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**PRELIMINARY GEOTECHNICAL ENGINEERING REPORT
I-89 SOUTHBOUND BARREL
MONTPELIER-WATERBURY IM 089-2(56)
MONTPELIER, MIDDLESEX & WATERBURY, VERMONT**

Prepared for:

Vermont Agency of Transportation (VTrans)
Construction Materials Bureau
2178 Airport Road, Unit B
Berlin, VT 05641

Prepared By:

GEODesign, Inc.
85 Granite Shed Lane, Unit #1
Montpelier, VT 05602

File No. 0750-012.21
October 31, 2023



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Montpelier, VT 05602
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Mr. Stephen Madden
Vermont Agency of Transportation (VTTrans)
Construction and Materials Bureau
2178 Airport Road, Unit B
Berlin, VT 05641

RE: Preliminary Geotechnical Engineering Report
I-89 Southbound Barrel
Montpelier-Waterbury IM 089-2(56)
Montpelier, Middlesex & Waterbury, VT

Dear Stephen:

GEODesign is submitting this geotechnical engineering report to be used for pavement design for the above captioned project. This report includes the subsurface data collected at the site, our summary of the subsurface conditions at the site, and geotechnical considerations for pavement design.

We appreciate the opportunity to be of service to you on this project. If you have any questions, please contact me at 802-674-2033 (ext. 213)

Sincerely,

GEODesign, Inc.



Jacob Wimett, P.E.
Senior Associate

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1.0 INTRODUCTION

This report summarizes subsurface findings and geotechnical recommendations for the proposed pavement rehabilitation project for a 10.5-mile section of Interstate 89 (I-89) starting at the bare bridge deck south of Exit 8 in Montpelier (MM 52.5) and extending northward to MM 63.0, just south of Exit 10 in Waterbury. We understand the scope of pavement rehabilitation is likely to be a deep mill and fill to replace all or most of the existing bonded structure, with cold-in-place recycle or pavement reclamation also being considered. The information contained in this preliminary report will be used to support VTrans' design. To that end, GEODesign completed a subsurface investigation that included roadway borings with dynamic cone penetration (DCP) testing, a ground penetrating radar (GPR) survey and laboratory soil gradation testing. The investigation and this report were performed and prepared in accordance with our Work Order Response dated July 6, 2023.

Explorations performed during this phase of work were widely spaced and focused only on the southbound barrel of the project limits. It is our understanding that further supplemental exploration of the southbound barrel, as well as explorations for the northbound barrel, are anticipated in the future.

2.0 SUMMARY OF FINDINGS

- GPR reported an average asphalt thickness of 7.3 inches in the travel lane and 8.0 inches in the passing lane. This matches closely with direct measurements of cores taken at 11 locations in each lane. (8.3" average thickness for both lanes based on the 11 discreet locations sampled.)
- The Subbase is on average between about 24 to 27-inches thick. The gradation of this material is generally suitable as a subbase material.
- There is a secondary fill layer between Subbase and Subgrade which we infer to be a "Sand Cushion" layer, as the historical plan provided to us for review depicts a Sand Cushion below the Subbase. The Sand Cushion is shown on this plan as being 6-inches thick. However, we found the Sand Cushion to generally be much thicker in our explorations, typically around 20-inches thick and extending to about 4 to 5-feet deep.
- Both the Sand Cushion and Subgrade materials are silty, are expected to have poor drainage characteristics, and are highly frost susceptible. These soils are present within design frost depths, and are a likely contributing factor to poor pavement performance.

3.0 SUBSURFACE EXPLORATIONS

3.1 General

Subsurface explorations for this project consisted of the following:

- Twenty-two (22) combined soil borings and asphalt cores were performed in the travel & passing lanes;
- Twenty-two (22) asphalt cores performed in the shoulders;
- DCP testing at every soil boring and coring location; and,
- A GPR survey of asphalt thickness in each traveled lane.

Soil boring locations are shown approximately in Figure 1 in Appendix A and depicted in tabular form in Appendix B.

3.2 Soil Borings & Asphalt Cores

At each mile marker, one combined soil boring/asphalt core was performed in each of the travel and passing lanes, and one asphalt core through each shoulder was completed between August 10 and September 7, 2023 by New England Boring Contractors using a truck mounted drill rig. The soil borings and asphalt cores were coordinated and overseen in the field by GEODesign personnel with VTrans Materials Section personnel also onsite throughout the explorations to collect, measure, and document asphalt cores. A Drilling Notes table summarizing the subsurface conditions encountered in the borings is included in Appendix B. It is our understanding that the VTrans Materials Section will be providing an independent memorandum with respect to asphalt core findings.

At all forty-four exploration locations, DCP testing was performed to refusal immediately after removing the asphalt core.

For the twenty-two soil borings performed in the travel/passing lanes, soil samples were collected by driving a 3-inch OD split-spoon sampler in 24-inch increments. At each boring, a total of three (3) split spoon samples were taken. In addition to the DCP test taken immediately below the asphalt, a second DCP test was taken in each boring following completion of the second split spoon sample.

3.3 Ground Penetrating Radar

A vehicle-based ground penetrating radar (GPR) survey was conducted by Infrasense, Inc. on September 28, 2023 to evaluate pavement layer thicknesses in each of the traveled lanes. Data was collected along the center of both the travel and passing lanes of the roadway within the project limits.

Refer to the GPR report in Appendix G for additional details related to the data collection and reduction methods used for this project.

4.0 LABORATORY TESTING

We performed soil gradation sieve analyses and moisture content determinations on approximately ½ of the soil samples collected by GEODesign. These results are provided in Appendix C.

5.0 SUBSURFACE CONDITIONS

Generalized subsurface conditions are discussed below. Because groundwater may fluctuate due to factors such as seasonal variations, temperature, rainfall, and other factors that differ from conditions at the time the subsurface explorations were made, groundwater may be encountered during construction even if not encountered in the explorations.

5.1 Typical Design Section Review

For our review, we were provided with a plan sheet by Boswell Engineering Co. titled “Typical Sections Interstate” dated August, 1957. This sheet was stamped “Constructed as Designed” and is included in Appendix D.

This plan indicates the following typical section:

- 3” Bituminous Concrete Pavement
- 2 – 4” Crushed Stone Base Course
- 24” Sub-Base of Crushed Rock
- 6” Sand Cushion

Our explorations noted several differences as follows:

1. Thicker asphalt was consistently observed, inferred to be due to overlays that have occurred since original construction.
2. We did not differentiate a 2 - 4” Crushed Stone base course from the underlying Crushed Rock subbase. However, it may have been present but not identified due to the degraded/mixed nature of the asphalt and aggregate at the bottom of many cores.
3. The “Sand Cushion” was notably thicker where encountered.

5.2 Generalized Section Observed in Explorations

The generalized section profile in the travel and passing lanes, accounting for the aggregation of the data collected in the subsurface explorations is as follows, with a visual depiction provided on Figure 2 in Appendix A and detailed descriptions at each boring location included in the Drilling Notes Summary Table in Appendix B:

- **7.3” (travel lane) to 8” (passing lane) ASPHALT (varies from 5.5 to 11 inches thick where measured)**
- **26” GRANULAR SUBBASE (varies from 18 to 39 inches thick where measured).**
- **21” SAND CUSHION (where present - varies from 0 to 33 inches thick).**
- **SUBGRADE**

Observations made from the explorations are provided below.

5.3 Conditions Observed in Borings

Asphalt Observations – The asphalt pavement thickness encountered in the borings performed in the travel and passing lanes varied from 5.5 to 11.0 inches with an average thickness of about 8.25 inches.

Granular Subbase – On average, about 26 inches of granular subbase material was observed below the bound asphalt section. Due to sampling limitations, transitions between the Subbase, Sand Cushion and Subgrade are approximate. Transitions reported have been rounded to the nearest 3” based on a combination of material changes noted in the sampler, hammer blows to drive the sampler, and density changes noted during DCP testing. On average, the granular subbase typically consisted of a sandy gravel with a fines content (i.e. the percentage retained on a No. 200 sieve) in the 5% to 8% range.

The granular subbase materials encountered compare favorably to gradation specifications for 704.05A (Fine) Crushed Gravel for Subbase, though it occasionally has a slightly elevated fines content (the 704.05A specification allows fines contents of up to 6%).

Sand Cushion – We noted a secondary fill material between the bottom of Subbase and top of Subgrade. We infer this fill to be the “Sand Cushion” that was indicated on the 1957 Typical Sections plan that was provided for our review. This material generally consisted of a sand and silt with little gravel. Fines contents varied were typically in the 30 to 70% range. This material does not compare well with current gradation specifications for 703.03 Sand Borrow and Cushion, which specifies a maximum fines content of 8%.

Subgrade – Subgrade materials typically were observed beginning between 4 and 5-feet deep and varied in consistency from sands and gravels, to glacial till, to sandy silt. It is possible that some of the subgrade samples represented either naturally deposited soils, a general fill placed below the structural section, or a mixture of the two.

5.4 Conditions Observed in Shoulder Cores

In general, we observed a thinner asphalt core section in the shoulders than in the travel and passing lanes. Asphalt thickness in the 11 cores taken in the shoulders varied from 3.0 to 7.0 inches, with average values in the left and right shoulders of 4.75 and 5.25 inches respectively.

While DCP testing did not routinely penetrate the underlying subbase, we did note that the stiffness of the subbase in the right shoulder generally compared well with the subbase below the travel and passing lanes. The subbase in the left shoulder, was often found to be weaker. Refer to the recommended effective modulus values in Section 7.1.2 of this report and the raw data in Appendix F for more detail.

5.5 Conditions Observed in GPR

Refer to Appendix G for a full copy of the report prepared by Infrasense for this project. A summary of their findings is as follows:

Asphalt - The GPR data analyses indicated an average asphalt (AC) pavement thickness of 7.3 and 8.0 inches in the travel and passing lanes, respectively. This is less than the average thickness observed in the soil borings (8.25" in each lane on average).

Base - The GPR method did note a transition in base materials generally starting about 3.4 to 3.9-inches (travel and passing lane respectively) below the bottom of the asphalt. This generally matches the 1957 Typical Sections showing a 2 to 4-inch layer of crushed stone over a crushed rock subbase. As noted earlier, our field personnel did not specifically note a differentiation between a crushed stone base and crushed rock subbase. This may be due to the degraded/mixed nature of the asphalt and aggregate at the bottom of many cores.

Subbase – The GPR method indicated average subbase thickness of 10.7 (travel lane) and 12.6-inches (passing lane). This was significantly less than what was measured in the field. Based on our prior experience with the methods used in the GPR survey, we do not recommend relying on the accuracy of the GPR for measurement of the subbase thickness.

6.0 DYNAMIC CONE PENETRATION (DCP) TESTING

The primary objective of the DCP testing was to estimate Resilient Modulus (M_R) values of the soil materials below the existing pavement for use by the pavement designer. Plots of DCP penetration index and correlated uncorrected values of M_R versus depth are included in Appendix E.

7.0 DESIGN CONSIDERATIONS AND RECOMMENDATIONS

7.1 Resilient Modulus of Subbase, Sand Cushion and Subgrade

7.1.1 DCP Data Reduction Methodology

The following equations were used to correlate the DCP penetration resistance to California Bearing Ratio (CBR), and CBR to Effective M_R . Where the DCP resistance exceeded defined

refusal, less than 2 mm of penetration for 3 blows, the CBR and M_R values were not used in our analysis. FHWA document NHI-05-037 provides the following approach to correlation of DCP data to M_R :

1. Correlate DCP Index (PR) to CBR through the following equation (where PR is the Penetration Index in millimeters per blow):

$$CBR = 292 / PR^{1.12} \text{ (from US Army Corps of Engineers)}$$

2. Correlate CBR to M_R through the following equation:

$$M_R \text{ (psi)} = 2555(CBR)^{0.64} \text{ (from Transportation and Road Research Laboratory)}$$

Following conversion of raw DCP data to discrete M_R points, GEODesign further reduced the data as follows:

1. Average the correlated M_R values within 1.5 standard deviations from the mean for each layer at each boring location, (to reduce the influence of outliers).
2. Convert the averaged value of measured M_R to Effective M_R used in pavement design in accordance Section 2.3.1 of Part II of the 1993 AASHTO Guide for Design of Pavement Structures.

7.1.2 Recommended Effective M_R Values for Design

Following the above methodology, we recommend the following Effective M_R for use in pavement design:

Subbase (Travel Lane, Passing Lane, Right Shoulder):	17,500 psi ¹
Subbase (Left Shoulder):	13,500 psi ¹
Sand Cushion (MM 53.5 to MM56.5)	5,500 psi ²
Sand Cushion (Elsewhere)	9,500 psi ²
Subgrade (MM 53.5 to MM56.5)	6,000 psi ²
Subgrade (Elsewhere)	8,500 psi ²

¹ These values represent the minimum Effective M_R within 1 standard deviation of the mean when comparing the computed values at each mile marker. While this is a reasonably conservative representative value for the project as a whole, it must be acknowledged that there will be locations with both better and worse conditions.

² Values represent minimum values in these respective stretches.

The correlated Effective M_R computed at each location is presented in the table below. It may be possible to further separate sections of the project length with different Effective M_R values from those provided above. However, given the wide spacing of boring locations (~ 1-Mile apart) we recommend additional test locations be performed at spacing not exceeding ¼-mile prior to attempting to further delineate or group regions with differing Effective M_R values for design.

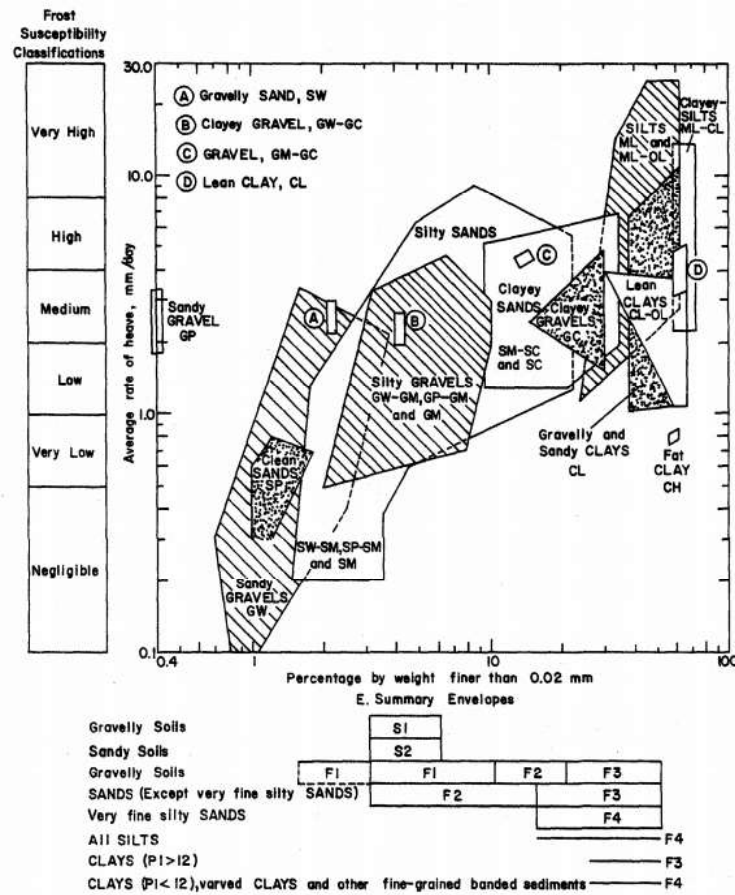
Effective Resilient Modulus Values By Location (psi)				
Mile Marker	L. Shoulder Subbase	R. Shoulder / Travel Lane / Passing Lane Subbase	Sand Cushion	Subgrade
52.85	17500	18500	13500	10000
54	10500	18500	5500	20000
55	13500	22500	NR	6000
56	8500	20000	9500	7000
57	15000	20500	NR	26500
58	20500	16000	14500	8500
59.05	20000	25500	10500	9500
60	17500	20000	NR	19000
61	15500	21500	18500	NR
62	19500	17500	27500	16500
63	14000	14500	NR	14500

7.2 Frost Susceptibility of Existing Soils Below Pavement

7.2.1 Methodology

We reviewed the frost susceptibility of the existing base layer and subgrade materials using criteria developed by the US Army Corps of Engineers in Engineer Manual EM110-3-138, Pavement Criteria for Seasonal Frost Considerations. The frost susceptibility classification (ranging from negligible to very high) can be evaluated based on USCS soil type and percent finer than 0.02 mm by weight using the chart below. Further “fine-tuning” of groupings with wide-ranging frost susceptibilities can be achieved through comparison with test cases provided in the manual. Hydrometer tests were not performed to determine the percent finer than 0.02 mm, but percent finer than 0.02 mm was estimated by extrapolating the results of the laboratory sieve gradation tests.

US Army Corps of Engineers Frost Susceptibility Classification Chart



7.2.2 Subbase Frost Grouping

Subbase layer samples generally fall into the S1 category for frost susceptibility. These soils are considered suitable for base and subbase materials and are associated with low frost susceptibility.

7.2.3 Sand Cushion Frost Grouping

Sand Cushion samples generally fell within the F3 and F4 frost groupings. These soils are considered frost susceptible. From our comparison of the lab data to reference testing provided in the EM 110-3-138 manual, the samples collected generally would classify as medium to high frost susceptibility. Generally, we do not consider this material to exhibit desirable characteristics for a Sand Borrow to be used within design frost depth. These soils could have a negative impact on pavement performance and should be taken into consideration in the repair design.

7.2.4 *Subgrade Frost Grouping*

The majority of the subgrade samples from the borings were also classified as F3 or F4 soils. From our comparison of the lab testing results and reference tests provided in the EM 110-3-138 manual, we would generally classify these materials as having high frost susceptibility. Based on conditions encountered in the soil borings, these frost-susceptible subgrade soils were frequently encountered within what would generally be considered depths where a frost-free Sand Borrow would be recommended.

7.3 Geotechnical Comments on Potential Rehabilitation Options.

Of particular geotechnical concern is existing Sand Cushion and Subgrade soils that are excessively silty in nature. These soils are typically slow draining, medium to highly frost susceptible, and are consistently present less than 3-feet below ground surface. Per the VTrans Pavement Design Guide, an interstate highway at this geographic location should be designed with frost-free soils to a minimum of 55-inches deep.

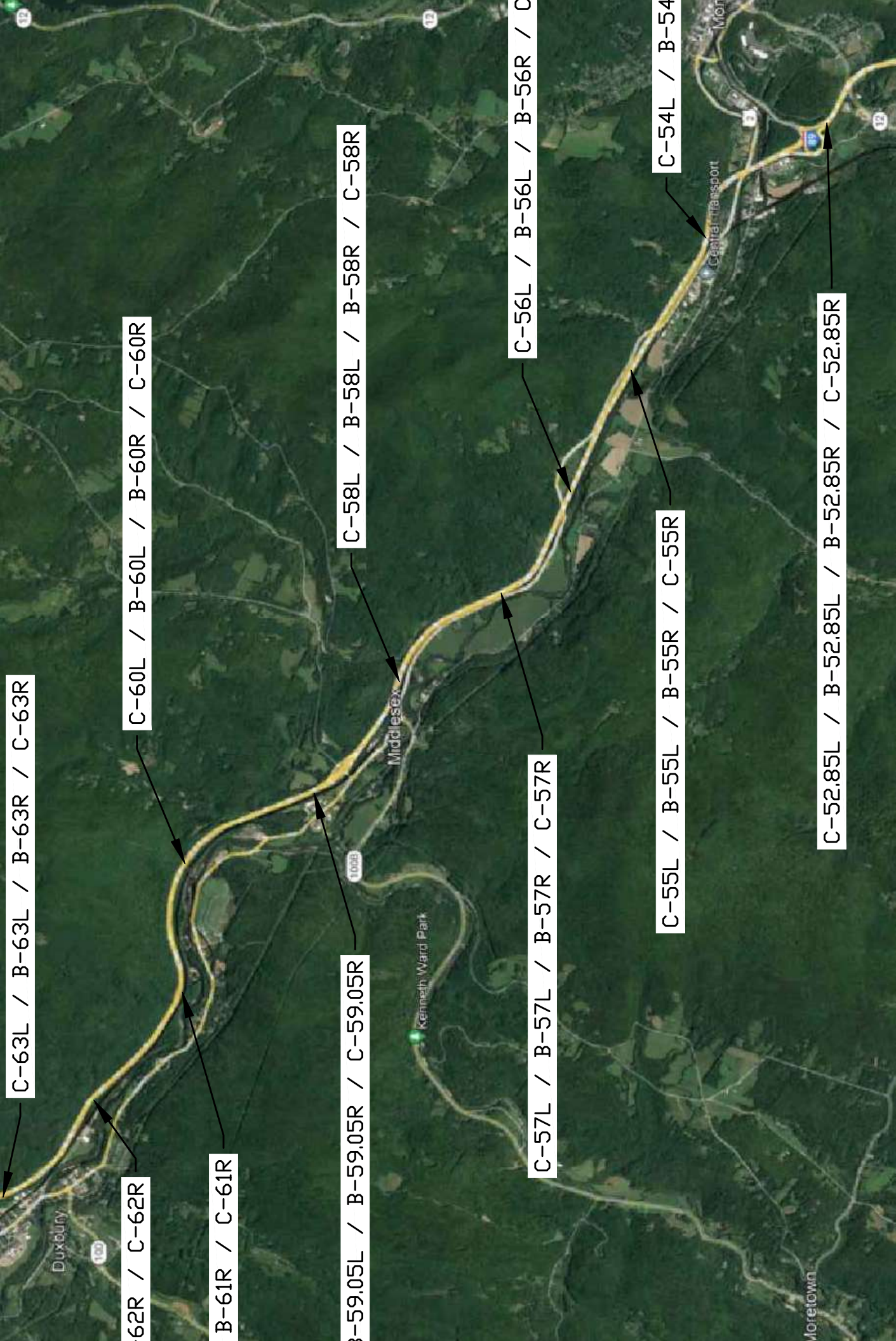
Approaches for pavement rehabilitation that do not address the unsuitability of the underlying soils are likely to underperform. As such, the preferred approach to dealing with these soils would be to reconstruct the road section with suitable frost-free materials placed within 55-inches of ground surface.

Alternatively, approaches such as full depth reclamation may assist with limiting the effects of frost and seasonal weakening of the silty soils underlying the subbase. However, drainage issues with the highly silty sand cushion and subgrade will remain.

8.0 REPORT LIMITATIONS

This preliminary geotechnical report is subject to the limitations in Appendix F.

APPENDIX A
FIGURES

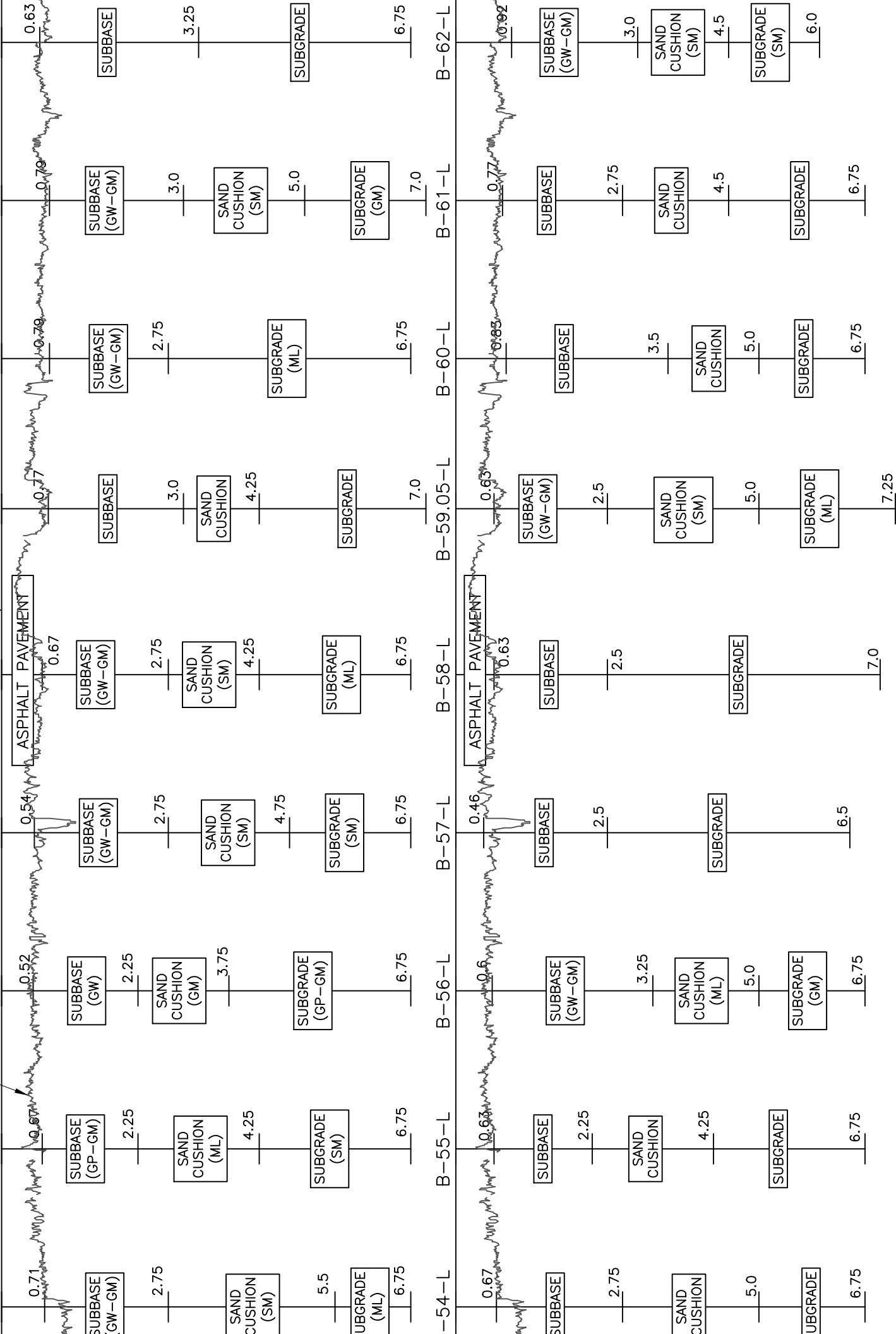


NOTE, BASED ON GOOGLE EARTH AND STREET VIEW OVERLAYS.
 TESTS WERE PERFORMED BY NEW ENGLAND BORING CONTRACTORS ON
 AUGUST 29, AND SEPTEMBER 7, 2023 AND OBSERVED AND LOGGED BY
 J. L. B. FOR INDIVIDUAL BOREHOLE INFORMATION.



GEO DESIGN
 85 GRANITE SHED LANE
 UNIT 1

MONTPEILER - WA
 PAVEMENT CORE AND SC
 INTERSTATE 89 SC
 MONTPEILER, MIDDLESEX
 077



CE TRANSITIONS SHOWN ARE APPROXIMATE.
 SCS WERE PERFORMED BY NEW ENGLAND BORING CONTRACTORS ON AUGUST 10, 11, 14 TO
 7, 2023 AND OBSERVED AND LOGGED BY GEODESIGN AND VTRANS PERSONNEL.
 ASURED FROM PAVEMENT CORES.
 O DESCRIPTIONS OF SOILS ENCOUNTERED IN THE EXPLORATIONS CONDUCTED FOR THIS
 BORINGS MAY VARY.
 B FOR INDIVIDUAL BOREHOLE INFORMATION.



MONTPEILER - WA
 PAVEMENT CORE AND
 INTERSTATE 89 SC
 MONTPEILER, MIDDLESEX
 075

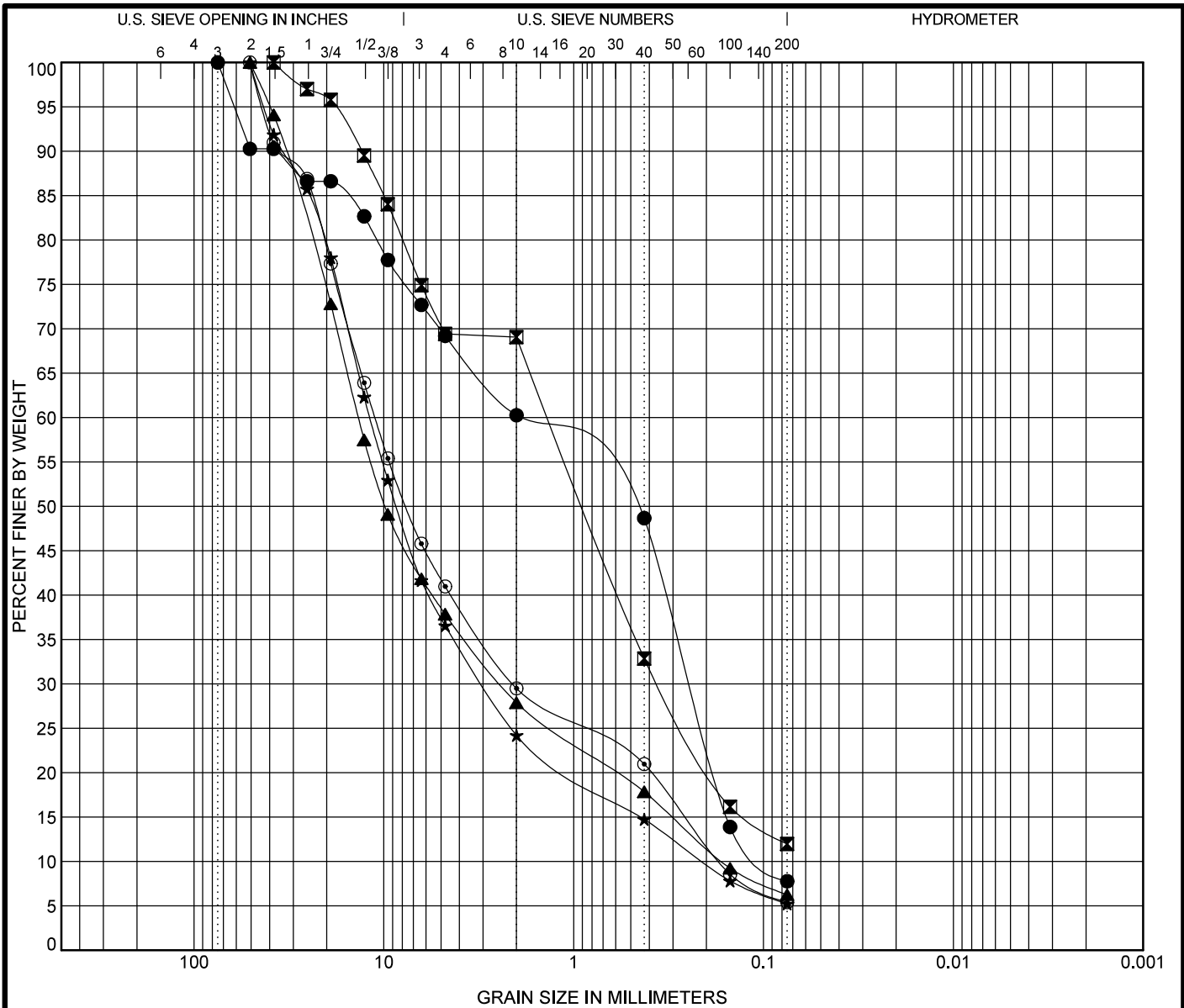
APPENDIX B
TABLES

BORING	DATE	APPRO. MARKER	CL. OFFS.	DEPTH	SAMPL.	HAM. B.C. (3" Split Not Per. D14)	COLOR, SOIL TYPE, MOISTURE	(Burmeister)	% MOIST.	AASHI. CLAS.	USCS	FROST
B-55-L	8/29/2023	55.0	10 L	0.0 - 0.63	6" Core	0.8' to 2.8': 22-31-30-20	7.5" Asphalt					
				0.63 - 2.25	SSL	2.8' to 4.8': 14-8-7-18	Wh-Gry f-c GRAVEL, little f-c Sand, little (-) Silt, moist (SUBBASE)					
				2.25 - 4.25	SSL	4.8' to 6.8': 37-32-21-16	Brm SILT, some f-m Sand, trace f Gravel, moist (SAND CUSHION)					
				4.25 - 6.75	SSL		Wh-Cobalt f-c GRAVEL, some f-c Sand, some Silt, moist (SUBGRADE)					
B-56-R	8/17/2023	56.0	11.5 R	0.0 - 0.52	6" Core	0.7 to 2.7': 28-24-26-16	6.25" Asphalt					
				0.52 - 2.25	SSL	2.7 to 4.7': 12-11-19-25	Brm-Gry f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)	3.6	A-1-a	GW		
				2.25 - 3.75	SSL	4.7' to 6.7': 20-31-25-15	Brm-Gry SILT and f-c GRAVEL, some little f-c Sand, moist (SAND CUSHION)	13.0	A-4	GM	F3	
				3.75 - 6.75	SSL		Gry f-c GRAVEL, little f-c Sand, little Silt moist (SUBGRADE)	2.3	A-1-a	GP-GM	F	
B-56-L	8/28/2023	56.0	9.25 L	0.0 - 0.6	6" Core	0.8' to 2.8': 19-21-21-24	7.25" Asphalt					
				0.6 - 3.25	SSL	2.8' to 4.8': 20-9-9-32	Wh-Gry f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)	3.2	A-1-a	GW-GM	S	
				3.25 - 5.0	SSL	4.8' to 6.8': 17-12-22-16	Brm SILT, little f-c Sand, moist (SAND CUSHION)	21.1	A-4	ML	F4	
				5.0 - 6.75	SSL		Gry-Cobalt f-c GRAVEL, some f-c Sand, little Silt, moist. (SUBGRADE - POSS. HIGHLY WEATHERED ROCK - Foliated bedrock-like appearance but friable and crumbles to soil when removed from the split spoon.)	2.3	A-1-a	GM	F2	
B-57-R	8/16/2023	57.0	10.75 R	0.0 - 0.54	6" Core	0.7 to 2.7': 26-26-24-23	6.5" Asphalt					
				0.54 - 2.75	SSL	2.7' to 4.7': 32-24-22-26	Gry-Brm f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)	5.6	A-1-a	GW-GM	S	
				2.75 - 4.75	SSL	4.7' to 6.7': 24-23-44-35	Brm f-m SAND, little (+) Silt, little (+) Gravel, moist (SAND CUSHION)	6.6	A-2-4	SM	F3	
				4.75 - 6.75	SSL		Brm f-m SAND and SILT, little (-) Gravel, moist (SUBGRADE)	13.0	A-4	SM	F3	
B-57-L	8/28/2023	57.0	8.75 L	0.0 - 0.46	6" Core	0.5' to 2.5': 32-51-44-41	5.5" Asphalt					
				0.46 - 2.5	SSL	2.5' to 4.5': 21-22-33-32	Brm-Gry f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)					
				2.5 - 6.5	SSL	4.5' to 6.5': 37-43-48-58	Olive-Brm f-m SAND and SILT, trace f Gravel, moist (SUBGRADE)					
B-58-R	8/14/2023	58.0	11.5 R	0.0 - 0.67	6" Core	0.8' to 2.8': 24-36-28-24	8" Asphalt					
				0.67 - 2.75	SSL	2.8' to 4.8': 13-20-22-21	Gry f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)	1.2	A-1-a	GW-GM	S	
				2.75 - 4.25	SSL	4.8' to 6.8': 20-16-16-15	Brm f SAND and SILT, moist. (SAND CUSHION)	11.2	A-4	SM	F3	
				4.25 - 6.75	SSL		Brm SILT and f SAND, moist (SUBGRADE)	22.3	A-4	ML	F4	
B-58-L	8/15/2023	58.0	9.5 L	0.0 - 0.63	6" Core	1.0' to 3.0': 27-29-22-19	7.5" Asphalt					
				0.63 - 2.5	SSL	3.0' to 5.0': 12-16-21-21	Brm-Gry f-c SAND and f-c GRAVEL, trace Silt, trace Wood fragments, moist (SUBBASE)					
				2.5 - 7.0	SSL	5.0' to 7.0': 10-12-14-13	Brm SILT, some f-c Sand, moist (SUBGRADE)					

BORING	DATE	APPRO. MARKER	CL. OFFS.	DEPTH	SAMPL.	HAM B/C (3" Split Not Per D14)	COLOR, SOIL TYPE, MOISTURE	(Burmeister)	% MOIST.	AASHI CLASS	USCS	FROST
B-59.05-R	8/14/2023	59.1	11.25 R	0.0 - 0.77	6" Core	1.0' to 3.0': 28-26-28-30	9.25" Asphalt					
				0.77 - 3.0	SSL	3.0' to 5.0': 14-20-20-13	Gry-Red f-c GRAVEL and f-c SAND, trace Silt, moist (SUBBASE)					
				3.0 - 4.25	SSL	5.0' to 7.0': 9-12-18-18	Brm f-m SAND, some Silt, trace Gravel, moist (SAND CUSHION)					
				4.25 - 7.0	SSL		Brm-Gry SILT to Clayey SILT, trace Sand, moist (SUBGRADE)					
B-59.05-L	8/15/2023	59.1	9.5 L	0.0 - 0.63	6" Core	1.2' to 3.2': 23-30-30-16	7.5" Asphalt					
				0.63 - 2.5	SSL	3.2' to 5.2': 12-11-10-11	Brm-Gry f-c SAND and f-c GRAVEL, trace Silt, moist (SUBBASE)	3.1	A-1-a	GW-GM	S	
				2.5 - 5.0	SSL	5.2' to 7.2': 13-13-16-18	Brm SILT and f-c SAND, some f Gravel, moist (SAND CUSHION)	12.4	A-4	SM	F3	
				5.0 - 7.25	SSL		Brm-Gry SILT to Clayey SILT, trace f-c Sand, moist (SUBGRADE)	22.3	A-4	ML	F4	
B-60-R	9/7/2023	60.0	8.25 R	0.0 - 0.79	6" Core	0.8' to 2.8': 34-49-57-40	9.5" Asphalt					
				0.79 - 2.75	SSL	2.8' to 4.8': 25-30-35-55	Gry-Brm f-c GRAVEL, little f-c Sand, trace Silt, moist (SUBBASE)	2.9	A-1-a	GW-GM	S	
				2.75 - 6.75	SSL	4.8' to 6.8': NR-NR-47-51	Gray-Brm to Brm SILT and f-c SAND, little f Gravel, moist (SUBGRADE)	13.3	A-4	ML	F4	
B-60-L	9/7/2023	60.0	7.5 L	0.0 - 0.83	6" Core	1.0' to 3.0': 23-30-30-16	10" Asphalt					
				0.83 - 3.5	SSL	3.0' to 5.0': 12-11-10-11	Gry-Brm f-c GRAVEL, some Sand, little Silt, moist (SUBBASE)					
				3.5 - 5.0	SSL	5.0' to 7.0': 13-13-16-18	Brm f-c SAND and SILT, trace f Gravel, moist (SAND CUSHION)					
				5.0 - 6.75	SSL		Gry SILT and f-c SAND, little f Gravel, moist (SUBGRADE)					
B-61-R	8/14/2023	61.0	11 R	0.0 - 0.79	6" Core	1.0' to 3.0': 10-29-36-34	9.5" Asphalt					
				0.79 - 3.0	SSL	3.0' to 5.0': 26-22-23-27	Gry-Brm f-c GRAVEL and f-c SAND, trace Silt, moist (SUBBASE)	2.4	A-1-a	GW-GM	S	
				3.0 - 5.0	SSL	5.0' to 7.0': 14-19-20-18	Brm f-m SAND, some f-c Gravel, little Silt, moist (SAND CUSHION)	4.6	A-2-4	SM	F2	
				5.0 - 7.0	SSL		Brm f-c GRAVEL and f-m SAND, little Silt, moist (SUBGRADE)	3.7	A-1-b	GM	F2	
B-61-L	8/15/2023	61.0	10 L	0.0 - 0.77	6" Core	0.7' to 2.7': 14-38-40-39	9.25" Asphalt					
				0.77 - 2.75	SSL	2.7' to 4.7': 24-2830-32	Gry-Brm f-c SAND and f-c GRAVEL, trace Silt, moist (SUBBASE)					
				2.75 - 4.5	SSL	4.7' to 6.7': 20-33-38-47	Brm f-m SAND, some Sil, trace Gravel, moist (SAND CUSHION)					
				4.5 - 6.75	SSL		Gry-Brm f-c SAND, little f-c Gravel, little Silt, moist. (SUBGRADE - POSS. HIGHLY WEATHERED ROCK - Foliated bedrock-like appearance but friable and crumbles to soil when removed from the split spoon.)					
B-62-R	8/10/2023	62.0	11.5 R	0.0 - 0.63	6" Core	0.7' to 2.7' 24-28-31-34;	7.5" Asphalt					
				0.63 - 3.25	SSL	2.7' to 4.7': 25-32-62-41	Gry f-c GRAVEL and f-c SAND, trace Silt, moist (SUBBASE)					

BORING	DATE D	APPRO MARK	CL OFFS	DEPT	SAMPL	HAM BLC (3" Split Not Per D14)	COLOR, SOIL TYPE, MOISTURE	(Burmeister)	% MOIST	AASH CLAS	USCS	FROST
B-62-L	8/11/2023	62.0	9.75 L	0.0 - 0.92	6" Core	1.0' to 3.0': 25-39-46-65	11" Asphalt					
				0.92 - 3.0	SSL	3.0' to 5.0': 26-18-33-42	Gry f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)	4.2	A-1-a	GW-GM	S	
				3.0 - 4.5	SSL	5.0' to 5.8': 43-100/4"	Brn f-m SAND and f-c GRAVEL, some Silt, moist (SAND CUSHION)	6.8	A-2-4	SM	F2	
				4.5 - 5.8	SSL		Grn f-m SAND, some Silt, little Gravel, moist (SUBGRADE - POSS. HIGHLY WEATHERED ROCK - Foliated bedrock-like appearance but friable and crumbles to soil when removed from the split spoon.)	11.8	A-2-4	SM	F3	
B-63-R	8/10/2023	63.0	10 R	0.0 - 0.79	6" Core	1.0' to 3.0': 23-44-41-39	9.5" Asphalt					
				0.79 - 3.5	SSL	3.0' to 5.0': 27-27-50-52	Gry f-c GRAVEL, some f-c Sand, trace Silt, moist (SUBBASE)	3.7	A-1-a	GP	S	
				3.5 - 7.0	SSL	5.0' to 7.0': 24-50-55-37	Brn-Gry f-m SAND, some Silt, trace f Gravel, moist (SUBGRADE)	11.8	A-2-4	SM	F3	
								11.2	A-2-4	SM	F2	
B-63-L	8/11/2023	63.0	9 L	0.0 - 0.75	6" Core	1.0' to 3.0': 18-27-43-18	9" Asphalt					
				0.75 - 2.5	SSL	3.0' to 5.0': 11-7-6-13	Brn-Gry f-c GRAVEL and f-c SAND, trace Silt, moist (SUBBASE)					
				2.5 - 3.5	SSL	5.0' to 7.0': 18-23-19-17	Brn f-m SAND, some Silt, moist (SAND CUSHION)					
				3.5 - 5.75	SSL		Gry SILT to Clayey SILT, trace f-c Sand, moist (SUBGRADE 1)					
				5.75 - 7.0	SSL		Brn f-m SAND and SILT, moist (SUBGRADE 2)					

APPENDIX C
SUBBASE SIEVES



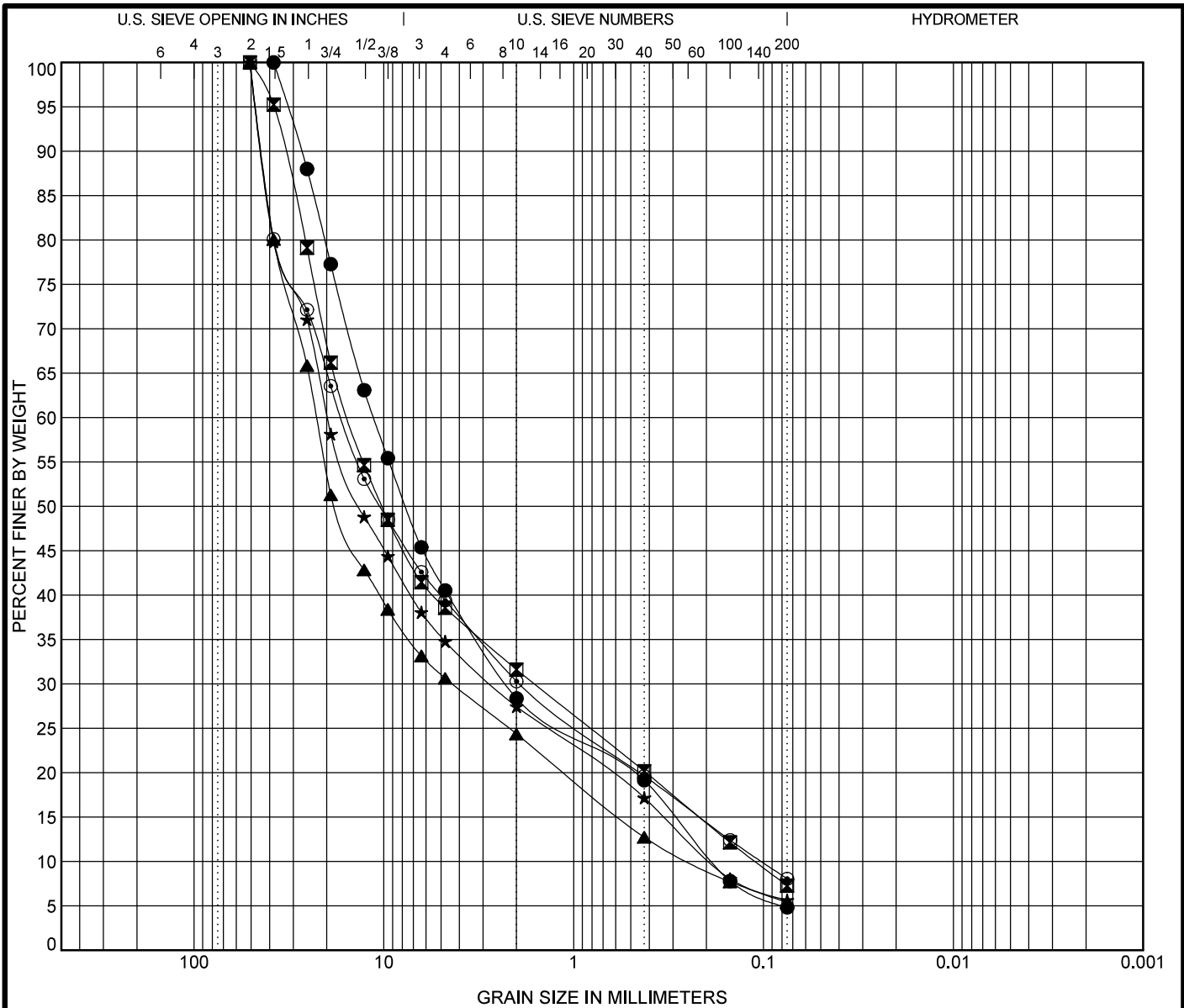
COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145, D2487)					LL	PL	PI	Cc	Cu
● B-52.85-L	1.0	A-1-b, SP-SM					NP	NP	NP	0.32	19.99
☒ B-52.85-L	3.0	A-1-b, SW-SM					NP	NP	NP	1.72	25.00
▲ B-54-R	0.8	A-1-a, GW-GM					NP	NP	NP	2.59	82.49
★ B-55-R	0.8	A-1-a, GP-GM					NP	NP	NP	3.66	56.77
⊙ B-56-L	0.8	A-1-a, GW-GM					NP	NP	NP	2.29	65.72
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay		
● B-52.85-L	1.0	75	1.931	0.243	0.097	39.7	52.5	7.8			
☒ B-52.85-L	3.0	38.1	1.357	0.356		30.9	57.1	12.0			
▲ B-54-R	0.8	50.8	13.576	2.405	0.165	72.1	21.6	6.3			
★ B-55-R	0.8	50.8	11.826	3.001	0.208	75.8	19.0	5.2			
⊙ B-56-L	0.8	50.8	11.126	2.078	0.169	70.5	24.1	5.4			



GRAIN SIZE DISTRIBUTION
 Project Name: Montpelier - Waterbury IM 089-2(56) -
 SUBBASE SIEVES
 Testing Performed By: BHA / JAC / KEW
 Testing Reviewed By: JFW
 Testing Date: September 12 through October 10, 2023
 Testing performed in general accordance with AASHTO T27 & T11.

GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23



COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145 , D2487)	LL	PL	PI	Cc	Cu
● B-56-R	0.8	A-1-a , GW	NP	NP	NP	2.43	61.58
☒ B-57-R	0.8	A-1-a , GW-GM	NP	NP	NP	1.52	138.62
▲ B-58-R	0.8	A-1-a , GP-GM	NP	NP	NP	3.47	93.71
★ B-59.05-L	1.0	A-1-a , GW-GM	NP	NP	NP	1.96	105.88
◎ B-60-R	0.8	A-1-a , GW-GM	NP	NP	NP	2.17	162.30

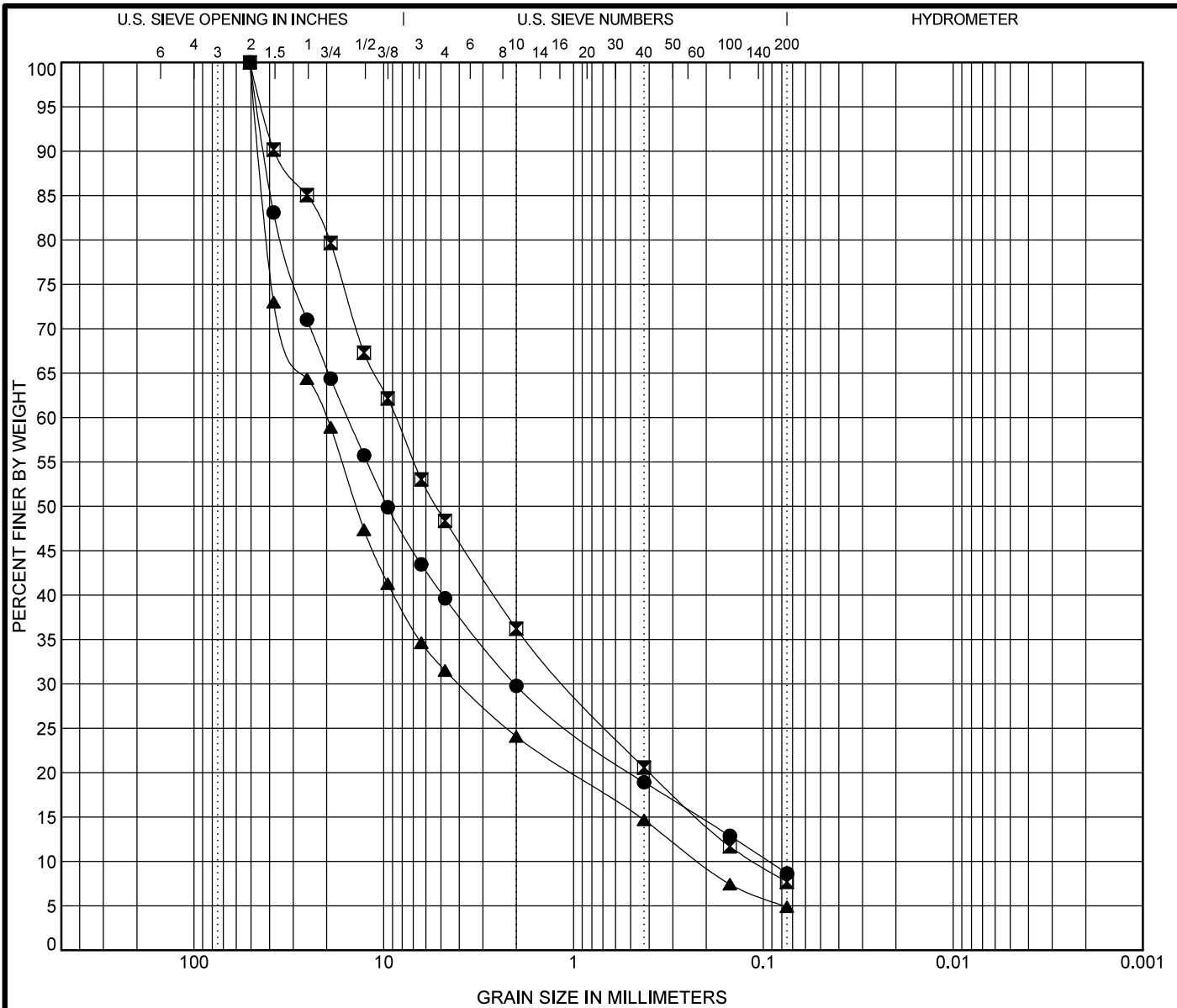
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-56-R	0.8	38.1	11.312	2.247	0.184	71.6	23.5	4.8	
☒ B-57-R	0.8	50.8	15.329	1.607	0.111	68.4	24.3	7.3	
▲ B-58-R	0.8	50.8	22.628	4.356	0.241	75.6	19.0	5.4	
★ B-59.05-L	1.0	50.8	19.859	2.701	0.188	72.5	21.8	5.6	
◎ B-60-R	0.8	50.8	16.601	1.919	0.102	69.7	22.2	8.0	



GEO DESIGN

GRAIN SIZE DISTRIBUTION
 Project Name: Montpelier - Waterbury IM 089-2(56) -
 SUBBASE SIEVES
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GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23



COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145 , D2487)	LL	PL	PI	Cc	Cu
● B-61-R	1.0	A-1-a , GW-GM	NP	NP	NP	2.87	165.77
☒ B-62-L	1.0	A-1-a , GW-GM	NP	NP	NP	1.21	77.40
▲ B-63-R	0.9	A-1-a , GP	NP	NP	NP	3.63	93.04

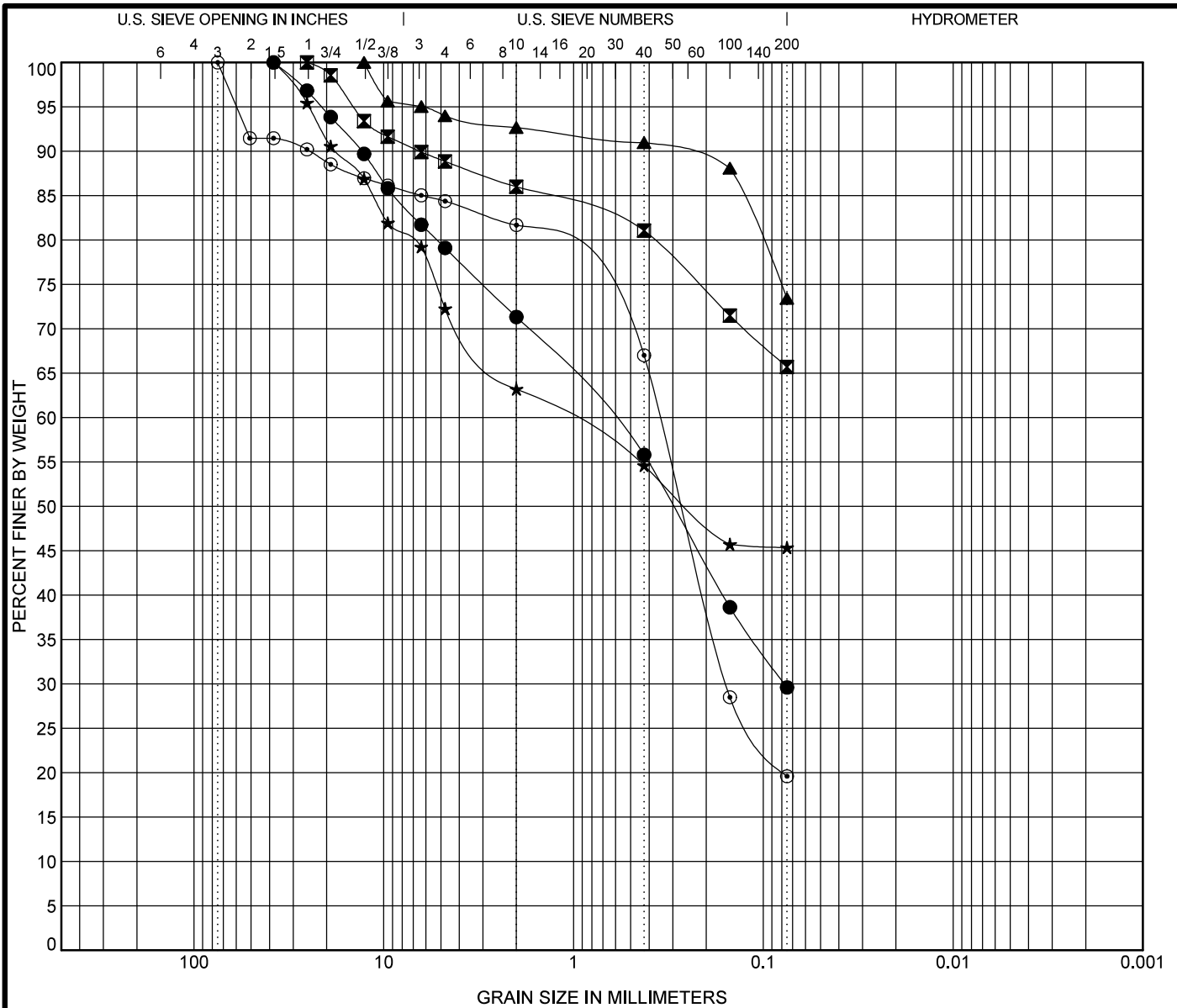
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-61-R	1.0	50.8	15.51	2.039	0.094	70.2	21.1	8.7	
☒ B-62-L	1.0	50.8	8.656	1.081	0.112	63.8	28.5	7.7	
▲ B-63-R	0.9	50.8	20.178	3.986	0.217	75.9	19.2	4.9	



GRAIN SIZE DISTRIBUTION
 Project Name: Montpelier - Waterbury IM 089-2(56) -
 SUBBASE SIEVES
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 Testing Reviewed By: JFW
 Testing Date: September 12 through October 10, 2023
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GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23

APPENDIX C
SAND CUSHION SIEVES



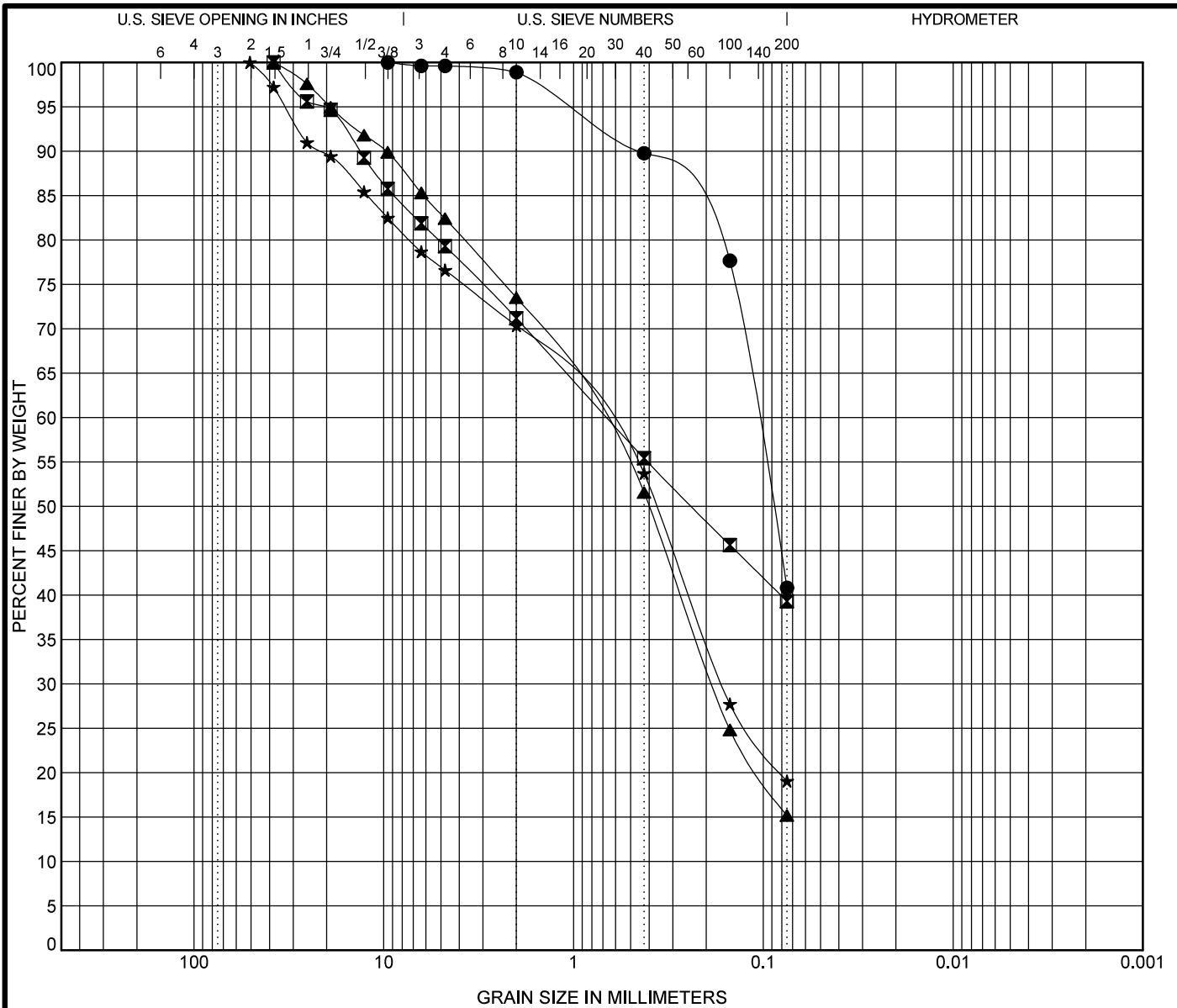
COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145, D2487)				LL	PL	PI	Cc	Cu
● B-54-R	2.8	A-2-4, SM				NP	NP	NP		
☒ B-55-R	2.8	A-4, ML				NP	NP	NP		
▲ B-56-L	2.8	A-4, ML				NP	NP	NP		
★ B-56-R	2.8	A-4, GM				NP	NP	NP		
◎ B-57-R	2.8	A-2-4, SM				NP	NP	NP		
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay	
● B-54-R	2.8	38.1	0.646	0.077		28.7	41.7	29.6		
☒ B-55-R	2.8	25.4				14.0	20.3	65.7		
▲ B-56-L	2.8	12.7				7.3	19.3	73.4		
★ B-56-R	2.8	38.1	1.124			36.8	17.8	45.4		
◎ B-57-R	2.8	75	0.352	0.156		18.3	62.1	19.6		



GRAIN SIZE DISTRIBUTION
 Project Name: Montpelier - Waterbury IM 089-2(56) - SAND CUSHION SIEVES
 Testing Performed By: BHA / JAC / KEW
 Testing Reviewed By: JFW
 Testing Date: September 12 through October 10, 2023
 Testing performed in general accordance with AASHTO T27 & T11.

GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23



COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145, D2487)	LL	PL	PI	Cc	Cu
● B-58-R	2.8	A-4, SM	NP	NP	NP		
☒ B-59.05-L	3.0	A-4, SM	NP	NP	NP		
▲ B-61-R	3.0	A-2-4, SM	NP	NP	NP		
★ B-62-L	3.0	A-2-4, SM	NP	NP	NP		

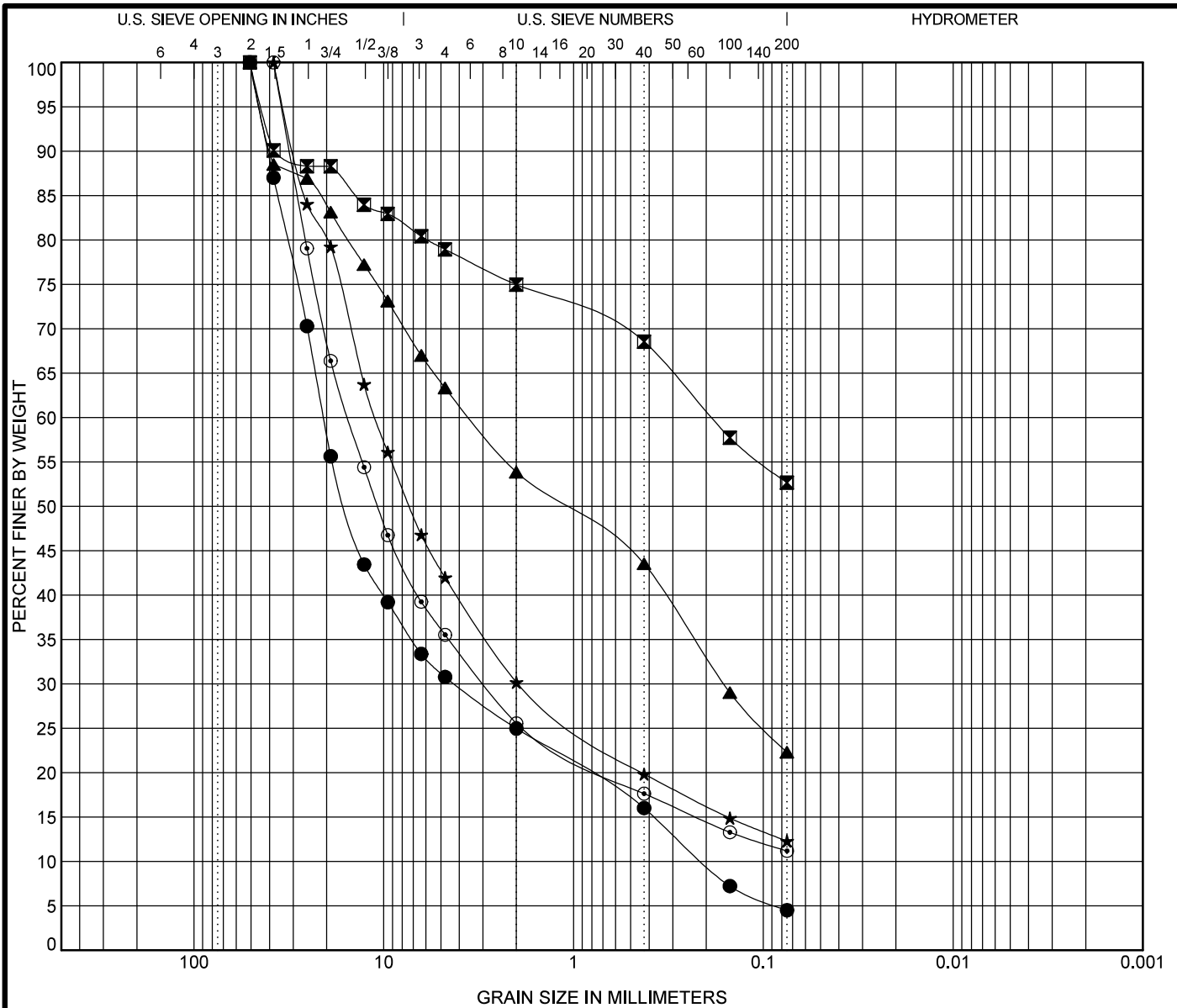
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-58-R	2.8	9.525	0.108			1.1	58.1	40.8	
☒ B-59.05-L	3.0	38.1	0.667			28.8	31.9	39.3	
▲ B-61-R	3.0	38.1	0.771	0.184		26.5	58.3	15.2	
★ B-62-L	3.0	50.8	0.762	0.164		29.6	51.3	19.1	



GRAIN SIZE DISTRIBUTION
 Project Name: Montpelier - Waterbury IM 089-2(56) - SAND CUSHION SIEVES
 Testing Performed By: BHA / JAC / KEW
 Testing Reviewed By: JFW
 Testing Date: September 12 through October 10, 2023
 Testing performed in general accordance with AASHTO T27 & T11.

GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23

APPENDIX C
SUBGRADE SIEVES



COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

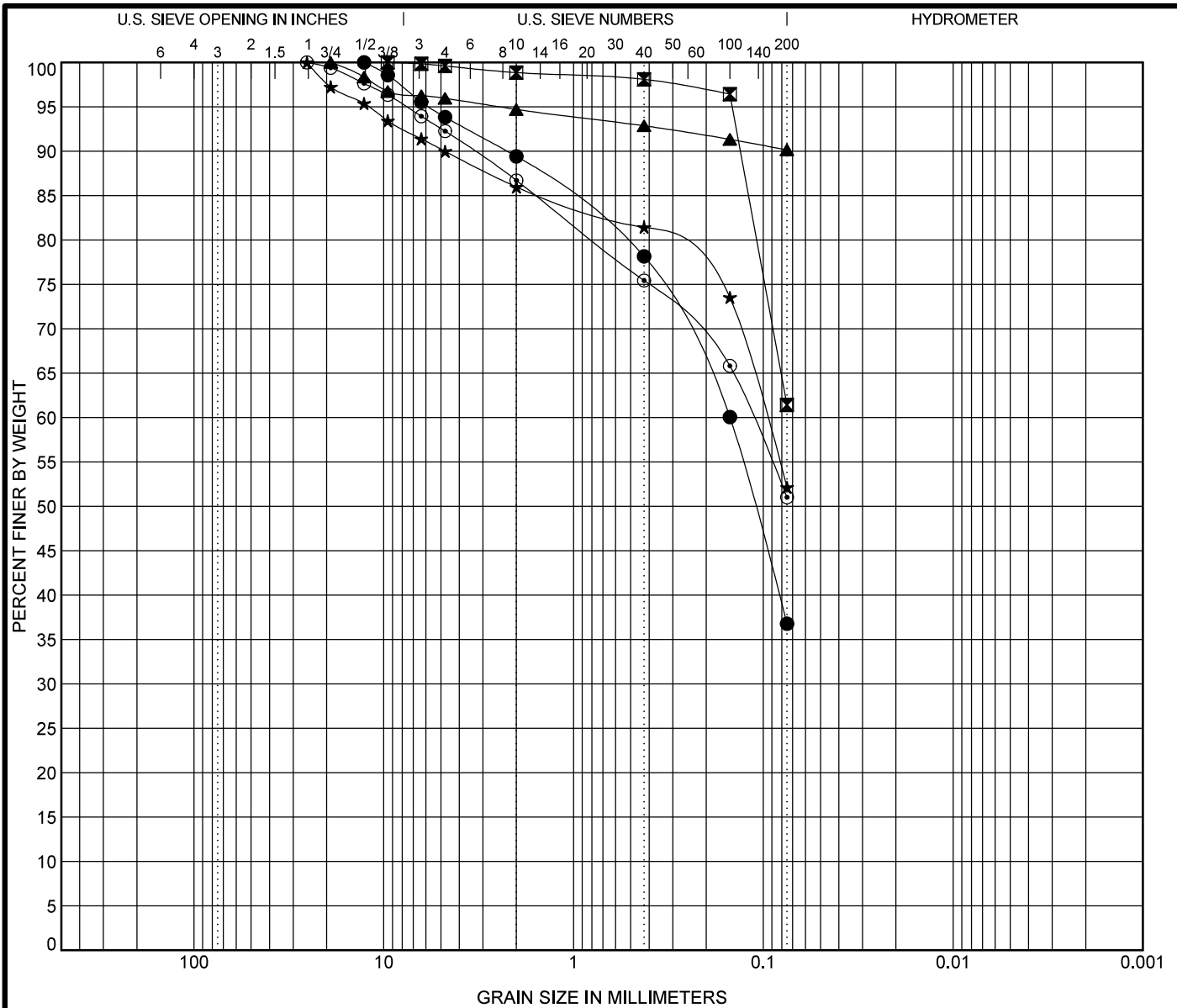
Boring	Start Depth (ft)	Classification (M145 , D2487)					LL	PL	PI	Cc	Cu
● B-52.85-L	5.0	A-1-a , GP					NP	NP	NP	4.14	99.56
☒ B-54-R	4.8	A-4 , ML					NP	NP	NP		
▲ B-55-R	4.8	A-1-b , SM					NP	NP	NP		
★ B-56-L	4.8	A-1-a , GM					NP	NP	NP	8.52	272.73
⊙ B-56-R	4.8	A-1-a , GP-GM					NP	NP	NP	11.12	302.96
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay		
● B-52.85-L	5.0	50.8	20.753	4.231	0.208	75.0	20.5	4.5			
☒ B-54-R	4.8	50.8	0.187			25.0	22.3	52.7			
▲ B-55-R	4.8	50.8	3.503	0.161		46.1	31.6	22.3			
★ B-56-L	4.8	38.1	11.029	1.95		69.8	17.9	12.3			
⊙ B-56-R	4.8	38.1	15.348	2.941		74.4	14.4	11.2			



GRAIN SIZE DISTRIBUTION

Project Name: Montpelier - Waterbury IM 089-2(56) - SUBGRADE SIEVES
 Testing Performed By: BHA / JAC / KEW
 Testing Reviewed By: JFW
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 Testing performed in general accordance with AASHTO T27 & T11.

GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23



COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145 , D2487)					LL	PL	PI	Cc	Cu
● B-57-R	4.8	A-4 , SM					NP	NP	NP		
☒ B-58-R	4.8	A-4 , ML					NP	NP	NP		
▲ B-59.05-L	5.0	A-4 , ML					NP	NP	NP		
★ B-60-R	2.8	A-4 , ML					NP	NP	NP		
◎ B-60-R	4.8	A-4 , ML					NP	NP	NP		

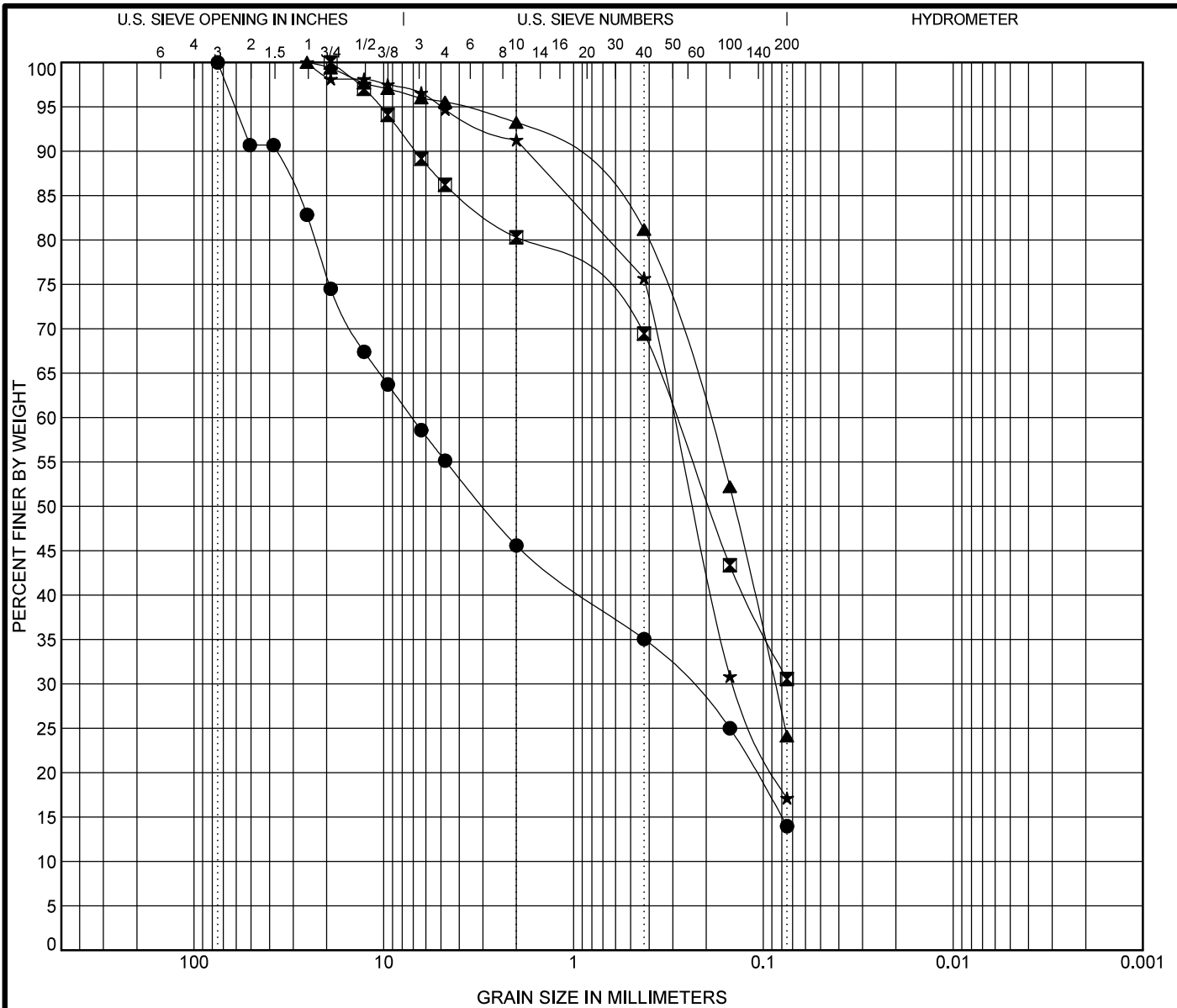
Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-57-R	4.8	12.7	0.15			10.6	52.6	36.8	
☒ B-58-R	4.8	9.525				1.1	37.4	61.4	
▲ B-59.05-L	5.0	19.05				5.3	4.6	90.2	
★ B-60-R	2.8	25.4	0.097			14.0	33.8	52.1	
◎ B-60-R	4.8	25.4	0.114			13.3	35.7	51.0	



GRAIN SIZE DISTRIBUTION

Project Name: Montpelier - Waterbury IM 089-2(56) - SUBGRADE SIEVES
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GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23



COBBLES	GRAVEL	SAND		SILT OR CLAY
		coarse	fine	

Boring	Start Depth (ft)	Classification (M145, D2487)					LL	PL	PI	Cc	Cu
● B-61-R	5.0	A-1-b, GM					NP	NP	NP		
☒ B-62-L	5.0	A-2-4, SM					NP	NP	NP		
▲ B-63-R	2.9	A-2-4, SM					NP	NP	NP		
★ B-63-R	4.9	A-2-4, SM					NP	NP	NP		

Boring	Start Depth (ft)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-61-R	5.0	75	7.102	0.252		54.4	31.6	14.0	
☒ B-62-L	5.0	19.05	0.291			19.7	49.8	30.5	
▲ B-63-R	2.9	25.4	0.198	0.087		6.8	69.1	24.1	
★ B-63-R	4.9	25.4	0.295	0.144		8.7	74.1	17.1	

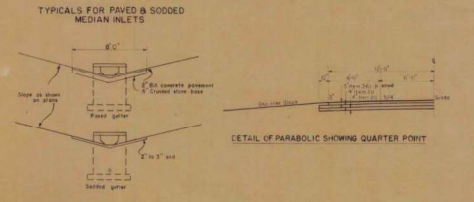
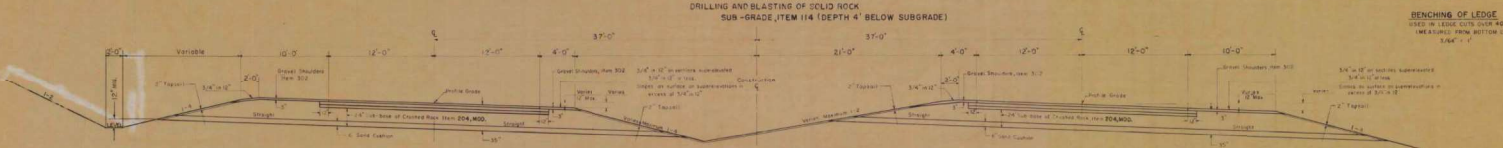
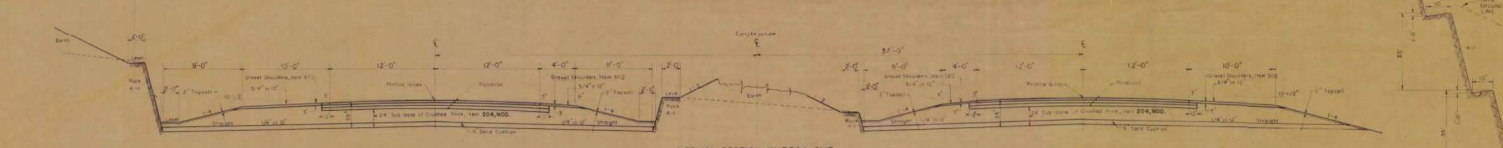
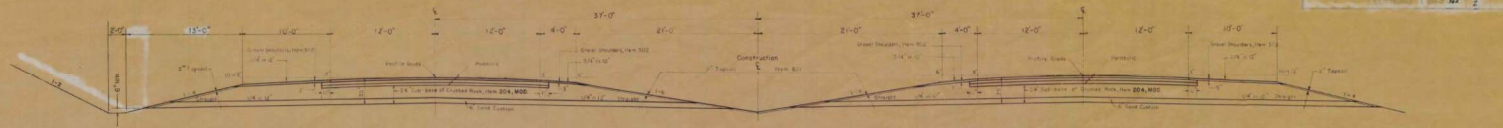


GRAIN SIZE DISTRIBUTION

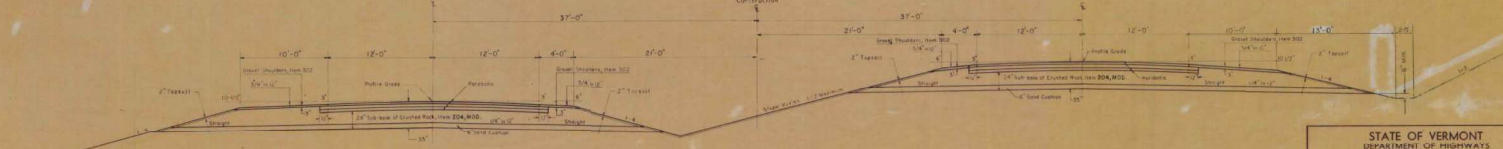
Project Name: Montpelier - Waterbury IM 089-2(56) - SUBGRADE SIEVES
 Testing Performed By: BHA / JAC / KEW
 Testing Reviewed By: JFW
 Testing Date: September 12 through October 10, 2023
 Testing performed in general accordance with AASHTO T27 & T11.

GEO SIEVE 750-12-21.GPJ VT AOT.GDT 10/11/23

APPENDIX D
1957 TYPICAL CONSTRUCTION DETAILS



3" BITUMINOUS CONCRETE PAVEMENT, ITEM 361 MOD.
2-4" CRUSHED STONE BASE COURSE, ITEM 211
24" SUB-BASE OF CRUSHED ROCK, ITEM 204 MOD.
3" GRAVEL SHOULDERS, ITEM 302
SINGLE TACK COAT OF CUTBACK ASPHALT WITH SAND COVER, ITEM 316-B, ON CRUSHED STONE BASE AT RATE OF 0.3 TO 0.5 GAL. PER SQ. YD.
DOUBLE TACK COAT OF BITUMINOUS MATERIAL WITH PEA STONE AND STONE CHITS SEAL, PRIME COAT OF REFINED TAR AND DOUBLE SEAL COAT OF CUTBACK ASPHALT, ITEM 315, ON GRAVEL SHOULDERS (MODIFIED)
CONSTRUCTED AS DESIGNED



GENERAL NOTES:
 When Shoulders are 17' feet or guard rail locations
 Whenever Item 204 MOD is used before match on Earth Slopes
 Match Item 204 MOD to be placed on all Earth Slopes
 See match Point, Item 204 MOD, to be placed as directed by the Engineer
 For rounding of slopes, see Road Way Standards, B-5
 Maximum width of Top of Rock Cut in Median shall be 160' (100) Feet

GENERAL NOTES (CONT):
 Seeding, Item 611 (per notes)
 Mulching, 250-45%
 Conoids Bluegrass 150-27%
 Dutch White Clover 100-18%
 Emerald Turf 150-20%
 Total 550-100%
 Water-Pay (after 15 August) 5000
 Fuel-Pay (10-10-01) 5000

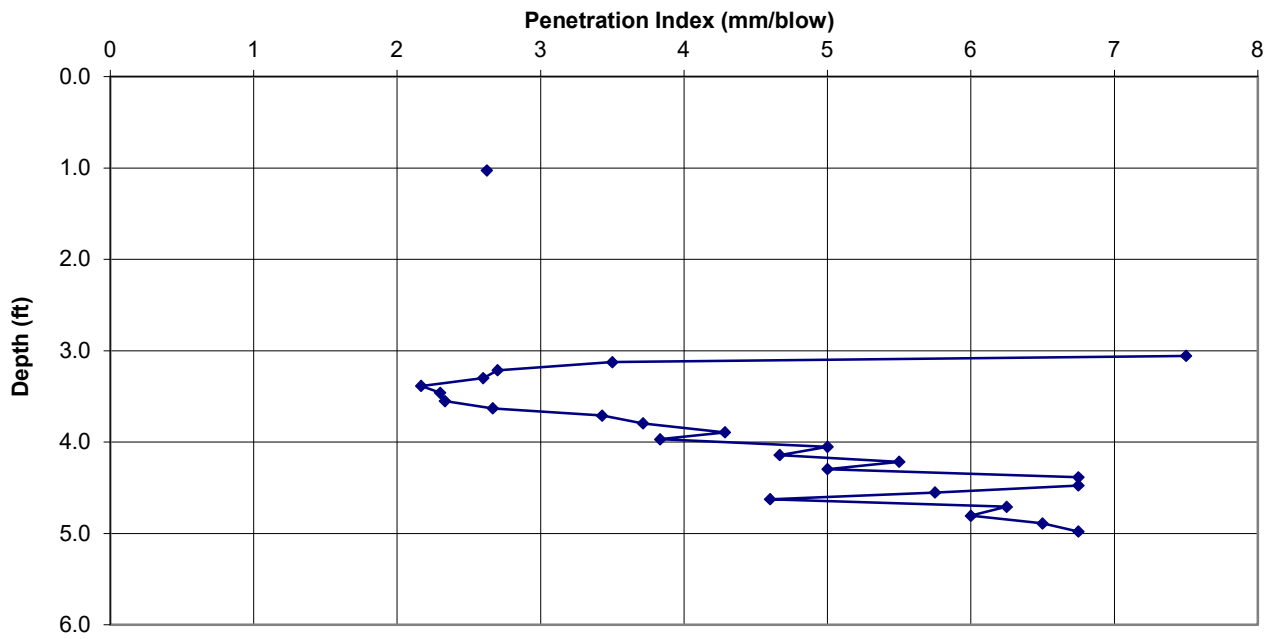
STATE OF VERMONT
 DEPARTMENT OF HIGHWAYS
 INTERSTATE PROJECT in the Towns of
 BERLIN - MONTPELIER - MIDDLESEX
 TYPICAL SECTIONS INTERSTATE

BOISWELL ENGINEERING CO.
 CONSULTING ENGINEERS
 REGISTERED PROFESSIONAL ENGINEERS
 DRAWN BY: [Name] CHECKED BY: [Name] SCALE: [Scale]
 PROJECT: 1-89-2 SHEET: 3 OF 3

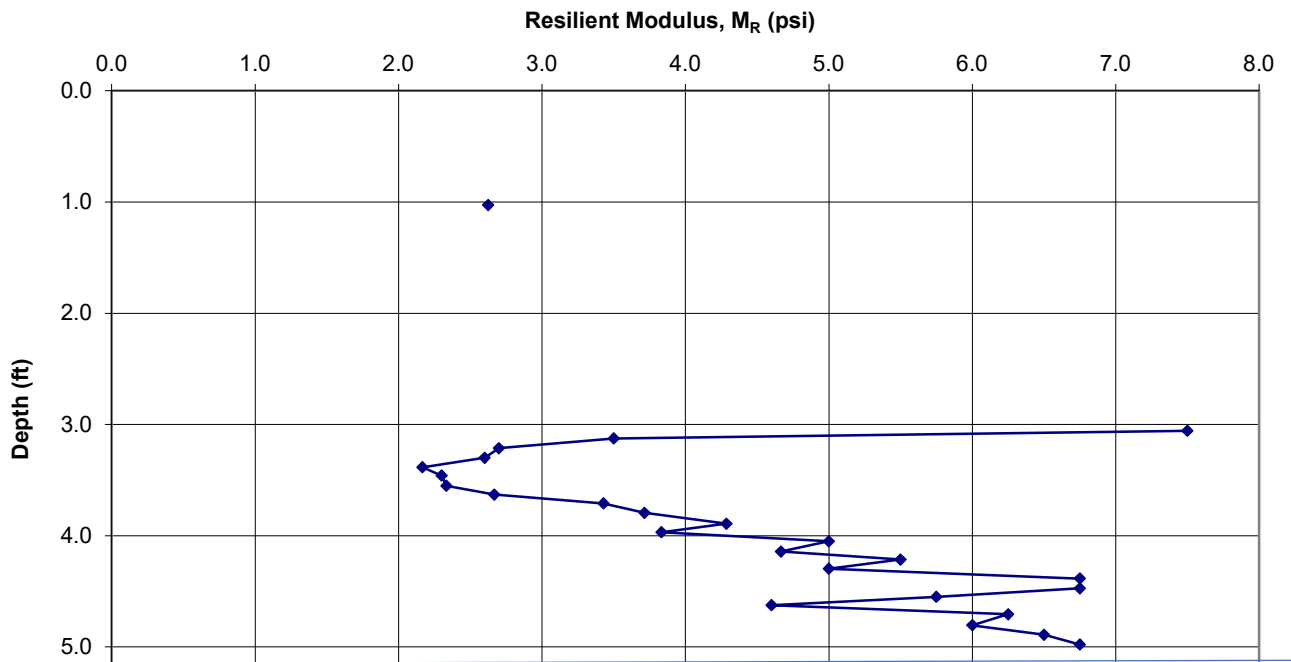
APPENDIX E

DCP PENETRATION INDEX AND RESILIENT MODULUS PLOTS

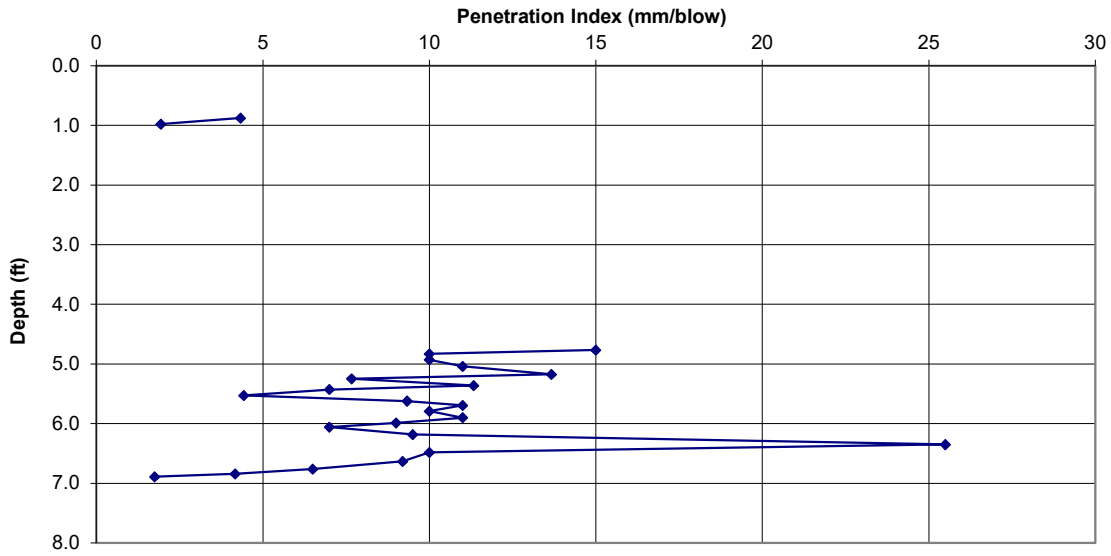
B-52.85-L - Penetration Index vs. Depth



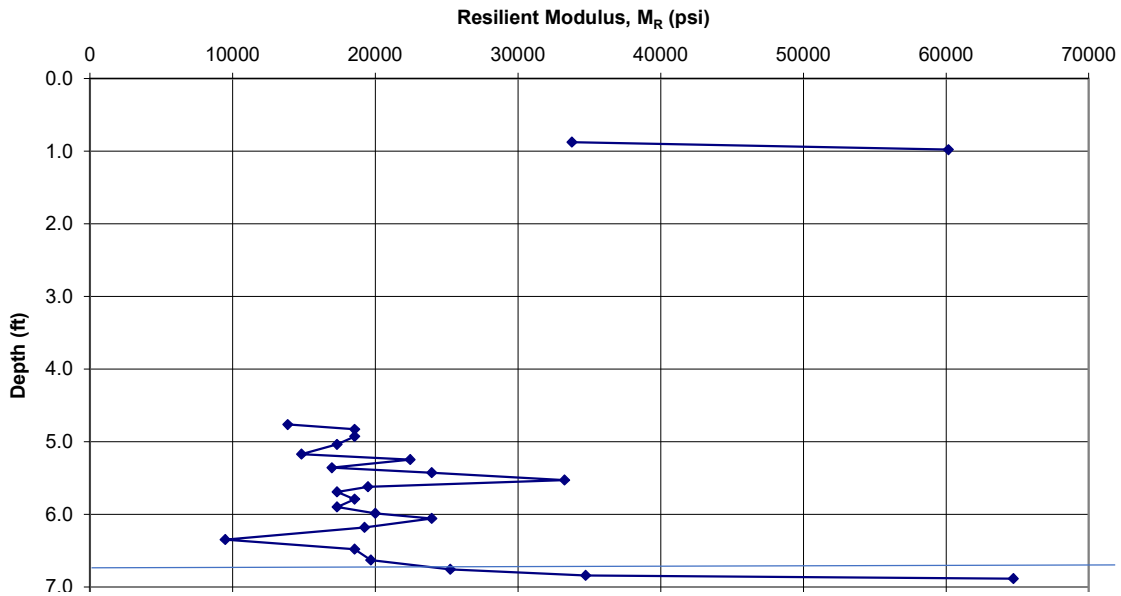
B-52.85-L - Resilient Modulus vs. Depth



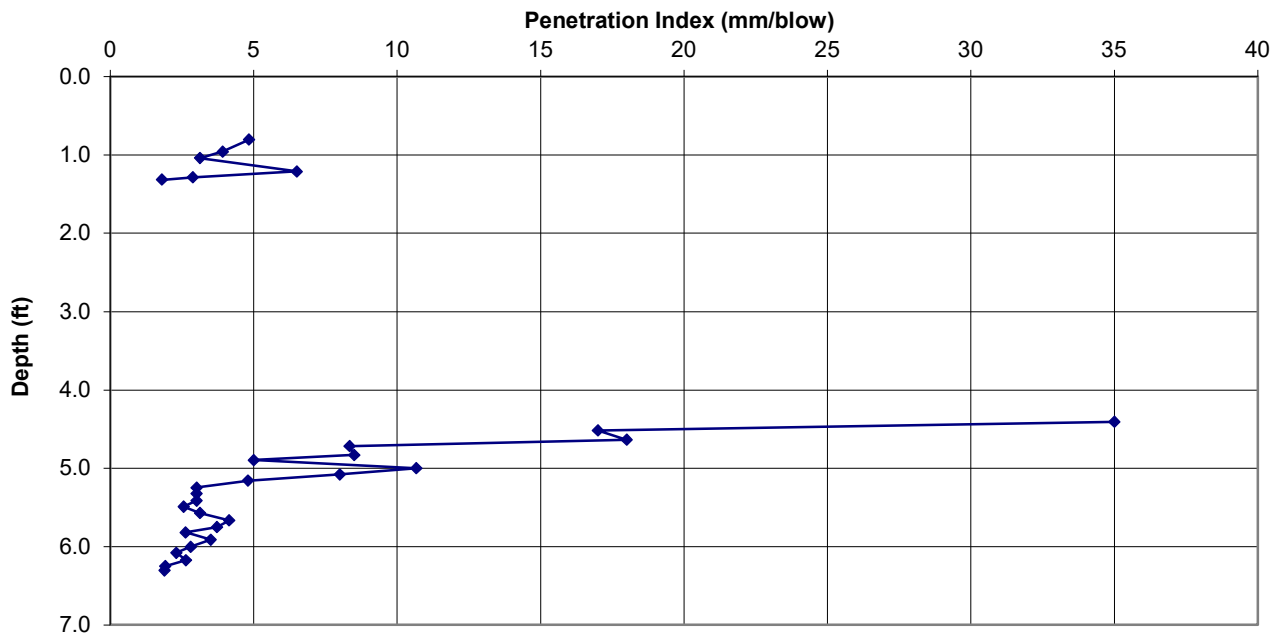
B-52.85-R - Penetration Index vs. Depth



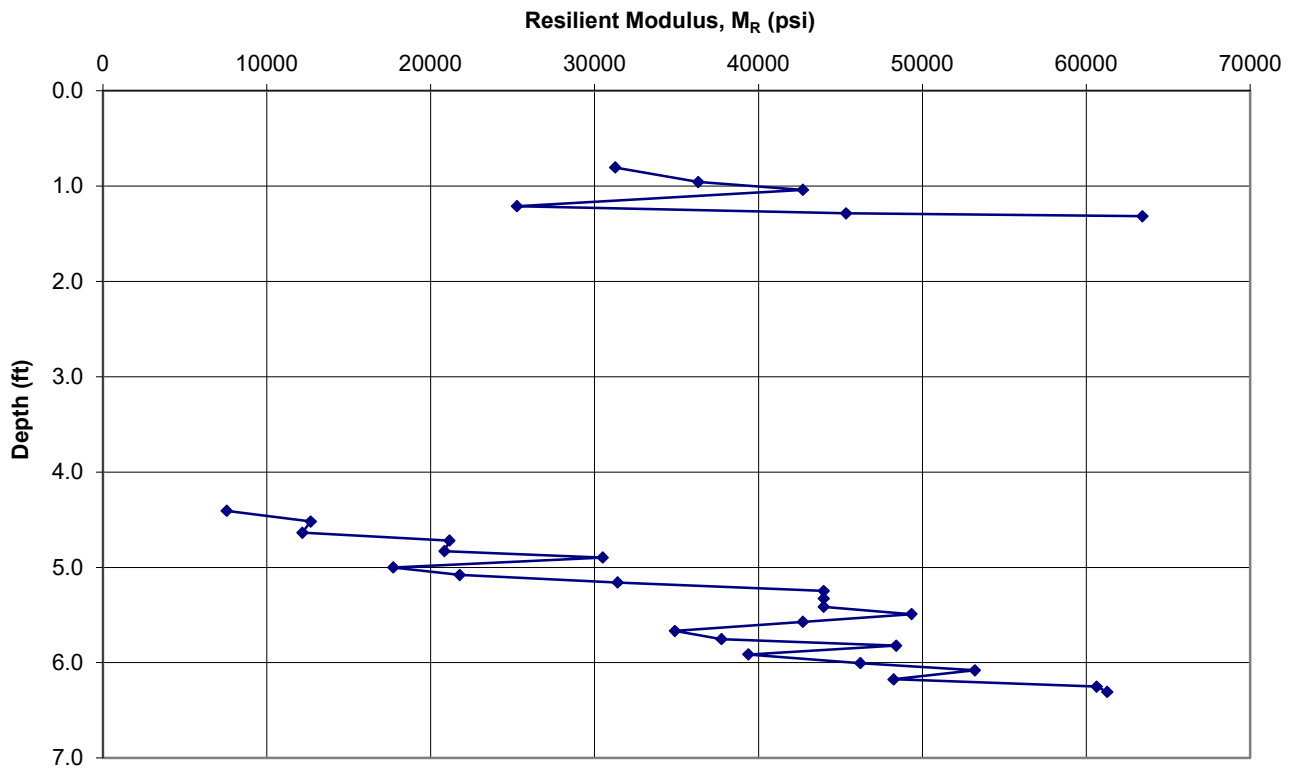
B-52.85-R - Resilient Modulus vs. Depth



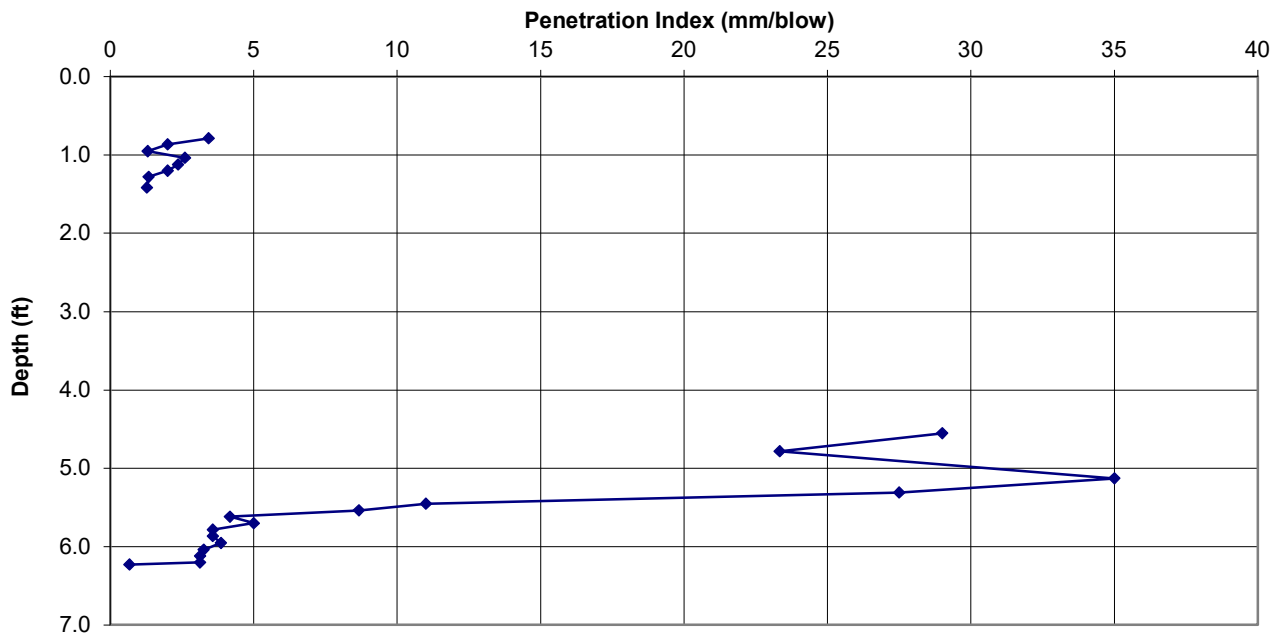
B-54-L - Penetration Index vs. Depth



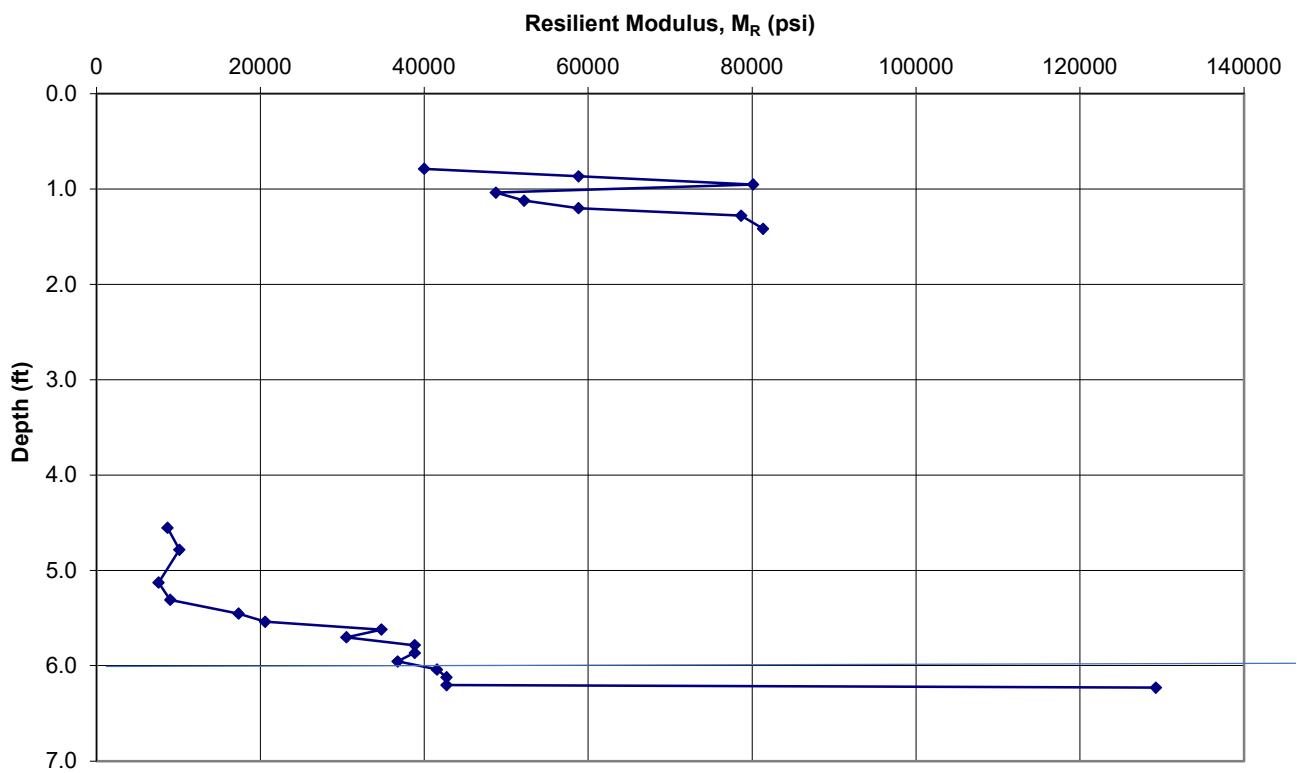
B-54-L - Resilient Modulus vs. Depth



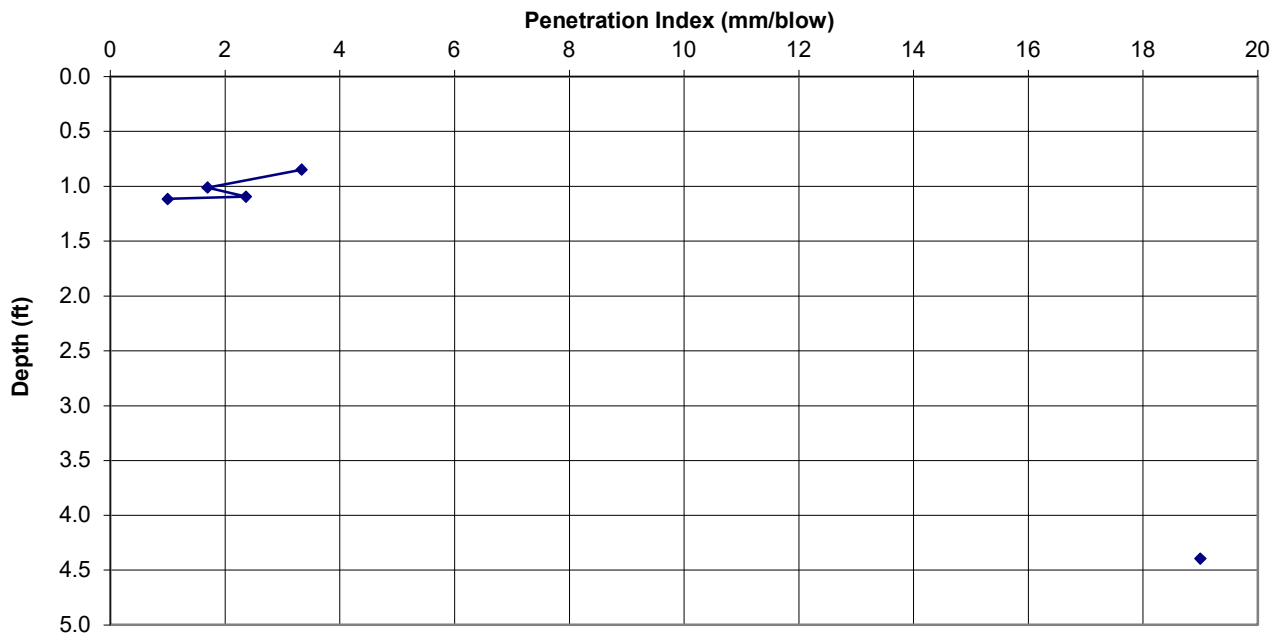
B-54-R - Penetration Index vs. Depth



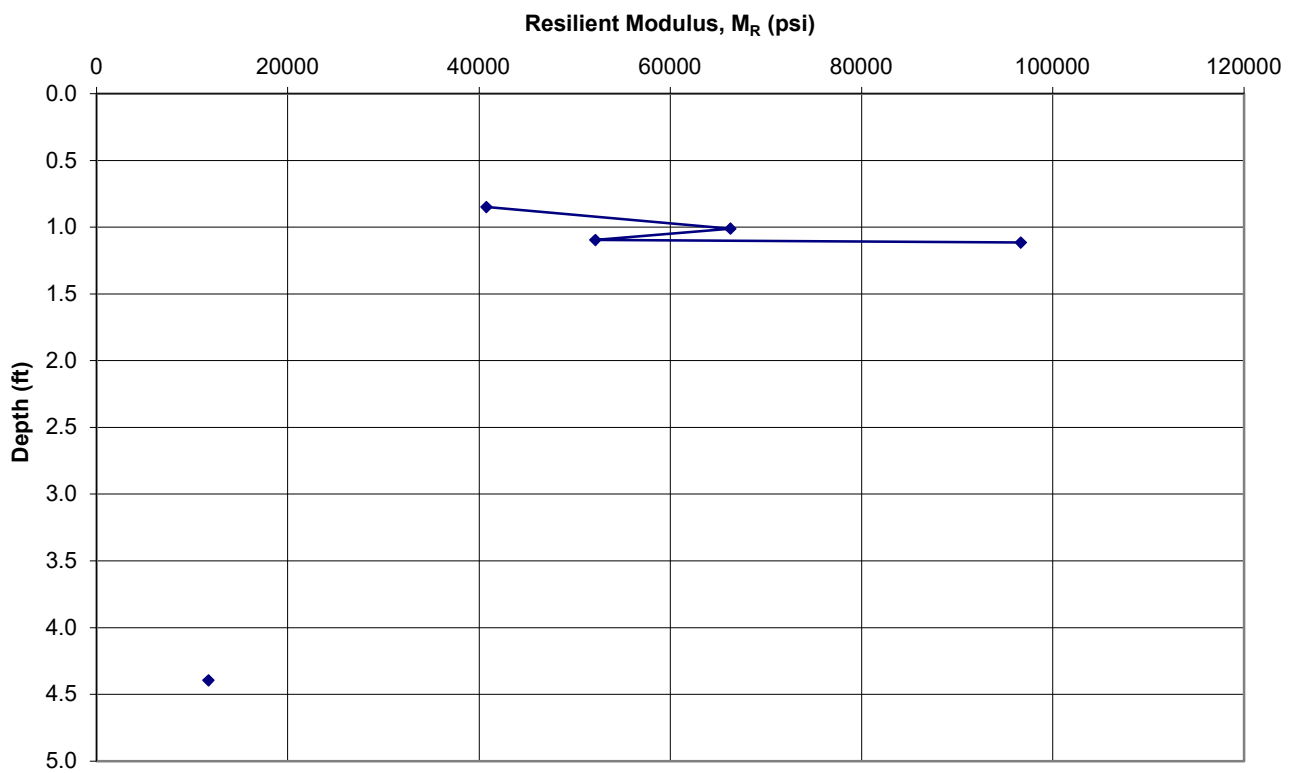
B-54-R - Resilient Modulus vs. Depth



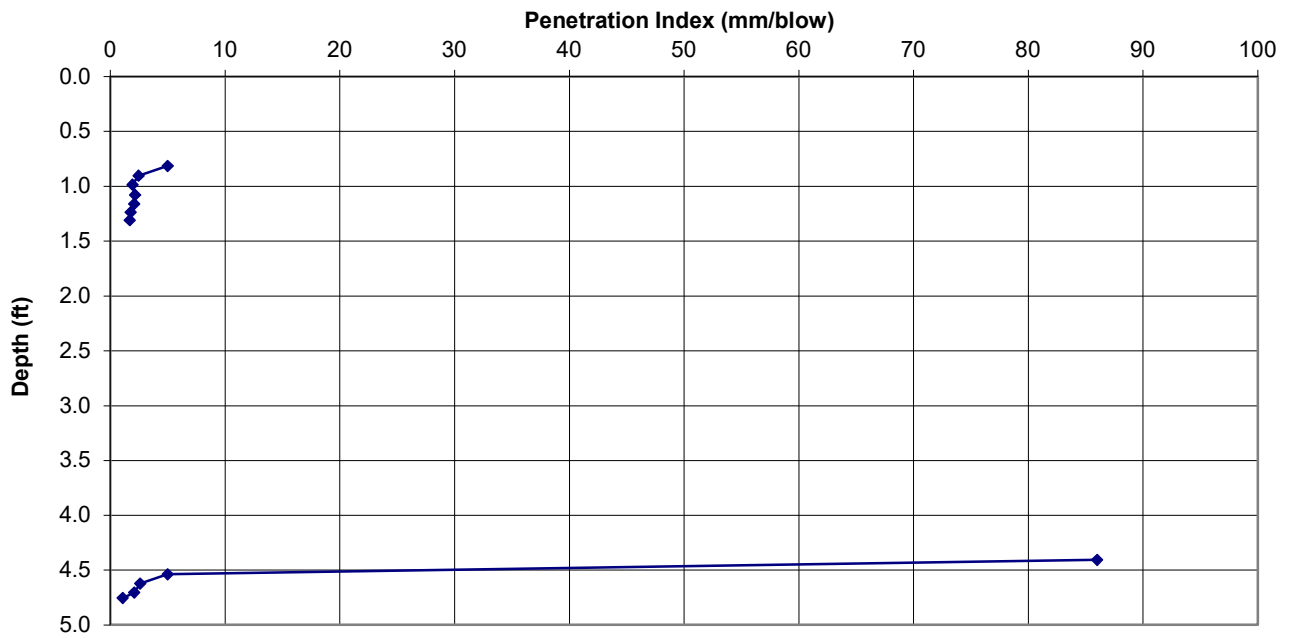
B-55-L - Penetration Index vs. Depth



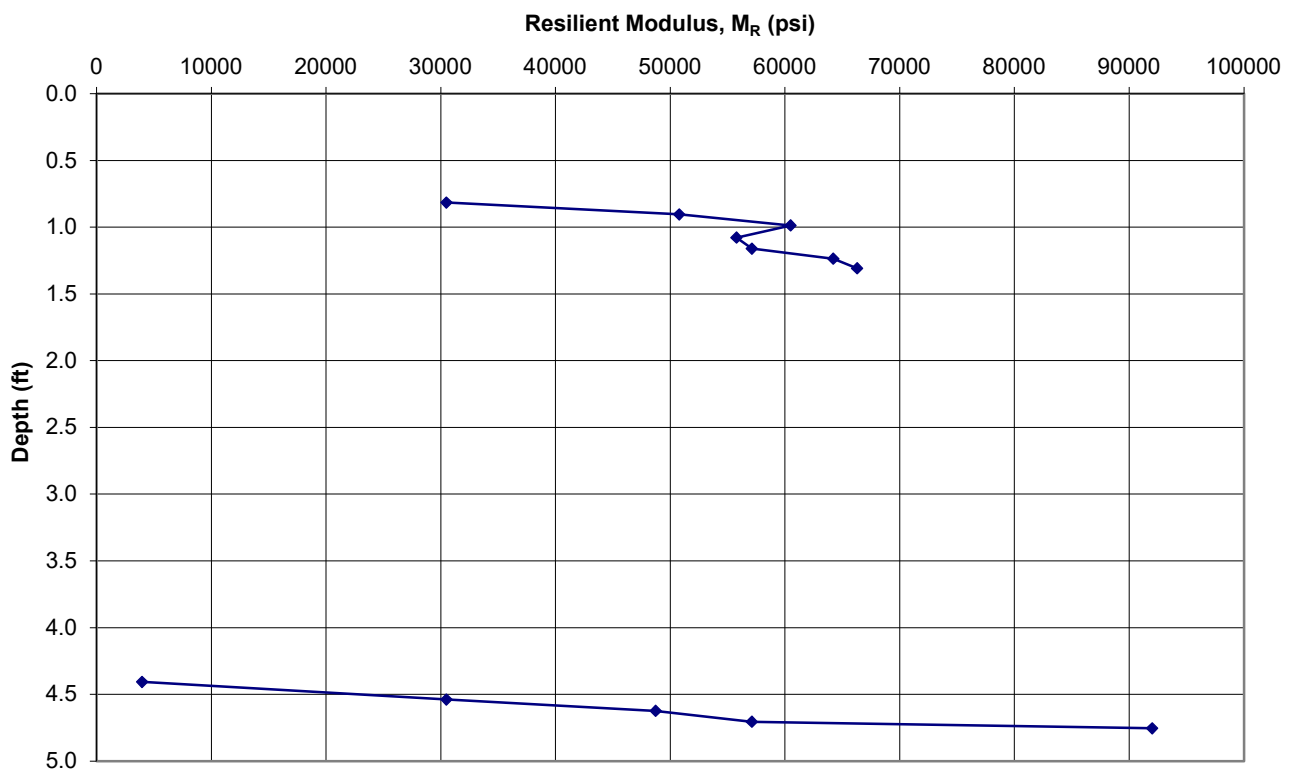
B-55-L - Resilient Modulus vs. Depth



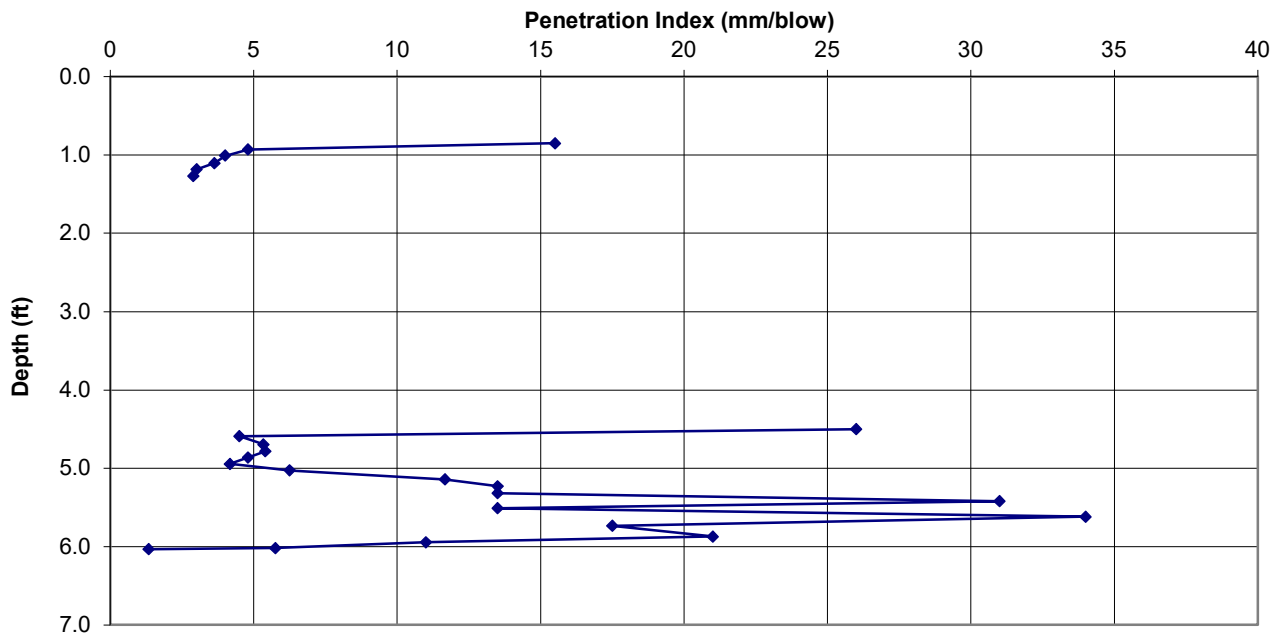
B-55-R - Penetration Index vs. Depth



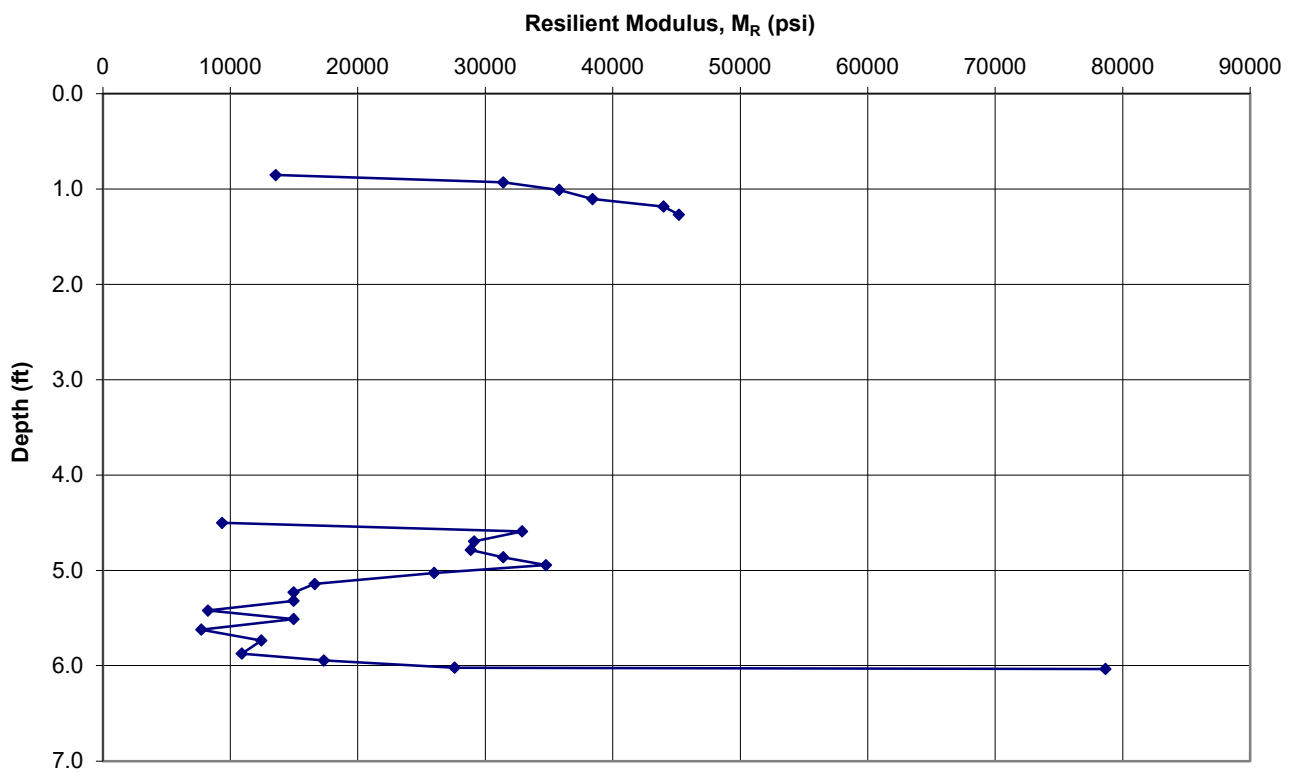
B-55-R - Resilient Modulus vs. Depth



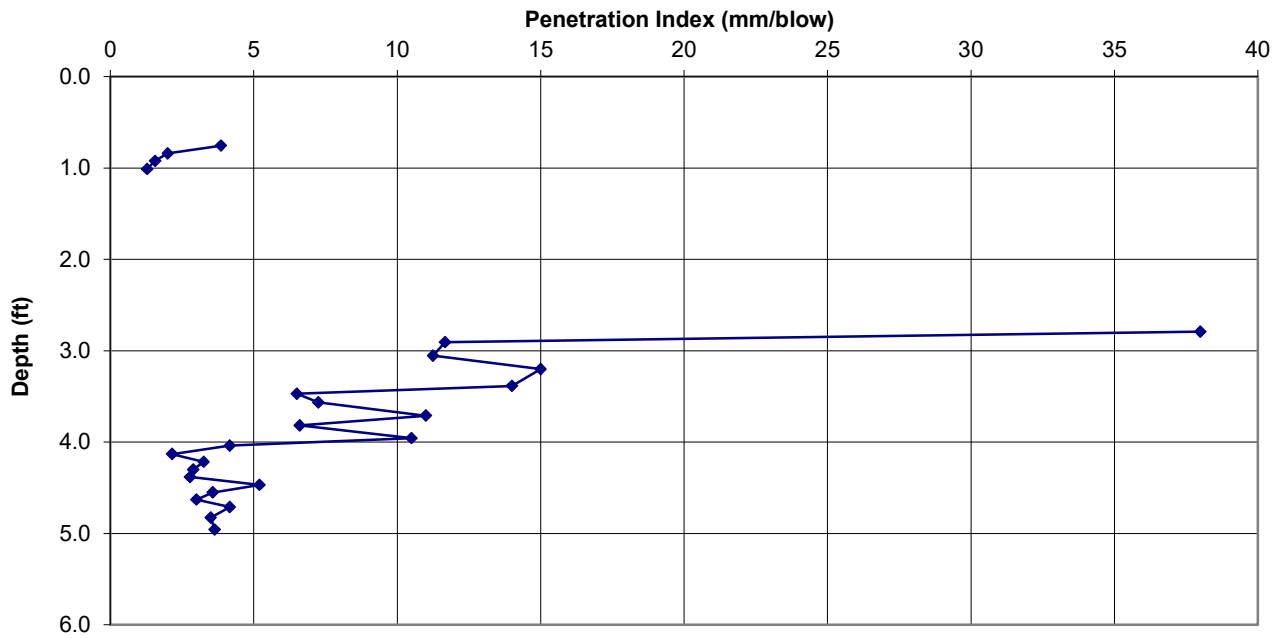
B-56-L - Penetration Index vs. Depth



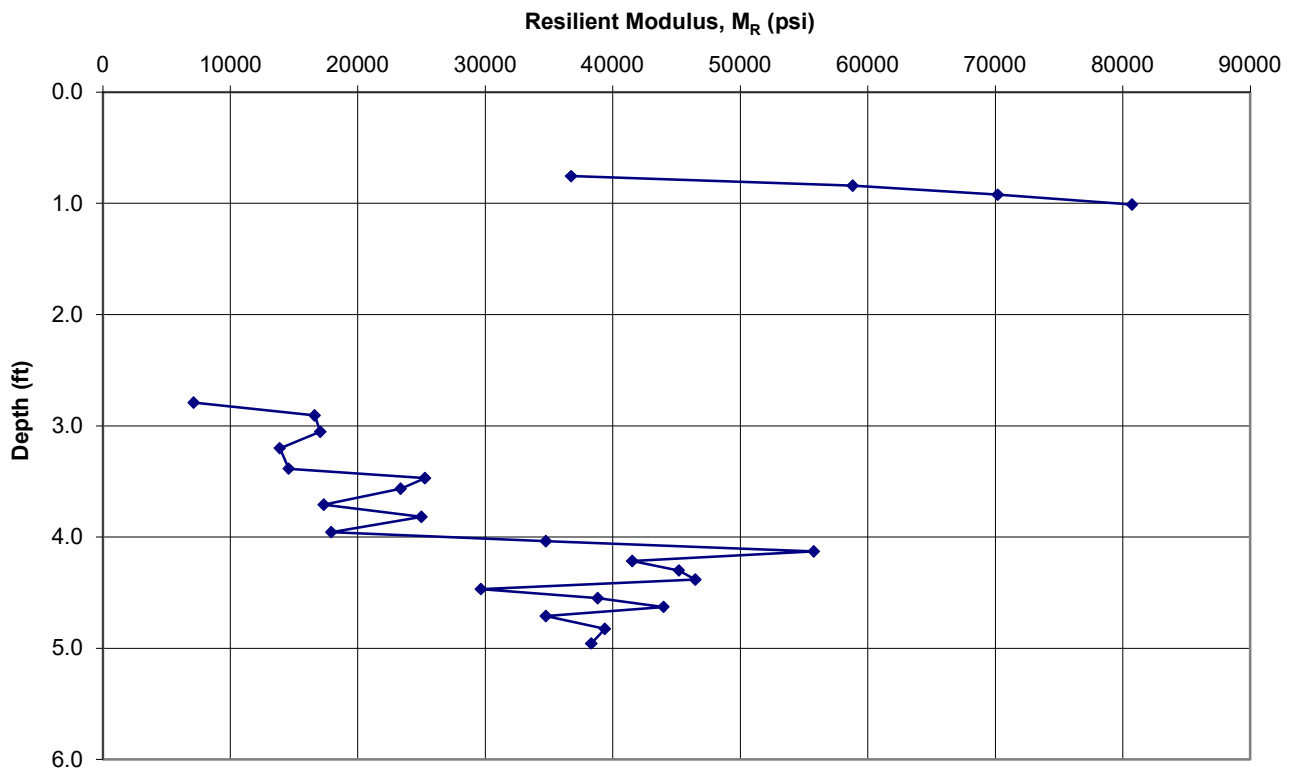
B-56-L - Resilient Modulus vs. Depth



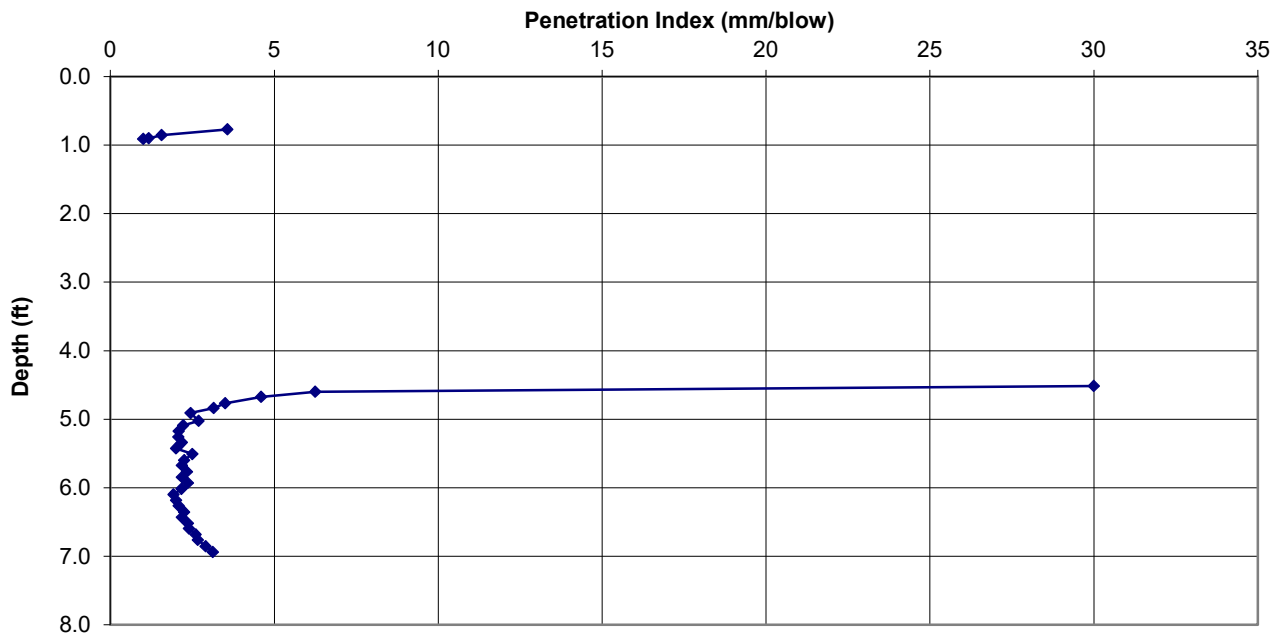
B-56-R - Penetration Index vs. Depth



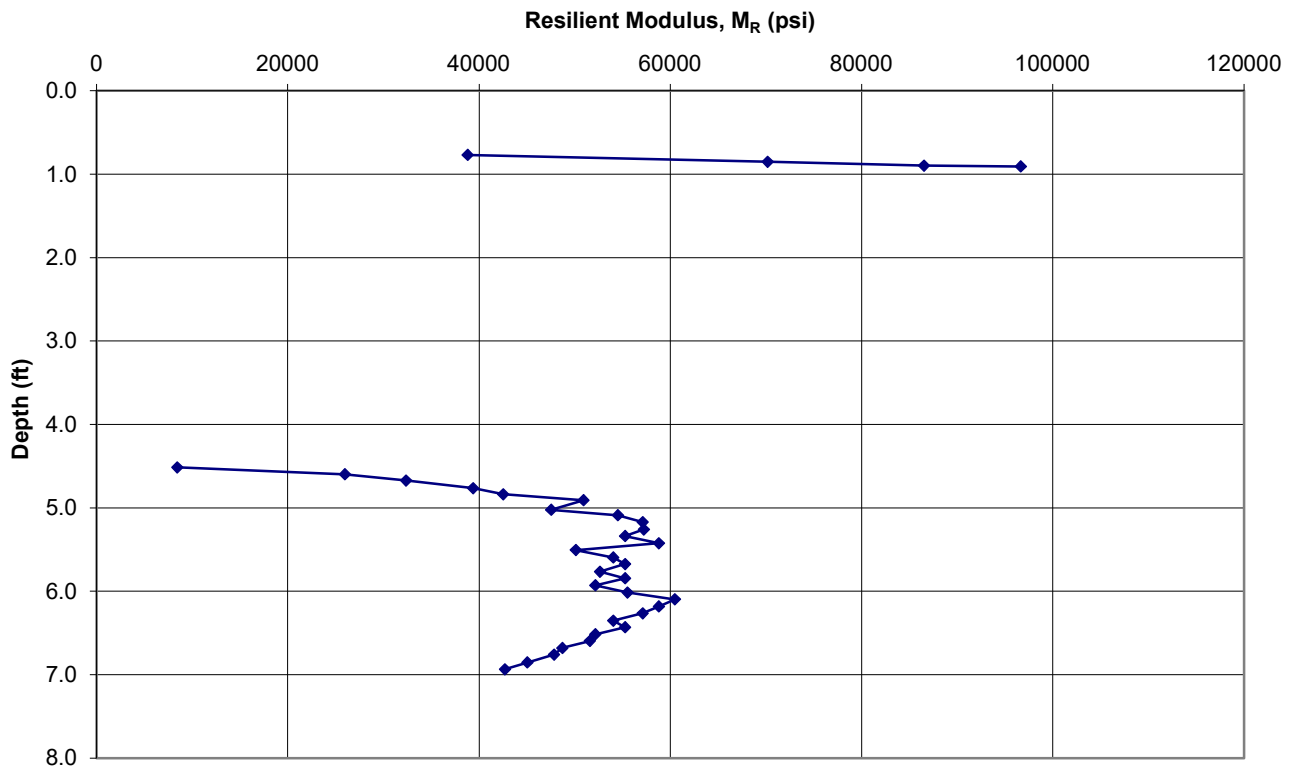
B-56-R - Resilient Modulus vs. Depth



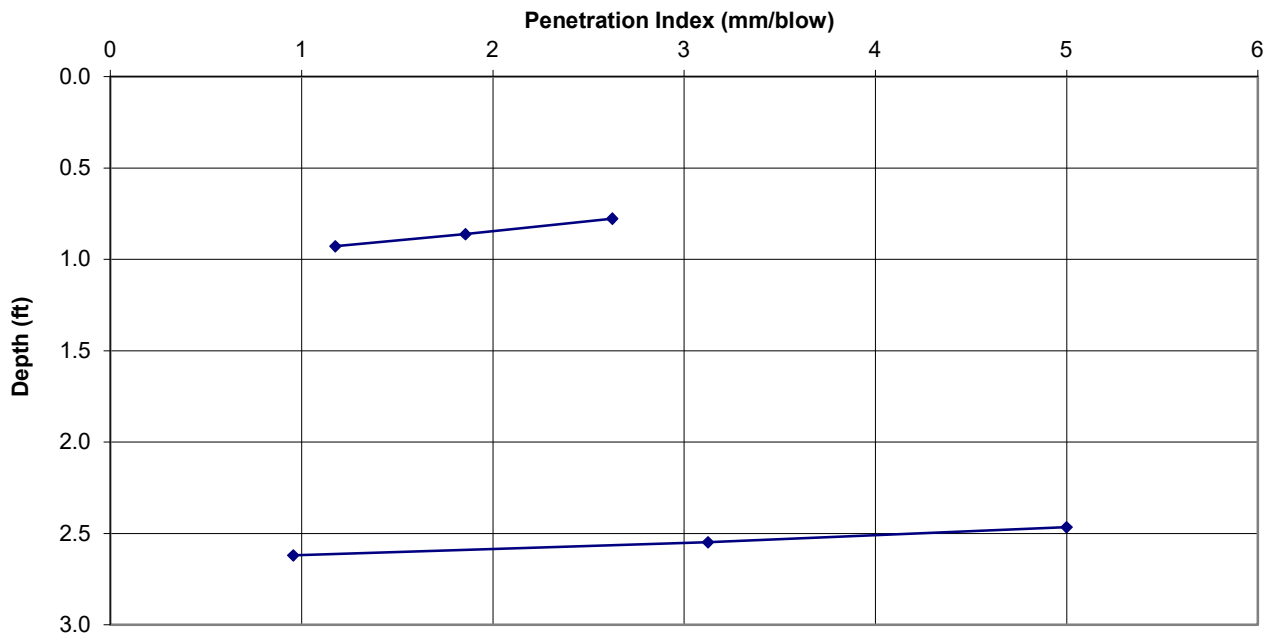
B-57-L - Penetration Index vs. Depth



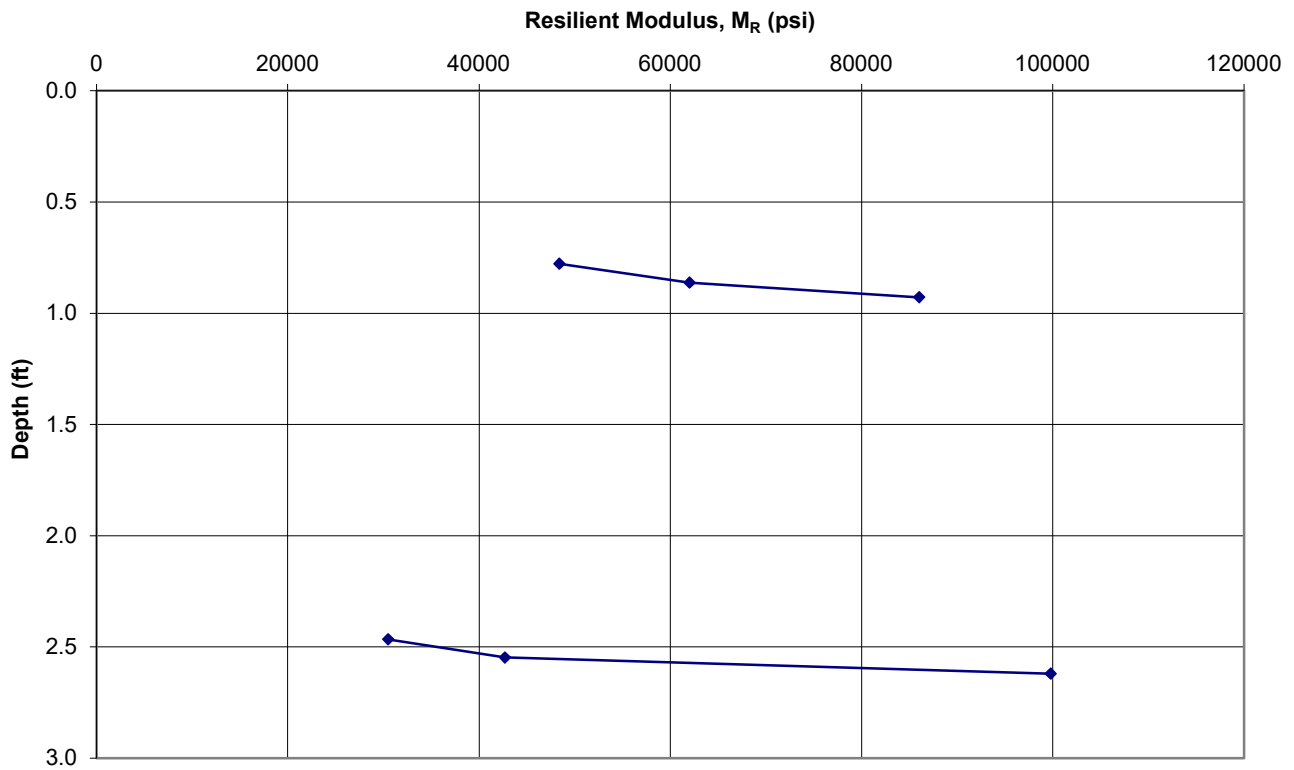
B-57-L - Resilient Modulus vs. Depth



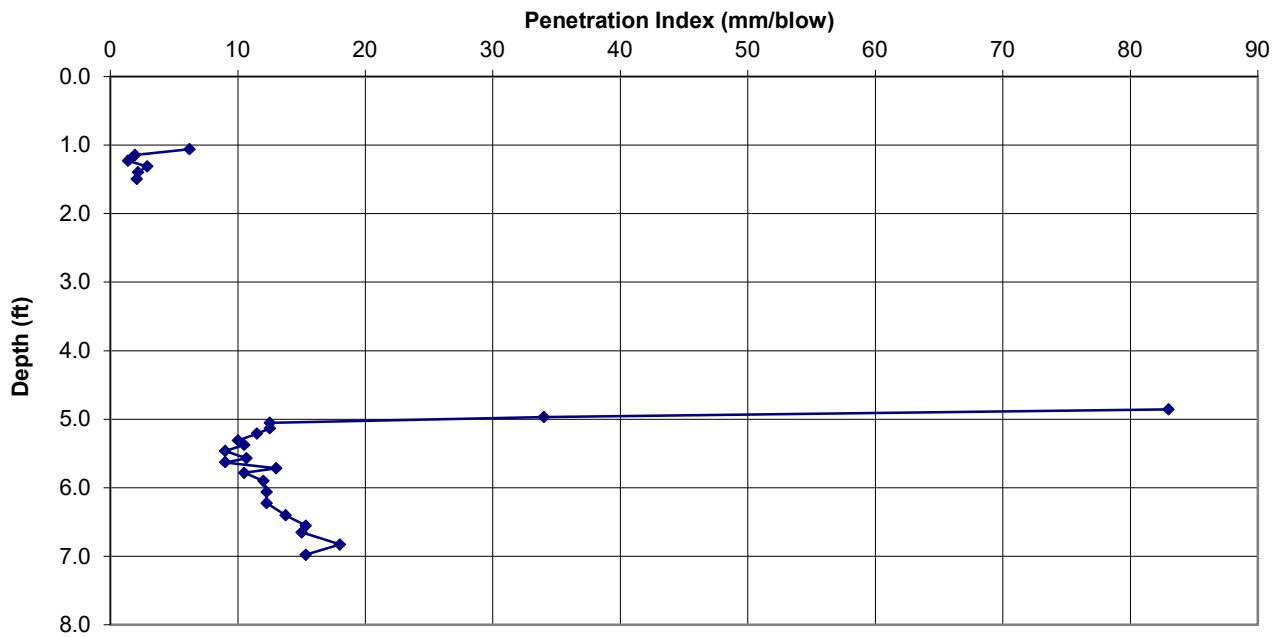
B-57-R - Penetration Index vs. Depth



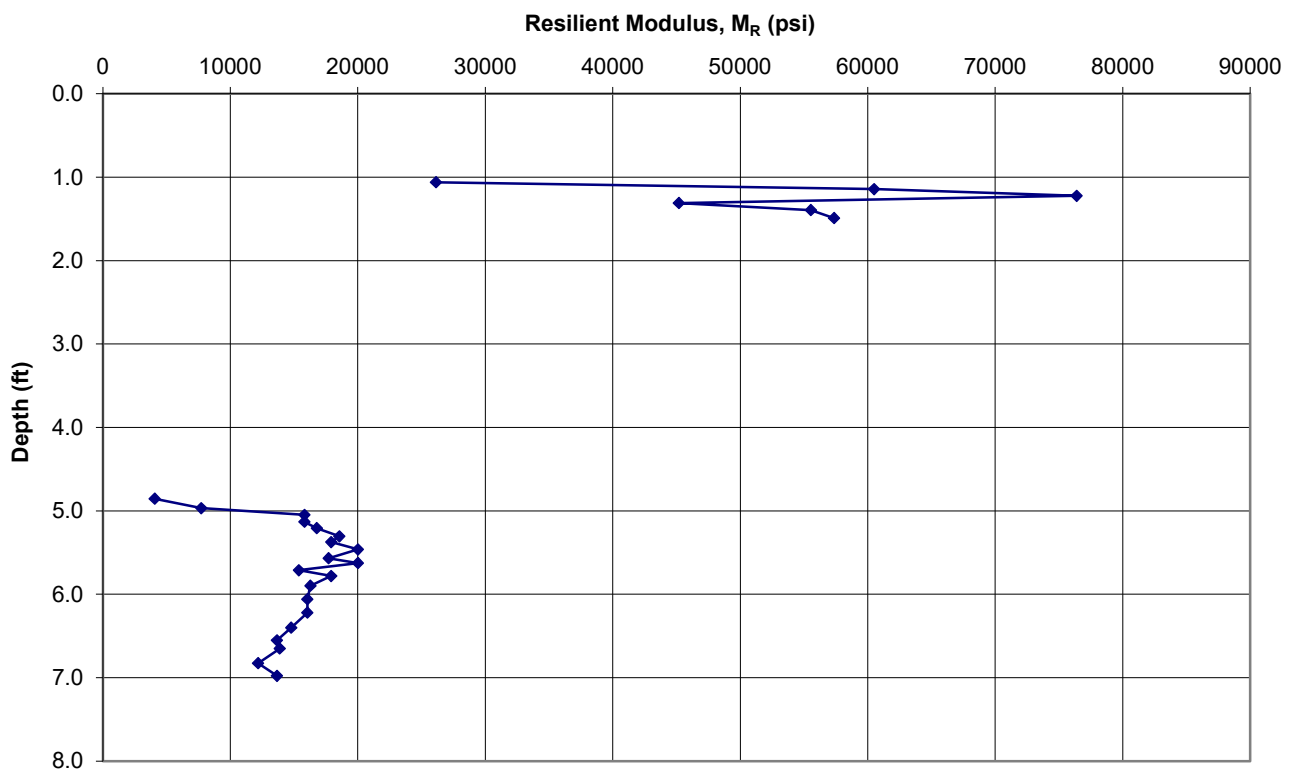
B-57-R - Resilient Modulus vs. Depth



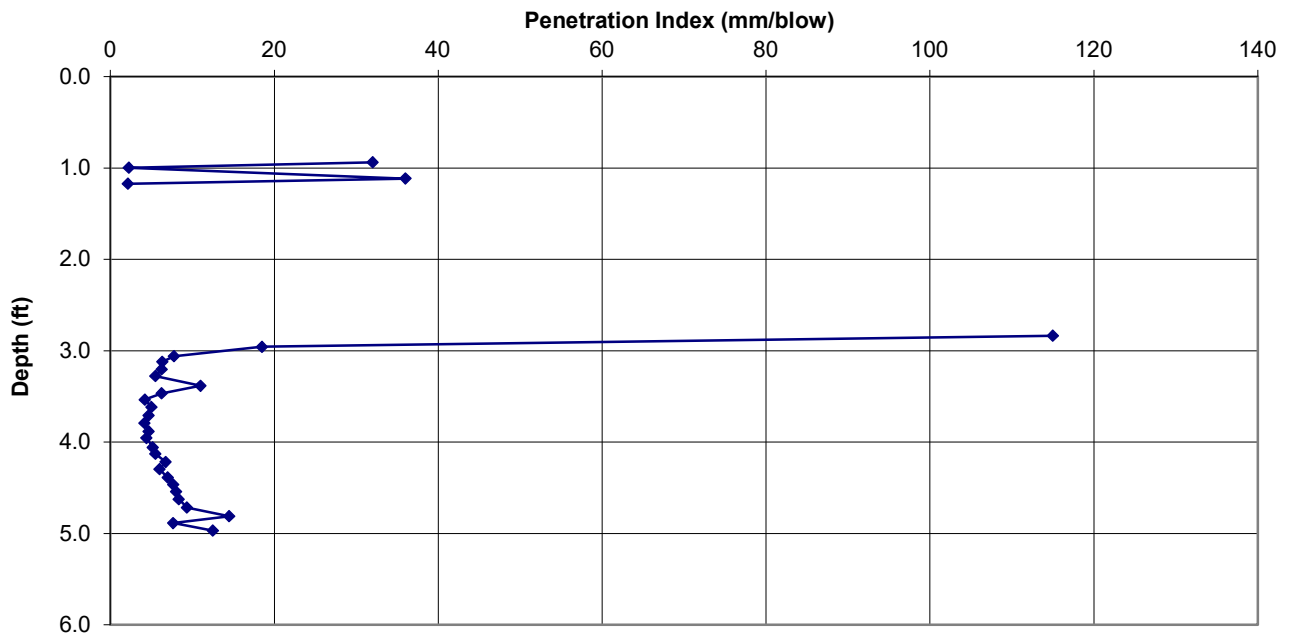
B-58-L - Penetration Index vs. Depth



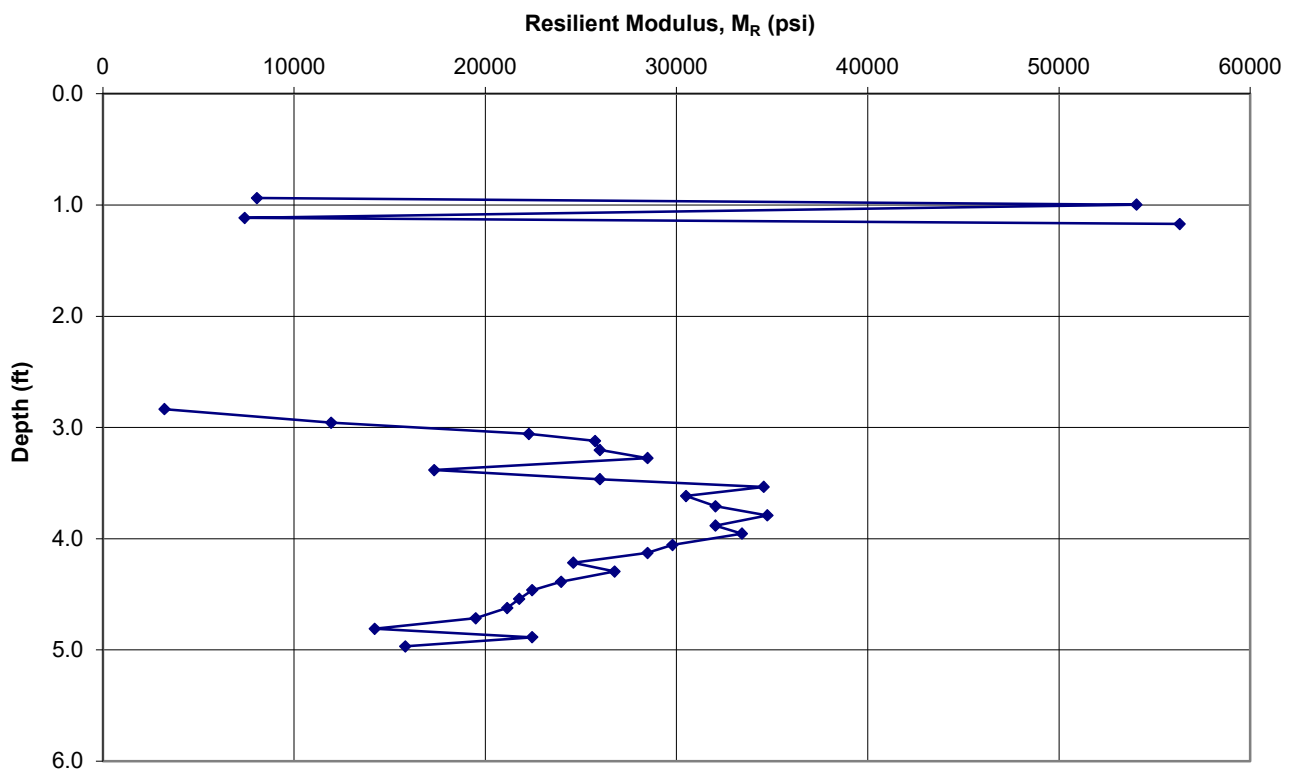
B-58-L - Resilient Modulus vs. Depth



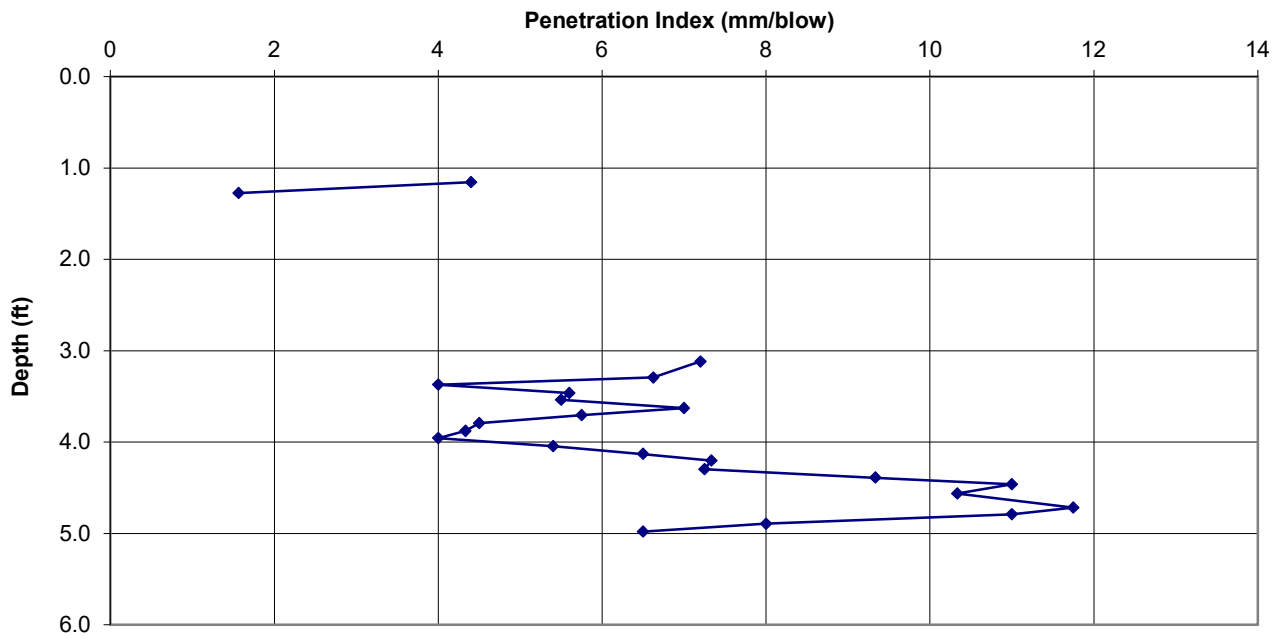
B-58-R - Penetration Index vs. Depth



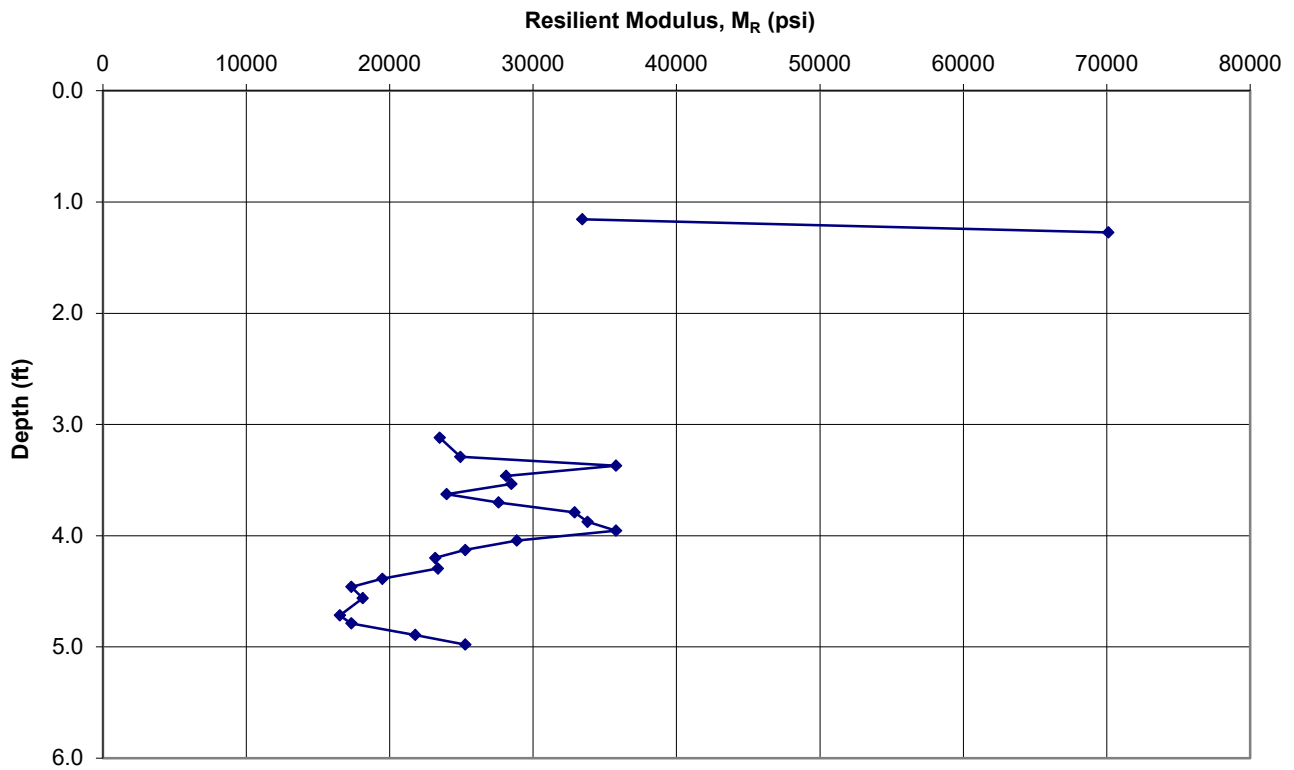
B-58-R - Resilient Modulus vs. Depth



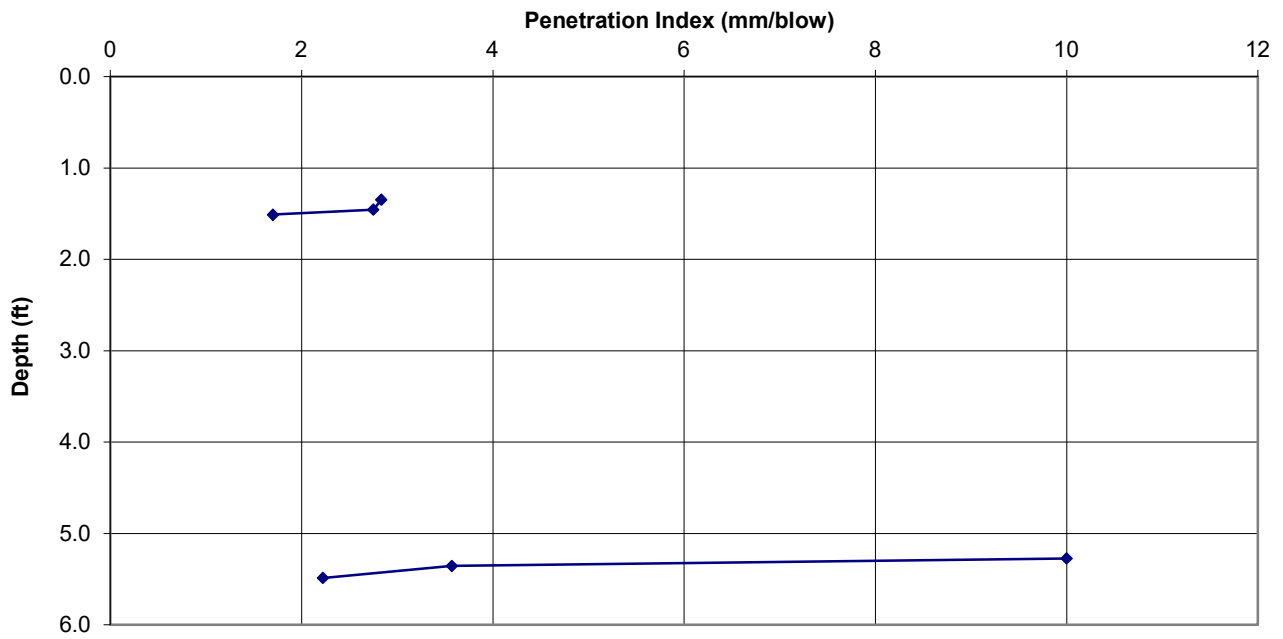
B-59.05-R - Penetration Index vs. Depth



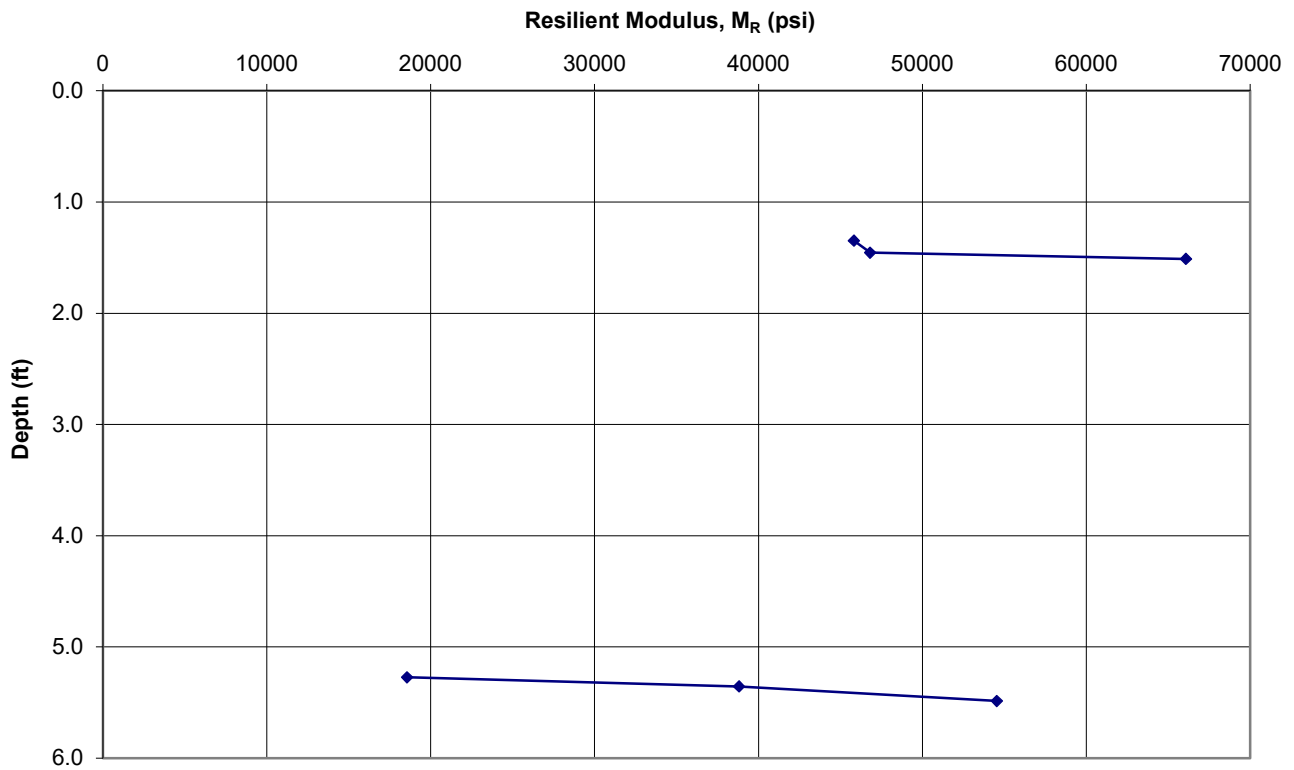
B-59.05-R - Resilient Modulus vs. Depth



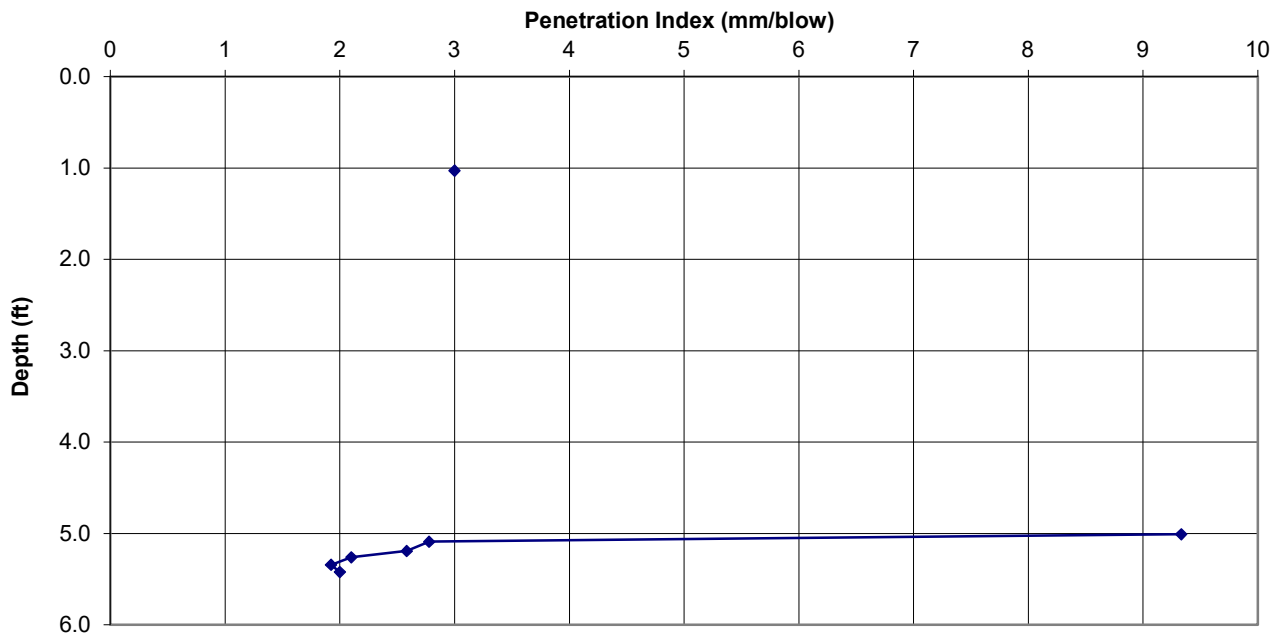
B-60-L - Penetration Index vs. Depth



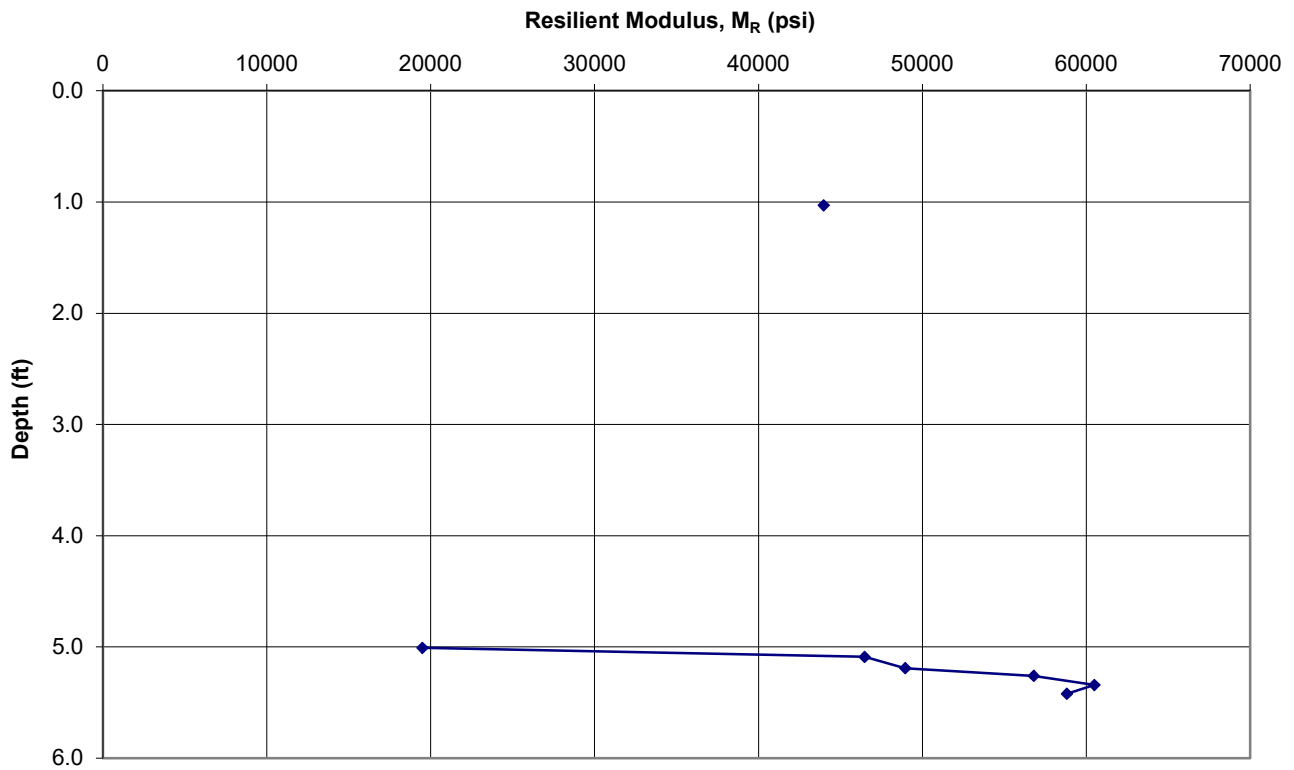
B-60-L - Resilient Modulus vs. Depth



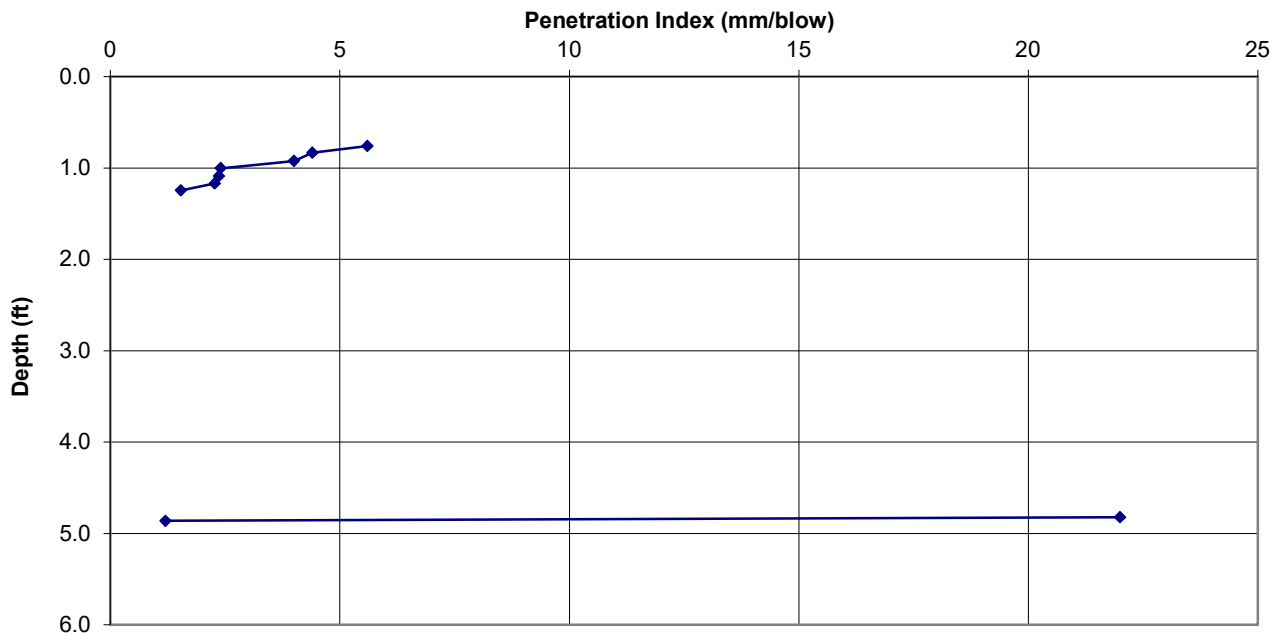
B-60-R - Penetration Index vs. Depth



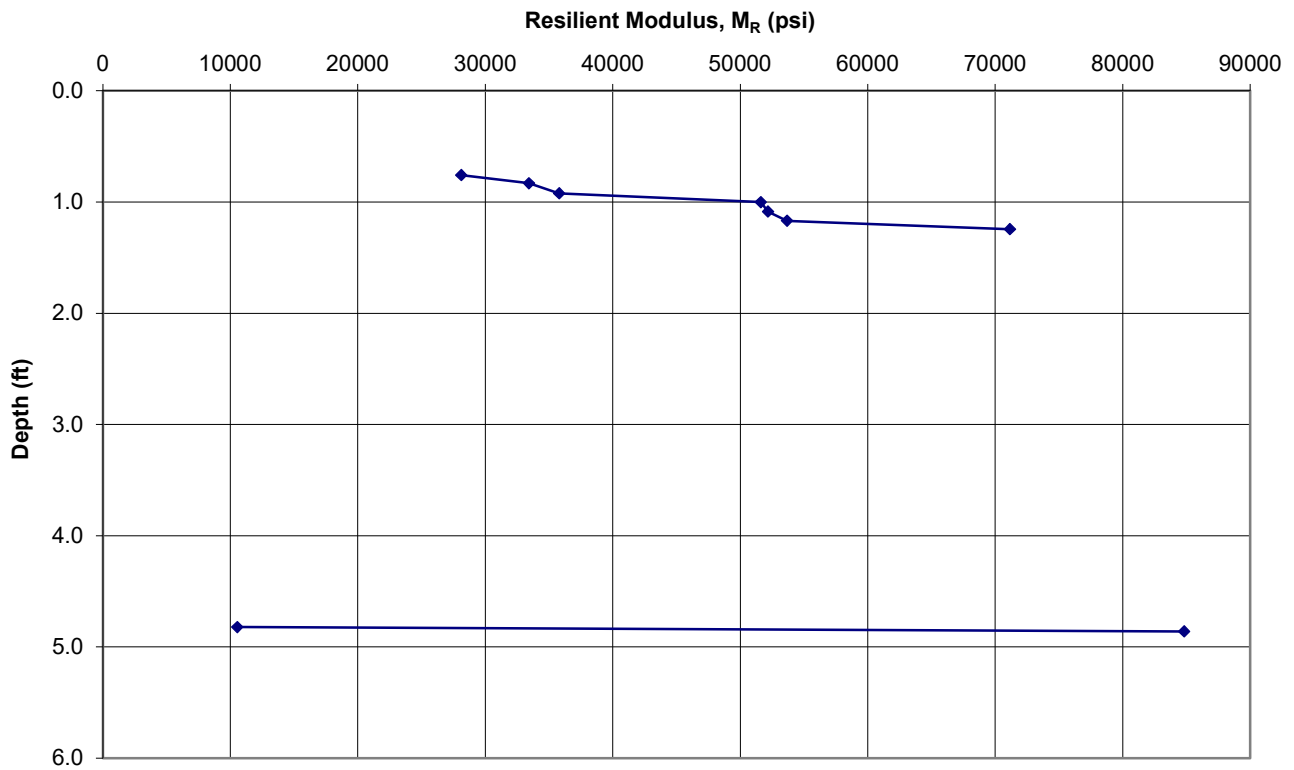
B-60-R - Resilient Modulus vs. Depth



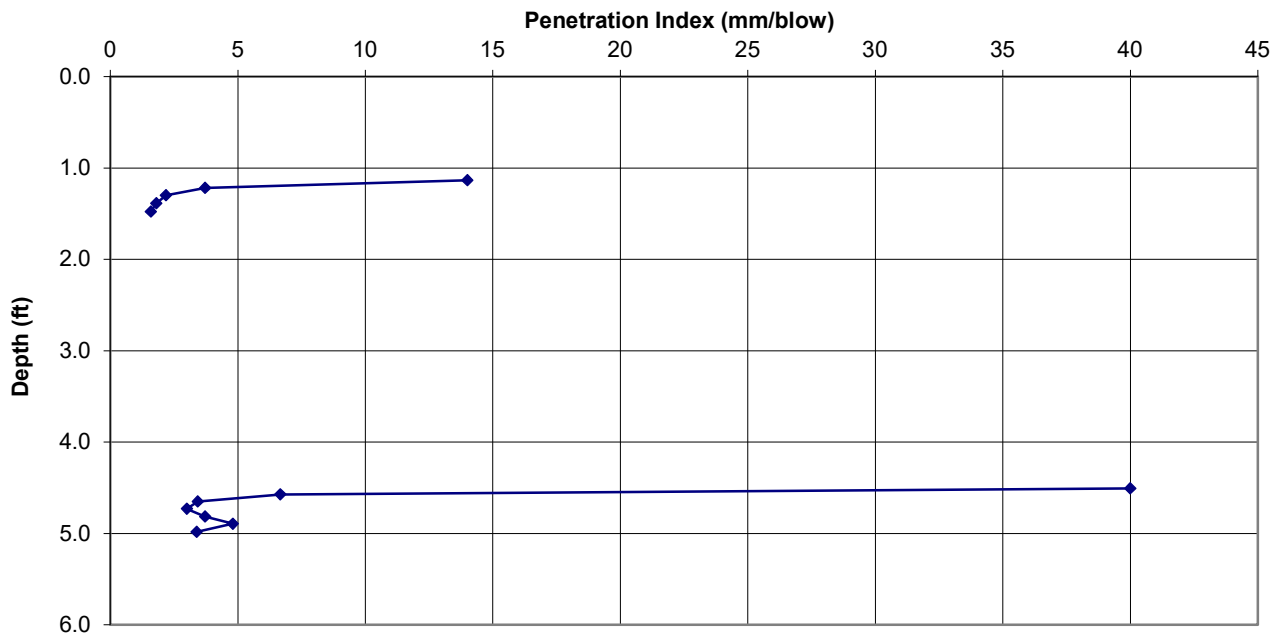
B-61-L - Penetration Index vs. Depth



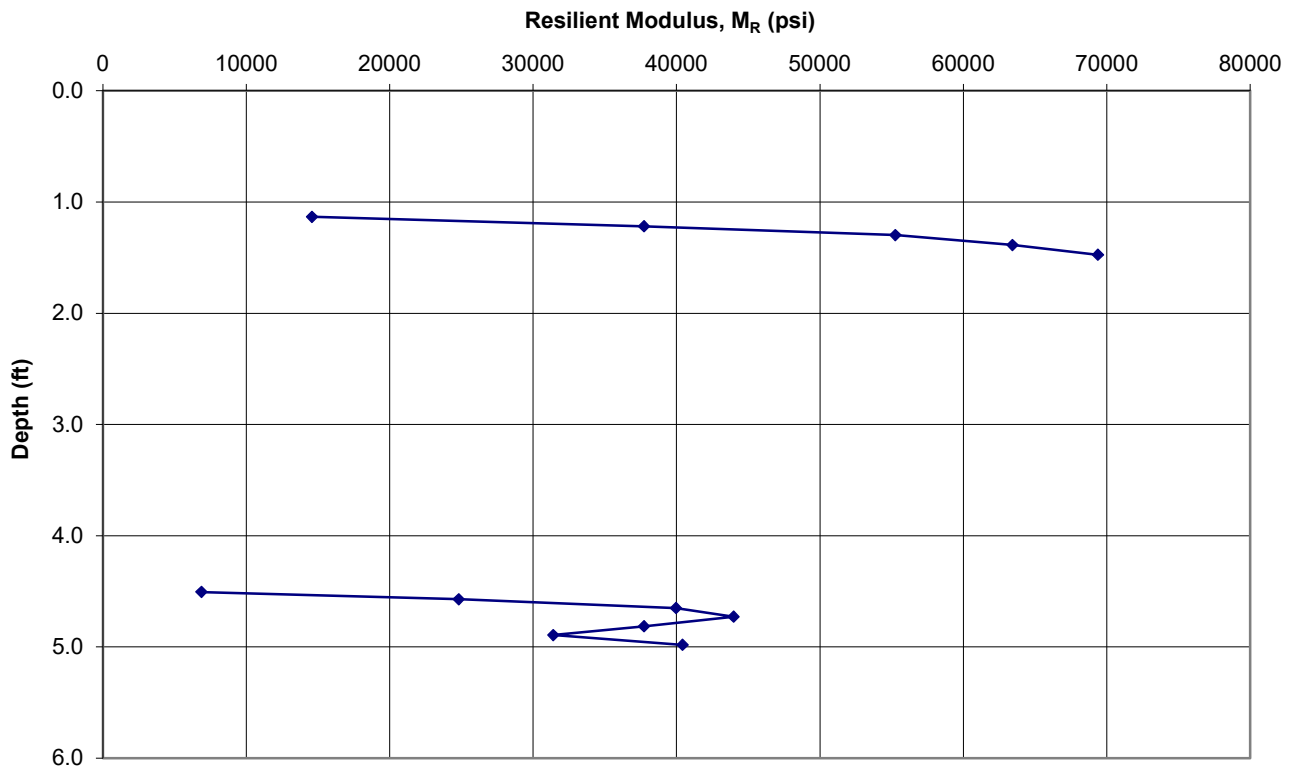
B-61-L - Resilient Modulus vs. Depth



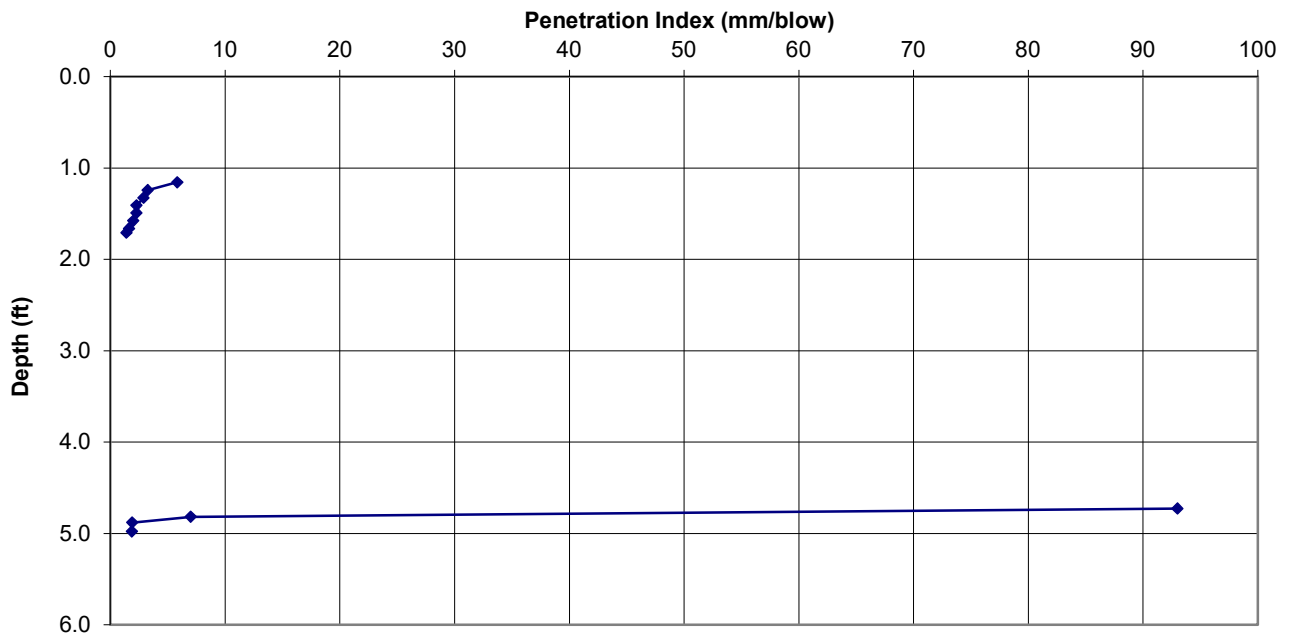
B-61-R - Penetration Index vs. Depth



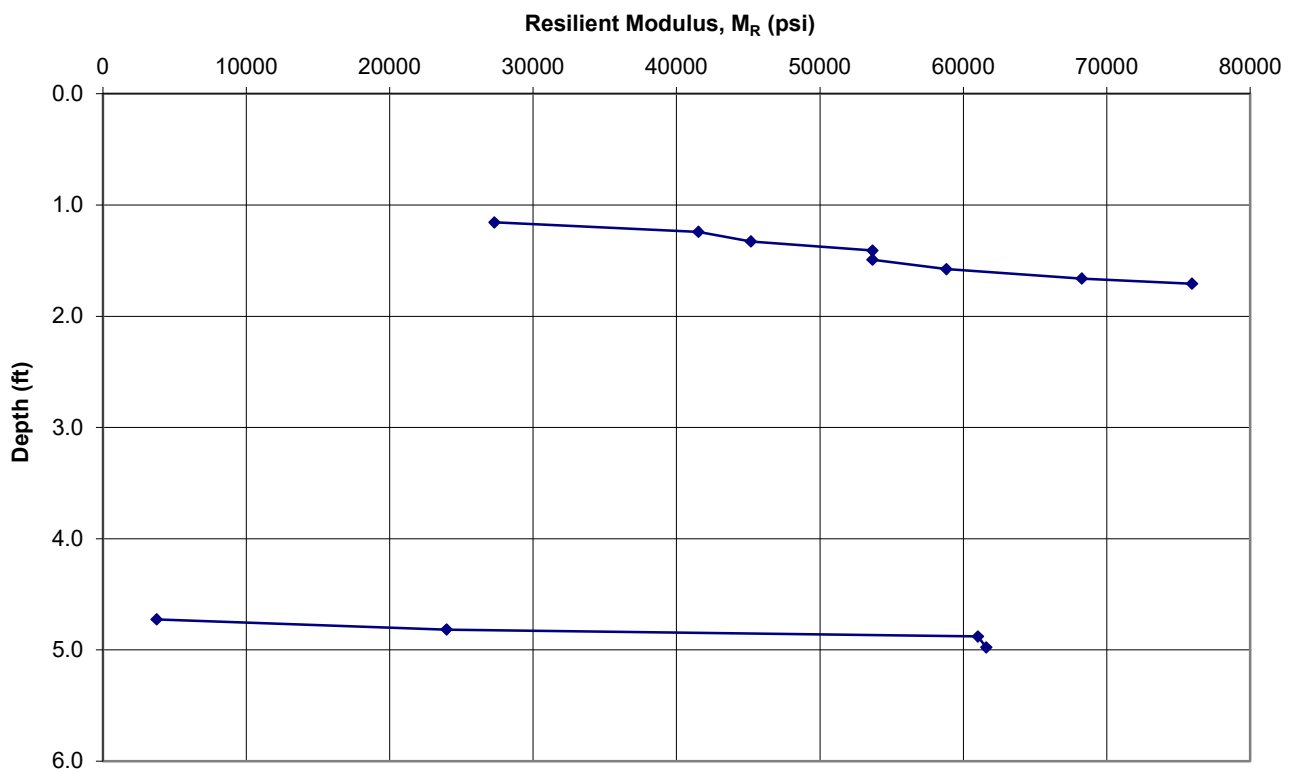
B-61-R - Resilient Modulus vs. Depth



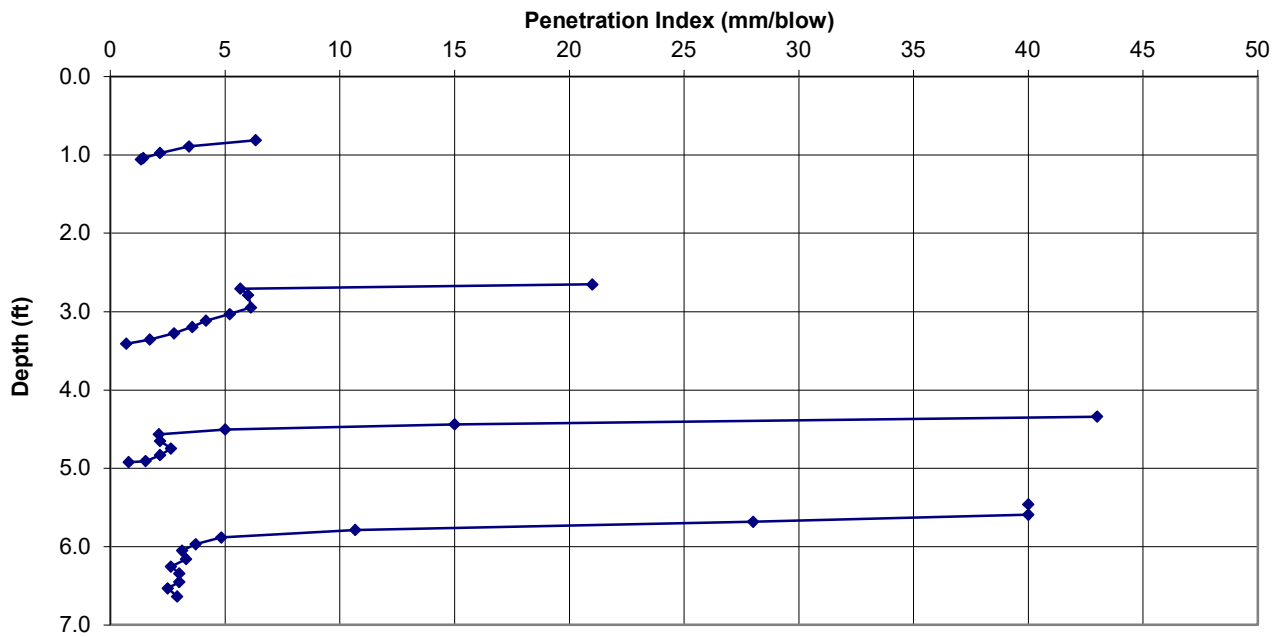
B-62-L - Penetration Index vs. Depth



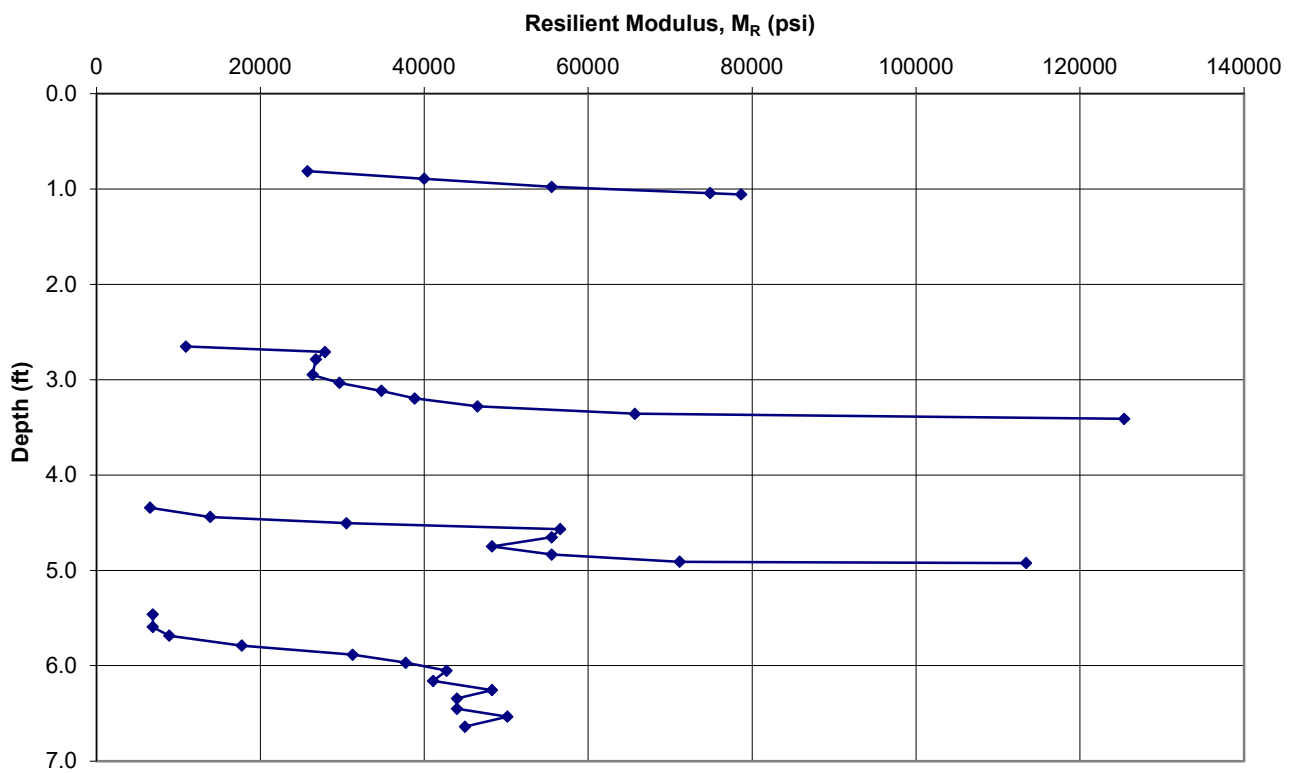
B-62-L - Resilient Modulus vs. Depth



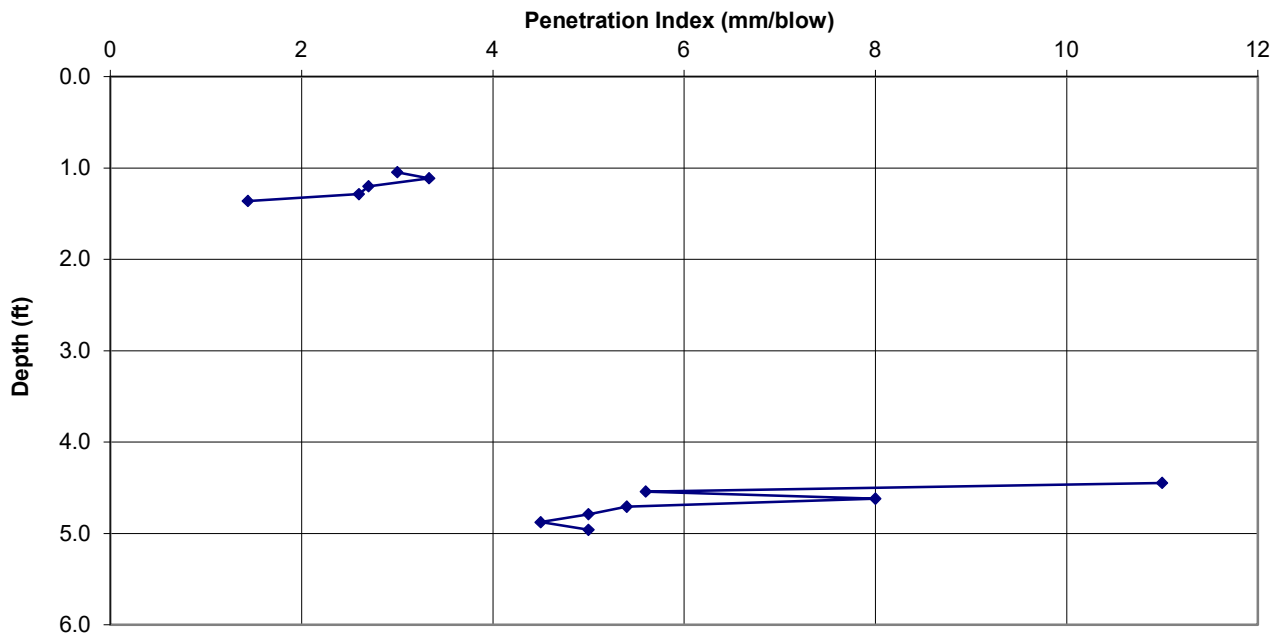
B-62-R - Penetration Index vs. Depth



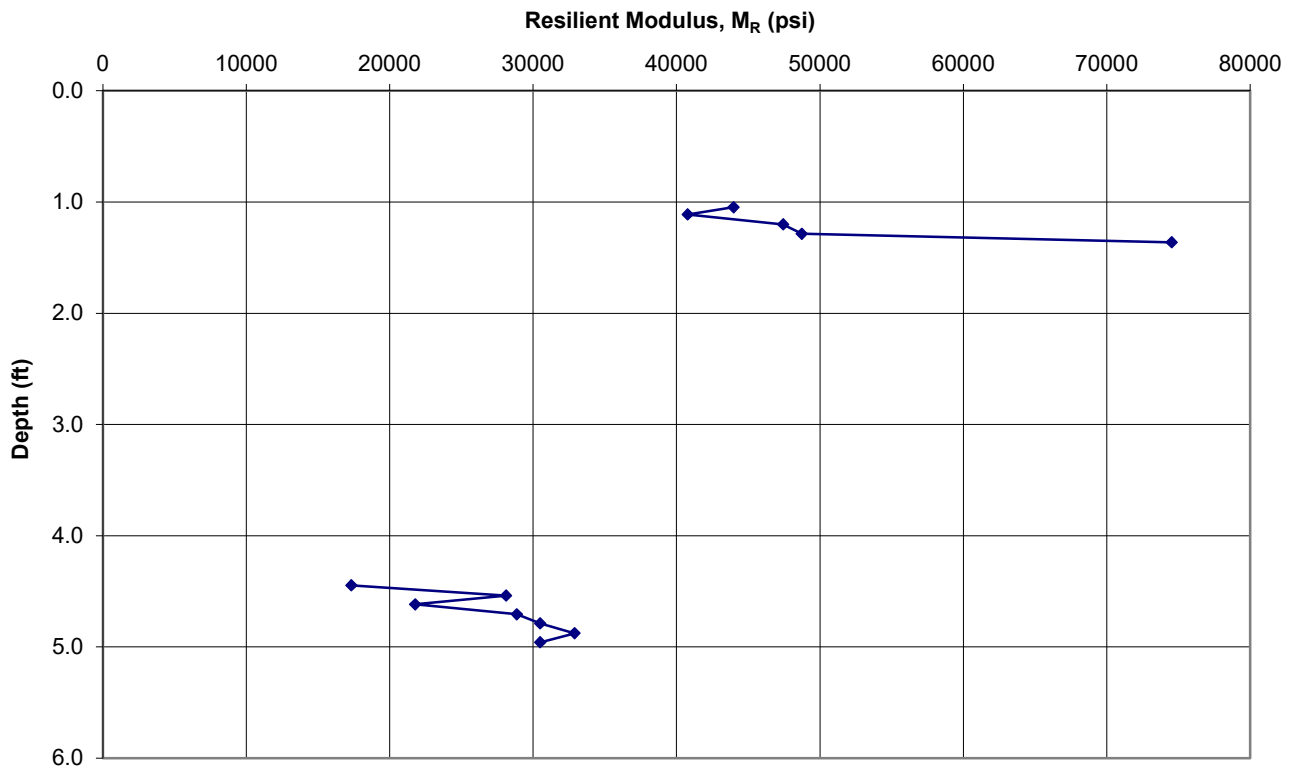
B-62-R - Resilient Modulus vs. Depth



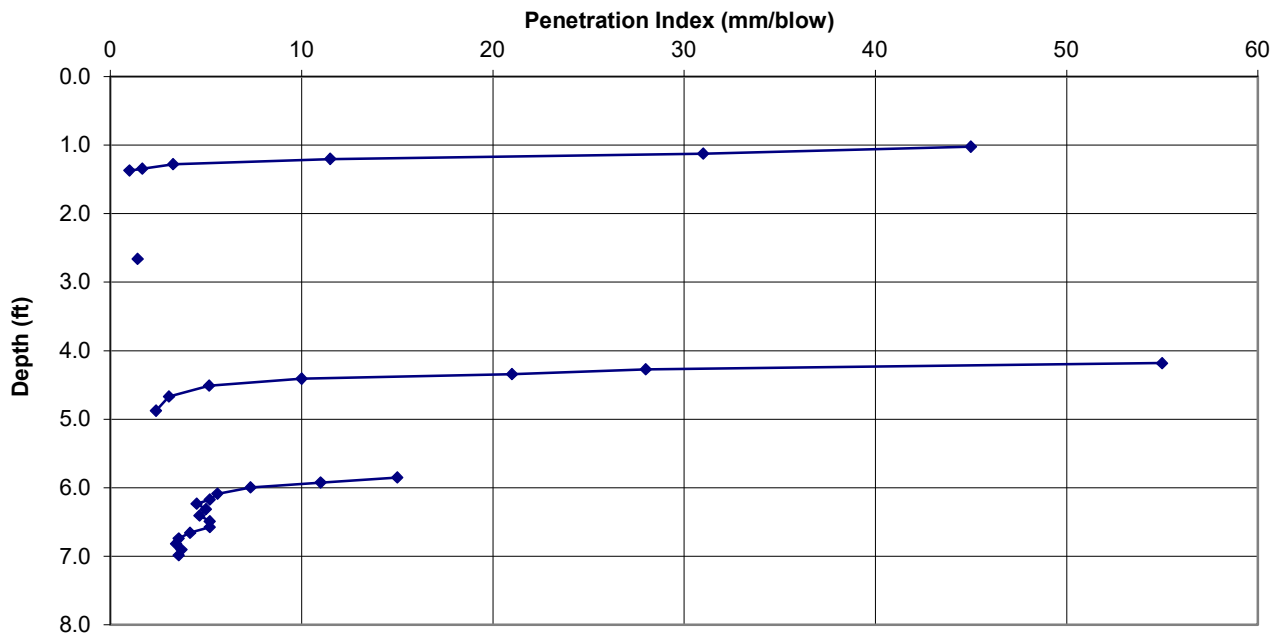
B-63-L - Penetration Index vs. Depth



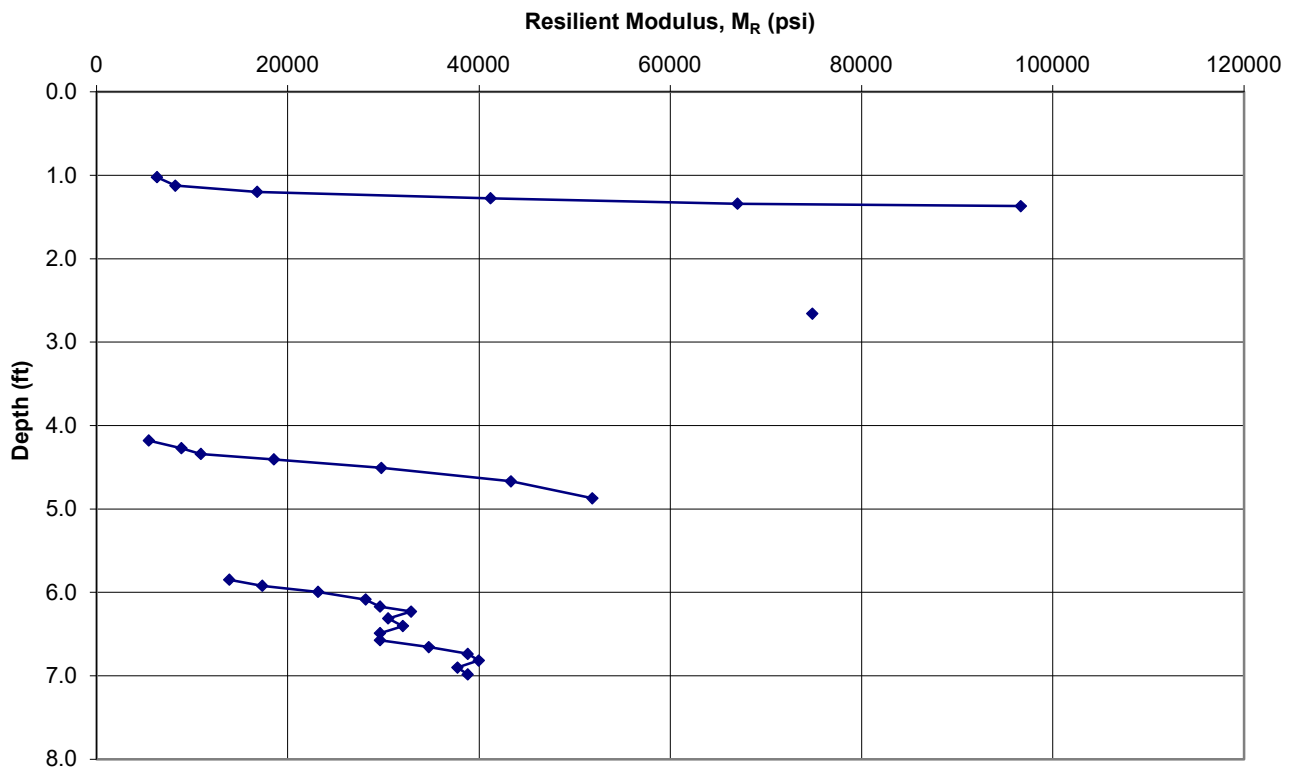
B-63-L - Resilient Modulus vs. Depth



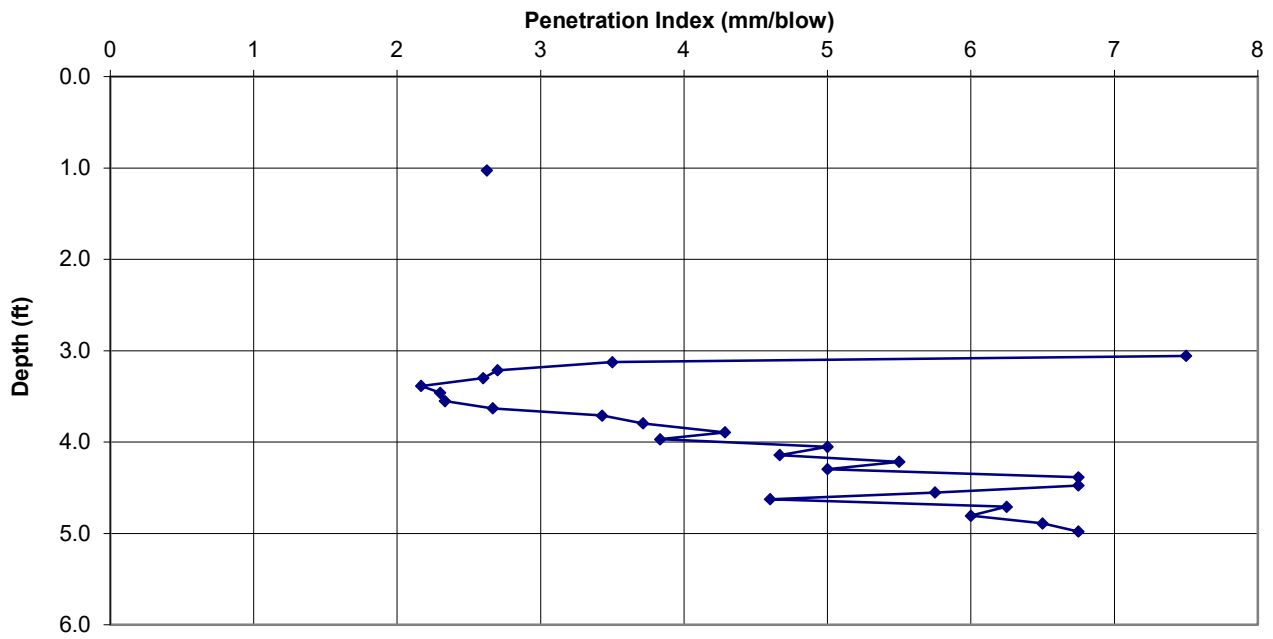
B-63-R - Penetration Index vs. Depth



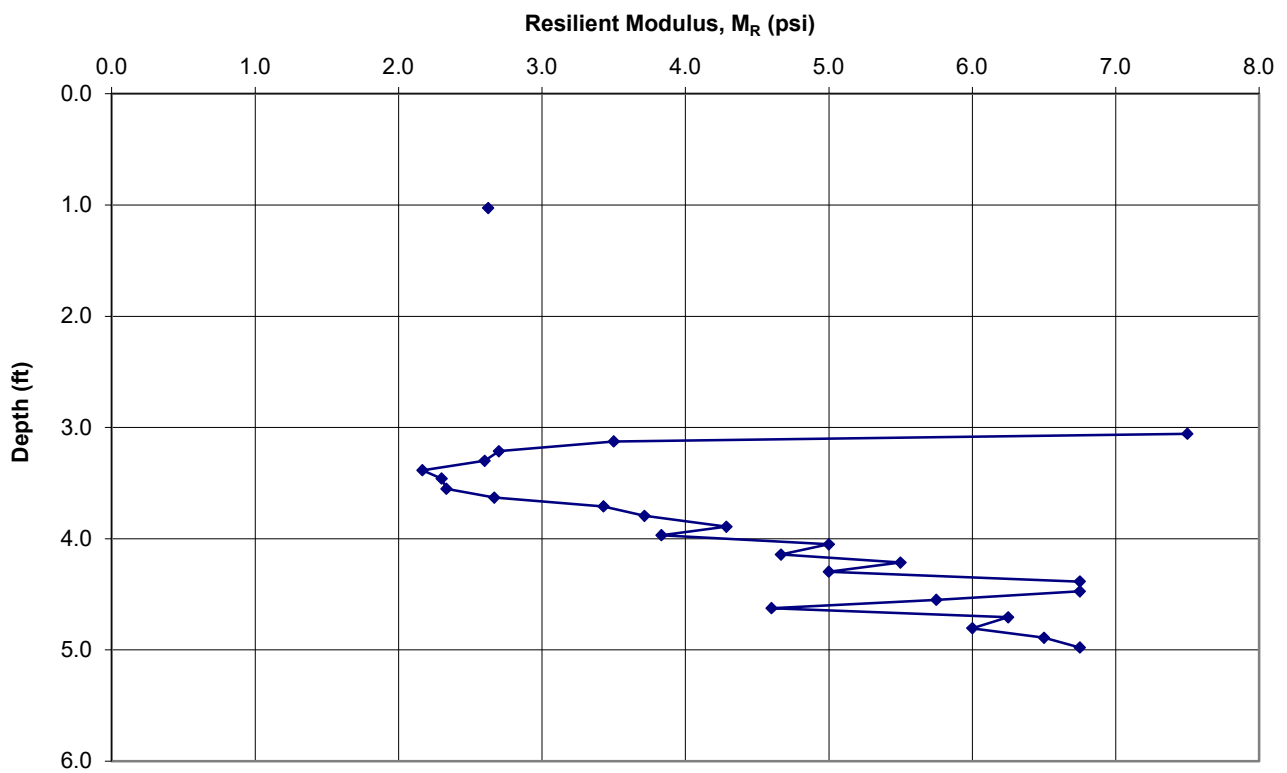
B-63-R - Resilient Modulus vs. Depth



B-52.85-L - Penetration Index vs. Depth



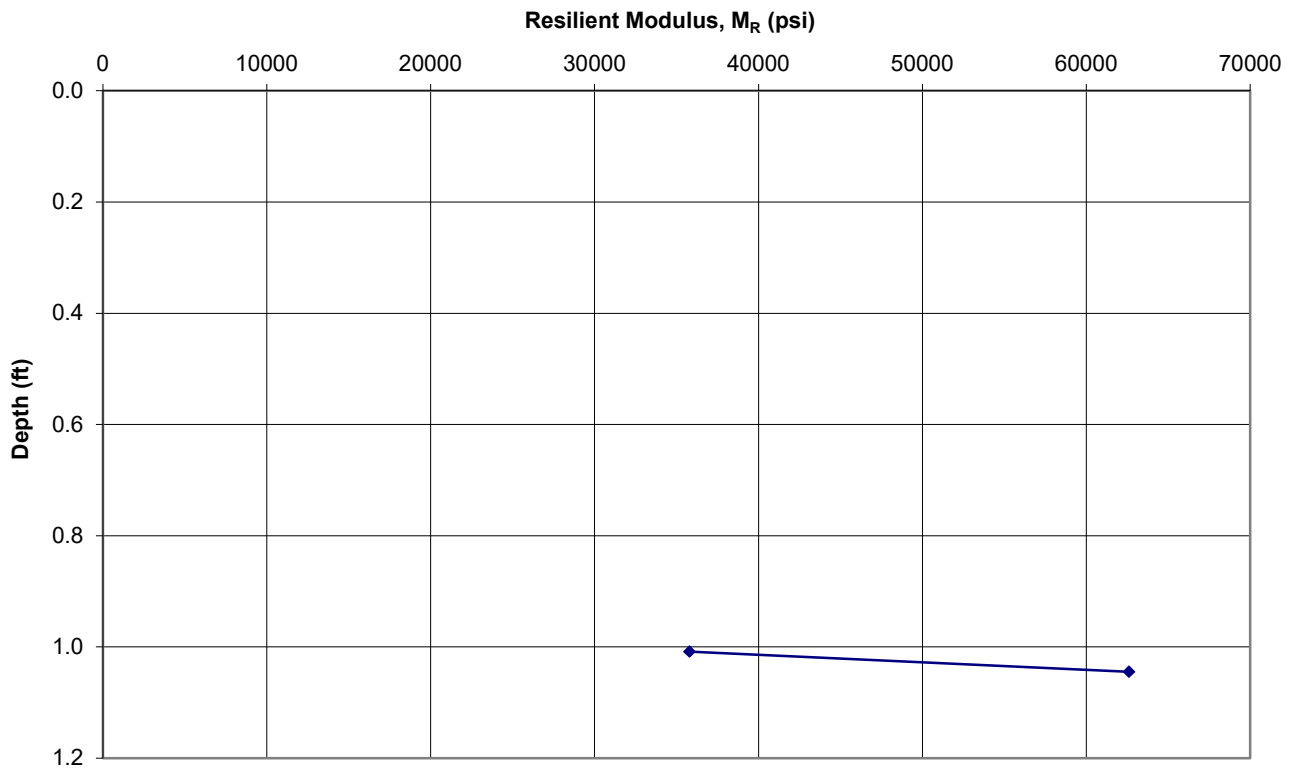
B-52.85-L - Resilient Modulus vs. Depth



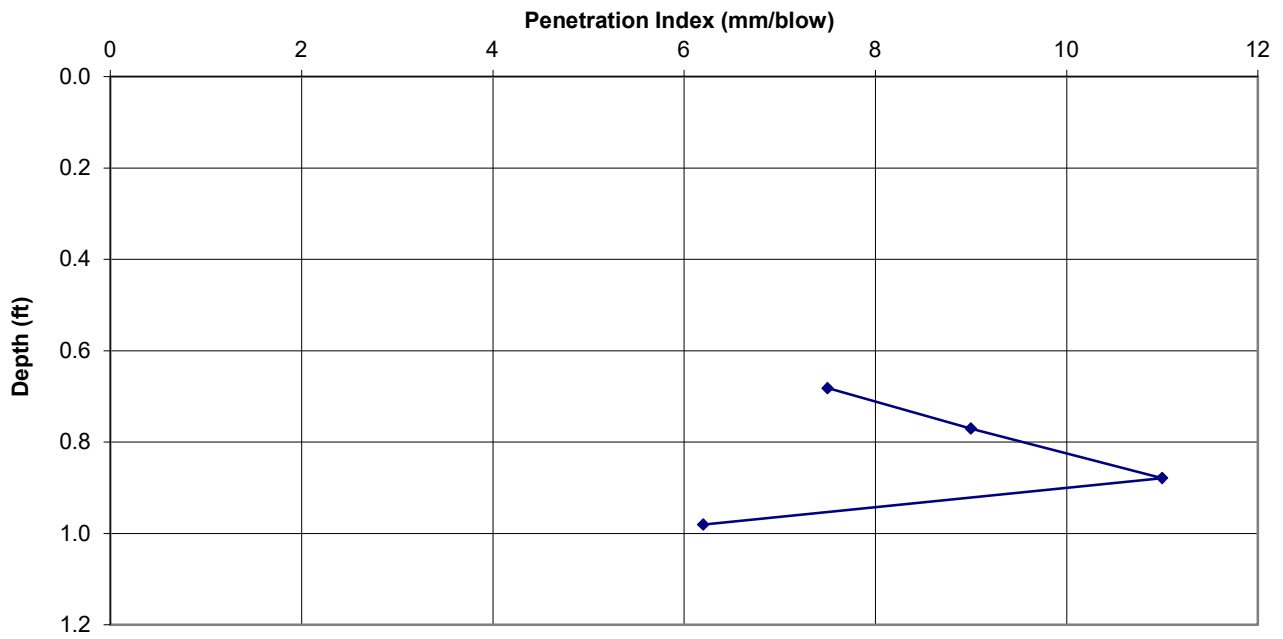
C-52.85-R - Penetration Index vs. Depth



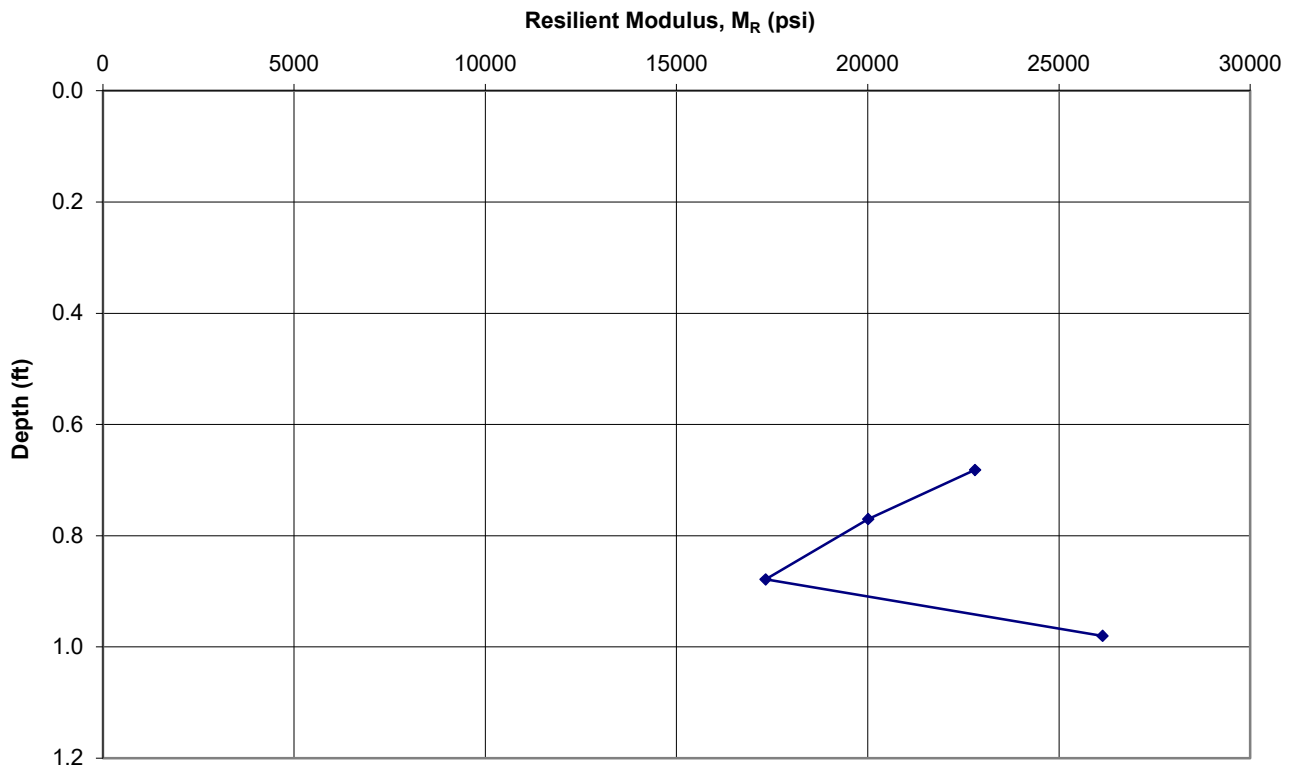
C-52.85-R - Resilient Modulus vs. Depth



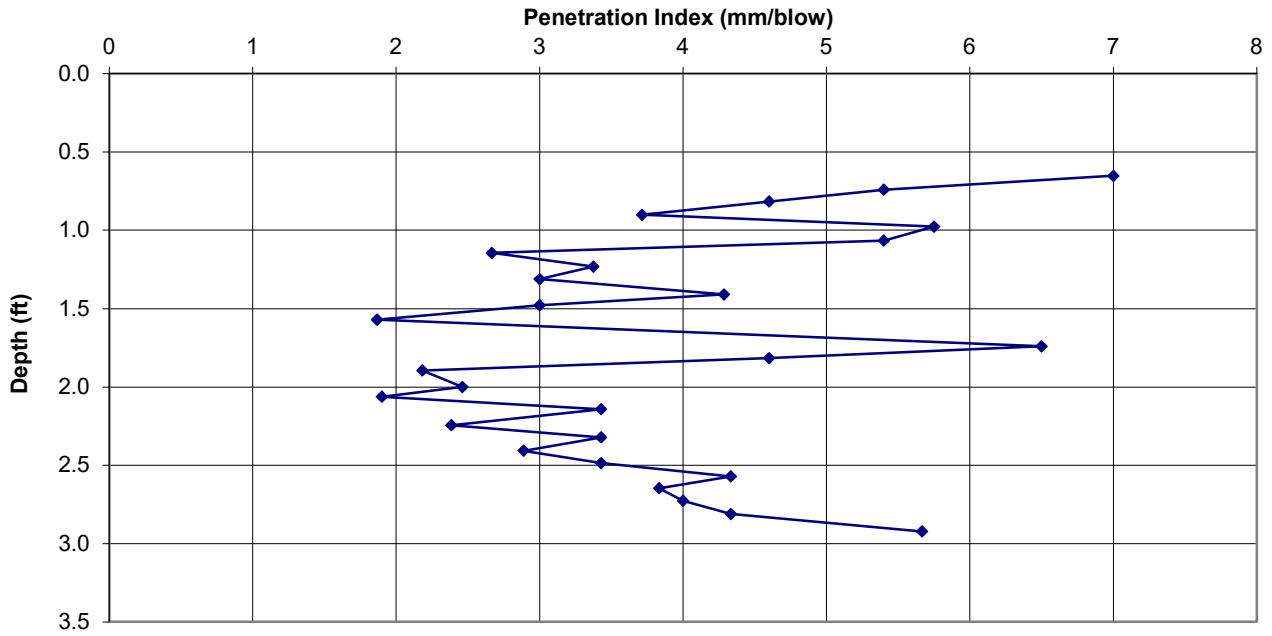
C-54-L - Penetration Index vs. Depth



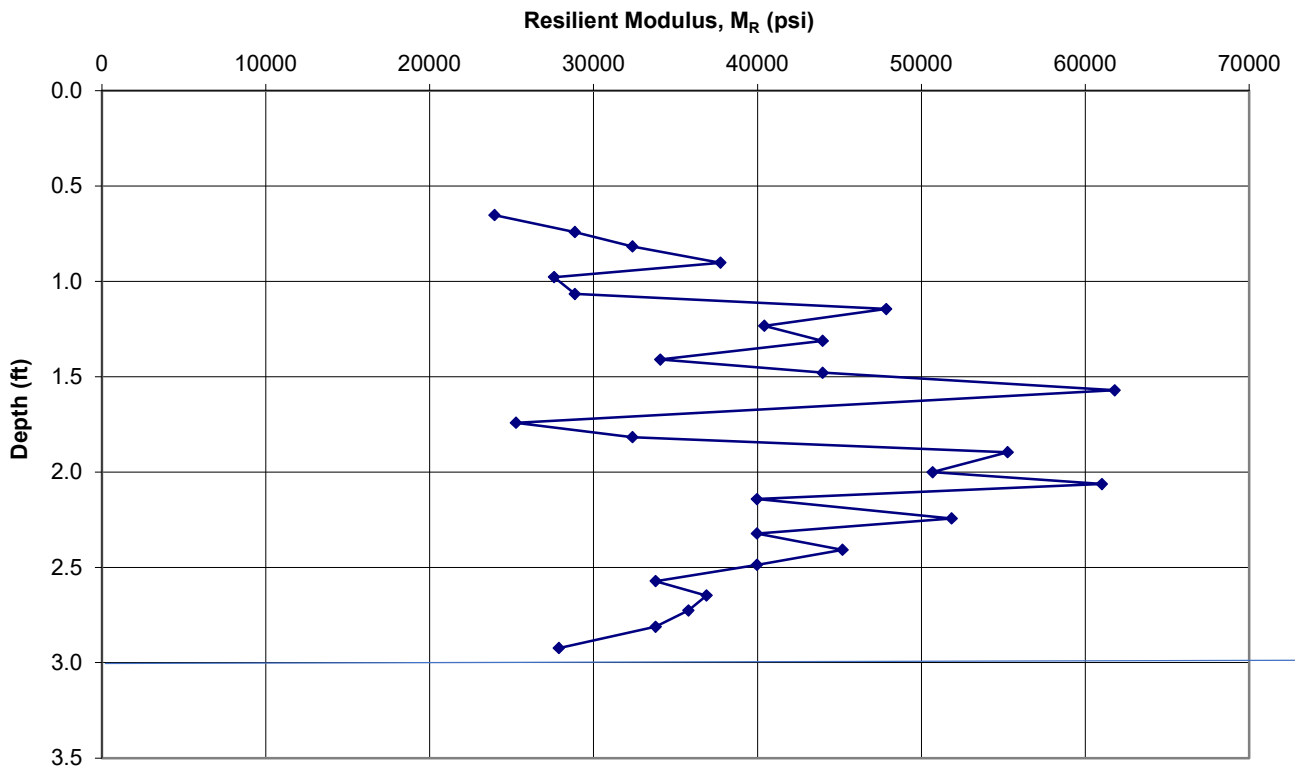
B-54-L - Resilient Modulus vs. Depth



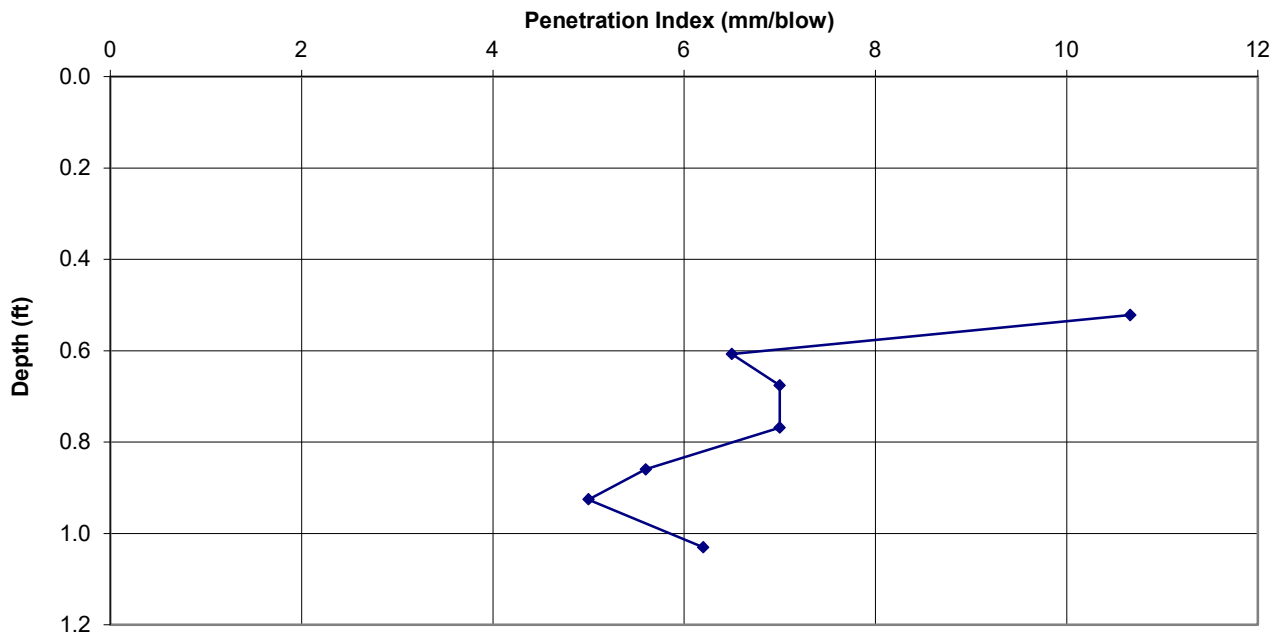
C-54-R - Penetration Index vs. Depth



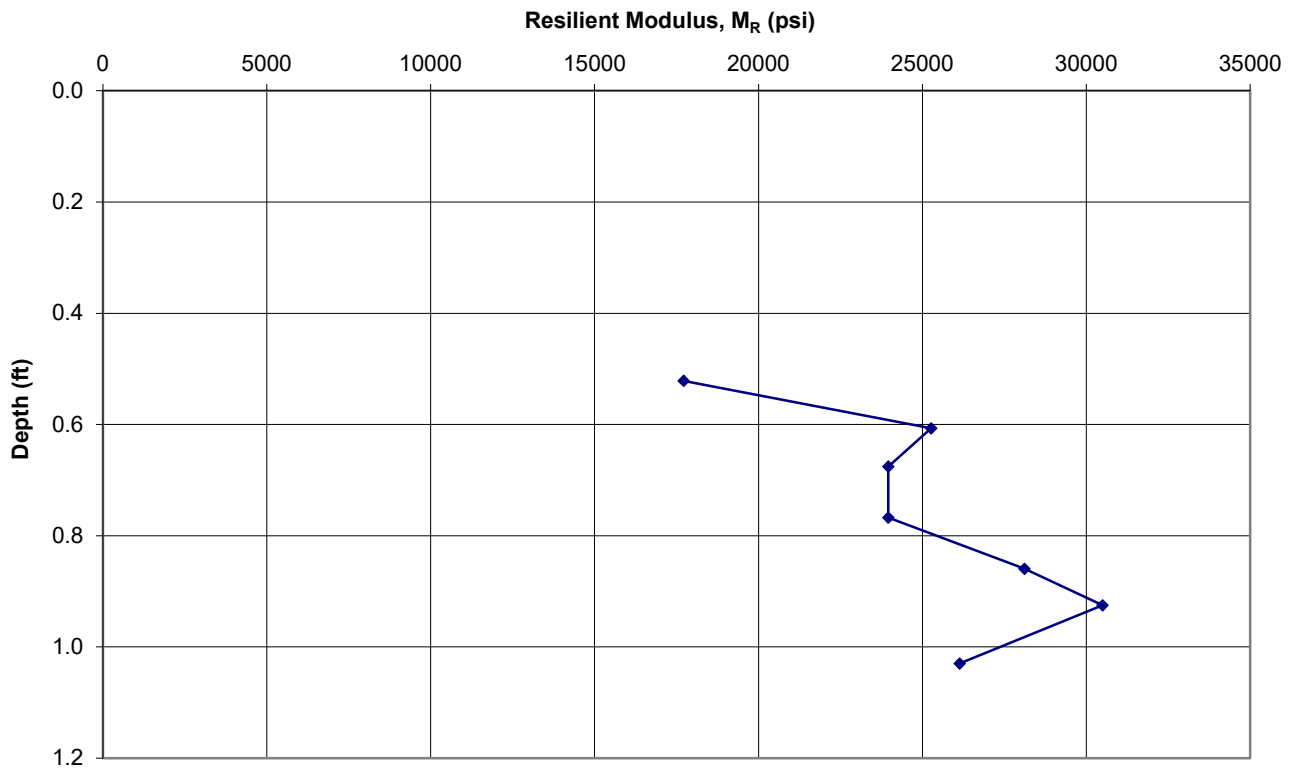
C-54-R - Resilient Modulus vs. Depth



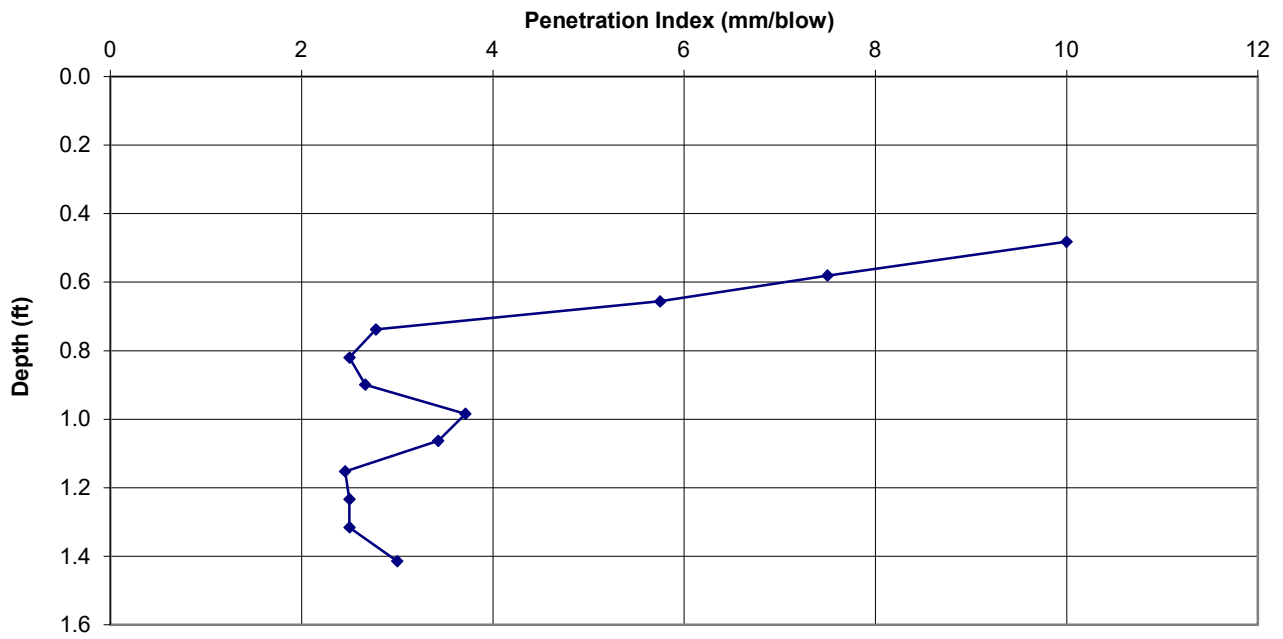
C-55-L - Penetration Index vs. Depth



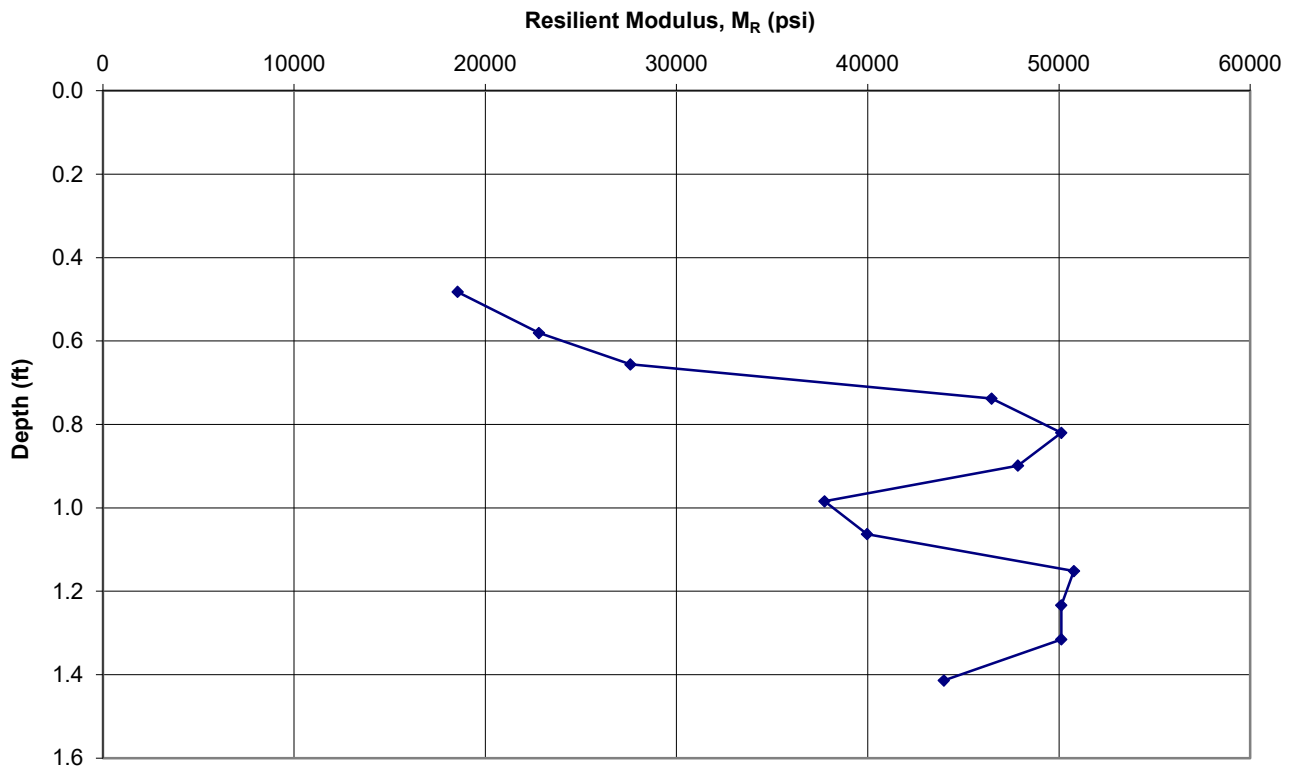
C-55-L - Resilient Modulus vs. Depth



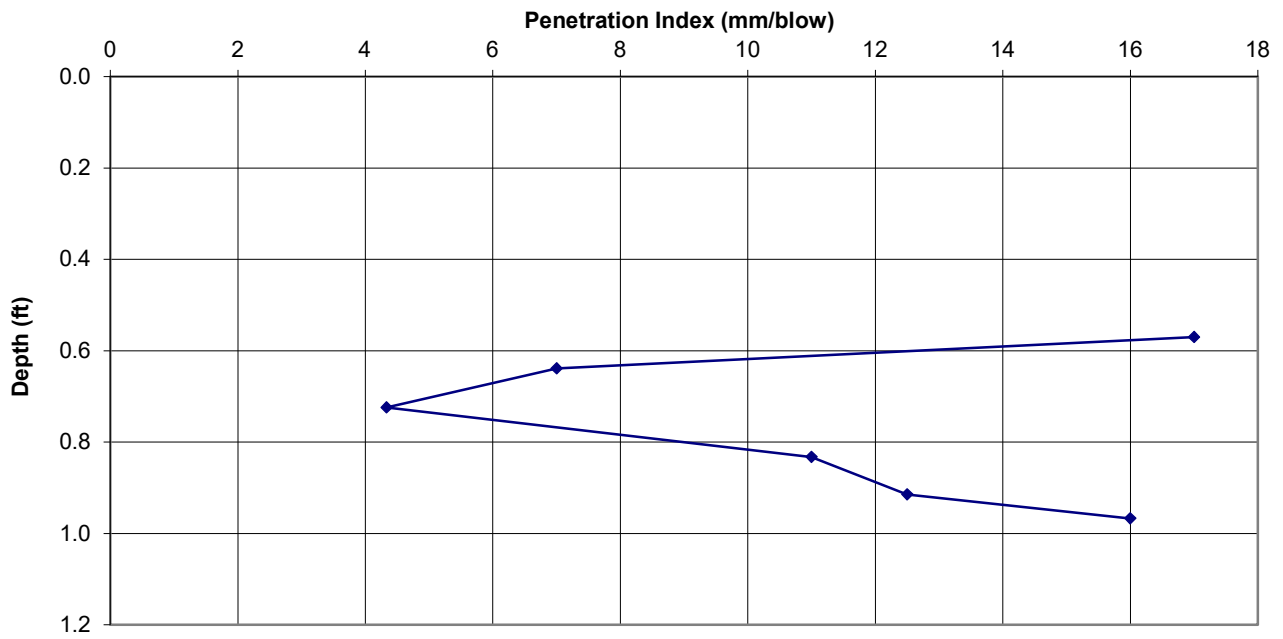
C-55-R - Penetration Index vs. Depth



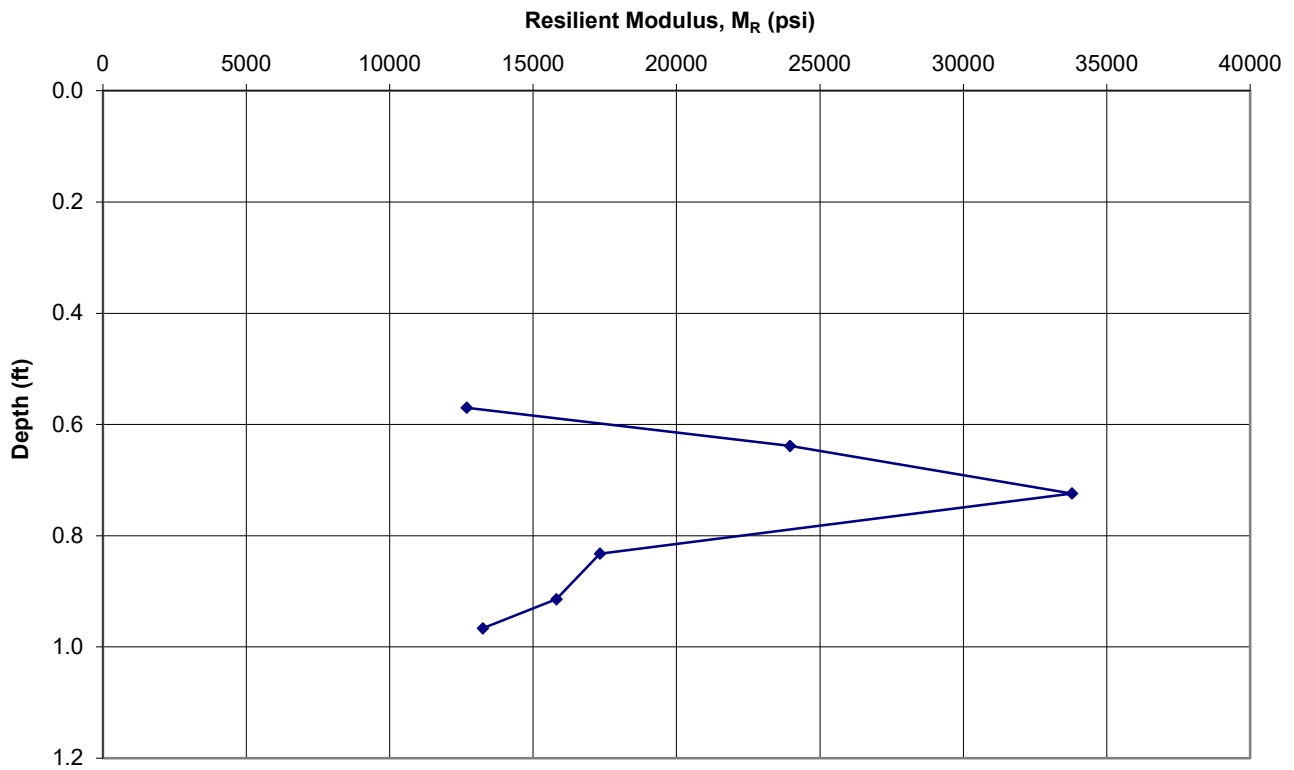
C-55-R - Resilient Modulus vs. Depth



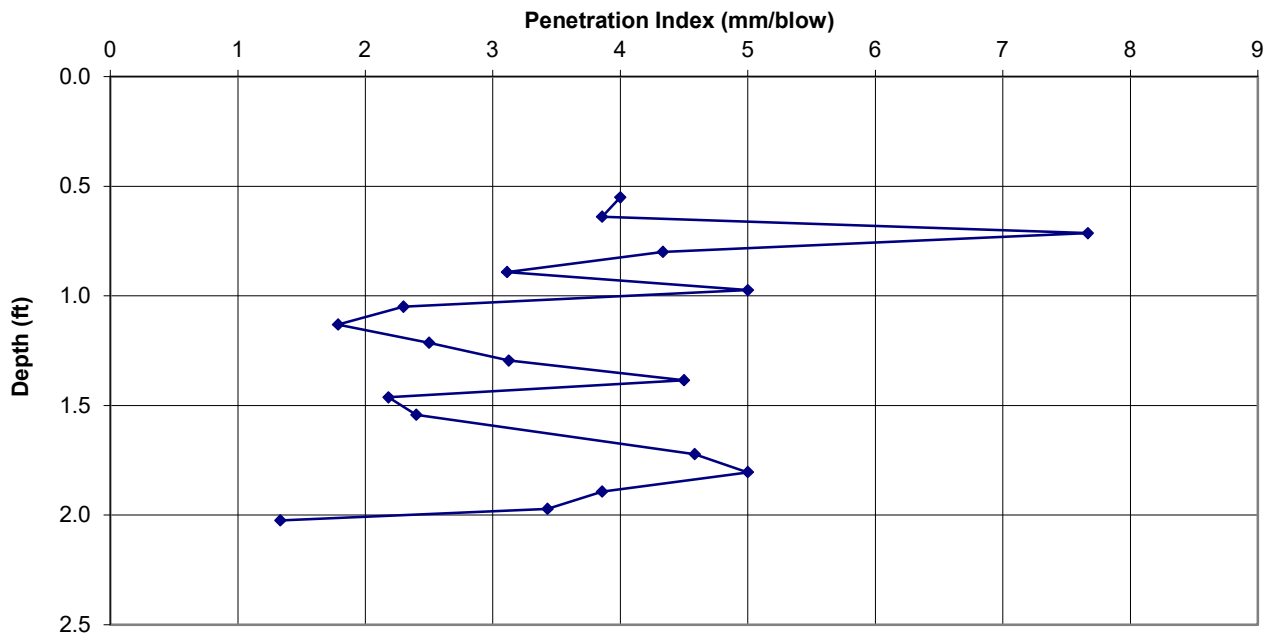
C-56-L - Penetration Index vs. Depth



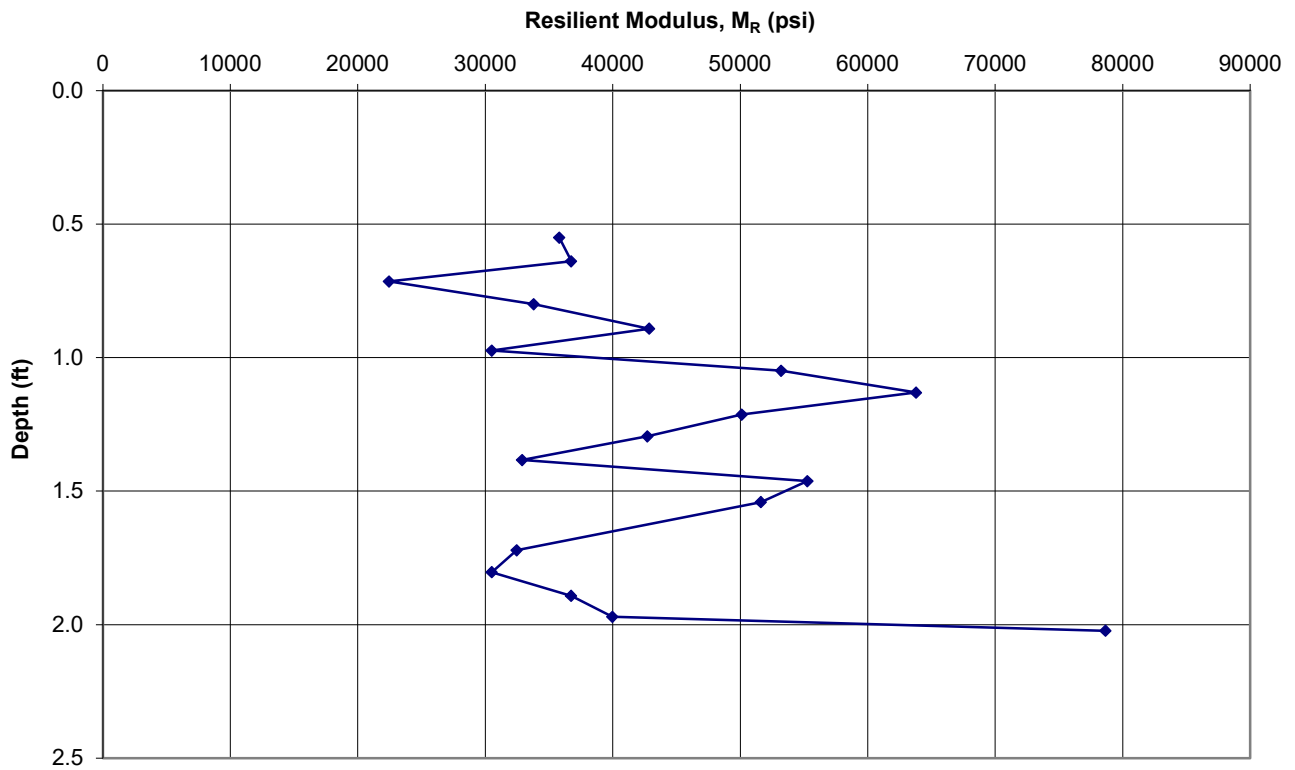
C-56-L - Resilient Modulus vs. Depth



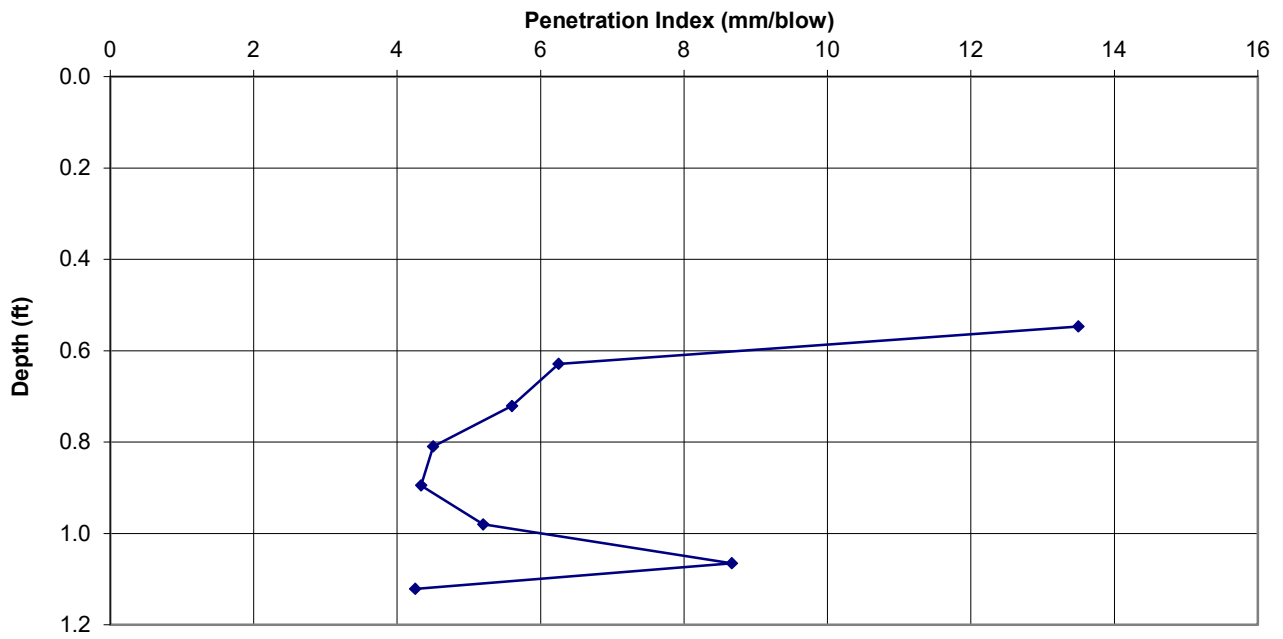
C-56-R - Penetration Index vs. Depth



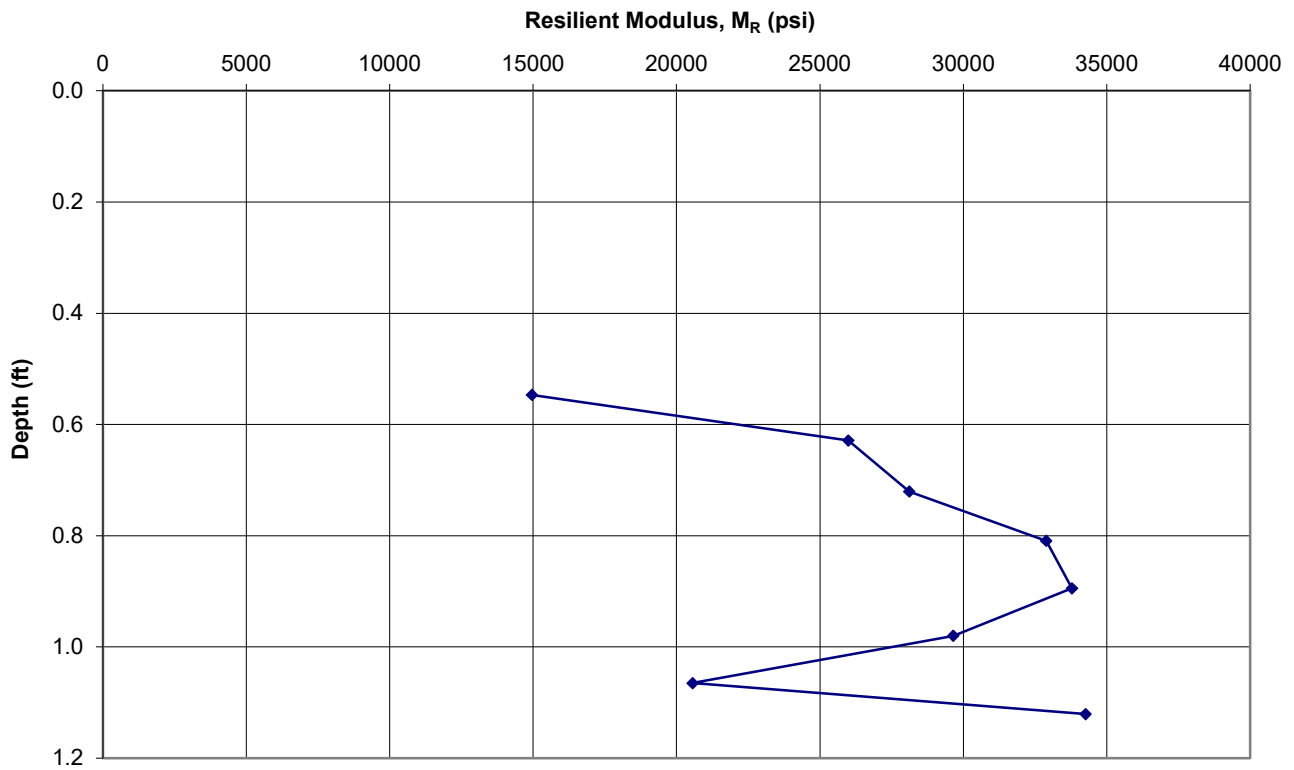
C-56-R - Resilient Modulus vs. Depth



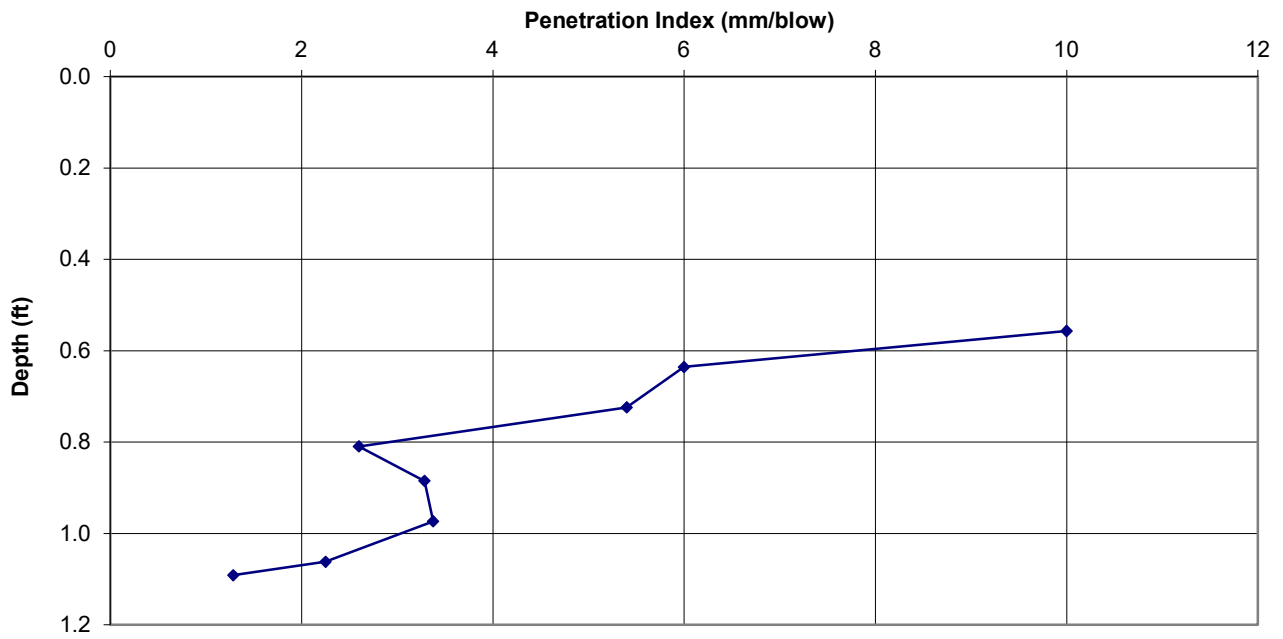
C-57-L - Penetration Index vs. Depth



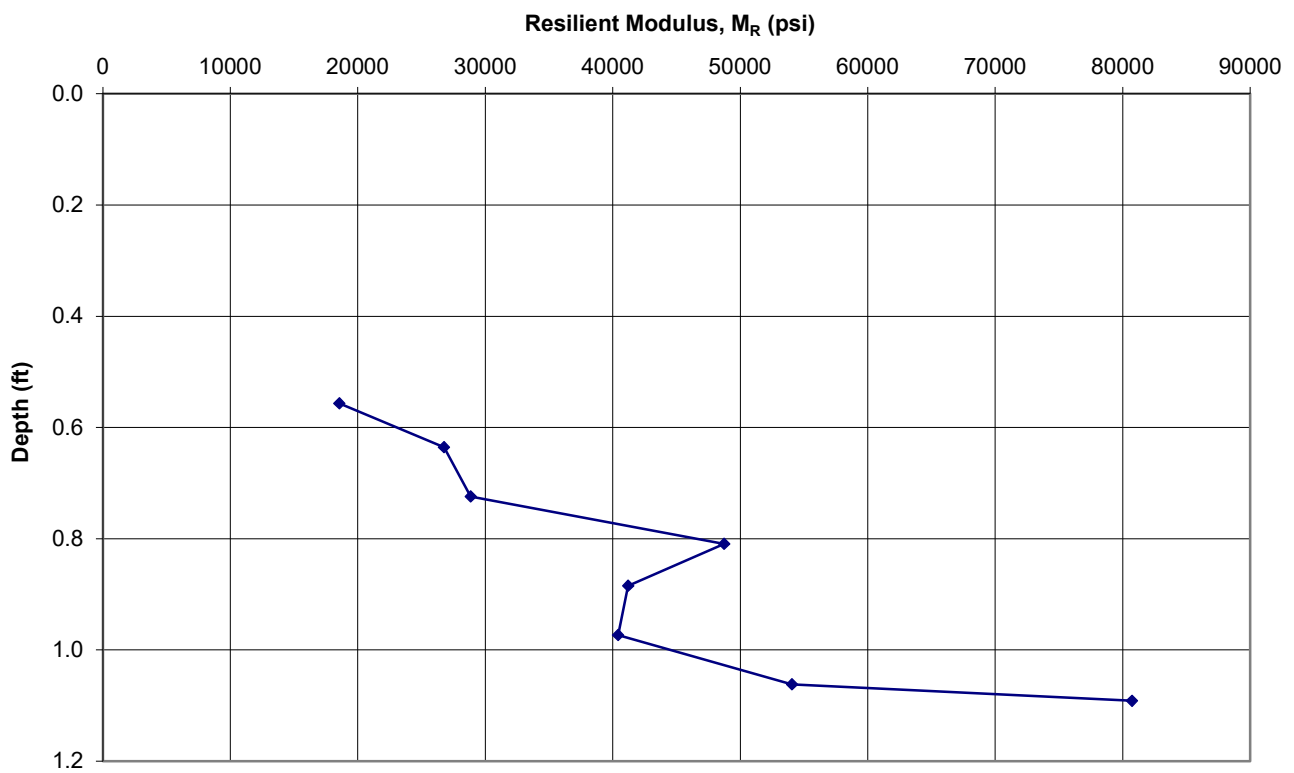
C-57-L - Resilient Modulus vs. Depth



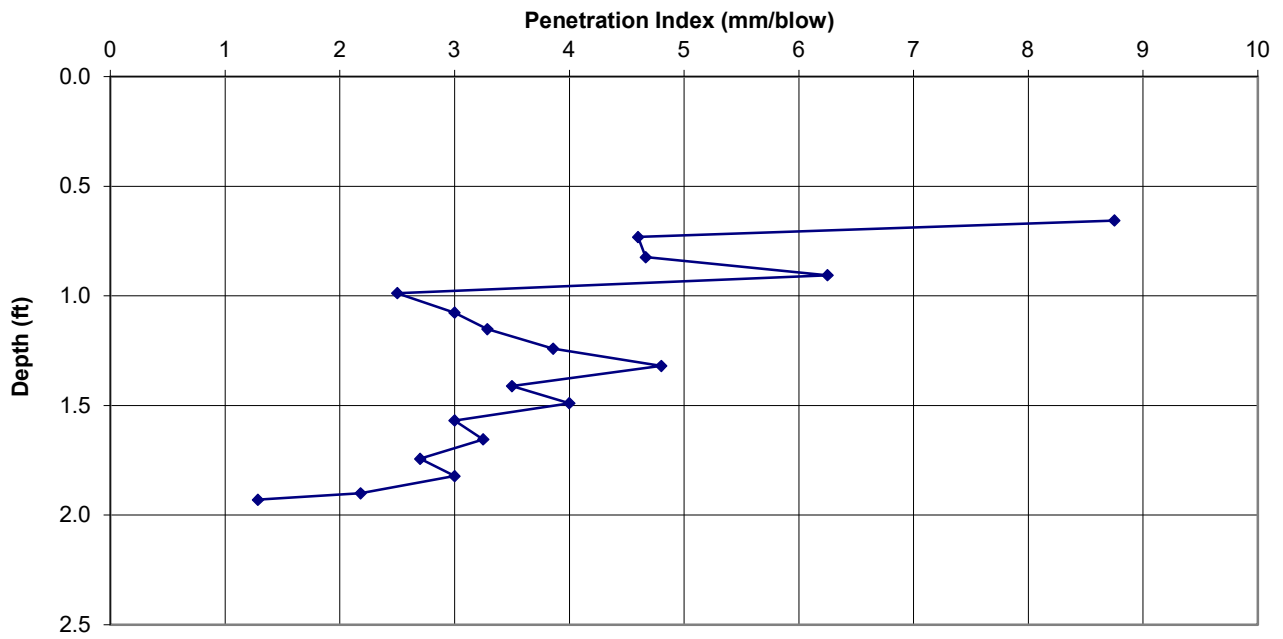
C-57-R - Penetration Index vs. Depth



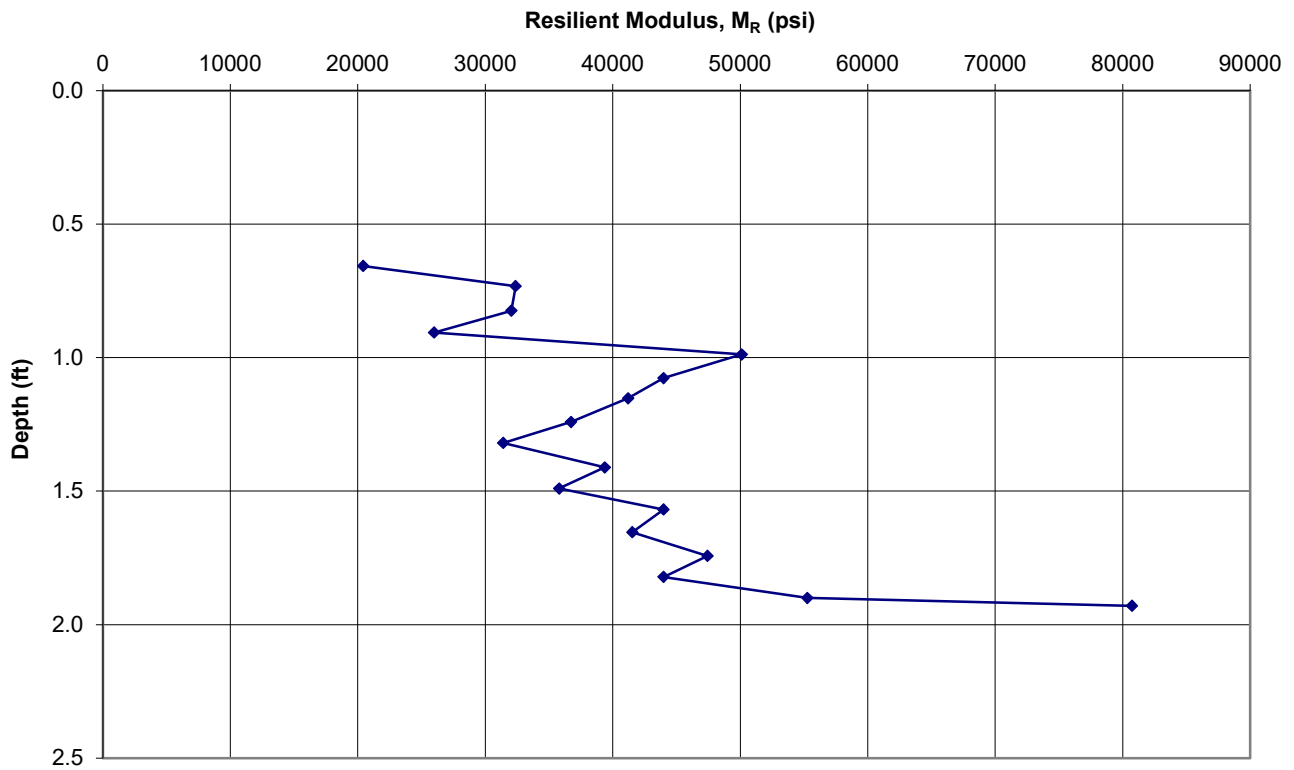
C-57-R - Resilient Modulus vs. Depth



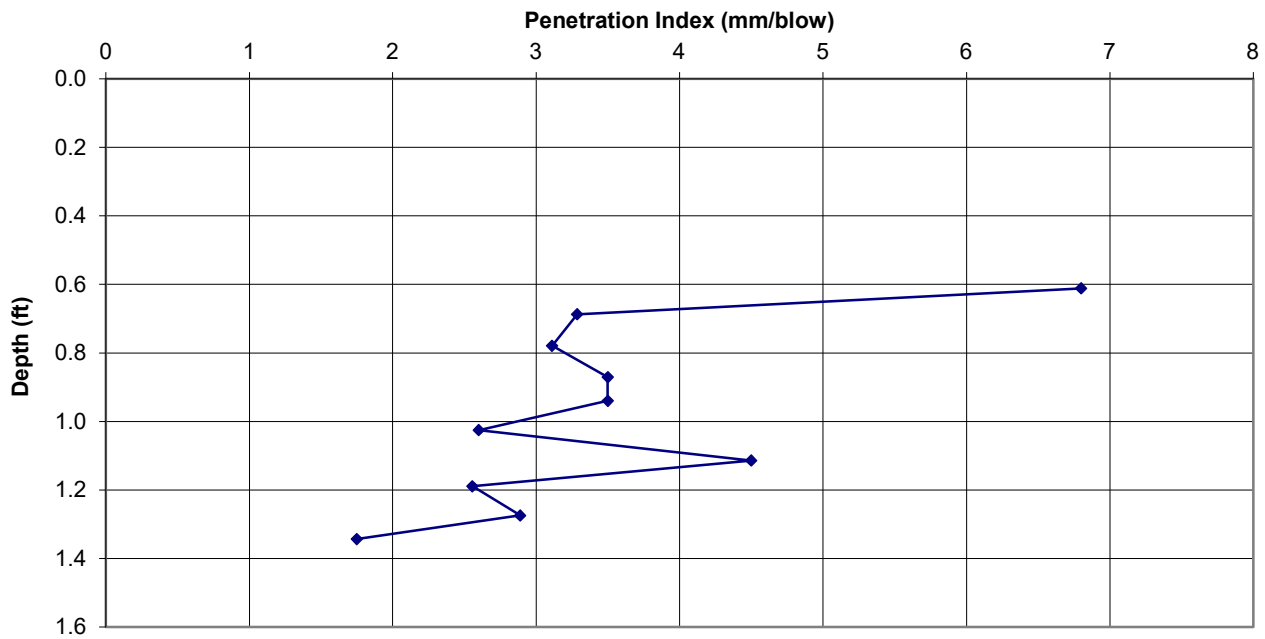
C-58-L - Penetration Index vs. Depth



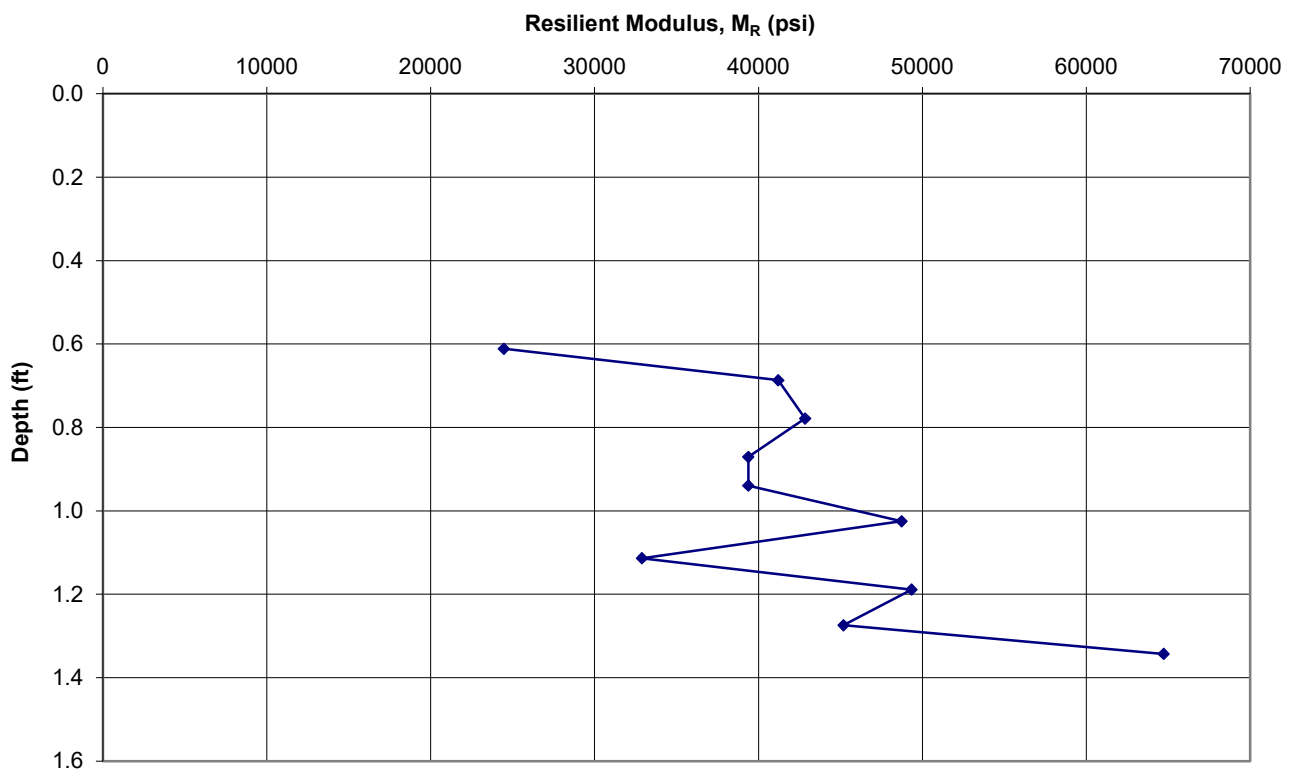
C-58-L - Resilient Modulus vs. Depth



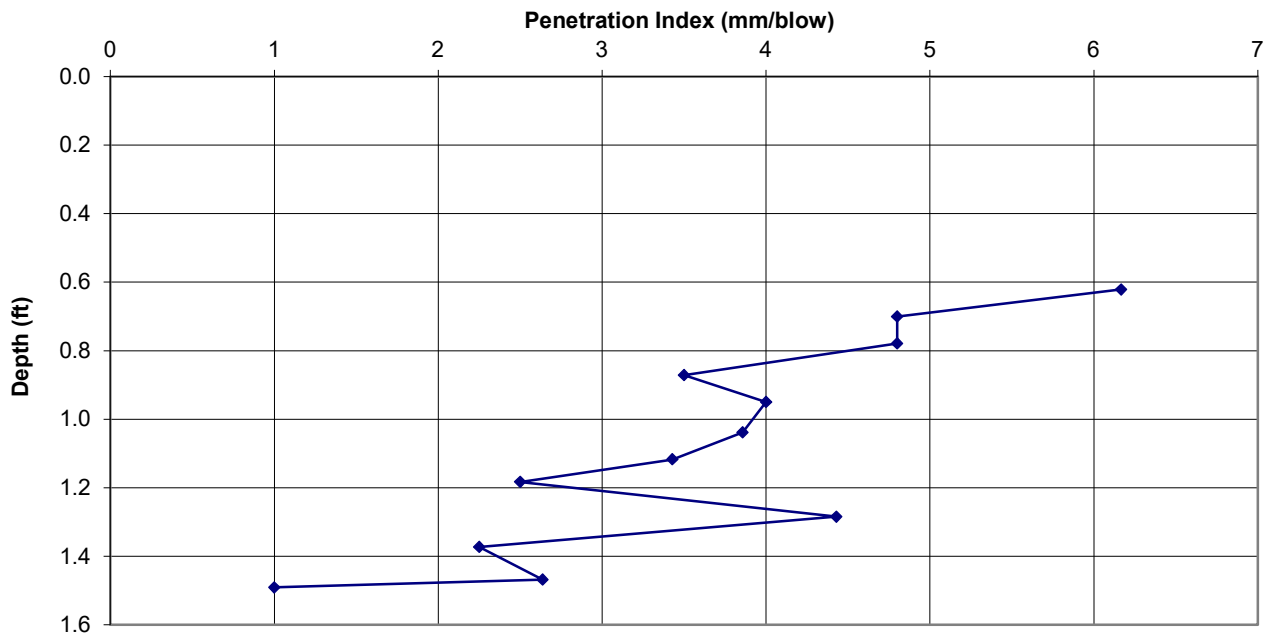
C-58-R - Penetration Index vs. Depth



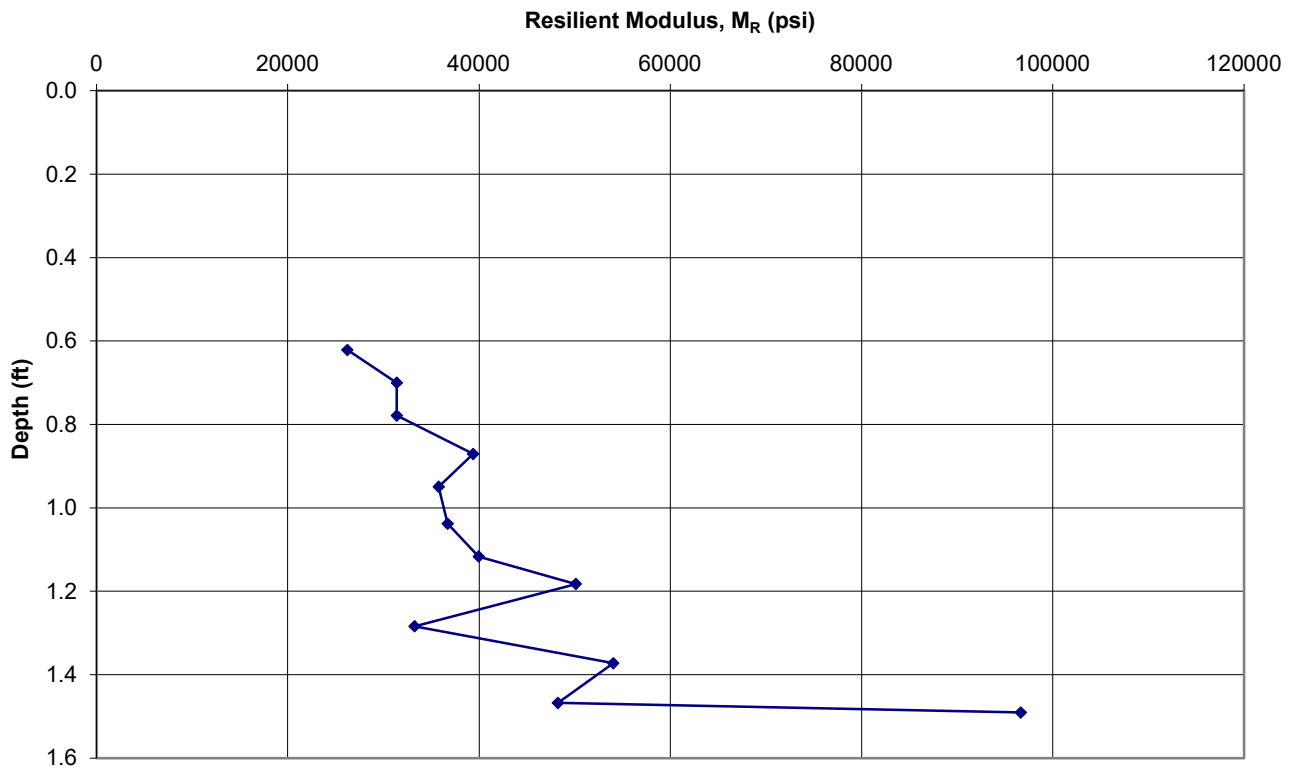
C-58-R - Resilient Modulus vs. Depth



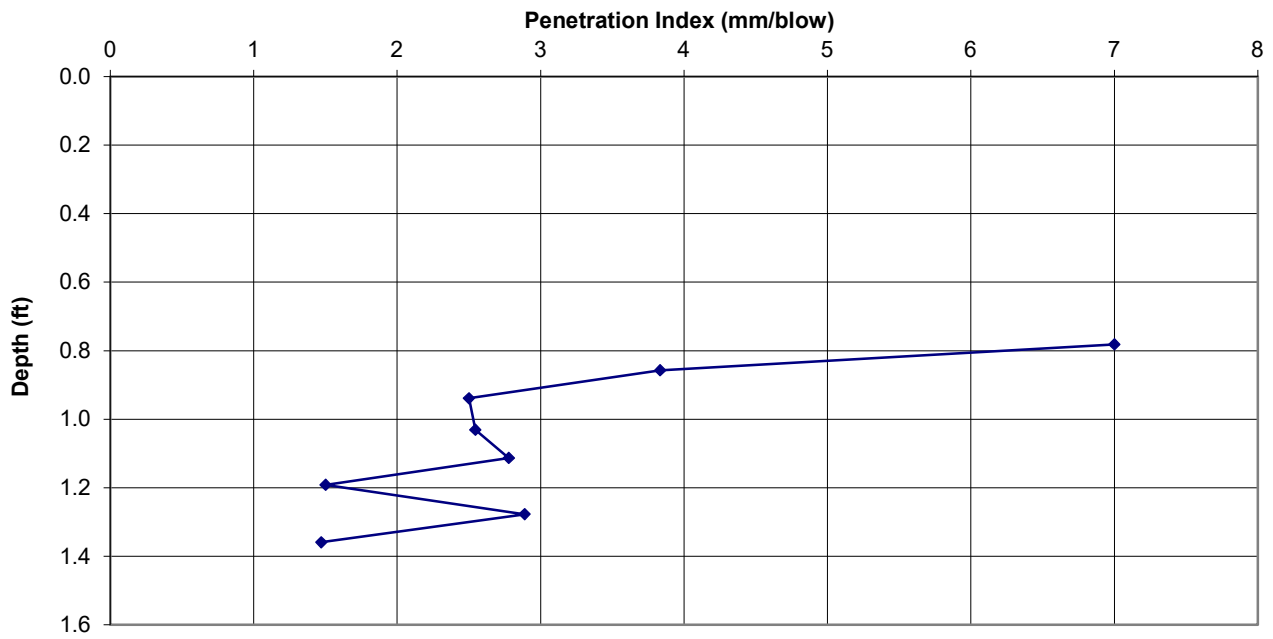
C-59.05-L - Penetration Index vs. Depth



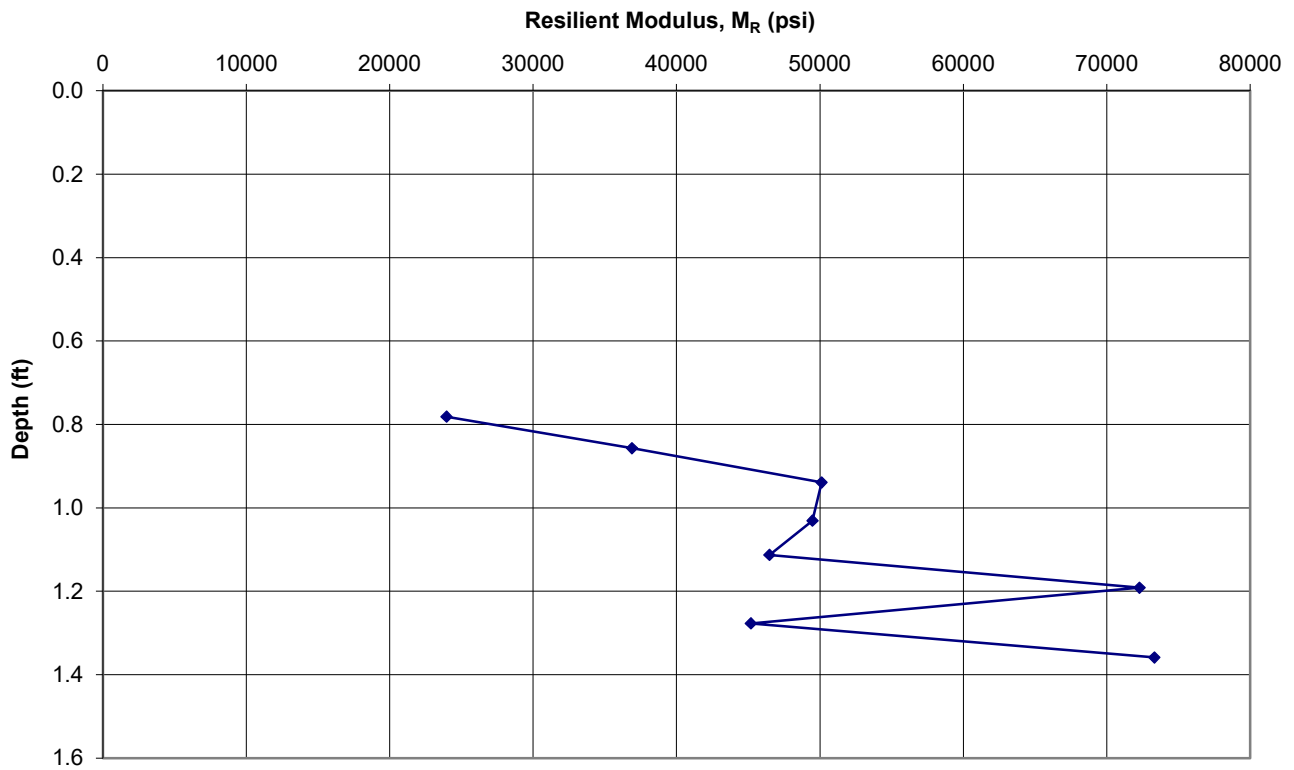
C-59.05-L - Resilient Modulus vs. Depth



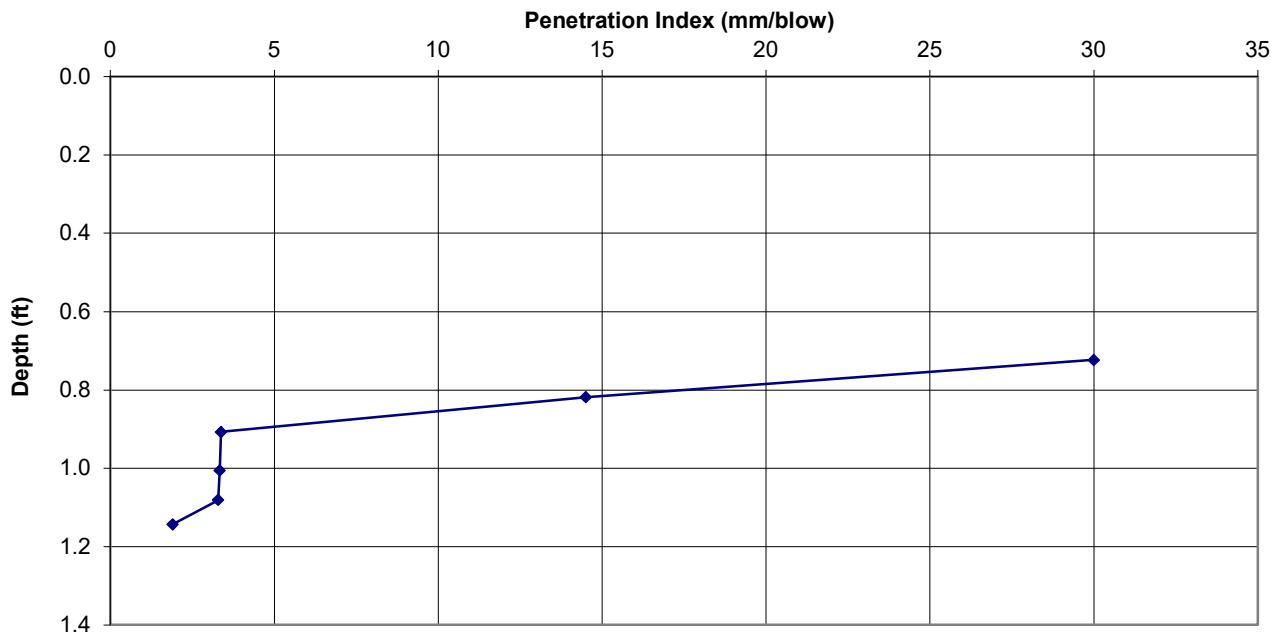
C-59.05-R - Penetration Index vs. Depth



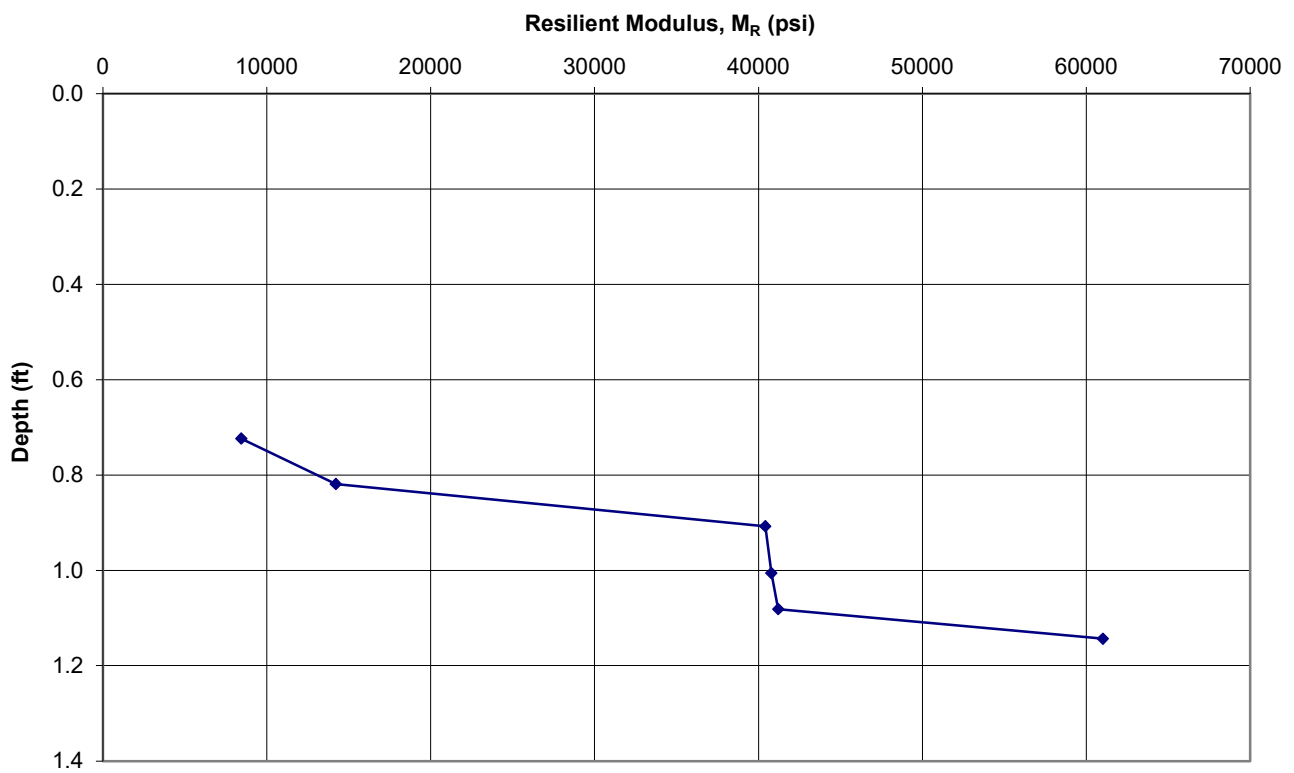
C-59.05-R - Resilient Modulus vs. Depth



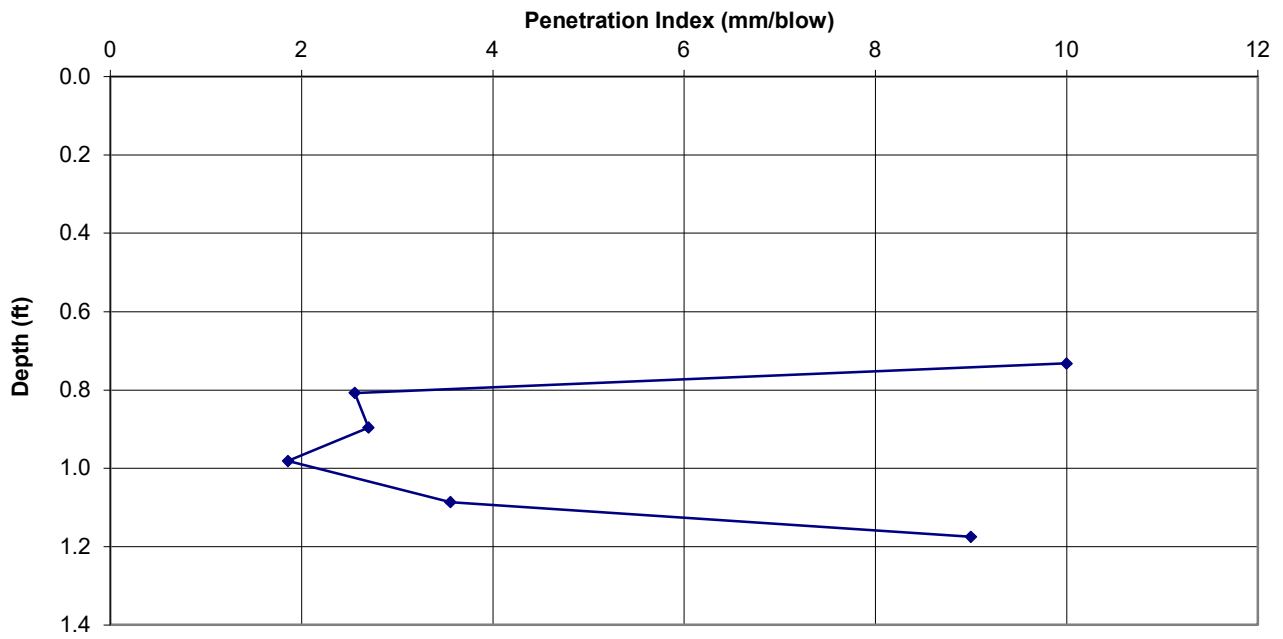
C-60-L - Penetration Index vs. Depth



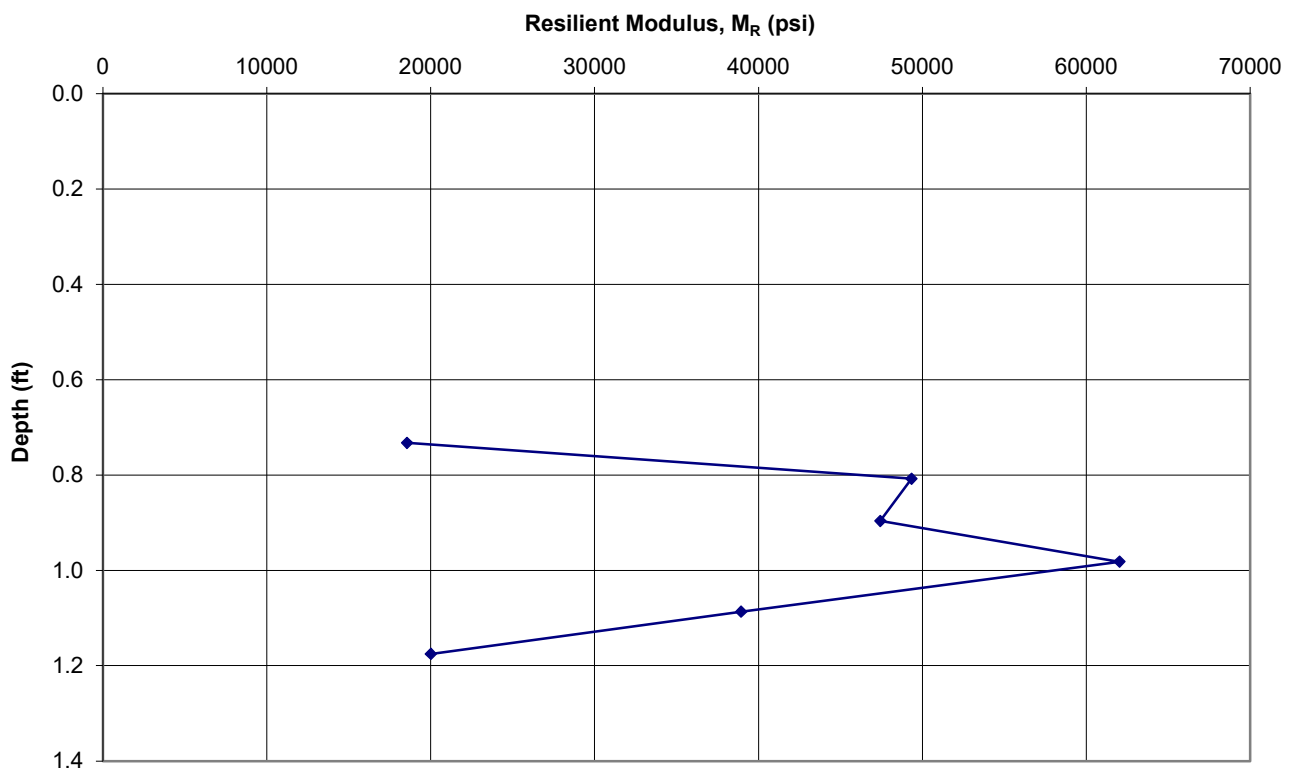
C-60-L - Resilient Modulus vs. Depth



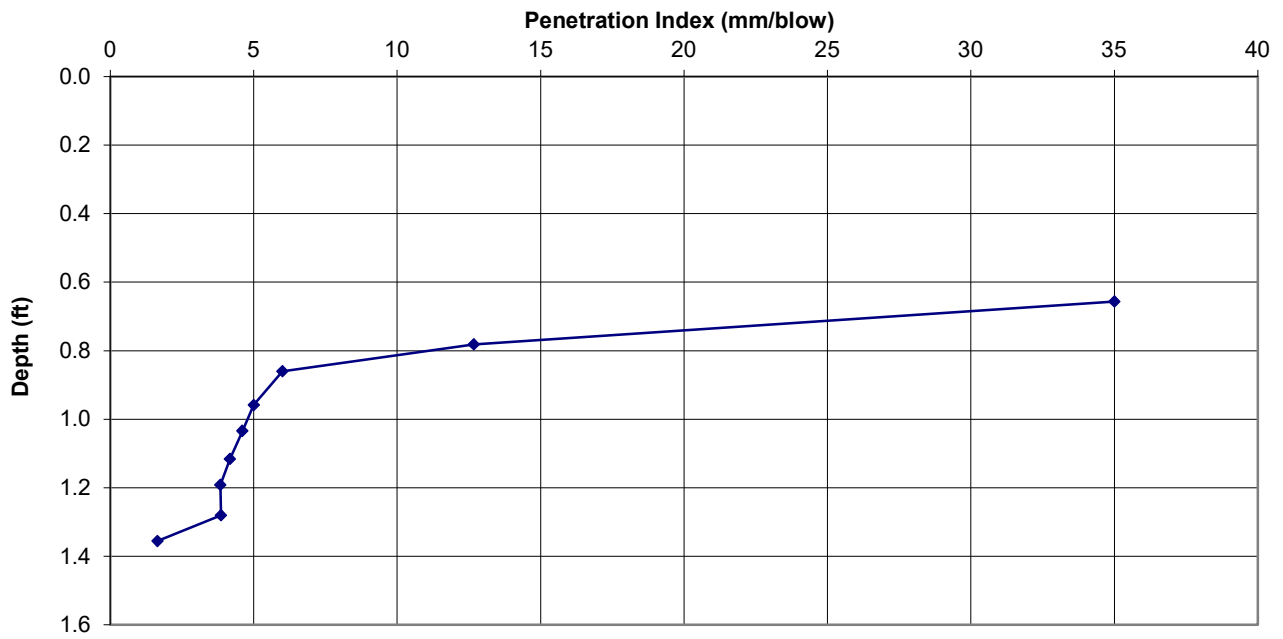
C-60-R - Penetration Index vs. Depth



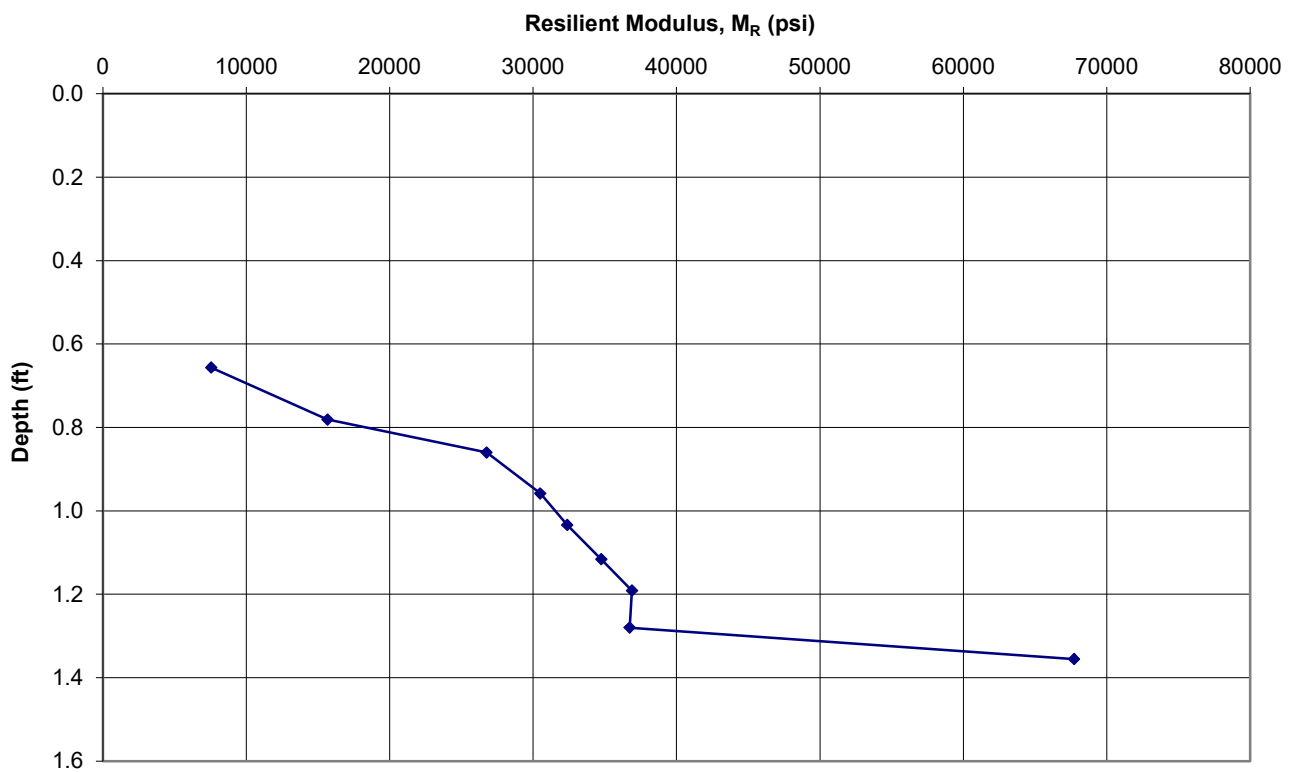
C-60-R - Resilient Modulus vs. Depth



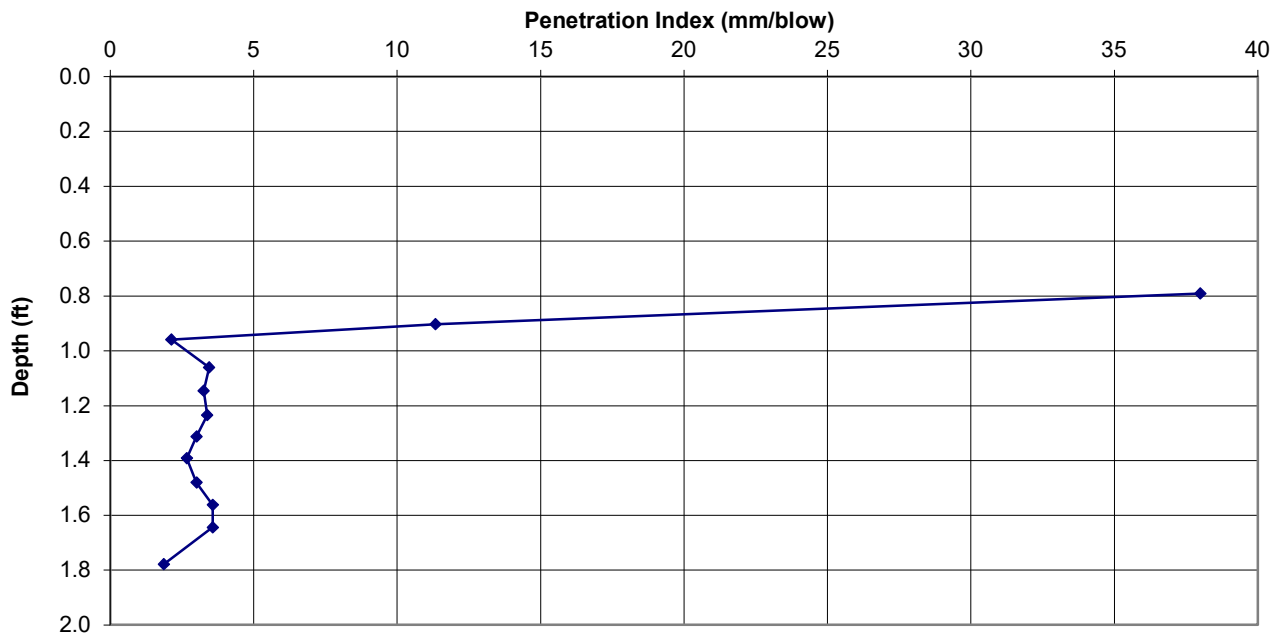
C-61-L - Penetration Index vs. Depth



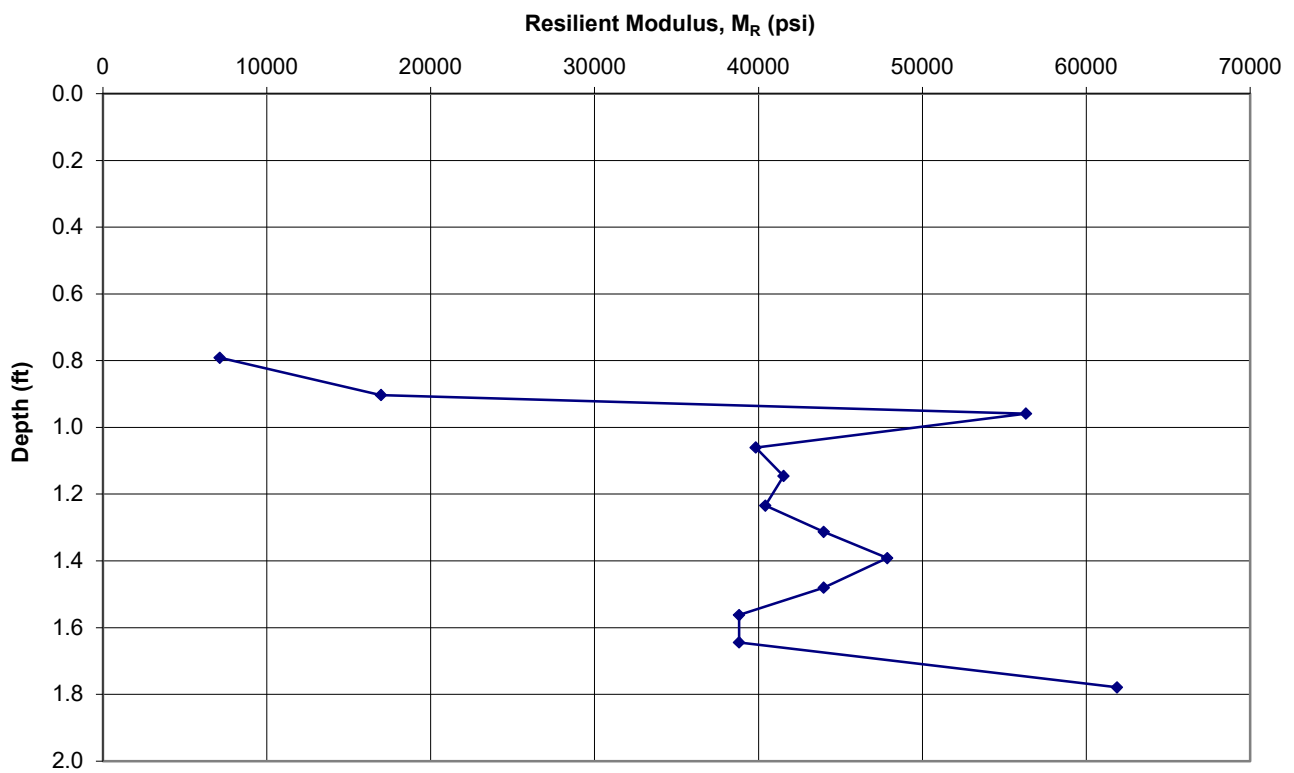
C-61-L - Resilient Modulus vs. Depth



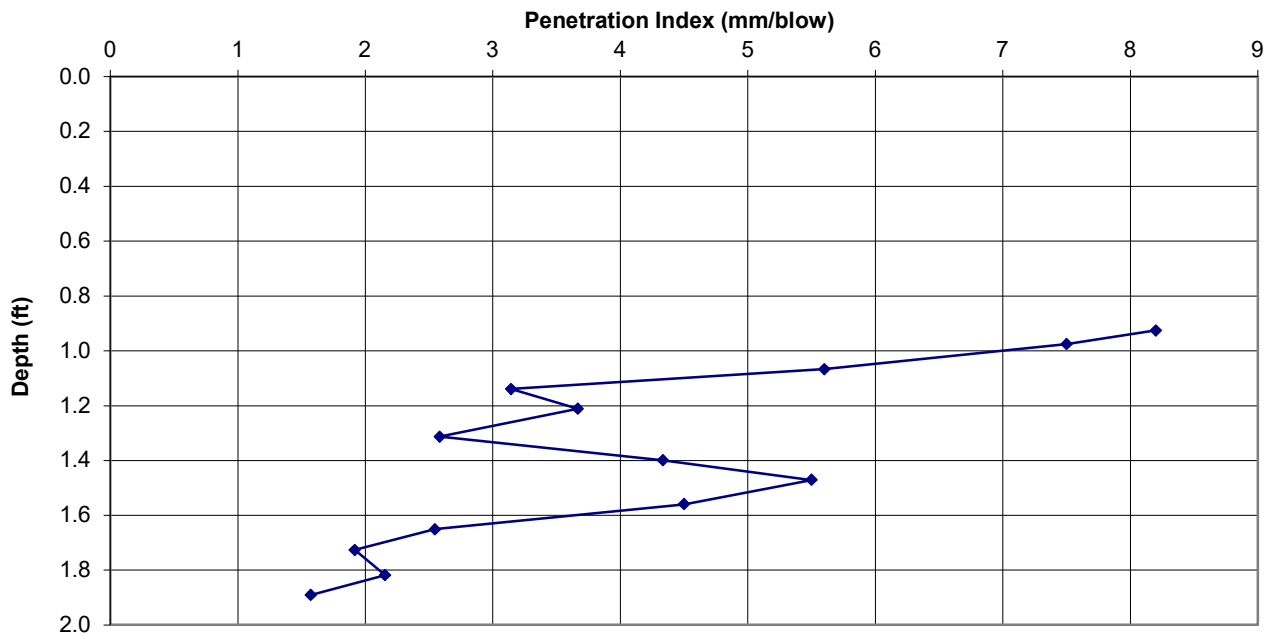
C-61-R - Penetration Index vs. Depth



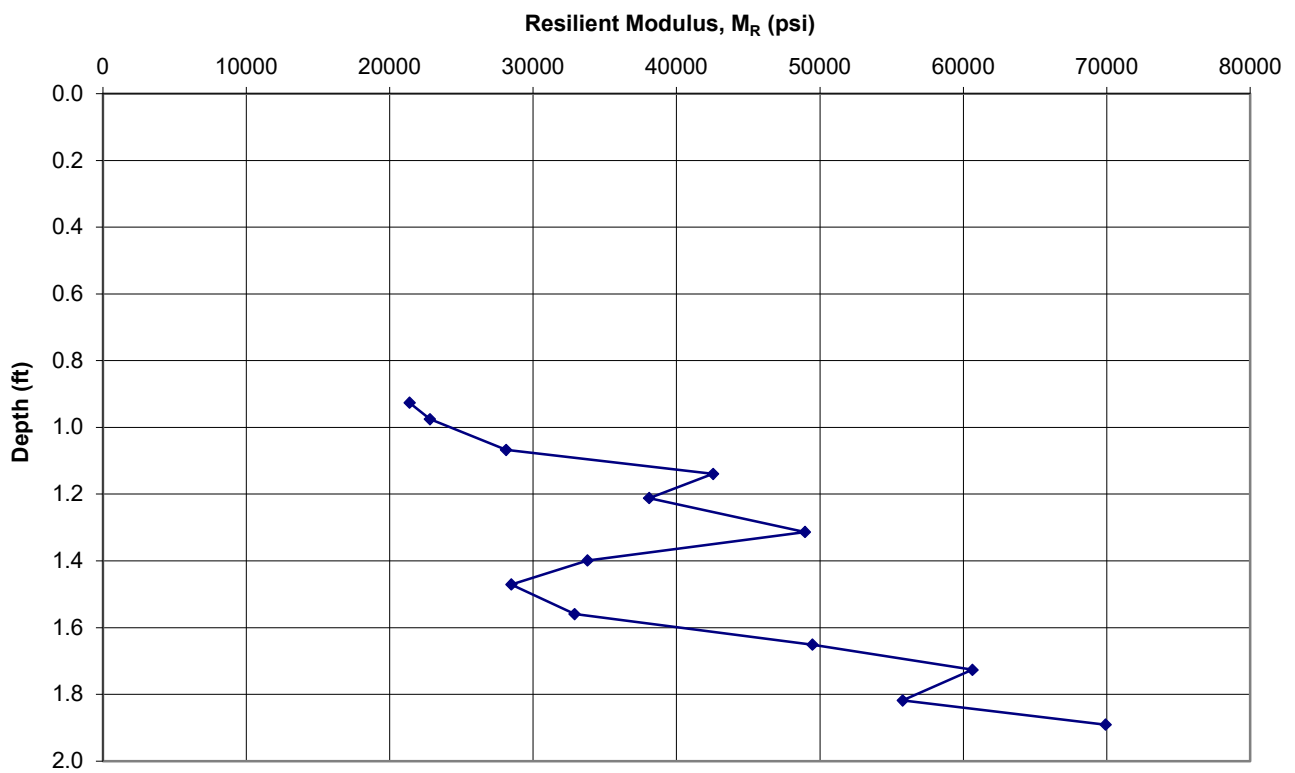
C-61-R - Resilient Modulus vs. Depth



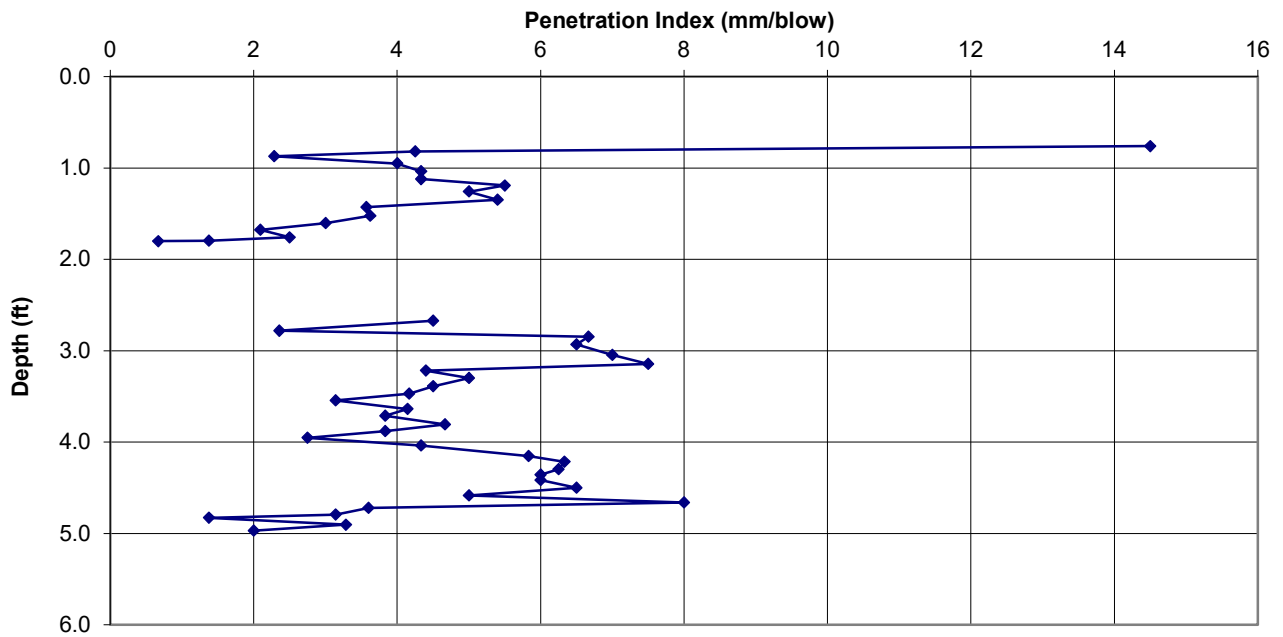
C-62-L - Penetration Index vs. Depth



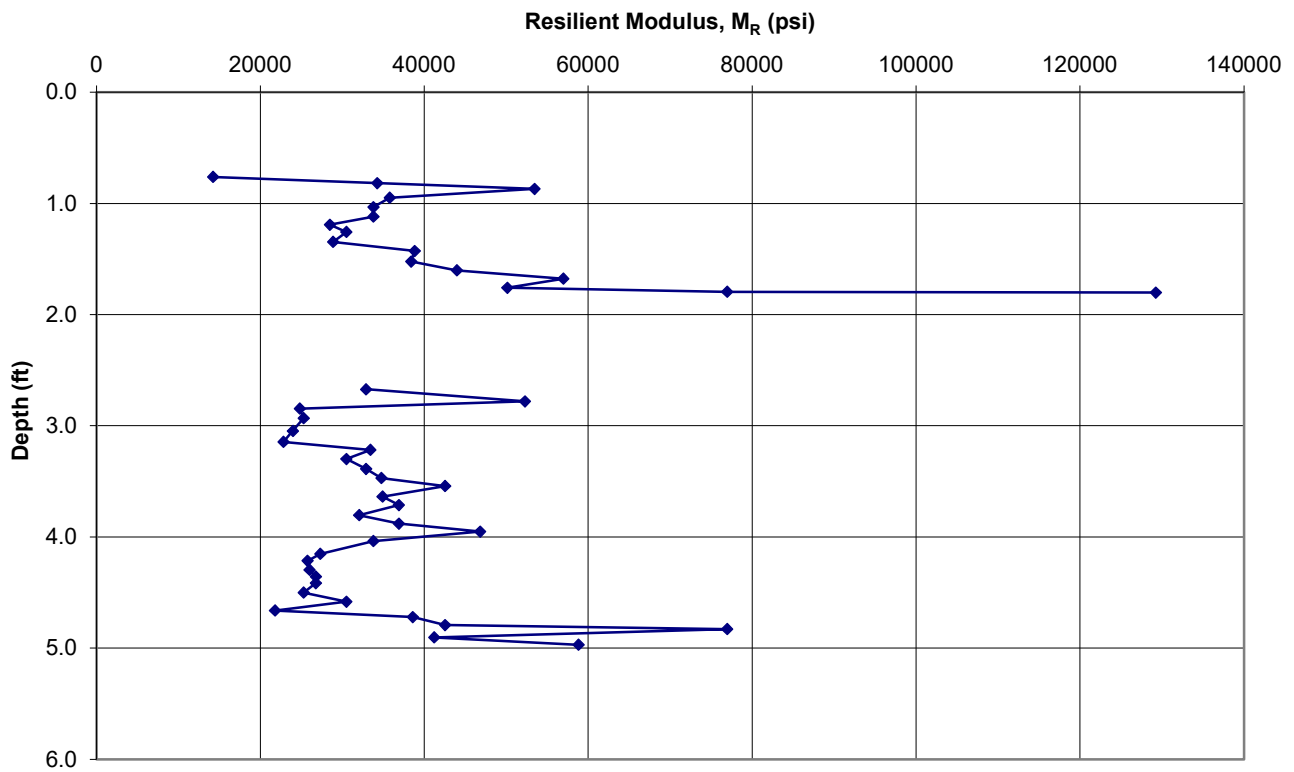
C-62-L - Resilient Modulus vs. Depth



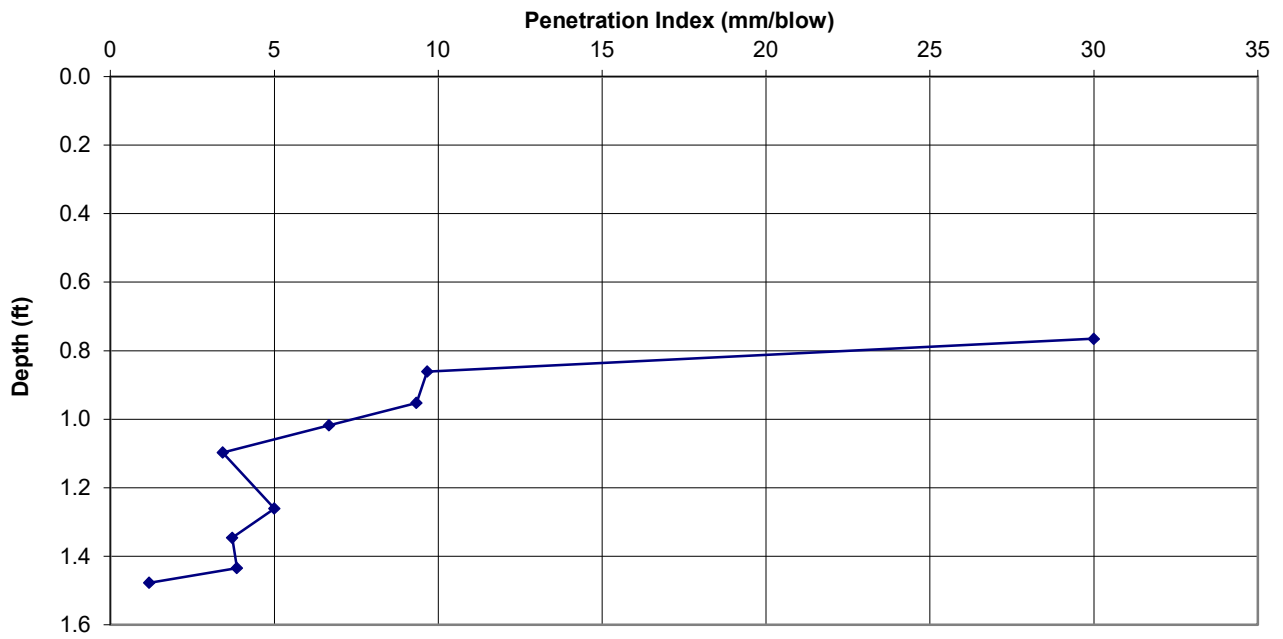
C-62-R - Penetration Index vs. Depth



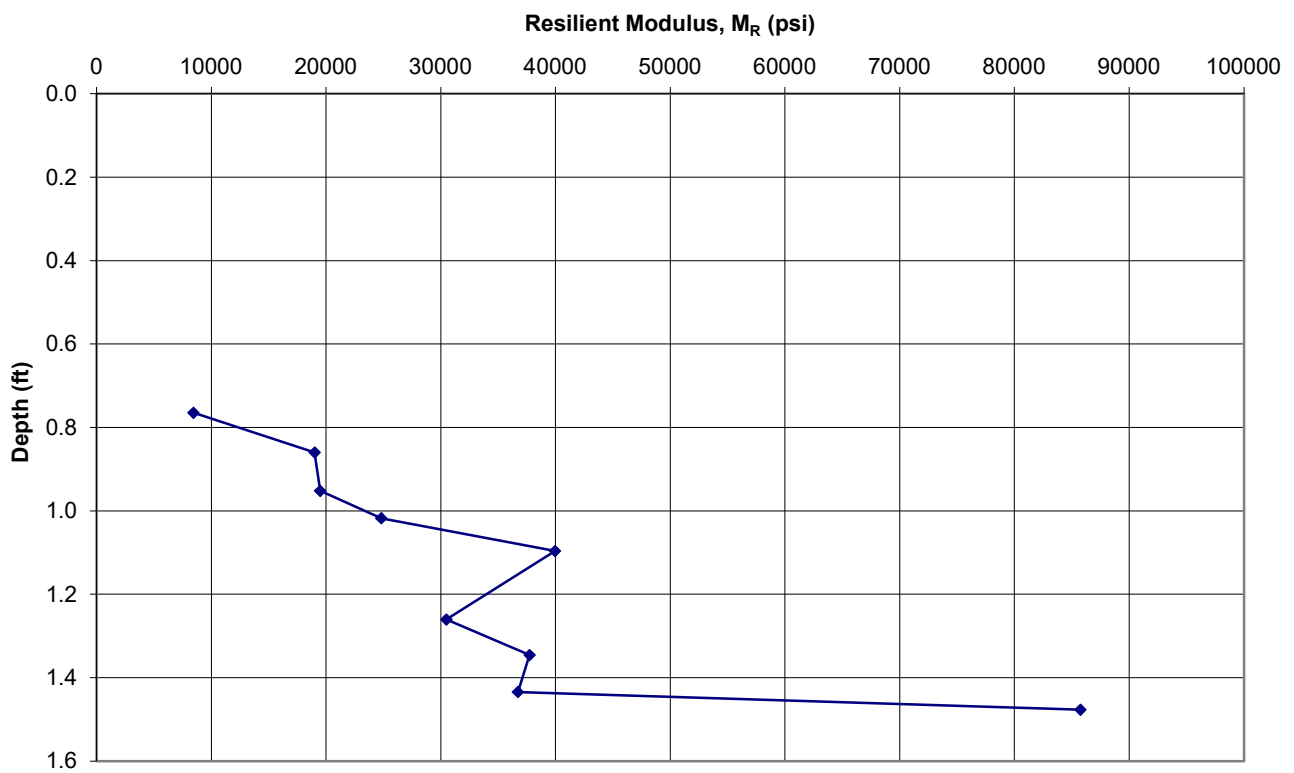
C-62-R - Resilient Modulus vs. Depth



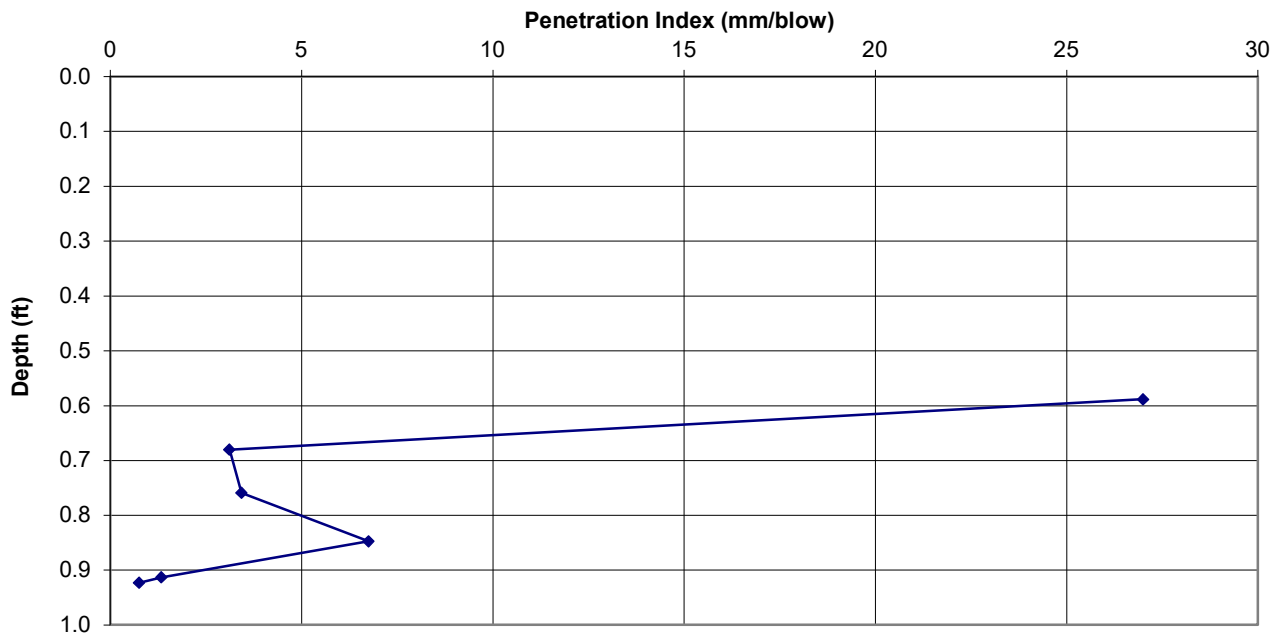
C-63-L - Penetration Index vs. Depth



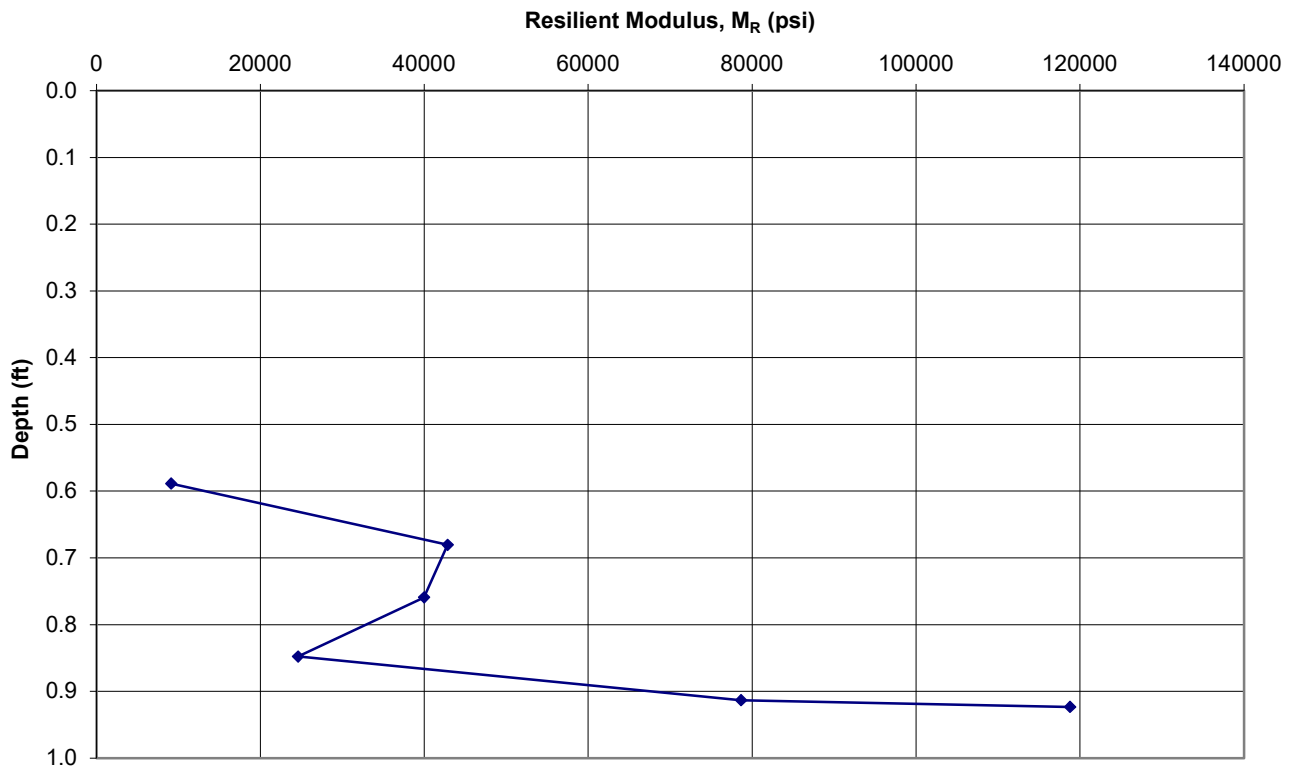
C-63-L - Resilient Modulus vs. Depth



C-63-R - Penetration Index vs. Depth



C-63-R - Resilient Modulus vs. Depth



APPENDIX F
REPORT LIMITATIONS



GEODesign, Inc.
85 Granite Shed Lane
Unit 1
Montpelier, VT 05602
(802) 674-2033

Geotechnical Limitations

Explorations

1. The analyses and recommendations submitted in this report are based in part upon the data obtained from widely spaced subsurface explorations. The nature and extent of variations between these explorations may not become evident until construction. If variations then appear evident, it will be necessary to reevaluate the recommendations of this report.
2. The generalized soil profile described in the text is intended to convey trends in subsurface conditions. The boundaries between strata are approximate and idealized and have been developed by interpretations of widely spaced explorations and samples; actual soil transitions are probably more erratic. For specific information, refer to the boring logs.
3. Water level readings and moisture conditions have been made in the explorations, and from the samples at times and under conditions stated on the logs. These data have been reviewed and interpretations have been made in the text of this report. However, it must be noted that fluctuations in the level of the groundwater and moisture condition may occur due to variations in rainfall, temperature, and other factors occurring since the time measurements were made.

Review

4. In the event that any changes in the nature, design or location of the proposed structures is planned, the conclusions and recommendations contained in this report shall not be considered valid unless the changes are reviewed and conclusions of this report modified or verified in writing by GEODesign, Inc. We recommend that we be provided the opportunity to review and comment on the finalized project design and relevant construction specifications in order that earthwork and foundation recommendations may be properly interpreted and implemented in the design and specifications.

Use of Report

5. This report has been prepared for the exclusive use of **VTrans**, for specific application to the **Montpelier-Waterbury IM 089-2(56)** project, as described in GEODesign's scope of services/ contract and related documents, in accordance with generally accepted soil and foundation engineering practices. No other warranty, express or implied, is made.
6. This report has been prepared for this specific project by GEODesign, Inc. This report is for design purposes only and is not sufficient to prepare an accurate bid. Contractors wishing a copy of the report may secure it with the understanding that its scope is limited to design considerations only, unless otherwise specified in the report.
7. Unless otherwise noted, the scope of our services did not include environmental assessment or investigation for the presence of hazardous or toxic materials in the soil, surface water, groundwater or air, on, below, or around this site.

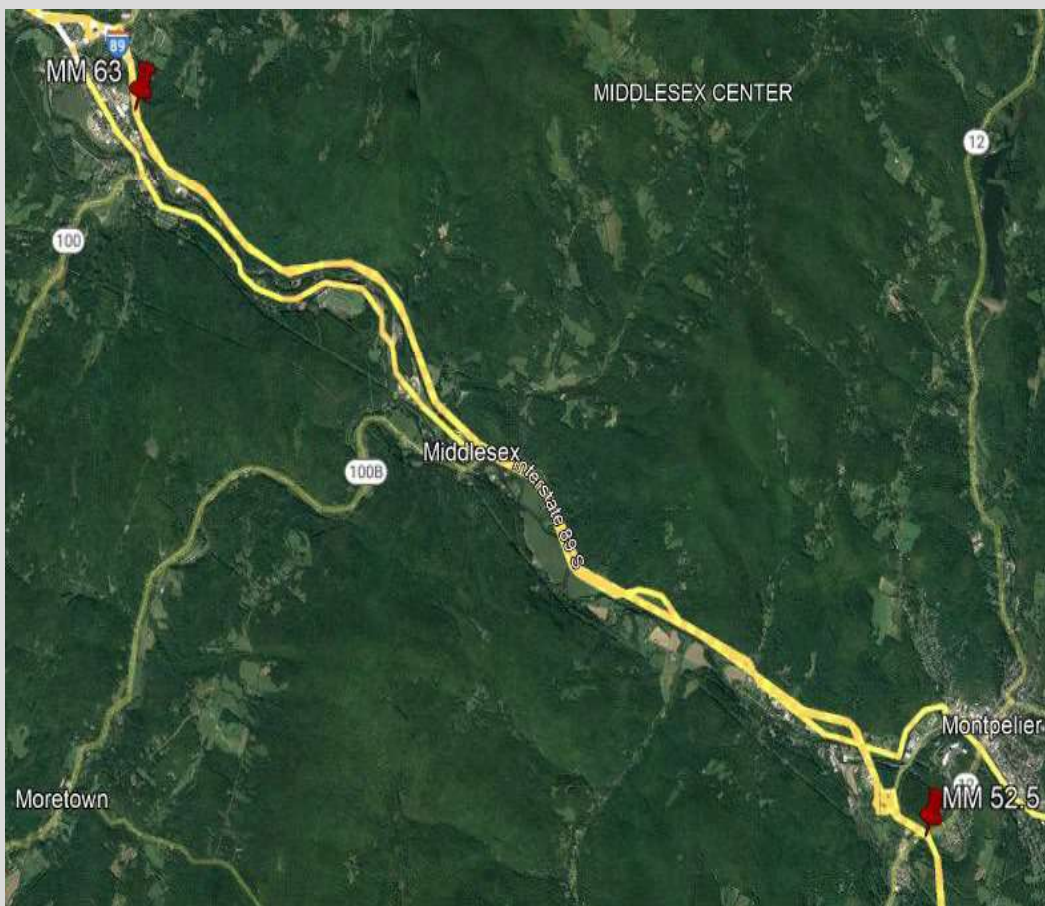
APPENDIX G
GROUND PENETRATING RADAR REPORT (BY INFRASENSE)

GPR Pavement Thickness Evaluation

I-89 SB, MM-63 to MM-52.5

Montpelier-Waterbury IM 089-2(56)

FINAL REPORT



SUBMITTED TO:

GEODesign, Inc.
85 Granite Shed Lane, Unit #1
Montpelier, VT 05602

SUBMITTED BY:

Infrasense, Inc.
21G Olympia Ave, Suite 45
Woburn, MA 01801

October 3, 2023

1. Introduction

The objective of this project was to evaluate the pavement structure along I-89 Southbound, between MM-63 and MM-52.5. The evaluation was carried out using vehicle-based ground penetrating radar (GPR) equipment, which provides continuous measurements of the bound and unbound materials. The following sections describe the data collection procedures, analysis methods, and resulting deliverables.

2. Data Collection

The GPR data collection was carried out on September 28th, 2023, at normal driving speed using a 1-GHz horn antenna system manufactured by GSSI, Inc. of Nashua, NH (see Figure 1). The vehicle is equipped with an electronic distance-measuring instrument (DMI) mounted to the rear wheel, providing synchronous distance data as the GPR data was collected; and a Trimble GPS unit, providing high resolution, differentially corrected geo-spatial information. The data collection and recording are controlled by the SIR-30 GPR system operated from within the survey vehicle. The data was collected at a rate of two scans per foot of travel along the centerline of each surveyed lane.



Figure 1 – Infrasense GPR Equipment Setup

3. Data Analysis and Results

3.1 Pavement Thickness

The GPR data was analyzed to identify the thickness of the asphalt concrete (AC) and underlying base layers, where detectable. The GPR data, when displayed in a gray scale "B-scan", reveals the pavement cross-section including the individual pavement layers. Figure 2a shows a representative sample of the data and identifies the layers detected and reported for the project section. Figure 2b shows the same sample data, but with the bottom of the asphalt (blue) and underlying base layer (green) "picked" by the GPR analyst. The software carries out the dielectric and thickness calculations on this picked data.

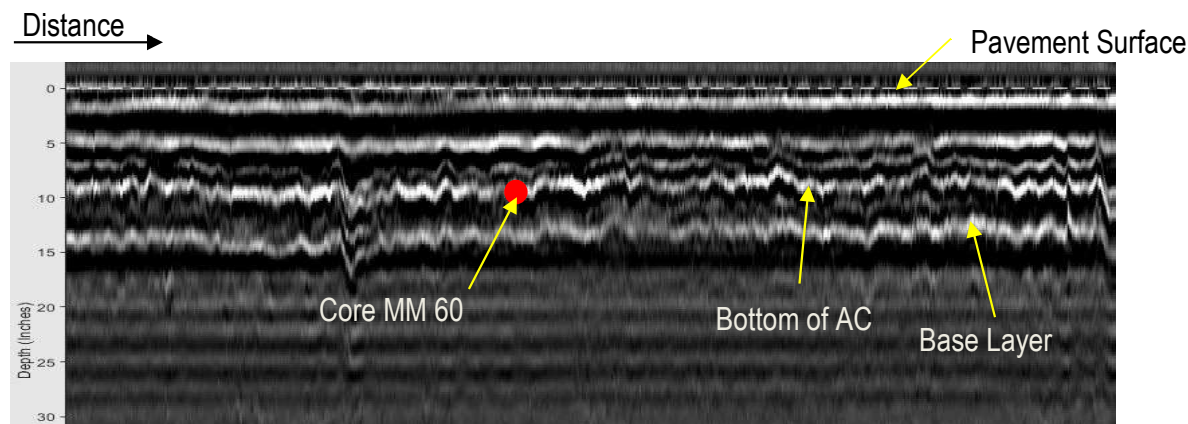


Figure 2a – Sample GPR Data Showing Pavement Layers
(Sample Along Centerline of SB Travel Lane)

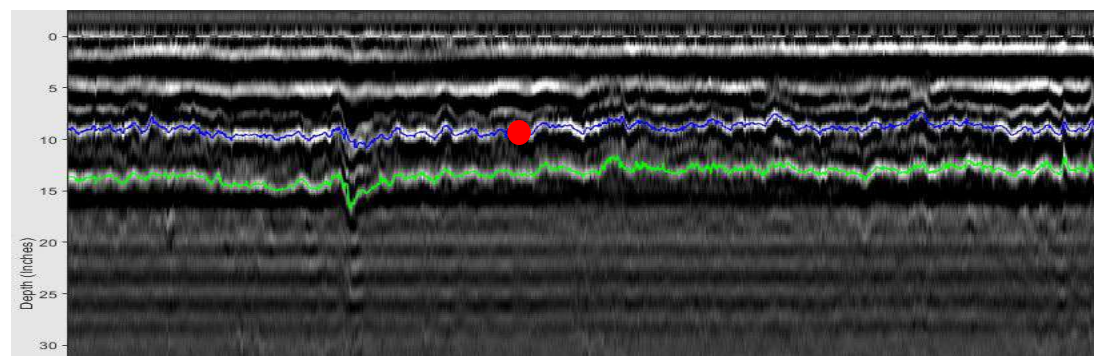


Figure 2b – Sample GPR Data Showing Pavement Layers "Picked" By Analyst
(Sample Along Centerline of SB Travel Lane)

The pavement layer thicknesses were calculated and reported at 25-foot increments. The GPR results show an average of 7.3 inches and 8.0 inches of AC in the travel lane and passing lane, respectively. A more detailed statistical summary of the layer thickness results is provided in Tables 1-3.

The pavement layer thickness results with corresponding distance referencing and GPS coordinates for each lane have been submitted as a tabular Excel file (see Attachment A). In addition, depth profile plots of the pavement structure have been provided as Attachment B. These are also included within the “Plots” tab of the Excel files, along with the core data. Additional information on the principles of GPR for pavement thickness measurements is provided as Attachment C.

Table 1 – Asphalt Thickness Statistics (in)

Lane	Average	Median	25th Percentile	75th Percentile
Travel Lane	7.3	7.4	6.1	8.3
Passing Lane	8.0	8.0	7.0	9.2

Table 2 – Base 1 Thickness Statistics (in)

Lane	Average	Median	25th Percentile	75th Percentile
Travel Lane	3.4	3.3	2.8	3.9
Passing Lane	3.9	3.8	3.1	4.5

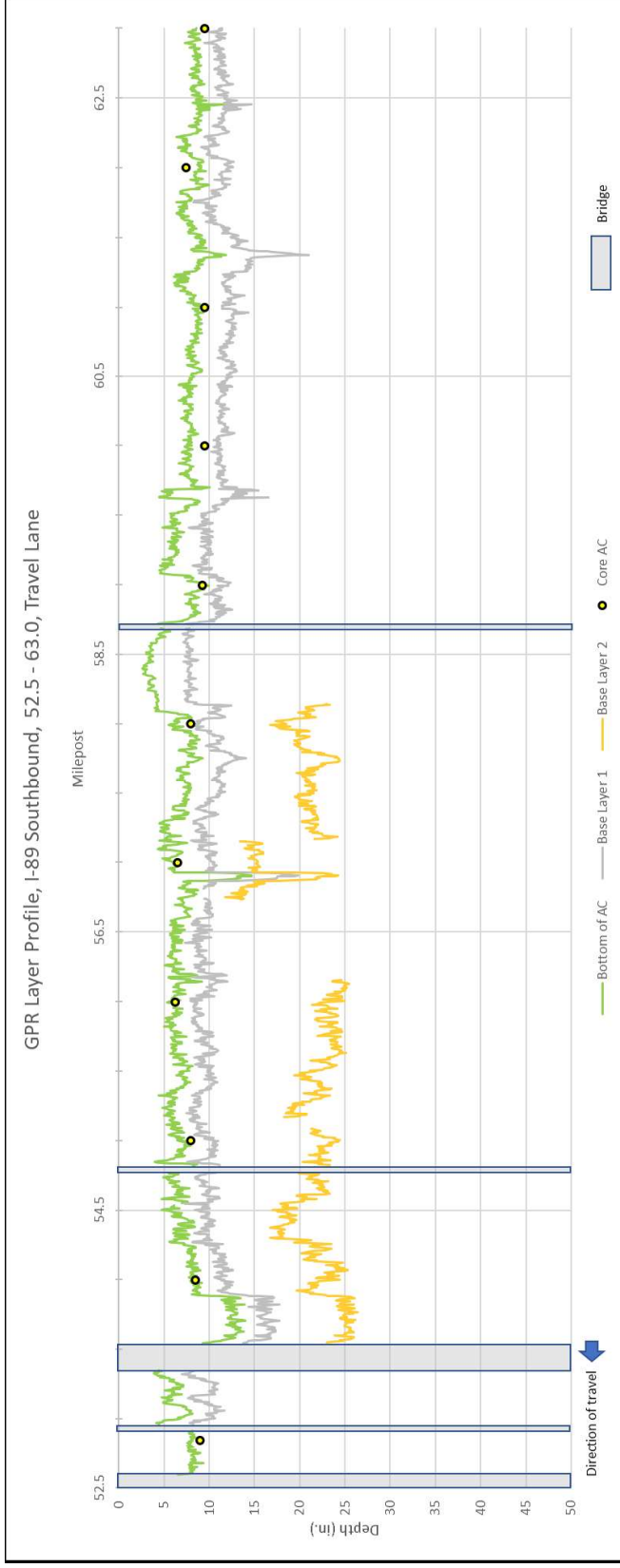
Table 3 – Base 2 Thickness Statistics (in)

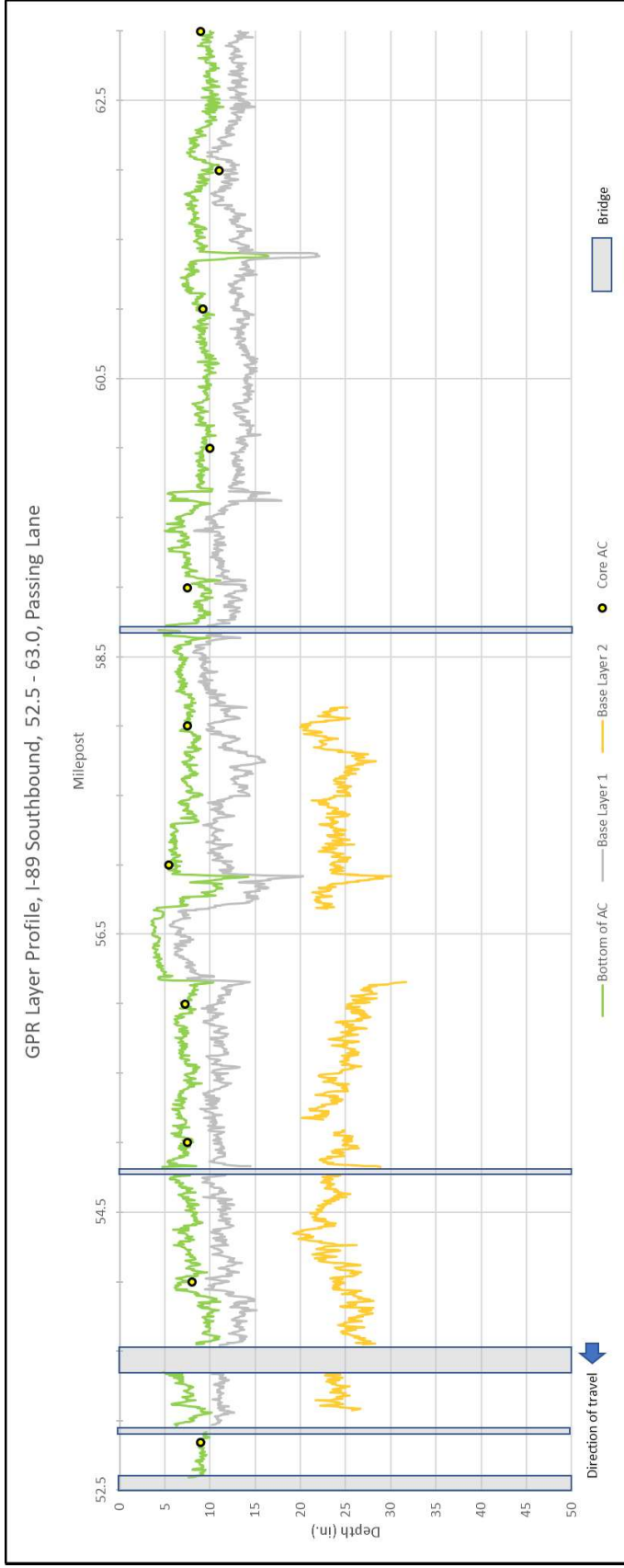
Lane	Average	Median	25th Percentile	75th Percentile
Travel Lane	10.7	10.6	9.1	12.8
Passing Lane	12.6	12.7	11.4	13.7

Coring measurements at 22 locations were provided to aid the GPR analysis by confirming the material type for each of the subsurface layers, and to calibrate the thickness calculations of these layers. The average percent error between the core measurements and the final GPR thickness results is 8.9%.

ATTACHMENT A

PAVEMENT LAYER THICKNESS PLOTS





ATTACHMENT B

TABULAR & GEOSPATIAL RESULTS

transmitted electronically as

" I-89 SB_GPR Pavement Structure.xlsx"

ATTACHMENT C

PRINCIPLES OF GPR FOR PAVEMENT EVALUATION

Ground penetrating radar operates by transmitting short pulses of electromagnetic energy into the pavement using an antenna attached to a survey vehicle. These pulses are reflected back to the antenna with an arrival time and amplitude that is related to the location and nature of dielectric discontinuities in the material (air/asphalt or asphalt/concrete, reinforcing steel, etc.). The reflected energy is captured and may be displayed on an oscilloscope to form a series of pulses that are referred to as the radar waveform. The waveform contains a record of the properties and thicknesses of the layers within the pavement (Figure C1).

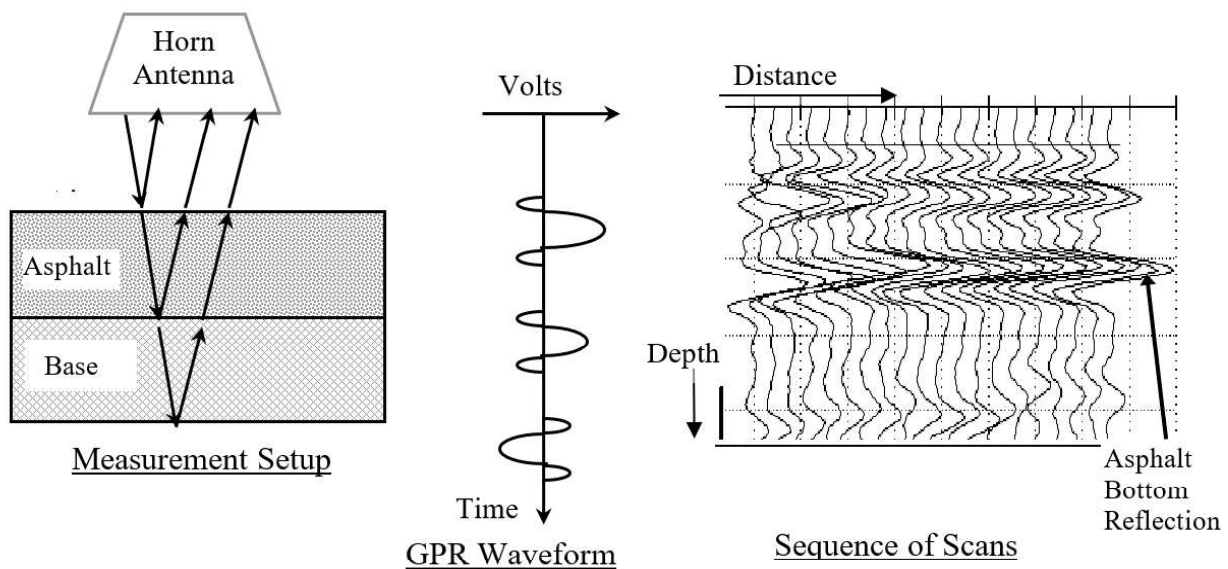


Figure C1 – Structure of the GPR Signal for Pavements

The sequence of scans shown on the right of Figure C1 is frequently coded in color or gray scale to produce the "b" scan representation, examples of which have been shown in the body of the report. The b-scan provides the equivalent of a cross sectional view of the pavement, with the individual pavement layers showing up as colored horizontal bands. The white and black bands indicate stronger reflections and occur when the dielectric contrast is greater. The grey regions indicate weaker reflections and occur when there is little dielectric contrast.

Layer thickness is calculated from the arrival time of the reflection from the top and bottom of each layer as follows:



$$\text{Thickness (in.)} = (5.9 t) / \sqrt{\epsilon_a} \quad (1)$$

where time (t) is measured in nanoseconds and ϵ_a is the relative dielectric permittivity or “dielectric constant” of the pavement layer (Roddis, et. al., 1992). Computation of the dielectric constant of the surface layer can be made by measuring the ratio of the radar reflection from the pavement surface to the radar amplitude incident on the pavement. The incident amplitude on the pavement is determined by measuring the reflection from a metal plate on the pavement surface, since the metal plate reflects 100% of the incident energy. Using this data, one obtains the asphalt dielectric constant, ϵ_a as follows:

$$\epsilon_a = [(A_{pl} + A)/(A_{pl} - A)]^2 \quad (2)$$

where A = amplitude of reflection from asphalt, and A_{pl} = amplitude of reflection from metal plate (negative of incident amplitude) (Roddis, et. al., 1992). Table C1 shows typical dielectric constants and associated GPR velocities for pavement materials. Note that the range of dielectric constant for asphalt is large, due to the variations in density and aggregate composition.

Table C1 – GPR Velocities and Dielectric Constants for Pavement Materials

VELOCITY			DIELECTRIC CONSTANT	NOTES
METRIC		ENGLISH		
M/NS	CM/NS	IN/NS		
0.90	9.0	3.54	11.00	typical for PCC 
0.100	10.0	3.94	9.00	
0.105	10.5	4.13	8.16	
0.110	11.0	4.33	7.44	
0.115	11.5	4.53	6.81	
0.120	12.0	4.72	6.25	
0.125	12.5	4.92	5.76	
0.130	13.0	5.12	5.33	
0.135	13.5	5.31	4.94	
0.140	14.0	5.51	4.59	
0.145	14.5	5.71	4.28	typical for AC 
0.150	15.0	5.90	4.00	
0.155	15.5	6.10	3.75	

A similar calculation can be made for the dielectric constant of the base material. Changes in base moisture content have a strong effect on the base dielectric constant, and thus the base dielectric constant can be used as an indicator of high moisture content.

The calculations described above are automated in Infrasense’s *winDecar*[®] data analysis software program for computing pavement layer thickness and changes in pavement layer properties. The analytical

techniques described above serve as the basis for data analysis carried out during this project, as described in Section 3 of the report.

References

- ASTM D 4748–98, “Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar.” Annual Book of ASTM Standards, American Society for Testing and Materials (March 1998).
- Maser, K.R., Scullion, T., “Influence of Asphalt Layering and Surface Treatments on Asphalt and Base Layer Thickness Computations Using Radar.” Texas DOTPD Report TX-92-1923-1, Austin, TX (1992b).
- Roddis, W.M., Kim, Maser, K.R., and Gisi, A.J., “Radar Pavement Thickness Evaluations for Varying Base Conditions,” Transportation Research Record No. 1355, TRB National Research Council, pp. 90-98, 1992.