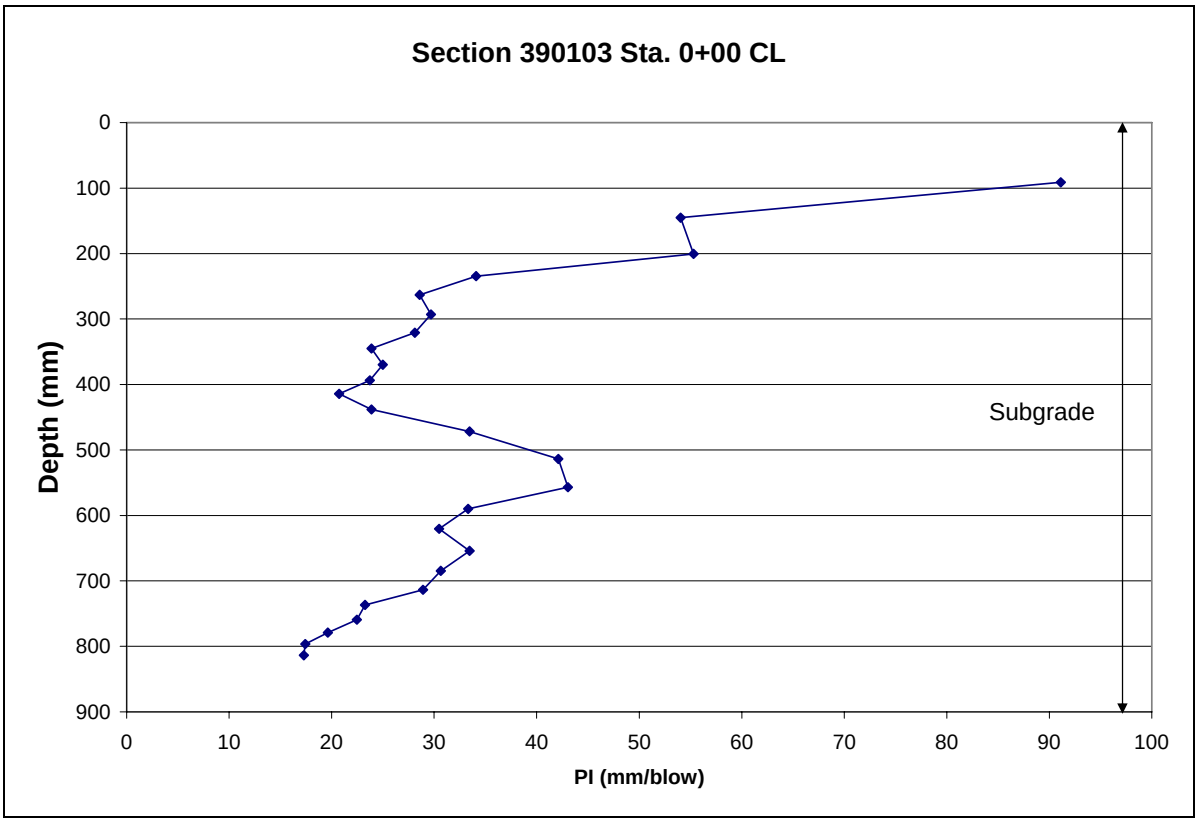
	109-1-11"		109-1-23"		109-1-37"		109-1-47"	
	CL	WP	CL	WP	CL	WP	CL	WP
ρ_{wet} (lb/cf)	131.3	126.4	130.3	131.6	132.8	134.8	136.5	137.9
ρ_{wet} (g/cc)	2.10	2.02	2.09	2.11	2.13	2.16	2.19	2.21
ρ_{dry}(lb/cf)	120.9	116.4	107.8	109.2	110.4	114.3	120.0	119.9
ρ_{dry}(g/cc)	1.94	1.86	1.73	1.75	1.77	1.83	1.92	1.92
Moisture content %	8.5	8.6	20.9	20.5	20.3	18.0	13.8	15.0
Volumetric MC %	16.5	16.0	36.1	35.9	35.9	33.0	26.5	28.8
e	0.394	0.448	0.564	0.544	0.527	0.475	0.405	0.406
S (%)	58.2	51.8	100.1	101.8	104.0	102.4	92.1	99.8

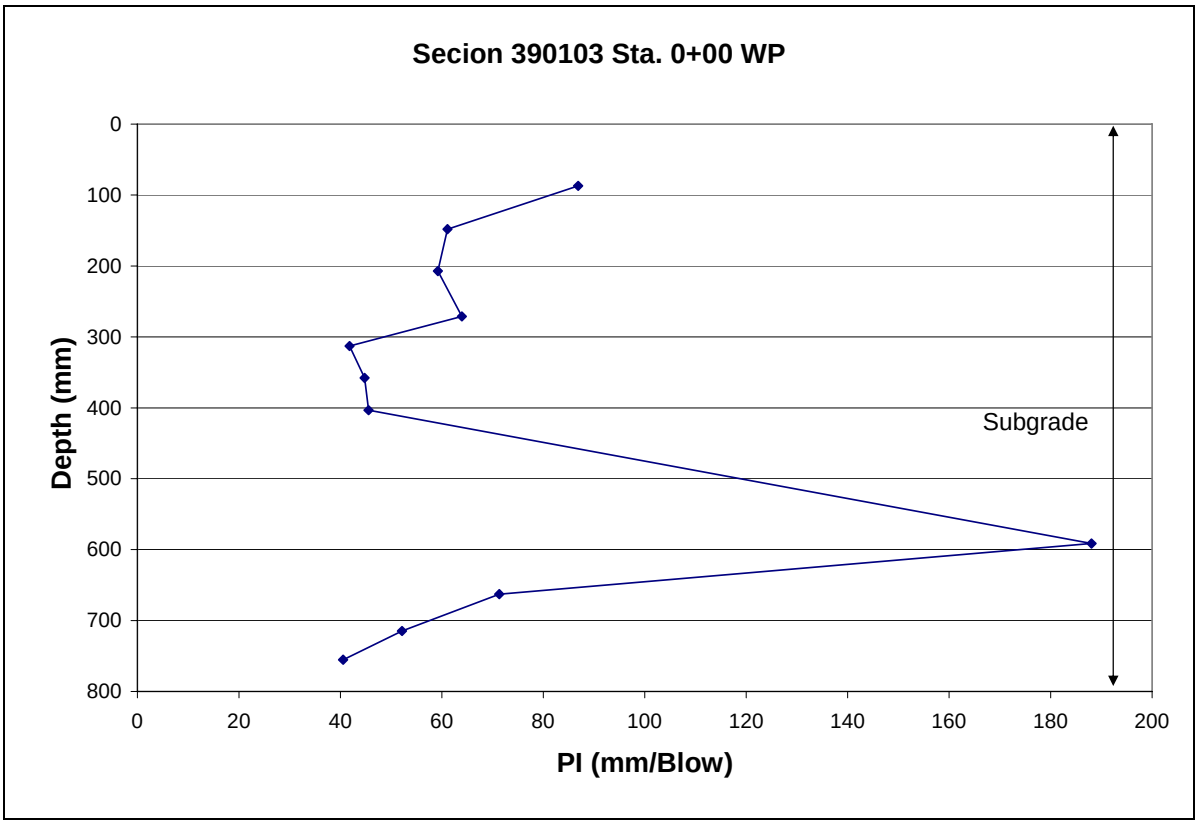
	109-2-23"		109-2-36"		109-2-49"	
	CL	WP	CL	WP	CL	WP
ρ_{wet} (lb/cf)	135.0	132.7	127.4	126.0	128.0	134.4
ρ_{wet} (g/cc)	2.16	2.13	2.04	2.02	2.05	2.15
ρ_{dry}(lb/cf)	116.4	112.9	104.2	102.9	108.6	113.8
ρ_{dry}(g/cc)	1.86	1.81	1.67	1.65	1.74	1.82
Moisture content %	15.9	17.5	22.3	22.4	17.8	18.1
Volumetric MC %	29.6	31.6	37.2	36.9	31.0	33.0
e	0.448	0.493	0.618	0.638	0.552	0.481
S (%)	95.8	95.8	97.5	94.8	87.0	101.6

	110-2-11"		110-2-23"		110-2-35"		110-2-48"	
	CL	WP	CL	WP	CL	WP	CL	WP
ρ_{wet} (lb/cf)	130.9	131.0	133.0	135.4	134.5	137.3	133.5	133.9
ρ_{wet} (g/cc)	2.10	2.10	2.13	2.17	2.15	2.20	2.14	2.14
ρ_{dry}(lb/cf)	105.5	107.6	113.0	117.7	113.4	118.7	118.3	114.4
ρ_{dry}(g/cc)	1.69	1.72	1.81	1.89	1.82	1.90	1.89	1.83
Moisture content %	24.1	21.8	16.8	15.1	18.6	15.7	12.9	17.0
Volumetric MC %	40.7	37.6	30.4	28.5	33.8	29.9	24.4	31.2
e	0.598	0.567	0.492	0.432	0.486	0.420	0.425	0.473
S (%)	108.9	103.9	92.3	94.3	103.2	100.9	82.0	97.0

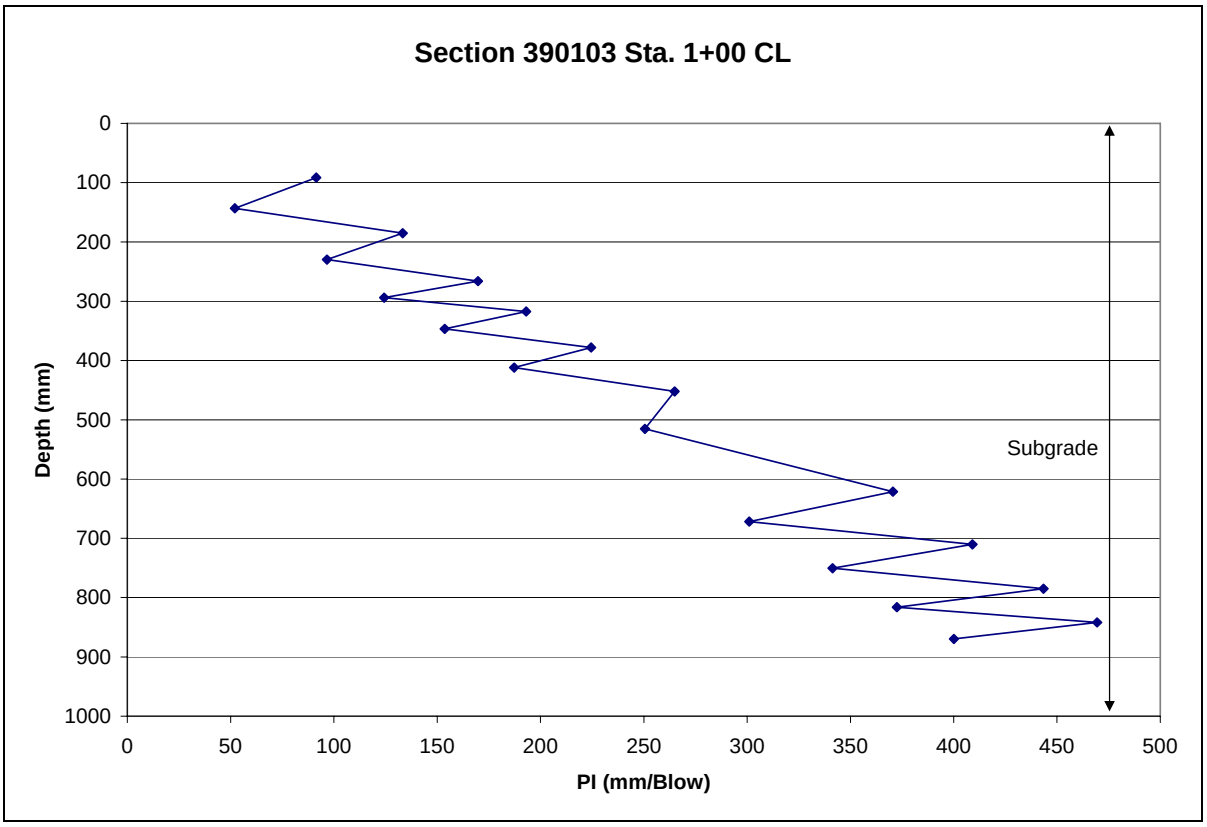
Appendix Q Dynamic Cone Penotrometer Tests

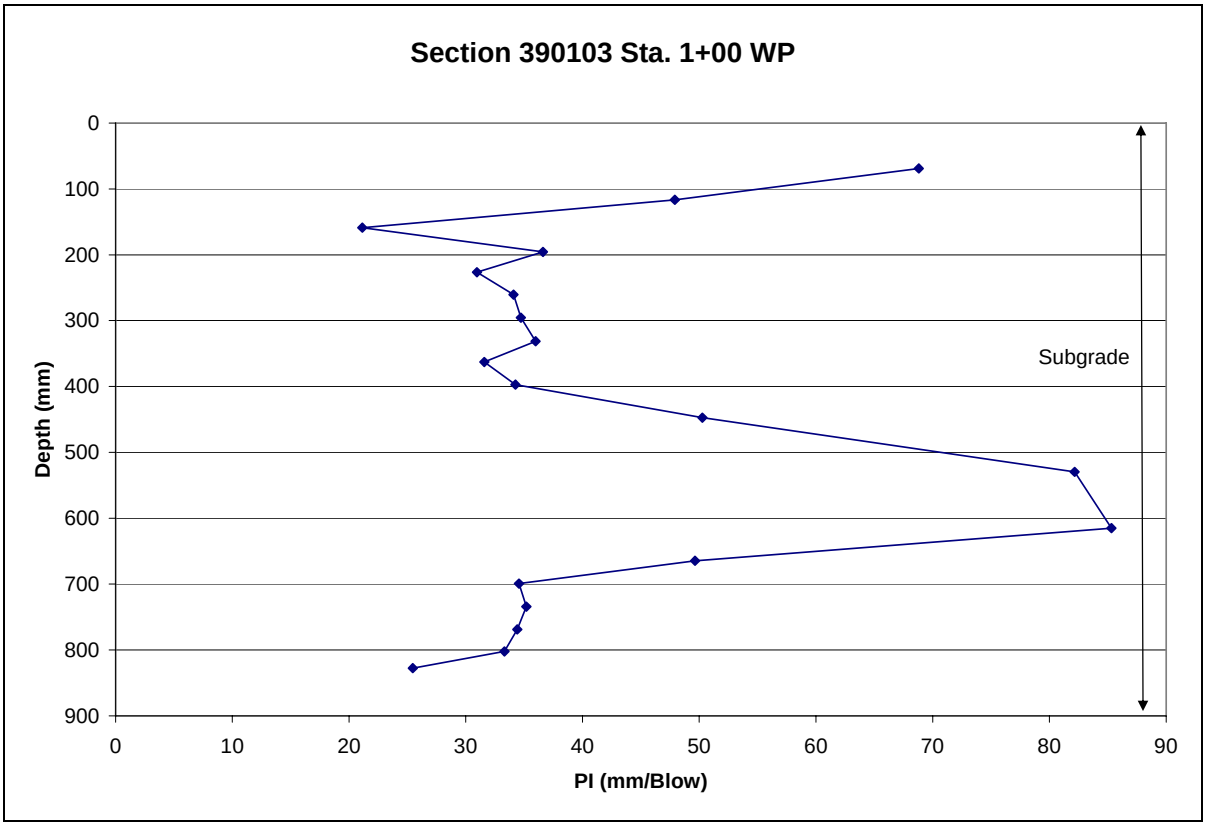
SECTION 390103


Section 390103 Sta. 0+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
100
PI (mm/blow)
Subgrade

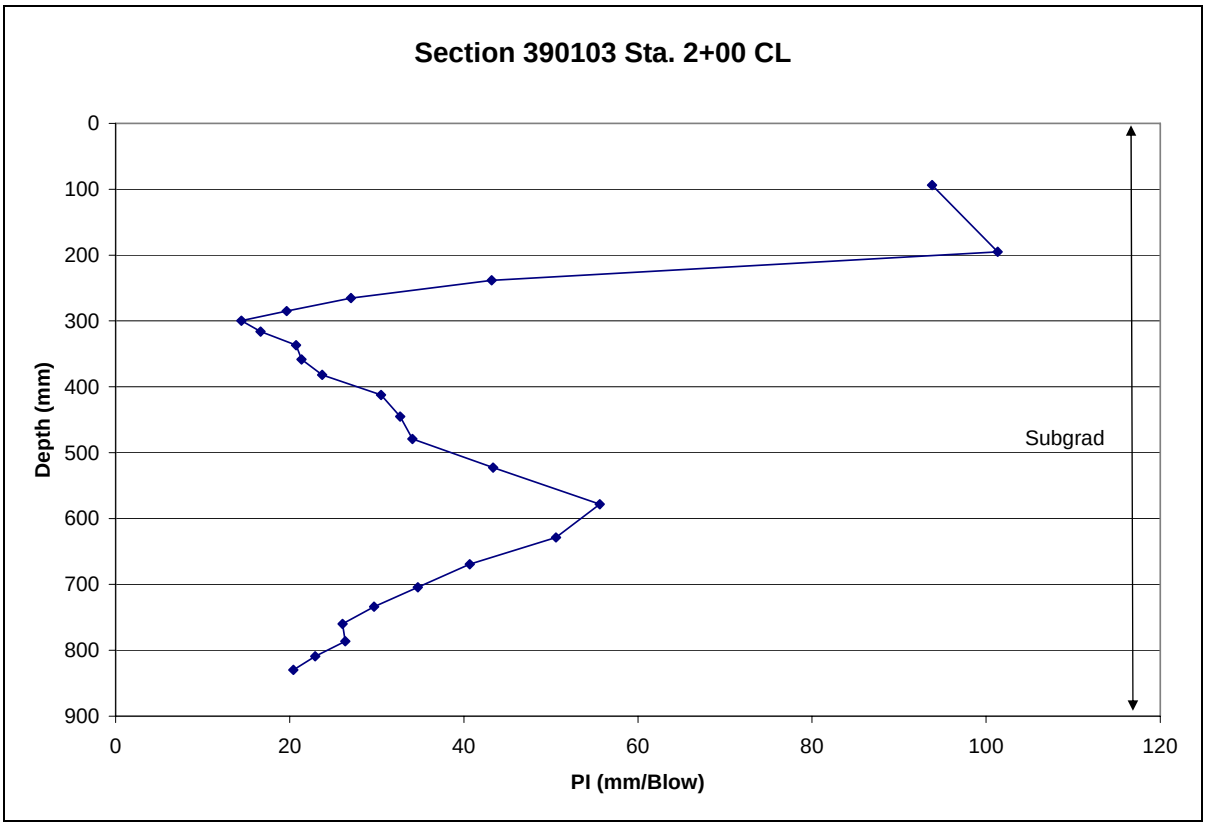

Secion 390103 Sta. 0+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
140
160
180
200
PI (mm/Blow)
Subgrade

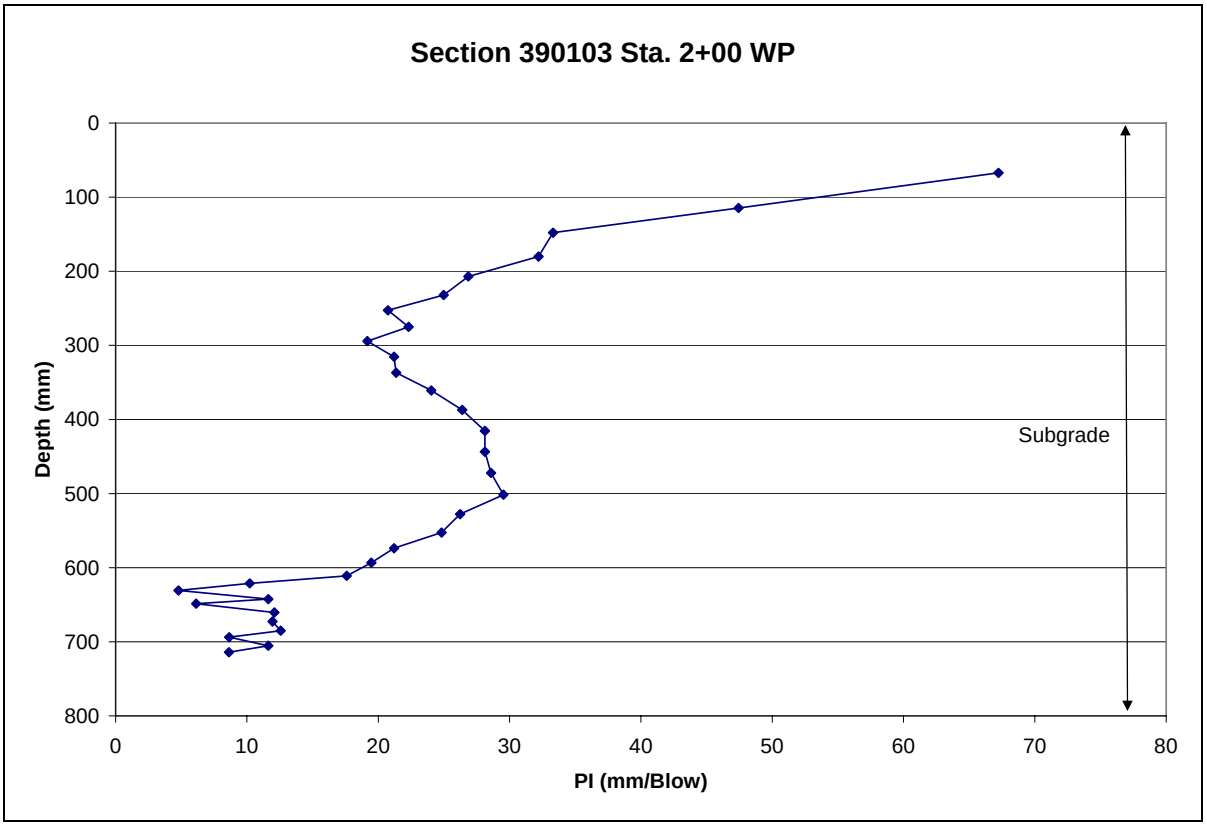
(25.4 mm = 1 in)


Section 390103 Sta. 1+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
300
350
400
450
500
PI (mm/Blow)
Subgrade

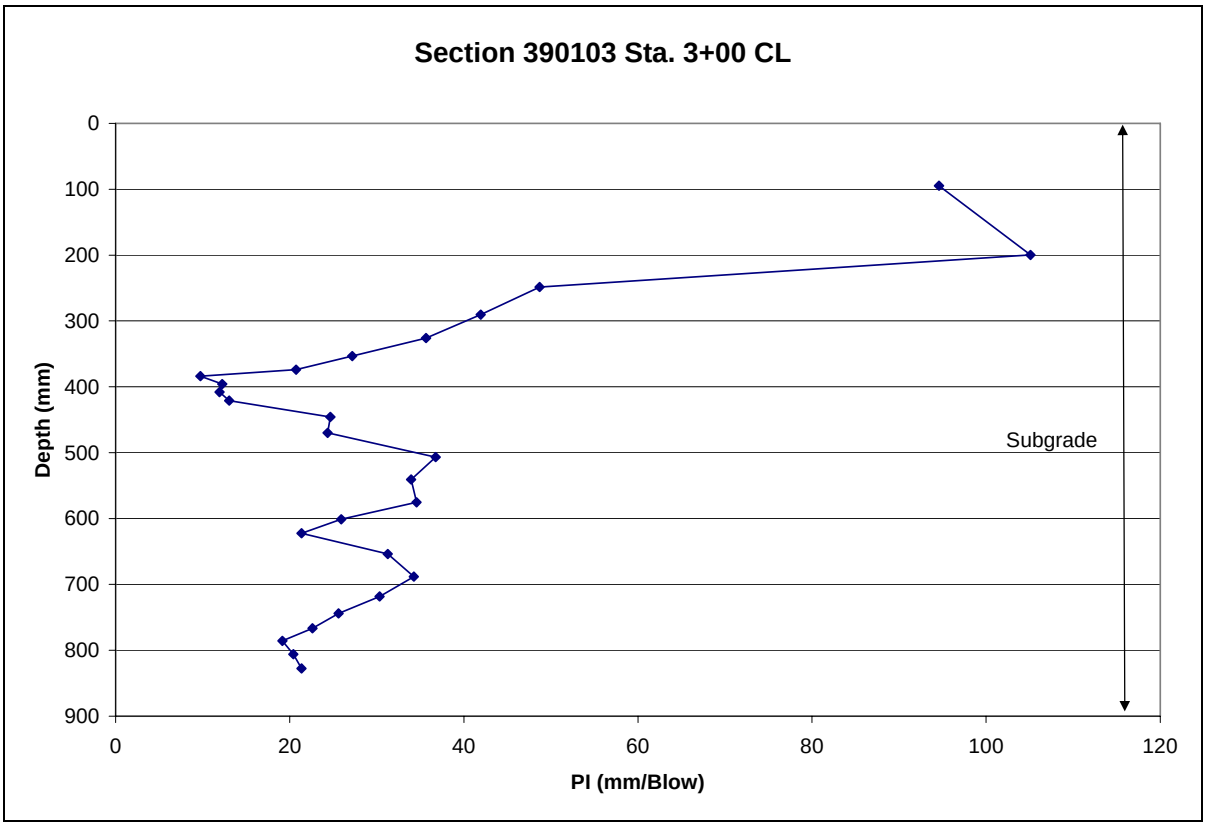

Section 390103 Sta. 1+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
PI (mm/Blow)
Subgrade

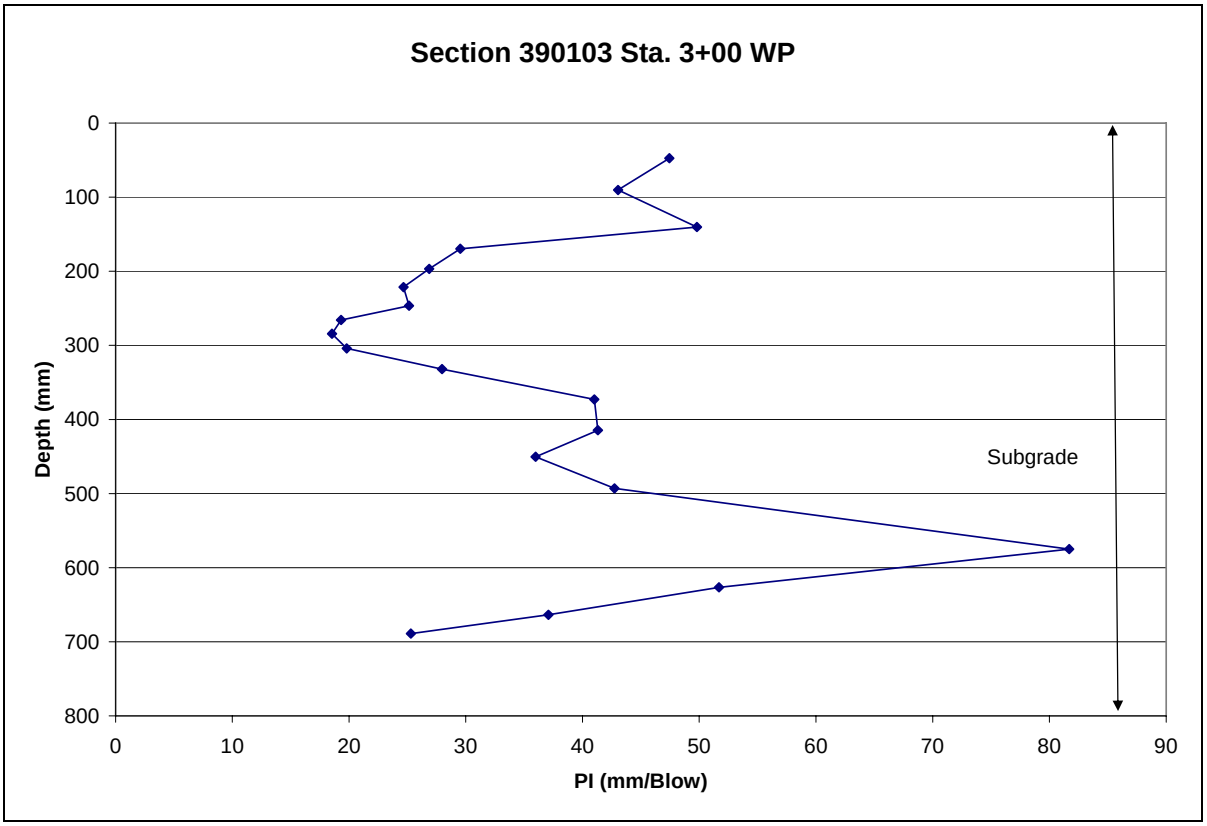
(25.4 mm = 1 in)


Section 390103 Sta. 2+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
PI (mm/Blow)
Subgrad


Section 390103 Sta. 2+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
70
80
PI (mm/Blow)
Subgrade

(25.4 mm = 1 in)


Section 390103 Sta. 3+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
PI (mm/Blow)
Subgrade


Section 390103 Sta. 3+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
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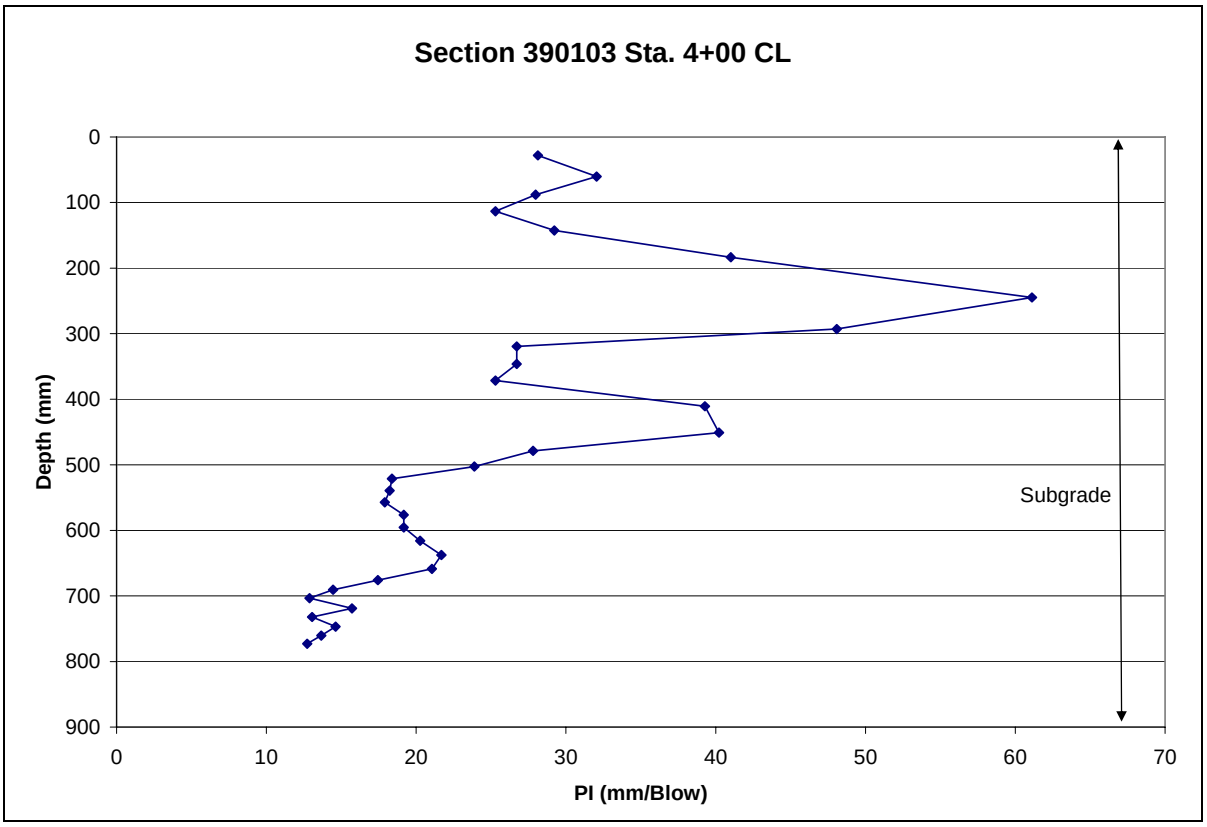
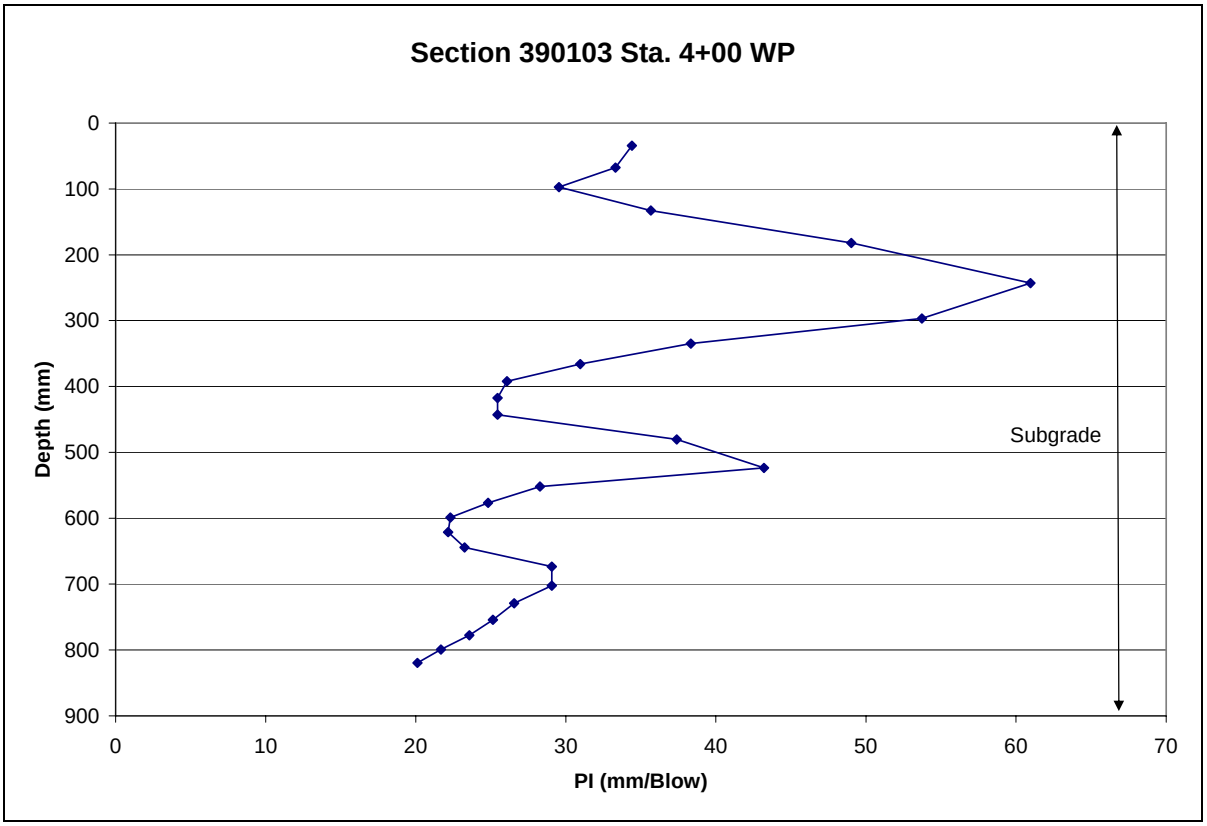
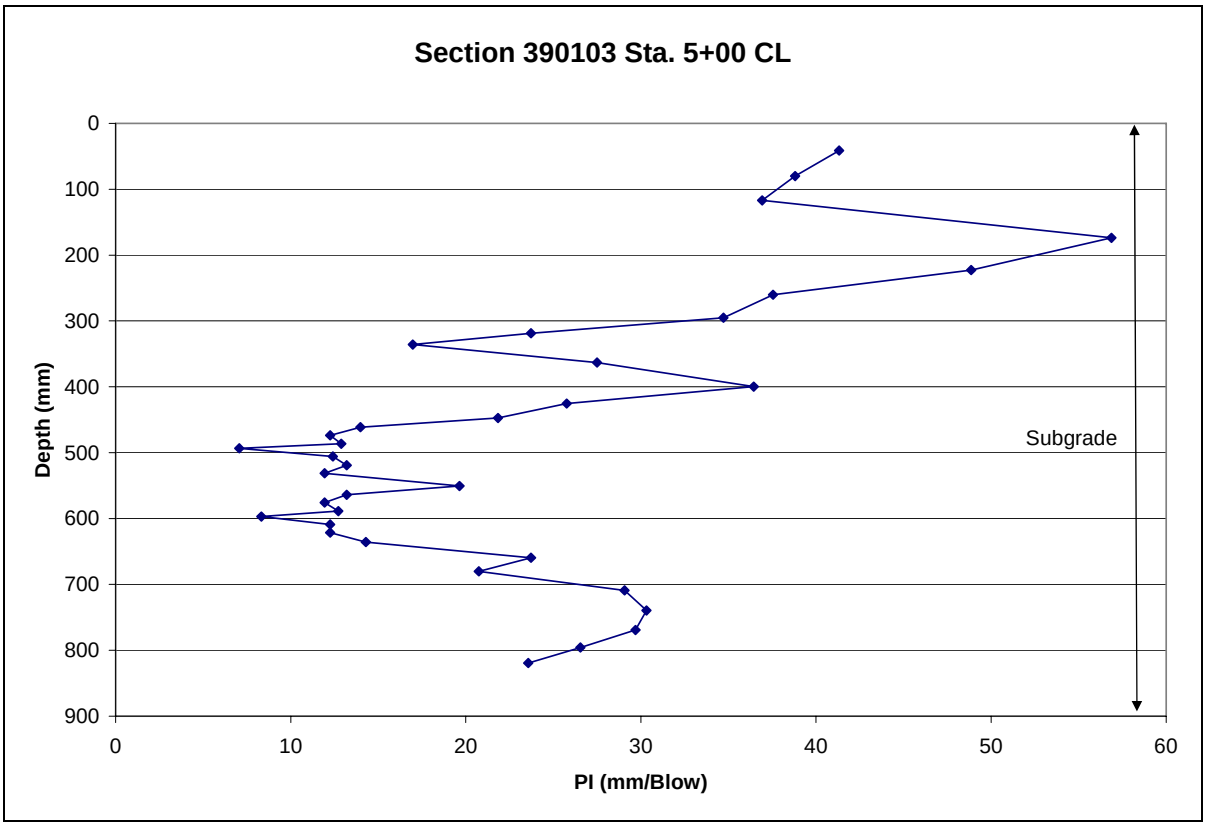
20
30
40
50
60
70
80
90
PI (mm/Blow)
Subgrade

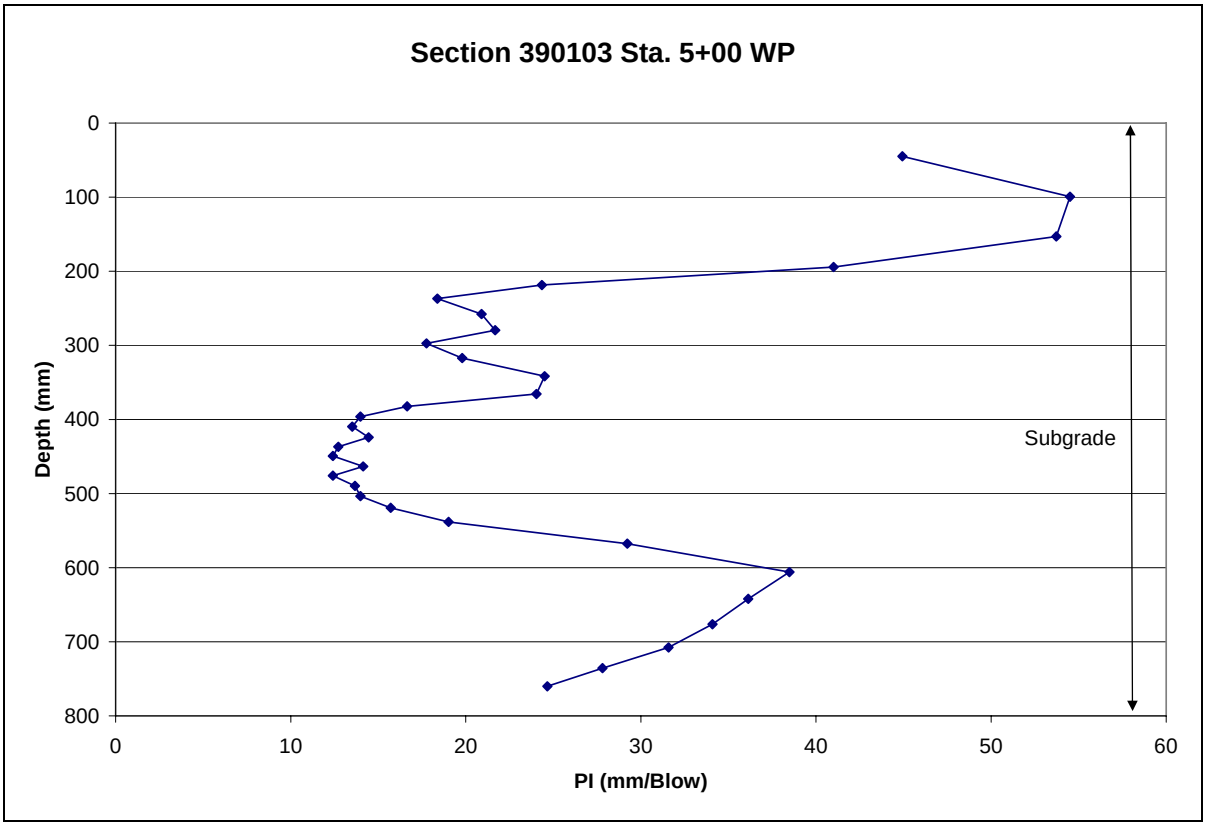
(25.4 mm = 1 in)


Section 390103 Sta. 4+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
PI (mm/Blow)
Subgrade

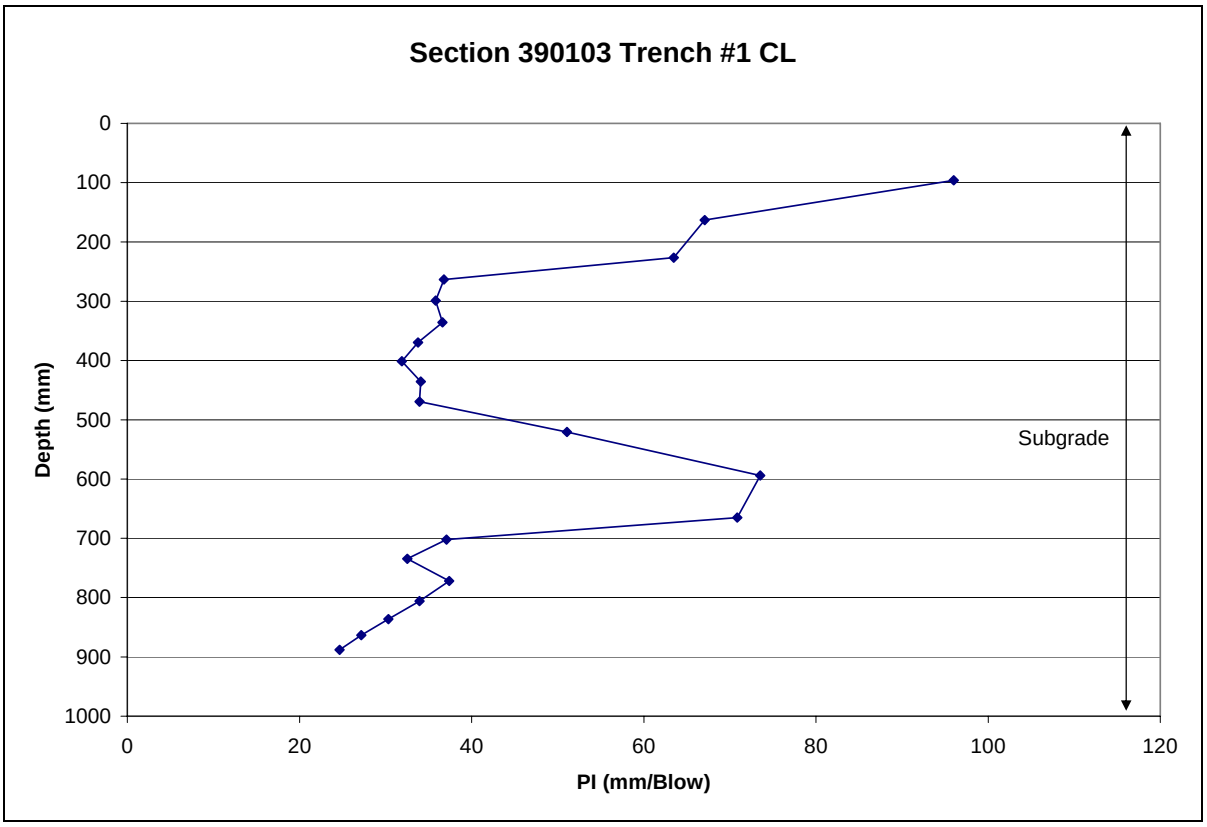

Section 390103 Sta. 4+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
PI (mm/Blow)
Subgrade

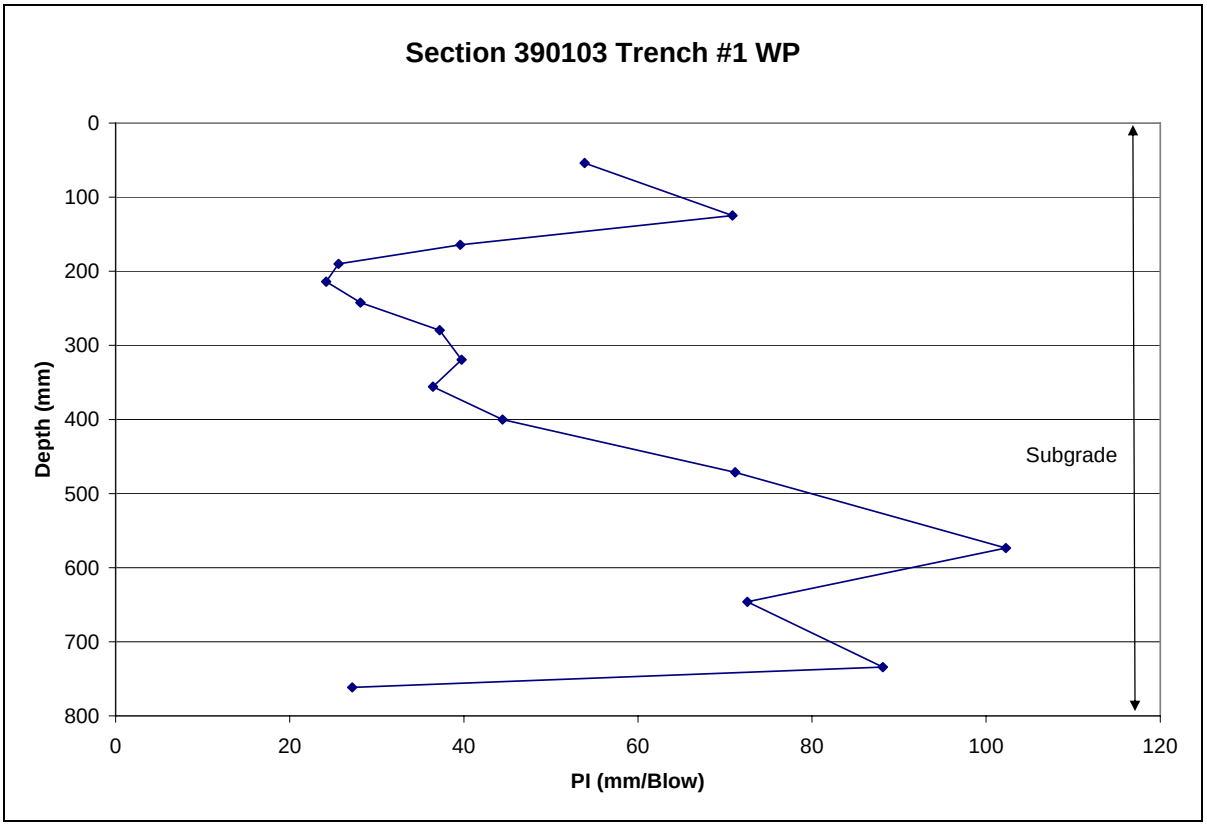
(25.4 mm = 1 in)


Section 390103 Sta. 5+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrade

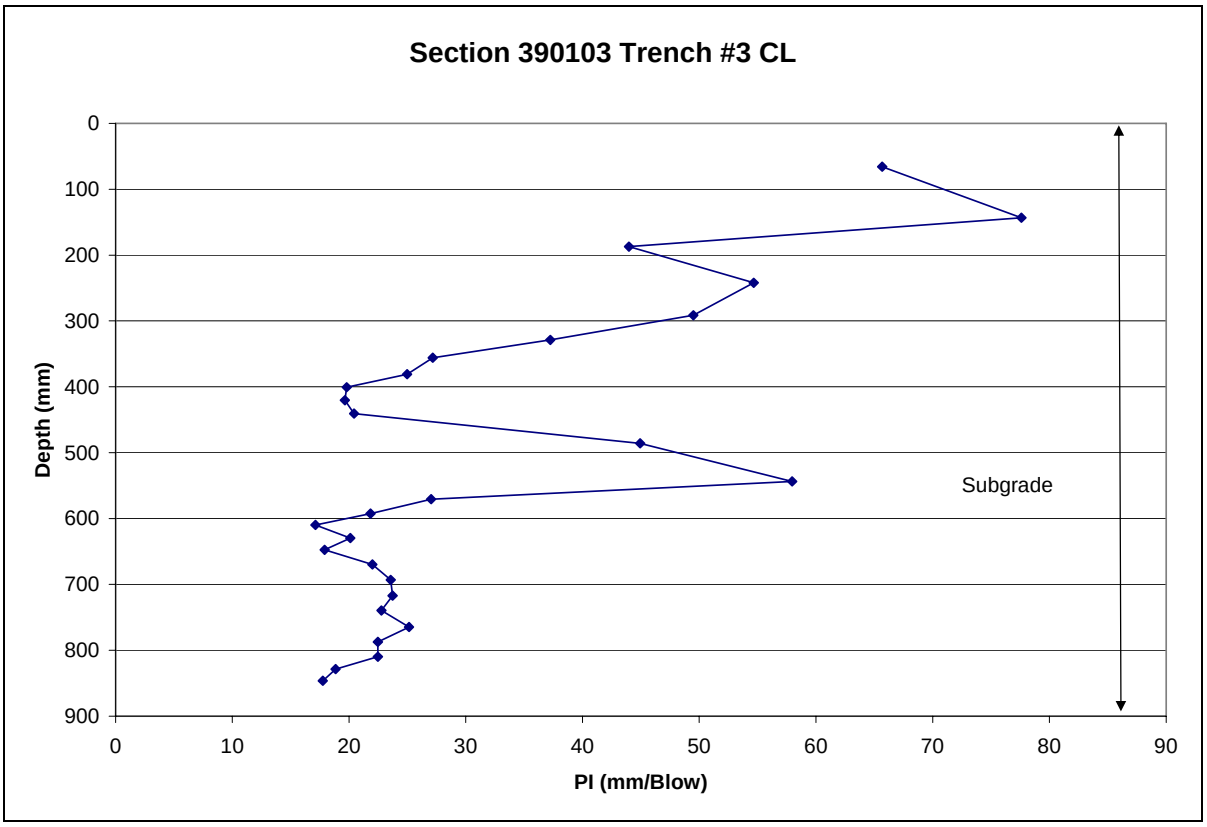

Section 390103 Sta. 5+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrade

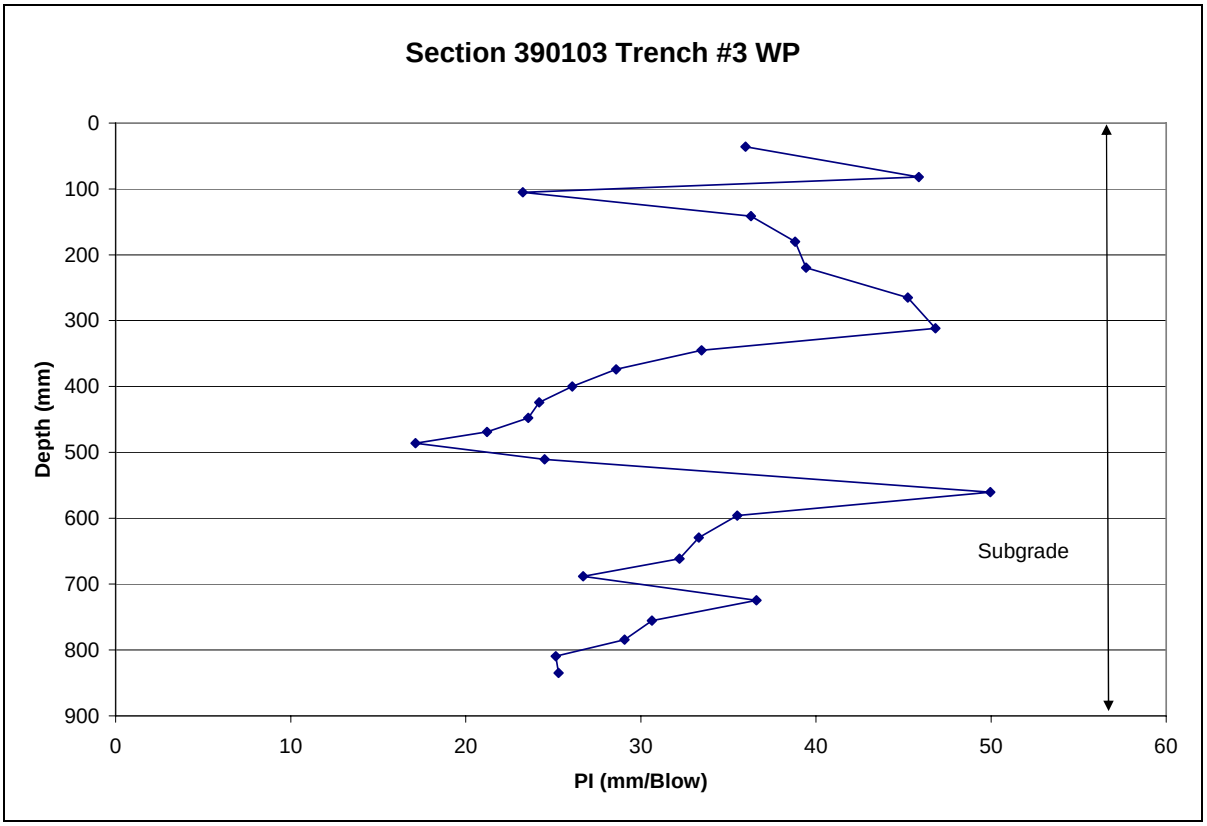
(25.4 mm = 1 in)


Section 390103 Trench #1 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
PI (mm/Blow)
Subgrade

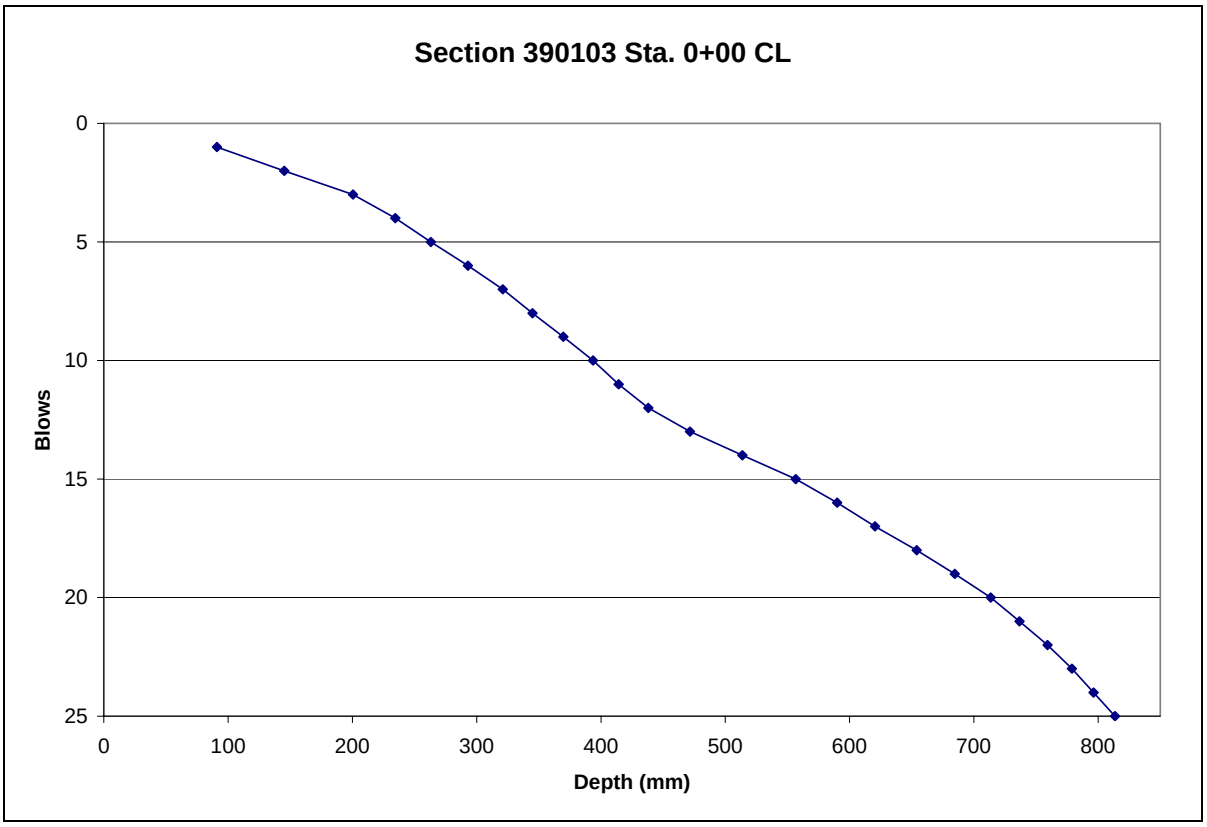

Section 390103 Trench #1 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
PI (mm/Blow)
Subgrade

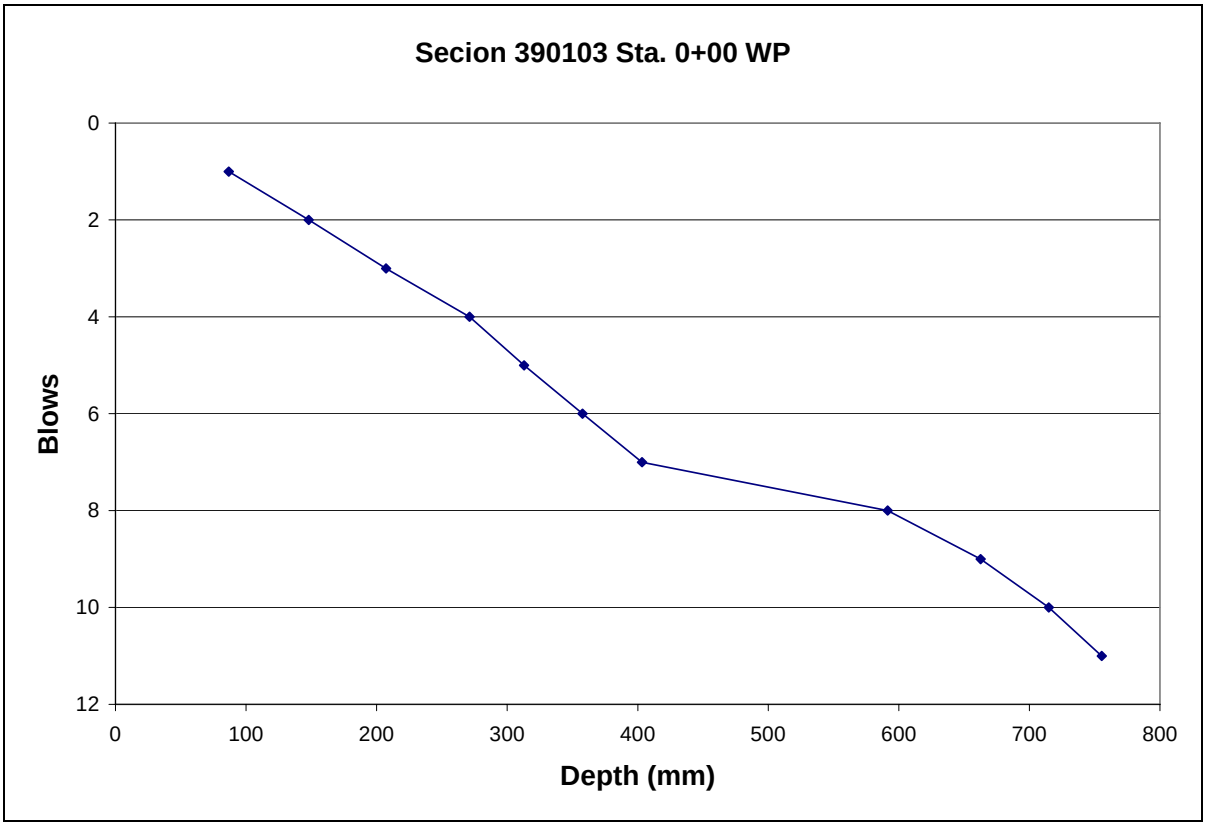
(25.4 mm = 1 in)


Section 390103 Trench #3 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
PI (mm/Blow)
Subgrade

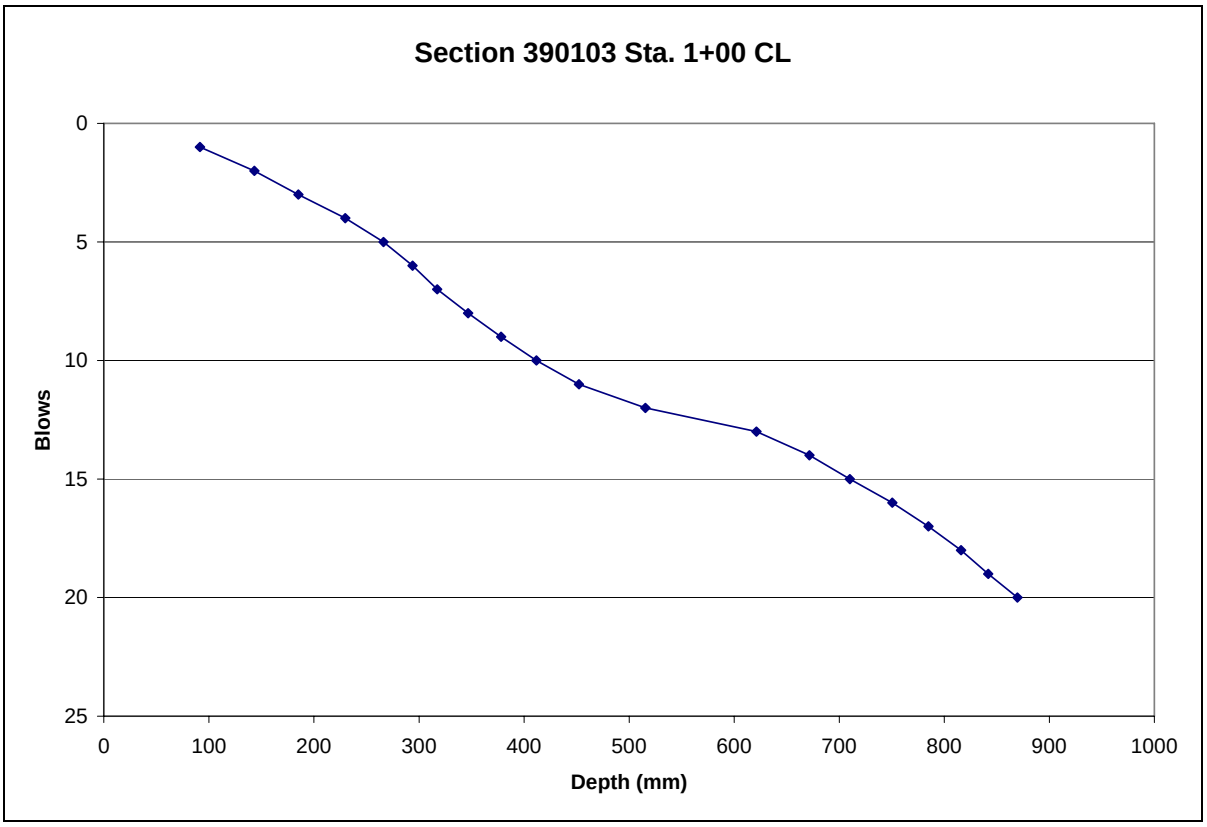

Section 390103 Trench #3 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrade

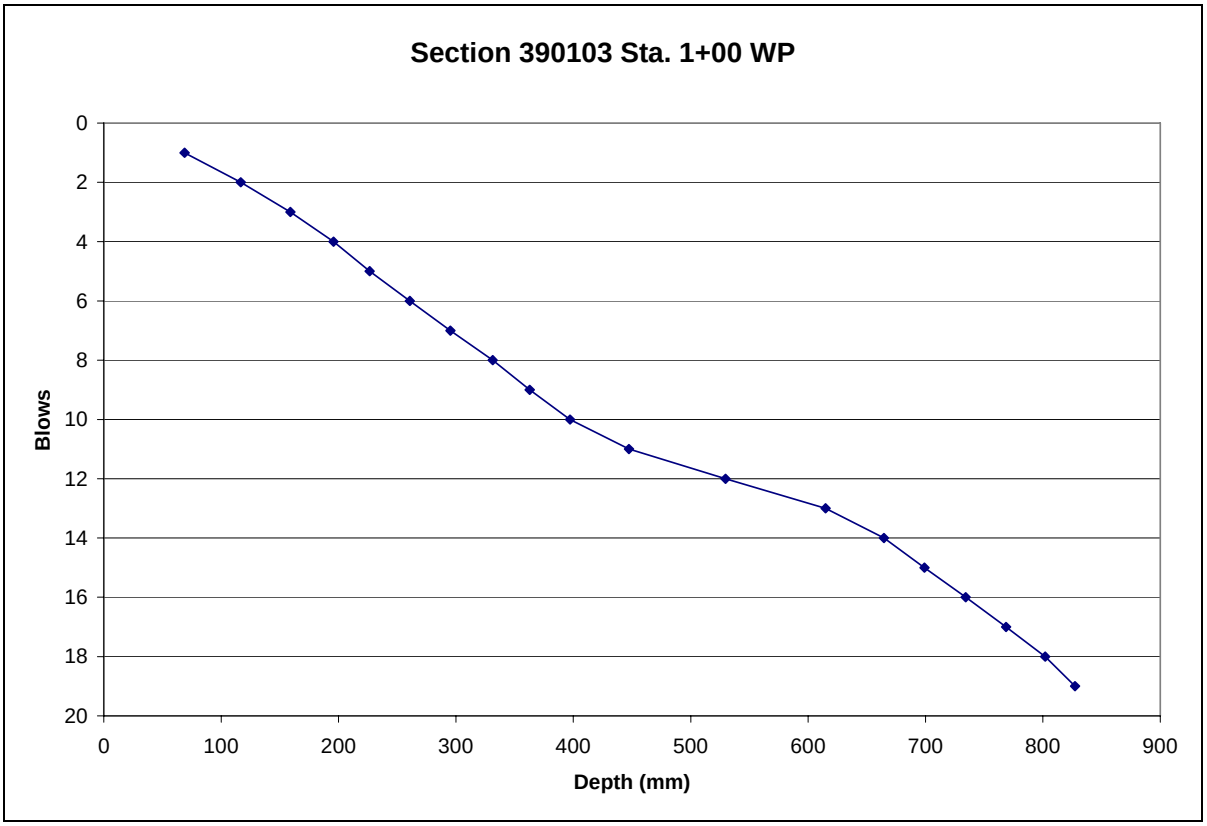
(25.4 mm = 1 in)


Section 390103 Sta. 0+00 CL
Blows
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
Depth (mm)

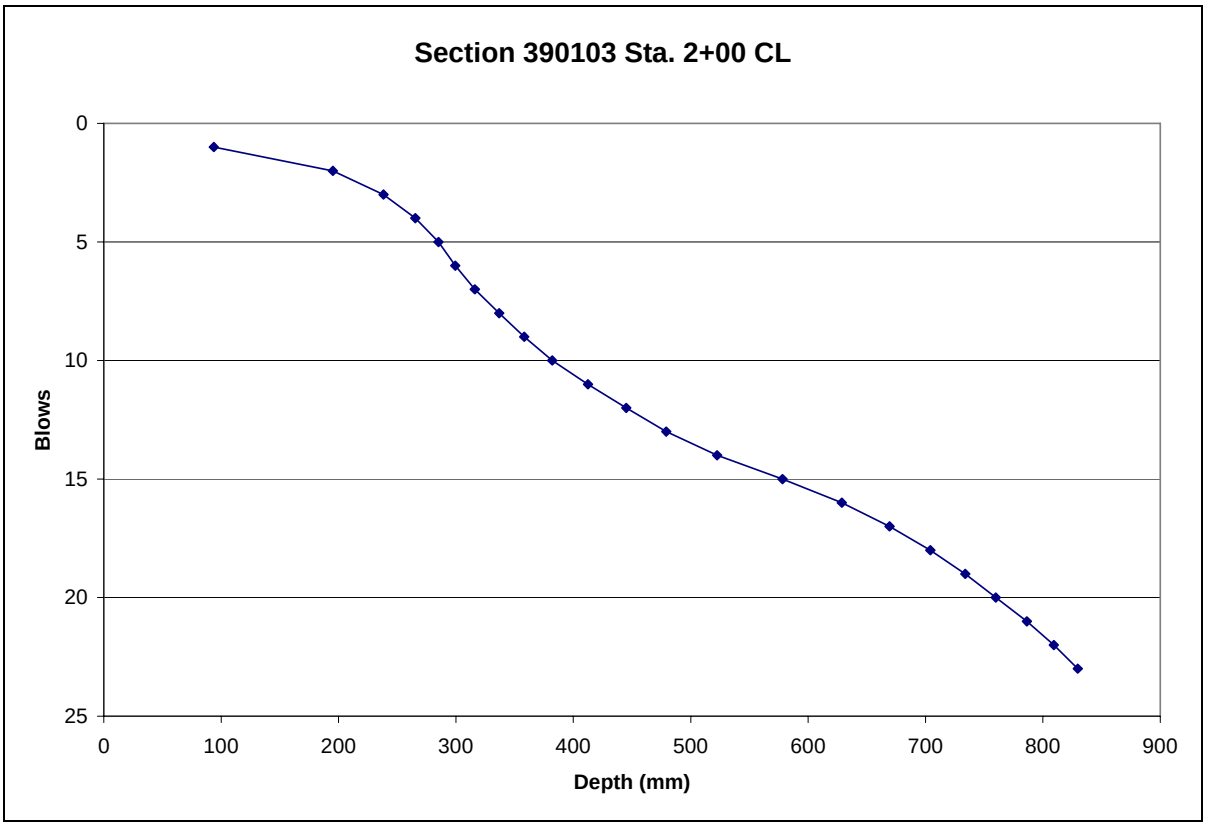

Secion 390103 Sta. 0+00 WP
Blows
0
2
4
6
8
10
12
0
100
200
300
400
500
600
700
800
Depth (mm)

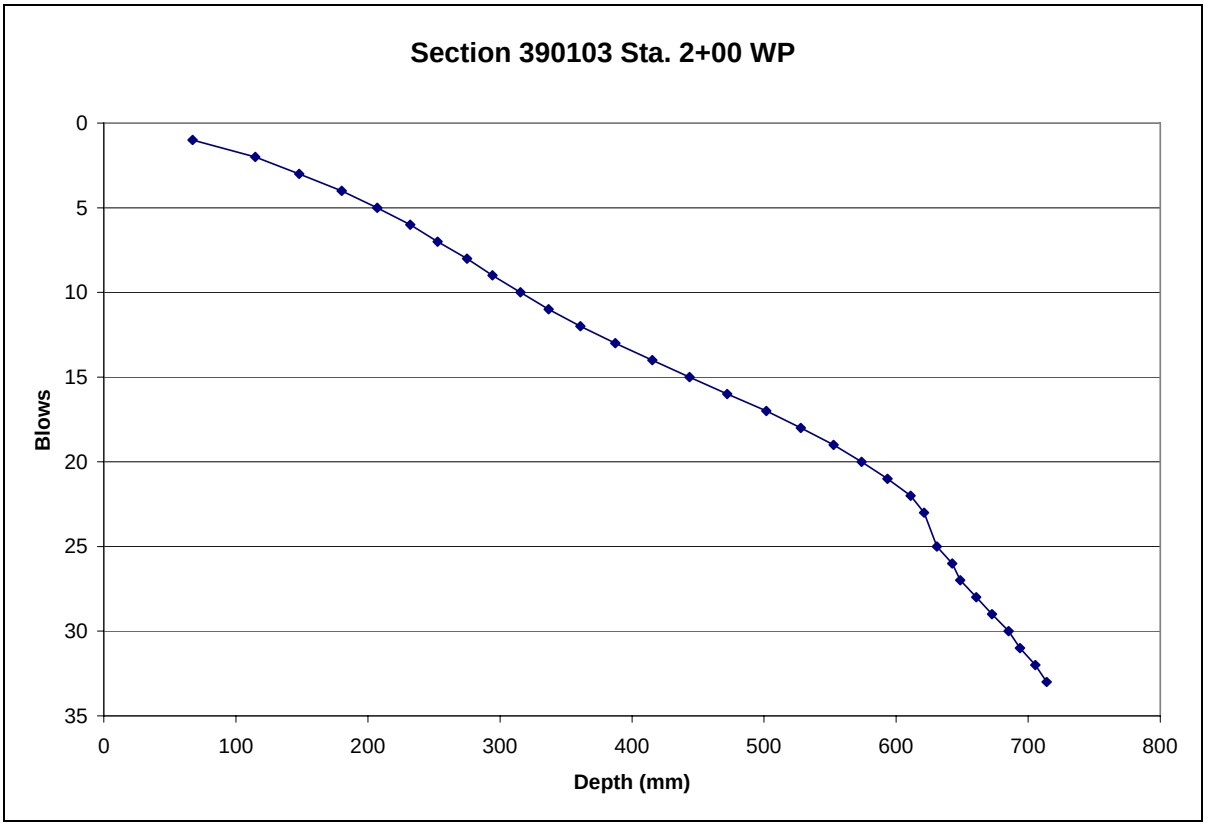
(25.4 mm = 1 in)


Section 390103 Sta. 1+00 CL
Blows
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

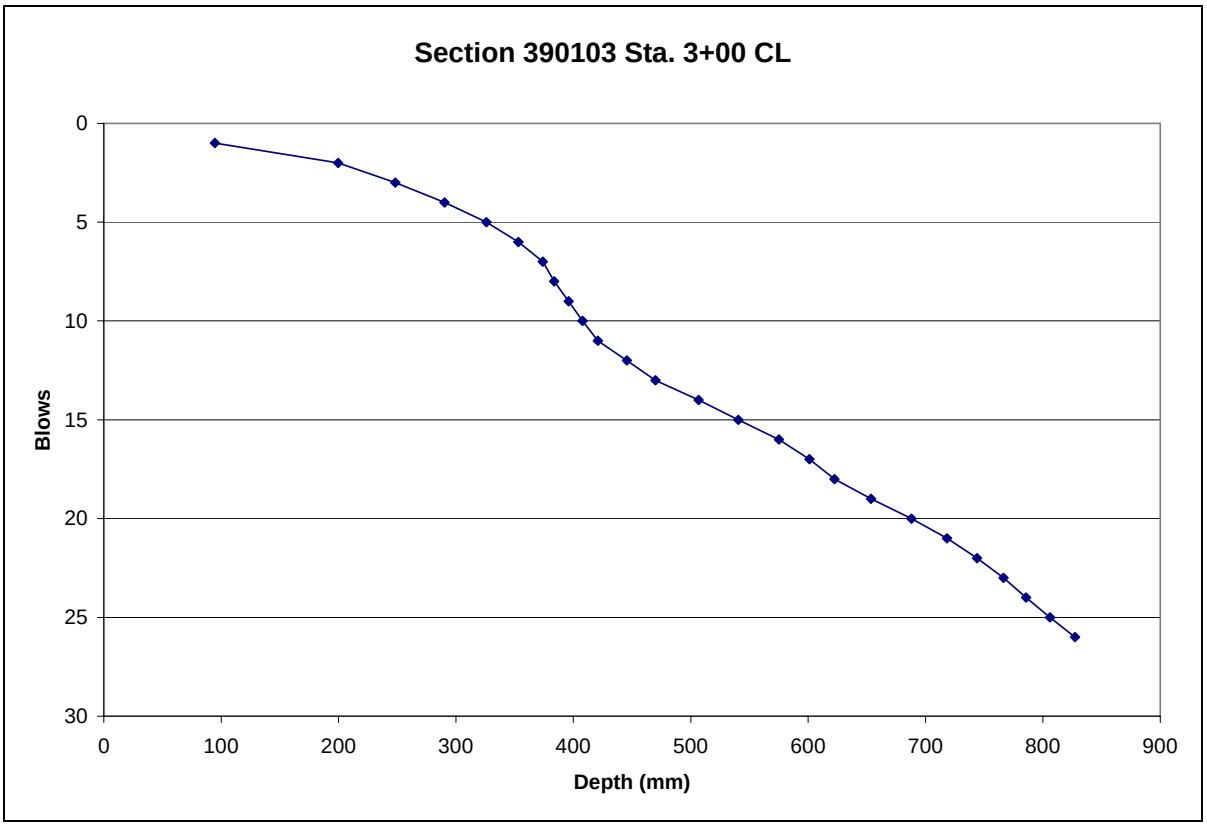

Section 390103 Sta. 1+00 WP
Blows
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
800
900
Depth (mm)

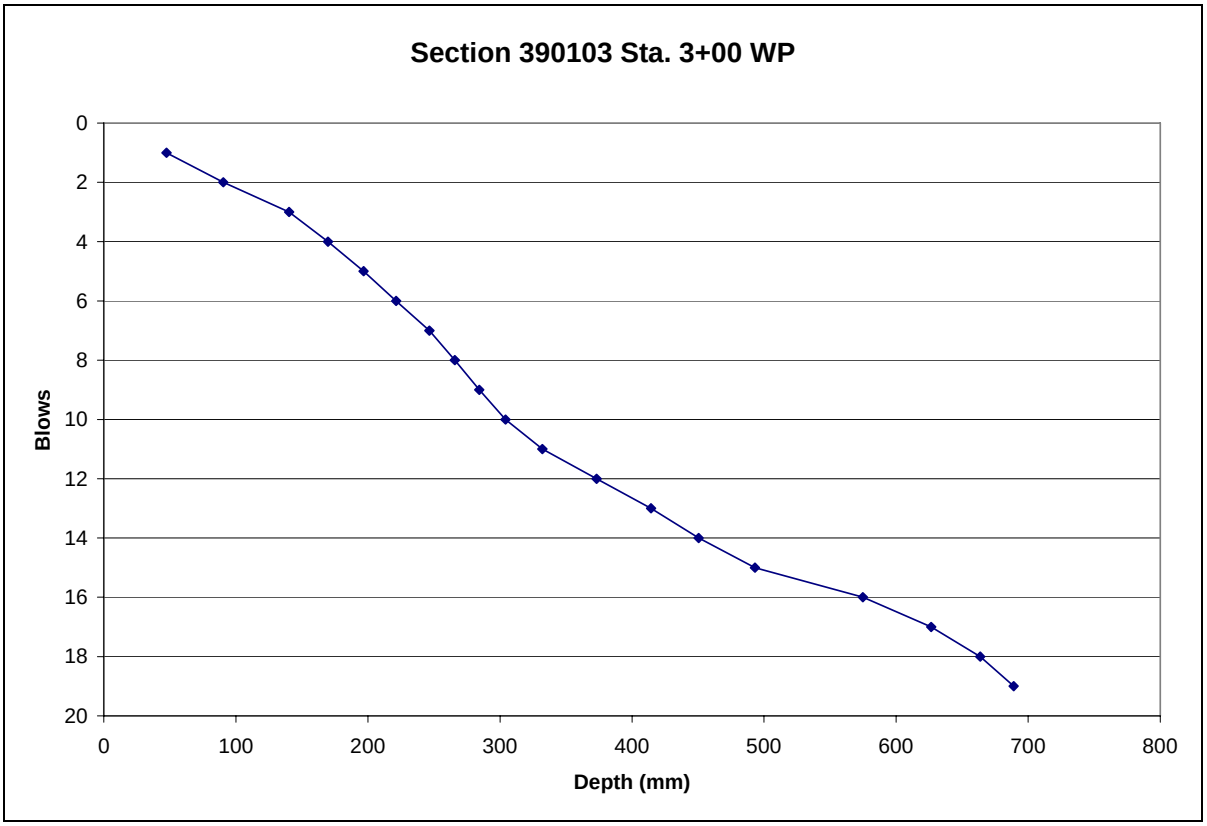
(25.4 mm = 1 in)


Section 390103 Sta. 2+00 CL
Blows
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
900
Depth (mm)

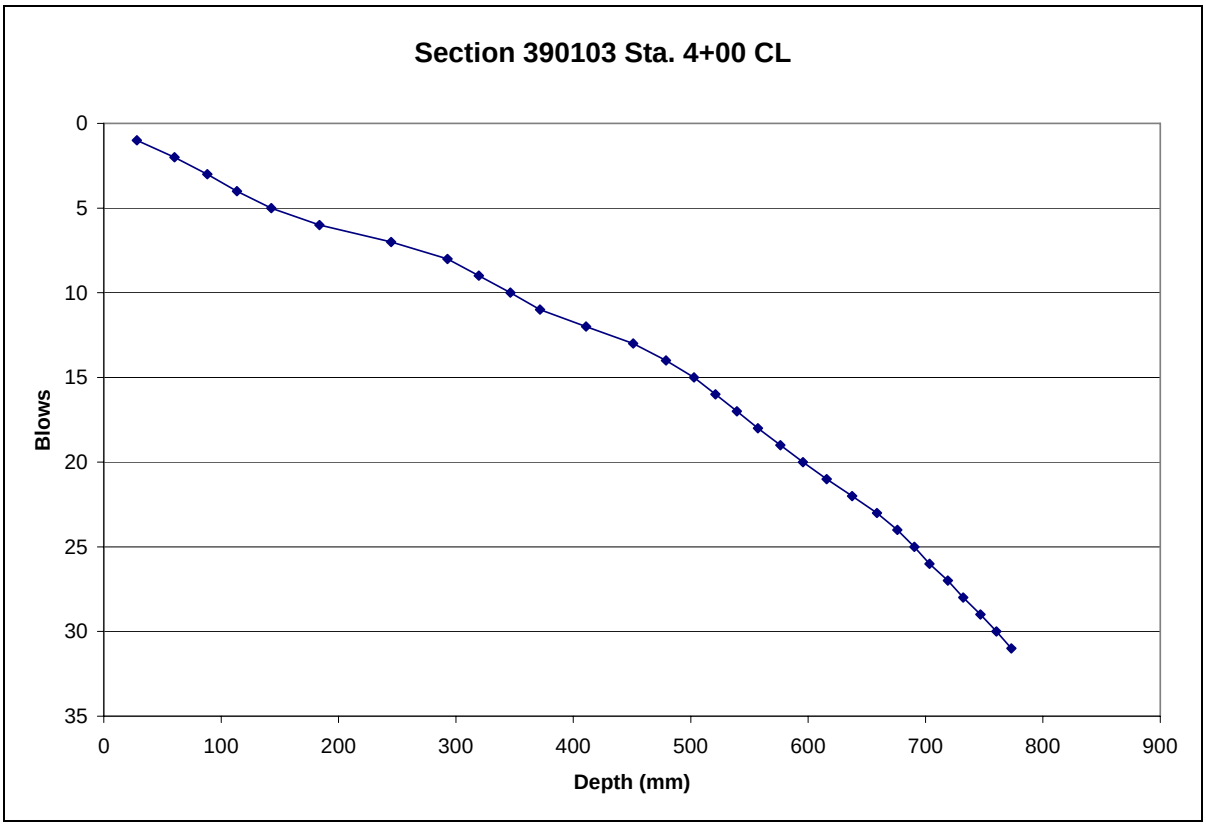

Section 390103 Sta. 2+00 WP
Blows
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
Depth (mm)

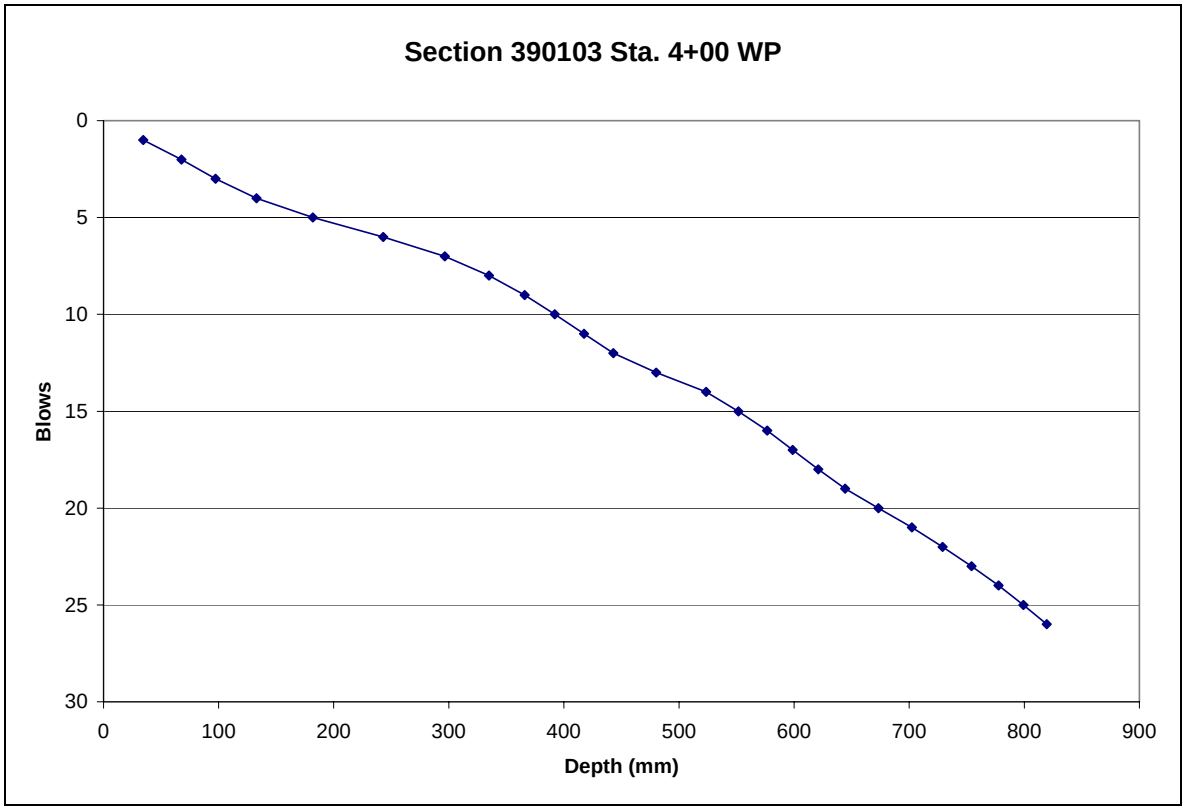
(25.4 mm = 1 in)


Section 390103 Sta. 3+00 CL
Blows
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900
Depth (mm)

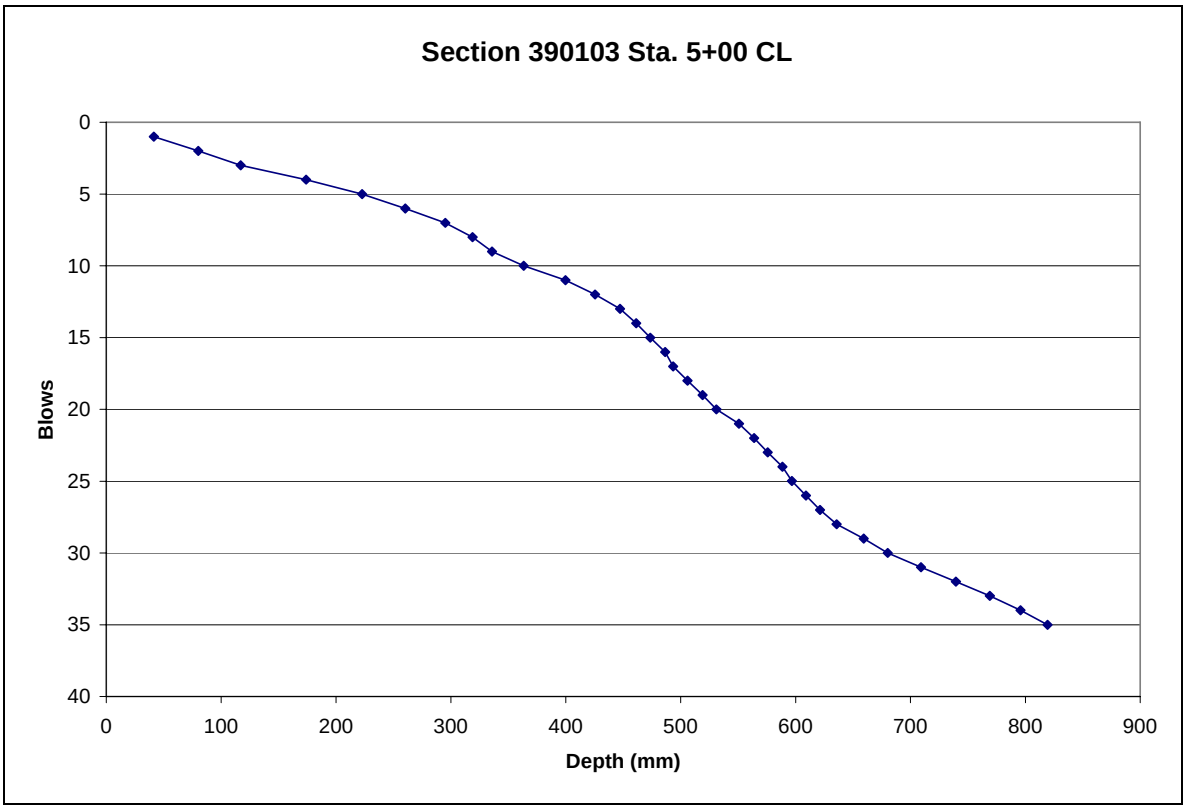

Section 390103 Sta. 3+00 WP
Blows
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
800
Depth (mm)

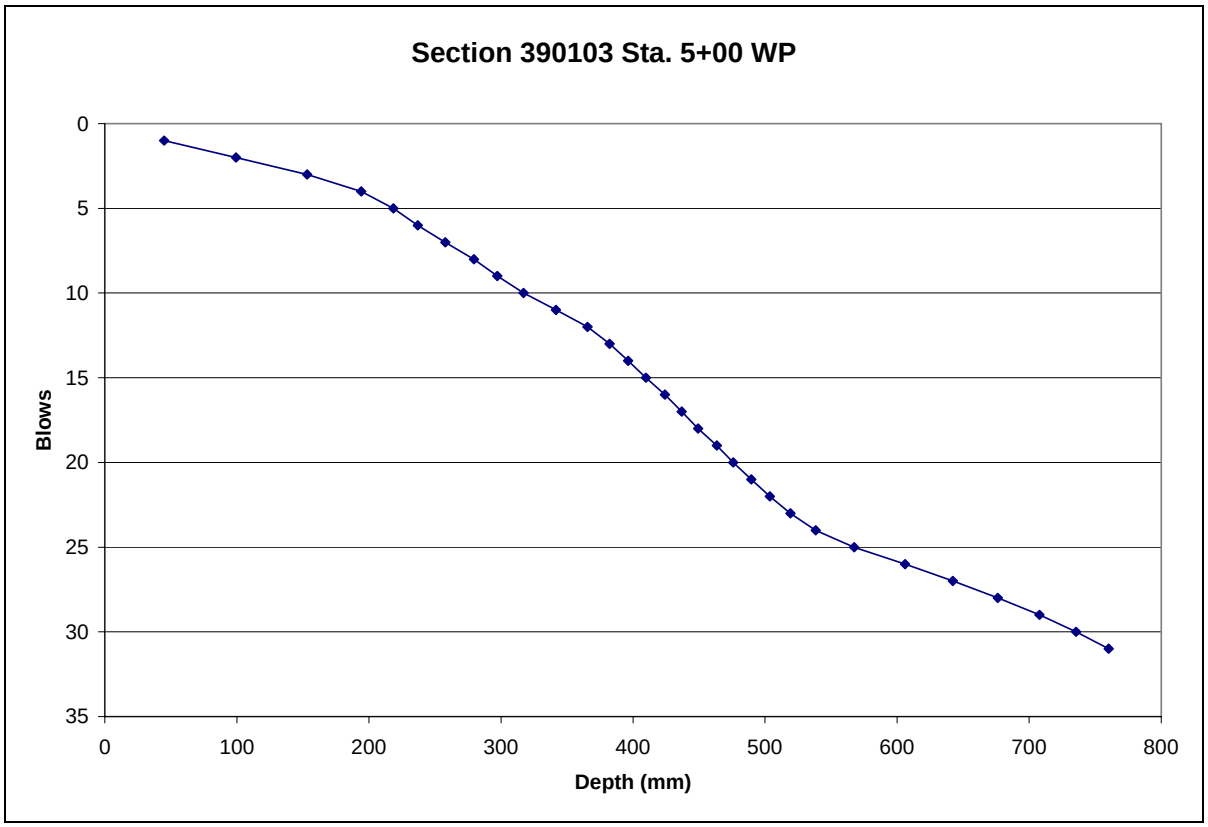
(25.4 mm = 1 in)


Section 390103 Sta. 4+00 CL
Blows
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
900
Depth (mm)

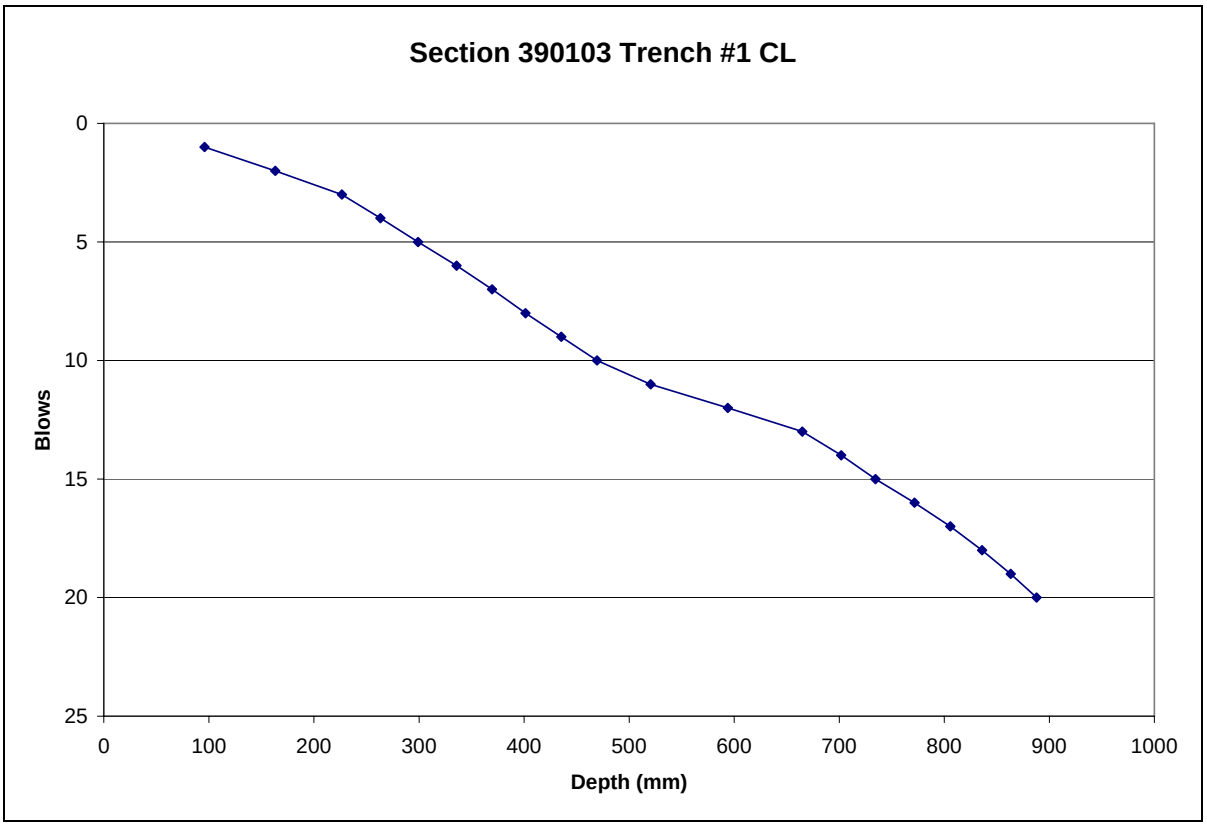

Section 390103 Sta. 4+00 WP
Blows
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900
Depth (mm)

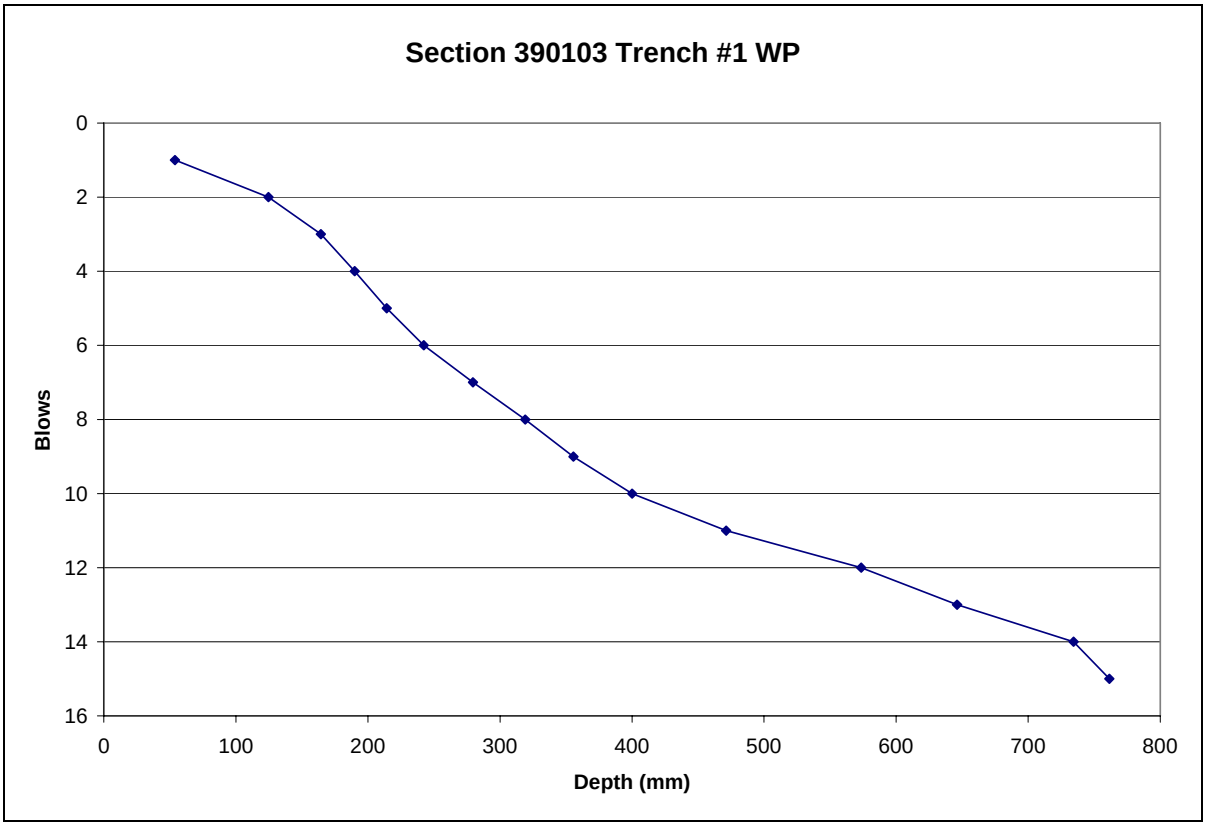
(25.4 mm = 1 in)


Section 390103 Sta. 5+00 CL
Blows
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800
900
Depth (mm)

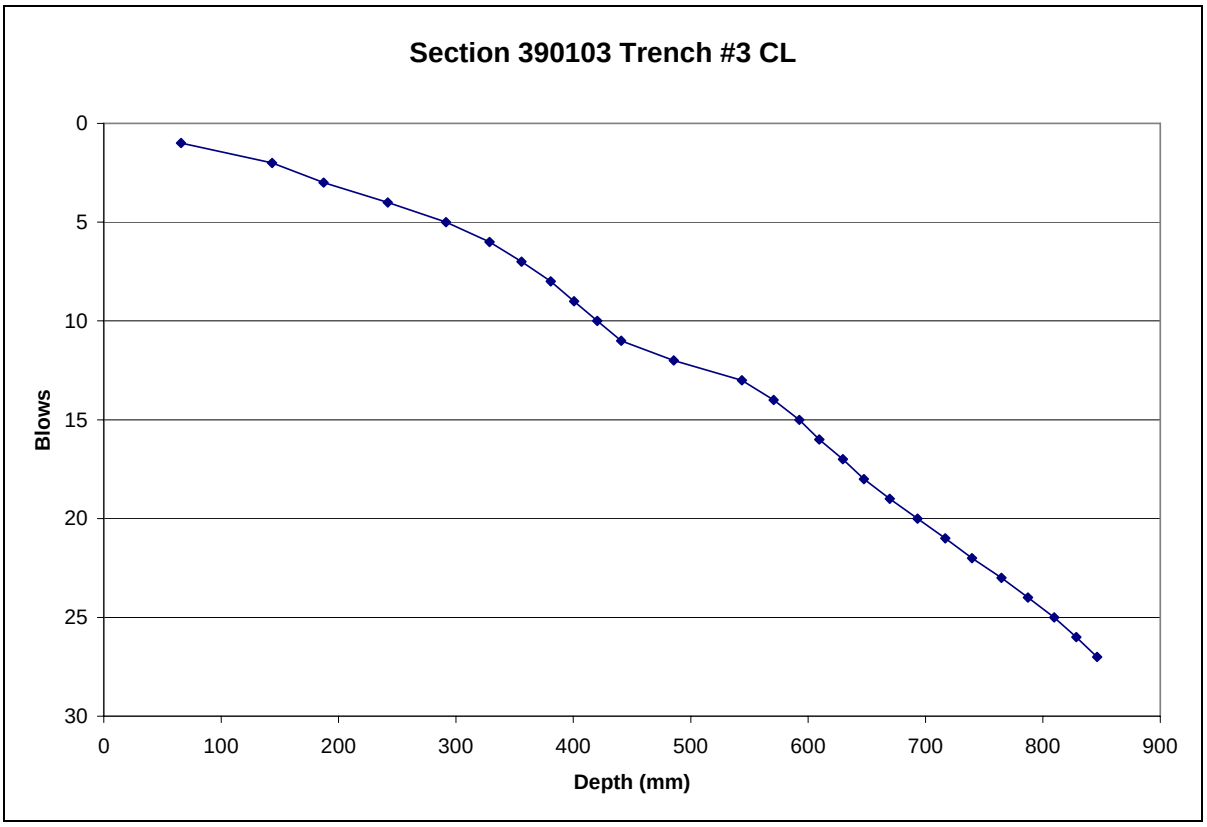

Section 390103 Sta. 5+00 WP
Blows
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
Depth (mm)

(25.4 mm = 1 in)


Section 390103 Trench #1 CL
Blows
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Section 390103 Trench #1 WP
Blows
0
2
4
6
8
10
12
14
16
0
100
200
300
400
500
600
700
800
Depth (mm)

(25.4 mm = 1 in)


Section 390103 Trench #3 CL
Blows
Depth (mm)
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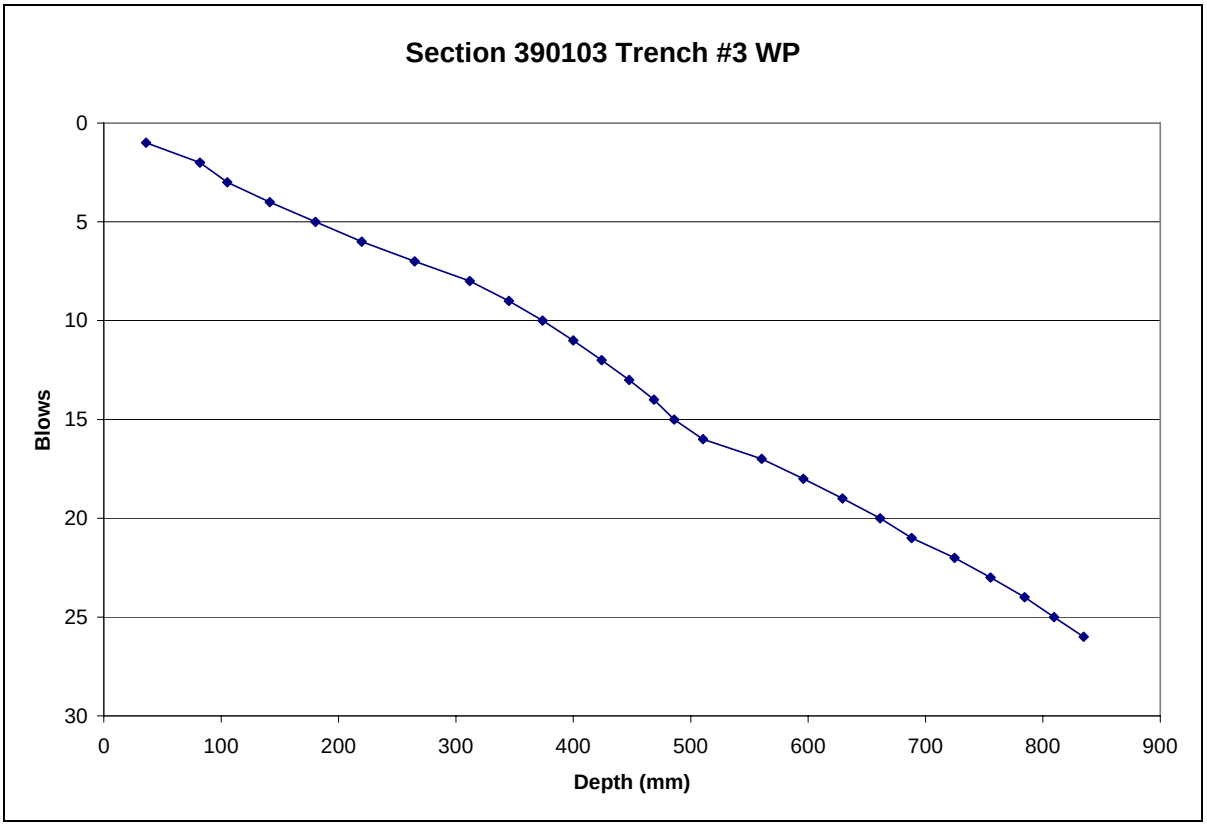
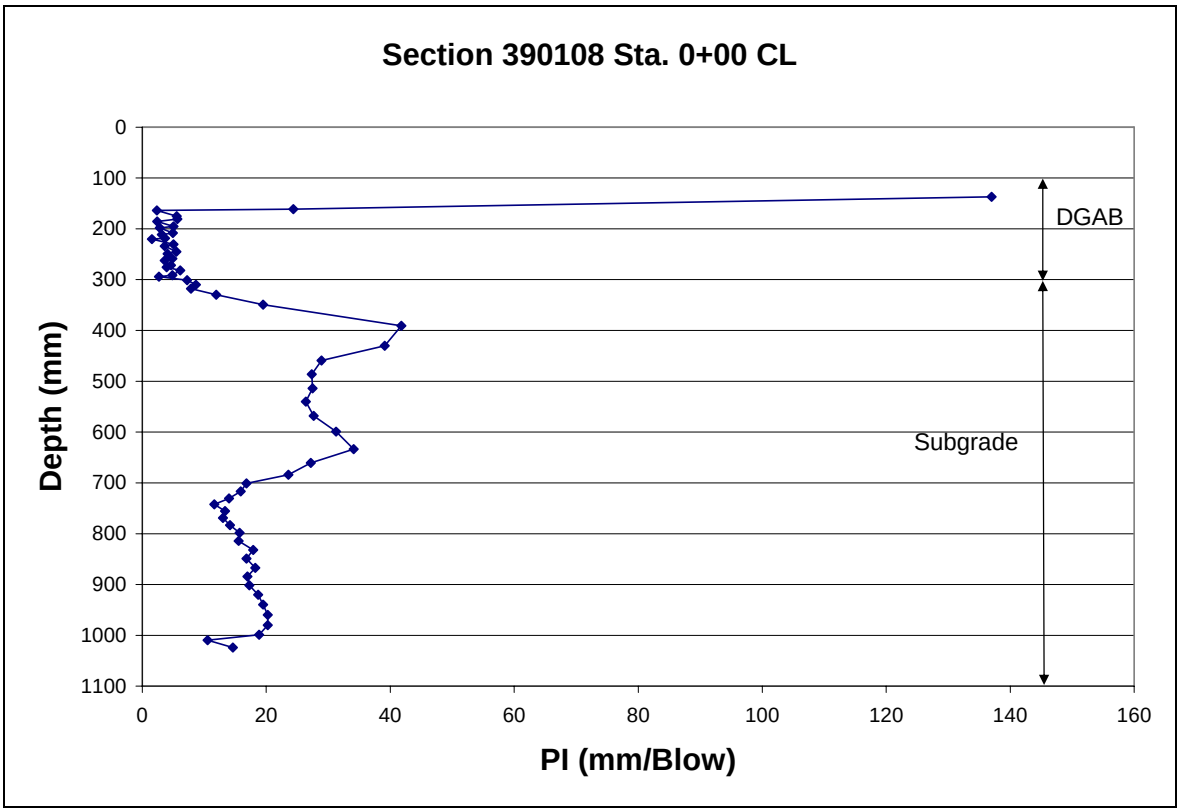
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900


Section 390103 Trench #3 WP
Blows
Depth (mm)
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900

(25.4 mm = 1 in)

SECTION 390108


Section 390108 Sta. 0+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
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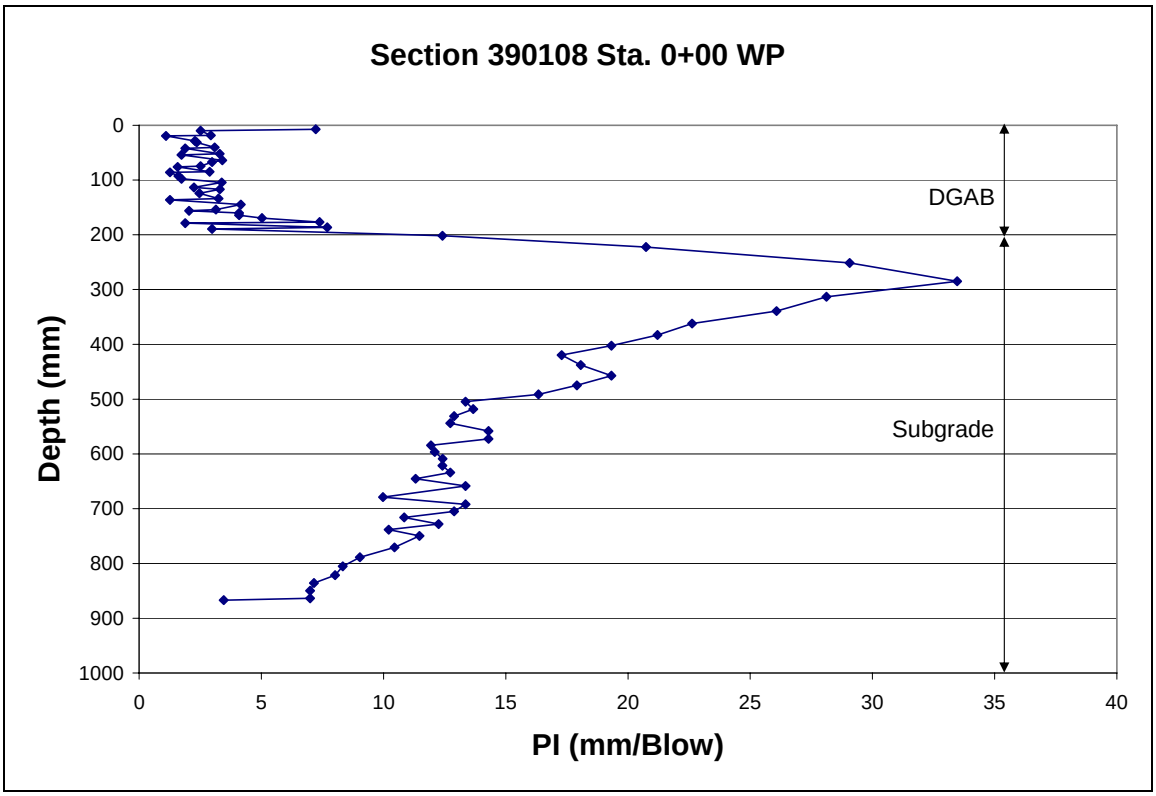
500
600
700
800
900
1000
1100
0
20
40
60
80
100
120
140
160


Section 390108 Sta. 0+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
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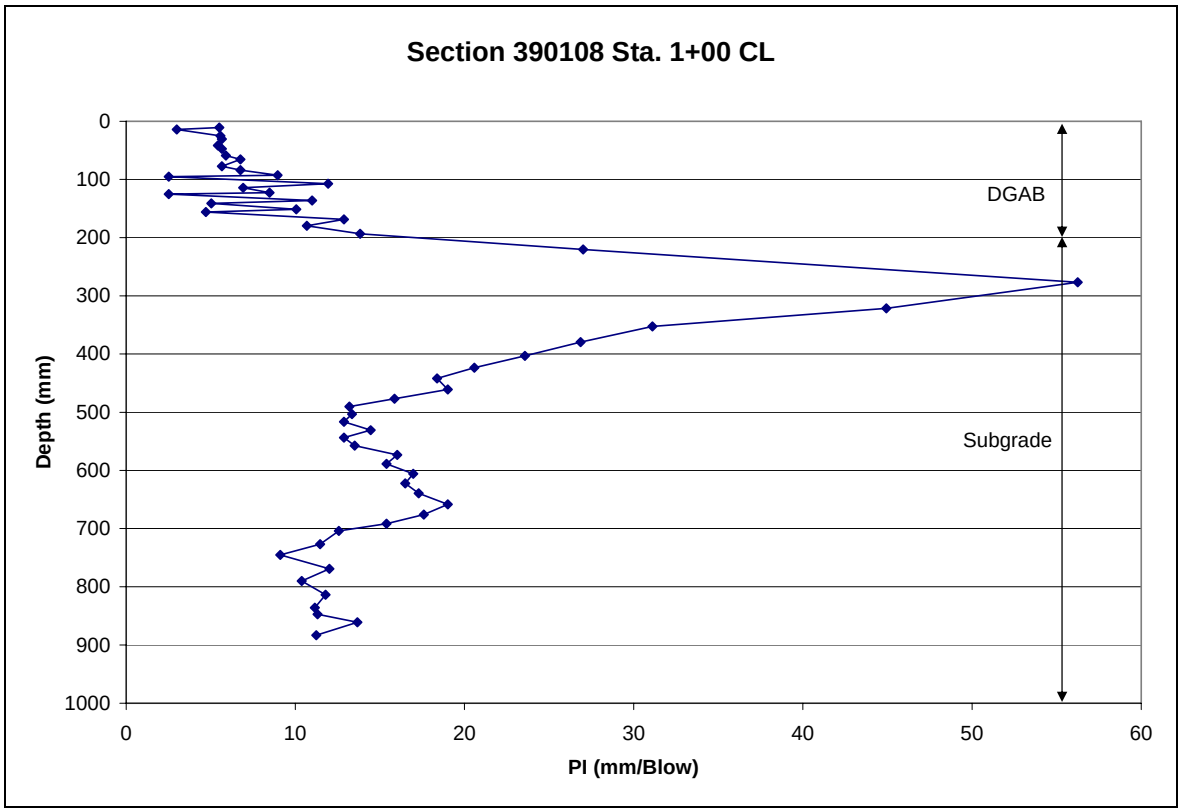
600
700
800
900
1000
0
5
10
15
20
25
30
35
40

(25.4 mm = 1 in)


Section 390108 Sta. 1+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
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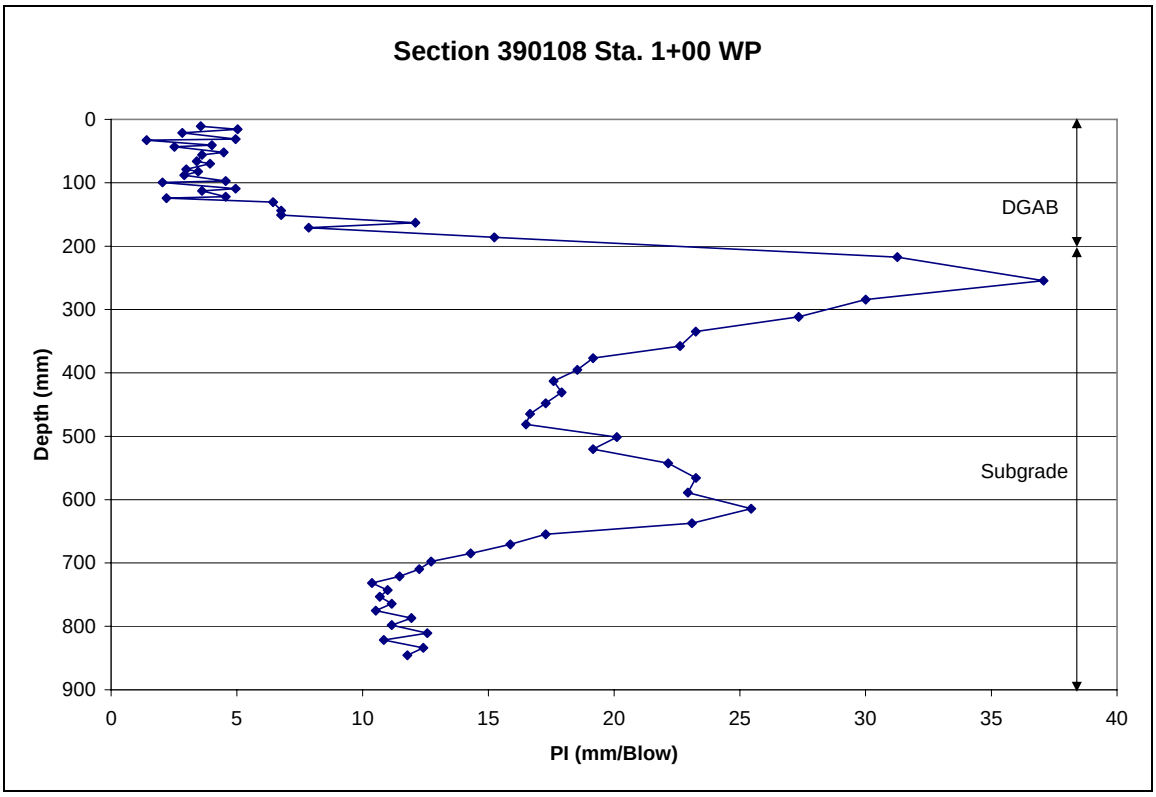
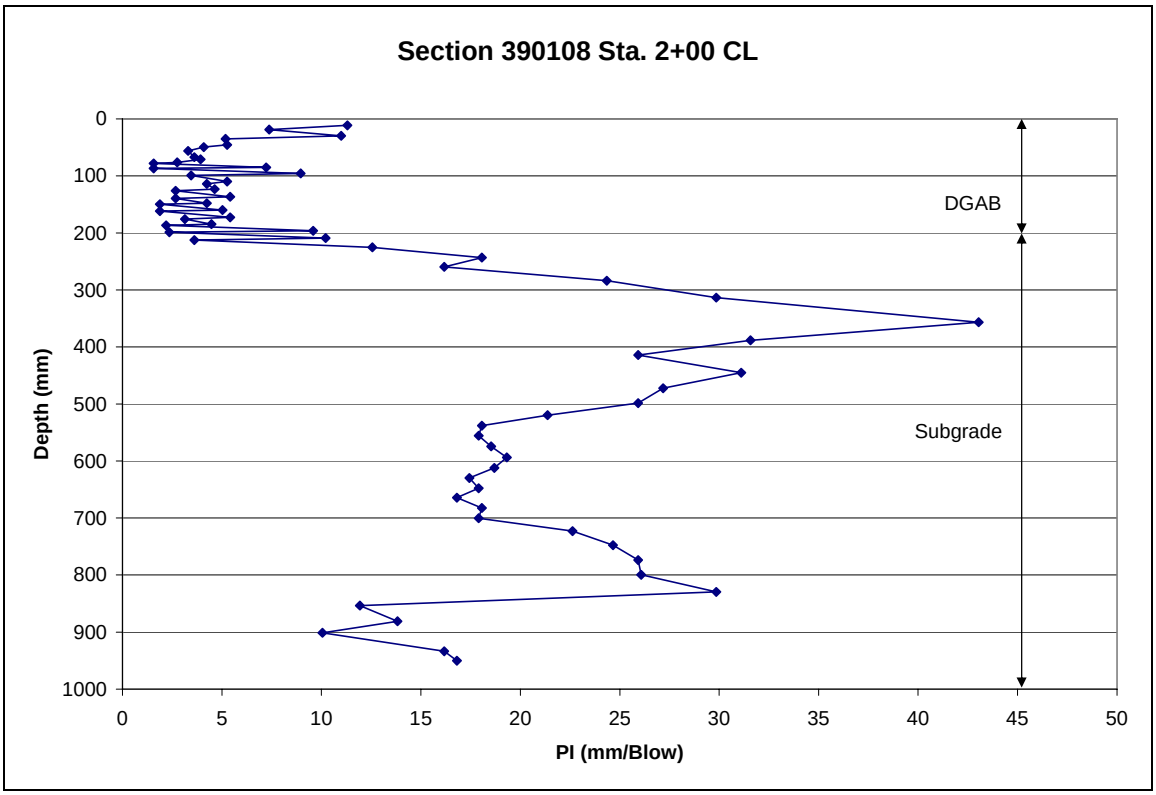
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60


Section 390108 Sta. 1+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30
35
40

(25.4 mm = 1 in)


Section 390108 Sta. 2+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
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600
700
800
900
1000
0
5
10
15
20
25
30
35
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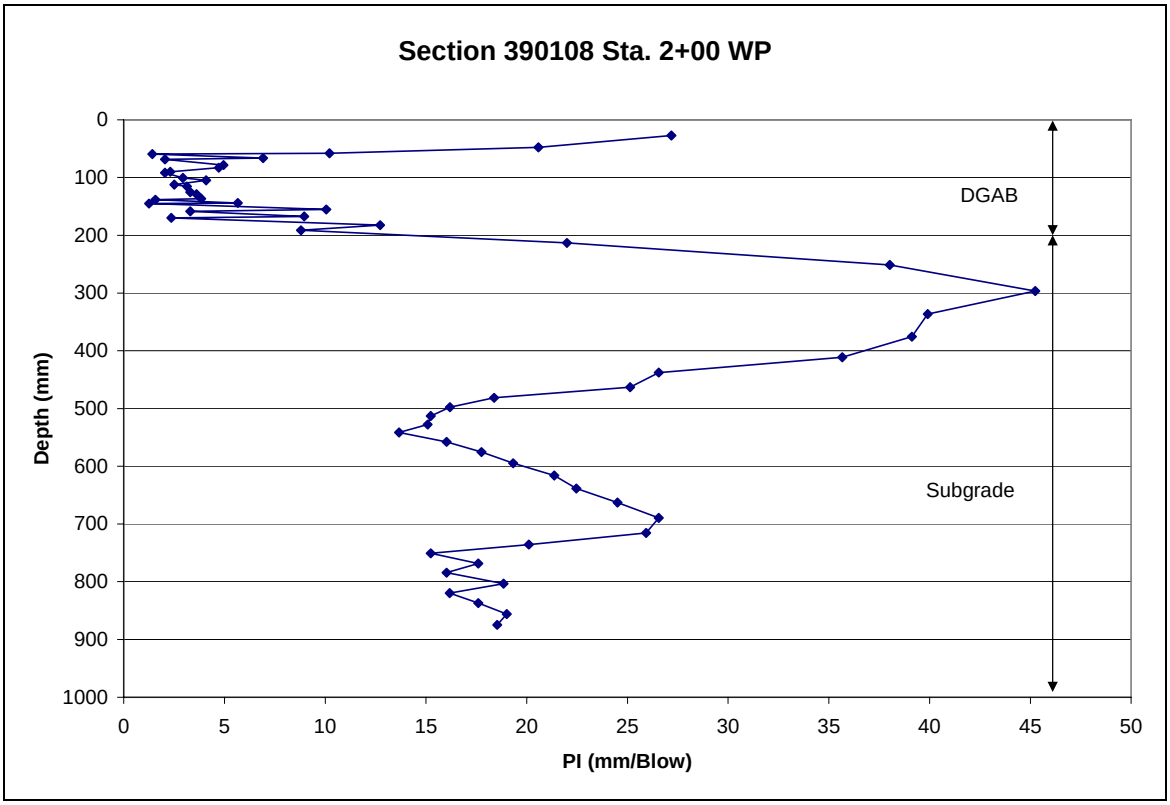
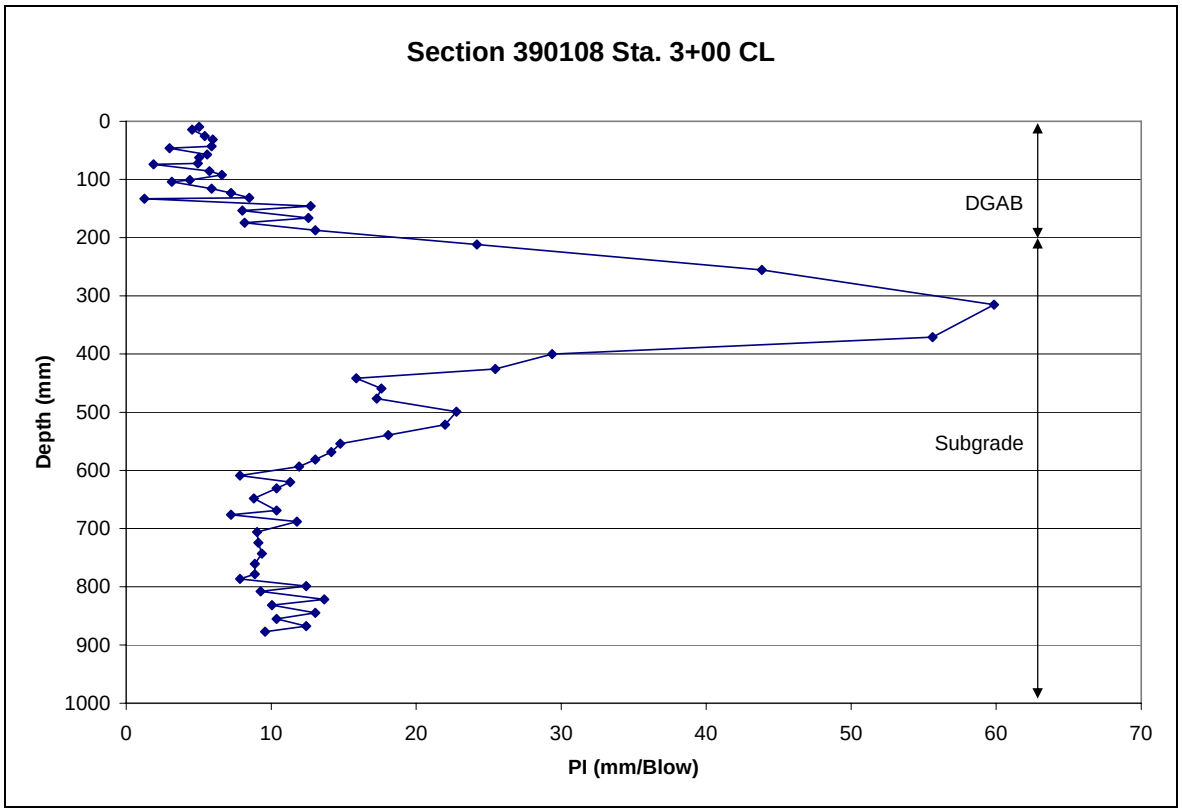
45
50


Section 390108 Sta. 2+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45
50

(25.4 mm = 1 in)


Section 390108 Sta. 3+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
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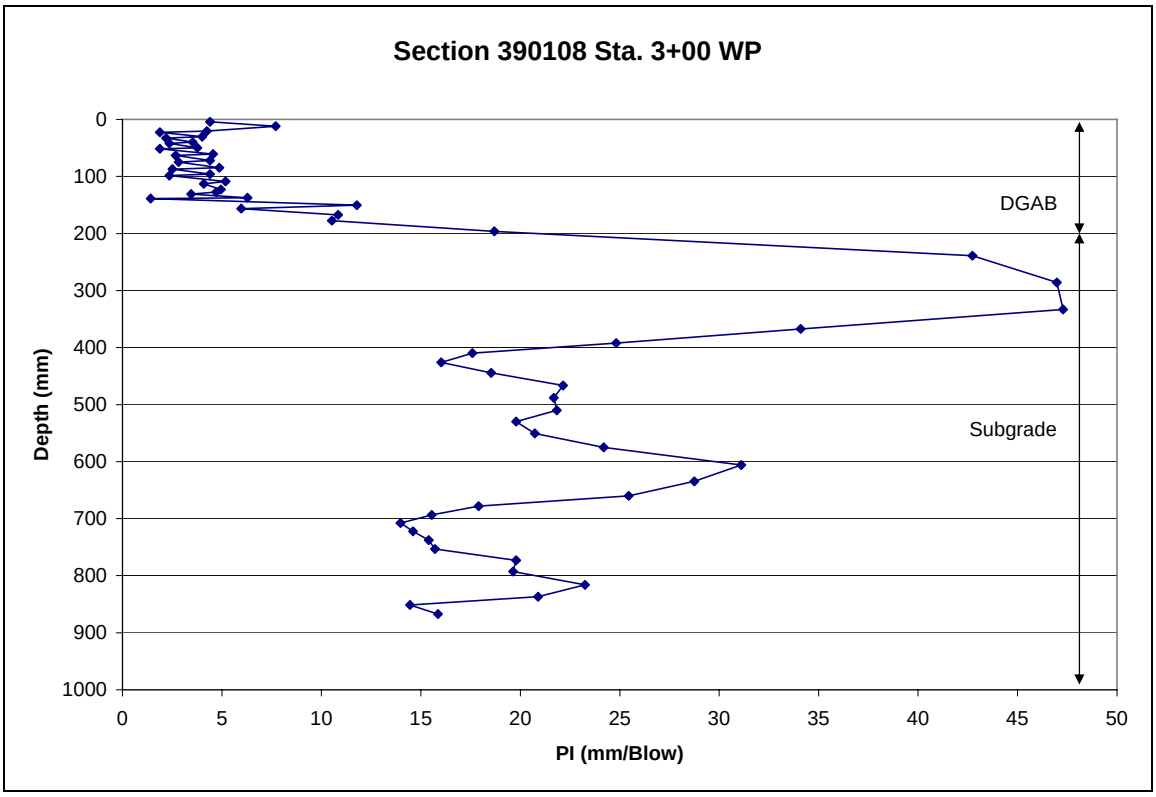
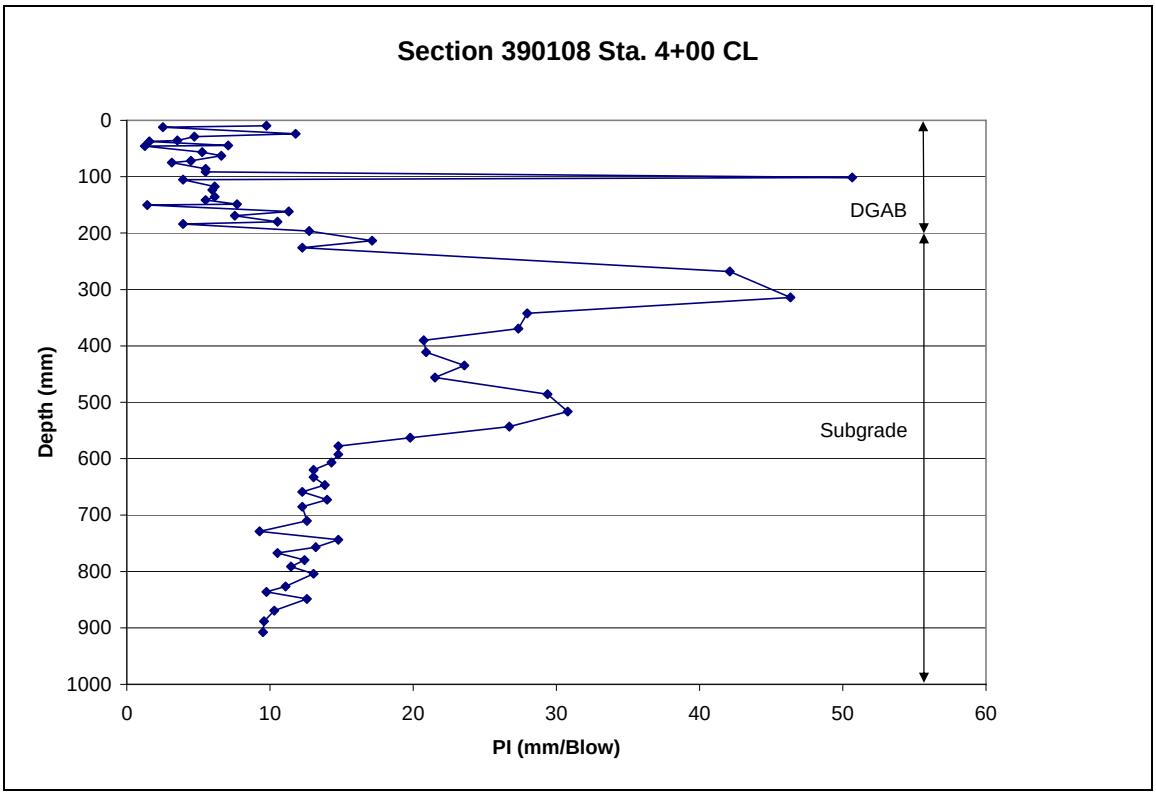
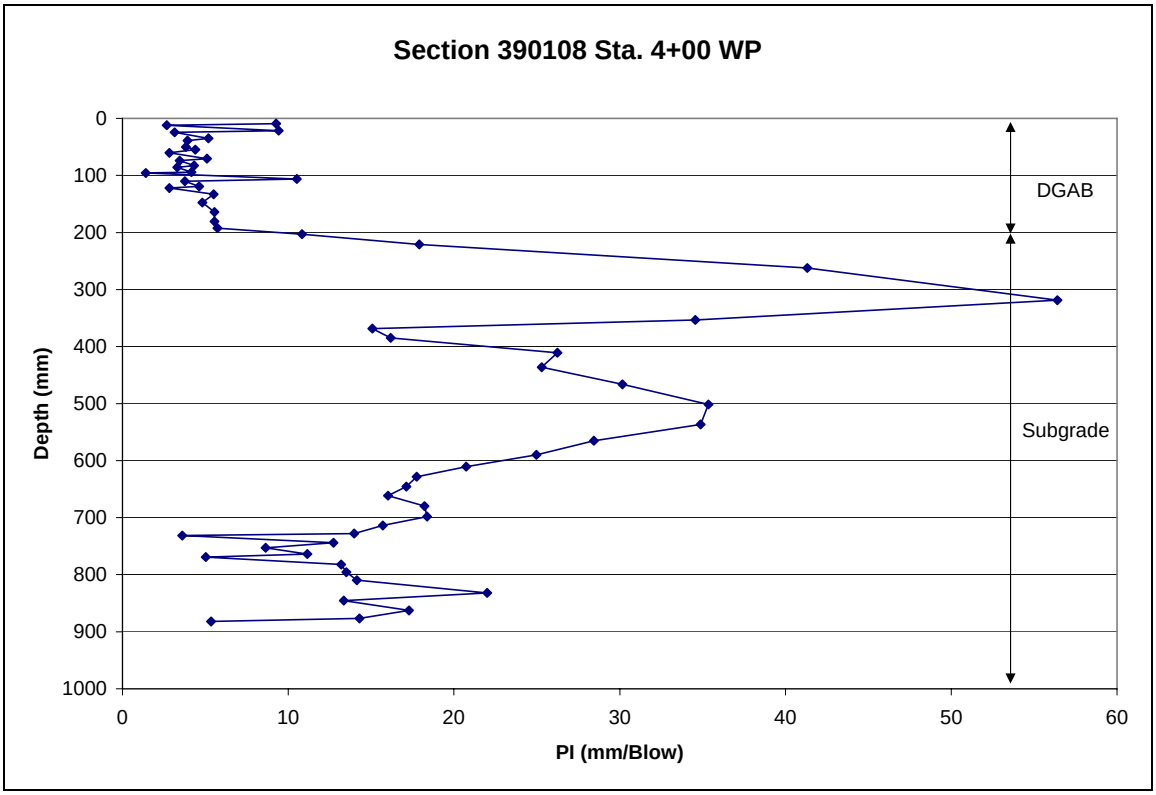
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70

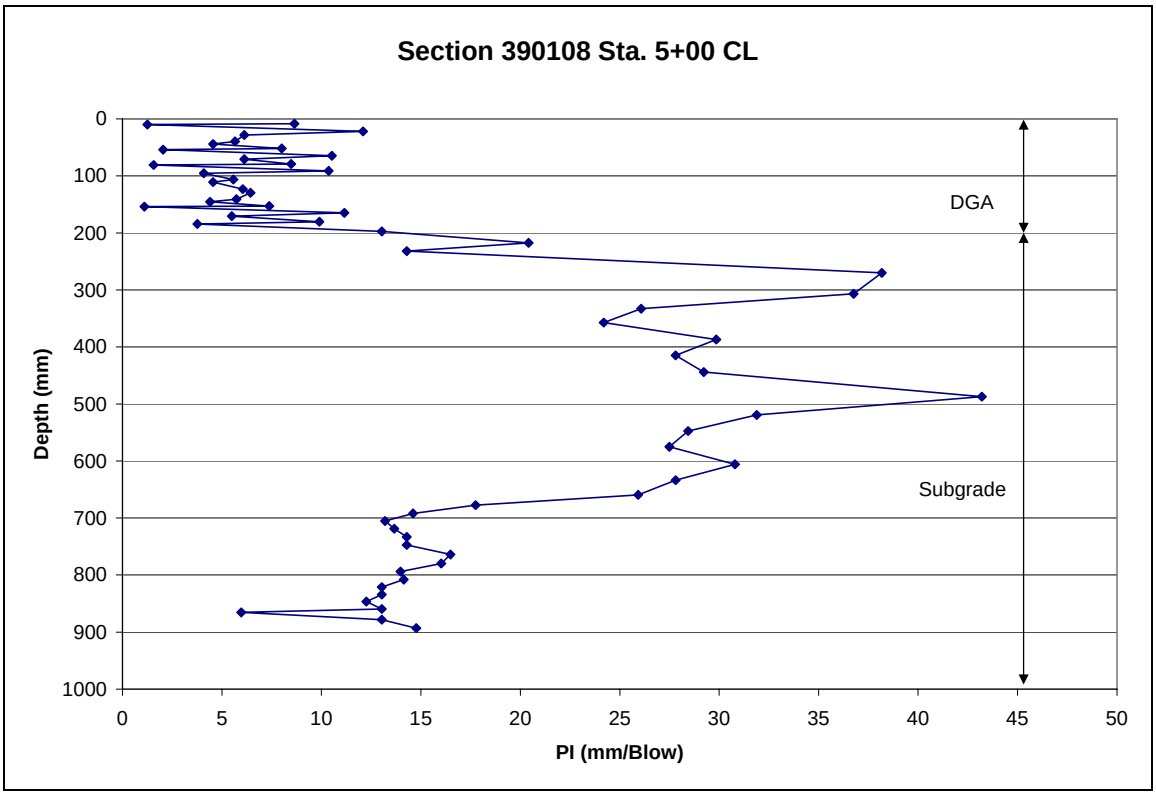

Section 390108 Sta. 3+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45
50

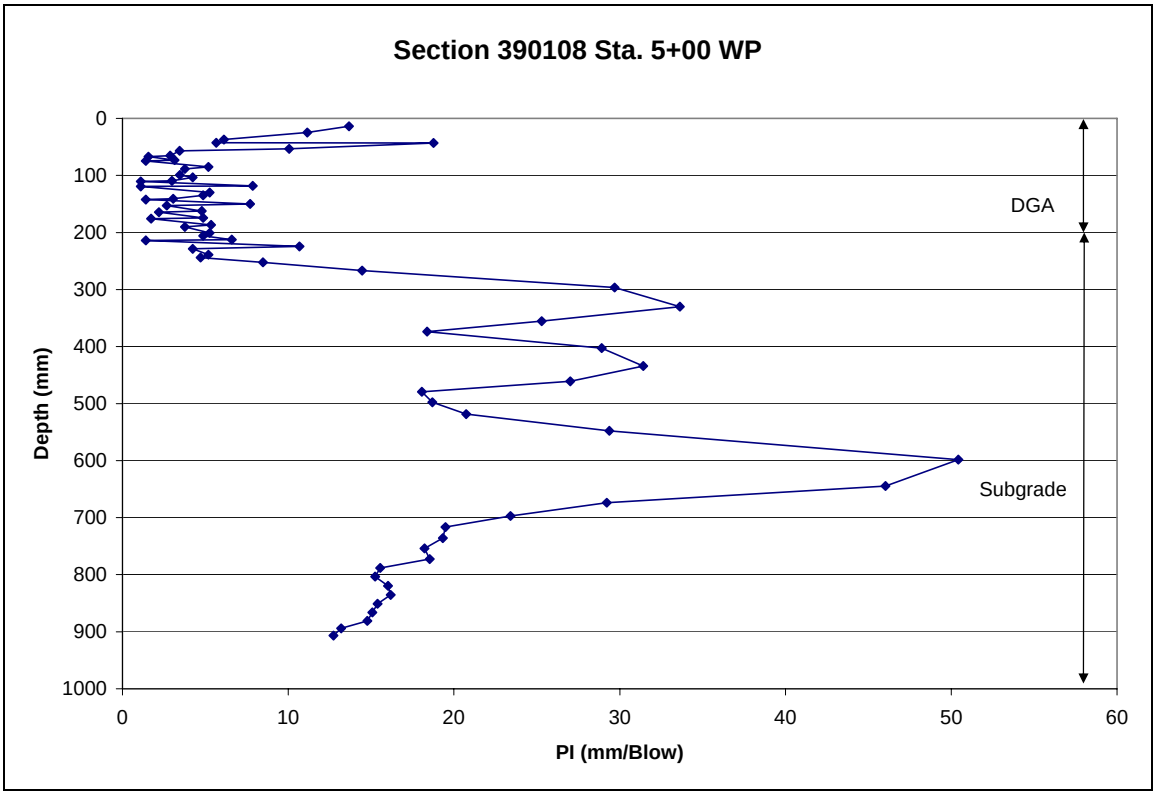
(25.4 mm = 1 in)


Section 390108 Sta. 4+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60

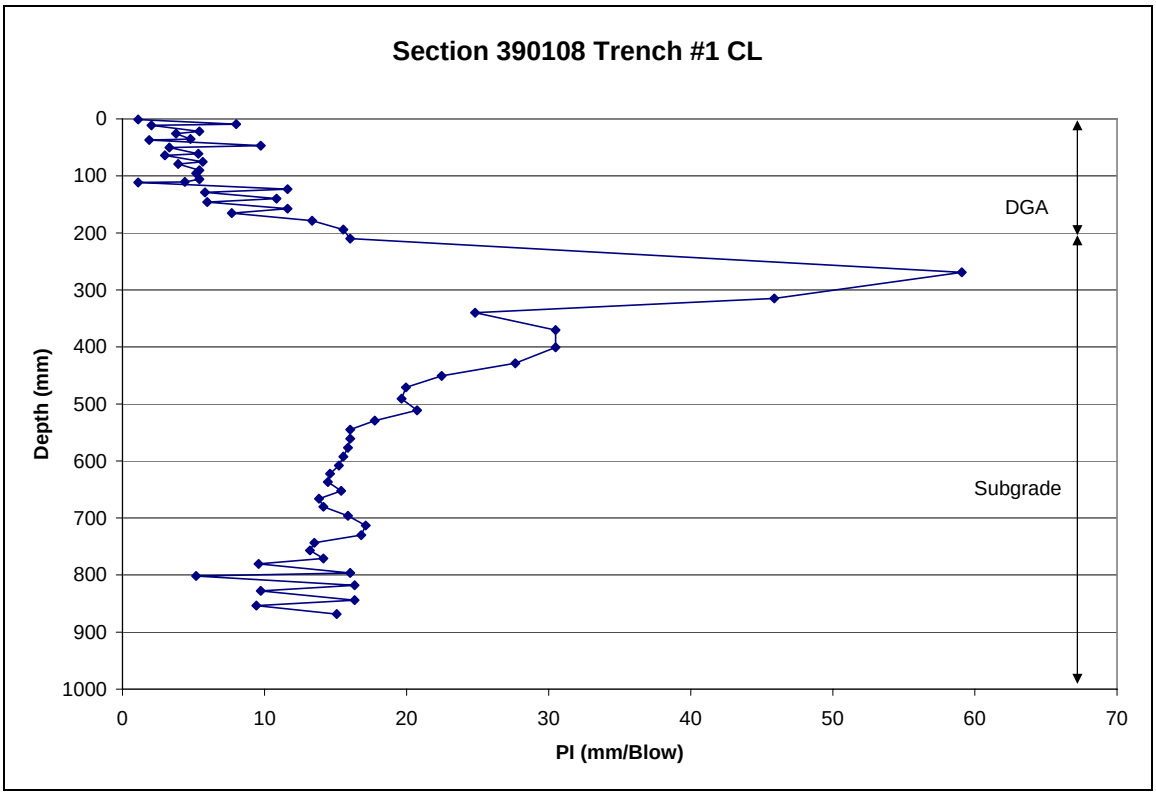

Section 390108 Sta. 4+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60

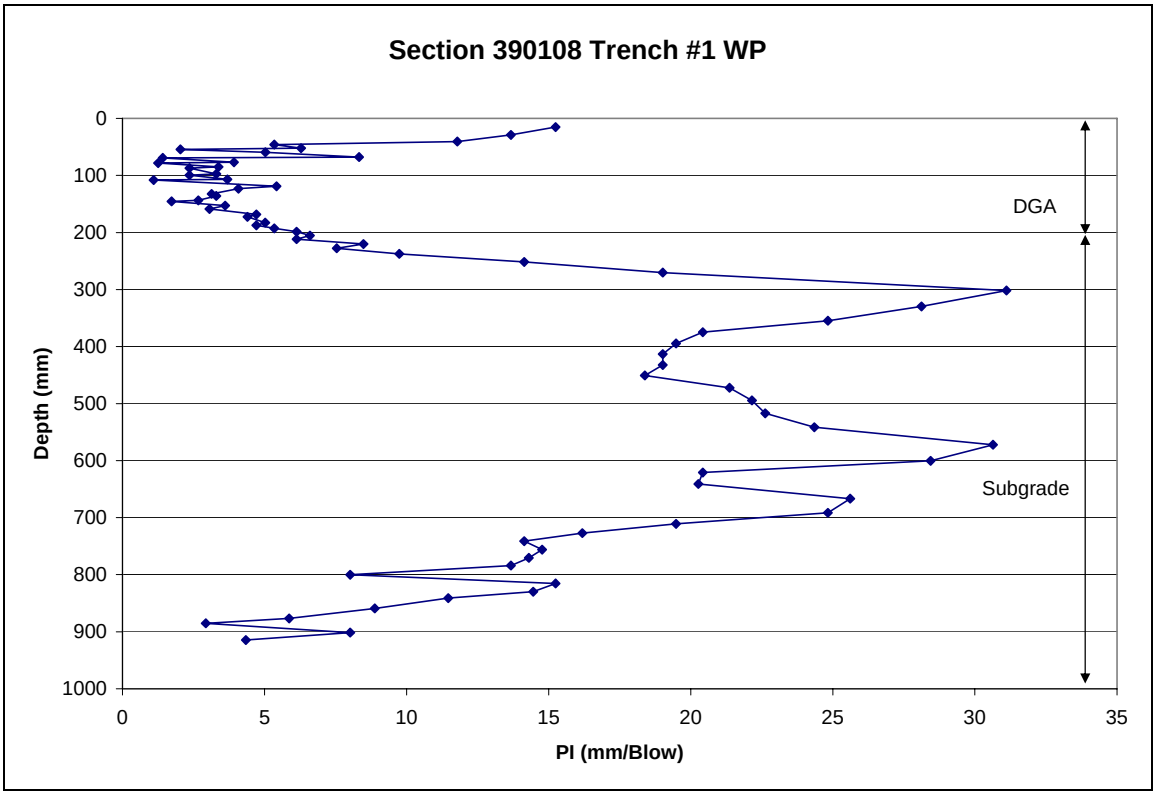
(25.4 mm = 1 in)


Section 390108 Sta. 5+00 CL
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45
50

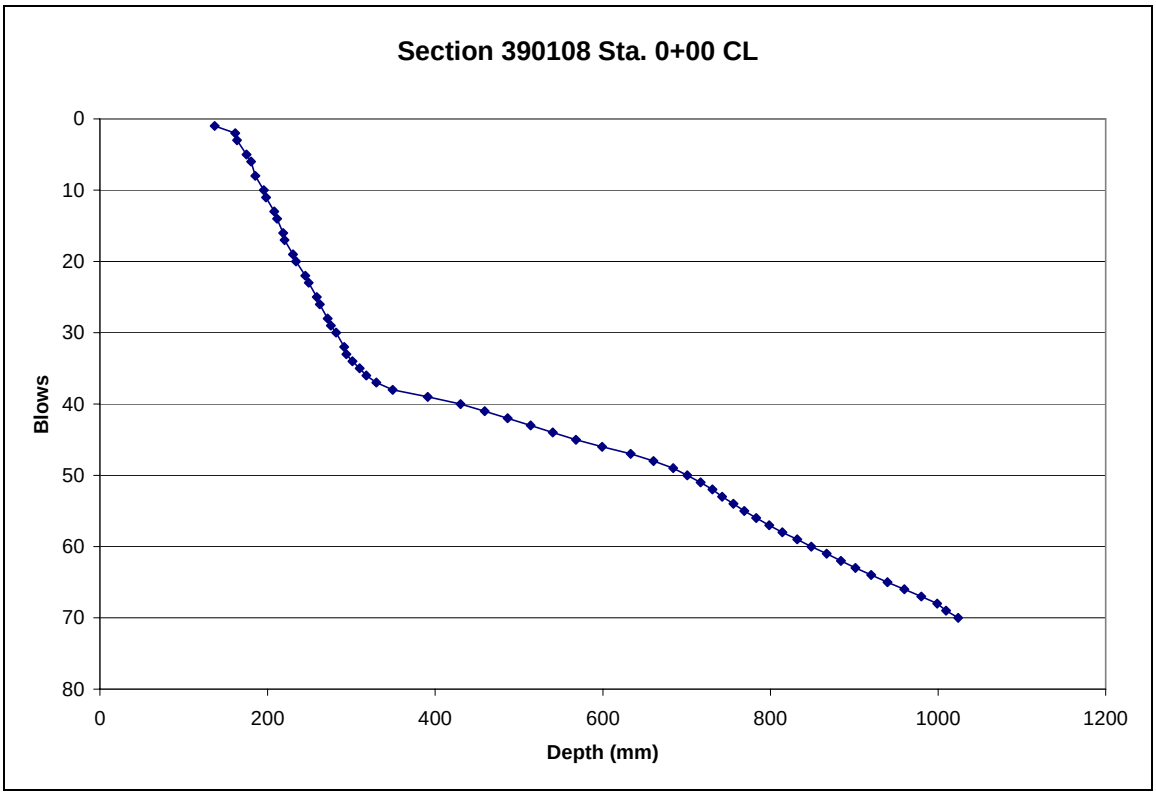

Section 390108 Sta. 5+00 WP
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60

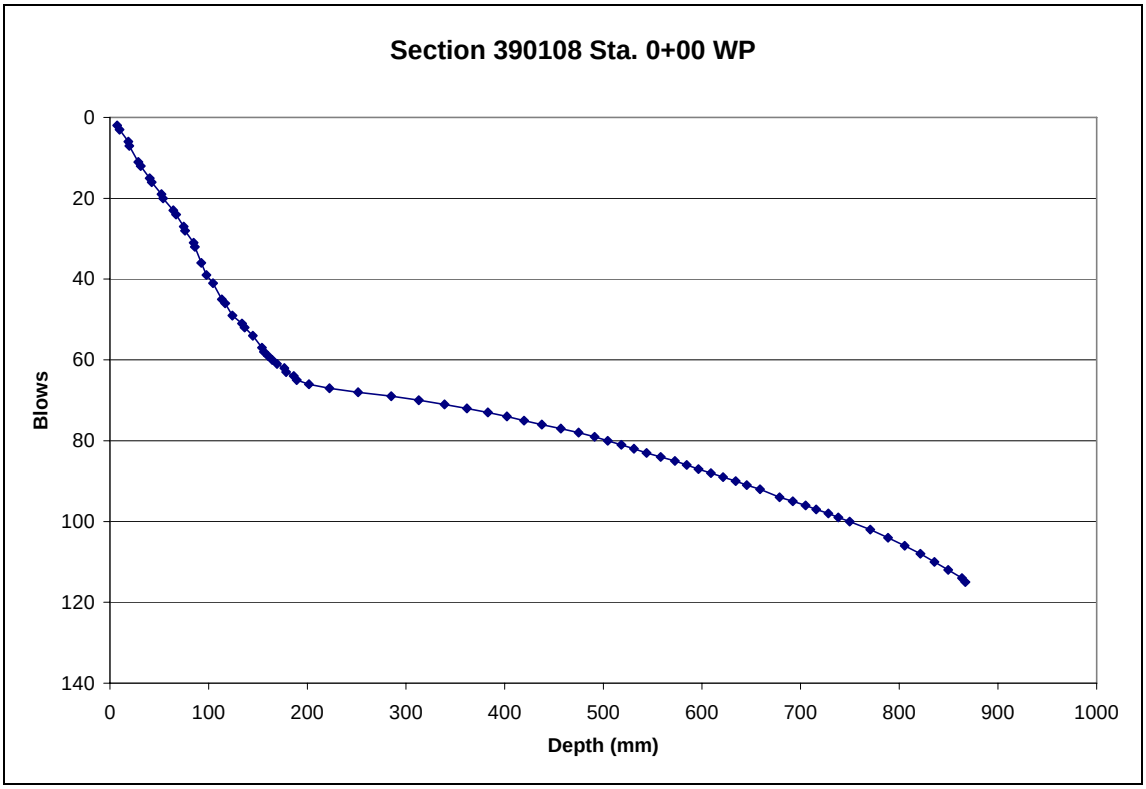
(25.4 mm = 1 in)


Section 390108 Trench #1 CL
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70

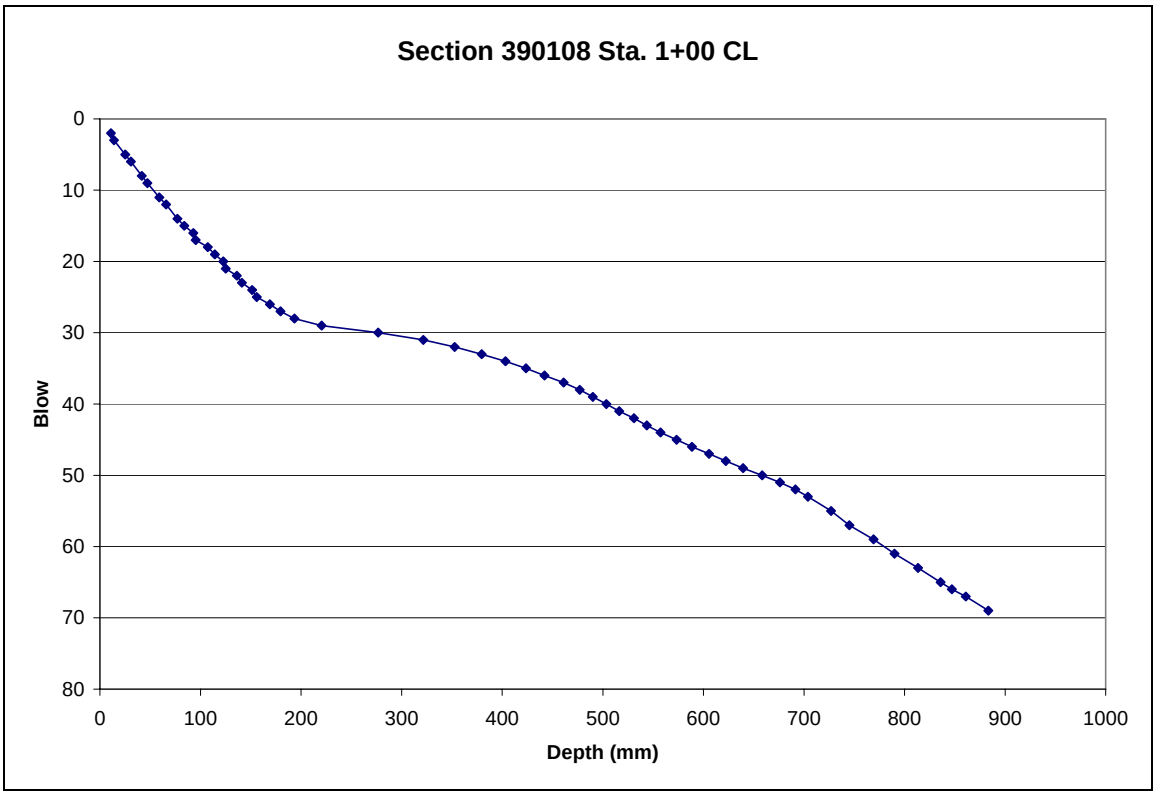

Section 390108 Trench #1 WP
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35

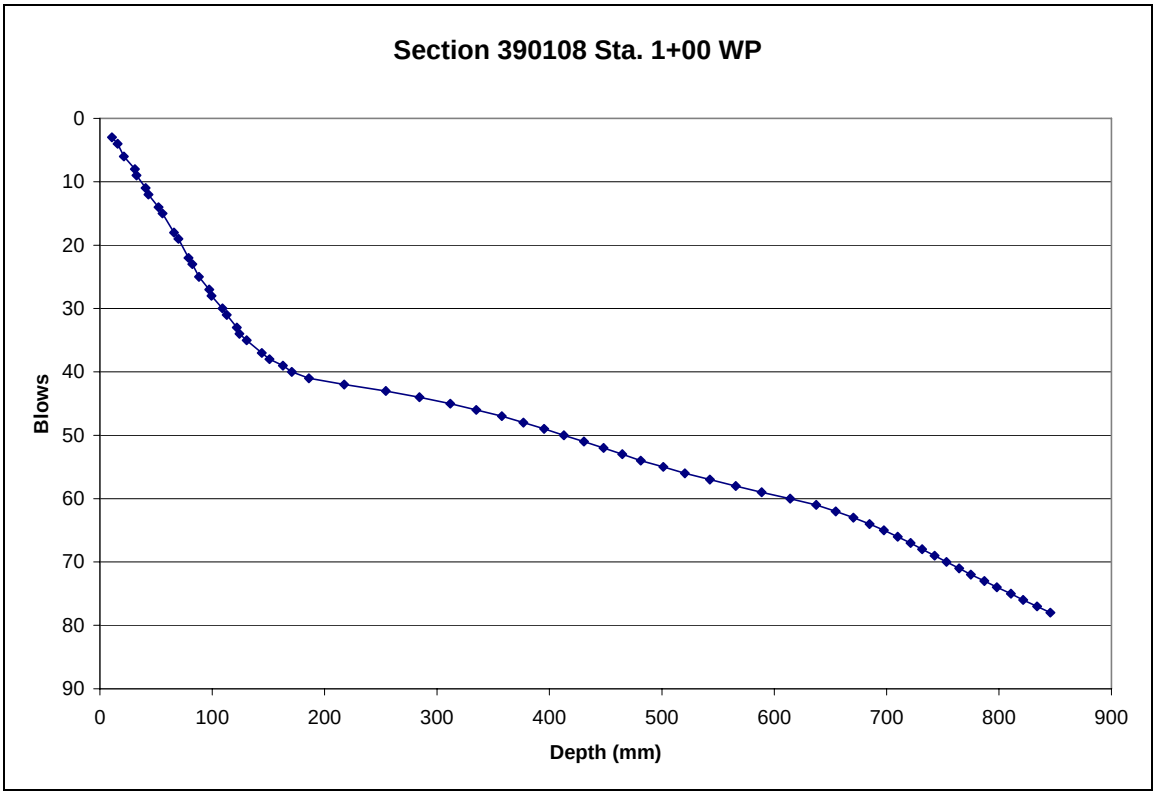
(25.4 mm = 1 in)


Section 390108 Sta. 0+00 CL
Blows
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
Depth (mm)

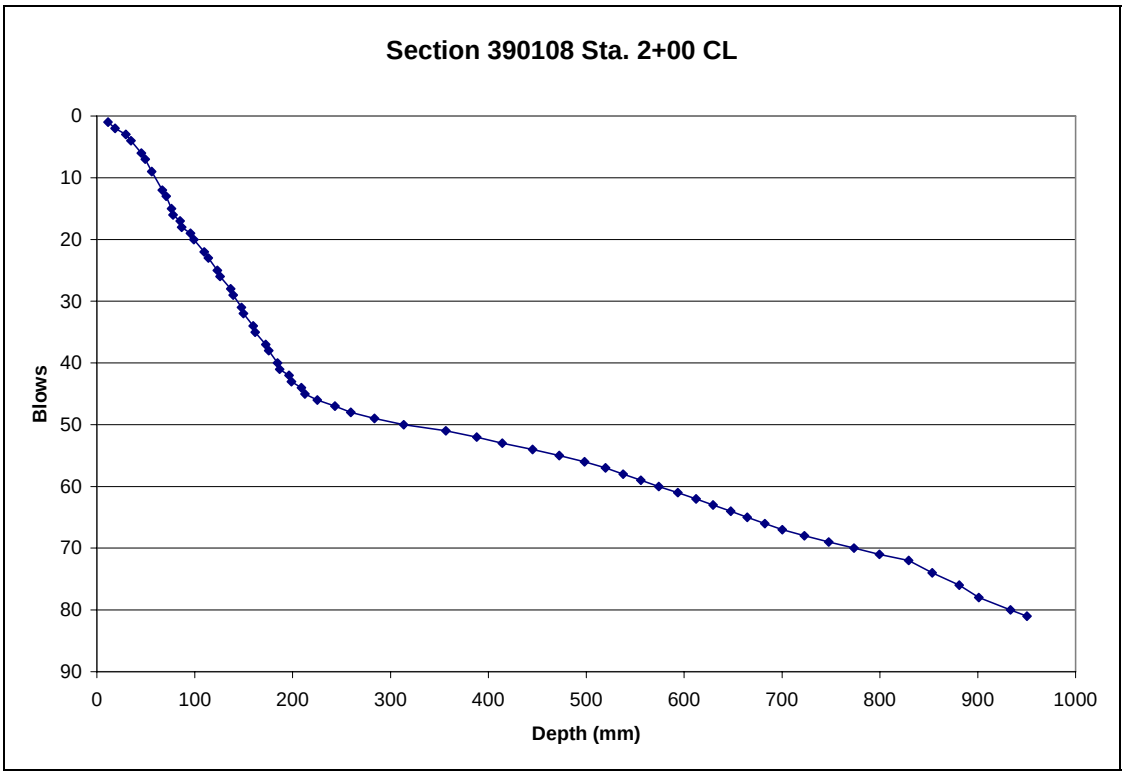

Section 390108 Sta. 0+00 WP
Blows
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

(25.4 mm = 1 in)


Section 390108 Sta. 1+00 CL
Blow
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Section 390108 Sta. 1+00 WP
Blows
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
Depth (mm)

(25.4 mm = 1 in)


Section 390108 Sta. 2+00 CL
Blows
Depth (mm)
0
10
20
30
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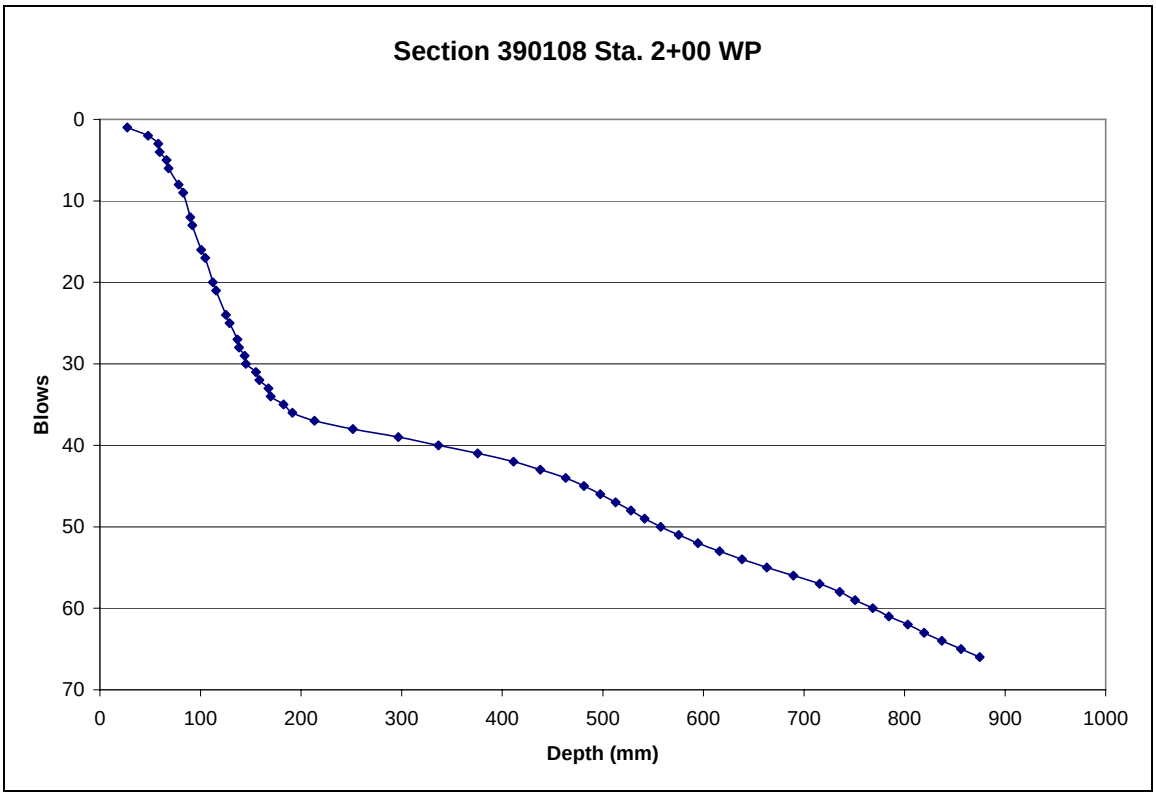
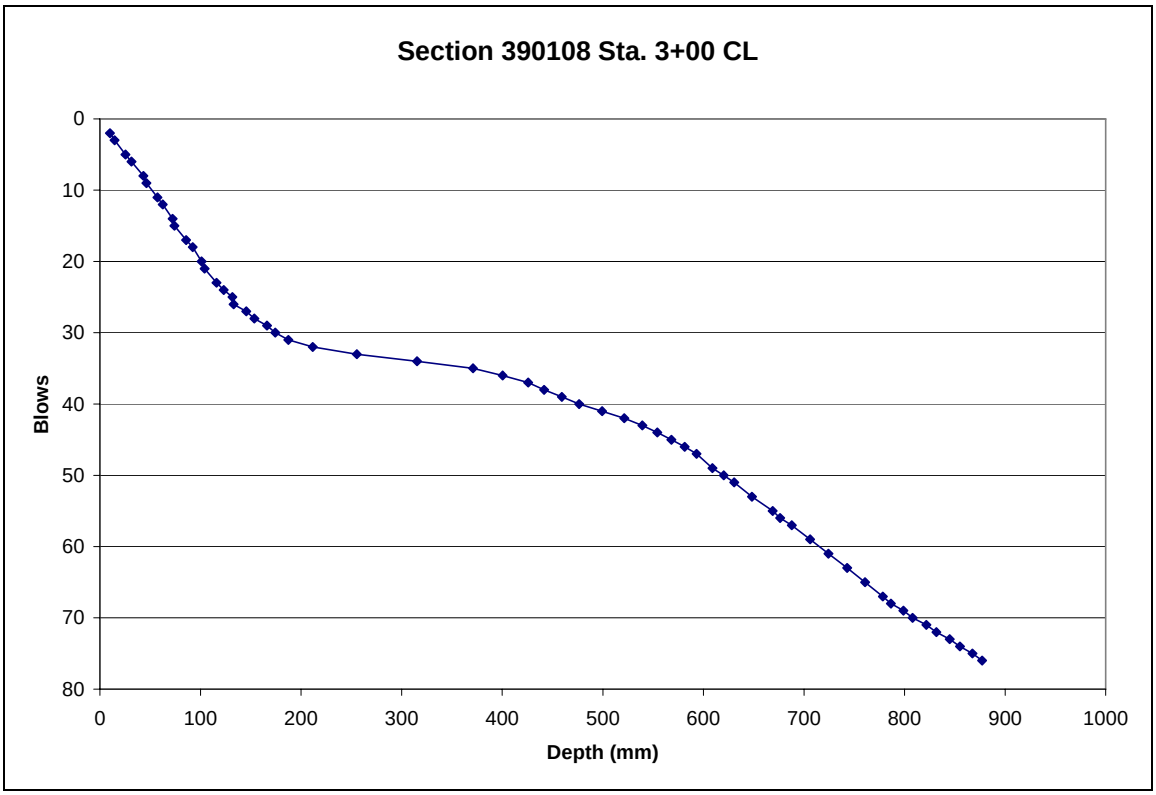
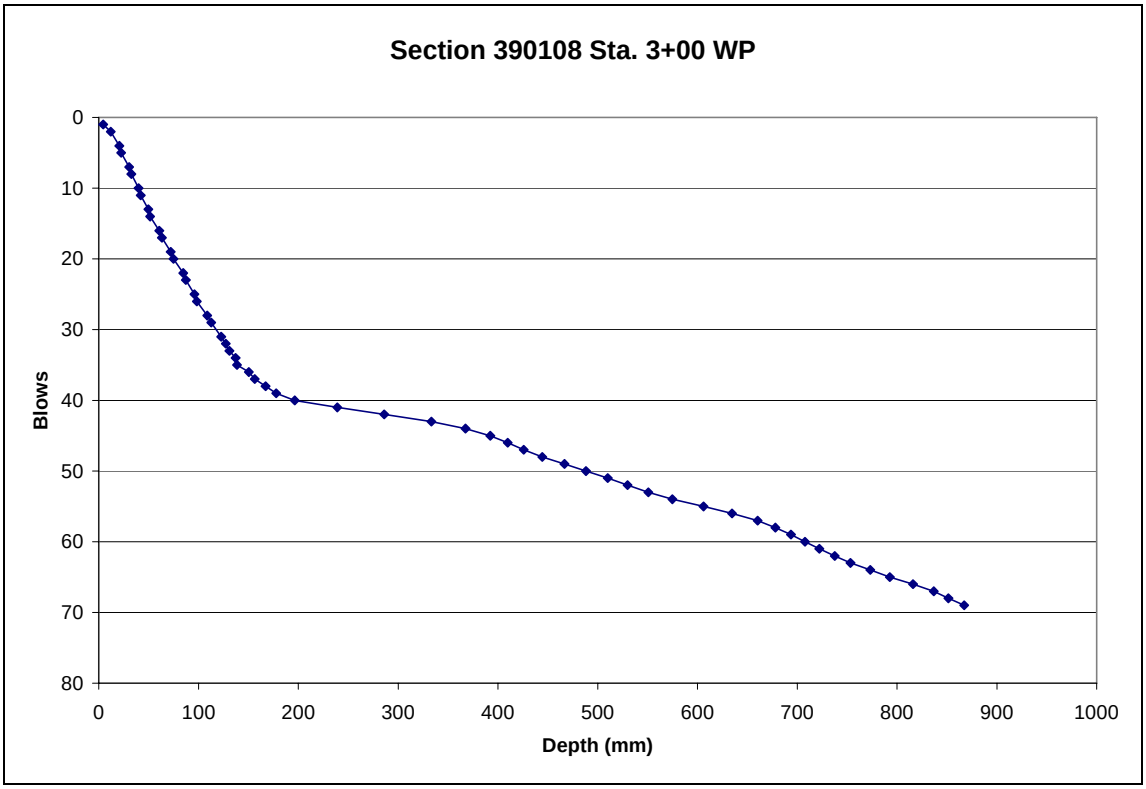
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000

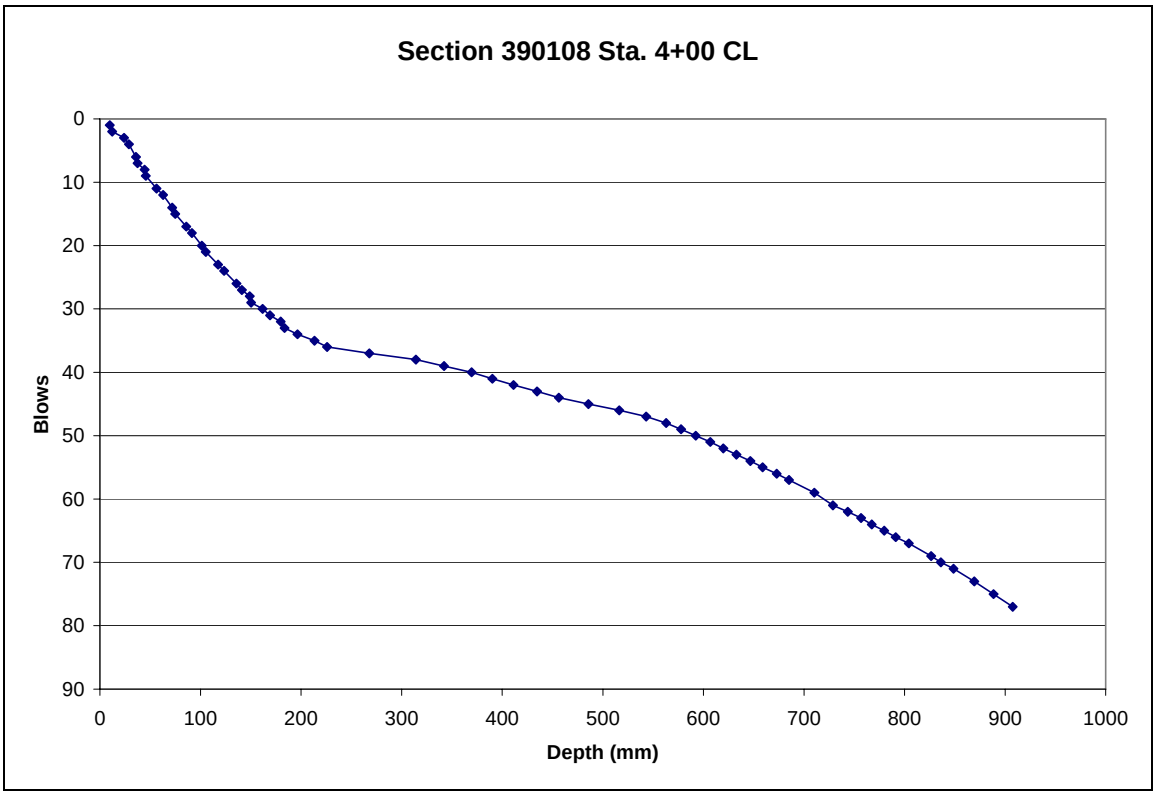

Section 390108 Sta. 2+00 WP
Blows
Depth (mm)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
900
1000

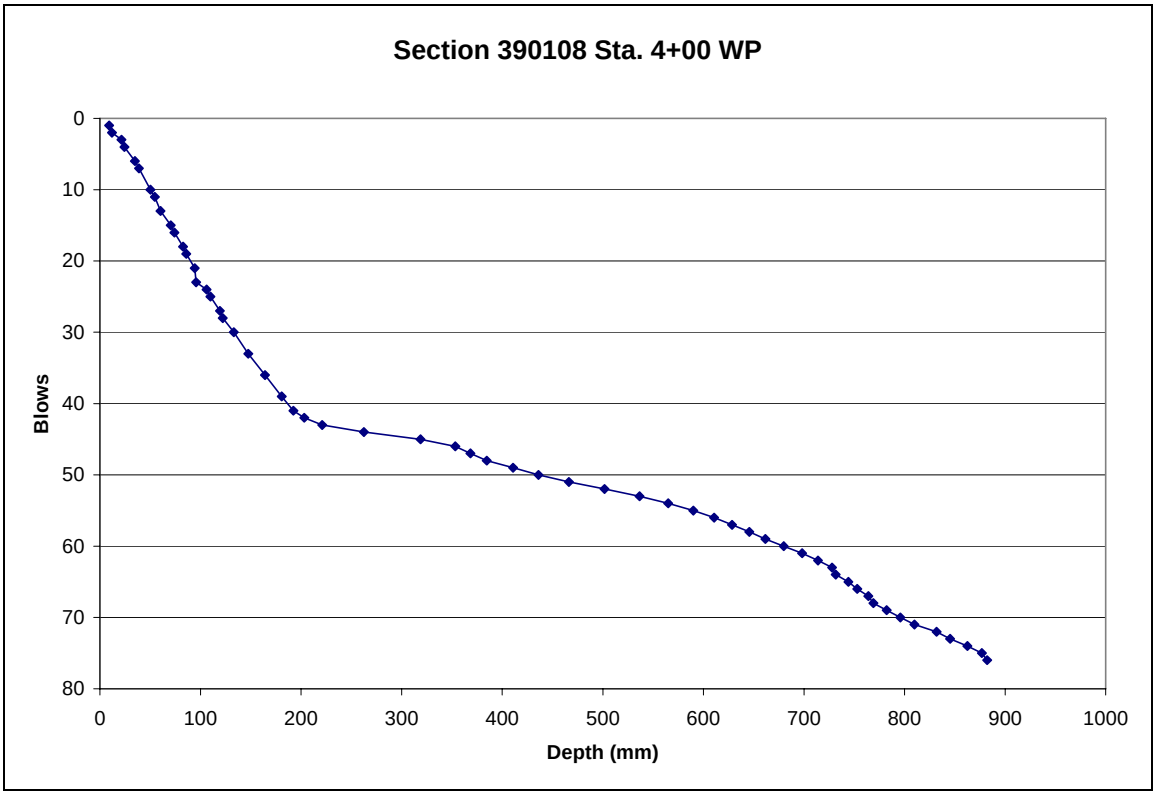
(25.4 mm = 1 in)


Section 390108 Sta. 3+00 CL
Blows
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

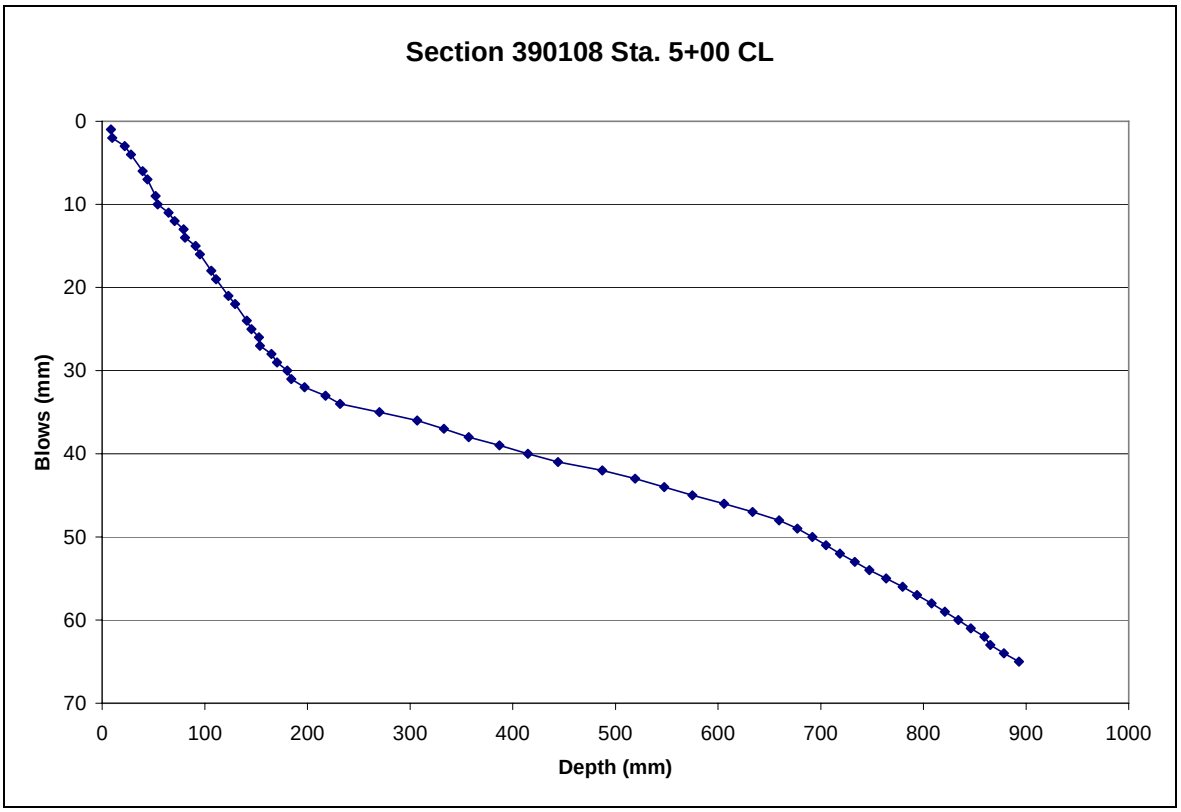

Section 390108 Sta. 3+00 WP
Blows
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

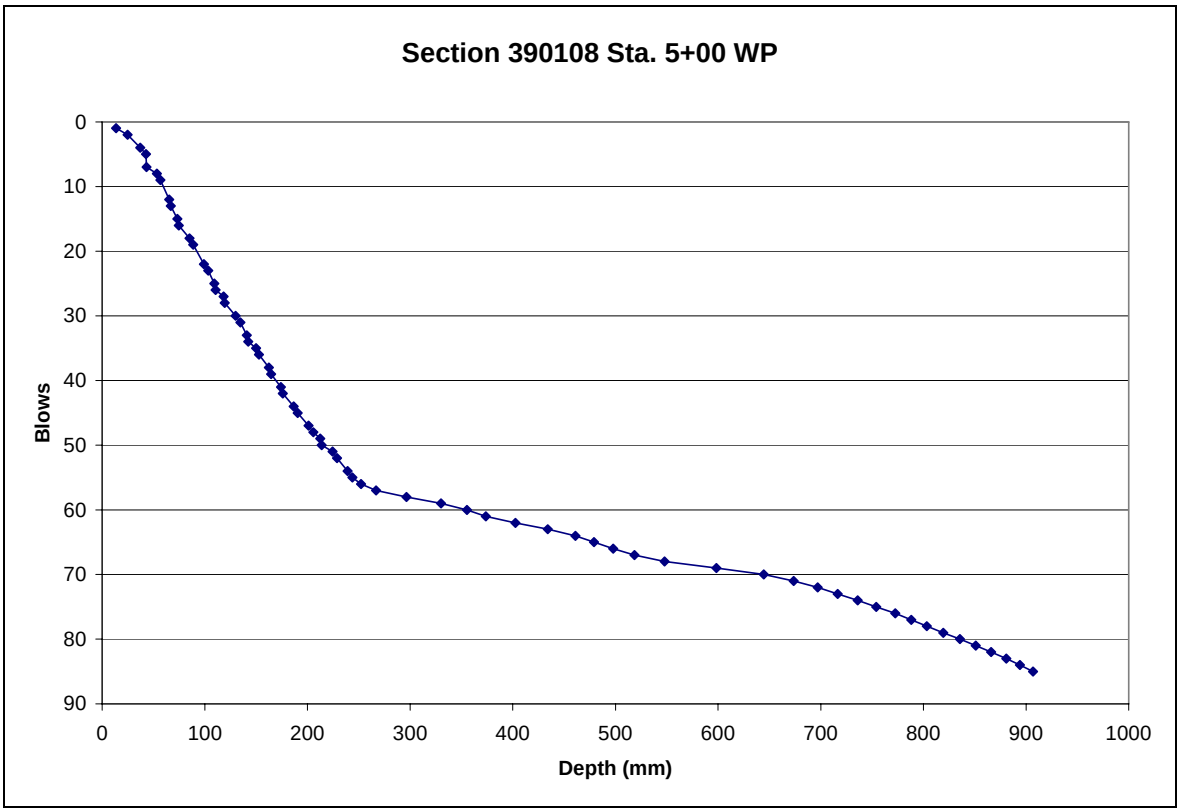
(25.4 mm = 1 in)


Section 390108 Sta. 4+00 CL
Blows
Depth (mm)
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000

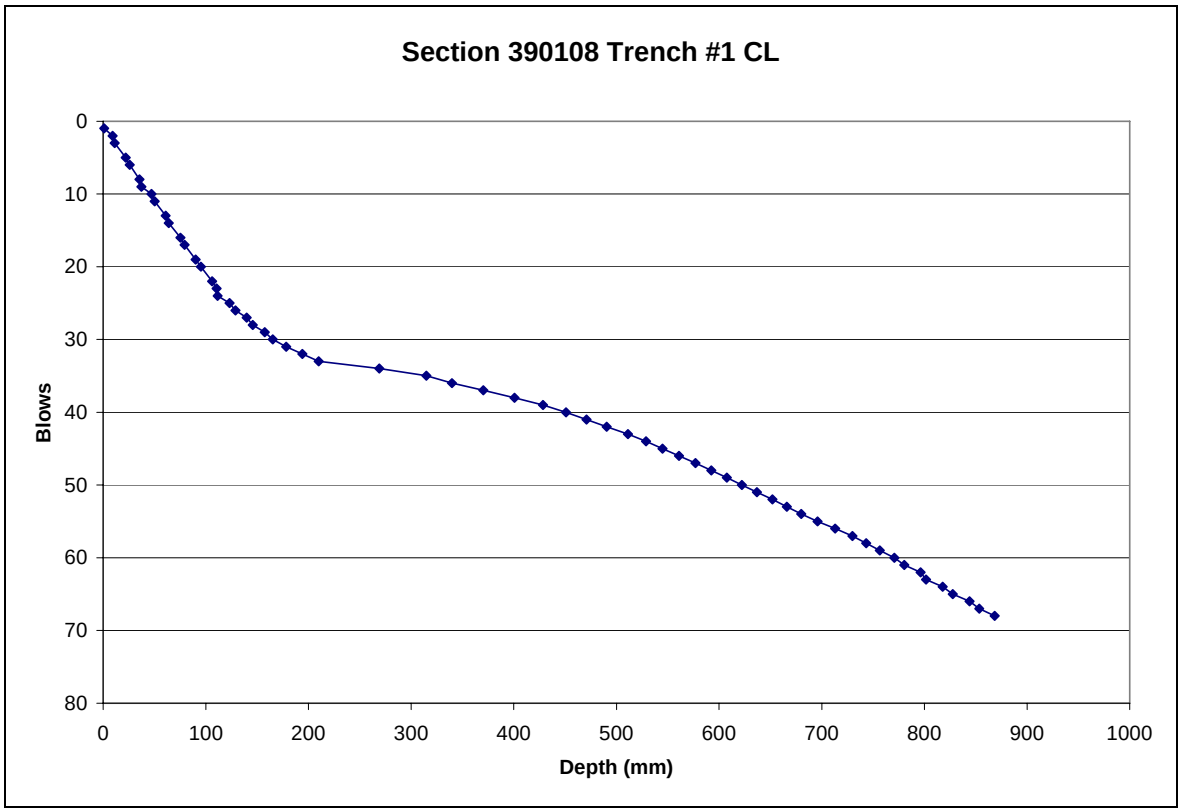

Section 390108 Sta. 4+00 WP
Blows
Depth (mm)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000

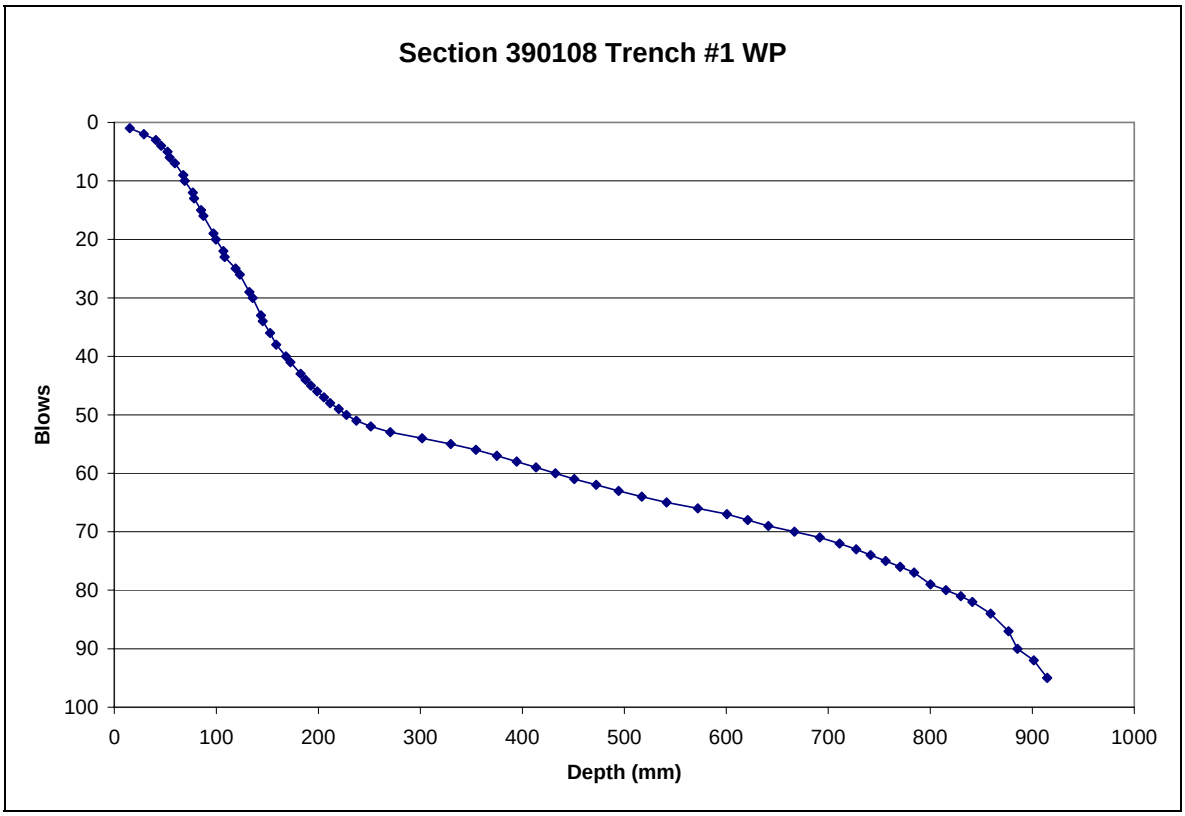
(25.4 mm = 1 in)


Section 390108 Sta. 5+00 CL
Blows (mm)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Section 390108 Sta. 5+00 WP
Blows
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

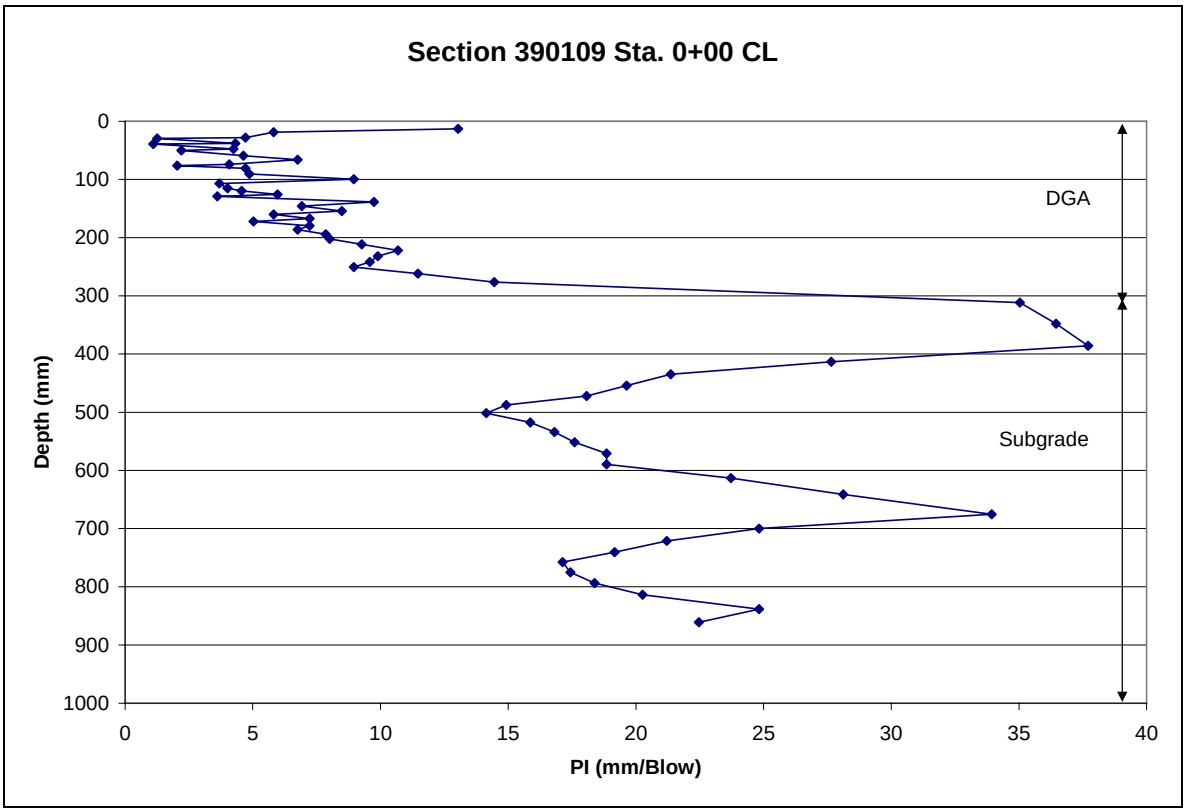
(25.4 mm = 1 in)


Section 390108 Trench #1 CL
Blows
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Section 390108 Trench #1 WP
Blows
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

(25.4 mm = 1 in)

SECTION 390109


Section 390109 Sta. 0+00 CL
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
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100
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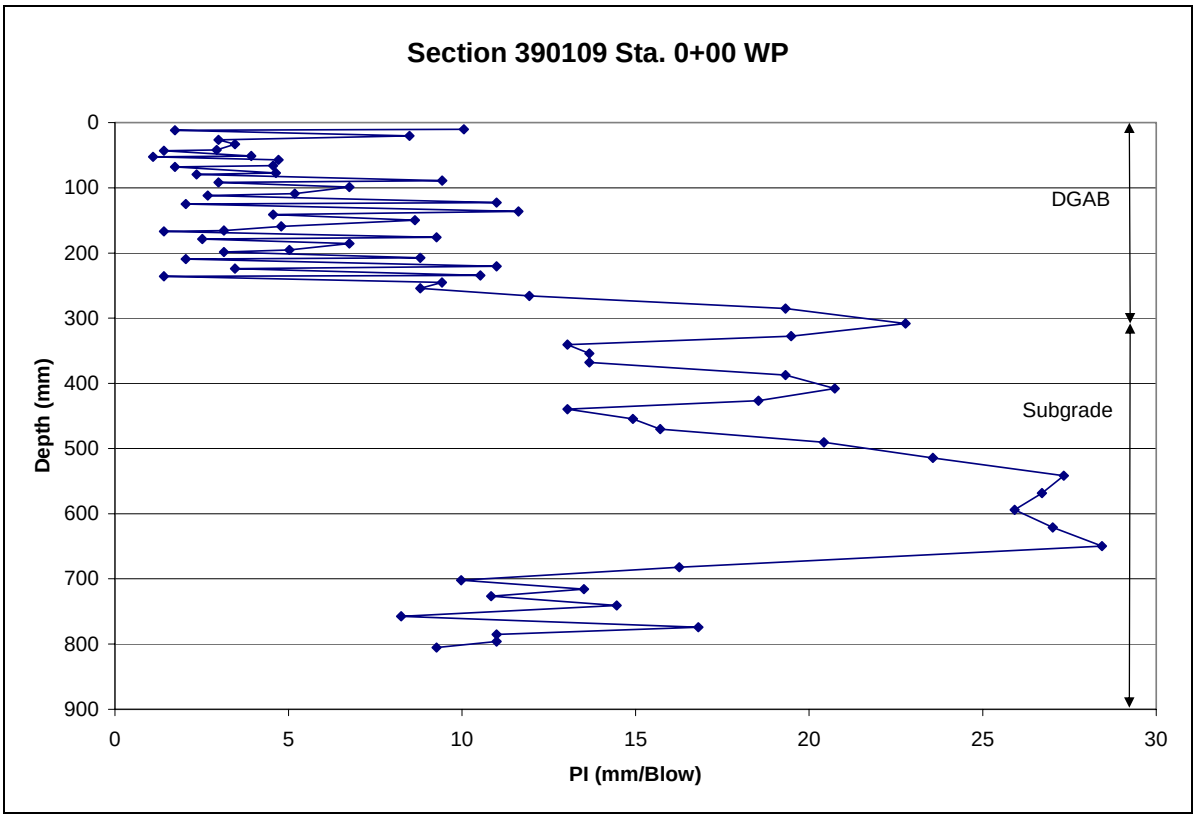
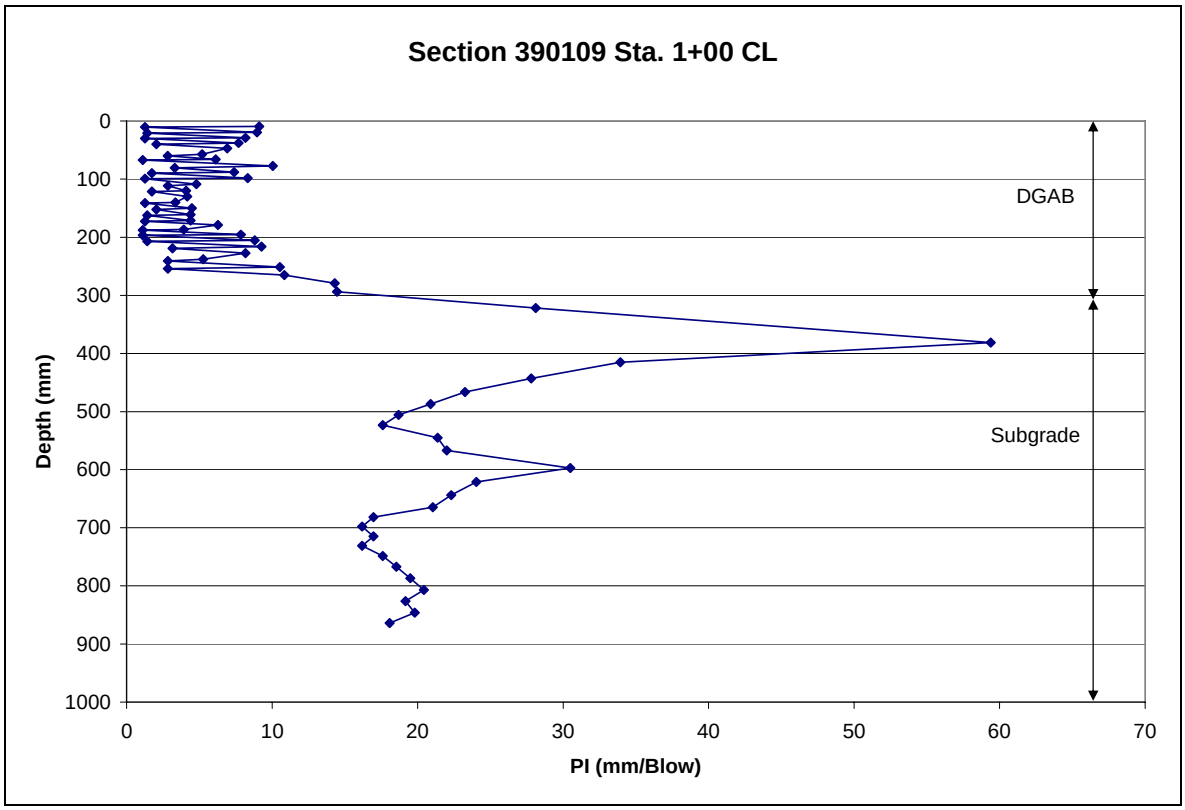
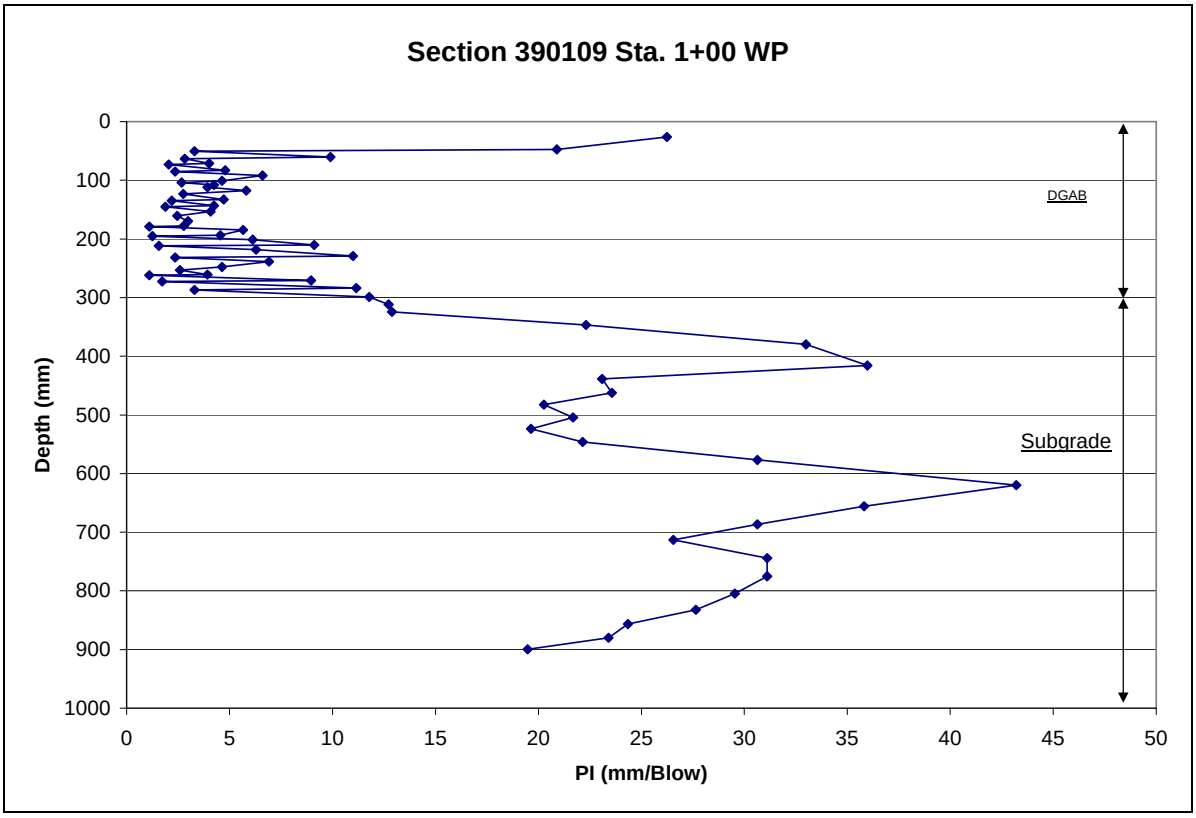
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40

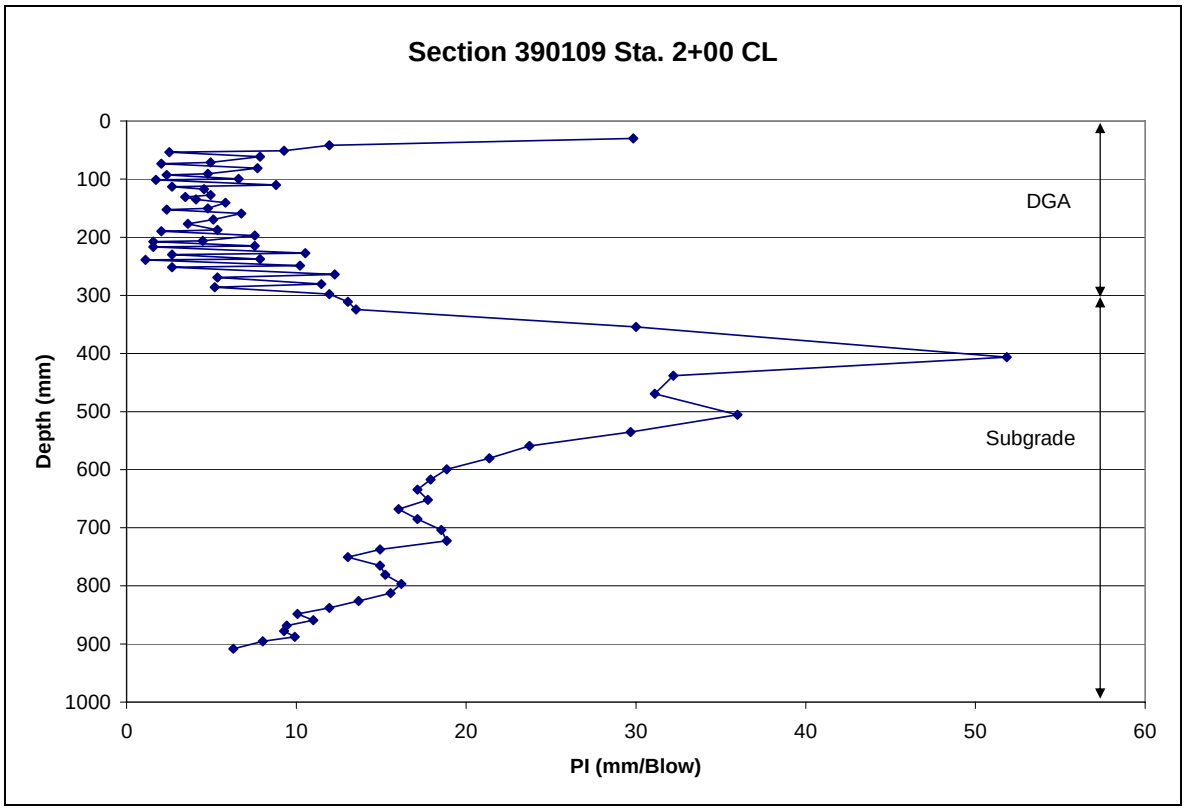

Section 390109 Sta. 0+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30

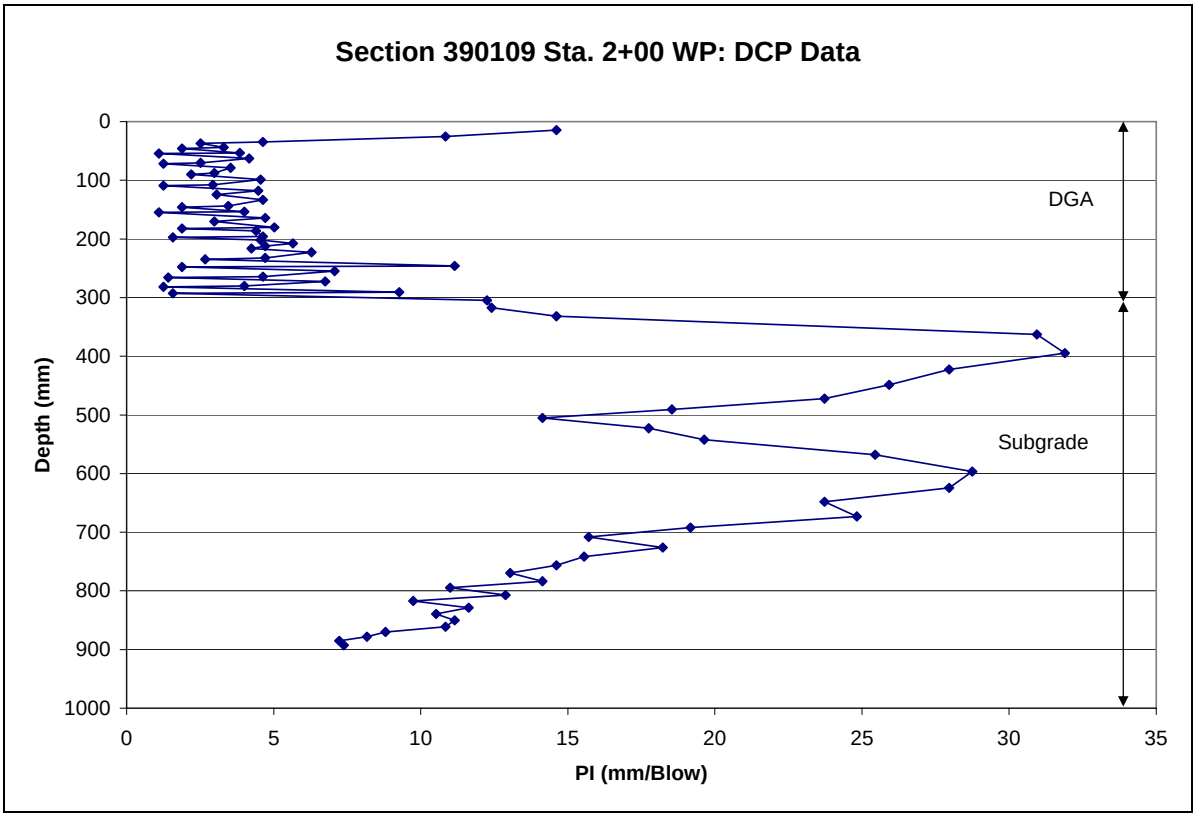
(25.4 mm = 1 in)


Section 390109 Sta. 1+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70

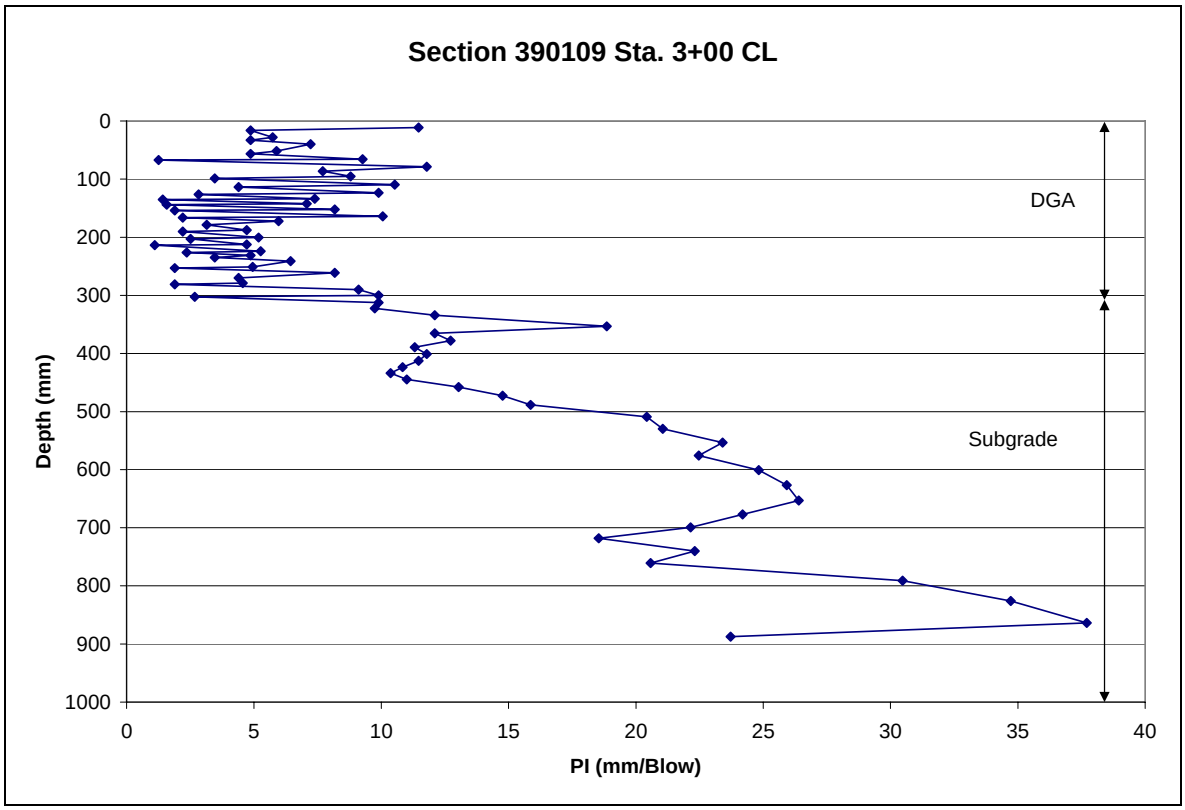

Section 390109 Sta. 1+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45
50

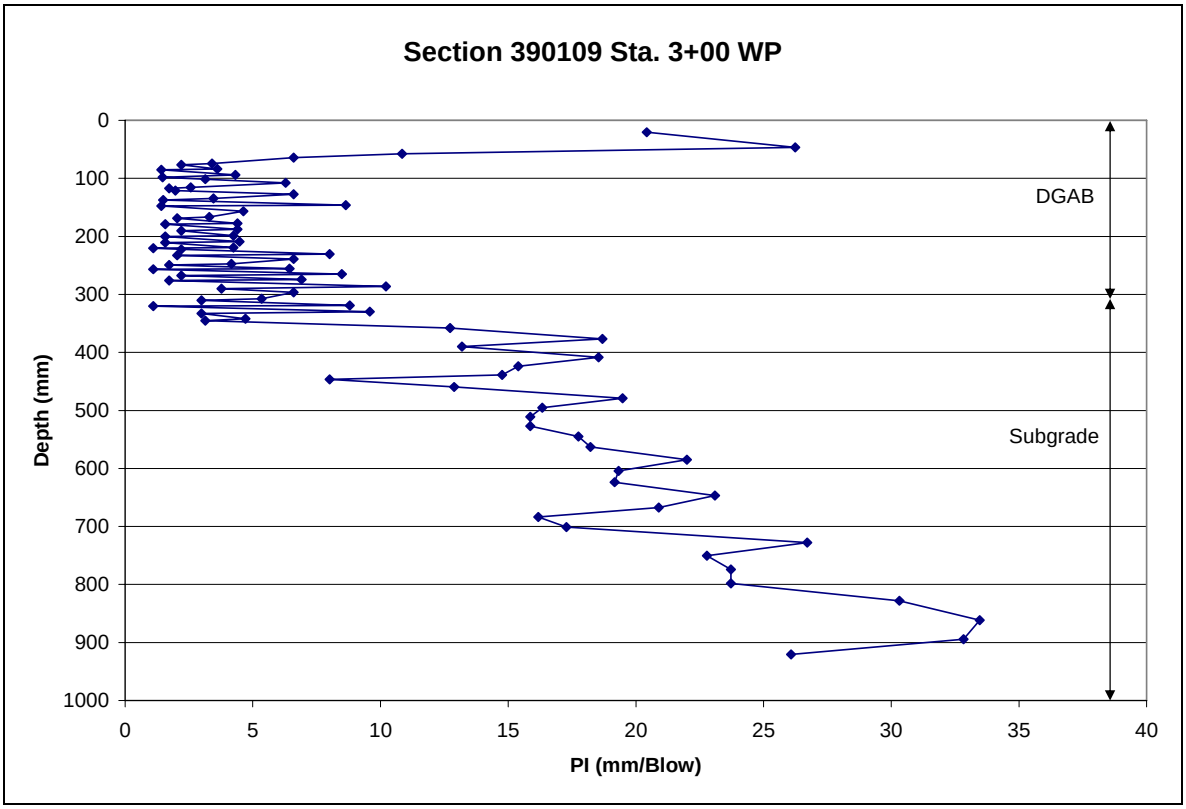
(25.4 mm = 1 in)


Section 390109 Sta. 2+00 CL
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60

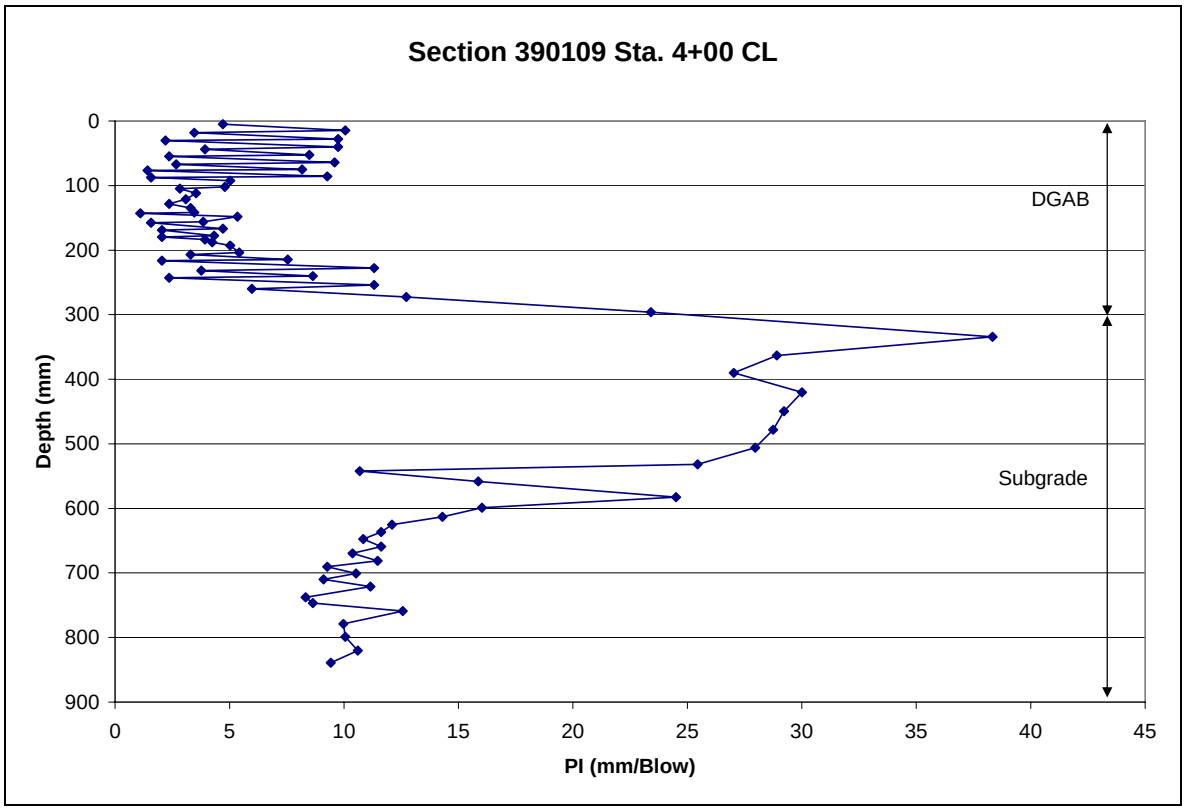

Section 390109 Sta. 2+00 WP: DCP Data
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35

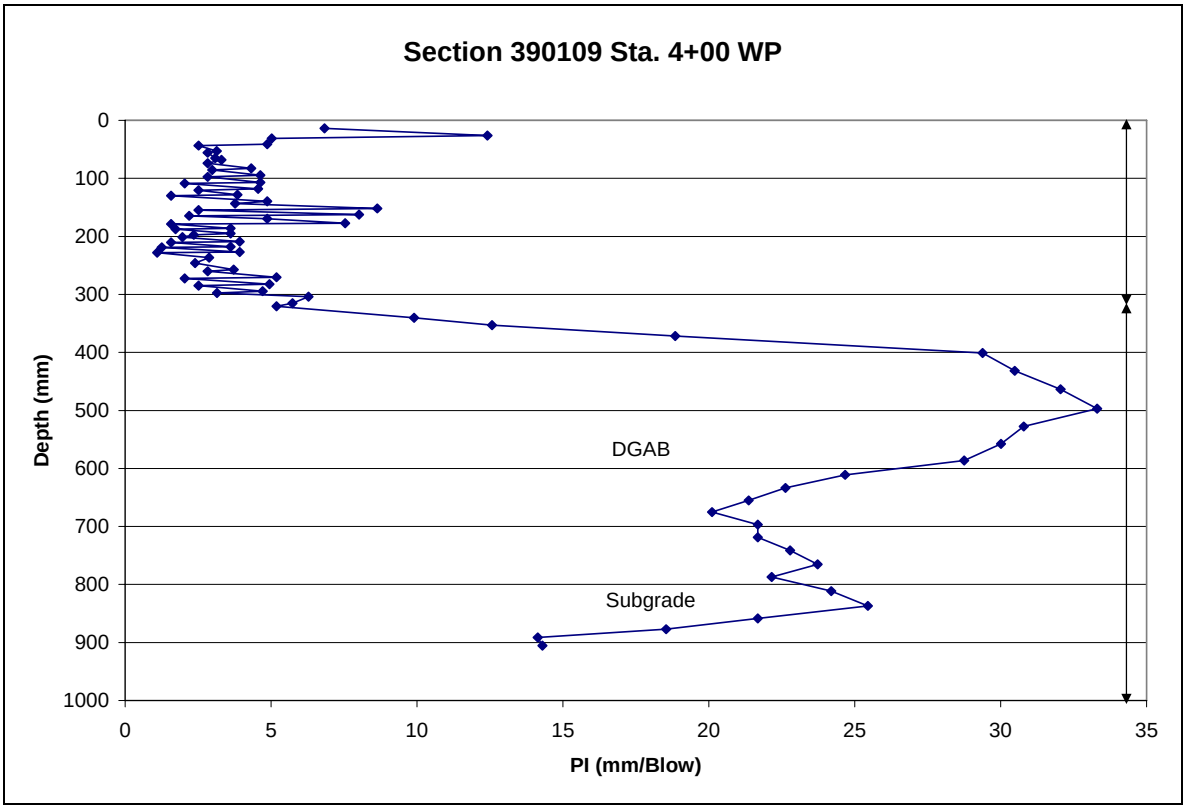
(25.4 mm = 1 in)


Section 390109 Sta. 3+00 CL
Depth (mm)
PI (mm/Blow)
DGA
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40

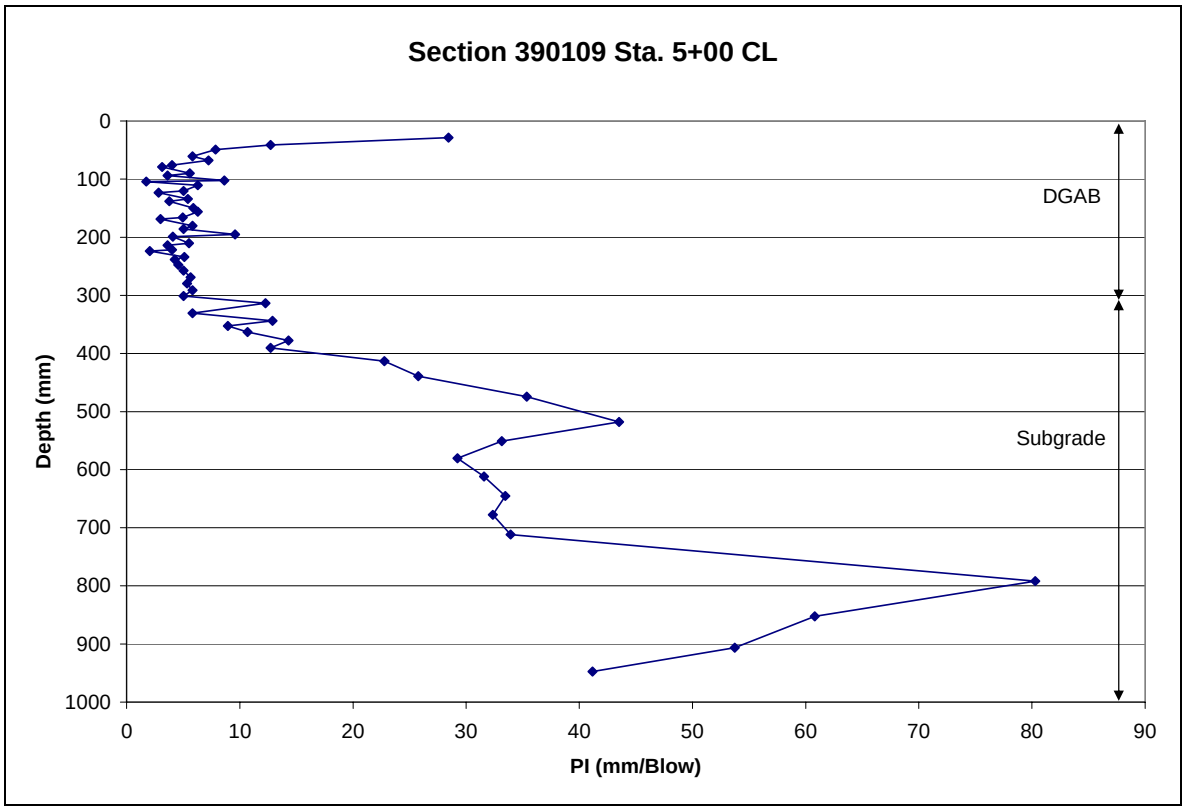

Section 390109 Sta. 3+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40

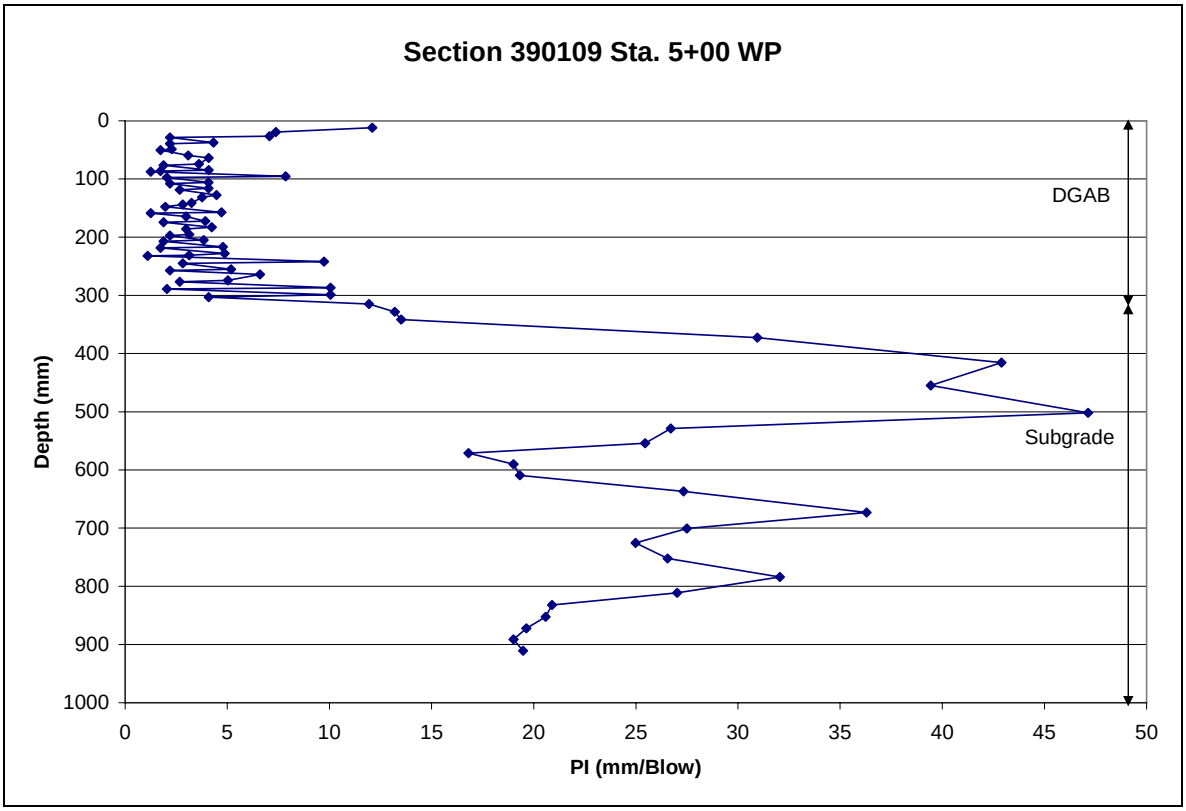
(25.4 mm = 1 in)


Section 390109 Sta. 4+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30
35
40
45

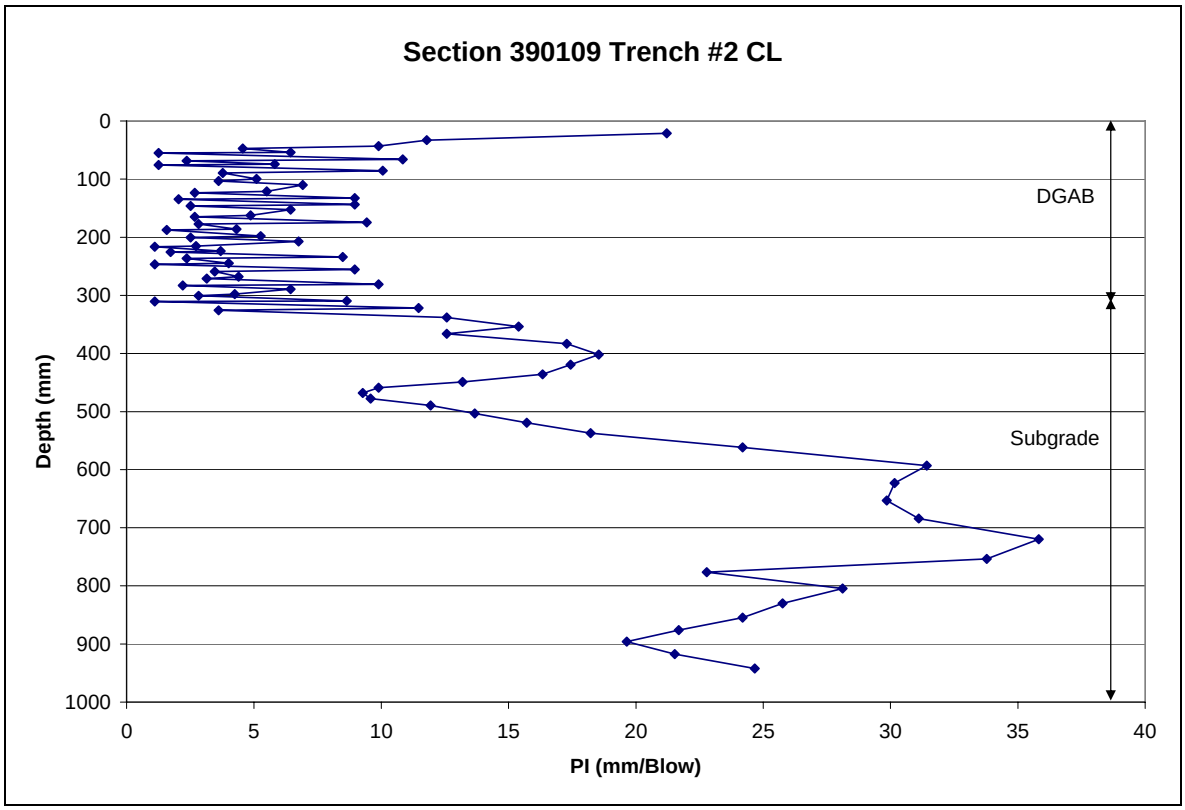

Section 390109 Sta. 4+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35

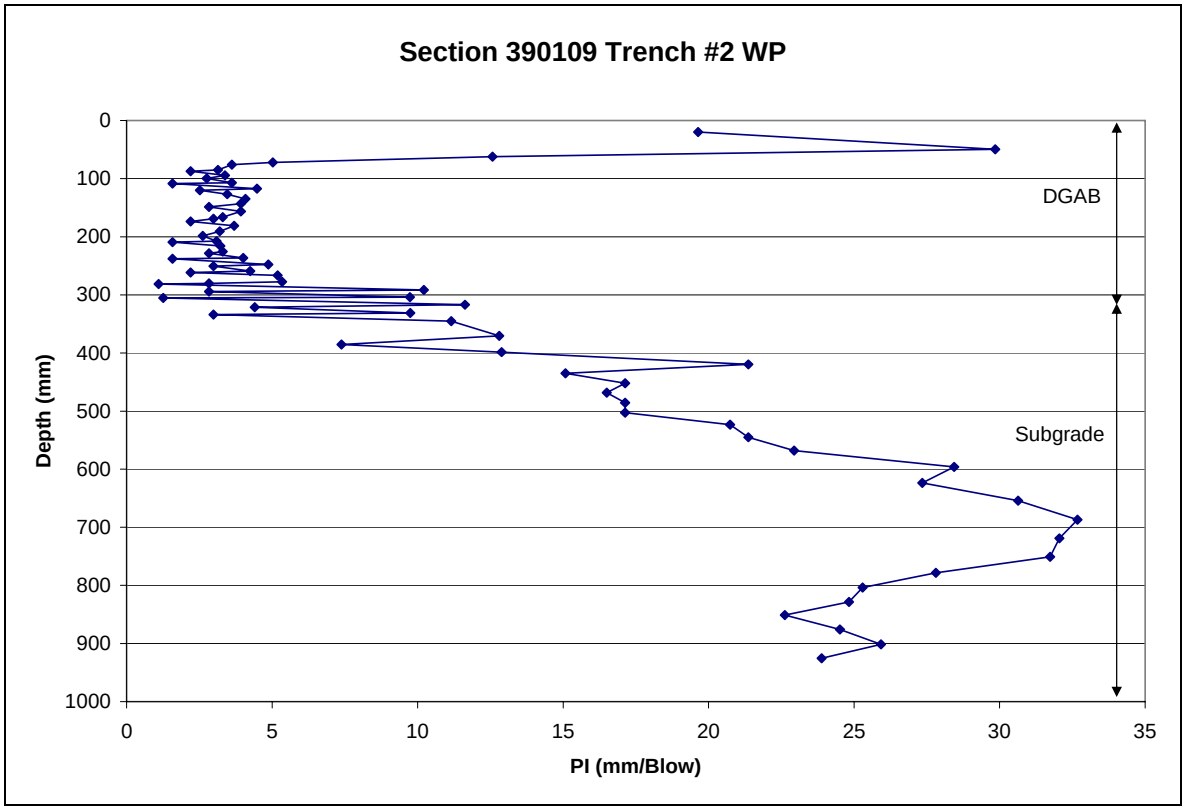
(25.4 mm = 1 in)


Section 390109 Sta. 5+00 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90

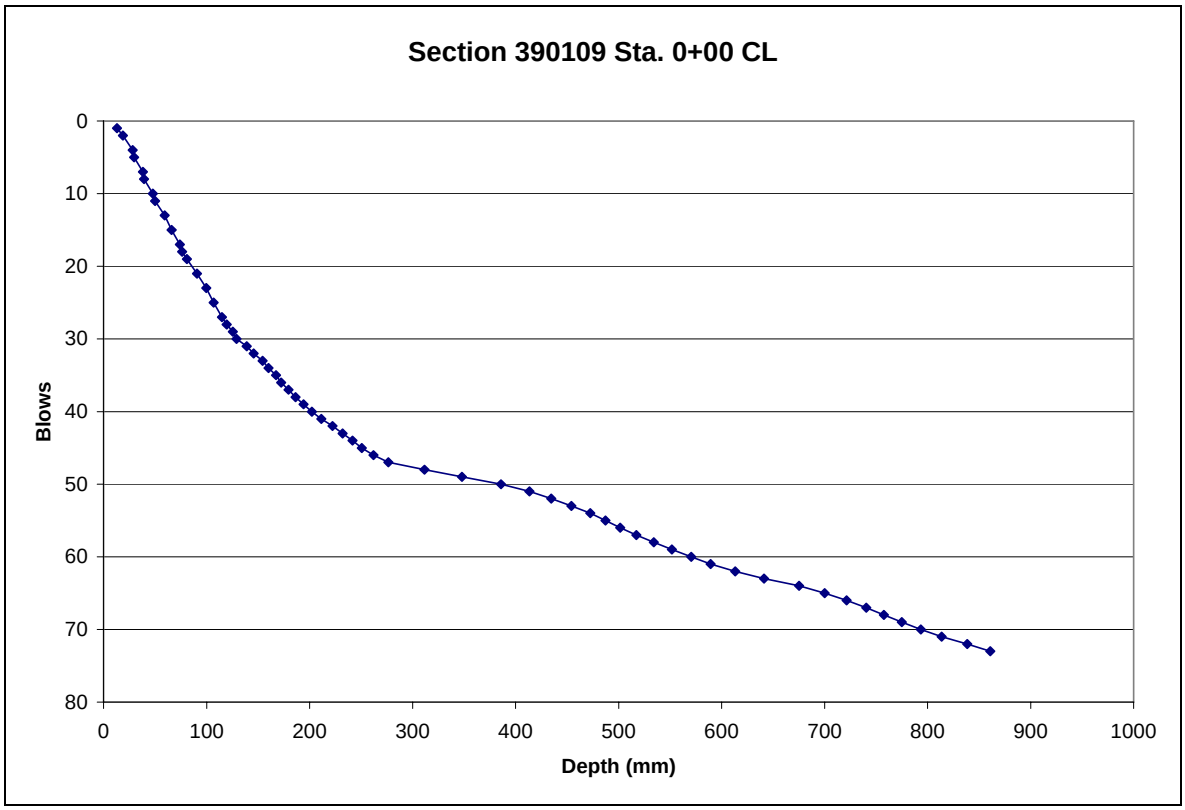

Section 390109 Sta. 5+00 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45
50

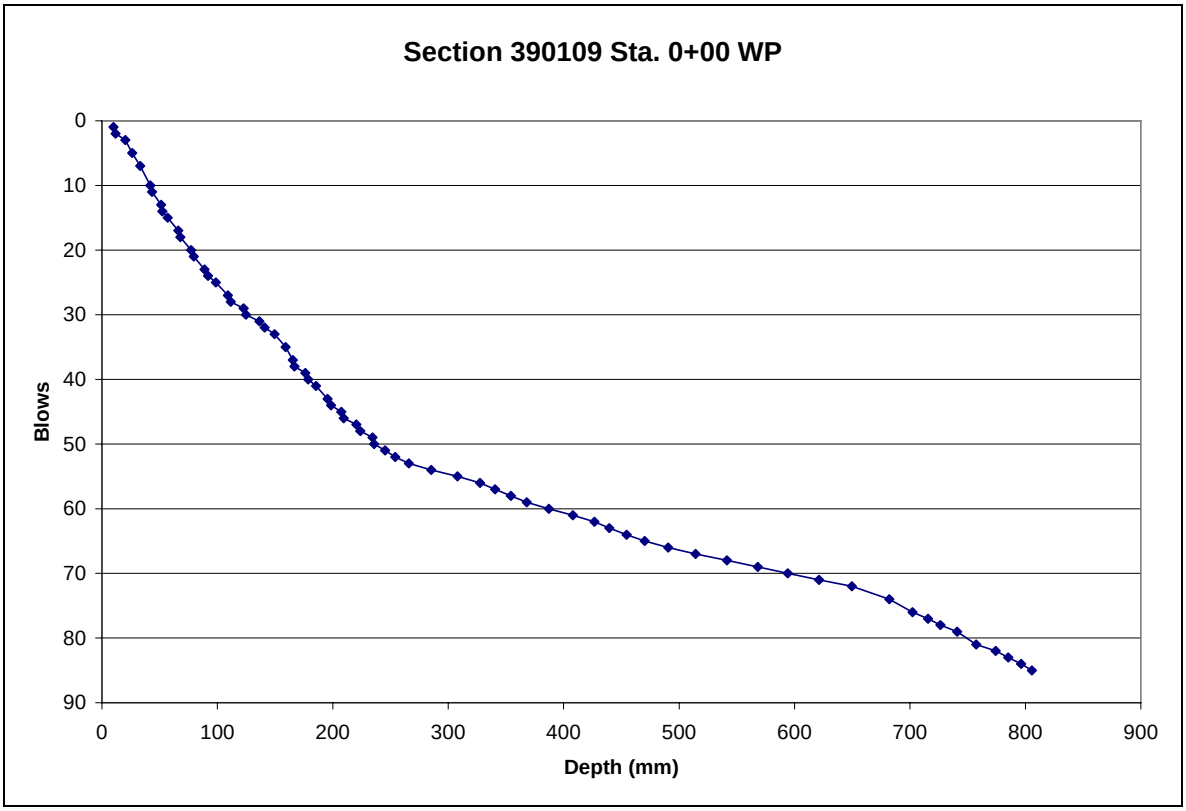
(25.4 mm = 1 in)


Section 390109 Trench #2 CL
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40

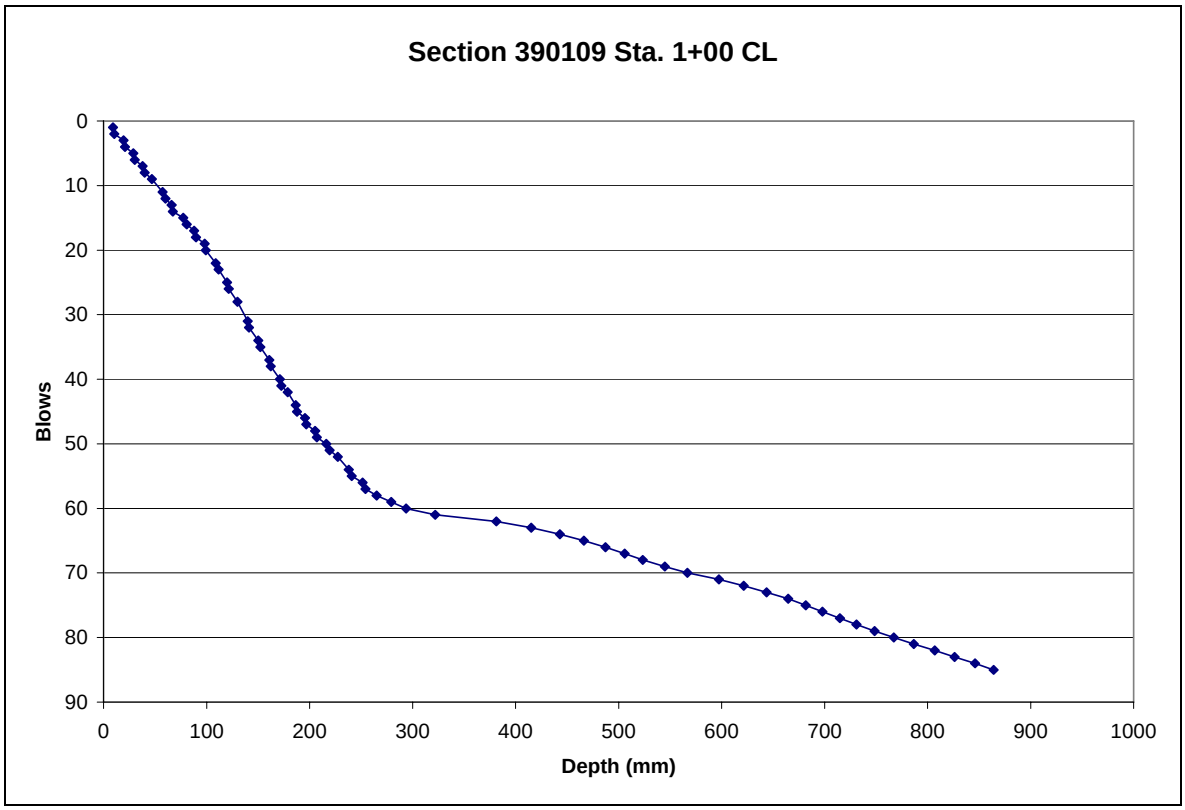

Section 390109 Trench #2 WP
Depth (mm)
PI (mm/Blow)
DGAB
Subgrade
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35

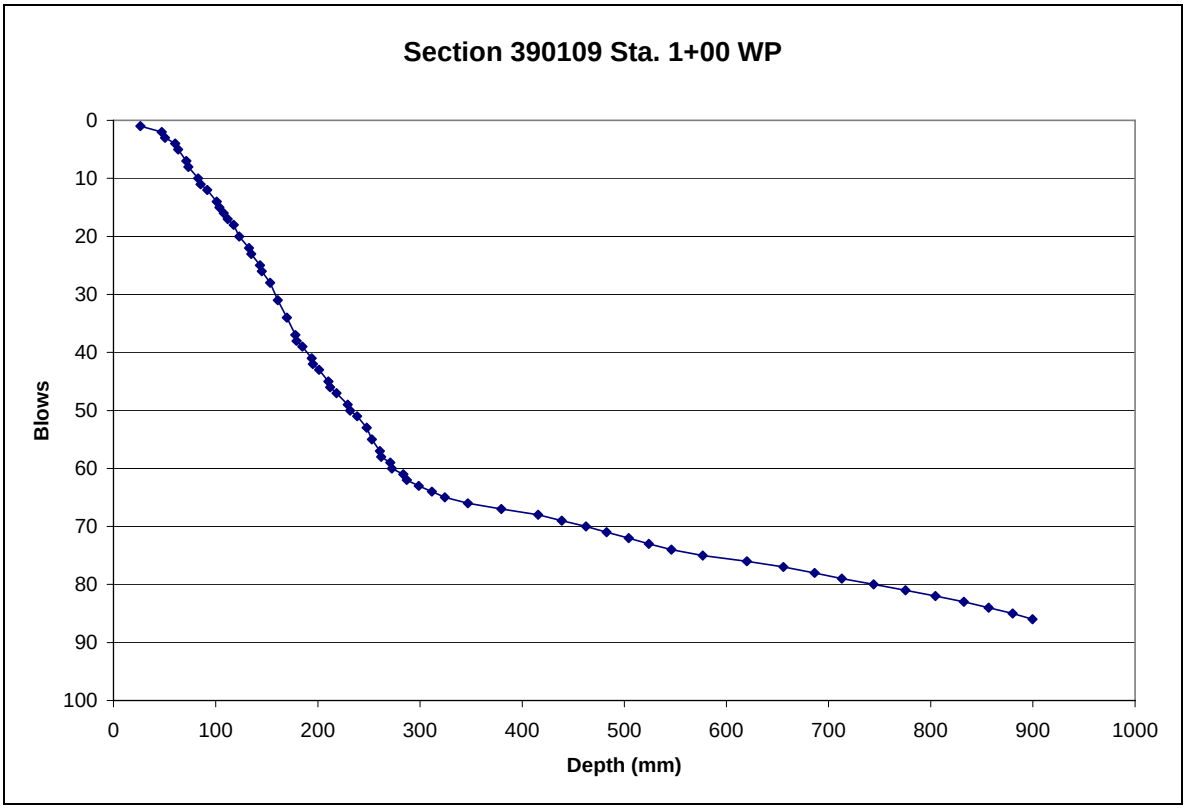
(25.4 mm = 1 in)


Section 390109 Sta. 0+00 CL
Blows
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

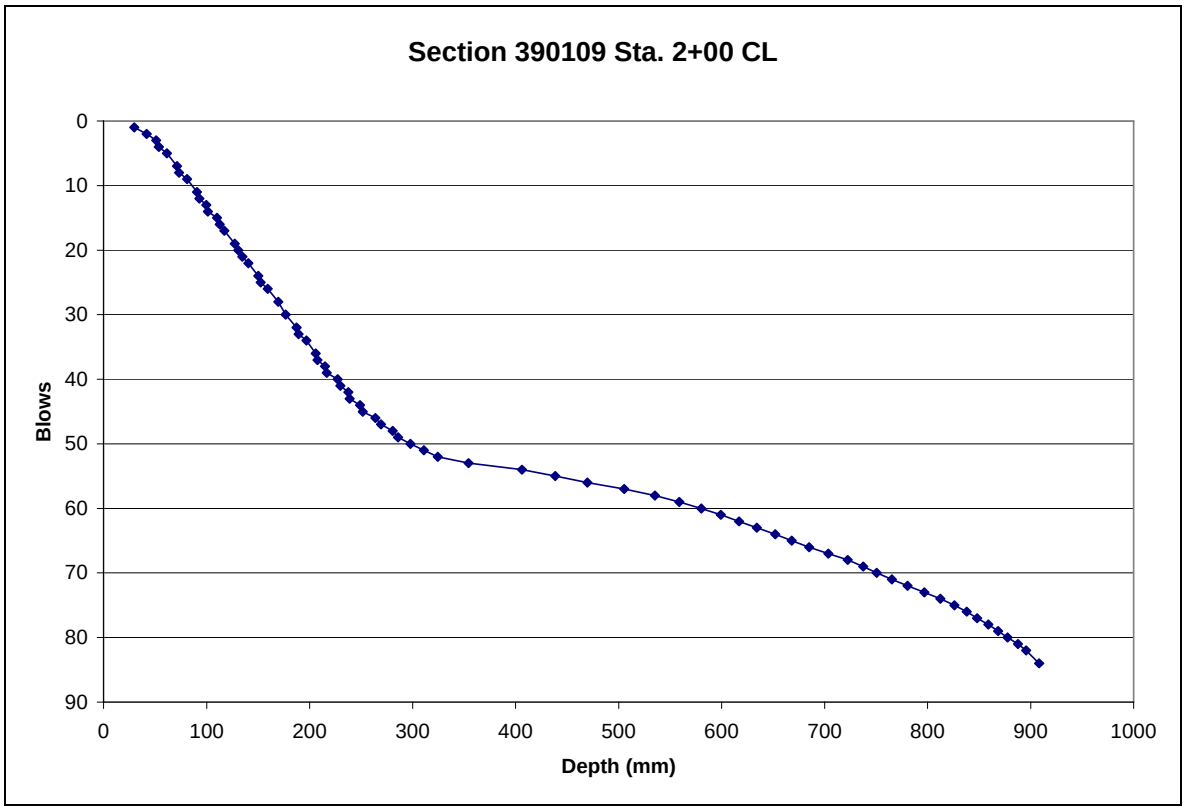

Section 390109 Sta. 0+00 WP
Blows
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
Depth (mm)

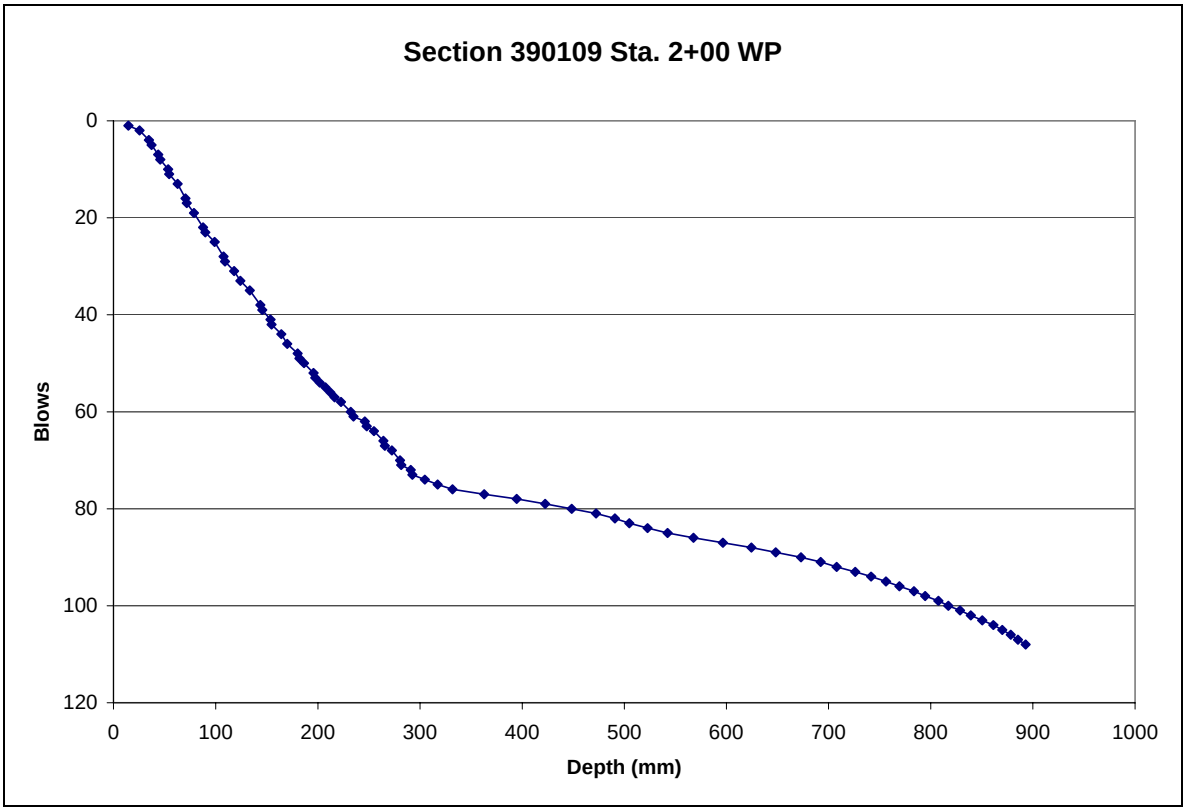
(25.4 mm = 1 in)


Section 390109 Sta. 1+00 CL
Blows
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

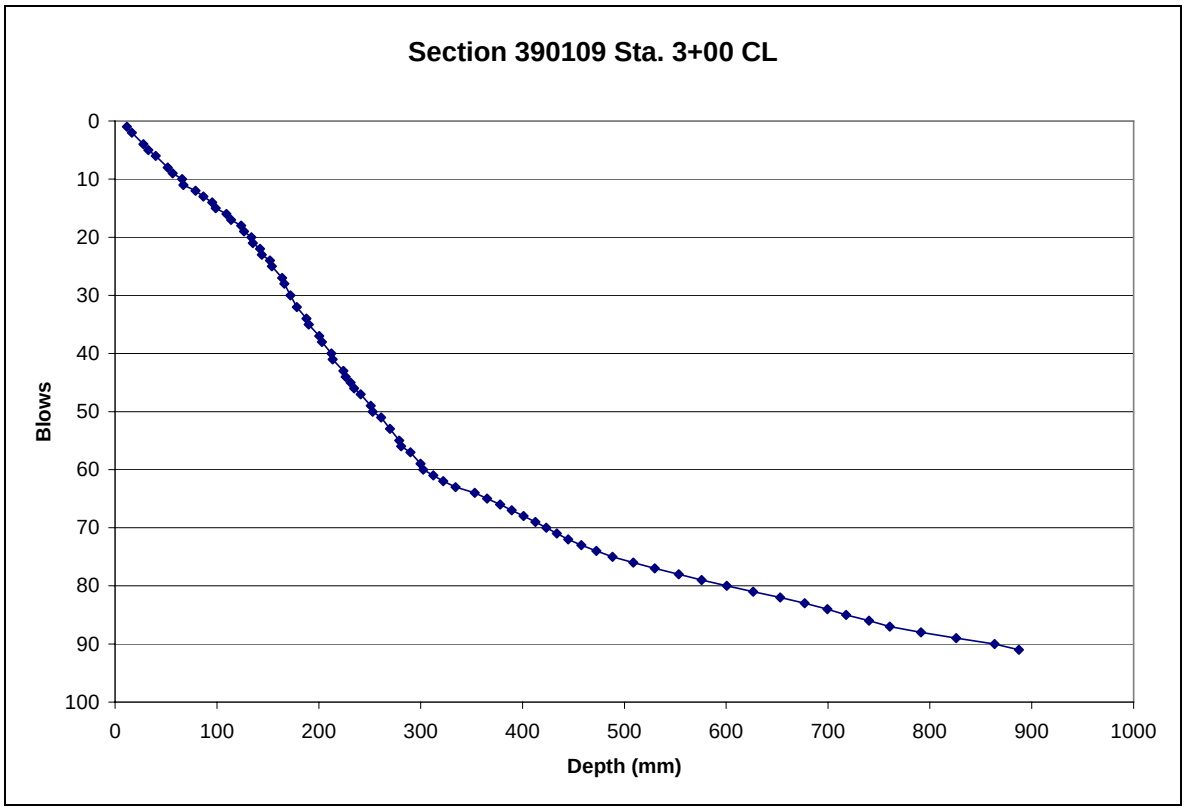

Section 390109 Sta. 1+00 WP
Blows
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

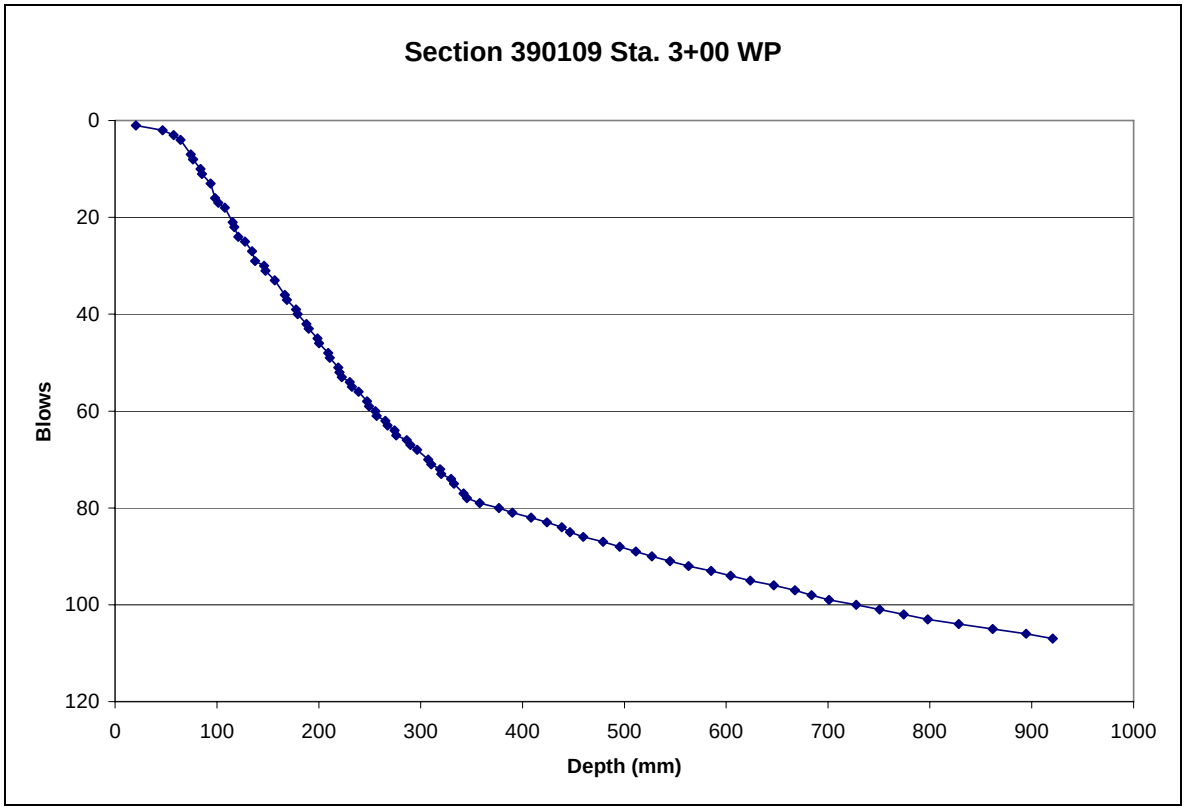
(25.4 mm = 1 in)


Section 390109 Sta. 2+00 CL
Blows
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

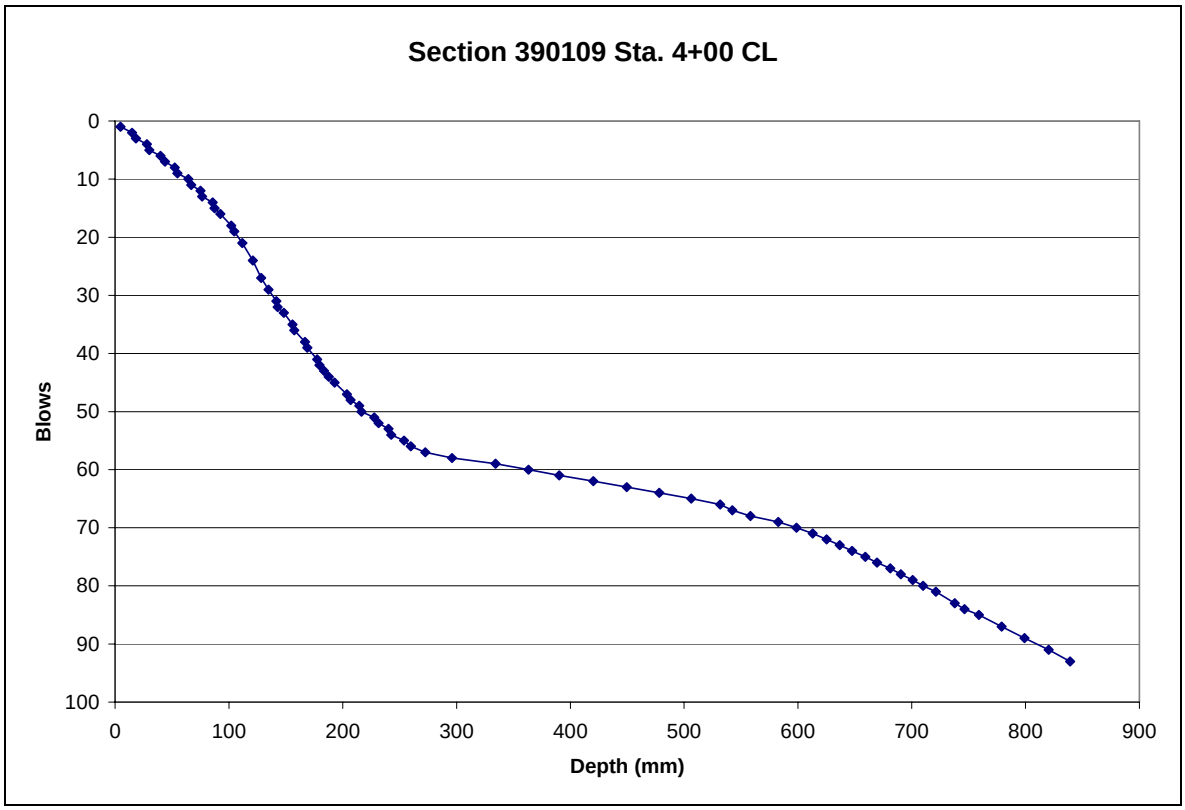

Section 390109 Sta. 2+00 WP
Blows
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

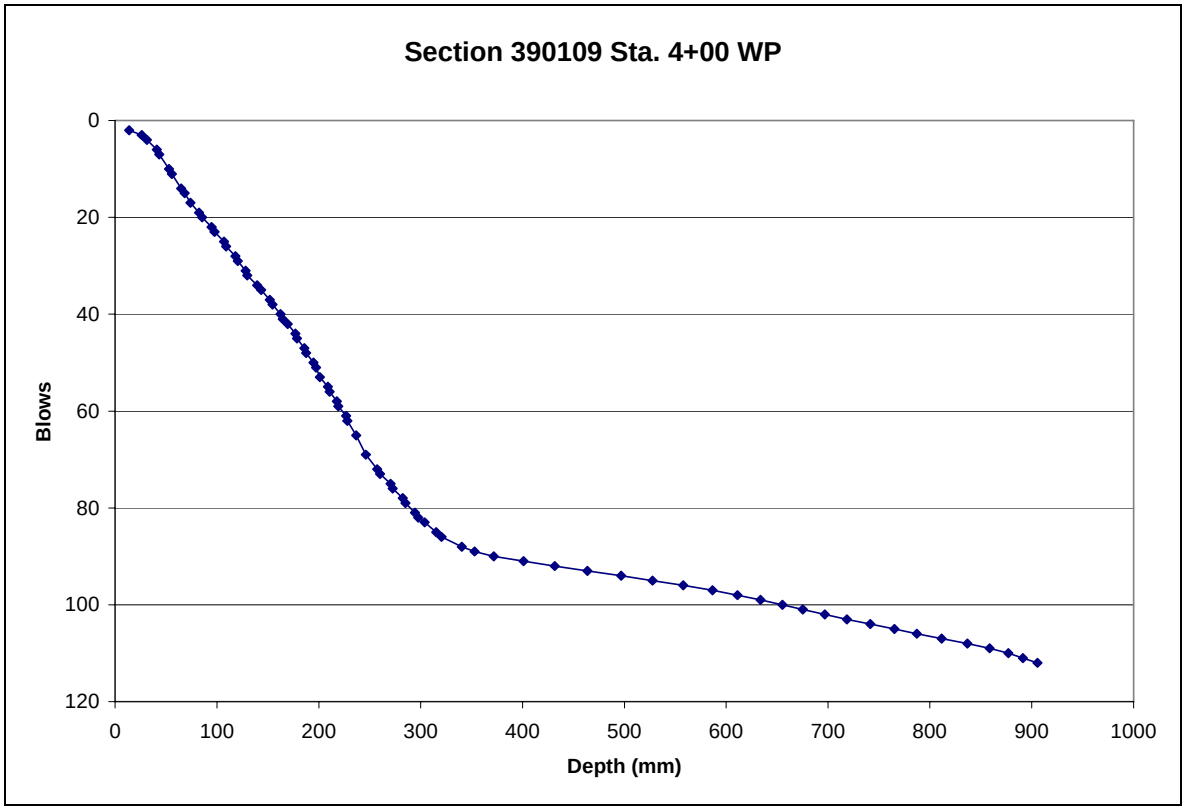
(25.4 mm = 1 in)


Section 390109 Sta. 3+00 CL
Blows
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

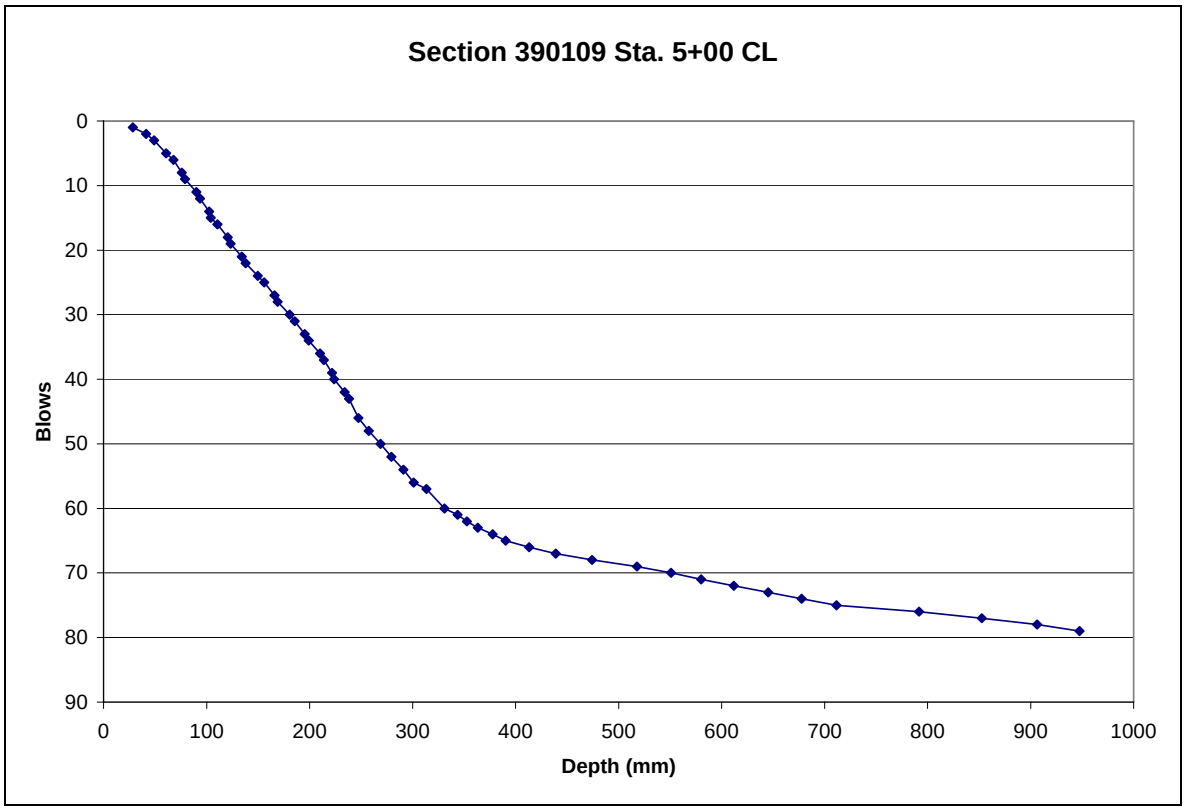

Section 390109 Sta. 3+00 WP
Blows
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

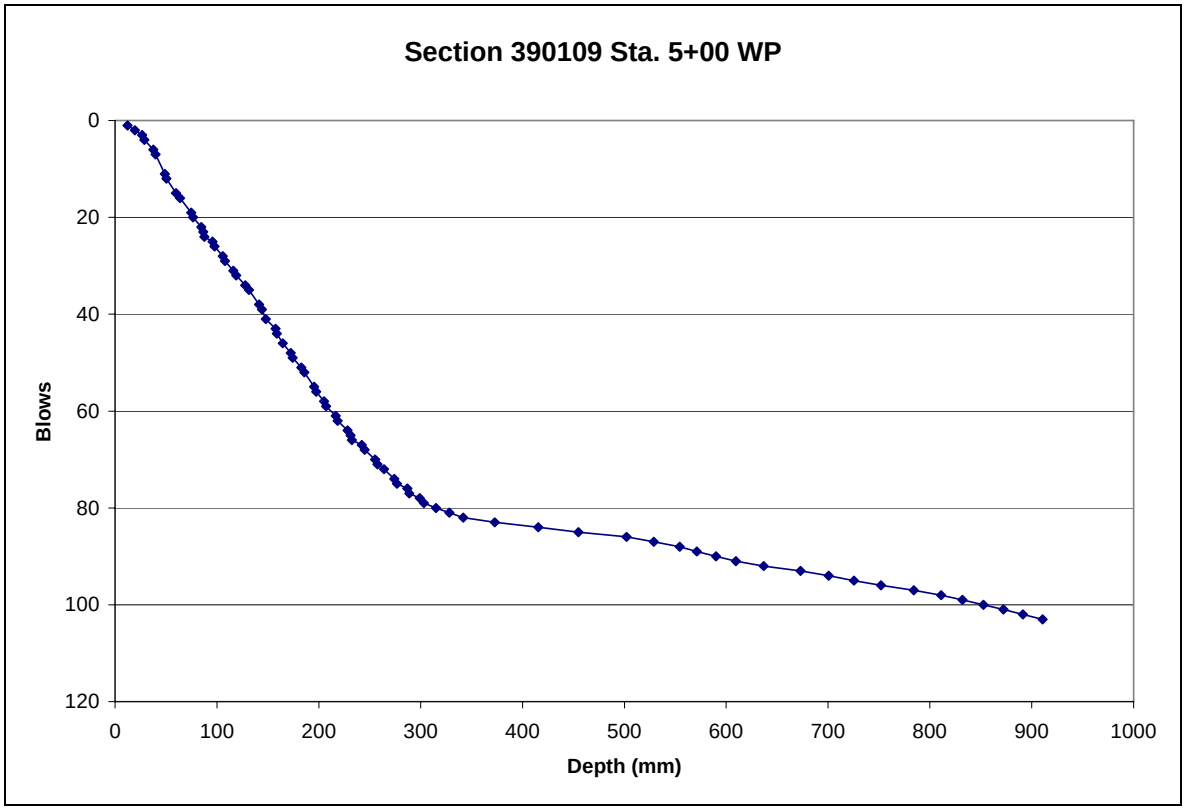
(25.4 mm = 1 in)


Section 390109 Sta. 4+00 CL
Blows
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
Depth (mm)

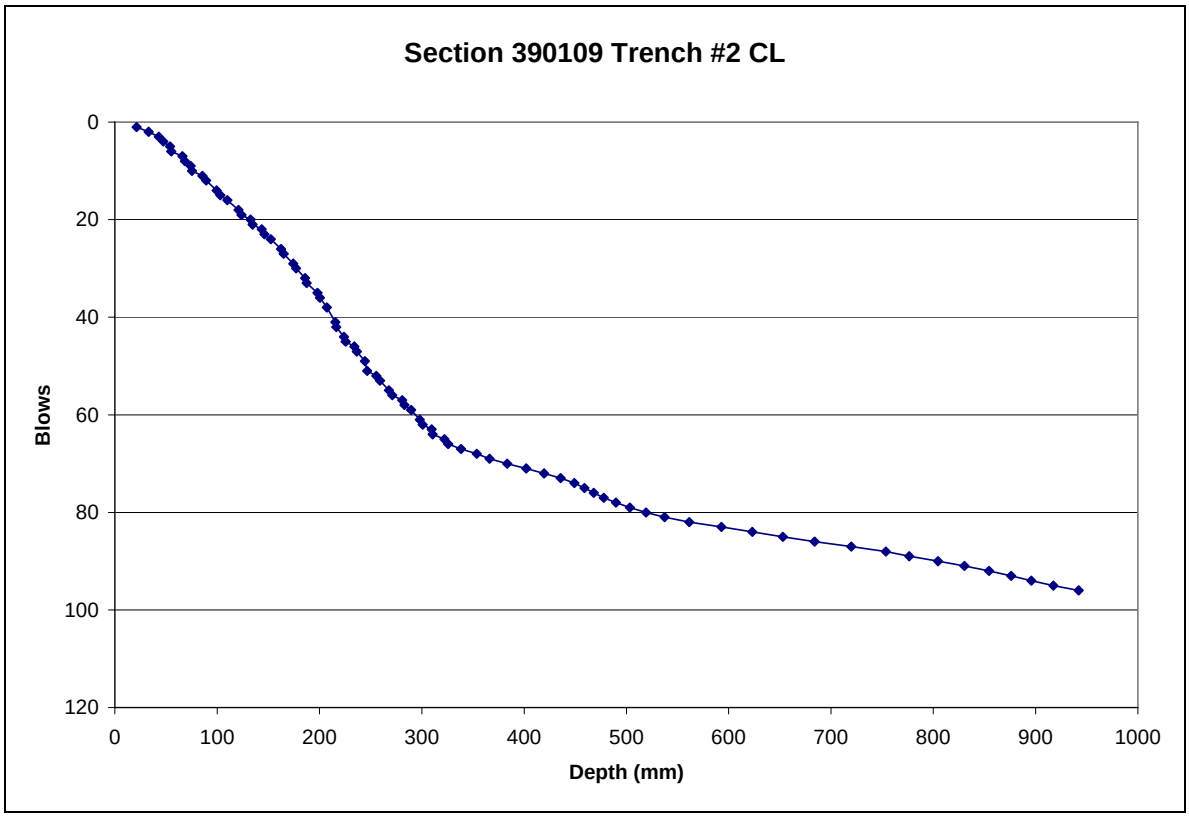

Section 390109 Sta. 4+00 WP
Blows
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

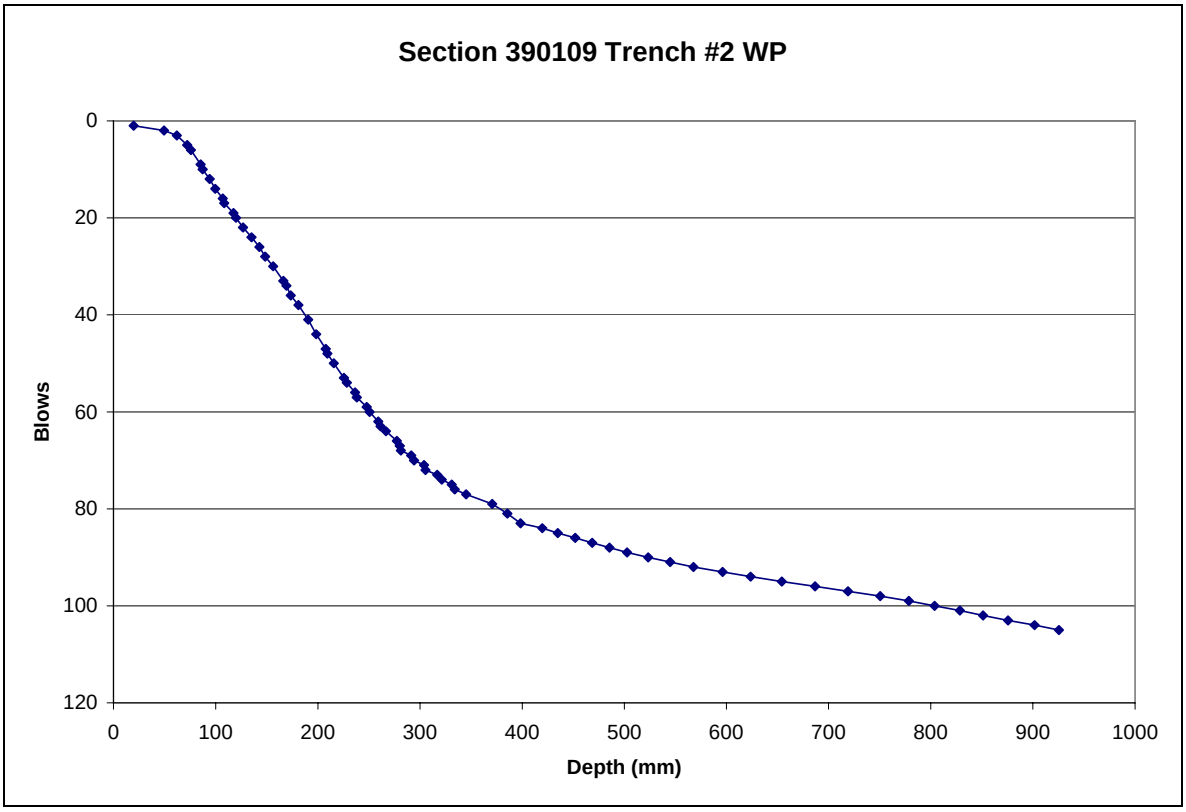
(25.4 mm = 1 in)


Section 390109 Sta. 5+00 CL
Blows
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Section 390109 Sta. 5+00 WP
Blows
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

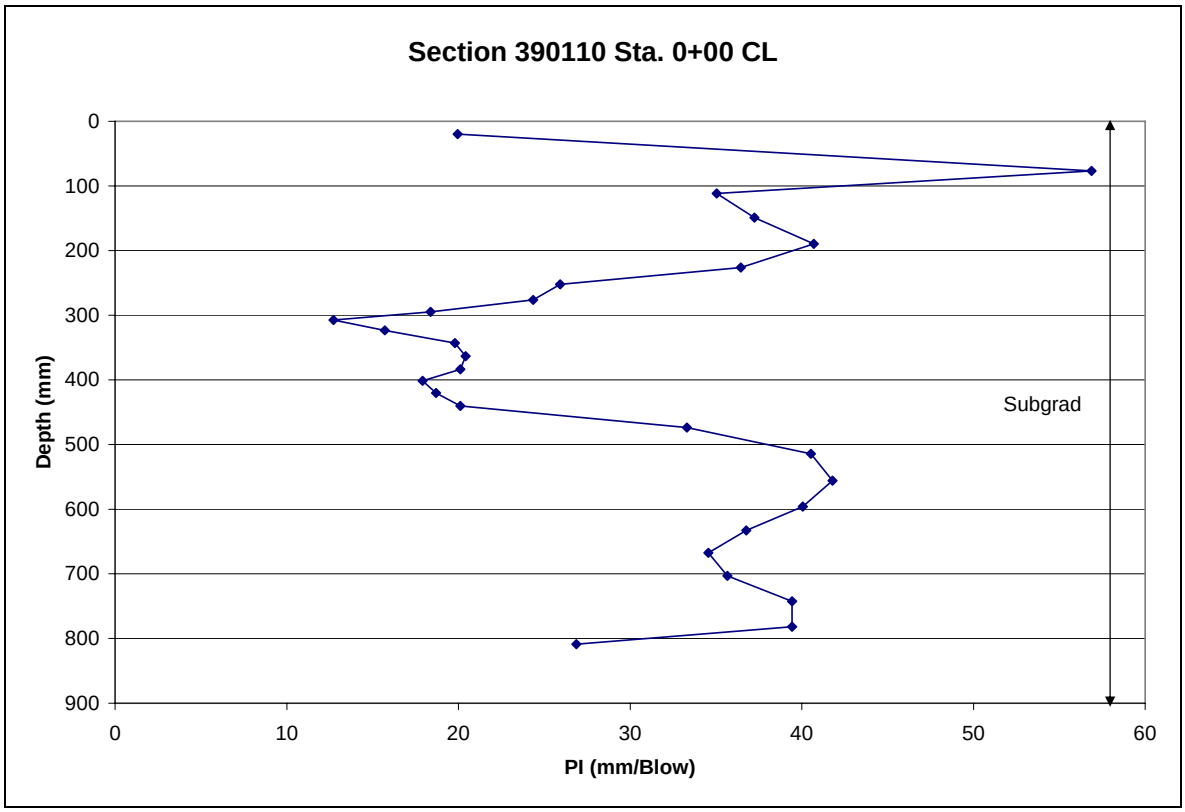
(25.4 mm = 1 in)

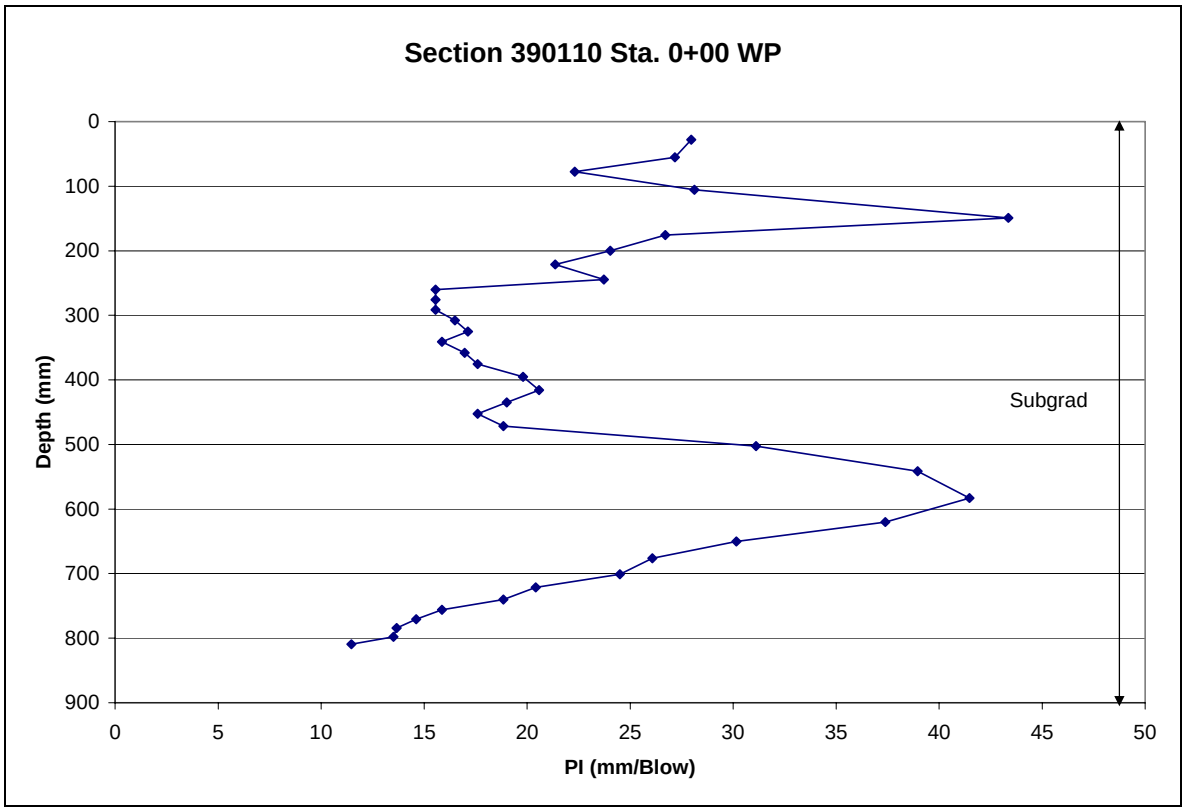

Section 390109 Trench #2 CL
Blows
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Section 390109 Trench #2 WP
Blows
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

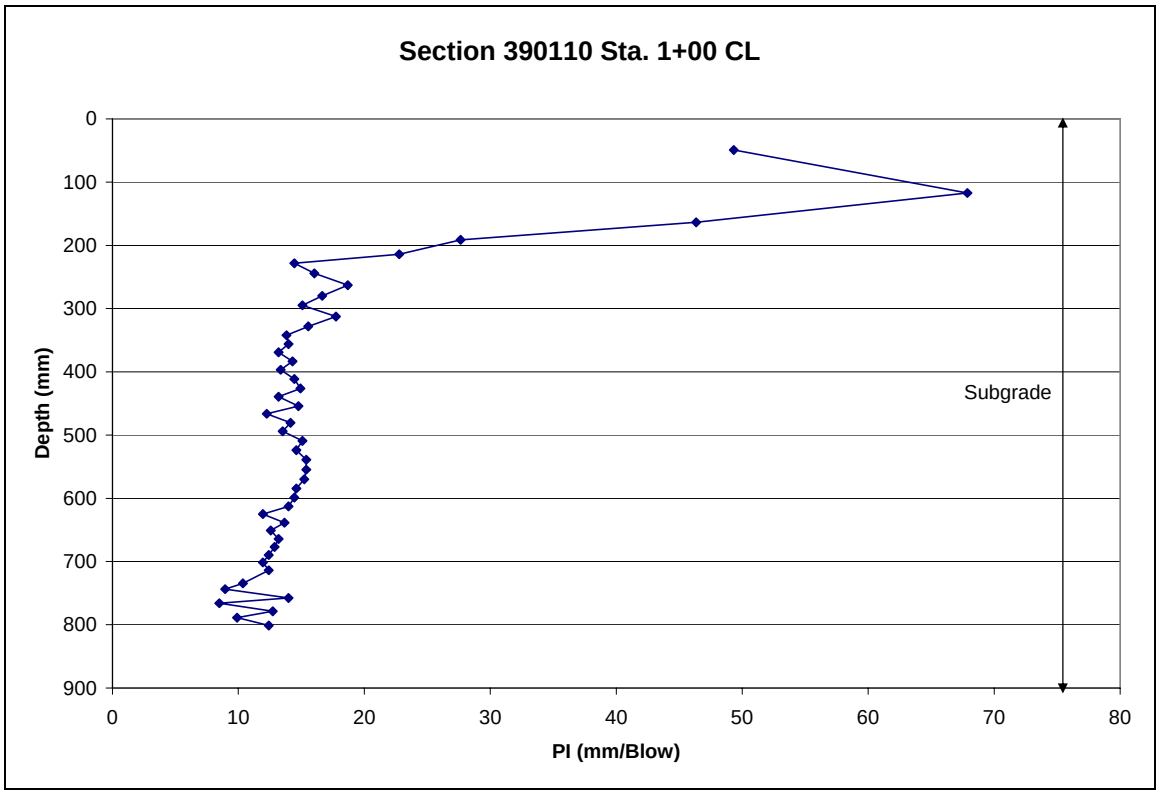
(25.4 mm = 1 in)

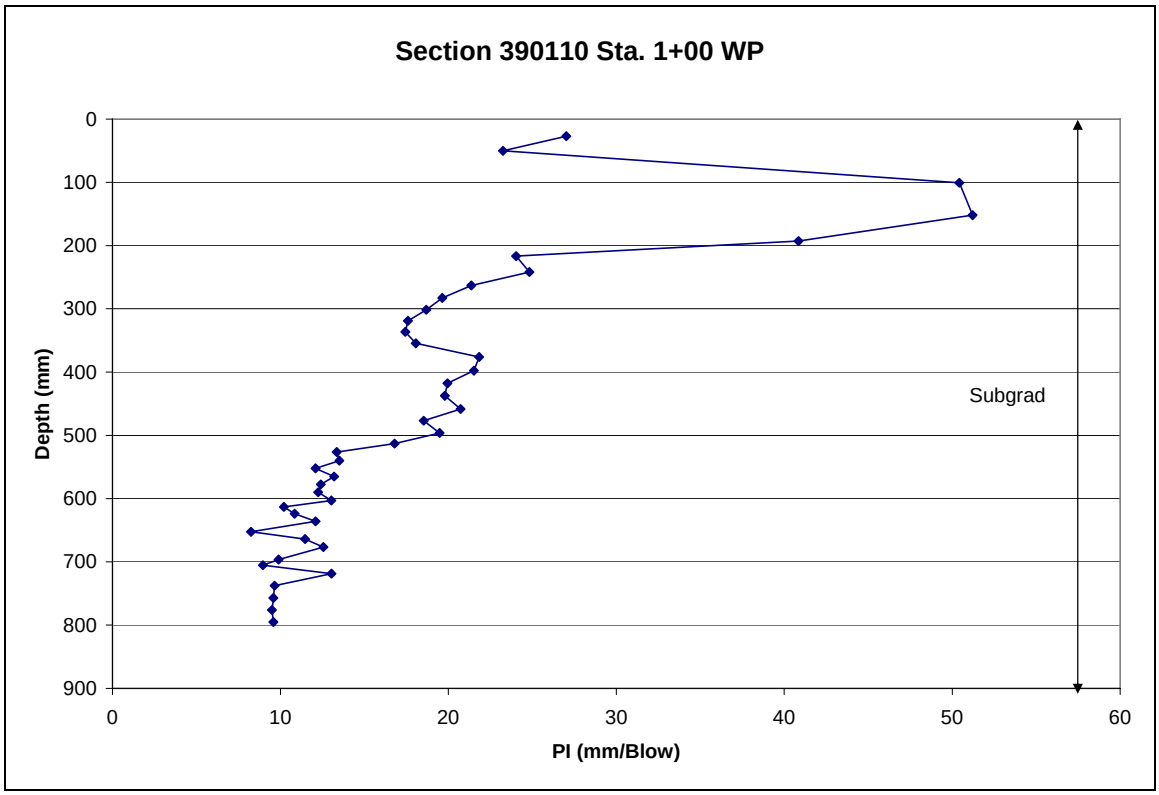
SECTION 390110


Section 390110 Sta. 0+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrad

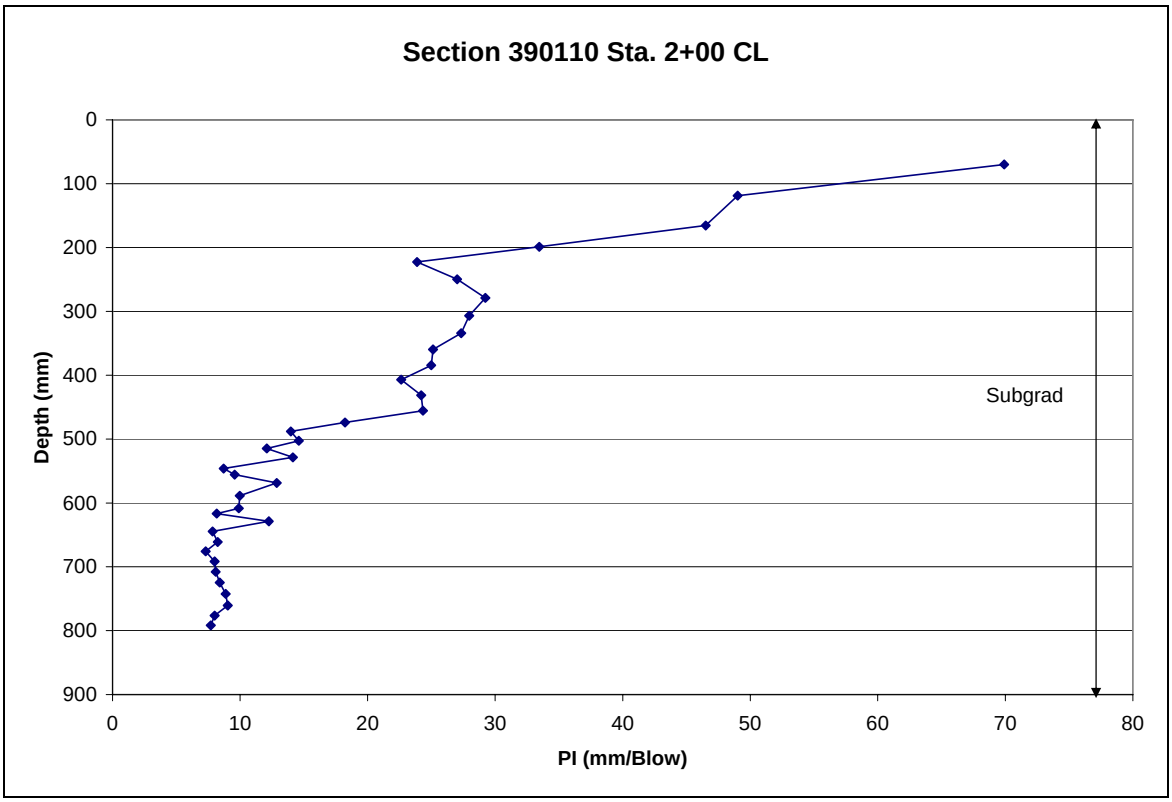

Section 390110 Sta. 0+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30
35
40
45
50
PI (mm/Blow)
Subgrad

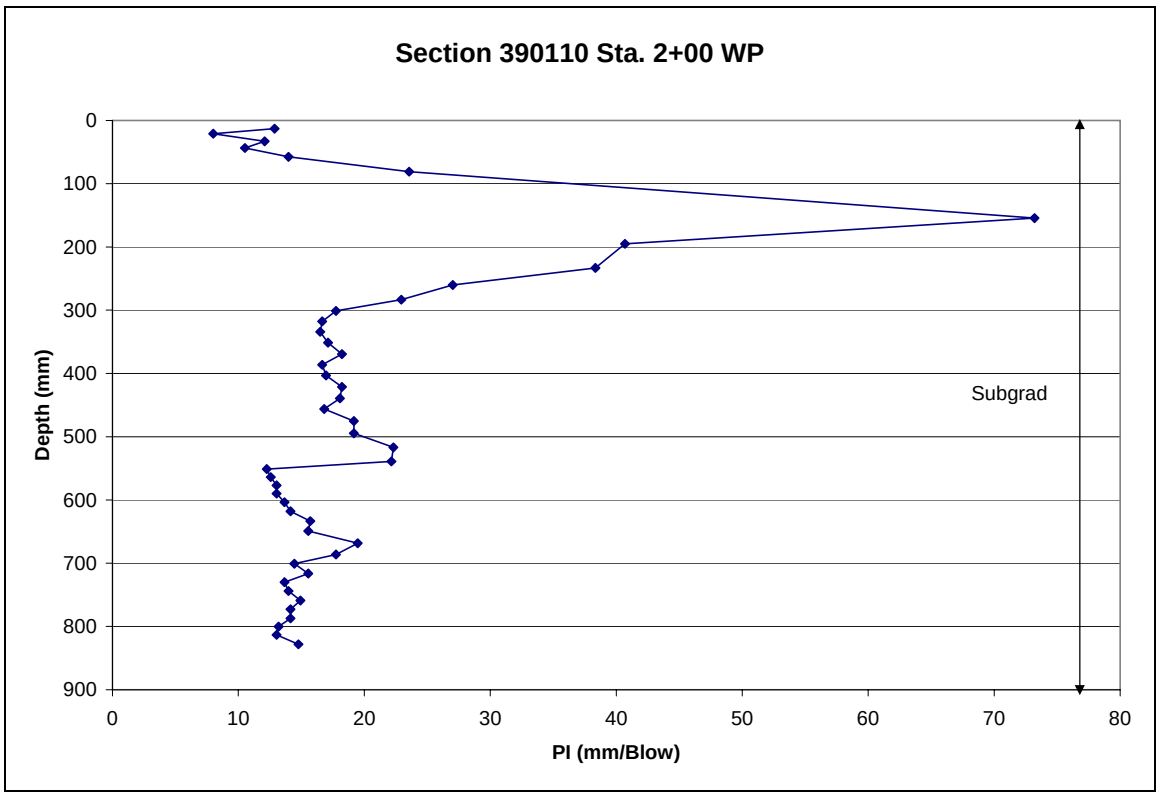
(25.4 mm = 1 in)


Section 390110 Sta. 1+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
PI (mm/Blow)
Subgrade

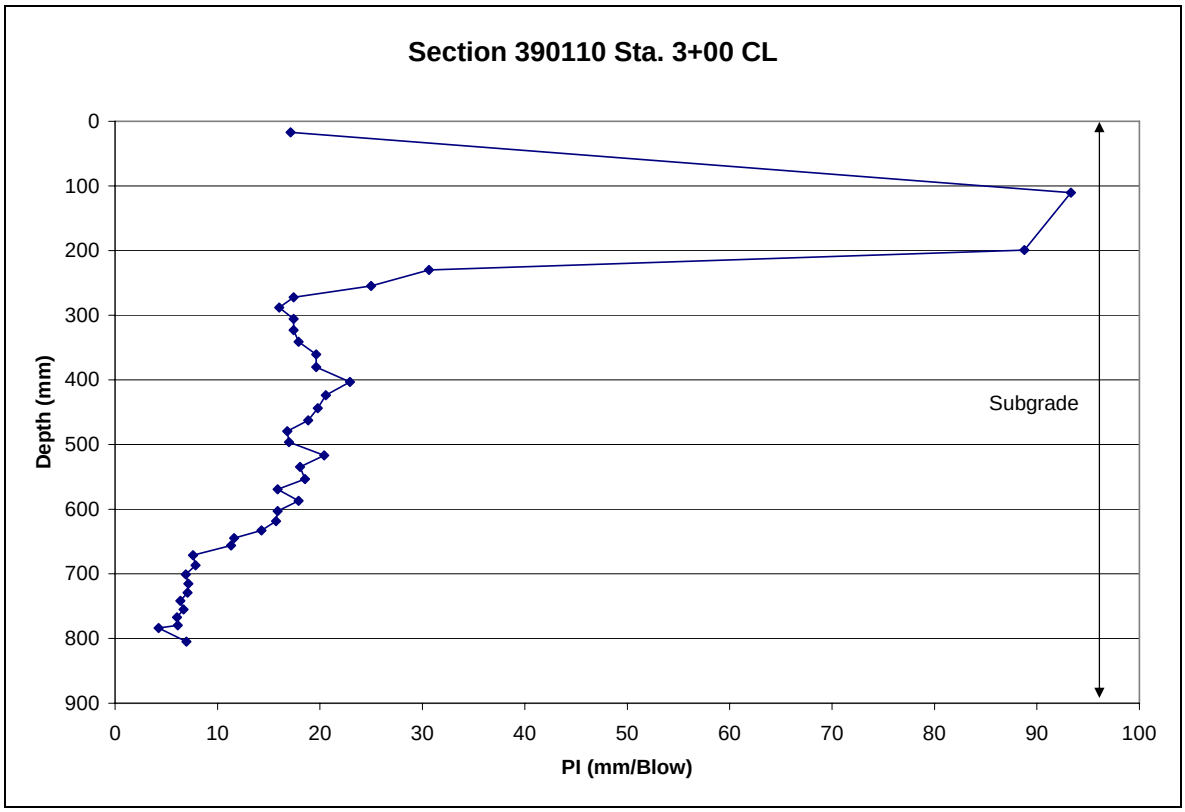

Section 390110 Sta. 1+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrad

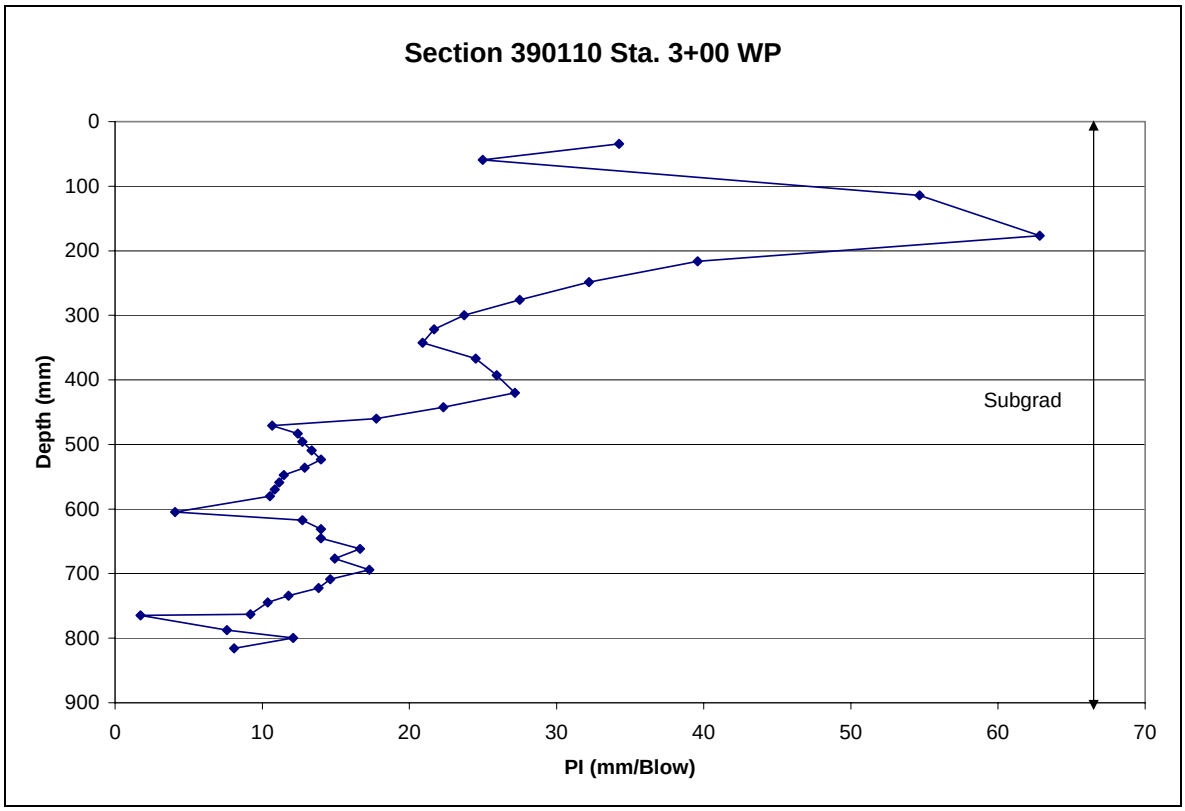
(25.4 mm = 1 in)


Section 390110 Sta. 2+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
PI (mm/Blow)
Subgrad

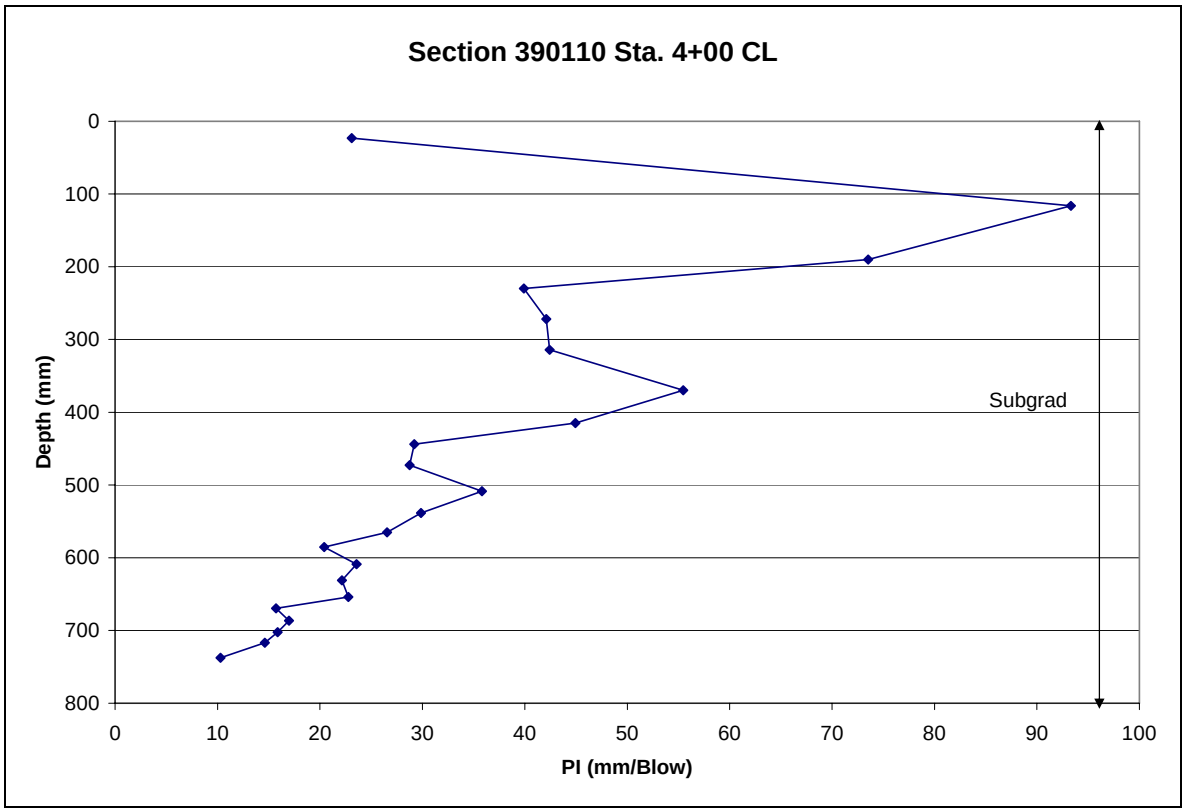

Section 390110 Sta. 2+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
PI (mm/Blow)
Subgrad

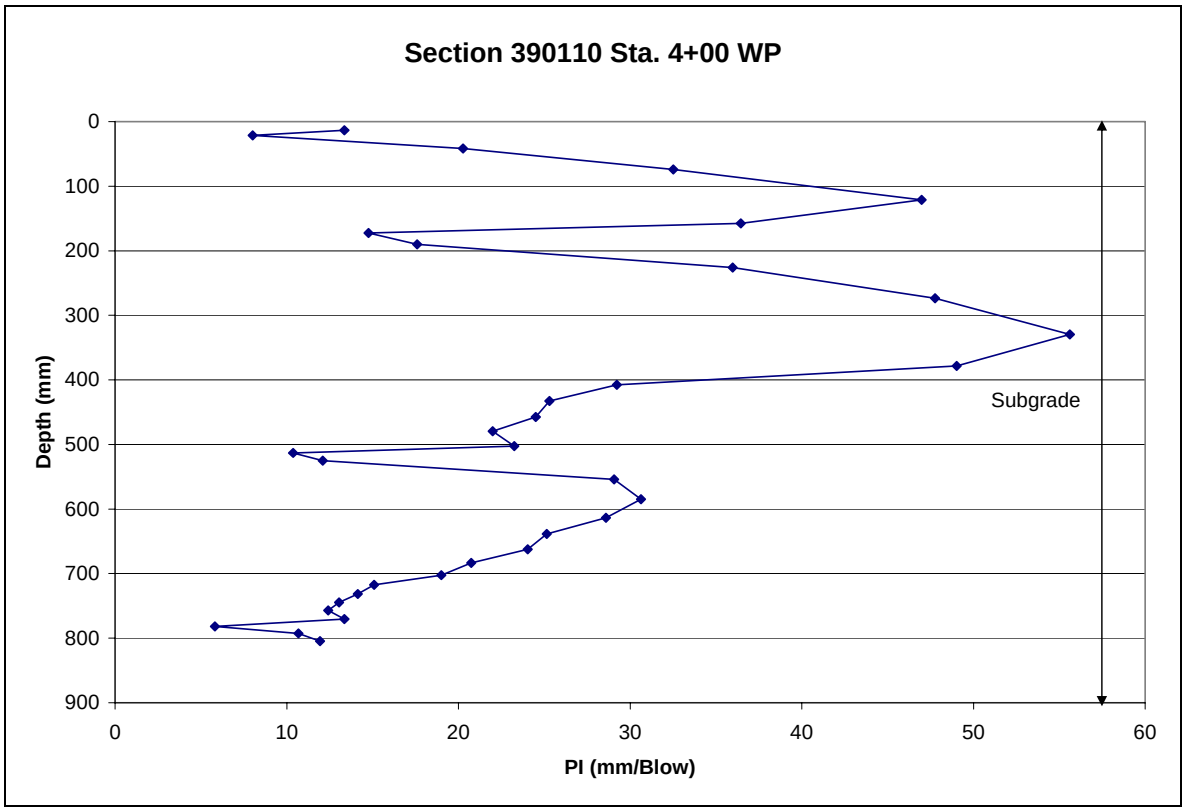
(25.4 mm = 1 in)


Section 390110 Sta. 3+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
100
PI (mm/Blow)
Subgrade

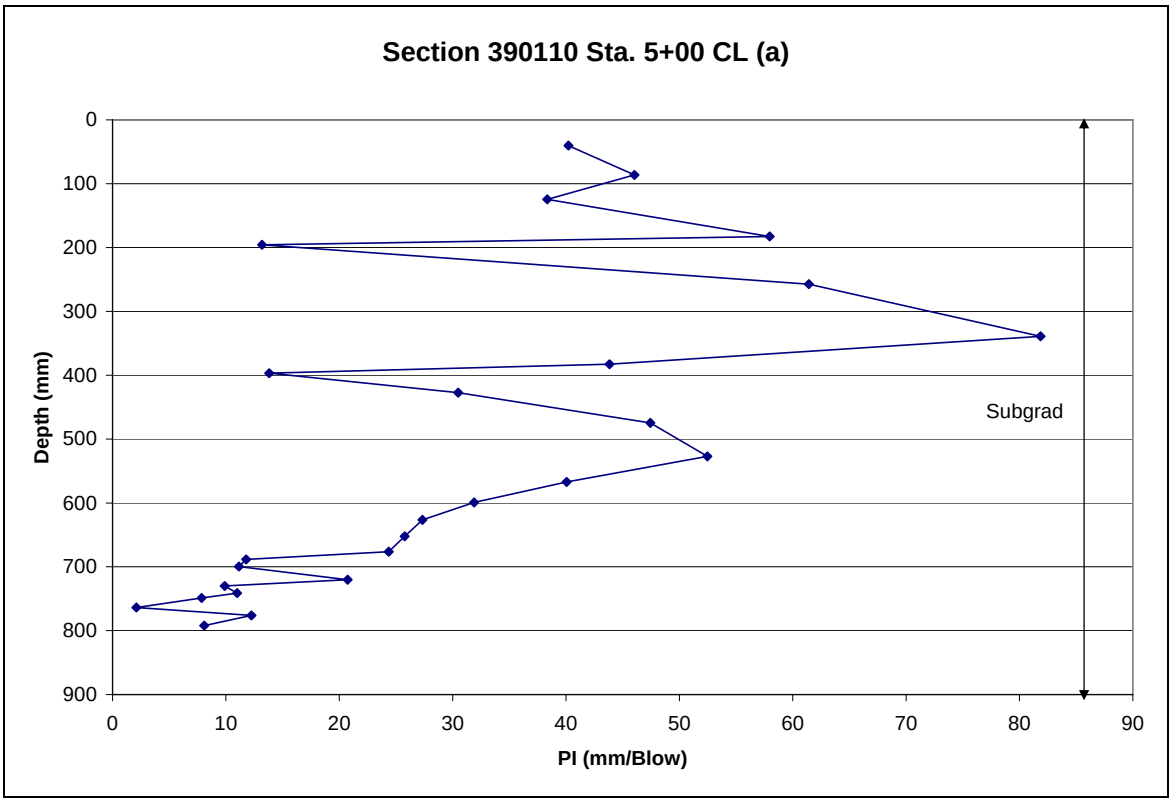

Section 390110 Sta. 3+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
PI (mm/Blow)
Subgrad

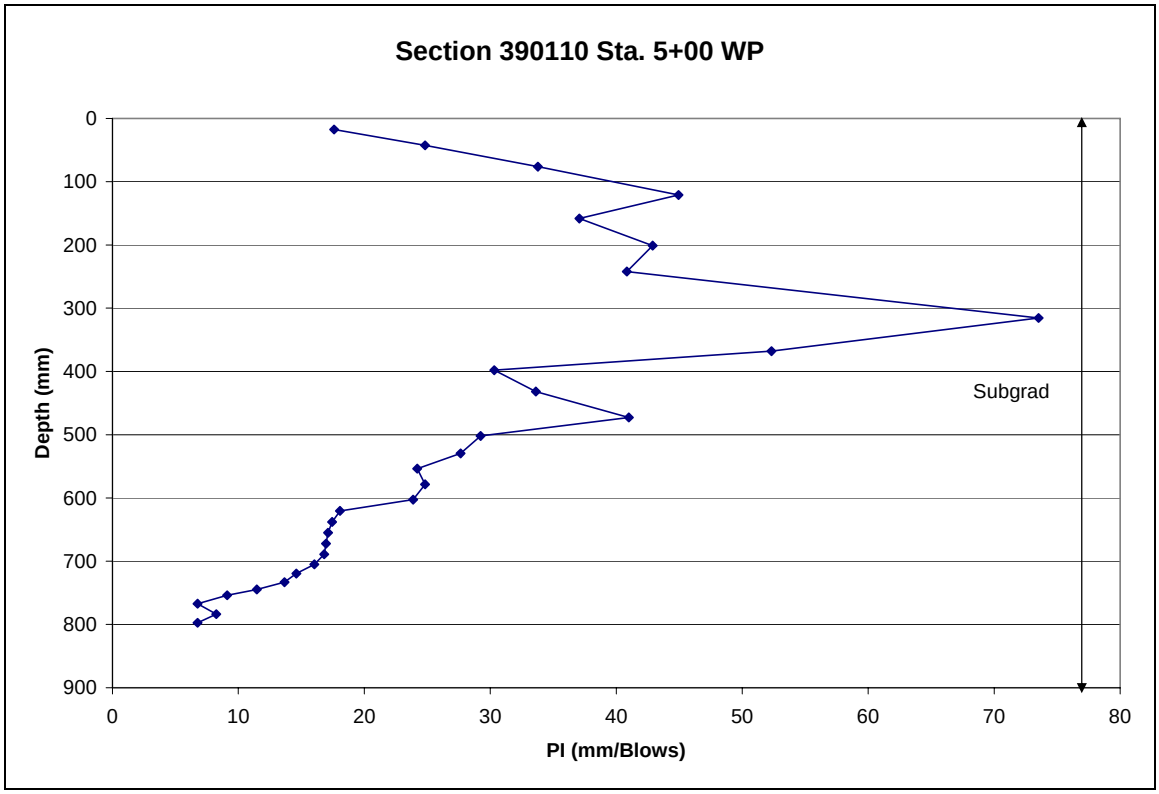
(25.4 mm = 1 in)


Section 390110 Sta. 4+00 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
70
80
90
100
PI (mm/Blow)
Subgrad

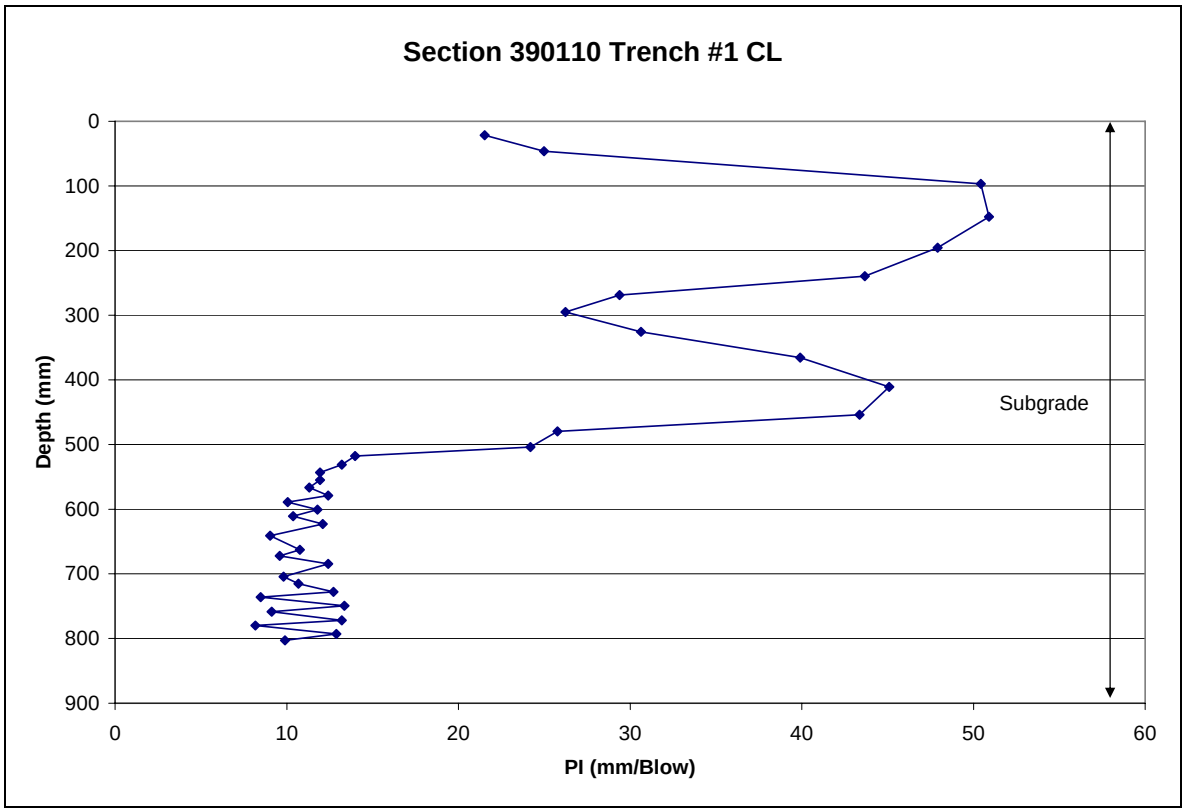

Section 390110 Sta. 4+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrade

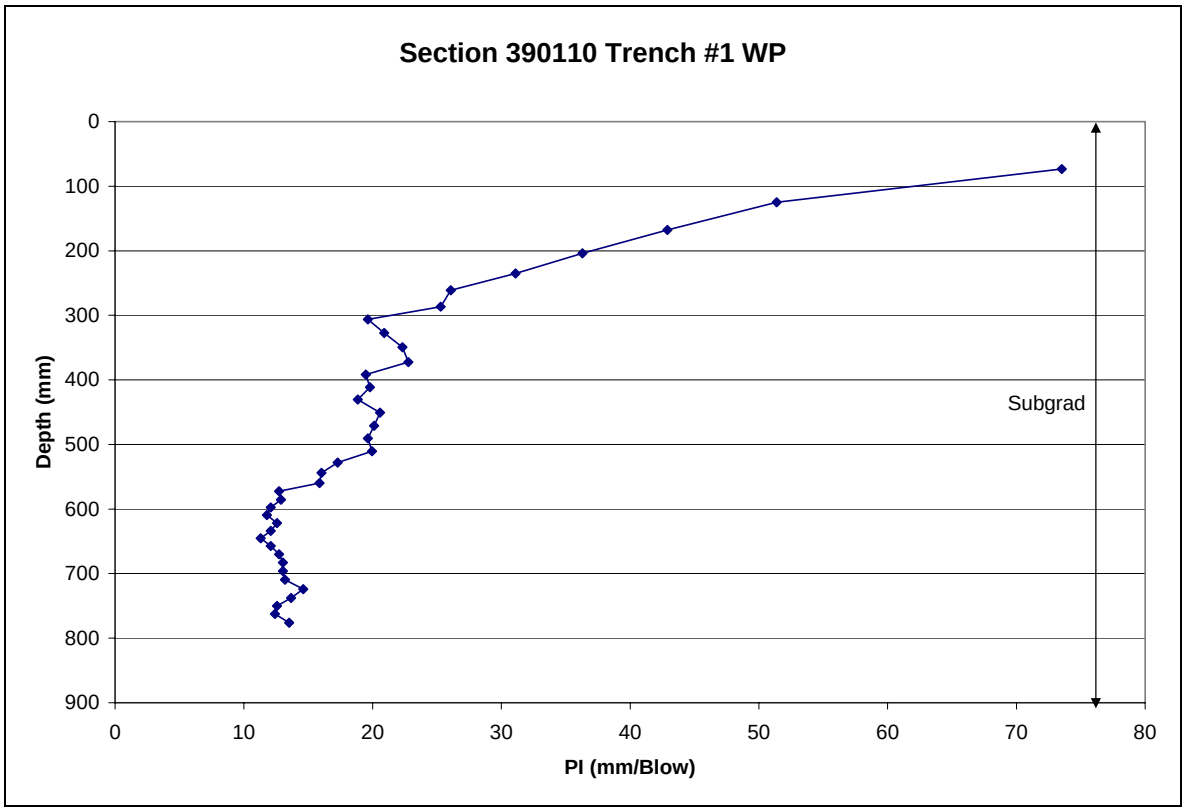
(25.4 mm = 1 in)


Section 390110 Sta. 5+00 CL (a)
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
PI (mm/Blow)
Subgrad

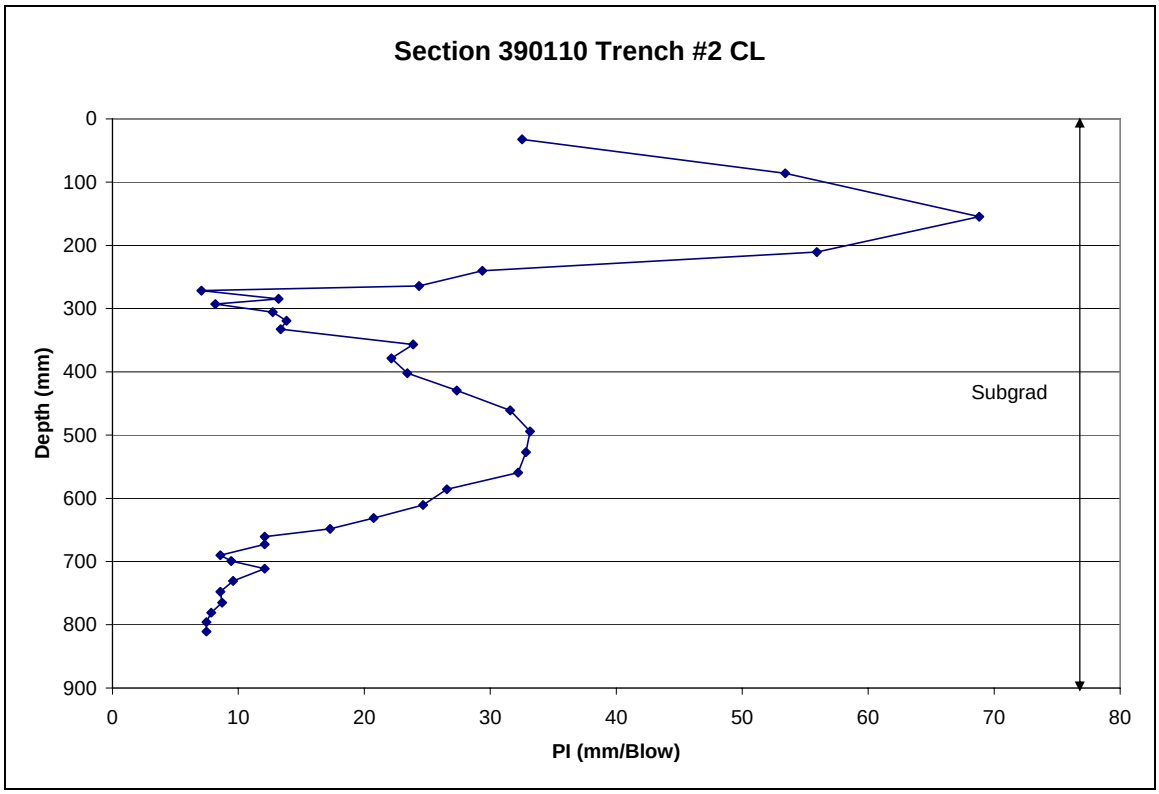

Section 390110 Sta. 5+00 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
PI (mm/Blows)
Subgrad

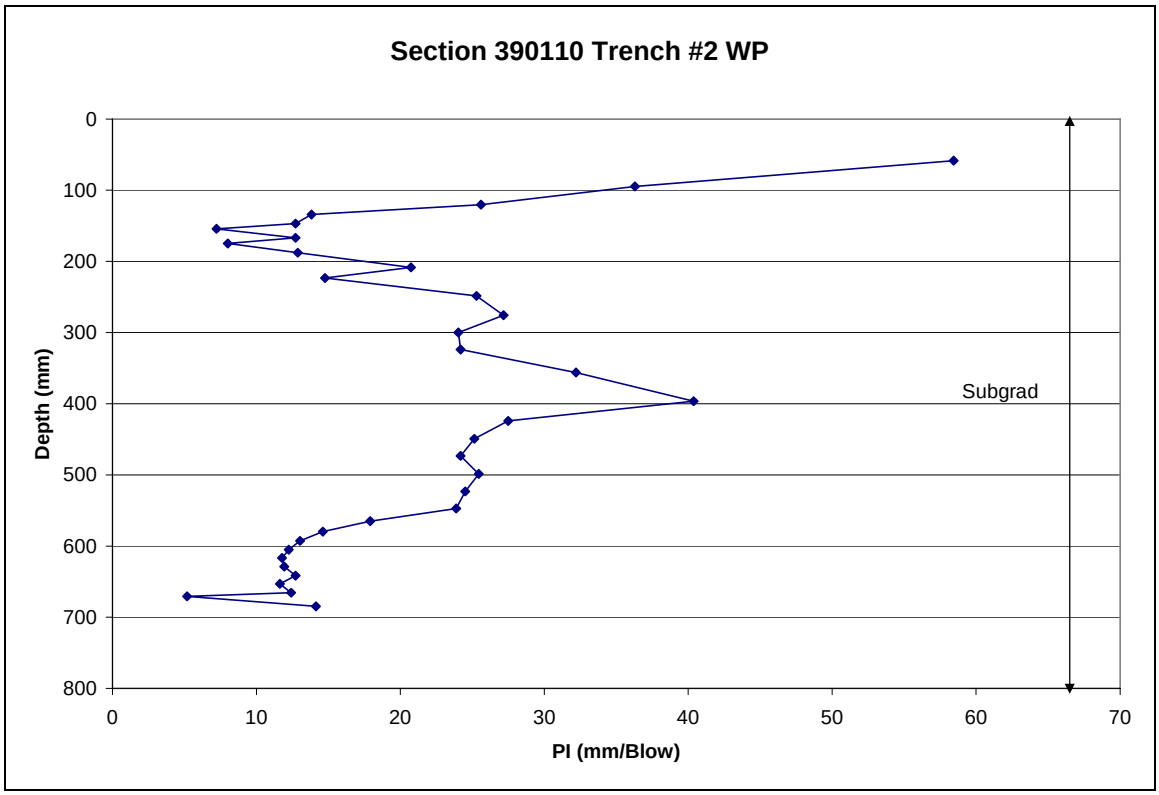
(25.4 mm = 1 in)


Section 390110 Trench #1 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
PI (mm/Blow)
Subgrade

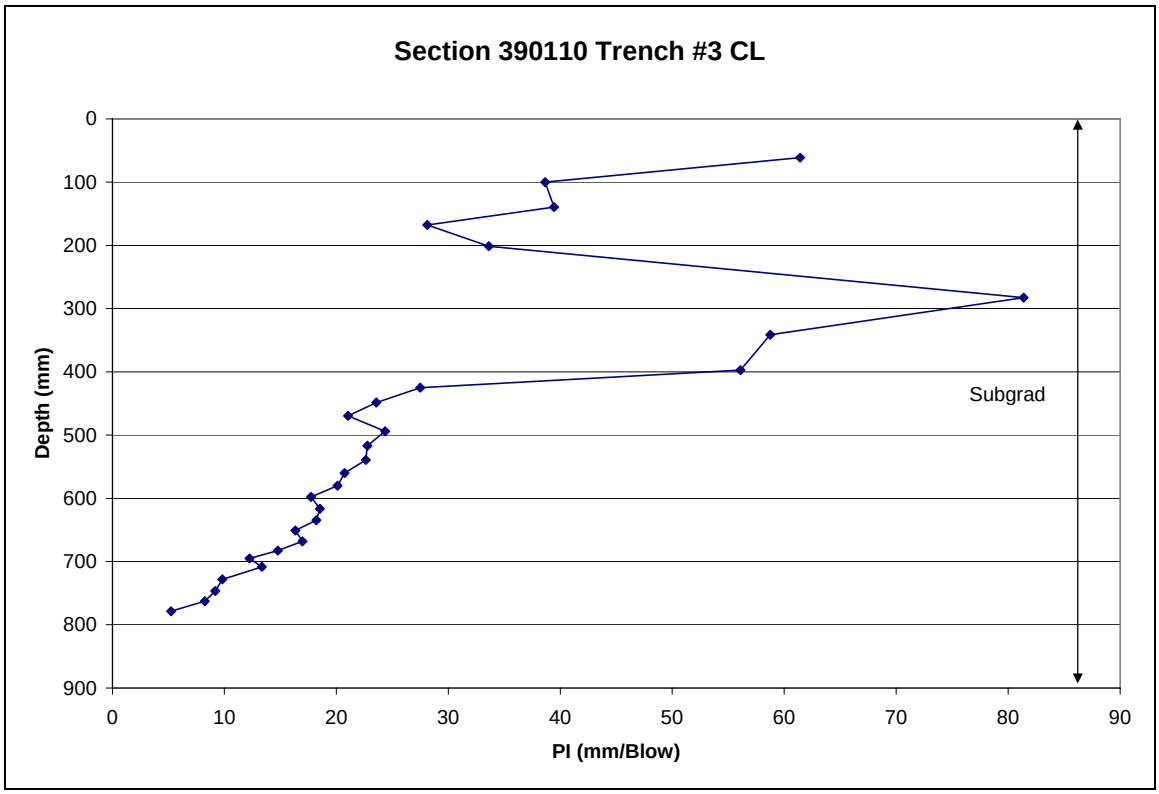

Section 390110 Trench #1 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
PI (mm/Blow)
Subgrad

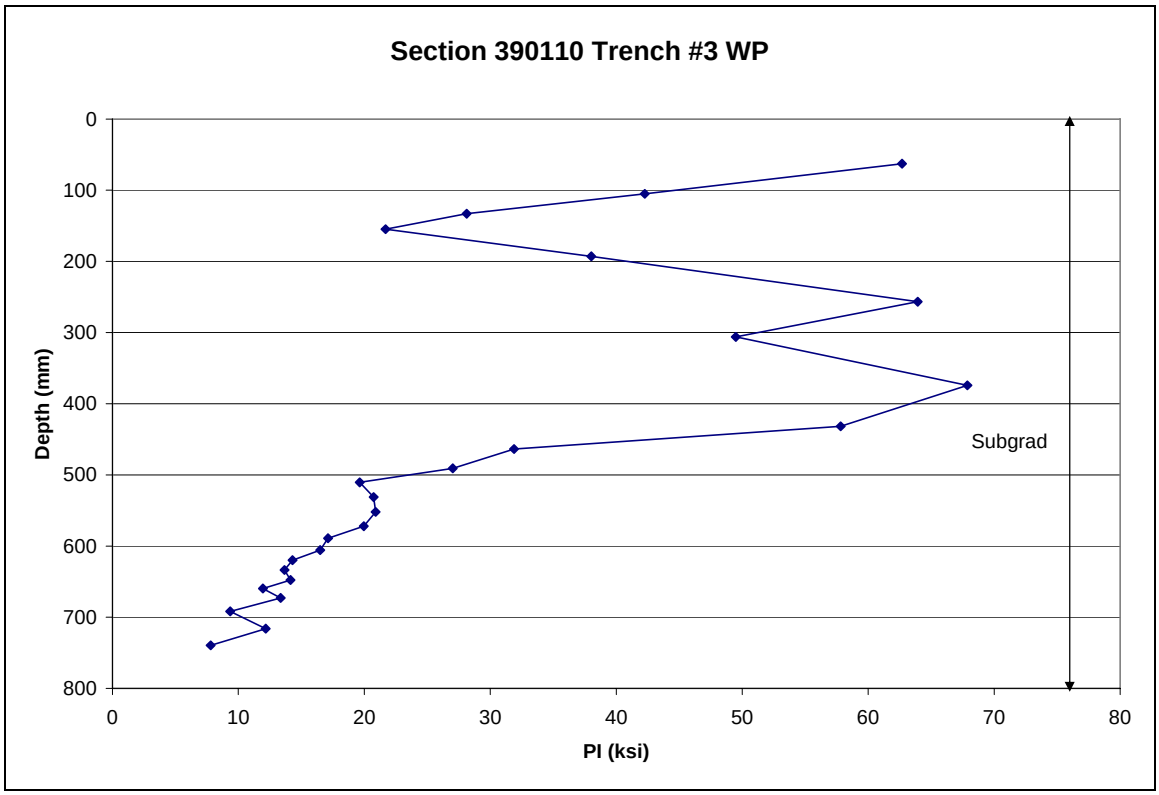
(25.4 mm = 1 in)


Section 390110 Trench #2 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
PI (mm/Blow)
Subgrad

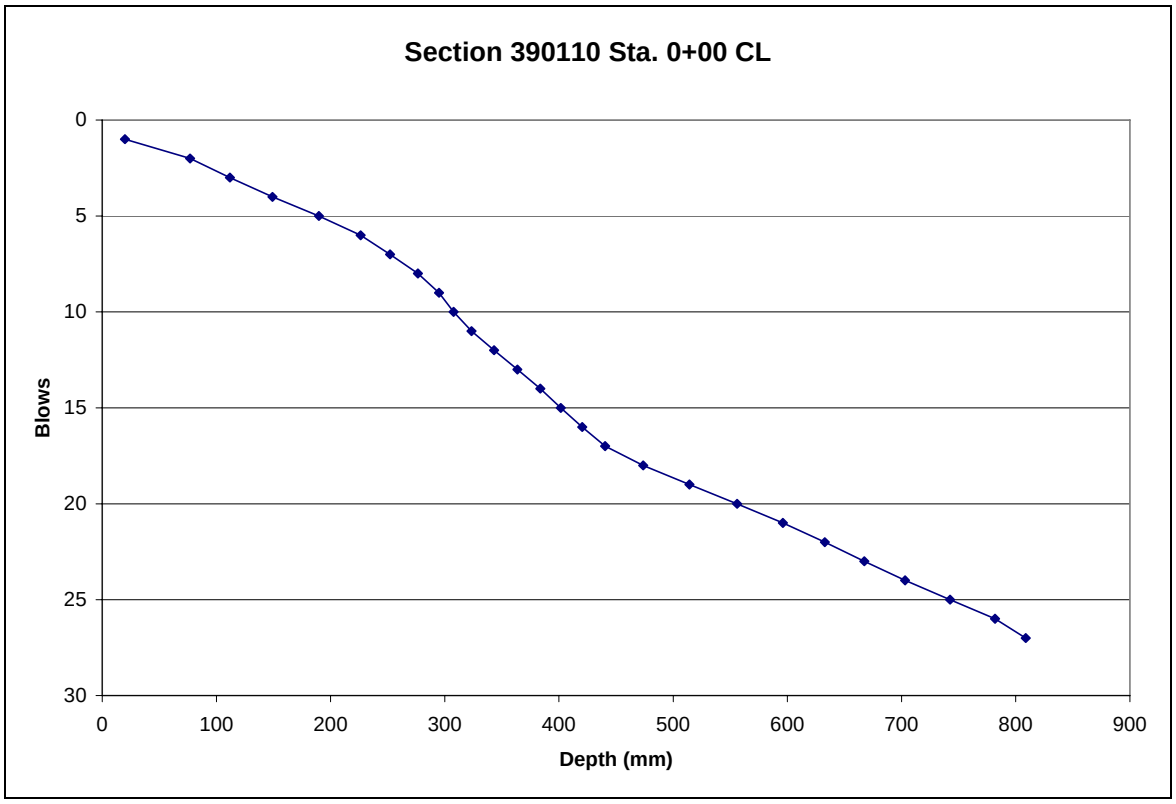

Section 390110 Trench #2 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
70
PI (mm/Blow)
Subgrad

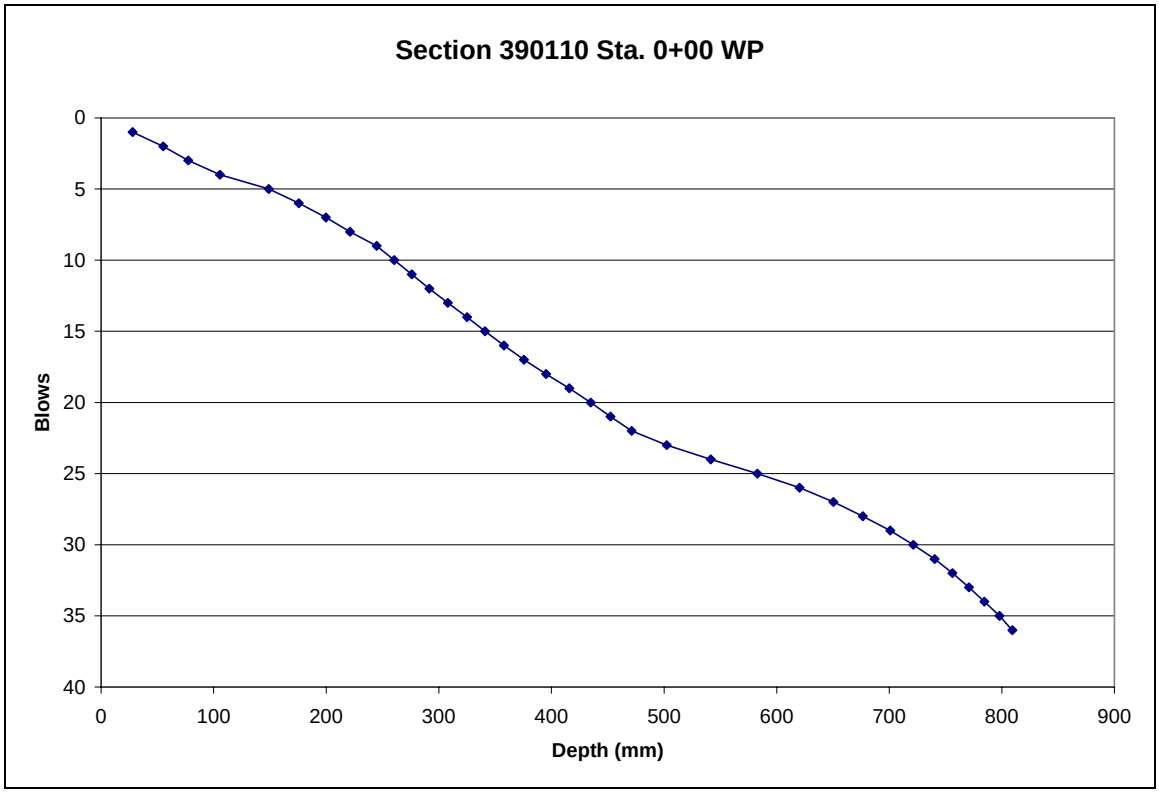
(25.4 mm = 1 in)


Section 390110 Trench #3 CL
Depth (mm)
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
PI (mm/Blow)
Subgrad

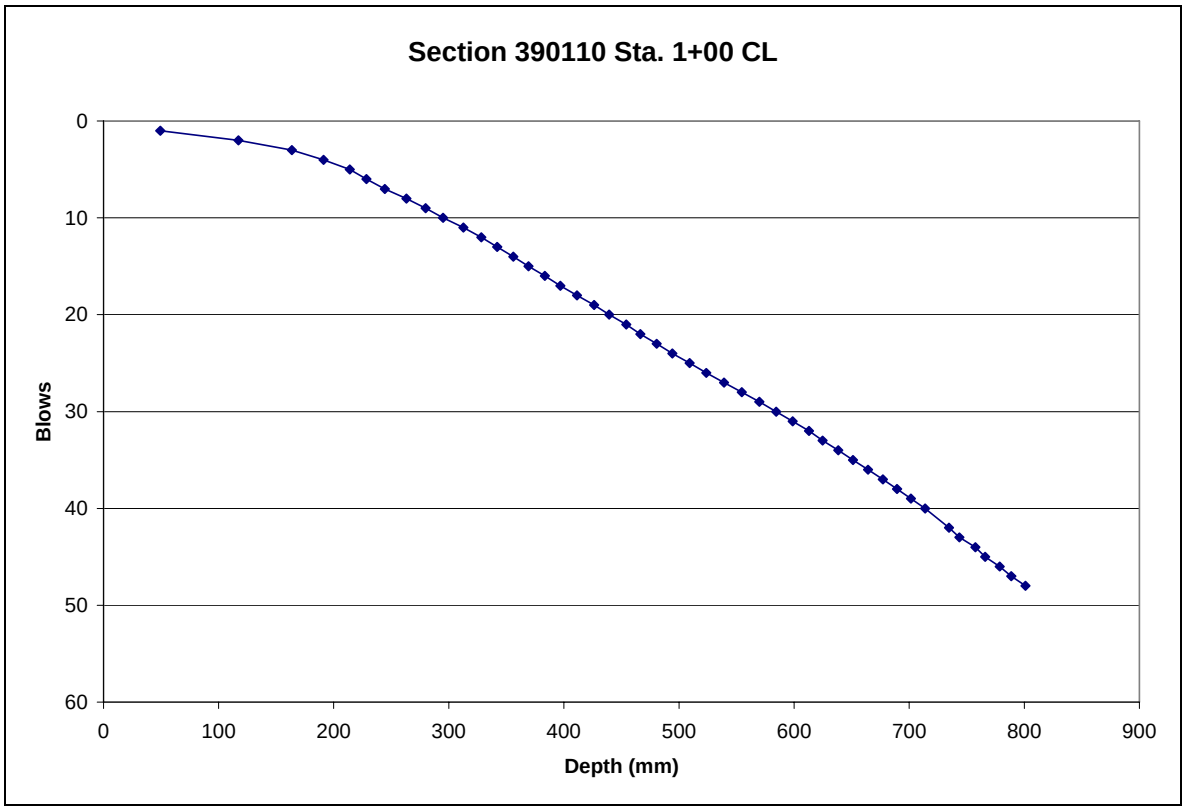

Section 390110 Trench #3 WP
Depth (mm)
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
70
80
PI (ksi)
Subgrad

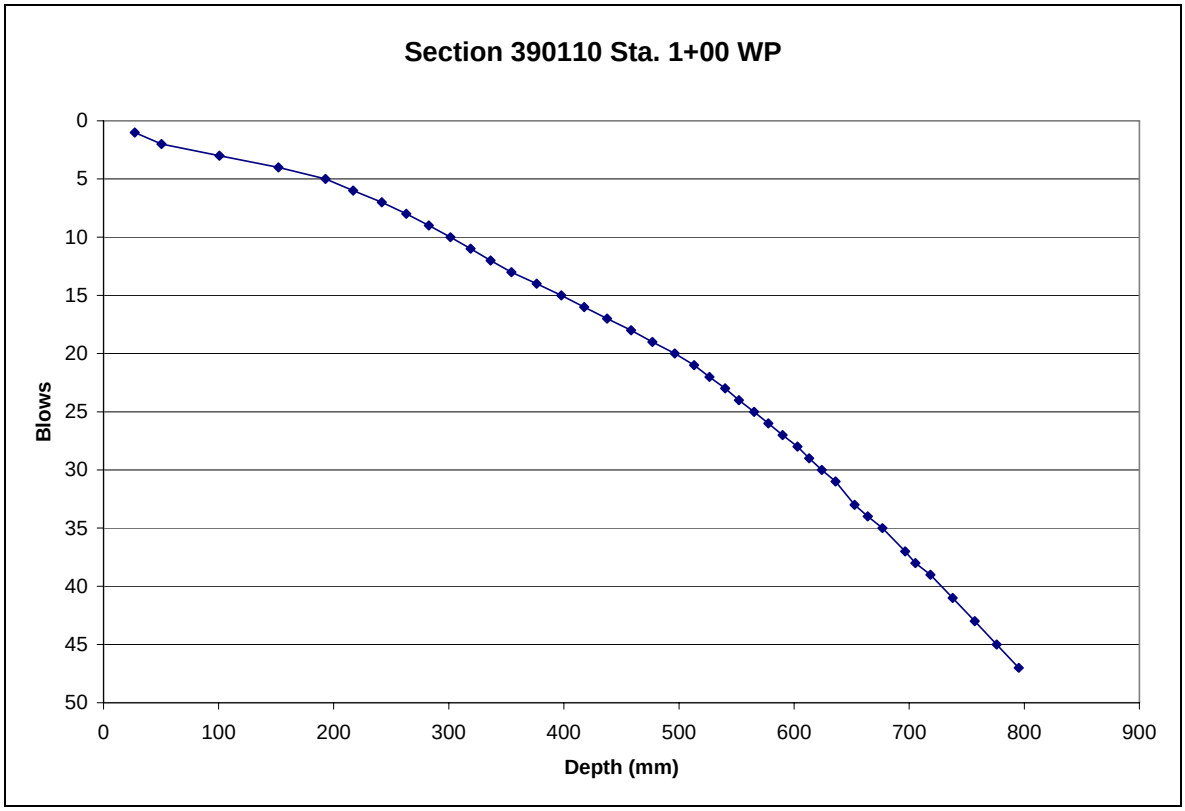
(25.4 mm = 1 in)


Section 390110 Sta. 0+00 CL
Blows
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900
Depth (mm)

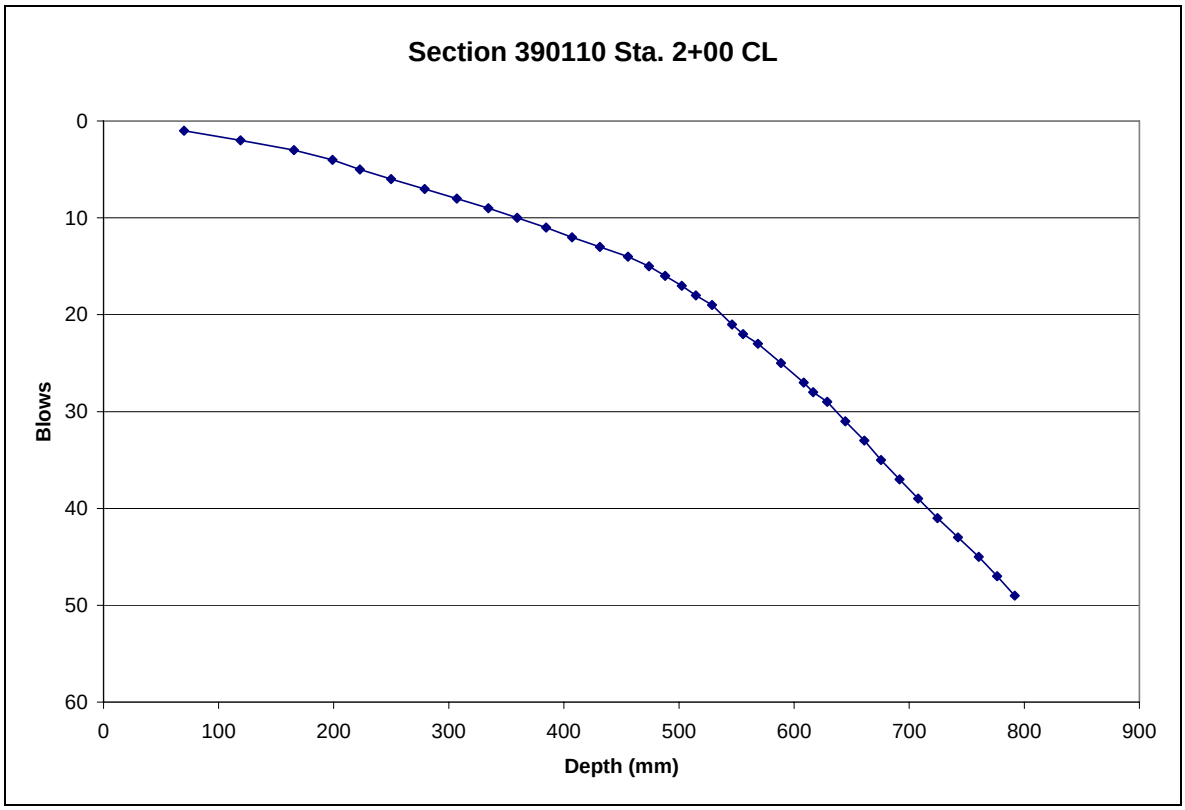

Section 390110 Sta. 0+00 WP
Blows
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800
900
Depth (mm)

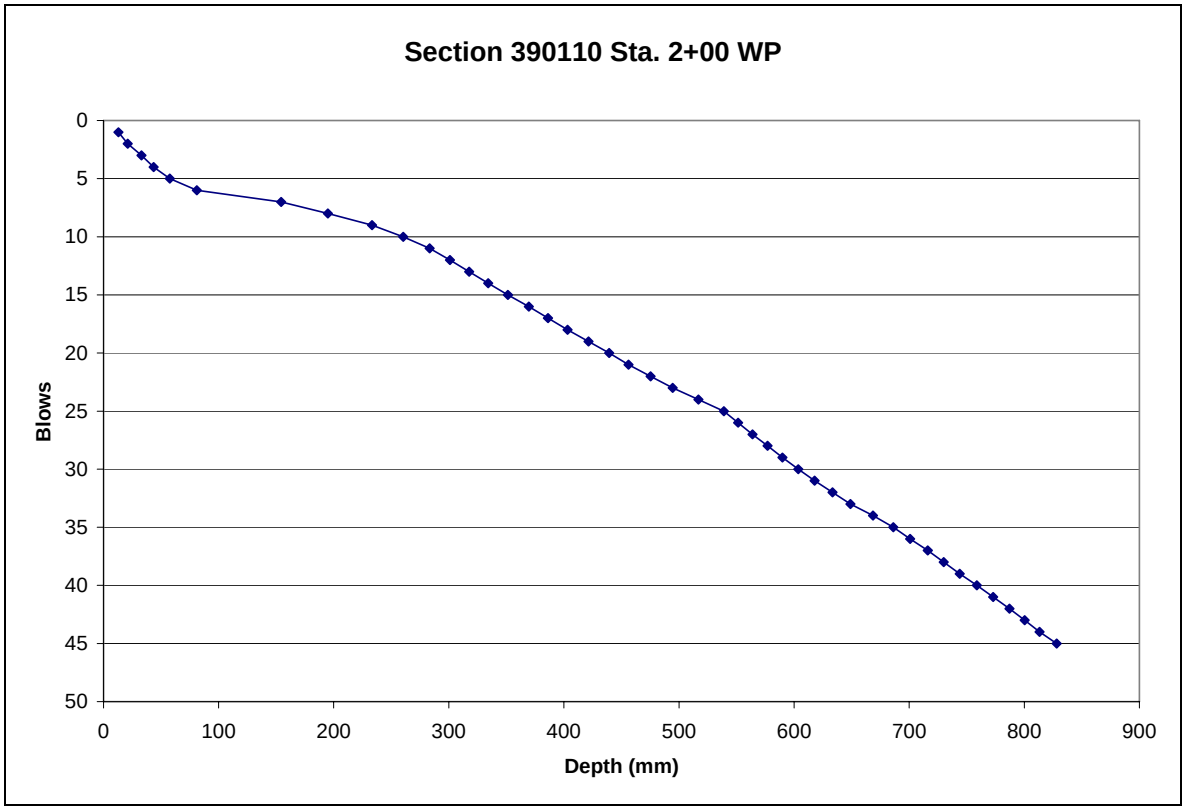
(25.4 mm = 1 in)


Section 390110 Sta. 1+00 CL
Blows
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
Depth (mm)

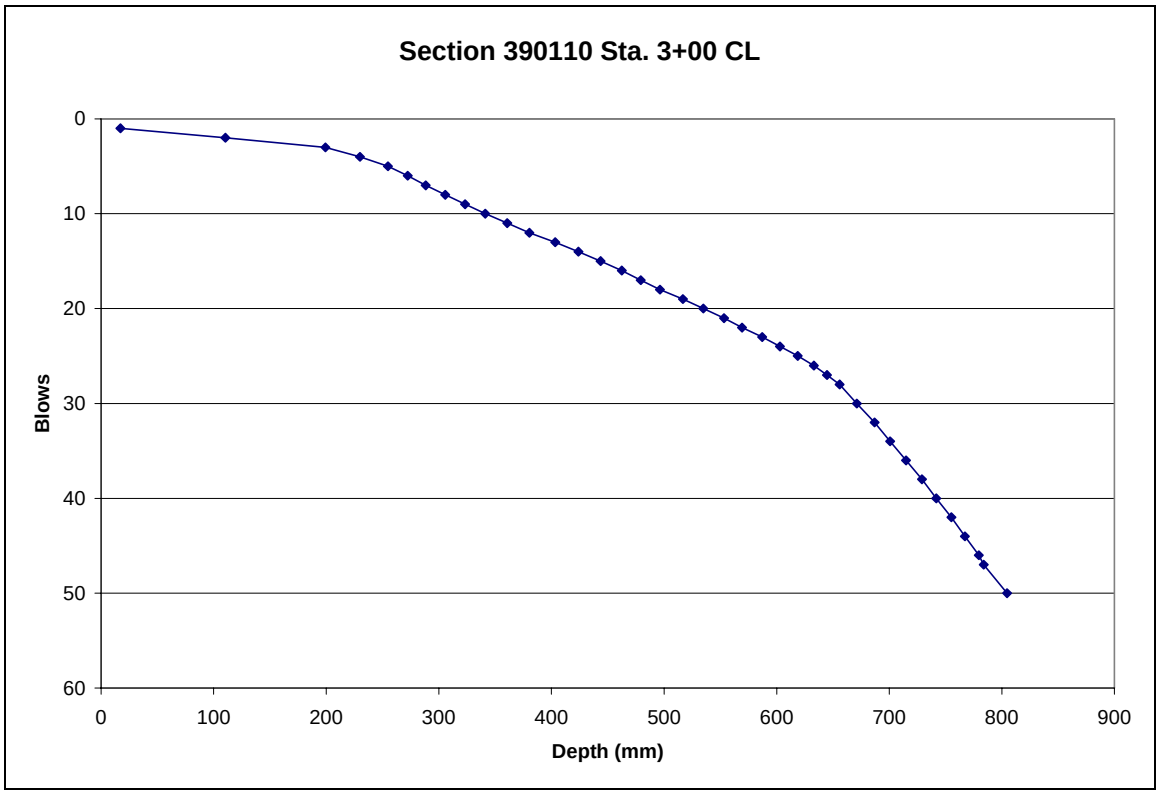

Section 390110 Sta. 1+00 WP
Blows
0
5
10
15
20
25
30
35
40
45
50
0
100
200
300
400
500
600
700
800
900
Depth (mm)

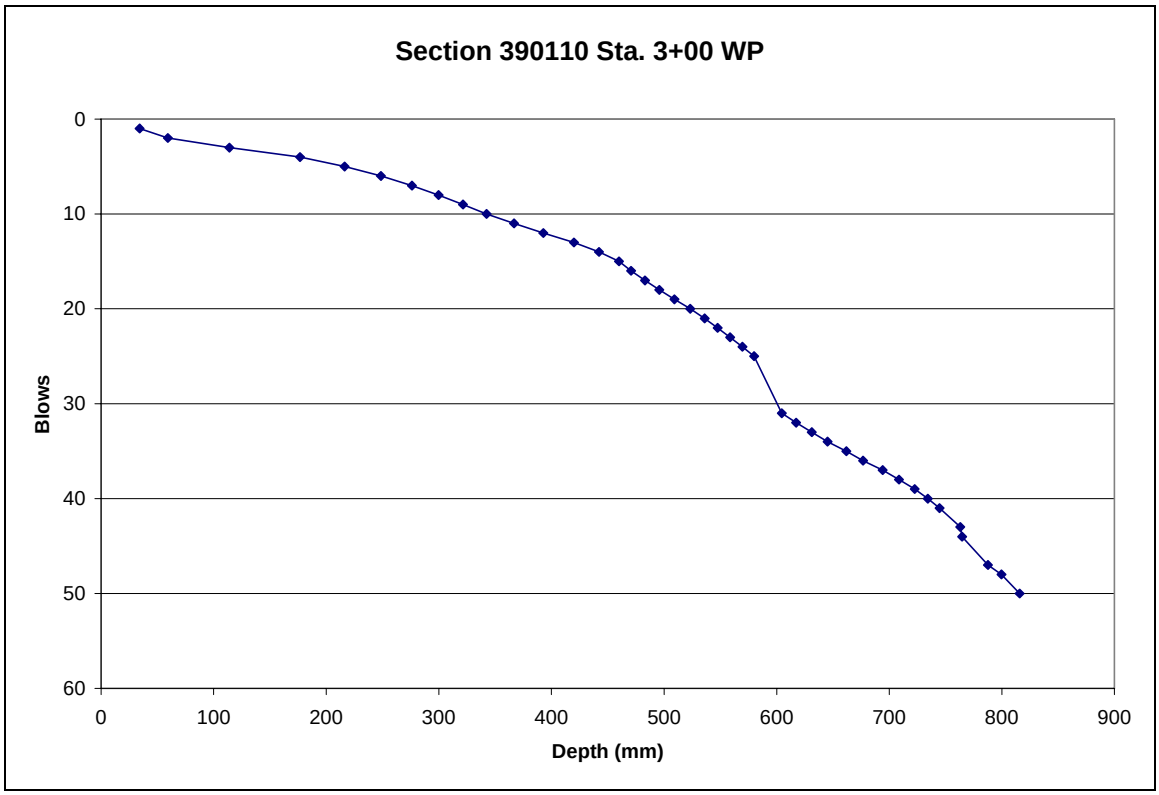
(25.4 mm = 1 in)


Section 390110 Sta. 2+00 CL
Blows
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
Depth (mm)

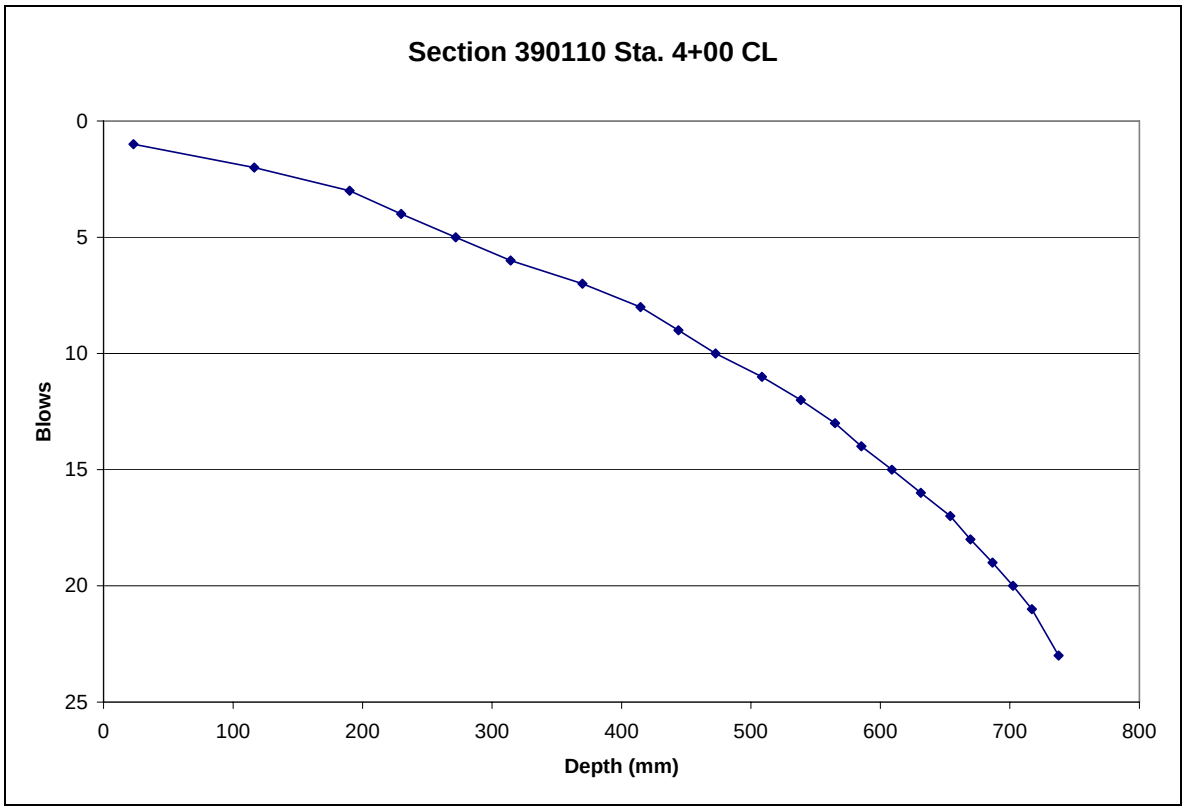

Section 390110 Sta. 2+00 WP
Blows
0
5
10
15
20
25
30
35
40
45
50
0
100
200
300
400
500
600
700
800
900
Depth (mm)

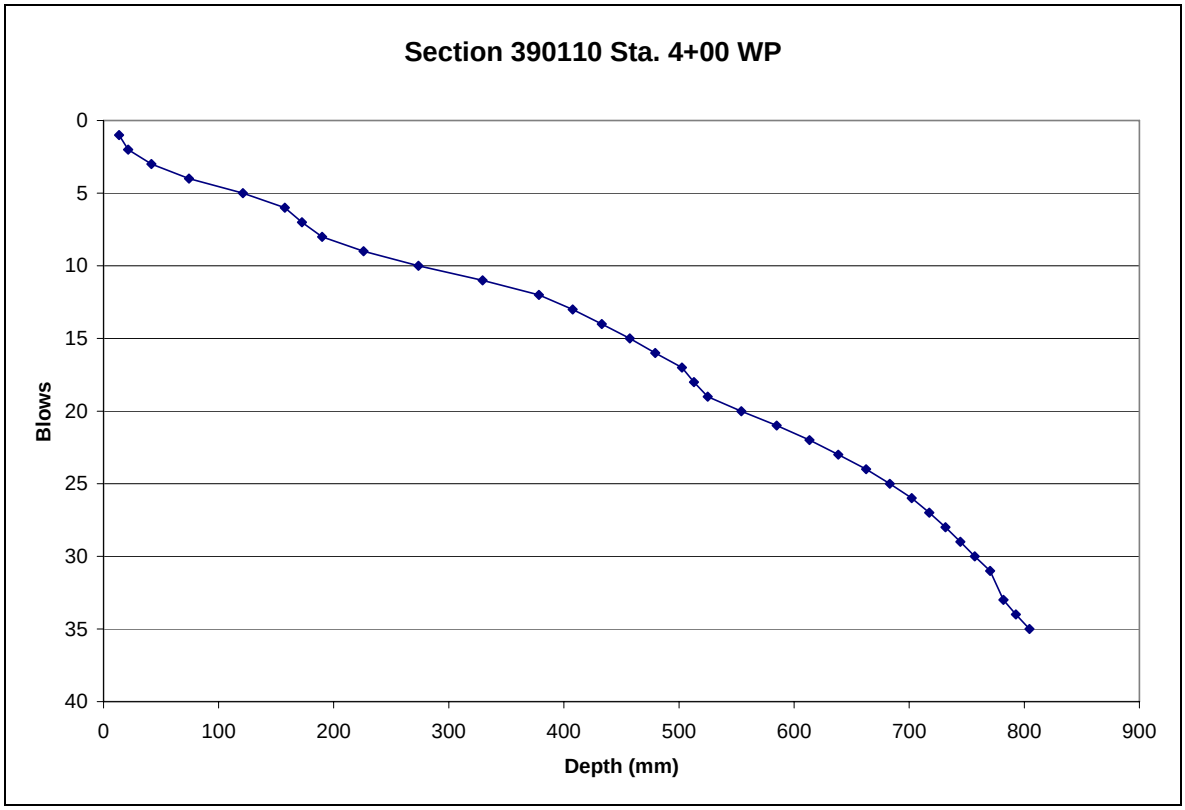
(25.4 mm = 1 in)


Section 390110 Sta. 3+00 CL
Blows
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
Depth (mm)

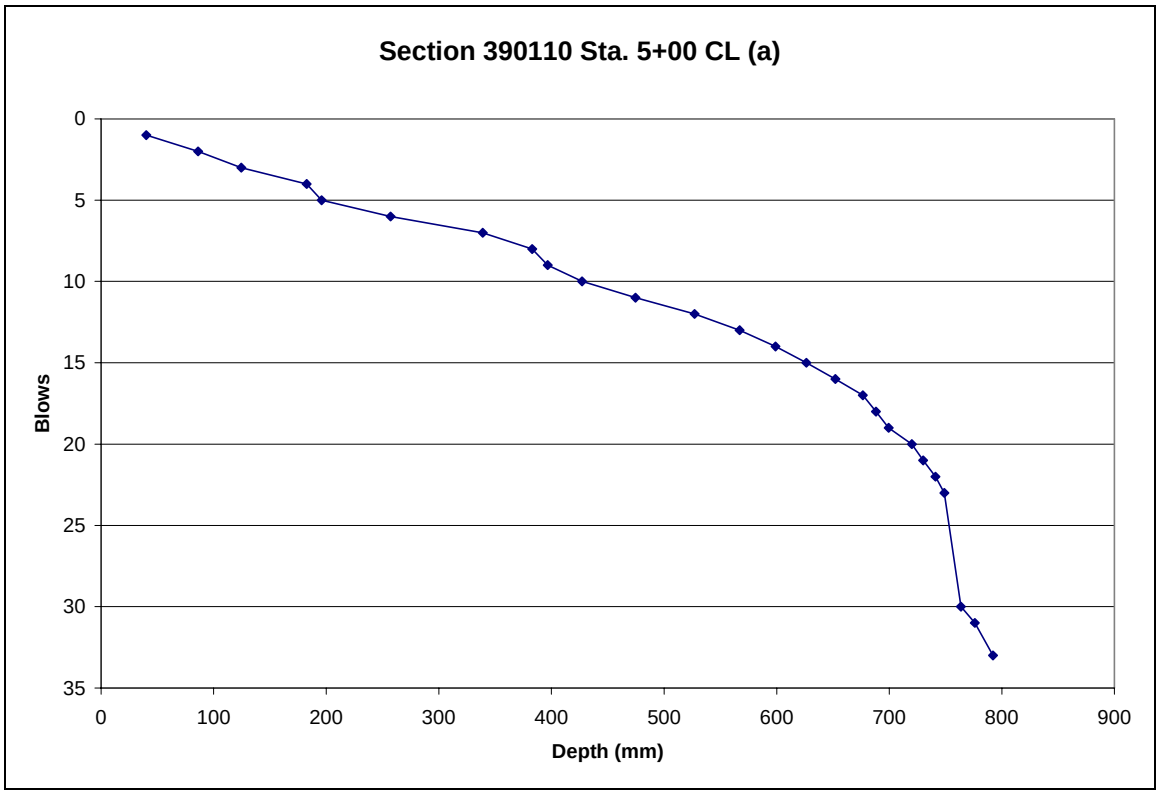

Section 390110 Sta. 3+00 WP
Blows
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
Depth (mm)

(25.4 mm = 1 in)


Section 390110 Sta. 4+00 CL
Blows
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
Depth (mm)


Section 390110 Sta. 4+00 WP
Blows
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800
900
Depth (mm)

(25.4 mm = 1 in)


Section 390110 Sta. 5+00 CL (a)
Blows
Depth (mm)
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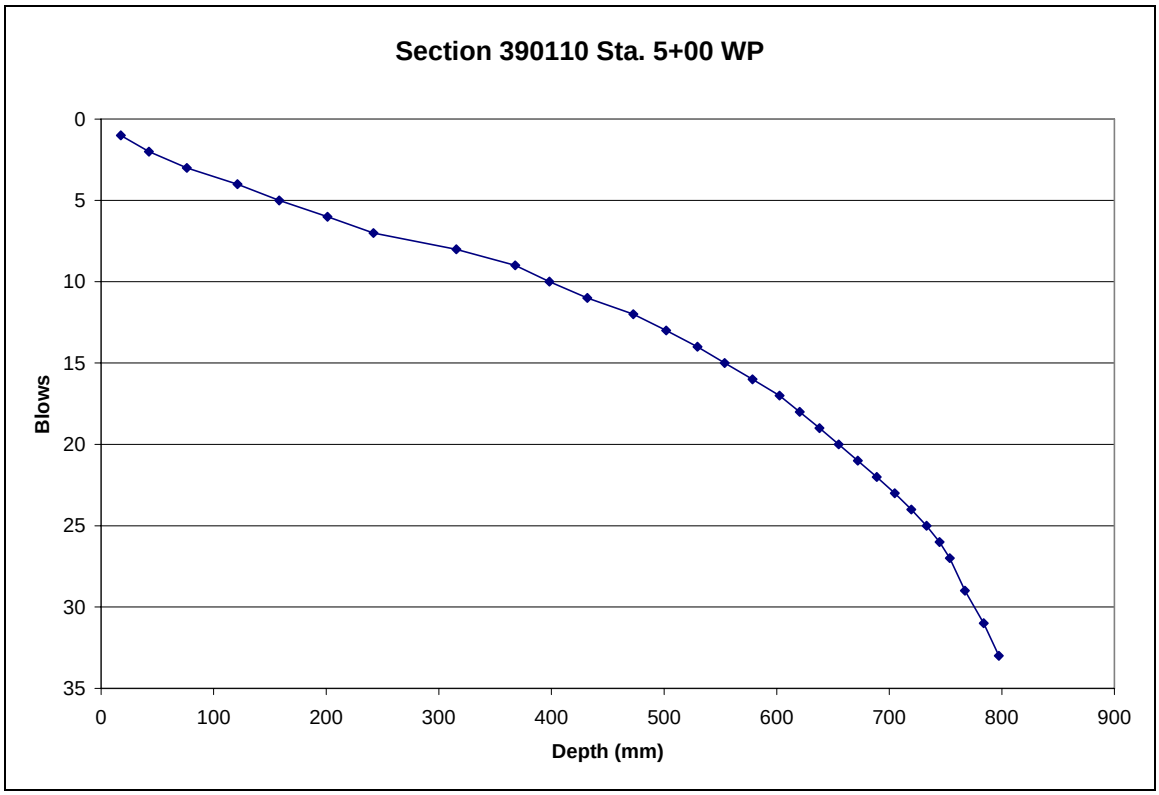
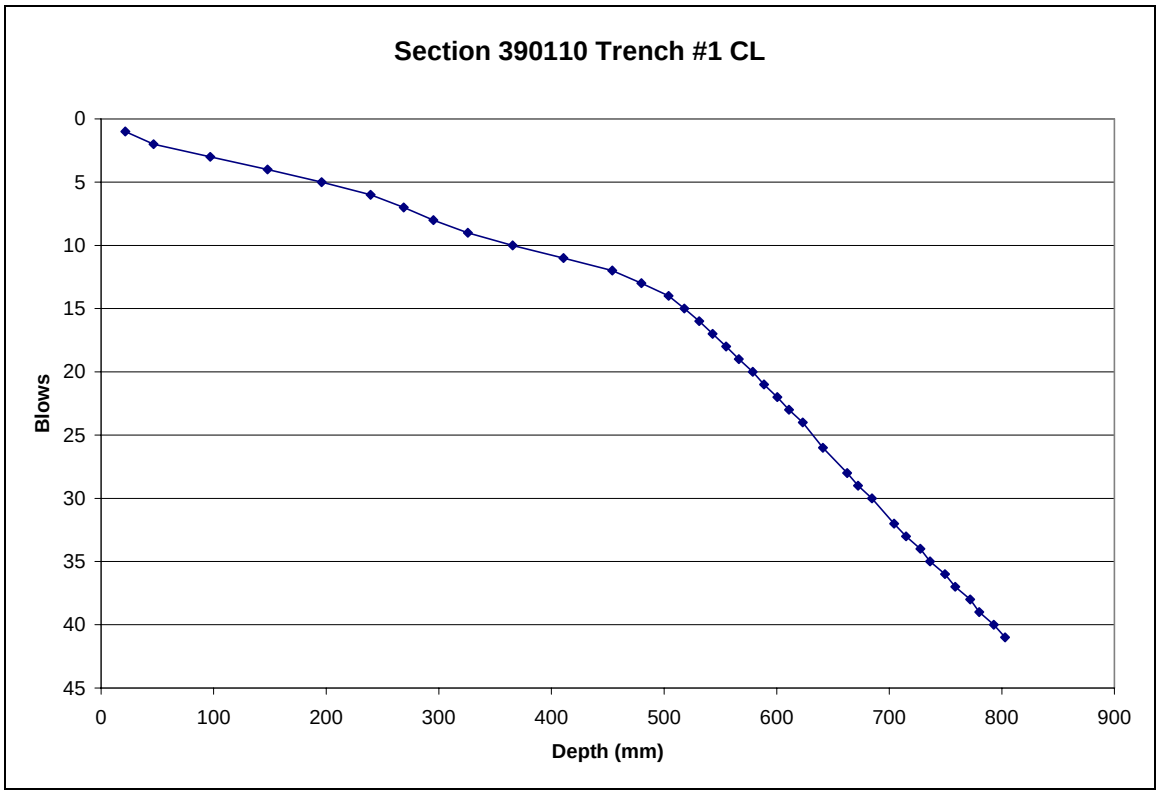
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
900


Section 390110 Sta. 5+00 WP
Blows
Depth (mm)
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
900

(25.4 mm = 1 in)


Section 390110 Trench #1 CL
Blows
Depth (mm)
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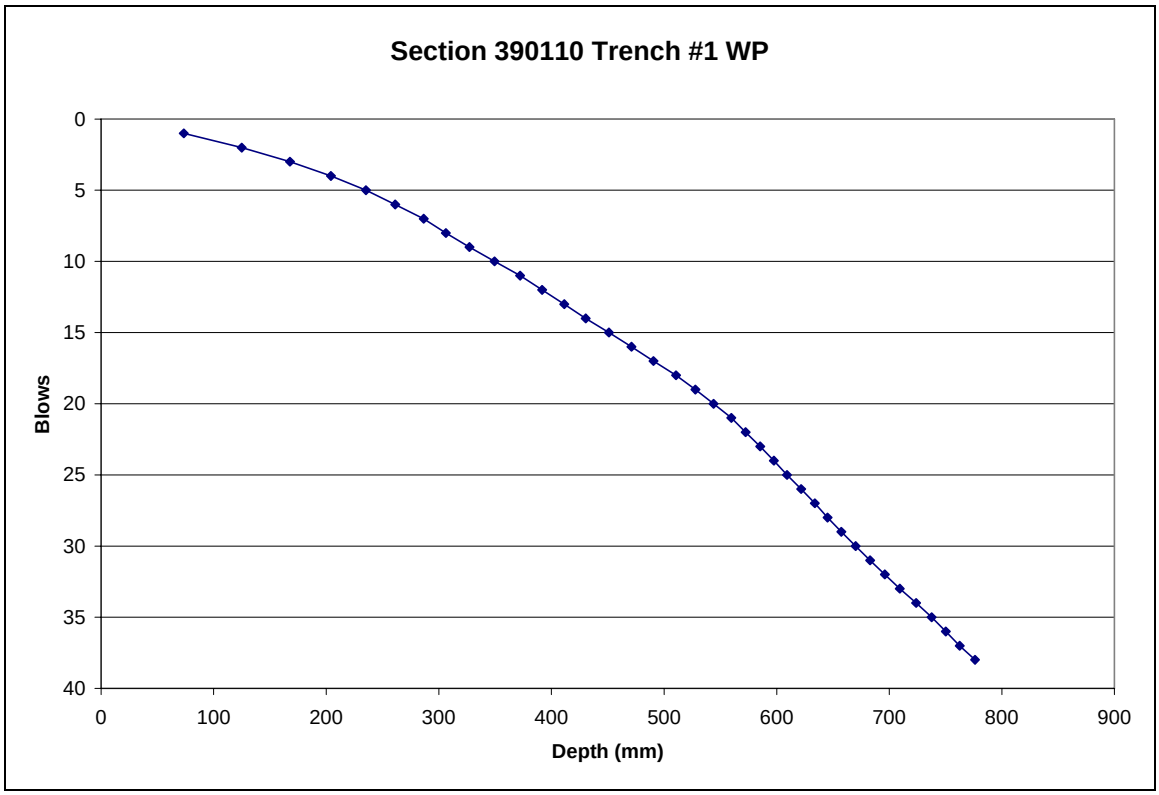
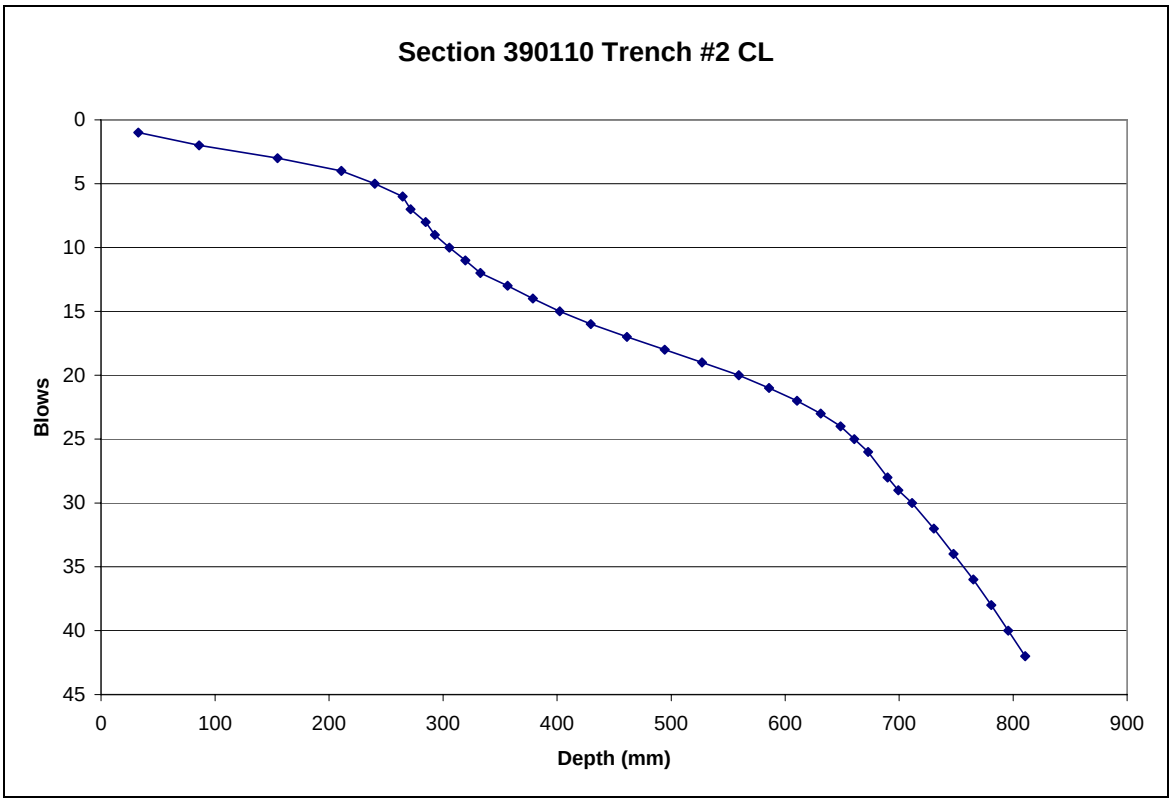
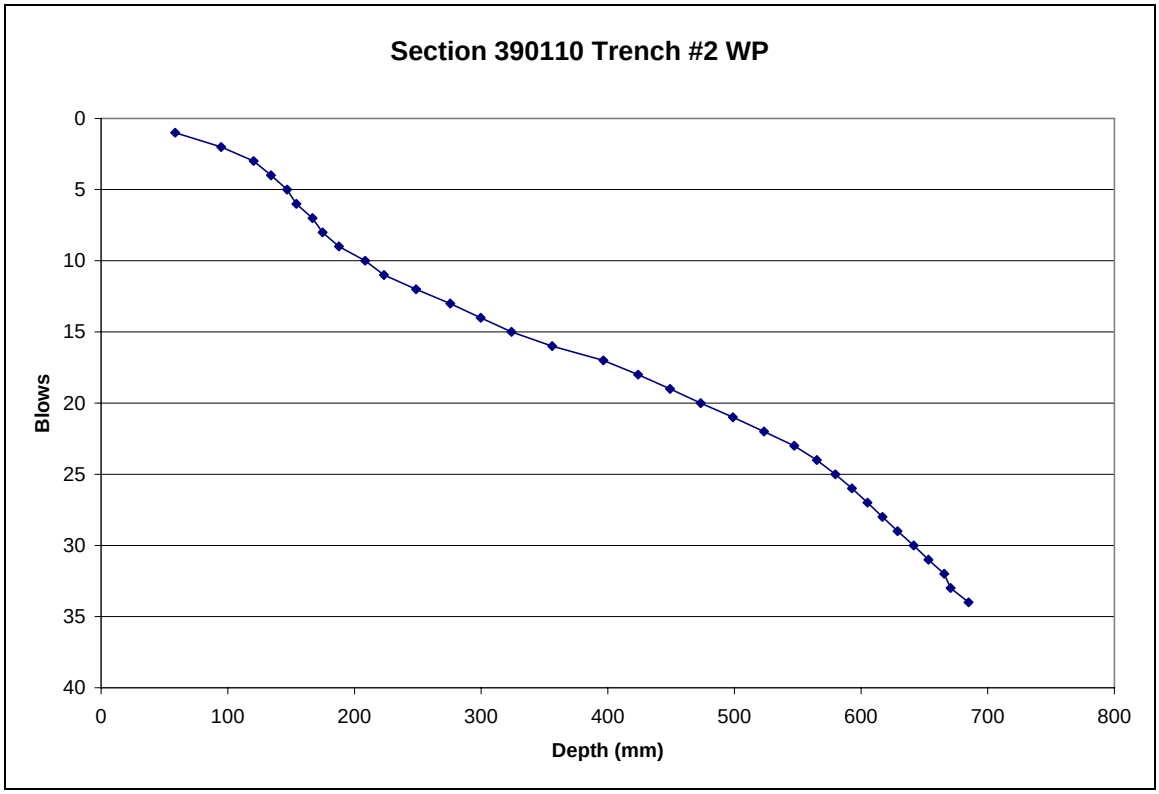
5
10
15
20
25
30
35
40
45
0
100
200
300
400
500
600
700
800
900

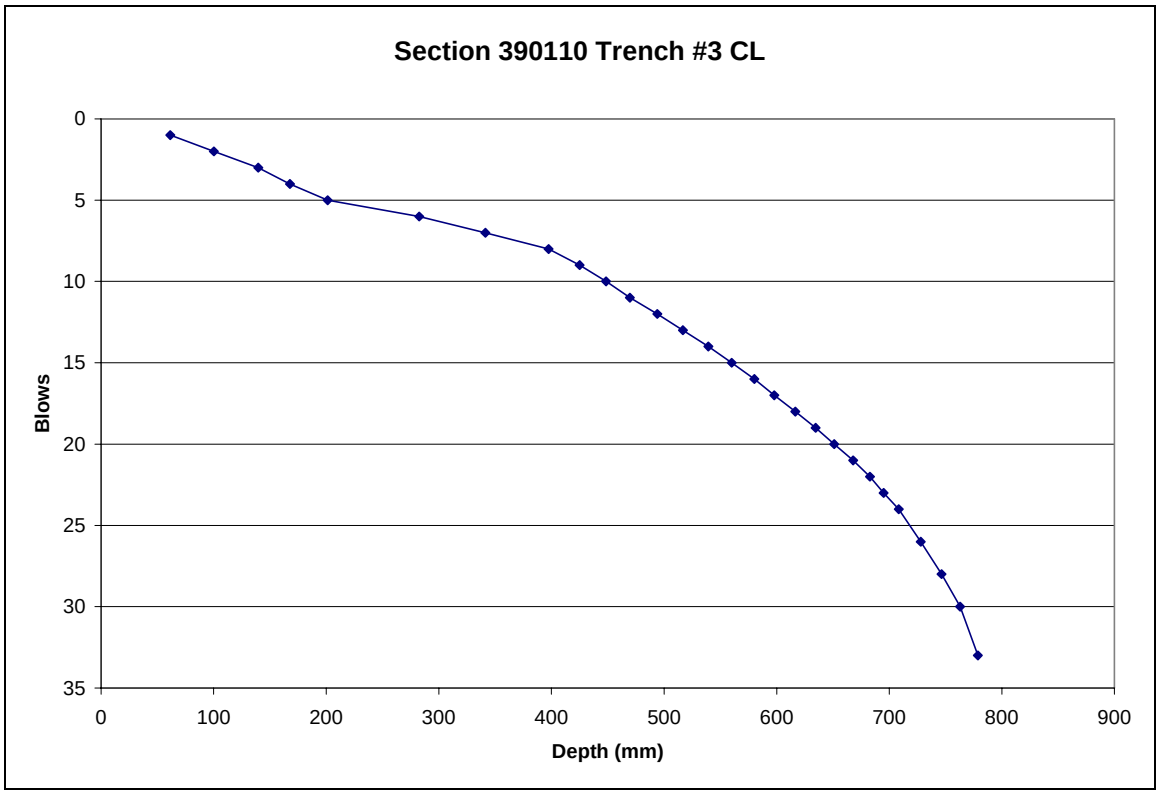

Section 390110 Trench #1 WP
Blows
Depth (mm)
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800
900

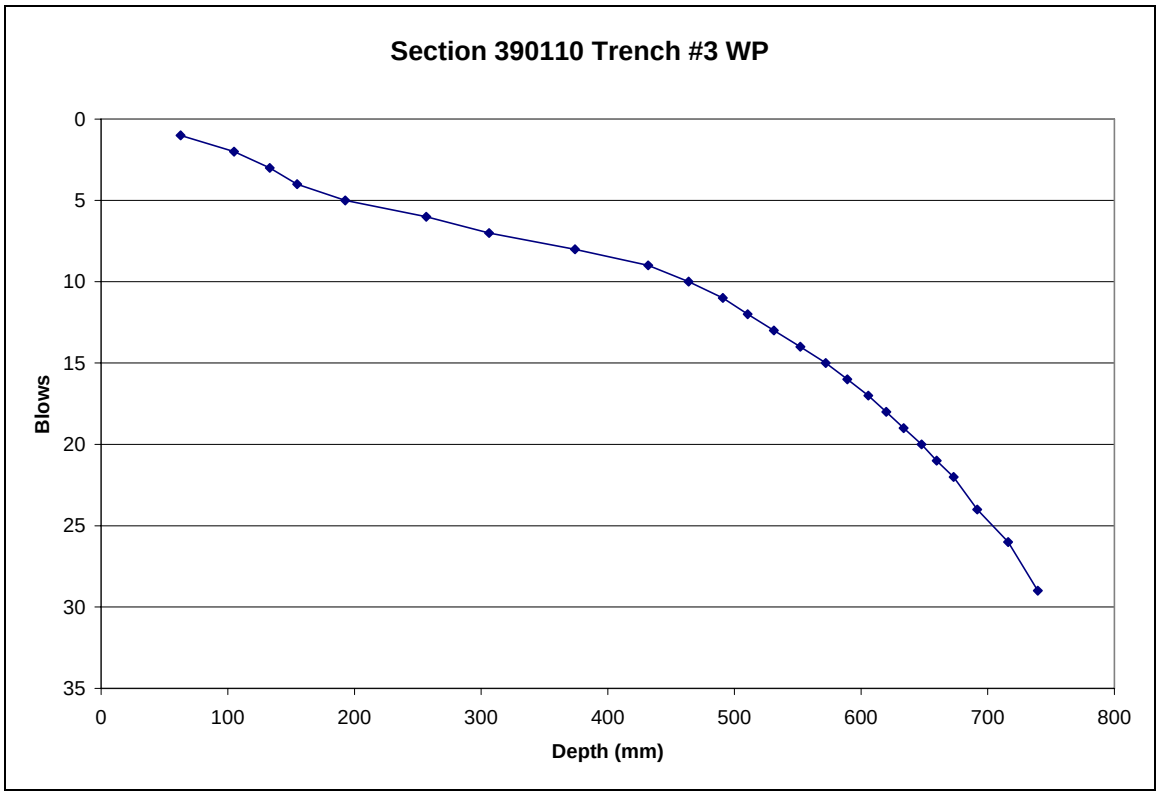
(25.4 mm = 1 in)


Section 390110 Trench #2 CL
Blows
0
5
10
15
20
25
30
35
40
45
0
100
200
300
400
500
600
700
800
900
Depth (mm)


Section 390110 Trench #2 WP
Blows
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800
Depth (mm)

(25.4 mm = 1 in)

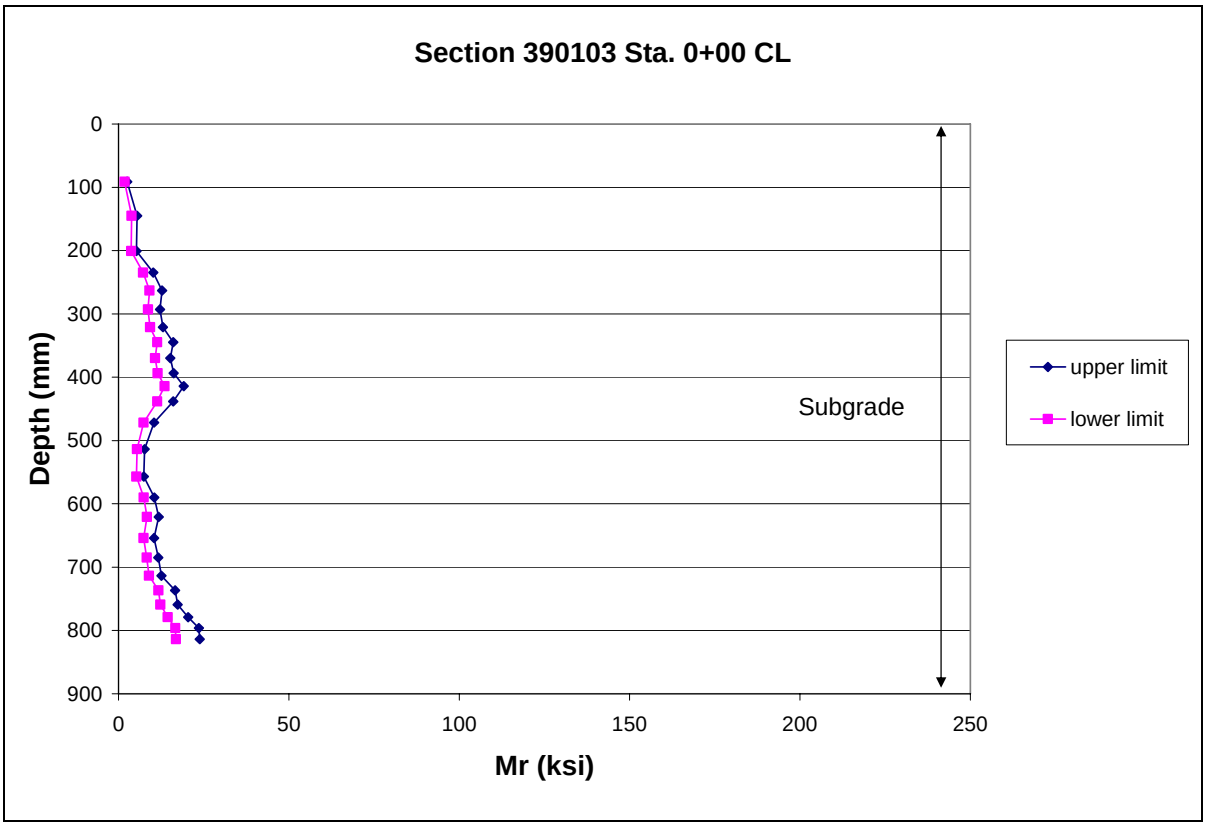

Section 390110 Trench #3 CL
Blows
Depth (mm)
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
900

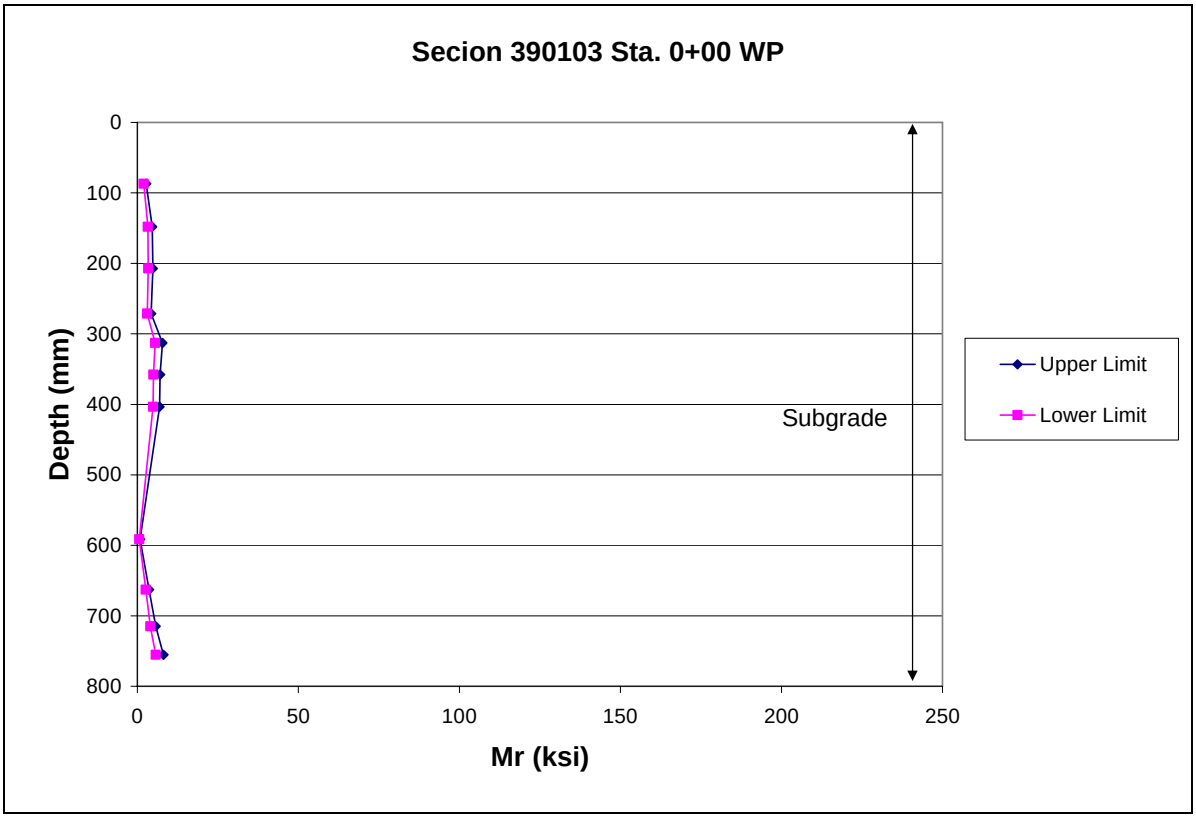

Section 390110 Trench #3 WP
Blows
Depth (mm)
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800

(25.4 mm = 1 in)

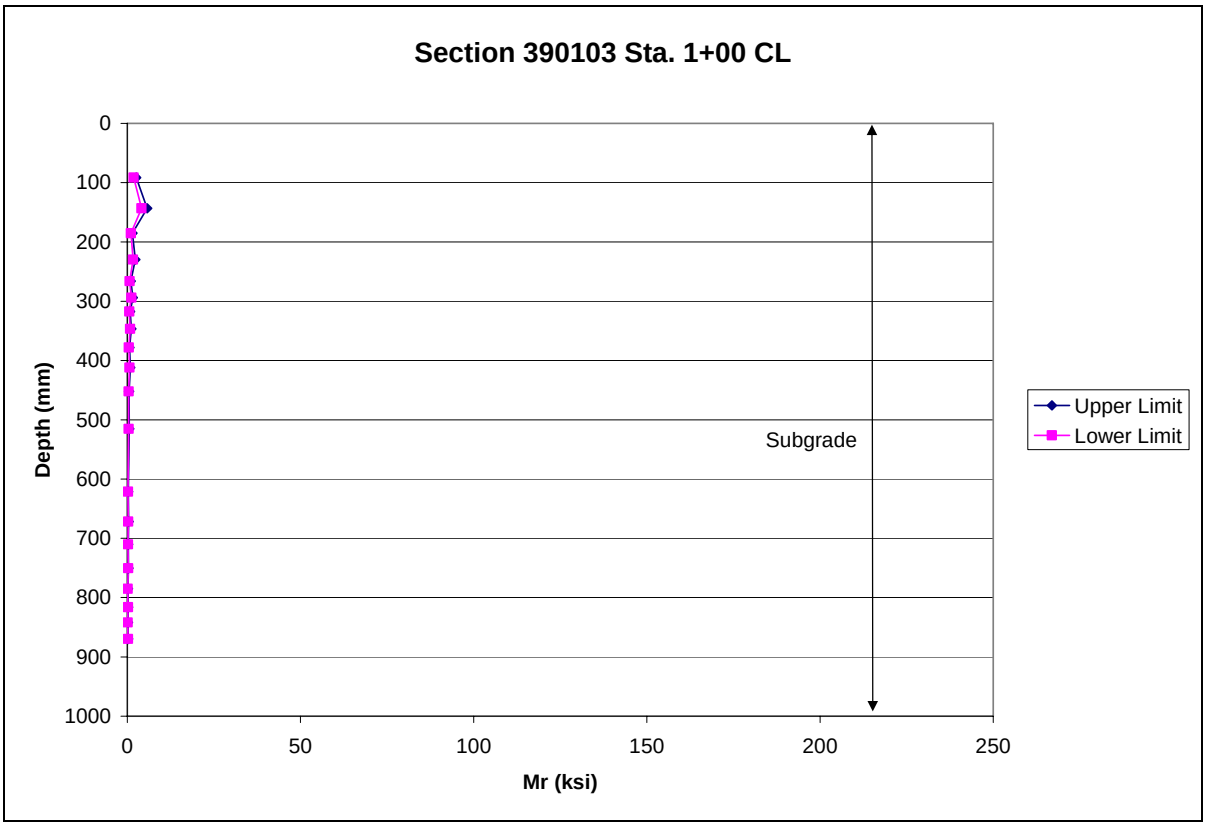
Appendix R DCP Resilient Modulus Plots

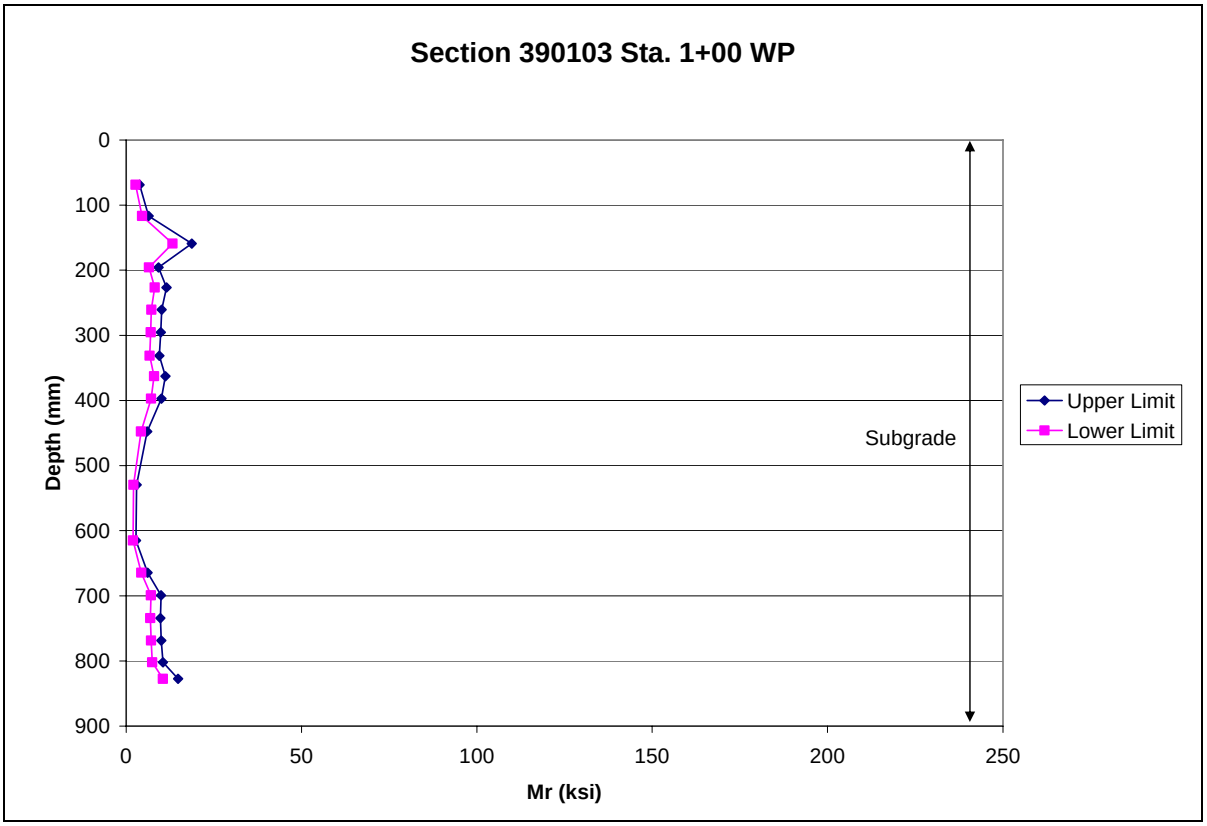
SECTION 390103



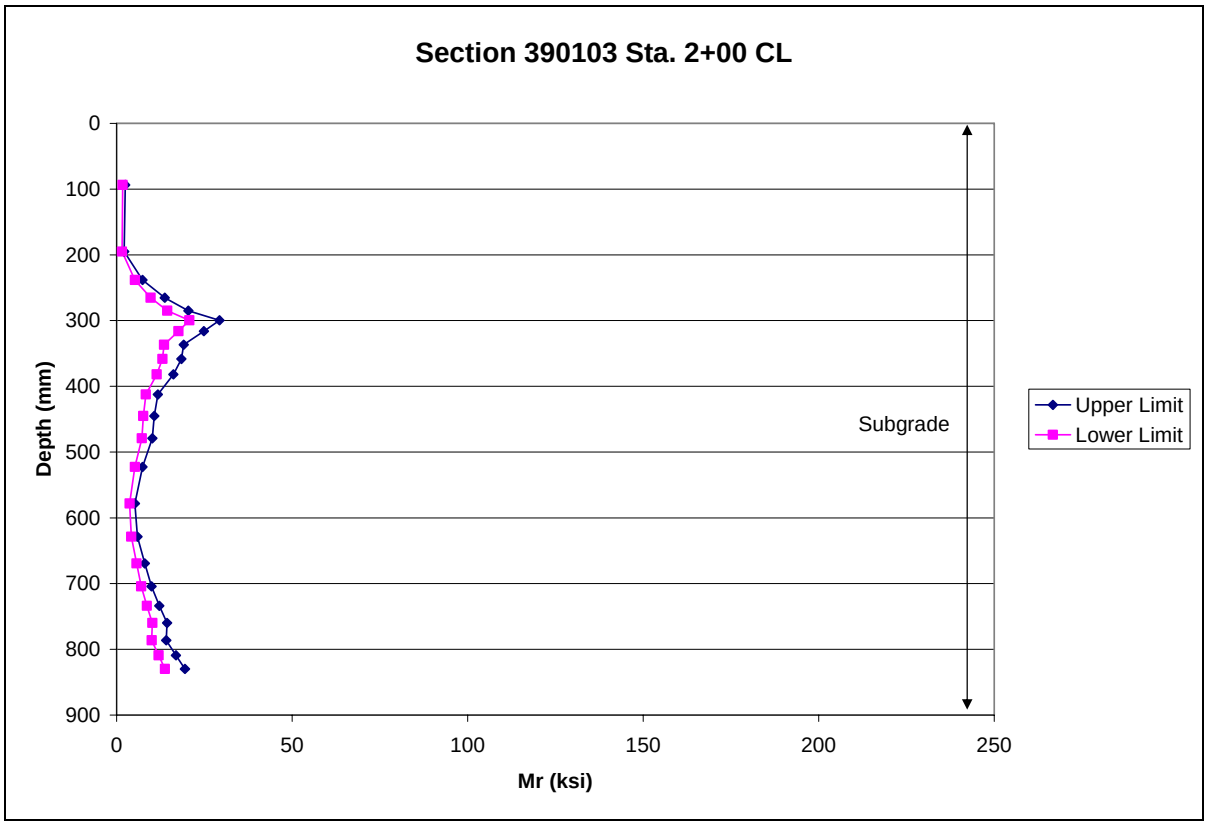


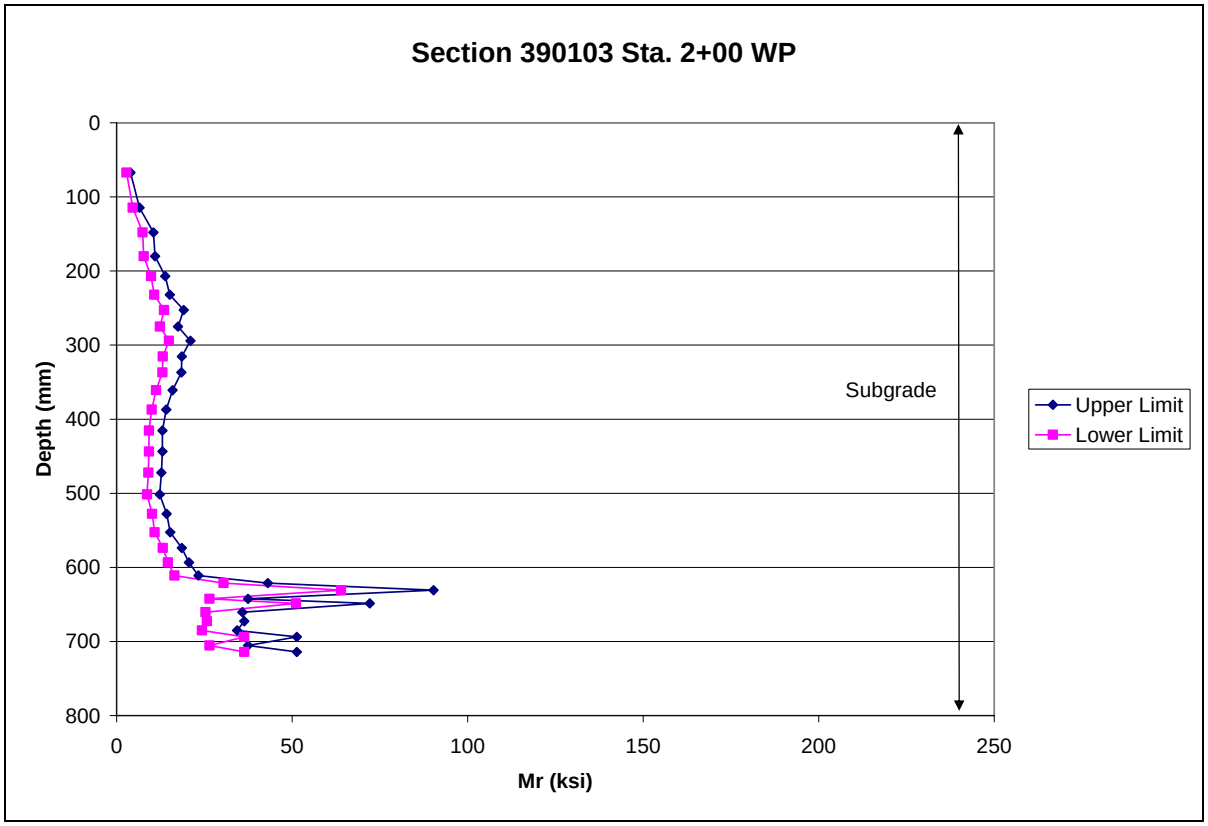
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



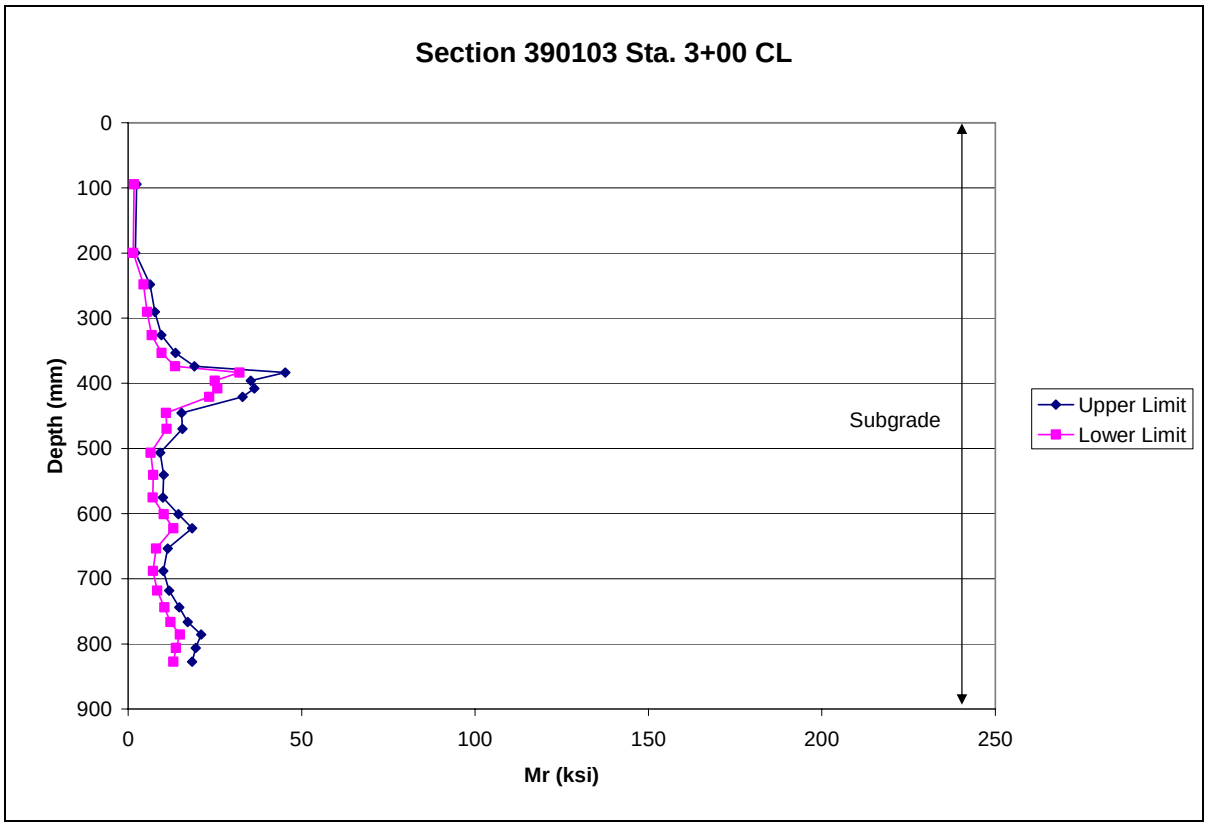


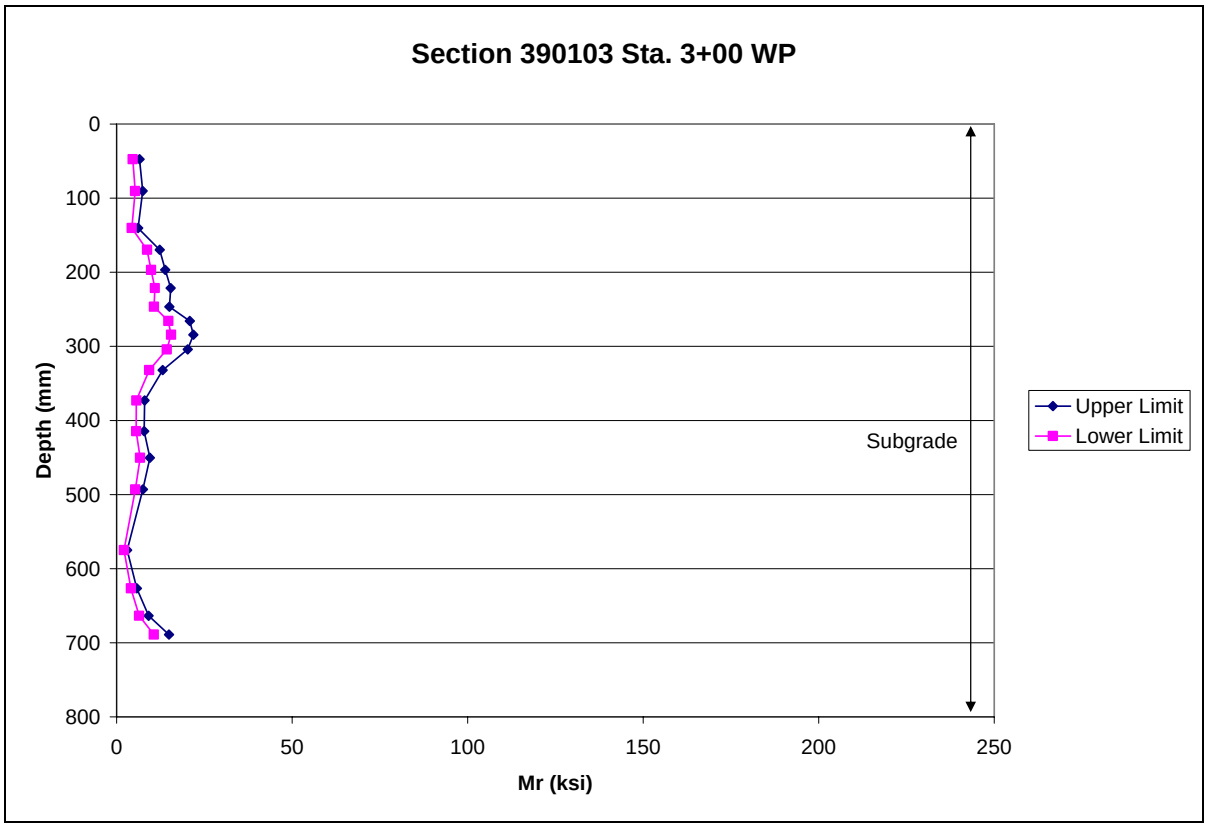
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



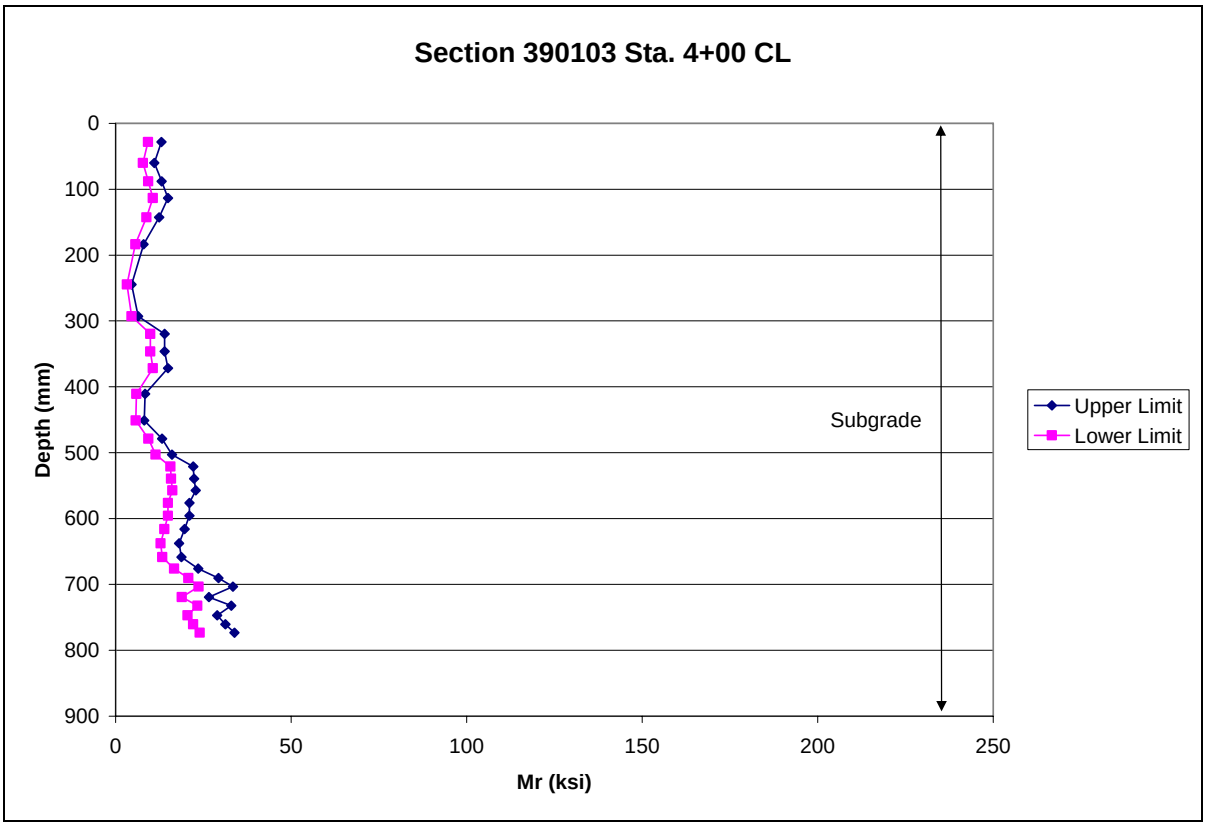


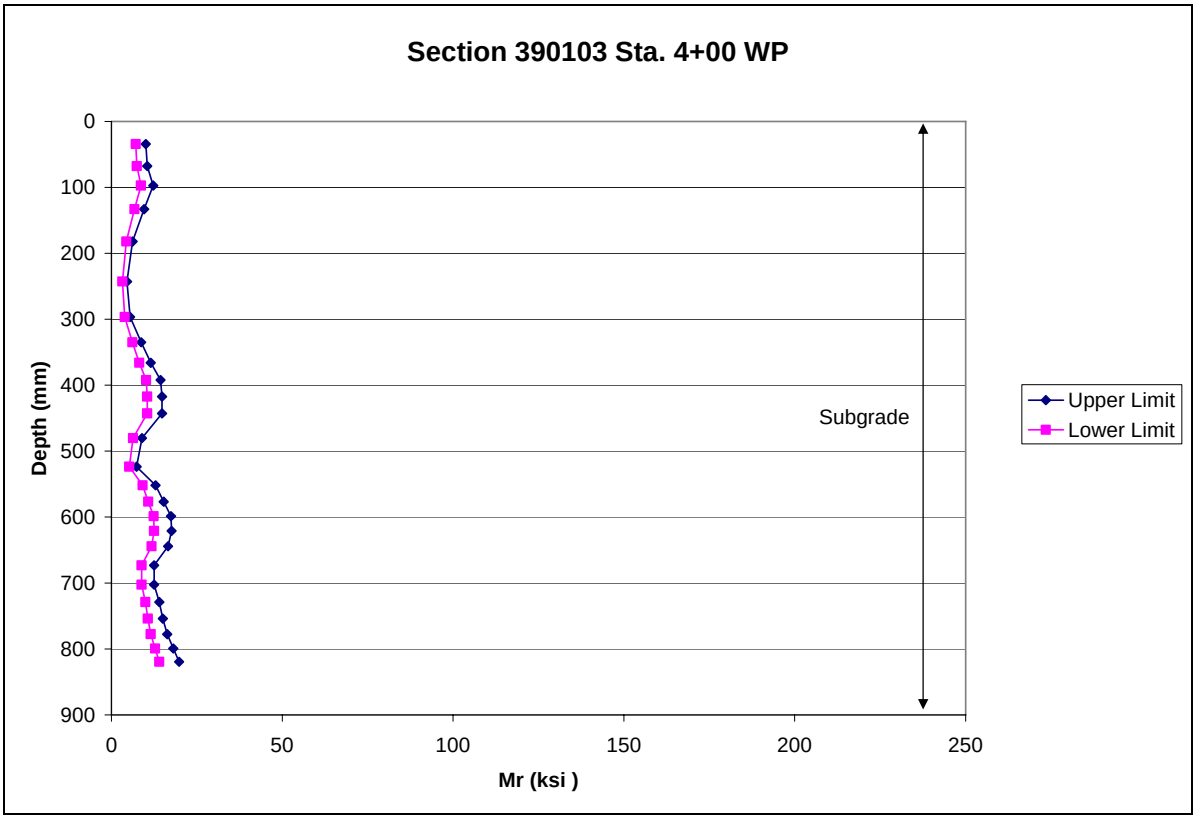
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



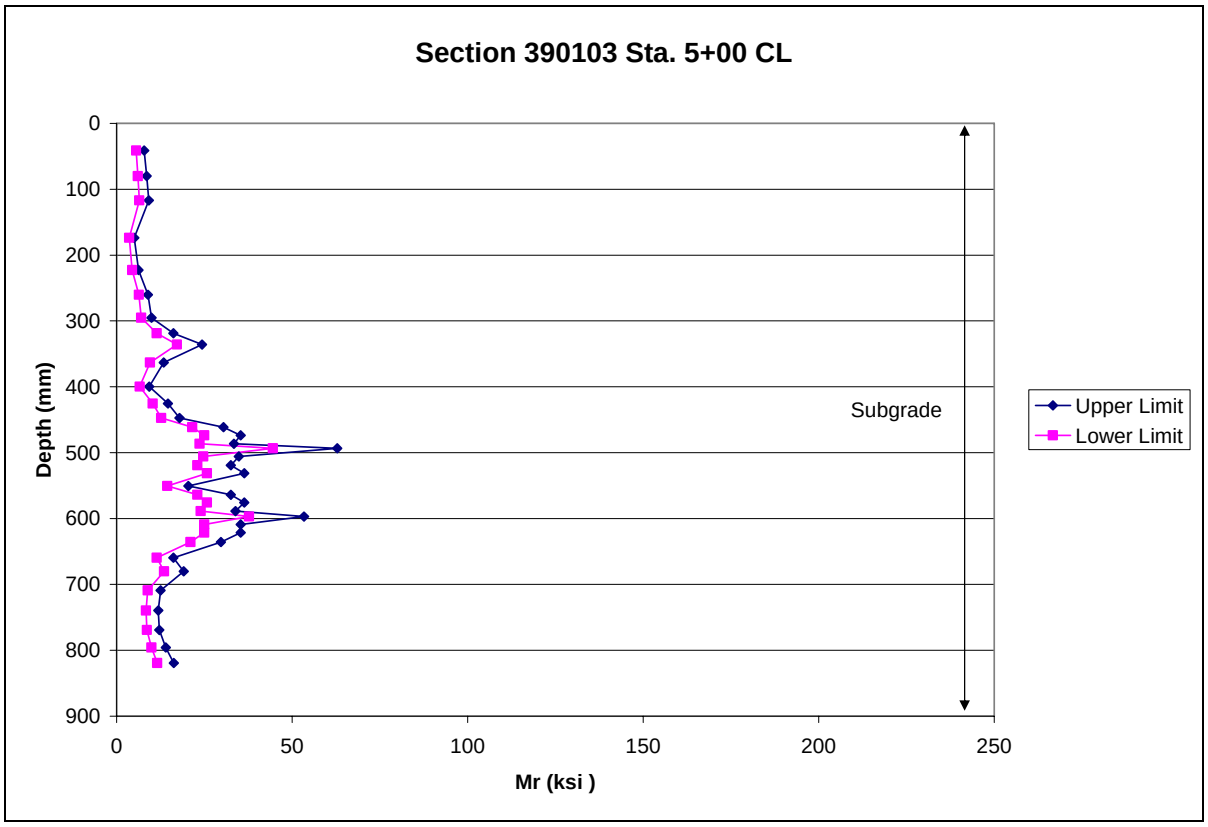


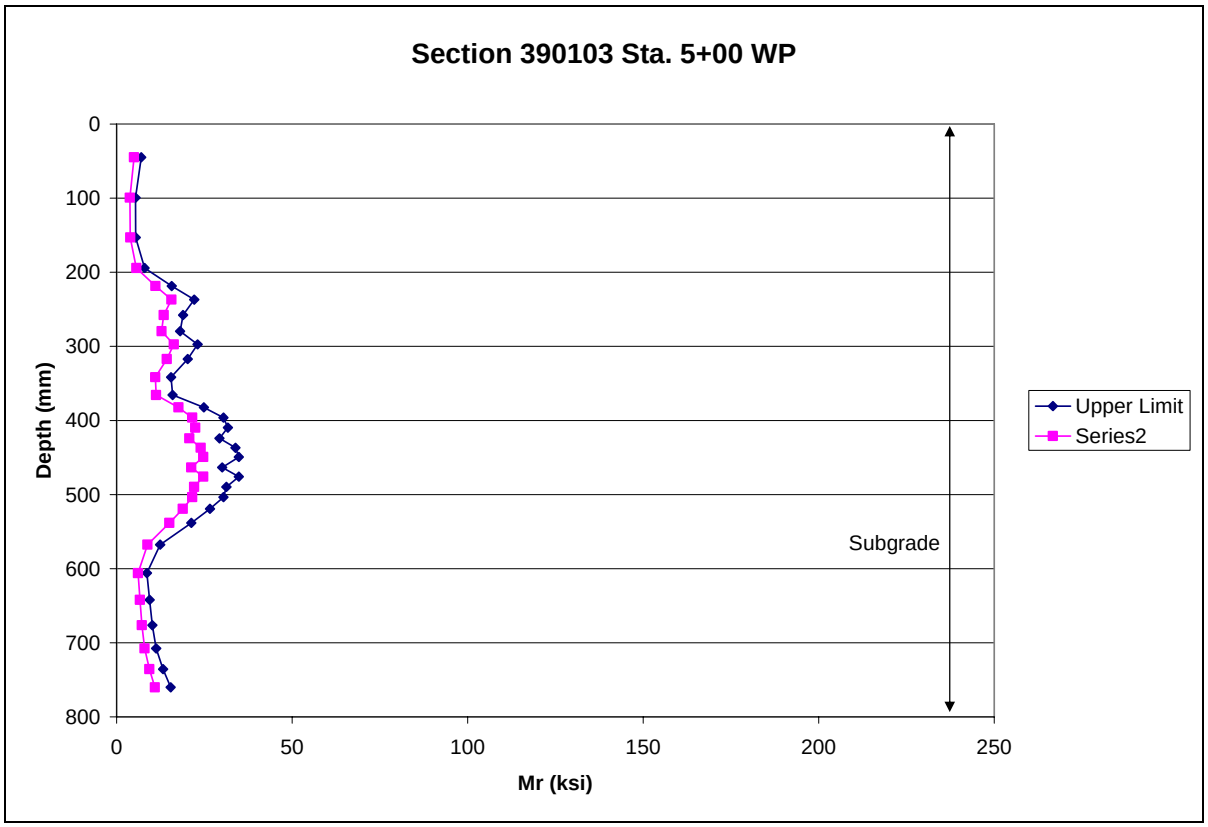
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



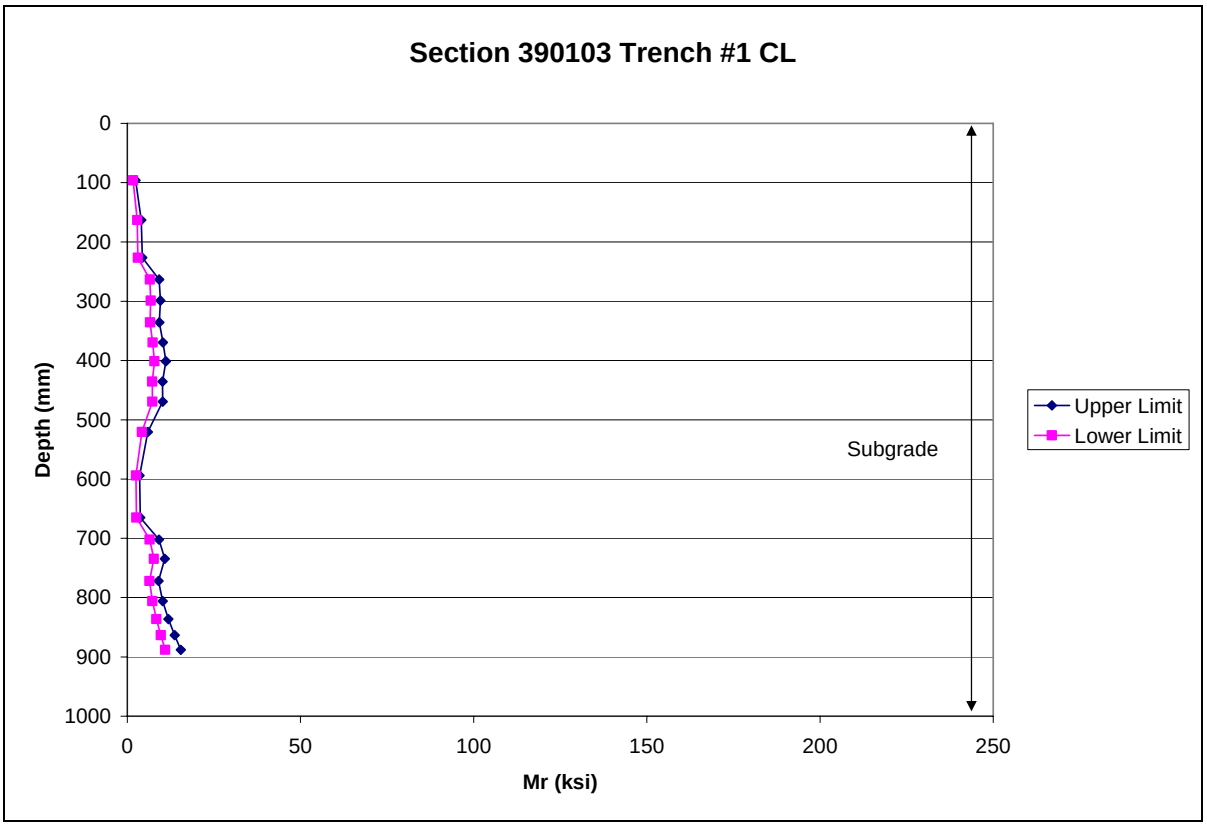


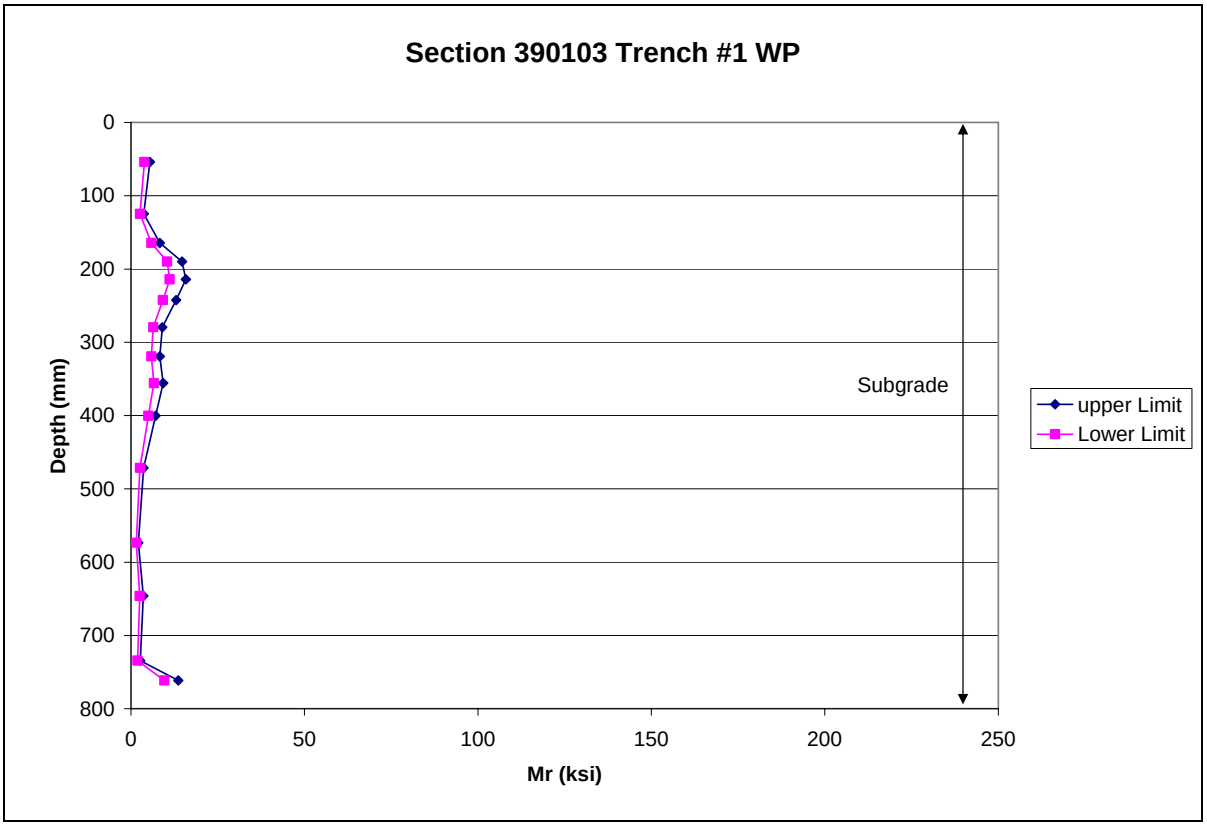
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



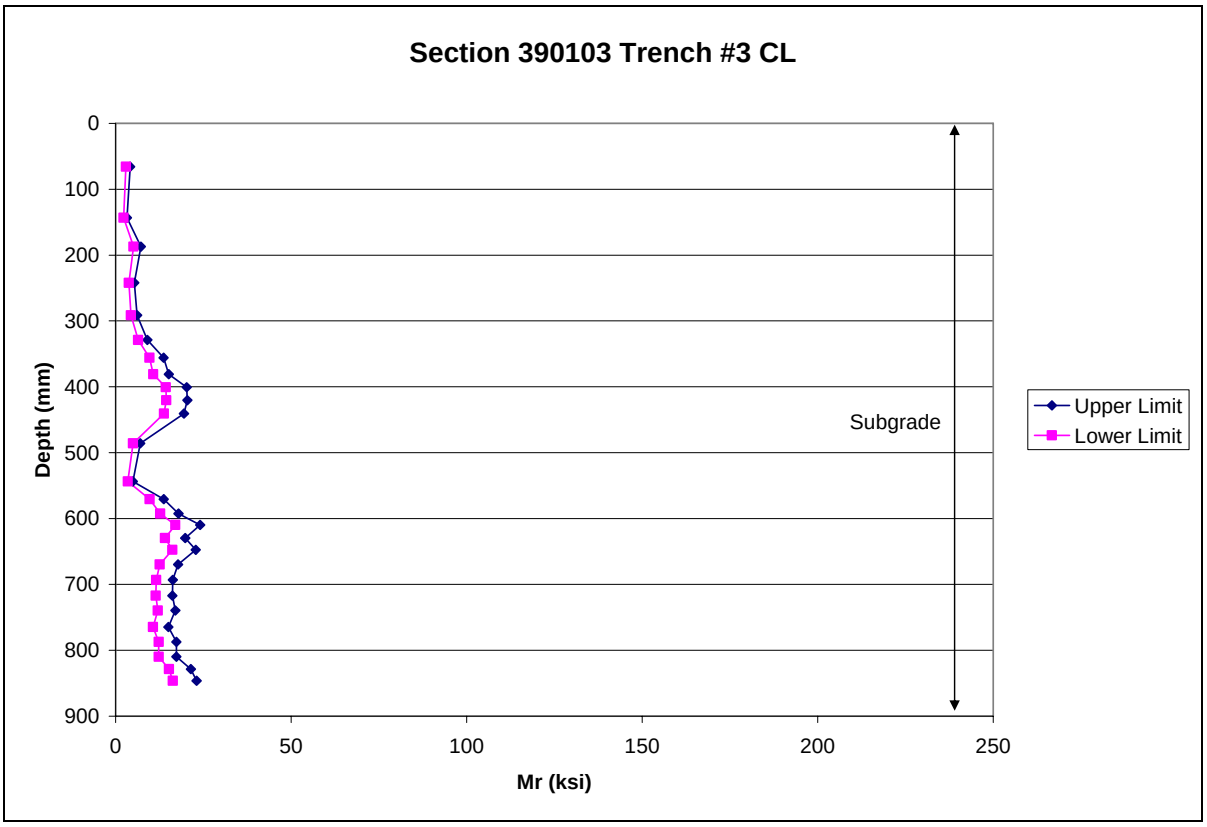


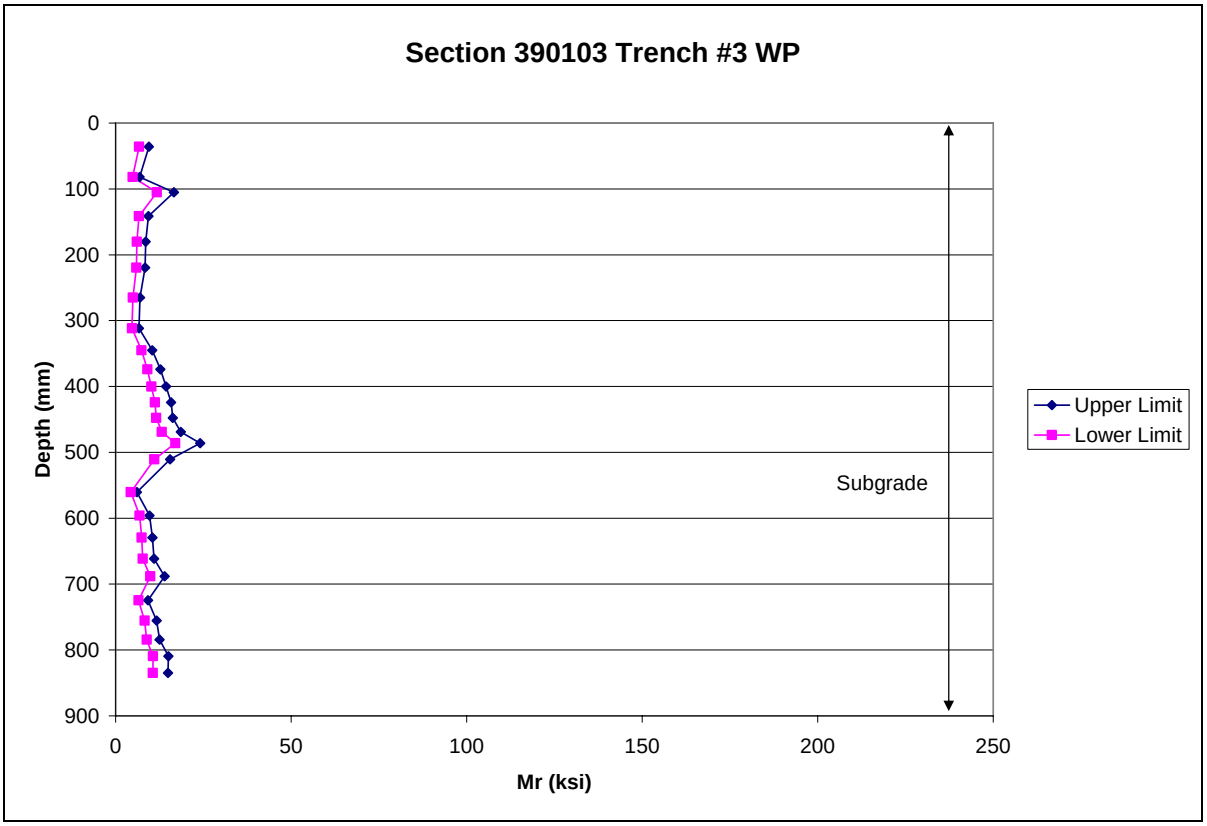
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)





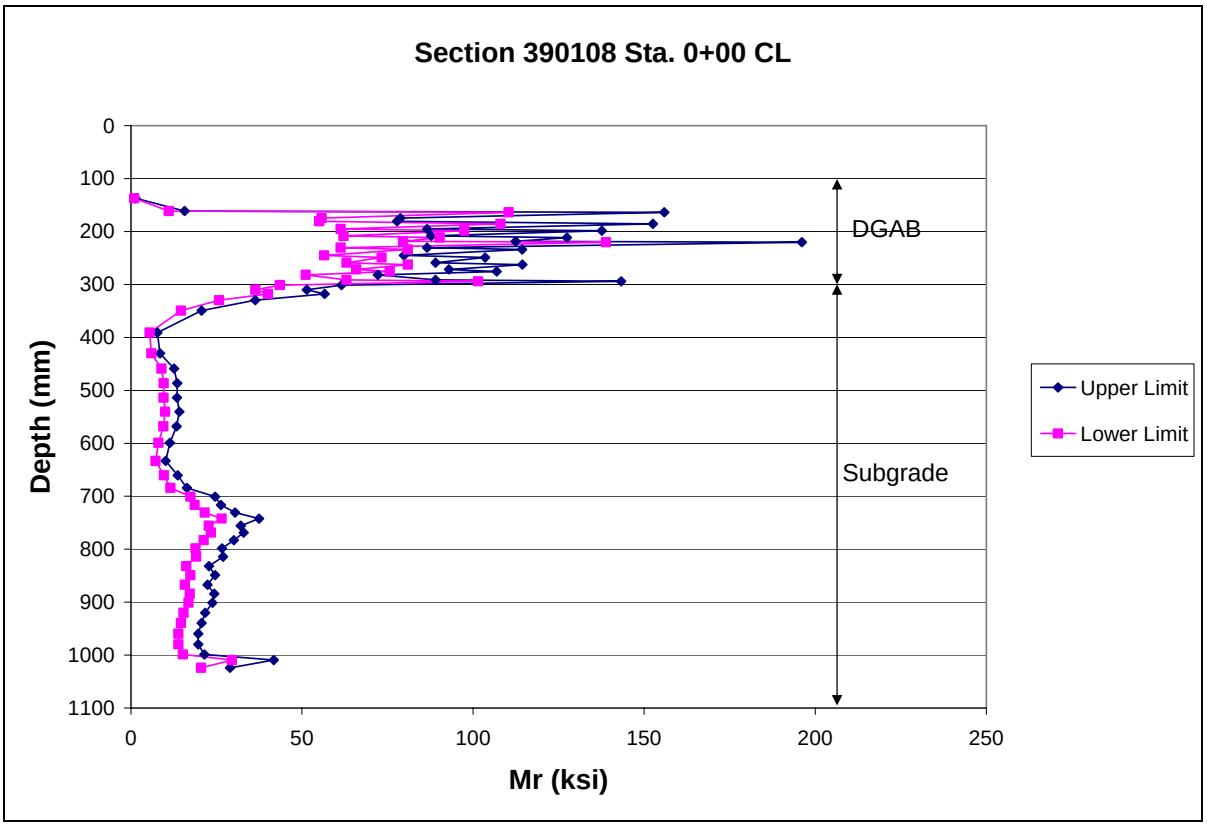
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

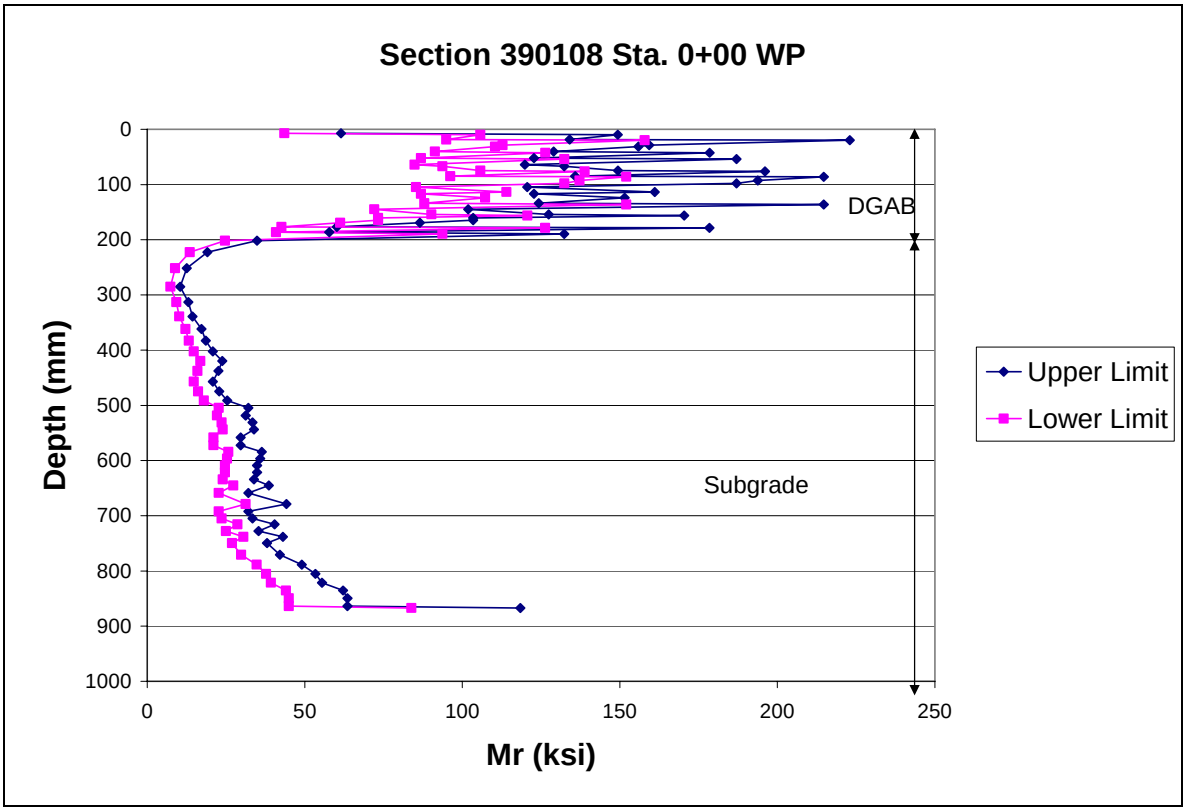




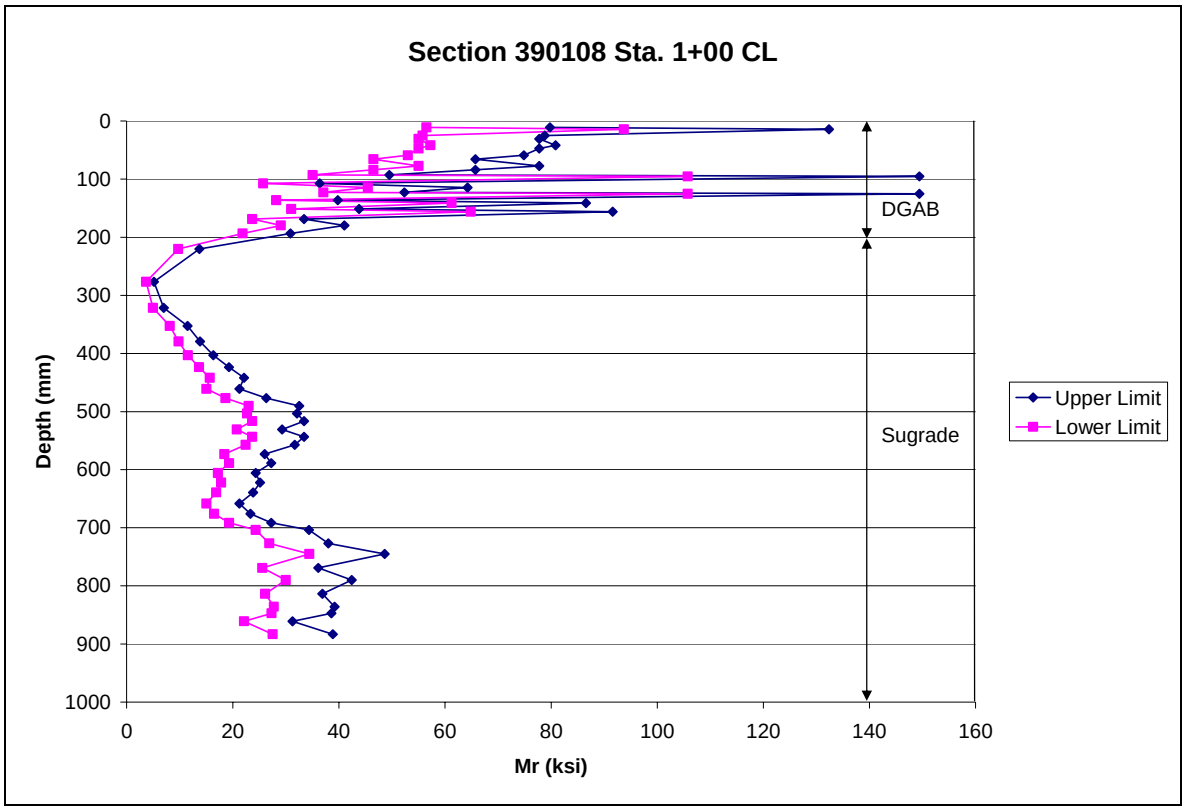
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

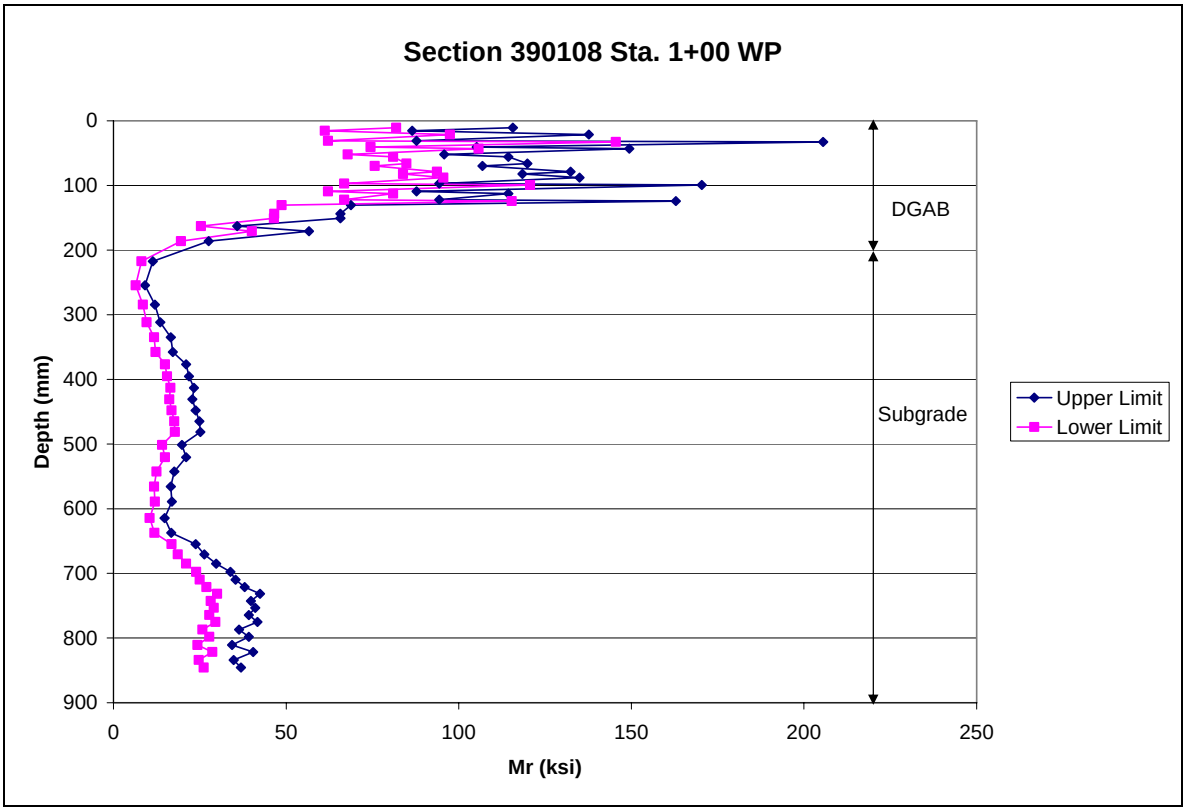
SECTION 390108



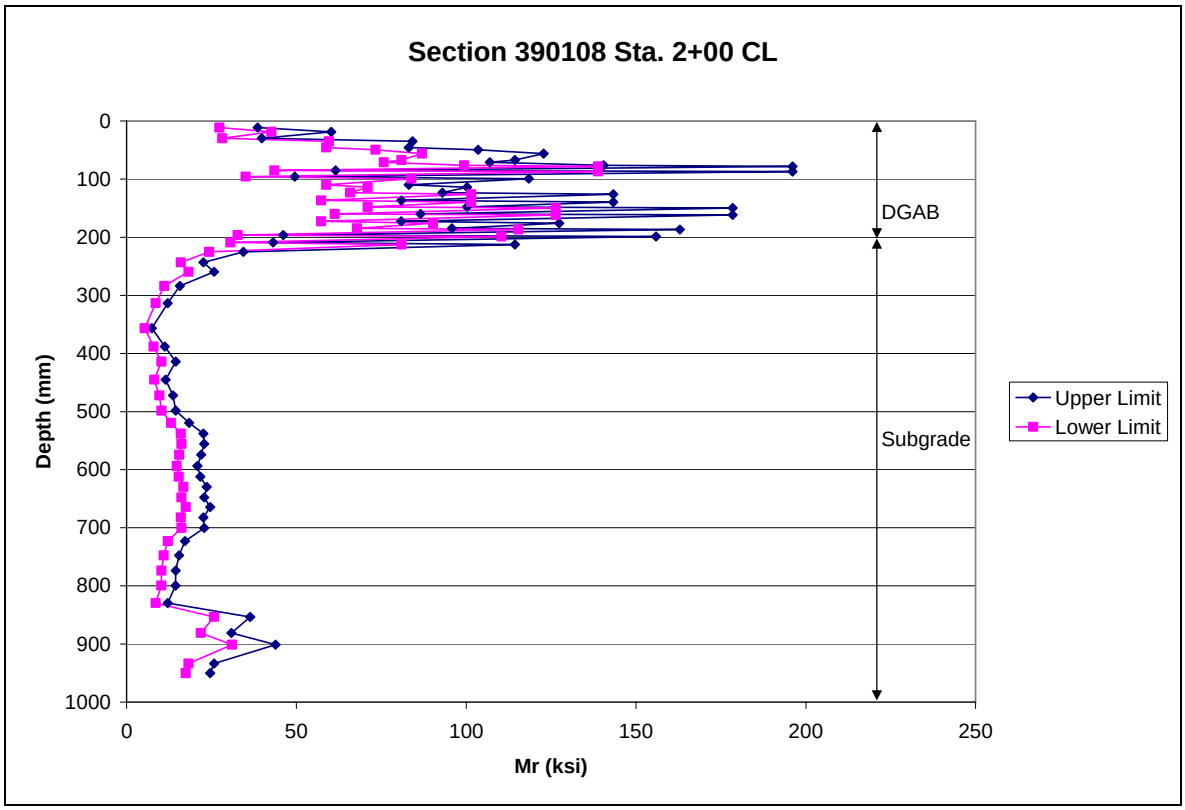


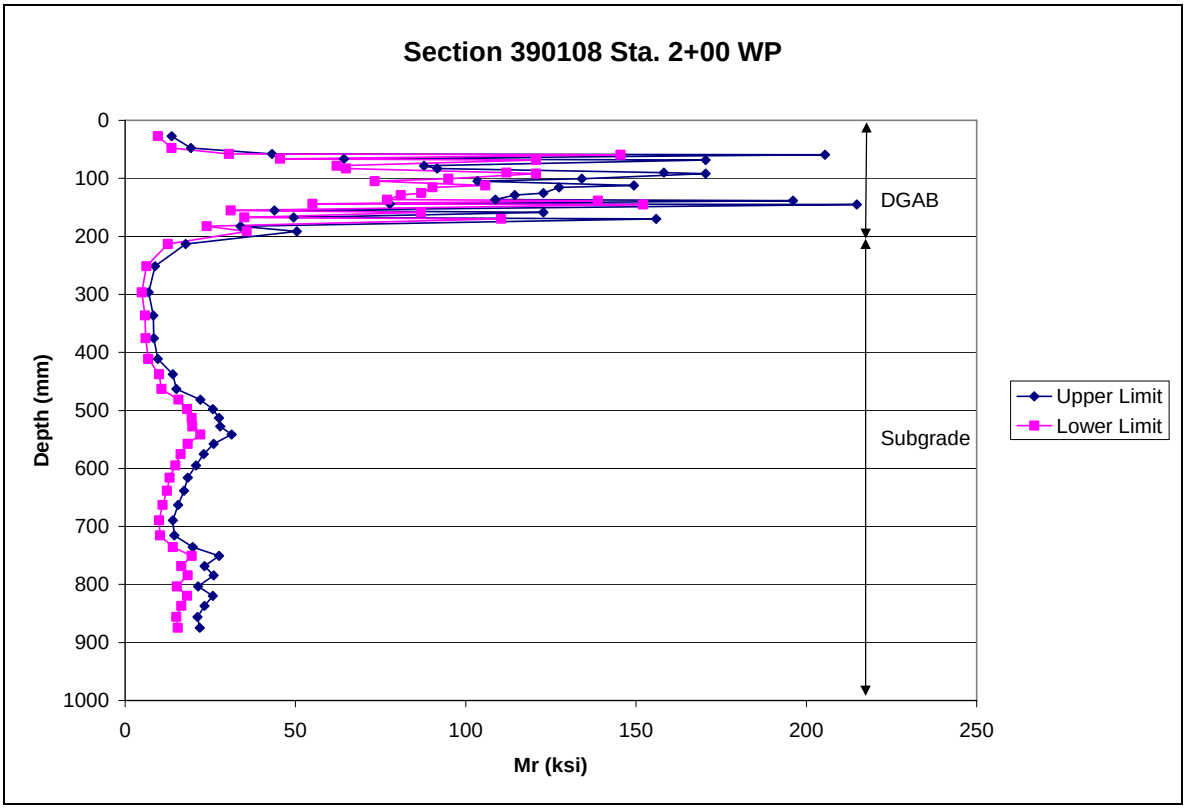
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



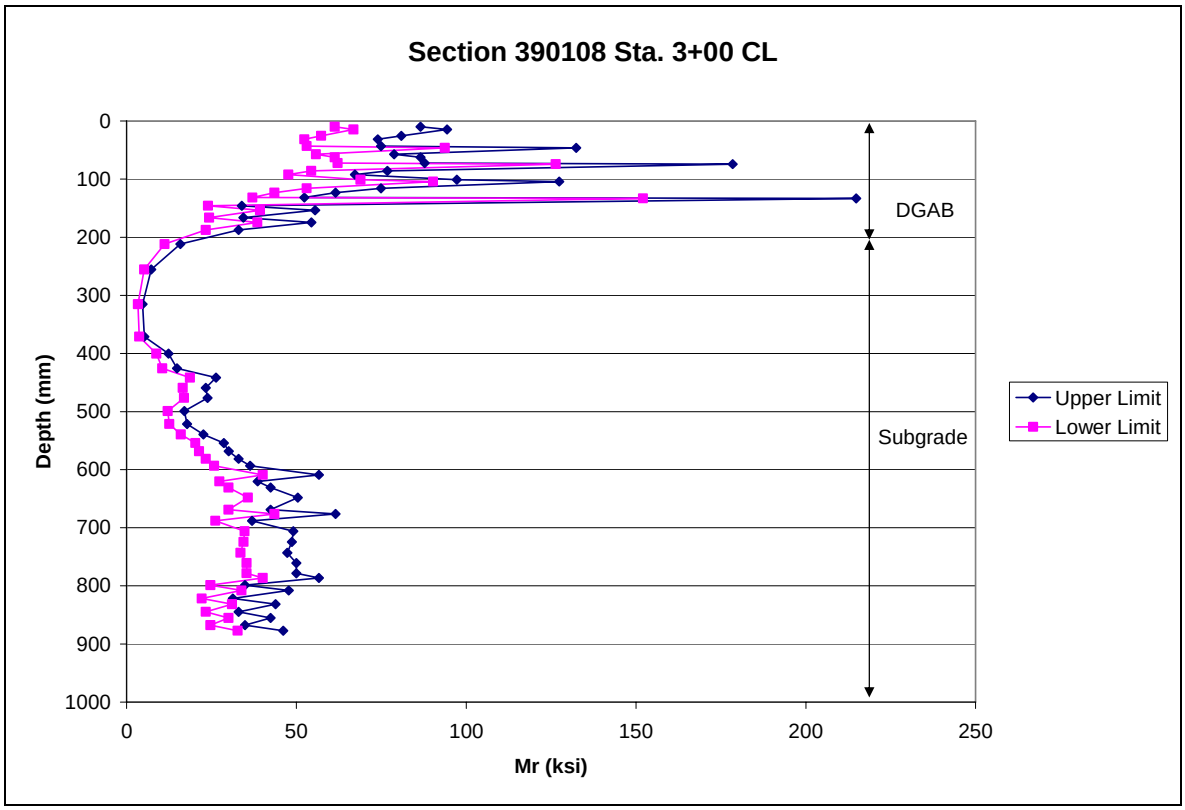


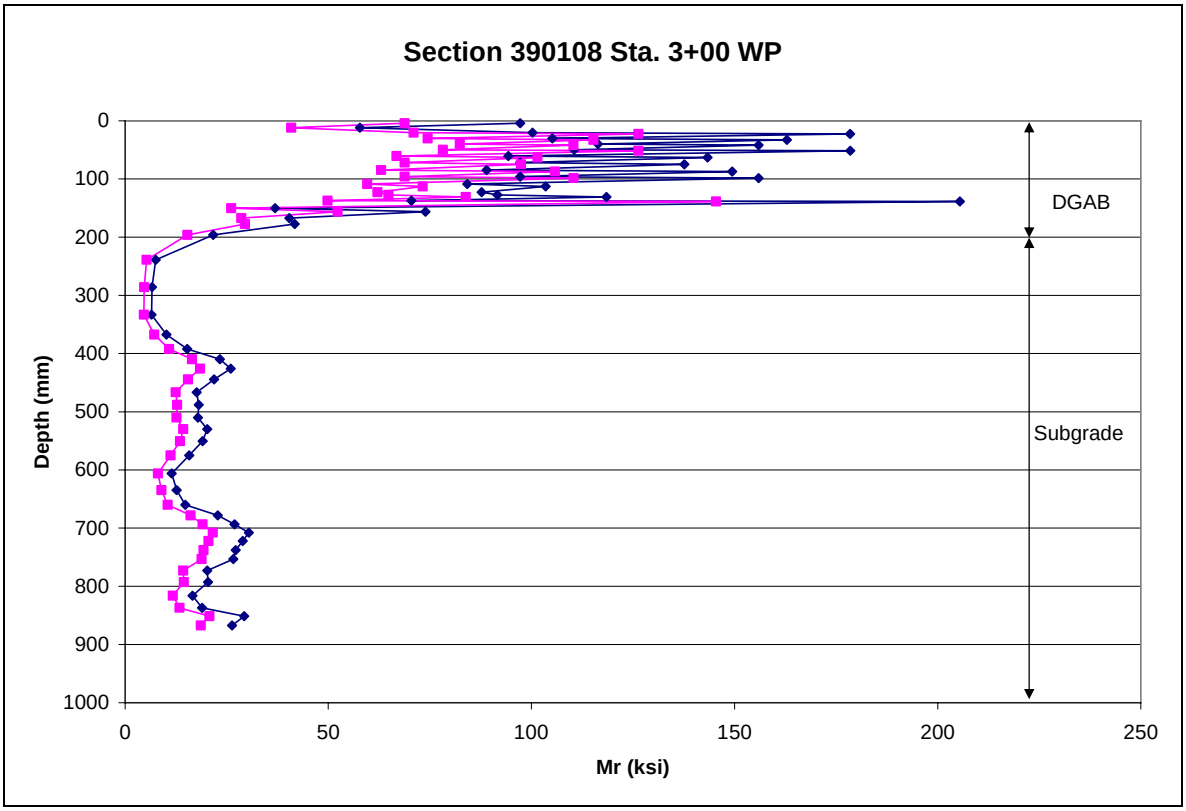
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



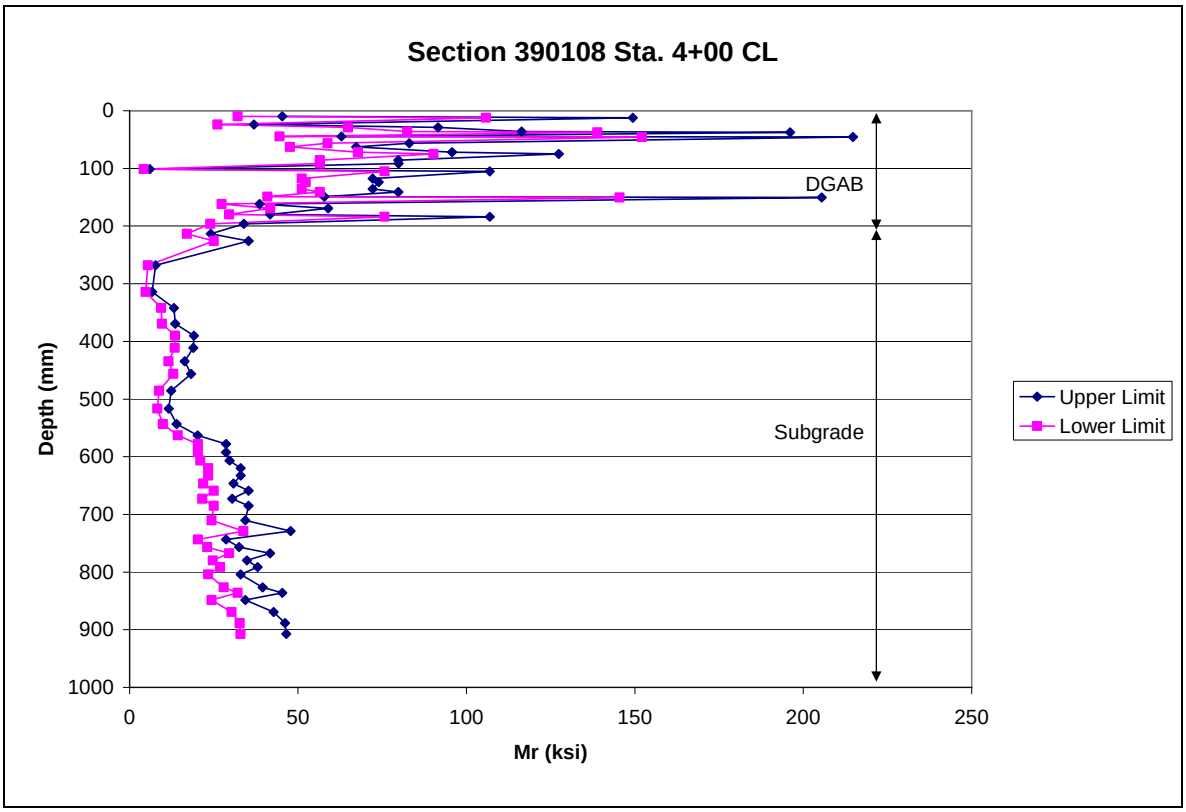


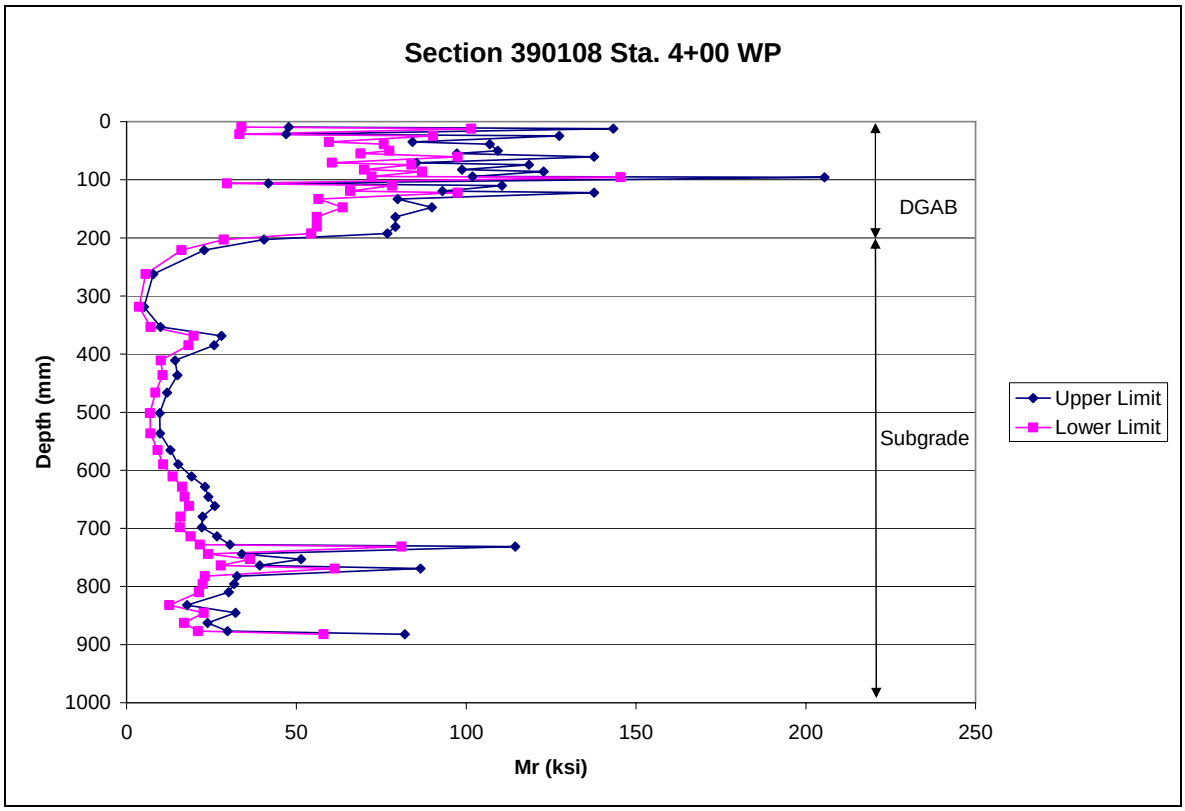
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



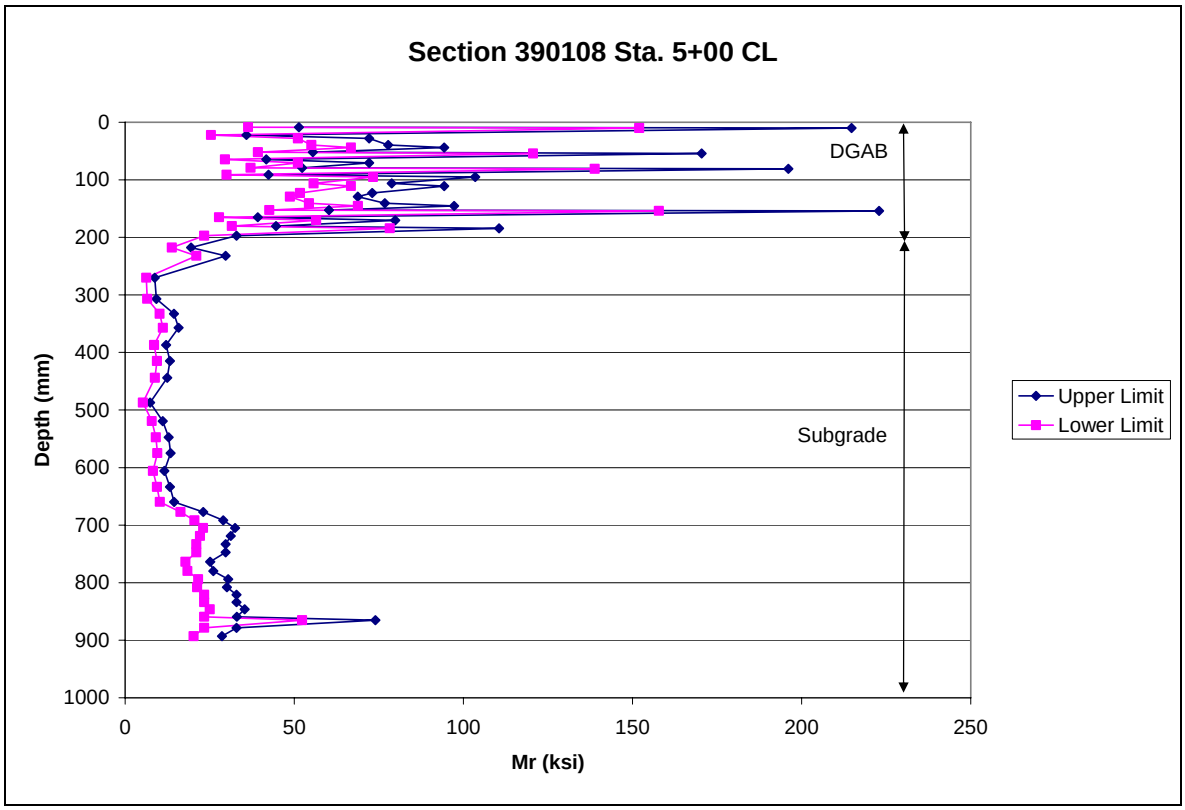


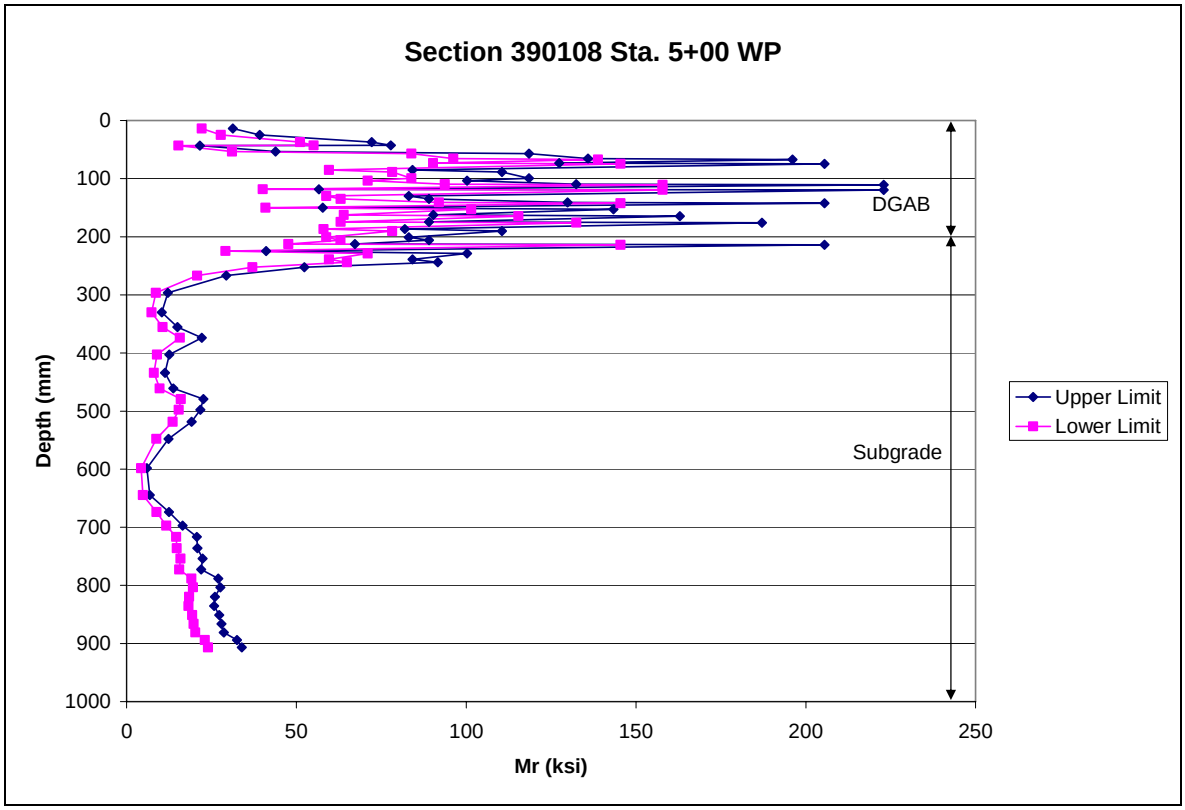
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



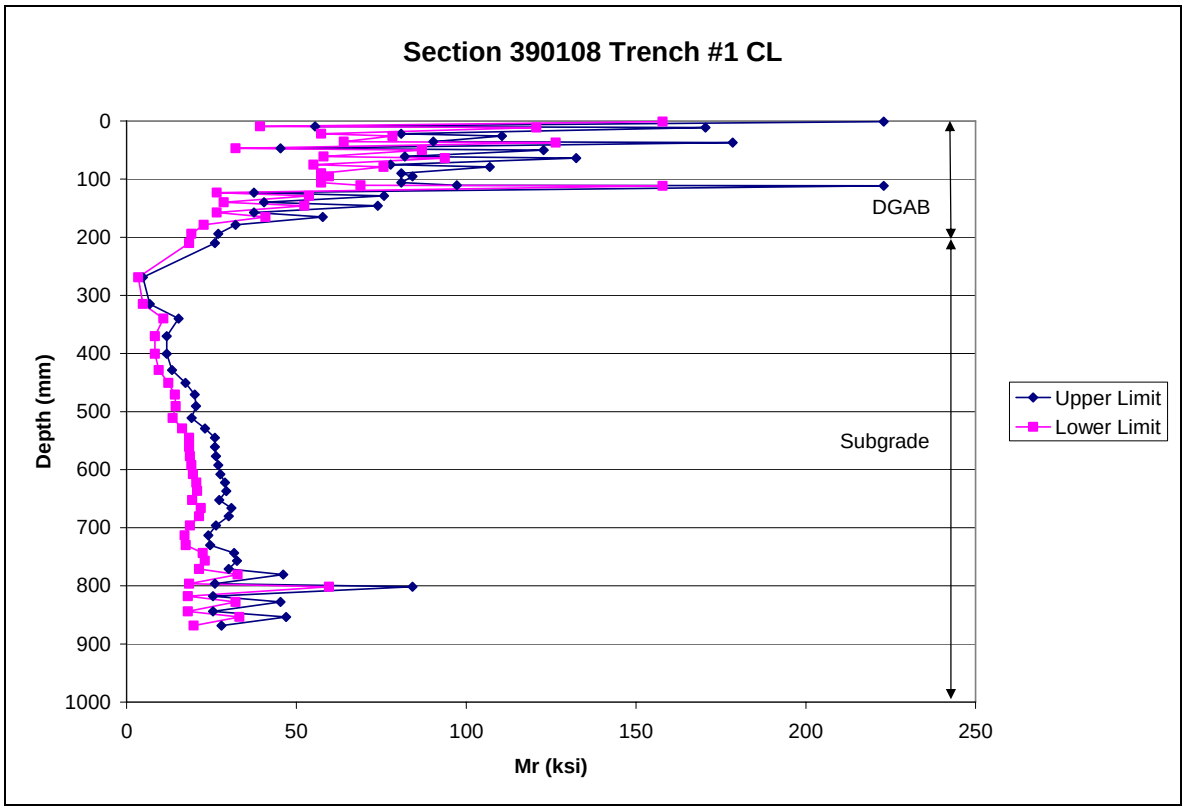


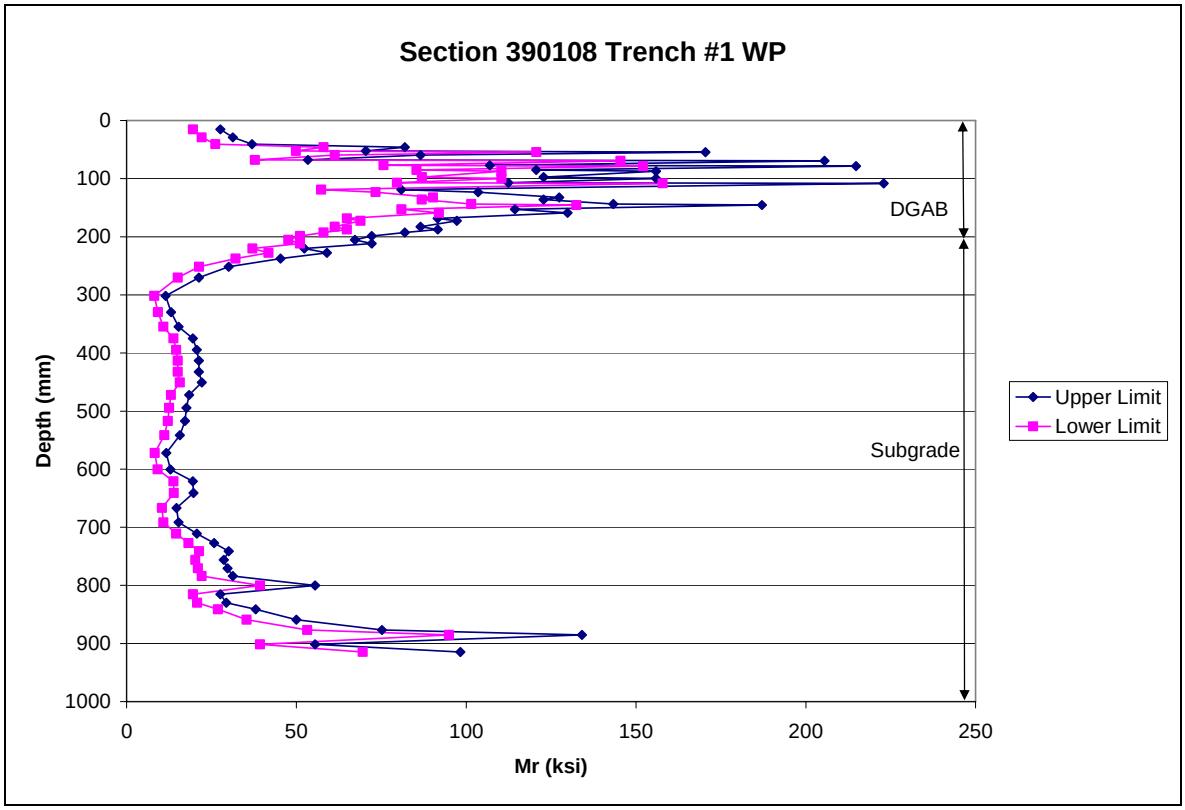
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)





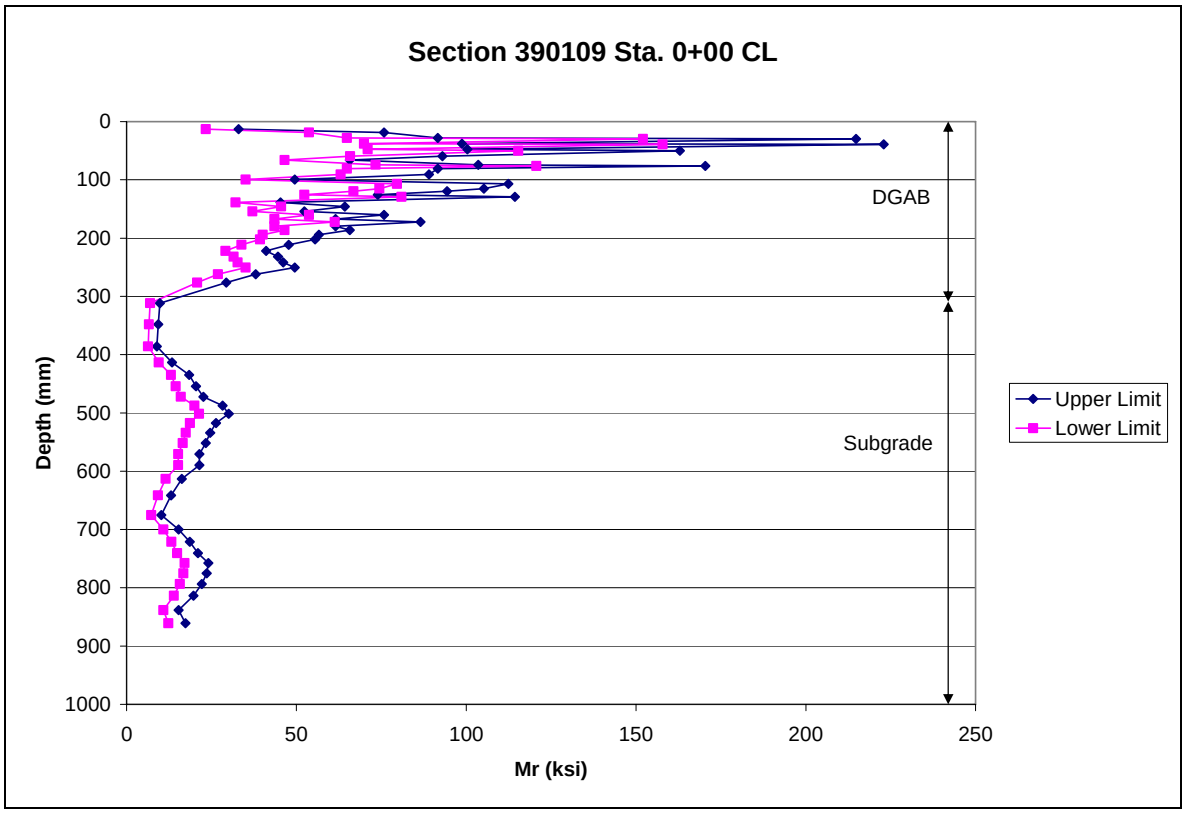
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

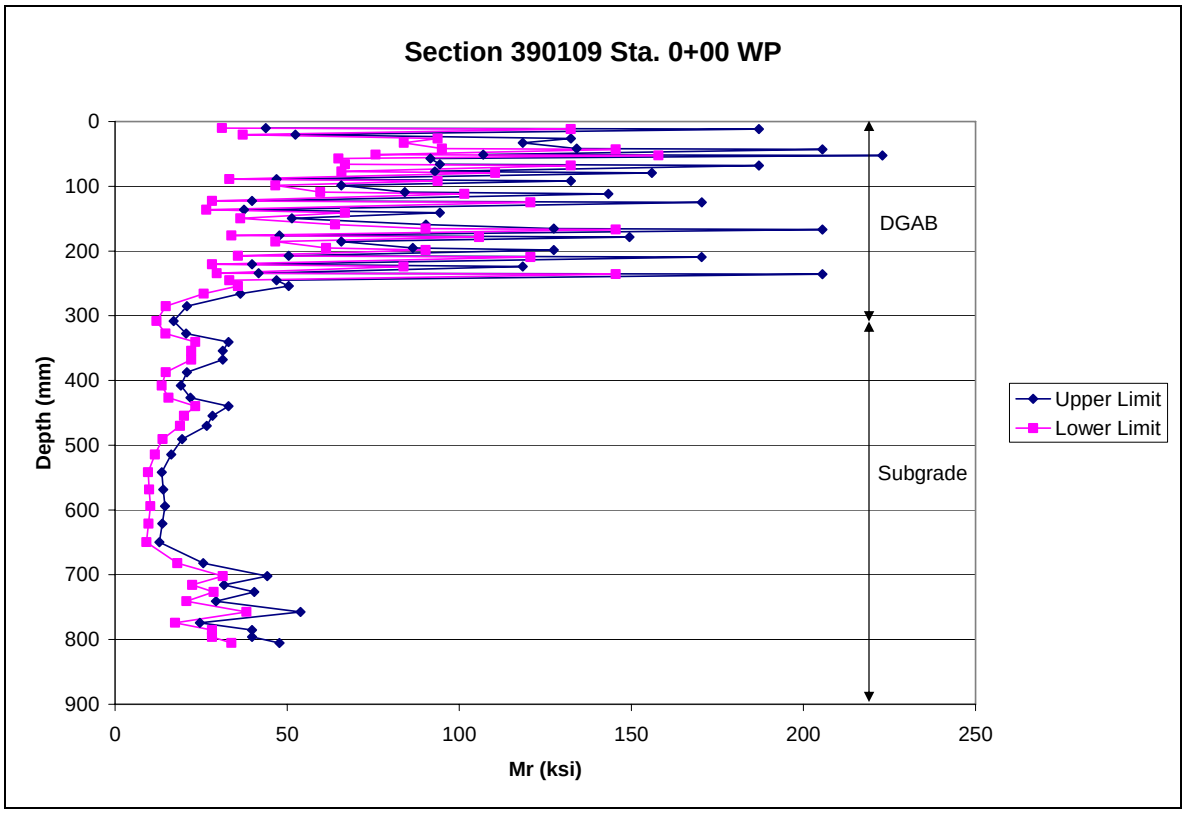




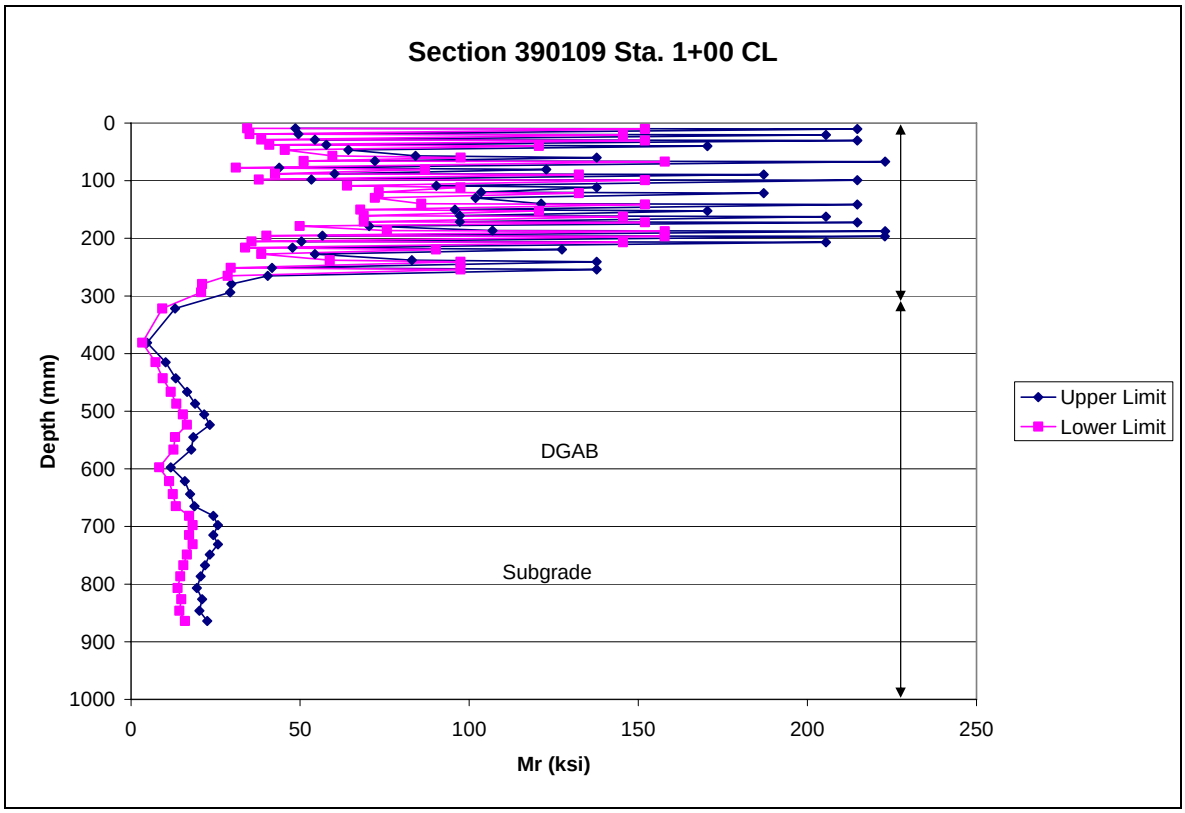
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

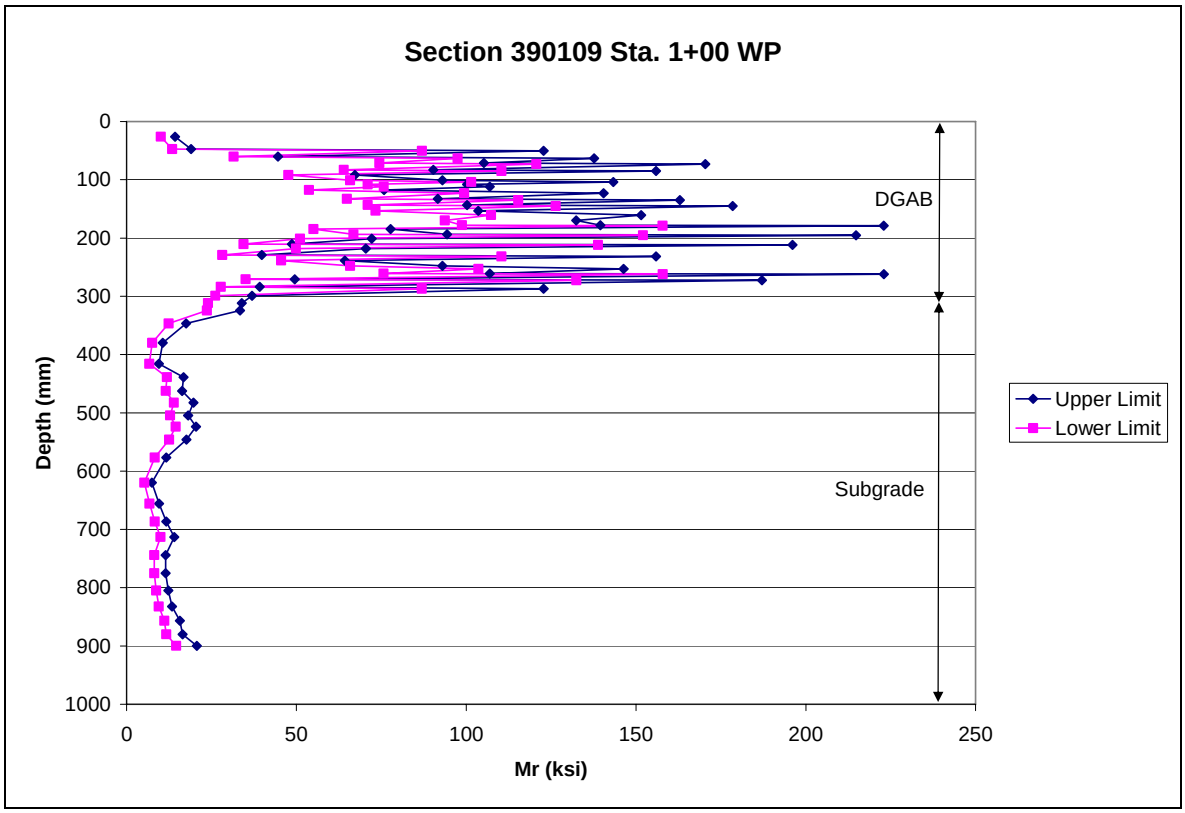
SECTION 390109



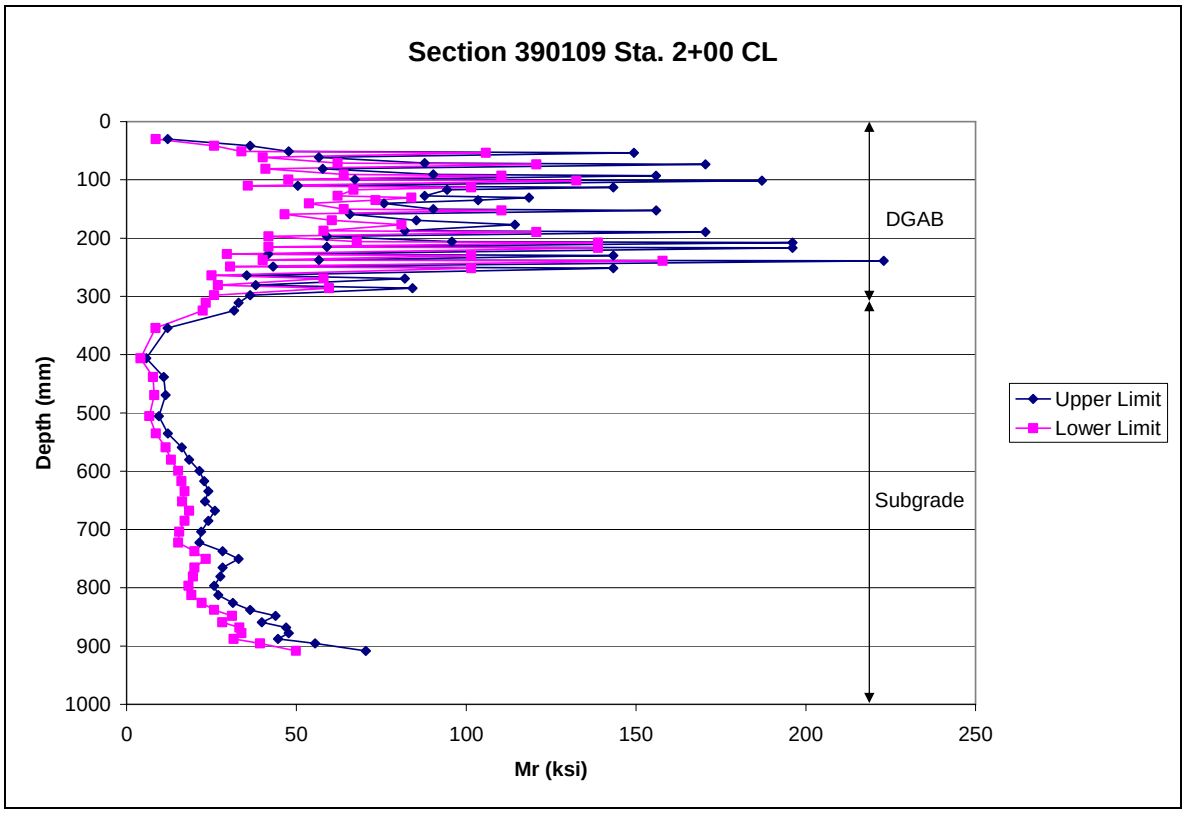


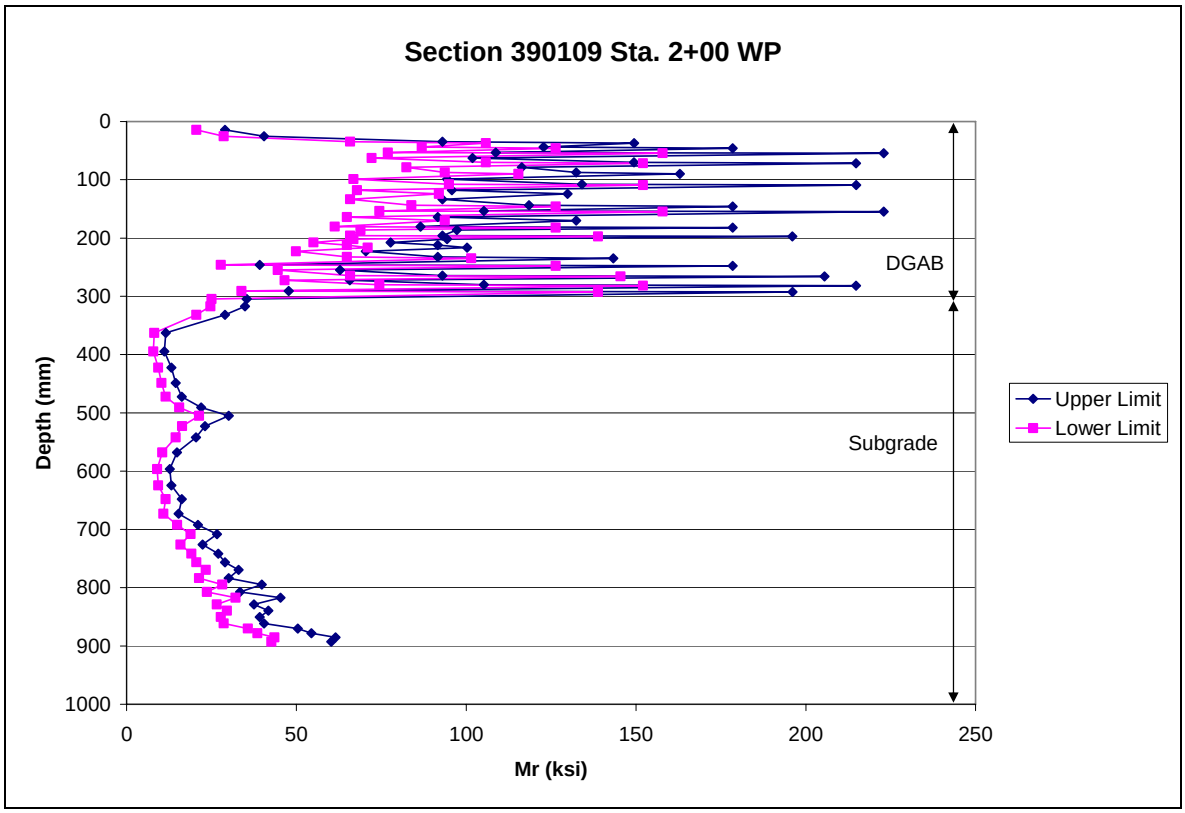
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



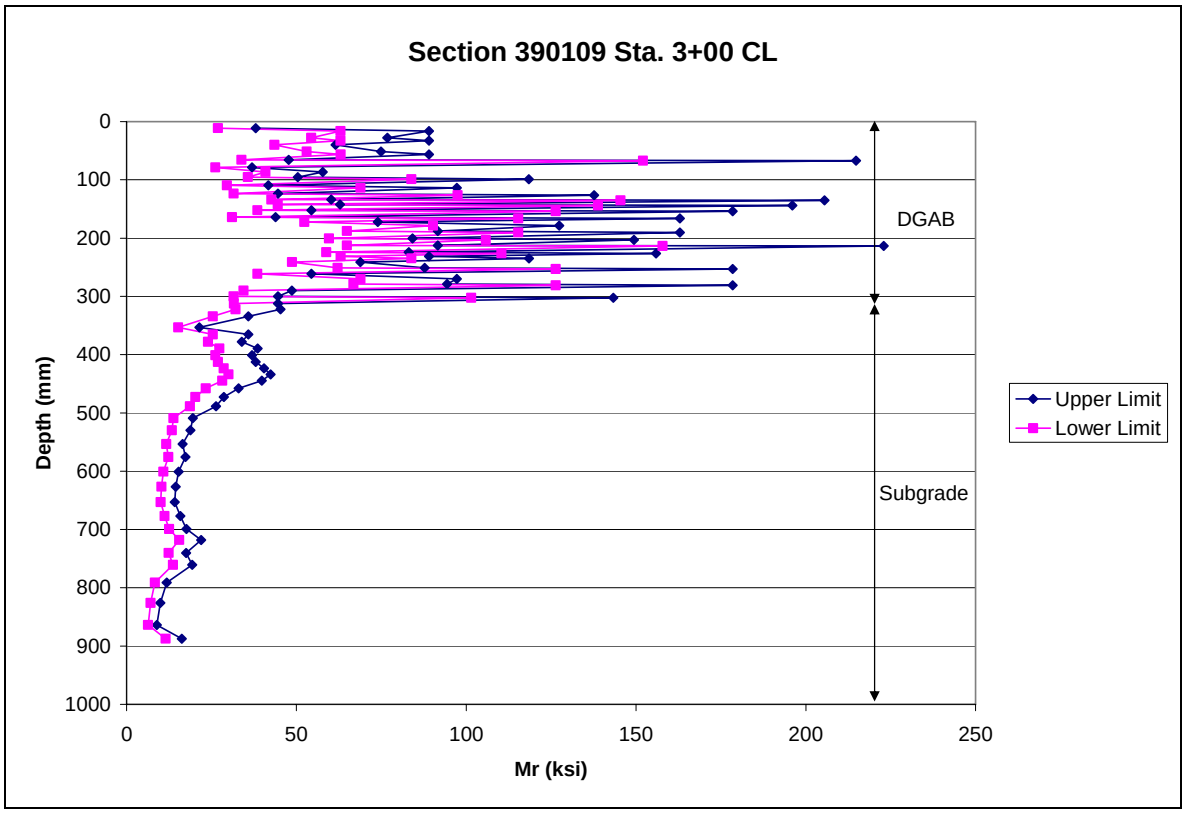


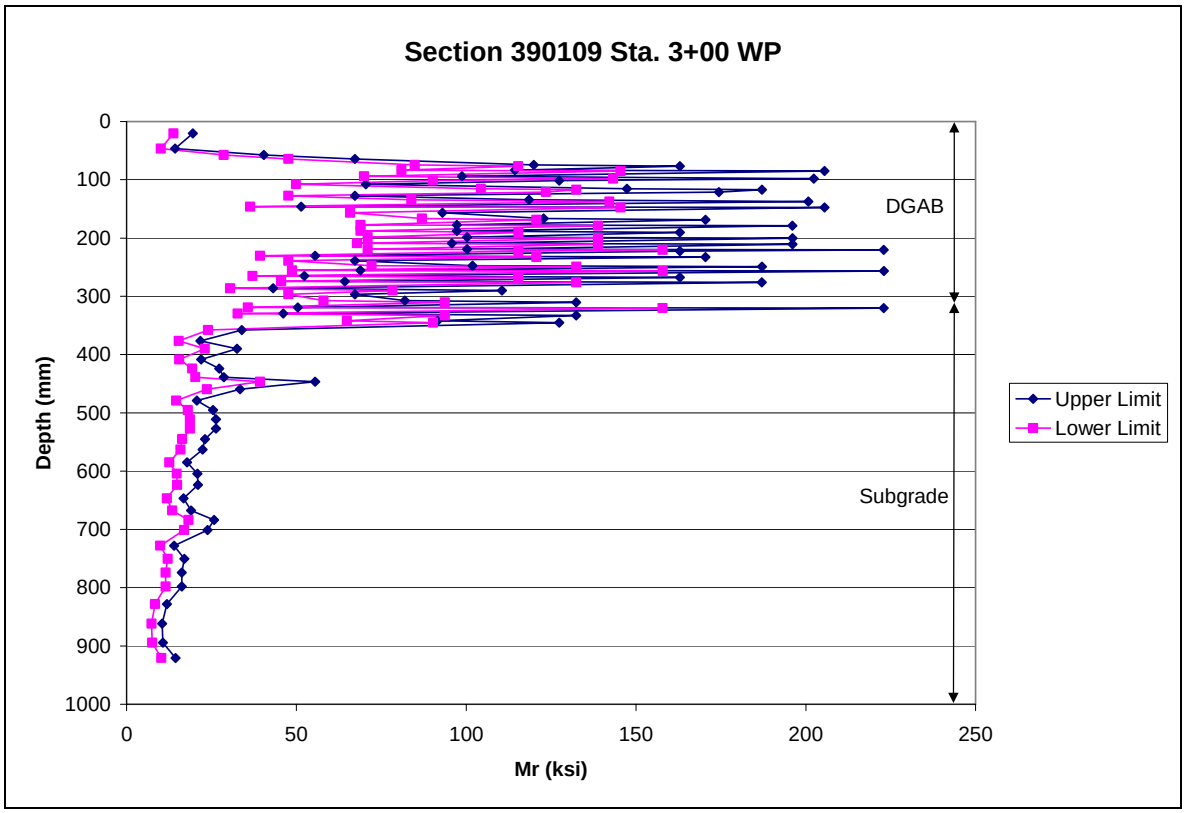
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



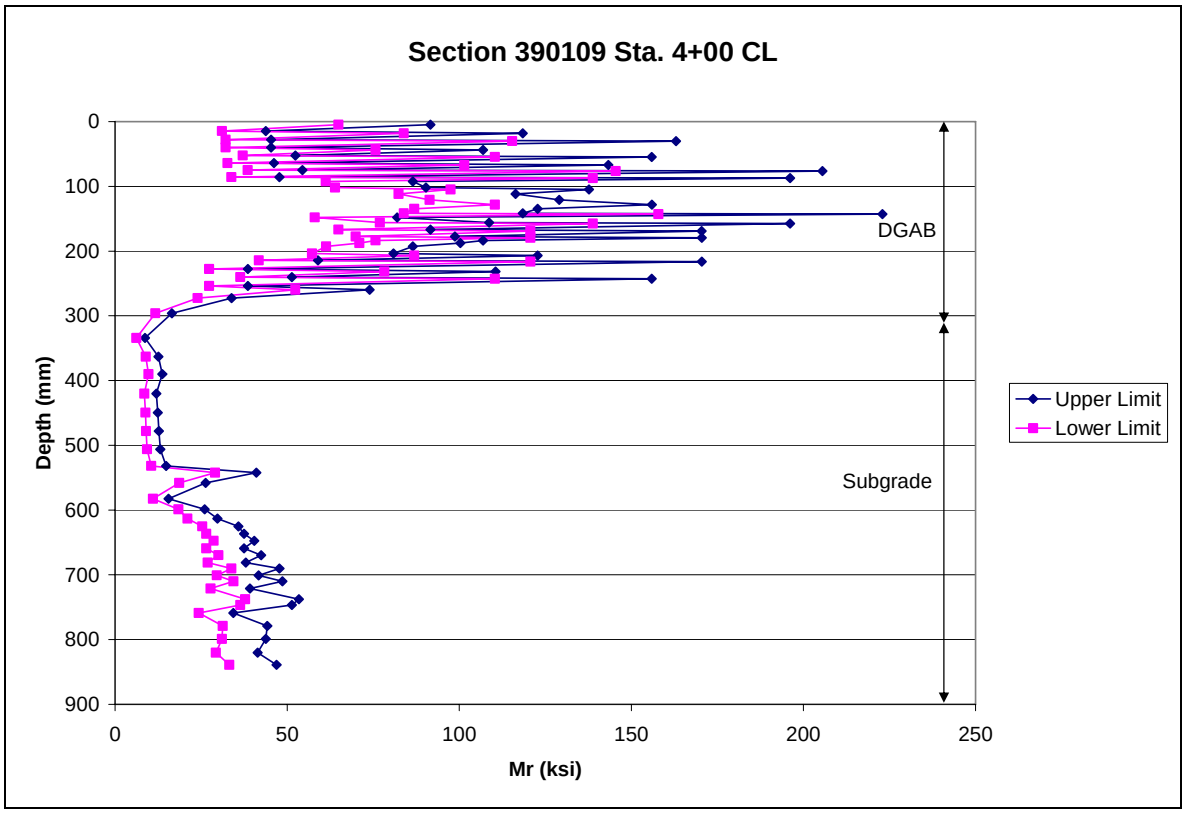


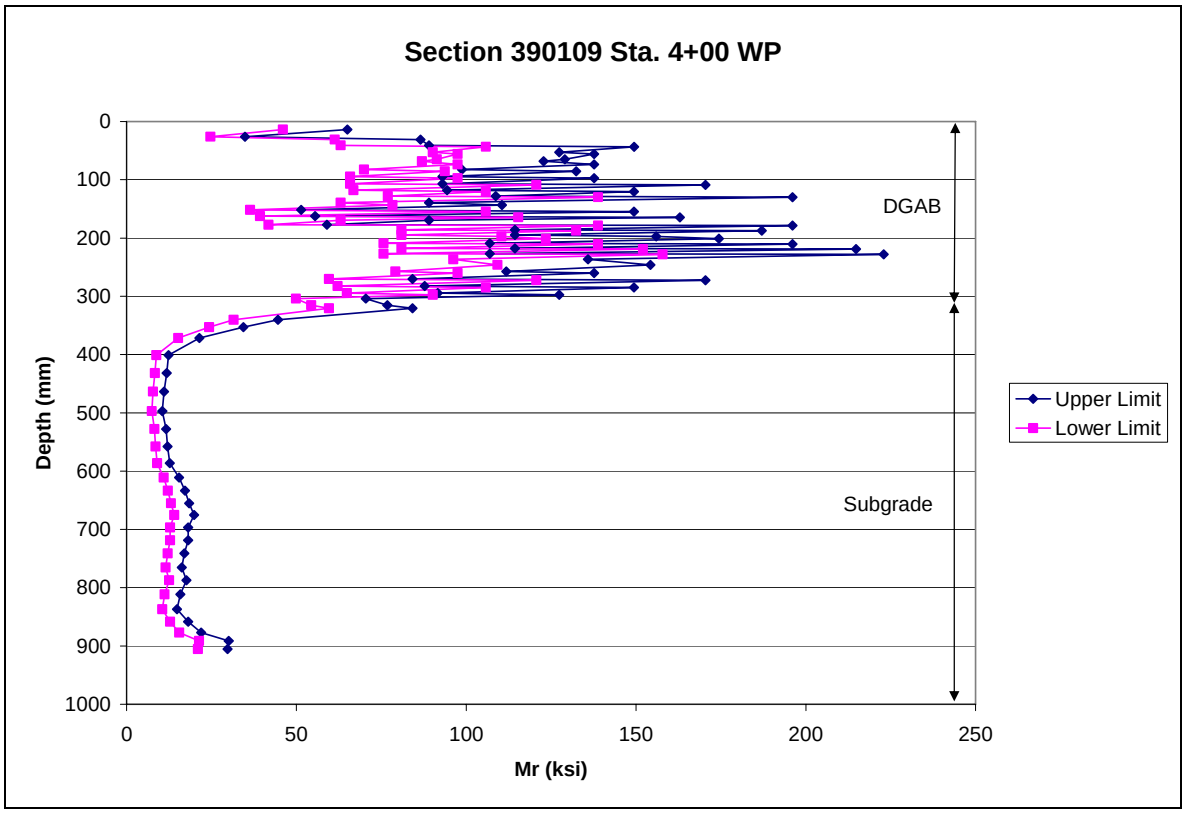
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



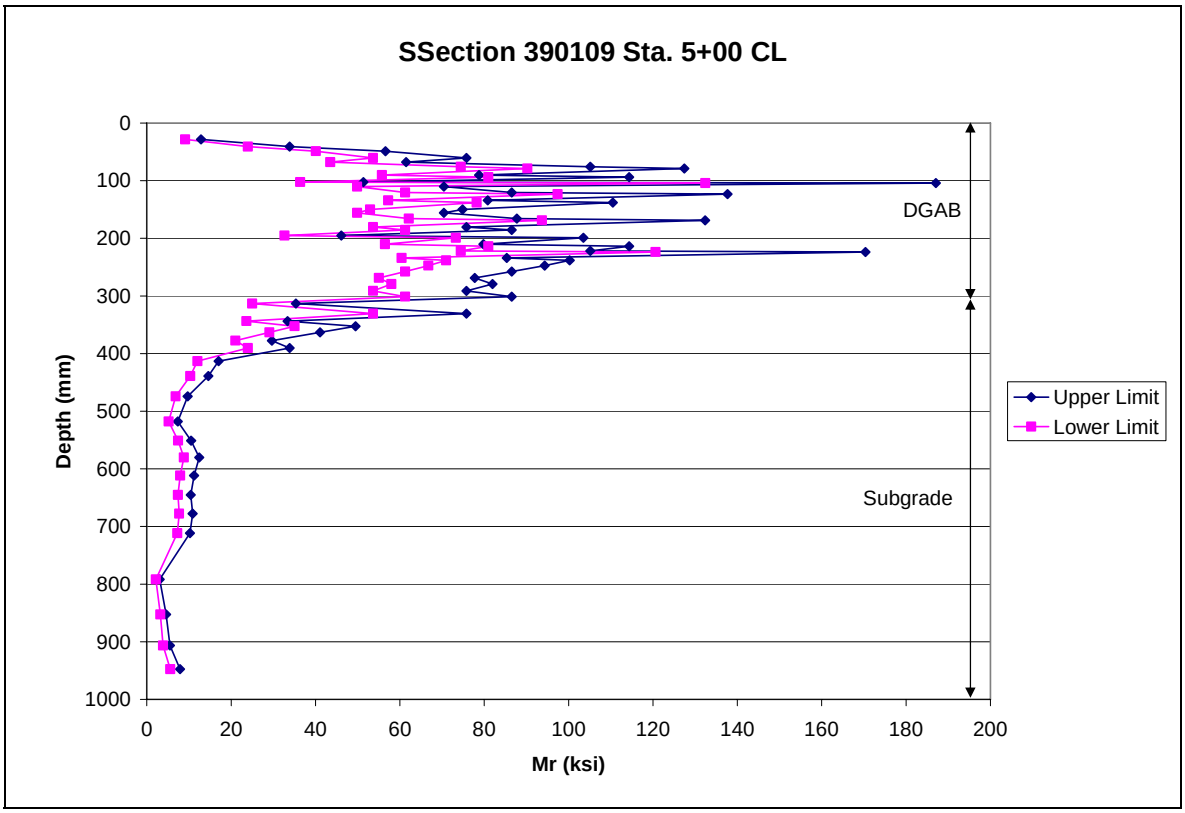


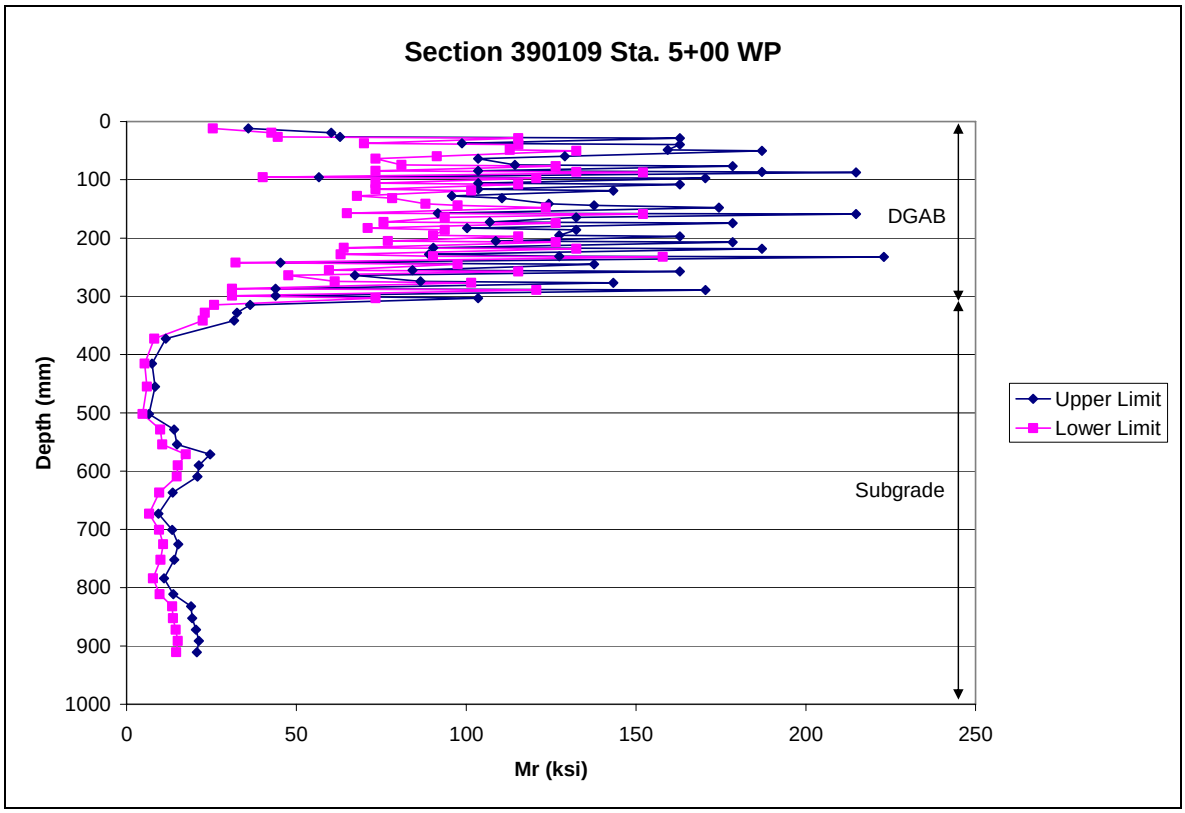
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



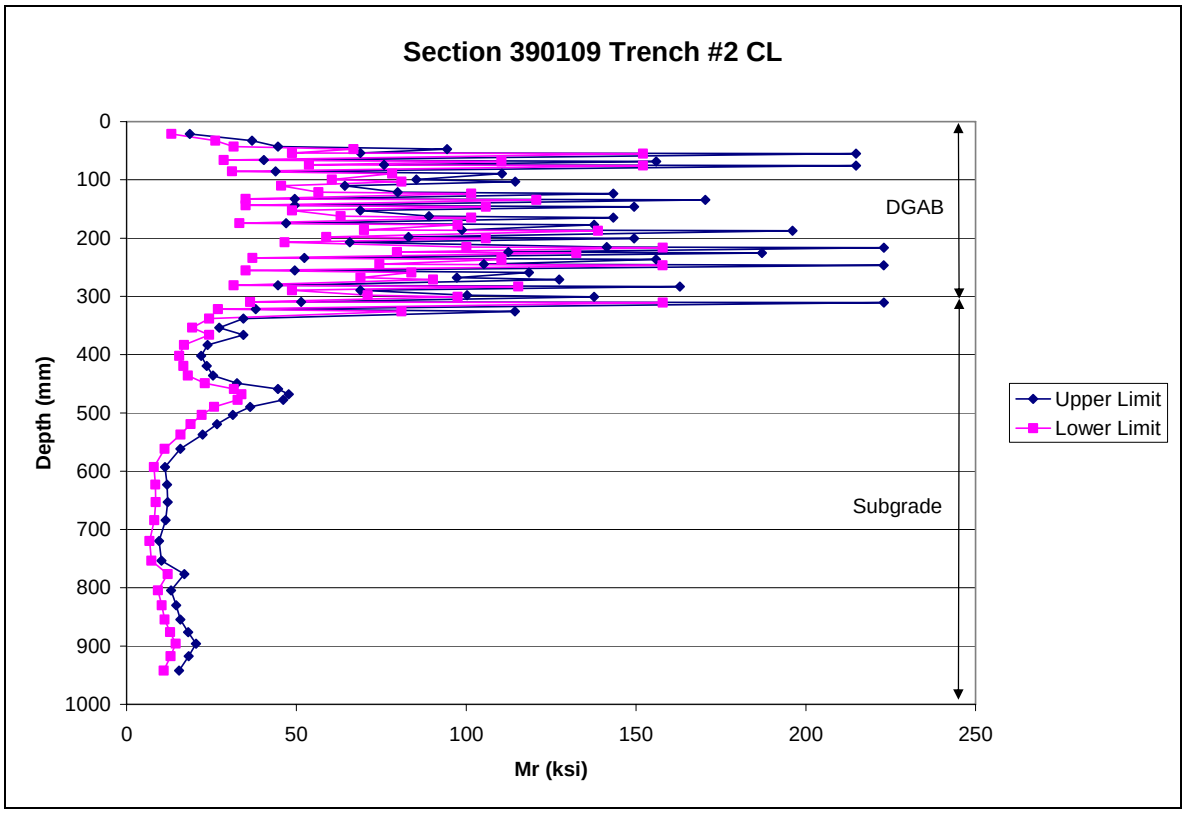


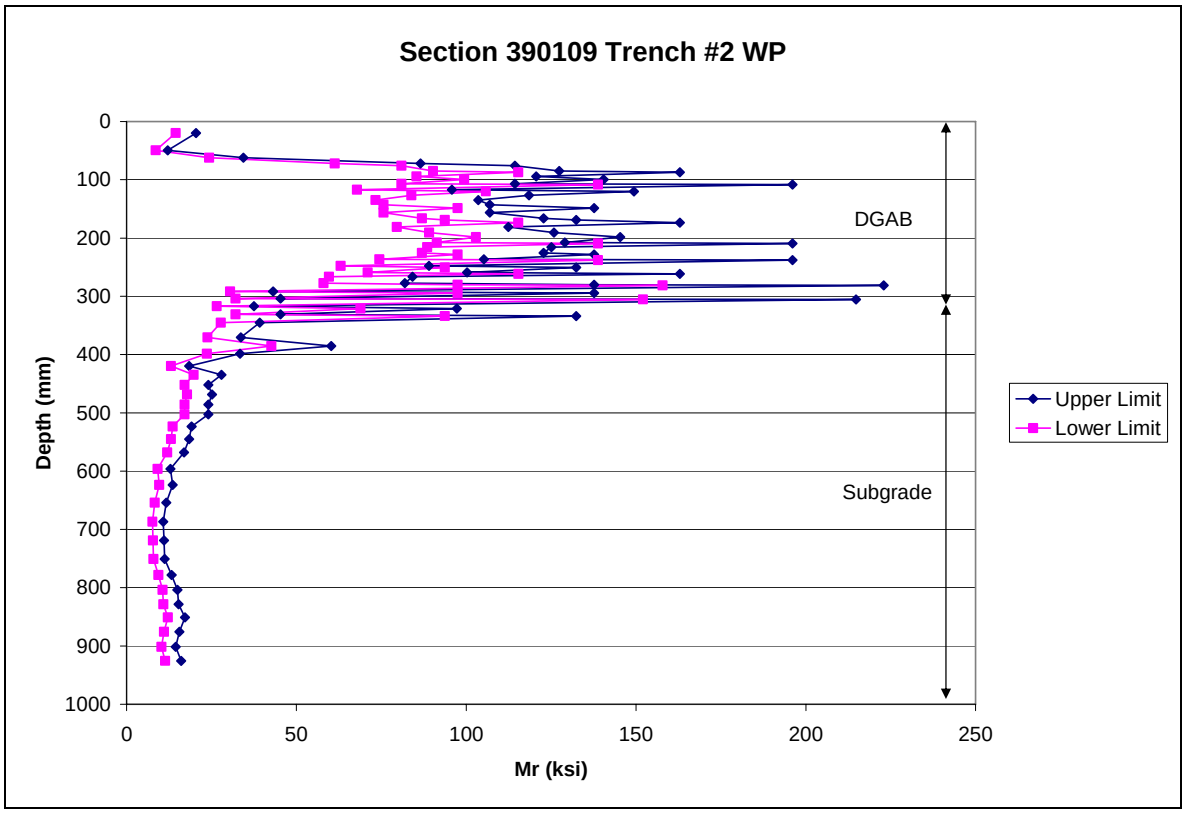
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)





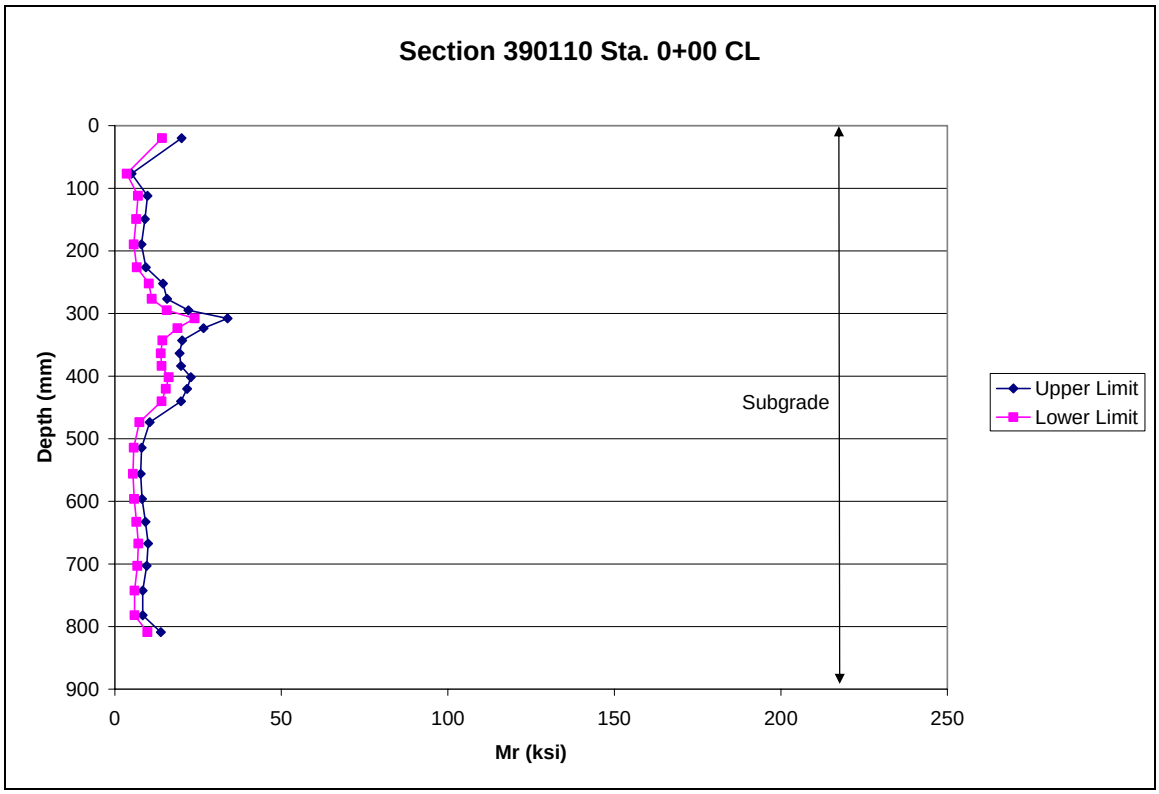
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

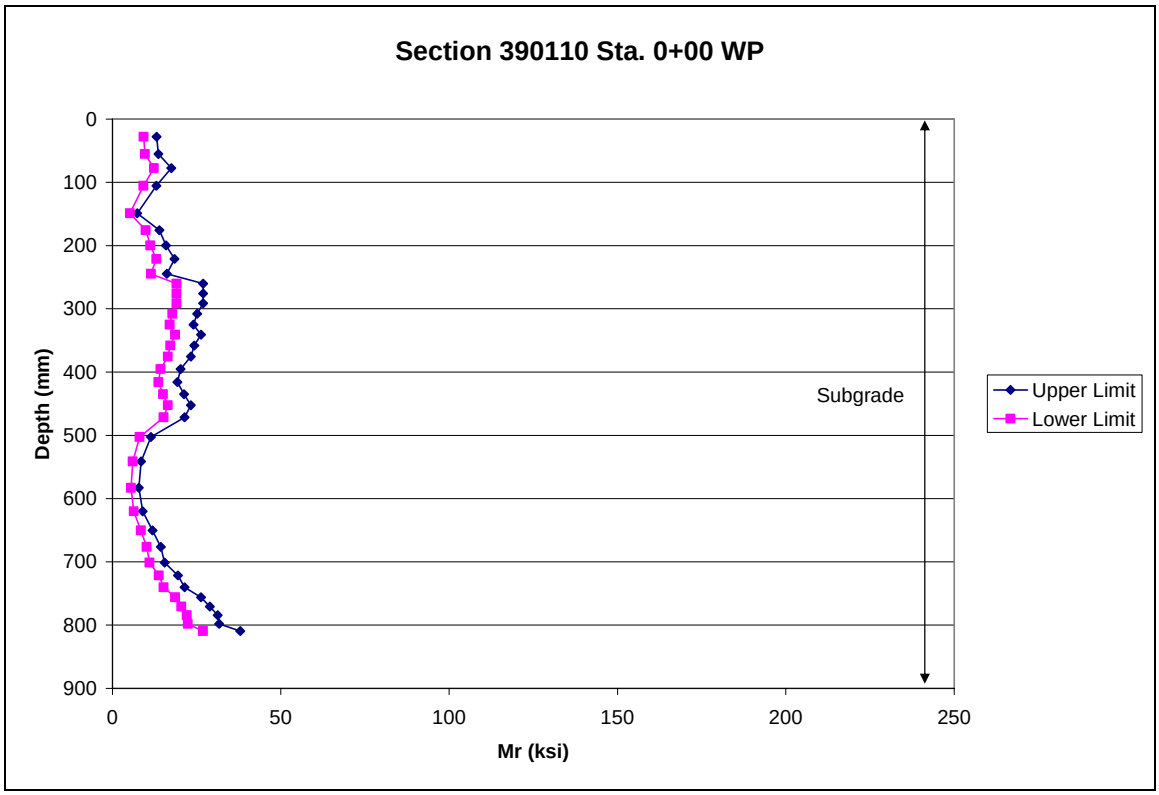




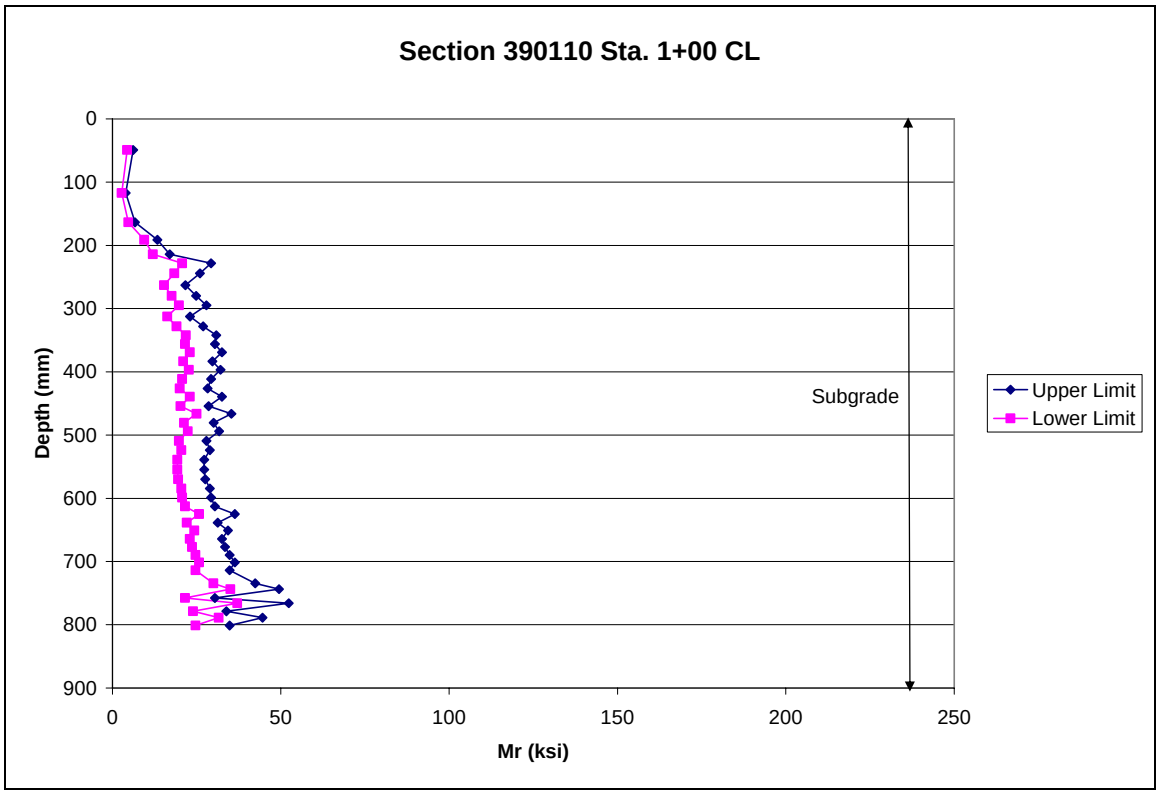
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

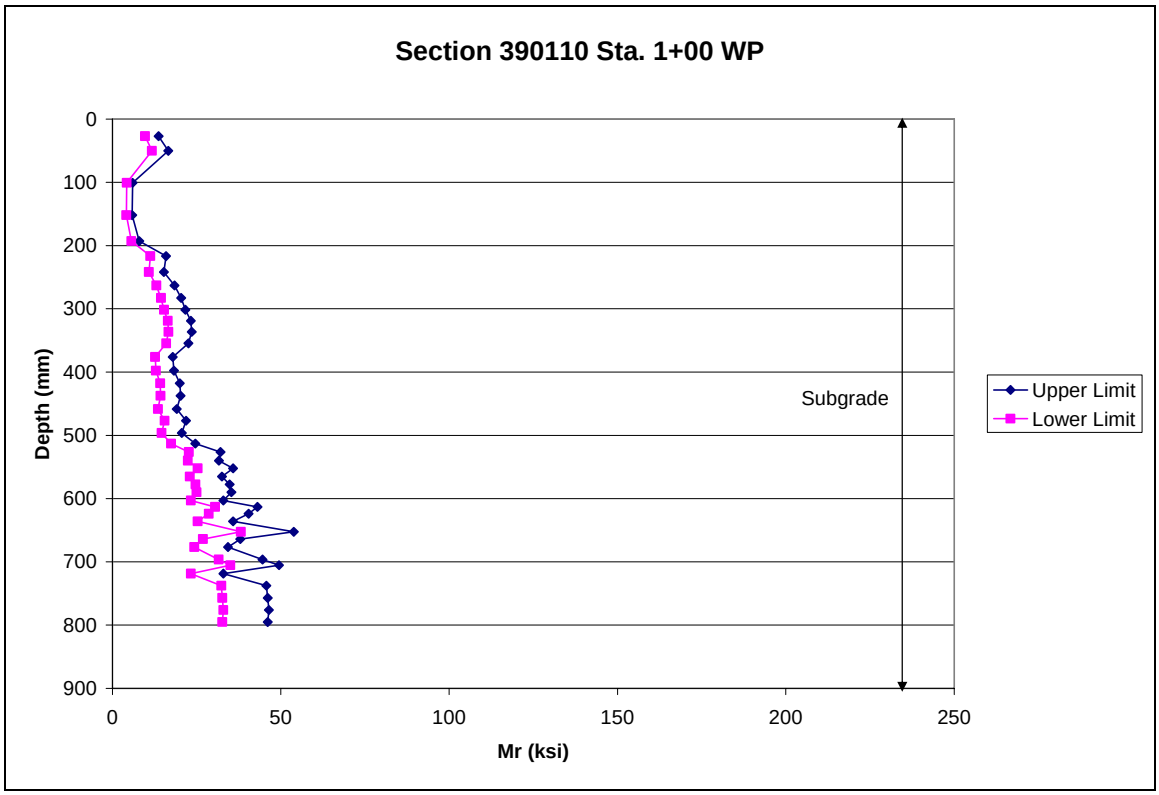
SECTION 390110



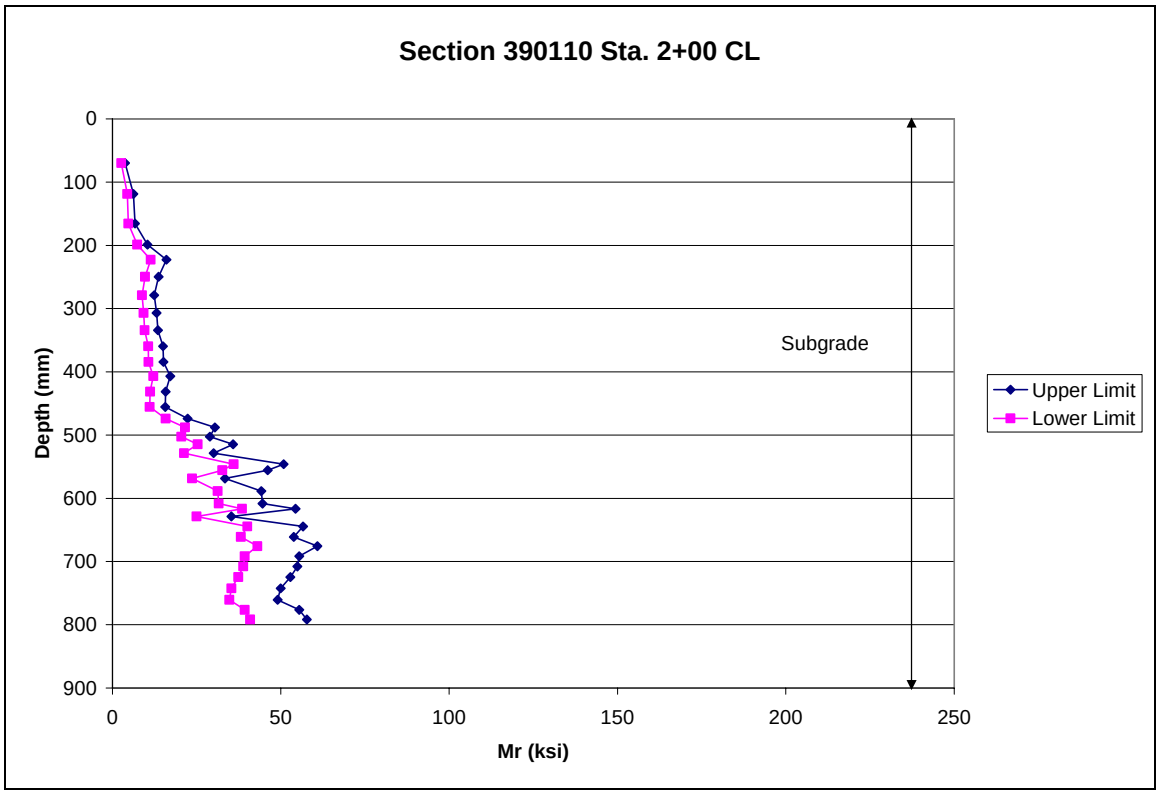


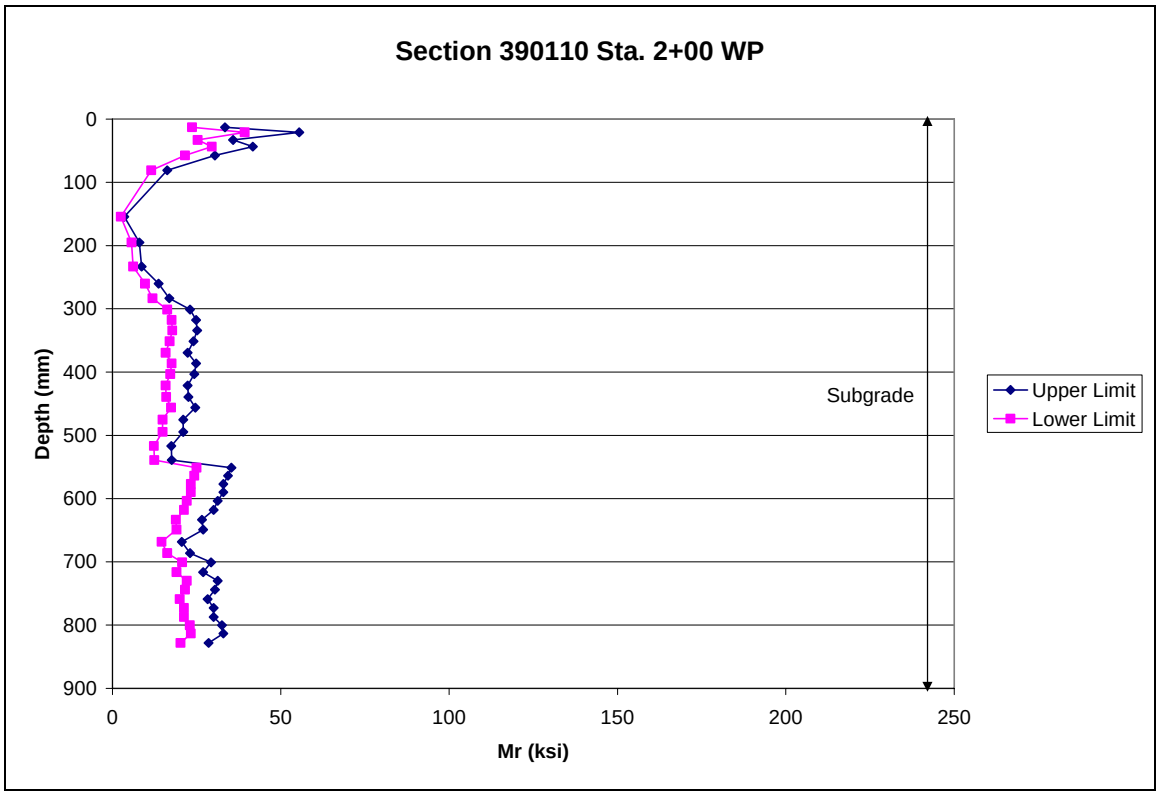
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



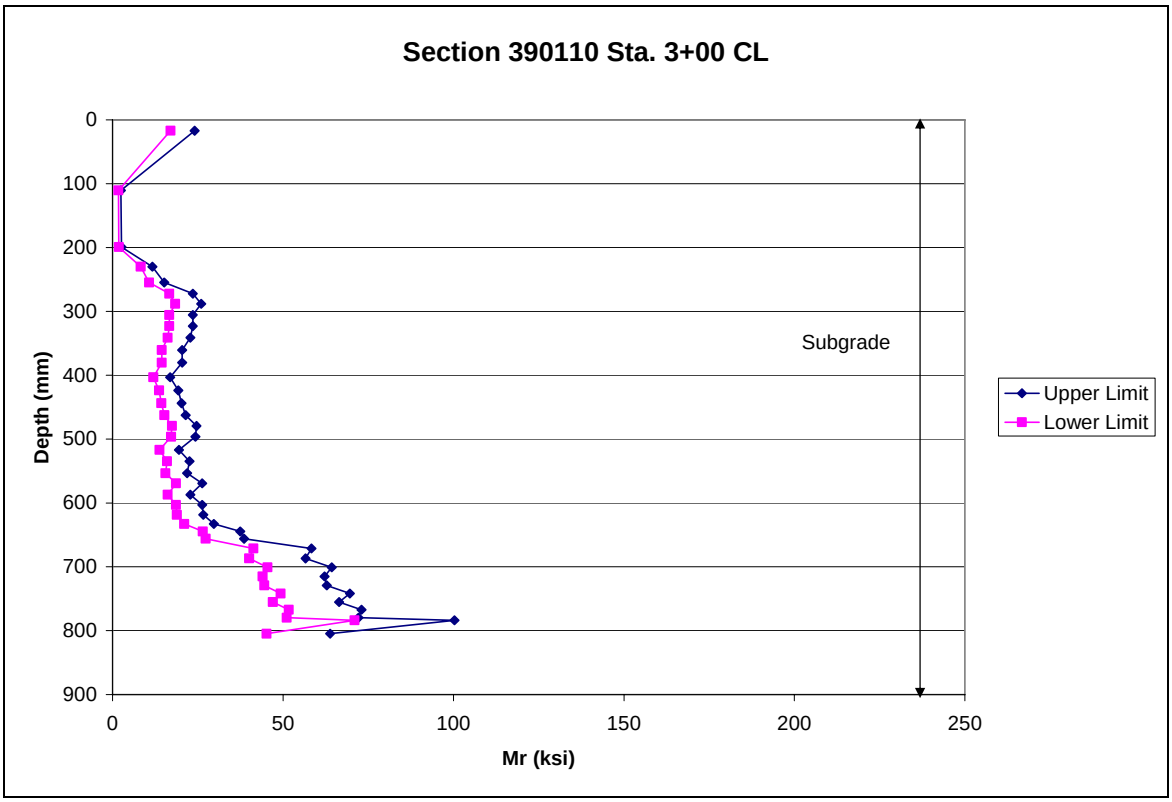


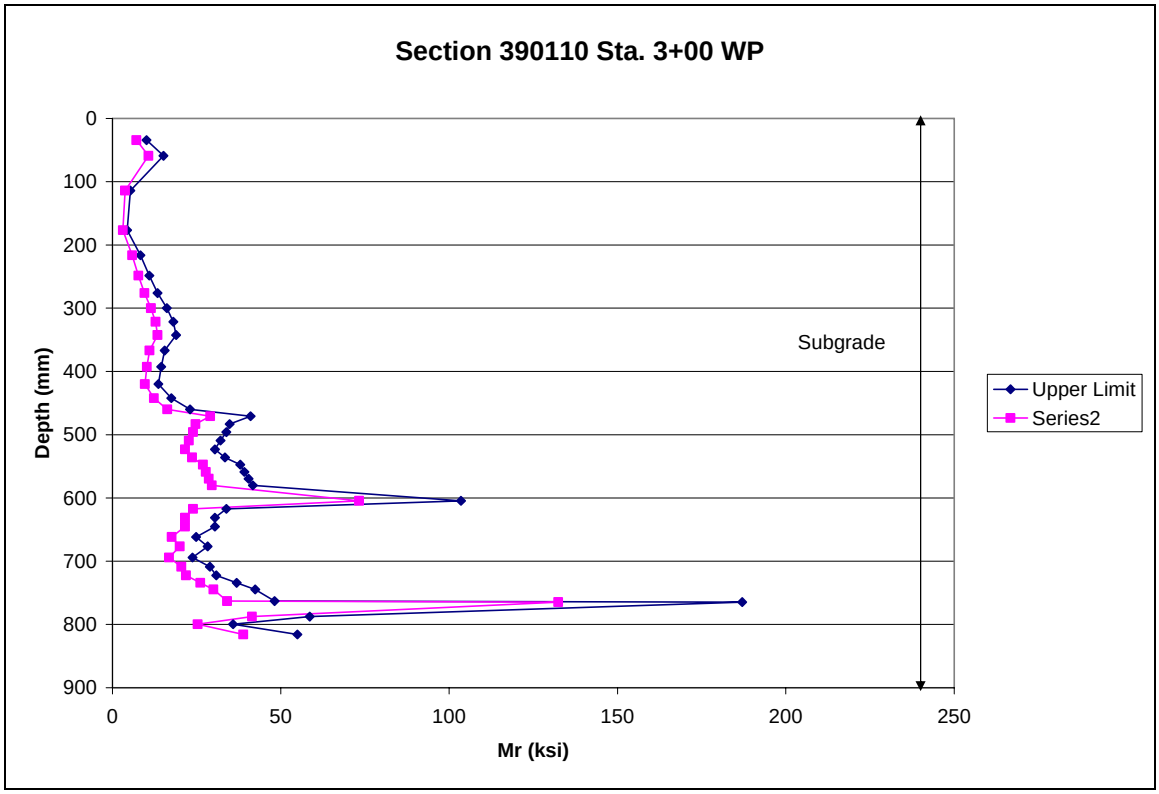
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



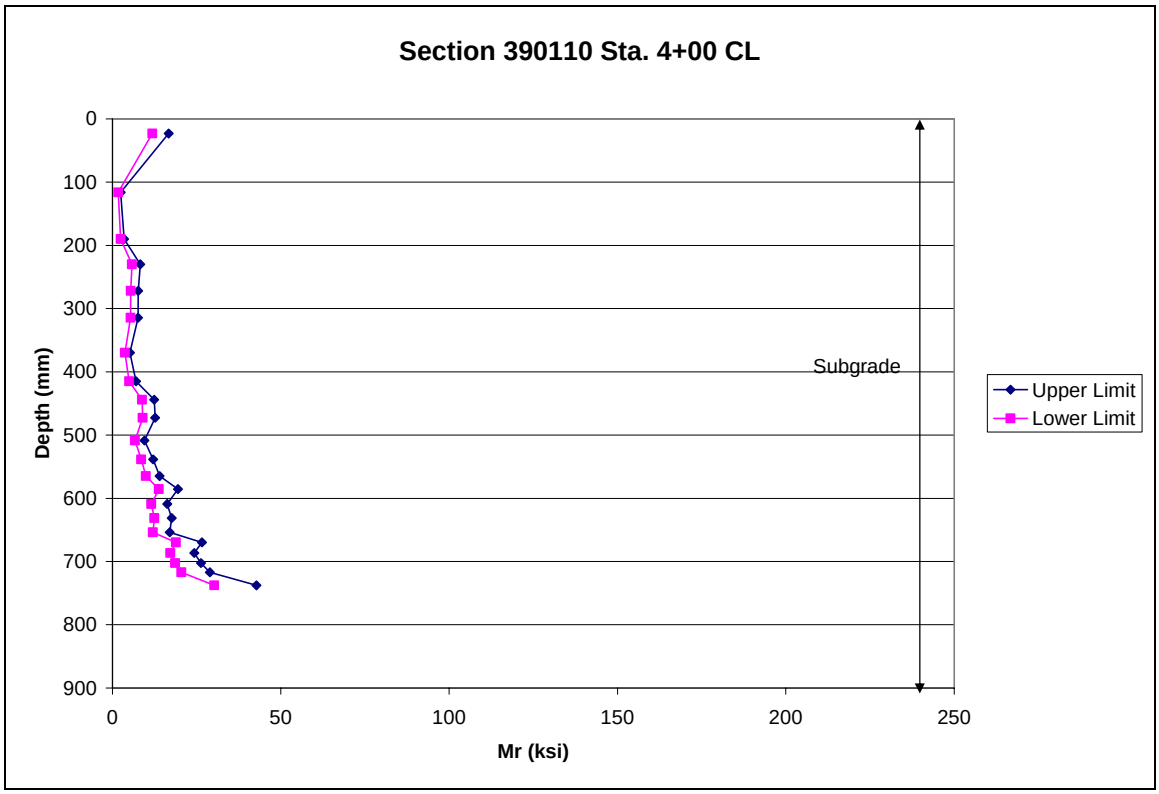


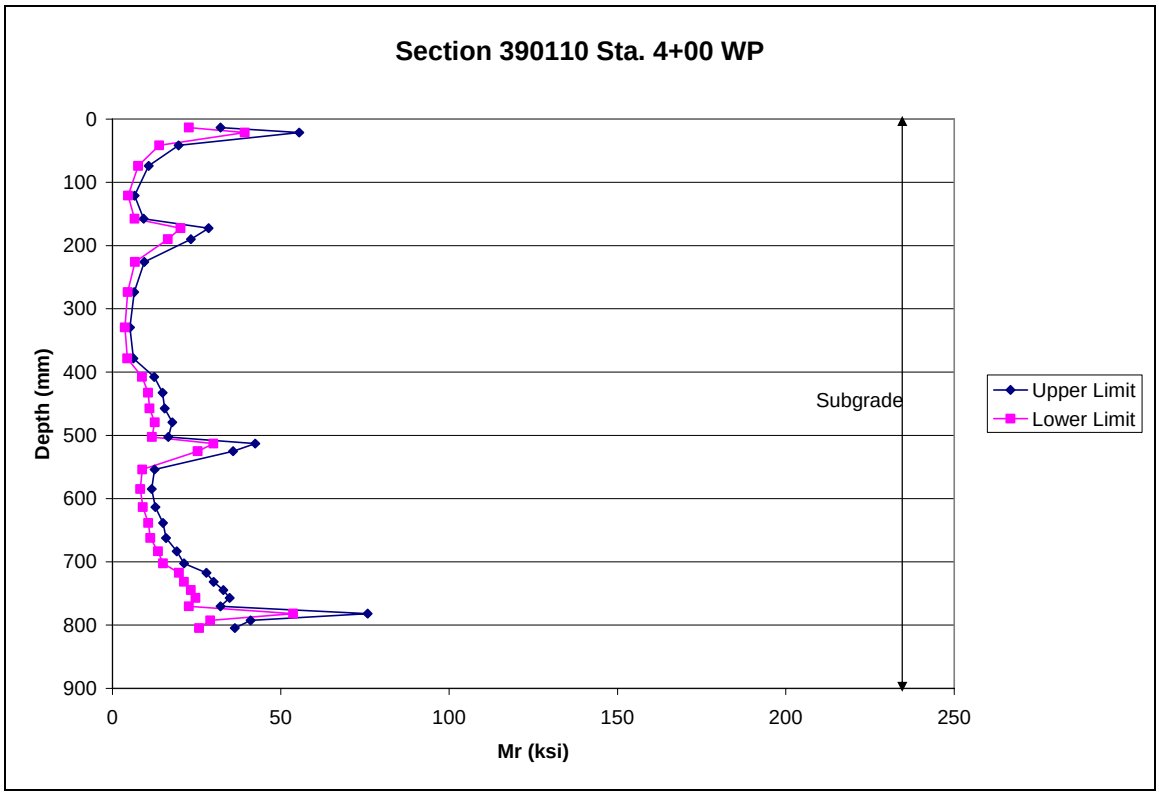
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



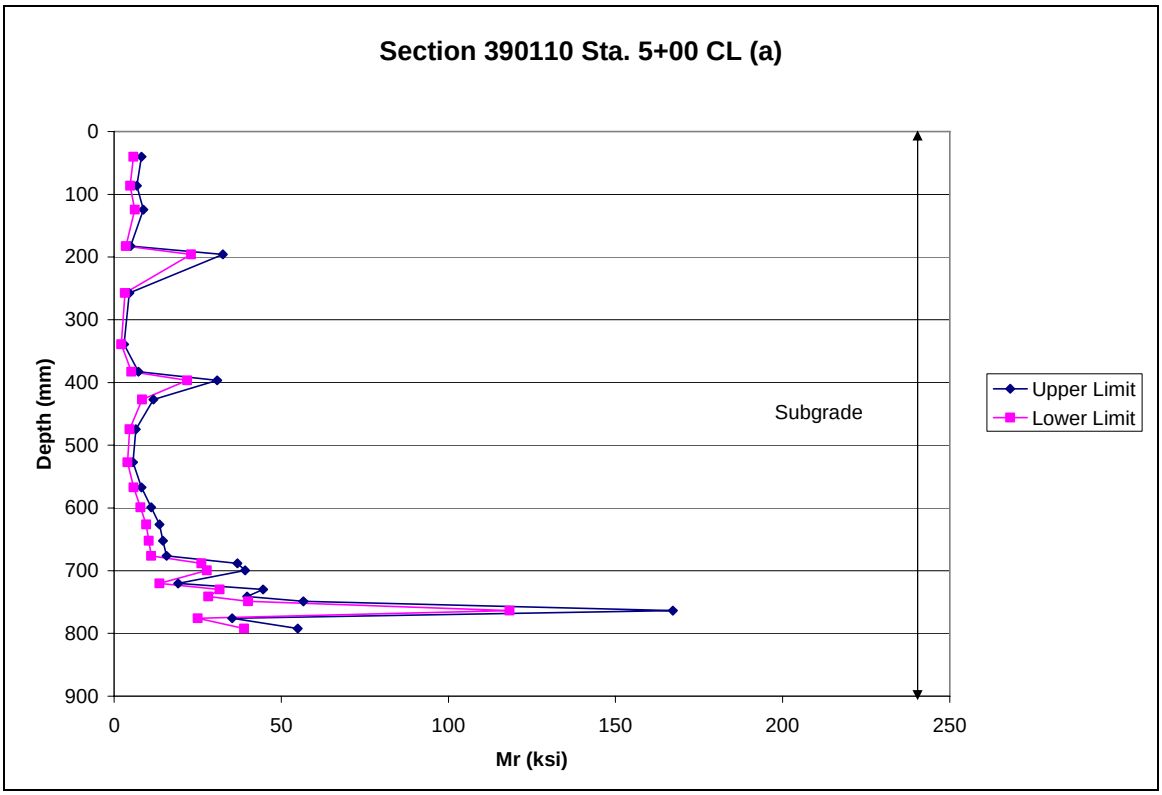


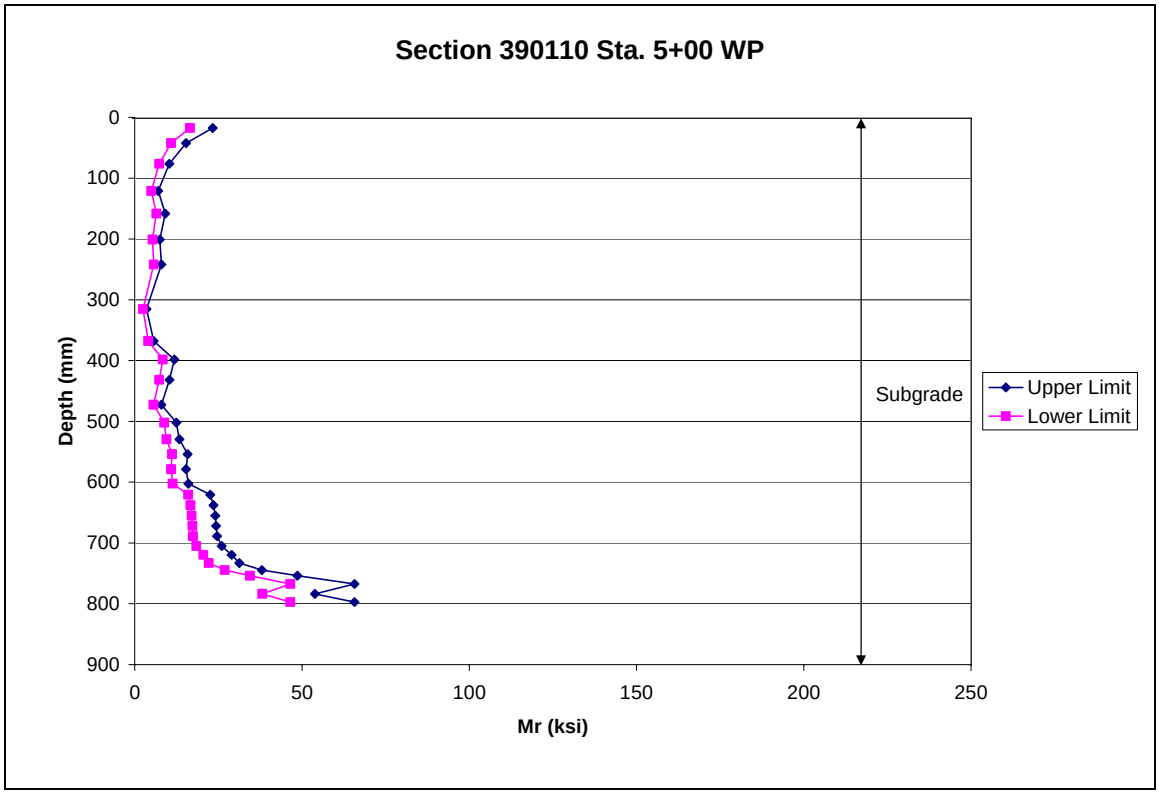
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



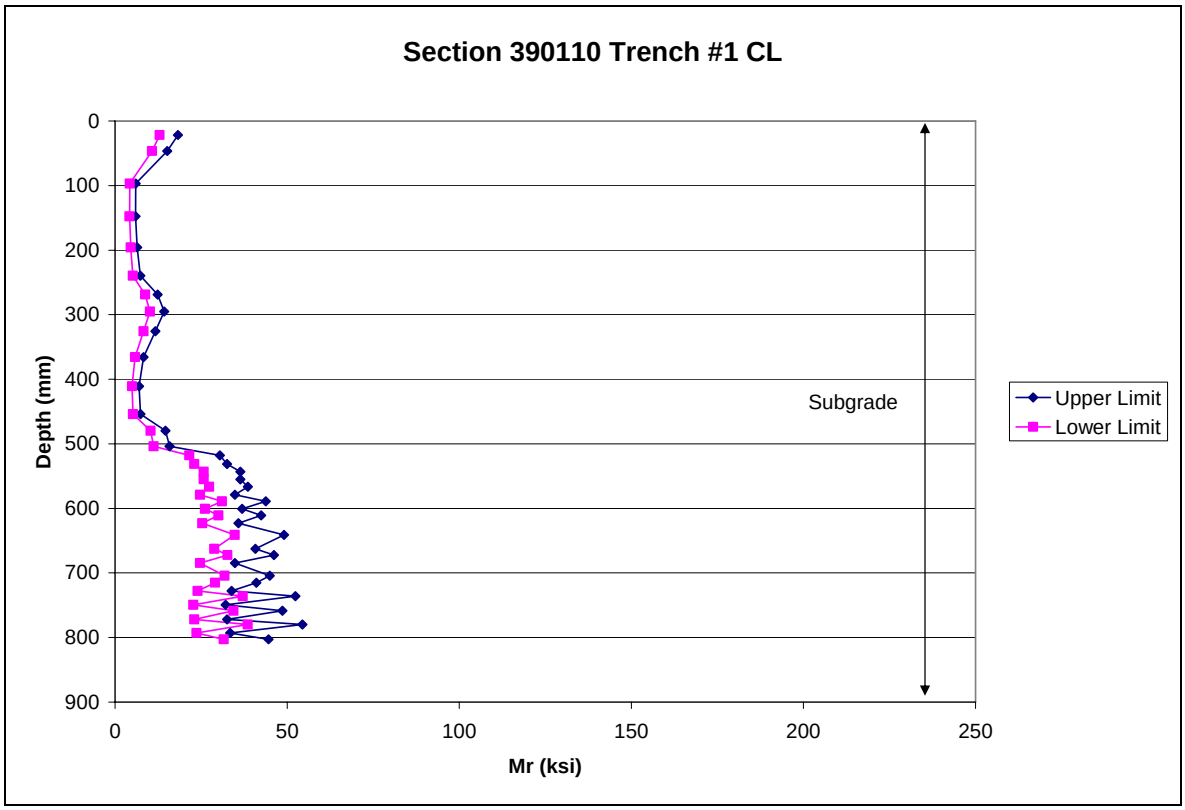


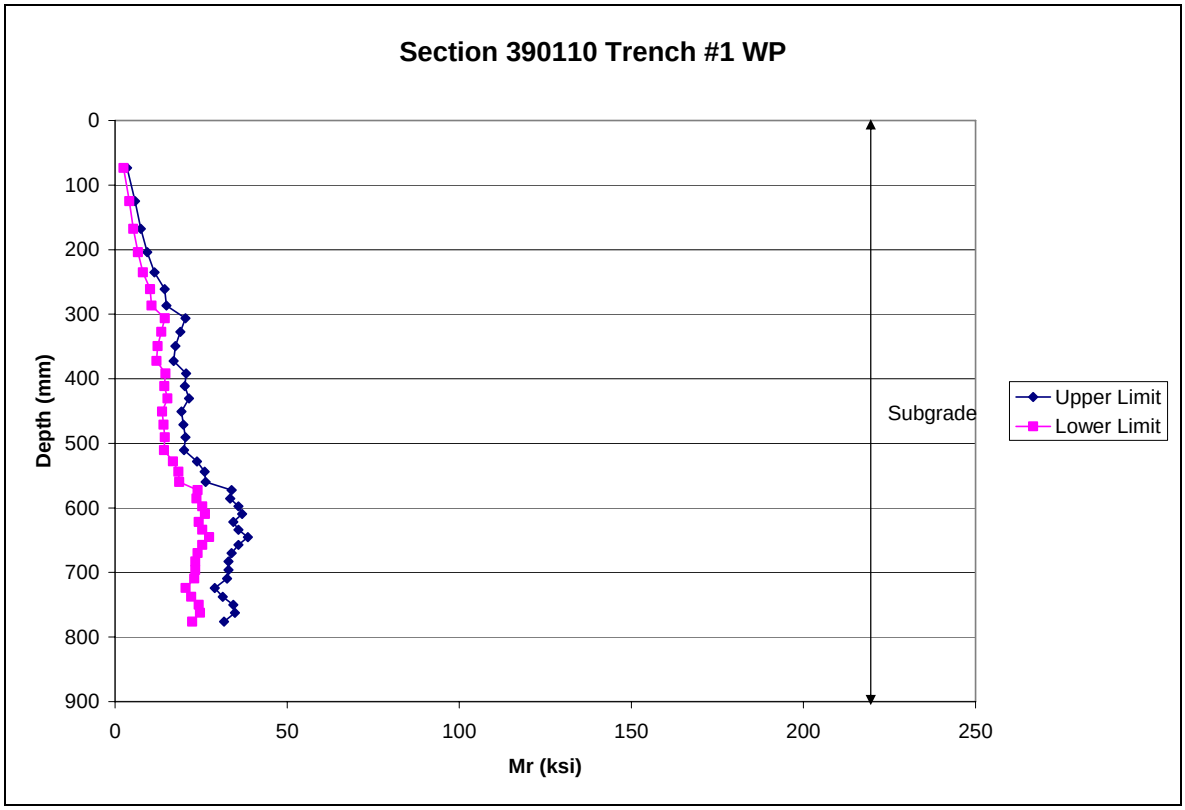
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



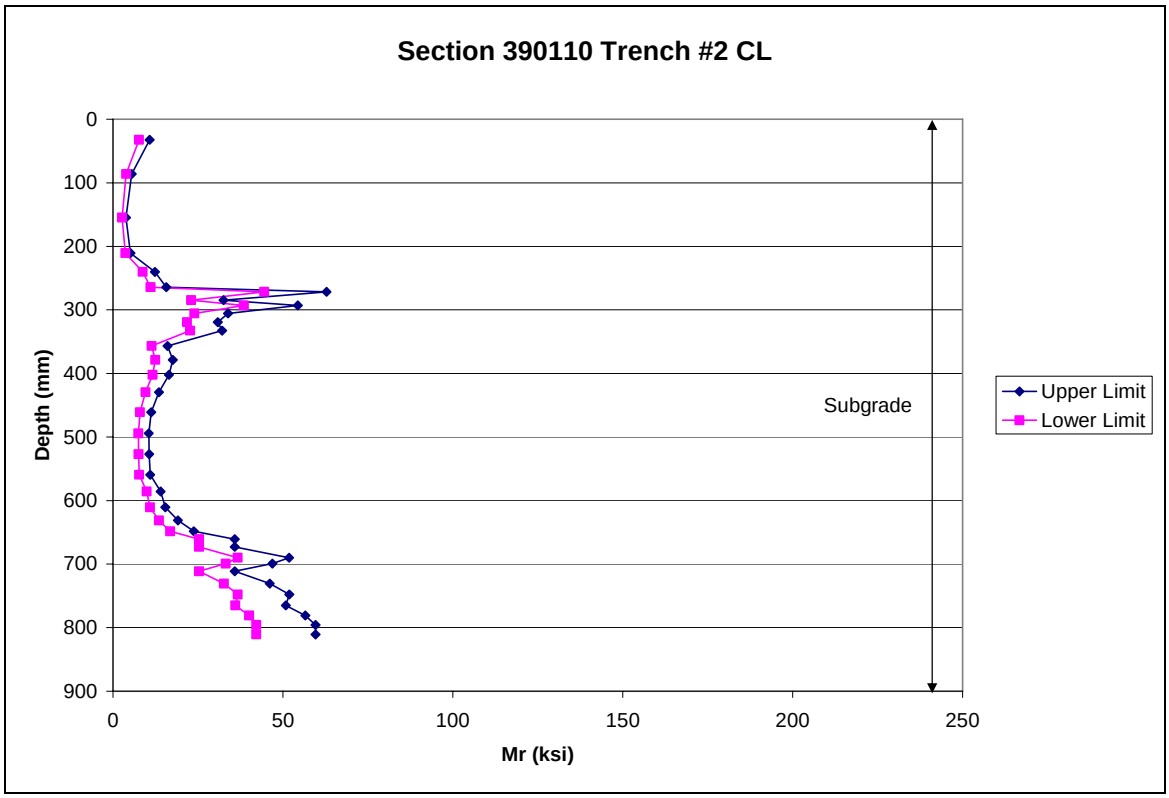


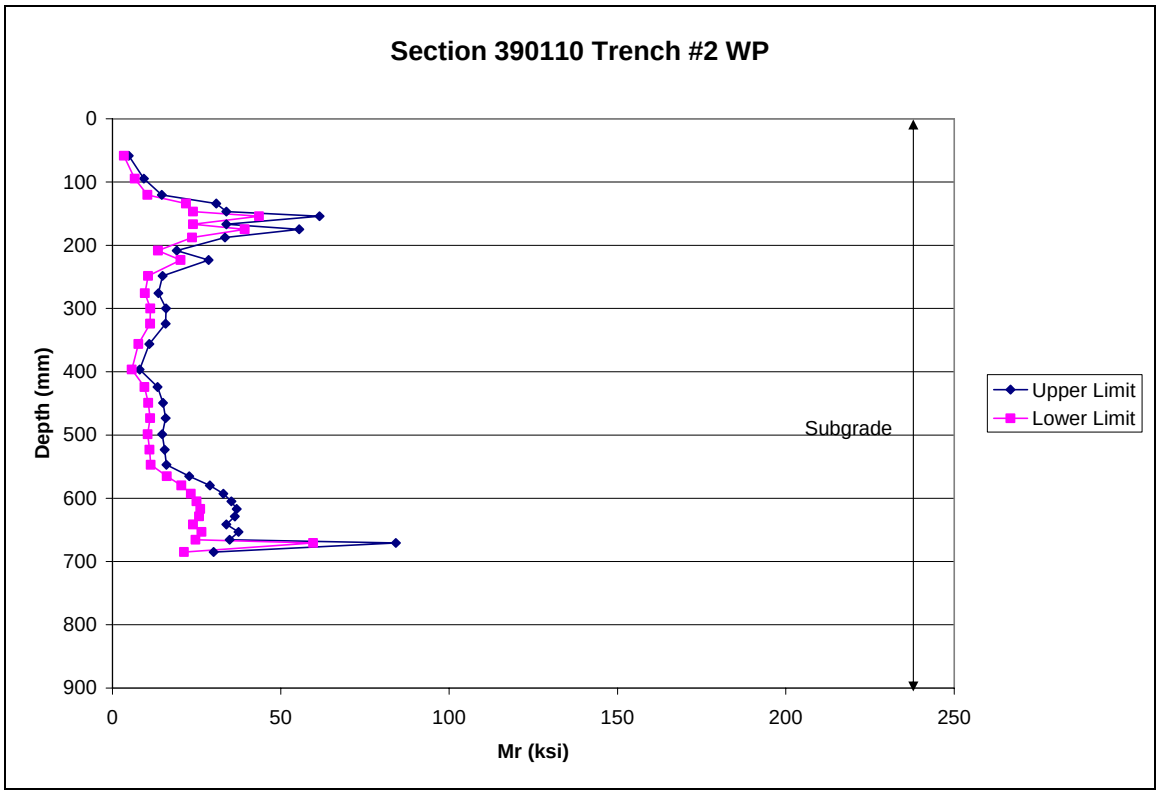
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)



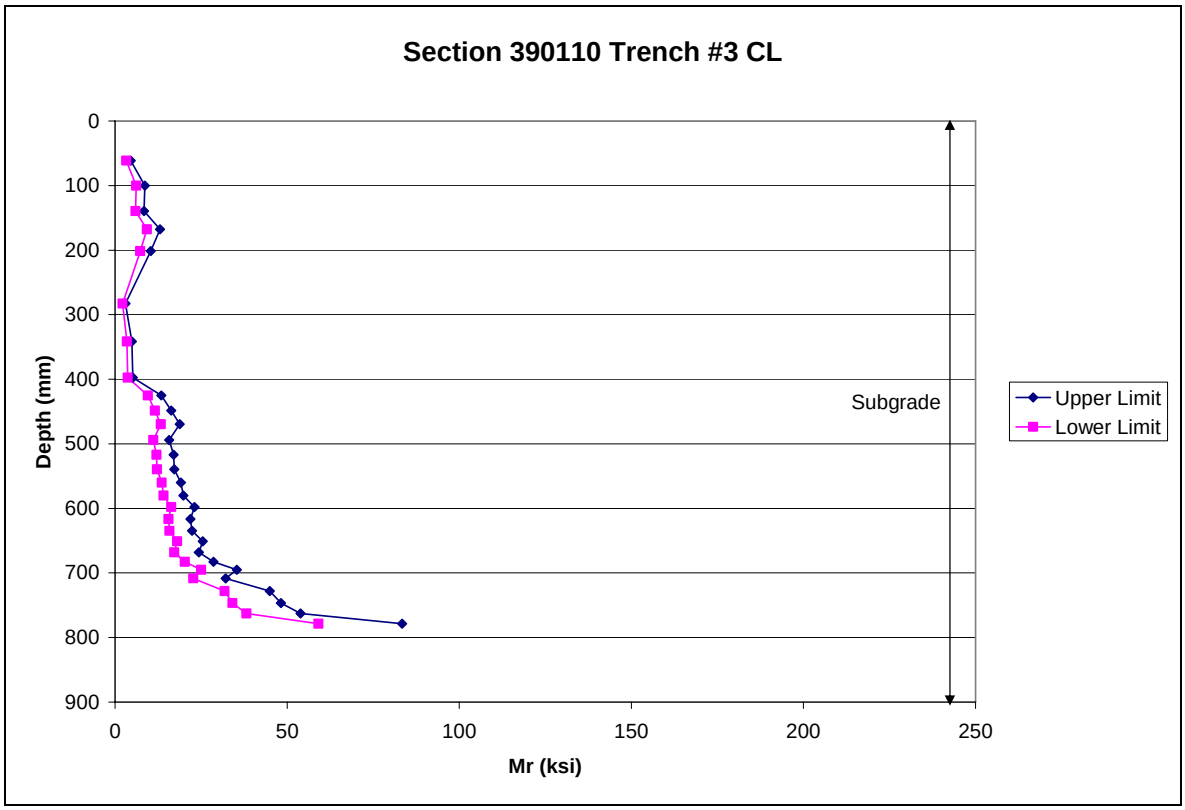


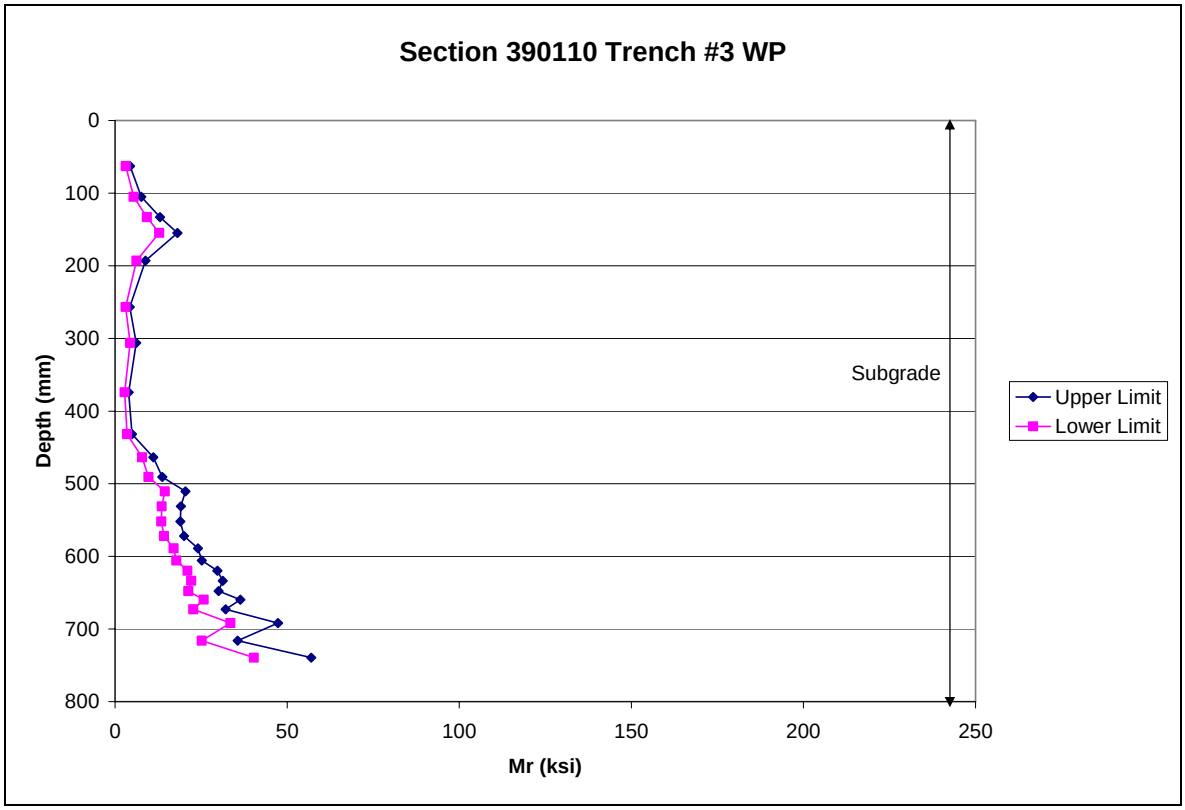
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)





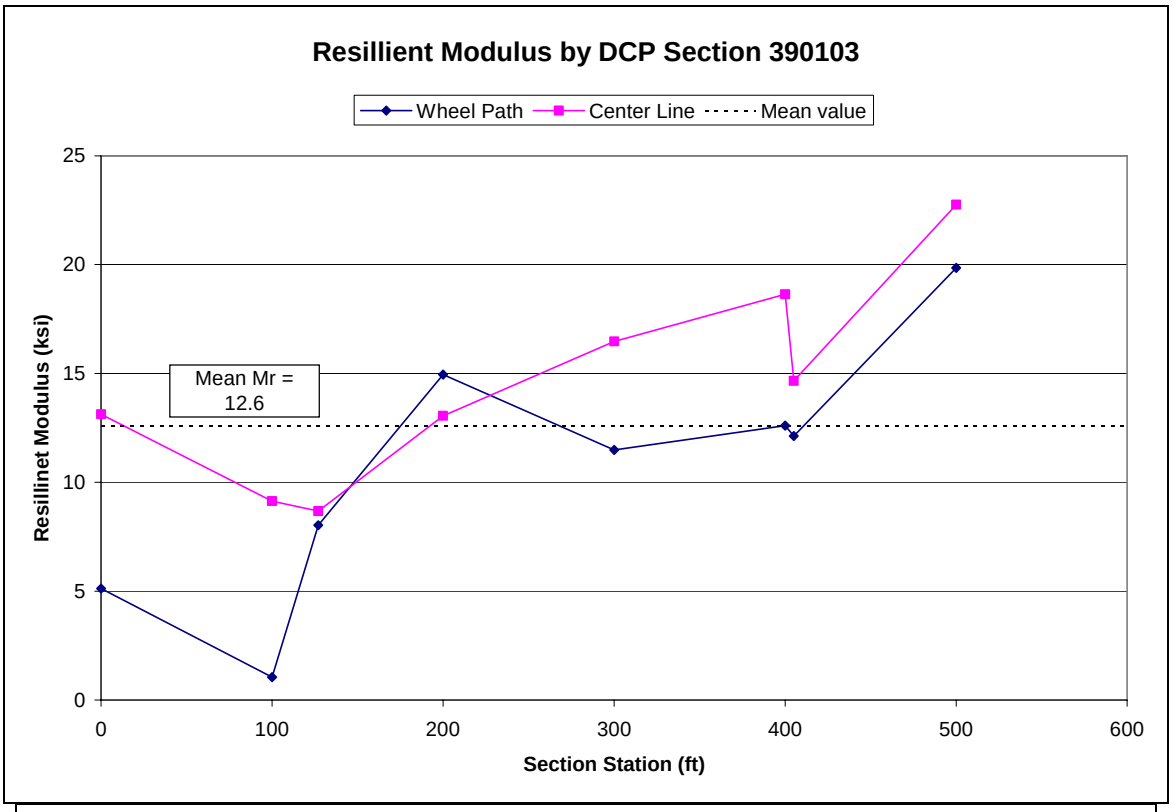
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

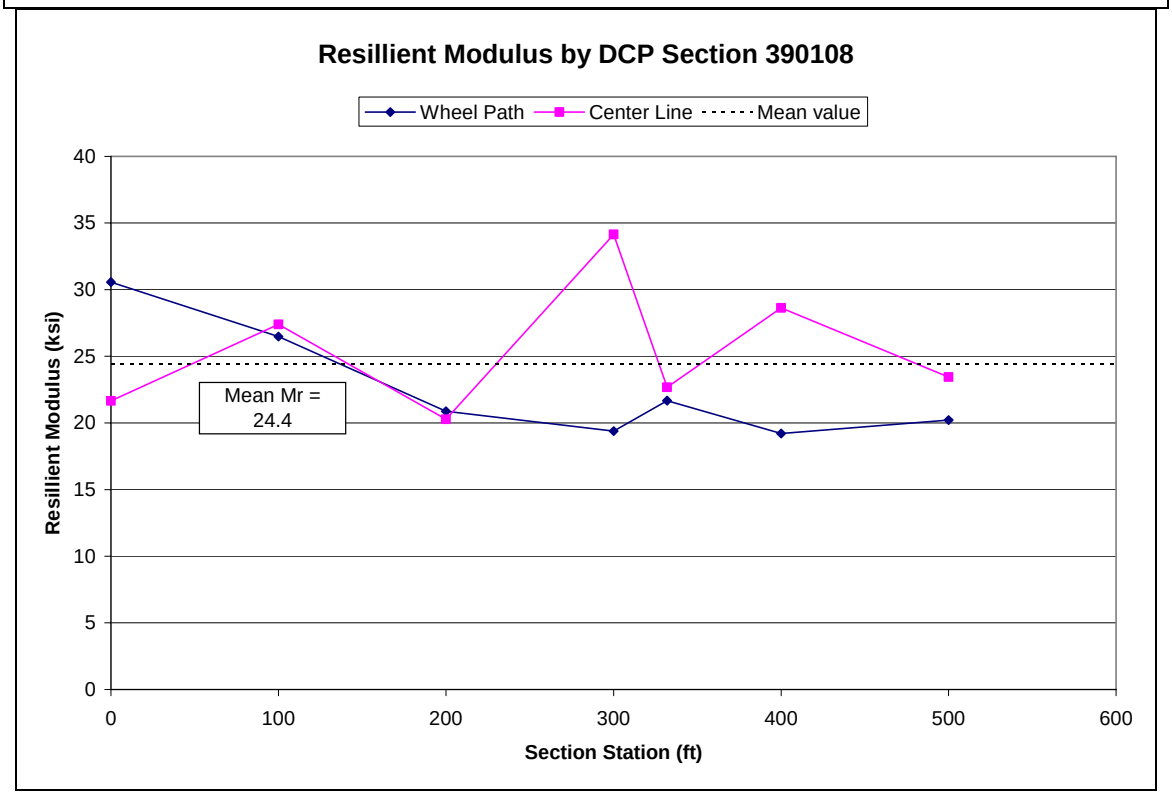




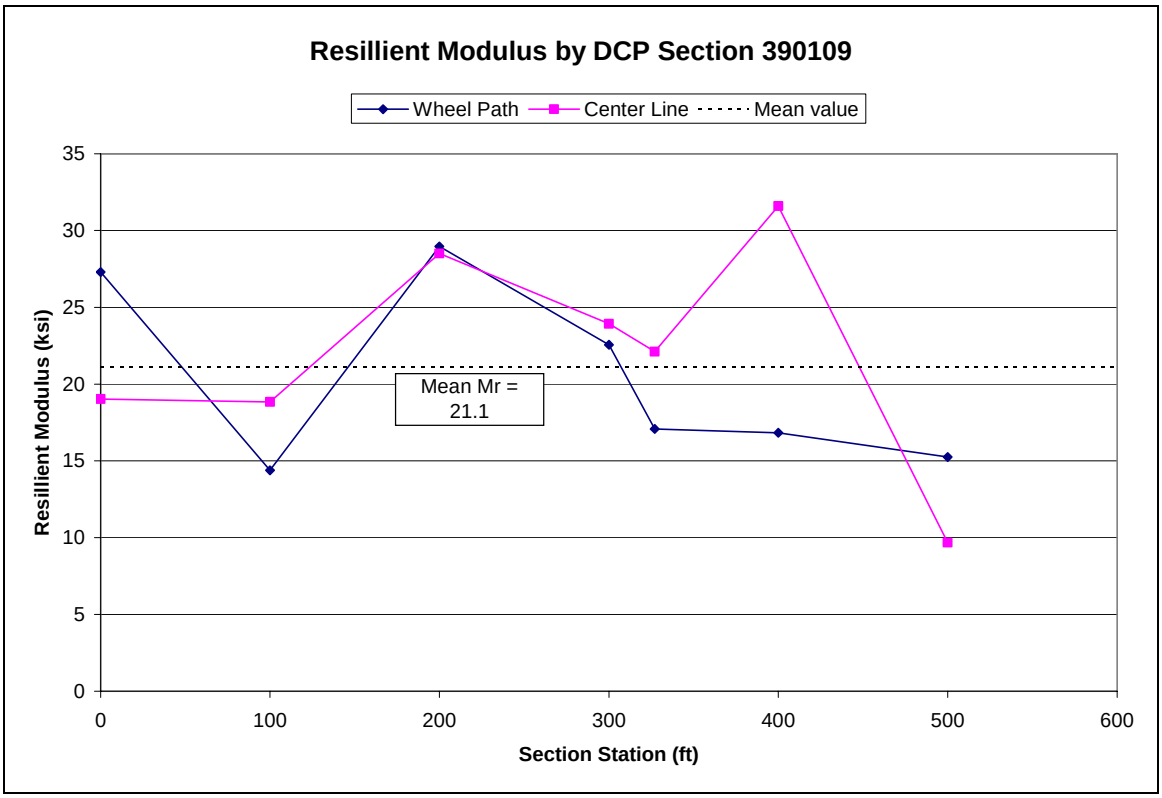
(25.4 mm = 1 in; 1 ksi = 6.89 MPa)

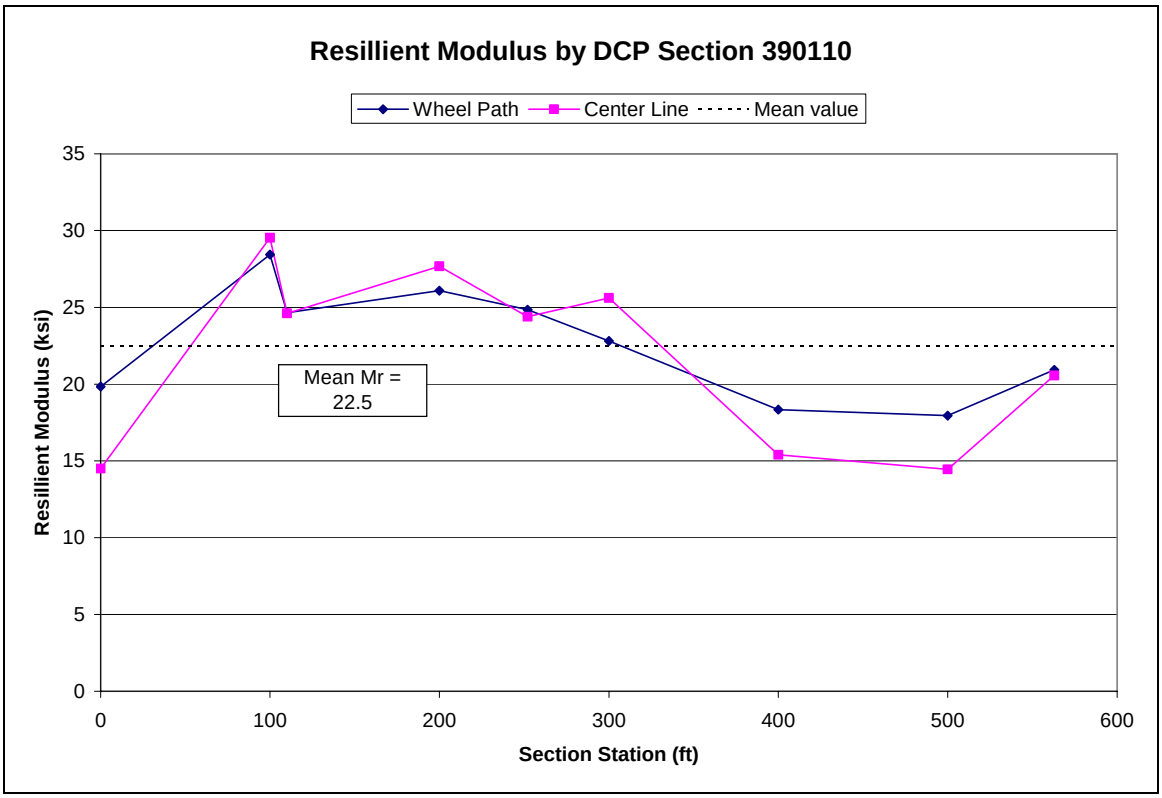
Appendix S DCP Average Resilient Modulus Plots





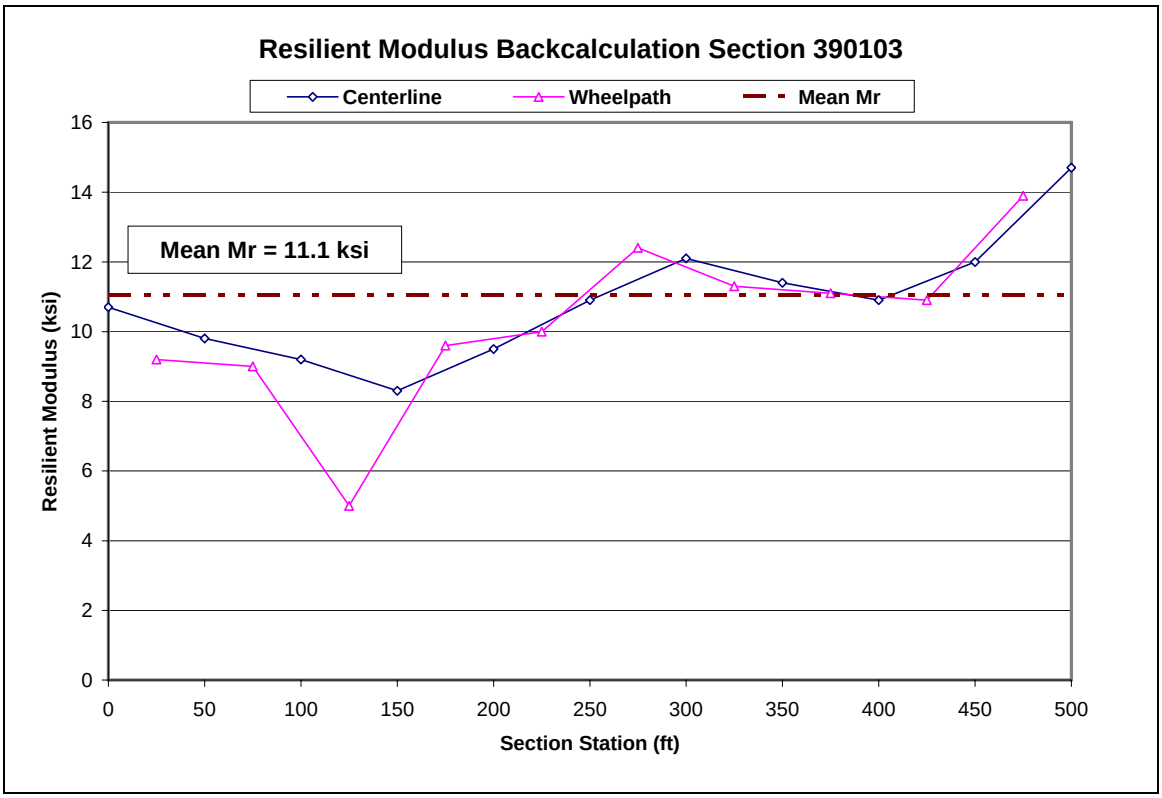
(1 ksi = 6.89 MPa; 1 ft = 0.305 m)

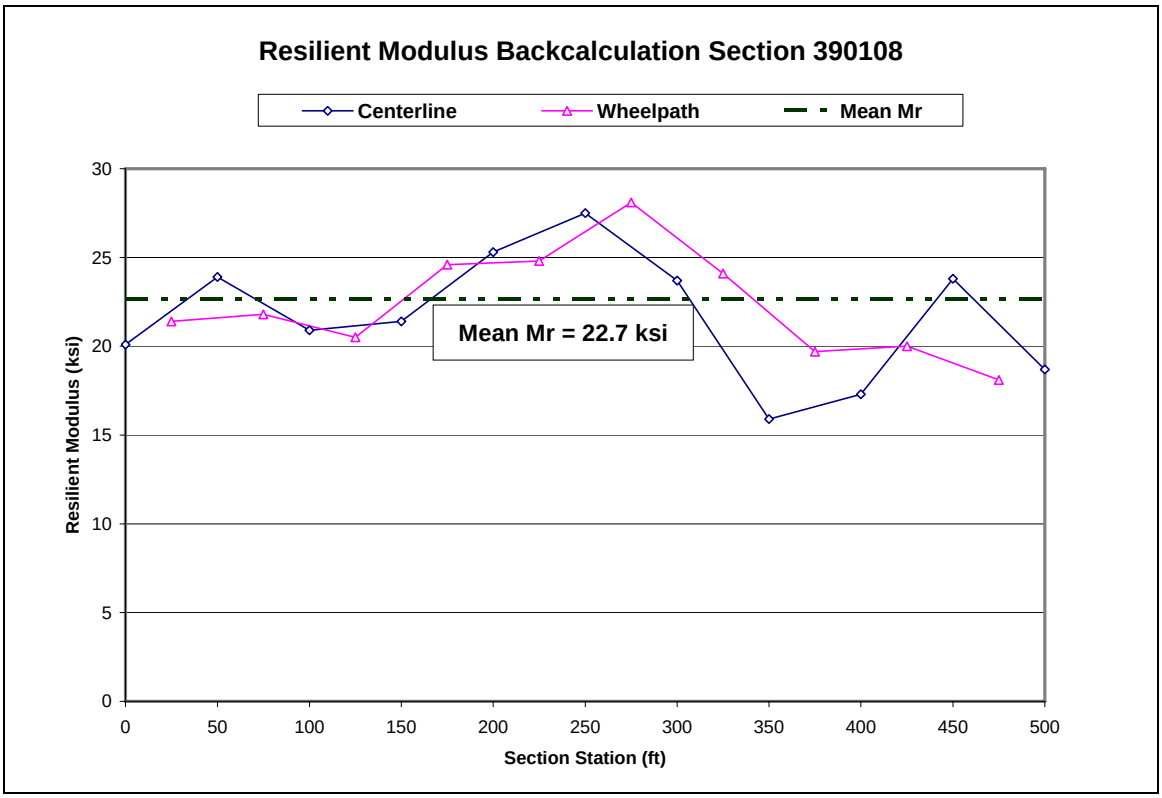




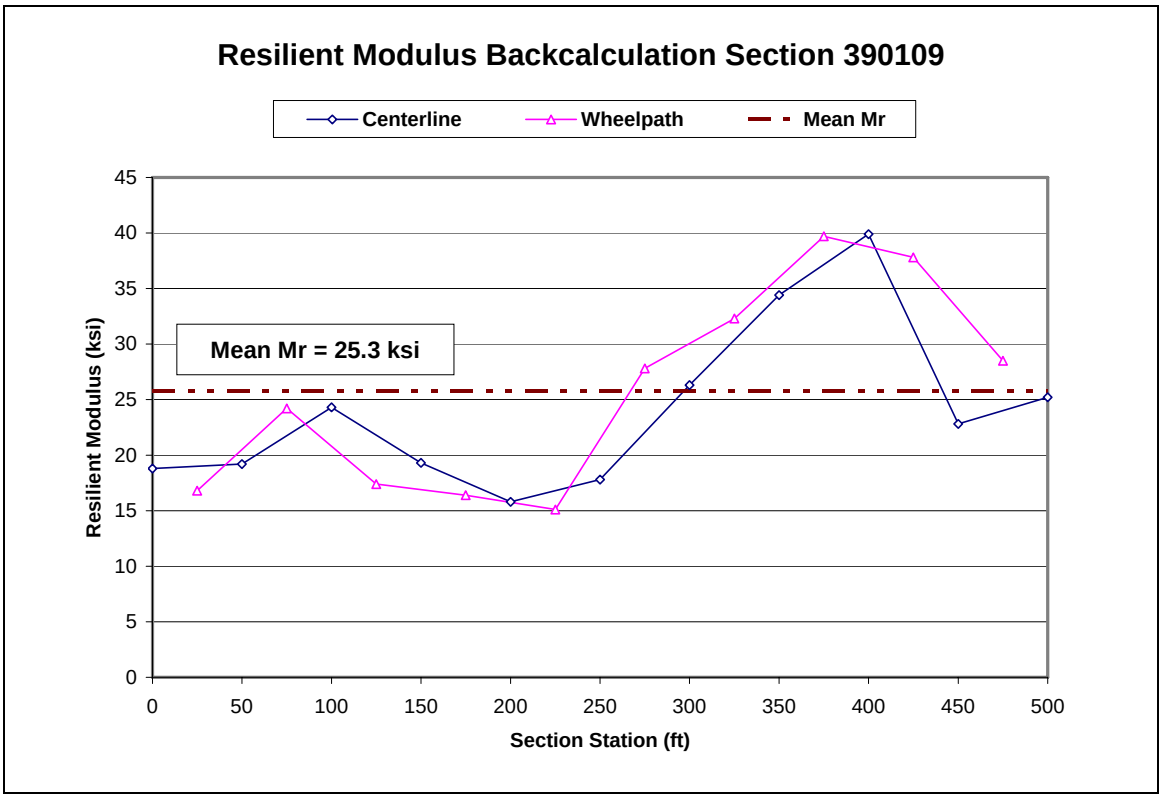
(1 ksi = 6.89 MPa; 1 ft = 0.305 m)

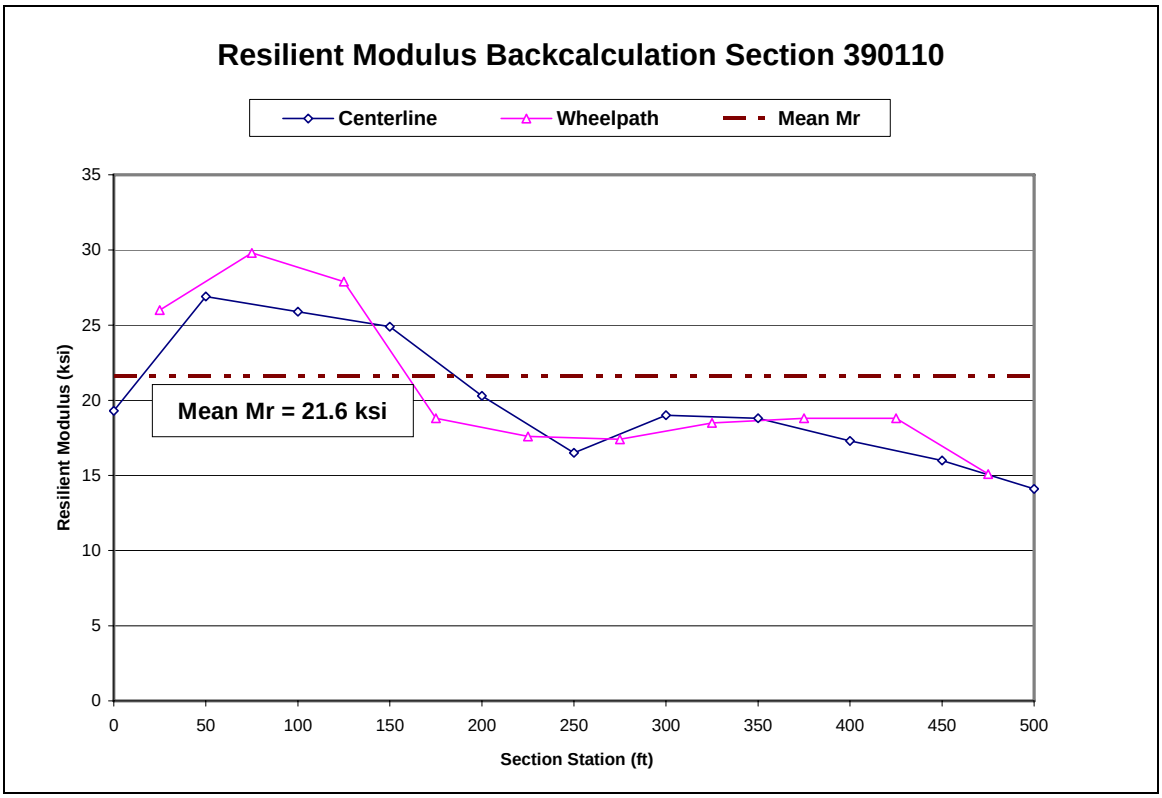
Appendix T Back Calculated Average Resilient Modulus Plots





(1 ksi = 6.89 MPa; 1 ft = 0.305 m)





(1 ksi = 6.89 MPa; 1 ft = 0.305 m)