FINAL REPORT
STRUCTURE FOUNDATION EXPLORATION
BRIDGE RAMP O OVER IR-71
BRIDGE NO. FRA-00071-28.294
FRA-71/270-28.27/25.99A
FRANKLIN COUNTY, OHIO
PID#: 105435

Prepared For:

TranSystems
1100 Superior Ave East, Suite 1000
Cleveland, OH 44144

Prepared by:

NATIONAL ENGINEERING AND ARCHITECTURAL SERVICES INC.
2800 Corporate Exchange Drive, Suite 240
Columbus, Ohio 43231

NEAS PROJECT 21-0012

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National Engineering & Architectural Services Inc.

EXECUTIVE SUMMARY

The Ohio Department of Transportation (ODOT) has proposed an interchange improvement project (FRA-71/270-28.27/25.99, PID# 105435) for the Interstate Route (IR) 270 and IR-71 on the north side of Columbus, Franklin County, Ohio. It is our understanding that the overall project objective is to improve capacity to the IR-270 and IR-71 interchange. The interchange and mainline improvements purposed to accomplish this objective include: 1) widening of the IR-71 freeway segment within the project limits; 2) the construction/reconstruction of 4 connecting ramps (Ramp K, O, P, M); 3) the replacement of the existing bridge structure FRA-00071-28.265 carrying Ramp K (IR-270 WB to IR-71 SB) over IR-71; 4) the replacement of the existing bridge structure FRA-00071-28.294 carrying Ramp O (IR-71 NB to IR-270 WB) over IR-71; and, 5) the superstructure replacement of the existing bridge structure FRA-00270-25.990A carrying Ramp K (IR-270 WB to IR-71 SB) over Ramp O.

National Engineering and Architectural Services Inc. (NEAS) has been contracted to perform geotechnical engineering services for the project. The purpose of the geotechnical engineering services is to perform geotechnical explorations within the project limits to obtain information concerning the subsurface soil and groundwater conditions relevant to the design and construction of the project. NEAS performed the site reconnaissance for the project between May 3, 2022, and May 7, 2022. The subsequent document presents the results of the structure foundation exploration with respect to the planned replacement of the existing bridge FRA-00071-28.294 carrying Ramp O over IR-71. As part of the referenced explorations, NEAS advanced 1 project boring and conducted laboratory testing to characterize the soils for engineering purposes.

The subsurface profile at the referenced site is generally consistent with the geological model for the project in regard to the materials encountered. The subsurface profile at proposed bridge site generally consists of surficial materials (i.e., pavement) underlain by existing embankment or historical fill soils followed by natural glacial till soils. Where encountered, the embankment fill at the site can generally be described as very stiff to hard cohesive soils. The natural glacial soils can be described as predominantly stiff to hard cohesive materials interbedded with several thin layers medium dense to very dense granular materials. Boulder was possibly encountered in boring B-010-0-64 at the elevations of 890.8 ft and 848.3 ft amsl and in boring B-001-1-64 at the elevation of 898.5 ft amsl. Bedrock was not encountered within depths of the project boring or two historic borings performed at the bridge site.

A deep foundation system analysis was performed at the referenced bridge replacement site based on developed soil profiles at the boring locations. For the analyses, 12-inch and 16-inch closed-ended cast-in-place (CIP) friction pipe piles were considered at abutments and center pier, respectively. Based on the loading information provided by TranSystems via email on January 2, 2024, to obtain the required UBV (pile resistance) at each substructure location, estimated pile lengths are anticipated to range from 70 to 90 ft with pile tip elevations ranging from 838.1 ft and 842.2 ft amsl, depending on the location and pile size. Based on our analysis, it is recommended that the proposed piles at all substructures be driven to the full estimated length and pile/soil setup be utilized to achieve the required UBV, and the estimated waiting time is about 14 days. Based on the pile drivability results, 12-inch CIP piles with a wall thickness of 0.25 inches at the abutments and 16-inch CIP piles with a wall thickness of 0.25 inches at the center pier would not be overstressed for ASTM A 252 Grade 3 steel during the pile installation process.

Global stability, external stability (i.e., bearing resistance, sliding resistance, and eccentricity), and settlement analyses were performed for the proposed mechanically stabilized earth (MSE) wall supported abutments. For these analyses, bottom-up construction of a MSE wall type was assumed. Based on the analyses performed for the proposed abutments, it is recommended that the soil reinforcement length is 100 percent of the total design height for the rear and forward abutment MSE walls. Utilizing the 100% soil reinforcement strap lengths, factored bearing resistances ranging from 5.7 to 8.3 kips per square foot (ksf) were calculated with respect to the provided sections. Based on the referenced bearing resistances, the maximum differential settlement across the length of the wall estimated to be less than 1% in the longitudinal direction. Capacity to demand ratios (CDR) for bearing resistance, sliding, and eccentricity were calculated at the Strength Limit State. Based on the calculated CDR values, it was determined that the proposed MSE wall abutments will provide adequate resistance to bearing, sliding and overturning assuming it is constructed in accordance with the recommendations provided within this report, as well as all applicable standards and specifications (i.e. ODOT, manufacturer, etc.) for MSE wall construction.

Based on our analysis the ground surface at the rear abutment is estimated to experience about 8.8 inches of immediate settlement and 4.1 inches of long-term (consolidation) settlement from the induced loads associated with the 24.0-ft high embankment. Since the new MSE wall embankment will induce a ground settlement greater than 0.4 inches after pile installation, therefore, it is our opinion that the piles at the abutment will be subjected to downdrag loads. The immediate settlement is expected to take place during construction prior to bridge loading and is not anticipated to be a concern. It is estimated that time required for 90% consolidation for each evaluated soil layers is on the order of 32 to 114 days. Ninety percent (90%) of the long-term settlement for all evaluated soil layers will take place about 40 days following the embankment construction.

A seismic site class was also determined at the overall bridge site, in which a Seismic Site Class of D is recommended.

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1. INTRODUCTION

1.1. General

National Engineering and Architectural Services Inc. (NEAS) presents our Structure Foundation Exploration Report for the planned replacement of bridge carrying Ramp O over IR 71 (SFN: 2511224), as part of the FRA-071/270-28.27/25.99A (PID# 105435) project. As part of the Safety and System Preservation project, it is our understanding that the overall project objective is to improve capacity to IR-270 Eastbound (EB) to IR-70 Northbound (NB) movement. The report presents a summary of the encountered surficial and subsurface conditions and our recommendations for bridge foundation design and construction in accordance with Load and Resistance Factor Design (LRFD) method as set forth in AASHTO's Publication Bridge Design Specifications, 9th Edition (BDS) (AASHTO, 2020), ODOT's 2020 Bridge Design Manual (BDM) (ODOT, 2023) and 2023 Geotechnical Design Manual (GDM) (ODOT, 2023).

The exploration was conducted in general accordance with NEAS, Inc.'s proposal to TranSystems, dated February 25, 2022, and with the provisions of ODOT's *Specifications for Geotechnical Explorations* (SGE) (ODOT, 2022).

The scope of work performed included: 1) a review of published geotechnical information; 2) performing 16 total test borings (1 utilized within this report as part of the referenced structure foundation exploration); 3) laboratory testing of soil samples in accordance with the SGE; 4) performing geotechnical engineering analysis to assess foundation design and construction considerations; and, 5) development of this summary report.

1.2. Proposed Construction

The existing FRA-00071-28.294 bridge carrying Ramp O over IR-71 is a four-span continuous steel rolled beam bridge with one lane of traffic on a concrete deck with an asphalt wearing course. The bridge sits atop stub-type concrete abutments and cap and column piers. The bridge is approximately 264 ft in length (abutment to abutment) with an approximate roadway width of 30 ft (safety curb to safety curb).

It is our understanding that ODOT plans to realign Ramp O and replace the existing bridge (FRA-00071-28.294). The replacement is proposed to consist of two-span continuous curved steel plate girders with composite reinforced concrete deck supported on reinforced concrete cap and column piers and semi-integral abutments founded on piles and MSE wall embankments. The proposed bridge is approximately 181.51 ft in length (abutment to abutment) with an approximate roadway width of 34 ft (toe to toe railing).

2. GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1. Geology and Physiography

The project site is located within the Columbus Lowland Till Plains, a subdivision of the Southern Ohio Loamy Till Plain. This is a moderately low relief (25 ft) lowland surrounded in all directions by relative uplands, having a broad regional slope toward the Scioto Valley, containing many larger streams. Elevations of the region range from 600 to 850 ft above mean sea level (amsl) (950 ft amsl near Powell Moraine). The geology within this region is described as Wisconsinan-age till that is high lime in the west to medium-lime in the east. The geology is also described as containing extensive outwash in Scioto Valley overlying deep Devonian- to Mississippian-age carbonate rocks, shales, and siltstones (ODGS, 1998).

Based on the Quaternary geology map of Ohio, the geology at the project site is mapped as late Wisconsinan-age silty loam till ground moraine that is flat to gently undulating, which is underlain by Devonian-age shale, and mudstone bedrock (Pavey, et al 1999).

Based on the Bedrock Geologic Units Map of Ohio (USGS & ODGS, 2006), bedrock within the project area consists of shale, and mudstone of the Ohio Shale formation. The Ohio Shale formation is comprised of Devonian-age shale, and mudstone. The shale in this formation is described as brownish black to greenish gray and weathers brown in color, carbonaceous to clayey, laminated to thin bedded, fissile partings, and a petroliferous odor. Bedrock is anticipated to generally rise from east to west throughout the project (ODGS, 2003). Based on the ODNR bedrock topography map of Ohio, bedrock elevations at the project site can be expected to be around the elevation of 850 to 800 ft amsl, putting bedrock at depths ranging from about 62 to 112 ft below ground surface (bgs).

The soils at the project site have been mapped (Web Soil Survey) by the Natural Resources Conservation Service (USDA, 2015) as primarily Udorthents-urban land complex throughout the project site. Udorthents are described as material that has been disturbed by cutting and filling operations and as such is not graded. Soils in the portion of the site north of Boswell Dr. and the central portion of exit 26 are mapped as Bennington silt loam. Soils in the Bennington series are characterized as very deep, somewhat poorly drained, soils formed in loamy till of medium lime content. These soils are on ground moraines and end moraines. The Bennington series is comprised of primarily fine-grained soils and classifies as A-4, A-6, and A-7 type soils according to the AASHTO method of soil classification. Soils in the portion of the site south of ramp 26 up to the western end of the bridge carrying exit 26 over IR-71 are mapped as Pewamo silty clay loam. Soils in the Pewamo series are characterized as very deep, very poorly drained, soils formed in till on moraines, near-shore zones (relict), and lake plains. These soils are on ground moraines and end moraines. The Bennington series is comprised of primarily fine-grained soils and classifies as A-6 and A-7 type soils according to the AASHTO method of soil classification.

2.2. Hydrology/Hydrogeology

Groundwater at the project site can be expected at an elevation consistent with that of the nearby tributary to Alum Creek. The water level of the tributary to Alum Creek may be generally representative of the local groundwater table. However, it should be noted that perched groundwater systems may be existent in areas due to the presence of fine-grained soils making it difficult for groundwater to permeate to the phreatic surface.

The project site is not located within a regulatory floodway zone based on available mapping by the Federal Emergency Management Agency's (FEMA) National Flood Hazard mapping program (FEMA, 2019).

2.3. Mining and Oil/Gas Production

No abandoned mines are noted on ODNR’s Abandoned Underground Mine Locator in the vicinity of the project site (ODNR [1], 2020).

No abandoned oil or gas wells are noted on ODNR’s Oil and Gas Well Locator in the vicinity of the project site (ODNR [1], 2020).

2.4. Historical Records and Previous Phases of Project Exploration

A historic record search was performed through ODOT's Transportation Information Management System (TIMS). The following report/plans were available for review and evaluation for this report:

- Soil Profile Sheets as part of ODOT project FRA-IR270-16.65N IR-71 Interchange, prepared by DE Leuw, Cather & Brill Consulting Engineers., dated April 13, 1964.

Two historical soil borings (B-001-1-64, and B-010-0-64) that were drilled as part of the 1964 Structure Exploration for ODOT project FRA-IR270-16.65N IR-71 Interchange were reviewed and are utilized in our report and analysis. A summary of the historic boring information (location, elevation, etc.) is provided in Table 1, and their locations are depicted on the Boring Location Plan provided in Appendix A. The historic boring logs of the borings utilized within this report are provided in Appendix B. It should be noted that the elevations in NAVD 88 are typically 0.6 feet to 1.8 feet lower than they are in NGVD 29; herein the elevations in NAVD 88 are 0.55 feet lower than they are in NGVD 29.

Table 1: Historic Boring Summary

Boring Number	Alignment	Historical Location (Sta/offset)	Latitude	Longitude	Elevation (NGVD 29) (ft)	Elevation (NAVD 88) (ft)	Existing Substructure	Depth (ft)
B-001-1-64	Ramp O	18+42, 5' LT	40.112415	-82.976870	906.5	905.9	Forward Abutment	51.0
B-010-0-64	Ramp O	15+67, 32' RT	40.112184	-82.975935	903.8	903.2	Rear Abutment	58.0

2.5. Field Reconnaissance

A field reconnaissance visit for 3 bridges (SFN: 2511372, 2511223, and 2511460) was conducted on May 3, 2022, at the interchange between IR-71 and IR-270 in Franklin County, Ohio. During our field reconnaissance, site conditions were noted and photographed. Land use at the project site can be described as a combination of woodland, residential and ODOT ROW (Right of Way).

The existing bridge carrying Ramp O over IR-71 (SFN: 2511223) is a four-span, steel multi-beam bridge with one lane of traffic on a concrete deck with an asphalt wearing course (Photograph 1). The bridge sits atop stub-type concrete abutments and cap and column piers. The roadway embankment slopes at the site generally appeared to be stable with no signs of instability observed during our site visit. The existing roadway embankments appeared to be at about a 2 Horizontal to 1 Vertical (2H:1V) slope and were heavily vegetated. Overall, the bridge appeared to be in fair condition with wear and degradation observed on the bridge superstructure and substructure. Heavy spalling, and exposed rebar was observed at the bridge deck ends and traffic barriers (Photographs 2 & 3). Netting was observed to be placed around the ends of the bridge deck to catch spalling concrete. Both abutments were observed to have cracking, and spalling. The joints above the abutments were also observed to have failed, with water staining the abutments (Photograph 4). The spill-through slopes were observed to be covered with rip-rap and some signs of erosion at the edges of the rip-rap was observed. The piers were observed to be in relatively good condition with minor surface cracking and pop-outs observed. The underside of the bridge deck was observed to be in good condition with the only signs of distress being cracking, spalling and exposed rebar near the edges of the bridge deck. No apparent signs of structural distress of the bridge due to geotechnical concerns were observed during our field reconnaissance visit.

In general, the existing bridge structure appeared to be well drained (except the bridge deck) with some signs of erosion at the bridge spill-through slopes. The asphalt wearing course was observed to be in poor condition with signs of surface wear. The areas near the edges of the bridge deck were noted as being especially distressed. Map cracking, and edge cracking was common in the asphalt wearing course as well as potholing and crack sealing deficiencies (Photograph 3). The adjacent ramp pavement was observed to be in better condition with only some edge cracking and crack sealing deficiencies observed. Water was directed to scuppers on the southern side of the bridge deck. Many of these scuppers were observed to be clogged, and water appeared to run through holes in the curb and traffic barrier. No signs of standing water were observed.

Photograph 1: Asphalt Wearing Surface of Bridge

Photograph 2: Spalling and Exposed Rebar at Bridge Deck Ends

Photograph 3: Heavy Spalling and Exposed Rebar at the Traffic Barrier and Curb

Photograph 4: Spill-Through Slope at Rear Abutment

3. GEOTECHNICAL EXPLORATION

3.1. Field Exploration Program

The bridge subsurface exploration was conducted by NEAS between August 3, 2022 and August 4, 2022 and included 1 borings drilled to a depth of 120 ft below ground surface (bgs). The boring location was selected by NEAS in general accordance with the guidelines contained in the SGE with the intent to evaluate subsurface soil and groundwater conditions. Boring was typically located within the planned project construction areas that were not restricted by underground utilities or dictated by terrain (e.g. steep embankment slopes). Project boring location was located in the field prior to drilling by NEAS personnel. Each individual project boring log (included within Appendix B) includes the recorded boring latitude and longitude location (based on the surveyed Ohio State Plane South, NAD83, location) and the corresponding ground surface elevation. The boring locations are depicted on the Boring Location Plan provided in Appendix A. Latitude/Longitude, elevations and stationing and offsets (pending) of the borings are shown on Table 2 below.

Table 2: Project Boring Summary

Boring Number	Alignment	Location (Sta/offset)	Latitude	Longitude	Elevation (NAVD 88) (ft)	Depth (ft)	Substructure
B-038-0-21	IR-71	139+20, 11' RT	40.112234	-82.976395	912.8	120.0	Center Pier

Project borings were drilled using a CME 75T truck-mounted drilling rig utilizing 3.25-inch (inner diameter) hollow stem auger. In general, soil samples were recovered at 2.5-ft interval to a depth of 30 ft bgs, and at 5.0-ft intervals thereafter using an 18-inch split spoon sampler (AASHTO T-206 "Standard Method for Penetration Test and Split Barrel Sampling of Soils."). The soil samples obtained from the exploration program were visually observed in the field by the NEAS field representative and preserved for review by a Geologist for possible laboratory testing. Standard penetration tests (SPT) were conducted using a CME auto hammer calibrated to be 79% efficient on January 24, 2022, as indicated on the boring logs.

Field /boring logs were prepared by drilling personnel, and included lithological description, SPT results recorded as blows per 6-inch increment of penetration and estimated unconfined shear strength values on specimens exhibiting cohesion (using a hand-penetrometer). Groundwater level observations were recorded both during and after the completion of drilling. These groundwater level observations are included on the individual boring logs. After completing the borings, the boreholes were backfilled with either auger cuttings, bentonite chips, or a combination of these materials, and patched with cold patch asphalt and/or quickset concrete where necessary and appropriate.

3.2. Laboratory Testing Program

The laboratory testing program consisted of classification testing and moisture content determinations. Data from the laboratory testing program was incorporated onto the boring logs (Appendix B). Soil samples are retained at the laboratory through completion and ODOT approval of Stage 2 plans, after which time they will be discarded.

3.2.1. Classification Testing

Representative soil samples were selected for index properties (Atterberg Limits) and gradation testing for classification purposes on approximately 21% of the samples. At each boring location, samples were selected for testing with the intent of identification and classification of all significant soil units. Soils not selected for testing were compared to laboratory tested samples/strata and classified visually. Moisture content testing was conducted on all samples. The laboratory testing was performed in general accordance with applicable AASHTO specifications.

A final classification of the soil strata was made in accordance with AASHTO M-145 "Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," as modified by ODOT "Classification of Soils" once laboratory test results became available. The results of the soil classification are presented on the boring logs provided in Appendix B.

3.2.2. Standard Penetration Test Results

Standard Penetration Tests (SPT) and split-barrel (commonly known as split-spoon) sampling of soils were performed at varying intervals (i.e., continuous, 2.5-ft, or 5.0-ft intervals) in the project borings performed. To account for the high efficiency (automatic) hammers used during SPT sampling, field SPT N-values were converted based on the calibrated efficiency (energy ratio) of the specific drill rig's hammer. Field N-values were converted to an equivalent rod energy of 60% (N_{60}) for use in analysis or for correlation purposes. The resulting N_{60} values are shown on the boring logs provided in Appendix B.

3.2.3. Consolidation Testing

One (1) consolidation test was performed in accordance with ASTM D 2435-04 “Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading” on relatively undisturbed cohesive soil sample collected from boring B-038-0-21; the results of the consolidation test are presented in Table 3 below, while the laboratory testing report is included with the associated boring log within Appendix B.

Table 3: Cosolidation Test Results

Boring Number	Depth (ft)	Elevation (ft)	Compression Index (Cc)	Recompression Index (Cr)	Preconsolidation Pressure (psf)	Void Rotio
B-038-0-21	15.5 - 15.6	897.3 - 897.2	0.085	0.010	4500	0.447

4. GEOTECHNICAL FINDINGS

The subsurface conditions encountered during NEAS’s explorations are described in the following subsections and/or on each boring log presented in Appendix B. The boring logs represent NEAS’s interpretation of the subsurface conditions encountered at each boring location based on our site observations, field logs, visual review of the soil samples by NEAS's geologist, and laboratory test results. The lines designating the interfaces between various soil strata on the boring logs represent the approximate interface location; the actual transition between strata may be gradual and indistinct. The subsurface soil and groundwater characterizations included herein, including summary test data, are based on the subsurface findings from the geotechnical explorations performed by NEAS as part of the referenced project, and consideration of the geological history of the site.

4.1. Subsurface Conditions

The subsurface profile at the referenced site is generally consistent with the geological model for the project in regard to the materials encountered. The subsurface profile at proposed bridge site generally consists of surficial materials (i.e., pavement) underlain by existing embankment or historical fill soils followed by natural glacial till soils. Where encountered, the embankment fill at the site can generally be described as very stiff to hard cohesive soils. The natural glacial soils can be described as predominantly stiff to hard cohesive materials interbedded with several thin layers medium dense to very dense granular materials. Boulder was possibly encountered in boring B-010-0-64 at the elevations of 890.8 ft and 848.3 ft amsl and in boring B-001-1-64 at the elevation of 898.5 ft amsl. Bedrock was not encountered within depths of the project boring or two historic borings performed at the bridge site.

4.1.1. Overburden Soil

At the proposed bridge site, three different materials were encountered immediately below the surficial pavement. In general, the three different overburden materials consisted of historical or embankment "man-made" fill soils and natural glacial till soils. These materials and the general profile underlying the site is further described below.

Fill soils were encountered in boring B-038-0-21 performed for the proposed structure. These fill soils were encountered immediately below the pavement section and extended to a depth approximate 9 ft bgs (approximate elevation 903 ft amsl). Based on laboratory testing results, a visual review of the soil samples obtained as well as the calculated Soil Behavior Index, the fill at the site is comprised of cohesive material and is classified on the boring logs as Sandy Silt (A-4a) and Silty Clay (A-6b). With respect to the soil strength of the fine-grained cohesive fill, these soils can be described as having a consistency of stiff to hard correlating to N_{60} values of 16 and 20 bpf and unconfined compressive strengths (estimated by means of hand penetrometer) between 4.0 and 4.5 tons per square foot (tsf). Natural moisture contents of the cohesive fill ranged from 12 percent to 20 percent. Based on a Atterberg Limits test performed on a representative sample of the cohesive fill material, the liquid and plastic limits ranged from 26 to 37 percent and from 16 to 21 percent, respectively.

The stratum encountered immediately beneath the fill consisted of natural cohesive glacial till. The natural cohesive glacial till soils in the borings extended to a depth of approximately 113.3 ft bgs (approximate elevation 799.5 ft amsl). The cohesive glacial till soils are classified on the boring logs as Sandy Silt (A-4a), Silt (A-4b), Silt and Clay (A-6a), Silty Clay (A-6b) and Clay (A-7-6). The cohesive soils can be described as having a stiff to hard consistency based on N_{60} values between 5 and 54 bpf and unconfined compressive strengths (estimated by means of hand penetrometer) between approximately 2.25 and in excess of 4.50 tons per square foot (tsf). Natural moisture contents of the cohesive soils ranged from 10 to 27 percent. The exception being various seams of non-cohesive material that were encountered within the borings performed and classified on the logs as Sandy Silt (A-4a), Silt (A-4b), and Gravel and Stone Fragments with Sand (A-1-b). These seams of cohesive soil were encountered at varying depths with thicknesses ranging from 2.0-ft to 7.5-ft. These non-cohesive soils are described as having a relative compactness of loose to dense correlating to N_{60} values between 5 and 43. The natural moisture content of the non-cohesive soils ranged from 11 to 24 percent.

Boulder was possibly encountered in boring B-010-0-64 at the elevations of 890.8 ft and 848.3 ft amsl and in boring B-001-1-64 at the elevation of 898.5 ft amsl.

The soils encountered directly underlying the natural cohesive soils at the site consisted of non-cohesive coarse soils in the project boring to a depth of approximately 120.0 ft bgs (approximate elevation 792.8 ft amsl). The non-cohesive coarse soils are classified on the boring log as Gravel and Stone Fragments (A-1-a) and Gravel and Stone Fragments with Sand, Silt, and Clay (A-2-6). These non-cohesive soils are described as having a relative compactness of very dense correlating to N_{60} values between 80 and 116. The natural moisture content of the non-cohesive soils ranged from 9 to 11 percent.

4.1.2. Groundwater

Groundwater measurements were taken during the drilling procedures and/or immediately following the completion of each borehole. Groundwater was not encountered in the project boring during drilling.

It should be noted that groundwater is affected by many hydrologic characteristics in the area and may vary from those measured at the time of the exploration.

4.1.3. Bedrock

Bedrock was not encountered within depths of the borings performed at the bridge site.

5. ANALYSES AND RECOMMENDATIONS

We understand that the existing approximately 264-ft long, four-span bridge structure carrying Ramp O over IR-71 in Franklin County, Ohio is proposed to be replaced with a new structure. Based on the information available at the time of this report, the existing structure will be replaced with new two-span bridge structure, designated as FRA-00071-28.294, atop cap and column pier and semi-integral abutments founded on piles and MSE wall embankments. It is anticipated that each of the proposed substructures will be supported by the natural subsurface material through the use of a deep foundation system consisting of driven "CIP" piles.

Based on the above information in addition to: 1) the soil characteristics gathered during the subsurface exploration (i.e., SPT results, laboratory test results, etc.); 2) the developed generalized soil profile and estimated engineering properties and other design assumptions presented in subsequent sections of this report; and, 3) the bridge site plan provided by TranSystems, Geotechnical design elements for the new bridge will include:

- Deep Foundation Design
  - Deep Foundation Analysis
  - Downdrag
  - Pile Drivability
- MSE Wall Design
  - External stability (bearing, sliding and eccentricity)
  - Settlement
  - Global Stability

The geotechnical engineering analyses were performed in accordance with ODOT's BDM (ODOT, 2023) and AASHTO's LRFD BDS (AASHTO, 2020). Design recommendations are provided in the following sections.

5.1. Soil Profile for Analysis

For analysis purposes, each boring log was reviewed, and a generalized material profile was developed for analysis. Utilizing the generalized soil profile, engineering properties for each soil strata were estimated based on their field (i.e., SPT N_{60} Values, hand penetrometer values, etc.) and laboratory (i.e., Atterberg Limits, grain size, etc.) test results using correlations provided in published engineering manuals, research reports and guidance documents. The developed soil profile and estimated engineering soil and rock properties (with cited correlation/reference material) used in our evaluation is summarized per boring within Tables 4 and 6 below.

Table 4: B-001-1-64 Soil Profile for Analysis

FRA-00071-28.294 Ramp O over IR-71: Soil Profile, B-001-1-64					
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**	**Setup Factor**
Silt Elevation (905.95 ft - 900.95 ft)	108	800	100	21	1.50
Sandy Silt Elevation (900.95 ft - 893.45 ft)	110	1,800	115	24	1.50
Gravel with Sand Elevation (893.45 ft - 890.95 ft)	118	-	-	33	1.00
Sandy Silt Elevation (890.95 ft - 870.95 ft)	118	3,700	200	26	1.50
Sandy Silt Elevation (870.95 ft - 860.95 ft)	125	5,400	250	27	1.50
Sandy Silt Elevation (860.95 ft - 855.95 ft)	130	8,000	250	28	1.50
Sandy Silt Elevation (855.95 ft - 855.45 ft)	125	5,750	250	28	1.50

otes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$ <52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2.*

Table 5: B-010-0-64 Soil Profile for Analysis

FRA-00071-28.294 Ramp O over IR-71: Soil Profile, B-010-0-64					
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**	**Setup Factor**
Silt Elevation (903.25 ft - 898.25 ft)	108	-	-	27	1.50
Sandy Silt Elevation (898.25 ft - 888.25 ft)	105	750	75	21	1.50
Sandy Silt Elevation (888.25 ft - 873.25 ft)	112	2,850	150	25	1.50
Sandy Silt Elevation (873.25 ft - 853.75 ft)	120	4,350	225	27	1.50
Silt and Clay Elevation (853.75 ft - 845.25 ft)	130	4,650	225	27	1.50

lues interpreted from Geotechnical Bulletin 7 Table 1.
lues calculated from Terzaghi and Peck (1967) if $N1_{60}$ <52, else Stroud and Butler (1975) was used.
lues interpreted from Geotechnical Bulletin 7 Table 2.

Table 6: B-038-0-21 Soil Profile for Analysis

FRA-00071-28.294 Ramp O over IR-71: Soil Profile, B-038-0-21					
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**	**Setup Factor**
Sandy Silt Elevation (912.8 ft - 908.3 ft)	112	2,400	150	25	1.50
Silty Clay Elevation (908.3 ft - 900.8 ft)	110	1,950	115	24	1.75
Clay Elevation (900.8 ft - 897.8 ft)	105	600	75	21	2.00
Sandy Silt Elevation (897.8 ft - 896.8 ft)	110	1,550	115	23	1.50
Gravel with Sand Elevation (896.8 ft - 894.8 ft)	115	-	-	32	1.00
Sandy Silt Elevation (894.8 ft - 888.3 ft)	110	2,000	115	24	1.50
Sandy Silt Elevation (888.3 ft - 879.8 ft)	118	3,700	200	26	1.50
Sandy Silt Elevation (879.8 ft - 824.8 ft)	112	2,350	150	24	1.50
Sandy Silt Elevation (824.8 ft - 799.5 ft)	120	5,200	225	27	1.50
Gravel Elevation (799.5 ft - 795.3 ft)	130	-	-	33	1.00
Gravel with Sand, Silt and Clay Elevation (795.3 ft - 792.8 ft)	130	-	-	35	1.20

lotes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2.*

5.2. Bridge Foundation Analysis and Recommendations

A foundation review was completed for a deep foundation system for the referenced bridge replacement based on the following design information: 1) the Site Plan for Bridge No. FRA-00071-28.294 conducted by TranSystems dated January 5, 2024; 2) historical plans; and 3) subsequent conversations with TranSystems. A deep pile foundation will be designed according to LRFD and ODOT BDM criteria. Utilizing the *GRLWeap* computer program, a static pile analysis (FHWA method) was performed to estimate required driven pile lengths needed to achieve the Ultimate Bearing Value (UBV) for a single pile. Input information for the *GRLWeap* program was based on the soil characteristics gathered during the geotechnical exploration (i.e., SPT results, laboratory test results, etc.) and our geotechnical experience. Tables 4 through 6 in Section 5.1. of this report present each soil strata and their engineering properties that were used in the analysis. Groundwater elevation used in the analysis was assumed to match that of each boring per substructure as encountered during our field investigation and as shown on each individual boring log (Appendix B).

5.2.1. Pile Foundation Analysis

Deep foundations will be used to support the substructures of the FRA-00071-28.294 bridge. Based on the site plan prepared by TranSystems, 12-in Cast-in-place (CIP) piles were proposed to support the abutments of the referenced bridge and 16-in CIP piles were proposed to support the center pier. The bottom footing is approximately at the elevation of 923.0 ft and 924.0 ft for the rear and forward abutment, respectively. The bottom of footing is at the elevation of 907.0 ft for the center pier. The vertical loads were provided by TranSystems through emails on January 2, 2024, with max factored load of 209.3 kips per pile at both abutment locations and with max factored load of 281.1 kips per pile at the center pier.

Based on the determined soil profile and our estimated engineering soil properties, a pile analysis was performed using the computer program *GRLWeap* to determine the estimated geotechnical pile length at each substructure (*GRLWeap* results included within Appendix C). For the purposes of this report and our analysis, the term 'geotechnical pile length' has been assumed to represent the length of pile from bottom of pile cap (assumed pier cap bearing elevations) to the depth at which the required Ultimate Bearing Value (UBV) is obtained. The EOID is determined due to the potential for soil disturbance caused during pile driving (development of high pore water pressure) near the pile perimeter. This disturbance could cause piles to potentially drive easily or “run” for extended depths and initial driving may not reach the indicated target UBV utilizing the estimated pile lengths. Therefore, it may be necessary to drive the CIP piles to the EOID and then let the piles “set-up” (reduction of pore water pressure in the soils adjacent to the pile) for an established time period based on the material at the substructure and the specific pile size.

The UBV and EOID values are determined in accordance with Section 305.3.2.4 of the ODOT BDM. The UBV is determined by dividing the total factored load for the highest loaded pile at each substructure by the appropriate driven pile resistance factor, while the EOID is determined by subtracting the amount of side resistance expected to gain from soil setup from the UBV value. The amount of side resistance expected to gain from soil setup is taken as the difference between the side resistance obtained in ultimate (post setup) conditions and the side resistance obtained during driving (dynamic) conditions at the determined geotechnical pile length. It is recommended that the piles for the referenced project be installed according to ODOT's Construction and Material Specifications (CMS) 507 and CMS 523, and therefore, a driven pile resistance factor of 0.7 should be used.

The estimated ultimate bearing values (UBV) and required geotechnical pile length following pile setup for three commonly used CIP piles per substructure location are given in Table 7 below (*Driven* results included within Appendix C). The referenced table also includes 1) the length of driven pile required in driving conditions for CIP piles driven to the respective UBV per substructure location; and 2) the estimated difference in pile length between a pile in ultimate and driving conditions. NEAS recommends performing a cost analysis to determine the preferred pile size.

Table 7: Deep Foundation Analysis Summary

Pile Type	Max Pile Reaction - Strength I (kips)	Required Ultimate Bearing Value(2) (kips)	Geotechnical Pile Length(1) (ft)	End of Initial Driving Value(3) (EOID)(kips)	Predicted Pile Length Accounting for Driving Losses (ft)	Pile Length Difference Ultimate vs. Driving Conditions (ft)	Setup Factor for Waiting Time (ft)
FRA-00071-28.294 (Ramp O): Rear Abutment, B-010-0-64 & B-038-0-21							
Case 1: Piles fully driven to the required UBV prior to construction of the MSE wall (13.9 ft below Bottom of footing)							
12-inch CIP	209.3	299.0	84.9	202.9	106.7	21.8	1.47
FRA-00071-28.294 (Ramp O): Center Pier, B-038-0-21							
16-inch CIP	281.1	401.6	66.0	274.8	83.2	17.2	1.46
FRA-00071-28.294 (Ramp O): Forward Abutment, B-001-0-64 & B-038-0-21							
Case 1: Piles fully driven to the required UBV prior to construction of the MSE wall (15.7 ft below Bottom of footing)							
12-inch CIP	209.3	299.0	81.8	203.2	102.7	20.9	1.47

Notes:
1. *The estimated length of pile from bottom of pile cap to the depth which the required UBV is obtained based on ultimate resistances.*
2. *The referenced resistance factor of 0.7 has been applied to Max Pile Reaction.*
3. *The EOID pile resistances per ODOT BDM Equation C305.3.2.4-4 based on driving resistances at the indicated geotechnical pile length.*

5.2.2. Downdrag

Based on our settlement analysis it was determined that the identified settlement magnitudes at the abutments may induce downdrag loading on the proposed foundations. Per Sections 305.3.2.2 and 305.4.1.2 “Downdrag and Drag Load” of the ODOT BDM, as greater than 0.4 inches of consolidation (long-term) settlement is anticipated to occur, a check should be performed to determine if the factored structural axial resistance of the pile at the Strength Limit State is equal to or greater than the combined effect of the factored downdrag load and the sum of factored loads (highest loaded pile at each substructure).

In order to perform this check, NEAS reviewed: 1) Bridge FRA-00071-28.294 site plan profile views accessed via ProjectWise on January 15, 2024; 2) the bridge loading information provided by TranSystems on January 2, 2024; and, 3) the proposed 12-inch CIP pile properties (i.e., minimum wall thicknesses given in Section 5.2.3. of this report and a 45 ksi yield stress, ASTM A 252 Grade 3 steel). Utilizing this information and geotechnical resistance information presented in Section 5.2.1 of this report, the location of the neutral plane for each location was determined utilizing the Goudreault and Fellenius (1994) method. At the depth of the neutral plane, it was subsequently determined that the combination of factored permanent, transient and downdrag loads was well below the factored structural axial resistance of the subject piles per ODOT BDM Section C305.3.3. Therefore, downdrag loads are not anticipated to be a concern for the project proposed pile foundations. A summary of the neutral plane analysis including depth to neutral plane, anticipated drag loading and combined factored loading is given in Table 8 below. Neutral plane and downdrag loading pile check results are included within Appendix C.

Table 8: Estimated Downdrag Load

Ramp O over IR-71 Bridge Downdrag Analysis Summary								
Location	Pile Type	Factored structural axial resistance (kips)	Case	Max Pile Reaction - Strength I (kips)	Depth to Neutral Plane (ft)	Nominal Downdrag Load (kips)	Factored Downdrag Load (kips)	Total Factored Load Including Downdrag (kips)
Rear Abutment	12-inch CIP	480	Case 3 - with conventional sand-filled pipe pile sleeves through the MSE wall fill (friction angle of 28°)	209.3	43.0	88.04	92.4	301.7
Forward Abutment	12-inch CIP	480	Case 3 - with conventional sand-filled pipe pile sleeves through the MSE wall fill (friction angle of 28°)	209.3	46.0	91.66	96.2	305.5

5.2.3. Pile Drivability

NEAS's drivability evaluation estimated a Delmag D 19-42 diesel hammer to determine if the 12-inch and 16-inch CIP piles with the minimum wall thickness of 0.25 inches for ASTM A 252 steel, would be overstressed at any time during pile installation. Based on the pile drivability results, 12-inch CIP piles with a wall thickness of 0.25 inches at the abutments and 16-inch CIP piles with a wall thickness of 0.25 inches at the center pier would not be overstressed for ASTM A 252 Grade 3 steel during the pile installation process. GRLWEAP Results can be found in Appendix C.

It should be noted that the driving resistance of CIP piles through soils encountered at the bridge site is expected to be high. Driveability is difficult to assess quantitatively as the field test results (i.e., SPT N_{60} values, pocket penetrometer values, etc.) tend to be very high. Furthermore, pile driveability is highly reliant upon the specific equipment used in construction; therefore, it is recommended that the contractor provide an analysis to demonstrate that the equipment and pile combination planned for use is capable of obtaining the UBV without over-stressing the piles.

Per the plan notes 606.7-1 of ODOT's 2023 BDM (ODOT, 2023), the maximum rated energy of the hammer used to install the piles shall be (44,000) foot-pounds. Ensure that stresses in the piles during driving do not exceed (45,000) pounds per square inch.

5.2.4. Pile Foundation Recommendations

Based on our evaluation of the subsurface conditions and our geotechnical engineering analysis for the proposed Bridge FRA-00071-28.294, it is our opinion that the bridge foundations can be supported on driven friction CIP piles seated within the stiff to hard natural glacial till material encountered at the site.

Steel points shall be provided to protect the tips of CIP pipe piles since the boulders were possibly encountered in borings B-001-1-64 and B-010-0-64.

We recommend that a driven pile foundation be used for support for the referenced substructure foundations. New CIP piles are recommended to be installed in accordance with Sections 507 and 523 of ODOT's CMS. During driving conditions and if driven to the UBVs indicated in Table 7 of this report, it is anticipated that the newly driven CIP piles would "run" for extended depths at each substructure location by greater than 10 ft. Therefore, it is recommended that the proposed piles at all substructures be driven to the full estimated length and pile/soil setup be utilized to achieve the required UBV. It is recommended that plan note 606.7-4 of ODOT's 2020 BDM "Piles Driven To Full Estimated Length With Pile/Soil Setup" be included on the plans for these substructures. At these locations, the first two piles at each substructure should be driven to the full Estimated Length indicated in Table 9 below. After driving and testing the first two piles, drive the remaining piles in the substructure to the same depth as the first two piles. After driving all piles to the estimated length, cease all driving operations at the substructure for a period specified in Table 9. After the specified waiting period, it is recommended that the pile driving contractor perform a restrike on both of the first two piles at each substructure. If the restrike test results indicate that both piles achieved the required UBV, all piles in the substructure may be accepted by the Engineer. If the restrike test results indicate that either of the two piles did not achieve the required UBV, immediately notify the Engineer so that the Engineer can notify the District Geotechnical Engineer, the Office of Construction Administration, and the Office of Geotechnical Engineering.

When new piles are installed in accordance with referenced construction specifications utilizing the referenced method as specified in the ODOT BDM CIP piles driven to the indicated UBVs may be used to support a total factored load (single pile) of the calculated result of the UBV multiplied by the driven pile resistance factor of 0.7. It should be noted that if preferred, methods B and C specified in Section 305.3.5.9 of ODOT's 2020 BDM can also be used to establish driving criteria accounting for the anticipated pile/soil setup.

Pile lengths based on: 1) our Deep Foundation Analysis (presented in Section 5.2.1); and, 2) the "Estimated Length" and "Order Length" definitions and formulas presented in Section 305.3.5.2 of the ODOT BDM, are presented in Table 9 below. The plan note 606.7-4 "Piles Driven To Full Estimated Length With Pile/Soil Setup" shall be provided in the bridge plan set.

Table 9: Estimated Pile Lengths

Pile Type	Bottom of Pile Cap Elevation (ft amsl)	Assumed Pile Cutoff Elevation (ft amsl)	Required UBV per Pile(kips)	Geotechnical Pile Length (ft)	Geotechnical Pile Tip Elevation (ft amsl)	Estimated Pile Length (ft)	Order Length (ft)	Wait Time (day)
FRA-00071-28.294 (Ramp O): Rear Abutment, B-010-0-64 & B-038-0-21								
12-inch CIP	923.0	924.0	299.0	84.9	838.1	90	95	14
FRA-00071-28.294 (Ramp O): Center Pier, B-038-0-21								
16-inch CIP	907.0	908.0	401.6	66.0	841.0	70	75	14
FRA-00071-28.294 (Ramp O): Forward Abutment, B-001-0-64 & B-038-0-21								
12-inch CIP	924.0	925.0	299.0	81.8	842.2	85	90	14

5.2.5. Parameters for Lateral Load Analysis

Deep foundation elements subjected to horizontal loads and/or moments should be analyzed for maximum bending moments and lateral deflections. Since axially loaded piles will require negligible moment, battered piles can be considered to resist the lateral loads. The required lateral load capacity can be obtained by increasing the diameter or the embedment depth of the foundation element. The generalized soil parameters, including recommended lateral soil modulus, and soil strain to be used to analyze the laterally loaded shaft by the p-y curve method are presented in Table 10 below. Furthermore, a resistance factor of 1.0 should be used when estimating the lateral geotechnical resistance of a single pile or pile group in accordance with LRFD BDS Tables 10.5.5.2.3-1 and 10.5.5.2.4-1.

Table 10: Generalized Soil Parameters for Lateral Load Analysis

LPILE Parameters For Soil							
Substructure (Boring Number)	p-y model	Below Ground Depth (ft)	Elevation (ft)	Effective Unit Weight (pcf)	Undrained Shear Strength (psf)	Lateral Soil Modulus Parameter, k (pci)	Soil Strain Parameter, E_{50} (%)
Center Pier (B-038-0-21)	Stiff Clay w/o Water	0.0 - 4.5	912.8 - 908.3	125	2,400	833	0.0056
	Stiff Clay w/o Water	4.5 - 12.0	908.3 - 900.8	122	1,950	681	0.0062
	Soft Clay	12.0 - 15.0	900.8 - 897.8	115	600	87	0.0132
	Stiff Clay w/o Water	15.0 - 16.0	897.8 - 896.8	120	1,550	542	0.0070
	Sand (Reese)	16.0 - 18.0	896.8 - 894.8	125	-	226	-
	Stiff Clay w/o Water	18.0 - 24.5	894.8 - 888.3	122	2,000	708	0.0060
	Stiff Clay w/o Water	24.5 - 33.0	888.3 - 879.8	128	3,700	1292	0.0046
	Stiff Clay w/o Water	33.0 - 88.0	879.8 - 824.8	122	2,350	818	0.0056
	Stiff Clay w/o Water	88.0 - 113.3	824.8 - 799.5	130	5,200	1817	0.0040
	Sand (Reese)	113.3 - 117.5	799.5 - 795.3	140	-	437	-
	Sand (Reese)	117.5 - 120.0	795.3 - 792.8	140	-	353	-

5.3. MSE Wall Foundation Analysis

A foundation review was completed for the proposed MSE walls located at the abutments based on the information presented in Section 5 of this report in addition to: 1) the soil characteristics gathered during the subsurface exploration (i.e., SPT results, laboratory test results, etc.); 2) the referenced Bridge Site Plan provided by TranSystems; and, 3) other design assumptions presented in subsequent sections of this report. Geotechnical analyses consisting of external stability (i.e., bearing resistance, eccentricity, and sliding resistance), global stability, and settlement were performed for the proposed MSE wall abutments in accordance with ODOT's BDM (ODOT, 2023) and AASHTO's LRFD BDS (AASHTO, 2020).

5.3.1. Retaining Wall Design Assumptions

As the proposed bridge substructure at the abutment locations is to consist of a cast-in-place semi-integral abutment with MSE wall, ODOT's BDM and AASHTO's LRFD BDS dictate analysis parameters and design minimums/constraints to be used in the analysis and design process. The referenced parameters and design minimums/constraints that were significant to our analyses consist of the following:

- Minimum reinforcement strap lengths of proposed MSE wall is to be 70% of the total wall height (as measured from proposed profile grade at the face of the wall to the top of the leveling pad) or 8 ft, whichever is greater, at the particular section of wall being analyzed, per BDM section 307.4-A;
- Minimum MSE wall embedment depths (as measured from top of the leveling pad to the lowest point on the ground surface within 4-ft of the face of the wall) are to conform to Figure 201-5 presented in ODOT's BDM and be the larger of 3 ft or the local frost depth;
- The use of spread footing supported abutments on MSE walls is not permitted because of their susceptibility to loss of bearing caused by erosion during the service life of the structure. Furthermore, piles require a minimum 15- foot embedment below the MSE wall.
- Soils below the bottom of leveling pad will be undercut a minimum of 1 ft and replaced Granular Material Type C according to the requirements of ODOT Construction & Materials Specifications Section 204.07 (CMS 204.07);

- Maximum allowable differential settlement in the longitudinal direction is 1%; and,
- Reinforced Zone and Retained Fill soils will meet the minimum design soil parameters per Table 840.04-1 of the ODOT Supplemental Specification 840 (SS-840) as shown in Table 11 below.

Table 11: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
Reinforced Zone	Select Granular Embankment (Backfill) Material	120	34	0
Retained Soil	On-site soil varying from sandy lean clay to silty sand	120	30	0
Notes: 1. *Table reproduced from Section 204.6.2.1 of 2007 ODOT Bridge Design Manual.*				

With respect to design constraints and assumptions specific to the proposed bridge abutment MSE walls, the geometry of the proposed walls (i.e., exposed wall heights, existing ground elevations, proposed bottom of wall elevation, etc.) is assumed to be consistent with that shown in the proposed Bridge Site Plan prepared by TranSystems.

5.3.2. External Stability

Based on our estimated geotechnical soil properties and the retaining wall design assumptions provided in Sections 5.1 and 5.3.1. of this report, respectively, an external stability analysis of the proposed MSE wall abutments was performed. The tallest estimated wall cross-sections for rear and forward abutment locations were evaluated for resistance to bearing pressure, sliding forces and overturning at the Strength Limit State for both drained and undrained conditions in accordance with Section 11.10.5 of the AASHTO's LRFD BDS. The cross-sections were evaluated assuming a maximum design wall height at the rear and forward abutment locations and the bearing elevations as shown in the referenced bridge site plans. Each cross-section was evaluated for resistance to bearing pressure, sliding forces and overturning at the Strength Limit State in accordance with Section 11.10.5 of the AASHTO's LRFD BDS. The capacity to demand ratios (CDRs) calculated for the referenced cross-sections with respect to bearing, sliding and overturning, as well as the calculated factored bearing resistances for rear abutment and forward abutment are presented in Table 12 and Table 13 below. (External Stability and Bearing Resistance Calculation Results can be found in Appendix D)

Table 12: External Stability Analysis Summary – Rear Abutment

MSE Wall Analysis Summary - Rear Abutment		
Bearing Conditions	**Rear Abutment**	
Design Wall Height (feet)	25.3	
Exposed Wall Height (feet)	21.1	
Length of Reinforecement (feet)	25.3	
Length of Reinf. To Height Ratio	1.0	
Adjacent Boring Locations	B-010-0-64 & B-038-0-21	
Assumed Soil Type	Stiff Cohesive	
Capactiy Demand Ratio (CDR)		
	Undrained	**Drained**
Sliding	1.8	1.8
Overturning / Eccentricity	4.0	4.0
Bearing Resistance	1.1	1.5
Factored Bearing Resistance (ksf)(1)	5.7	7.7
Notes: 1. *Bearing Resistance calculated in accordance to Section 11.10.5.4 of 2020 LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of 2020 LRFD BDS.*		

Table 13: External Stability Analysis Summary – Forward Abutment

MSE Wall Analysis Summary - Forward Abutment		
Bearing Conditions	**Forward Abutment**	
Design Wall Height (feet)	28.0	
Exposed Wall Height (feet)	23.4	
Length of Reinforecement (feet)	28.0	
Length of Reinf. To Height Ratio	1.0	
Adjacent Boring Locations	B-001-1-64 & B-038-0-21	
Assumed Soil Type	Stiff Cohesive	
Capactiy Demand Ratio (CDR)		
	Undrained	**Drained**
Sliding	1.7	1.8
Overturning / Eccentricity	4.0	4.0
Bearing Resistance	1.0	1.5
Factored Bearing Resistance (ksf)(1)	5.9	8.3

Notes:
1. *Bearing Resistance calculated in accordance to Section 11.10.5.4 of 2020 LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of 2020 LRFD BDS.*

Based on the external stability analysis summary, it should be noted that the soil reinforcement is 100% of the total design height. Reinforcement length is recommended to be increased as required per BDM section 201.4.1 and LRFD section 11.10.2.1 for soft foundation soils encountered.

5.3.3. Settlement

The planned bridge consists of semi-integral abutments founded on piles and MSE wall embankments which there will be about 24.0 feet of new embankment fill. In order to estimate the maximum total and differential settlement that could result within the subsurface soils supporting the proposed semi-integral rear abutment, NEAS reviewed: 1) the proposed Bridge Site Plan prepared by TranSystems; 2) Service Limit State loading conditions; and, 3) test borings and laboratory data developed as part of this report. Utilizing this information and the software entitled FoSSA 2.0 by ADAMA Engineering, Inc., settlement models were developed and analyzed for both elastic (immediate) and consolidation (long term) settlement.

Based on our analysis the ground surface at the rear abutment is estimated to experience about 8.8 inches of immediate settlement and 4.1 inches of long-term (consolidation) settlement from the induced loads associated with the 24.0-ft high embankment. The settlement analysis results can be found in Appendix E. Since the new MSE wall embankment will induce a ground settlement greater than 0.4 inches after pile installation, therefore, it is our opinion that the piles at the abutment will be subjected to downdrag loads. The immediate settlement is expected to take place during construction prior to bridge loading and is not anticipated to be a concern. It is estimated that time required for 90% consolidation for each evaluated soil layers is on the order of 32 to 114 days. Ninety percent (90%) of the long-term settlement for all evaluated soil layers will take place about 40 days following embankment construction. If the project schedule can tolerate a delay between the substantial completion of the site earthwork in this area and commencement of the structure/pavement construction, postponing construction and allowing the potentially damaging settlements to take place should be considered to prevent additional costs associated with reconstruction, repairs and maintenance.

In terms of the actual waiting period until the begin of structure/pavement construction, it is recommended that a settlement monitoring program be designed and implemented to verify that the settlements have dissipated to a level acceptable by the Geotechnical Engineer and determine the time period at which permanent structure/pavement construction may begin. With respect to the settlement monitoring plan, it is recommended that settlement platforms per Item 7 of ODOT's "Geotechnical Bulletin #4, *Guidelines for the use of Geotechnical Instrumentation*", dated December 22, 2011 (GB4) be installed at the southern corners of the abutments where there is the highest embankment fill.

5.3.4. Global Stability

For purposes of evaluating the stability of the abutment MSE walls, NEAS reviewed the cross-section and project boring logs to determine the subsurface soil conditions that posed the greatest potential for slope instability. Based on our review, NEAS developed a representative cross-sectional model at each abutment to use as the basis for global stability analyses. The models were developed from NEAS's interpretation of the available information which included: 1) the proposed Bridge Site Plan prepared by TranSystems; 2) a live load surcharge of 250 psf, accounting for traffic induced loads; and, 3) test borings and laboratory data developed as part of this report. With respect to the soil's engineering properties, the provided Soil Profile Estimated Engineering Properties presented in Section 5.1 of this report were used in our analyses.

The above referenced slope stability models were analyzed for long-term (Effective Stress) slope stability utilizing the software entitled Slide 7.0 by Rocscience, Inc. Specifically, the Modified Bishop and Janbu analysis methods were used to calculate a factor of safety (FOS) for circular type slope failures. The FOS is the ratio of the resisting forces and the driving forces, with the desired safety factor being more than about 1.54 which equates to an AASHTO resistance factor less than 0.65 (per AASHTO, 2020 - the specified resistance factors are essentially the inverse of the FOS that should be targeted in slope stability programs). For this analysis, a resistance factor of 0.65 or lower is targeted as the slope contains or supports a structural element.

Based on our slope stability analyses for the referenced MSE walls section, the minimum slope stability safety factor for long-term (Effective Stress) conditions exceeded the desired value of 1.54. The results of the analyses are summarized in Table 14. Based on the results of the analyses, it is our opinion that the subsurface conditions encountered at this location are generally satisfactory and the site can be considered to be stable at short-term and long-term condition. The graphical output of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) is presented in Appendix F.

Table 14: Global Stability Analysis Summary

Global Stability Analsysis at Bridge FRA-00071-28.294					
Location	**Boring No.**	**Description**	**Minimum Factor of Safety**	**Equivalent Resistance Factor**	**Status (OK/NG)**
Rear Abutment	B-010-0-64 & B-038-0-21	Short Term	2.27	0.44	OK
		Long Term	2.01	0.50	OK
Forward Abutement	B-001-1-64 & B-038-0-21	Short Term	1.71	0.59	OK
		Long Term	1.78	0.56	OK

5.3.5. MSE Wall Recommendation

MSE wall soil reinforcement: we recommend that the soil reinforcement length is 100 percent of the wall design height for the rear and forward abutment MSE walls. Reinforcement length is recommended to be increased as required per BDM section 201.4.1 and LRFD section 11.10.2.1 for soft foundation soils encountered.

MSE wall reinforced backfill: we recommend the use of granular material meeting the requirements of ODOT's Supplemental Specification 840 (SS-840) Section 840.03.E "Select Granular Backfill" (SGB). Furthermore, it is recommended that, at a minimum, SGB be placed as backfill material within the limits shown in Figures 303.5.1-3 and 303.5.1-5 of ODOT's BDM (ODOT, 2023). With respect to placement, it is recommended that SGB be placed in accordance with SS-840 Section 840.06.I "Select Granular Backfill Placement".

Drainage: It is recommended that adequate drainage is maintained/controlled during and after construction of the retaining wall, and that roadway drainage is carefully controlled around the retaining wall location in order to prevent ponding, erosion of reinforced or retained backfill soil, loss of shear strength of foundation soils due to saturation, and other drainage related issues.

It is recommended that internal drainage of the retaining wall (reinforced fill) be designed as indicated in Section 307.4 and as shown in Figures 201-5 through 201-7 of the ODOT BDM. We recommend the wall drainage material conform to the requirements of SS-840, Section 840.03.F "Backfill Drainage Material" and wall drainage be constructed in accordance with SS-840 Section 840.06.F "Wall Drainage". Furthermore, it is recommended that the barrier or curb at the roadway extend at least 25 ft beyond the MSE wall limits, and outlet to a piped collection system (i.e., collection basin/inlet) located beyond the extents of the wall. Where a barrier or curb is not present, it is recommended that a paved channel (swale) be placed directly behind the top of the wall. The paved channel should be designed to intercept surface water and direct it to an outlet as well as reduce the potential for surface water from overtopping the wall. The designer should anticipate and address in design and detailing the possibility of water runoff from extreme events which will overtop the drainage swale and run down the wall face.

5.4. Seismic Site Class

Based on the results of the subsurface exploration, laboratory test data, and the AASHTO Site Class Definitions indicated in Table 3.10.3.1-1 of the *LRFD Bridge Design Specifications, 9th Edition* (AASHTO LRFD, 2020), the average Standard Penetration Test blow count $\overline{N}$ for B-038-1-21 is 27 blows/ft. Therefore, the project site is classified as Site Class of D - Stiff Soil, with $15<\overline{N}<50$ blows/ft.

6. QUALIFICATIONS

This investigation was performed in accordance with accepted geotechnical engineering practice for the purpose of characterizing the subsurface conditions at the site of the proposed Bridge FRA-00071-28.294 carrying Ramp O over IR-71 for the FRA-71/270-28.27/25.99A (PID# 105435) project. This report has been prepared for TranSystems, ODOT and their design consultants to be used solely in evaluating the soils underlying the indicated structures and presenting geotechnical engineering recommendations specific to this project. The assessment of general site environmental conditions or the presence of pollutants in the soil, rock and groundwater of the site was beyond the scope of this geotechnical exploration. Our recommendations are based on the results of our field explorations, laboratory test results from representative soil samples, and geotechnical engineering analyses. The results of the field explorations and laboratory tests, which form the basis of our recommendations, are presented in the appendices as noted. This report does not reflect any variations that may occur between the borings or elsewhere on the site, or variations whose nature and extent may not become evident until a later stage of construction. In the event that any changes occur in the nature, design or location of the proposed structural work, the conclusions and recommendations contained in this report should not be considered valid until they are reviewed and have been modified or verified in writing by a geotechnical engineer.

It has been a pleasure to be of service to TranSystems in performing this geotechnical exploration for the FRA-71/270-28.27/25.99A (PID# 105435) project. Please call if there are any questions, or if we can be of further service.

Respectfully Submitted,

Chunmei (Melinda) He, Ph.D., P.E.
Project Manager

Zhao Mankoci, Ph.D., P.E.
Geotechnical Engineer

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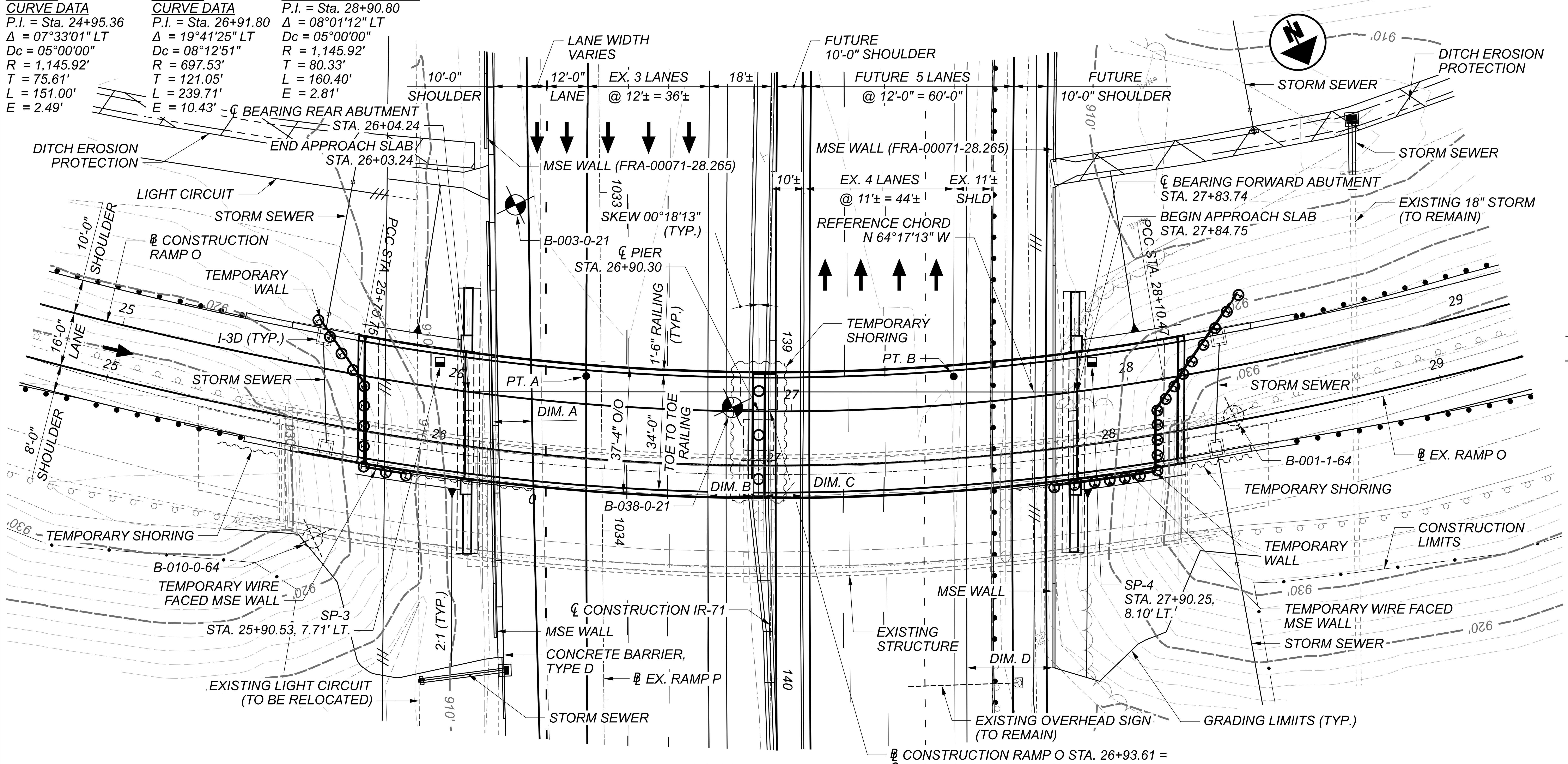
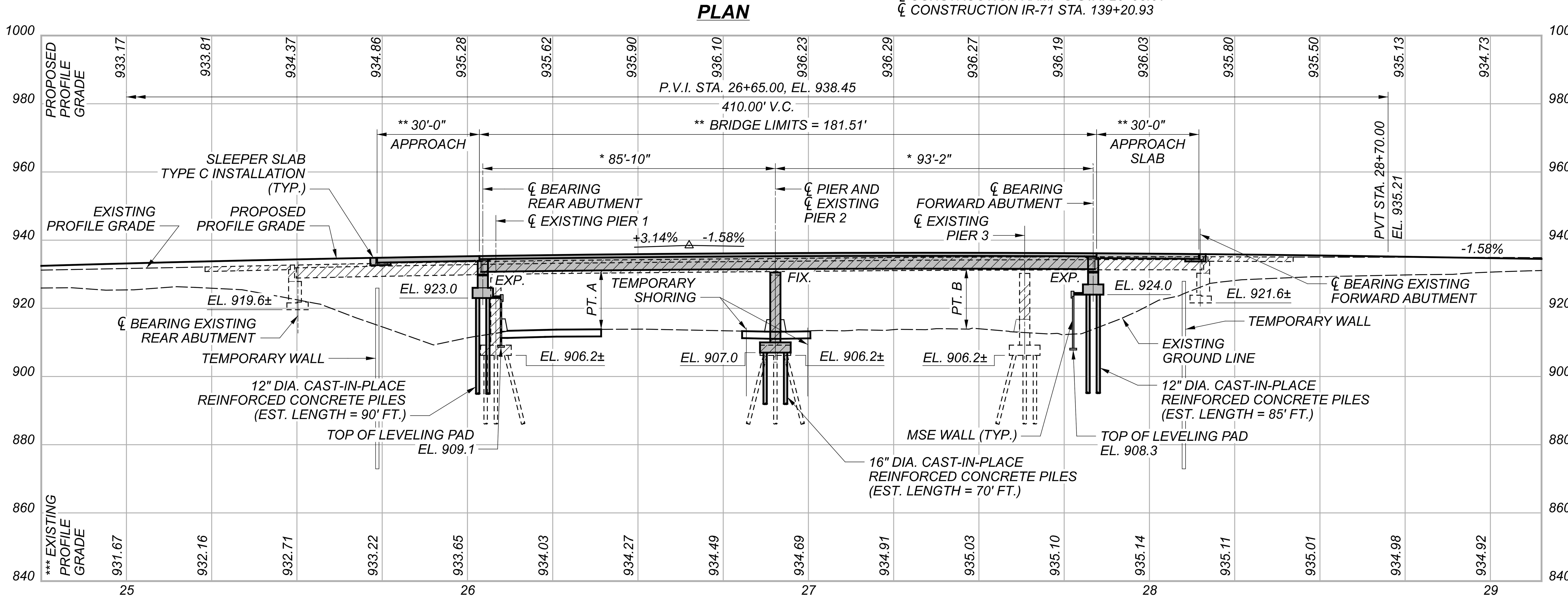
APPENDIX A

SITE PLAN

RAMP O CURVE DATA	RAMP O CURVE DATA	RAMP O CURVE DATA
P.I. = Sta. 24+95.36	P.I. = Sta. 26+91.80	P.I. = Sta. 28+90.80
Δ = 07°33'01" LT	Δ = 19°41'25" LT	Δ = 08°01'12" LT
Dc = 05°00'00"	Dc = 08°12'51"	Dc = 05°00'00"
R = 1,145.92'	R = 697.53'	R = 1,145.92'
T = 75.61'	T = 121.05'	T = 80.33'
L = 151.00'	L = 239.71'	L = 160.40'
E = 2.49'	E = 10.43'	E = 2.81'



PLAN



PROFILE ALONG ℄ CONSTRUCTION RAMP O

BENCHMARK DATA

BM #1 STA. 155+78.70 (CL EX. IR-71) ELEV. 897.11 , OFFSET 98.04', RT.
BM #2 STA. 133+67.41 (CL EX. IR-71) ELEV. 909.34 , OFFSET 332.20', LT.

FOR ADDITIONAL BENCHMARK INFORMATION, SEE ROADWAY PLAN SHEET P.004.

NOTES:

EARTHWORK LIMITS SHOWN ARE APPROXIMATE. ACTUAL SLOPES SHALL CONFORM TO PLAN CROSS SECTIONS.

ALL EXISTING BRIDGE ELEVATIONS HAVE BEEN ADJUSTED TO THE CURRENT PROJECT SURVEY ELEVATIONS AND ARE APPROXIMATELY 0.80 FEET LOWER THAN THE ELEVATIONS IN THE ORIGINAL PLANS.

DESIGN TRAFFIC:

2023 ADT = 14,720 2023 ADTT = 883
2043 ADT = 16,740 2043 ADTT = 1,004
DIRECTIONAL DISTRIBUTION = N/A

LEGEND:

- PROJECT BORING LOCATION
- HISTORIC BORING LOCATION
- * INDICATES MEASURED ALONG REFERENCE CHORD
- ** INDICATES MEASURED ALONG ℄ CONSTRUCTION RAMP O
- *** INDICATES ELEVATION ALONG ℄ EXISTING RAMP O
- LIMITS OF REMOVAL
- PROPOSED STRUCTURE
- ● 16'-6" REQUIRED MINIMUM VERTICAL CLEARANCE

PT. A: 16'-6¾" ACTUAL MINIMUM VERTICAL CLEARANCE
PT. B: 16'-8⅜" ACTUAL MINIMUM VERTICAL CLEARANCE

HORIZONTAL CLEARANCES:
DIM. A: 11'-9' ACTUAL HORIZONTAL CLEARANCE, 30'-0" REQUIRED
DIM. B: 13'-2¾" ACTUAL HORIZONTAL CLEARANCE, 30'-0" REQUIRED
DIM. C: 11'-7" ACTUAL HORIZONTAL CLEARANCE, 30'-0" REQUIRED
DIM. D: 25'-5⅜" ACTUAL HORIZONTAL CLEARANCE, 30'-0" REQUIRED

EXISTING STRUCTURE

TYPE: 4 SPAN CONTINUOUS STEEL ROLLED BEAMS WITH REINFORCED CONCRETE DECK AND SUBSTRUCTURE
SPANS: 57'-3"±, 81'-9"±, 73'-0"±, 51'-0"± C/C BEARINGS MEASURED ALONG REFERENCE TANGENT
ROADWAY: 30'-0"± F/F SAFETY CURB
LOADING: CF=2000(57) ADEQUATE FOR AASHTO ALTERNATE LOADING
SKEW: NONE TO REFERENCE TANGENT
WEARING SURFACE: 2"± MONOLITHIC CONCRETE
APPROACH SLABS: 25'-0"± LONG (AS-1-54)
ALIGNMENT: 8°± CURVE LEFT
SUPERELEVATION: 0.083± FT/FT
STRUCTURE FILE NUMBER: 2511223
DATE BUILT: 1966
DISPOSITION: TO BE REPLACED

PROPOSED STRUCTURE

TYPE: 2 SPAN CONTINUOUS CURVED STEEL PLATE GIRDERS (ASTM A709 GRADE 50W) WITH COMPOSITE REINFORCED CONCRETE DECK SUPPORTED ON REINFORCED CONCRETE CAP AND COLUMN PIER AND SEMI-INTEGRAL ABUTMENTS FOUNDED ON PILES AND MSE WALL EMBANKMENTS
SPANS: 85'-10", 93'-2" C/C BEARINGS ALONG REFERENCE CHORD
ROADWAY: 34'-0" TOE/TOE RAILING
LOADING: HL93 AND 0.060 KSF FUTURE WEARING SURFACE
SKEW: 0°18'13" LEFT FORWARD TO REFERENCE CHORD
WEARING SURFACE: 1" MONOLITHIC CONCRETE
APPROACH SLABS: 30' LONG, 17" THICK (AS-1-15 & AS-2-15)
ALIGNMENT: 8°12'51" CURVE LEFT
SUPERELEVATION: 0.060 FT/FT
DECK AREA: 6776 SF
COORDINATES: LATITUDE 40°06'43.84" N
LONGITUDE 82°58'33.60" W

SITE PLAN
BRIDGE NO. FRA-00071-28.294
IR-71 UNDER RAMP O IR-71 NB TO IR-270 WB

SFN	2511224
DESIGN AGENCY	TRANSYSTEMS, 1100 SUPERIOR AVE E, STE 1000, CLEVELAND, OHIO 44114
DESIGNER	JPD
CHECKER	EA
REVIEWER	NFF 01/24/24
PROJECT ID	105435
SUBSET	1
TOTAL	47
SHEET	P.586
TOTAL	730

MODEL: CLP_RAMP_O - Plan 3 [Sheet] PAPERSIZE: 34x22 (in.) DATE: 1/30/2024 TIME: 4:20:50 PM USER: btavarello
pw:\\hq-pwint01.a-e.transyscorp.com:transyscorp-pw1\Documents\Projects_2020\CL402\402200080\Agency_Folders\400-Engineering\Structures\SFN_2511224\Sheets\105435_SFN_2511224_SP001.dgn

APPENDIX B

BORING LOGS AND TEST RESULTS

B-001-1-64

LOG OF BORING

Date Started 4-6-64 Sampler Type SS Dia. 1 3/8" Water Elev. ______

Date Completed 4-7-64 Casing: Length 26' Dia. 3 1/2"

Boring No. B-1 Station & Offset 18+42, 5' Lt (FORWARD ABUTMENT) Surface Elev. 906.5'

Elev.	Depth	Std. Pen. (N)	Rec. ft.	Loss ft.	Description	Sample No.	% Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W. C.	SHTL Class.
906.5	0														
904.0	2, 4	3/4			Brownish-Gray Sandy Silt	1	0	8	13	52	27	21	10	27	A-4b
901.5	6	5/8			Brown Gravelly Sandy Silt	2	15	9	13	32	31	26	7	18	A-4a
899.0	8				No Sample Recovered - Boulders										
896.5	10	7/10			Gray Sandy Gravelly Silt	3	23	8	11	28	30	22	6	13	A-4a
894.0	12, 14	11/14			Gray Silty Sandy Gravel	4	42	14	23	10	11	NP	NP	14	A-1-b
891.5	16	13/18			Gray Silty Gravelly Sand	5	31	18	13	29	9	NP	NP	11	A-4a
889.0	18	21/22			Gray Silty Gravelly Sand	6	22	15	25	23	15	NP	NP	11	A-4a
886.5	20, 22, 24	14/18			Gray Gravelly Sandy Silt	7	15	13	14	33	25	21	6	13	A-4a
881.5	26, 28	13/16			Gray Sandy Gravelly Silt	7	23	9	12	33	23	21	5	11	A-4a
876.5	30, 32, 34	13/17			Gray Gravelly Sandy Silt	9	22	11	18	13	36	22	6	13	A-4a
871.5	36, 38	21/23			Gray Sandy Silt	10	14	14	16	28	28	20	5	10	A-4a
866.5	40					11	32	11	13	22	22	21	5	13	A-4a

FRA-71-3567

LOG OF BORING

Date Started 4-6-64
Date Completed 4-7-64
Boring No. B-1

Sampler Type SS Dia. 1 3/8"
Casing: Length 26' Dia. 3 1/2"
Station & Offset 18+42, 5' Lt (FORWARD ABUTMENT)

Water Elev. ______
Surface Elev. 906.5'

Elev.	Depth	Std. Pen. (N)	Rec. ft.	Loss ft.	Description	Sample No.	% Agg.	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W. C.	SHTL Class.
906.5	0														
904.0	2, 4	3/4			Brownish-Gray Sandy Silt	1	0	8	13	52	27	21	10	27	
901.5	6	5/8			Brown Gravelly Sandy Silt	2	15	9	13	32	31	26	7	18	
899.0	8				No Sample Recovered - Boulders										
896.5	10	7/10			Gray Sandy Gravelly Silt	3	23	8	11	28	30	22	6	13	
894.0	12, 14	11/14			Gray Silty Sandy Gravel	4	42	14	23	10	11	NP	NP	14	
891.5	16	13/18			Gray Silty Gravelly Sand	5	31	18	13	29	9	NP	NP	11	
889.0	18	21/22			Gray Silty Gravelly Sand	6	22	15	25	23	15	NP	NP	11	
886.5	20	14/18			Gray Gravelly Sandy Silt	7	15	13	14	33	25	21	6	13	
	22, 24														
881.5	26	13/16			Gray Sandy Gravelly Silt	7	23	9	12	33	23	21	5	11	
	28														
876.5	30	13/17			Gray Gravelly Sandy Silt	9	22	11	18	13	36	22	6	13	
	32, 34														
871.5	36	21/23			Gray Sandy Silt	10	14	14	16	28	28	20	5	10	
	38														
866.5	40, 42	19/27			Gray Sandy Gravelly Silt	11	32	11	13	22	22	21	5	13	
	44														
861.5	46	50* (0.7')			Gray Sandy Gravelly Silt	12	30	10	11	28	21	20	6	10	A-4a
	48														
856.5	50														
855.5		19/29			Gray Gravelly Sandy Silt	13	15	9	16	36	24	NP	NP	13	A-4a

BOTTOM OF BORING

*REFUSAL

LOG OF BORING

Date Started 4-8-64 Sampler Type SS Dia. 1 3/8" Water Elev. ______

Date Completed 4-8-64 Casing: Length 26' Dia. 3 1/2"

Boring No. B-10 Station & Offset 15+67, 32' Rt (REAR ABUTMENT) Surface Elev. 903.8'

Elev.	Depth	Std. Pen. (N)	Rec. ft.	Loss ft.	Description	Sample No.	% Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W. C.	SHTL Class.
903.8	0														
901.3	2														
	4	2/3			Brown Gravelly Silt	1	14	2	10	54	20	NP	NP	24	A-4b
898.8	6	2/4			Gray Sandy Silt	2	12	8	15	37	28	25	8	18	A-4a
896.3	8	2/3			Gray Sandy Gravelly Silt	3	30	8	11	27	24	25	7	19	A-4a
893.8	10	3/5			Gray Sandy Gravelly Silt	4	26	11	15	27	21	19	4	18	A-4a
891.3	12														
	14				No Sample Recovered - Boulder										
888.8	16	9/10			Gray Gravelly Sandy Silt	5	23	12	14	26	25	21	5	10	A-4a
886.3	18	12/13			Gray Sandy Gravelly Silt	6	30	14	10	24	22	21	5	12	A-4a
883.8	20	14/17			Brown Gravelly Sandy Silt	7	20	11	14	27	28	21	6	12	A-4a
	22														
	24														
878.8	26	9/12			Brown Sandy Silt	8	14	8	14	35	29	22	8	13	A-4a
	28														
873.8	30														
	32	15/17			Gray Sandy Gravelly Silt	9	24	8	14	27	27	21	7	14	A-4a
	34														
868.8	36	18/20			Gray Sandy Gravelly Silt	10	20	12	7	44	17	NP	NP	11	A-4a
	38														
863.8	40														
	42	15/21			Gray Gravelly Sandy Silt	11	18	8	14	30	30	21	5	13	A-4a
	44														
858.8	46	16/24			Gray Sandy Gravelly Silt	12	37	9	11	22	21	21	5	12	A-4a
	48														
853.8	50														
	52	16/23			Gray Sandy Gravelly Clay	13	18	11	6	32	33	34	13	18	A-6a
848.8	54														
	56				No Sample Recovered - Boulder										
845.8	58				BOTTOM OF BORING										

PROJECT: FRA-071/270-28.27/25.99A	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 26+82, 1' LT.	EXPLORATION ID B-038-0-21
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: RAMP O	
PID: 105435 SFN: 2511224	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/24/22	ELEVATION: 912.8 (MSL) EOB: 120.0 ft.	PAGE 1 OF 4
START: 8/3/22 END: 8/4/22	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 79	LAT / LONG: 40.112234, -82.976395	

MATERIAL DESCRIPTION AND NOTES	ELEV. 912.8
18.0" ASPHALT AND 6.0" BASE (DRILLERS DESCRIPTION)	910.8
HARD, BROWNISH GRAY, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, DAMP	908.3
VERY STIFF TO HARD, BROWNISH GRAY AND BROWN, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP TO MOIST SS-4 BECOMES DARK GRAY, TRACE SAND, SLIGHTLY ORGANIC	900.8
VERY STIFF, BROWN MOTTLED WITH GRAY AND ORANGISH BROWN, **CLAY**, SOME SILT, SOME SAND, TRACE GRAVEL, IRON STAINING, DAMP	897.8
HARD, BROWN, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, DAMP	896.8
MEDIUM DENSE, GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, BOTTOM 12.0" OF ST-1 WOULD NOT EXTRUDE, MOIST	894.8
STIFF TO HARD, GRAY, **SANDY SILT**, LITTLE TO SOME CLAY, TRACE GRAVEL, DAMP	

DEPTHS: 1 – 29

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	SO4 ppm	HOLE SEALED
4 6 9	20	100	SS-1	4.50	6	13	19	38	24	26	16	10	12	A-4a (5)	-	
3 5 8	17	100	SS-2	4.50	6	7	11	41	35	37	21	16	18	A-6b (10)	-	
3 6 6	16	100	SS-3	4.50	-	-	-	-	-	-	-	-	20	A-6b (V)	-	
2 5 7	16	100	SS-4	4.00	-	-	-	-	-	-	-	-	26	A-6b (V)	-	
1 2 2	5	100	SS-5	2.25	-	-	-	-	-	-	-	-	27	A-7-6 (V)	-	
		88	ST-1	4.25	7	13	17	36	27	27	18	9	14	A-4a (6)	-	
3 8 8	21	100	SS-6A	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	-	
			SS-6B	3.50	-	-	-	-	-	-	-	-	12	A-4a (V)	-	
2 5 9	18	100	SS-7	4.00	9	16	21	34	20	21	14	7	12	A-4a (4)	-	
3 5 7	16	56	SS-8	3.75	-	-	-	-	-	-	-	-	11	A-4a (V)	-	
6 10 13	30	17	SS-9	4.25	-	-	-	-	-	-	-	-	11	A-4a (V)	-	
7 8 11	25	22	SS-10	3.50	-	-	-	-	-	-	-	-	12	A-4a (V)	-	

STANDARD ODOT LOG W/ SULFATES (8.5 X 11) - OH DOT.GDT - 9/7/22 14:06 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\FRA-071-270-28.27-25.99 AIGINT FILES\FRA-71-270 REPLACEMENT B

MATERIAL DESCRIPTION AND NOTES	ELEV. 882.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	SO4 ppm	HOLE SEALED
STIFF TO HARD, GRAY, **SANDY SILT**, LITTLE TO SOME CLAY, TRACE GRAVEL, DAMP *(continued)*		31	17 15 14	38	22	SS-11	2.50	-	-	-	-	-	-	-	-	14	A-4a (V)	-	
		35–36	5 9 9	24	100	SS-12	2.50	-	-	-	-	-	-	-	-	14	A-4a (V)	-	
		40–41	4 5 8	17	100	SS-13	2.75	-	-	-	-	-	-	-	-	13	A-4a (V)	-	
		45–46	5 5 6	14	100	SS-14	2.00	-	-	-	-	-	-	-	-	14	A-4a (V)	-	
VERY STIFF TO HARD, GRAY, **SANDY SILT**, LITTLE CLAY, TRACE TO LITTLE GRAVEL, DAMP	864.5																		
		50–51	3 7 9	21	100	SS-15	4.00	10	15	24	34	17	19	14	5	12	A-4a (3)	-	
		55–56	3 5 8	17	100	SS-16	3.50	-	-	-	-	-	-	-	-	12	A-4a (V)	-	
		60–61	3 5 9	18	100	SS-17	4.00	-	-	-	-	-	-	-	-	11	A-4a (V)	-	

PID: 105435	SFN: 2511224	PROJECT: FRA-071/270-28.27/25.99A	STATION / OFFSET: 26+82, 1' LT.	START: 8/3/22	END: 8/4/22	PG 3 OF 4	B-038-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 850.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	SO4 ppm	HOLE SEALED
VERY STIFF TO HARD, GRAY, **SANDY SILT**, LITTLE CLAY, TRACE TO LITTLE GRAVEL, DAMP *(continued)*		63, 64																	
		65–66	4 4 7	14	100	SS-18	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	-	
	844.5	67, 68																	
VERY STIFF TO HARD, GRAY, **SANDY SILT**, SOME CLAY, TRACE TO LITTLE GRAVEL, DAMP TO MOIST		69																	
		70–71	3 6 10	21	100	SS-19	2.75	7	13	18	38	24	22	15	7	12	A-4a (5)	-	
		72, 73, 74																	
		75–76	5 7 10	22	100	SS-20	4.25	-	-	-	-	-	-	-	-	12	A-4a (V)	-	
		77, 78, 79																	
		80–81	4 8 12	26	100	SS-21	2.50	-	-	-	-	-	-	-	-	14	A-4a (V)	-	
		82, 83, 84																	
		85–86	4 6 11	22	100	SS-22	2.75	-	-	-	-	-	-	-	-	15	A-4a (V)	-	
		87, 88, 89																	
		90–91	12 19 22	54	100	SS-23	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	-	
		92, 93, 94																	

PID: 105435	SFN: 2511224	PROJECT: FRA-071/270-28.27/25.99A	STATION / OFFSET: 26+82, 1' LT.	START: 8/3/22	END: 8/4/22	PG 4 OF 4	B-038-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 818.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	SO4 ppm	HOLE SEALED
VERY STIFF TO HARD, GRAY, **SANDY SILT**, SOME CLAY, TRACE TO LITTLE GRAVEL, DAMP TO MOIST *(continued)*		95, 96	9 / 13 / 20	43	100	SS-24	4.50	-	-	-	-	-	-	-	-	11	A-4a (V)	-	
		97, 98, 99, 100, 101	5 / 9 / 16	33	100	SS-25	3.00	-	-	-	-	-	-	-	-	16	A-4a (V)	-	
		102, 103, 104, 105, 106	7 / 10 / 19	38	100	SS-26	2.75	-	-	-	-	-	-	-	-	12	A-4a (V)	-	
	799.5	107, 108, 109, 110, 111, 112, 113	10 / 16 / 22	50	100	SS-27	4.50	-	-	-	-	-	-	-	-	11	A-4a (V)	-	
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS**, LITTLE SAND, TRACE SILT, TRACE CLAY, WET	795.3	114, 115, 116, 117	8 / 20 / 41	80	33	SS-28	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	-	
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND, SILT, AND CLAY**, DAMP	792.8	118, 119, EOB 120	10 / 39 / 49	116	39	SS-29	-	-	-	-	-	-	-	-	-	11	A-2-6 (V)	-	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; PUMPED 250 GAL. BENTONITE GROUT

NEAS
National Engineering & Architectural Services Inc.

5710 Westbourne Avenue
Columbus, OH 43213
614.892.0162

Consolidation Test

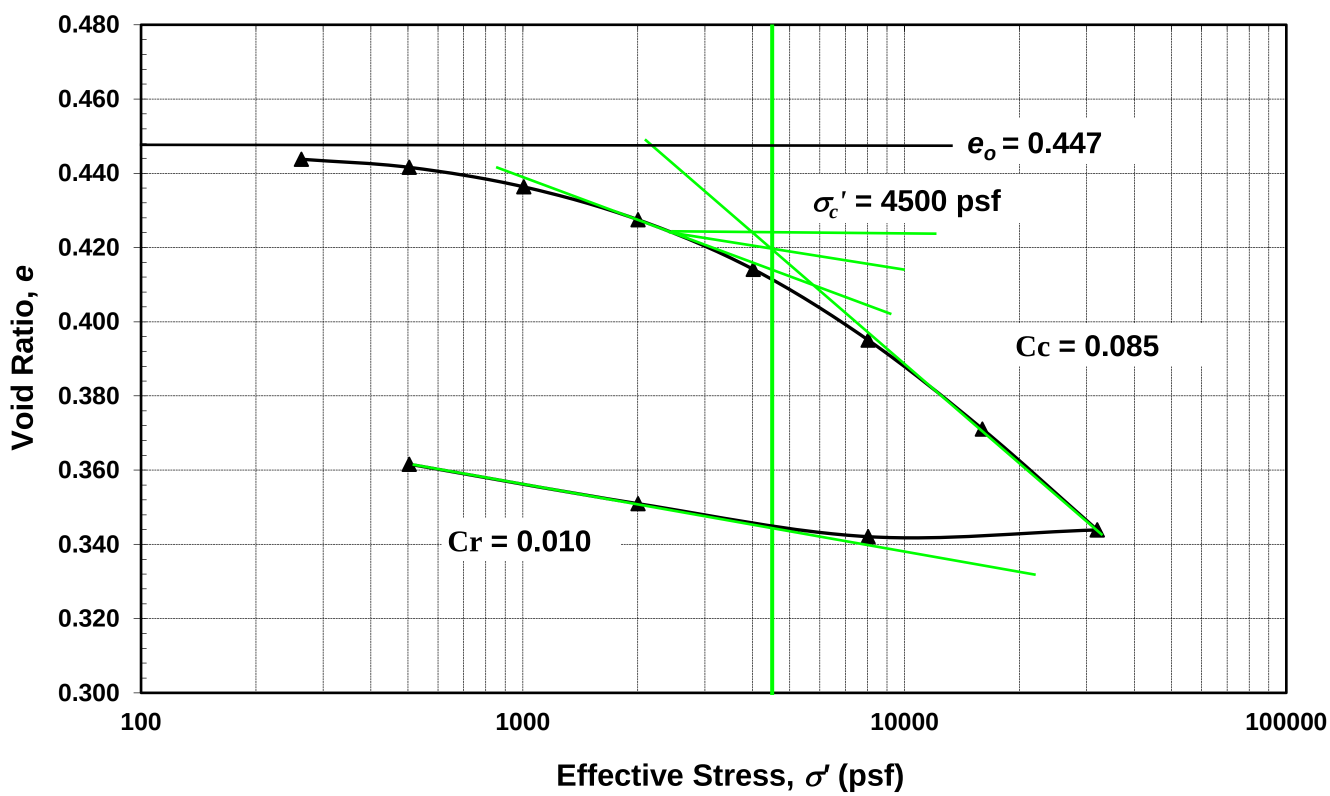
Project Name:	FRA-71/270-28.71/25.99	Prepared by:	LR
Source:	B-038-0-21 ST-1 (15.5'-15.6')	Checked by:	ZM
Description:	Hard, brown, SANDY SILT, some clay, trace gravel, damp.	Date:	8/22/2022

Test Specification:	ASTM D 2435		
Initial Void Ratio:	0.447	Initial Bulk Unit Weight (lb/ft^3):	133
In-situ Vertical Effective Stress (psf):	1900	Dry Unit Weight (lb/ft^3):	116

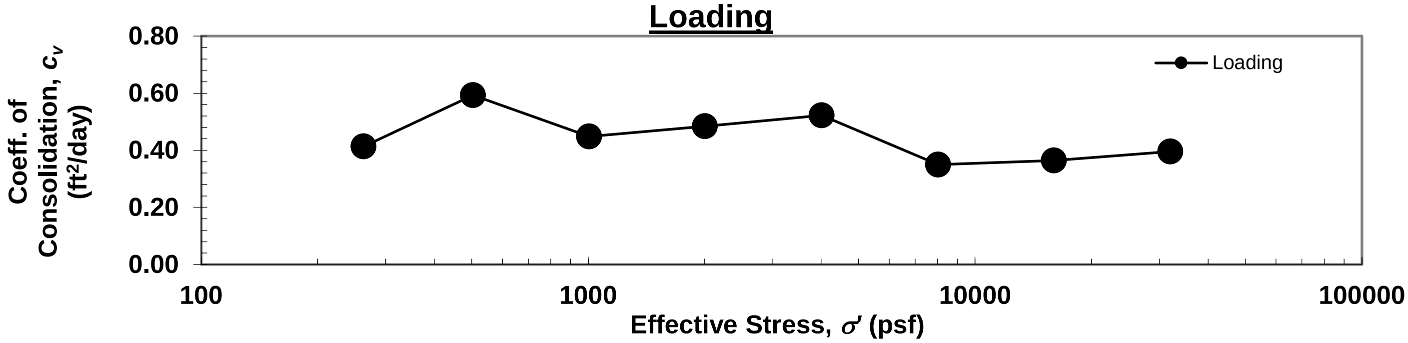
Compression and Swelling Index

Compression Index (*Cc*):	0.085	Preconsolidation Pressure (σ_c') (psf):	**4500**
Recompression Index (*Cr*):	0.010	Over-Consolidation Ratio (*OCR*) (psf):	**2.4**

Consolidation Curve



Loading

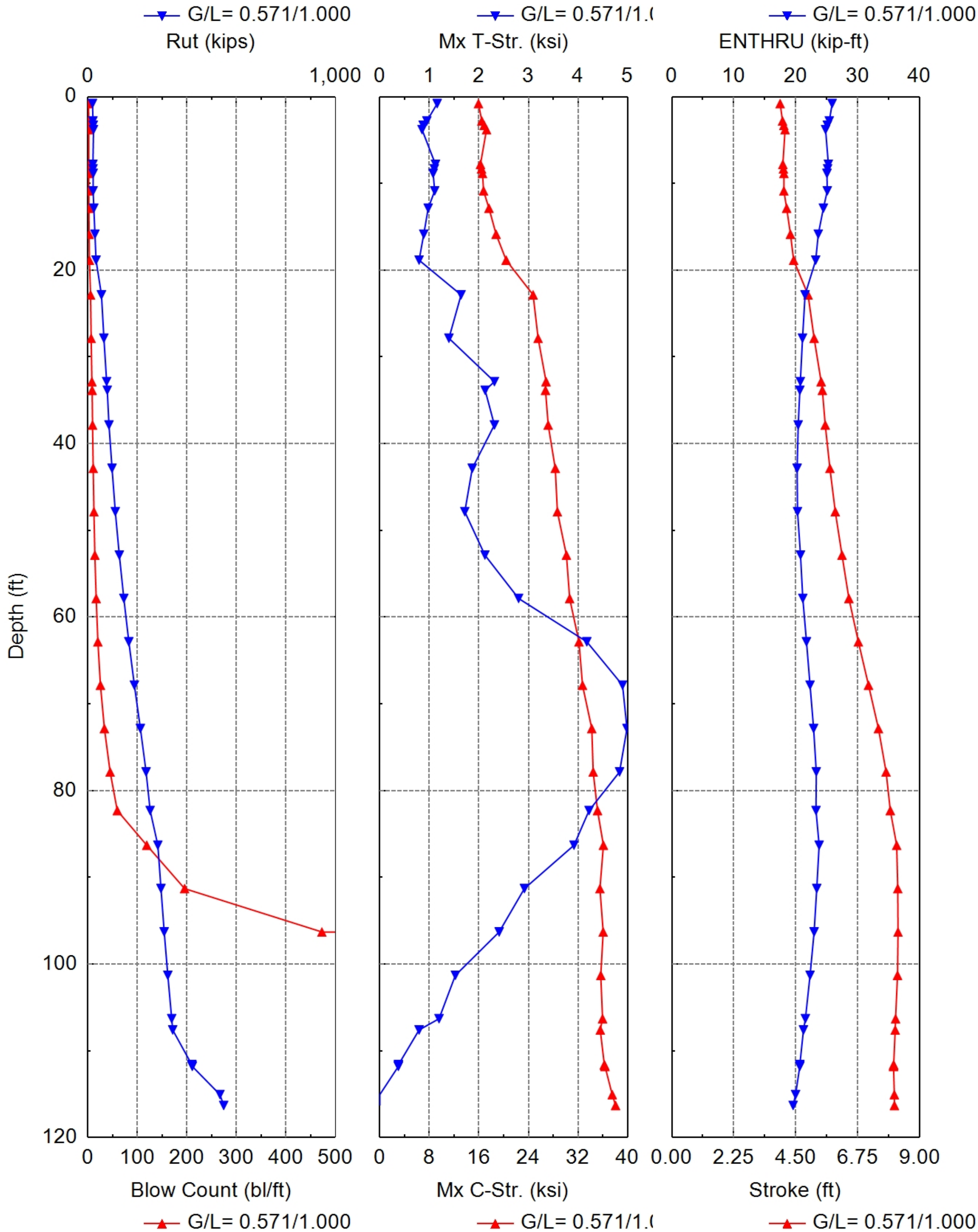


APPENDIX C

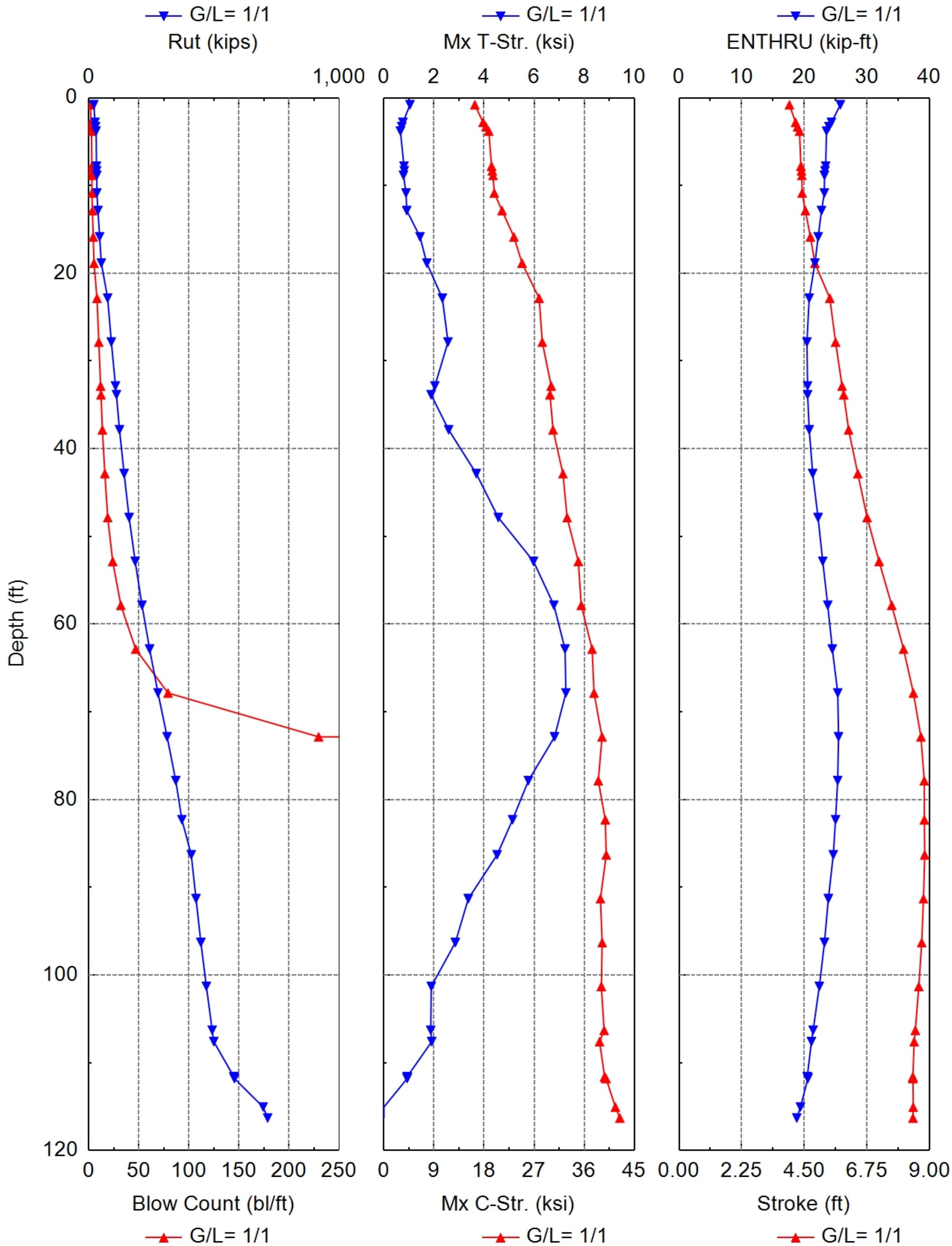
DEEP FOUNDATION ANALYSIS

REAR ABUTMENT

Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.571/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
0.8	18.9	1.9	17.0	1.5	15.928	1.159	3.94	25.9	D 19-32
2.8	20.5	6.7	13.8	1.7	16.469	0.950	4.02	25.4	D 19-32
3.3	21.7	7.9	13.8	1.9	16.844	0.875	4.07	25.1	D 19-32
3.8	22.9	9.1	13.8	2.0	17.232	0.852	4.12	24.8	D 19-32
7.8	20.4	14.6	5.8	1.8	16.247	1.123	4.04	25.3	D 19-32
8.3	21.0	14.8	6.2	1.9	16.419	1.100	4.06	25.2	D 19-32
8.8	21.6	15.0	6.6	1.9	16.583	1.076	4.07	25.1	D 19-32
10.9	21.2	15.9	5.3	1.9	16.749	1.107	4.07	25.1	D 19-32
12.9	24.2	18.9	5.3	2.2	17.628	0.977	4.17	24.5	D 19-32
15.9	28.7	23.4	5.3	2.6	18.775	0.887	4.31	23.7	D 19-32
18.9	33.1	27.8	5.3	3.1	20.406	0.793	4.43	23.2	D 19-32
22.9	54.9	34.8	20.1	5.5	24.754	1.640	4.95	21.5	D 19-32
27.9	64.8	44.6	20.1	6.7	25.560	1.395	5.17	21.1	D 19-32
32.9	75.7	55.6	20.1	8.2	26.845	2.313	5.43	20.8	D 19-32
33.9	78.3	58.2	20.1	8.6	26.749	2.126	5.47	20.7	D 19-32
37.9	85.3	68.7	16.6	9.5	27.188	2.313	5.58	20.4	D 19-32
42.9	97.6	81.0	16.6	10.8	28.331	1.866	5.75	20.2	D 19-32
47.9	110.8	94.2	16.6	12.3	28.677	1.715	5.94	20.3	D 19-32
52.9	127.0	110.4	16.6	14.1	30.133	2.121	6.18	20.8	D 19-32
57.9	145.2	128.6	16.6	16.8	30.655	2.802	6.44	21.2	D 19-32
62.9	165.5	148.9	16.6	20.3	32.162	4.179	6.78	21.8	D 19-32
67.9	187.8	171.2	16.6	25.4	32.730	4.900	7.15	22.3	D 19-32
72.9	212.1	195.5	16.6	33.4	34.227	4.989	7.51	22.9	D 19-32
77.9	235.1	218.5	16.6	45.0	34.456	4.839	7.79	23.3	D 19-32
82.3	251.5	234.9	16.6	59.4	35.154	4.223	7.94	23.3	D 19-32
86.3	282.6	247.3	35.3	118.9	36.105	3.919	8.17	23.8	D 19-32
91.3	295.2	259.8	35.3	195.3	35.544	2.918	8.21	23.4	D 19-32
96.3	308.2	272.9	35.3	472.4	36.071	2.409	8.22	23.0	D 19-32
101.3	322.8	287.5	35.3	9999.0	35.679	1.525	8.20	22.3	D 19-32
106.3	338.4	303.1	35.3	9999.0	35.964	1.195	8.13	21.6	D 19-32
107.6	342.6	307.3	35.3	9999.0	35.599	0.792	8.12	21.3	D 19-32
111.6	419.5	335.0	84.5	9999.0	36.255	0.376	8.06	20.7	D 19-32
111.7	420.6	336.1	84.5	9999.0	36.312	0.375	8.06	20.7	D 19-32
111.8	421.7	337.2	84.5	9999.0	36.363	0.374	8.06	20.7	D 19-32
115.1	533.3	373.6	159.6	9999.0	37.530	0.000	8.09	20.0	D 19-32
116.3	548.4	388.7	159.6	9999.0	38.070	0.000	8.09	19.6	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
0.8	19.9	2.9	17.0	1.6	16.349	1.043	3.97	25.8	D 19-32
2.8	25.1	11.3	13.8	2.2	17.817	0.759	4.19	24.4	D 19-32
3.3	27.2	13.4	13.8	2.5	18.350	0.716	4.26	24.0	D 19-32
3.8	29.3	15.5	13.8	2.7	18.849	0.658	4.33	23.6	D 19-32
7.8	30.7	24.9	5.8	3.0	19.349	0.801	4.38	23.4	D 19-32
8.3	31.4	25.2	6.2	3.1	19.479	0.814	4.40	23.3	D 19-32
8.8	32.0	25.5	6.6	3.1	19.615	0.781	4.42	23.2	D 19-32
10.9	32.2	26.9	5.3	3.1	19.832	0.882	4.43	23.2	D 19-32
12.9	36.6	31.3	5.3	3.6	21.244	0.914	4.54	22.8	D 19-32
15.9	43.3	38.0	5.3	4.4	23.364	1.443	4.72	22.2	D 19-32
18.9	50.0	44.7	5.3	5.2	24.832	1.713	4.88	21.7	D 19-32
22.9	75.3	55.1	20.1	8.2	27.898	2.335	5.42	20.8	D 19-32
27.9	90.1	70.0	20.1	10.0	28.469	2.559	5.63	20.4	D 19-32
32.9	106.5	86.4	20.1	11.8	30.070	2.035	5.86	20.5	D 19-32
33.9	110.5	90.3	20.1	12.2	29.852	1.885	5.92	20.5	D 19-32
37.9	122.6	106.0	16.6	13.6	30.404	2.587	6.10	20.8	D 19-32
42.9	141.0	124.4	16.6	16.0	32.180	3.691	6.43	21.4	D 19-32
47.9	161.0	144.4	16.6	18.9	32.926	4.570	6.76	22.2	D 19-32
52.9	185.2	168.6	16.6	23.9	34.939	5.976	7.19	23.0	D 19-32
57.9	212.6	195.9	16.6	32.0	35.474	6.789	7.65	23.8	D 19-32
62.9	242.9	226.3	16.6	46.8	37.420	7.236	8.07	24.5	D 19-32
67.9	276.4	259.8	16.6	79.1	37.766	7.268	8.43	25.4	D 19-32
72.9	312.9	296.3	16.6	229.5	39.202	6.817	8.70	25.5	D 19-32
77.9	347.3	330.7	16.6	9999.0	38.535	5.770	8.82	25.3	D 19-32
82.3	371.9	355.3	16.6	9999.0	39.785	5.139	8.82	25.0	D 19-32
86.3	409.3	373.9	35.3	9999.0	39.957	4.521	8.83	24.6	D 19-32
91.3	428.1	392.8	35.3	9999.0	38.912	3.372	8.79	23.9	D 19-32
96.3	447.7	412.4	35.3	9999.0	39.231	2.853	8.72	23.2	D 19-32
101.3	469.5	434.2	35.3	9999.0	39.077	1.893	8.62	22.4	D 19-32
106.3	492.9	457.6	35.3	9999.0	39.582	1.871	8.50	21.4	D 19-32
107.6	499.3	463.9	35.3	9999.0	38.765	1.909	8.45	21.2	D 19-32
111.6	579.5	495.0	84.5	9999.0	39.670	0.927	8.41	20.5	D 19-32
111.7	580.6	496.1	84.5	9999.0	39.775	0.936	8.40	20.6	D 19-32
111.8	581.7	497.1	84.5	9999.0	39.936	0.930	8.41	20.6	D 19-32
115.1	696.2	536.6	159.6	9999.0	41.604	0.000	8.42	19.4	D 19-32

116.3	714.3	554.7	159.6	9999.0	42.405	0.000	8.41	18.8	D 19-32

Refusal occurred; no driving time output possible.

Ramp O over IR71 + RB CIP12 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Clay	112.0	2.4	0.0	1.15	21.60
0.8	Clay	112.0	2.4	0.0	1.15	21.60
0.8	Clay	110.0	1.9	0.0	1.34	17.55
5.8	Clay	110.0	1.9	0.0	1.34	17.55
5.8	Sand	108.0	0.0	26.0	0.13	5.52
10.9	Sand	108.0	0.0	26.0	0.24	10.23
10.9	Clay	115.0	0.7	0.0	0.75	6.75
10.9	Clay	115.0	0.7	0.0	0.75	6.75
10.9	Clay	115.0	0.7	0.0	0.71	6.75
20.9	Clay	115.0	0.7	0.0	0.71	6.75
20.9	Clay	122.0	2.8	0.0	1.05	25.65
35.9	Clay	122.0	2.8	0.0	1.05	25.65
35.8	Clay	122.0	2.3	0.0	1.76	21.15
84.3	Clay	122.0	2.3	0.0	1.76	21.15
84.3	Clay	130.0	5.0	0.0	1.35	45.00
109.6	Clay	130.0	5.0	0.0	1.35	45.00
109.6	Sand	140.0	0.0	35.0	3.32	107.60
113.8	Sand	140.0	0.0	35.0	3.47	107.60
113.8	Sand	140.0	0.0	37.0	4.52	203.27
116.3	Sand	140.0	0.0	37.0	4.63	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	116.300	Pile Penetration: (ft)	116.300
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	9.2	30,000.0	492.0	3.1	0
116.3	9.2	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

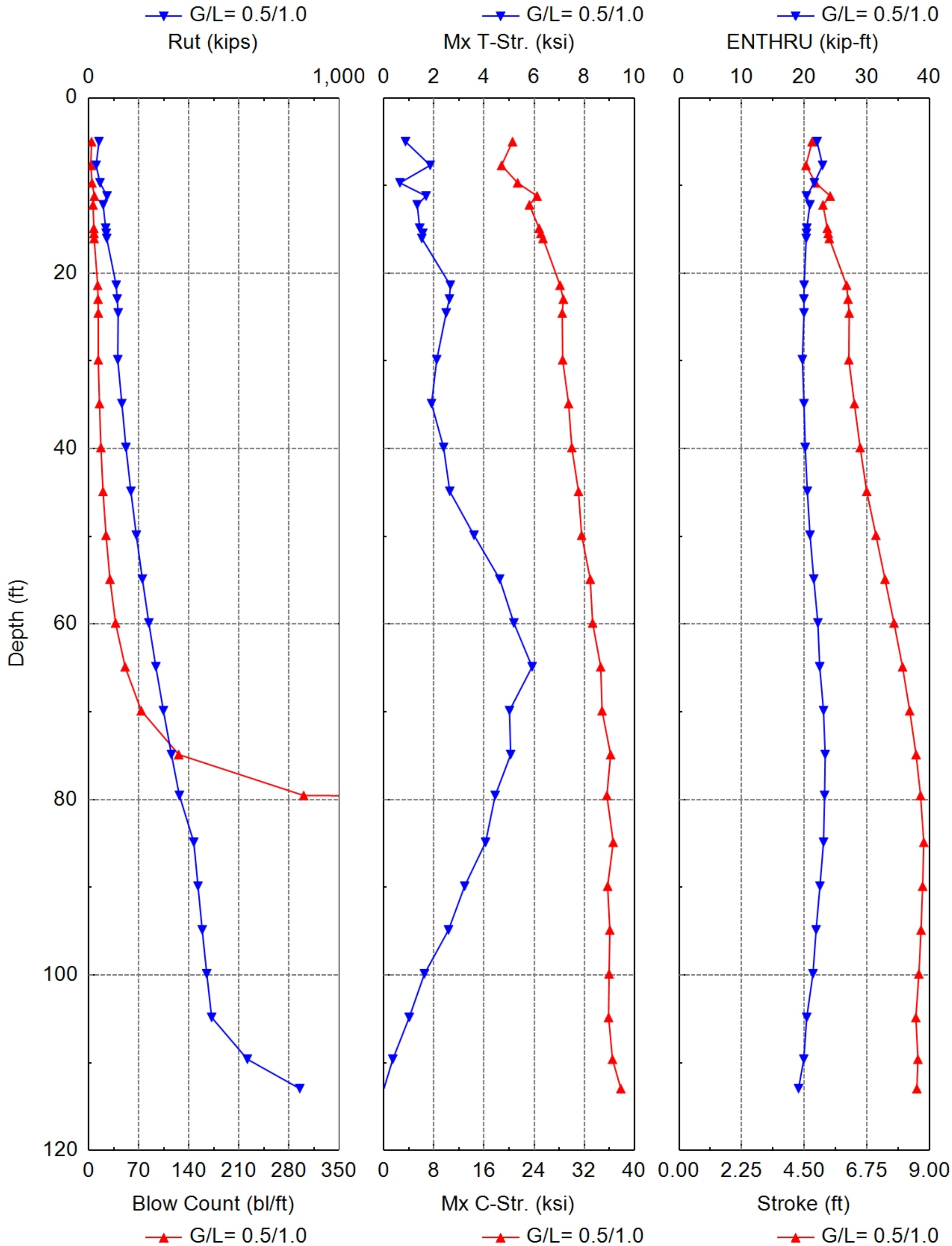
Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	1.2	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
0.8	1.2	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
0.8	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
2.5	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
4.1	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
5.8	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
5.8	0.1	5.5	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
7.5	0.2	7.1	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
9.2	0.2	8.7	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
10.9	0.2	10.2	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
10.9	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
10.9	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
10.9	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
12.5	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
14.2	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
15.9	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
17.5	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
19.2	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
20.9	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
20.9	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
22.5	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
24.2	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
25.9	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
27.5	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
29.2	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
30.9	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
32.5	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1

34.2	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
35.9	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
35.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
37.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
39.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
40.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
42.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
44.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
45.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
47.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
49.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
50.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
52.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
54.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
55.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
57.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
59.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
60.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
62.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
64.3	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
65.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
67.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
69.3	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
70.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
72.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
74.3	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
75.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
77.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
79.3	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
81.0	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
82.6	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
84.3	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
84.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
86.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
87.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
89.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
91.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
92.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
94.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
96.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1

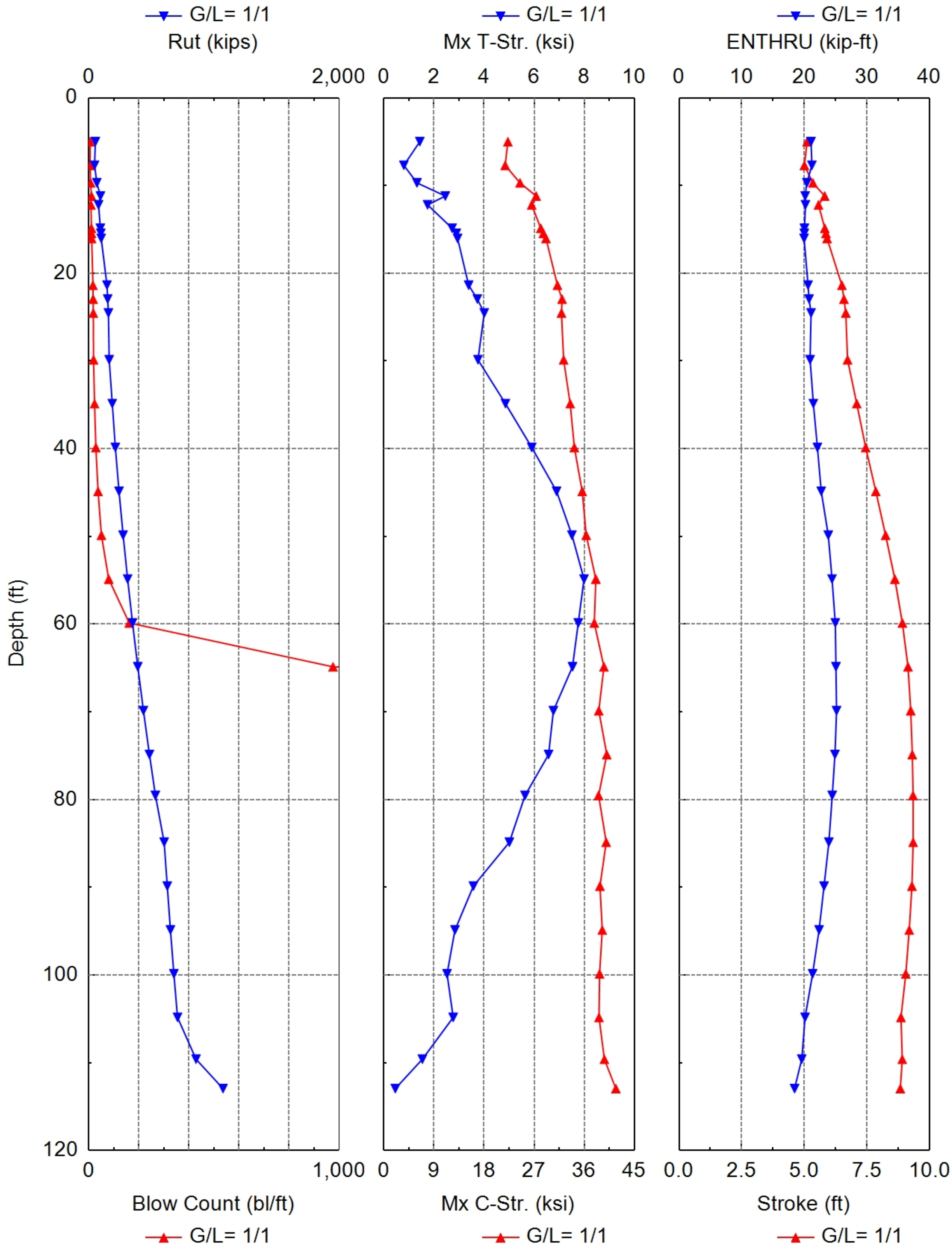
97.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
99.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
101.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
102.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
104.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
106.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
107.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
109.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
109.6	3.3	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
111.7	3.4	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
113.8	3.5	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
113.8	4.5	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
115.1	4.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
116.3	4.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1

Center Pier

Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.500/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	40.5	16.0	24.5	3.9	20.543	0.864	4.78	22.1	D 19-32
7.7	29.2	21.7	7.5	2.8	18.791	1.849	4.56	22.9	D 19-32
9.7	44.7	25.3	19.5	4.5	21.368	0.640	4.91	21.6	D 19-32
11.2	72.9	29.5	43.4	7.8	24.460	1.684	5.43	20.4	D 19-32
12.2	57.4	32.3	25.1	5.9	23.244	1.330	5.17	20.9	D 19-32
14.9	67.3	42.2	25.1	7.0	24.796	1.431	5.33	20.4	D 19-32
15.5	69.5	44.3	25.1	7.3	25.079	1.554	5.36	20.4	D 19-32
16.0	71.6	46.5	25.1	7.5	25.420	1.514	5.40	20.3	D 19-32
21.4	109.4	62.9	46.5	12.4	28.140	2.653	6.02	20.0	D 19-32
23.0	113.4	66.9	46.5	12.9	28.669	2.617	6.07	19.9	D 19-32
24.5	117.3	70.8	46.5	13.3	28.487	2.488	6.12	20.0	D 19-32
29.9	115.7	86.2	29.5	13.2	28.556	2.110	6.10	19.7	D 19-32
34.9	132.1	102.6	29.5	14.9	29.506	1.902	6.30	20.0	D 19-32
39.9	148.5	119.0	29.5	17.0	30.014	2.384	6.51	20.2	D 19-32
44.9	168.0	138.5	29.5	19.9	31.084	2.631	6.75	20.5	D 19-32
49.9	189.9	160.4	29.5	24.1	31.586	3.599	7.08	20.9	D 19-32
54.9	213.9	184.4	29.5	29.6	32.964	4.625	7.40	21.5	D 19-32
59.9	239.9	210.3	29.5	37.4	33.345	5.190	7.73	22.2	D 19-32
64.9	267.9	238.4	29.5	50.8	34.638	5.919	8.03	22.5	D 19-32
69.9	298.0	268.4	29.5	73.3	34.847	5.014	8.29	23.1	D 19-32
74.9	330.1	300.6	29.5	125.7	36.222	5.064	8.52	23.3	D 19-32
79.5	361.9	332.4	29.5	300.4	35.624	4.446	8.68	23.3	D 19-32
84.9	419.4	356.5	62.8	9999.0	36.637	4.063	8.80	23.1	D 19-32
89.9	436.1	373.3	62.8	9999.0	35.748	3.225	8.76	22.5	D 19-32
94.9	452.9	390.1	62.8	9999.0	36.092	2.580	8.70	21.9	D 19-32
99.9	471.2	408.4	62.8	9999.0	35.976	1.620	8.62	21.4	D 19-32
104.8	490.7	427.9	62.8	9999.0	35.897	1.011	8.51	20.4	D 19-32
109.6	633.2	483.0	150.2	9999.0	36.515	0.357	8.59	19.9	D 19-32
113.0	842.7	558.9	283.8	9999.0	37.853	0.000	8.55	19.1	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	52.5	28.0	24.5	5.6	22.281	1.434	5.12	21.1	D 19-32
7.7	46.0	38.4	7.5	4.9	21.794	0.797	5.01	21.2	D 19-32

9.7	64.2	44.7	19.5	7.1	24.462	1.321	5.35	20.4	D 19-32
11.2	93.2	49.8	43.4	10.7	27.361	2.452	5.82	20.2	D 19-32
12.2	77.7	52.6	25.1	8.6	26.558	1.745	5.57	20.2	D 19-32
14.9	92.6	67.5	25.1	10.6	28.197	2.726	5.82	20.0	D 19-32
15.5	95.8	70.7	25.1	11.0	28.657	2.891	5.87	20.0	D 19-32
16.0	99.0	73.9	25.1	11.4	29.131	2.943	5.91	20.0	D 19-32
21.4	145.1	98.6	46.5	16.6	31.190	3.386	6.51	20.6	D 19-32
23.0	151.0	104.5	46.5	17.3	32.026	3.734	6.59	20.8	D 19-32
24.5	156.9	110.4	46.5	18.0	31.914	4.008	6.66	21.1	D 19-32
29.9	162.9	133.4	29.5	18.9	32.297	3.757	6.73	20.9	D 19-32
34.9	187.5	158.0	29.5	23.0	33.480	4.855	7.10	21.5	D 19-32
39.9	212.1	182.6	29.5	28.2	34.230	5.906	7.46	22.1	D 19-32
44.9	241.4	211.9	29.5	37.0	35.645	6.898	7.86	22.7	D 19-32
49.9	274.3	244.8	29.5	50.5	36.363	7.512	8.25	23.8	D 19-32
54.9	310.2	280.7	29.5	79.6	38.089	7.992	8.62	24.4	D 19-32
59.9	349.2	319.7	29.5	161.5	37.816	7.763	8.92	25.0	D 19-32
64.9	391.3	361.7	29.5	975.5	39.545	7.531	9.15	25.1	D 19-32
69.9	436.4	406.8	29.5	9999.0	38.616	6.770	9.25	25.2	D 19-32
74.9	484.5	455.0	29.5	9999.0	40.056	6.578	9.32	24.9	D 19-32
79.5	532.3	502.7	29.5	9999.0	38.586	5.637	9.35	24.5	D 19-32
84.9	601.8	539.0	62.8	9999.0	39.956	5.011	9.35	23.9	D 19-32
89.9	626.9	564.1	62.8	9999.0	38.826	3.574	9.30	23.2	D 19-32
94.9	652.1	589.2	62.8	9999.0	39.249	2.839	9.20	22.4	D 19-32
99.9	679.6	616.8	62.8	9999.0	38.764	2.522	9.06	21.3	D 19-32
104.8	708.8	646.0	62.8	9999.0	38.658	2.767	8.86	20.1	D 19-32
109.6	856.8	706.5	150.2	9999.0	39.628	1.536	8.92	19.6	D 19-32
113.0	1072.3	788.5	283.8	9999.0	41.685	0.455	8.84	18.5	D 19-32

Refusal occurred; no driving time output possible.

GRLWEAP: Wave Equation Analysis of Pile Foundations

Ramp O over IR71 + CP CIP16 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth	Soil Type	Spec. Wt	Su	Phi	Unit Rs	Unit Rt
ft	-	lb/ft³	ksf	°	ksf	ksf
0.0	Clay	110.0	1.9	0.0	1.34	17.55
6.2	Clay	110.0	1.9	0.0	1.34	17.55
6.2	Clay	105.0	0.6	0.0	0.58	5.40
9.2	Clay	105.0	0.6	0.0	0.58	5.40
9.2	Clay	110.0	1.5	0.0	1.25	13.95
10.2	Clay	110.0	1.5	0.0	1.25	13.95
10.2	Sand	115.0	0.0	32.0	0.57	28.14
12.2	Sand	115.0	0.0	32.0	0.69	33.09
12.2	Clay	120.0	2.0	0.0	2.00	18.00
12.2	Clay	120.0	2.0	0.0	2.00	18.00
12.2	Clay	120.0	2.0	0.0	1.32	18.00
18.7	Clay	120.0	2.0	0.0	1.32	18.00
18.7	Clay	128.0	3.7	0.0	0.89	33.30
27.2	Clay	128.0	3.7	0.0	0.89	33.30
27.2	Clay	122.0	2.3	0.0	1.76	21.15
82.2	Clay	122.0	2.3	0.0	1.76	21.15
82.2	Clay	130.0	5.0	0.0	1.29	45.00
107.5	Clay	130.0	5.0	0.0	1.29	45.00
107.5	Sand	140.0	0.0	35.0	4.98	107.60
111.7	Sand	140.0	0.0	35.0	5.20	107.60
111.7	Sand	140.0	0.0	37.0	6.97	203.27
114.2	Sand	140.0	0.0	37.0	7.14	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	114.200	Pile Penetration: (ft)	114.200
Pile Size: (ft)	1.33	Toe Area: (in²)	201.06

Pile Profile

Lb Top	X-Area	E-Modulus	Spec. Wt	Perim.	Crit. Index
ft	in²	ksi	lb/ft³	ft	-
0.0	12.4	30,000.0	492.0	4.2	0
114.2	12.4	30,000.0	492.0	4.2	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	415.000	530.000	2.000	0.800	0.120	109976.010
Helmet Wt.	3.400	kips				

SOIL RESISTANCE DISTRIBUTION

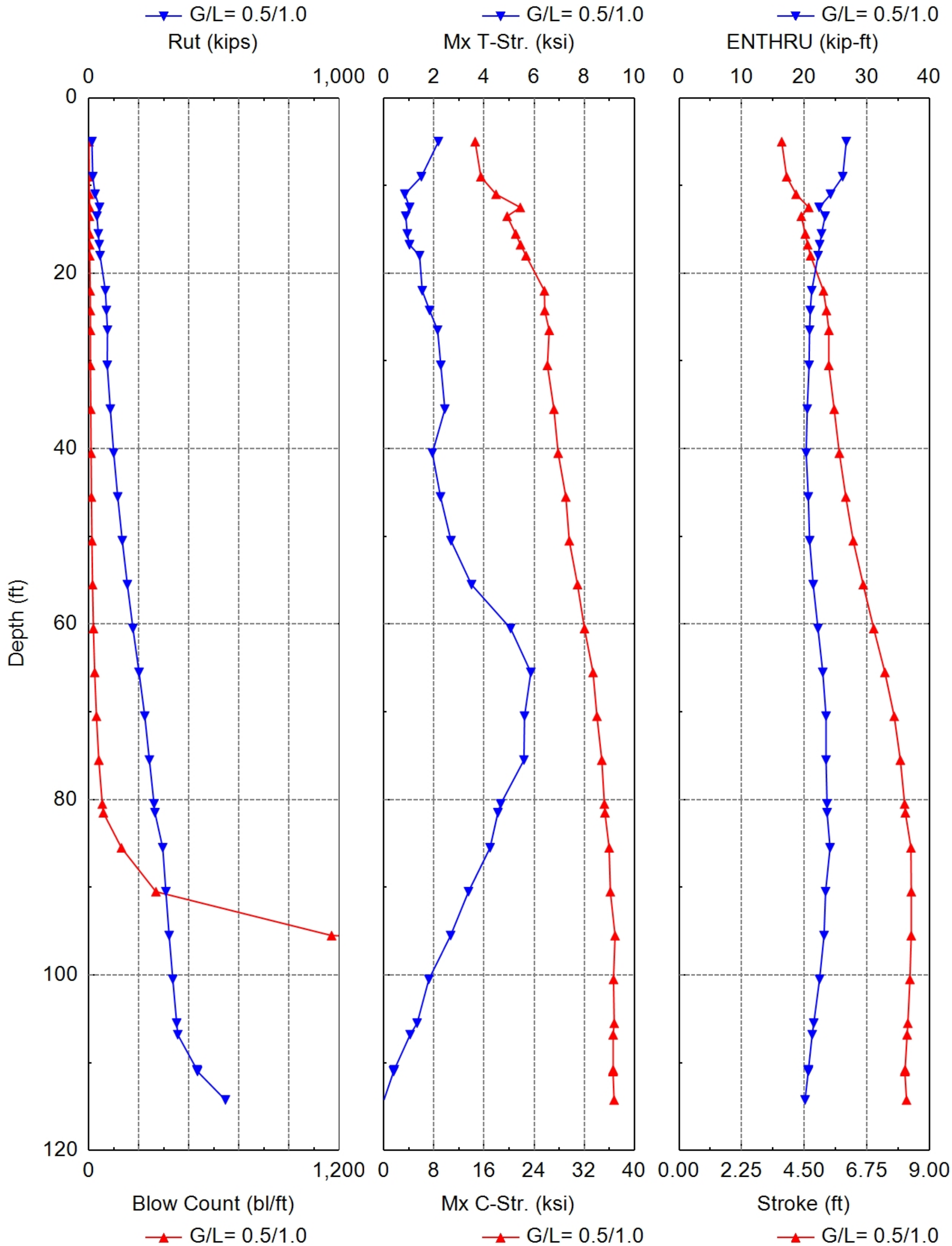
Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	1.3	17.5	0.10	0.16	0.20	0.15	1.8	6.0	168.0	201.1
2.1	1.3	17.5	0.10	0.16	0.20	0.15	1.8	6.0	168.0	201.1
4.1	1.3	17.5	0.10	0.16	0.20	0.15	1.8	6.0	168.0	201.1
6.2	1.3	17.5	0.10	0.16	0.20	0.15	1.8	6.0	168.0	201.1
6.2	0.6	5.4	0.10	0.21	0.20	0.15	2.0	6.0	168.0	201.1
7.7	0.6	5.4	0.10	0.21	0.20	0.15	2.0	6.0	168.0	201.1
9.2	0.6	5.4	0.10	0.21	0.20	0.15	2.0	6.0	168.0	201.1
9.2	1.3	13.9	0.10	0.17	0.15	0.15	1.5	6.0	168.0	201.1
10.2	1.3	13.9	0.10	0.17	0.15	0.15	1.5	6.0	168.0	201.1
10.2	0.6	28.1	0.10	0.18	0.05	0.15	1.0	6.0	1.0	201.1
11.2	0.6	31.1	0.10	0.18	0.05	0.15	1.0	6.0	1.0	201.1
12.2	0.7	33.1	0.10	0.18	0.05	0.15	1.0	6.0	1.0	201.1
12.2	2.0	18.0	0.10	0.16	0.15	0.15	1.5	6.0	168.0	201.1
12.2	2.0	18.0	0.10	0.16	0.15	0.15	1.5	6.0	168.0	201.1
12.2	1.3	18.0	0.10	0.16	0.15	0.15	1.5	6.0	168.0	201.1
14.4	1.3	18.0	0.10	0.16	0.15	0.15	1.5	6.0	168.0	201.1
16.5	1.3	18.0	0.10	0.16	0.15	0.15	1.5	6.0	168.0	201.1
18.7	1.3	18.0	0.10	0.16	0.15	0.15	1.5	6.0	168.0	201.1
18.7	0.9	33.3	0.10	0.14	0.15	0.15	1.5	6.0	168.0	201.1
20.4	0.9	33.3	0.10	0.14	0.15	0.15	1.5	6.0	168.0	201.1
22.1	0.9	33.3	0.10	0.14	0.15	0.15	1.5	6.0	168.0	201.1
23.8	0.9	33.3	0.10	0.14	0.15	0.15	1.5	6.0	168.0	201.1
25.5	0.9	33.3	0.10	0.14	0.15	0.15	1.5	6.0	168.0	201.1
27.2	0.9	33.3	0.10	0.14	0.15	0.15	1.5	6.0	168.0	201.1
27.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1

28.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
30.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
32.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
33.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
35.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
37.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
38.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
40.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
42.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
43.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
45.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
47.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
48.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
50.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
52.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
53.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
55.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
57.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
58.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
60.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
62.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
63.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
65.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
67.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
68.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
70.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
72.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
73.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
75.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
77.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
78.9	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
80.5	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
82.2	1.8	21.1	0.10	0.15	0.15	0.15	1.5	6.0	168.0	201.1
82.2	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
83.9	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
85.6	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
87.3	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
88.9	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
90.6	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
92.3	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1

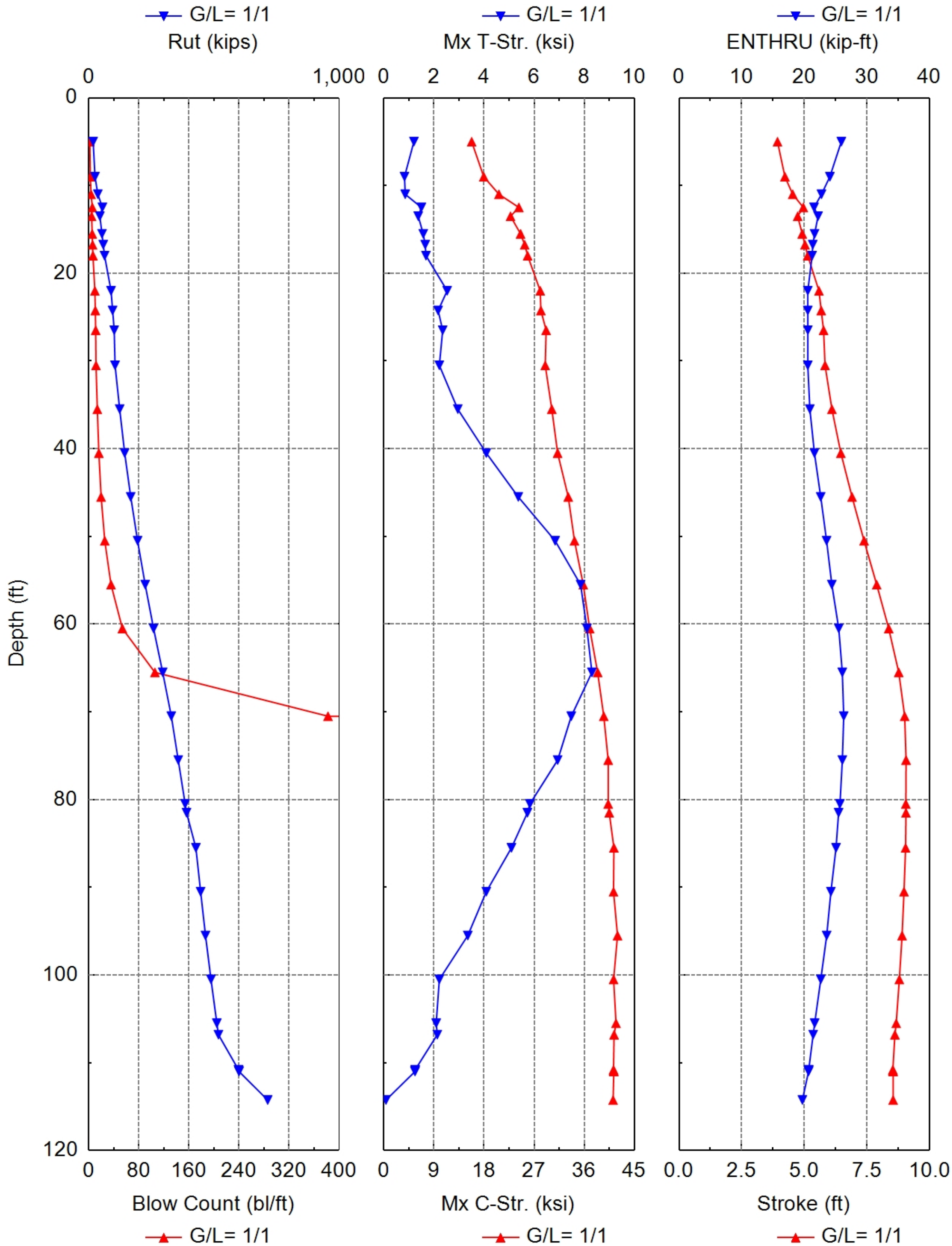
94.0	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
95.7	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
97.4	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
99.1	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
100.8	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
102.4	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
104.1	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
105.8	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
107.5	1.3	45.0	0.10	0.13	0.15	0.15	1.5	6.0	168.0	201.1
107.5	5.0	107.6	0.10	0.14	0.05	0.15	1.0	6.0	1.0	201.1
109.6	5.1	107.6	0.10	0.14	0.05	0.15	1.0	6.0	1.0	201.1
111.7	5.2	107.6	0.10	0.14	0.05	0.15	1.0	6.0	1.0	201.1
111.7	7.0	203.3	0.10	0.13	0.10	0.15	1.2	6.0	24.0	201.1
113.0	7.1	203.3	0.10	0.13	0.10	0.15	1.2	6.0	24.0	201.1
114.2	7.1	203.3	0.10	0.13	0.10	0.15	1.2	6.0	24.0	201.1

Forward Abutment

Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.500/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	12.4	6.8	5.7	1.1	14.581	2.177	3.69	26.7	D 19-32
9.0	15.7	11.5	4.2	1.4	15.488	1.496	3.87	26.2	D 19-32
11.0	25.1	14.2	11.0	2.3	17.923	0.835	4.21	24.2	D 19-32
12.5	42.9	16.9	26.0	4.2	21.790	1.030	4.66	22.4	D 19-32
13.5	32.6	18.4	14.1	3.0	19.691	0.873	4.40	23.3	D 19-32
15.5	38.2	24.0	14.1	3.6	21.049	0.934	4.54	22.8	D 19-32
16.8	41.6	27.5	14.1	4.0	21.827	1.022	4.62	22.5	D 19-32
18.0	45.1	30.9	14.1	4.4	22.703	1.425	4.73	22.2	D 19-32
22.0	66.3	40.2	26.2	6.9	25.640	1.532	5.19	21.2	D 19-32
24.3	70.5	44.4	26.2	7.4	25.690	1.827	5.30	21.0	D 19-32
26.5	74.7	48.6	26.2	8.0	26.406	2.144	5.39	20.9	D 19-32
30.5	73.8	57.2	16.6	7.9	26.127	2.274	5.38	20.8	D 19-32
35.5	86.1	69.5	16.6	9.5	27.161	2.434	5.58	20.5	D 19-32
40.5	99.4	82.8	16.6	11.0	27.838	1.937	5.76	20.3	D 19-32
45.5	115.6	99.0	16.6	12.6	29.069	2.262	6.00	20.7	D 19-32
50.5	133.8	117.2	16.6	15.0	29.613	2.680	6.26	20.9	D 19-32
55.5	154.0	137.4	16.6	18.0	30.931	3.499	6.62	21.4	D 19-32
60.5	176.3	159.7	16.6	22.0	32.040	5.062	7.00	22.2	D 19-32
65.5	200.7	184.1	16.6	28.2	33.409	5.869	7.40	23.0	D 19-32
70.5	223.6	207.0	16.6	36.7	34.037	5.615	7.73	23.5	D 19-32
75.5	242.1	225.5	16.6	48.0	34.813	5.594	7.96	23.5	D 19-32
80.5	260.5	243.9	16.6	64.8	35.220	4.665	8.11	23.7	D 19-32
81.5	264.2	247.6	16.6	69.7	35.312	4.553	8.14	23.7	D 19-32
85.5	295.3	260.0	35.3	156.4	35.985	4.239	8.34	24.1	D 19-32
90.5	307.9	272.5	35.3	321.8	36.173	3.378	8.35	23.4	D 19-32
95.5	320.9	285.6	35.3	1163.8	36.932	2.664	8.35	23.2	D 19-32
100.5	335.5	300.1	35.3	9999.0	36.683	1.796	8.30	22.5	D 19-32
105.5	351.1	315.7	35.3	9999.0	36.793	1.327	8.23	21.5	D 19-32
106.8	355.3	320.0	35.3	9999.0	36.627	1.049	8.20	21.3	D 19-32
110.8	432.1	347.6	84.5	9999.0	36.628	0.415	8.13	20.7	D 19-32
110.9	433.2	348.7	84.5	9999.0	36.621	0.393	8.12	20.7	D 19-32
111.0	434.3	349.8	84.5	9999.0	36.597	0.389	8.12	20.6	D 19-32
114.3	545.7	386.1	159.6	9999.0	36.772	0.000	8.18	20.1	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	17.5	11.8	5.7	1.6	15.771	1.199	3.93	25.9	D 19-32
9.0	24.7	20.5	4.2	2.4	17.944	0.822	4.23	24.1	D 19-32
11.0	36.1	25.2	11.0	3.6	20.682	0.852	4.54	22.8	D 19-32
12.5	54.5	28.6	26.0	5.7	24.256	1.497	4.96	21.6	D 19-32
13.5	44.3	30.1	14.1	4.5	22.759	1.371	4.74	22.2	D 19-32
15.5	52.6	38.5	14.1	5.4	24.562	1.572	4.92	21.7	D 19-32
16.8	57.8	43.7	14.1	6.0	25.306	1.650	5.03	21.4	D 19-32
18.0	63.0	48.8	14.1	6.6	25.836	1.680	5.14	21.3	D 19-32
22.0	88.9	62.7	26.2	9.7	28.094	2.526	5.59	20.6	D 19-32
24.3	95.2	69.0	26.2	10.4	28.218	2.166	5.68	20.6	D 19-32
26.5	101.4	75.3	26.2	11.0	29.156	2.348	5.77	20.6	D 19-32
30.5	104.9	88.2	16.6	11.5	28.992	2.215	5.83	20.6	D 19-32
35.5	123.3	106.7	16.6	13.6	30.176	2.951	6.11	20.9	D 19-32
40.5	143.2	126.6	16.6	16.1	31.223	4.089	6.46	21.6	D 19-32
45.5	167.5	150.9	16.6	19.7	33.137	5.368	6.91	22.6	D 19-32
50.5	194.8	178.2	16.6	25.5	34.249	6.839	7.39	23.6	D 19-32
55.5	225.2	208.6	16.6	35.5	35.830	7.857	7.90	24.4	D 19-32
60.5	258.7	242.1	16.6	53.7	36.984	8.107	8.38	25.5	D 19-32
65.5	295.2	278.6	16.6	105.6	38.413	8.308	8.78	26.1	D 19-32
70.5	329.6	313.0	16.6	382.2	39.515	7.484	9.01	26.3	D 19-32
75.5	357.2	340.6	16.6	9999.0	40.315	6.939	9.07	26.1	D 19-32
80.5	384.9	368.3	16.6	9999.0	40.317	5.830	9.06	25.7	D 19-32
81.5	390.4	373.8	16.6	9999.0	40.495	5.732	9.06	25.5	D 19-32
85.5	427.7	392.4	35.3	9999.0	41.334	5.094	9.05	25.1	D 19-32
90.5	446.6	411.2	35.3	9999.0	41.272	4.092	8.99	24.3	D 19-32
95.5	466.2	430.8	35.3	9999.0	41.990	3.351	8.91	23.6	D 19-32
100.5	488.0	452.7	35.3	9999.0	41.282	2.214	8.80	22.6	D 19-32
105.5	511.4	476.1	35.3	9999.0	41.721	2.088	8.68	21.7	D 19-32
106.8	517.8	482.4	35.3	9999.0	41.373	2.133	8.62	21.4	D 19-32
110.8	597.9	513.4	84.5	9999.0	41.268	1.249	8.54	20.7	D 19-32
110.9	599.0	514.4	84.5	9999.0	41.297	1.246	8.54	20.7	D 19-32
111.0	600.0	515.5	84.5	9999.0	41.321	1.242	8.55	20.7	D 19-32
114.3	714.4	554.8	159.6	9999.0	41.190	0.082	8.55	19.7	D 19-32

Refusal occurred; no driving time output possible.

GRLWEAP: Wave Equation Analysis of Pile Foundations

Ramp O over IR71 + FB CIP12 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth	Soil Type	Spec. Wt	Su	Phi	Unit Rs	Unit Rt
ft	-	lb/ft³	ksf	°	ksf	ksf
0.0	Clay	108.0	0.8	0.0	0.75	7.20
7.5	Clay	108.0	0.8	0.0	0.75	7.20
7.5	Clay	105.0	0.6	0.0	0.58	5.40
10.5	Clay	105.0	0.6	0.0	0.58	5.40
10.5	Clay	110.0	1.5	0.0	1.25	13.95
11.5	Clay	110.0	1.5	0.0	1.25	13.95
11.5	Sand	115.0	0.0	32.0	0.43	31.40
13.5	Sand	115.0	0.0	32.0	0.51	33.09
13.5	Clay	120.0	2.0	0.0	2.00	18.00
13.5	Clay	120.0	2.0	0.0	2.00	18.00
13.5	Clay	120.0	2.0	0.0	1.32	18.00
20.0	Clay	120.0	2.0	0.0	1.32	18.00
20.0	Clay	128.0	3.7	0.0	0.89	33.30
28.5	Clay	128.0	3.7	0.0	0.89	33.30
28.5	Clay	122.0	2.3	0.0	1.76	21.15
83.5	Clay	122.0	2.3	0.0	1.76	21.15
83.5	Clay	130.0	5.0	0.0	1.35	45.00
108.8	Clay	130.0	5.0	0.0	1.35	45.00
108.8	Sand	140.0	0.0	35.0	3.31	107.60
113.0	Sand	140.0	0.0	35.0	3.45	107.60
113.0	Sand	140.0	0.0	37.0	4.50	203.27
115.5	Sand	140.0	0.0	37.0	4.61	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	115.500	Pile Penetration: (ft)	115.500
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top	X-Area	E-Modulus	Spec. Wt	Perim.	Crit. Index
ft	in²	ksi	lb/ft³	ft	-
0.0	9.2	30,000.0	492.0	3.1	0
115.5	9.2	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

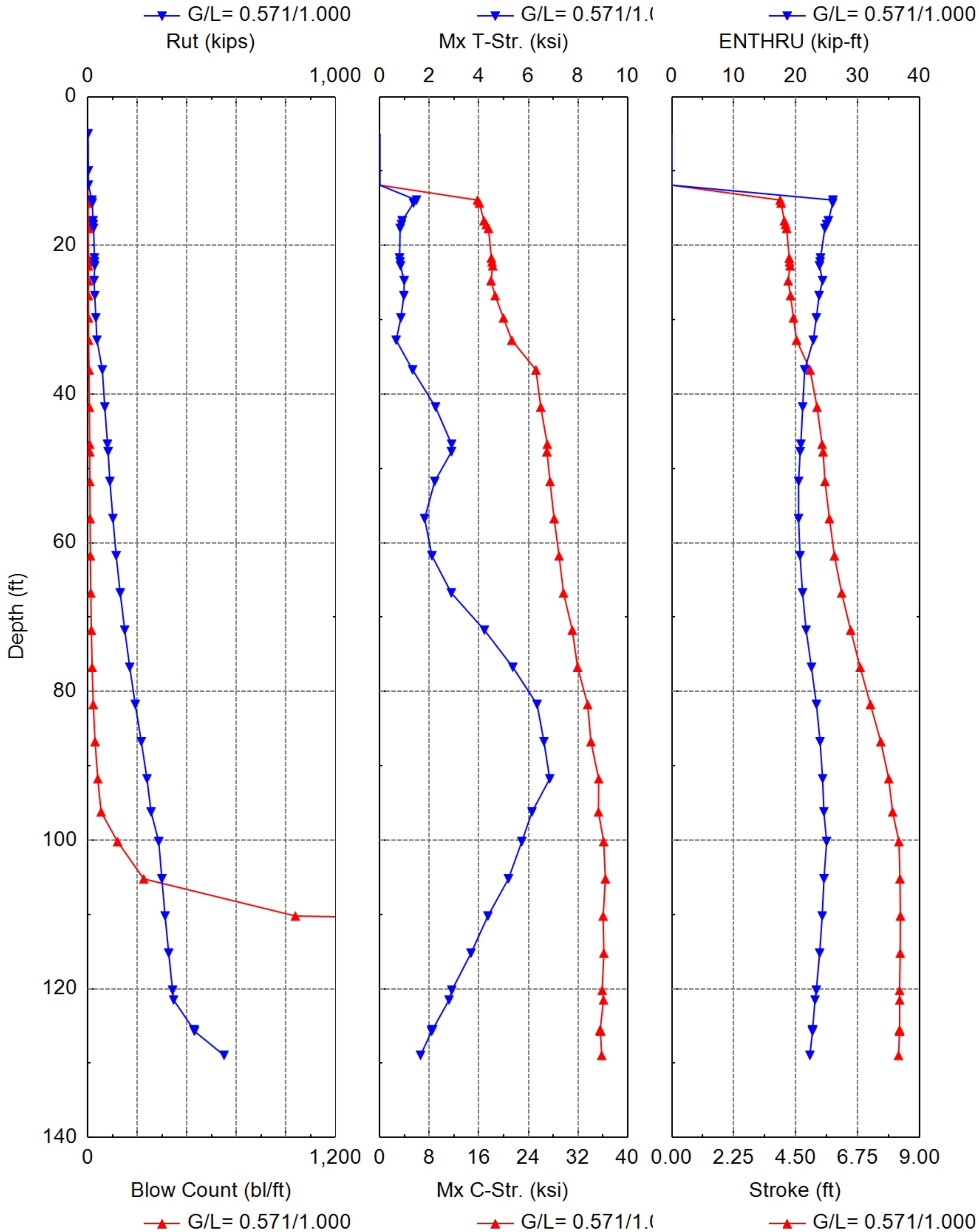
Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
1.9	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
3.8	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
5.6	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
7.5	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
7.5	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
9.0	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
10.5	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
10.5	1.3	13.9	0.10	0.13	0.15	0.15	1.5	6.0	168.0	113.1
11.5	1.3	13.9	0.10	0.13	0.15	0.15	1.5	6.0	168.0	113.1
11.5	0.4	31.4	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
12.5	0.5	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
13.5	0.5	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
13.5	2.0	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
13.5	2.0	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
13.5	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
15.7	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
17.8	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
20.0	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
20.0	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
21.7	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
23.4	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
25.1	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
26.8	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
28.5	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1

28.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
30.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
31.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
33.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
35.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
36.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
38.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
40.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
41.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
43.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
45.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
46.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
48.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
50.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
51.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
53.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
55.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
56.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
58.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
60.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
61.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
63.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
65.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
66.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
68.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
70.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
71.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
73.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
75.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
76.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
78.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
80.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
81.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
83.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
83.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
85.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
86.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
88.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
90.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
91.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1

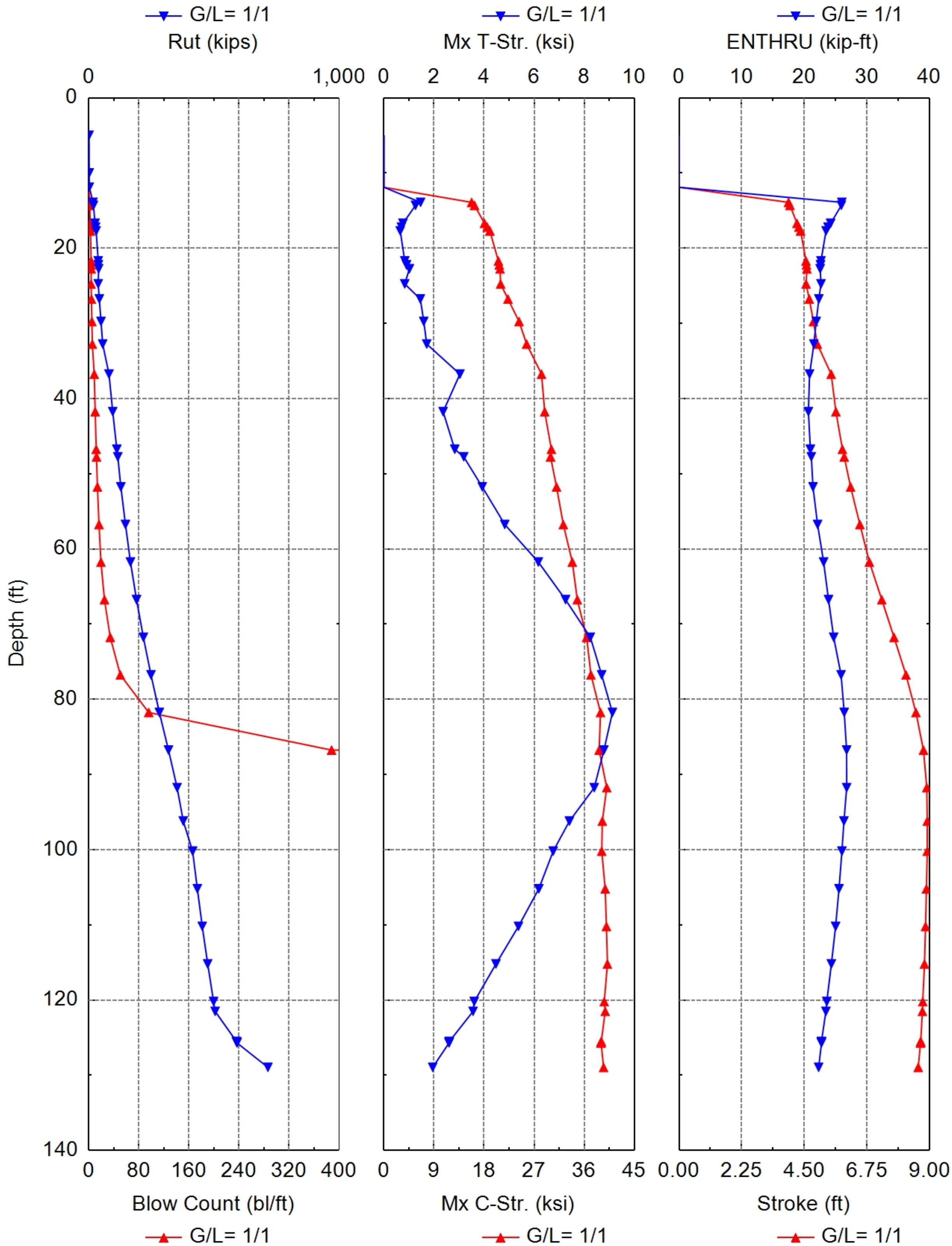
93.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
95.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
97.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
98.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
100.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
102.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
103.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
105.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
107.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
108.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
108.8	3.3	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
110.9	3.4	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
113.0	3.5	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
113.0	4.5	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
114.3	4.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
115.5	4.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1

DRIVIABILITY ANALYSIS

Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.571/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	0.8	0.0	0.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.61	0.0	D 19-32
11.9	2.0	0.0	2.0	0.3	0.000	0.000	10.61	0.0	D 19-32
13.9	17.0	0.0	17.0	1.4	15.777	1.480	3.94	26.0	D 19-32
14.3	18.0	1.0	17.0	1.5	16.069	1.360	3.97	26.0	D 19-32
16.7	20.5	6.8	13.8	1.7	16.816	0.904	4.09	25.3	D 19-32
17.2	21.7	8.0	13.8	1.8	17.190	0.873	4.13	25.0	D 19-32
17.7	23.0	9.2	13.8	2.0	17.541	0.820	4.17	24.7	D 19-32
21.7	26.5	16.0	10.5	2.4	18.009	0.796	4.27	24.0	D 19-32
22.2	27.0	16.6	10.5	2.4	18.126	0.817	4.28	24.0	D 19-32
22.8	27.6	17.2	10.5	2.5	18.227	0.837	4.29	23.8	D 19-32
24.8	24.8	19.5	5.3	2.1	17.951	0.983	4.23	24.3	D 19-32
26.8	27.8	22.5	5.3	2.5	18.617	0.972	4.31	23.8	D 19-32
29.8	32.3	27.0	5.3	2.9	19.965	0.851	4.42	23.3	D 19-32
32.8	36.7	31.4	5.3	3.4	21.310	0.659	4.53	22.8	D 19-32
36.8	58.5	38.4	20.1	5.8	25.203	1.323	5.02	21.5	D 19-32
41.8	68.4	48.2	20.1	7.2	25.985	2.248	5.28	21.1	D 19-32
46.8	79.3	59.2	20.1	8.6	27.040	2.898	5.46	20.8	D 19-32
47.8	81.9	61.8	20.1	8.9	26.982	2.893	5.49	20.7	D 19-32
51.7	88.9	72.2	16.6	9.6	27.478	2.216	5.57	20.5	D 19-32
56.7	101.2	84.5	16.6	10.8	28.144	1.808	5.73	20.5	D 19-32
61.7	114.4	97.8	16.6	12.3	28.946	2.104	5.91	20.7	D 19-32
66.7	130.6	114.0	16.6	14.3	29.661	2.887	6.17	21.1	D 19-32
71.7	148.8	132.2	16.6	17.0	31.078	4.223	6.50	21.7	D 19-32
76.7	169.1	152.5	16.6	20.6	31.934	5.370	6.84	22.5	D 19-32
81.7	191.4	174.8	16.6	26.1	33.558	6.348	7.22	23.4	D 19-32
86.7	215.7	199.1	16.6	34.9	34.088	6.626	7.59	23.9	D 19-32
91.7	238.7	222.1	16.6	48.3	35.340	6.859	7.88	24.4	D 19-32
96.2	255.1	238.5	16.6	64.0	35.305	6.144	8.02	24.6	D 19-32
100.2	286.2	250.9	35.3	143.8	36.144	5.733	8.25	25.0	D 19-32
105.2	298.8	263.4	35.3	270.3	36.422	5.192	8.29	24.6	D 19-32
110.2	311.8	276.5	35.3	1005.3	36.057	4.364	8.31	24.3	D 19-32
115.2	326.4	291.1	35.3	9999.0	36.176	3.681	8.30	23.9	D 19-32
120.2	342.0	306.7	35.3	9999.0	35.907	2.908	8.27	23.3	D 19-32
121.5	346.2	310.9	35.3	9999.0	36.119	2.793	8.28	23.1	D 19-32
125.5	427.8	343.3	84.5	9999.0	35.581	2.128	8.28	22.7	D 19-32
125.6	429.1	344.6	84.5	9999.0	35.589	2.101	8.28	22.7	D 19-32

125.7	430.4	345.9	84.5	9999.0	35.627	2.092	8.27	22.7	D 19-32
129.0	549.9	390.3	159.6	9999.0	35.829	1.642	8.24	22.3	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	0.8	0.0	0.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.61	0.0	D 19-32
11.9	2.0	0.0	2.0	0.3	0.000	0.000	10.61	0.0	D 19-32
13.9	17.0	0.0	17.0	1.4	15.765	1.466	3.94	26.0	D 19-32
14.3	18.5	1.5	17.0	1.5	16.284	1.263	3.99	25.9	D 19-32
16.7	25.1	11.3	13.8	2.2	18.079	0.760	4.24	24.2	D 19-32
17.2	27.2	13.5	13.8	2.5	18.576	0.699	4.31	23.8	D 19-32
17.7	29.3	15.6	13.8	2.7	19.044	0.652	4.37	23.5	D 19-32
21.7	37.5	27.0	10.5	3.7	20.571	0.833	4.56	22.7	D 19-32
22.2	38.3	27.9	10.5	3.8	20.722	0.902	4.58	22.6	D 19-32
22.8	39.2	28.8	10.5	3.9	20.885	1.019	4.60	22.6	D 19-32
24.8	37.6	32.3	5.3	3.6	20.973	0.831	4.57	22.7	D 19-32
26.8	42.0	36.7	5.3	4.2	22.301	1.454	4.68	22.3	D 19-32
29.8	48.7	43.4	5.3	4.9	24.294	1.593	4.83	21.9	D 19-32
32.8	55.4	50.1	5.3	5.6	25.652	1.710	4.97	21.5	D 19-32
36.8	80.7	60.5	20.1	8.7	28.326	3.036	5.47	20.9	D 19-32
41.8	95.5	75.4	20.1	10.2	28.900	2.365	5.64	20.7	D 19-32
46.8	111.9	91.7	20.1	11.9	30.102	2.830	5.87	21.0	D 19-32
47.8	115.8	95.7	20.1	12.3	29.949	3.189	5.94	21.1	D 19-32
51.7	128.0	111.4	16.6	13.8	31.026	3.928	6.17	21.4	D 19-32
56.7	146.4	129.8	16.6	16.3	32.244	4.828	6.50	22.1	D 19-32
61.7	166.4	149.7	16.6	19.4	33.861	6.170	6.84	23.1	D 19-32
66.7	190.6	174.0	16.6	25.0	34.760	7.255	7.29	23.9	D 19-32
71.7	218.0	201.3	16.6	34.3	36.440	8.245	7.73	24.7	D 19-32
76.7	248.3	231.7	16.6	50.4	37.211	8.697	8.16	25.9	D 19-32
81.7	281.8	265.2	16.6	95.7	38.929	9.127	8.52	26.4	D 19-32
86.7	318.3	301.7	16.6	387.9	38.685	8.789	8.79	26.8	D 19-32
91.7	352.7	336.1	16.6	9999.0	40.051	8.400	8.91	26.8	D 19-32
96.2	377.3	360.7	16.6	9999.0	39.256	7.410	8.92	26.3	D 19-32
100.2	414.6	379.3	35.3	9999.0	39.152	6.761	8.92	26.0	D 19-32
105.2	433.5	398.1	35.3	9999.0	39.769	6.187	8.89	25.6	D 19-32
110.2	453.1	417.8	35.3	9999.0	39.995	5.373	8.86	25.0	D 19-32

115.2	474.9	439.6	35.3	9999.0	40.177	4.475	8.82	24.3	D 19-32
120.2	498.3	463.0	35.3	9999.0	39.597	3.608	8.76	23.6	D 19-32
121.5	504.7	469.3	35.3	9999.0	39.773	3.561	8.75	23.5	D 19-32
125.5	589.6	505.1	84.5	9999.0	39.071	2.613	8.69	22.8	D 19-32
125.6	590.9	506.4	84.5	9999.0	38.998	2.605	8.69	22.8	D 19-32
125.7	592.2	507.7	84.5	9999.0	39.038	2.603	8.68	22.8	D 19-32
129.0	715.3	555.7	159.6	9999.0	39.483	1.948	8.60	22.3	D 19-32

Refusal occurred; no driving time output possible.

GRLWEAP: Wave Equation Analysis of Pile Foundations

Ramp O over IR71 + RB CIP12 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	120.0	0.0	0.0	0.00	0.00
13.9	Sand	120.0	0.0	0.0	0.00	2.96
13.9	Clay	112.0	2.4	0.0	2.40	21.60
13.9	Clay	112.0	2.4	0.0	2.40	21.60
13.9	Clay	112.0	2.4	0.0	1.15	21.60
14.7	Clay	112.0	2.4	0.0	1.15	21.60
14.7	Clay	110.0	1.9	0.0	1.34	17.55
19.7	Clay	110.0	1.9	0.0	1.34	17.55
19.7	Sand	108.0	0.0	26.0	0.47	13.32
24.7	Sand	108.0	0.0	26.0	0.58	13.32
24.7	Clay	115.0	0.7	0.0	0.75	6.75
24.8	Clay	115.0	0.7	0.0	0.75	6.75
24.8	Clay	115.0	0.7	0.0	0.71	6.75
34.7	Clay	115.0	0.7	0.0	0.71	6.75
34.7	Clay	122.0	2.8	0.0	1.05	25.65
49.7	Clay	122.0	2.8	0.0	1.05	25.65
49.7	Clay	122.0	2.3	0.0	1.76	21.15
98.2	Clay	122.0	2.3	0.0	1.76	21.15
98.2	Clay	130.0	5.0	0.0	1.35	45.00
123.5	Clay	130.0	5.0	0.0	1.35	45.00
123.5	Sand	140.0	0.0	35.0	4.07	107.60
127.7	Sand	140.0	0.0	35.0	4.22	107.60
127.7	Sand	140.0	0.0	37.0	5.49	203.27
130.2	Sand	140.0	0.0	37.0	5.61	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	130.200	Pile Penetration: (ft)	130.200
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	9.2	30,000.0	492.0	3.1	0
130.2	9.2	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

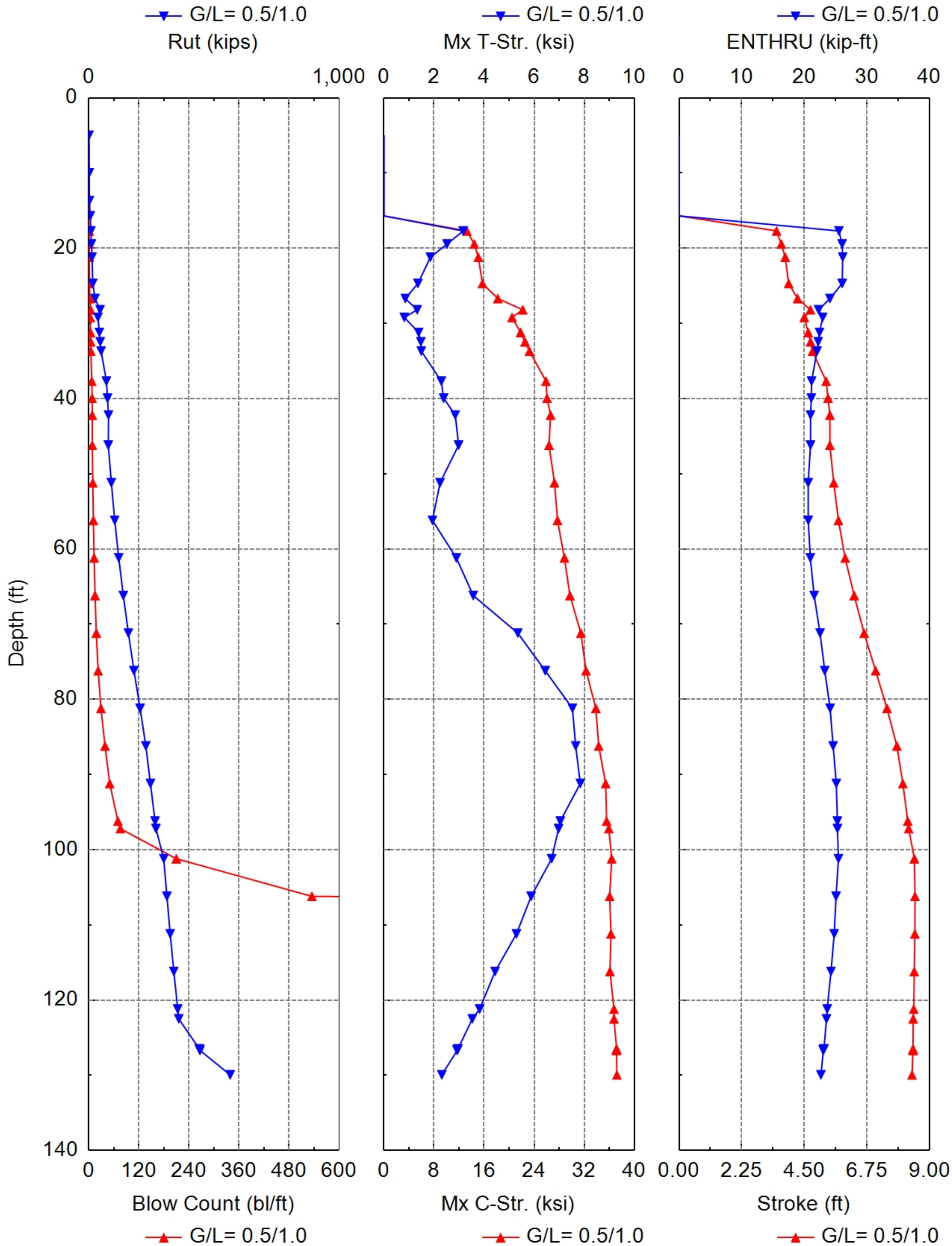
SOIL RESISTANCE DISTRIBUTION

Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	0.0	0.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
1.7	0.0	0.4	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
3.5	0.0	0.7	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
5.2	0.0	1.1	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
7.0	0.0	1.5	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
8.7	0.0	1.9	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
10.4	0.0	2.2	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
12.2	0.0	2.6	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
13.9	0.0	3.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
13.9	2.4	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
13.9	2.4	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
13.9	1.2	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
14.7	1.2	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
14.7	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
16.4	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
18.0	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
19.7	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
19.7	0.5	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
21.4	0.5	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
23.1	0.5	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
24.7	0.6	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
24.7	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
24.8	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1

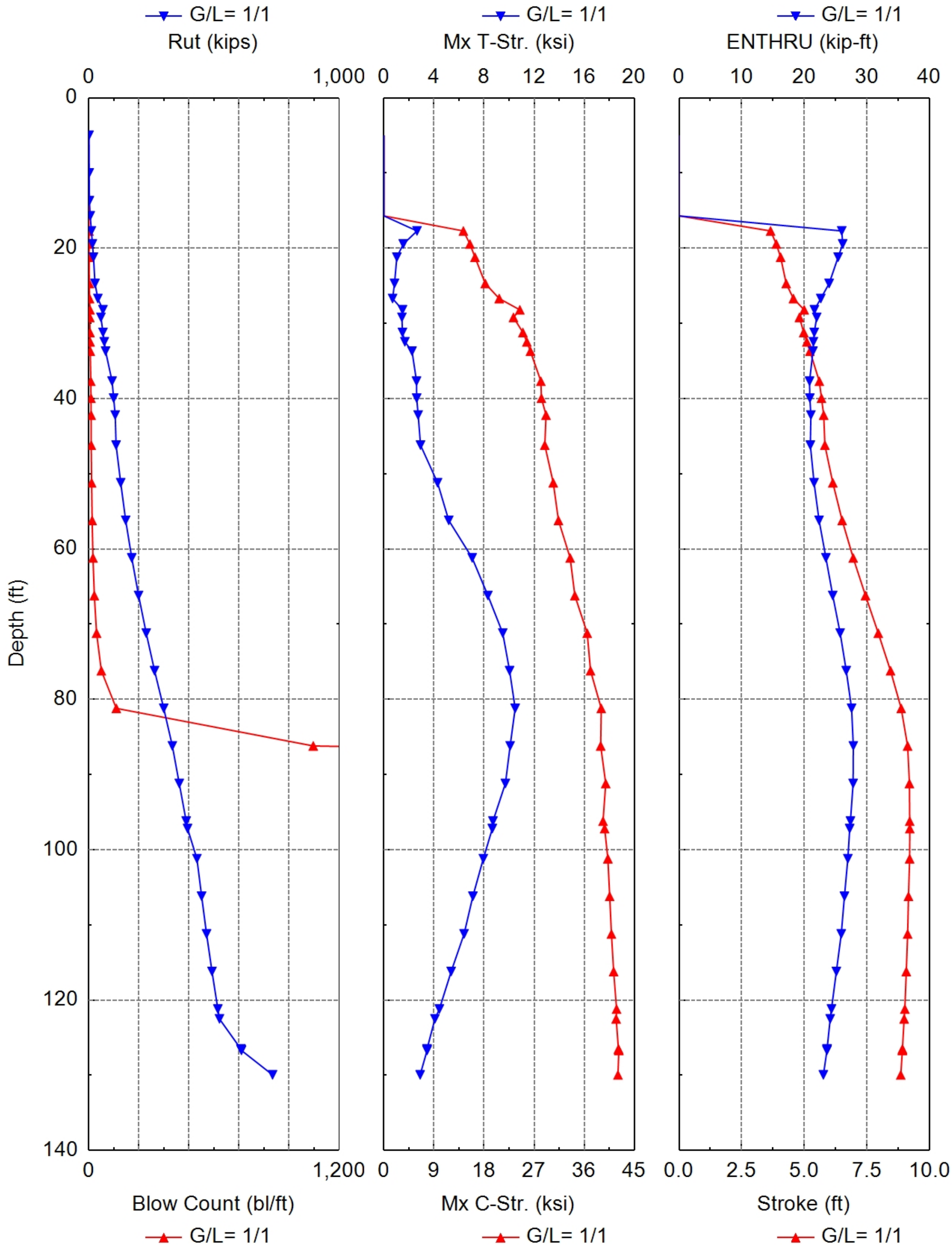
24.8	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
26.4	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
28.1	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
29.8	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
31.4	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
33.1	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
34.7	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
34.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
36.4	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
38.1	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
39.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
41.4	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
43.1	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
44.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
46.4	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
48.1	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
49.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
49.7	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
51.4	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
53.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
54.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
56.4	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
58.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
59.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
61.4	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
63.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
64.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
66.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
68.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
69.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
71.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
73.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
74.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
76.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
78.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
79.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
81.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
83.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
84.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
86.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1

88.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
89.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
91.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
93.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
94.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
96.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
98.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
98.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
99.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
101.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
103.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
104.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
106.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
108.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
110.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
111.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
113.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
115.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
116.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
118.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
120.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
121.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
123.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
123.5	4.1	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
125.6	4.1	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
127.7	4.2	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
127.7	5.5	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
129.0	5.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
130.2	5.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1

Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.500/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	0.8	0.0	0.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.61	0.0	D 19-32
13.7	2.3	0.0	2.3	0.3	0.000	0.000	10.61	0.0	D 19-32
15.7	5.7	0.0	5.7	0.3	0.000	0.000	10.61	0.0	D 19-32
17.7	8.4	2.7	5.7	0.9	13.259	3.165	3.51	25.5	D 19-32
19.5	10.7	5.1	5.7	1.0	14.446	2.523	3.68	26.1	D 19-32
21.2	13.1	7.4	5.7	1.2	15.086	1.857	3.82	26.2	D 19-32
24.7	15.8	11.5	4.2	1.4	15.740	1.360	3.94	26.1	D 19-32
26.7	25.1	14.2	11.0	2.3	18.203	0.855	4.26	24.1	D 19-32
28.2	44.9	18.9	26.0	4.4	22.188	1.330	4.72	22.3	D 19-32
29.2	36.7	22.5	14.1	3.3	20.469	0.815	4.50	23.0	D 19-32
31.2	42.2	28.1	14.1	4.0	21.834	1.387	4.64	22.4	D 19-32
32.5	45.7	31.6	14.1	4.4	22.545	1.476	4.73	22.2	D 19-32
33.7	49.1	35.0	14.1	4.7	23.251	1.495	4.80	22.0	D 19-32
37.7	70.4	44.3	26.2	7.3	25.902	2.294	5.29	21.2	D 19-32
40.0	74.6	48.5	26.2	7.8	26.056	2.384	5.36	21.1	D 19-32
42.2	78.8	52.6	26.2	8.3	26.634	2.850	5.42	21.0	D 19-32
46.2	77.9	61.3	16.6	8.3	26.376	2.984	5.42	21.0	D 19-32
51.2	90.2	73.6	16.6	9.6	27.251	2.243	5.56	20.6	D 19-32
56.2	103.5	86.9	16.6	10.9	27.733	1.939	5.73	20.6	D 19-32
61.2	119.7	103.0	16.6	12.7	28.837	2.893	5.97	21.0	D 19-32
66.2	137.9	121.3	16.6	15.0	29.727	3.569	6.30	21.6	D 19-32
71.2	158.1	141.5	16.6	18.0	31.467	5.347	6.65	22.5	D 19-32
76.2	180.4	163.8	16.6	22.4	32.297	6.444	7.07	23.3	D 19-32
81.2	204.8	188.2	16.6	29.1	33.862	7.529	7.48	24.1	D 19-32
86.2	227.7	211.1	16.6	38.9	34.315	7.659	7.83	24.6	D 19-32
91.2	246.1	229.5	16.6	50.1	35.432	7.844	8.05	25.1	D 19-32
96.2	264.6	248.0	16.6	69.8	35.579	7.045	8.22	25.3	D 19-32
97.2	268.3	251.6	16.6	75.6	35.935	6.976	8.26	25.3	D 19-32
101.2	299.4	264.0	35.3	209.7	36.382	6.699	8.46	25.5	D 19-32
106.2	311.9	276.6	35.3	534.7	36.062	5.883	8.48	25.1	D 19-32
111.2	325.0	289.7	35.3	9999.0	36.271	5.293	8.48	24.8	D 19-32
116.2	339.6	304.2	35.3	9999.0	36.108	4.441	8.46	24.3	D 19-32
121.2	355.2	319.8	35.3	9999.0	36.755	3.822	8.44	23.7	D 19-32
122.5	359.4	324.1	35.3	9999.0	36.755	3.532	8.42	23.6	D 19-32
126.5	441.5	357.0	84.5	9999.0	37.178	2.955	8.41	23.2	D 19-32
126.6	442.9	358.3	84.5	9999.0	37.132	2.930	8.41	23.1	D 19-32

126.7	444.2	359.7	84.5	9999.0	37.165	2.928	8.41	23.1	D 19-32
130.0	564.5	404.9	159.6	9999.0	37.224	2.312	8.38	22.7	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	0.8	0.0	0.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.61	0.0	D 19-32
13.7	2.3	0.0	2.3	0.3	0.000	0.000	10.61	0.0	D 19-32
15.7	5.7	0.0	5.7	0.3	0.000	0.000	10.61	0.0	D 19-32
17.7	10.4	4.8	5.7	1.0	14.284	2.644	3.66	26.0	D 19-32
19.5	14.5	8.9	5.7	1.3	15.465	1.548	3.89	26.2	D 19-32
21.2	18.7	13.0	5.7	1.7	16.372	1.034	4.06	25.4	D 19-32
24.7	24.7	20.5	4.2	2.3	18.214	0.848	4.28	24.0	D 19-32
26.7	36.2	25.2	11.0	3.6	20.722	0.693	4.57	22.6	D 19-32
28.2	56.6	30.6	26.0	5.8	24.429	1.486	5.00	21.6	D 19-32
29.2	48.3	34.2	14.1	4.8	23.286	1.442	4.81	22.0	D 19-32
31.2	56.7	42.6	14.1	5.7	24.981	1.480	4.98	21.6	D 19-32
32.5	61.9	47.7	14.1	6.3	25.694	1.680	5.11	21.5	D 19-32
33.7	67.1	52.9	14.1	7.0	26.324	2.246	5.23	21.4	D 19-32
37.7	93.0	66.8	26.2	9.8	28.213	2.607	5.60	20.9	D 19-32
40.0	99.2	73.1	26.2	10.4	28.309	2.619	5.69	20.9	D 19-32
42.2	105.5	79.4	26.2	11.1	29.140	2.738	5.78	21.1	D 19-32
46.2	108.9	92.3	16.6	11.5	28.916	2.926	5.83	21.0	D 19-32
51.2	127.4	110.8	16.6	13.5	30.437	4.286	6.14	21.6	D 19-32
56.2	147.3	130.7	16.6	16.1	31.371	5.179	6.52	22.4	D 19-32
61.2	171.6	155.0	16.6	20.1	33.475	7.050	6.96	23.5	D 19-32
66.2	198.9	182.3	16.6	26.5	34.318	8.308	7.45	24.6	D 19-32
71.2	229.3	212.7	16.6	37.3	36.538	9.492	7.96	25.7	D 19-32
76.2	262.7	246.1	16.6	60.1	37.140	10.040	8.45	26.7	D 19-32
81.2	299.3	282.6	16.6	131.8	39.059	10.486	8.87	27.6	D 19-32
86.2	333.7	317.1	16.6	1075.7	38.959	10.083	9.13	27.8	D 19-32
91.2	361.3	344.7	16.6	9999.0	39.867	9.705	9.20	27.8	D 19-32
96.2	388.9	372.3	16.6	9999.0	39.379	8.711	9.21	27.4	D 19-32
97.2	394.5	377.9	16.6	9999.0	39.676	8.660	9.22	27.3	D 19-32
101.2	431.8	396.5	35.3	9999.0	40.254	7.940	9.21	27.0	D 19-32
106.2	450.6	415.3	35.3	9999.0	40.583	7.107	9.17	26.4	D 19-32
111.2	470.3	434.9	35.3	9999.0	40.891	6.405	9.13	25.9	D 19-32

116.2	492.1	456.7	35.3	9999.0	41.290	5.375	9.08	25.1	D 19-32
121.2	515.5	480.1	35.3	9999.0	41.818	4.432	9.02	24.4	D 19-32
122.5	521.8	486.5	35.3	9999.0	41.748	4.078	8.99	24.2	D 19-32
126.5	607.3	522.8	84.5	9999.0	42.150	3.444	8.92	23.7	D 19-32
126.6	608.6	524.1	84.5	9999.0	42.189	3.447	8.92	23.6	D 19-32
126.7	609.9	525.4	84.5	9999.0	42.227	3.448	8.92	23.6	D 19-32
130.0	734.0	574.3	159.6	9999.0	42.066	2.893	8.86	23.1	D 19-32

Refusal occurred; no driving time output possible.

GRLWEAP: Wave Equation Analysis of Pile Foundations

Ramp O over IR71 + FB CIP12 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	120.0	0.0	0.0	0.00	0.00
15.7	Sand	120.0	0.0	0.0	0.00	3.35
15.7	Clay	108.0	0.8	0.0	0.80	7.20
15.7	Clay	108.0	0.8	0.0	0.80	7.20
15.7	Clay	108.0	0.8	0.0	0.75	7.20
23.2	Clay	108.0	0.8	0.0	0.75	7.20
23.2	Clay	105.0	0.6	0.0	0.58	5.40
26.2	Clay	105.0	0.6	0.0	0.58	5.40
26.2	Clay	110.0	1.5	0.0	1.25	13.95
27.2	Clay	110.0	1.5	0.0	1.25	13.95
27.2	Sand	115.0	0.0	32.0	1.08	33.09
29.2	Sand	115.0	0.0	32.0	1.15	33.09
29.2	Clay	120.0	2.0	0.0	2.00	18.00
29.2	Clay	120.0	2.0	0.0	2.00	18.00
29.2	Clay	120.0	2.0	0.0	1.32	18.00
35.7	Clay	120.0	2.0	0.0	1.32	18.00
35.7	Clay	128.0	3.7	0.0	0.89	33.30
44.2	Clay	128.0	3.7	0.0	0.89	33.30
44.2	Clay	122.0	2.3	0.0	1.76	21.15
99.2	Clay	122.0	2.3	0.0	1.76	21.15
99.2	Clay	130.0	5.0	0.0	1.35	45.00
124.5	Clay	130.0	5.0	0.0	1.35	45.00
124.5	Sand	140.0	0.0	35.0	4.15	107.60
128.7	Sand	140.0	0.0	35.0	4.30	107.60
128.7	Sand	140.0	0.0	37.0	5.60	203.27
131.2	Sand	140.0	0.0	37.0	5.72	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	131.200	Pile Penetration: (ft)	131.200
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	9.2	30,000.0	492.0	3.1	0
131.2	9.2	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.555
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

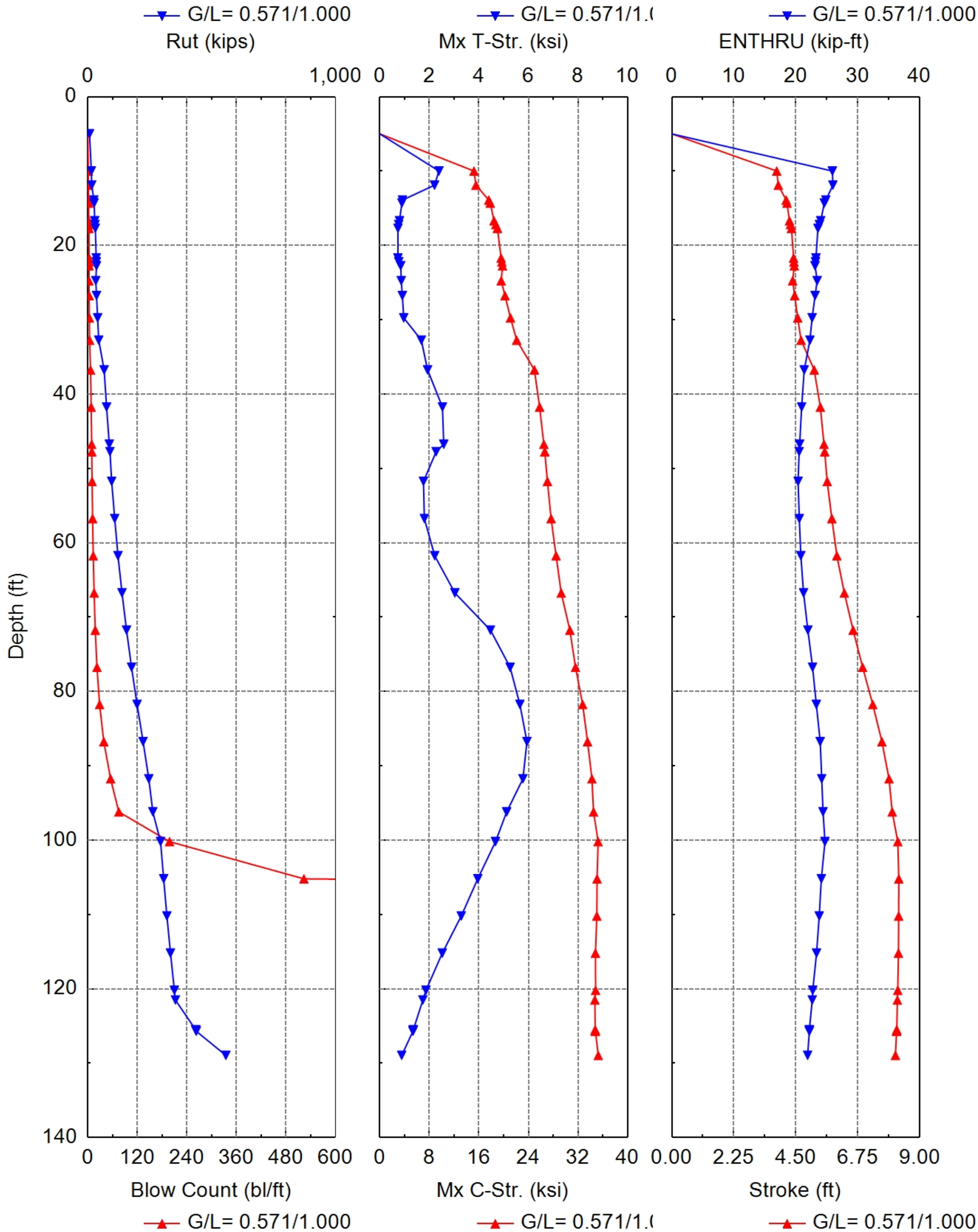
Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	0.0	0.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
1.7	0.0	0.4	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
3.5	0.0	0.7	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
5.2	0.0	1.1	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
7.0	0.0	1.5	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
8.7	0.0	1.9	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
10.5	0.0	2.2	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
12.2	0.0	2.6	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
14.0	0.0	3.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
15.7	0.0	3.3	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
15.7	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
15.7	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
15.7	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
17.6	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
19.5	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
21.3	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
23.2	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
23.2	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
24.7	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
26.2	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
26.2	1.3	13.9	0.10	0.13	0.15	0.15	1.5	6.0	168.0	113.1

27.2	1.3	13.9	0.10	0.13	0.15	0.15	1.5	6.0	168.0	113.1
27.2	1.1	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
28.2	1.1	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
29.2	1.2	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
29.2	2.0	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
29.2	2.0	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
29.2	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
31.4	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
33.5	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
35.7	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
35.7	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
37.4	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
39.1	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
40.8	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
42.5	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
44.2	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
44.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
45.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
47.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
49.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
50.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
52.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
54.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
55.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
57.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
59.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
60.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
62.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
64.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
65.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
67.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
69.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
70.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
72.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
74.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
75.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
77.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
79.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
80.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
82.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1

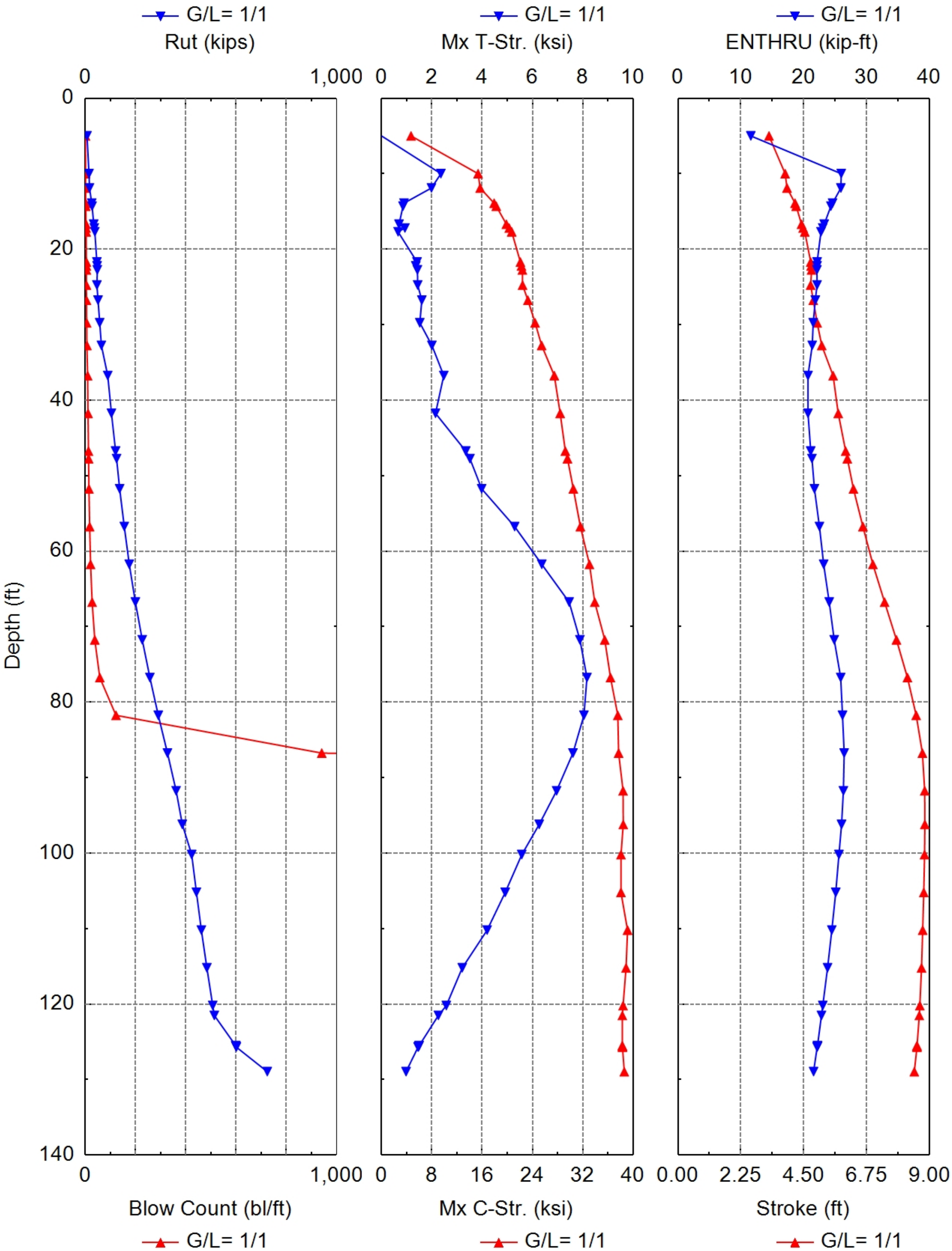
84.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
85.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
87.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
89.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
90.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
92.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
94.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
95.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
97.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
99.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
99.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
100.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
102.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
104.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
105.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
107.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
109.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
111.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
112.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
114.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
116.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
117.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
119.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
121.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
122.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
124.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
124.5	4.2	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
126.6	4.2	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
128.7	4.3	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
128.7	5.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
130.0	5.7	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
131.2	5.7	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1

DOWNDRAG ANALYSIS

Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.571/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	6.8	0.9	5.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	14.1	3.8	10.4	1.2	15.197	2.388	3.81	25.9	D 19-32
11.9	15.8	5.3	10.5	1.2	15.519	2.209	3.87	26.0	D 19-32
13.9	24.3	7.3	17.0	1.9	17.593	0.915	4.16	24.9	D 19-32
14.3	25.2	8.3	17.0	2.0	17.831	0.891	4.19	24.6	D 19-32
16.7	27.8	14.0	13.8	2.3	18.444	0.794	4.28	24.0	D 19-32
17.2	29.0	15.2	13.8	2.5	18.725	0.760	4.31	23.8	D 19-32
17.7	30.2	16.4	13.8	2.6	18.988	0.734	4.35	23.6	D 19-32
21.7	33.7	23.3	10.5	3.0	19.587	0.731	4.43	23.3	D 19-32
22.2	34.3	23.8	10.5	3.1	19.703	0.764	4.44	23.2	D 19-32
22.8	34.9	24.4	10.5	3.1	19.816	0.846	4.45	23.1	D 19-32
24.8	32.1	26.8	5.3	2.8	19.596	0.866	4.39	23.5	D 19-32
26.8	35.1	29.8	5.3	3.1	20.213	0.910	4.47	23.1	D 19-32
29.8	39.5	34.2	5.3	3.6	21.099	0.966	4.58	22.7	D 19-32
32.8	44.0	38.7	5.3	4.2	22.101	1.677	4.70	22.3	D 19-32
36.8	65.8	45.6	20.1	6.6	24.960	1.928	5.17	21.4	D 19-32
41.8	75.6	55.5	20.1	8.0	25.805	2.528	5.40	21.0	D 19-32
46.8	86.6	66.4	20.1	9.3	26.487	2.580	5.53	20.6	D 19-32
47.8	89.2	69.1	20.1	9.5	26.639	2.273	5.56	20.6	D 19-32
51.7	96.1	79.5	16.6	10.2	27.064	1.762	5.65	20.4	D 19-32
56.7	108.4	91.8	16.6	11.5	27.657	1.797	5.82	20.6	D 19-32
61.7	121.7	105.1	16.6	13.0	28.465	2.218	6.00	20.8	D 19-32
66.7	137.9	121.3	16.6	15.2	29.293	3.031	6.27	21.3	D 19-32
71.7	156.1	139.5	16.6	18.0	30.686	4.467	6.59	22.0	D 19-32
76.7	176.4	159.7	16.6	22.1	31.601	5.259	6.93	22.7	D 19-32
81.7	198.7	182.0	16.6	28.5	32.756	5.654	7.30	23.3	D 19-32
86.7	223.0	206.4	16.6	38.6	33.544	5.940	7.63	24.0	D 19-32
91.7	245.9	229.3	16.6	55.1	34.256	5.776	7.89	24.2	D 19-32
96.2	262.3	245.7	16.6	75.0	34.510	5.120	8.01	24.4	D 19-32
100.2	293.5	258.1	35.3	197.9	35.254	4.670	8.21	24.7	D 19-32
105.2	306.0	270.7	35.3	523.3	35.083	3.954	8.25	24.1	D 19-32
110.2	319.1	283.8	35.3	9999.0	35.042	3.288	8.24	23.8	D 19-32
115.2	333.7	298.3	35.3	9999.0	34.818	2.522	8.23	23.4	D 19-32
120.2	349.3	313.9	35.3	9999.0	34.843	1.864	8.21	22.8	D 19-32
121.5	353.5	318.1	35.3	9999.0	34.721	1.738	8.20	22.7	D 19-32
125.5	435.1	350.6	84.5	9999.0	34.780	1.353	8.17	22.2	D 19-32
125.6	436.4	351.9	84.5	9999.0	34.793	1.346	8.17	22.2	D 19-32

125.7	437.7	353.2	84.5	9999.0	34.809	1.338	8.17	22.2	D 19-32
129.0	557.2	397.6	159.6	9999.0	35.274	0.883	8.13	21.9	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	6.9	1.1	5.8	0.8	4.689	0.000	3.26	11.6	D 19-32
10.0	14.9	4.5	10.4	1.2	15.356	2.359	3.84	26.0	D 19-32
11.9	16.8	6.4	10.5	1.3	15.686	1.983	3.91	25.9	D 19-32
13.9	25.7	8.8	17.0	2.0	17.904	0.892	4.19	24.6	D 19-32
14.3	27.2	10.2	17.0	2.1	18.249	0.852	4.23	24.3	D 19-32
16.7	33.8	20.1	13.8	3.0	19.861	0.695	4.43	23.3	D 19-32
17.2	35.9	22.2	13.8	3.2	20.309	0.929	4.48	23.0	D 19-32
17.7	38.0	24.3	13.8	3.5	20.703	0.656	4.54	22.8	D 19-32
21.7	46.2	35.7	10.5	4.5	22.088	1.410	4.76	22.1	D 19-32
22.2	47.1	36.6	10.5	4.6	22.259	1.362	4.77	22.1	D 19-32
22.8	47.9	37.5	10.5	4.7	22.400	1.427	4.78	22.1	D 19-32
24.8	46.3	41.0	5.3	4.5	22.433	1.436	4.75	22.1	D 19-32
26.8	50.8	45.5	5.3	4.9	23.279	1.601	4.84	21.9	D 19-32
29.8	57.5	52.1	5.3	5.7	24.433	1.521	4.98	21.5	D 19-32
32.8	64.2	58.8	5.3	6.5	25.469	2.002	5.15	21.4	D 19-32
36.8	89.4	69.2	20.1	9.5	27.482	2.474	5.56	20.7	D 19-32
41.8	104.2	84.1	20.1	11.0	28.416	2.145	5.74	20.7	D 19-32
46.8	120.6	100.5	20.1	12.8	29.240	3.350	6.01	21.1	D 19-32
47.8	124.6	104.4	20.1	13.2	29.578	3.514	6.07	21.3	D 19-32
51.7	136.7	120.1	16.6	14.7	30.510	3.981	6.28	21.7	D 19-32
56.7	155.1	138.5	16.6	17.4	31.634	5.293	6.62	22.5	D 19-32
61.7	175.1	158.5	16.6	21.1	33.077	6.373	6.98	23.2	D 19-32
66.7	199.3	182.7	16.6	27.3	33.913	7.460	7.40	24.1	D 19-32
71.7	226.7	210.1	16.6	38.0	35.514	7.890	7.83	24.9	D 19-32
76.7	257.1	240.4	16.6	57.8	36.421	8.170	8.22	25.9	D 19-32
81.7	290.5	273.9	16.6	122.3	37.588	8.049	8.53	26.2	D 19-32
86.7	327.0	310.4	16.6	940.8	37.713	7.612	8.75	26.5	D 19-32
91.7	361.4	344.8	16.6	9999.0	38.425	6.961	8.84	26.3	D 19-32
96.2	386.0	369.4	16.6	9999.0	38.453	6.270	8.84	26.0	D 19-32
100.2	423.4	388.0	35.3	9999.0	38.094	5.577	8.83	25.6	D 19-32
105.2	442.2	406.9	35.3	9999.0	38.087	4.919	8.80	25.1	D 19-32
110.2	461.8	426.5	35.3	9999.0	39.138	4.199	8.76	24.5	D 19-32

115.2	483.6	448.3	35.3	9999.0	38.897	3.210	8.72	23.8	D 19-32
120.2	507.0	471.7	35.3	9999.0	38.419	2.575	8.66	23.0	D 19-32
121.5	513.4	478.0	35.3	9999.0	38.308	2.261	8.64	22.8	D 19-32
125.5	598.3	513.8	84.5	9999.0	38.304	1.495	8.56	22.2	D 19-32
125.6	599.6	515.1	84.5	9999.0	38.343	1.481	8.56	22.2	D 19-32
125.7	600.9	516.4	84.5	9999.0	38.324	1.452	8.56	22.2	D 19-32
129.0	724.0	564.4	159.6	9999.0	38.618	0.974	8.46	21.6	D 19-32

Refusal occurred; no driving time output possible.

GRLWEAP: Wave Equation Analysis of Pile Foundations

Ramp O over IR71 + RB CIP12 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	120.0	0.0	28.0	0.00	0.00
13.9	Sand	120.0	0.0	28.0	0.40	13.32
13.9	Clay	112.0	2.4	0.0	2.40	21.60
13.9	Clay	112.0	2.4	0.0	2.40	21.60
13.9	Clay	112.0	2.4	0.0	1.15	21.60
14.7	Clay	112.0	2.4	0.0	1.15	21.60
14.7	Clay	110.0	1.9	0.0	1.34	17.55
19.7	Clay	110.0	1.9	0.0	1.34	17.55
19.7	Sand	108.0	0.0	26.0	0.47	13.32
24.7	Sand	108.0	0.0	26.0	0.58	13.32
24.7	Clay	115.0	0.7	0.0	0.75	6.75
24.8	Clay	115.0	0.7	0.0	0.75	6.75
24.8	Clay	115.0	0.7	0.0	0.71	6.75
34.7	Clay	115.0	0.7	0.0	0.71	6.75
34.7	Clay	122.0	2.8	0.0	1.05	25.65
49.7	Clay	122.0	2.8	0.0	1.05	25.65
49.7	Clay	122.0	2.3	0.0	1.76	21.15
98.2	Clay	122.0	2.3	0.0	1.76	21.15
98.2	Clay	130.0	5.0	0.0	1.35	45.00
123.5	Clay	130.0	5.0	0.0	1.35	45.00
123.5	Sand	140.0	0.0	35.0	4.07	107.60
127.7	Sand	140.0	0.0	35.0	4.22	107.60
127.7	Sand	140.0	0.0	37.0	5.49	203.27
130.2	Sand	140.0	0.0	37.0	5.61	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	130.200	Pile Penetration: (ft)	130.200
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	9.2	30,000.0	492.0	3.1	0
130.2	9.2	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	0.0	0.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
1.7	0.0	2.6	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
3.5	0.1	5.1	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
5.2	0.1	7.7	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
7.0	0.2	10.3	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
8.7	0.2	12.9	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
10.4	0.3	13.3	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
12.2	0.3	13.3	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
13.9	0.4	13.3	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
13.9	2.4	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
13.9	2.4	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
13.9	1.2	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
14.7	1.2	21.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
14.7	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
16.4	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
18.0	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
19.7	1.3	17.5	0.10	0.12	0.20	0.15	1.8	6.0	168.0	113.1
19.7	0.5	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
21.4	0.5	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
23.1	0.5	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
24.7	0.6	13.3	0.10	0.20	0.10	0.15	1.5	6.0	24.0	113.1
24.7	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
24.8	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1

24.8	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
26.4	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
28.1	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
29.8	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
31.4	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
33.1	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
34.7	0.7	6.7	0.10	0.15	0.15	0.15	1.5	6.0	168.0	113.1
34.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
36.4	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
38.1	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
39.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
41.4	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
43.1	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
44.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
46.4	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
48.1	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
49.7	1.0	25.6	0.10	0.11	0.15	0.15	1.5	6.0	168.0	113.1
49.7	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
51.4	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
53.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
54.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
56.4	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
58.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
59.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
61.4	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
63.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
64.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
66.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
68.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
69.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
71.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
73.1	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
74.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
76.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
78.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
79.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
81.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
83.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
84.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
86.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1

88.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
89.8	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
91.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
93.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
94.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
96.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
98.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
98.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
99.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
101.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
103.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
104.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
106.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
108.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
110.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
111.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
113.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
115.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
116.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
118.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
120.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
121.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
123.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
123.5	4.1	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
125.6	4.1	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
127.7	4.2	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
127.7	5.5	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
129.0	5.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
130.2	5.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1

FRA-00071-28.294 (Ramp O) Rear Abutment	
Max. Factored Load (kips)	Max Service Load (kips)
209.3	154.40

ULTIMATE - SUMMARY OF CAPACITIES

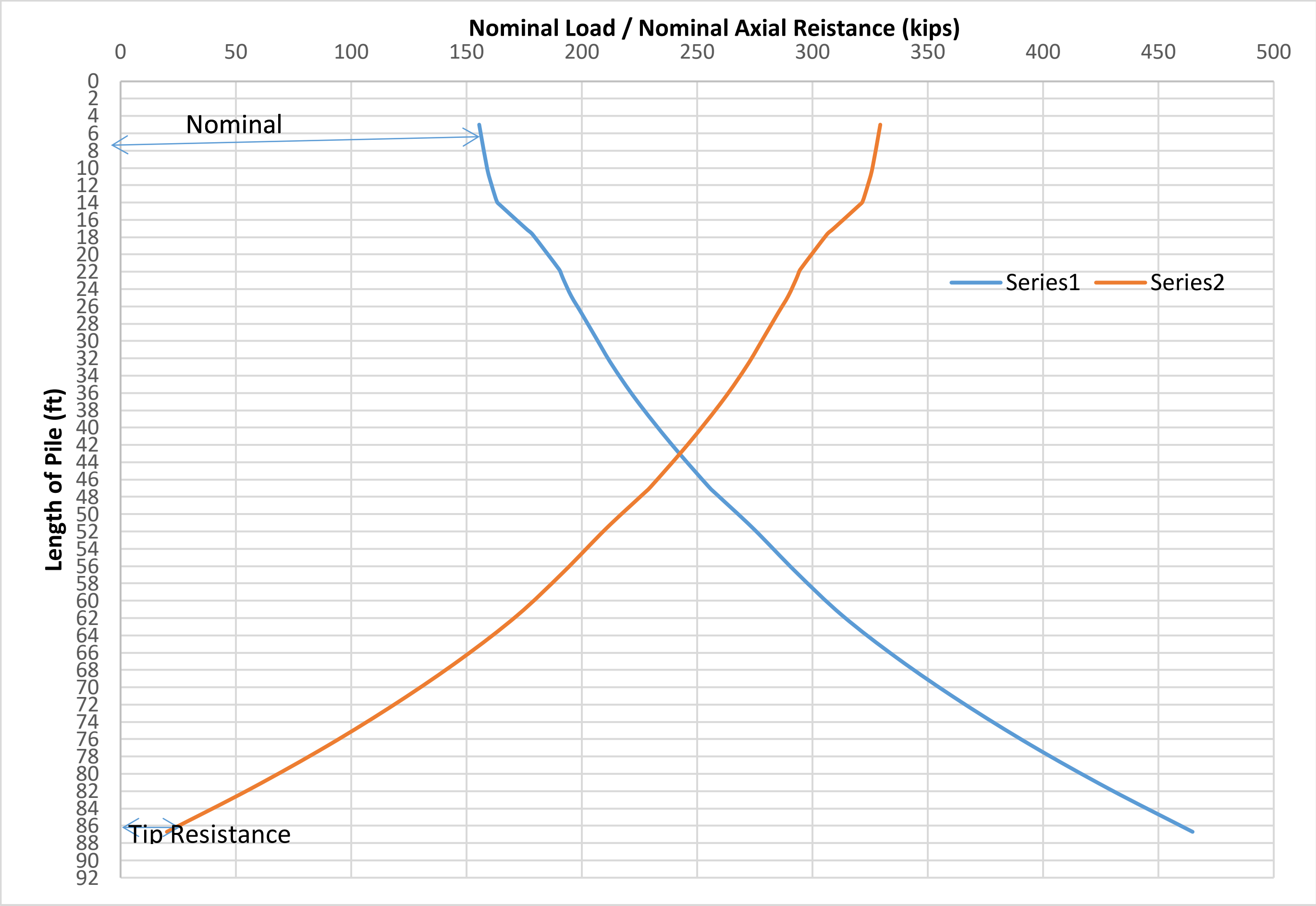
Depth (ft)	Skin Friction (kips)	End Bearing (kips)	Total Capacity (kips)	DC+DD(kips)	Unit Skin Friction (kips)	Upward skin Friction (kips)	Upward Skin + Mobilized end bearing (kips)
5.00	1.10	5.80	6.90	155.50	0.00	309.30	329.40
10.00	4.50	10.40	14.90	158.90	3.40	305.90	326.00
11.90	6.40	10.50	16.80	160.80	1.90	304.00	324.10
13.90	8.80	17.00	25.70	163.20	2.40	301.60	321.70
14.30	10.20	17.00	27.20	164.60	1.40	300.20	320.30
16.70	20.10	13.80	33.80	174.50	9.90	290.30	310.40
17.20	22.20	13.80	35.90	176.60	2.10	288.20	308.30
17.70	24.30	13.80	38.00	178.70	2.10	286.10	306.20
21.70	35.70	10.50	46.20	190.10	11.40	274.70	294.80
22.20	36.60	10.50	47.10	191.00	0.90	273.80	293.90
22.80	37.50	10.50	47.90	191.90	0.90	272.90	293.00
24.80	41.00	5.30	46.30	195.40	3.50	269.40	289.50
26.80	45.50	5.30	50.80	199.90	4.50	264.90	285.00
29.80	52.10	5.30	57.50	206.50	6.60	258.30	278.40
32.80	58.80	5.30	64.20	213.20	6.70	251.60	271.70
36.80	69.20	20.10	89.40	223.60	10.40	241.20	261.30
41.80	84.10	20.10	104.20	238.50	14.90	226.30	246.40
46.80	100.50	20.10	120.60	254.90	16.40	209.90	230.00
47.80	104.40	20.10	124.60	258.80	3.90	206.00	226.10
51.70	120.10	16.60	136.70	274.50	15.70	190.30	210.40
56.70	138.50	16.60	155.10	292.90	18.40	171.90	192.00
61.70	158.50	16.60	175.10	312.90	20.00	151.90	172.00
66.70	182.70	16.60	199.30	337.10	24.20	127.70	147.80
71.70	210.10	16.60	226.70	364.50	27.40	100.30	120.40
76.70	240.40	16.60	257.10	394.80	30.30	70.00	90.10
81.70	273.90	16.60	290.50	428.30	33.50	36.50	56.60
86.70	310.40	16.60	327.00	464.80	36.50	0.00	20.10

Driven Depth	Skin Friction
41.70	84.10
46.70	100.50

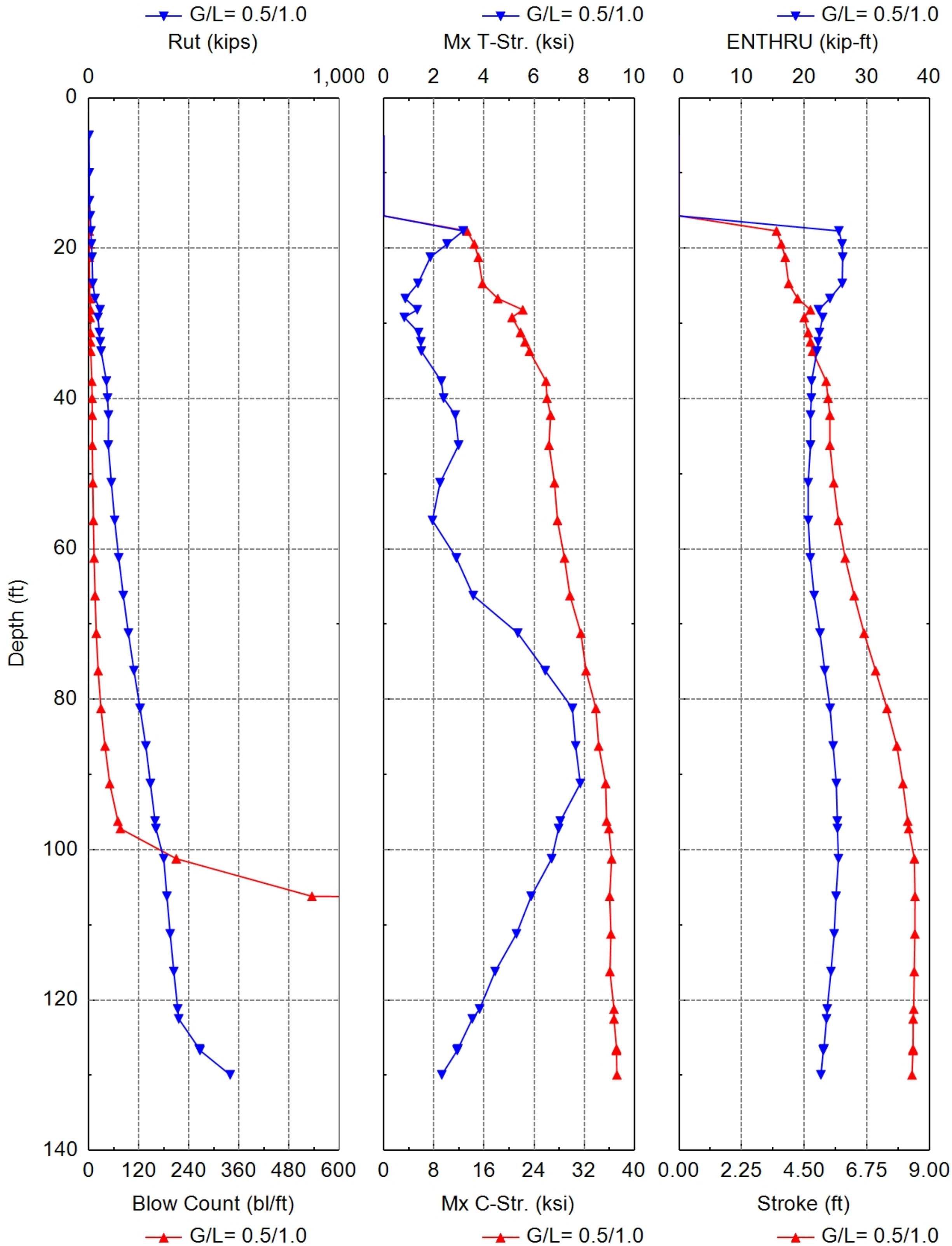
Neutral Plane Depth (ft)	43.00
Skin Friction at Neutral Plan (kips)	88.36
Factored Load+Factored Downdrag (kips)	302.08

<

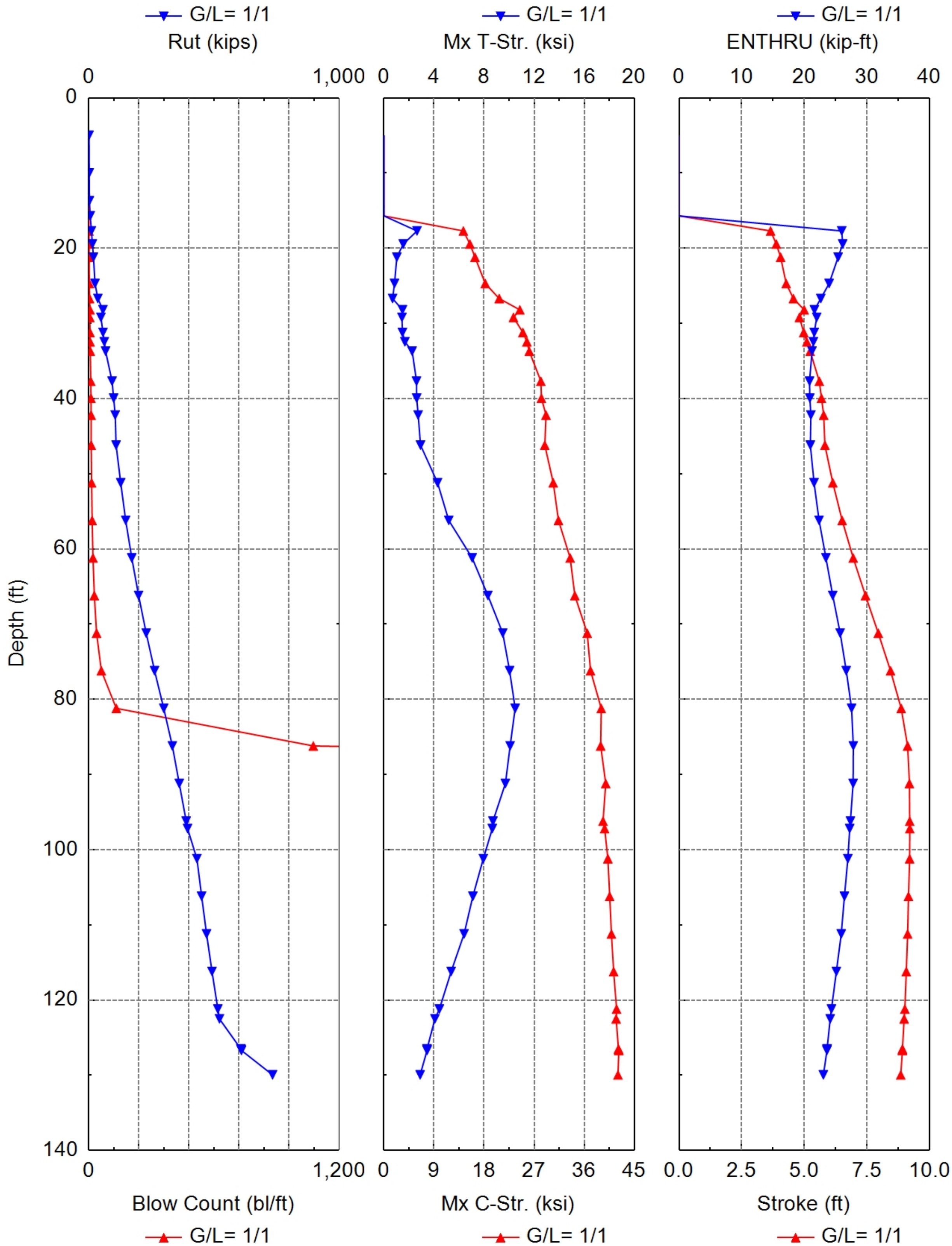
Factored Strucure Resistance (kips)
480



Driveability Analysis Summary



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.500/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	0.8	0.0	0.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.61	0.0	D 19-32
13.7	2.3	0.0	2.3	0.3	0.000	0.000	10.61	0.0	D 19-32
15.7	5.7	0.0	5.7	0.3	0.000	0.000	10.61	0.0	D 19-32
17.7	8.4	2.7	5.7	0.9	13.259	3.165	3.51	25.5	D 19-32
19.5	10.7	5.1	5.7	1.0	14.446	2.523	3.68	26.1	D 19-32
21.2	13.1	7.4	5.7	1.2	15.086	1.857	3.82	26.2	D 19-32
24.7	15.8	11.5	4.2	1.4	15.740	1.360	3.94	26.1	D 19-32
26.7	25.1	14.2	11.0	2.3	18.204	0.855	4.26	24.1	D 19-32
28.2	44.9	18.9	26.0	4.4	22.188	1.330	4.72	22.3	D 19-32
29.2	36.7	22.5	14.1	3.3	20.469	0.815	4.50	23.0	D 19-32
31.2	42.2	28.1	14.1	4.0	21.835	1.387	4.64	22.4	D 19-32
32.5	45.7	31.6	14.1	4.4	22.545	1.476	4.73	22.2	D 19-32
33.7	49.1	35.0	14.1	4.7	23.251	1.495	4.80	22.0	D 19-32
37.7	70.4	44.3	26.2	7.3	25.902	2.294	5.29	21.2	D 19-32
40.0	74.6	48.5	26.2	7.8	26.056	2.384	5.36	21.1	D 19-32
42.2	78.8	52.6	26.2	8.3	26.634	2.850	5.42	21.0	D 19-32
46.2	77.9	61.3	16.6	8.3	26.376	2.984	5.42	21.0	D 19-32
51.2	90.2	73.6	16.6	9.6	27.251	2.243	5.56	20.6	D 19-32
56.2	103.5	86.9	16.6	10.9	27.733	1.939	5.73	20.6	D 19-32
61.2	119.7	103.0	16.6	12.7	28.837	2.893	5.97	21.0	D 19-32
66.2	137.9	121.3	16.6	15.0	29.727	3.569	6.30	21.6	D 19-32
71.2	158.1	141.5	16.6	18.0	31.467	5.347	6.65	22.5	D 19-32
76.2	180.4	163.8	16.6	22.4	32.297	6.444	7.07	23.3	D 19-32
81.2	204.8	188.2	16.6	29.1	33.862	7.529	7.48	24.1	D 19-32
86.2	227.7	211.1	16.6	38.9	34.315	7.659	7.83	24.6	D 19-32
91.2	246.1	229.5	16.6	50.1	35.432	7.844	8.05	25.1	D 19-32
96.2	264.6	248.0	16.6	69.8	35.579	7.045	8.22	25.3	D 19-32
97.2	268.3	251.6	16.6	75.6	35.935	6.976	8.26	25.3	D 19-32
101.2	299.4	264.0	35.3	209.7	36.382	6.699	8.46	25.5	D 19-32
106.2	311.9	276.6	35.3	534.7	36.062	5.883	8.48	25.1	D 19-32
111.2	325.0	289.7	35.3	9999.0	36.271	5.293	8.48	24.8	D 19-32
116.2	339.6	304.2	35.3	9999.0	36.108	4.441	8.46	24.3	D 19-32
121.2	355.2	319.8	35.3	9999.0	36.755	3.822	8.44	23.7	D 19-32
122.5	359.4	324.1	35.3	9999.0	36.755	3.532	8.42	23.6	D 19-32
126.5	441.5	357.0	84.5	9999.0	37.178	2.955	8.41	23.2	D 19-32
126.6	442.9	358.3	84.5	9999.0	37.132	2.930	8.41	23.1	D 19-32

126.7	444.2	359.7	84.5	9999.0	37.165	2.928	8.41	23.1	D 19-32
130.0	564.5	404.9	159.6	9999.0	37.224	2.312	8.38	22.7	D 19-32

Refusal occurred; no driving time output possible.

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
5.0	0.8	0.0	0.8	0.3	0.000	0.000	10.61	0.0	D 19-32
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.61	0.0	D 19-32
13.7	2.3	0.0	2.3	0.3	0.000	0.000	10.61	0.0	D 19-32
15.7	5.7	0.0	5.7	0.3	0.000	0.000	10.61	0.0	D 19-32
17.7	10.4	4.8	5.7	1.0	14.284	2.644	3.66	26.0	D 19-32
19.5	14.5	8.9	5.7	1.3	15.465	1.548	3.89	26.2	D 19-32
21.2	18.7	13.0	5.7	1.7	16.372	1.034	4.06	25.4	D 19-32
24.7	24.7	20.5	4.2	2.3	18.214	0.848	4.28	24.0	D 19-32
26.7	36.2	25.2	11.0	3.6	20.722	0.693	4.57	22.6	D 19-32
28.2	56.6	30.6	26.0	5.8	24.429	1.486	5.00	21.6	D 19-32
29.2	48.3	34.2	14.1	4.8	23.286	1.442	4.81	22.0	D 19-32
31.2	56.7	42.6	14.1	5.7	24.981	1.480	4.98	21.6	D 19-32
32.5	61.9	47.7	14.1	6.3	25.694	1.680	5.11	21.5	D 19-32
33.7	67.1	52.9	14.1	7.0	26.123	2.254	5.24	21.2	D 19-32
37.7	93.0	66.8	26.2	9.8	28.213	2.607	5.60	20.9	D 19-32
40.0	99.2	73.1	26.2	10.4	28.309	2.619	5.69	20.9	D 19-32
42.2	105.5	79.4	26.2	11.1	29.140	2.738	5.78	21.1	D 19-32
46.2	108.9	92.3	16.6	11.5	28.917	2.926	5.83	21.0	D 19-32
51.2	127.4	110.8	16.6	13.5	30.437	4.286	6.14	21.6	D 19-32
56.2	147.3	130.7	16.6	16.1	31.371	5.179	6.52	22.4	D 19-32
61.2	171.6	155.0	16.6	20.1	33.475	7.050	6.96	23.5	D 19-32
66.2	198.9	182.3	16.6	26.5	34.318	8.308	7.45	24.6	D 19-32
71.2	229.3	212.7	16.6	37.3	36.538	9.492	7.96	25.7	D 19-32
76.2	262.7	246.1	16.6	60.1	37.140	10.040	8.45	26.7	D 19-32
81.2	299.3	282.6	16.6	131.8	39.059	10.486	8.87	27.6	D 19-32
86.2	333.7	317.1	16.6	1075.9	38.959	10.083	9.13	27.8	D 19-32
91.2	361.3	344.7	16.6	9999.0	39.867	9.705	9.20	27.8	D 19-32
96.2	388.9	372.3	16.6	9999.0	39.379	8.711	9.21	27.4	D 19-32
97.2	394.5	377.9	16.6	9999.0	39.676	8.660	9.22	27.3	D 19-32
101.2	431.8	396.5	35.3	9999.0	40.254	7.940	9.21	27.0	D 19-32
106.2	450.6	415.3	35.3	9999.0	40.583	7.107	9.17	26.4	D 19-32
111.2	470.3	434.9	35.3	9999.0	40.891	6.405	9.13	25.9	D 19-32

116.2	492.1	456.7	35.3	9999.0	41.290	5.375	9.08	25.1	D 19-32
121.2	515.5	480.1	35.3	9999.0	41.818	4.432	9.02	24.4	D 19-32
122.5	521.8	486.5	35.3	9999.0	41.748	4.078	8.99	24.2	D 19-32
126.5	607.3	522.8	84.5	9999.0	42.150	3.444	8.92	23.7	D 19-32
126.6	608.6	524.1	84.5	9999.0	42.189	3.447	8.92	23.6	D 19-32
126.7	609.9	525.4	84.5	9999.0	42.227	3.448	8.92	23.6	D 19-32
130.0	734.0	574.3	159.6	9999.0	42.067	2.893	8.86	23.1	D 19-32

Refusal occurred; no driving time output possible.

GRLWEAP: Wave Equation Analysis of Pile Foundations

Ramp O over IR71 + FB CIP12 1/11/2024
NATIONAL ENGINEERING AND ARCHITECTURAL GRLWEAP 14.1.20.1

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth	Soil Type	Spec. Wt	Su	Phi	Unit Rs	Unit Rt
ft	-	lb/ft³	ksf	°	ksf	ksf
0.0	Sand	120.0	0.0	0.0	0.00	0.00
15.7	Sand	120.0	0.0	0.0	0.00	3.35
15.7	Clay	108.0	0.8	0.0	0.80	7.20
15.7	Clay	108.0	0.8	0.0	0.80	7.20
15.7	Clay	108.0	0.8	0.0	0.75	7.20
23.2	Clay	108.0	0.8	0.0	0.75	7.20
23.2	Clay	105.0	0.6	0.0	0.58	5.40
26.2	Clay	105.0	0.6	0.0	0.58	5.40
26.2	Clay	110.0	1.5	0.0	1.25	13.95
27.2	Clay	110.0	1.5	0.0	1.25	13.95
27.2	Sand	115.0	0.0	32.0	1.08	33.09
29.2	Sand	115.0	0.0	32.0	1.15	33.09
29.2	Clay	120.0	2.0	0.0	2.00	18.00
29.2	Clay	120.0	2.0	0.0	2.00	18.00
29.2	Clay	120.0	2.0	0.0	1.32	18.00
35.7	Clay	120.0	2.0	0.0	1.32	18.00
35.7	Clay	128.0	3.7	0.0	0.89	33.30
44.2	Clay	128.0	3.7	0.0	0.89	33.30
44.2	Clay	122.0	2.3	0.0	1.76	21.15
99.2	Clay	122.0	2.3	0.0	1.76	21.15
99.2	Clay	130.0	5.0	0.0	1.35	45.00
124.5	Clay	130.0	5.0	0.0	1.35	45.00
124.5	Sand	140.0	0.0	35.0	4.15	107.60
128.7	Sand	140.0	0.0	35.0	4.30	107.60
128.7	Sand	140.0	0.0	37.0	5.60	203.27
131.2	Sand	140.0	0.0	37.0	5.72	203.27

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	131.200	Pile Penetration: (ft)	131.200
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top	X-Area	E-Modulus	Spec. Wt	Perim.	Crit. Index
ft	in²	ksi	lb/ft³	ft	-
0.0	9.2	30,000.0	492.0	3.1	0
131.2	9.2	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	40	Made By:	DELMAG
Model	D 19-32	Type:	OED

Hammer Data

ID	Ram Wt	Ram L.	Ram Ar.	Rtd. Stk	Effic.	Rtd. Energy
-	kips	in	in²	ft	-	kip-ft
40	4.000	129.1	124.7	10.6	0.80	42.4

DRIVE SYSTEM FOR DELMAG D 19-32-OED

Type	X-Area	E-Modulus	Thickness	COR	Round-out	Stiffness
-	in²	ksi	in	-	in	kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Set. F.	Limit D.	Set. T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.0	0.0	0.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
1.7	0.0	0.4	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
3.5	0.0	0.7	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
5.2	0.0	1.1	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
7.0	0.0	1.5	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
8.7	0.0	1.9	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
10.5	0.0	2.2	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
12.2	0.0	2.6	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
14.0	0.0	3.0	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
15.7	0.0	3.3	0.10	0.11	0.10	0.15	1.2	6.0	1.0	113.1
15.7	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
15.7	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
15.7	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
17.6	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
19.5	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
21.3	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
23.2	0.8	7.2	0.10	0.15	0.20	0.15	1.8	6.0	168.0	113.1
23.2	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
24.7	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
26.2	0.6	5.4	0.10	0.16	0.20	0.15	2.0	6.0	168.0	113.1
26.2	1.3	13.9	0.10	0.13	0.15	0.15	1.5	6.0	168.0	113.1

27.2	1.3	13.9	0.10	0.13	0.15	0.15	1.5	6.0	168.0	113.1
27.2	1.1	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
28.2	1.1	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
29.2	1.2	33.1	0.10	0.13	0.05	0.15	1.0	6.0	1.0	113.1
29.2	2.0	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
29.2	2.0	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
29.2	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
31.4	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
33.5	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
35.7	1.3	18.0	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
35.7	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
37.4	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
39.1	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
40.8	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
42.5	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
44.2	0.9	33.3	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
44.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
45.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
47.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
49.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
50.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
52.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
54.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
55.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
57.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
59.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
60.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
62.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
64.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
65.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
67.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
69.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
70.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
72.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
74.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
75.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
77.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
79.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
80.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
82.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1

84.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
85.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
87.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
89.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
90.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
92.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
94.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
95.9	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
97.5	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
99.2	1.8	21.1	0.10	0.12	0.15	0.15	1.5	6.0	168.0	113.1
99.2	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
100.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
102.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
104.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
105.9	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
107.6	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
109.3	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
111.0	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
112.7	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
114.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
116.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
117.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
119.4	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
121.1	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
122.8	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
124.5	1.4	45.0	0.10	0.10	0.15	0.15	1.5	6.0	168.0	113.1
124.5	4.2	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
126.6	4.2	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
128.7	4.3	107.6	0.10	0.11	0.05	0.15	1.0	6.0	1.0	113.1
128.7	5.6	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
130.0	5.7	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1
131.2	5.7	203.3	0.10	0.10	0.10	0.15	1.2	6.0	24.0	113.1

FRA-00071-28.294 (Ramp O) Forward Abutment	
Max. Factored Load (kips)	**Max Service Load (kips)**
209.3	154.40

ULTIMATE - SUMMARY OF CAPACITIES

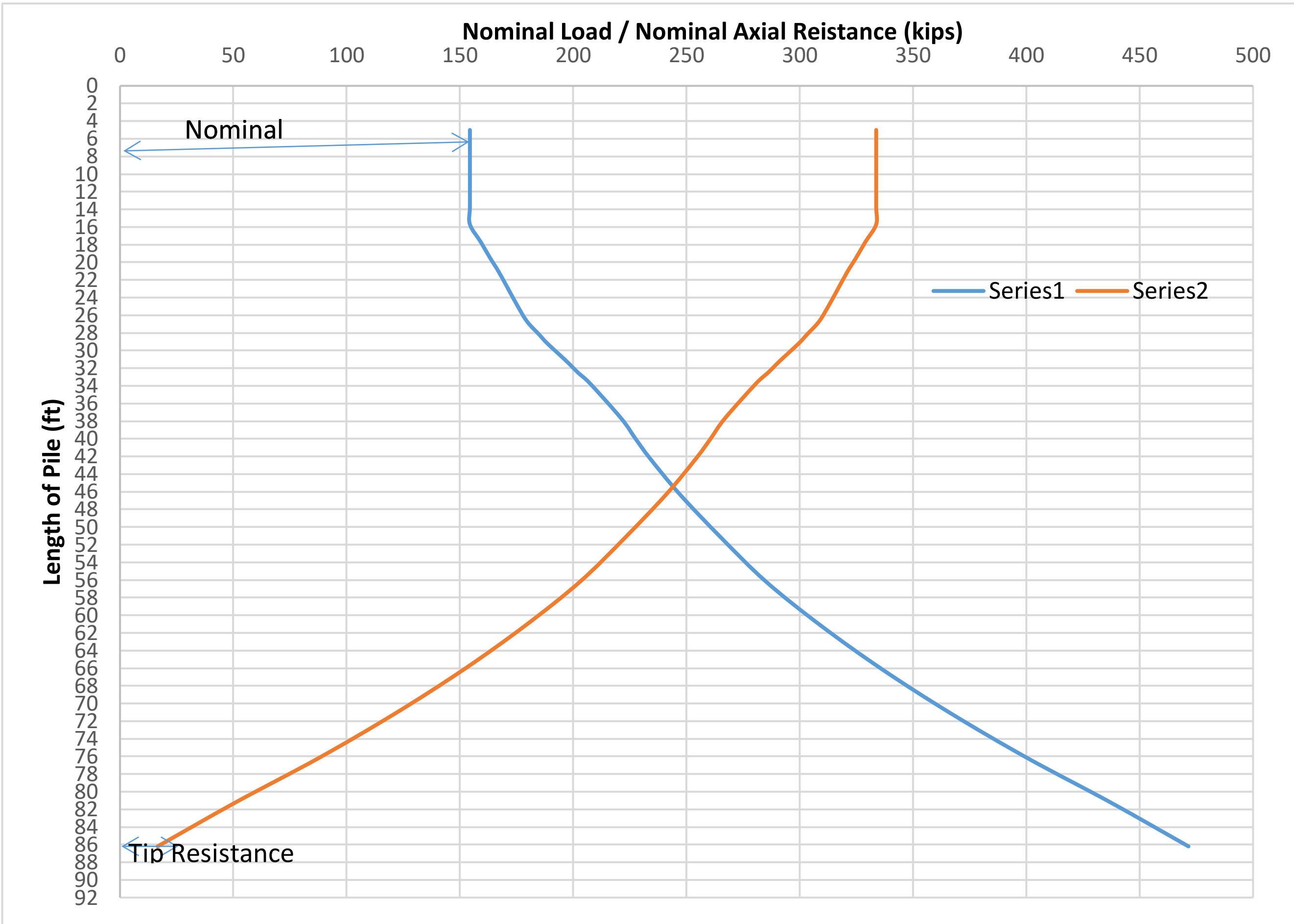
Depth (ft)	Skin Friction (kips)	End Bearing (kips)	Total Capacity (kips)	DC+DD(kips)	Unit Skin Friction (kips)	Upward skin Friction (kips)	Upward Skin + Mobilized end bearing (kips)
5.00	0.00	0.80	0.80	154.40	0.00	317.10	333.70
10.00	0.00	1.70	1.70	154.40	0.00	317.10	333.70
13.70	0.00	2.30	2.30	154.40	0.00	317.10	333.70
15.70	0.00	5.70	5.70	154.40	0.00	317.10	333.70
17.70	4.80	5.70	10.40	159.20	4.80	312.30	328.90
19.50	8.90	5.70	14.50	163.30	4.10	308.20	324.80
21.20	13.00	5.70	18.70	167.40	4.10	304.10	320.70
24.70	20.50	4.20	24.70	174.90	7.50	296.60	313.20
26.70	25.20	11.00	36.20	179.60	4.70	291.90	308.50
28.20	30.60	26.00	56.60	185.00	5.40	286.50	303.10
29.20	34.20	14.10	48.30	188.60	3.60	282.90	299.50
31.20	42.60	14.10	56.70	197.00	8.40	274.50	291.10
32.50	47.70	14.10	61.90	202.10	5.10	269.40	286.00
33.70	52.90	14.10	67.10	207.30	5.20	264.20	280.80
37.70	66.80	26.20	93.00	221.20	13.90	250.30	266.90
40.00	73.10	26.20	99.20	227.50	6.30	244.00	260.60
42.20	79.40	26.20	105.50	233.80	6.30	237.70	254.30
46.20	92.30	16.60	108.90	246.70	12.90	224.80	241.40
51.20	110.80	16.60	127.40	265.20	18.50	206.30	222.90
56.20	130.70	16.60	147.30	285.10	19.90	186.40	203.00
61.20	155.00	16.60	171.60	309.40	24.30	162.10	178.70
66.20	182.30	16.60	198.90	336.70	27.30	134.80	151.40
71.20	212.70	16.60	229.30	367.10	30.40	104.40	121.00
76.20	246.10	16.60	262.70	400.50	33.40	71.00	87.60
81.20	282.60	16.60	299.30	437.00	36.50	34.50	51.10
86.20	317.10	16.60	333.70	471.50	34.50	0.00	16.60

Driven Depth	Skin Friction
42.20	79.40
46.20	92.30

Neutral Plane Depth (ft)	46.00
Skin Friction at Neutral Plan (kips)	91.66
Factored Load+Factored Downdrag (kips)	305.54

<

Factored Strucure Resistance (kips)
480



APPENDIX D

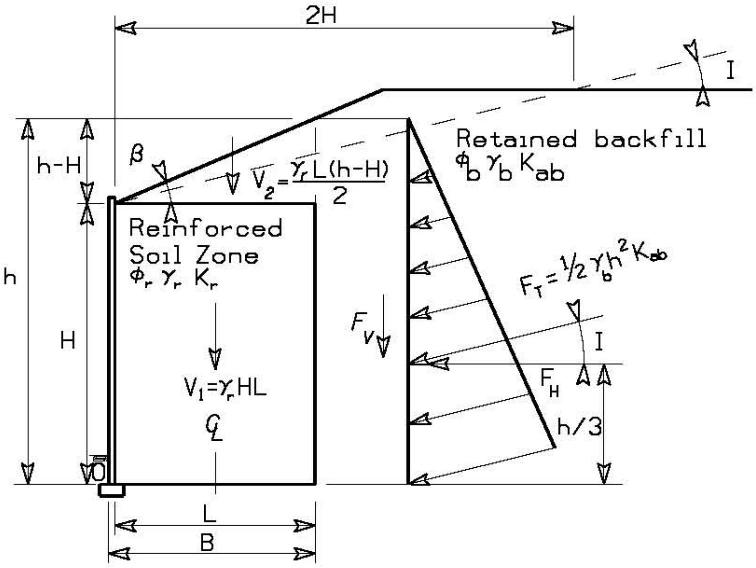
EXTERNAL STABILITY ANALYSIS – MSE WALLS

Objective: To evaluate the external stability of MSE wall design with vertical wall face and broken backslope case.

Method: In accordance with ODOT Bridge Design Manual, 2022 [Sect. 307.4] and LRFD Bridge Design Specifications, 9th Ed., 2020, [Sect. 3.11.5.8 and Sect. 11.10.5].

Assumptions:

- **Horizontal backfill, Infinite backslope or Broken backslope behind MSE wall, see LRFD Sect. 3.11.5.8.1.**
- **For battered or vertical walls with a back face of wall angle of θ to horizontal.**
- **Not for sheet type reinforcement. If so, use different assessment for Sliding parameter ϕ_μ.**
- **MSE wall not acting as abutment, if so must meet minimum embedment depth of H/10 if no slope in front of wall**



Givens:

Wall Geometry:

$H_e := 21.1\ ft$ — Exposed wall height (Proposed profile grade to the top of wall)

$\theta := 90 \cdot deg$ — Angle of back face of wall to horizontal: 90 deg for vertical or near vertical walls (per Berg et al., 2009; near vertical = 80 deg < θ < 100 deg)

$\beta_{BackSlope} := 0\ deg$ — Inclination of ground slope behind face of wall. If it is horizontal backfill behind MSE wall, $\beta_{Backslope}$ = 0 deg

$\lambda := 0\ ft$ — Horizontal distance from the back of MSE wall to the top of slope. If it is infinite slope behind MSE Wall, input λ larger than 2H; If it is horizontal backfill behind MSE wall, λ = 0 ft

Reinforced Backfill Soil Design Parameters:

$\phi'_r := 34\ deg$ — Effective angle of internal friction (Per BDM Table 307-1)

$\gamma_r := 120\ \frac{lbf}{ft^3}$ — Unit weight (Per BDM Table 307-1)

$c'_r := 0\ \frac{lbf}{ft^2}$ — Effective Cohesion

Retained Backfill Soil Design Parameters:

$\phi'_b := 30\ deg$ — Effective angle of internal friction (Per BDM Table 307-1)

$\gamma_b := 120\ \frac{lbf}{ft^3}$ — Unit weight (Per BDM Table 307-1)

$c'_b := 0\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta := 0.67 \cdot \phi'_b$ $\quad \delta = 20.1\ deg$ — Friction angle between backfill and wall taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

Soil Design Parameters for Bearing Resistance (Average 1.0 B Below Leveling Pad)

Drained Conditions (Effective Stress):

$\phi'_{fd} := 23\ deg$ — Effective angle of internal friction

$\gamma_{fd} := 110\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{fd} := 115\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{fdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$Su_{fdu} := 1550\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Undercut & Replacement Design Parameters:

$\phi_{Re} := 34\ deg$ — Angle of internal friction for Replacement soil - Item 203 Granular Material Type C, C&MS 703.16.C. ODOT BDM Table 307-1.

$c_{Re} := 0\ \frac{lbf}{ft^2}$ — Cohesion for Replacement soil - Item 203 Granular Material Type C, C&MS 703.16.C. ODOT BDM Table 307-1.

$\gamma_{Re} := 130\ \frac{lbf}{ft^3}$ — Unit Weight for Replacement soil - Item 203 Granular Material Type C, C&MS 703.16.C. ODOT BDM Table 307-1.

$\delta_{Re} := 0.67 \cdot \phi_{Re}$ $\quad \delta_{Re} = 22.8\ deg$ — Friction angle between Replacement soils and footing taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

$D_{undercut} := 0.0\ ft$ — Depth of Undercut below bottom of footing

Foundation Surcharge Soil Parameters

$\gamma_q := 120 \cdot \frac{lbf}{ft^3}$ — Unit weight of Soil above bearing depth (Used in Bearing Resistance of Soil Calculation LRFD 10.6.3.1.2a-1)

Depth of Embedment Check:

$d_{frost} := 3\ ft$ $\quad d_{user} := 4.2\ ft$ — Local Frost Depth / User Input

$Slope_{fw} := 0\ deg$

Inclination of ground slope in front of wall :

- Horizontal: **0**
- 3H:1V: **18.435**
- 2H:1V: **26.565**
- 1.5H:1V: **33.690**

$d_{est} := \max\left(d_{frost}, 3\ ft, d_{user}\right)$ $\quad d_{est} = 4.2\ ft$

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 25.3\ ft$

$$d_{eSlope} := \text{if}\left(Slope_{fw} < 1\ deg, \frac{H_{est}}{20}, \text{if}\left(Slope_{fw} < 26.565\ deg, \frac{H_{est}}{10}, \text{if}\left(Slope_{fw} < 33.69\ deg, \frac{H_{est}}{7}, \frac{H_{est}}{5}\right)\right)\right)$$

$d_{eSlope} = 1.3\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

$d_e := \max\left(d_{est}, d_{eSlope}\right)$ $\quad d_e = 4.2\ ft$ — Minimum Required Embedment Depth used in analysis.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 25.3\ ft$ — Inital design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 25.3\ ft$

User inputted value (if changes need to be made to satisfy other requirements)

$L := \max(8 \cdot ft, 0.7 \cdot H, L_{user})$ $\quad L = 25.3\ ft$

Length of Reinforcement

Live Load Surcharge Parameters:

$SUR := \text{if}\left(L < \lambda, 0\ \frac{lbf}{ft^2}, 250\ \frac{lbf}{ft^2}\right) = 250\ \frac{lbf}{ft^2}$

Live load surcharge (per LRFD BDS [3.11.6.4])

$SUR_{@MSE} := \text{if}\left(L < \lambda, 0\ \frac{lbf}{ft^2}, 250\ \frac{lbf}{ft^2}\right) = 250\ \frac{lbf}{ft^2}$

Live load surcharge above the MSE Wall soil reinforcement (per LRFD BDS [3.11.6.4])

Calculations:

Active Earth Pressure:

$H_{BackSlope} := \lambda \cdot \tan(\beta_{BackSlope})$ $\quad H_{BackSlope} = 0\ ft$

Height of Slope behind the MSE wall

$h := \text{if}\left(L < \lambda, H + L \cdot \tan(\beta_{BackSlope}), H + H_{BackSlope}\right)$

$h = 25.3\ ft$

Height of retained fill at the back of the reinforced soil

$I := \text{atan}\left(\frac{H_{BackSlope}}{2 \cdot H}\right)$ $\quad \beta := \text{if}\left(\lambda < 2 \cdot H, I, \beta_{BackSlope}\right)$

$I = 0\ deg$ $\quad \beta = 0\ deg$

Angle of friction between retained backfill and reinforced soil

$$\Gamma := \left(1 + \sqrt{\frac{(\sin(\phi'_b + \delta) \cdot \sin(\phi'_b - \beta))}{(\sin(\theta - \delta) \cdot \sin(\theta + \beta))}}\right)^2 = 2.6867$$

$$k_{ab} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{ab} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot h^2 \cdot k_{ab}$ $\quad F_T = 11416.4\ \frac{lbf}{ft}$

Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot h \cdot k_{ab}$ $\quad F_{SUR} = 1880.2\ \frac{lbf}{ft}$

Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\quad V_1 = 76810.8\ \frac{lbf}{ft}$

Soil backfill - reinforced soil (EV)

$V_2 := \text{if}\left(L < \lambda, \frac{1}{2} \cdot \gamma_b \cdot L \cdot (h - H), \frac{1}{2} \cdot \gamma_b \cdot \lambda \cdot (h - H)\right)$

$V_2 = 0\ \frac{lbf}{ft}$

Triangular Soil backfill - backslope soil (EV)

$V_3 := \text{if}\left(L < \lambda, 0 \cdot \frac{lbf}{ft}, \gamma_b \cdot (L - \lambda) \cdot (h - H)\right)$

$V_3 = 0\ \frac{lbf}{ft}$

Rectangular Soil backfill - backslope soil (EV)

$V_4 := F_T \cdot \sin(\beta)$ $\quad V_4 = 0 \ \frac{lbf}{ft}$ Active earth force resultant (vertical component - EH)

$V_5 := F_{SUR} \cdot \sin(\beta)$ $\quad V_5 = 0 \ \frac{lbf}{ft}$ Live Load Surcharge (vertical component - LS)

$V_6 := SUR_{@MSE} \cdot (L - \lambda)$ $\quad V_6 = 6325 \ \frac{lbf}{ft}$ Live Load Surcharge above MSE Wall soil reinforcement

Moment Arm (The pivot is at the toe of MSE Wall "O"): | Moment:

$d_{v1} := \frac{L}{2}$ $\quad d_{v1} = 12.7 \ ft$ $\quad MV_1 := V_1 \cdot d_{v1}$ $\quad MV_1 = 971656.6 \ \frac{lbf \cdot ft}{ft}$

$d_{v2} := \text{if}\left(L < \lambda, \frac{2\ L}{3}, \frac{2 \cdot \lambda}{3}\right)$ $\quad d_{v2} = 0 \ ft$ $\quad MV_2 := V_2 \cdot d_{v2}$ $\quad MV_2 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v3} := \text{if}\left(L < \lambda, 0 \cdot ft, \lambda + \frac{(L - \lambda)}{2}\right)$ $\quad d_{v3} = 12.7 \ ft$ $\quad MV_3 := V_3 \cdot d_{v3}$ $\quad MV_3 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v4} := L$ $\quad d_{v4} = 25.3 \ ft$ $\quad MV_4 := V_4 \cdot d_{v4}$ $\quad MV_4 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v5} := L$ $\quad d_{v5} = 25.3 \ ft$ $\quad MV_5 := V_5 \cdot d_{v5}$ $\quad MV_5 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v6} := \text{if}\left(L < \lambda, 0 \cdot ft, \lambda + \frac{(L - \lambda)}{2}\right)$ $\quad d_{v6} = 12.7 \ ft$ $\quad MV_6 := V_6 \cdot d_{v6}$ $\quad MV_6 = 80011.3 \ \frac{lbf \cdot ft}{ft}$

Horizontal Loads:

$H_1 := F_T \cdot \cos(\beta) = 11416.4 \ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} \cdot \cos(\beta) = 1880.2 \ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: | Moment:

$d_{h1} := \frac{h}{3}$ $\quad d_{h1} = 8.4 \ ft$ $\quad MH_1 := H_1 \cdot d_{h1}$ $\quad MH_1 = 96278.2 \ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{h}{2}$ $\quad d_{h2} = 12.7 \ ft$ $\quad MH_2 := H_2 \cdot d_{h2}$ $\quad MH_2 = 23784.1 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1 + V_2 + V_3$ $\quad V_{EV} = 76810.8 \ \frac{lbf}{ft}$

$V_{EH} := V_4$ $\quad V_{EH} = 0 \ \frac{lbf}{ft}$

$V_{LS} := V_5$ $\quad V_{LS} = 0 \ \frac{lbf}{ft}$

$V_{LS@MSE} := V_6$ $\quad V_{LS@MSE} = 6325 \ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 11416.4 \ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 1880.2 \ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{EV} := MV_1 + MV_2 + MV_3$ $\quad M_{EV} = 971656.6 \ \frac{lbf \cdot ft}{ft}$

$M_{EH1} := MV_4$ $\quad M_{EH1} = 0 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1} := MV_5$ $\quad M_{LS1} = 0 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1@MSE} := MV_6$ $\quad M_{LS1@MSE} = 80011.3 \ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_1$ $\quad M_{EH2} = 96278.2 \ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 23784.1 \ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

Strength Limit State I: EV(min) = 1.00 EV(max) = 1.35
EH(min) = 0.90 EH(max) = 1.50
LS = 1.75

Strength Limit State Ia:
(Sliding and Eccentricity) $\quad Ia_{EV} := 1 \quad Ia_{EH} := 1.5 \quad Ia_{LS} := 1.75$

Strength Limit State Ib:
(Bearing Capacity) $\quad Ib_{EV} := 1.35 \quad Ib_{EH} := 1.5 \quad Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot \left(\left(Ia_{EV} \cdot V_{EV} \right) + \left(Ia_{EH} \cdot V_{EH} \right) + Ia_{LS} \cdot \left(V_{LS} + V_{LS@MSE} \right) \right)$ $\quad V_{Ia} = 87879.6 \ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{EV} \cdot V_{EV} \right) + \left(Ib_{EH} \cdot V_{EH} \right) + Ib_{LS} \cdot \left(V_{LS} + V_{LS@MSE} \right) \right)$ $\quad V_{Ib} = 114763.3 \ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{EH} \cdot H_{EH} \right) + \left(Ia_{LS} \cdot H_{LS} \right) \right)$ $\quad H_{Ia} = 20414.9 \ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{EH} \cdot H_{EH} \right) + \left(Ib_{LS} \cdot H_{LS} \right) \right)$ $\quad H_{Ib} = 20414.9 \ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot \left(\left(Ia_{EV} \cdot M_{EV} \right) + \left(Ia_{EH} \cdot M_{EH1} \right) + Ia_{LS} \cdot \left(M_{LS1} + M_{LS1@MSE} \right) \right)$ $\quad MV_{Ia} = 1111676.3 \ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot \left(\left(Ib_{EV} \cdot M_{EV} \right) + \left(Ib_{EH} \cdot M_{EH1} \right) + Ib_{LS} \cdot \left(M_{LS1} + M_{LS1@MSE} \right) \right)$ $\quad MV_{Ib} = 1451756.1 \ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{EH} \cdot M_{EH2} \right) + \left(Ia_{LS} \cdot M_{LS2} \right) \right)$ $\quad MH_{Ia} = 186039.6 \ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{EH} \cdot M_{EH2} \right) + \left(Ib_{LS} \cdot M_{LS2} \right) \right)$ $\quad MH_{Ib} = 186039.6 \ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the Effective Bearing Length (Strength Ib) about the Toe "O" of base length (the pivot):

$\Sigma M_R := MV_{Ib}$ $\quad \Sigma M_R = 1451756.1 \ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 186039.6 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 114763.3 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $\quad x = 11 \ ft$ Distance from Point "O" the resultant intersects the base

$e := \left| \frac{L}{2} - x \right|$ $\quad e = 1.62 \ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2]**. The effective bearing width is equal to B-2e.

$B' := L - 2 \cdot e + D_{undercut}$ $\quad B' = 22.1 \ ft$ Effective Footing Width, Assumed at the bottom of Undercut and Replacement

Foundation Layout:

$L_{Wall} := 123 \ ft$ Assumed Footing Length (Wall Section Length)

$D_f := d_e$ $\quad D_f = 4.2 \ ft$ Footing embedment

$D_F := D_f + D_{undercut}$ Embenment Depth at bottom of Undercut

$d_w := D_f$ Depth of Groundwater below ground surface in front of wall

Drained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi'_{fd} > 0, e^{\pi \cdot \tan(\phi'_{fd})} \cdot \tan\left(45 \ deg + \frac{\phi'_{fd}}{2}\right)^2, 1.0\right) \qquad N_q = 8.66$$

$$N_c := \text{if}\left(\phi'_{fd} > 0, \frac{N_q - 1}{\tan(\phi'_{fd})}, 5.14\right) \qquad N_c = 18.05$$

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_{fd}) \qquad N_\gamma = 8.2$$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$$s_c := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.086$$

$$s_q := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_{fd})\right), 1\right) \qquad s_q = 1.076$$

$$s_\gamma := \text{if}\left(\phi'_{fd} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.928$$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $\quad i_q = 1$

$i_\gamma := 1$ $\quad i_\gamma = 1$

$i_c := 1$ $\quad i_c = 1$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$C_{wq} := \text{if}\left(d_w \ge D_f, 1.0, 0.5\right)$ $\quad C_{wq} = 1$

$C_{w\gamma} := \text{if}\left(d_w \ge (1.5 \cdot L) + D_f, 1.0, 0.5\right)$ $\quad C_{w\gamma} = 0.5$

Depth Correction Factor per Hanson (1970):

$$d_q := 1 + 2 \cdot \tan(\phi'_{fd}) \cdot \left(1 - \sin(\phi'_{fd})\right)^2 \cdot \text{atan}\left(\frac{D_F}{B'}\right)$$

$d_q = 1.06$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 19.602$

$N_{qm} := N_q \cdot s_q \cdot d_q \cdot i_q$ $\quad N_{qm} = 9.873$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 7.614$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$q_{nd} := c'_{fd} \cdot N_{cm} + \gamma_q \cdot D_F \cdot N_{qm} \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 11848.6 \ \frac{lbf}{ft^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.65$ — Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 7.7 \ ksf$ — Factored bearing resistance Drained Conditions

Undrained Conditions (Total Stress):

$$N_q := \text{if}\left(\phi_{fdu} > 0, e^{\pi \cdot \tan(\phi_{fdu})} \cdot \tan\left(45\ deg + \frac{\phi_{fdu}}{2}\right)^2, 1.0\right)$$ $\quad N_q = 1$

$$N_c := \text{if}\left(\phi_{fdu} > 0, \frac{N_q - 1}{\tan(\phi_{fdu})}, 5.14\right)$$ $\quad N_c = 5.14$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fdu})$ $\quad N_\gamma = 0$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$$s_c := \text{if}\left(\phi_{fdu} > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$$ $\quad s_c = 1.036$

$$s_q := \text{if}\left(\phi_{fdu} > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_{fdu})\right), 1\right)$$ $\quad s_q = 1$

$s_\gamma := \text{if}\left(\phi_{fdu} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $\quad s_\gamma = 1$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $\quad i_q = 1$

$i_\gamma := 1$ $\quad i_\gamma = 1$

$i_c := 1$ $\quad i_c = 1$

Depth Correction Factor per Hanson (1970):

$$d_q := 1 + 2 \cdot \tan\left(\phi'_{fd}\right) \cdot \left(1 - \sin\left(\phi'_{fd}\right)\right)^2 \cdot \text{atan}\left(\frac{D_F}{B'}\right)$$

$d_q = 1.06$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 5.324$

$N_{qm} := N_q \cdot s_q \cdot d_q \cdot i_q$ $\quad N_{qm} = 1.059$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 0$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$q_{nu} := Su_{fdu} \cdot N_{cm} + \gamma_q \cdot D_F \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nu} = 8818.3 \ \frac{lbf}{ft^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.65$ — Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $\quad q_{Ru} = 5.7 \ ksf$ — Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 7.7 \ ksf$

Undrained Conditions: $q_{Ru} = 5.7 \ ksf$

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

Compute the resultant location about the toe "O" of base length (the pivot):

$e := \left|\frac{L}{2} - x\right|$ $\quad e = 1.62 \ ft$ — Wall eccentricity, **Note:** The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2]**. The effective bearing width is equal to B-2e.

$\sigma_v := \frac{\Sigma V}{B'}$ $\quad \sigma_v = 5202.8 \ \frac{lbf}{ft^2}$ — Bearing Stress

Bearing Resistance Capacity:Demand Ratio (CDR)

Drained Conditions: $CDR_{Bearing\_d} := \frac{q_{Rd}}{\sigma_v}$ — Is the CDR > or = to 1.0? $CDR_{Bearing\_d} = 1.48$

Undrained Conditions: $CDR_{Bearing\_u} := \frac{q_{Ru}}{\sigma_v}$ — Is the CDR > or = to 1.0? $CDR_{Bearing\_u} = 1.10$

Limiting Eccentricity at Base of MSE Wall (Strength Ia):

$e_{max} := \frac{L}{3}$ $e_{max} = 8.4\ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 1111676.3\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 186039.6\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 87879.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 10.5\ ft$ Distance from Point "O" the resultant intersects the base

$e := \left| \frac{L}{2} - x \right|$ $e = 2.12\ ft$ Wall eccentricity

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 3.98$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$R_u := H_{Ia}$ $R_u = 20414.9\ \frac{lbf}{ft}$

Drained Conditions (Effective Stress):

Compute sliding resistance between soil and foundation:

$\Sigma V := V_{Ia}$ $\Sigma V = 87879.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_{fd})$ $R_{\tau d} = 37302.7\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_\tau := 1.0$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

Drained Conditions: $\phi R_{n\_d} := \phi_\tau \cdot R_{\tau d}$ $R_{R\_d} := \phi R_{n\_d}$ $R_{R\_d} = 37.3\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding\_d} := \frac{R_{R\_d}}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding\_d} = 1.83$

Undrained Conditions (Total Stress):

Compute sliding resistance between soil and foundation:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 87879.6 \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ia)

$e = 2.12\ ft$ — Wall eccentricity, Calculated in above Limiting Eccentricity at Base of Wall (Strength Ia) Section.

$B := L$ — Footing base width

$\frac{B}{6} = 4.2\ ft$ — If e < B/6 the resultant is in the middle one-third

$\sigma_{vmax} := \frac{\Sigma V}{B} \cdot \left(1 + 6 \cdot \frac{e}{B}\right)$ $\quad \sigma_{vmax} = 5217.4 \frac{lbf}{ft^2}$ — Max vertical stress (if resultant is in the middle one-third of base) **LRFD [11.6.3.2-2]**.

$\sigma_{vmin} := \frac{\Sigma V}{B} \cdot \left(1 - 6 \cdot \frac{e}{B}\right)$ $\quad \sigma_{vmin} = 1729.6 \frac{lbf}{ft^2}$ — Max verical stress (if resultant is in the middle one-third of base) **LRFD [11.6.3.2-2]**.

$q_{max} := \frac{1}{2} \cdot \sigma_{vmax}$ $\quad q_{max} = 2608.7 \frac{lbf}{ft^2}$ — Max unit shear resistance as 1/2 max vertical stress **LRFD [10.6.3.4]**.

$q_{min} := \frac{1}{2} \cdot \sigma_{vmin}$ $\quad q_{min} = 864.8 \frac{lbf}{ft^2}$ — Minimum unit shear resistance as 1/2 minimum vertical stress **LRFD [10.6.3.4]**.

Determine which Cohesive Soil Resistance Case is Present:

$Case_1 := \text{if}\left(q_{max} > Su_{fdu} > q_{min} \ge 0, 1, 0\right)$ $\quad Case_1 = 1$

$Case_2 := \text{if}\left(Su_{fdu} > q_{max} > q_{min} \ge 0, 1, 0\right)$ $\quad Case_2 = 0$

$Case_3 := \text{if}\left(q_{max} > q_{min} > Su_{fdu}, 1, 0\right)$ $\quad Case_3 = 0$

$Case_4 := \text{if}\left(q_{min} < 0, \text{if}\left(Su_{fdu} < q_{max}, 1, 0\right), 0\right)$ $\quad Case_4 = 0$

$Case_5 := \text{if}\left(q_{min} < 0, \text{if}\left(Su_{fdu} > q_{max}, 1, 0\right), 0\right)$ $\quad Case_5 = 0$

Unit Shear Resistance for Case 1:

$S_1 := Su_{fdu} - q_{min} = 685.2 \frac{lbf}{ft^2}$ $\quad S_2 := q_{min} = 864.8 \frac{lbf}{ft^2}$

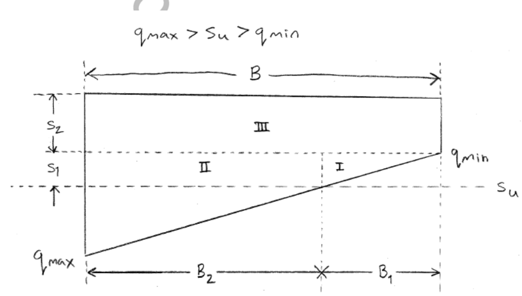
$B_1 := \frac{B \cdot \left(Su_{fdu} - q_{min}\right)}{q_{max} - q_{min}} = 9.9\ ft$ $\quad B_2 := \frac{B \cdot \left(q_{max} - Su_{fdu}\right)}{q_{max} - q_{min}} = 15.4\ ft$

$B_3 := B = 25.3\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B_1 = 3405.6 \frac{lbf}{ft}$ $\quad II := S_1 \cdot B_2 = 10524 \frac{lbf}{ft}$

$III := S_2 \cdot B_3 = 21879.7 \frac{lbf}{ft}$

$R_{\tau\_case1} := I + II + III = 35809.4 \frac{lbf}{ft}$



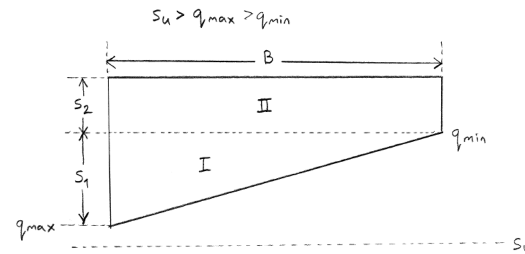
Unit Shear Resistance for Case 2:

$S_1 := q_{max} - q_{min} = 1743.9\ \frac{lbf}{ft^2}$ $\quad S_2 := q_{min} = 864.8\ \frac{lbf}{ft^2}$

$B = 25.3\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B = 22060\ \frac{lbf}{ft}$ $\quad II := S_2 \cdot B = 21879.7\ \frac{lbf}{ft}$

$R_{\tau\_case2} := I + II = 43939.8\ \frac{lbf}{ft}$



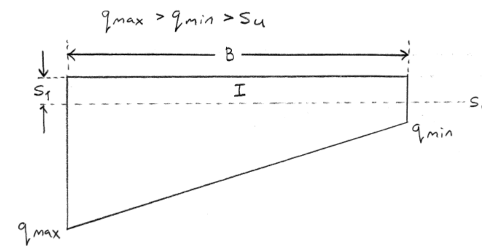
Unit Shear Resistance for Case 3:

$S_1 := Su_{fdu} = 1550\ \frac{lbf}{ft^2}$

$B = 25.3\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B = 19607.5\ \frac{lbf}{ft}$

$R_{\tau\_case3} := I = 19607.5\ \frac{lbf}{ft}$



Unit Shear Resistance for Case 4:

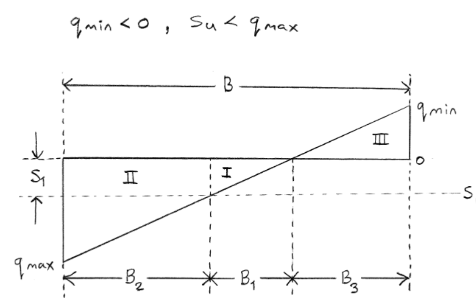
$S_1 := Su_{fdu} = 1550\ \frac{lbf}{ft^2}$

$B_3 := \frac{B \cdot (-q_{min})}{q_{max} - q_{min}} = -12.5\ ft$ $\quad B_1 := \left(\frac{Su_{fdu}}{q_{max}}\right) \cdot (B - B_3) = 22.5\ ft$

$B_2 := B - (B_1 + B_3) = 15.4\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B_1 = 17427.6\ \frac{lbf}{ft}$ $\quad II := S_1 \cdot B_2 = 23807\ \frac{lbf}{ft}$

$R_{\tau\_case4} := I + II = 41234.6\ \frac{lbf}{ft}$



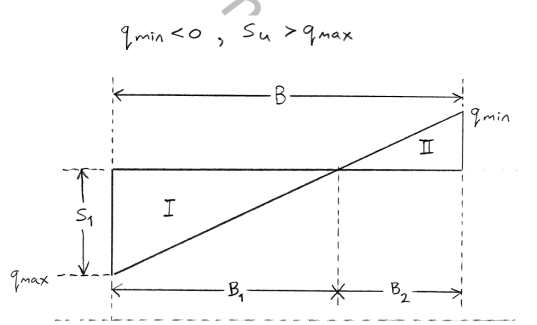
Unit Shear Resistance for Case 5:

$S_1 := q_{max} = 2608.7\ \frac{lbf}{ft^2}$

$B_1 := \frac{B \cdot q_{max}}{q_{max} - q_{min}} = 37.8\ ft$ $\quad B_2 := B - B_1 = -12.5\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B_1 = 49365\ \frac{lbf}{ft}$

$R_{\tau\_case5} := I = 49365\ \frac{lbf}{ft}$



Define the Applicable Case:

$R_\tau := R_{\tau\_case1}$ $\qquad R_\tau = 35809.4\ \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Cohesive Soils

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_{ep} := 0.5$ $\qquad$ Resistance factor for passive resistance specified in **LRFD Table 10.5.5.2.2-1**

$\phi_\tau := 1.0$ $\qquad$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

$\phi R_n := \phi_\tau \cdot R_\tau$ $\qquad R_R := \phi R_n$

Factored Sliding Resistance to be used in CDR Calculations: $R_R = 35809.394\ \frac{lbf}{ft}$

Sliding Capacity:Demand Ratio (CDR)

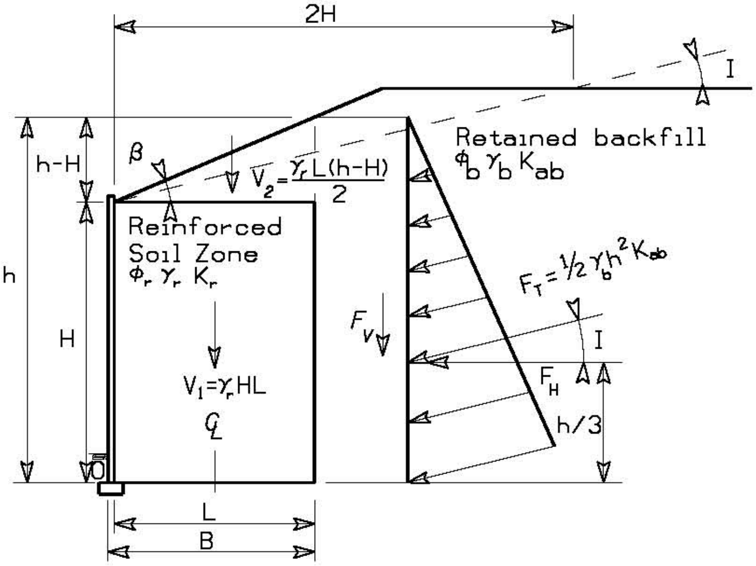
$CDR_{Sliding\_u} := \frac{R_R}{R_u}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding\_u} = 1.75$

Objective: To evaluate the external stability of MSE wall design with vertical wall face and broken backslope case.

Method: In accordance with ODOT Bridge Design Manual, 2022 [Sect. 307.4] and LRFD Bridge Design Specifications, 9th Ed., 2020, [Sect. 3.11.5.8 and Sect. 11.10.5].

Assumptions:

- **Horizontal backfill, Infinite backslope or Broken backslope behind MSE wall, see LRFD Sect. 3.11.5.8.1.**
- **For battered or vertical walls with a back face of wall angle of θ to horizontal.**
- **Not for sheet type reinforcement. If so, use different assessment for Sliding parameter ϕ_μ.**
- **MSE wall not acting as abutment, if so must meet minimum embedment depth of H/10 if no slope in front of wall**



Givens:

Wall Geometry:

$H_e := 23.4\ ft$ — Exposed wall height (Proposed profile grade to the top of wall)

$\theta := 90 \cdot deg$ — Angle of back face of wall to horizontal: 90 deg for vertical or near vertical walls (per Berg et al., 2009; near vertical = 80 deg < θ < 100 deg)

$\beta_{BackSlope} := 0\ deg$ — Inclination of ground slope behind face of wall. If it is horizontal backfill behind MSE wall, $\beta_{Backslope}$ = 0 deg

$\lambda := 0\ ft$ — Horizontal distance from the back of MSE wall to the top of slope. If it is infinite slope behind MSE Wall, input λ larger than 2H; If it is horizontal backfill behind MSE wall, λ = 0 ft

Reinforced Backfill Soil Design Parameters:

$\phi'_r := 34\ deg$ — Effective angle of internal friction (Per BDM Table 307-1)

$\gamma_r := 120\ \frac{lbf}{ft^3}$ — Unit weight (Per BDM Table 307-1)

$c'_r := 0\ \frac{lbf}{ft^2}$ — Effective Cohesion

Retained Backfill Soil Design Parameters:

$\phi'_b := 30\ deg$ — Effective angle of internal friction (Per BDM Table 307-1)

$\gamma_b := 120\ \frac{lbf}{ft^3}$ — Unit weight (Per BDM Table 307-1)

$c'_b := 0\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta := 0.67 \cdot \phi'_b$ $\delta = 20.1\ deg$ — Friction angle between backfill and wall taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

Soil Design Parameters for Bearing Resistance (Average 1.0 B Below Leveling Pad)

Drained Conditions (Effective Stress):

$\phi'_{fd} := 23\ deg$ — Effective angle of internal friction

$\gamma_{fd} := 110\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{fd} := 115\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{fdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$Su_{fdu} := 1600\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Undercut & Replacement Design Parameters:

$\phi_{Re} := 34\ deg$ — Angle of internal friction for Replacement soil - Item 203 Granular Material Type C, C&MS 703.16.C. ODOT BDM Table 307-1.

$c_{Re} := 0\ \frac{lbf}{ft^2}$ — Cohesion for Replacement soil - Item 203 Granular Material Type C, C&MS 703.16.C. ODOT BDM Table 307-1.

$\gamma_{Re} := 130\ \frac{lbf}{ft^3}$ — Unit Weight for Replacement soil - Item 203 Granular Material Type C, C&MS 703.16.C. ODOT BDM Table 307-1.

$\delta_{Re} := 0.67 \cdot \phi_{Re}$ $\quad \delta_{Re} = 22.8\ deg$ — Friction angle between Replacement soils and footing taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

$D_{undercut} := 0.0\ ft$ — Depth of Undercut below bottom of footing

Foundation Surcharge Soil Parameters

$\gamma_q := 120 \cdot \frac{lbf}{ft^3}$ — Unit weight of Soil above bearing depth (Used in Bearing Resistance of Soil Calculation LRFD 10.6.3.1.2a-1)

Depth of Embedment Check:

$d_{frost} := 3\ ft$ $\quad d_{user} := 4.6\ ft$ — Local Frost Depth / User Input

$Slope_{fw} := 0\ deg$

Inclination of ground slope in front of wall :

- Horizontal: **0**
- 3H:1V: **18.435**
- 2H:1V: **26.565**
- 1.5H:1V: **33.690**

$d_{est} := \max\left(d_{frost}, 3\ ft, d_{user}\right)$ $\quad d_{est} = 4.6\ ft$

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 28\ ft$

$$d_{eSlope} := \text{if}\left(Slope_{fw} < 1\ deg, \frac{H_{est}}{20}, \text{if}\left(Slope_{fw} < 26.565\ deg, \frac{H_{est}}{10}, \text{if}\left(Slope_{fw} < 33.69\ deg, \frac{H_{est}}{7}, \frac{H_{est}}{5}\right)\right)\right)$$

$d_{eSlope} = 1.4\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

$d_e := \max\left(d_{est}, d_{eSlope}\right)$ $\quad d_e = 4.6\ ft$ — Minimum Required Embedment Depth used in analysis.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 28\ ft$ — Inital design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 28\ ft$ — User inputted value (if changes need to be made to satisfy other requirements)

$L := \max(8 \cdot ft, 0.7 \cdot H, L_{user})$ $\quad L = 28\ ft$ — Length of Reinforcement

Live Load Surcharge Parameters:

$SUR := \text{if}\left(L < \lambda, 0\ \frac{lbf}{ft^2}, 250\ \frac{lbf}{ft^2}\right) = 250\ \frac{lbf}{ft^2}$ — Live load surcharge (per LRFD BDS [3.11.6.4])

$SUR_{@MSE} := \text{if}\left(L < \lambda, 0\ \frac{lbf}{ft^2}, 250\ \frac{lbf}{ft^2}\right) = 250\ \frac{lbf}{ft^2}$ — Live load surcharge above the MSE Wall soil reinforcement (per LRFD BDS [3.11.6.4])

Calculations:

Active Earth Pressure:

$H_{BackSlope} := \lambda \cdot \tan(\beta_{BackSlope})$ $\quad H_{BackSlope} = 0\ ft$ — Height of Slope behind the MSE wall

$h := \text{if}\left(L < \lambda, H + L \cdot \tan(\beta_{BackSlope}), H + H_{BackSlope}\right)$

$h = 28\ ft$ — Height of retained fill at the back of the reinforced soil

$I := \text{atan}\left(\frac{H_{BackSlope}}{2 \cdot H}\right)$ $\quad I = 0\ deg$

$\beta := \text{if}(\lambda < 2 \cdot H, I, \beta_{BackSlope})$ $\quad \beta = 0\ deg$ — Angle of friction between retained backfill and reinforced soil

$$\Gamma := \left(1 + \sqrt{\frac{(\sin(\phi'_b + \delta) \cdot \sin(\phi'_b - \beta))}{(\sin(\theta - \delta) \cdot \sin(\theta + \beta))}}\right)^2 = 2.6867$$

$$k_{ab} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \quad k_{ab} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot h^2 \cdot k_{ab}$ $\quad F_T = 13983.1\ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot h \cdot k_{ab}$ $\quad F_{SUR} = 2080.8\ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\quad V_1 = 94080\ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := \text{if}\left(L < \lambda, \frac{1}{2} \cdot \gamma_b \cdot L \cdot (h - H), \frac{1}{2} \cdot \gamma_b \cdot \lambda \cdot (h - H)\right)$

$V_2 = 0\ \frac{lbf}{ft}$ — Triangular Soil backfill - backslope soil (EV)

$V_3 := \text{if}\left(L < \lambda, 0 \cdot \frac{lbf}{ft}, \gamma_b \cdot (L - \lambda) \cdot (h - H)\right)$

$V_3 = 0\ \frac{lbf}{ft}$ — Rectangular Soil backfill - backslope soil (EV)

$V_4 := F_T \cdot \sin(\beta)$ $\quad V_4 = 0 \ \frac{lbf}{ft}$ Active earth force resultant (vertical component - EH)

$V_5 := F_{SUR} \cdot \sin(\beta)$ $\quad V_5 = 0 \ \frac{lbf}{ft}$ Live Load Surcharge (vertical component - LS)

$V_6 := SUR_{@MSE} \cdot (L - \lambda)$ $\quad V_6 = 7000 \ \frac{lbf}{ft}$ Live Load Surcharge above MSE Wall soil reinforcement

Moment Arm (The pivot is at the toe of MSE Wall "O"): | Moment:

$d_{v1} := \frac{L}{2}$ $\quad d_{v1} = 14 \ ft$ $\quad MV_1 := V_1 \cdot d_{v1}$ $\quad MV_1 = 1317120 \ \frac{lbf \cdot ft}{ft}$

$d_{v2} := \text{if}\left(L < \lambda, \frac{2\ L}{3}, \frac{2 \cdot \lambda}{3}\right)$ $\quad d_{v2} = 0 \ ft$ $\quad MV_2 := V_2 \cdot d_{v2}$ $\quad MV_2 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v3} := \text{if}\left(L < \lambda, 0 \cdot ft, \lambda + \frac{(L - \lambda)}{2}\right)$ $\quad d_{v3} = 14 \ ft$ $\quad MV_3 := V_3 \cdot d_{v3}$ $\quad MV_3 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v4} := L$ $\quad d_{v4} = 28 \ ft$ $\quad MV_4 := V_4 \cdot d_{v4}$ $\quad MV_4 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v5} := L$ $\quad d_{v5} = 28 \ ft$ $\quad MV_5 := V_5 \cdot d_{v5}$ $\quad MV_5 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v6} := \text{if}\left(L < \lambda, 0 \cdot ft, \lambda + \frac{(L - \lambda)}{2}\right)$ $\quad d_{v6} = 14 \ ft$ $\quad MV_6 := V_6 \cdot d_{v6}$ $\quad MV_6 = 98000 \ \frac{lbf \cdot ft}{ft}$

Horizontal Loads:

$H_1 := F_T \cdot \cos(\beta) = 13983.1 \ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} \cdot \cos(\beta) = 2080.8 \ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: | Moment:

$d_{h1} := \frac{h}{3}$ $\quad d_{h1} = 9.3 \ ft$ $\quad MH_1 := H_1 \cdot d_{h1}$ $\quad MH_1 = 130509 \ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{h}{2}$ $\quad d_{h2} = 14 \ ft$ $\quad MH_2 := H_2 \cdot d_{h2}$ $\quad MH_2 = 29131.5 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1 + V_2 + V_3$ $\quad V_{EV} = 94080 \ \frac{lbf}{ft}$

$V_{EH} := V_4$ $\quad V_{EH} = 0 \ \frac{lbf}{ft}$

$V_{LS} := V_5$ $\quad V_{LS} = 0 \ \frac{lbf}{ft}$

$V_{LS@MSE} := V_6$ $\quad V_{LS@MSE} = 7000 \ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 13983.1 \ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2080.8 \ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{EV} := MV_1 + MV_2 + MV_3$ $\quad M_{EV} = 1317120 \ \frac{lbf \cdot ft}{ft}$

$M_{EH1} := MV_4$ $\quad M_{EH1} = 0 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1} := MV_5$ $\qquad M_{LS1} = 0 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1@MSE} := MV_6$ $\qquad M_{LS1@MSE} = 98000 \ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_1$ $\qquad M_{EH2} = 130509 \ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\qquad M_{LS2} = 29131.5 \ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

Strength Limit State I: EV(min) = 1.00 EV(max) = 1.35
EH(min) = 0.90 EH(max) = 1.50
LS = 1.75

Strength Limit State Ia: (Sliding and Eccentricity) $Ia_{EV} := 1$ $\quad Ia_{EH} := 1.5$ $\quad Ia_{LS} := 1.75$

Strength Limit State Ib: (Bearing Capacity) $Ib_{EV} := 1.35$ $\quad Ib_{EH} := 1.5$ $\quad Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot \left(\left(Ia_{EV} \cdot V_{EV} \right) + \left(Ia_{EH} \cdot V_{EH} \right) + Ia_{LS} \cdot \left(V_{LS} + V_{LS@MSE} \right) \right)$ $\qquad V_{Ia} = 106330 \ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{EV} \cdot V_{EV} \right) + \left(Ib_{EH} \cdot V_{EH} \right) + Ib_{LS} \cdot \left(V_{LS} + V_{LS@MSE} \right) \right)$ $\qquad V_{Ib} = 139258 \ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{EH} \cdot H_{EH} \right) + \left(Ia_{LS} \cdot H_{LS} \right) \right)$ $\qquad H_{Ia} = 24616.1 \ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{EH} \cdot H_{EH} \right) + \left(Ib_{LS} \cdot H_{LS} \right) \right)$ $\qquad H_{Ib} = 24616.1 \ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot \left(\left(Ia_{EV} \cdot M_{EV} \right) + \left(Ia_{EH} \cdot M_{EH1} \right) + Ia_{LS} \cdot \left(M_{LS1} + M_{LS1@MSE} \right) \right)$ $\qquad MV_{Ia} = 1488620 \ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot \left(\left(Ib_{EV} \cdot M_{EV} \right) + \left(Ib_{EH} \cdot M_{EH1} \right) + Ib_{LS} \cdot \left(M_{LS1} + M_{LS1@MSE} \right) \right)$ $\qquad MV_{Ib} = 1949612 \ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{EH} \cdot M_{EH2} \right) + \left(Ia_{LS} \cdot M_{LS2} \right) \right)$ $\qquad MH_{Ia} = 246743.6 \ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{EH} \cdot M_{EH2} \right) + \left(Ib_{LS} \cdot M_{LS2} \right) \right)$ $\qquad MH_{Ib} = 246743.6 \ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the Effective Bearing Length (Strength Ib) about the Toe "O" of base length (the pivot):

$\Sigma M_R := MV_{Ib}$ $\Sigma M_R = 1949612 \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 246743.6 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 139258 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 12.2\ ft$ Distance from Point "O" the resultant intersects the base

$e := \left|\frac{L}{2} - x\right|$ $e = 1.77\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2]**. The effective bearing width is equal to B-2e.

$B' := L - 2 \cdot e + D_{undercut}$ $B' = 24.5\ ft$ Effective Footing Width, Assumed at the bottom of Undercut and Replacement

Foundation Layout:

$L_{Wall} := 142\ ft$ Assumed Footing Length (Wall Section Length)

$D_f := d_e$ $D_f = 4.6\ ft$ Footing embedment

$D_F := D_f + D_{undercut}$ Embenment Depth at bottom of Undercut

$d_w := D_f$ Depth of Groundwater below ground surface in front of wall

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_{fd} > 0, e^{\pi \cdot \tan(\phi'_{fd})} \cdot \tan\left(45\ deg + \frac{\phi'_{fd}}{2}\right)^2, 1.0\right)$ $N_q = 8.66$

$N_c := \text{if}\left(\phi'_{fd} > 0, \frac{N_q - 1}{\tan(\phi'_{fd})}, 5.14\right)$ $N_c = 18.05$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_{fd})$ $N_\gamma = 8.2$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.083$

$s_q := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_{fd})\right), 1\right)$ $s_q = 1.073$

$s_\gamma := \text{if}\left(\phi'_{fd} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.931$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $\quad i_q = 1$

$i_\gamma := 1$ $\quad i_\gamma = 1$

$i_c := 1$ $\quad i_c = 1$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$C_{wq} := \text{if}\left(d_w \ge D_f, 1.0, 0.5\right)$ $\quad C_{wq} = 1$

$C_{w\gamma} := \text{if}\left(d_w \ge (1.5 \cdot L) + D_f, 1.0, 0.5\right)$ $\quad C_{w\gamma} = 0.5$

Depth Correction Factor per Hanson (1970):

$$d_q := 1 + 2 \cdot \tan\left(\phi'_{fd}\right) \cdot \left(1 - \sin\left(\phi'_{fd}\right)\right)^2 \cdot \operatorname{atan}\left(\frac{D_F}{B'}\right)$$

$d_q = 1.06$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 19.54$

$N_{qm} := N_q \cdot s_q \cdot d_q \cdot i_q$ $\quad N_{qm} = 9.839$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 7.637$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$q_{nd} := c'_{fd} \cdot N_{cm} + \gamma_q \cdot D_F \cdot N_{qm} \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 12814.4 \ \frac{lbf}{ft^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.65$ — Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 8.3 \ ksf$ — Factored bearing resistance Drained Conditions

Undrained Conditions (Total Stress):

$N_q := \text{if}\left(\phi_{fdu} > 0, e^{\pi \cdot \tan\left(\phi_{fdu}\right)} \cdot \tan\left(45\ deg + \frac{\phi_{fdu}}{2}\right)^2, 1.0\right)$ $\quad N_q = 1$

$N_c := \text{if}\left(\phi_{fdu} > 0, \frac{N_q - 1}{\tan\left(\phi_{fdu}\right)}, 5.14\right)$ $\quad N_c = 5.14$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_{fdu}\right)$ $\quad N_\gamma = 0$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi_{fdu} > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $\quad s_c = 1.034$

$s_q := \text{if}\left(\phi_{fdu} > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan\left(\phi_{fdu}\right)\right), 1\right)$ $\quad s_q = 1$

$s_\gamma := \text{if}\left(\phi_{fdu} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 1$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $i_q = 1$

$i_\gamma := 1$ $i_\gamma = 1$

$i_c := 1$ $i_c = 1$

Depth Correction Factor per Hanson (1970):

$$d_q := 1 + 2 \cdot \tan\left(\phi'_{fd}\right) \cdot \left(1 - \sin\left(\phi'_{fd}\right)\right)^2 \cdot \text{atan}\left(\frac{D_F}{B'}\right)$$

$d_q = 1.06$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 5.317$

$N_{qm} := N_q \cdot s_q \cdot d_q \cdot i_q$ $N_{qm} = 1.059$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 0$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$q_{nu} := Su_{fdu} \cdot N_{cm} + \gamma_q \cdot D_F \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 9125.9 \frac{lbf}{ft^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.65$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 5.9\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 8.3\ ksf$

Undrained Conditions: $q_{Ru} = 5.9\ ksf$

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

Compute the resultant location about the toe "O" of base length (the pivot):

$e := \left|\frac{L}{2} - x\right|$ $e = 1.77\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2]**. The effective bearing width is equal to B-2e.

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 5694.2 \frac{lbf}{ft^2}$ Bearing Stress

Bearing Resistance Capacity:Demand Ratio (CDR)

Drained Conditions: $CDR_{Bearing\_d} := \frac{q_{Rd}}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_d} = 1.46$

Undrained Conditions: $CDR_{Bearing\_u} := \frac{q_{Ru}}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_u} = 1.04$

Limiting Eccentricity at Base of MSE Wall (Strength Ia):

$e_{max} := \frac{L}{3}$ $e_{max} = 9.3\ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 1488620\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 246743.6\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 106330\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 11.7\ ft$ Distance from Point "O" the resultant intersects the base

$e := \left| \frac{L}{2} - x \right|$ $e = 2.32\ ft$ Wall eccentricity

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 4.02$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$R_u := H_{Ia}$ $R_u = 24616.1\ \frac{lbf}{ft}$

Drained Conditions (Effective Stress):

Compute sliding resistance between soil and foundation:

$\Sigma V := V_{Ia}$ $\Sigma V = 106330\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_{fd})$ $R_{\tau d} = 45134.4\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_\tau := 1.0$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

Drained Conditions: $\phi R_{n\_d} := \phi_\tau \cdot R_{\tau d}$ $R_{R\_d} := \phi R_{n\_d}$ $R_{R\_d} = 45.1\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding\_d} := \frac{R_{R\_d}}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding\_d} = 1.83$

Undrained Conditions (Total Stress):

Compute sliding resistance between soil and foundation:

$\Sigma V := V_{Ia}$ $\Sigma V = 106330 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e = 2.32\ ft$ Wall eccentricity, Calculated in above Limiting Eccentricity at Base of Wall (Strength Ia) Section.

$B := L$ Footing base width

$\frac{B}{6} = 4.7\ ft$ If e < B/6 the resultant is in the middle one-third

$\sigma_{vmax} := \frac{\Sigma V}{B} \cdot \left(1 + 6 \cdot \frac{e}{B}\right)$ $\sigma_{vmax} = 5685.8 \frac{lbf}{ft^2}$ Max vertical stress (if resultant is in the middle one-third of base) **LRFD [11.6.3.2-2]**.

$\sigma_{vmin} := \frac{\Sigma V}{B} \cdot \left(1 - 6 \cdot \frac{e}{B}\right)$ $\sigma_{vmin} = 1909.2 \frac{lbf}{ft^2}$ Max verical stress (if resultant is in the middle one-third of base) **LRFD [11.6.3.2-2]**.

$q_{max} := \frac{1}{2} \cdot \sigma_{vmax}$ $q_{max} = 2842.9 \frac{lbf}{ft^2}$ Max unit shear resistance as 1/2 max vertical stress **LRFD [10.6.3.4]**.

$q_{min} := \frac{1}{2} \cdot \sigma_{vmin}$ $q_{min} = 954.6 \frac{lbf}{ft^2}$ Minimum unit shear resistance as 1/2 minimum vertical stress **LRFD [10.6.3.4]**.

Determine which Cohesive Soil Resistance Case is Present:

$Case_1 := \text{if}\left(q_{max} > Su_{fdu} > q_{min} \ge 0, 1, 0\right)$ $Case_1 = 1$

$Case_2 := \text{if}\left(Su_{fdu} > q_{max} > q_{min} \ge 0, 1, 0\right)$ $Case_2 = 0$

$Case_3 := \text{if}\left(q_{max} > q_{min} > Su_{fdu}, 1, 0\right)$ $Case_3 = 0$

$Case_4 := \text{if}\left(q_{min} < 0, \text{if}\left(Su_{fdu} < q_{max}, 1, 0\right), 0\right)$ $Case_4 = 0$

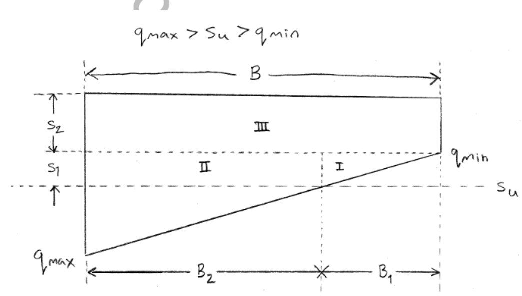
$Case_5 := \text{if}\left(q_{min} < 0, \text{if}\left(Su_{fdu} > q_{max}, 1, 0\right), 0\right)$ $Case_5 = 0$

Unit Shear Resistance for Case 1:

$S_1 := Su_{fdu} - q_{min} = 645.4 \frac{lbf}{ft^2}$ $S_2 := q_{min} = 954.6 \frac{lbf}{ft^2}$

$B_1 := \frac{B \cdot \left(Su_{fdu} - q_{min}\right)}{q_{max} - q_{min}} = 9.6\ ft$ $B_2 := \frac{B \cdot \left(q_{max} - Su_{fdu}\right)}{q_{max} - q_{min}} = 18.4\ ft$

$B_3 := B = 28\ ft$



$I := \frac{1}{2} \cdot S_1 \cdot B_1 = 3088.4 \frac{lbf}{ft}$ $II := S_1 \cdot B_2 = 11895 \frac{lbf}{ft}$

$III := S_2 \cdot B_3 = 26728.2 \frac{lbf}{ft}$

$R_{\tau\_case1} := I + II + III = 41711.6 \frac{lbf}{ft}$

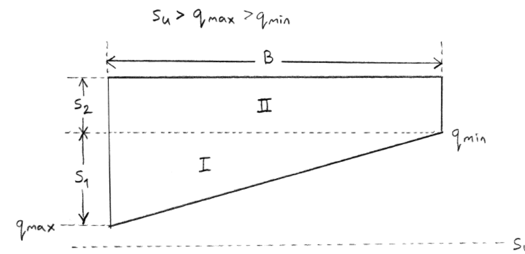
Unit Shear Resistance for Case 2:

$S_1 := q_{max} - q_{min} = 1888.3\ \frac{lbf}{ft^2}$ $S_2 := q_{min} = 954.6\ \frac{lbf}{ft^2}$

$B = 28\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B = 26436.8\ \frac{lbf}{ft}$ $II := S_2 \cdot B = 26728.2\ \frac{lbf}{ft}$

$R_{\tau\_case2} := I + II = 53165\ \frac{lbf}{ft}$



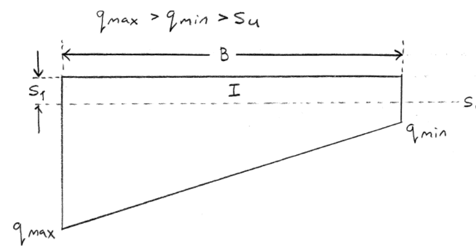
Unit Shear Resistance for Case 3:

$S_1 := Su_{fdu} = 1600\ \frac{lbf}{ft^2}$

$B = 28\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B = 22400\ \frac{lbf}{ft}$

$R_{\tau\_case3} := I = 22400\ \frac{lbf}{ft}$



Unit Shear Resistance for Case 4:

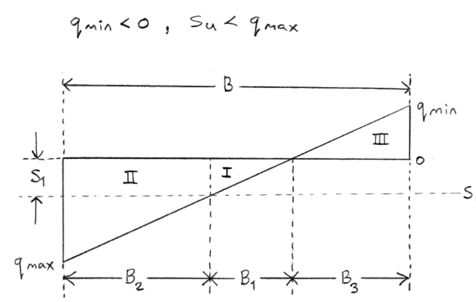
$S_1 := Su_{fdu} = 1600\ \frac{lbf}{ft^2}$

$B_3 := \frac{B \cdot (-q_{min})}{q_{max} - q_{min}} = -14.2\ ft$ $B_1 := \left(\frac{Su_{fdu}}{q_{max}}\right) \cdot (B - B_3) = 23.7\ ft$

$B_2 := B - (B_1 + B_3) = 18.4\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B_1 = 18979.6\ \frac{lbf}{ft}$ $II := S_1 \cdot B_2 = 29487.7\ \frac{lbf}{ft}$

$R_{\tau\_case4} := I + II = 48467.3\ \frac{lbf}{ft}$



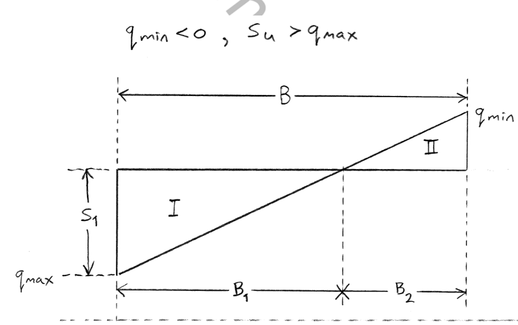
Unit Shear Resistance for Case 5:

$S_1 := q_{max} = 2842.9\ \frac{lbf}{ft^2}$

$B_1 := \frac{B \cdot q_{max}}{q_{max} - q_{min}} = 42.2\ ft$ $B_2 := B - B_1 = -14.2\ ft$

$I := \frac{1}{2} \cdot S_1 \cdot B_1 = 59920.7\ \frac{lbf}{ft}$

$R_{\tau\_case5} := I = 59920.7\ \frac{lbf}{ft}$



Define the Applicable Case:

$R_\tau := R_{\tau\_case1}$ $\quad R_\tau = 41711.6\ \frac{lbf}{ft}$ Nominal sliding resistance Cohesive Soils

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_{ep} := 0.5$ Resistance factor for passive resistance specified in **LRFD Table 10.5.5.2.2-1**

$\phi_\tau := 1.0$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

$\phi R_n := \phi_\tau \cdot R_\tau$ $\quad R_R := \phi R_n$

Factored Sliding Resistance to be used in CDR Calculations: $R_R = 41711.593\ \frac{lbf}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding\_u} := \frac{R_R}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding\_u} = 1.69$

APPENDIX E

SETTLEMENT ANALYSIS

FRA-0071-28.294

PROJECT IDENTIFICATION

Title: FRA-0071-28.294
Project Number: -
Client: ODOT
Designer: ZM
Station Number: Rear Abutment STA. 26+00

Description:
B-010-0-64 & B-038-0-21

Company's information:

Name: NEAS, Inc.
Street:
,
Telephone #:
Fax #:
E-Mail:

Original file path and name: C:\Users\s ..... -0071-28.294 RearAbut_STA26+00_B-010-64 - Copy.2ST
Original date and time of creating this file: 8/25/2022

GEOMETRY: Analysis of a 3D-Approximate geometry

INPUT DATA – FOUNDATION LAYERS – 7 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	125.00	0.35	A-6b
2	120.00	0.30	A-4b
3	133.00	0.35	A-4a
4	125.00	0.35	A-4a
5	130.00	0.35	A-4a
6	140.00	0.35	A-6a
7	140.00	0.30	Granular Materials

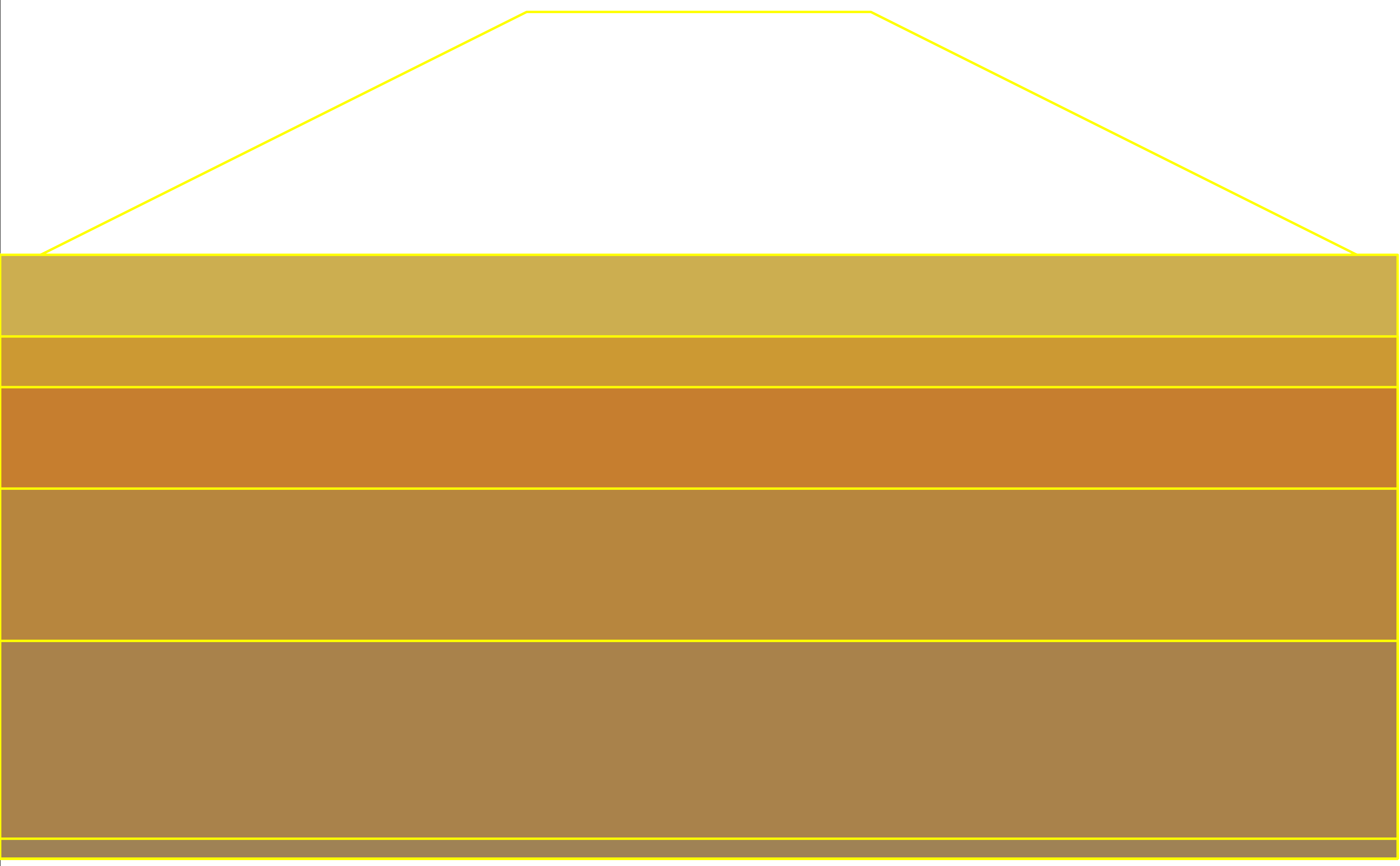
INPUT DATA – EMBANKMENT LAYERS – 1 layers

	Wet Unit Weight, γ [lb/ft³]	Description of Soil
1	120.00	Embankment Fills

INPUT DATA OF WATER

Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]
1	0.00	840.00
2	10.00	840.00
3	25.00	840.00
4	40.00	840.00

DRAWING OF SPECIFIED GEOMETRY



INPUT DATA FOR CONSOLIDATION –– $\alpha = 1/2$

Layer #	Underging Consolidation [Yes/No]	OCR = Pc / Po	Cc	Cr	e0	Cv [ft ²/day]	Drains at :	Shear Strength Data S	Shear Strength Data m	CREEP Ca/Cc
1	Yes	6.00	0.160	0.016	0.442	0.4300	Top & Bot.	0.400	0.800	0.0500
2	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	Yes	2.40	0.085	0.010	0.447	0.5000	Top & Bot.	0.400	0.800	0.0500
4	Yes	2.00	0.118	0.012	0.324	0.7000	Top & Bot.	0.400	0.800	0.0500
5	Yes	2.40	0.125	0.013	0.345	0.7000	Top & Bot.	0.400	0.800	0.0500
6	Yes	2.40	0.180	0.018	0.497	0.3600	Top & Bot.	0.400	0.800	0.0500
7	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Secondary Comprassion (Creep) : Settlement is calculated at t2/t1 = 10.0

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
1	-65.00	0.00	1	400000	0.3500	-0.0011	911.35	911.30	0.05
			2	100000	0.3000	0.0002			
			3	60000	0.3500	0.0101			
			4	200000	0.3500	0.0161			
			5	300000	0.3500	0.0224			
			6	700000	0.3500	0.0047			
			7	900000	0.3000	0.0025			
2	-52.00	0.00	1	400000	0.3500	0.0071	911.35	911.14	0.21
			2	100000	0.3000	0.0241			
			3	60000	0.3500	0.0789			
			4	200000	0.3500	0.0436			
			5	300000	0.3500	0.0409			
			6	700000	0.3500	0.0073			
			7	900000	0.3000	0.0037			
3	-39.00	0.00	1	400000	0.3500	0.0155	911.35	910.95	0.40
			2	100000	0.3000	0.0533			
			3	60000	0.3500	0.1694			
			4	200000	0.3500	0.0791			
			5	300000	0.3500	0.0631			
			6	700000	0.3500	0.0103			
			7	900000	0.3000	0.0050			
4	-26.00	0.00	1	400000	0.3500	0.0240	911.35	910.77	0.58
			2	100000	0.3000	0.0824			
			3	60000	0.3500	0.2576			
			4	200000	0.3500	0.1133			
			5	300000	0.3500	0.0840			
			6	700000	0.3500	0.0131			
			7	900000	0.3000	0.0062			
5	-13.00	0.00	1	400000	0.3500	0.0298	911.35	910.65	0.70
			2	100000	0.3000	0.1011			
			3	60000	0.3500	0.3145			
			4	200000	0.3500	0.1365			
			5	300000	0.3500	0.0988			
			6	700000	0.3500	0.0150			
			7	900000	0.3000	0.0070			
6	0.00	0.00	1	400000	0.3500	0.0294	911.35	910.62	0.73
			2	100000	0.3000	0.1026			
			3	60000	0.3500	0.3270			
			4	200000	0.3500	0.1440			
			5	300000	0.3500	0.1041			
			6	700000	0.3500	0.0157			
			7	900000	0.3000	0.0073			
7	13.00	0.00	1	400000	0.3500	0.0298	911.35	910.65	0.70
			2	100000	0.3000	0.1011			
			3	60000	0.3500	0.3146			
			4	200000	0.3500	0.1366			
			5	300000	0.3500	0.0989			
			6	700000	0.3500	0.0150			
			7	900000	0.3000	0.0070			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
8	26.00	0.00	1	400000	0.3500	0.0240	911.35	910.77	0.58
			2	100000	0.3000	0.0824			
			3	60000	0.3500	0.2577			
			4	200000	0.3500	0.1135			
			5	300000	0.3500	0.0843			
			6	700000	0.3500	0.0131			
			7	900000	0.3000	0.0062			
9	39.00	0.00	1	400000	0.3500	0.0155	911.35	910.95	0.40
			2	100000	0.3000	0.0533			
			3	60000	0.3500	0.1695			
			4	200000	0.3500	0.0793			
			5	300000	0.3500	0.0634			
			6	700000	0.3500	0.0104			
			7	900000	0.3000	0.0050			
10	52.00	0.00	1	400000	0.3500	0.0071	911.35	911.14	0.21
			2	100000	0.3000	0.0241			
			3	60000	0.3500	0.0789			
			4	200000	0.3500	0.0437			
			5	300000	0.3500	0.0412			
			6	700000	0.3500	0.0074			
			7	900000	0.3000	0.0038			
11	65.00	0.00	1	400000	0.3500	-0.0011	911.35	911.29	0.06
			2	100000	0.3000	0.0001			
			3	60000	0.3500	0.0101			
			4	200000	0.3500	0.0162			
			5	300000	0.3500	0.0227			
			6	700000	0.3500	0.0048			
			7	900000	0.3000	0.0026			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	-65.00	0.00	911.35	0.02	911.33
2	-52.00	0.00	911.35	0.13	911.22
3	-39.00	0.00	911.35	0.21	911.14
4	-26.00	0.00	911.35	0.29	911.06
5	-13.00	0.00	911.35	0.34	911.01
6	0.00	0.00	911.35	0.34	911.01
7	13.00	0.00	911.35	0.34	911.01
8	26.00	0.00	911.35	0.29	911.06
9	39.00	0.00	911.35	0.21	911.14
10	52.00	0.00	911.35	0.13	911.22
11	65.00	0.00	911.35	0.02	911.33

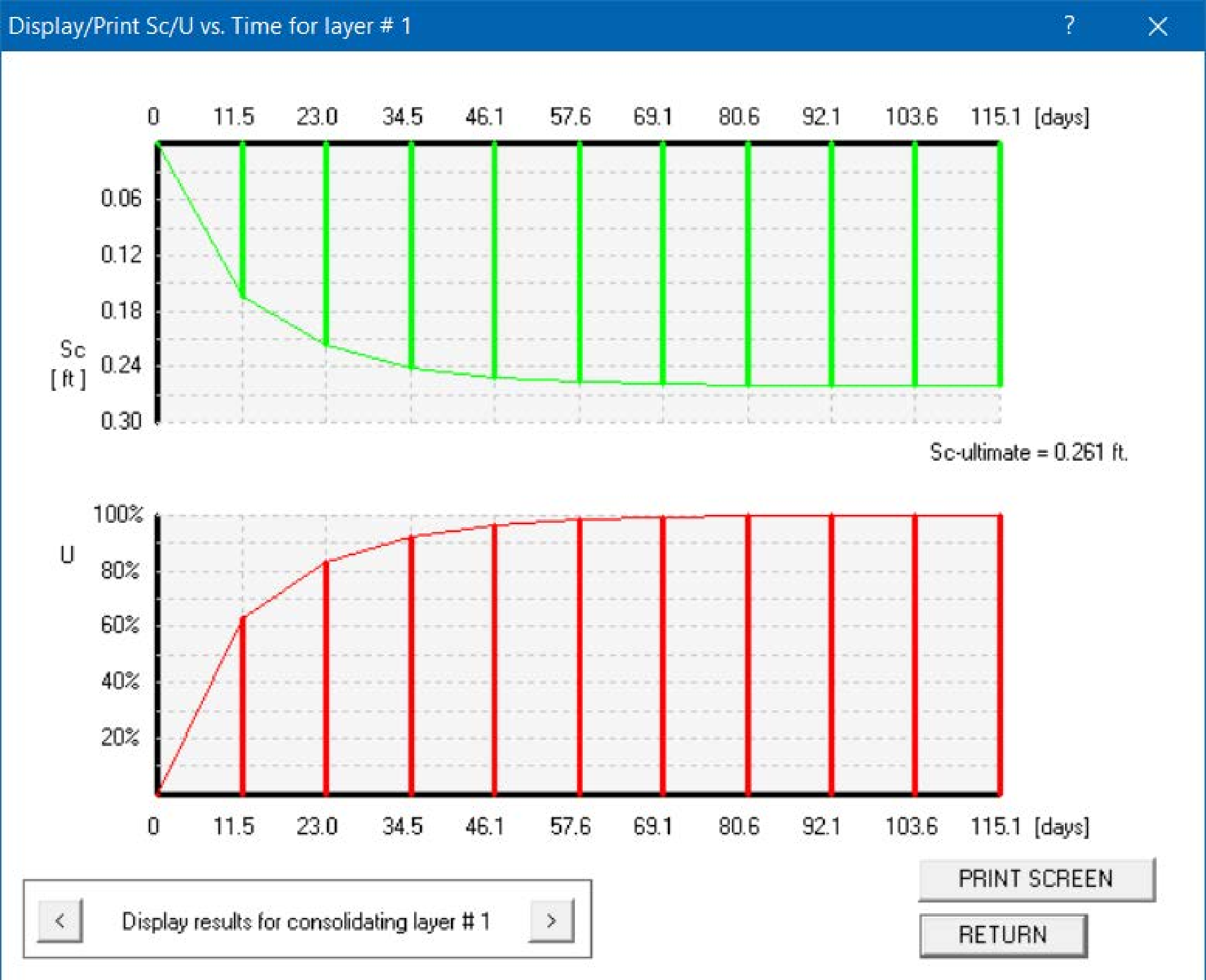
*Note: Final Z is calculated assuming only 'Ultimate Settlement' exists.

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	1	0.00	911.35	A-6b
2	1	0.00	903.30	A-4b
3	1	0.00	898.30	A-4a
4	1	0.00	888.30	A-4a
5	1	0.00	873.30	A-4a
6	1	0.00	853.80	A-6a
7	1	0.00	845.30	Granular Materials

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

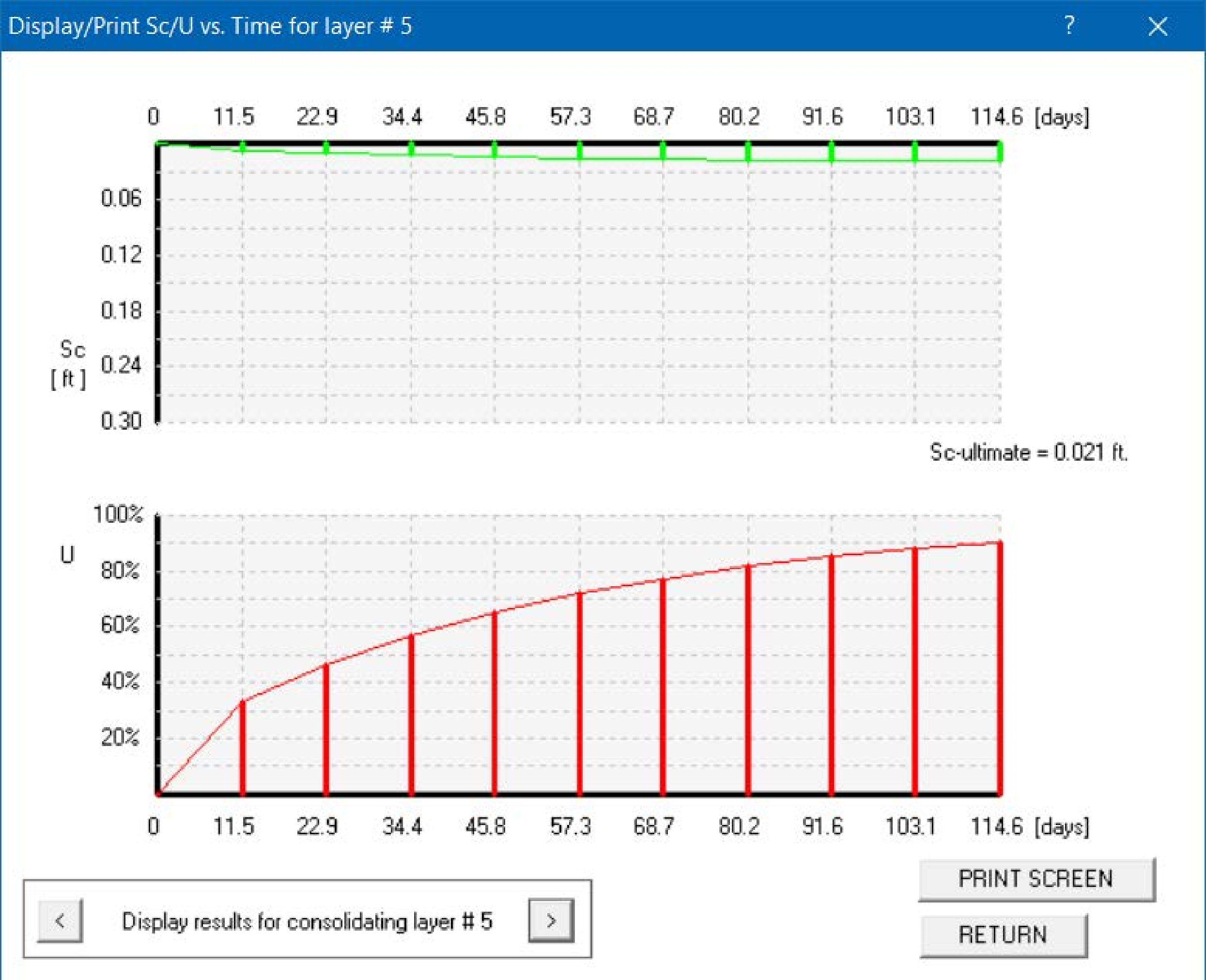
Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	X1 = -65.00 [ft]	1	-17.00	935.28	Embankment Fills
	X2 = 65.00 [ft]	2	17.00	935.28	



Display/Print Sc/U vs. Time for layer # 1
0
11.5
23.0
34.5
46.1
57.6
69.1
80.6
92.1
103.6
115.1 [days]
0.06
0.12
0.18
Sc
[ft]
0.24
0.30
Sc-ultimate = 0.261 ft.
100%
U
80%
60%
40%
20%
0
11.5
23.0
34.5
46.1
57.6
69.1
80.6
92.1
103.6
115.1 [days]
PRINT SCREEN
RETURN
<
Display results for consolidating layer # 1
>

Display/Print Sc/U vs. Time for layer # 3
0
11.4
22.8
34.2
45.6
57.0
68.5
79.9
91.3
102.7
114.1 [days]
0.06
0.12
0.18
Sc
[ft]
0.24
0.30
Sc-ultimate = 0.027 ft.
100%
U
80%
60%
40%
20%
0
11.4
22.8
34.2
45.6
57.0
68.5
79.9
91.3
102.7
114.1 [days]
PRINT SCREEN
Display results for consolidating layer # 3
RETURN

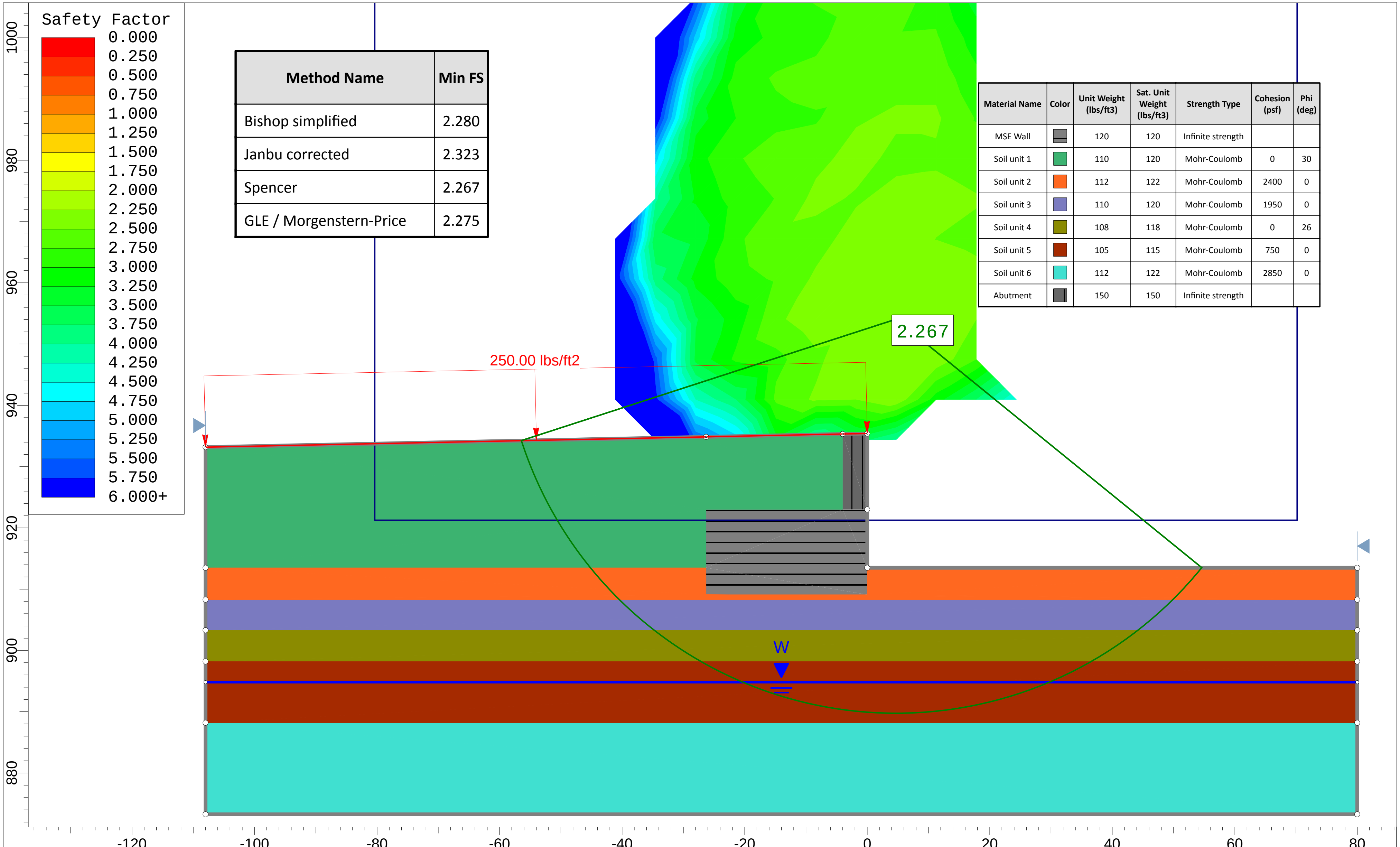
Display/Print Sc/U vs. Time for layer # 4
0
11.5
22.9
34.4
45.8
57.3
68.7
80.2
91.6
103.1
114.6 [days]
0.06
0.12
0.18
Sc
[ft]
0.24
0.30
Sc-ultimate = 0.028 ft.
100%
U
80%
60%
40%
20%
0
11.5
22.9
34.4
45.8
57.3
68.7
80.2
91.6
103.1
114.6 [days]
PRINT SCREEN
RETURN
<
Display results for consolidating layer # 4
>


Display/Print Sc/U vs. Time for layer # 5
0
11.5
22.9
34.4
45.8
57.3
68.7
80.2
91.6
103.1
114.6 [days]
Sc
[ft]
0.06
0.12
0.18
0.24
0.30
Sc-ultimate = 0.021 ft.
U
100%
80%
60%
40%
20%
PRINT SCREEN
RETURN
Display results for consolidating layer # 5


Display/Print Sc/U vs. Time for layer # 6
0
11.5
23.0
34.5
46.0
57.6
69.1
80.6
92.1
103.6
115.1 [days]
0.06
0.12
0.18
0.24
0.30
Sc
[ft]
Sc-ultimate = 0.007 ft.
100%
80%
60%
40%
20%
U
PRINT SCREEN
RETURN
Display results for consolidating layer # 6

APPENDIX F

GLOBAL STABILITY ANALYSIS

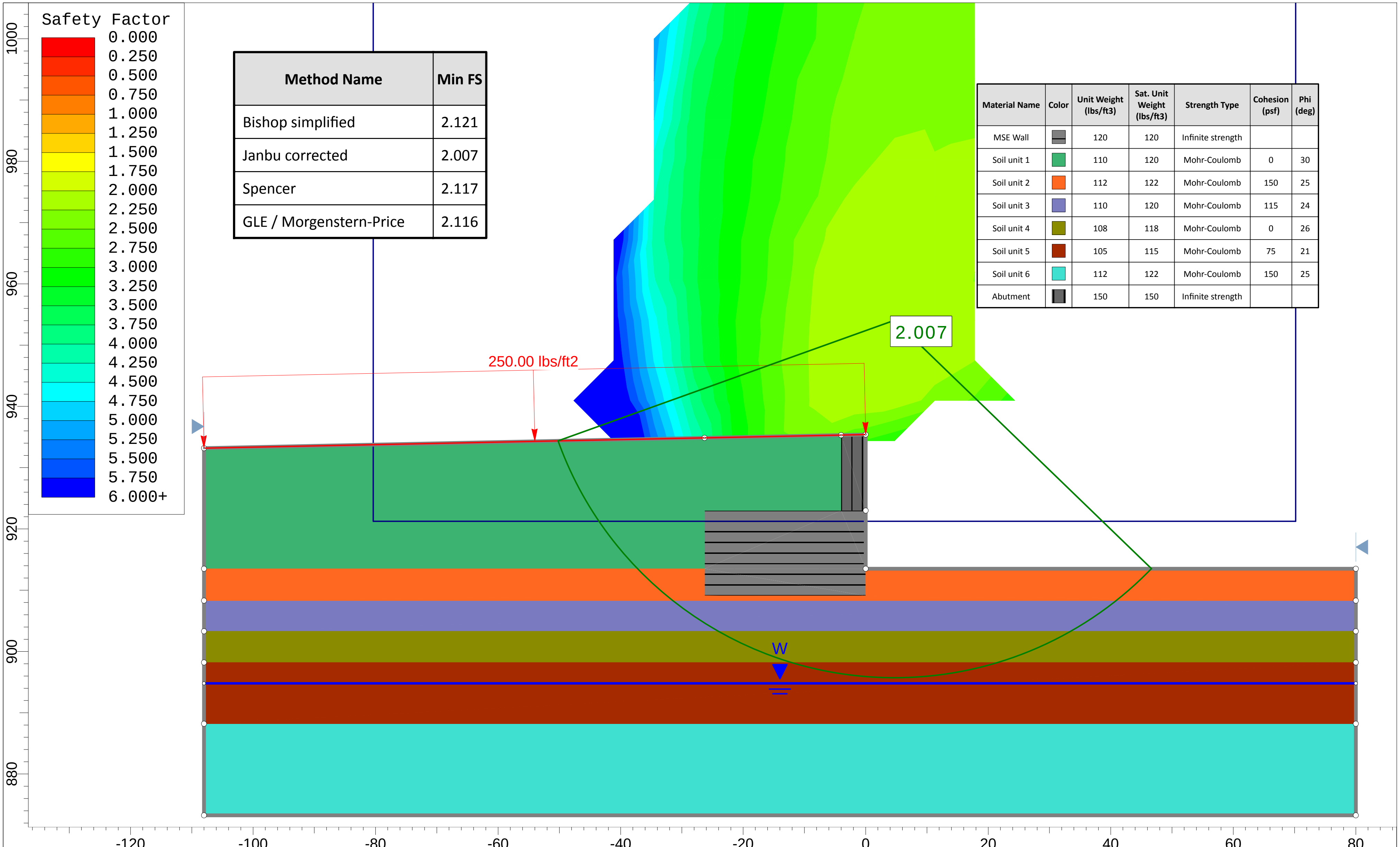


Method Name	Min FS
Bishop simplified	2.280
Janbu corrected	2.323
Spencer	2.267
GLE / Morgenstern-Price	2.275

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Wall		120	120	Infinite strength		
Soil unit 1		110	120	Mohr-Coulomb	0	30
Soil unit 2		112	122	Mohr-Coulomb	2400	0
Soil unit 3		110	120	Mohr-Coulomb	1950	0
Soil unit 4		108	118	Mohr-Coulomb	0	26
Soil unit 5		105	115	Mohr-Coulomb	750	0
Soil unit 6		112	122	Mohr-Coulomb	2850	0
Abutment		150	150	Infinite strength		

SLIDEINTERPRET 7.038

Project	FRA-71/270-28.294		
Analysis Description	Ramp O over IR-71 Bridge Rear Abutment		
Drawn By ZM	*Scale* 1:260	*Company*	NEAS Inc.
Date 09/05/22		*File Name*	FRA-71-28.294 Ramp O over IR71_RearAbut_Total_B038&B010.slim

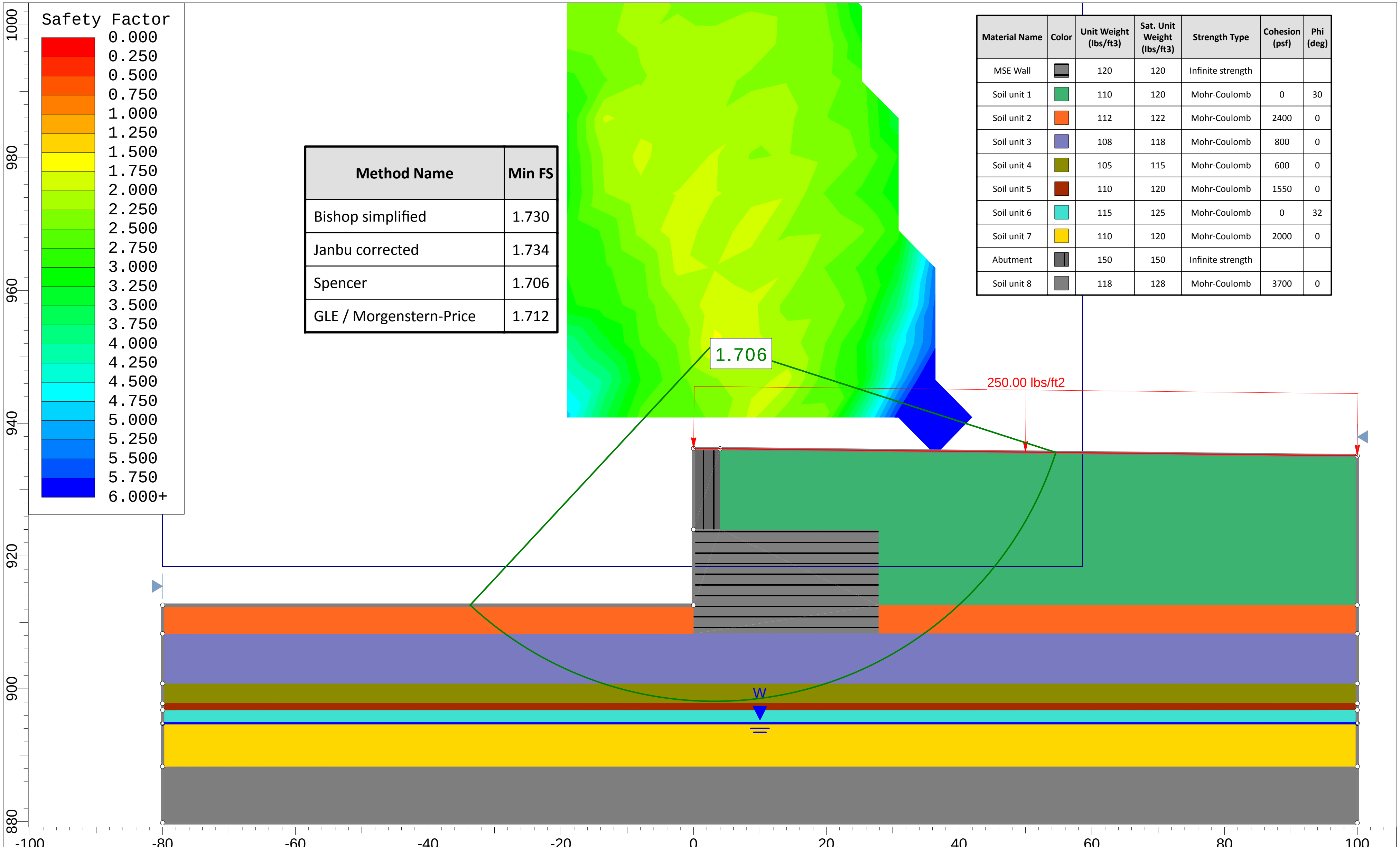


Method Name	Min FS
Bishop simplified	2.121
Janbu corrected	2.007
Spencer	2.117
GLE / Morgenstern-Price	2.116

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Wall		120	120	Infinite strength		
Soil unit 1		110	120	Mohr-Coulomb	0	30
Soil unit 2		112	122	Mohr-Coulomb	150	25
Soil unit 3		110	120	Mohr-Coulomb	115	24
Soil unit 4		108	118	Mohr-Coulomb	0	26
Soil unit 5		105	115	Mohr-Coulomb	75	21
Soil unit 6		112	122	Mohr-Coulomb	150	25
Abutment		150	150	Infinite strength		

Project	FRA-71/270-28.294		
Analysis Description	Ramp O over IR-71 Bridge Rear Abutment		
Drawn By	ZM	*Scale*	1:260
Company	NEAS Inc.		
Date	09/05/22	*File Name*	FRA-71-28.294 Ramp O over IR71_RearAbut_Effective_B038&B010.slim

SLIDEINTERPRET 7.038

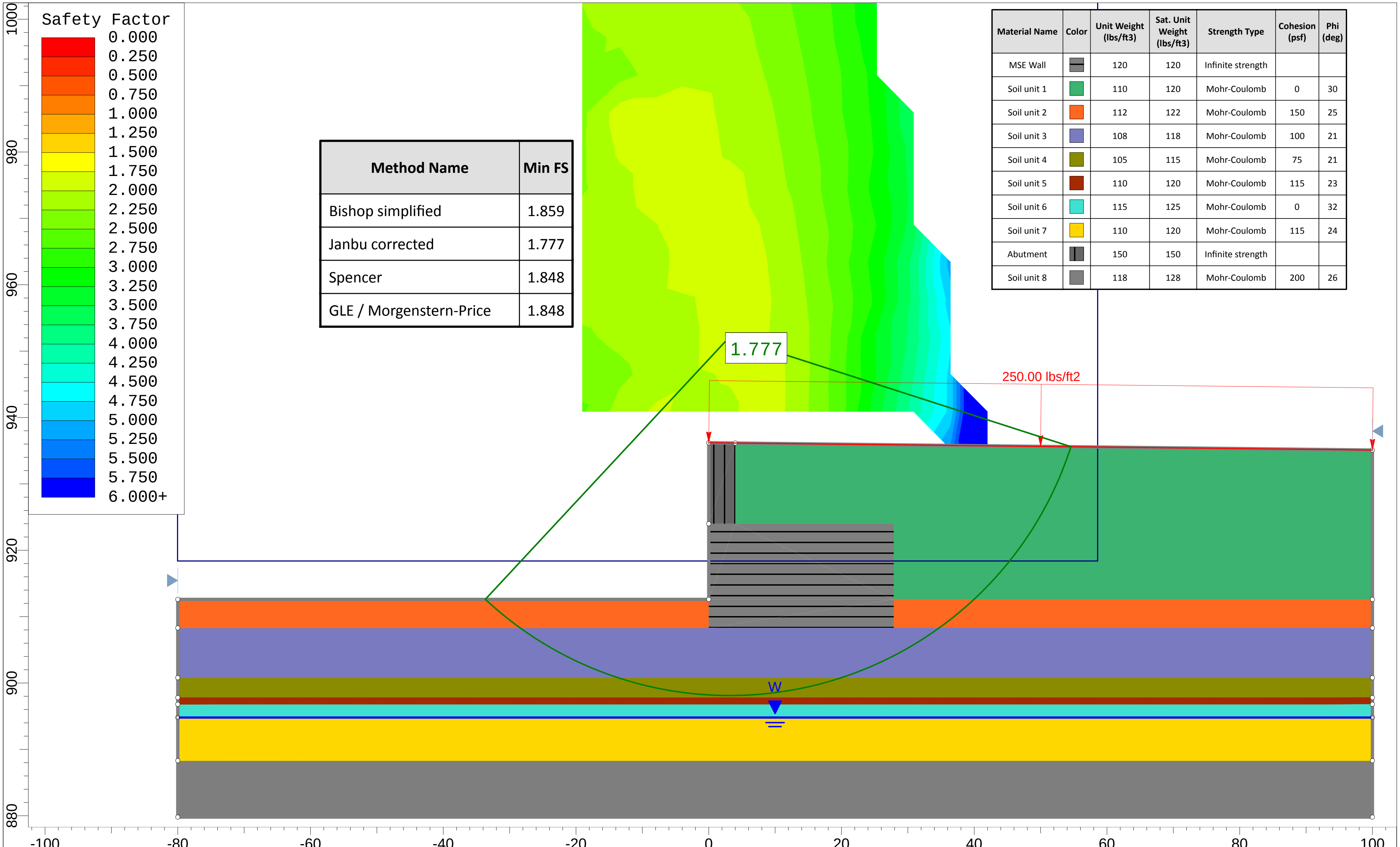


Method Name	Min FS
Bishop simplified	1.730
Janbu corrected	1.734
Spencer	1.706
GLE / Morgenstern-Price	1.712

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Wall		120	120	Infinite strength		
Soil unit 1		110	120	Mohr-Coulomb	0	30
Soil unit 2		112	122	Mohr-Coulomb	2400	0
Soil unit 3		108	118	Mohr-Coulomb	800	0
Soil unit 4		105	115	Mohr-Coulomb	600	0
Soil unit 5		110	120	Mohr-Coulomb	1550	0
Soil unit 6		115	125	Mohr-Coulomb	0	32
Soil unit 7		110	120	Mohr-Coulomb	2000	0
Abutment		150	150	Infinite strength		
Soil unit 8		118	128	Mohr-Coulomb	3700	0

Project	FRA-71/270-28.294
Analysis Description	Ramp O over IR-71 Bridge Forward Abutment
Drawn By	ZM
Scale	1:240
Company	NEAS Inc.
Date	09/05/22
File Name	FRA-71-28.294 Ramp O over IR71_ForwAbut_Total_B038&B01.slim

SLIDEINTERPRET 7.038



Method Name	Min FS
Bishop simplified	1.859
Janbu corrected	1.777
Spencer	1.848
GLE / Morgenstern-Price	1.848

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Wall		120	120	Infinite strength		
Soil unit 1		110	120	Mohr-Coulomb	0	30
Soil unit 2		112	122	Mohr-Coulomb	150	25
Soil unit 3		108	118	Mohr-Coulomb	100	21
Soil unit 4		105	115	Mohr-Coulomb	75	21
Soil unit 5		110	120	Mohr-Coulomb	115	23
Soil unit 6		115	125	Mohr-Coulomb	0	32
Soil unit 7		110	120	Mohr-Coulomb	115	24
Abutment		150	150	Infinite strength		
Soil unit 8		118	128	Mohr-Coulomb	200	26

rocscience

SLIDEINTERPRET 7.038

Project	FRA-71/270-28.294		
Analysis Description	Ramp O over IR-71 Bridge Forward Abutment		
Drawn By	ZM	*Scale* 1:240	*Company* NEAS Inc.
Date	09/05/22	*File Name*	FRA-71-28.294 Ramp O over IR71_ForwAbut_Effective_B038&B01.slim