River Street (SR 164)
Soil Stabilization
Willoughby, Ohio

Geotechnical Subsurface Investigation and Conceptual Alternatives Evaluation Report

City of Willoughby
Ohio

December 21, 2023

CT Project No. 231093

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CT Consultants, Inc.
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December 21, 2023 CT Project No. 231093

Mr. Robert Fiala
City of Willoughby
1 Public Square
Willoughby, Ohio 44094

Re: Geotechnical Subsurface Investigation & Conceptual Alternatives Evaluation
River Street Soil Stabilization
Willoughby, Ohio

Dear Mr. Fiala:

Following is the final report of the geotechnical subsurface investigation performed by CT Consultants, Inc. (CT) for the referenced project conducted for City of Willoughby. This study was performed in accordance with CT Proposal No. P231093, dated June 28, 2023..

This report contains the results of our study, our engineering interpretation of the results with respect to the project characteristics, and our recommendations for design and construction of a proposed soldier pile retaining wall. Soil samples collected during this investigation will be stored at our laboratory for 90 days from the date of this report. The samples will be discarded after this time unless you request that they be saved or delivered to you.

Should you have any questions regarding this report or require additional information, please contact our office.

Respectfully,

CT Consultants, Inc.

Imad El Hajjar
Geotechnical Project Manager

Curtis E. Roupe, P.E.
Vice President/Market Leader

GEOTECHNICAL SUBSURFACE INVESTIGATION
RIVER STREET SOIL STABILIZATION
WILLOUGHBY, OHIO

FOR

CITY OF WILLOUGHBY
1 PUBLIC SQUARE
WILLOUGHBY, OHIO 44094

SUBMITTED

DECEMBER 21, 2023
CT PROJECT NO. 231094

CT CONSULTANTS, INC.
8150 STERLING COURT
MENTOR , OH 44060
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1.0 INTRODUCTION

This report describes the investigative and testing procedures, presents the findings, discusses our evaluations and conclusions, and provides our design and construction recommendations for a proposed soldier pile retaining wall.

This report has been prepared for City of Willoughby. This study was performed in accordance with CT Proposal No. P231093, dated June 28, 2023.

The purpose of this investigation was to evaluate the subsurface conditions and laboratory data relative to the design and construction of pavements at the referenced site. This investigation included two (2) test borings, field and laboratory soil testing, and a geotechnical engineering evaluation of the test results.

This report includes:

- A description of the subsurface soil and groundwater conditions encountered in the borings.
- Design recommendations for a proposed retaining wall.
- Recommendations concerning soil and groundwater-related construction procedures such as site preparation, earthwork, pavement subgrade preparation, and related field testing.

2.0 INVESTIGATIVE PROCEDURES

This subsurface investigation included two (2) test borings performed on September 15 and 18, 2023 and were designated as B-1 and B-2. Two borings were conducted along River Street, in the general area of the proposed site for the retaining wall. Ground surface elevations at the boring locations were depicted from Google Earth and are reported to the nearest foot. The approximate locations of the test borings are shown on the Test Boring Location Plan (Plate 2.0).

The test borings were performed in general accordance with geotechnical investigative procedures outlined in ASTM Standard D 1586, ASTM D 1452, or ASTM D 6151. The test borings performed during this investigation were drilled with a truck-mounted drill rig with utilizing 3¼-inch diameter hollow-stem augers. The borings extended approximately 40 feet below surface grades and included 10 feet of rock coring.

During auger advancement, soil samples were collected continuously within the overburden soils strata and at approximate 2.5-foot intervals therafter. Split-spoon samples were obtained by the Standard Penetration Test (SPT) Method (ASTM D 1586), which consists of driving a 2-inch outside diameter split-barrel sampler into the soil with a 140-pound weight falling freely through a distance of 30 inches. The sampler was driven in three successive 6-inch increments with the number of blows per increment being recorded. The sum of the number of blows required to advance the sampler the second and third 6-inch increments is termed the Standard Penetration Resistance (N-value) and is presented on the Logs of Test Borings which are attached to this report. The split-spoon samples were sealed in jars and transported to our laboratory for further classification and testing.

Two ten-foot core runs were completed immediately following auger refusal in Borings B-1 and B-2. Recovery of the core is expressed as the percentage ratio of the recovered rock length to the total length of the core run. The Rock Quality Designation (RQD) is the percentage ratio of the summed length of rock pieces 4 inches long and greater to the total length of the run. The rock core samples are designated as "NQ2" on the Logs of Test Borings. The rock cores were documented in photographic core logs, which are attached to this report.

Soil and rock conditions encountered in the test borings are presented in the Logs of Test Borings, along with information related to sample data, SPT results, water conditions observed in the borings, and laboratory test data. It should be noted that these logs have been prepared on the basis of laboratory classification and testing as well as field logs of the encountered soils.

All samples of the subsoils were visually or manually classified using the Unified Soil Classification System (ASTM D 2487 and D 2488) and were tested in the laboratory for moisture content (ASTM D 2216). An Atterberg limits test (ASTM D 4318) and particle size analysis (ASTM D 6913 and D 7928) were performed on select samples. Dry density determination and compressive strength tests (ASTM D 2166 were also performed on select samples. Rock Core Unconfined Compressive Strength Tests (ASTM D 7012 Method C) were performed on intact rock samples. The results of these tests are presented on the Logs of Test Borings and Grain Size Distribution sheet attached to this report.

Experience indicates that the actual subsoil conditions at a site could vary from those generalized on the basis of test borings made at specific locations, especially at previously developed sites. Therefore, it is essential that a geotechnical engineer be retained to provide soil engineering services during the site preparation, excavation, and foundation phases of the proposed project. This is to observe compliance with the design concepts, specifications, and recommendations, and to allow design changes in the event subsurface conditions differ from those anticipated prior to the start of construction.

3.0 PROPOSED CONSTRUCTION

The proposed project involves constructing drilled shafts with soldier pile and plug pile shafts type retaining wall spanning around 175 feet in length. The associated shafts piles are planned to be anchored (ie. Socketed) into the underlying intact shale bedrock.

During a site inspection conducted by CT on March 29, 2023, coupled with online aerial and street view assessments around the junction of River Street and South Street, a notably visible area of distress—a crown or head scarp—was identified along River Street near its intersection with South Street. This distressed area sits at an elevation of approximately 695 feet above mean sea level (msl), which is roughly 100 feet higher in elevation than the Chagrin River surface at 595 feet msl. The terrain between the Chagrin River and the road exhibits a steep slope, much steeper than 0.5:1 gradient in most sections.

4.0 GENERAL SITE AND SUBSURFACE CONDITIONS

4.1 General Site Conditions

The project area featured asphalt pavements displaying longitudinal and transverse cracking, which seemed to have been sealed.

In boring B-1, the surface materials encountered comprised 11 inches of asphalt overlying 3 inches of crushed stone aggregates. On the other hand, boring B-2 revealed 8 inches of asphalt overlying 4 inches of brick, with an underlying layer of 3 inches of crushed stone aggregates.

4.2 General Site Geology

Published geologic maps from the Ohio Department of Natural Resources (ODNR) indicate that the project site is located within the glaciated portion of Ohio. The geologic deposits covering the site consists of Holocene-age Alluvial deposits (a) consisting of alluvium and alluvial terraces, deposited in present and former floodplains, ranges from silty clay in areas of fine-grained deposits to coarse sand, gravel, or cobbles in areas of shallow bedrock.

Bedrock in the project area is broadly mapped on the "Geologic Map of Ohio" as Upper Devonian aged Shale of the Ohio Shale formations. The borings performed for this exploration encountered weathered bedrock at elevations ranging from approximate Elevs. 685 to 682.5 and sound rock at elevations ranging from approximate Elevs. 665 to 664. Bedrock was generally sloping upward from south to north, and from east to west.

4.3 General Soil and Rock Conditions

The findings from both field and laboratory tests indicate that the subsoils beneath the pavement materials can be characterized as a shallow layer of alluvial deposits overlying decomposed and weathered shale layers, which in turn overlay a sound (i.e., more intact) shale bedrock.

The deposits alluvial comprise a mix of cohesive and granular soils, extending to a depth of approximately 5½ feet below the existing grades, ranging from Elevations 690± to 689± feet. The cohesive soils predominantly consisted of lean clay (CL) silty clay (CL-ML), silt (ML) sandy silt (ML), lean clay (CL) mixed with varying portions of sand and gravel . SPT N-values for the cohesive soils ranged from 4 to 6 blows per foot (bpf) which is indicative of medium stiff consistency. Unconfined compressive strengths were on the order of 1,660 to 9,000 pounds per square foot. Moisture contents ranged from 13 to 23 percent. The granular soils consisted of silty sand (SM) or clayey sand (SC) mixed with varying portions of gravel, sand and shale fragments. SPT N-values for the granular soils ranged from 3 to 7 bpf wich is indicative of very loose to loose compactness. Moisture contents ranged from 12 to 16 percent.

A layer of severely weathered/decomposed shale bedrock was encountered underlying the alluvial deposits and extended to approximately 11 to 12½ feet, ranging from Elevations 685± to 682± feet. This stratum comprises a combination of sand, and gravel mixed with varying proportions of shale fragments. SPT N-values ranged from 12 to 65 bpf. Moisture contents ranged from 10 to 13 percent.

Shale Bedrock was encountered underlying the decomposed bedrock stratum in both borings. The upper 17½ to 19 feet of bedrock was highly weathered such that it was augerable. Based on auger refusal, the more intact bedrock was encountered at depths on the order of 30 feet (Elevs. 666± to 665±). The depths of encountered rock are summarized in the following table.

Table 4.3 Summary of Rock depth

Boring No.	Ground Surface Elev. (feet)	Depth to Weathered Bedrock (feet)	Top of Weathered Bedrock Elev. (feet)	Depth to Sound Bedrock (feet)	Top of Sound Bedrock Elev. (feet)
B-1	696	11	685	30	666
B-2	695	12.5	682.5	30	665

The rock core recovery ranged from 98 to 100 percent. RQD values for the core runs ranged from 15 to 37 percent, indicating the rock mass quality of the bedrock can be generally described as varying from poor to fair. An intact specimen of shale for compressive strength testing was obtained, resulting in an unconfined compressive strength ranging from 5,510 pounds per square inch (psi), indicating that the Shale can be characterized as moderately strong.

Additional descriptions of the stratigraphy encountered in the borings are presented on the Logs of Test Borings. A rock core photographic log is attached to this report.

4.4 Groundwater Conditions

Groundwater was initially encountered during drilling at a depth of 30 feet in Borings B-1 and B-2 (Elev. 666± and 665±). Water was noted upon completion of drilling and rock coring operations at a depth of 32 feet (Elev. 664±) in Boring B-1 and at a depth of 21½ feet (Elev. 643±) in Boring B-2. However, these water levels were affected by water introduced during rock coring. It should be noted that the boreholes were drilled and sealed within the same day, and stabilized water levels may not have occurred over this limited time period.

Based on the soil characteristics and moisture conditions encountered in the borings, it is our opinion that the "normal" groundwater level will generally be encountered at the bottom of the decomposed bedrock layer at depths of approximately 11 to 12 ½ feet below existing grades. However, this investigation did not include research of possible hydrological influences at the project site. It should be noted that groundwater elevations can fluctuate with seasonal and climatic influences. Therefore, the groundwater conditions may vary at different times of the year from those encountered during this investigation.

5.0 DESIGN RECOMMENDATIONS

The following conclusions and recommendations are based on our understanding of the proposed construction and on the data obtained during the field investigation. If the project information or location as outlined is incorrect or should change significantly, a review of these recommendations should be made by CT. These recommendations are subject to the satisfactory completion of the recommended site and subgrade preparation and fill placement operations described in Section 6.0, "Construction Recommendations."

5.1 Slope Stability Analyses and Slope Repair Recommendations

The scope of this project included slope stability analyses performed to "back-calculate" soil properties and evaluate appropriate values for remedial design considerations. In accordance with Ohio Department of Transportations(ODOT) geotechnical bulleting, GB-7, evaluation of soil properties included "back-calculation" utilizing slope stability analyses such that the worst-case potential failure surface exhibited a factor of safety of 1.0, and coincided with the known points of shear failure, as indicated by the apparent top scarp that was observed along the guardrail. We performed global slope stability analyses using the 2-D Limit Equilibrium Slope Stability Program Slide 6.0 by Rocscience to evaluate the Existing slope failure based on the available site topographic information.

Using this program, a myriad of potential failure surfaces can be generated theoretically, from which the factor of safety can be determined as to whether sufficient resisting soil strength can be mobilized to counteract the driving forces (weight of soil, seepage, and surcharge loads) that would cause the slope to move downward. The factor of safety is the ratio of the resisting forces to the driving forces. Global instability typically is manifested by pronounced movements of a large arc or wedge of soil that result in bulging at the toe of the slope as well as observable displacement of soil at or near the crest of the slope. This crest displacement may be exhibited by a near-vertical tension crack at the back edge of the displaced soil mass, or may be significant enough to exhibit a downward movement of soil that creates a "scarp" such that a sharp drop occurs in an otherwise level ground surface. Global instability of the embankment at this site could create a significant impact due to the potential for such movement to encompass a portion of the roadway and existing utilities.

We analyzed a representative slope section situated within the targeted remediation area, specifically focusing on the section with the most pronounced degree of slope.

Shear strength parameters for the new embankment fill were determined using ODOT GB-2 as a general guideline. Remaining soil strengths were evaluated based on unconfined compressive strength test results, hand penetrometer readings as well as SPT N-values, moisture content, unit weight (density), and soil plasticity data of the encountered soils. Correlations with published data from ODOT GB-7 “Drilled Shaft Landslide Stabilization Design” Table 1 “Typical Unit Weight Relationships for Various Soils” and Table 2 “Typical Strength Values for Various Soils” were also utilized to estimate soil properties. In general, low to average long-term effective stress internal angle of friction (ϕ’), along with a low to average residual cohesion (c’) was used in our analyses for the native soils.

The groundwater table was modeled at 11 to 12 ½ feet below the existing roadway and extending consistently and parallel to the slope face, aligning with the water elevation within the Chagrin River at Elev. 596 feet. Additionally, an average surcharge load of 250 pounds per square foot (psf) was modeled for the roadway area.

Once the failure surface was modeled with a factor of safety of 1.0 using the soil profile encountered during this investigation, global stability analyses were performed using circular failure mode for the short-term conditions (i.e., end of construction) using total stress soil parameters (TSSP). The soil parameters utilized for analysis of the wall are also presented on the wall slope stability outputs attached to this report.

The results of the slop stability analyses are summarized in the following table:

Table 5.1A Slope Stability Analysis Summary		
Model	Method	Factor of Safety
1	Effective Stress Soil Parameters (ESSP) - Calibration Model – Existing Conditions	0.91
2	Total Stress Soil Parameters (TSSP) - Existing Conditions	1.33
3	ESSP – Proposed Conditions (i.e., With Retaining Wall)	1.33
4	TSSP – Proposed Conditions (i.e., With Retaining Wall)	1.73

After reviewing our stability analysis outlined in Appendix H, it seems that the failure mechanism is a shallow-seated circular failure that transpires along the interface of the decomposed bedrock layer and the weathered, comparatively more intact layer of shale bedrock. As such, remedial measures both geometric and structural would require substantial work outside of the existing right-of-way in areas exhibiting very steep grades.

Therefore, we recommend protecting the roadway against on-going and potential slope failures by constructing a retaining wall structure.

We considered a retaining wall along the slope between the road and the river to determine what would be required to achieve factors of safety 1.3. In these analyses, we determined that the required shear resistance provided by the wall was on the order of 20,000 lb/ft, requiring a minimum rock socket depth of 5 feet embedded into the solid rock layer..

Based on the results of our slope stability analysis, the depth of the failure plane below the road, and the depth of bedrock, options for protecting the road include soldier pile and lagging, and secant, tangent, or plug pile walls. A soldier pile and lagging wall would likely consist of a structural W or HP section set in a drilled shaft filled with concrete. The soldier piles would likely be spaced at 4 feet on center and lagging would be set to a depth that would retain the soil on the upslope side as the slope below the wall continued to fail and slide toward the river. Tangent, secant, and plug pile walls are all variations of continuous drilled pier walls that would retain the soil up slope of the wall and protect the road. Reinforcement could consist of a W and HP structural section or deformed bar reinforcement. With plug pile walls every second pier is reinforced. The drilled shafts should be drilled into bedrock with a minimum embedment of 5 feet into moderately hard shale.

We performed laterally loaded pile analyses using LPILE to preliminarily estimate the head deflection, maximum moment, and maximum shear force in the drilled shafts. We analyzed 30-inch-diameter drilled piers with W 24 x 62 steel reinforcement. Service loading (unfactored) is evaluated to make sure the shaft deflection is within tolerable limits. Strength loading (factored) is evaluated to verify the shafts satisfies structural code requirements.

Table 3 shows the results of the LPILE analyses. Graphs of deflection, shear, and moment with depth are included in the attachments. The calculated displacement, shear, and moment depends on the stiffness of the pier and hence the final diameter and reinforcement. Analyses should be rerun with the final reinforcement based on the structural design as a check on the displacement, shear, moment, and soil reaction.

Table 5.1B Retaining Wall Lateral Earth Pressure Calculation Summary

Case	Avg. Height of the Wall Above Bedrock (ft)	Design Max Moment (inch-lbs)	Design Max Shear (lbs)	Head Deflection (in)
Unfactored Loading	30	3,533,998	73,437	0.2
Factored Loading	30	5,567,579	115,583	0.3

Granular soils were encountered in the test borings. Additionally, the "normal" groundwater level is anticipated at 11 to 12½ feet below existing grades. As such, temporary steel casing is anticipated to be required for support of the shaft walls and/or to seal the borehole from groundwater. During concrete placement, as the steel casing is withdrawn, sufficient concrete should be maintained above the bottom of the casing to counteract any hydrostatic head and prevent collapse or "necking" of the shaft. Care must be taken during concreting and removal of any temporary casing to prevent the possibility of soil intrusions. The contractor should submit procedures for shaft installation prior to the start of work.

5.2 Subgrades

After the retaining wall is constructed, the nearby pavement area may need to be repaired. We recommend removing all pavement materials, including the aggregate base, to expose the underlying subgrade.

5.2.1 Subgrades Evaluation

An evaluation of the subgrade soils was completed in general accordance with ODOT Geotechnical Design Manual (GDM) Section 600 (July 21, 2023). As part of this evaluation, the ODOT "Subgrade Analysis" worksheet (V14.6, 02/11/2022) was completed and is attached to this report.

Final pavement grades are assumed to approximate existing grades. Based on the existing pavement cross-sections encountered in the borings, the proposed subgrade is presumed to be 18 to 25 inches below the existing top of pavement grades (represented as a 15 to 2.1 feet cut in the ODOT "Subgrade Analysis" worksheet).

Based on the GDM , soils classified as ODOT A-4b, A-2-5, A-5, A-7-5, A-8a, A-8b, or rock have been designated as being problematic with respect to pavement subgrade support. None of these soil types were encountered at planned subgrade elevations in the borings performed for this exploration.

Based on the GDM criteria, subgrade soils with moisture contents greater than 3 percent above optimum likely indicate the presence of unstable subgrade that may require some form of subgrade modification. Most of the tested subgrade soil samples were greater than 3 percent below the optimum as determined using the GDM criteria. Thus, where moisture contents were dry of optimum, they were appreciably dry of optimum.

The type and thickness of subgrade modification is determined by the GDM criteria based on the average, low SPT N_{60}-value (N_{60L}) of the subgrade soils in a particular portion of the project area, hand penetrometer value, soil type, and moisture content. Based on these criteria, both borings (B-1 and B-2 contained subgrade soils which indicated subgrade modification is likely to be required. Subgrade modification for these borings was indicated to include planned undercutting of 16 to 24 inches of the existing subgrade and replacement with granular engineered fill.

It should be noted that the GDM analyses are used as a pre-construction tool to plan subgrade modification alternatives. Actual subgrade modification will depend on field observations of proof-rolling conditions at the time of construction. Changes in soil moisture content could create more or less favorable subgrade conditions that may result in adjustments to subgrade modification or soil stabilization requirements at the time of construction.

5.2.2 Flexible (Asphalt) Pavement Design

Based on the GDM subgrade analysis, a design CBR value of 8 percent was determined for the project using the ODOT "Subgrade Analysis" spreadsheet. It should be noted that the CBR determination by this spreadsheet is based on the average Group Index of all the evaluated samples

It should also be noted that the design CBR value is based on subgrades compacted to at least 100 percent of the maximum dry density as determined by ASTM D 698 (Standard Proctor) or verified as stable through proof-rolling in accordance with Section 5.5 of this report.

All pavement design and paving operations should conform to ODOT specifications. The pavement and subgrade preparation procedures outlined in this report should result in a reasonably workable and satisfactory pavement. It should be recognized, however, that all pavements need repairs or overlays over time as a result of progressive yielding under repeated loading for a prolonged period.

It is recommended that proof rolling, placement of aggregate base, and placement of asphalt be performed within as short a time period as possible. Exposure of the aggregate base to rain, snow, or freezing conditions may lead to deterioration of the subgrade and/or base materials due to excessive moisture conditions and to difficulties in achieving the required compaction.

5.2.3 Pavement Drainage

Based on the poorly-drained nature of the silty and clayey subgrade soils that are expected throughout the site, it is anticipated that surface water infiltration may collect in the aggregate base course. Without adequate drainage, water will remain in the base for extended periods of time, creating localized wet, soft pockets. The presence of these pockets will increase the likelihood that pavement distress (cracking, potholes, etc.) will develop. Drainage features may include grading the subgrade surface to slope downward to the outside edge of pavements and/or providing longitudinal edge drains connected to storm sewers or other outlets. A system of "finger drains" could also be installed near catch basins within the pavement areas to collect surface water, thus reducing the potential for freeze-thaw effects on the pavement.

5.3 Construction

5.3.1 Sedimentation and Erosion Control

In planning the implementation of earthwork operations, special consideration should be given to provide measures to prevent or reduce soil erosion and the subsequent sedimentation into nearby waterways. These measures may include some or all of the following:

1. Scheduling of earthwork operations such that erodible areas are kept as small as possible and are exposed for the shortest possible time.
2. Using special grading practices, along with diversion or interceptor structures, to reduce the amount of run-off water from an erodible area.
3. Providing vegetative buffer zones, filter berms, or sedimentation basins to trap sediment from surface run-off water.

A specific and detailed soil erosion and sedimentation control program and permits may be required by local, state, or federal regulatory agencies.

5.3.2 Site and subgrade Preparation

Site and subgrade preparation activities should conform to ODOT Construction and Materials Specifications (CMS) Item 204 specifications. Site preparation activities should include the removal of vegetation, topsoil, root mats, pavements, structures, and other deleterious

non-soil materials from all proposed culvert and roadway replacement areas. The actual amount of required stripping should be determined in the field by a geotechnical engineer or qualified representative.

Upon completion of the clearing and undercutting activities, all areas that are to receive fill, or that have been excavated to proposed final subgrade elevation, should be inspected by a geotechnical engineer. Pavement subgrades should be proof rolled in accordance with ODOT CMS 204.06.

Any unsuitable materials observed during the inspection and proof-rolling operations should be undercut and replaced with compacted fill, or stabilized in place utilizing conventional remedial measures such as discing, aeration, and recompaction. As stated previously, based on the conditions encountered during our exploration, where subgrade soil moisture contents were wet of optimum, they were significantly wet of optimum. As such, scarification and aeration methods may not be feasible to achieve satisfactory proof rolling and stabilization of the predominantly cohesive subgrades. However, scarification and aeration methods may be utilized if areas where granular subgrades wet of optimum are present, provided weather conditions and construction schedule will allow such soil modification.

The GDM subgrade analysis indicates planned over-excavation of unsuitable subgrade soils to a depth of 16 to 18 inches and replacement with new granular engineered fill for the entire extent of the project. Due to the relatively small project area, global chemical stabilization is not anticipated to be economical compared to over-excavation and replacement with granular engineered fill.

5.3.3 Temporary Excavations and Permanent Slopes

The sides of the temporary excavations should be adequately sloped to provide stable sides and safe working conditions. Otherwise, the excavation must be properly braced against lateral movements. In any case, applicable Occupational Safety and Health Administration (OSHA) standards must be followed. It is the responsibility of the installation contractor to develop appropriate installation methods and specify pertinent equipment prior to commencement of work, and to obtain the services of a geotechnical engineer to design or approve sloped or benched excavations and/or lateral bracing systems as required by OSHA criteria.

If the excavation is to be performed with sloped banks, adequate stable slopes must be provided in accordance with OSHA criteria. Based on the test borings, it is likely that excavations will encounter a range of soil conditions that include the following OSHA designations:

- Type A soils (cohesive soils with unconfined compressive strengths of

3,000 pounds per square foot (psf) or greater),

- Type B soils (cohesive soils with unconfined compressive strengths greater than 1,000 psf but less than 3,000 psf), and
- Type C soils (native granular soils or unstable rock).

For temporary excavations in Type A, B, and C soils, side slopes must be no steeper than ¾ horizontal to 1 vertical (¾H:1V), 1H:1V, and 1½H:1V, respectively. For situations where a higher strength soil is underlain by a lower strength soil and the excavation extends into the lower strength soil, the slope of the entire excavation is governed by that required by the lower strength soil. In all cases, flatter slopes may be required if lower strength soils or adverse seepage conditions are encountered during construction.

5.3.4 Construction Dewatering and Groundwater Control

Groundwater conditions encountered during our exploration are summarized in Section 4.3.

During construction, methods should be taken to divert the waterway flow around the construction area.

Based on the soil characteristics and groundwater conditions encountered in the borings, it is our opinion that the "normal" groundwater level can generally be expected at depths on the order of 11 to 12½ feet below existing roadway grades.

If construction does not occur during a particularly wet period, adequate control of groundwater seepage into excavations should be achievable by minor dewatering systems, such as pumping from prepared sumps.

5.3.5 Fill

Material for engineered fill or backfill required to achieve design grades should meet ODOT Item 203 "Embankment Fill" placement and compaction requirements.

The upper profile on-site soils consist of predominantly native cohesive soils. For the cohesive soils, a sheepsfoot roller should provide the most effective soil compaction. Where existing pavement base materials remain or new dense-graded aggregate pavement base materials are placed, a vibratory smooth-drum roller would be required to provide effective compaction.

6.0

7.0 QUALIFICATION OF RECOMMENDATIONS

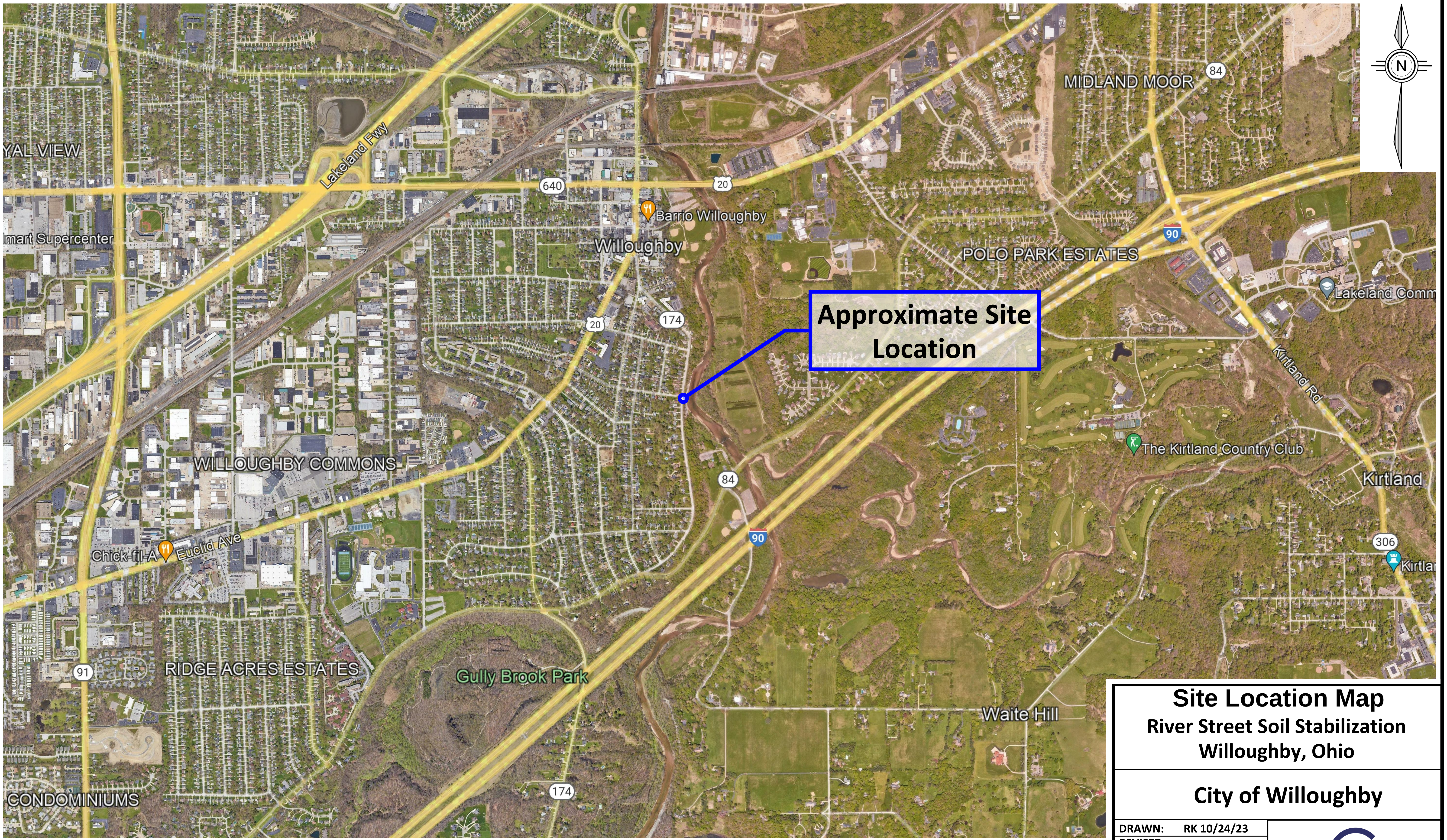
Our evaluation of design and construction conditions for pavements and to support the design and installation of a drilled shaft wall to stabilize slope movements has been based on our understanding of the site and project information and the data obtained during our field investigation. The general subsurface conditions were based on interpretation of the subsurface data at specific boring locations. Regardless of the thoroughness of a subsurface investigation, there is the possibility that conditions between borings will differ from those at the boring locations, that conditions are not as anticipated by the designers, or that the construction process has altered the soil conditions. This potential is increased at previously developed sites. Therefore, experienced geotechnical engineers should observe earthwork construction to confirm that the conditions anticipated in design are noted. Otherwise, CT assumes no responsibility for construction compliance with the design concepts, specifications, or recommendations.

The design recommendations in this report have been developed on the basis of the previously described project characteristics and subsurface conditions. If project criteria or locations change, a qualified geotechnical engineer should be permitted to determine whether the recommendations must be modified. The findings of such a review will be presented in a supplemental report.

The nature and extent of variations between the borings may not become evident until the course of construction. If such variations are encountered, it will be necessary to reevaluate the recommendations of this report after on-site observations of the conditions.

Our professional services have been performed, our findings derived, and our recommendations prepared in accordance with generally accepted geotechnical engineering principles and practices. This warranty is in lieu of all other warranties either expressed or implied. CT is not responsible for the conclusions, opinions, or recommendations of others based on this data.

Plates



0' 1,600' 3,200'

Notes: Aerial Basemap obtained From Google Earth and dated 04/27/2022.

Site Location Map

River Street Soil Stabilization
Willoughby, Ohio

City of Willoughby

DRAWN:	RK 10/24/23
REVISED:	---
Project No.:	231093
Drawing No.:	Plate 1.0

100 YEARS
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Legend:

B-1

Approximate Test Boring Location

0' 50' 100'

N

Notes: Aerial Basemap obtained From Google Earth and dated 04/27/2022

Test Boring Location Plan

River Street Soil Stabilization
Willoughby, Ohio

City of Willoughby

DRAWN:	RK 10/24/23
REVISED:	---
Project No.:	231093
Drawing No.:	Plate 2.0

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APPENDIX A

Logs of Test Borings

CT Consultants, Inc.
1915 N 12th Street
Toledo Ohio 43604
Telephone: (419)324-2222

BORING NUMBER B-1

CLIENT City of Willoughby
PROJECT NAME River Street Soil Stabilization
PROJECT NUMBER 231093
PROJECT LOCATION Willoughby, OH
DRILLING CONTRACTOR Ohio TestBor, Inc. Corey Keith
RIG NO. B-57
GROUND ELEVATION 696 ft
DRILLING METHOD HSA
GROUND WATER LEVELS:
DATE STARTED 9/18/23 **COMPLETED** 9/18/23
∇ **AT TIME OF DRILLING** 30.0 ft / Elev 666.0 ft
LOGGED BY KKC **CHECKED BY** RK
▼ **AT END OF DRILLING** 32.0 ft / Elev 664.0 ft
NOTES Auger refusal encountered at 30.0 feet and 10.0 feet of rock cored.
0hrs AFTER DRILLING Backfilled w/Cuttings

MATERIAL DESCRIPTION	Bottom Depth
ASPHALT - 11 Inches	0.9'
BRICK - 4 Inches	1.1'
CRUSHED STONE - 3 Inches	1.5'
Moist Loose Brown/Gray SILTY SAND w/Gravel (SM)	2.5'
Moist Loose Brown/Gray CLAYEY SAND w/Trace Gravel (SC)	3.3'
Moist Medium Stiff Brown LEAN CLAY w/Sand and Trace Gravel (CL)	3.5'
Moist Medium Stiff Brown SILTY CLAY w/Trace Sand and Gravel (CL-ML)	4.5'
Moist Loose Gray CLAYEY SAND w/Shale Fragments (SC)	5.5'
Moist Medium Dense Brown/Gray SEVERELY WEATHERED/DECOMPOSED SHALE @7.5': w/Trace Iron Oxide Stain Seam	11.0'
Gray WEATHERED SHALE	

SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	UNCONF. COMP. STR. (tsf)	DRY UNIT WT. (pcf)	MC	SPT N VALUE
SS 1a	100	5-3	NP		12	
SS 1b	100	2	NP		13	
SS 1c	100	2	0.87	111	15	
SS 2a	100	1-2	1.52	100	23	
SS 2b	100	4-5	NP		14	
SS 3	100	3-5-7-10 (12)	NP		13	
SS 4	100	5-11-19-28 (30)	NP		12	
SS 5	100	17-32-50/3"	NP		5	>>
SS 6	100	26-50/5"	NP		5	>>
SS 7	100	42-50/2"	NP		4	>>
SS 8	100	44-50/3"	NP		4	>>

(Continued Next Page)

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BORING NUMBER B-1

CLIENT City of Willoughby **PROJECT NAME** River Street Soil Stabilization
PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH

ELEVATION (ft)	DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	UNCONF. COMP. STR. (tsf)	DRY UNIT WT. (pcf)	PL / MC / LL (20 40 60 80); ▲ SPT N VALUE ▲ (20 40 60 80)
675				SS 9	100	50	NP		5
				SS 10	100	50/5"	NP		4 >>
670	25								
				SS 11	100	50/4"	NP		3 >>
	30		30.0'						
665			GRAY THIN LAMINATED SLIGHTLY TO MODERETLY WEATHERED SHALE						
660	35			RC 1	98 (15)				
	40		40.0'						
			Bottom of hole at 40.0 feet.						

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BORING NUMBER B-2

CLIENT City of Willoughby
PROJECT NAME River Street Soil Stabilization
PROJECT NUMBER 231093
PROJECT LOCATION Willoughby, OH
DRILLING CONTRACTOR Ohio TestBor, Inc. Corey Keith
RIG NO. B-57
GROUND ELEVATION 695 ft
DRILLING METHOD HSA
GROUND WATER LEVELS:
DATE STARTED 9/15/23 **COMPLETED** 9/15/23
∇ **AT TIME OF DRILLING** 30.0 ft / Elev 665.0 ft
LOGGED BY KKC **CHECKED BY** RK
▼ **AT END OF DRILLING** 21.5 ft / Elev 673.5 ft
NOTES Auger refusal encountered at 30.0 feet and 10.0 feet of rock cored.
0hrs AFTER DRILLING Backfilled w/Cuttings

ELEVATION (ft)	DEPTH (ft)	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	UNCONF. COMP. STR. (tsf)	DRY UNIT WT. (pcf)	MC (PL/MC/LL 20 40 60 80; ▲ SPT N VALUE ▲ 20 40 60 80)
695	0	ASPHALT - 8 Inches 0.7'						
		BRICK - 5 Inches 1.1'						
		CRUSHED STONE - 12 Inches 2.1'	SS 1a	100	2-1	0.83	113	16
		Moist Very Loose Brown CLAYEY SAND w/Trace Gravel (SC) 2.5'	SS 1b	100	2-3	1.52	99	20
690	5	Moist Medium Stiff Brown SILTY CLAY w/Trace Sand and Gravel (CL-ML) 5.0'	SS 2a	100	2-2-4 (6)	1.60	102	20
		Moist Medium Stiff Brown/Gray SILT w/Sand and Trace Gravel (ML) 5.5'	SS 2b	100	8	4.50		17
		Moist Medium Dense Brown/Gray SEVERELY WEATHERED/DECOMPOSED SHALE w/Trace Iron Oxide Stain Seam	SS 3	100	5-10-14-21 (24)	NP		13
		@7.5': Dense	SS 4	100	6-14-22-38 (36)	NP		10
685	10	@10': Very Dense						
			SS 5a	100	12-15	NP		8
		12.5'	SS 5b	100	50	NP		8
		GRAY WEATHERED SHALE	SS 6	100	32-50/3"	NP		4 >>
680	15		SS 7	100	25-50/4"	NP		5 >>
			SS 8	100	44-50/2"	NP		4 >>
			SS 9	100	50	NP		5
675	20		SS 10	100	50	NP		4

(Continued Next Page)

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BORING NUMBER B-2

CLIENT City of Willoughby **PROJECT NAME** River Street Soil Stabilization

PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH

ELEVATION (ft)	DEPTH (ft)	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	UNCONF. COMP. STR. (tsf)	DRY UNIT WT. (pcf)	PL / MC / LL (20 40 60 80)	▲ SPT N VALUE ▲ (20 40 60 80)
			SS 11	100	50/5"	NP		4	>>
670	25		SS 12	100	50/5"	NP		4	>>
			SS 13	100	50/5"	NP		4	>>
			SS 14	100	50/3"	NP		3	>>
665	30	30.0'							
		GRAY THIN LAMINATED SLIGHTLY TO MODERETLY WEATHERED SHALE							
660	35	@35': Qu - 5510 PSI	RC 1	98 (38)		396	159		
655	40	40.0'							
		Bottom of hole at 40.0 feet.							

APPENDIX B

Legend Key

LEGEND KEY

Unified Soil Classification System Soil Symbols

GW - WELL GRADED GRAVEL Includes Gravel-Sand mixtures, little or no fines.

GP - POORLY GRADED GRAVEL Includes Gravel-Sand mixtures, little or no fines.

GM - SILTY GRAVEL Includes Gravel-Sand-Silt mixtures.

GC - CLAYEY GRAVEL Includes Gravel-Sand-Clay mixtures.

SW - WELL GRADED SAND Includes Gravelly Sands, little or no fines.

SP - POORLY GRADED SAND Includes Gravelly Sands, little or no fines.

SM - SILTY SAND Includes Sand-Silt mixtures.

SC - CLAYEY SAND Includes Sand-Clay mixtures.

ML - SILT Includes Silt with Sand and Sandy Silt.

CL - LEAN CLAY Includes Sandy Lean Clay and Lean Clay with Sand and Gravel.

MH - ELASTIC SILT Includes Sandy Elastic Silt and Elastic Silt with Sand.

CH - FAT CLAY Includes Sandy Fat Clay and Fat Clay with Sand.

CL-ML - SILTY CLAY Includes Clayey Silt of low plasticity.

OL - ORGANIC SILT and ORGANIC CLAY of low plasticity.

OH - ORGANIC SILT and ORGANIC CLAY of medium to high plasticity.

Pt - PEAT Includes humus, swamp and other soils with high organic content.

FILL MATERIAL - Includes controlled and non-controlled soil and non-soil materials.

TOPSOIL

ASPHALT - Bituminous Asphalt

CONCRETE - Includes broken concrete rubble.

Sample Symbols

SS - Split Spoon

ST - Shelby Tube

RC - Rock Core

GS - Geoprobe Sleeve

AU - Auger Cuttings

GB - Grab

Notes:

1. Exploratory borings were drilled on September 15 and 18, 2023 utilizing 3¼ -inch inside diameter hollow-stem augers. Rock coring was completed using a NQ sized bit.
2. These logs are subject to the limitations, conclusions, and recommendations in the report and should not be interpreted separate from the report.
3. The borings were located in the field by CT Consultants, Inc. in accordance with the provided information.
4. Ground surface elevation for all borings were obtained by CT via a hand-held GPS device and are reported to the nearest foot.
5. Unconfined Compressive Strength (tsf):
   NP = Non-Plastic

APPENDIX C

Tabulation of Laboratory Test Data

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SUMMARY OF LABORATORY RESULTS

CLIENT City of Willoughby
PROJECT NAME River Street Soil Stabilization
PROJECT NUMBER 231093
PROJECT LOCATION Willoughby, OH

Borehole	Depth	Liquid Limit	Plastic Limit	Plasticity Index	Maximum Size (mm)	%<#200 Sieve	Class-ification	Water Content (%)	Dry Density (pcf)	Satur-ation (%)	Void Ratio
B-1	1.5	14	11	3	19	28	SM	11.6			
B-1	2.5	20	12	8	25	49	SC	13.1			
B-1	3.0							15.1	110.7		
B-1	3.5							22.6	99.7		
B-1	4.5							13.9			
B-1	5.5	21	12	9	19	72	CL	12.9			
B-1	7.5							11.7			
B-1	11.0							5.3			
B-1	13.5							4.7			
B-1	16.0							4.4			
B-1	18.5							4.2			
B-1	21.0							4.9			
B-1	23.5							4.2			
B-1	28.5							3.4			
B-2	1.5	27	13	14	19	40	SC	16.0	113.5		
B-2	2.5							20.4	99.0		
B-2	3.5	23	16	7	9.5	86	CL-ML	20.1	102.0		
B-2	5.0	19	16	3	9.5	74	ML	17.0			
B-2	5.5							13.5			
B-2	7.5							10.0			
B-2	11.0							8.4			
B-2	12.0							8.2			
B-2	12.5							4.3			
B-2	14.5							4.7			
B-2	16.5							4.3			
B-2	19.0							5.0			
B-2	20.0							4.2			
B-2	23.0							3.9			
B-2	25.0							4.4			
B-2	26.0							4.1			
B-2	29.0							3.5			
B-2	35.0							0.0	159.4		

APPENDIX D

Laboratory Test Results

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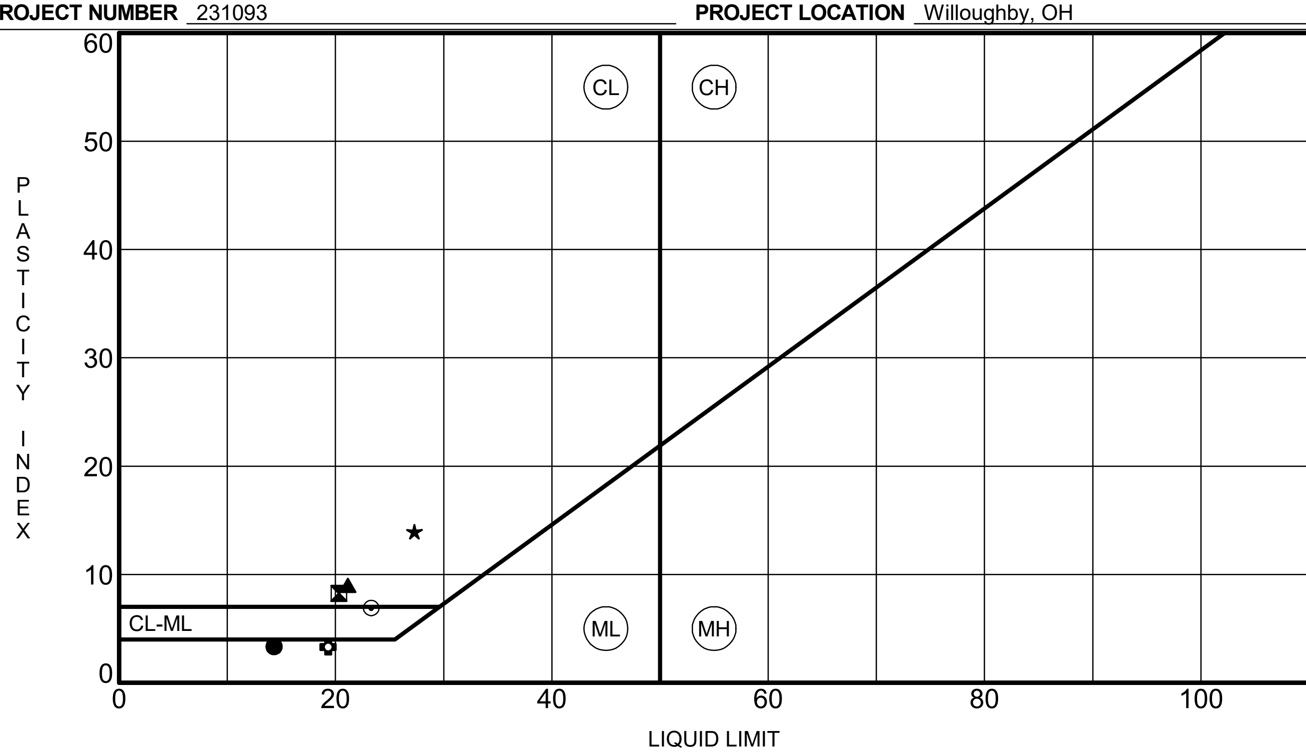
ATTERBERG LIMITS' RESULTS

CLIENT City of Willoughby

PROJECT NAME River Street Soil Stabilization

PROJECT NUMBER 231093

PROJECT LOCATION Willoughby, OH



	Specimen Identification		LL	PL	PI	Fines	Classification
●	**B-1**	**1.5**	**14**	**11**	**3**	**28**	**SILTY SAND with GRAVEL (SM)**
⧗	**B-1**	**2.5**	**20**	**12**	**8**	**49**	**CLAYEY SAND (SC)**
▲	**B-1**	**5.5**	**21**	**12**	**9**	**72**	**LEAN CLAY with SAND (CL)**
★	**B-2**	**1.5**	**27**	**13**	**14**	**40**	**CLAYEY SAND (SC)**
⊙	**B-2**	**3.5**	**23**	**16**	**7**	**86**	**SILTY CLAY (CL-ML)**
✿	**B-2**	**5.0**	**19**	**16**	**3**	**74**	**SILT with SAND (ML)**

GRAIN SIZE DISTRIBUTION

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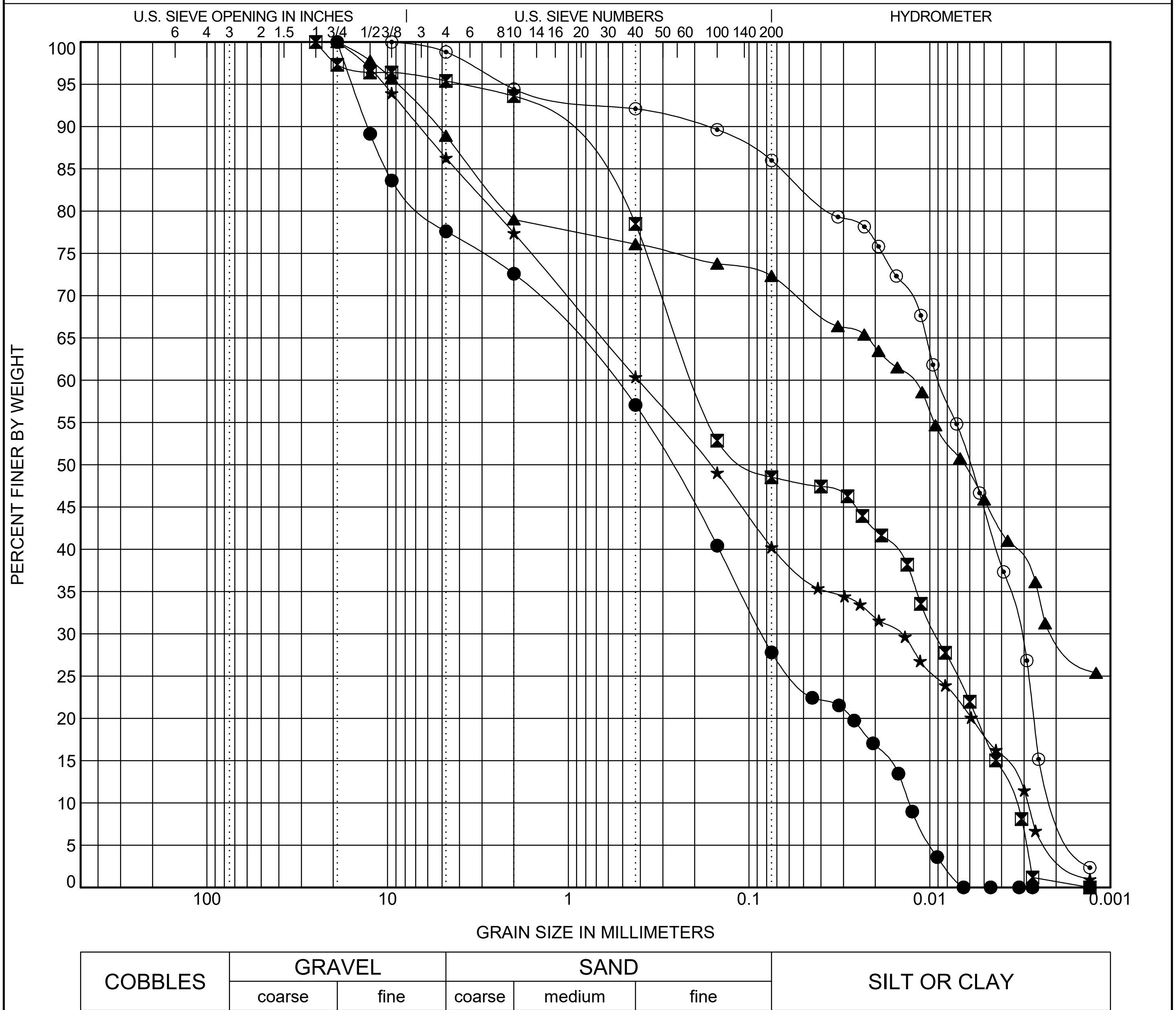
CLIENT City of Willoughby **PROJECT NAME** River Street Soil Stabilization

PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH



	Specimen Identification		USCS Classification	LL	PL	PI	Cc	Cu
●	B-1	1.5	SILTY SAND with GRAVEL (SM)	14	11	3	1.0	43.8
⊠	B-1	2.5	CLAYEY SAND (SC)	20	12	8	0.1	59.2
▲	B-1	5.5	LEAN CLAY with SAND (CL)	21	12	9		
★	B-2	1.5	CLAYEY SAND (SC)	27	13	14	0.2	143.1
⊙	B-2	3.5	SILTY CLAY (CL-ML)	23	16	7	0.6	4.6

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	B-1	1.5	19	0.569	0.085	0.013	22.4	49.8	27.8	0.0
⊠	B-1	2.5	25	0.201	0.009	0.003	4.6	46.9	30.3	18.2
▲	B-1	5.5	19	0.013	0.002		11.1	16.6	26.4	45.9
★	B-2	1.5	19	0.411	0.015	0.003	13.7	46.0	22.2	18.1
⊙	B-2	3.5	9.5	0.009	0.003	0.002	1.2	12.8	41.1	44.9

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GRAIN SIZE DISTRIBUTION

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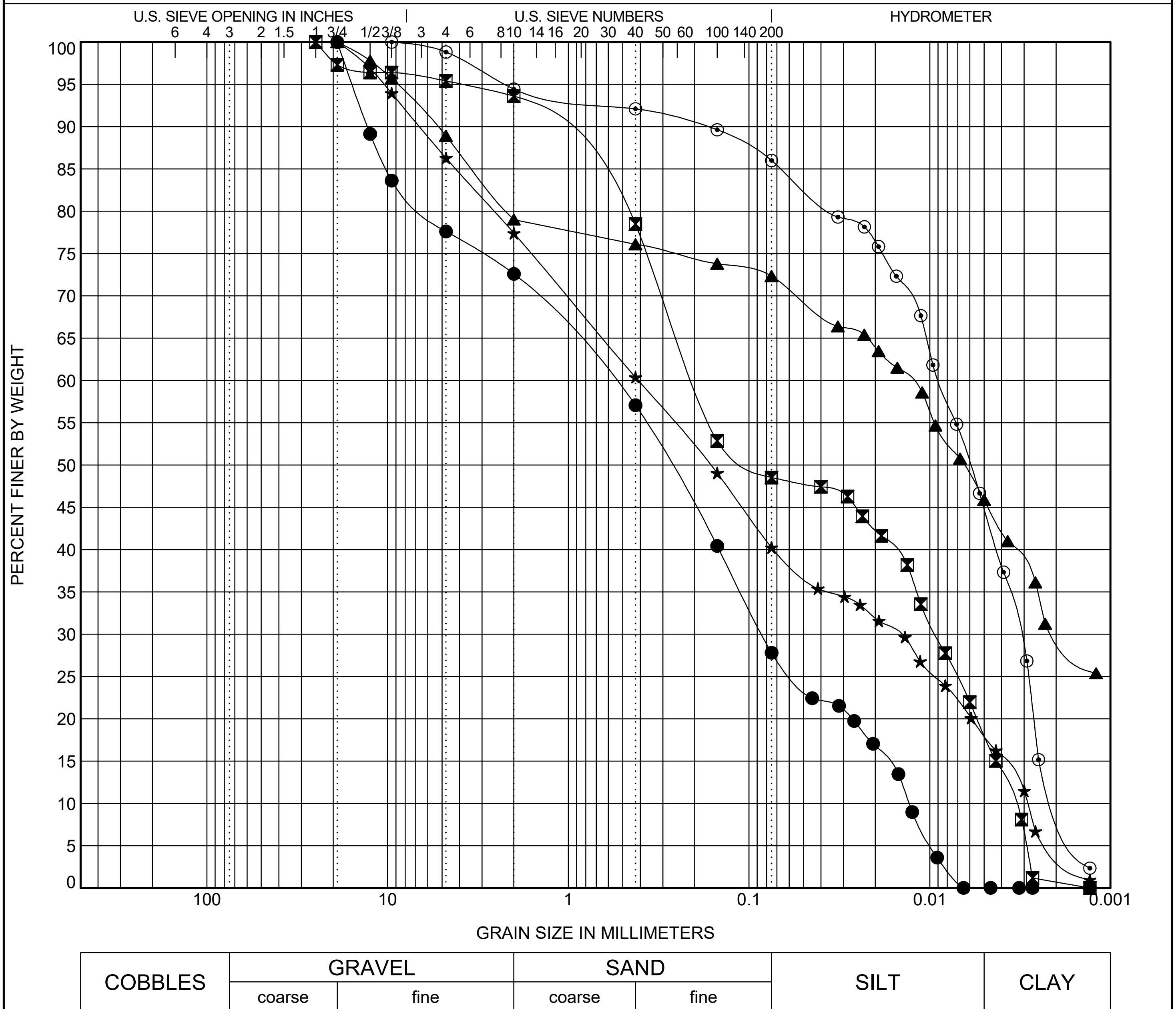
PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH



Specimen Identification		OHDOT Classification	LL	PL	PI	Cc	Cu
● B-1	1.5	A-2-4 (0)	14	11	3	1.0	43.8
⊠ B-1	2.5	A-4a (3)	20	12	8	0.1	59.2
▲ B-1	5.5	A-4a (7)	21	12	9		
★ B-2	1.5	A-4a (2)	27	13	14	0.2	143.1
⊙ B-2	3.5	A-4a (8)	23	16	7	0.6	4.6

Specimen Identification		D100	D50	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-1	1.5	19	0.273	0.085	0.013	27.4	44.8	27.8	0.0
⊠ B-1	2.5	25	0.095	0.009	0.003	6.4	45.1	30.3	18.2
▲ B-1	5.5	19	0.006	0.002		21.0	6.7	26.4	45.9
★ B-2	1.5	19	0.164	0.015	0.003	22.6	37.2	22.2	18.1
⊙ B-2	3.5	9.5	0.006	0.003	0.002	5.6	8.4	41.1	44.9

SILT-CLAY BOUNDARY = 0.005 MILLIMETERS

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GRAIN SIZE DISTRIBUTION

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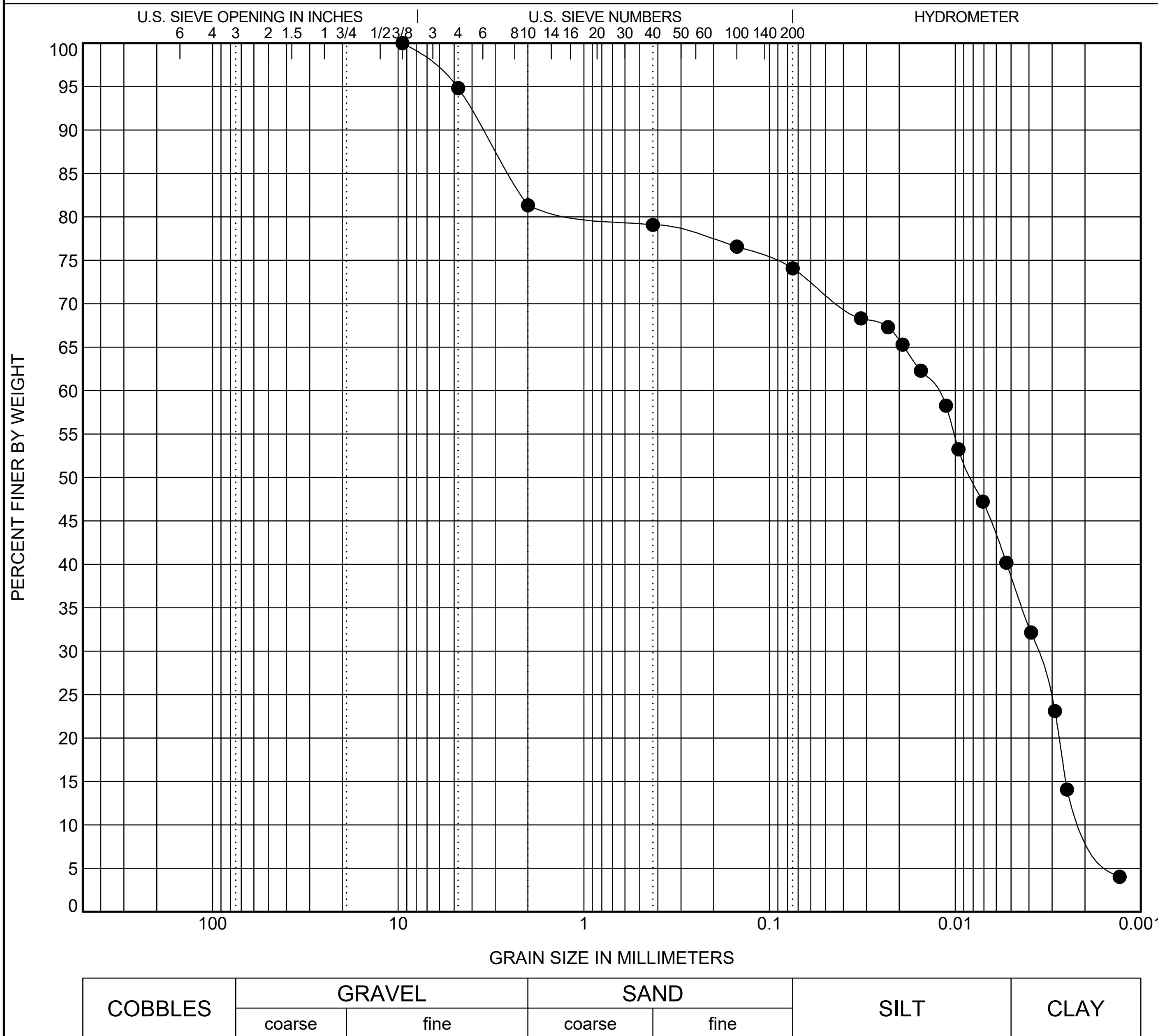
PROJECT NAME River Street Soil Stabilization
PROJECT NUMBER 231093
PROJECT LOCATION Willoughby, OH



	Specimen Identification		OHDOT Classification	LL	PL	PI	Cc	Cu
●	**B-2**	**5.0**	**A-4a (8)**	**19**	**16**	**3**	**0.5**	**6.7**

	Specimen Identification		D100	D50	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**B-2**	**5.0**	**9.5**	**0.008**	**0.004**	**0.002**	**18.7**	**7.3**	**35.4**	**38.7**

SILT-CLAY BOUNDARY = 0.005 MILLIMETERS

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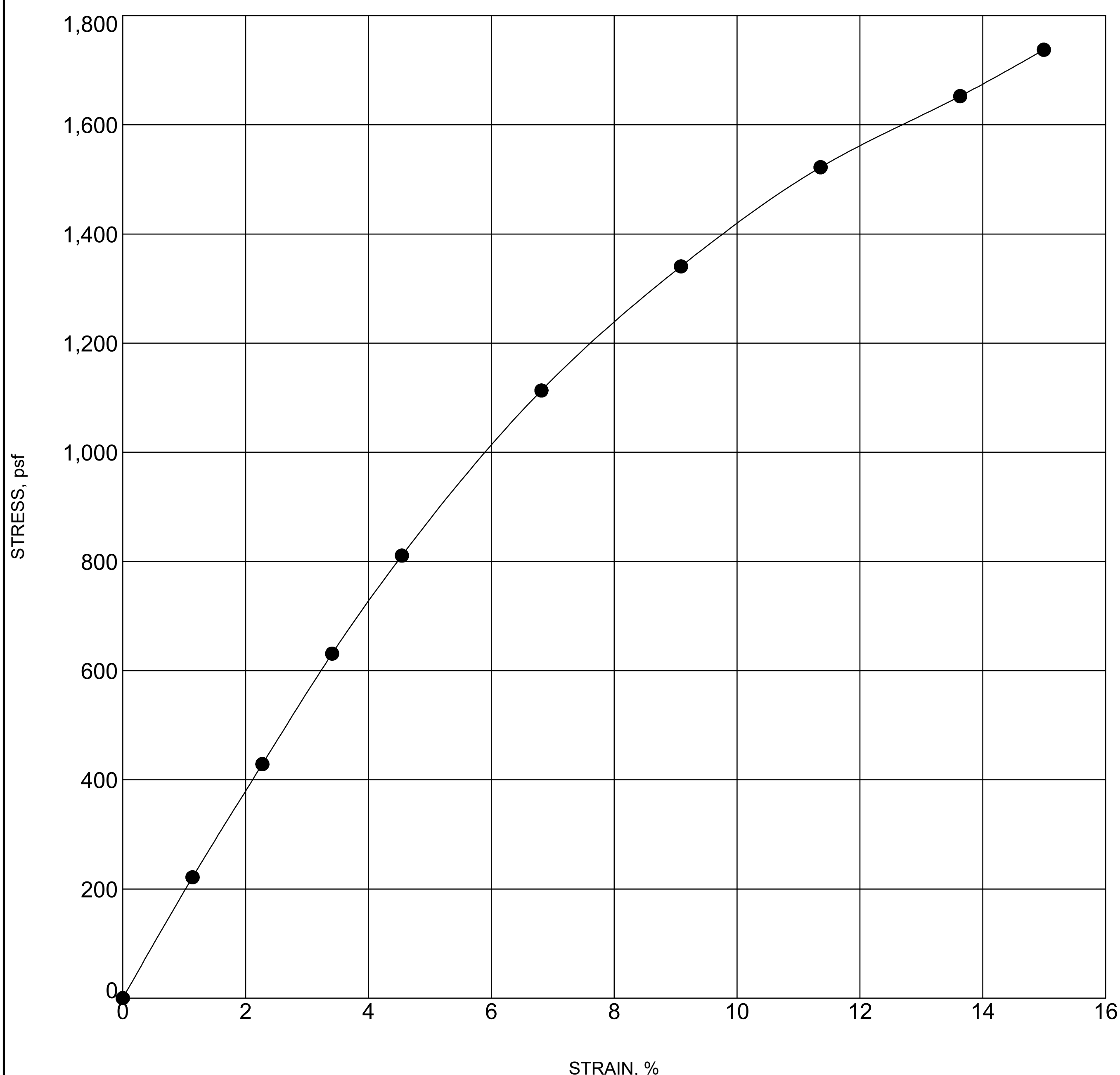
UNCONFINED COMPRESSION TEST

CLIENT City of Willoughby
PROJECT NAME River Street Soil Stabilization
PROJECT NUMBER 231093
PROJECT LOCATION Willoughby, OH



	Specimen Identification		Classification	γ_d	MC%
●	**B-1**	**3.0**		**107**	**19**

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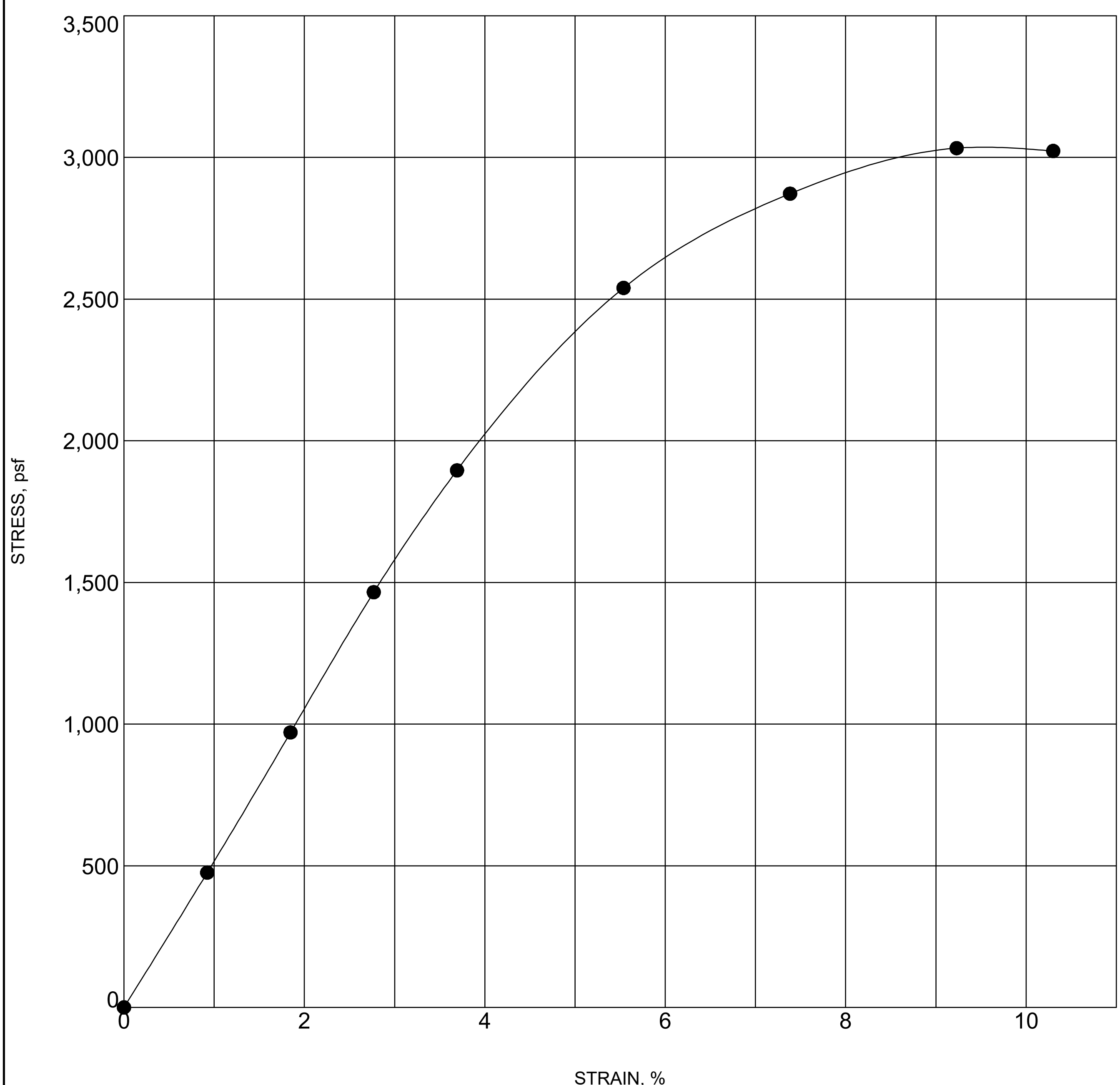
UNCONFINED COMPRESSION TEST

CLIENT City of Willoughby

PROJECT NAME River Street Soil Stabilization

PROJECT NUMBER 231093

PROJECT LOCATION Willoughby, OH



	Specimen Identification		Classification	γ_d	MC%
●	**B-1**	**3.5**		**100**	**23**

UNCONFINED 231093.GPJ GINT US LAB.GDT 10/24/23

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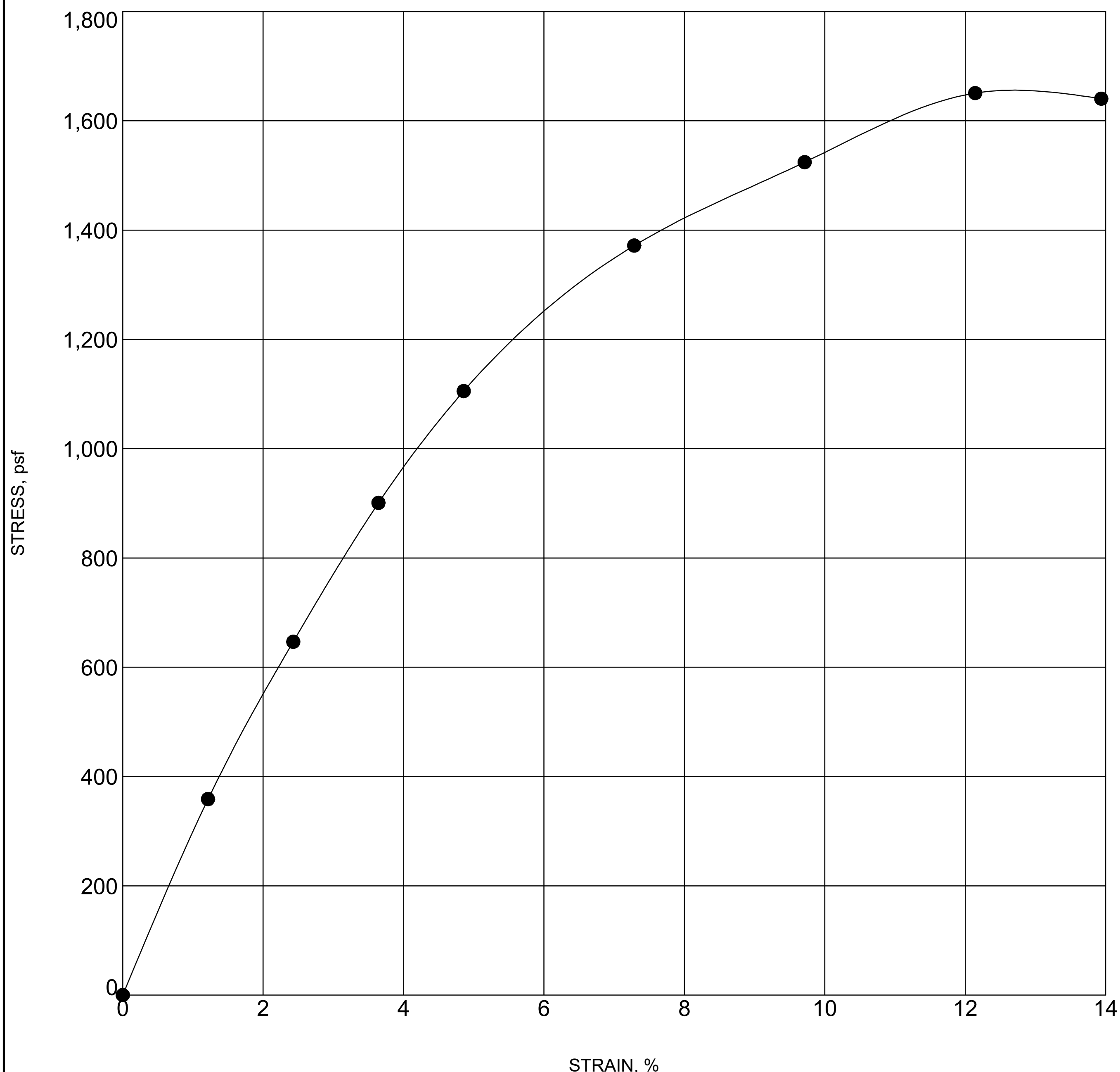
UNCONFINED COMPRESSION TEST

CLIENT City of Willoughby **PROJECT NAME** River Street Soil Stabilization

PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH



	Specimen Identification		Classification	γ_d	MC%
●	**B-2**	**1.5**		**114**	**16**

UNCONFINED 231093.GPJ GINT US LAB.GDT 10/24/23

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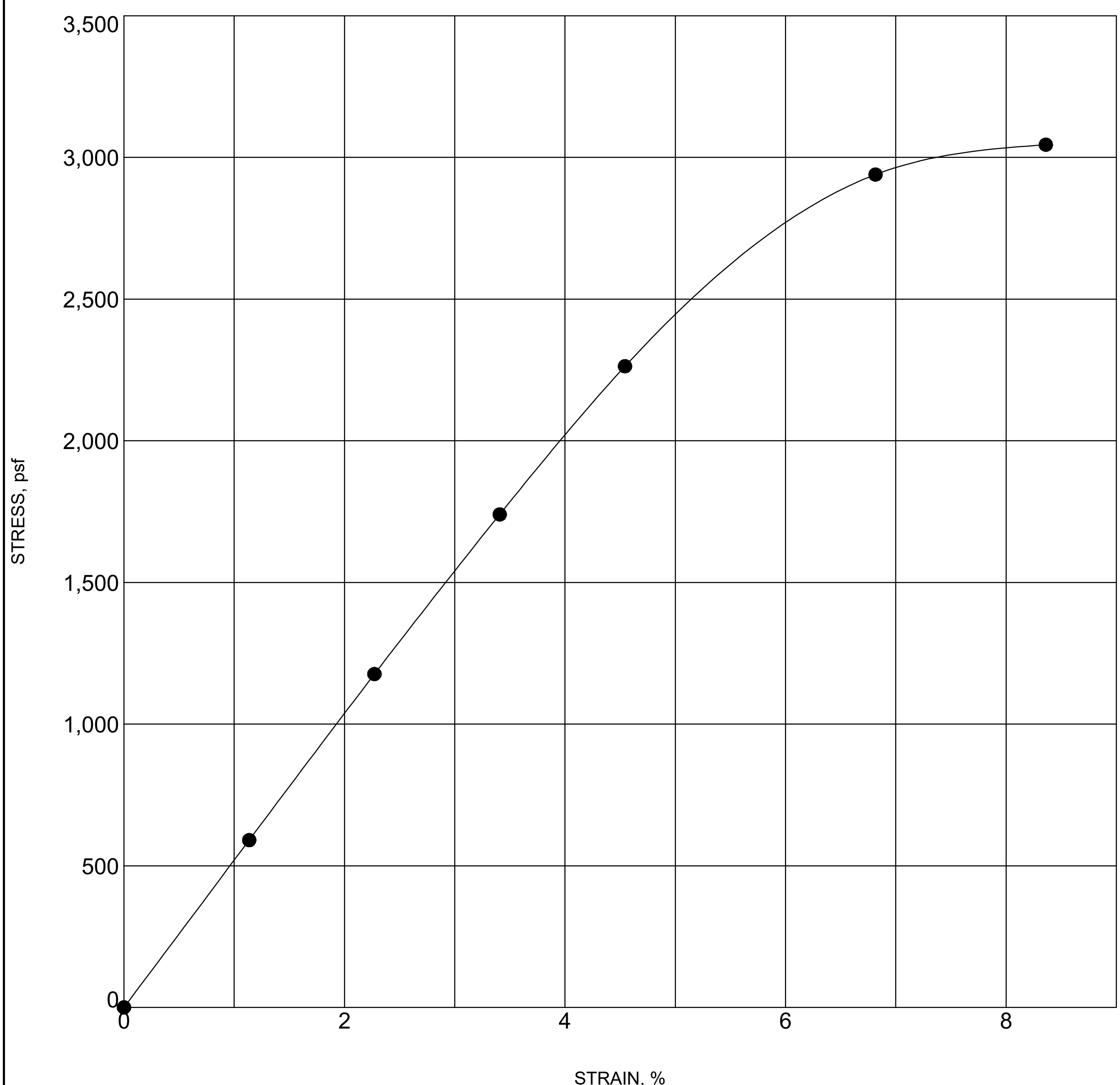
UNCONFINED COMPRESSION TEST

CLIENT City of Willoughby **PROJECT NAME** River Street Soil Stabilization

PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH



	Specimen Identification		Classification	γ_d	MC%
●	**B-2**	**2.5**		**99**	**20**

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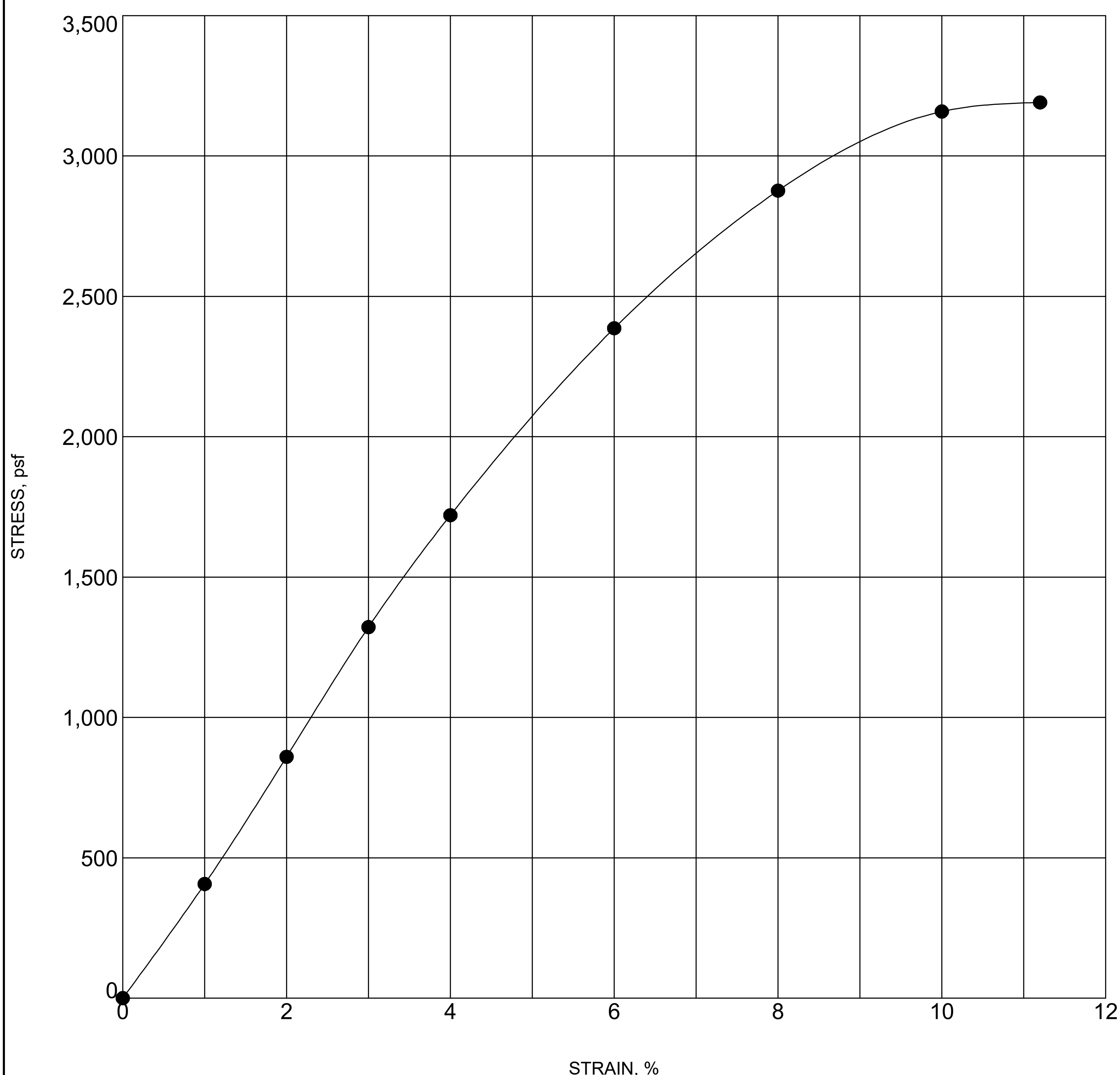
UNCONFINED COMPRESSION TEST

CLIENT City of Willoughby
PROJECT NAME River Street Soil Stabilization
PROJECT NUMBER 231093
PROJECT LOCATION Willoughby, OH



	Specimen Identification		Classification	γ_d	MC%
●	**B-2**	**3.5**		**102**	**20**

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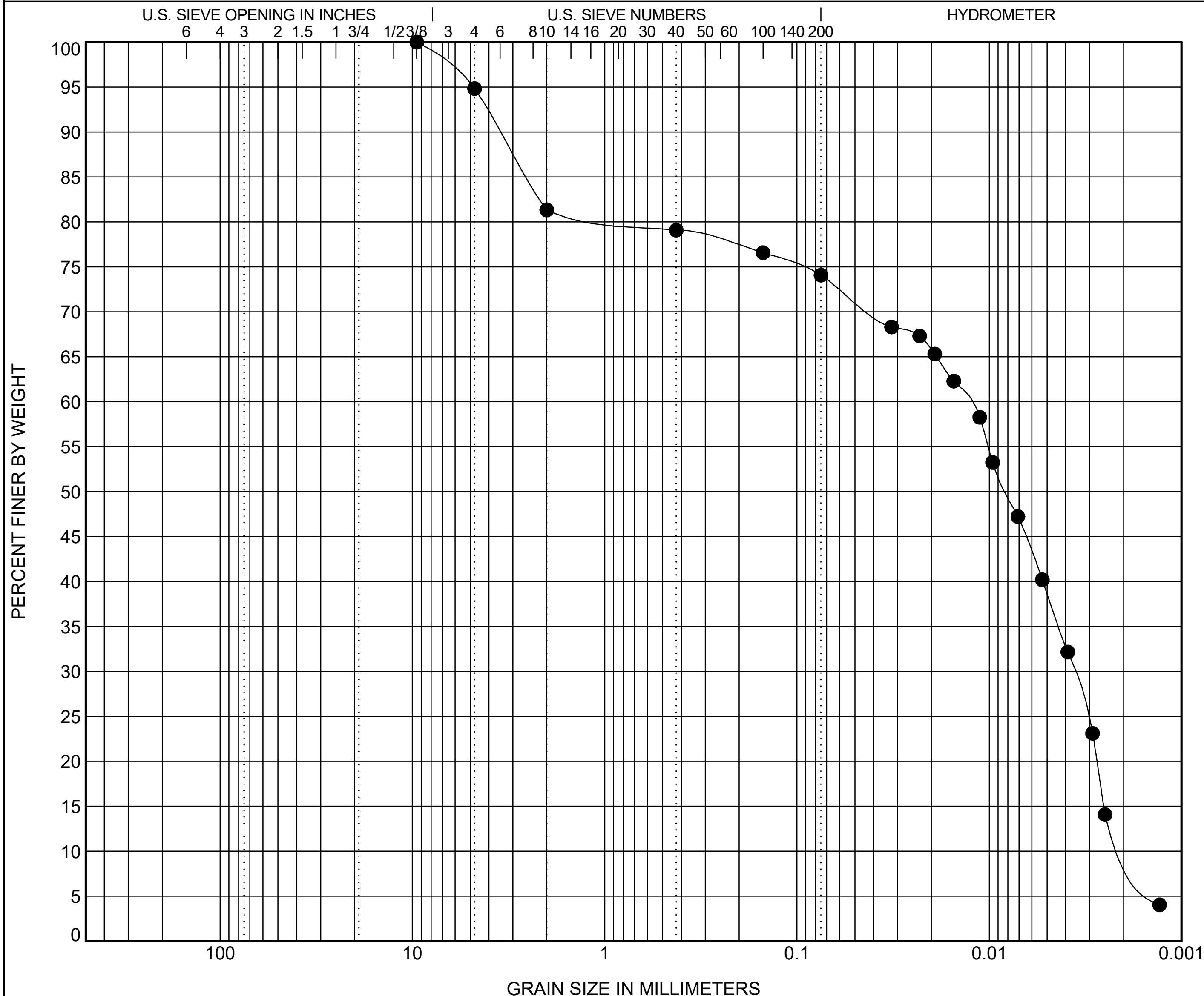
GRAIN SIZE DISTRIBUTION

CLIENT City of Willoughby **PROJECT NAME** River Street Soil Stabilization

PROJECT NUMBER 231093 **PROJECT LOCATION** Willoughby, OH



	Specimen Identification		USCS Classification	LL	PL	PI	Cc	Cu
●	**B-2**	**5.0**	**SILT with SAND (ML)**	**19**	**16**	**3**	**0.5**	**6.7**

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**B-2**	**5.0**	**9.5**	**0.013**	**0.004**	**0.002**	**5.2**	**20.7**	**35.4**	**38.7**

APPENDIX E

Rock Core Photo Log

100Th Anniversary
LEADING THROUGH THE NEXT 100 YEARS

CORE PHOTO LOG – B - 1

Project: River Street Soil Stabilization
Project Location: Willoughby, Ohio
CT Project No.: 231093
Core Date: September 18, 2023

Core Run	Depth (feet)	Elevation (feet)
RC-1	30 to 40	666 to 656

Begin RC-1

End RC-1

CORE PHOTO LOG – B - 2

Project: River Street Soil Stabilization
Project Location: Willoughby, Ohio
CT Project No.: 231093
Core Date: September 18, 2023

Core Run	Depth (feet)	Elevation (feet)
RC-1	30 to 40	665 to 655

Begin RC-1

End RC-1

APPENDIX F

Site Photographs

SITE RECONNAISSANCE PHOTOGRAPHS

Photo 1: Depicting the general site conditions at the crest; looking south along River Street.

Photo 2: Depicting the general site conditions at the crest; looking north along River Street.

SITE RECONNAISSANCE PHOTOGRAPHS

Photo 3: Looking north along river street at adjacent retaining wall

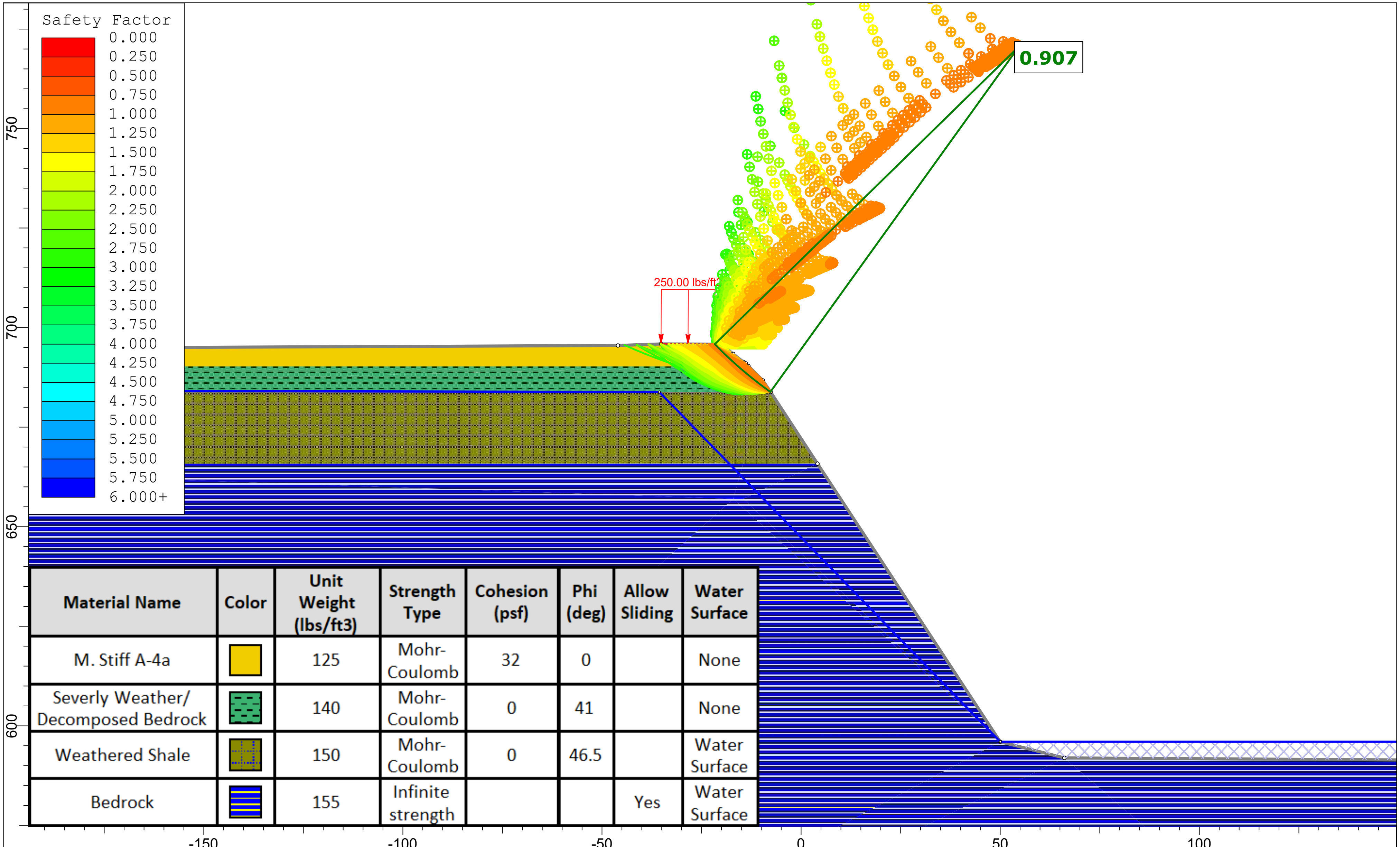
Photo 4: Depicting the magnitude of the slope looking north along River Street.

SITE RECONNAISSANCE PHOTOGRAPHS

Photo 5: Looking east over the edge of the slope to River below.

APPENDIX G

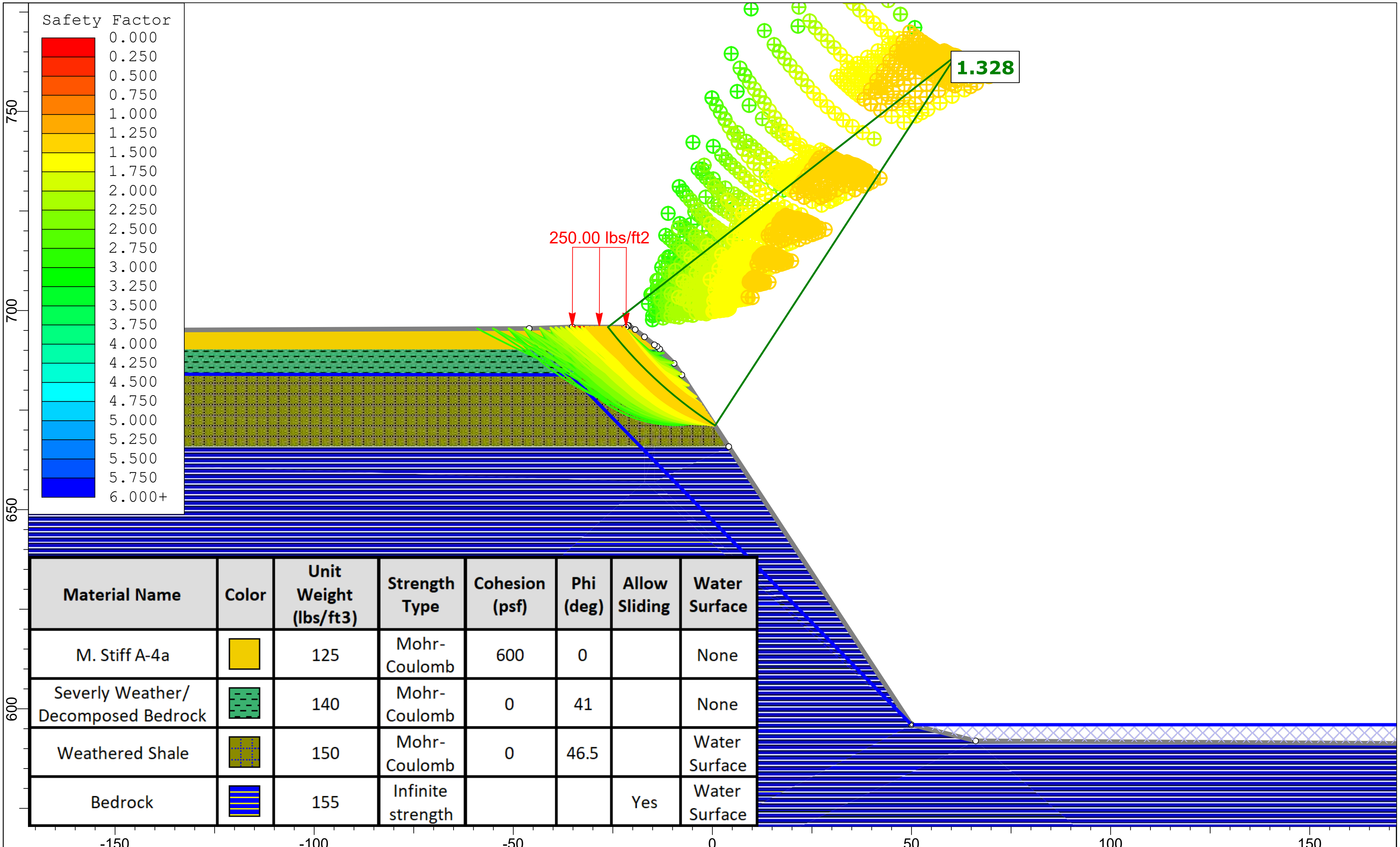
Slope Stability Analysis Outputs



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface
M. Stiff A-4a		125	Mohr-Coulomb	32	0		None
Severly Weather/ Decomposed Bedrock		140	Mohr-Coulomb	0	41		None
Weathered Shale		150	Mohr-Coulomb	0	46.5		Water Surface
Bedrock		155	Infinite strength			Yes	Water Surface

LEADING THROUGH the next 100 years
www.ctconsultants.com

Project	SLIDE - An Interactive Slope Stability Program		
Group	ESSP - Exising Conditions - Calibration Model.slim	Scenario	ESSP - Exising Conditions - Calibration Model.slim
Drawn By		Company	
Date	12/7/2023, 4:26:10 PM	File Name	ESSP - Exising Conditions - Calibration Model.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface
M. Stiff A-4a		125	Mohr-Coulomb	600	0		None
Severly Weather/ Decomposed Bedrock		140	Mohr-Coulomb	0	41		None
Weathered Shale		150	Mohr-Coulomb	0	46.5		Water Surface
Bedrock		155	Infinite strength			Yes	Water Surface

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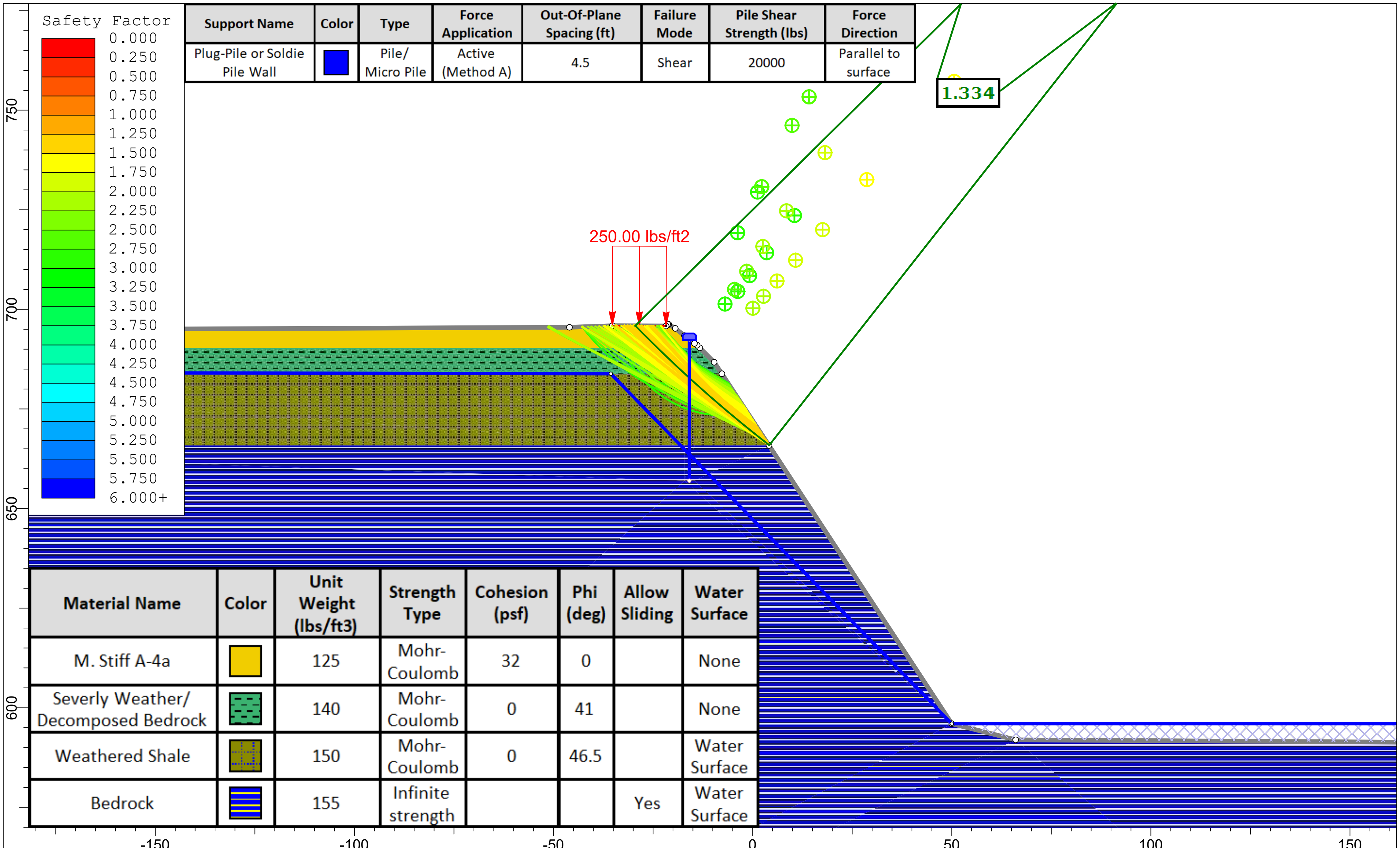
Project	SLIDE - An Interactive Slope Stability Program		
Group	TSSP - Exising Conditions.slim	Scenario	TSSP - Exising Conditions.slim
Drawn By		Company	
Date	12/7/2023, 4:26:10 PM	File Name	TSSP - Exising Conditions.slim



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)	Force Direction
Plug-Pile or Soldie Pile Wall		Pile/ Micro Pile	Active (Method A)	4.5	Shear	20000	Parallel to surface

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface
M. Stiff A-4a		125	Mohr-Coulomb	32	0		None
Severly Weather/ Decomposed Bedrock		140	Mohr-Coulomb	0	41		None
Weathered Shale		150	Mohr-Coulomb	0	46.5		Water Surface
Bedrock		155	Infinite strength			Yes	Water Surface

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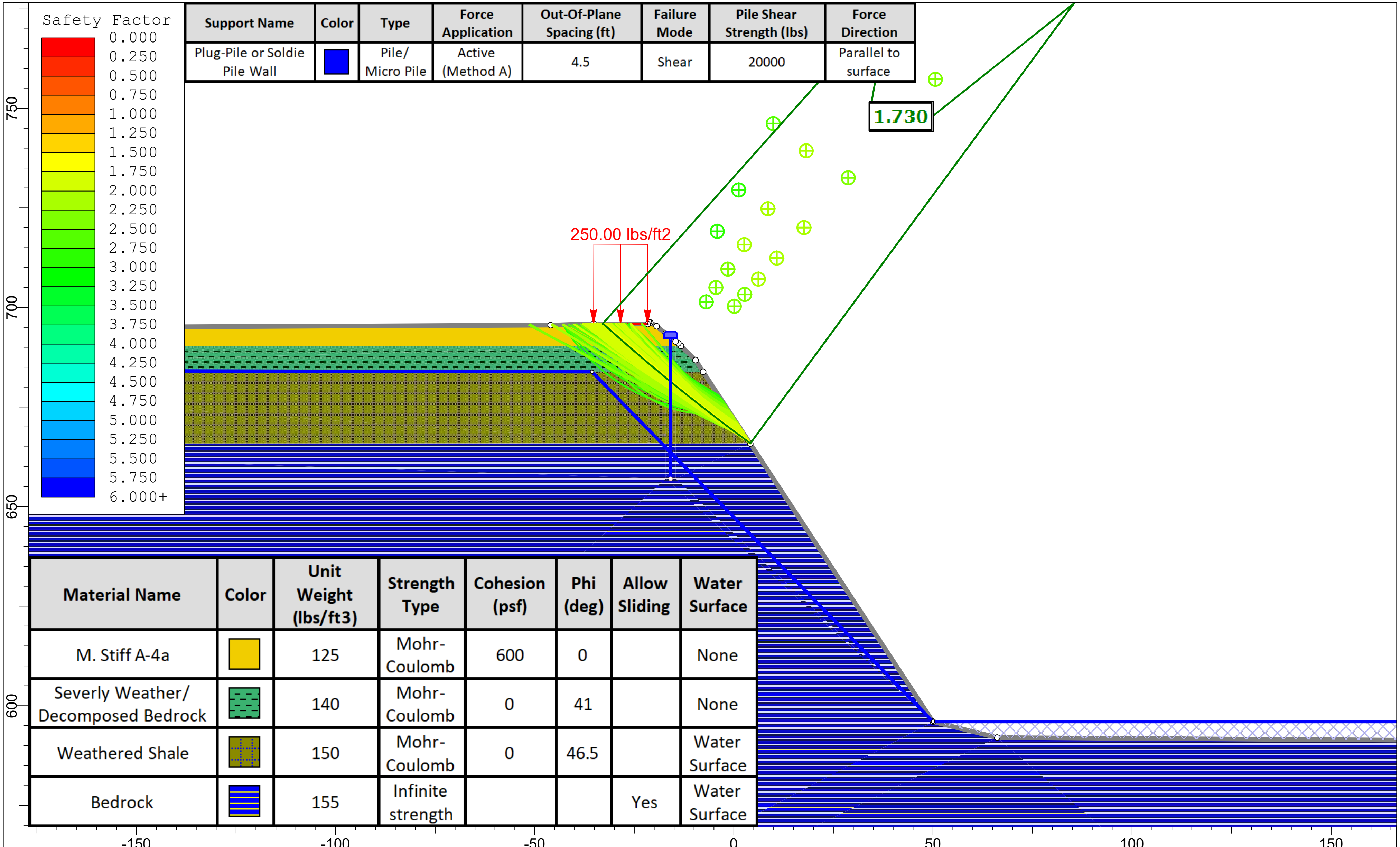
Project	SLIDE - An Interactive Slope Stability Program

Group	ESSP - Proposed Conditions.slim	*Scenario*	ESSP - Proposed Conditions.slim
Drawn By	IJH	*Company*	CT Consultants
Date	12/7/2023, 4:26:10 PM	*File Name*	ESSP - Proposed Conditions.slim



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)	Force Direction
Plug-Pile or Soldie Pile Wall		Pile/ Micro Pile	Active (Method A)	4.5	Shear	20000	Parallel to surface

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface
M. Stiff A-4a		125	Mohr-Coulomb	600	0		None
Severly Weather/ Decomposed Bedrock		140	Mohr-Coulomb	0	41		None
Weathered Shale		150	Mohr-Coulomb	0	46.5		Water Surface
Bedrock		155	Infinite strength			Yes	Water Surface

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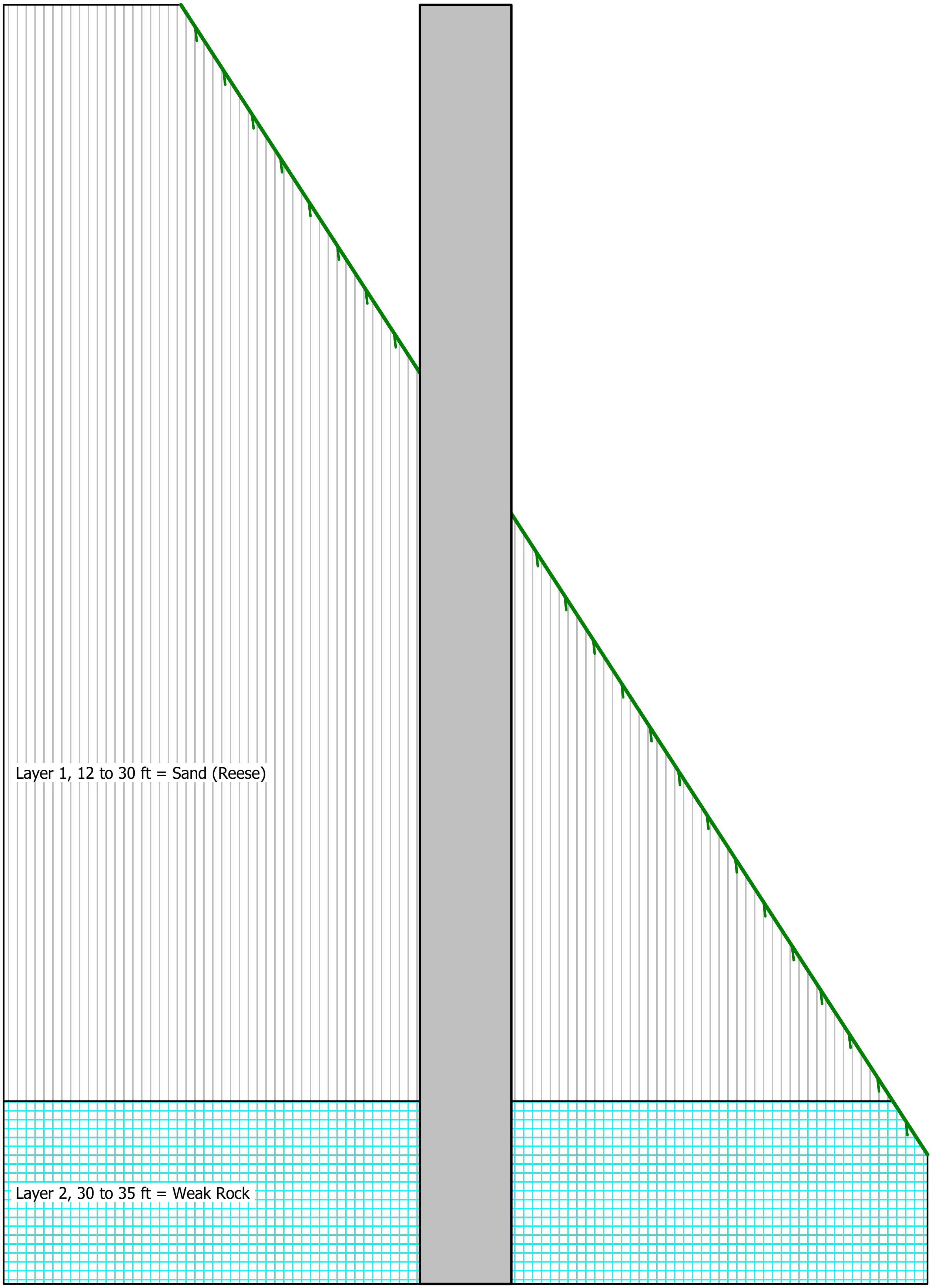
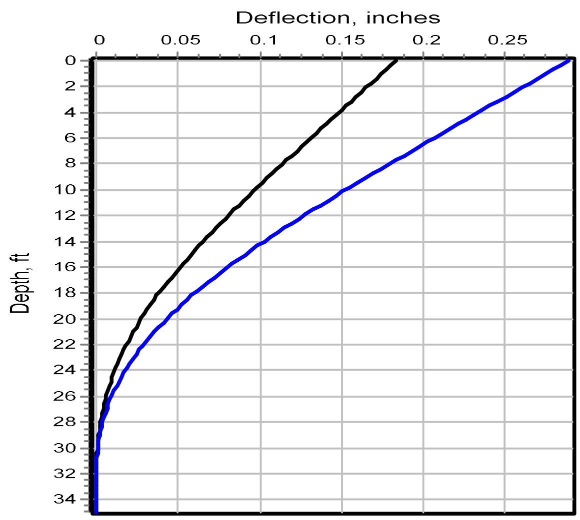
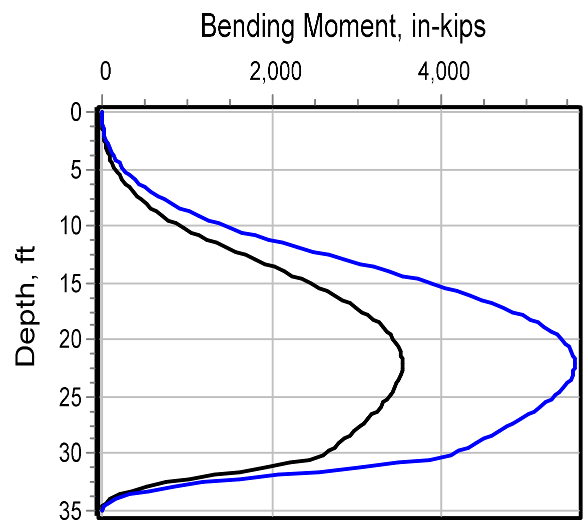
Project	SLIDE - An Interactive Slope Stability Program		
Group	TSSP - Proposed Conditions.slim	*Scenario*	TSSP - Proposed Conditions.slim
Drawn By	IJH	*Company*	CT Consultants
Date	12/7/2023, 4:26:10 PM	*File Name*	TSSP - Proposed Conditions.slim

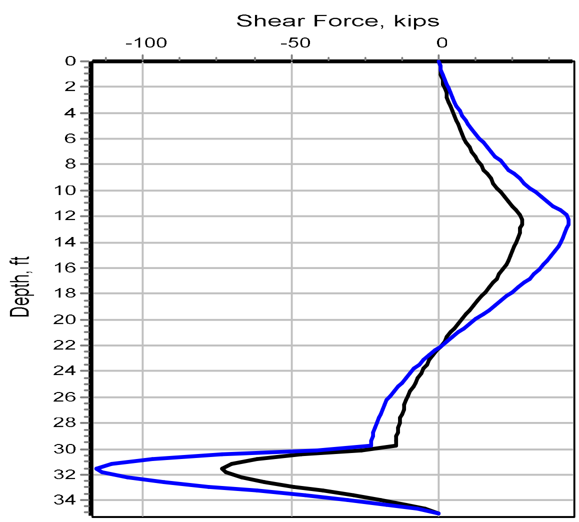
APPENDIX H

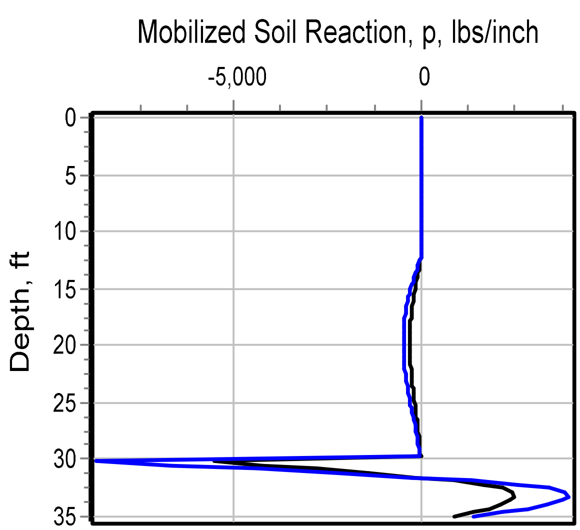
L-Pile Analysis Outputs


Layer 1, 12 to 30 ft = Sand (Reese)
Layer 2, 30 to 35 ft = Weak Rock


Deflection, inches
0
0.05
0.1
0.15
0.2
0.25
Depth, ft
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34


Bending Moment, in-kips
0
2,000
4,000
Depth, ft
0
5
10
15
20
25
30
35


Shear Force, kips
-100
-50
0
Depth, ft
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34


Mobilized Soil Reaction, p, lbs/inch
-5,000
0
Depth, ft
0
5
10
15
20
25
30
35

==

LPile for Windows, Version 2019-11.008

Analysis of Individual Piles and Drilled Shafts
Subjected to Lateral Loading Using the p-y Method

==

This copy of LPile is being used by:

Serial Number of Security Device: 562484188

This copy of LPile is licensed for exclusive use by:

TTL Associates, Inc., Toledo, OH

Files Used for Analysis

Path to file locations:
\\mtr-fs01.ctc.local\mtr-projects$\2023\231093\PHASE\06 Geotechnical Analysis\Project Data\Calculations\Lpile\

Name of input data file:
HP 10x42 - 30-inch Dia.lp11d

Name of output report file:
HP 10x42 - 30-inch Dia.lp11o

Name of plot output file:
HP 10x42 - 30-inch Dia.lp11p

Name of runtime message file:
HP 10x42 - 30-inch Dia.lp11r

Date and Time of Analysis

Date: December 15, 2023   Time: 13:04:36

Problem Title

Project Name: River Street Soil Stabilization

Job Number: 231093

Client: City of Willoughby

Engineer: IJH

Description: Lateral Shaft Resistance

Program Options and Settings

Computational Options:
 - Conventional Analysis
Engineering Units Used for Data Input and Computations:
 - US Customary System Units (pounds, feet, inches)

Analysis Control Options:

- Maximum number of iterations allowed	=	500
- Deflection tolerance for convergence	=	1.0000E-05 in
- Maximum allowable deflection	=	100.0000 in
- Number of pile increments	=	100

Loading Type and Number of Cycles of Loading:
 - Static loading specified

- Analysis uses p-y modification factors for p-y curves
- Analysis uses layering correction (Method of Georgiadis)
- Analysis includes loading by multiple distributed lateral loads acting on pile
- Loading by lateral soil movements acting on pile not selected
- Input of shear resistance at the pile tip not selected
- Input of moment resistance at the pile tip not selected
- Input of side resistance moment along pile not selected
- Computation of pile-head foundation stiffness matrix not selected
- Push-over analysis of pile not selected
- Buckling analysis of pile not selected

Output Options:
- Output files use decimal points to denote decimal symbols.
- Values of pile-head deflection, bending moment, shear force, and soil reaction are printed for full length of pile.
- Printing Increment (nodal spacing of output points) = 1
- No p-y curves to be computed and reported for user-specified depths
- Print using wide report formats

Pile Structural Properties and Geometry

```
Number of pile sections defined                          =            1
Total length of pile                                     =       35.000 ft
Depth of ground surface below top of pile                =      12.0000 ft
```

Pile diameters used for p-y curve computations are defined using 2 points.

p-y curves are computed using pile diameter values interpolated with depth over the length of the pile. A summary of values of pile diameter vs. depth follows.

Point No.	Depth Below Pile Head feet	Pile Diameter inches
1	0.000	30.0000
2	35.000	30.0000

Input Structural Properties for Pile Sections:

Pile Section No. 1:

```
   Section 1 is an elastic pile
   Cross-sectional Shape                                 =   Circular Pile
```

```
   Length of section                                      =    35.000000 ft
   Width of top of section                                =    30.000000 in
   Width of bottom of section                             =    30.000000 in
   Top Area                                               =    98.500000 sq. in
   Bottom Area                                            =   706.858347 sq. in
   Moment of Inertia at Top                               =       31100. in^4
   Moment of Inertia at Bottom                            =       39761. in^4
   Elastic Modulus                                        =    29000000. psi
```

Ground Slope and Pile Batter Angles

```
Ground Slope Angle                                        =       57.000 degrees
                                                          =        0.995 radians

Pile Batter Angle                                         =        0.000 degrees
                                                          =        0.000 radians
```

Soil and Rock Layering Information

The soil profile is modelled using 2 layers

Layer 1 is sand, p-y criteria by Reese et al., 1974

```
   Distance from top of pile to top of layer              =    12.000000 ft
   Distance from top of pile to bottom of layer           =    30.000000 ft
   Effective unit weight at top of layer                  =   140.000000 pcf
   Effective unit weight at bottom of layer               =   150.000000 pcf
   Friction angle at top of layer                         =    60.000000 deg.
   Friction angle at bottom of layer                      =    60.000000 deg.
   Subgrade k at top of layer                             =    90.000000 pci
   Subgrade k at bottom of layer                          =   225.000000 pci
```

Layer 2 is weak rock, p-y criteria by Reese, 1997

```
   Distance from top of pile to top of layer              =    30.000000 ft
   Distance from top of pile to bottom of layer           =    35.000000 ft
   Effective unit weight at top of layer                  =   155.000000 pcf
   Effective unit weight at bottom of layer               =   155.000000 pcf
   Uniaxial compressive strength at top of layer          =        5000. psi
   Uniaxial compressive strength at bottom of layer       =        5000. psi
   Initial modulus of rock at top of layer                =      100000. psi
```

```
   Initial modulus of rock at bottom of layer          =      100000. psi
   RQD of rock at top of layer                         =    36.000000 %
   RQD of rock at bottom of layer                      =    36.000000 %
   k rm of rock at top of layer                        =    0.0002700
   k rm of rock at bottom of layer                     =    0.0002700
```

(Depth of the lowest soil layer extends 0.000 ft below the pile tip)

**** Warning - Possible Input Data Error ****

Values entered for effective unit weights of soil were outside the limits of 20 pcf to 140 pcf.

The maximum input value, in layer   1, for effective unit weight = 140.00 pcf

This data may be erroneous. Please check your data.

**** Warning - Possible Input Data Error ****

Values entered for effective unit weight of rock were outside the limits of 50 pcf to 150 pcf.

The maximum input value, in layer   1, for effective unit weight = 155.00 pcf

This data may be erroneous. Please check your data.

```
--------------------------------------------------------------------------------
                        Summary of Input Soil Properties
--------------------------------------------------------------------------------

Layer         Soil Type          Layer      Effective    Angle of     Uniaxial
              E50                    Rock Mass
Layer           Name             Depth       Unit Wt.    Friction        qu
RQD %           or           kpy        Modulus
 Num.     (p-y Curve Type)        ft           pcf          deg.         psi
              krm          pci          psi
-----   -------------------   ----------   ----------   ----------   ----------
----------   ----------   ----------   ----------
  1             Sand             12.0000     140.0000      60.0000       --
 --           --           90.0000       --
          (Reese, et al.)        30.0000     150.0000      60.0000       --
 --           --          225.0000       --
  2             Weak             30.0000     155.0000       --           5000.
36.0000     2.70E-04       --           100000.
                Rock             35.0000     155.0000       --           5000.
```

36.0000	2.70E-04	--	100000.

p-y Modification Factors for Group Action

Distribution of p-y modifiers with depth defined using 2 points

Point No.	Depth X ft	p-mult	y-mult
1	12.000	0.8000	1.0000
2	30.000	0.8000	1.0000

Static Loading Type

Static loading criteria were used when computing p-y curves for all analyses.

Distributed Lateral Loading for Individual Load Cases

Distributed lateral load intensity for Load Case 1 defined using 2 points

Point No.	Depth X in	Dist. Load lb/in
1	0.000	45.000
2	144.000	340.000

Distributed lateral load intensity for Load Case 2 defined using 2 points

Point No.	Depth X in	Dist. Load lb/in
1	0.000	75.000
2	144.000	530.000

```
--------------------------------------------------------------------------------
                Pile-head Loading and Pile-head Fixity Conditions
--------------------------------------------------------------------------------

Number of loads specified = 2

Load    Load         Condition                Condition           Axial Thrust
Compute Top y     Run Analysis
 No.    Type           1                        2                  Force, lbs
vs. Pile Length
-----   ----   --------------------   -----------------------   ----------------
---------------    ------------
   1     1     V =       0.0000 lbs   M =       0.0000 in-lbs         0.0000000
    No               Yes
   2     1     V =       0.0000 lbs   M =       0.0000 in-lbs         0.0000000
    No               Yes

V = shear force applied normal to pile axis
M = bending moment applied to pile head
y = lateral deflection normal to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applied to pile head
Values of top y vs. pile lengths can be computed only for load types with
specified shear loading (Load Types 1, 2, and 3).
Thrust force is assumed to be acting axially for all pile batter angles.



--------------------------------------------------------------------------------
     Computations of Nominal Moment Capacity and Nonlinear Bending Stiffness
--------------------------------------------------------------------------------

Axial thrust force values were determined from pile-head loading conditions

Number of Pile Sections Analyzed = 1

Pile Section No. 1:
-------------------
Moment-curvature properties were derived from elastic section properties



--------------------------------------------------------------------------------
            Layering Correction Equivalent Depths of Soil & Rock Layers
--------------------------------------------------------------------------------


         Top of    Equivalent
          Layer     Top Depth  Same Layer  Layer is        F0          F1
Layer     Below       Below      Type As    Rock or     Integral    Integral
```

No.	Pile Head ft	Grnd Surf ft	Layer Above	is Below Rock Layer	for Layer lbs	for Layer lbs
1	12.0000	0.00	N.A.	No	0.00	9677878.
2	30.0000	18.0000	No	Yes	N.A.	N.A.

Notes: The F0 integral of Layer n+1 equals the sum of the F0 and F1 integrals for Layer n. Layering correction equivalent depths are computed only for soil types with both shallow-depth and deep-depth expressions for peak lateral load transfer. These soil types are soft and stiff clays, non-liquefied sands, and cemented c-phi soil.

Computed Values of Pile Loading and Deflection
for Lateral Loading for Load Case Number 1

Pile-head conditions are Shear and Moment (Loading Type 1)

Shear force at pile head = 0.0 lbs
Applied moment at pile head = 0.0 in-lbs
Axial thrust load on pile head = 0.0 lbs

Depth X feet	Deflect. y inches	Bending Moment in-lbs	Shear Force lbs	Slope S radians	Total Stress psi*	Bending Stiffness lb-in^2	Soil Res. p lb/inch	Soil Spr. Es*H lb/inch	Distrib. Lat. Load lb/inch
0.00	0.1831	1.28E-05	0.00	-7.25E-04	6.16E-09	9.02E+11	0.00	0.00	47.1510
0.3500	0.1800	415.8723	211.5859	-7.25E-04	0.2001	9.02E+11	0.00	0.00	53.6042
0.7000	0.1770	1777.	454.7922	-7.25E-04	0.8529	9.06E+11	0.00	0.00	62.2083
1.0500	0.1739	4236.	734.1359	-7.25E-04	2.0277	9.09E+11	0.00	0.00	70.8125
1.4000	0.1709	7944.	1050.	-7.25E-04	3.7930	9.11E+11	0.00	0.00	79.4167
1.7500	0.1678	13053.	1401.	-7.25E-04	6.2165	9.13E+11	0.00	0.00	88.0208
2.1000	0.1648	19714.	1789.	-7.25E-04	9.3654	9.16E+11	0.00	0.00	96.6250
2.4500	0.1617	28080.	2213.	-7.25E-04	13.3060	9.18E+11	0.00	0.00	105.2292

2.8000	0.1587	38303.	2673.	-7.25E-04	18.1042	9.20E+11	0.00	0.00	113.8333
3.1500	0.1556	50533.	3169.	-7.25E-04	23.8248	9.23E+11	0.00	0.00	122.4375
3.5000	0.1526	64923.	3701.	-7.24E-04	30.5324	9.25E+11	0.00	0.00	131.0417
3.8500	0.1496	81625.	4270.	-7.24E-04	38.2904	9.27E+11	0.00	0.00	139.6458
4.2000	0.1465	100790.	4874.	-7.24E-04	47.1620	9.30E+11	0.00	0.00	148.2500
4.5500	0.1435	122570.	5515.	-7.23E-04	57.2094	9.32E+11	0.00	0.00	156.8542
4.9000	0.1404	147117.	6192.	-7.23E-04	68.4945	9.34E+11	0.00	0.00	165.4583
5.2500	0.1374	174582.	6905.	-7.22E-04	81.0781	9.37E+11	0.00	0.00	174.0625
5.6000	0.1344	205119.	7654.	-7.21E-04	95.0207	9.39E+11	0.00	0.00	182.6667
5.9500	0.1313	238877.	8439.	-7.20E-04	110.3821	9.41E+11	0.00	0.00	191.2708
6.3000	0.1283	276009.	9261.	-7.19E-04	127.2213	9.44E+11	0.00	0.00	199.8750
6.6500	0.1253	316668.	10118.	-7.18E-04	145.5969	9.46E+11	0.00	0.00	208.4792
7.0000	0.1223	361004.	11012.	-7.16E-04	165.5666	9.48E+11	0.00	0.00	217.0833
7.3500	0.1193	409169.	11942.	-7.14E-04	187.1877	9.51E+11	0.00	0.00	225.6875
7.7000	0.1163	461315.	12908.	-7.12E-04	210.5169	9.53E+11	0.00	0.00	234.2917
8.0500	0.1133	517594.	13910.	-7.10E-04	235.6100	9.56E+11	0.00	0.00	242.8958
8.4000	0.1103	578158.	14948.	-7.08E-04	262.5226	9.58E+11	0.00	0.00	251.5000
8.7500	0.1074	643158.	16022.	-7.05E-04	291.3094	9.60E+11	0.00	0.00	260.1042
9.1000	0.1044	712747.	17133.	-7.02E-04	322.0246	9.63E+11	0.00	0.00	268.7083
9.4500	0.1015	787075.	18280.	-6.99E-04	354.7218	9.65E+11	0.00	0.00	277.3125
9.8000	0.09853	866296.	19462.	-6.95E-04	389.4540	9.68E+11	0.00	0.00	285.9167
10.1500	0.09562	950560.	20681.	-6.91E-04	426.2737	9.70E+11	0.00	0.00	294.5208
10.5000	0.09273	1040019.	21936.	-6.87E-04	465.2326	9.72E+11	0.00	0.00	303.1250
10.8500	0.08985	1134825.	23228.	-6.83E-04	506.3822	9.75E+11	0.00	0.00	311.7292
11.2000	0.08699	1235131.	24555.	-6.77E-04	549.7730	9.77E+11	0.00	0.00	320.3333

```
   11.5500    0.08416   1341087.      25918.   -6.72E-04   595.4553   9.80E+11
0.00       0.00   328.9375
   11.9000    0.08135   1452845.      27165.   -6.66E-04   643.4786   9.82E+11
0.00       0.00   264.4870
   12.2500    0.07856   1569269.      27684.   -6.59E-04   693.3226   9.85E+11
-17.3236   926.1000       0.00
   12.6000    0.07581   1685388.      27561.   -6.53E-04   742.7822   9.87E+11
-41.2646       2286.       0.00
   12.9500    0.07308   1800778.      27338.   -6.45E-04   791.6740   9.89E+11
-64.7362       3720.       0.00
   13.3000    0.07039   1915027.      27018.   -6.37E-04   839.8199   9.92E+11
-87.6277       5228.       0.00
   13.6500    0.06773   2027729.      26603.   -6.29E-04   887.0480   9.94E+11
-109.8343      6811.       0.00
   14.0000    0.06511   2138495.      26097.   -6.20E-04   933.1937   9.97E+11
-131.2574      8467.       0.00
   14.3500    0.06252   2246945.      25503.   -6.11E-04   978.0997   9.99E+11
-151.8055     10198.       0.00
   14.7000    0.05998   2352717.      24824.   -6.01E-04      1022.   1.00E+12
-171.3937     12002.       0.00
   15.0500    0.05747   2455466.      24065.   -5.91E-04      1064.   1.00E+12
-189.9442     13881.       0.00
   15.4000    0.05501   2554864.      23231.   -5.81E-04      1104.   1.01E+12
-207.3864     15834.       0.00
   15.7500    0.05259   2650603.      22326.   -5.70E-04      1142.   1.01E+12
-223.6573     17860.       0.00
   16.1000    0.05022   2742398.      21355.   -5.59E-04      1179.   1.01E+12
-238.7012     19961.       0.00
   16.4500    0.04790   2829982.      20323.   -5.47E-04      1214.   1.01E+12
-252.4701     22136.       0.00
   16.8000    0.04563   2913112.      19237.   -5.35E-04      1246.   1.02E+12
-264.9234     24386.       0.00
   17.1500    0.04341   2991569.      18101.   -5.23E-04      1277.   1.02E+12
-276.0284     26709.       0.00
   17.5000    0.04124   3065157.      16921.   -5.11E-04      1305.   1.02E+12
-285.7599     29106.       0.00
   17.8500    0.03912   3133704.      15703.   -4.98E-04      1331.   1.02E+12
-294.1003     31577.       0.00
   18.2000    0.03705   3197063.      14453.   -4.85E-04      1355.   1.03E+12
-301.0393     34123.       0.00
   18.5500    0.03504   3255112.      13177.   -4.72E-04      1376.   1.03E+12
-306.5744     36742.       0.00
   18.9000    0.03309   3307752.      11881.   -4.58E-04      1395.   1.03E+12
-310.7100     39436.       0.00
   19.2500    0.03119   3354912.      10570.   -4.45E-04      1411.   1.03E+12
-313.4578     42204.       0.00
   19.6000    0.02936   3396543.       9251.   -4.31E-04      1425.   1.04E+12
-314.8363     45046.       0.00
   19.9500    0.02757   3432620.       7928.   -4.17E-04      1437.   1.04E+12
-314.8709     47961.       0.00
```

20.3000	0.02585	3463142.	6609.	-4.03E-04	1446.	1.04E+12	-313.5933	50951.	0.00
20.6500	0.02419	3488133.	5297.	-3.89E-04	1453.	1.04E+12	-311.0416	54015.	0.00
21.0000	0.02258	3507637.	3999.	-3.75E-04	1457.	1.05E+12	-307.2598	57154.	0.00
21.3500	0.02103	3521720.	2718.	-3.61E-04	1460.	1.05E+12	-302.2976	60366.	0.00
21.7000	0.01955	3530472.	1462.	-3.47E-04	1460.	1.05E+12	-296.2101	63652.	0.00
22.0500	0.01812	3533998.	232.5368	-3.33E-04	1458.	1.05E+12	-289.0576	67013.	0.00
22.4000	0.01675	3532425.	-964.3852	-3.19E-04	1453.	1.06E+12	-280.9052	70447.	0.00
22.7500	0.01544	3525897.	-2125.	-3.05E-04	1447.	1.06E+12	-271.8224	73956.	0.00
23.1000	0.01419	3514574.	-3246.	-2.91E-04	1439.	1.06E+12	-261.8830	77538.	0.00
23.4500	0.01299	3498631.	-4323.	-2.77E-04	1429.	1.07E+12	-251.1644	81195.	0.00
23.8000	0.01186	3478258.	-5354.	-2.63E-04	1417.	1.07E+12	-239.7477	84926.	0.00
24.1500	0.01078	3453656.	-6336.	-2.50E-04	1404.	1.07E+12	-227.7172	88731.	0.00
24.5000	0.00976	3425037.	-7266.	-2.36E-04	1389.	1.07E+12	-215.1600	92610.	0.00
24.8500	0.00879	3392622.	-8142.	-2.23E-04	1372.	1.08E+12	-202.1658	96563.	0.00
25.2000	0.00788	3356641.	-8963.	-2.10E-04	1354.	1.08E+12	-188.8267	100590.	0.00
25.5500	0.00703	3317330.	-9728.	-1.97E-04	1335.	1.08E+12	-175.2364	104692.	0.00
25.9000	0.00623	3274927.	-10435.	-1.84E-04	1315.	1.08E+12	-161.4907	108867.	0.00
26.2500	0.00548	3229675.	-11084.	-1.72E-04	1294.	1.09E+12	-147.6867	113117.	0.00
26.6000	0.00479	3181819.	-11676.	-1.59E-04	1272.	1.09E+12	-133.9224	117440.	0.00
26.9500	0.00415	3131599.	-12210.	-1.47E-04	1248.	1.09E+12	-120.2970	121838.	0.00
27.3000	0.00355	3079258.	-12687.	-1.35E-04	1225.	1.09E+12	-106.9104	126309.	0.00
27.6500	0.00301	3025031.	-13108.	-1.23E-04	1200.	1.10E+12	-93.8628	130855.	0.00
28.0000	0.00252	2969148.	-13476.	-1.12E-04	1175.	1.10E+12	-81.2548	135475.	0.00
28.3500	0.00207	2911832.	-13792.	-1.01E-04	1150.	1.10E+12	-69.1869	140169.	0.00
28.7000	0.00167	2853295.	-14059.	-8.97E-05	1124.	1.10E+12	-57.7598	144937.	0.00

29.0500	0.00132	2793740.	-14279.	-7.89E-05	1098.	1.11E+12	-47.0737	149779.	0.00
29.4000	0.00101	2733354.	-14456.	-6.85E-05	1071.	1.11E+12	-37.2285	154696.	0.00
29.7500	7.45E-04	2672311.	-14593.	-5.82E-05	1045.	1.11E+12	-28.3237	159686.	0.00
30.1000	5.22E-04	2610769.	-26189.	-4.83E-05	1018.	1.12E+12	-5494.	4.42E+07	0.00
30.4500	3.39E-04	2452321.	-46564.	-3.88E-05	954.3747	1.12E+12	-4209.	5.21E+07	0.00
30.8000	1.96E-04	2219629.	-61275.	-3.00E-05	861.7463	1.12E+12	-2796.	5.99E+07	0.00
31.1500	8.75E-05	1937611.	-70113.	-2.22E-05	750.4531	1.12E+12	-1412.	6.78E+07	0.00
31.5000	9.49E-06	1630682.	-73437.	-1.55E-05	630.0646	1.13E+12	-170.7932	7.56E+07	0.00
31.8500	-4.30E-05	1320741.	-72001.	-1.00E-05	509.0878	1.13E+12	854.3025	8.34E+07	0.00
32.2000	-7.48E-05	1025870.	-66791.	-5.68E-06	394.4820	1.13E+12	1627.	9.13E+07	0.00
32.5500	-9.07E-05	759694.	-58880.	-2.37E-06	291.4297	1.13E+12	2140.	9.91E+07	0.00
32.9000	-9.47E-05	531275.	-49319.	2.18E-08	203.3179	1.14E+12	2412.	1.07E+08	0.00
33.2500	-9.05E-05	345410.	-39058.	1.64E-06	131.8723	1.14E+12	2474.	1.15E+08	0.00
33.6000	-8.10E-05	203188.	-28898.	2.65E-06	77.3890	1.14E+12	2364.	1.23E+08	0.00
33.9500	-6.83E-05	102664.	-19482.	3.21E-06	39.0086	1.14E+12	2120.	1.30E+08	0.00
34.3000	-5.40E-05	39543.	-11296.	3.47E-06	14.9890	1.15E+12	1777.	1.38E+08	0.00
34.6500	-3.91E-05	7776.	-4707.	3.56E-06	2.9405	1.15E+12	1360.	1.46E+08	0.00
35.0000	-2.41E-05	0.00	0.00	3.57E-06	0.00	1.15E+12	882.6682	7.70E+07	0.00

* The above values of total stress are combined axial and bending stresses.

Output Summary for Load Case No. 1:

```
Pile-head deflection             =     0.18305477 inches
Computed slope at pile head      =    -0.00072539 radians
Maximum bending moment           =       3533998. inch-lbs
Maximum shear force              =        -73437. lbs
Depth of maximum bending moment  =    22.05000000 feet below pile head
Depth of maximum shear force     =    31.50000000 feet below pile head
Number of iterations             =              6
Number of zero deflection points =              1
```

Computed Values of Pile Loading and Deflection
for Lateral Loading for Load Case Number 2

Pile-head conditions are Shear and Moment (Loading Type 1)

Shear force at pile head = 0.0 lbs
Applied moment at pile head = 0.0 in-lbs
Axial thrust load on pile head = 0.0 lbs

Depth X feet	Deflect. y inches	Bending Moment in-lbs	Shear Force lbs	Slope S radians	Total Stress psi*	Bending Stiffness lb-in^2	Soil Res. p lb/inch	Soil Spr. Es*H lb/inch	Distrib. Lat. Load lb/inch
0.00	0.2885	-5.11E-05	-3.38E-07	-0.00114	2.46E-08	9.02E+11	0.00	0.00	78.3177
0.3500	0.2837	690.7622	349.8359	-0.00114	0.3323	9.02E+11	0.00	0.00	88.2708
0.7000	0.2789	2939.	748.4422	-0.00114	1.4102	9.06E+11	0.00	0.00	101.5417
1.0500	0.2741	6978.	1203.	-0.00114	3.3400	9.09E+11	0.00	0.00	114.8125
1.4000	0.2693	13042.	1713.	-0.00114	6.2270	9.11E+11	0.00	0.00	128.0833
1.7500	0.2644	21366.	2279.	-0.00114	10.1755	9.13E+11	0.00	0.00	141.3542
2.1000	0.2596	32183.	2900.	-0.00114	15.2886	9.16E+11	0.00	0.00	154.6250
2.4500	0.2548	45728.	3578.	-0.00114	21.6683	9.18E+11	0.00	0.00	167.8958
2.8000	0.2500	62234.	4311.	-0.00114	29.4157	9.20E+11	0.00	0.00	181.1667
3.1500	0.2452	81937.	5099.	-0.00114	38.6308	9.23E+11	0.00	0.00	194.4375
3.5000	0.2404	105069.	5944.	-0.00114	49.4123	9.25E+11	0.00	0.00	207.7083
3.8500	0.2356	131865.	6844.	-0.00114	61.8582	9.27E+11	0.00	0.00	220.9792
4.2000	0.2308	162559.	7800.	-0.00114	76.0654	9.30E+11	0.00	0.00	234.2500
4.5500	0.2261	197385.	8812.	-0.00114	92.1296	9.32E+11	0.00	0.00	247.5208

4.9000	0.2213	236578.	9879.	-0.00114	110.1457	9.34E+11	0.00	0.00	260.7917
5.2500	0.2165	280371.	11002.	-0.00114	130.2075	9.37E+11	0.00	0.00	274.0625
5.6000	0.2117	328998.	12181.	-0.00114	152.4078	9.39E+11	0.00	0.00	287.3333
5.9500	0.2069	382695.	13416.	-0.00114	176.8384	9.41E+11	0.00	0.00	300.6042
6.3000	0.2022	441693.	14706.	-0.00113	203.5901	9.44E+11	0.00	0.00	313.8750
6.6500	0.1974	506229.	16053.	-0.00113	232.7528	9.46E+11	0.00	0.00	327.1458
7.0000	0.1927	576535.	17454.	-0.00113	264.4155	9.48E+11	0.00	0.00	340.4167
7.3500	0.1879	652846.	18912.	-0.00113	298.6660	9.51E+11	0.00	0.00	353.6875
7.7000	0.1832	735396.	20425.	-0.00112	335.5915	9.53E+11	0.00	0.00	366.9583
8.0500	0.1785	824420.	21995.	-0.00112	375.2778	9.56E+11	0.00	0.00	380.2292
8.4000	0.1738	920151.	23619.	-0.00112	417.8103	9.58E+11	0.00	0.00	393.5000
8.7500	0.1691	1022823.	25300.	-0.00111	463.2729	9.60E+11	0.00	0.00	406.7708
9.1000	0.1645	1132670.	27036.	-0.00111	511.7492	9.63E+11	0.00	0.00	420.0417
9.4500	0.1598	1249927.	28828.	-0.00110	563.3213	9.65E+11	0.00	0.00	433.3125
9.8000	0.1552	1374828.	30676.	-0.00110	618.0708	9.68E+11	0.00	0.00	446.5833
10.1500	0.1506	1507606.	32580.	-0.00109	676.0782	9.70E+11	0.00	0.00	459.8542
10.5000	0.1461	1648496.	34539.	-0.00108	737.4232	9.72E+11	0.00	0.00	473.1250
10.8500	0.1415	1797732.	36554.	-0.00108	802.1846	9.75E+11	0.00	0.00	486.3958
11.2000	0.1370	1955548.	38625.	-0.00107	870.4404	9.77E+11	0.00	0.00	499.6667
11.5500	0.1325	2122179.	40751.	-0.00106	942.2675	9.80E+11	0.00	0.00	512.9375
11.9000	0.1281	2297857.	42694.	-0.00105	1018.	9.82E+11	0.00	0.00	412.3322
12.2500	0.1237	2480809.	43516.	-0.00104	1096.	9.85E+11	-20.8481	707.6530	0.00
12.6000	0.1194	2663393.	43337.	-0.00103	1174.	9.87E+11	-64.3623	2264.	0.00
12.9500	0.1151	2844842.	42988.	-0.00102	1251.	9.89E+11	-101.9527	3720.	0.00
13.3000	0.1109	3024493.	42484.	-0.00100	1326.	9.92E+11	-138.0021	5228.	0.00

13.6500	0.1067	3201709.	41831.	-9.91E-04	1401.	9.94E+11
-172.9715	6811.	0.00				
14.0000	0.1025	3375874.	41034.	-9.77E-04	1473.	9.97E+11
-206.7062	8467.	0.00				
14.3500	0.09846	3546392.	40098.	-9.62E-04	1544.	9.99E+11
-239.0617	10198.	0.00				
14.7000	0.09445	3712694.	39029.	-9.47E-04	1612.	1.00E+12
-269.9045	12002.	0.00				
15.0500	0.09050	3874234.	37834.	-9.31E-04	1678.	1.00E+12
-299.1122	13881.	0.00				
15.4000	0.08663	4030498.	36520.	-9.15E-04	1742.	1.01E+12
-326.5738	15834.	0.00				
15.7500	0.08282	4181001.	35095.	-8.98E-04	1802.	1.01E+12
-352.1901	17860.	0.00				
16.1000	0.07909	4325292.	33566.	-8.80E-04	1860.	1.01E+12
-375.8735	19961.	0.00				
16.4500	0.07543	4462952.	31941.	-8.62E-04	1914.	1.01E+12
-397.5483	22136.	0.00				
16.8000	0.07185	4593600.	30231.	-8.43E-04	1965.	1.02E+12
-417.1510	24386.	0.00				
17.1500	0.06835	4716889.	28442.	-8.24E-04	2013.	1.02E+12
-434.6300	26709.	0.00				
17.5000	0.06493	4832511.	26584.	-8.04E-04	2057.	1.02E+12
-449.9458	29106.	0.00				
17.8500	0.06159	4940196.	24667.	-7.84E-04	2098.	1.02E+12
-463.0706	31577.	0.00				
18.2000	0.05834	5039713.	22699.	-7.64E-04	2135.	1.03E+12
-473.9887	34123.	0.00				
18.5500	0.05518	5130868.	20690.	-7.43E-04	2168.	1.03E+12
-482.6958	36742.	0.00				
18.9000	0.05210	5213508.	18649.	-7.22E-04	2198.	1.03E+12
-489.1992	39436.	0.00				
19.2500	0.04911	5287520.	16585.	-7.00E-04	2224.	1.03E+12
-493.5174	42204.	0.00				
19.6000	0.04622	5352825.	14508.	-6.79E-04	2246.	1.04E+12
-495.6796	45046.	0.00				
19.9500	0.04341	5409387.	12426.	-6.57E-04	2264.	1.04E+12
-495.7258	47961.	0.00				
20.3000	0.04070	5457204.	10348.	-6.35E-04	2278.	1.04E+12
-493.7062	50951.	0.00				
20.6500	0.03808	5496312.	8283.	-6.13E-04	2289.	1.04E+12
-489.6806	54015.	0.00				
21.0000	0.03555	5526782.	6239.	-5.91E-04	2296.	1.05E+12
-483.7186	57154.	0.00				
21.3500	0.03311	5548719.	4224.	-5.69E-04	2300.	1.05E+12
-475.8984	60366.	0.00				
21.7000	0.03077	5562262.	2245.	-5.47E-04	2300.	1.05E+12
-466.3070	63652.	0.00				
22.0500	0.02852	5567579.	310.3270	-5.24E-04	2296.	1.05E+12
-455.0393	67013.	0.00				

22.4000	0.02636	5564868.	-1574.	-5.02E-04	2290.	1.06E+12	-442.1978	70447.	0.00
22.7500	0.02430	5554358.	-3401.	-4.80E-04	2280.	1.06E+12	-427.8921	73956.	0.00
23.1000	0.02233	5536300.	-5165.	-4.58E-04	2267.	1.06E+12	-412.2384	77538.	0.00
23.4500	0.02045	5510969.	-6861.	-4.36E-04	2251.	1.07E+12	-395.3586	81195.	0.00
23.8000	0.01866	5478665.	-8484.	-4.15E-04	2232.	1.07E+12	-377.3805	84926.	0.00
24.1500	0.01697	5439703.	-10029.	-3.93E-04	2211.	1.07E+12	-358.4368	88731.	0.00
24.5000	0.01536	5394419.	-11493.	-3.72E-04	2187.	1.07E+12	-338.6647	92610.	0.00
24.8500	0.01384	5343161.	-12873.	-3.51E-04	2161.	1.08E+12	-318.2055	96563.	0.00
25.2000	0.01241	5286289.	-14165.	-3.30E-04	2133.	1.08E+12	-297.2039	100590.	0.00
25.5500	0.01106	5224175.	-15368.	-3.10E-04	2103.	1.08E+12	-275.8079	104692.	0.00
25.9000	0.00981	5157196.	-16481.	-2.90E-04	2071.	1.08E+12	-254.1680	108867.	0.00
26.2500	0.00863	5085733.	-17503.	-2.70E-04	2037.	1.09E+12	-232.4370	113117.	0.00
26.6000	0.00754	5010170.	-18434.	-2.50E-04	2002.	1.09E+12	-210.7694	117440.	0.00
26.9500	0.00653	4930888.	-19274.	-2.31E-04	1966.	1.09E+12	-189.3212	121838.	0.00
27.3000	0.00559	4848268.	-20025.	-2.13E-04	1928.	1.09E+12	-168.2496	126309.	0.00
27.6500	0.00474	4762679.	-20688.	-1.94E-04	1890.	1.10E+12	-147.7124	130855.	0.00
28.0000	0.00396	4674485.	-21267.	-1.76E-04	1850.	1.10E+12	-127.8676	135475.	0.00
28.3500	0.00326	4584035.	-21764.	-1.58E-04	1810.	1.10E+12	-108.8738	140169.	0.00
28.7000	0.00263	4491665.	-22184.	-1.41E-04	1769.	1.10E+12	-90.8890	144937.	0.00
29.0500	0.00208	4397691.	-22530.	-1.24E-04	1728.	1.11E+12	-74.0712	149779.	0.00
29.4000	0.00159	4302411.	-22809.	-1.08E-04	1686.	1.11E+12	-58.5773	154696.	0.00
29.7500	0.00117	4206097.	-23025.	-9.16E-05	1645.	1.11E+12	-44.5639	159686.	0.00
30.1000	8.21E-04	4108997.	-41269.	-7.60E-05	1603.	1.12E+12	-8643.	4.42E+07	0.00
30.4500	5.34E-04	3859438.	-73323.	-6.10E-05	1502.	1.12E+12	-6621.	5.21E+07	0.00
30.8000	3.08E-04	3493085.	-96463.	-4.72E-05	1356.	1.12E+12	-4398.	5.99E+07	0.00

31.1500	1.38E-04	3049150.	-110361.	-3.49E-05	1181.	1.12E+12	-2220.	6.78E+07	0.00
31.5000	1.48E-05	2566054.	-115583.	-2.44E-05	991.4743	1.13E+12	-266.7740	7.56E+07	0.00
31.8500	-6.78E-05	2078252.	-113317.	-1.58E-05	801.0749	1.13E+12	1346.	8.34E+07	0.00
32.2000	-1.18E-04	1614195.	-105111.	-8.93E-06	620.7129	1.13E+12	2561.	9.13E+07	0.00
32.5500	-1.43E-04	1195319.	-92657.	-3.72E-06	458.5419	1.13E+12	3369.	9.91E+07	0.00
32.9000	-1.49E-04	835879.	-77607.	3.78E-08	319.8894	1.14E+12	3797.	1.07E+08	0.00
33.2500	-1.42E-04	543419.	-61456.	2.58E-06	207.4689	1.14E+12	3894.	1.15E+08	0.00
33.6000	-1.27E-04	319644.	-45468.	4.17E-06	121.7440	1.14E+12	3720.	1.23E+08	0.00
33.9500	-1.07E-04	161490.	-30649.	5.06E-06	61.3604	1.14E+12	3337.	1.30E+08	0.00
34.3000	-8.49E-05	62192.	-17769.	5.47E-06	23.5745	1.15E+12	2797.	1.38E+08	0.00
34.6500	-6.15E-05	12226.	-7404.	5.60E-06	4.6235	1.15E+12	2139.	1.46E+08	0.00
35.0000	-3.79E-05	0.00	0.00	5.63E-06	0.00	1.15E+12	1388.	7.70E+07	0.00

* The above values of total stress are combined axial and bending stresses.

Output Summary for Load Case No. 2:

```
Pile-head deflection             =     0.28846716 inches
Computed slope at pile head      =    -0.00114389 radians
Maximum bending moment           =       5567579. inch-lbs
Maximum shear force              =       -115583. lbs
Depth of maximum bending moment  =    22.05000000 feet below pile head
Depth of maximum shear force     =    31.50000000 feet below pile head
Number of iterations             =              6
Number of zero deflection points =              1
```

Summary of Pile-head Responses for Conventional Analyses

Definitions of Pile-head Loading Conditions:

Load Type 1: Load 1 = Shear, V, lbs, and Load 2 = Moment, M, in-lbs
Load Type 2: Load 1 = Shear, V, lbs, and Load 2 = Slope, S, radians
Load Type 3: Load 1 = Shear, V, lbs, and Load 2 = Rot. Stiffness, R, in-lbs/rad.
Load Type 4: Load 1 = Top Deflection, y, inches, and Load 2 = Moment, M, in-lbs

Load Type 5: Load 1 = Top Deflection, y, inches, and Load 2 = Slope, S, radians

Load Case No.	Load Type 1	Pile-head Load 1	Load Type 2	Pile-head Load 2	Axial Loading lbs	Pile-head Deflection inches	Pile-head Rotation radians	Max Shear in Pile lbs	Max Moment in Pile in-lbs
1	V, lb	0.00	M, in-lb	0.00	0.00	0.1831	-7.25E-04	-73437.	3533998.
2	V, lb	0.00	M, in-lb	0.00	0.00	0.2885	-0.00114	-115583.	5567579.

Maximum pile-head deflection = 0.2884671628 inches
Maximum pile-head rotation = -0.0011438878 radians = -0.065540 deg.

Summary of Warning Messages

The following warning was reported 306 times

**** Warning ****

An unreasonable value was input for friction angle has been specified for a soil layer defined using the sand criteria. The input value is either smaller than 20 degrees or higher than 48 degrees. The input data should be checked for correctness.

The following warning was reported 90 times

**** Warning ****

An unreasonable input value for unconfined compressive strength has been specified for a soil defined using the weak rock criteria. The input value is greater than 500 psi. Please check your input data for correctness.

The analysis ended normally.

APPENDIX I

Subgrade Analysis Output

OHIO DEPARTMENT OF TRANSPORTATION

OFFICE OF GEOTECHNICAL ENGINEERING

PLAN SUBGRADES
Geotechnical Design Manual Section 600

Instructions: Enter data in the shaded cells only.
(Enter state route number, project description,county, consultant's name, prepared by name, and date prepared. This information will be transferred to all other sheets. The date prepared must be entered in the appropriate cell on this sheet to remove these instructions prior to printing.)

River Street Soil Stabilization
SR 164 - Willoughby Ohio

CT Consultants, Inc.

Prepared By: Imad El Hajjar, EI
Date prepared: Thursday, November 16, 2023

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216-217-5449
ihajjar@ctconsultants.com

NO. OF BORINGS: 2

#	Boring ID	Alignment	Station	Offset	Dir	Drill Rig	ER	Boring EL.	Proposed Subgrade EL	Cut Fill
1	B-1	River Road SR 174	-	-	-	Mobile B-57	83	696.0	694.5	1.5 C
2	B-2	River Road SR 174	-	-	-	CME 75 Truck Mounted	83	695.0	692.9	2.1 C

#	Boring	Sample	Sample Depth		Subgrade Depth		Standard Penetration		HP (tsf)	Physical Characteristics						Moisture		Ohio DOT		Sulfate Content (ppm)	Problem		Excavate and Replace (Item 204)		Recommendation (Enter depth in inches)
			From	To	From	To	N_{60}	N_{60L}		LL	PL	PI	% Silt	% Clay	P200	M_C	M_{OPT}	Class	GI		Unsuitable	Unstable	Unsuitable	Unstable	
1	B	SS-1	1.5	3.5	0.0	2.0	7		NP	14	11	3	28	0	28	6	10	A-2-4	0			N_{60}		16"	**16"**
	1	SS-2	3.5	5.5	2.0	4.0	8		1.5	20	12	8	6	45	51	5	10	A-4a	3						**204 Geotextile**
		SS-3	5.5	7.5	4.0	6.0	17		NP	21	12	9	11	17	28	6	10	A-4a	0						
								7																	
2	B	SS-1	1.5	3.5	-0.6	1.4	4		1.17	27	13	14	26	46	72	4	10	A-4a	8			HP		24"	**24"**
	2	SS-2	3.5	5.5	1.4	3.4	8		3.05	23	16	7	41	45	86	4	11	A-4a	8			N_{60}			**204 Geotextile**
		SS-3	5.5	7.5	3.4	5.4	33		NP	19	16	3	35	39	74	3	11	A-4a	8						
								4																	

OHIO DEPARTMENT OF TRANSPORTATION

Subgrade Analysis

V. 14.6 2/11/2022

PID: SR 164 - Wil

County-Route-Section: River Street Soil Stabilization
No. of Borings: 2

Geotechnical Consultant: CT Consultants, Inc.
Prepared By: Imad El Hajjar, EI
Date prepared: 11/16/2023

Chemical Stabilization Options		
320	Rubblize & Roll	No
206	Cement Stabilization	Option
	Lime Stabilization	No
206	Depth	14''

Excavate and Replace Stabilization Options	
Global Geotextile Average(N60L): Average(HP):	 21'' 12''
Global Geogrid Average(N60L): Average(HP):	 15'' 0''

Design CBR	8

% Samples within 6 feet of subgrade			
$N_{60} \leq 5$	17%	HP ≤ 0.5	0%
$N_{60} < 12$	67%	0.5 < HP ≤ 1	0%
$12 \leq N_{60} < 15$	0%	1 < HP ≤ 2	33%
$N_{60} \geq 20$	17%	HP > 2	17%
M+	0%		
Rock	0%		
Unsuitable	0%		

Excavate and Replace at Surface	
Average	20''
Maximum	24''
Minimum	16''

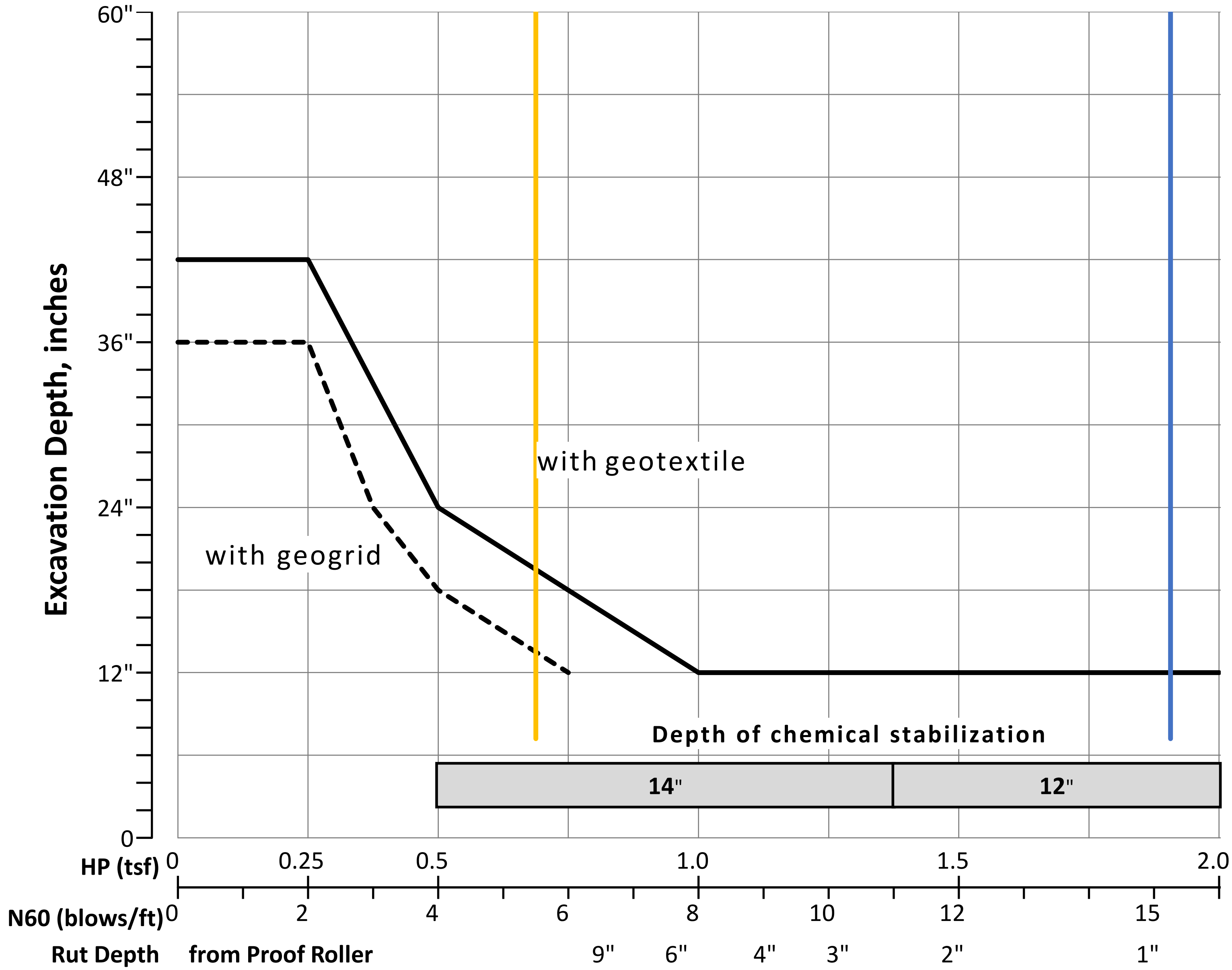
% Proposed Subgrade Surface	
Unstable & Unsuitable	75%
Unstable	75%
Unsuitable	0%

	N_{60}	N_{60L}	HP	LL	PL	PI	Silt	Clay	P 200	M_C	M_{OPT}	GI
Average	13	6	1.91	21	13	7	25	32	57	5	10	5
Maximum	33	7	3.05	27	16	14	41	46	86	6	11	8
Minimum	4	4	1.17	14	11	3	6	0	28	3	10	0

Classification Counts by Sample

ODOT Class	Rock	A-1-a	A-1-b	A-2-4	A-2-5	A-2-6	A-2-7	A-3	A-3a	A-4a	A-4b	A-5	A-6a	A-6b	A-7-5	A-7-6	A-8a	A-8b	Totals
Count	0	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	6
Percent	0%	0%	0%	17%	0%	0%	0%	0%	0%	83%	0%	0%	0%	0%	0%	0%	0%	0%	100%
% Rock|Granular|Cohesive	0%	100%								0%									100%
Surface Class Count	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	4
Surface Class Percent	0%	0%	0%	25%	0%	0%	0%	0%	0%	75%	0%	0%	0%	0%	0%	0%	0%	0%	100%

Fig. 600-1 – Subgrade Stabilization



OVERRIDE TABLE

Calculated Average	New Values	Check to Override
1.91		☐ HP
5.54		☐ N60L

Average HP

Average N_{60L}