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DESIGN MEMORANDUM

Date: April 11, 2025

To: Mr. Vince Amato, Burgess & Niple, Inc.

From: Brendan P. Andrews P.E., NEAS Inc.

RE: **Geotechnical Design Memorandum**
Project HAM-75-1.05, PID 122048
Bridge HAM-75-0123E (Pedestrian Bridge over Ramp V & Winchell Avenue) Replacement
City of Cincinnati, Hamilton County, Ohio

INTRODUCTION

Per your request, this memorandum presents preliminary foundation design information for the proposed Bridge HAM-75-0123E replacement as part of the overall Ohio Department of Transportation (ODOT) HAM-75-1.05 (PID 113361/122048) project located in the City of Cincinnati, Hamilton County, Ohio. A summary of: 1) the proposed replacement structure; 2) the existing site conditions; 3) the surficial and subsurface conditions via historical and project borings; and, 4) our preliminary recommendations for bridge foundation design is presented below.

NEAS's preliminary analyses have been performed in accordance with Load and Resistance Factor Design (LRFD) method as set forth in AASHTO's Publication LRFD Bridge Design Specifications, 9th Edition (BDS) (AASHTO, 2020) and ODOT's 2021 LRFD Bridge Design Manual (BDM) (ODOT, 2021).

PROPOSED/EXISTING SITE CONDITIONS

Proposed Construction

The existing Bridge HAM-75-0125E consists of a single span, reinforce concrete bridge originally built in 1961. The referenced bridge carries a pedestrian walkway over Winchell Avenue (Ave) and the Interstate Route 75 (IR-75) northbound (NB) exit ramp to Ezzard Charles Drive (Dr) and Liberty Street (St) (i.e., Ramp V). The existing bridge is about 36 ft in length (clear face to face of piers) with a deck width of 8 ft. As Ramp V as well as Winchell Ave are planned to be widened as part of the overall project, Bridge HAM-75-0123E is planned to be replaced with a lengthened structure to traverse the widened roadways. Based on the available Bridge Stage 3 Site Plan developed by Palmer Engineering (Palmer) dated December 19, 2024, the new structure will be a single span pre-stressed concrete box beam bridge. The proposed bridge will have a composite reinforced concrete deck supported by a stub type abutments with a mechanically stabilized earth (MSE) wall proposed at the rear abutment. The proposed substructures will utilize a deep foundation system consisting of driven friction piles at the rear abutment and a tangent friction drilled shaft wall at the forward abutment. The proposed bridge will be approximately 60 ft in length (abutment to abutment) with a width of 8 ft (curb to curb).

Historical Records

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

- Structure Foundation Exploration sheets prepared as part of State of Ohio Department of Highways project HAM-25-0.83 for the Pedestrian Overpass at Ramp "A" bridge, prepared by Vogt. Ivers. Seaman & Associates.

Two (2) historical soil borings that were drilled as part of the above indicated 1959 subsurface investigation for the Pedestrian Overpass at Ramp "A" bridge were reviewed and considered in our evaluation of the proposed bridge foundations. A summary of the utilized historic boring information (location, elevation, etc.) is provided in Table 1 below.

Table 1: Historical Boring Summary

Boring Number	Latitude	Longitude	Elevation (NAVD 88) (ft)	Depth (ft)	Proposed Substructure
B-009-A-59	39.107042	-84.530518	507.3	41.5	Rear Abutment
B-009-B-59	39.107029	-84.530653	508.2	31.5	Forward Abutment

Notes:
1. Based on locations as mapped in ODOT's Transportation Information Mapping System (TIMS).

Site Reconnaissance

A field reconnaissance visit for the HAM-75-0123E bridge site was conducted on January 17, 2022, during which site conditions were noted and photographed. During our field reconnaissance, no geohazards were observed within the immediate vicinity of the proposed bridge site. Land use of the area surrounding the proposed project site can be described as a as multi-family residential and institutional properties.

The existing bridge over Winchell Ave and Ramp V consists of a single span concrete slab bridge with full height abutments. In the area of the referenced bridge, Winchell Ave and Ramp V are situated within the cut slope associated with IR-75 and its location downslope of the surrounding property. The pedestrian path is generally located at the higher grades upslope of IR-75. Existing slopes adjacent to the subject bridge and extending downslope to IR-75 were observed to be about at about 3 Horizontal to 1 Vertical (3H:1V) with no apparent signs of instability observed. The overall bridge structure appeared to be in fair condition with some signs of some signs of wear were observed at the abutments and along the underside of the bridge deck (Photograph 1). Noted signs of wear consisted of minor cracking, spalling and efflorescence. No apparent signs of distress due to geotechnical concerns were noted during our field reconnaissance visit.

The bridge deck and concrete wearing course was observed to be in good condition, although it should be noted that at the time of our visit a majority of the existing deck was covered with snow. With respect to drainage, the bridge deck appeared to be well drained with no signs of ponding or drainage issues observed during our field visit. The bridge deck drained to scuppers in the shoulder of the bridge deck near each of the abutments. These drained to downspouts attached to the backside of the abutments.

Photograph 1: Overall Bridge Condition

SUBSURFACE EXPLORATION

The exploration for the bridge HAM-75-0123E replacement was conducted by NEAS between January 26, 2022 and February 11, 2022. The exploration for the referenced structure included 2 borings drilled to depths ranging from of 85.0 to 101.5 ft below ground surface (bgs). Boring logs for the borings performed are attached. A summary of the exploration locations including latitude/longitude location information and elevations of the subject structure exploration are shown in Table 2 below. Additional information with respect to the subsurface exploration can be found in the Geotechnical Exploration Report for the overall project, HAM-75-1.05 (PID 113361).

Table 2: Structure Boring Summary

Boring Number	Latitude	Longitude	Elevation (NAVD 88) (ft)	Depth (ft)	Structure
B-026-0-21	39.107057	-84.530375	505.6	85.0	Forward Abutment
B-027-0-21	39.107091	-84.530900	501.0	101.5	Rear Abutment

Notes:
1. *As-drilled boring location and corresponding ground surface elevation was surveyed in the field by NEAS Inc or estimated off topographic data collected along IR-75.*

SUBSURFACE CONDITIONS

At the site of the proposed replacement structure, three different materials were encountered below the surficial material. In general, the three different overburden materials consisted of historical or embankment “man-made” fill soils, natural alluvial deposits, followed by natural sands. These materials and the general profile underlying the site is further described below.

Fill soils were encountered in each of the borings performed for the proposed structure with soils identified as fill being encountered immediately below the pavement section or at the ground surface and extended to depths ranging from 17.0 to 18.0 ft bgs (approximate elevations 486.1 to 484.0 ft above mean sea level (amsl)). Based on laboratory testing results and a visual review of the soil samples obtained, the fill at the site is comprised of both cohesive and non-cohesive, coarse- and fine-grained material and is classified on the boring logs as Gravel with Sand (A-1-b), non-cohesive Silt (A-4b), Silt and Clay (A-6a), Silty Clay (A-6b), Clay (A-7-6) as well as both cohesive and non-cohesive Sandy Silt (A-4a). With respect to the soil strength, the non-cohesive fill soils can be described as having a relative compactness of medium dense to dense correlating to converted SPT-N values (N_{60}) between 11 and 29 blows per foot (bpf). Natural moisture contents of the non-cohesive fill ranged from 2 to 22 percent. With respect to the soil strength of the cohesive fill, these soils can be described as having a consistency of stiff to hard correlating to N_{60} values between 10 and 24 bpf and unconfined compressive strengths (estimated by means of hand penetrometer) between approximately 1.25 and 4.5 tons per square foot (tsf). Natural moisture contents of the cohesive fill ranged from 15 to 28 percent. Based on Atterberg Limits tests performed on representative samples of the cohesive fill material, the liquid and plastic limits ranged from 29 to 45 percent and from 20 to 24 percent, respectively.

The stratum encountered immediately beneath the fill consisted of natural alluvial soils comprised of a mix of fine-grained cohesive and coarse- and fine-grained non-cohesive soils that extended to depths between 70.5 and 93.3 ft bgs (approximate elevations 435.1 and 417.7 ft amsl). Based on laboratory testing results and a visual review of the soil samples obtained within this stratum, these soils are comprised of material classified on the boring logs as Fine Sand (A-3), non-cohesive Sandy Silt (A-4a), Silty Clay (A-6b) as well as cohesive and non-cohesive Silt (A-4b). With respect to the soil strength of the fine-grained cohesive material encountered within this stratum, these soils can be described as having a consistency of medium stiff to very stiff correlating to N_{60} values between 8 and 13 bpf and unconfined compressive strengths (estimated by means of hand penetrometer) between 1.25 and 2.75 tsf. Natural moisture contents of the cohesive soils ranged from 21 to 26 percent. Based on Atterberg Limits tests performed on representative samples of the cohesive alluvial material, the liquid and plastic limits ranged from 27 to 40 percent and from 19 to 21 percent, respectively. With respect to the soil strength of the non-cohesive alluvium, these soils can be described as having a relative compactness of very loose to medium dense correlating to N_{60} values between 4 and 23 bpf. Natural moisture contents of the non-cohesive soils ranged from 5 to 36 percent.

The stratum encountered immediately beneath the alluvium, consisted of a natural sand layer which extended to termination depth of the boring between 85.0 and 101.5 ft bgs (approximate elevations 420.6 and 399.5 ft amsl). Based on laboratory testing results and a visual review of the soil samples obtained within this stratum, these soils are comprised of granular material and are classified on the boring logs as Coarse and Fine Sand (A-3a) and non-cohesive Sandy Silt (A-4a). With respect to the soil strength, the natural sands can be described as having a relative compactness of medium dense to dense correlating to N_{60} values between 18 and 34 bpf. Natural moisture contents of the sands ranged from 12 to 26 percent.

Groundwater

Groundwater measurements were taken during the boring drilling procedures at each borehole location; however, groundwater was not encountered during drilling in either of the project borings performed at the proposed bridge site. 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. The specific groundwater readings are included on the attached boring logs.

ANALYSES AND RECOMMENDATIONS

Soil Profile for Bridge Foundation Analysis

For friction pile and drilled shaft analysis purposes, each boring drilled for proposed Bridge HAM-75-0123E was reviewed, and a generalized material profile was developed. Utilizing the generalized soil profile, engineering properties for each soil stratum were estimated based on their field (i.e., SPT N_{60} Values, hand penetrometer values, etc.) and laboratory test (i.e., Atterberg Limits, grain size, etc.) results using correlations provided in published engineering manuals, research reports and guidance documents. Engineering soil properties were estimated for each individual classified layer per boring location. The developed soil profiles and estimated engineering soil properties for use in analysis of Bridge HAM-75-0123E (with cited correlation/reference material) are summarized within Tables 3 and 4 below.

Table 3: Soil Profile and Estimated Engineering Properties - At Boring B-026-0-21

Bridge HAM-75-0123E: Rear Abutment / Forward Abutment, B-026-0-21					
Soil Description	Unit Weight(1) (pcf)	Undrained Shear Strength(2) (psf)	Effective Cohesion(3) (psf)	Effective Friction Angle(3) (degrees)	Setup Factor (f_{su})
Sandy Silt Depth (505.6 ft - 497.1 ft)	122	-	-	33	1.2
Clay Depth (497.1 ft - 495.1 ft)	122	2350	200	24	2.0
Gravel with Sand Depth (495.1 ft - 492.6 ft)	125	-	-	35	1.0
Clay Depth (492.6 ft - 491.1 ft)	122	2350	200	24	2.0
Silt Depth (491.1 ft - 487.6 ft)	115	-	-	31	1.5
Fine Sand Depth (487.6 ft - 484.2 ft)	115	-	-	33	1.2
Silt Depth (484.2 ft - 472.3 ft)	115	-	-	30	1.5
Fine Sand Depth (472.3 ft - 467.3 ft)	115	-	-	30	1.2
Silt Depth (467.3 ft - 462.3 ft)	120	1500	150	24	1.5
Silt Depth (462.3 ft - 442.3 ft)	120	-	-	28	1.5
Silt Depth (442.3 ft - 435.1 ft)	125	-	-	30	1.5
Coarse and Fine Sand Depth (435.1 ft - 420.6 ft)	125	-	-	32	1.0
Notes: *1. Values calculated per ODOT GDM Section 404/1304 and/or ODOT BDM Table 305-2.*					

Table 4: Soil Profile and Estimated Engineering Properties - At Boring B-027-0-21

Bridge HAM-75-0123E: Forward Abutment, B-027-0-21					
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**	**Setup Factor (f_{su})**
Sandy Silt Depth (501 ft - 497.1 ft)	125	-	-	38	1.2
Silty Clay Depth (497.1 ft - 494 ft)	115	1250	150	23	1.75
Sandy Silt Depth (494 ft - 491.5 ft)	125	-	-	31	1.2
Silt and Clay Depth (491.5 ft - 489 ft)	120	3000	250	25	1.5
Sandy Silt Depth (489 ft - 484 ft)	120	1250	150	24	1.5
Silty Clay Depth (484 ft - 470.5 ft)	110	1200	100	22	1.75
Fine Sand Depth (470.5 ft - 466.5 ft)	120	-	-	30	1.2
Silt Depth (466.5 ft - 457.7 ft)	125	-	-	30	1.5
Sandy Silt Depth (457.7 ft - 437.7 ft)	125	-	-	30	1.2
Silt Depth (437.7 ft - 427.7 ft)	120	-	-	27	1.5
Silt Depth (427.7 ft - 417.7 ft)	125	-	-	29	1.5
Sandy Silt Depth (417.7 ft - 407.7 ft)	128	-	-	31	1.2
Coarse and Fine Sand Depth (407.7 ft - 399.5 ft)	128	-	-	33	1.0

Notes:
1. *Values calculated per ODOT GDM Section 404/1304 and/or ODOT BDM Table 305-2.*

Pile Foundation Analysis

Based on the determined soil profile and our estimated engineering soil properties, a friction pile analysis utilizing CIP piles was performed using the computer program *GRLWEAP 14* to determine the estimated geotechnical pile length at each substructure location (*GRLWEAP 14* results attached). 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 pile cap bearing elevation) to the depth at which the required Ultimate Bearing Value (UBV) is obtained. For our analysis it is assumed that the proposed pile cap elevations will match those shown in the Bridge Stage 3 plans developed by Burgess & Niple, Inc. (B&N) dated November 19, 2024. Based on the soil profile encountered at the site, it is our opinion that pile resistances obtained during dynamic testing (driving) may be reduced due to the potential for soil disturbance (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 resistances may not reach the indicated target UBV utilizing the estimated pile lengths. This reduced resistance value obtained at the end of driving the estimated pile length is designated as the End of Initial Driving resistance or EOID. If the EOID is significantly different than the required UBV, it may be necessary to let the piles “set up” (reduction of pore water pressure in the soils adjacent to the pile) for an established time period. To estimate the potential effects of this disturbance during driving, the setup factors presented in Table 4 of the previous section of this memo are used to estimate driving strength losses as well as the side resistance expected to gain following the setup period.

The UBV and EOID values are determined in accordance with Section 305.3.2.4 and 305.3.5.9 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 skin friction (Rs), pile tip bearing values (Rp) for ultimate and during driving conditions are summarized in Table 5 (GRLWEAP 14 results attached). The referenced table also includes 1) required geotechnical pile length for a 12-inch diameter CIP pile driven to the respective pile UBV at the proposed rear abutment; 2) the length of driven pile required in driving conditions for CIP pile driven to the respective UBV per substructure location; and 3) the estimated difference in pile length between a pile in ultimate and driving conditions.

Table 5: Deep Foundation Analysis Summary

Pile Type	Ultimate Conditions		Driving Conditions		Pile Length Difference Ultimate vs. Driving Conditions (ft)	End of Initial Driving Value(3) (kips)	Setup Factor (f_{su})
	Geotechnical Pile Length(1) (ft)	Ultimate Bearing Value(2) (kips)	Driven Pile Length(1) (ft)	Bearing Value During Driving(2)(4) (kips)			
HAM-75-0125E Rear Abutment, B-026-0-21							
12-inch CIP pile	54.2	80.0	65.2	80.0	11.0	59	1.4

Notes:
1. *The length of pile from bottom of pile cap (pile cap bearing elevation) to the depth at which the required UBV is obtained.*
2. *Resistance factor for driven piles, dynamic analysis and static load test methods (BDM Table 305-1) for piles installed according to C&MS 507 using dynamic test methods according to C&MS 523 has not been applied to values calculated.*
3. *EOID is based on driving resistance obtained at the indicated geotechnical pile length.*

Pile Drivability

NEAS's pile drivability evaluation estimated a Delmag D19-42 diesel hammer to determine if the pile type or size being considered would be overstressed (i.e., compressive stresses experienced by pile during driving are greater than 90% of the yield strength of the steel) at any time during pile installation. The results of the evaluation indicated that the referenced CIP pile sizes would not be overstressed during the pile installation process based on: 1) a minimum wall thickness of 0.25-inches; 2) the use of ASTM A 252 Grade 2 steel piles; 3) a pile hammer with a minimum rated energy of 42,000 ft-lbs; and, 4) our developed model used in the computer program *GRLWEAP* by GRL Engineers, Inc. Based on the results of our drivability analysis, it was determined that the referenced piles would not be overstressed during pile installation. *GRLWEAP* results are attached.

It should be noted that the driving resistance of CIP piles through soils encountered at the bridge site is expected to be high. Drivability 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 drivability 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.

Pile Foundation Recommendations

Based on our evaluation of the subsurface conditions and our geotechnical engineering analysis for the proposed Bridge HAM-75-0123E, it is our opinion that the rear abutment foundation can be supported on driven friction CIP piles seated within the dense natural sand encountered at the site.

We recommend that a driven pile foundation be used for support for the proposed bridge rear abutment foundations. New 12-inch diameter CIP piles consisting of ASTM A 252, Grade 2 steel are recommended to be installed in accordance with Sections 507 and 523 of ODOT's CMS. Driven to the UBVs indicated in Table 5 of this report, it is anticipated that the newly driven CIP piles may “run” for extended depths during driving conditions at the proposed rear abutment (i.e., run lengths greater than 10 ft). However, as the piles were only estimated to run for about 11.0 ft (1.0-ft further than the guideline established within ODOT’s BDM at which length setup should be utilized) and as there are a relatively small number of piles proposed at the rear abutment (six total piles), we do mot recommend that pile/soil setup be utilized during the installation process at the referenced substructure. It is recommended that the proposed piles be driven to the required UBV and that all applicable plan notes provided in Section 606.2 be included in the plans.

For piles driven to the UBV indicated in Table 5, a 12-inch diameter CIP pile may be used to support a total factored load (single pile) of 56 kips at the rear abutment. For piles driven to the indicated UBV, pile tip elevations are estimated to be approximately 442 ft amsl at the rear abutment location.

Pile lengths based on: 1) our Deep Foundation Analysis (presented in a previous section of this memo); 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 6 below.

Table 6: Estimated Pile Lengths

Pile Type	Bottom of Pile Cap Elevation (ft amsl)	Geotechnical Pile Length (ft)	Geotechnical Pile Tip Elevation (ft amsl)	Estimated Pile Length$^{(1)}$ (ft)	Order Length$^{(1)}$ (ft)
HAM-75-0125E Rear Abutment, B-026-0-21					
12-inch CIP	507.2	65.2	442.0	70	75

Notes:
1. *Based on definitions and formulas presented in Section 305.3.5.2 of the 2020 BDM.*

Drilled Shaft Analysis

A friction drilled shaft analysis was performed at the proposed forward abutment location of Bridge HAM-75-0123E in accordance with the LRFD BDS using the computer program *SHAFT v2017* to determine the axial resistance of the proposed drilled shaft foundations. Specifically, procedures in Section 10.8.3.5.1 and Section 10.8.3.5.2 were used to calculate the axial resistances of the proposed friction drilled shafts for cohesive soils and cohesionless soils, respectively. The nominal and factored side and tip resistances were computed based on: 1) the soil profile and estimated engineering properties presented in the *Soil Profile for Analysis* section of this memo; and, 2) an assumed shaft diameter of 5-ft at the forward abutment. Nominal tip and side resistances were multiplied by the appropriate resistance factors for cohesive and cohesionless soils per LRFD BDS Table 10.5.5.2.4-1.

Nominal and factored axial resistances for the proposed design lengths of each of the drilled shafts proposed at the forward abutment location are provided in Table 7 below. *SHAFT v2017* results are attached.

Table 7: Drilled Shaft Analysis Summary

Drilled Shaft ID(1)	Diameter (inches)	Drilled Shaft Depth (ft)(1)	Drilled Shaft Tip Elevation (ft amsl)(1)	Nominal Tip Resistance (kips)	Nominal Side Resistance (kips)	Factored Tip Resistance (kips)	Factored Side Resistance (kips)	Total Factored Shaft Resistance (kips)
Shaft 140	60	30.4	471.4	183.0	648.2	18.3	271.0	289.3
Shaft 141	60	31.6	470.2	177.5	692.4	17.7	289.4	307.2
Shaft 142	60	31.6	470.2	177.5	692.4	17.7	289.4	307.2
Shaft 143	60	27.8	474.0	100.4	552.7	10.0	231.0	241.1

Notes:
1. Based on values from "Drilled Shaft Locations and Elevations - Wall 2" table provided in Wall 02 - Stage 2 plans prepared by Palmer Engineering dated December 19, 2024.

MSE Wall Abutment Analysis and Recommendations

Retaining Wall Design Assumptions

As the proposed rear abutment is planned as an MSE wall type abutment, 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 walls are 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 section of wall being analyzed, per ODOT’s 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;
- 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%. (BDM Section 307.1.6); 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 10 below.

Table 8: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
Reinforced Zone	Select Granular Backfill	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 840.04 - A-1 of ODOT's SS 840.

With respect to design constraints and assumptions specific to the MSE wall abutment, the geometry of the proposed wall (i.e., exposed wall heights, existing ground elevations, proposed final grade behind/at the toe of the wall, etc.) is assumed to be consistent with that shown in the proposed Bridge HAM-75-0123E Stage 3 site plan developed by Palmer dated December 19, 2024.

Soil Profile for MSE Wall Analysis

For proposed retaining wall external stability, global stability and settlement analyses purposes, the boring drilled for the rear abutment of the proposed HAM-75-0123E bridge (boring B-027-0-21) was reviewed and a generalized material profile was developed for analysis to represent worse case conditions at the indicated MSE wall location. Utilizing the generalized soil profile, engineering properties for each soil strata were estimated based on the field (i.e., SPT N60 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 properties for use in external and global stability analyses (with sited correlation/reference material) is summarized within Table 9 below. Settlement parameters (with sited correlation/reference material) developed for the proposed rear abutment MSE wall are presented below within Table 10 below.

Table 9: Soil Profile and Estimated Engineering Properties - At Boring B-027-0-21

Bridge HAM-75-0123E: MSE Wall Abutment, B-027-0-21				
Soil Description	Unit Weight(1) (pcf)	Undrained Shear Strength(2) (psf)	Effective Cohesion(3) (psf)	Effective Friction Angle(3) (degrees)
Soil Type 1 - Cohesive (Fill) Depth (507.2 ft - 484 ft)	120	1750	200	24
Soil Type 2 - Cohesive (Natural) Depth (484 ft - 466.5 ft)	115	1200	100	22
Soil Type 3 - Granular (Natural) Depth (466.5 ft - 417.7 ft)	125	-	-	30

Notes:
1. *Values calculated per ODOT GDM Section 404/1304 and/or ODOT BDM Table 305-2.*

Table 10: Settlement Parameters for Analysis – Rear Abutment MSE Wall

HAM-75-0123E Rear Abutment: Settlement Analysis B-027-0-21								
Soil Description	Unit Weight (pcf)	Elastic Modulus(1) (psf)	Poissons Ratio(1), v	Void Ratio e_o	Compression Index(2), C_c	Recompression Index(3), C_r	OCR(4)	Coeff. of Consol.(5), C_v
Cohesive Soil 1	118	640000	0.40	0.710	0.20	0.041	6.5	0.50
Granular Soil 1	125	98000	0.25	-	-	-	-	-

Notes:
1. *Values interpreted from 2017 AASHTO LRFD BDS Table C10.4.6.3-1*
2. *Values calculated from Kulhawy and Mayne, 1990, Equation 6-6.*
3. *Values calculated from Kulhawy and Mayne, 1990, Equation 6-9.*
4. *Values interpreted from Mayne and Kemper, 1988, Figure 7.*
5. *Values interpreted from FHWA GEC No. 5, Boeckmann, et al., 2016, Figure 6-37.*
6. *Borings utilized to esimate soil stratificaiton, layer thickness and consolidation charactersistics include: B-051-4-23, B-051-6-23, B-054-0-18, B-038-1-23 and B-038-2-23.*

External Stability

Based on our estimated engineering soil properties, the developed generalized profile and the retaining wall design assumptions provided in the previous sections of this memo, external stability analyses of the proposed MSE wall abutments were performed. External stability was evaluated at one (1) cross-section (tallest section) along the proposed MSE wall alignment. The 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-section with respect to bearing, sliding and overturning, as well as the calculated factored bearing resistance and bearing pressures are presented in Table 11 below. (External Stability and Bearing Resistance Calculation External stability analysis results are attached.

Table 11: External Stability Analysis Summary

Dimensions	
Design Wall Height (feet)	23.7
Exposed Wall Height (feet)	18.4
Length of Reinforcement (feet)	16.8
Length of Reinf. To Height Ratio	0.7
Approximate Station[(1)]	1+08.4
Capactiy Demand Ratio (CDR)	
Bearing Capacity	1.19
Overturning / Eccentricity	1.54
Sliding	1.05
Factored Bearing Resistance (ksf)[(2)]	7.2
Maximum Service Bearing Pressure	4.2
Maximum Factor Bearing Pressure	6.0

Notes:

1. *Stationing in reference to retaining wall alignment.*
2. *Bearing Resistance calculated in accordance to Section 11.10.5.4 of 2014 LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of 2014 LRFD BDS.*

Global Stability Analysis

For purposes of evaluating the stability of the proposed MSE wall abutment, NEAS reviewed the proposed profile along the length of the retaining wall to determine the subsurface conditions that posed the greatest potential for slope instability. In general, sections along the proposed wall alignments were reviewed to determine the sections that would represent a combination of existing subsurface conditions and planned site grading that would be most critical to slope stability (i.e., maximum total wall height, maximum embankment height measured from toe of slope to top of wall, proposed/existing grades behind and in front of the wall, weak and/or thick soil layer, etc.). Based on our review of the available information at the referenced location and the associated soil properties, one (1) section for the rear abutment MSE wall was estimated to be most "critical" and was analyzed for global stability. The sections analyzed for global stability for the proposed wall consisted of the maximum wall-height sections at approximate STA. 1+08 (proposed retaining wall alignment).

For the indicated sections, NEAS developed a representative cross-sectional model to use as the basis for global stability analysis. The model was developed from NEAS's interpretation of the available information which included: 1) the proposed Bridge HAM-75-0123E Stage 3 site plan developed by Palmer dated December 19, 2024; 2) a live load surcharge of 90 pounds per square foot (psf) accounting for pedestrian traffic induced loads; and, 3) test borings and laboratory data developed as part of this project. With respect to the soil's engineering properties, the provided generalized soil profile and estimated engineering properties presented in the *Soil Profile for MSE Wall Analysis* section of this memo were used in our analysis.

The above referenced global stability model was analyzed for long-term (Effective Stress) and short-term (Total Stress) slope stability utilizing the software entitled Slide2 by Rocscience, Inc. Specifically, the Spencer analysis method was 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 1.5 which equates to an AASHTO resistance factor less than 0.65 (per AASHTO's LRFD BDS, 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 was targeted as the MSE wall abutment contains or supports a structural element of the proposed bridge. Based on our slope stability analyses for the referenced MSE wall section, the minimum slope stability factor was estimated to be about 1.84

(0.54 resistance factor). Graphical outputs of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) are attached.

Settlement and Downdrag Analysis

In order to estimate the maximum total and differential settlement that could result within the subsurface soils supporting the proposed MSE wall abutment at the rear abutment location, NEAS reviewed: 1) the proposed Bridge HAM-75-0123E Stage 3 site plan developed by Palmer dated December 19, 2024; 2) Service Limit State loading conditions; and, 3) the generalized subsurface profile and Settlement Parameters for Analysis provided in the *Soil Profile for MSE Wall Analysis* section of this memo. Utilizing this information and the software entitled *Settle3* by Rocscience Inc., a settlement model was developed and analyzed for both elastic (immediate) and consolidation (long term) settlement.

Based on our analysis, the estimated maximum total long-term settlement that could occur along the length of proposed MSE wall abutment as a result of the induced wall and embankment loads is estimated to be about 2.5 inches. The maximum differential settlement along the length of the proposed MSE wall abutment is estimated to be less than 1 percent. With respect to potential downdrag effects induced by these settlement magnitudes on the proposed pile foundations at the rear abutment location, these effects can be mitigated in the specification of a waiting period following wall/embankment construction. It is anticipated that approximately 90 percent of the estimated long-term settlement will be complete within 450 days following the application of new retaining wall and/or embankment loading. Outputs of the settlement analysis program are attached.

In lieu of specifying a waiting period to mitigate impacts of potential downdrag loads on the proposed rear abutment pile foundation, a downdrag analysis was performed per Sections 305.3.2.2 and 305.4.1.2 "Downdrag and Drag Load" of the ODOT BDM, to determine if the factored structural axial resistance of the pile or shaft 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) the referenced Stage 3 bridge site plan developed by Palmer; 2) the bridge loading information provided by B&N on December 20, 2024; and, 3) the proposed 12-inch CIP pile properties (i.e., a minimum wall thickness of 0.25-inches and a 35 ksi yield stress). Utilizing this information and geotechnical resistance information presented in *Soil Profile for Bridge Foundation Analysis*s section of this report, the location of the neutral plane for the rear abutment piles was determined utilizing the Goudreault and Fellenius (1994) method. At the depth of the neutral plane (i.e., calculated to be 20.8 ft below pile cap), it was subsequently determined that the combination of factored permanent and downdrag loads (i.e., calculated to be 68.2 kips) was well below the factored structural axial resistance of the subject piles. Based on our analyses, the total vertical pile deflection due to both long-term soil settlement at the neutral plane as well as the elastic compression of the pile above the neutral plane was estimated to be about 0.1 inches. Therefore, downdrag loads are not anticipated to be a concern for the project proposed pile foundations. Neutral plane and downdrag loading pile check results are attached.

SOIL BORING LOGS

PROJECT: HAM-75-1.05	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 55X	STATION / OFFSET: 65+05, 211' RT.	EXPLORATION ID B-026-0-21
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: IR-75	
PID: 113361 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 505.6 (MSL) EOB: 85.0 ft.	PAGE 1 OF 3
START: 1/26/22 END: 1/27/22	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.9	LAT / LONG: 39.107057, -84.530375	

MATERIAL DESCRIPTION AND NOTES	ELEV. 505.6
MEDIUM DENSE, BROWN, **SANDY SILT**, TRACE CLAY, TRACE GRAVEL, CONTAINS COAL AND BRICK FRAGMENTS, MOIST **(FILL)**	497.1
HARD, BROWNISH GRAY, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, MOIST **(FILL)**	495.1
MEDIUM DENSE, BROWN AND GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, DAMP **(FILL)**	492.6
VERY STIFF, BROWN, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, MOIST **(FILL)**	491.1
MEDIUM DENSE, BROWN, **SILT**, LITTLE CLAY, LITTLE SAND, TRACE GRAVEL, WET **(FILL)**	487.6
MEDIUM DENSE, BROWN AND GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, CONTAINS BRICK FRAGMENTS, DAMP **(FILL)**	486.1
MEDIUM DENSE, BROWN AND ORANGISH BROWN, **FINE SAND**, TRACE COARSE SAND, TRACE SILT, TRACE CLAY, TRACE GRAVEL, CONTAINS IRON STAINING, DAMP	484.2
MEDIUM DENSE, BROWN, **SILT**, TRACE CLAY, TRACE SAND, TRACE GRAVEL, WET	

DEPTHS	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
3–4.5	6 5 3	11	22	SS-1	-	-	-	-	-	-	-	-	-	14	A-4a (V)	
5.5–7	1 5 6	15	39	SS-2	-	5	18	35	32	10	NP	NP	NP	16	A-4a (1)	
8–9.5	8 5 9	19	100	SS-3A	-	-	-	-	-	-	-	-	-	15	A-4a (V)	
				SS-3B	4.50	0	1	1	32	66	45	24	21	25	A-7-6 (13)	
10.5–12	7 5 9	19	100	SS-4A	4.50	-	-	-	-	-	-	-	-	24	A-7-6 (V)	
				SS-4B	-	-	-	-	-	-	-	-	-	2	A-1-b (V)	
13–14.5	8 5 9	19	100	SS-5A	-	-	-	-	-	-	-	-	-	6	A-1-b (V)	
				SS-5B	4.00	-	-	-	-	-	-	-	-	28	A-7-6 (V)	
15.5–17	3 6 7	18	100	SS-6	-	0	0	13	73	14	NP	NP	NP	22	A-4b (8)	
18–19.5	3 11 10	29	100	SS-7A	-	-	-	-	-	-	-	-	-	21	A-4b (V)	
				SS-7B	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
20.5–22	3 8 7	20	100	SS-8	-	-	-	-	-	-	-	-	-	6	A-3 (V)	
23–24.5	2 4 8	16	100	SS-9	-	-	-	-	-	-	-	-	-	27	A-4b (V)	
25.5–27	2 4 5	12	100	SS-10	-	0	0	6	85	9	NP	NP	NP	24	A-4b (8)	

PID: 113361	SFN:	PROJECT: HAM-75-1.05	STATION / OFFSET: 65+05, 211' RT.	START: 1/26/22	END: 1/27/22	PG 2 OF 3	B-026-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 475.6	DEPTHS	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
MEDIUM DENSE, BROWN, **SILT**, TRACE CLAY, TRACE SAND, TRACE GRAVEL, WET *(continued)*		31	3 7 7	19	100	SS-11	-	-	-	-	-	-	-	-	-	24	A-4b (V)	
	472.3	32 – 33																
MEDIUM DENSE, BROWN, **FINE SAND**, TRACE COARSE SAND, TRACE SILT, TRACE CLAY, TRACE GRAVEL, WET		34 – 35																
		36	4 4 4	11	100	SS-12	-	-	-	-	-	-	-	-	-	30	A-3 (V)	
	467.3	37 – 38																
VERY STIFF, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, MOIST		39 – 40																
		41	3 4 5	12	100	SS-13	2.25	0	0	3	76	21	27	21	6	24	A-4b (8)	
	462.3	42 – 43																
VERY LOOSE TO MEDIUM DENSE, GRAY, **SILT**, TRACE TO LITTLE CLAY, TRACE SAND, TRACE GRAVEL, WET		44 – 45																
		46	2 3 4	10	100	SS-14	-	-	-	-	-	-	-	-	-	25	A-4b (V)	
		47 – 50																
		51	2 3 4	10	100	SS-15	-	-	-	-	-	-	-	-	-	30	A-4b (V)	
		52 – 55																
		56	0 2 3	7	100	SS-16	-	0	0	1	86	13	NP	NP	NP	28	A-4b (8)	
		57 – 60																
		61	0 0 3	4	100	SS-17	-	-	-	-	-	-	-	-	-	32	A-4b (V)	

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 4/10/25 12:05 - X:\1ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2024 ARCHIVE\HAM-75-1.05\GINT FILES\HAI

PID: 113361	SFN:	PROJECT: HAM-75-1.05	STATION / OFFSET: 65+05, 211' RT.	START: 1/26/22	END: 1/27/22	PG 3 OF 3	B-026-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 443.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY LOOSE TO MEDIUM DENSE, GRAY, **SILT**, TRACE TO LITTLE CLAY, TRACE SAND, TRACE GRAVEL, WET *(continued)*		63, 64																
		65–66	2 6 6	16	100	SS-18	-	0	0	8	85	7	NP	NP	NP	26	A-4b (8)	
	435.1	67, 68, 69																
MEDIUM DENSE, GRAY, **COARSE AND FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, MOIST		70–71	2 6 7	18	100	SS-19A	-	-	-	-	-	-	-	-	-	21	A-4b (V)	
						SS-19B	-	-	-	-	-	-	-	-	-	16	A-3a (V)	
		72, 73, 74																
		75–76	4 6 7	18	100	SS-20	-	-	-	-	-	-	-	-	-	14	A-3a (V)	
		77, 78, 79																
		80–81	6 7 8	20	100	SS-21	-	-	-	-	-	-	-	-	-	14	A-3a (V)	
		82, 83																
	420.6	84 – EOB 85	7 7 9	22	56	SS-22	-	-	-	-	-	-	-	-	-	12	A-3a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. DRILLED AS STAKED.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 50 GAL. BENTONITE GROUT; SHOVELED SOIL CUTTINGS

PROJECT: HAM-75-1.05	DRILLING FIRM / OPERATOR: NEAS / ASHBAUGH	DRILL RIG: CME 55T	STATION / OFFSET: 65+82, 79' RT.
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT: IR-75
PID: 113361 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 501.0 (MSL) EOB: 101.5 ft.
START: 2/10/22 END: 2/11/22	SAMPLING METHOD: SPT	ENERGY RATIO (%): 68.4	LAT / LONG: 39.107091, -84.530900

EXPLORATION ID B-027-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 501.0
5.0" ASPHALT AND 7.0" CONCRETE AND 6.0" BASE (DRILLERS DESCRIPTION)	499.5
HARD, BROWN, **SANDY SILT**, LITTLE CLAY, LITTLE GRAVEL, CONTAINS BRICK FRAGMENTS, MOIST **(FILL)**	497.1
STIFF TO VERY STIFF, BROWN, **SILTY CLAY**, SOME SAND, LITTLE GRAVEL, CONTAINS BRICK FRAGMENTS, DAMP **(FILL)**	494.0
STIFF, BROWNISH GRAY, **SANDY SILT**, LITTLE CLAY, LITTLE GRAVEL, DAMP **(FILL)**	491.5
VERY STIFF, BROWNISH GRAY AND BLACK, **SILT AND CLAY**, SOME SAND, LITTLE GRAVEL, SLIGHTLY ORGANIC, DAMP **(FILL)**	489.0
HARD, BROWNISH GRAY AND BLACK, **SANDY SILT**, SOME CLAY, LITTLE STONE FRAGMENTS, CONTAINS BRICK AND GLASS FRAGMENTS, DAMP **(FILL)**	486.5
VERY STIFF, BROWN, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, DAMP **(FILL)**	484.0
STIFF TO VERY STIFF, BROWN MOTTLED WITH GRAY, **SILTY CLAY**, LITTLE SAND, TRACE TO LITTLE GRAVEL, MOIST	

DEPTHS	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
3	7-10-11	24	67	SS-1	4.25	15	13	31	24	17	24	14	10	15	A-4a (1)
5–6	8-5-4	10	61	SS-2	2.00	-	-	-	-	-	-	-	-	18	A-6b (V)
8	6-6-8	16	56	SS-3	1.25	13	18	20	30	19	25	16	9	15	A-4a (3)
10–11	7-11-10	24	78	SS-4	3.00	-	-	-	-	-	-	-	-	15	A-6a (V)
13	7-5-4	10	89	SS-5	4.25	14	13	21	31	21	29	20	9	18	A-4a (3)
15–16	4-5-4	10	72	SS-6	3.00	-	-	-	-	-	-	-	-	15	A-6a (V)
18	4-4-4	9	78	SS-7	2.50	-	-	-	-	-	-	-	-	26	A-6b (V)
20–21	3-3-4	8	72	SS-8	2.75	-	-	-	-	-	-	-	-	21	A-6b (V)
23	3-4-4	9	67	SS-9	2.00	1	3	11	44	41	40	19	21	24	A-6b (12)
25–26	3-5-6	13	78	SS-10	2.25	-	-	-	-	-	-	-	-	26	A-6b (V)
28	4-4-5	10	83	SS-11	1.25	-	-	-	-	-	-	-	-	26	A-6b (V)

HOLE SEALED

PID: 113361	SFN:	PROJECT: HAM-75-1.05	STATION / OFFSET: 65+82, 79' RT.	START: 2/10/22	END: 2/11/22	PG 2 OF 4	B-027-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 471.0	
LOOSE TO MEDIUM DENSE, BROWN, **FINE SAND**, TRACE COARSE SAND, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP	470.5	466.5
MEDIUM DENSE, BROWN AND GRAY, **SILT**, LITTLE SAND, LITTLE CLAY, TRACE GRAVEL, WET	466.5	457.7
MEDIUM DENSE, BROWN AND GRAY, **SANDY SILT**, TRACE CLAY, TRACE GRAVEL, WET	457.7	

DEPTHS	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
30.5–32	4, 5, 4	10	78	SS-12A	2.25	-	-	-	-	-	-	-	-	22	A-6b (V)
				SS-12B	-	-	-	-	-	-	-	-	-	7	A-3 (V)
33–34.5	5, 6, 7	15	72	SS-13	-	-	-	-	-	-	-	-	-	5	A-3 (V)
35–36.5	5, 6, 9	17	89	SS-14	-	0	3	15	65	17	NP	NP	NP	23	A-4b (8)
38–39.5	5, 7, 7	16	78	SS-15	-	-	-	-	-	-	-	-	-	27	A-4b (V)
40–41.5	5, 6, 8	16	89	SS-16	-	0	0	11	78	11	NP	NP	NP	28	A-4b (8)
45–46.5	5, 8, 9	19	89	SS-17	-	-	-	-	-	-	-	-	-	36	A-4a (V)
50–51.5	6, 9, 11	23	100	SS-18	-	0	1	59	33	7	NP	NP	NP	26	A-4a (1)
55–56.5	6, 7, 10	19	100	SS-19	-	-	-	-	-	-	-	-	-	25	A-4a (V)
60–61.5	5, 6, 5	13	72	SS-20	-	-	-	-	-	-	-	-	-	32	A-4a (V)

MATERIAL DESCRIPTION AND NOTES	ELEV. 438.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
	437.7	63																
LOOSE TO MEDIUM DENSE, GRAY, **SILT**, SOME SAND, TRACE CLAY, TRACE GRAVEL, WET		65–66	4 3 4	8	78	SS-21	-	0	1	26	64	9	NP	NP	NP	27	A-4b (8)	
		70–71	3 3 4	8	83	SS-22	-	-	-	-	-	-	-	-	-	28	A-4b (V)	
		75–76	3 5 7	14	72	SS-23	-	-	-	-	-	-	-	-	-	25	A-4b (V)	
		80–81	4 6 9	17	89	SS-24	-	0	0	23	68	9	NP	NP	NP	26	A-4b (8)	
	417.7	83																
MEDIUM DENSE, GRAY, **SANDY SILT**, TRACE CLAY, TRACE GRAVEL, WET		85–86	7 9 11	23	100	SS-25	-	0	0	63	34	3	NP	NP	NP	23	A-4a (0)	
		90–91	10 11 13	27	100	SS-26	-	-	-	-	-	-	-	-	-	26	A-4a (V)	
	407.7	93																
		94																

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 4/10/25 12:05 - X:\1ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2024 ARCHIVE\HAM-75-1.05\GINT FILES\HAI

PID: 113361 | SFN: | PROJECT: HAM-75-1.05 | STATION / OFFSET: 65+82, 79' RT. | START: 2/10/22 | END: 2/11/22 | PG 4 OF 4 | B-027-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 406.7	DEPTHS	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
DENSE, GRAY, **COARSE AND FINE SAND**, TRACE SILT, TRACE GRAVEL, TRACE CLAY, WET *(continued)*		95 – 96	12 13 15	32	100	SS-27	-	-	-	-	-	-	-	-	-	22	A-3a (V)	
	399.5	100 – 101 (EOB)	14 14 16	34	100	SS-28	-	-	-	-	-	-	-	-	-	19	A-3a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. DRILLED AS STAKED.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; PUMPED 100 GAL. BENTONITE GROUT; POURED 2 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

DRIVEN PILE ANALYSIS

REAR ABUTMENT

SOIL PROFILE

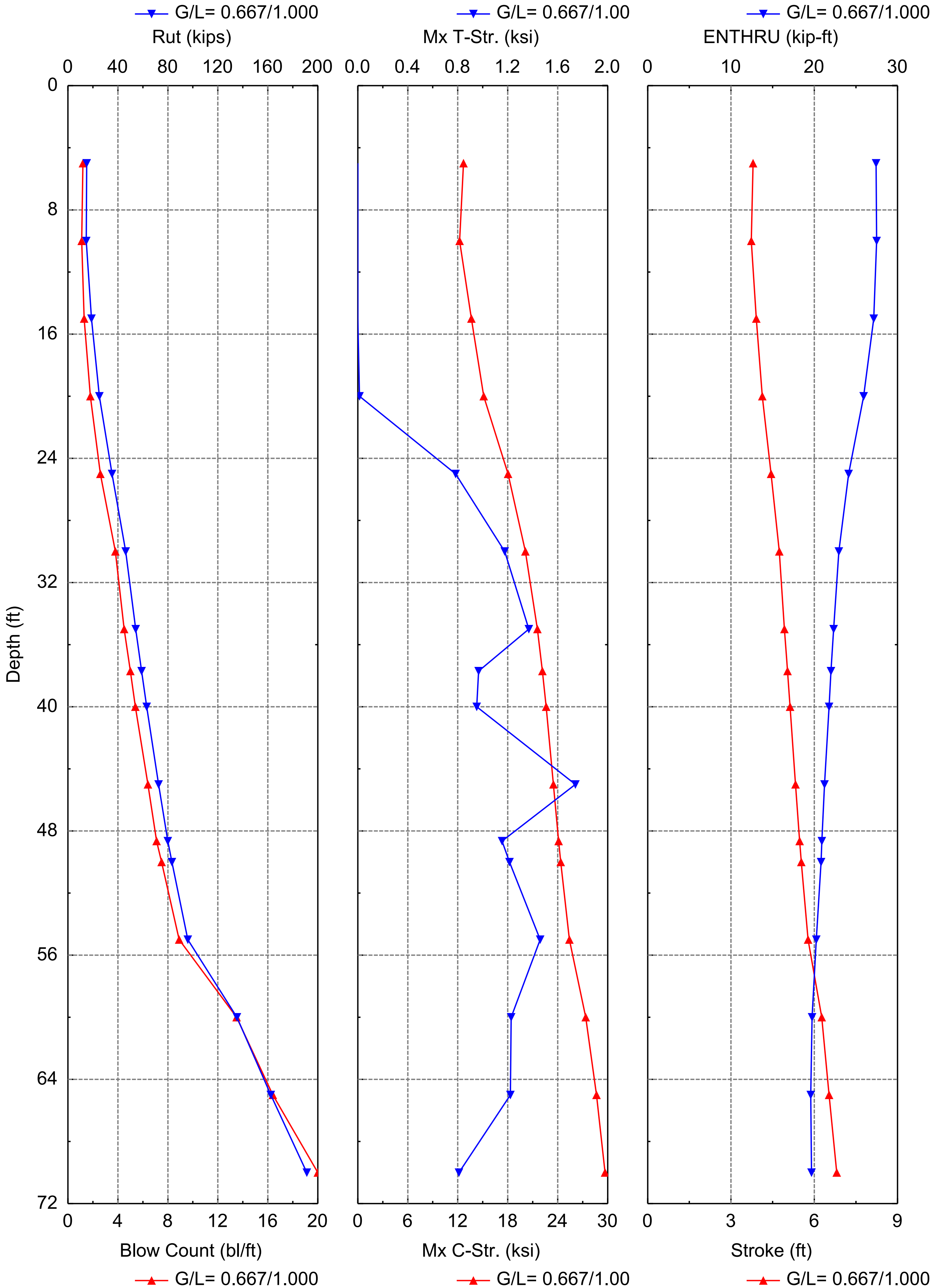
Depth	Soil Type	Spec. Wt	Su	Phi	Unit Rs	Unit Rt
ft	-	lb/ft³	ksf	°	ksf	ksf
0.0	Sand	115.0	0.0	31.0	0.00	0.00
3.2	Sand	115.0	0.0	31.0	0.11	7.85
3.2	Sand	115.0	0.0	33.0	0.14	11.29
6.6	Sand	115.0	0.0	33.0	0.29	23.28
6.6	Sand	115.0	0.0	30.0	0.21	13.21
18.5	Sand	115.0	0.0	30.0	0.59	13.32
18.5	Sand	115.0	0.0	30.0	0.59	13.32
23.5	Sand	115.0	0.0	30.0	0.75	13.32
23.5	Clay	120.0	1.5	0.0	1.19	13.50
28.5	Clay	120.0	1.5	0.0	1.19	13.50
28.5	Sand	120.0	0.0	28.0	0.71	13.32
48.5	Sand	120.0	0.0	28.0	0.99	13.32
48.5	Sand	125.0	0.0	30.0	1.15	13.32
55.7	Sand	125.0	0.0	30.0	1.27	13.32
55.7	Sand	125.0	0.0	32.0	1.58	33.09
70.2	Sand	125.0	0.0	32.0	1.89	33.09

0.0 ft @ Ele. 490.75 ft amsl (Bottom of Foundation Prep Layer)
Pile Cap Ele. = 507.2 ft amsl
No overburden above driving elevation (i.e., for bearing/pile length calculation)
UBV = 80.0 kips

Driveability Analysis Summary
Gain/Loss Factor at Shaft/Toe = 0.667/1.000

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	15.1	1.2	13.8	1.2	12.693	0.000	3.80	27.4	D 19-42
10.0	14.6	4.2	10.5	1.1	12.228	0.000	3.73	27.5	D 19-42
15.0	18.8	8.4	10.5	1.3	13.630	0.000	3.91	27.1	D 19-42
20.0	25.2	14.7	10.5	1.8	15.122	0.013	4.13	25.9	D 19-42
25.0	35.3	24.7	10.6	2.6	18.035	0.783	4.45	24.1	D 19-42
30.0	46.3	35.8	10.5	3.8	20.120	1.176	4.74	22.9	D 19-42
35.0	54.3	43.8	10.5	4.5	21.558	1.369	4.93	22.3	D 19-42
37.7	58.9	48.5	10.5	5.0	22.158	0.967	5.03	22.0	D 19-42
40.0	63.1	52.6	10.5	5.4	22.617	0.952	5.13	21.8	D 19-42
45.0	72.5	62.1	10.5	6.4	23.478	1.741	5.32	21.2	D 19-42
48.7	80.0	69.5	10.5	7.1	24.114	1.154	5.47	20.9	D 19-42
50.0	83.2	72.8	10.5	7.5	24.360	1.214	5.53	20.8	D 19-42
55.0	96.0	85.5	10.5	8.9	25.404	1.460	5.77	20.2	D 19-42
60.0	135.3	109.3	26.0	13.5	27.370	1.227	6.27	19.7	D 19-42
65.0	162.4	136.4	26.0	16.4	28.662	1.221	6.53	19.6	D 19-42
70.0	191.2	165.2	26.0	20.0	29.681	0.810	6.81	19.7	D 19-42

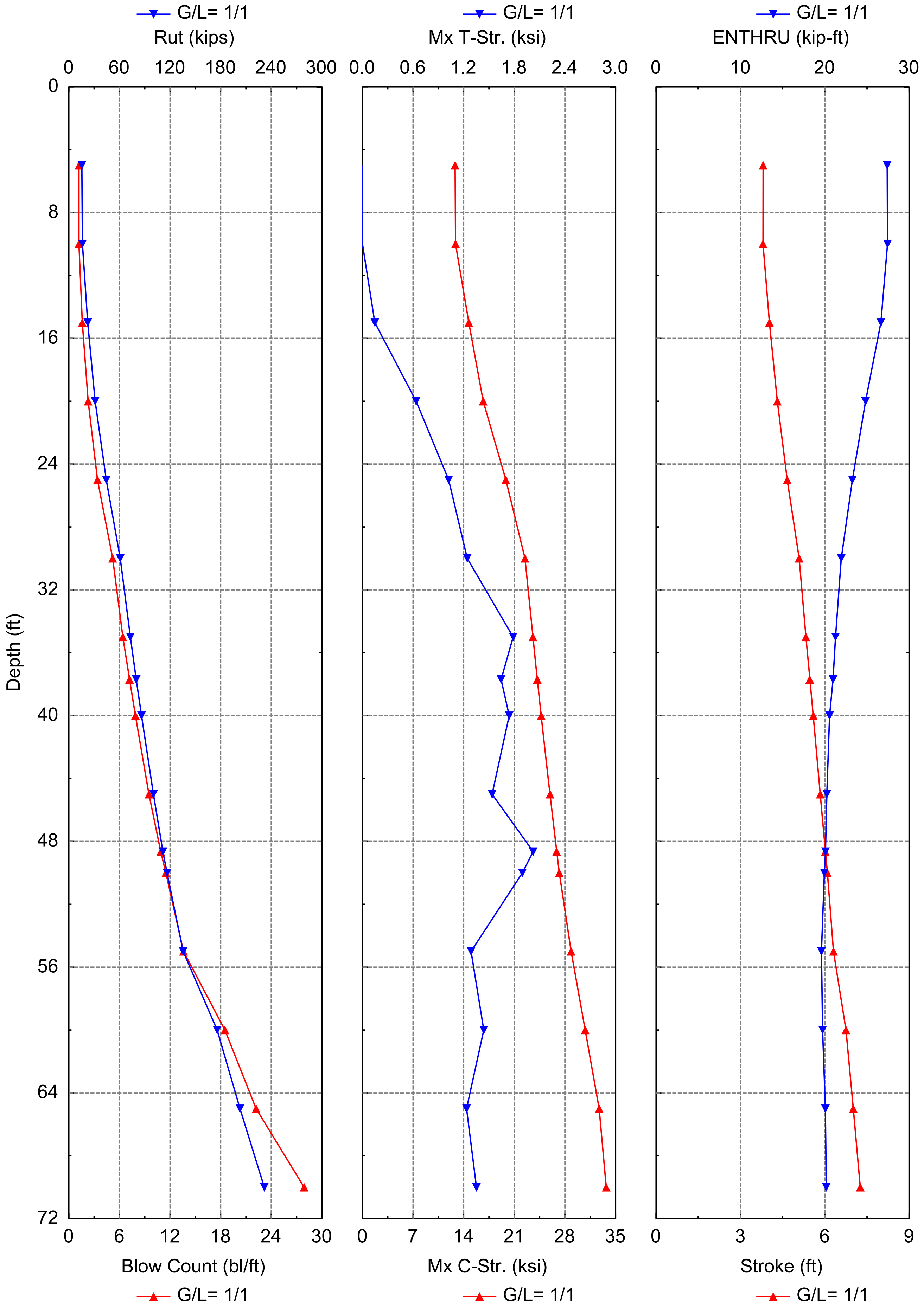
Total driving time: 9 minutes; Total Number of Blows: 418 (starting at penetration 5.0 ft)


G/L= 0.667/1.000
Rut (kips)
0 40 80 120 160 200
G/L= 0.667/1.00
Mx T-Str. (ksi)
0.0 0.4 0.8 1.2 1.6 2.0
G/L= 0.667/1.000
ENTHRU (kip-ft)
0 10 20 30
Depth (ft)
0 8 16 24 32 40 48 56 64 72
0 4 8 12 16 20
Blow Count (bl/ft)
G/L= 0.667/1.000
0 6 12 18 24 30
Mx C-Str. (ksi)
G/L= 0.667/1.00
0 3 6 9
Stroke (ft)
G/L= 0.667/1.000

Driveability Analysis Summary
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	15.4	1.6	13.8	1.2	12.816	0.000	3.81	27.4	D 19-42
10.0	16.1	5.7	10.5	1.2	12.873	0.000	3.80	27.4	D 19-42
15.0	22.4	12.0	10.5	1.6	14.715	0.147	4.03	26.7	D 19-42
20.0	31.2	20.7	10.5	2.3	16.710	0.637	4.31	24.8	D 19-42
25.0	44.4	33.8	10.6	3.4	19.834	1.022	4.66	23.3	D 19-42
30.0	61.0	50.5	10.5	5.2	22.470	1.242	5.09	22.0	D 19-42
35.0	73.0	62.6	10.5	6.4	23.587	1.787	5.33	21.3	D 19-42
37.7	80.0	69.5	10.5	7.2	24.168	1.644	5.47	21.0	D 19-42
40.0	86.2	75.7	10.5	7.9	24.715	1.740	5.59	20.6	D 19-42
45.0	100.4	89.9	10.5	9.5	25.941	1.536	5.84	20.2	D 19-42
48.7	111.5	101.0	10.5	10.9	26.856	2.024	6.02	20.1	D 19-42
50.0	116.4	106.0	10.5	11.5	27.231	1.896	6.09	19.9	D 19-42
55.0	135.5	125.1	10.5	13.6	28.857	1.288	6.31	19.6	D 19-42
60.0	175.8	149.8	26.0	18.5	30.802	1.438	6.75	19.7	D 19-42
65.0	202.9	176.9	26.0	22.2	32.737	1.234	7.01	20.1	D 19-42
70.0	231.7	205.7	26.0	27.9	33.721	1.351	7.26	20.2	D 19-42

Total driving time: 12 minutes; Total Number of Blows: 589 (starting at penetration 5.0 ft)


G/L= 1/1
Rut (kips)
0 60 120 180 240 300
G/L= 1/1
Mx T-Str. (ksi)
0.0 0.6 1.2 1.8 2.4 3.0
G/L= 1/1
ENTHRU (kip-ft)
0 10 20 30
Depth (ft)
0 8 16 24 32 40 48 56 64 72
0 6 12 18 24 30
Blow Count (bl/ft)
G/L= 1/1
0 7 14 21 28 35
Mx C-Str. (ksi)
G/L= 1/1
0 3 6 9
Stroke (ft)
G/L= 1/1

GRLWEAP: Wave Equation Analysis of Pile Foundations

Pedestrian Bridge HAM-75-0123E + RA12IN 12/30/2024
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.

HAMMER DATA

Hammer Model:	D 19-42	Made By:	DELMAG
Hammer ID:	41	Hammer Type:	OED
Hammer Database Type:	PDI		
Hammer Database Name:			PDIHammer.gwh

Hammer and Drive System Segment Data

Segment	Weight	Stiffness	COR	C-Slack	Damping
-	kips	kips/in	-	in	kips/ft/s
1	0.800	140,084.4	1.000	0.000	
2	0.800	140,084.4	1.000	0.000	
3	0.800	140,084.4	1.000	0.000	
4	0.800	140,084.4	1.000	0.000	
5	0.800	70,754.7	0.900	0.120	
Imp Block	0.753	109,976.0	0.800	0.120	
Helmet	2.500				5.3

Ram Weight: (kips)	4.00	Ram Length: (ft)	10.76
Ram Area: (in²)	124.69		
Maximum (Eq) Stroke: (ft)	10.81	Actual (Eq) Stroke: (ft)	10.81
Efficiency:	0.800	Rated Energy: (kip-ft)	43.24
Maximum Pressure: (psi)	1,600.00	Actual Pressure: (psi)	1,600.00
Combustion Delay: (ms)	2.00	Ignition Duration: (ms)	2.00
Expansion Exponent:	1.25		

Hammer Cushion		Pile Cushion	
Cross Sect. Area: (in²)	415.00	Cross Sect. Area: (in²)	0.00
Elastic Modulus: (ksi)	530.0	Elastic Modulus: (ksi)	0.0
Thickness: (in)	2.00	Thickness: (in)	0.00
Coeff. of Restitution:	0.800	Coeff. of Restitution:	0.500
RoundOut: (in)	0.120	RoundOut: (in)	0.120
Stiffness: (kips/in)	109,976.0	Stiffness: (kips/in)	0.0
Helmet Weight: (kips)	2.500		

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	75.000	Pile Penetration: (ft)	70.000
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Table of Depths Analyzed with Driving System Modifiers

Depth ft	Temp Length ft	Wait Time Hr	Hammer -
5.00	75.0	0.0	DELMAG D 19-42
10.00	75.0	0.0	DELMAG D 19-42
15.00	75.0	0.0	DELMAG D 19-42
20.00	75.0	0.0	DELMAG D 19-42
25.00	75.0	0.0	DELMAG D 19-42
30.00	75.0	0.0	DELMAG D 19-42
35.00	75.0	0.0	DELMAG D 19-42
36.74	75.0	0.0	DELMAG D 19-42
40.00	75.0	0.0	DELMAG D 19-42
45.00	75.0	0.0	DELMAG D 19-42
47.50	75.0	0.0	DELMAG D 19-42
50.00	75.0	0.0	DELMAG D 19-42
55.00	75.0	0.0	DELMAG D 19-42
60.00	75.0	0.0	DELMAG D 19-42
65.00	75.0	0.0	DELMAG D 19-42
70.00	75.0	0.0	DELMAG D 19-42

Other Information for DELMAG D 19-42

Depth ft	Stroke ft	Diesel Pressure %	Efficiency -	P.C. Stiff. Fact. -	P.C. COR -
5.00	10.8	100.0	0.80	1.0	0.50
10.00	10.8	100.0	0.80	1.0	0.50
15.00	10.8	100.0	0.80	1.0	0.50
20.00	10.8	100.0	0.80	1.0	0.50
25.00	10.8	100.0	0.80	1.0	0.50
30.00	10.8	100.0	0.80	1.0	0.50
35.00	10.8	100.0	0.80	1.0	0.50
36.74	10.8	100.0	0.80	1.0	0.50
40.00	10.8	100.0	0.80	1.0	0.50
45.00	10.8	100.0	0.80	1.0	0.50
47.50	10.8	100.0	0.80	1.0	0.50
50.00	10.8	100.0	0.80	1.0	0.50
55.00	10.8	100.0	0.80	1.0	0.50
60.00	10.8	100.0	0.80	1.0	0.50
65.00	10.8	100.0	0.80	1.0	0.50
70.00	10.8	100.0	0.80	1.0	0.50

PILE, SOIL, ANALYSIS OPTIONS

Analysis type:	Driveability Analysis	Soil Damping Option:	Smith

Max No Analysis Iterations:	0	Time Increment/Critical:	160
Residual Stress Analysis:	0	Analysis Time-Input(ms):	0
Output Level:	Normal	Gravitational Acceleration (ft/s²):	32.169
Hammer Gravity (ft/s²):	32.169	Pile Gravity (ft/s²):	32.169

DRIVEABILITY ANALYSIS

Analysis Depth (ft)	70.00	Standard Soil Setup	
Hammer Name	DELMAG D 19-42	Hammer ID	41
Diesel Pressure: (psi)	230.40	Stroke (ft)	10.81
Efficiency	0.80		
Shaft Gain/Loss Factor	0.667	Toe Gain/Loss Factor	1.000
Shaft Gain/Loss Factor	1.000	Toe Gain/Loss Factor	1.000

SOIL RESISTANCE PARAMETERS

Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Setup F. -	Limit D. ft	Setup T. Hours	EB Area in²
0.00	0.0	0.0	0.10	0.141	0.100	0.1	1.5	6.56	24.0	113.10
1.60	0.1	3.9	0.10	0.141	0.100	0.1	1.5	6.56	24.0	113.10
3.20	0.1	7.9	0.10	0.141	0.100	0.1	1.5	6.56	24.0	113.10
3.20	0.1	11.3	0.10	0.131	0.050	0.1	1.2	6.56	24.0	113.10
4.90	0.2	17.3	0.10	0.131	0.050	0.1	1.2	6.56	24.0	113.10
6.60	0.3	23.3	0.10	0.131	0.050	0.1	1.2	6.56	24.0	113.10
6.60	0.2	13.2	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
8.30	0.3	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
10.00	0.3	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
11.70	0.4	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
13.40	0.4	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
15.10	0.5	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
16.80	0.5	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
18.50	0.6	13.3	0.10	0.155	0.100	0.1	1.5	6.56	24.0	113.10
18.50	0.6	13.3	0.10	0.179	0.050	0.1	1.2	6.56	24.0	113.10
20.17	0.6	13.3	0.10	0.179	0.050	0.1	1.2	6.56	24.0	113.10
21.83	0.7	13.3	0.10	0.179	0.050	0.1	1.2	6.56	24.0	113.10
23.50	0.7	13.3	0.10	0.179	0.050	0.1	1.2	6.56	24.0	113.10
23.50	1.2	13.5	0.10	0.129	0.150	0.1	1.5	6.56	24.0	113.10
28.50	1.2	13.5	0.10	0.129	0.150	0.1	1.5	6.56	24.0	113.10
28.50	0.7	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
30.17	0.7	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
31.83	0.8	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
36.83	0.8	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
38.50	0.9	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
45.17	0.9	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
46.83	1.0	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
48.50	1.0	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
48.50	1.1	13.3	0.10	0.169	0.100	0.1	1.5	6.56	24.0	113.10
50.30	1.2	13.3	0.10	0.169	0.100	0.1	1.5	6.56	24.0	113.10
53.90	1.2	13.3	0.10	0.169	0.100	0.1	1.5	6.56	24.0	113.10

55.70	1.3	13.3	0.10	0.169	0.100	0.1	1.5	6.56	24.0	113.10
55.70	1.6	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
57.51	1.6	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
59.33	1.7	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
62.95	1.7	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
64.76	1.8	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
66.58	1.8	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
68.39	1.9	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10
70.00	1.9	33.1	0.10	0.162	0.050	0.1	1.0	6.56	1.0	113.10

PILE PROFILE

Lb Top	X-Area	E-Mod	Spec. Wt	Perim.	C-Index	Wave Sp	Impedance
ft	in²	ksi	lb/ft³	ft	-	ft/s	kips/ft/s
0.00	9.2	30,000	492.00	3.142	0	16,806.4	16.5
75.00	9.2	30,000	492.00	3.142	0	16,806.4	16.5

PILE AND SOIL MODEL Total Capacity Rut (kips): 191.213

Seg.	Weight	Stiffn.	C-Slk	T-Slk	COR	Ru	Js/Jt	Qs/Qt	LbTop	Perim.	X-Area
-	kips	kips/in	in	in	-	kips	s/ft	in	ft	ft	in²
1	0.10	7,075	0.12	0.00	0.85	0.0	0.000	0.10	3.26	3.14	9.2
2	0.10	7,075	0.00	0.00	1.00	0.1	0.100	0.10	6.52	3.14	9.2
3	0.10	7,075	0.00	0.00	1.00	1.0	0.067	0.10	9.78	3.14	9.2
4	0.10	7,075	0.00	0.00	1.00	1.9	0.071	0.10	13.04	3.14	9.2
5	0.10	7,075	0.00	0.00	1.00	2.1	0.100	0.10	16.30	3.14	9.2
6	0.10	7,075	0.00	0.00	1.00	2.8	0.100	0.10	19.57	3.14	9.2
7	0.10	7,075	0.00	0.00	1.00	3.5	0.100	0.10	22.83	3.14	9.2
8	0.10	7,075	0.00	0.00	1.00	5.1	0.060	0.10	26.09	3.14	9.2
9	0.10	7,075	0.00	0.00	1.00	6.6	0.087	0.10	29.35	3.14	9.2
10	0.10	7,075	0.00	0.00	1.00	8.1	0.150	0.10	32.61	3.14	9.2
11	0.10	7,075	0.00	0.00	1.00	5.8	0.119	0.10	35.87	3.14	9.2
12	0.10	7,075	0.00	0.00	1.00	5.2	0.100	0.10	39.13	3.14	9.2
13	0.10	7,075	0.00	0.00	1.00	5.5	0.100	0.10	42.39	3.14	9.2
14	0.10	7,075	0.00	0.00	1.00	5.9	0.100	0.10	45.65	3.14	9.2
15	0.10	7,075	0.00	0.00	1.00	6.2	0.100	0.10	48.91	3.14	9.2
16	0.10	7,075	0.00	0.00	1.00	6.5	0.100	0.10	52.17	3.14	9.2
17	0.10	7,075	0.00	0.00	1.00	7.4	0.100	0.10	55.43	3.14	9.2
18	0.10	7,075	0.00	0.00	1.00	8.3	0.100	0.10	58.70	3.14	9.2
19	0.10	7,075	0.00	0.00	1.00	11.6	0.078	0.10	61.96	3.14	9.2
20	0.10	7,075	0.00	0.00	1.00	16.8	0.050	0.10	65.22	3.14	9.2
21	0.10	7,075	0.00	0.00	1.00	17.5	0.050	0.10	68.48	3.14	9.2
22	0.10	7,075	0.00	0.00	1.00	18.3	0.050	0.10	71.74	3.14	9.2
23	0.10	7,075	0.00	0.00	1.00	19.0	0.050	0.10	75.00	3.14	9.2

Toe	26.0	0.149	0.16	75.00

2.365 kips total unreduced pile weight (g = 32.169 ft/s²)
2.365 kips total reduced pile weight (g = 32.169 ft/s²)

OTHER OPTIONS

Pile Damping (%):	1	Pile Damping Fact. (kips/ft/s):	0.329

EXTREMA TABLE at 70.0 FT; HAMMER: D 19-42

Shaft/Toe Gain/Loss Factor = 0.667/1.000

Rut = 191.2 kips Rtoe = 26.0 kips Time Inc. = 0.076 ms

Hammer DELMAG D 19-42 Efficiency 0.800

Lb Top ft	Mx.T-For. kips	Mx.C-For kips	Mx.T-Str. ksi	Mx.C-Str. ksi	Mx Vel. ft/s	Mx Dis. in	ENTHRU kip-ft
3.3	0.0	262.7	0.00	28.46	13.66	1.091	19.67
6.5	3.1	264.7	0.33	28.69	13.56	1.067	19.50
9.8	5.7	268.1	0.61	29.05	13.40	1.043	19.28
13.0	6.5	270.5	0.71	29.31	13.20	1.020	18.96
16.3	7.2	272.2	0.77	29.49	12.99	0.997	18.56
19.6	7.5	273.6	0.81	29.65	12.73	0.975	18.09
22.8	6.9	273.9	0.75	29.68	12.43	0.952	17.54
26.1	5.5	272.9	0.59	29.57	12.06	0.931	16.92
29.3	2.3	268.9	0.25	29.14	11.64	0.911	16.17
32.6	0.0	256.9	0.00	27.84	11.31	0.891	15.12
35.9	0.0	235.3	0.00	25.50	11.04	0.873	14.10
39.1	0.0	230.4	0.00	24.96	10.75	0.855	13.37
42.4	0.0	226.3	0.00	24.52	10.44	0.838	12.70
45.7	0.0	217.5	0.00	23.57	10.13	0.822	12.03
48.9	0.0	207.4	0.00	22.47	9.77	0.806	11.34
52.2	0.0	201.5	0.00	21.83	9.39	0.789	10.64
55.4	0.0	196.0	0.00	21.24	8.95	0.773	9.90
58.7	0.0	189.5	0.00	20.54	8.48	0.758	9.09
62.0	0.0	180.5	0.00	19.56	8.07	0.743	8.17
65.2	0.0	162.1	0.00	17.56	8.78	0.731	7.04
68.5	0.0	136.9	0.00	14.83	9.55	0.721	5.77
71.7	0.0	107.8	0.00	11.68	9.70	0.714	4.48
75.0	0.0	80.4	0.00	8.71	9.94	0.708	3.82

Converged Stroke (ft) 6.81 Fixed Combustion Pressure (psi) 1,600.0

(Eq) Strokes Analyzed and Last Return (ft)

10.81 6.32 6.89 6.79 6.81

Shaft/Toe Gain/Loss Factor = 1.000/1.000

Rut = 231.7 kips Rtoe = 26.0 kips Time Inc. = 0.076 ms

Hammer DELMAG D 19-42 Efficiency 0.800

Lb Top ft	Mx.T-For. kips	Mx.C-For kips	Mx.T-Str. ksi	Mx.C-Str. ksi	Mx Vel. ft/s	Mx Dis. in	ENTHRU kip-ft
3.3	0.0	294.7	0.00	31.93	14.54	1.015	20.18
6.5	4.7	300.3	0.51	32.54	14.40	0.982	19.86
9.8	8.7	305.0	0.95	33.05	14.18	0.948	19.46

13.0	11.4	307.5	1.23	33.32	13.91	0.914	18.91
16.3	12.5	310.0	1.35	33.59	13.59	0.881	18.27
19.6	12.2	311.2	1.32	33.72	13.25	0.850	17.55
22.8	9.9	310.1	1.07	33.61	12.89	0.821	16.76
26.1	5.7	306.2	0.62	33.17	12.40	0.794	15.97
29.3	0.1	300.0	0.01	32.51	11.77	0.767	15.09
32.6	0.0	284.4	0.00	30.82	11.22	0.742	13.79
35.9	0.0	255.4	0.00	27.68	10.77	0.718	12.51
39.1	0.0	245.6	0.00	26.62	10.32	0.697	11.61
42.4	0.0	237.4	0.00	25.73	9.84	0.677	10.81
45.7	0.0	231.0	0.00	25.03	9.35	0.657	10.01
48.9	0.0	221.5	0.00	24.00	8.82	0.639	9.22
52.2	0.0	212.1	0.00	22.99	8.36	0.621	8.44
55.4	0.0	198.5	0.00	21.51	7.92	0.605	7.63
58.7	0.0	181.0	0.00	19.62	7.50	0.590	6.76
62.0	0.0	158.7	0.00	17.20	7.15	0.576	5.86
65.2	0.0	141.5	0.00	15.34	7.70	0.562	4.95
68.5	0.0	122.5	0.00	13.28	8.18	0.551	4.02
71.7	0.0	101.0	0.00	10.94	8.79	0.543	3.08
75.0	0.0	74.1	0.00	8.03	9.29	0.537	2.61

Converged Stroke (ft) 7.26 Fixed Combustion Pressure (psi) 1,600.0
(Eq) Strokes Analyzed and Last Return (ft)
10.81 6.91 7.31 7.26

SUMMARY TABLE at 70.0 FT; HAMMER: D 19-42

Rut	Bl Ct	Stk Dn	Stk Up	Mx T-Str	LTop	Mx C-Str	LTop	ENTHRU	Bl Rt	ActRes
kips	b/ft	ft	ft	ksi	ft	ksi	ft	kip-ft	b/min	kips
191.2	20.0	6.81	0.00	0.81	19.6	29.68	22.8	19.7	45.1	191.2
231.7	27.9	7.26	0.00	1.35	16.3	33.72	19.6	20.2	43.6	231.7

SUMMARY OVER DEPTHS

G/L at Shaft and Toe: 0.667/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Bl Ct b/ft	Mx C-Str ksi	Mx T-Str ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	15.1	1.2	13.8	1.2	12.69	0.00	3.80	27.4	D 19-42
10.0	14.6	4.2	10.5	1.1	12.23	0.00	3.73	27.5	D 19-42
15.0	18.8	8.4	10.5	1.3	13.63	0.00	3.91	27.1	D 19-42
20.0	25.2	14.7	10.5	1.8	15.12	0.01	4.13	25.9	D 19-42
25.0	35.3	24.7	10.6	2.6	18.04	0.78	4.45	24.1	D 19-42
30.0	46.3	35.8	10.5	3.8	20.12	1.18	4.74	22.9	D 19-42
35.0	54.3	43.8	10.5	4.5	21.56	1.37	4.93	22.3	D 19-42
36.7	57.3	46.8	10.5	4.8	21.93	1.00	4.99	22.1	D 19-42
40.0	63.1	52.6	10.5	5.4	22.62	0.95	5.13	21.8	D 19-42
45.0	72.5	62.1	10.5	6.4	23.48	1.74	5.32	21.2	D 19-42
47.5	77.5	67.1	10.5	6.9	23.88	1.44	5.42	21.0	D 19-42
50.0	83.2	72.8	10.5	7.5	24.36	1.21	5.53	20.8	D 19-42
55.0	96.0	85.5	10.5	8.9	25.40	1.46	5.77	20.2	D 19-42
60.0	135.3	109.3	26.0	13.5	27.37	1.23	6.27	19.7	D 19-42
65.0	162.4	136.4	26.0	16.4	28.66	1.22	6.53	19.6	D 19-42
70.0	191.2	165.2	26.0	20.0	29.68	0.81	6.81	19.7	D 19-42

G/L at Shaft and Toe: 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Bl Ct b/ft	Mx C-Str ksi	Mx T-Str ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	15.4	1.6	13.8	1.2	12.82	0.00	3.81	27.4	D 19-42
10.0	16.1	5.7	10.5	1.2	12.87	0.00	3.80	27.4	D 19-42
15.0	22.4	12.0	10.5	1.6	14.72	0.15	4.03	26.7	D 19-42
20.0	31.2	20.7	10.5	2.3	16.71	0.64	4.31	24.8	D 19-42
25.0	44.4	33.8	10.6	3.4	19.83	1.02	4.66	23.3	D 19-42
30.0	61.0	50.5	10.5	5.2	22.47	1.24	5.09	22.0	D 19-42
35.0	73.0	62.6	10.5	6.4	23.59	1.79	5.33	21.3	D 19-42
36.7	77.5	67.0	10.5	6.9	23.97	1.58	5.42	21.1	D 19-42
40.0	86.2	75.7	10.5	7.9	24.71	1.74	5.59	20.6	D 19-42
45.0	100.4	89.9	10.5	9.5	25.94	1.54	5.84	20.2	D 19-42
47.5	107.9	97.4	10.5	10.4	26.46	1.94	5.96	20.1	D 19-42
50.0	116.4	106.0	10.5	11.5	27.23	1.90	6.09	19.9	D 19-42
55.0	135.5	125.1	10.5	13.6	28.86	1.29	6.31	19.6	D 19-42
60.0	175.8	149.8	26.0	18.5	30.80	1.44	6.75	19.7	D 19-42
65.0	202.9	176.9	26.0	22.2	32.74	1.23	7.01	20.1	D 19-42
70.0	231.7	205.7	26.0	27.9	33.72	1.35	7.26	20.2	D 19-42

DRIVEN PILE ANALYSIS FOR DOWNDRAG

SOIL PROFILE

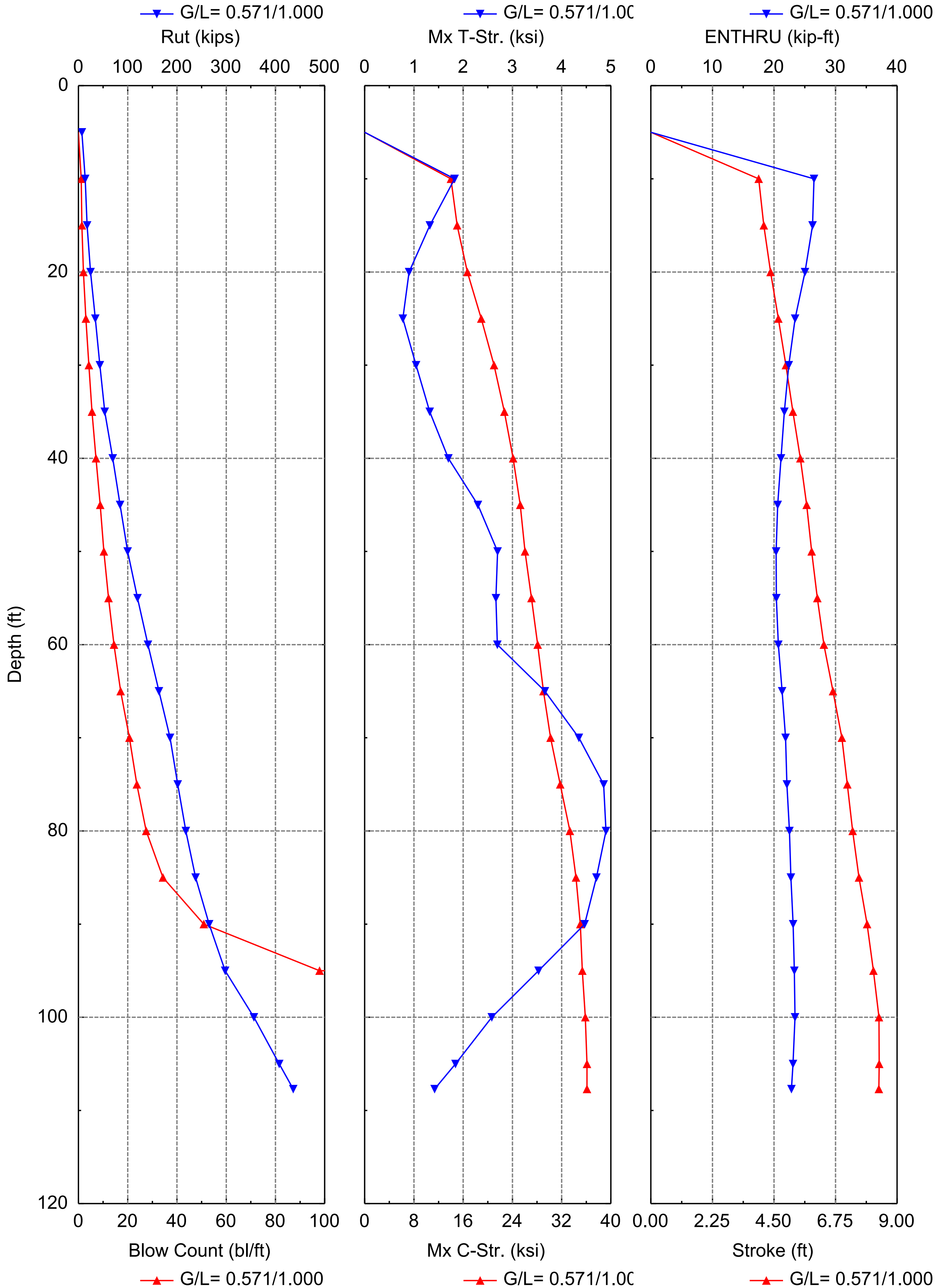
Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
16.4	Sand	125.0	0.0	28.0	0.49	13.32
16.4	Clay	120.0	3.0	0.0	0.94	27.00
18.2	Clay	120.0	3.0	0.0	0.94	27.00
18.2	Clay	120.0	1.2	0.0	1.01	11.25
23.2	Clay	120.0	1.2	0.0	1.01	11.25
23.2	Clay	110.0	1.2	0.0	1.07	10.80
36.7	Clay	110.0	1.2	0.0	1.07	10.80
36.7	Sand	120.0	0.0	30.0	1.21	13.32
40.7	Sand	120.0	0.0	30.0	1.32	13.32
40.7	Sand	125.0	0.0	30.0	1.32	13.32
49.5	Sand	125.0	0.0	30.0	1.48	13.32
49.5	Sand	125.0	0.0	30.0	1.48	13.32
69.5	Sand	125.0	0.0	30.0	1.83	13.32
69.5	Sand	120.0	0.0	27.0	1.45	13.32
79.5	Sand	120.0	0.0	27.0	1.58	13.32
79.5	Sand	125.0	0.0	29.0	1.85	13.32
89.5	Sand	125.0	0.0	29.0	2.01	13.32
89.5	Sand	128.0	0.0	31.0	2.42	20.71
99.5	Sand	128.0	0.0	31.0	2.62	20.71
99.5	Sand	128.0	0.0	33.0	3.19	50.11
107.7	Sand	128.0	0.0	33.0	3.40	50.11

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	0.8	6.1	0.0	0.000	0.000	0.00	0.0	D 19-42
10.0	13.6	3.1	10.5	1.1	14.006	1.826	3.94	26.5	D 19-42
15.0	17.5	7.0	10.5	1.4	15.025	1.322	4.13	26.3	D 19-42
20.0	24.5	15.7	8.8	2.0	16.684	0.902	4.37	25.0	D 19-42
25.0	34.2	25.7	8.5	3.0	18.930	0.775	4.66	23.4	D 19-42
30.0	43.5	35.0	8.5	4.2	21.017	1.044	4.93	22.4	D 19-42
35.0	53.4	44.9	8.5	5.5	22.684	1.321	5.19	21.7	D 19-42
40.0	69.7	59.2	10.5	7.1	24.116	1.700	5.46	21.1	D 19-42
45.0	84.4	73.9	10.5	8.8	25.271	2.299	5.69	20.6	D 19-42
50.0	99.9	89.4	10.5	10.3	26.051	2.699	5.88	20.3	D 19-42
55.0	119.9	109.4	10.5	12.2	27.092	2.666	6.08	20.4	D 19-42
60.0	141.1	130.6	10.5	14.4	28.104	2.695	6.32	20.7	D 19-42
65.0	163.4	152.9	10.5	17.1	29.039	3.660	6.66	21.3	D 19-42
70.0	185.9	175.5	10.5	20.7	30.201	4.350	6.98	21.9	D 19-42
75.0	201.5	191.0	10.5	23.7	31.768	4.853	7.18	22.1	D 19-42
80.0	218.0	207.6	10.5	27.5	33.343	4.900	7.38	22.5	D 19-42
85.0	237.9	227.4	10.5	34.3	34.318	4.705	7.61	22.8	D 19-42
90.0	265.4	249.1	16.3	50.9	35.038	4.466	7.90	23.1	D 19-42
95.0	297.8	281.6	16.3	97.9	35.353	3.532	8.13	23.3	D 19-42
100.0	356.3	316.9	39.4	9999.0	35.844	2.581	8.34	23.4	D 19-42
105.0	407.6	368.3	39.4	9999.0	36.115	1.843	8.34	23.1	D 19-42
107.7	436.2	396.8	39.4	9999.0	36.120	1.420	8.33	22.8	D 19-42

Refusal occurred; no driving time output possible.

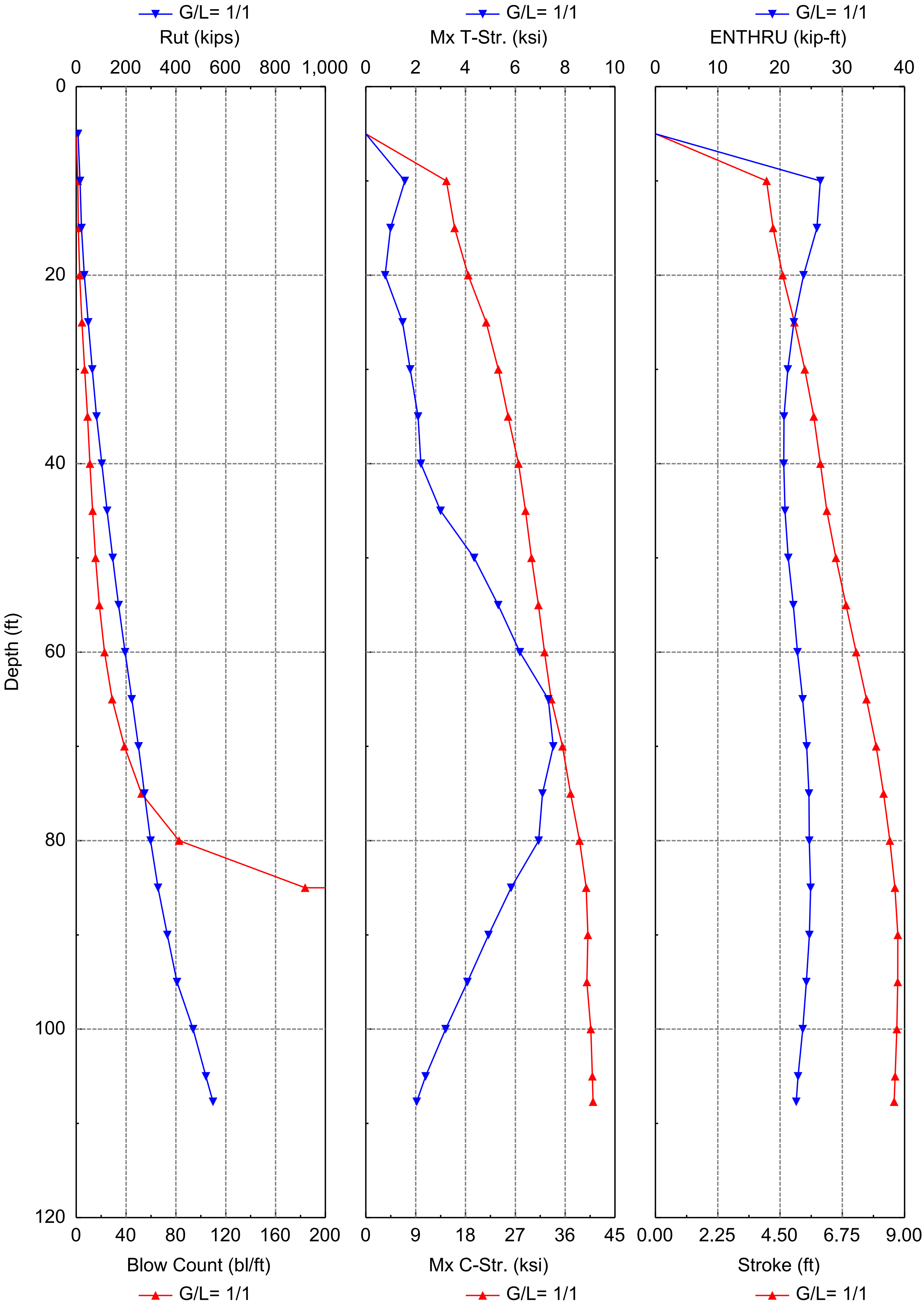


G/L= 0.571/1.000
Rut (kips)
0 100 200 300 400 500
G/L= 0.571/1.00
Mx T-Str. (ksi)
0 1 2 3 4 5
G/L= 0.571/1.000
ENTHRU (kip-ft)
0 10 20 30 40
Depth (ft)
0 20 40 60 80 100 120
0 20 40 60 80 100
Blow Count (bl/ft)
G/L= 0.571/1.000
0 8 16 24 32 40
Mx C-Str. (ksi)
G/L= 0.571/1.00
0.00 2.25 4.50 6.75 9.00
Stroke (ft)
G/L= 0.571/1.000

Driveability Analysis Summary
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	7.2	1.2	6.1	0.0	0.000	0.000	0.00	0.0	D 19-42
10.0	15.2	4.7	10.5	1.2	14.546	1.561	4.01	26.5	D 19-42
15.0	21.0	10.6	10.5	1.7	16.023	0.990	4.25	25.9	D 19-42
20.0	32.3	23.5	8.8	2.8	18.486	0.773	4.59	23.8	D 19-42
25.0	47.9	39.4	8.5	4.6	21.727	1.475	5.02	22.2	D 19-42
30.0	64.1	55.7	8.5	6.7	23.913	1.780	5.39	21.3	D 19-42
35.0	81.4	72.9	8.5	9.1	25.698	2.094	5.72	20.6	D 19-42
40.0	102.5	92.1	10.5	11.0	27.574	2.209	5.96	20.6	D 19-42
45.0	123.8	113.4	10.5	13.1	28.834	2.997	6.19	20.8	D 19-42
50.0	146.5	136.0	10.5	15.5	29.902	4.347	6.52	21.3	D 19-42
55.0	170.5	160.1	10.5	18.5	31.165	5.311	6.88	22.1	D 19-42
60.0	195.9	185.4	10.5	22.7	32.268	6.181	7.25	22.8	D 19-42
65.0	222.7	212.2	10.5	28.8	33.477	7.324	7.62	23.6	D 19-42
70.0	250.2	239.7	10.5	38.7	35.518	7.520	7.97	24.3	D 19-42
75.0	273.6	263.1	10.5	52.4	36.974	7.088	8.24	24.6	D 19-42
80.0	298.3	287.9	10.5	82.5	38.589	6.935	8.47	24.7	D 19-42
85.0	328.1	317.6	10.5	183.7	39.801	5.829	8.65	24.9	D 19-42
90.0	365.6	349.3	16.3	9999.0	40.101	4.922	8.75	24.7	D 19-42
95.0	404.5	388.2	16.3	9999.0	39.910	4.077	8.75	24.2	D 19-42
100.0	469.0	429.7	39.4	9999.0	40.635	3.200	8.72	23.6	D 19-42
105.0	520.3	481.0	39.4	9999.0	40.906	2.397	8.66	22.9	D 19-42
107.7	548.9	509.5	39.4	9999.0	41.030	2.041	8.62	22.6	D 19-42

Refusal occurred; no driving time output possible.


G/L= 1/1
Rut (kips)
0 200 400 600 800 1,000
G/L= 1/1
Mx T-Str. (ksi)
0 2 4 6 8 10
G/L= 1/1
ENTHRU (kip-ft)
0 10 20 30 40
Depth (ft)
0 20 40 60 80 100 120
0 40 80 120 160 200
Blow Count (bl/ft)
G/L= 1/1
0 9 18 27 36 45
Mx C-Str. (ksi)
G/L= 1/1
0.00 2.25 4.50 6.75 9.00
Stroke (ft)
G/L= 1/1

GRLWEAP: Wave Equation Analysis of Pile Foundations

Pedestrian Bridge HAM-75-0123E + RA12IN 1/6/2025
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.

HAMMER DATA

Hammer Model:	D 19-42	Made By:	DELMAG
Hammer ID:	41	Hammer Type:	OED
Hammer Database Type:	PDI		
Hammer Database Name:			PDIHammer.gwh

Hammer and Drive System Segment Data

Segment	Weight	Stiffness	COR	C-Slack	Damping
-	kips	kips/in	-	in	kips/ft/s
1	0.800	140,084.4	1.000	0.000	
2	0.800	140,084.4	1.000	0.000	
3	0.800	140,084.4	1.000	0.000	
4	0.800	140,084.4	1.000	0.000	
5	0.800	70,754.7	0.900	0.120	
Imp Block	0.753	109,976.0	0.800	0.120	
Helmet	2.500				5.3

Ram Weight: (kips)	4.00	Ram Length: (ft)	10.76
Ram Area: (in²)	124.69		
Maximum (Eq) Stroke: (ft)	10.81	Actual (Eq) Stroke: (ft)	10.81
Efficiency:	0.800	Rated Energy: (kip-ft)	43.24
Maximum Pressure: (psi)	1,600.00	Actual Pressure: (psi)	1,600.00
Combustion Delay: (ms)	2.00	Ignition Duration: (ms)	2.00
Expansion Exponent:	1.25		

Hammer Cushion		Pile Cushion	
Cross Sect. Area: (in²)	415.00	Cross Sect. Area: (in²)	0.00
Elastic Modulus: (ksi)	530.0	Elastic Modulus: (ksi)	0.0
Thickness: (in)	2.00	Thickness: (in)	0.00
Coeff. of Restitution:	0.800	Coeff. of Restitution:	0.500
RoundOut: (in)	0.120	RoundOut: (in)	0.120
Stiffness: (kips/in)	109,976.0	Stiffness: (kips/in)	0.0
Helmet Weight: (kips)	2.500		

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	110.000	Pile Penetration: (ft)	107.700
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Table of Depths Analyzed with Driving System Modifiers

Depth	Temp Length	Wait Time	Hammer
ft	ft	Hr	-
5.00	110.0	0.0	DELMAG D 19-42
10.00	110.0	0.0	DELMAG D 19-42
15.00	110.0	0.0	DELMAG D 19-42
20.00	110.0	0.0	DELMAG D 19-42
25.00	110.0	0.0	DELMAG D 19-42
30.00	110.0	0.0	DELMAG D 19-42
35.00	110.0	0.0	DELMAG D 19-42
40.00	110.0	0.0	DELMAG D 19-42
45.00	110.0	0.0	DELMAG D 19-42
50.00	110.0	0.0	DELMAG D 19-42
55.00	110.0	0.0	DELMAG D 19-42
60.00	110.0	0.0	DELMAG D 19-42
65.00	110.0	0.0	DELMAG D 19-42
70.00	110.0	0.0	DELMAG D 19-42
75.00	110.0	0.0	DELMAG D 19-42
80.00	110.0	0.0	DELMAG D 19-42
85.00	110.0	0.0	DELMAG D 19-42
90.00	110.0	0.0	DELMAG D 19-42
95.00	110.0	0.0	DELMAG D 19-42
100.00	110.0	0.0	DELMAG D 19-42
105.00	110.0	0.0	DELMAG D 19-42
107.70	110.0	0.0	DELMAG D 19-42

Other Information for DELMAG D 19-42

Depth	Stroke	Diesel Pressure	Efficiency	P.C. Stiff. Fact.	P.C. COR
ft	ft	%	-	-	-
5.00	10.8	100.0	0.80	1.0	0.50
10.00	10.8	100.0	0.80	1.0	0.50
15.00	10.8	100.0	0.80	1.0	0.50
20.00	10.8	100.0	0.80	1.0	0.50
25.00	10.8	100.0	0.80	1.0	0.50
30.00	10.8	100.0	0.80	1.0	0.50
35.00	10.8	100.0	0.80	1.0	0.50
40.00	10.8	100.0	0.80	1.0	0.50
45.00	10.8	100.0	0.80	1.0	0.50
50.00	10.8	100.0	0.80	1.0	0.50
55.00	10.8	100.0	0.80	1.0	0.50
60.00	10.8	100.0	0.80	1.0	0.50
65.00	10.8	100.0	0.80	1.0	0.50

70.00	10.8	100.0	0.80	1.0	0.50
75.00	10.8	100.0	0.80	1.0	0.50
80.00	10.8	100.0	0.80	1.0	0.50
85.00	10.8	100.0	0.80	1.0	0.50
90.00	10.8	100.0	0.80	1.0	0.50
95.00	10.8	100.0	0.80	1.0	0.50
100.00	10.8	100.0	0.80	1.0	0.50
105.00	10.8	100.0	0.80	1.0	0.50
107.70	10.8	100.0	0.80	1.0	0.50

PILE, SOIL, ANALYSIS OPTIONS

Analysis type:	Driveability Analysis	Soil Damping Option:	Smith
Max No Analysis Iterations:	0	Time Increment/Critical:	160
Residual Stress Analysis:	0	Analysis Time-Input(ms):	0
Output Level:	Normal	Gravitational Acceleration (ft/s²):	32.169
Hammer Gravity (ft/s²):	32.169	Pile Gravity (ft/s²):	32.169

DRIVEABILITY ANALYSIS

Analysis Depth (ft)	107.70	Standard Soil Setup	
Hammer Name	DELMAG D 19-42	Hammer ID	41
Diesel Pressure: (psi)	230.40	Stroke (ft)	10.81
Efficiency	0.80		
Shaft Gain/Loss Factor	0.571	Toe Gain/Loss Factor	1.000
Shaft Gain/Loss Factor	1.000	Toe Gain/Loss Factor	1.000

SOIL RESISTANCE PARAMETERS

Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Setup F.	Limit D.	Setup T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.00	0.0	0.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
1.82	0.1	2.8	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
3.64	0.1	5.6	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
5.47	0.2	8.4	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
7.29	0.2	11.2	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
9.11	0.3	13.3	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
10.93	0.3	13.3	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
12.76	0.4	13.3	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
14.58	0.4	13.3	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
16.40	0.5	13.3	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
16.40	0.9	27.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
18.20	0.9	27.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
18.20	1.0	11.2	0.10	0.135	0.150	0.1	1.5	6.56	168.0	113.10
23.20	1.0	11.2	0.10	0.135	0.150	0.1	1.5	6.56	168.0	113.10
23.20	1.1	10.8	0.10	0.136	0.200	0.1	1.8	6.56	168.0	113.10
36.70	1.1	10.8	0.10	0.136	0.200	0.1	1.8	6.56	168.0	113.10
36.70	1.2	13.3	0.10	0.170	0.050	0.1	1.2	6.56	24.0	113.10
38.70	1.3	13.3	0.10	0.170	0.050	0.1	1.2	6.56	24.0	113.10
40.70	1.3	13.3	0.10	0.170	0.050	0.1	1.2	6.56	24.0	113.10
40.70	1.3	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
42.46	1.4	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
47.74	1.4	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
49.50	1.5	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
49.50	1.5	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
52.83	1.5	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
54.50	1.6	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
57.83	1.6	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
59.50	1.7	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
64.50	1.7	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
66.17	1.8	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
69.50	1.8	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10

69.50	1.4	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
71.17	1.5	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
76.17	1.5	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
77.83	1.6	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
79.50	1.6	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
79.50	1.8	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
81.17	1.9	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
84.50	1.9	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
86.17	2.0	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
89.50	2.0	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
89.50	2.4	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
91.17	2.5	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
94.50	2.5	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
96.17	2.6	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
99.50	2.6	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
99.50	3.2	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
101.55	3.2	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
103.60	3.3	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
105.65	3.3	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
107.70	3.4	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10

PILE PROFILE

Lb Top	X-Area	E-Mod	Spec. Wt	Perim.	C-Index	Wave Sp	Impedance
ft	in²	ksi	lb/ft³	ft	-	ft/s	kips/ft/s
0.00	9.2	30,000	492.00	3.142	0	16,806.4	16.5
110.00	9.2	30,000	492.00	3.142	0	16,806.4	16.5

PILE AND SOIL MODEL Total Capacity Rut (kips): 436.155

Seg.	Weight	Stiffn.	C-Slk	T-Slk	COR	Ru	Js/Jt	Qs/Qt	LbTop	Perim.	X-Area
-	kips	kips/in	in	in	-	kips	s/ft	in	ft	ft	in²
1	0.10	7,131	0.12	0.00	0.85	0.0	0.150	0.10	3.24	3.14	9.2
2	0.10	7,131	0.00	0.00	1.00	0.5	0.150	0.10	6.47	3.14	9.2
3	0.10	7,131	0.00	0.00	1.00	1.2	0.150	0.10	9.71	3.14	9.2
4	0.10	7,131	0.00	0.00	1.00	1.8	0.150	0.10	12.94	3.14	9.2
5	0.10	7,131	0.00	0.00	1.00	2.5	0.150	0.10	16.18	3.14	9.2
6	0.10	7,131	0.00	0.00	1.00	3.8	0.150	0.10	19.41	3.14	9.2
7	0.10	7,131	0.00	0.00	1.00	6.7	0.150	0.10	22.65	3.14	9.2
8	0.10	7,131	0.00	0.00	1.00	6.8	0.156	0.10	25.88	3.14	9.2
9	0.10	7,131	0.00	0.00	1.00	6.2	0.200	0.10	29.12	3.14	9.2
12	0.10	7,131	0.00	0.00	1.00	6.2	0.200	0.10	38.82	3.14	9.2
13	0.10	7,131	0.00	0.00	1.00	10.4	0.057	0.10	42.06	3.14	9.2
14	0.10	7,131	0.00	0.00	1.00	9.7	0.086	0.10	45.29	3.14	9.2

15	0.10	7,131	0.00	0.00	1.00	9.4	0.100	0.10	48.53	3.14	9.2
16	0.10	7,131	0.00	0.00	1.00	9.8	0.100	0.10	51.76	3.14	9.2
17	0.10	7,131	0.00	0.00	1.00	12.7	0.100	0.10	55.00	3.14	9.2
18	0.10	7,131	0.00	0.00	1.00	13.2	0.100	0.10	58.24	3.14	9.2
19	0.10	7,131	0.00	0.00	1.00	13.7	0.100	0.10	61.47	3.14	9.2
20	0.10	7,131	0.00	0.00	1.00	14.2	0.100	0.10	64.71	3.14	9.2
21	0.10	7,131	0.00	0.00	1.00	14.7	0.100	0.10	67.94	3.14	9.2
22	0.10	7,131	0.00	0.00	1.00	15.1	0.100	0.10	71.18	3.14	9.2
23	0.10	7,131	0.00	0.00	1.00	11.0	0.100	0.10	74.41	3.14	9.2
24	0.10	7,131	0.00	0.00	1.00	10.2	0.100	0.10	77.65	3.14	9.2
25	0.10	7,131	0.00	0.00	1.00	10.5	0.100	0.10	80.88	3.14	9.2
26	0.10	7,131	0.00	0.00	1.00	12.1	0.100	0.10	84.12	3.14	9.2
27	0.10	7,131	0.00	0.00	1.00	12.9	0.100	0.10	87.35	3.14	9.2
28	0.10	7,131	0.00	0.00	1.00	13.3	0.100	0.10	90.59	3.14	9.2
29	0.10	7,131	0.00	0.00	1.00	18.0	0.100	0.10	93.82	3.14	9.2
30	0.10	7,131	0.00	0.00	1.00	21.1	0.100	0.10	97.06	3.14	9.2
31	0.10	7,131	0.00	0.00	1.00	21.7	0.100	0.10	100.29	3.14	9.2
32	0.10	7,131	0.00	0.00	1.00	27.7	0.071	0.10	103.53	3.14	9.2
33	0.10	7,131	0.00	0.00	1.00	33.3	0.050	0.10	106.76	3.14	9.2
34	0.10	7,131	0.00	0.00	1.00	34.1	0.050	0.10	110.00	3.14	9.2
Toe						39.4	0.149	0.14	110.00		

3.468 kips total unreduced pile weight (g = 32.169 ft/s²)
3.468 kips total reduced pile weight (g = 32.169 ft/s²)

OTHER OPTIONS

Pile Damping (%):	1	Pile Damping Fact. (kips/ft/s):	0.329

EXTREMA TABLE at 107.7 FT; HAMMER: D 19-42

Shaft/Toe Gain/Loss Factor = 0.571/1.000

Rut = 436.2 kips | Rtoe = 39.4 kips | Time Inc. = 0.076 ms

Hammer DELMAG D 19-42 Efficiency 0.800

Lb Top ft	Mx.T-For. kips	Mx.C-For kips	Mx.T-Str. ksi	Mx.C-Str. ksi	Mx Vel. ft/s	Mx Dis. in	ENTHRU kip-ft
3.2	0.0	317.0	0.00	34.35	16.20	1.049	22.84
6.5	5.3	321.8	0.57	34.87	16.01	1.008	22.31
9.7	9.6	326.0	1.04	35.32	15.74	0.967	21.67
12.9	12.4	329.2	1.34	35.67	15.40	0.926	20.90
16.2	13.1	331.6	1.42	35.93	14.94	0.884	20.03
19.4	12.5	333.3	1.35	36.12	14.38	0.841	19.02
22.6	10.5	332.5	1.13	36.04	13.84	0.799	17.74
25.9	5.0	325.8	0.54	35.30	13.29	0.757	16.30
29.1	0.0	318.9	0.00	34.55	12.73	0.715	14.90
32.4	0.0	311.7	0.00	33.78	12.18	0.675	13.58
35.6	0.0	304.5	0.00	32.99	11.66	0.635	12.35
38.8	0.0	297.3	0.00	32.21	11.17	0.596	11.19
42.1	0.0	293.1	0.00	31.76	10.67	0.556	10.10
45.3	0.0	285.3	0.00	30.92	10.15	0.518	9.09
48.5	0.0	279.5	0.00	30.29	9.57	0.481	8.13
51.8	0.0	271.7	0.00	29.44	8.99	0.444	7.22
55.0	0.0	263.6	0.00	28.57	8.47	0.407	6.30
58.2	0.0	259.0	0.00	28.07	7.98	0.371	5.37
61.5	0.0	252.3	0.00	27.34	7.53	0.336	4.51
64.7	0.0	240.4	0.00	26.05	7.12	0.303	3.76
67.9	0.0	224.3	0.00	24.31	6.73	0.273	3.10
71.2	0.0	207.0	0.00	22.43	6.39	0.246	2.51
74.4	0.0	197.9	0.00	21.44	6.14	0.222	2.08
77.6	0.0	191.7	0.00	20.77	5.90	0.199	1.75
80.9	0.0	180.9	0.00	19.61	5.66	0.177	1.46
84.1	0.0	167.2	0.00	18.11	5.43	0.156	1.19
87.4	0.0	152.2	0.00	16.50	5.17	0.136	0.95
90.6	0.0	139.5	0.00	15.11	4.91	0.117	0.74
93.8	0.0	127.9	0.00	13.86	4.62	0.101	0.57
97.1	0.0	109.7	0.00	11.89	4.33	0.087	0.43
100.3	0.0	91.8	0.00	9.95	4.14	0.077	0.32
103.5	0.0	74.3	0.00	8.05	4.23	0.072	0.25
106.8	0.0	57.0	0.00	6.17	4.74	0.068	0.18
110.0	0.0	35.2	0.00	3.81	5.06	0.066	0.14

Converged Stroke (ft) 8.33 Fixed Combustion Pressure (psi) 1,600.0

(Eq) Strokes Analyzed and Last Return (ft)
10.81 8.41 8.33

Shaft/Toe Gain/Loss Factor = 1.000/1.000
Rut = 548.9 kips Rtoe = 39.4 kips Time Inc. = 0.076 ms
Hammer DELMAG D 19-42 Efficiency 0.800

Lb Top ft	Mx.T-For. kips	Mx.C-For kips	Mx.T-Str. ksi	Mx.C-Str. ksi	Mx Vel. ft/s	Mx Dis. in	ENTHRU kip-ft
3.2	0.0	365.1	0.00	39.57	16.59	0.958	22.60
6.5	7.9	370.1	0.86	40.10	16.33	0.912	21.90
9.7	14.5	374.3	1.57	40.56	15.95	0.865	21.05
12.9	18.3	377.3	1.98	40.88	15.48	0.818	20.05
16.2	18.8	378.6	2.04	41.03	14.86	0.772	18.94
19.4	16.5	377.9	1.79	40.95	14.10	0.725	17.68
22.6	11.4	373.5	1.24	40.48	13.30	0.679	16.12
25.9	0.9	361.1	0.10	39.13	12.39	0.634	14.40
29.1	0.0	348.1	0.00	37.72	11.46	0.590	12.69
32.4	0.0	332.7	0.00	36.06	10.57	0.547	11.04
35.6	0.0	318.5	0.00	34.52	9.77	0.505	9.55
38.8	0.0	304.8	0.00	33.02	9.12	0.464	8.20
42.1	0.0	292.8	0.00	31.73	8.53	0.425	7.09
45.3	0.0	282.0	0.00	30.56	8.07	0.388	6.16
48.5	0.0	270.6	0.00	29.33	7.63	0.352	5.27
51.8	0.0	258.0	0.00	27.96	7.21	0.318	4.44
55.0	0.0	244.9	0.00	26.53	6.81	0.285	3.68
58.2	0.0	234.4	0.00	25.40	6.42	0.252	2.99
61.5	0.0	225.0	0.00	24.38	6.07	0.222	2.39
64.7	0.0	210.2	0.00	22.77	5.72	0.194	1.90
67.9	0.0	191.8	0.00	20.78	5.39	0.169	1.47
71.2	0.0	174.6	0.00	18.92	5.11	0.148	1.14
74.4	0.0	163.2	0.00	17.68	4.85	0.130	0.90
77.6	0.0	151.0	0.00	16.37	4.61	0.114	0.71
80.9	0.0	134.2	0.00	14.54	4.38	0.100	0.57
84.1	0.0	116.2	0.00	12.59	4.13	0.086	0.44
87.4	0.0	100.2	0.00	10.86	3.90	0.075	0.34
90.6	0.0	92.1	0.00	9.98	3.67	0.065	0.27
93.8	0.0	82.4	0.00	8.93	3.43	0.057	0.21
97.1	0.0	68.5	0.00	7.43	3.21	0.050	0.16
100.3	0.0	59.3	0.00	6.43	3.05	0.046	0.14
103.5	4.3	52.7	0.46	5.71	3.10	0.046	0.11
106.8	7.0	42.1	0.76	4.56	3.55	0.047	0.08
110.0	0.0	25.8	0.00	2.80	3.91	0.047	0.06

Converged Stroke (ft) 8.62 Fixed Combustion Pressure (psi) 1,600.0
(Eq) Strokes Analyzed and Last Return (ft)
10.81 8.70 8.62

SUMMARY TABLE at 107.7 FT; HAMMER: D 19-42

Rut	Bl Ct	Stk Dn	Stk Up	Mx T-Str	LTop	Mx C-Str	LTop	ENTHRU	Bl Rt	ActRes
kips	b/ft	ft	ft	ksi	ft	ksi	ft	kip-ft	b/min	kips
436.2	9,999	8.33	0.00	1.42	16.2	36.12	19.4	22.8	40.7	377.5
548.9	9,999	8.62	0.00	2.04	16.2	41.03	16.2	22.6	40.1	419.1

SUMMARY OVER DEPTHS

G/L at Shaft and Toe: 0.571/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Bl Ct b/ft	Mx C-Str ksi	Mx T-Str ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	6.8	0.8	6.1	0.0	0.00	0.00	0.00	0.0	D 19-42
10.0	13.6	3.1	10.5	1.1	14.01	1.83	3.94	26.5	D 19-42
15.0	17.5	7.0	10.5	1.4	15.02	1.32	4.13	26.3	D 19-42
20.0	24.5	15.7	8.8	2.0	16.68	0.90	4.37	25.0	D 19-42
25.0	34.2	25.7	8.5	3.0	18.93	0.77	4.66	23.4	D 19-42
30.0	43.5	35.0	8.5	4.2	21.02	1.04	4.93	22.4	D 19-42
35.0	53.4	44.9	8.5	5.5	22.68	1.32	5.19	21.7	D 19-42
40.0	69.7	59.2	10.5	7.1	24.12	1.70	5.46	21.1	D 19-42
45.0	84.4	73.9	10.5	8.8	25.27	2.30	5.69	20.6	D 19-42
50.0	99.9	89.4	10.5	10.3	26.05	2.70	5.88	20.3	D 19-42
55.0	119.9	109.4	10.5	12.2	27.09	2.67	6.08	20.4	D 19-42
60.0	141.1	130.6	10.5	14.4	28.10	2.69	6.32	20.7	D 19-42
65.0	163.4	152.9	10.5	17.1	29.04	3.66	6.66	21.3	D 19-42
70.0	185.9	175.5	10.5	20.7	30.20	4.35	6.98	21.9	D 19-42
75.0	201.5	191.0	10.5	23.7	31.77	4.85	7.18	22.1	D 19-42
80.0	218.0	207.6	10.5	27.5	33.34	4.90	7.38	22.5	D 19-42
85.0	237.9	227.4	10.5	34.3	34.32	4.71	7.61	22.8	D 19-42
90.0	265.4	249.1	16.3	50.9	35.04	4.47	7.90	23.1	D 19-42
95.0	297.8	281.6	16.3	97.9	35.35	3.53	8.13	23.3	D 19-42
100.0	356.3	316.9	39.4	9,999.0	35.84	2.58	8.34	23.4	D 19-42
105.0	407.6	368.3	39.4	9,999.0	36.11	1.84	8.34	23.1	D 19-42
107.7	436.2	396.8	39.4	9,999.0	36.12	1.42	8.33	22.8	D 19-42

G/L at Shaft and Toe: 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Bl Ct b/ft	Mx C-Str ksi	Mx T-Str ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	7.2	1.2	6.1	0.0	0.00	0.00	0.00	0.0	D 19-42
10.0	15.2	4.7	10.5	1.2	14.55	1.56	4.01	26.5	D 19-42
15.0	21.0	10.6	10.5	1.7	16.02	0.99	4.25	25.9	D 19-42
20.0	32.3	23.5	8.8	2.8	18.49	0.77	4.59	23.8	D 19-42
25.0	47.9	39.4	8.5	4.6	21.73	1.47	5.02	22.2	D 19-42
30.0	64.1	55.7	8.5	6.7	23.91	1.78	5.39	21.3	D 19-42
35.0	81.4	72.9	8.5	9.1	25.70	2.09	5.72	20.6	D 19-42
40.0	102.5	92.1	10.5	11.0	27.57	2.21	5.96	20.6	D 19-42
45.0	123.8	113.4	10.5	13.1	28.83	3.00	6.19	20.8	D 19-42
50.0	146.5	136.0	10.5	15.5	29.90	4.35	6.52	21.3	D 19-42
55.0	170.5	160.1	10.5	18.5	31.17	5.31	6.88	22.1	D 19-42
60.0	195.9	185.4	10.5	22.7	32.27	6.18	7.25	22.8	D 19-42

65.0	222.7	212.2	10.5	28.8	33.48	7.32	7.62	23.6	D 19-42
70.0	250.2	239.7	10.5	38.7	35.52	7.52	7.97	24.3	D 19-42
75.0	273.6	263.1	10.5	52.4	36.97	7.09	8.24	24.6	D 19-42
80.0	298.3	287.9	10.5	82.5	38.59	6.94	8.47	24.7	D 19-42
85.0	328.1	317.6	10.5	183.7	39.80	5.83	8.65	24.9	D 19-42
90.0	365.6	349.3	16.3	9,999.0	40.10	4.92	8.75	24.7	D 19-42
95.0	404.5	388.2	16.3	9,999.0	39.91	4.08	8.75	24.2	D 19-42
100.0	469.0	429.7	39.4	9,999.0	40.64	3.20	8.72	23.6	D 19-42
105.0	520.3	481.0	39.4	9,999.0	40.91	2.40	8.66	22.9	D 19-42
107.7	548.9	509.5	39.4	9,999.0	41.03	2.04	8.62	22.6	D 19-42

DRIVABILITY ANALYSIS

REAR ABUTMENT

SOIL PROFILE

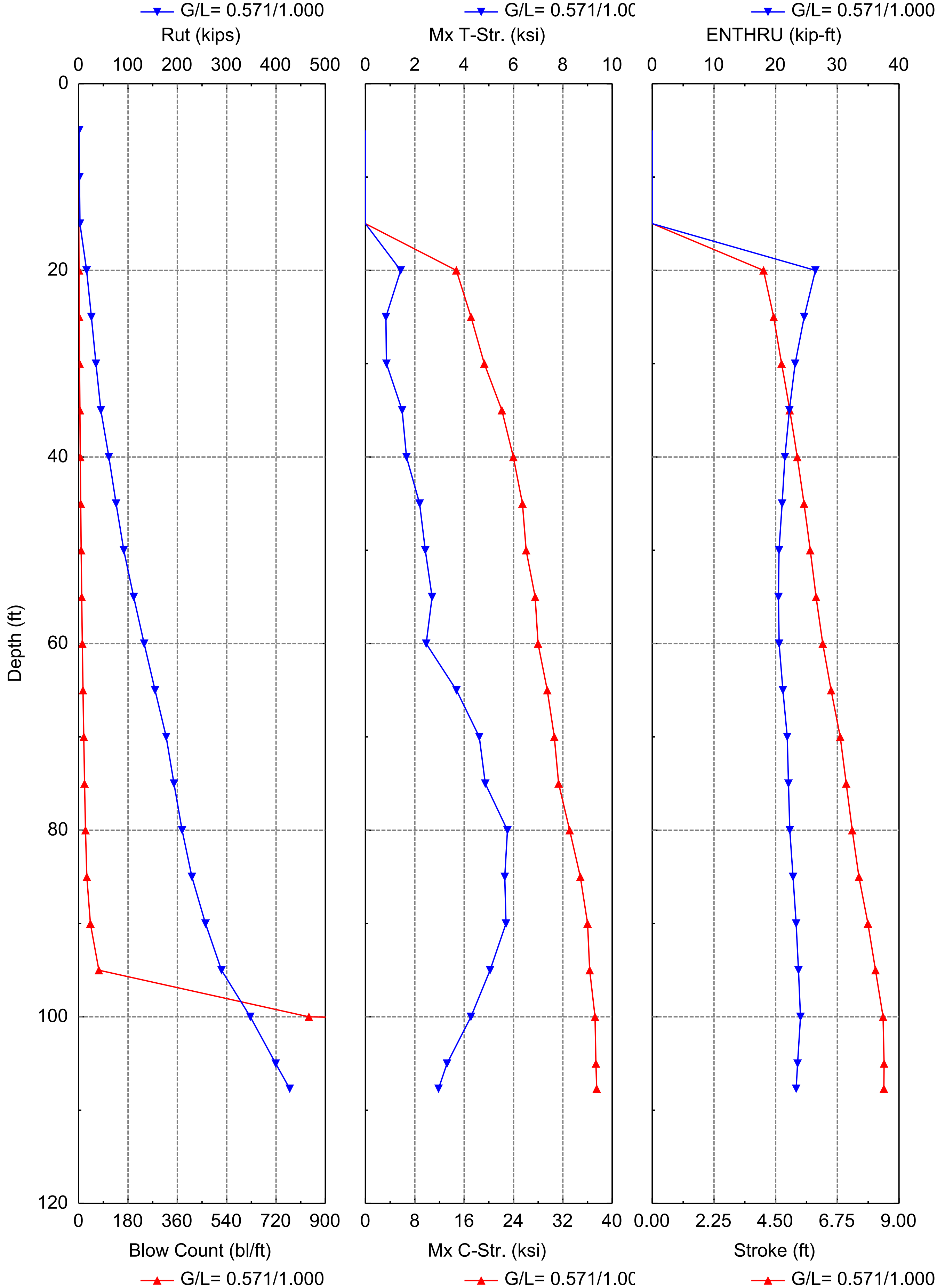
Depth	Soil Type	Spec. Wt	Su	Phi	Unit Rs	Unit Rt
ft	-	lb/ft³	ksf	°	ksf	ksf
0.0	Sand	125.0	0.0	0.0	0.00	0.00
16.4	Sand	125.0	0.0	0.0	0.00	3.64
16.4	Clay	120.0	3.0	0.0	0.94	27.00
18.2	Clay	120.0	3.0	0.0	0.94	27.00
18.2	Clay	120.0	1.2	0.0	1.01	11.25
23.2	Clay	120.0	1.2	0.0	1.01	11.25
23.2	Clay	110.0	1.2	0.0	1.07	10.80
36.7	Clay	110.0	1.2	0.0	1.07	10.80
36.7	Sand	120.0	0.0	30.0	1.21	13.32
40.7	Sand	120.0	0.0	30.0	1.32	13.32
40.7	Sand	125.0	0.0	30.0	1.32	13.32
49.5	Sand	125.0	0.0	30.0	1.48	13.32
49.5	Sand	125.0	0.0	30.0	1.48	13.32
69.5	Sand	125.0	0.0	30.0	1.83	13.32
69.5	Sand	120.0	0.0	27.0	1.45	13.32
79.5	Sand	120.0	0.0	27.0	1.58	13.32
79.5	Sand	125.0	0.0	29.0	1.85	13.32
89.5	Sand	125.0	0.0	29.0	2.01	13.32
89.5	Sand	128.0	0.0	31.0	2.42	20.71
99.5	Sand	128.0	0.0	31.0	2.62	20.71
99.5	Sand	128.0	0.0	33.0	3.19	50.11
107.7	Sand	128.0	0.0	33.0	3.40	50.11

0.0 ft @ Ele. 507.2 ft amsl (Bottom of Pile Cap)
Bottom of Foundation Prep. Ele. = 490.75 ft amsl:
16.4 ft of zero-friction overburden above driving elevation (i.e., drivability analysis)
to account for piles driven after MSE wall construction
UBV = 80.0 kips

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	0.9	0.0	0.9	0.3	0.000	0.000	10.81	0.0	D 19-42
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.81	0.0	D 19-42
15.0	2.6	0.0	2.6	0.3	0.000	0.000	10.81	0.0	D 19-42
20.0	16.1	7.2	8.8	1.3	14.728	1.429	4.06	26.4	D 19-42
25.0	25.8	17.3	8.5	2.2	17.119	0.830	4.43	24.6	D 19-42
30.0	35.1	26.6	8.5	3.3	19.261	0.851	4.71	23.2	D 19-42
35.0	45.0	36.5	8.5	4.6	22.115	1.488	5.01	22.2	D 19-42
40.0	61.3	50.8	10.5	6.1	23.974	1.662	5.29	21.5	D 19-42
45.0	76.0	65.5	10.5	7.6	25.451	2.197	5.53	21.0	D 19-42
50.0	91.5	81.0	10.5	9.3	26.043	2.425	5.76	20.5	D 19-42
55.0	111.5	101.0	10.5	11.2	27.500	2.701	5.98	20.4	D 19-42
60.0	132.6	122.2	10.5	13.3	27.969	2.463	6.22	20.6	D 19-42
65.0	154.9	144.5	10.5	15.7	29.467	3.688	6.52	21.2	D 19-42
70.0	177.5	167.0	10.5	18.8	30.616	4.612	6.85	21.9	D 19-42
75.0	193.1	182.6	10.5	21.4	31.319	4.854	7.07	22.1	D 19-42
80.0	209.6	199.1	10.5	24.9	33.099	5.752	7.29	22.3	D 19-42
85.0	229.4	219.0	10.5	30.0	34.837	5.645	7.54	22.8	D 19-42
90.0	257.0	240.7	16.3	42.7	36.003	5.697	7.87	23.3	D 19-42
95.0	289.4	273.2	16.3	73.8	36.347	5.050	8.14	23.7	D 19-42
100.0	347.9	308.5	39.4	839.9	37.210	4.275	8.42	24.0	D 19-42
105.0	399.2	359.8	39.4	9999.0	37.358	3.306	8.45	23.6	D 19-42
107.7	427.7	388.4	39.4	9999.0	37.488	2.960	8.45	23.3	D 19-42

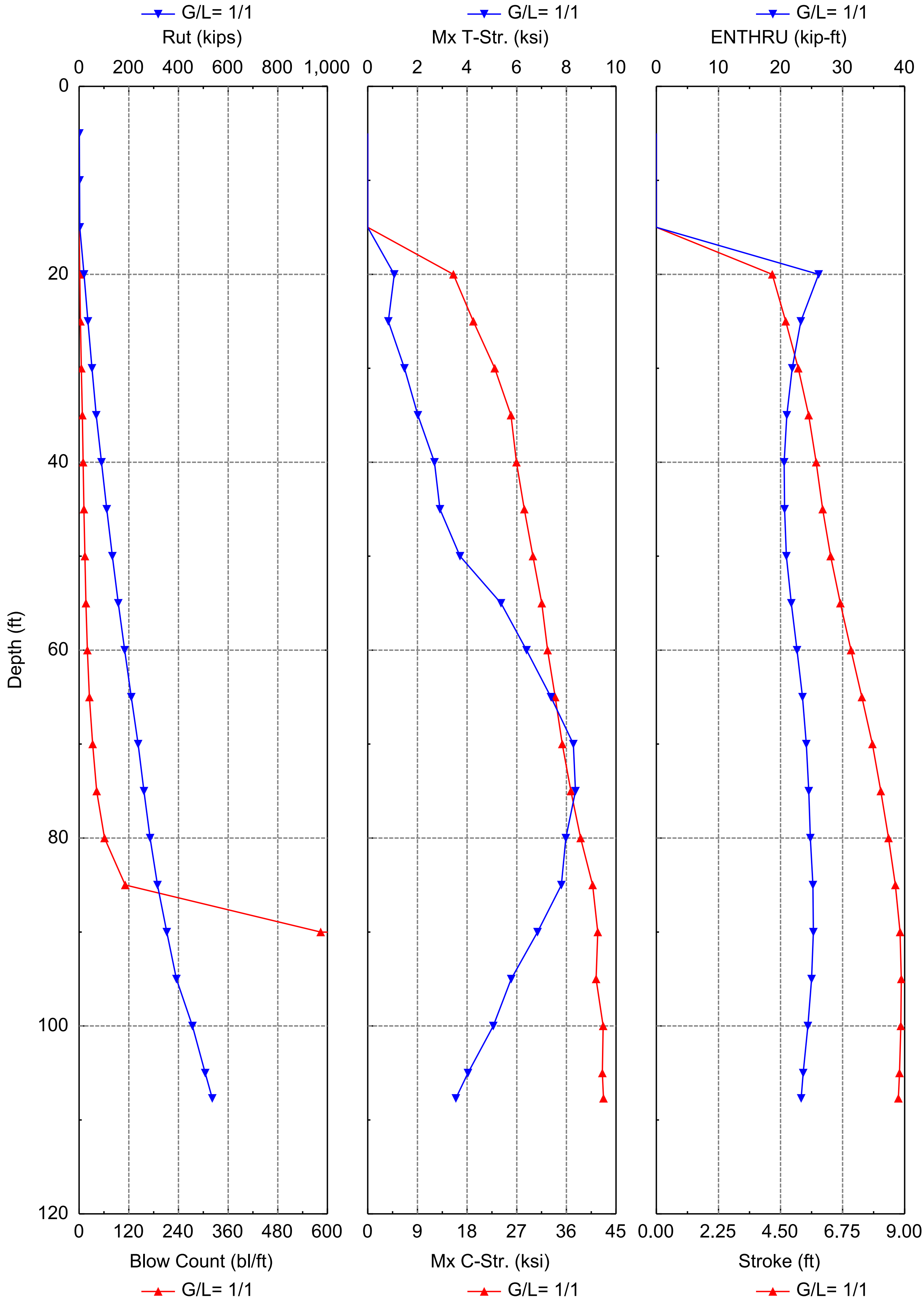
Refusal occurred; no driving time output possible.


G/L= 0.571/1.000
Rut (kips)
0 100 200 300 400 500
G/L= 0.571/1.00
Mx T-Str. (ksi)
0 2 4 6 8 10
G/L= 0.571/1.000
ENTHRU (kip-ft)
0 10 20 30 40
Depth (ft)
0 20 40 60 80 100 120
0 180 360 540 720 900
Blow Count (bl/ft)
G/L= 0.571/1.000
0 8 16 24 32 40
Mx C-Str. (ksi)
G/L= 0.571/1.00
0.00 2.25 4.50 6.75 9.00
Stroke (ft)
G/L= 0.571/1.000

Driveability Analysis Summary
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	0.9	0.0	0.9	0.3	0.000	0.000	10.81	0.0	D 19-42
10.0	1.7	0.0	1.7	0.3	0.000	0.000	10.81	0.0	D 19-42
15.0	2.6	0.0	2.6	0.3	0.000	0.000	10.81	0.0	D 19-42
20.0	19.7	10.9	8.8	1.5	15.518	1.068	4.20	26.1	D 19-42
25.0	35.2	26.8	8.5	3.2	19.127	0.830	4.69	23.3	D 19-42
30.0	51.5	43.0	8.5	5.3	23.012	1.475	5.14	21.9	D 19-42
35.0	68.8	60.3	8.5	7.6	25.953	2.020	5.52	21.0	D 19-42
40.0	89.9	79.4	10.5	9.7	26.944	2.685	5.79	20.6	D 19-42
45.0	111.2	100.7	10.5	11.6	28.373	2.907	6.03	20.7	D 19-42
50.0	133.9	123.4	10.5	13.9	29.932	3.717	6.31	20.9	D 19-42
55.0	157.9	147.4	10.5	16.5	31.538	5.365	6.67	21.7	D 19-42
60.0	183.3	172.8	10.5	19.9	32.593	6.396	7.05	22.6	D 19-42
65.0	210.0	199.6	10.5	24.8	33.963	7.378	7.45	23.5	D 19-42
70.0	237.6	227.1	10.5	32.5	35.255	8.279	7.83	24.2	D 19-42
75.0	260.9	250.5	10.5	42.5	36.805	8.367	8.13	24.5	D 19-42
80.0	285.7	275.2	10.5	61.2	38.584	7.978	8.41	24.8	D 19-42
85.0	315.5	305.0	10.5	111.3	40.758	7.795	8.66	25.2	D 19-42
90.0	352.9	336.7	16.3	583.7	41.688	6.834	8.83	25.3	D 19-42
95.0	391.9	375.6	16.3	9999.0	41.369	5.778	8.88	25.0	D 19-42
100.0	456.4	417.0	39.4	9999.0	42.646	5.055	8.86	24.4	D 19-42
105.0	507.7	468.4	39.4	9999.0	42.520	4.037	8.81	23.6	D 19-42
107.7	536.2	496.9	39.4	9999.0	42.714	3.550	8.77	23.3	D 19-42

Refusal occurred; no driving time output possible.


G/L= 1/1
Rut (kips)
0 200 400 600 800 1,000
G/L= 1/1
Mx T-Str. (ksi)
0 2 4 6 8 10
G/L= 1/1
ENTHRU (kip-ft)
0 10 20 30 40
Depth (ft)
0 20 40 60 80 100 120
0 120 240 360 480 600
Blow Count (bl/ft)
G/L= 1/1
0 9 18 27 36 45
Mx C-Str. (ksi)
G/L= 1/1
0.00 2.25 4.50 6.75 9.00
Stroke (ft)
G/L= 1/1

GRLWEAP: Wave Equation Analysis of Pile Foundations

Pedestrian Bridge HAM-75-0123E + RA12IN 12/31/2024
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.

HAMMER DATA

Hammer Model:	D 19-42	Made By:	DELMAG
Hammer ID:	41	Hammer Type:	OED
Hammer Database Type:	PDI		
Hammer Database Name:			PDIHammer.gwh

Hammer and Drive System Segment Data

Segment	Weight	Stiffness	COR	C-Slack	Damping
-	kips	kips/in	-	in	kips/ft/s
1	0.800	140,084.4	1.000	0.000	
2	0.800	140,084.4	1.000	0.000	
3	0.800	140,084.4	1.000	0.000	
4	0.800	140,084.4	1.000	0.000	
5	0.800	70,754.7	0.900	0.120	
Imp Block	0.753	109,976.0	0.800	0.120	
Helmet	2.500				5.3

Ram Weight: (kips)	4.00	Ram Length: (ft)	10.76
Ram Area: (in²)	124.69		
Maximum (Eq) Stroke: (ft)	10.81	Actual (Eq) Stroke: (ft)	10.81
Efficiency:	0.800	Rated Energy: (kip-ft)	43.24
Maximum Pressure: (psi)	1,600.00	Actual Pressure: (psi)	1,600.00
Combustion Delay: (ms)	2.00	Ignition Duration: (ms)	2.00
Expansion Exponent:	1.25		

Hammer Cushion		Pile Cushion	
Cross Sect. Area: (in²)	415.00	Cross Sect. Area: (in²)	0.00
Elastic Modulus: (ksi)	530.0	Elastic Modulus: (ksi)	0.0
Thickness: (in)	2.00	Thickness: (in)	0.00
Coeff. of Restitution:	0.800	Coeff. of Restitution:	0.500
RoundOut: (in)	0.120	RoundOut: (in)	0.120
Stiffness: (kips/in)	109,976.0	Stiffness: (kips/in)	0.0
Helmet Weight: (kips)	2.500		

PILE INPUT

Uniform Pile		Pile Type:	Closed-End Pipe
Pile Length: (ft)	110.000	Pile Penetration: (ft)	107.700
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Table of Depths Analyzed with Driving System Modifiers

Depth ft	Temp Length ft	Wait Time Hr	Hammer -
5.00	110.0	0.0	DELMAG D 19-42
10.00	110.0	0.0	DELMAG D 19-42
15.00	110.0	0.0	DELMAG D 19-42
20.00	110.0	0.0	DELMAG D 19-42
25.00	110.0	0.0	DELMAG D 19-42
30.00	110.0	0.0	DELMAG D 19-42
35.00	110.0	0.0	DELMAG D 19-42
40.00	110.0	0.0	DELMAG D 19-42
45.00	110.0	0.0	DELMAG D 19-42
50.00	110.0	0.0	DELMAG D 19-42
55.00	110.0	0.0	DELMAG D 19-42
60.00	110.0	0.0	DELMAG D 19-42
65.00	110.0	0.0	DELMAG D 19-42
70.00	110.0	0.0	DELMAG D 19-42
75.00	110.0	0.0	DELMAG D 19-42
80.00	110.0	0.0	DELMAG D 19-42
85.00	110.0	0.0	DELMAG D 19-42
90.00	110.0	0.0	DELMAG D 19-42
95.00	110.0	0.0	DELMAG D 19-42
100.00	110.0	0.0	DELMAG D 19-42
105.00	110.0	0.0	DELMAG D 19-42
107.70	110.0	0.0	DELMAG D 19-42

Other Information for DELMAG D 19-42

Depth ft	Stroke ft	Diesel Pressure %	Efficiency -	P.C. Stiff. Fact. -	P.C. COR -
5.00	10.8	100.0	0.80	1.0	0.50
10.00	10.8	100.0	0.80	1.0	0.50
15.00	10.8	100.0	0.80	1.0	0.50
20.00	10.8	100.0	0.80	1.0	0.50
25.00	10.8	100.0	0.80	1.0	0.50
30.00	10.8	100.0	0.80	1.0	0.50
35.00	10.8	100.0	0.80	1.0	0.50
40.00	10.8	100.0	0.80	1.0	0.50
45.00	10.8	100.0	0.80	1.0	0.50
50.00	10.8	100.0	0.80	1.0	0.50
55.00	10.8	100.0	0.80	1.0	0.50
60.00	10.8	100.0	0.80	1.0	0.50
65.00	10.8	100.0	0.80	1.0	0.50

70.00	10.8	100.0	0.80	1.0	0.50
75.00	10.8	100.0	0.80	1.0	0.50
80.00	10.8	100.0	0.80	1.0	0.50
85.00	10.8	100.0	0.80	1.0	0.50
90.00	10.8	100.0	0.80	1.0	0.50
95.00	10.8	100.0	0.80	1.0	0.50
100.00	10.8	100.0	0.80	1.0	0.50
105.00	10.8	100.0	0.80	1.0	0.50
107.70	10.8	100.0	0.80	1.0	0.50

PILE, SOIL, ANALYSIS OPTIONS

Analysis type:	Driveability Analysis	Soil Damping Option:	Smith
Max No Analysis Iterations:	0	Time Increment/Critical:	160
Residual Stress Analysis:	0	Analysis Time-Input(ms):	0
Output Level:	Normal	Gravitational Acceleration (ft/s²):	32.169
Hammer Gravity (ft/s²):	32.169	Pile Gravity (ft/s²):	32.169

DRIVEABILITY ANALYSIS

Analysis Depth (ft)	107.70	Standard Soil Setup	
Hammer Name	DELMAG D 19-42	Hammer ID	41
Diesel Pressure: (psi)	230.40	Stroke (ft)	10.81
Efficiency	0.80		
Shaft Gain/Loss Factor	0.571	Toe Gain/Loss Factor	1.000
Shaft Gain/Loss Factor	1.000	Toe Gain/Loss Factor	1.000

SOIL RESISTANCE PARAMETERS

Depth	Unit Rs	Unit Rt	Qs	Qt	Js	Jt	Setup F.	Limit D.	Setup T.	EB Area
ft	ksf	ksf	in	in	s/ft	s/ft	-	ft	Hours	in²
0.00	0.0	0.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
1.82	0.0	0.4	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
3.64	0.0	0.8	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
5.47	0.0	1.2	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
7.29	0.0	1.6	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
9.11	0.0	2.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
10.93	0.0	2.4	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
12.76	0.0	2.8	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
14.58	0.0	3.2	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
16.40	0.0	3.6	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
16.40	0.9	27.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
18.20	0.9	27.0	0.10	0.110	0.150	0.1	1.5	6.56	168.0	113.10
18.20	1.0	11.2	0.10	0.135	0.150	0.1	1.5	6.56	168.0	113.10
23.20	1.0	11.2	0.10	0.135	0.150	0.1	1.5	6.56	168.0	113.10
23.20	1.1	10.8	0.10	0.136	0.200	0.1	1.8	6.56	168.0	113.10
36.70	1.1	10.8	0.10	0.136	0.200	0.1	1.8	6.56	168.0	113.10
36.70	1.2	13.3	0.10	0.170	0.050	0.1	1.2	6.56	24.0	113.10
38.70	1.3	13.3	0.10	0.170	0.050	0.1	1.2	6.56	24.0	113.10
40.70	1.3	13.3	0.10	0.170	0.050	0.1	1.2	6.56	24.0	113.10
40.70	1.3	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
42.46	1.4	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
47.74	1.4	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
49.50	1.5	13.3	0.10	0.159	0.100	0.1	1.5	6.56	24.0	113.10
49.50	1.5	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
52.83	1.5	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
54.50	1.6	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
57.83	1.6	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
59.50	1.7	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
64.50	1.7	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
66.17	1.8	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10
69.50	1.8	13.3	0.10	0.157	0.100	0.1	1.2	6.56	24.0	113.10

69.50	1.4	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
71.17	1.5	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
76.17	1.5	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
77.83	1.6	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
79.50	1.6	13.3	0.10	0.200	0.100	0.1	1.5	6.56	24.0	113.10
79.50	1.8	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
81.17	1.9	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
84.50	1.9	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
86.17	2.0	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
89.50	2.0	13.3	0.10	0.173	0.100	0.1	1.5	6.56	24.0	113.10
89.50	2.4	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
91.17	2.5	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
94.50	2.5	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
96.17	2.6	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
99.50	2.6	20.7	0.10	0.152	0.100	0.1	1.2	6.56	24.0	113.10
99.50	3.2	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
101.55	3.2	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
103.60	3.3	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
105.65	3.3	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10
107.70	3.4	50.1	0.10	0.141	0.050	0.1	1.0	6.56	1.0	113.10

PILE PROFILE

Lb Top	X-Area	E-Mod	Spec. Wt	Perim.	C-Index	Wave Sp	Impedance
ft	in²	ksi	lb/ft³	ft	-	ft/s	kips/ft/s
0.00	9.2	30,000	492.00	3.142	0	16,806.4	16.5
110.00	9.2	30,000	492.00	3.142	0	16,806.4	16.5

PILE AND SOIL MODEL Total Capacity Rut (kips): 427.731

Seg.	Weight	Stiffn.	C-Slk	T-Slk	COR	Ru	Js/Jt	Qs/Qt	LbTop	Perim.	X-Area
-	kips	kips/in	in	in	-	kips	s/ft	in	ft	ft	in²
1	0.10	7,131	0.12	0.00	0.85	0.0	0.000	0.10	3.24	3.14	9.2
2	0.10	7,131	0.00	0.00	1.00	0.0	0.000	0.10	6.47	3.14	9.2
5	0.10	7,131	0.00	0.00	1.00	0.0	0.000	0.10	16.18	3.14	9.2
6	0.10	7,131	0.00	0.00	1.00	1.4	0.150	0.10	19.41	3.14	9.2
7	0.10	7,131	0.00	0.00	1.00	6.7	0.150	0.10	22.65	3.14	9.2
8	0.10	7,131	0.00	0.00	1.00	6.8	0.156	0.10	25.88	3.14	9.2
9	0.10	7,131	0.00	0.00	1.00	6.2	0.200	0.10	29.12	3.14	9.2
12	0.10	7,131	0.00	0.00	1.00	6.2	0.200	0.10	38.82	3.14	9.2
13	0.10	7,131	0.00	0.00	1.00	10.4	0.057	0.10	42.06	3.14	9.2
14	0.10	7,131	0.00	0.00	1.00	9.7	0.086	0.10	45.29	3.14	9.2
15	0.10	7,131	0.00	0.00	1.00	9.4	0.100	0.10	48.53	3.14	9.2
16	0.10	7,131	0.00	0.00	1.00	9.8	0.100	0.10	51.76	3.14	9.2

17	0.10	7,131	0.00	0.00	1.00	12.7	0.100	0.10	55.00	3.14	9.2
18	0.10	7,131	0.00	0.00	1.00	13.2	0.100	0.10	58.24	3.14	9.2
19	0.10	7,131	0.00	0.00	1.00	13.7	0.100	0.10	61.47	3.14	9.2
20	0.10	7,131	0.00	0.00	1.00	14.2	0.100	0.10	64.71	3.14	9.2
21	0.10	7,131	0.00	0.00	1.00	14.7	0.100	0.10	67.94	3.14	9.2
22	0.10	7,131	0.00	0.00	1.00	15.1	0.100	0.10	71.18	3.14	9.2
23	0.10	7,131	0.00	0.00	1.00	11.0	0.100	0.10	74.41	3.14	9.2
24	0.10	7,131	0.00	0.00	1.00	10.2	0.100	0.10	77.65	3.14	9.2
25	0.10	7,131	0.00	0.00	1.00	10.5	0.100	0.10	80.88	3.14	9.2
26	0.10	7,131	0.00	0.00	1.00	12.1	0.100	0.10	84.12	3.14	9.2
27	0.10	7,131	0.00	0.00	1.00	12.9	0.100	0.10	87.35	3.14	9.2
28	0.10	7,131	0.00	0.00	1.00	13.3	0.100	0.10	90.59	3.14	9.2
29	0.10	7,131	0.00	0.00	1.00	18.0	0.100	0.10	93.82	3.14	9.2
30	0.10	7,131	0.00	0.00	1.00	21.1	0.100	0.10	97.06	3.14	9.2
31	0.10	7,131	0.00	0.00	1.00	21.7	0.100	0.10	100.29	3.14	9.2
32	0.10	7,131	0.00	0.00	1.00	27.7	0.071	0.10	103.53	3.14	9.2
33	0.10	7,131	0.00	0.00	1.00	33.3	0.050	0.10	106.76	3.14	9.2
34	0.10	7,131	0.00	0.00	1.00	34.1	0.050	0.10	110.00	3.14	9.2
Toe						39.4	0.149	0.14	110.00		

3.468 kips total unreduced pile weight (g = 32.169 ft/s²)
3.468 kips total reduced pile weight (g = 32.169 ft/s²)

OTHER OPTIONS

Pile Damping (%):	1	Pile Damping Fact. (kips/ft/s):	0.329

EXTREMA TABLE at 107.7 FT; HAMMER: D 19-42

Shaft/Toe Gain/Loss Factor = 0.571/1.000

Rut = 427.7 kips   Rtoe = 39.4 kips   Time Inc. = 0.076 ms

Hammer   DELMAG D 19-42   Efficiency   0.800

Lb Top ft	Mx.T-For. kips	Mx.C-For kips	Mx.T-Str. ksi	Mx.C-Str. ksi	Mx Vel. ft/s	Mx Dis. in	ENTHRU kip-ft
3.2	0.0	310.9	0.00	33.69	16.33	1.097	23.31
6.5	6.3	317.9	0.68	34.44	16.26	1.057	22.84
9.7	11.8	324.5	1.28	35.16	16.15	1.016	22.35
12.9	16.6	330.1	1.80	35.77	15.95	0.974	21.84
16.2	20.7	335.1	2.25	36.31	15.58	0.931	21.31
19.4	24.7	341.7	2.68	37.03	15.02	0.888	20.65
22.6	27.3	346.0	2.96	37.49	14.44	0.844	19.47
25.9	21.2	339.1	2.30	36.74	13.88	0.800	17.93
29.1	14.5	331.7	1.57	35.94	13.32	0.757	16.43
32.4	9.2	324.3	0.99	35.14	12.78	0.715	15.01
35.6	4.9	316.6	0.54	34.31	12.24	0.674	13.68
38.8	0.6	309.9	0.07	33.58	11.76	0.633	12.42
42.1	0.0	305.4	0.00	33.10	11.28	0.591	11.23
45.3	0.0	297.5	0.00	32.24	10.75	0.551	10.11
48.5	0.0	292.7	0.00	31.71	10.16	0.511	9.05
51.8	0.0	284.5	0.00	30.83	9.52	0.473	8.05
55.0	0.0	276.3	0.00	29.94	8.89	0.434	7.04
58.2	0.0	271.6	0.00	29.43	8.35	0.396	6.02
61.5	0.0	264.3	0.00	28.64	7.86	0.359	5.07
64.7	0.0	251.8	0.00	27.29	7.41	0.325	4.24
67.9	0.0	235.5	0.00	25.52	6.98	0.295	3.54
71.2	0.0	218.6	0.00	23.69	6.63	0.267	2.92
74.4	0.0	208.0	0.00	22.54	6.36	0.241	2.43
77.6	0.0	201.4	0.00	21.83	6.10	0.217	2.05
80.9	0.0	190.6	0.00	20.65	5.86	0.193	1.71
84.1	0.0	177.4	0.00	19.22	5.60	0.171	1.40
87.4	0.0	162.5	0.00	17.61	5.33	0.149	1.13
90.6	0.0	147.2	0.00	15.95	5.07	0.129	0.89
93.8	0.0	135.1	0.00	14.64	4.76	0.111	0.69
97.1	0.0	116.2	0.00	12.59	4.46	0.096	0.51
100.3	0.0	97.6	0.00	10.58	4.26	0.082	0.37
103.5	0.0	79.5	0.00	8.61	4.36	0.076	0.27
106.8	0.0	60.0	0.00	6.50	4.87	0.071	0.19
110.0	0.0	37.7	0.00	4.08	5.17	0.068	0.15

Converged Stroke (ft)   8.45   Fixed Combustion Pressure (psi)   1,600.0

(Eq) Strokes Analyzed and Last Return (ft)

10.81	8.56	8.45	8.45

Shaft/Toe Gain/Loss Factor = 1.000/1.000

Rut = 536.2 kips Rtoe = 39.4 kips Time Inc. = 0.076 ms

Hammer DELMAG D 19-42 Efficiency 0.800

Lb Top ft	Mx.T-For. kips	Mx.C-For kips	Mx.T-Str. ksi	Mx.C-Str. ksi	Mx Vel. ft/s	Mx Dis. in	ENTHRU kip-ft
3.2	0.0	358.1	0.00	38.81	16.80	1.019	23.32
6.5	9.7	363.0	1.05	39.33	16.72	0.972	22.69
9.7	17.7	369.5	1.92	40.04	16.60	0.925	22.03
12.9	23.8	376.9	2.58	40.85	16.36	0.877	21.36
16.2	28.4	384.2	3.07	41.63	15.87	0.828	20.67
19.4	32.1	391.4	3.48	42.41	15.07	0.779	19.83
22.6	32.8	394.2	3.55	42.71	14.25	0.731	18.35
25.9	21.9	381.1	2.38	41.30	13.34	0.683	16.43
29.1	9.9	367.7	1.07	39.84	12.40	0.637	14.53
32.4	0.0	351.5	0.00	38.09	11.48	0.591	12.69
35.6	0.0	336.4	0.00	36.45	10.63	0.547	11.02
38.8	0.0	321.8	0.00	34.87	9.97	0.505	9.51
42.1	0.0	310.3	0.00	33.63	9.30	0.464	8.28
45.3	0.0	299.2	0.00	32.42	8.64	0.425	7.24
48.5	0.0	286.8	0.00	31.08	8.13	0.387	6.23
51.8	0.0	274.2	0.00	29.71	7.66	0.350	5.27
55.0	0.0	261.0	0.00	28.28	7.22	0.314	4.40
58.2	0.0	251.7	0.00	27.28	6.80	0.279	3.59
61.5	0.0	241.4	0.00	26.16	6.39	0.246	2.89
64.7	0.0	225.8	0.00	24.47	6.03	0.216	2.30
67.9	0.0	206.6	0.00	22.38	5.68	0.191	1.83
71.2	0.0	188.8	0.00	20.46	5.36	0.169	1.45
74.4	0.0	177.5	0.00	19.24	5.09	0.149	1.15
77.6	0.0	165.0	0.00	17.88	4.84	0.131	0.92
80.9	0.0	147.6	0.00	15.99	4.58	0.114	0.73
84.1	0.0	127.6	0.00	13.83	4.33	0.098	0.56
87.4	0.0	109.8	0.00	11.89	4.07	0.084	0.43
90.6	0.0	99.4	0.00	10.77	3.82	0.073	0.33
93.8	0.0	87.7	0.00	9.51	3.57	0.064	0.26
97.1	0.0	72.3	0.00	7.83	3.34	0.056	0.20
100.3	0.0	62.2	0.00	6.74	3.16	0.049	0.15
103.5	1.0	55.1	0.11	5.97	3.21	0.049	0.12
106.8	4.3	43.8	0.46	4.75	3.67	0.049	0.09
110.0	0.0	26.9	0.00	2.91	4.03	0.049	0.07

Converged Stroke (ft) 8.77 Fixed Combustion Pressure (psi) 1,600.0
(Eq) Strokes Analyzed and Last Return (ft)
10.81 8.90 8.78 8.77

SUMMARY TABLE at 107.7 FT; HAMMER: D 19-42

Rut	Bl Ct	Stk Dn	Stk Up	Mx T-Str	LTop	Mx C-Str	LTop	ENTHRU	Bl Rt	ActRes
kips	b/ft	ft	ft	ksi	ft	ksi	ft	kip-ft	b/min	kips
427.7	9,999	8.45	0.00	2.96	22.6	37.49	22.6	23.3	40.5	375.3
536.2	9,999	8.77	0.00	3.55	22.6	42.71	22.6	23.3	39.8	419.0

SUMMARY OVER DEPTHS

G/L at Shaft and Toe: 0.571/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Bl Ct b/ft	Mx C-Str ksi	Mx T-Str ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	0.9	0.0	0.9	0.0	0.00	0.00	10.81	0.0	D 19-42
10.0	1.7	0.0	1.7	0.0	0.00	0.00	10.81	0.0	D 19-42
15.0	2.6	0.0	2.6	0.0	0.00	0.00	10.81	0.0	D 19-42
20.0	16.1	7.2	8.8	1.3	14.73	1.43	4.06	26.4	D 19-42
25.0	25.8	17.3	8.5	2.2	17.12	0.83	4.43	24.6	D 19-42
30.0	35.1	26.6	8.5	3.3	19.26	0.85	4.71	23.2	D 19-42
35.0	45.0	36.5	8.5	4.6	22.12	1.49	5.01	22.2	D 19-42
40.0	61.3	50.8	10.5	6.1	23.97	1.66	5.29	21.5	D 19-42
45.0	76.0	65.5	10.5	7.6	25.45	2.20	5.53	21.0	D 19-42
50.0	91.5	81.0	10.5	9.3	26.04	2.43	5.76	20.5	D 19-42
55.0	111.5	101.0	10.5	11.2	27.50	2.70	5.98	20.4	D 19-42
60.0	132.6	122.2	10.5	13.3	27.97	2.46	6.22	20.6	D 19-42
65.0	154.9	144.5	10.5	15.7	29.47	3.69	6.52	21.2	D 19-42
70.0	177.5	167.0	10.5	18.8	30.62	4.61	6.85	21.9	D 19-42
75.0	193.1	182.6	10.5	21.4	31.32	4.85	7.07	22.1	D 19-42
80.0	209.6	199.1	10.5	24.9	33.10	5.75	7.29	22.3	D 19-42
85.0	229.4	219.0	10.5	30.0	34.84	5.65	7.54	22.8	D 19-42
90.0	257.0	240.7	16.3	42.7	36.00	5.70	7.87	23.3	D 19-42
95.0	289.4	273.2	16.3	73.8	36.35	5.05	8.14	23.7	D 19-42
100.0	347.9	308.5	39.4	839.9	37.21	4.28	8.42	24.0	D 19-42
105.0	399.2	359.8	39.4	9,999.0	37.36	3.31	8.45	23.6	D 19-42
107.7	427.7	388.4	39.4	9,999.0	37.49	2.96	8.45	23.3	D 19-42

G/L at Shaft and Toe: 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Bl Ct b/ft	Mx C-Str ksi	Mx T-Str ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	0.9	0.0	0.9	0.0	0.00	0.00	10.81	0.0	D 19-42
10.0	1.7	0.0	1.7	0.0	0.00	0.00	10.81	0.0	D 19-42
15.0	2.6	0.0	2.6	0.0	0.00	0.00	10.81	0.0	D 19-42
20.0	19.7	10.9	8.8	1.5	15.52	1.07	4.20	26.1	D 19-42
25.0	35.2	26.8	8.5	3.2	19.13	0.83	4.69	23.3	D 19-42
30.0	51.5	43.0	8.5	5.3	23.01	1.48	5.14	21.9	D 19-42
35.0	68.8	60.3	8.5	7.6	25.95	2.02	5.52	21.0	D 19-42
40.0	89.9	79.4	10.5	9.7	26.94	2.68	5.79	20.6	D 19-42
45.0	111.2	100.7	10.5	11.6	28.37	2.91	6.03	20.7	D 19-42
50.0	133.9	123.4	10.5	13.9	29.93	3.72	6.31	20.9	D 19-42
55.0	157.9	147.4	10.5	16.5	31.54	5.37	6.67	21.7	D 19-42
60.0	183.3	172.8	10.5	19.9	32.59	6.40	7.05	22.6	D 19-42

65.0	210.0	199.6	10.5	24.8	33.96	7.38	7.45	23.5	D 19-42
70.0	237.6	227.1	10.5	32.5	35.26	8.28	7.83	24.2	D 19-42
75.0	260.9	250.5	10.5	42.5	36.80	8.37	8.13	24.5	D 19-42
80.0	285.7	275.2	10.5	61.2	38.58	7.98	8.41	24.8	D 19-42
85.0	315.5	305.0	10.5	111.3	40.76	7.80	8.66	25.2	D 19-42
90.0	352.9	336.7	16.3	583.7	41.69	6.83	8.83	25.3	D 19-42
95.0	391.9	375.6	16.3	9,999.0	41.37	5.78	8.88	25.0	D 19-42
100.0	456.4	417.0	39.4	9,999.0	42.65	5.05	8.86	24.4	D 19-42
105.0	507.7	468.4	39.4	9,999.0	42.52	4.04	8.81	23.6	D 19-42
107.7	536.2	496.9	39.4	9,999.0	42.71	3.55	8.77	23.3	D 19-42

FORWARD ABUTMENT DRILLED SHAFT ANALYSIS

```
=========================================================================

                  SHAFT for Windows, Version 2017.8.12

                   Serial Number :  156012233

                VERTICALLY LOADED DRILLED SHAFT ANALYSIS
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                       All Rights Reserved

=========================================================================


Path to file locations      : C:\Users\karens\Desktop\
Name of input data file     : HAM-75-0123E_FA_5ftShaft123124.sf8d
Name of output file         : HAM-75-0123E_FA_5ftShaft123124.sf8o
Name of plot output file    : HAM-75-0123E_FA_5ftShaft123124.sf8p
Name of runtime file        : HAM-75-0123E_FA_5ftShaft123124.sf8r


-------------------------------------------------------------------------
                     Time and Date of Analysis
-------------------------------------------------------------------------

          Date:  January 02, 2025     Time:  14:54:24

Project HAM-75-01.05 - Bridge HAM-75-0123E - Forward Abutment Drilled Sh


PROPOSED DEPTH =      60.0 FT
----------------


NUMBER OF LAYERS =    8
------------------


WATER TABLE DEPTH =      23.0 FT.
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SOIL INFORMATION
---------------

LAYER NO  1----SAND

  AT THE TOP
```

```
  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                       = 0.120E+01  (*)
  INTERNAL FRICTION ANGLE, DEG.                         = 0.000E+00
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST         = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                            = 0.122E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT              = 0.100E+11
  DEPTH, FT                                             = 0.000E+00

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                       = 0.102E+01  (*)
  INTERNAL FRICTION ANGLE, DEG.                         = 0.000E+00
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST         = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                            = 0.122E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT              = 0.100E+11
  DEPTH, FT                                             = 0.125E+02

  LRFD RESISTANCE FACTOR (SIDE FRICTION)                = 0.000E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)               = 0.000E+00


LAYER NO  2----SAND

  AT THE TOP

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                       = 0.102E+01  (*)
  INTERNAL FRICTION ANGLE, DEG.                         = 0.310E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST         = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                            = 0.115E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT              = 0.100E+11
  DEPTH, FT                                             = 0.125E+02

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                       = 0.970E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                         = 0.310E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST         = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                            = 0.115E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT              = 0.100E+11
  DEPTH, FT                                             = 0.154E+02

  LRFD RESISTANCE FACTOR (SIDE FRICTION)                = 0.418E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)               = 0.100E+00


LAYER NO  3----SAND
```

```
  AT THE TOP

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                     = 0.970E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                       = 0.330E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.115E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.154E+02

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                     = 0.915E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                       = 0.330E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.115E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.188E+02

  LRFD RESISTANCE FACTOR (SIDE FRICTION)              = 0.418E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)             = 0.100E+00


LAYER NO  4----SAND

  AT THE TOP

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                     = 0.915E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                       = 0.300E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.115E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.188E+02

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                     = 0.693E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                       = 0.300E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.115E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.357E+02

  LRFD RESISTANCE FACTOR (SIDE FRICTION)              = 0.418E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)             = 0.100E+00
```

```
LAYER NO  5----CLAY

  AT THE TOP

  STRENGTH REDUCTION FACTOR-ALPHA                     = 0.550E+00  (*)
  END BEARING COEFFICIENT-Nc                          = 0.900E+01  (*)
  UNDRAINED SHEAR STRENGTH, LB/SQ FT                  = 0.150E+04
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.120E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.357E+02


  AT THE BOTTOM

  STRENGTH REDUCTION FACTOR-ALPHA                     = 0.550E+00  (*)
  END BEARING COEFFICIENT-Nc                          = 0.900E+01  (*)
  UNDRAINED SHEAR STRENGTH, LB/SQ FT                  = 0.150E+04
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.120E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.407E+02


  LRFD RESISTANCE FACTOR (SIDE FRICTION)              = 0.428E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)             = 0.200E+00


LAYER NO  6----SAND

  AT THE TOP

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                     = 0.639E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                       = 0.280E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.120E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.407E+02

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                     = 0.448E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                       = 0.280E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST       = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                          = 0.120E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT            = 0.100E+11
  DEPTH, FT                                           = 0.607E+02
```

```
  LRFD RESISTANCE FACTOR (SIDE FRICTION)             = 0.418E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)            = 0.100E+00


LAYER NO  7----SAND

  AT THE TOP

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                    = 0.448E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                      = 0.300E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST      = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                         = 0.125E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT           = 0.100E+11
  DEPTH, FT                                          = 0.607E+02

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                    = 0.388E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                      = 0.300E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST      = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                         = 0.125E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT           = 0.100E+11
  DEPTH, FT                                          = 0.679E+02

  LRFD RESISTANCE FACTOR (SIDE FRICTION)             = 0.418E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)            = 0.100E+00


LAYER NO  8----SAND

  AT THE TOP

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                    = 0.388E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                      = 0.320E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST      = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                         = 0.125E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT           = 0.100E+11
  DEPTH, FT                                          = 0.679E+02

  AT THE BOTTOM

  SIDE FRICTION PROCEDURE, BETA METHOD
  SKIN FRICTION COEFFICIENT- BETA                    = 0.275E+00  (*)
  INTERNAL FRICTION ANGLE, DEG.                      = 0.320E+02
  BLOWS PER FOOT FROM STANDARD PENETRATION TEST      = 0.000E+00
  SOIL UNIT WEIGHT, LB/CU FT                         = 0.125E+03
  MAXIMUM LOAD TRANSFER FOR SOIL, LB/SQ FT           = 0.100E+11
```

```
  DEPTH, FT                                             = 0.824E+02

  LRFD RESISTANCE FACTOR (SIDE FRICTION)                = 0.418E+00
  LRFD RESISTANCE FACTOR (TIP RESISTANCE)               = 0.100E+00


(*) ESTIMATED BY THE PROGRAM BASED ON OTHER PARAMETERS


INPUT DRILLED SHAFT INFORMATION
------------------------------

 MINIMUM SHAFT DIAMETER    =    5.000  FT.
 MAXIMUM SHAFT DIAMETER    =    5.000  FT.
 RATIO BASE/SHAFT DIAMETER =    0.000  FT.
 ANGLE OF BELL             =    0.000  DEG.
 IGNORED TOP PORTION       =   12.500  FT.
 IGNORED BOTTOM PORTION    =    0.000  FT.
 ELASTIC MODULUS, Ec       = 0.360E+07 LB/SQ IN


COMPUTATION RESULTS
-------------------


- CASE ANALYZED      :     1
  VARIATION LENGTH   :     1
  VARIATION DIAMETER :     1


DRILLED SHAFT INFORMATION

-------------------------

 DIAMETER OF STEM          =    5.000  FT.
 DIAMETER OF BASE          =    5.000  FT.
 END OF STEM TO BASE       =    0.000  FT.
 ANGLE OF BELL             =    0.000  DEG.
 IGNORED TOP PORTION       =   12.500  FT.
 IGNORED BOTTOM PORTION    =    0.000  FT.
 AREA OF ONE PERCENT STEEL =   28.278  SQ.IN.
 ELASTIC MODULUS, Ec       = 0.360E+07 LB/SQ IN
```

```
 VOLUME OF UNDERREAM       =    0.000  CU.YDS.
 SHAFT LENGTH              =   60.000  FT.
```

PREDICTED RESULTS

```
QS      = ULTIMATE SIDE RESISTANCE;
QB      = ULTIMATE BASE RESISTANCE;
WT      = WEIGHT OF DRILLED SHAFT (UPLIFT CAPACITY ONLY);
QU      = TOTAL ULTIMATE RESISTANCE;
LRFD QS = TOTAL SIDE FRICTION USING LRFD RESISTANCE FACTOR
          TO THE ULTIMATE SIDE RESISTANCE;
LRFD QB = TOTAL BASE BEARING USING LRFD RESISTANCE FACTOR
          TO THE ULTIMATE BASE RESISTANCE
LRFD QU = TOTAL CAPACITY WITH LRFD RESISTANCE FACTOR.
```

LENGTH (FT)	VOLUME (CU.YDS)	QS (TONS)	QB (TONS)	QU (TONS)	LRFD QS (TONS)	LRFD QB (TONS)	LRFD QU (TONS)
13.0	9.46	26.09	4.63	30.72	10.91	0.46	11.37
14.0	10.18	12.03	14.89	26.91	5.03	1.49	6.52
15.0	10.91	24.73	9.10	33.82	10.34	0.91	11.25
16.0	11.64	52.18	4.63	56.81	21.81	0.46	22.27
17.0	12.36	66.89	1.57	68.46	27.96	0.16	28.12
18.0	13.09	82.18	0.00	82.18	34.35	0.00	34.35
19.0	13.82	98.04	0.00	98.04	40.98	0.00	40.98
20.0	14.55	114.45	0.00	114.45	47.84	0.00	47.84
21.0	15.27	131.38	0.00	131.38	54.91	0.00	54.91
22.0	16.00	148.81	0.00	148.81	62.20	0.00	62.20
23.0	16.73	166.72	0.00	166.72	69.69	0.00	69.69
24.0	17.46	184.89	0.00	184.89	77.29	0.00	77.29
25.0	18.18	203.11	0.00	203.11	84.90	0.00	84.90
26.0	18.91	221.37	0.00	221.37	92.53	0.00	92.53
27.0	19.64	239.66	15.35	255.01	100.18	1.53	101.71
28.0	20.36	257.99	32.09	290.08	107.84	3.21	111.05
29.0	21.09	276.34	50.23	326.57	115.51	5.02	120.53
30.0	21.82	294.70	69.76	364.47	123.19	6.98	130.16
31.0	22.55	313.09	90.69	403.78	130.87	9.07	139.94
32.0	23.27	331.48	92.09	423.57	138.56	9.21	147.77
33.0	24.00	349.87	87.90	437.77	146.25	8.79	155.04
34.0	24.73	368.26	78.14	446.40	153.93	7.81	161.75
35.0	25.46	386.65	62.79	449.44	161.62	6.28	167.90
36.0	26.18	405.04	41.86	446.90	169.31	8.37	177.68
37.0	26.91	411.52	25.12	436.64	172.08	5.02	177.10
38.0	27.64	418.00	12.56	430.56	174.85	2.51	177.37
39.0	28.37	424.48	4.19	428.67	177.63	0.84	178.46
40.0	29.09	430.96	0.00	430.96	180.40	0.00	180.40
41.0	29.82	437.44	0.00	437.44	183.17	0.00	183.17
42.0	30.55	455.79	0.00	455.79	190.84	0.00	190.84
43.0	31.27	474.11	0.00	474.11	198.50	0.00	198.50

44.0	32.00	492.40	0.00	492.40	206.15	0.00	206.15
45.0	32.73	510.65	0.00	510.65	213.78	0.00	213.78
46.0	33.46	528.86	0.00	528.86	221.39	0.00	221.39
47.0	34.18	547.03	0.00	547.03	228.98	0.00	228.98
48.0	34.91	565.13	0.00	565.13	236.55	0.00	236.55
49.0	35.64	583.18	0.00	583.18	244.09	0.00	244.09
50.0	36.37	601.16	0.00	601.16	251.61	0.00	251.61
51.0	37.09	619.07	0.00	619.07	259.10	0.00	259.10
52.0	37.82	636.91	0.00	636.91	266.55	0.00	266.55
53.0	38.55	654.66	0.00	654.66	273.97	0.00	273.97
54.0	39.27	672.33	0.00	672.33	281.36	0.00	281.36
55.0	40.00	689.90	0.00	689.90	288.70	0.00	288.70
56.0	40.73	707.38	0.00	707.38	296.01	0.00	296.01
57.0	41.46	724.76	0.00	724.76	303.27	0.00	303.27
58.0	42.18	742.02	0.00	742.02	310.49	0.00	310.49
59.0	42.91	759.17	10.11	769.28	317.66	1.01	318.67
60.0	43.64	776.21	21.13	797.34	324.78	2.11	326.89

AXIAL LOAD VS SETTLEMENT CURVES

RESULT FROM TREND (AVERAGED) LINE

TOP LOAD TON	TOP MOVEMENT IN.	TIP LOAD TON	TIP MOVEMENT IN.
0.4706E-01	0.1401E-04	0.1233E-03	0.1000E-04
0.2353E+00	0.7005E-04	0.6164E-03	0.5000E-04
0.4706E+00	0.1401E-03	0.1233E-02	0.1000E-03
0.2360E+02	0.7009E-02	0.6164E-01	0.5000E-02
0.3540E+02	0.1052E-01	0.9246E-01	0.7500E-02
0.4721E+02	0.1402E-01	0.1233E+00	0.1000E-01
0.1180E+03	0.3505E-01	0.3082E+00	0.2500E-01
0.2359E+03	0.7010E-01	0.6164E+00	0.5000E-01
0.3264E+03	0.1030E+00	0.9246E+00	0.7500E-01
0.4086E+03	0.1350E+00	0.1233E+01	0.1000E+00
0.6279E+03	0.3045E+00	0.3082E+01	0.2500E+00
0.7318E+03	0.5640E+00	0.6093E+01	0.5000E+00
0.7372E+03	0.6645E+00	0.7291E+01	0.6000E+00
0.7404E+03	0.1565E+01	0.1353E+02	0.1500E+01
0.7462E+03	0.3066E+01	0.2145E+02	0.3000E+01

RESULT FROM UPPER-BOUND LINE

TOP LOAD TON	TOP MOVEMENT IN.	TIP LOAD TON	TIP MOVEMENT IN.

0.6521E-01	0.1552E-04	0.1761E-03	0.1000E-04
0.3260E+00	0.7758E-04	0.8805E-03	0.5000E-04
0.6521E+00	0.1552E-03	0.1761E-02	0.1000E-03
0.3274E+02	0.7766E-02	0.8805E-01	0.5000E-02
0.4911E+02	0.1165E-01	0.1321E+00	0.7500E-02
0.6549E+02	0.1553E-01	0.1761E+00	0.1000E-01
0.1637E+03	0.3884E-01	0.4403E+00	0.2500E-01
0.3261E+03	0.7762E-01	0.8805E+00	0.5000E-01
0.4422E+03	0.1127E+00	0.1321E+01	0.7500E-01
0.5450E+03	0.1466E+00	0.1761E+01	0.1000E+00
0.7343E+03	0.3140E+00	0.4403E+01	0.2500E+00
0.7713E+03	0.5676E+00	0.8524E+01	0.5000E+00
0.7726E+03	0.6678E+00	0.1014E+02	0.6000E+00
0.7757E+03	0.1568E+01	0.1606E+02	0.1500E+01
0.7825E+03	0.3069E+01	0.2282E+02	0.3000E+01

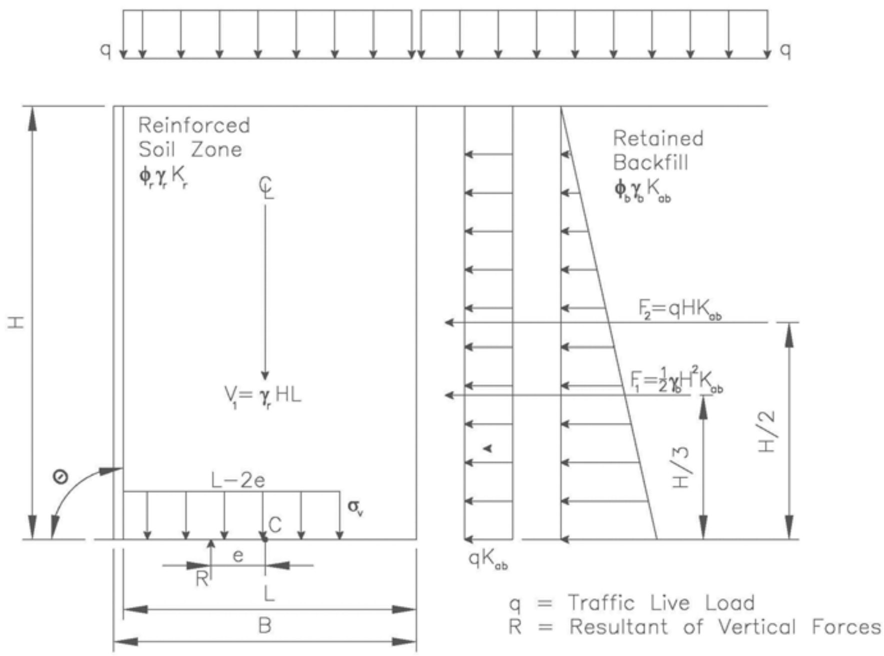
RESULT FROM LOWER-BOUND LINE

TOP LOAD TON	TOP MOVEMENT IN.	TIP LOAD TON	TIP MOVEMENT IN.
0.2985E-01	0.1256E-04	0.7044E-04	0.1000E-04
0.1492E+00	0.6281E-04	0.3522E-03	0.5000E-04
0.2985E+00	0.1256E-03	0.7044E-03	0.1000E-03
0.1495E+02	0.6283E-02	0.3522E-01	0.5000E-02
0.2243E+02	0.9424E-02	0.5283E-01	0.7500E-02
0.2991E+02	0.1257E-01	0.7044E-01	0.1000E-01
0.7477E+02	0.3142E-01	0.1761E+00	0.2500E-01
0.1495E+03	0.6283E-01	0.3522E+00	0.5000E-01
0.2141E+03	0.9343E-01	0.5283E+00	0.7500E-01
0.2746E+03	0.1236E+00	0.7044E+00	0.1000E+00
0.5183E+03	0.2949E+00	0.1761E+01	0.2500E+00
0.6922E+03	0.5604E+00	0.3663E+01	0.5000E+00
0.7016E+03	0.6613E+00	0.4438E+01	0.6000E+00
0.7051E+03	0.1562E+01	0.1099E+02	0.1500E+01
0.7099E+03	0.3063E+01	0.2008E+02	0.3000E+01

REAR ABUTMENT MSE WALL
EXTERNAL STABILITY ANALYSIS

Objective: To evaluate the external stability of MSE wall design with vertical wall face and horizontal backfill.
Method: In accordance with ODOT Bridge Design Manual, 2013 [Sect. 307] LRFD Bridge Design Specifications, 8th Ed., 2018, [Sect. 11.10.5].
Assumptions:

- **Horizontal backfill behind MSE wall on granular (drained) soils.**
- **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**
- **Load combinations and wall configuration are as shown below:**



Givens:

<u>Wall Geometry:</u>

$H_e := 18.4 \cdot ft$ — Exposed wall height

$\theta := 90 \cdot deg$ — 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)

<u>Reinforced Backfill Soil Design Parameters:</u>

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

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

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

<u>Retained Backfill Soil Design Parameters</u>:

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

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

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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 24 \cdot deg$ Effective angle of internal friction

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ Unit weight

$c'_f := 200 \cdot \frac{lbf}{ft^2}$ Cohesion

$\delta_{fd} := 0.67 \cdot \phi'_f$ $\delta_{fd} = 16.1\ deg$ Friction angle between embedment soils and MSE wall fill specified in **LRFD BDS C3.11.5.3 (degrees)**

Undrained Conditions (Total Stress):

$\phi_f := 0 \cdot deg$ Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 120\ \frac{lbf}{ft^3}$ Unit weight

$c_f := 1750 \cdot \frac{lbf}{ft^2}$ Cohesion (Use Su if Angle of internal friction = 0 deg)

Foundation Surcharge Soil Parameters:

$\gamma_q := 125 \cdot \frac{lbf}{ft^3}$ 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:

$d_{frost} := 3\ ft$ $d_{user} := 5.3\ ft$ Local Frost Depth

$Slope_{fw} := 0\ deg$

Inclination of ground slope in front of wall :

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

$d_{est} := \max\left(d_{frost}, 3\ ft, d_{user}\right)$ $d_{est} = 5.3\ ft$

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 23.7\ ft$

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

$d_{eSlope} = 1.2\ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

$d_e := \max\left(d_{est}, d_{eSlope}\right)$ $d_e = 5.3\ ft$ Minimum Required Embedment Depth used in analysis.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 23.7\ ft$ Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 16.83 \cdot ft$ User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 16.8\ ft$ Length of Reinforcement

Live Load Surcharge Parameters:

$SUR := 250 \cdot \frac{lbf}{ft^2}$

Live load surcharge (per **LRFD BDS [3.11.6.4]** & **BDM [307.1.1]**)
Note: If vehicular loading is within 1 ft of the backface of the wall and with a design height, H, less than 20 ft, see **LRFD BDS Section 3.11.6.4 and Table 3.11.6.4-2** for adjusted surcharge load calculation.
Note: When traffic vehicular live loads are not present within 0.5*H from the back of the reinforced zone let SUR equal 100 psf to account for construction loads.

Calculations:

Active Earth Pressure:

$\beta := 0 \qquad \delta := \beta$

Inclination of ground slope behind face of wall and angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.3333$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 11233.8 \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 1975 \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 47864.5 \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 4207.5 \frac{lbf}{ft}$ — Live Load Surcharge - (LS)

Moment Arm: | Moment:

$d_{v1} := 0 \cdot ft \qquad d_{v1} = 0\ ft \qquad MV_1 := V_1 \cdot d_{v1} \qquad MV_1 = 0 \frac{lbf \cdot ft}{ft}$

$d_{v2} := 0\ ft \qquad d_{v2} = 0\ ft \qquad MV_2 := V_2 \cdot d_{v2} \qquad MV_2 = 0 \frac{lbf \cdot ft}{ft}$

Horizontal Loads:

$H_1 := F_T = 11233.8 \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 1975 \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: | Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 7.9\ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 88747 \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 11.9\ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 23403.8 \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 47864.5\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 4207.5\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 11233.8\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 1975\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{EV} := MV_1$ $\quad M_{EV} = 0\ \frac{lbf \cdot ft}{ft}$

$M_{LS} := MV_2$ $\quad M_{LS} = 0\ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_1$ $\quad M_{EH2} = 88747\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 23403.8\ \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 47864.5\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 71980.2\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 20307\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 20307\ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot (Ia_{EV} \cdot M_{EV})$ $\quad MV_{Ia} = 0\ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot ((Ib_{EV} \cdot M_{EV}) + (Ib_{LS} \cdot M_{LS}))$ $\quad MV_{Ib} = 0\ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 174077.1\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 174077.1\ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the Effective Bearing Length (Strength Ib):

$\Sigma M_R := MV_{Ib}$ — $\Sigma M_R = 0\ \frac{lbf \cdot ft}{ft}$ — Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 174077.1\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 71980.2\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 2.4\ ft$ — Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ — $B' = 12\ ft$ — Effective Bearing Width

Foundation Layout:

$L_{Wall} := 16.83 \cdot ft$ — Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ — $H' = 20307\ \frac{lbf}{ft}$ — Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ — $V' = 71980.2\ \frac{lbf}{ft}$ — Summation of Vertical Loads (Strength Ib)

$D_f := d_e$ — $D_f = 5.3\ ft$ — Footing embedment

$d_w := 0 \cdot ft$ — Depth of Groundwater below Bearing Grade

$\theta' := 90 \cdot deg$ — Direction of H' and V' resultant measured from wall back face **LRFD [Figure C10.6.3.1.2a-1]**

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right)$ — $N_q = 9.6$

$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right)$ — $N_c = 19.32$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f)$ — $N_\gamma = 9.4$

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

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ — $s_c = 1.354$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ — $s_q = 1.317$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ — $s_\gamma = 0.715$

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]**:

$C_{wq} := \text{if}\left(d_w \geq 0, 1, 0.5\right)$ $\quad C_{wq} = 1$

$C_{w\gamma} := \text{if}\left(d_w > 1.5 \cdot B', 1, 0.5\right)$ $\quad C_{w\gamma} = 0.5$

Depth Correction Factor per **Hanson (1970):**

$$d_q := \text{if}\left(\frac{D_f}{B'} \leq 1, 1 + 2 \cdot \tan\left(\phi'_f\right) \cdot \left(1 - \sin\left(\phi'_f\right)\right)^2 \cdot \frac{D_f}{B'}, 1 + 2 \cdot \tan\left(\phi'_f\right) \cdot \left(1 - \sin\left(\phi'_f\right)\right)^2 \cdot \text{atan}\left(\frac{D_f}{B'}\right)\right)$$

$d_q = 1.1$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 26.167$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad N_{qm} = 12.65$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 6.751$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 17203.8 \ \frac{lbf}{ft^2}$

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 11.2 \ ksf$ — Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

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

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

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\quad N_\gamma = 0$

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

$$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.143$$

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

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

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

$i_q := 1 \qquad i_q = 1$

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

$i_c := 1 \qquad i_c = 1$

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

$N_{cm} := N_c \cdot s_c \cdot i_c \qquad N_{cm} = 5.873$

$N_{qm} := N_q \cdot s_q \cdot i_q \qquad N_{qm} = 1$

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

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

$$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma} \qquad q_{nu} = 11031.2 \ \frac{lbf}{ft^2}$$

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

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

$q_{Ru} := \phi_b \cdot q_{nu} \qquad q_{Ru} = 7.2 \ ksf$ — Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 11.2 \ ksf$

Undrained Conditions: $q_{Ru} = 7.2 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Ru}$

$q_R = 7.2 \ ksf$

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

Compute the resultant location (distance from Point 'O'):

$\Sigma M_R := MV_{Ib}$ — $\Sigma M_R = 0 \ \frac{lbf \cdot ft}{ft}$ — Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 174077.1 \ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 71980.2 \ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 2.4 \ ft$ — Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ — $B' = 12 \ ft$ — Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ — $\sigma_v = 6001.8 \ \frac{lbf}{ft^2}$ — Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ — Is the CDR > or = to 1.0? — $CDR_{Bearing} = 1.19$

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

$e_{max} := \frac{L}{3}$ — $e_{max} = 5.6 \ ft$ — Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ — $\Sigma M_R = 0 \ \frac{lbf \cdot ft}{ft}$ — Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ — $\Sigma M_O = 174077.1 \ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ — $\Sigma V = 47864.5 \ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 3.6 \ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ — Is the CDR > or = to 1.0? — $CDR_{Eccentricity} = 1.54$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 20307 \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$k'_{pd} := 3.6$ Passive Earth Pressure Coefficient from **LRFD Figure 3.11.5.4-2**

$y_1 := 3.8\ ft$ Depth to where passive pressure may begin to be utilized in front of wall. (Typically d_{frost})

$y_2 := 3.8\ ft$ Depth to bottom of passive pressure zone in front of wall.

$r_{ep1} := \left(k'_{pd} \cdot \gamma_f \cdot y_1 + 2 \cdot c'_f \cdot \sqrt{k'_{pd}}\right) \cdot \cos\left(\delta_{fd}\right)$ Nominal passive pressure at y1

$r_{ep2} := \left(k'_{pd} \cdot \gamma_f \cdot y_2 + 2 \cdot c'_f \cdot \sqrt{k'_{pd}}\right) \cdot \cos\left(\delta_{fd}\right)$ Nominal passive pressure at y2

$R_{ep} := \frac{r_{ep1} + r_{ep2}}{2} \cdot \left(y_2 - y_1\right)$ $\qquad R_{ep} = 0 \frac{lbf}{ft}$ Nominal passive resistance Drained Conditions

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 47864.5 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right) + R_{ep}$ $\qquad R_{\tau d} = 21310.7 \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 21.311 \frac{kip}{ft}$

Undrained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 47864.5 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$\sigma'_v := \Sigma V$ $\qquad \sigma'_v = 47864.5 \frac{lbf}{ft}$

$R_{\tau u} := min\left(\frac{\sigma'_v}{2}, c_f \cdot L\right)$ $\qquad R_{\tau u} = 23932.3 \frac{lbf}{ft}$ Nominal sliding resistance Undrained Conditions

Nominal Sliding Resistance Undrained Conditions:

Undrained Conditions: $R_{\tau u} = 23.932 \frac{kip}{ft}$

Nominal Sliding Resistance to be used in CDR Calculations: $R_\tau := R_{\tau d}$

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.**

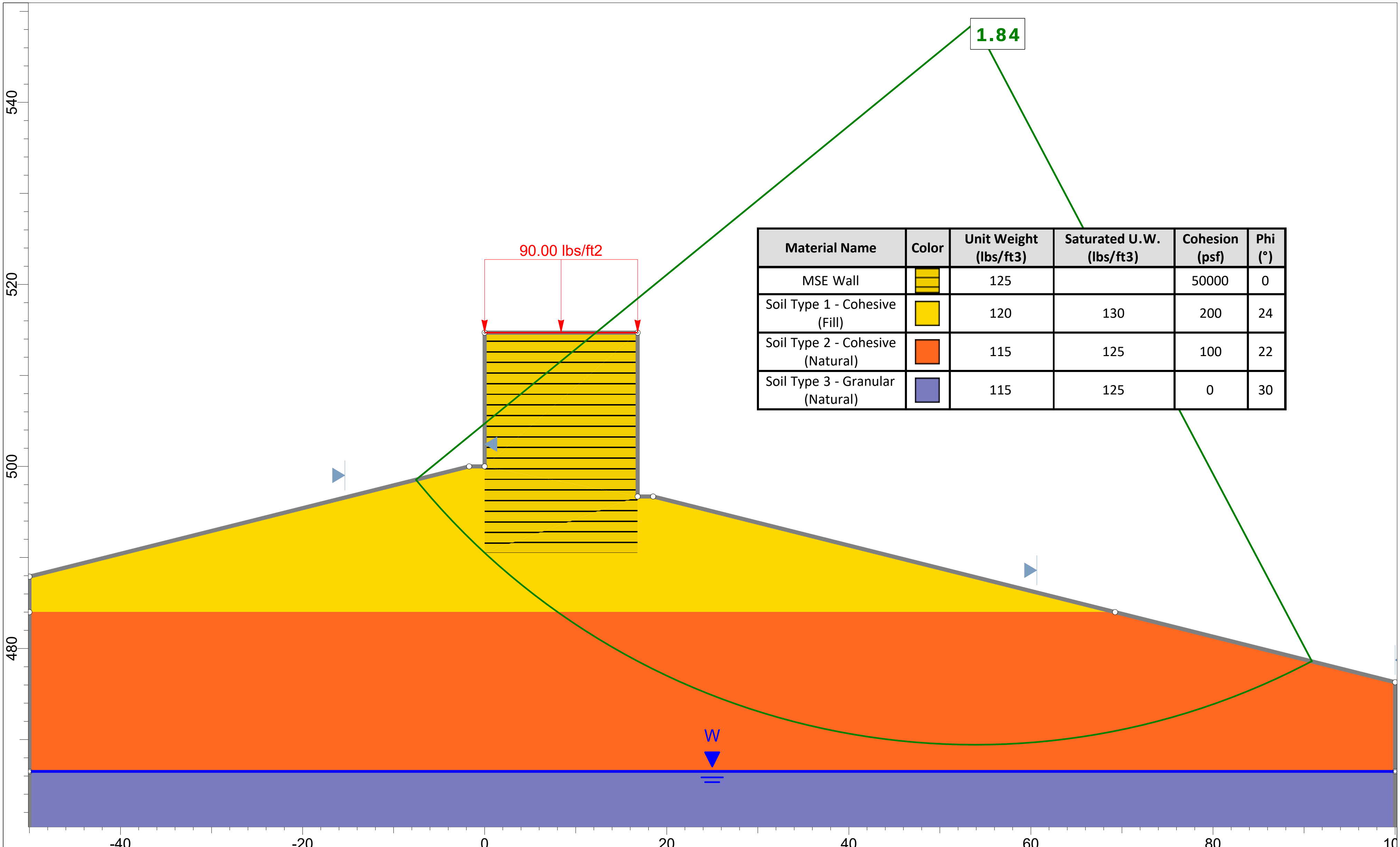
$\phi R_n := \phi_\tau \cdot R_\tau$ $\qquad R_R := \phi R_n$

$R_R = 21.3 \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.05$

REAR ABUTMENT MSE WALL
GLOBAL STABILITY ANALYSIS



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Cohesion (psf)	Phi (°)
MSE Wall		125		50000	0
Soil Type 1 - Cohesive (Fill)		120	130	200	24
Soil Type 2 - Cohesive (Natural)		115	125	100	22
Soil Type 3 - Granular (Natural)		115	125	0	30

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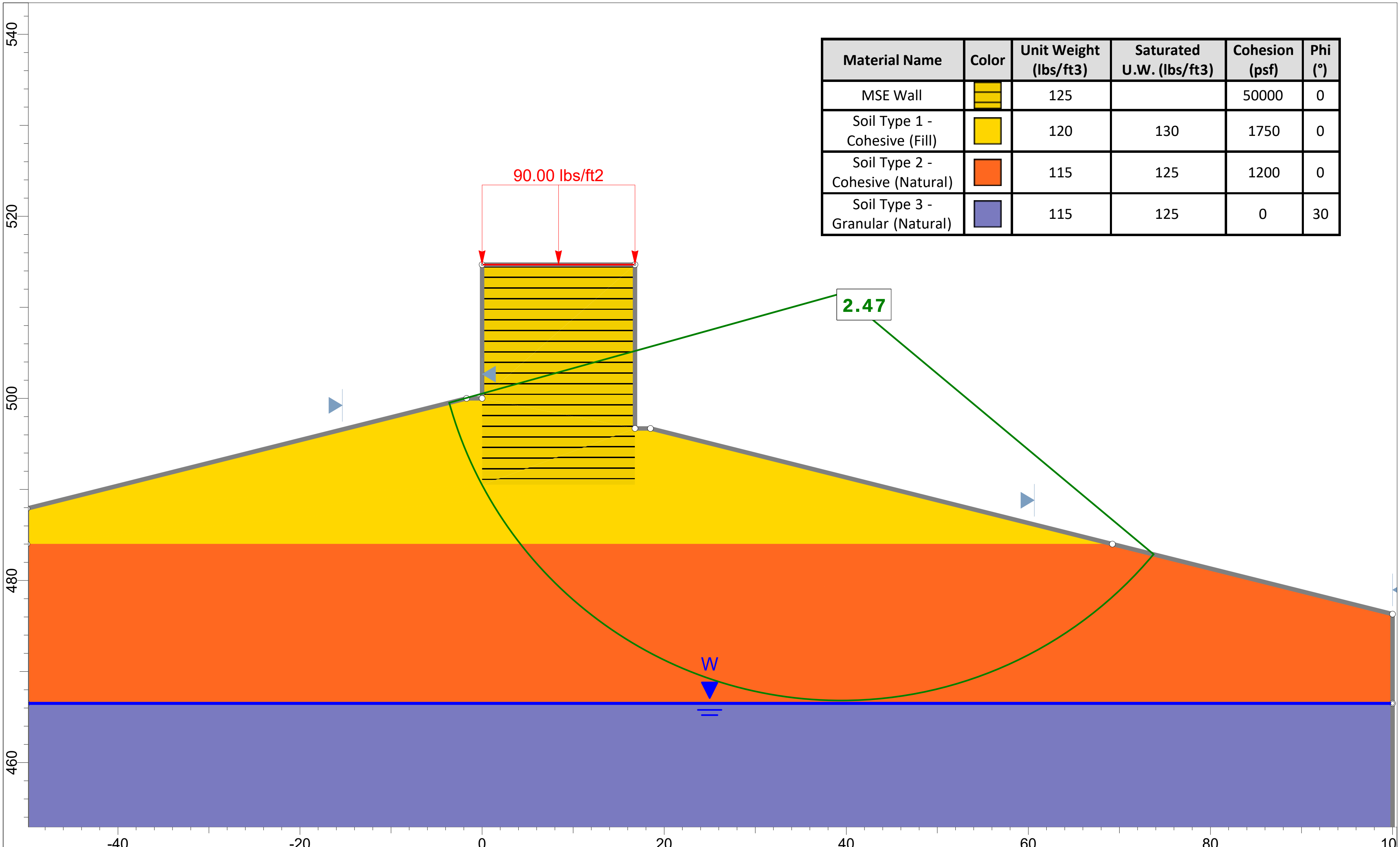
SLIDEINTERPRET 9.034

Project	HAM-75-01.05 (PID 113361)		
Group	Group 1	*Scenario*	Master Scenario
Drawn By	KCA	*Company*	NEAS Inc.
Date	1/3/2025, 6:04:34 PM	*File Name*	RA_EffCirc_B-027_010325.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Cohesion (psf)	Phi (°)
MSE Wall		125		50000	0
Soil Type 1 - Cohesive (Fill)		120	130	1750	0
Soil Type 2 - Cohesive (Natural)		115	125	1200	0
Soil Type 3 - Granular (Natural)		115	125	0	30

Project	HAM-75-01.05 (PID 113361)		
Group	Group 1	*Scenario*	Master Scenario
Drawn By	KCA	*Company*	NEAS Inc.
Date	1/3/2025, 6:04:34 PM	*File Name*	RA_TotCirc_B-027_010325.slmd

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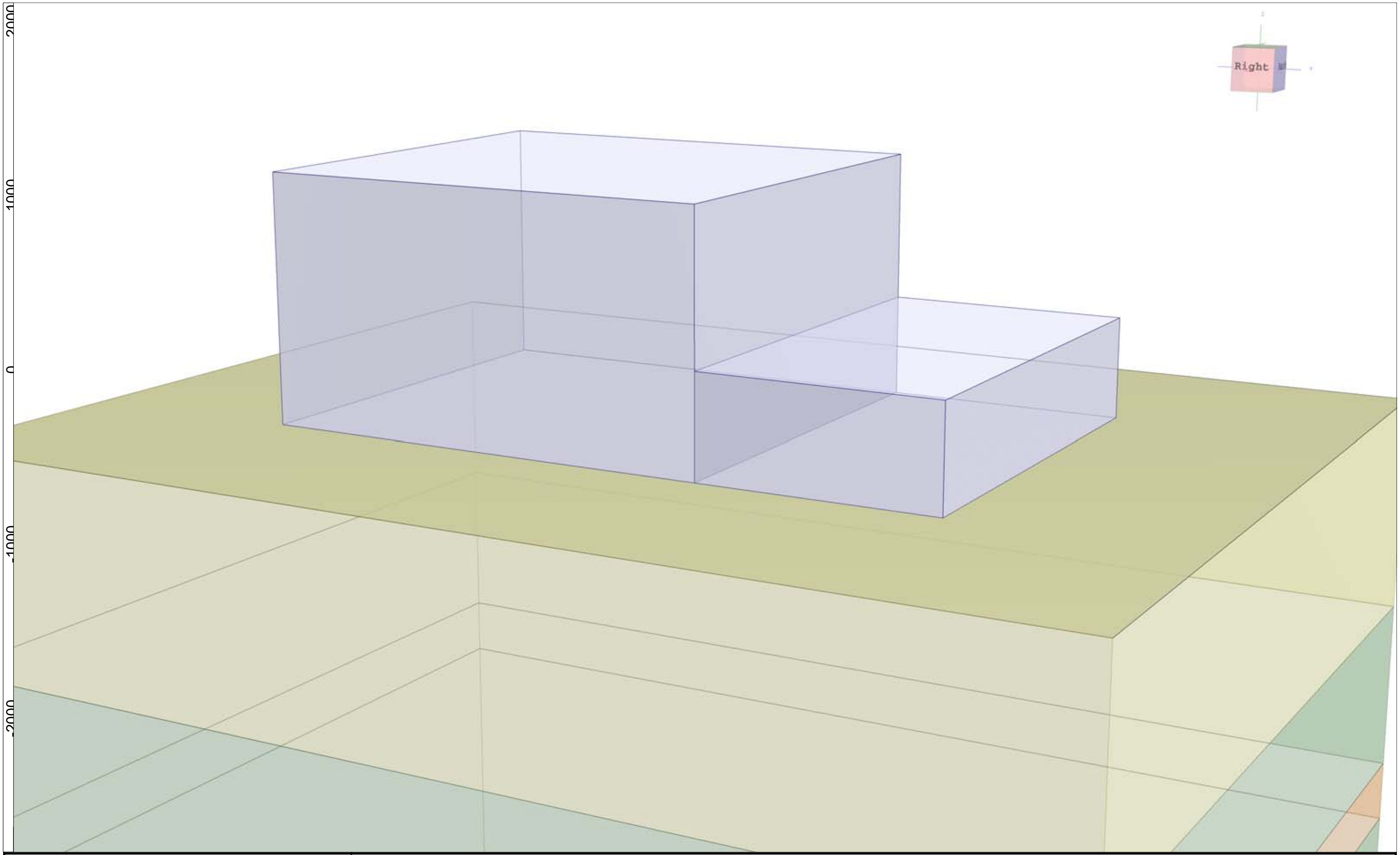
SLIDEINTERPRET 9.034

REAR ABUTMENT MSE WALL
SETTLMENT ANALYSIS

HAM-75-01.05 (PID 122048)
NEAS Inc.
Report Creation Date: 2025/01/06, 00:15:26



rocscience	Project	HAM-75-01.05 (PID 122048)	
	Analysis Description	Bridge HAM-75-0125E Rear Abutment	
	Drawn By: KCA	Company: NEAS Inc.	
SETTLE3 5.024	Date: 12/31/2024, 4:05:52 PM	File Name: HAM-75-0125E_RA.s3z	

Table of Contents

Settle3 Analysis Information

HAM-75-01.05 (PID 122048)

Project Settings

Document Name	HAM-75-0125E_RA.s3z
Project Title	HAM-75-01.05 (PID 122048)
Analysis	Bridge HAM-75-0125E Rear Abutment
Author	KCA
Company	NEAS Inc.
Date Created	12/31/2024, 4:05:52 PM
Last saved with Settle3 version	5.024
Stress Computation Method	Boussinesq
Stress Units	Imperial, stress as ksf
Settlement Units	inches
Time-dependent Consolidation Analysis	
Time Units	days
Permeability Units	feet/day

Advanced Settings

Start of secondary consolidation (% of primary)	95
Min. stress for secondary consolidation (% of initial)	1
Reset time when load changes for secondary consolidation	No
Minimum settlement ratio for subgrade modulus	0.9
Use average poisson's ratio to calculate layered stresses	
Update Cv in each time step (improves consolidation accuracy)	
Ignore negative effective stresses in settlement calculations	
Add field points to load edges	

Soil Profile

Layer Option	Horizontal Soil Layers
Vertical Axis	Elevation
Ground Elevation (ft)	503

Stage Settings

Stage #	Name	Time [days]
1	Stage 1	0
2	Stage 2	210
3	Stage 3	450
4	Stage 4	10000

Results

Time taken to compute: 0.520792 seconds

Stage: Stage 1 = 0 d

Data Type	Minimum	Maximum
Total Settlement [in]	0	1.09492
Total Consolidation Settlement [in]	0	0
Virgin Consolidation Settlement [in]	0	0
Recompression Consolidation Settlement [in]	0	0
Immediate Settlement [in]	0	1.09492
Secondary Settlement [in]	0	0
Loading Stress ZZ [ksf]	0.0220044	1.38
Loading Stress XX [ksf]	-0.0133433	1.10485
Loading Stress YY [ksf]	-0.0205296	0.930533
Effective Stress ZZ [ksf]	0	8.23064
Effective Stress XX [ksf]	0.223	8.23088
Effective Stress YY [ksf]	0.0884915	8.22914
Total Stress ZZ [ksf]	0.265	12.8342
Total Stress XX [ksf]	0.488	12.8341
Total Stress YY [ksf]	0.353491	12.8327
Modulus of Subgrade Reaction (Total) [ksf/ft]	0	17.7207
Modulus of Subgrade Reaction (Immediate) [ksf/ft]	0	17.7207
Modulus of Subgrade Reaction (Consolidation) [ksf/ft]	0	0
Total Strain	0.000224679	0.00279049
Pore Water Pressure [ksf]	0.124994	4.60359
Excess Pore Water Pressure [ksf]	0.0220044	1.38
Degree of Consolidation [%]	0	0
Pre-consolidation Stress [ksf]	0.0184847	37.0275
Over-consolidation Ratio	4.5	6.5
Void Ratio	0	0.709605
Permeability [ft/d]	0	0.0228742
Coefficient of Consolidation [ft^2/d]	0	0.1
Hydroconsolidation Settlement [in]	0	0
Average Degree of Consolidation [%]	0	0
Undrained Shear Strength	0	0

Stage: Stage 2 = 210 d

Data Type	Minimum	Maximum
Total Settlement [in]	0	3.29334
Total Consolidation Settlement [in]	0	2.19933
Virgin Consolidation Settlement [in]	0	0.977822
Recompression Consolidation Settlement [in]	0	1.22151
Immediate Settlement [in]	0	1.09492
Secondary Settlement [in]	0	0
Loading Stress ZZ [ksf]	0.0220044	1.38
Loading Stress XX [ksf]	-0.0133433	1.10485
Loading Stress YY [ksf]	-0.0205296	0.930533
Effective Stress ZZ [ksf]	0.265	8.25407
Effective Stress XX [ksf]	0.488	8.25396
Effective Stress YY [ksf]	0.353491	8.25256
Total Stress ZZ [ksf]	0.265	12.8342
Total Stress XX [ksf]	0.488	12.8341
Total Stress YY [ksf]	0.353491	12.8327
Modulus of Subgrade Reaction (Total) [ksf/ft]	0	6.18152
Modulus of Subgrade Reaction (Immediate) [ksf/ft]	0	17.7207
Modulus of Subgrade Reaction (Consolidation) [ksf/ft]	0	9.28958
Total Strain	0.000224679	0.240824
Pore Water Pressure [ksf]	-6.14617e-08	4.58016
Excess Pore Water Pressure [ksf]	-6.14617e-08	0.444557
Degree of Consolidation [%]	0	99.6108
Pre-consolidation Stress [ksf]	0.267825	37.0275
Over-consolidation Ratio	1	6.33577
Void Ratio	0	0.709103
Permeability [ft/d]	0	0.557907
Coefficient of Consolidation [ft^2/d]	0	0.5
Hydroconsolidation Settlement [in]	0	0
Average Degree of Consolidation [%]	0	52.8575
Undrained Shear Strength	0	0.0690081

Stage: Stage 3 = 450 d

Data Type	Minimum	Maximum
Total Settlement [in]	0	3.48389
Total Consolidation Settlement [in]	0	2.39013
Virgin Consolidation Settlement [in]	0	0.977871
Recompression Consolidation Settlement [in]	0	1.41226
Immediate Settlement [in]	0	1.09492
Secondary Settlement [in]	0	0
Loading Stress ZZ [ksf]	0.0220044	1.38
Loading Stress XX [ksf]	-0.0133433	1.10485
Loading Stress YY [ksf]	-0.0205296	0.930533
Effective Stress ZZ [ksf]	0.265	8.25407
Effective Stress XX [ksf]	0.488	8.25396
Effective Stress YY [ksf]	0.353491	8.25256
Total Stress ZZ [ksf]	0.265	12.8342
Total Stress XX [ksf]	0.488	12.8341
Total Stress YY [ksf]	0.353491	12.8327
Modulus of Subgrade Reaction (Total) [ksf/ft]	0	5.95058
Modulus of Subgrade Reaction (Immediate) [ksf/ft]	0	17.7207
Modulus of Subgrade Reaction (Consolidation) [ksf/ft]	0	8.54309
Total Strain	0.000224679	0.240824
Pore Water Pressure [ksf]	-4.31637e-06	4.58016
Excess Pore Water Pressure [ksf]	-4.31637e-06	0.243846
Degree of Consolidation [%]	0	99.7682
Pre-consolidation Stress [ksf]	0.267825	37.0275
Over-consolidation Ratio	1	6.20981
Void Ratio	0	0.70876
Permeability [ft/d]	0	0.557907
Coefficient of Consolidation [ft^2/d]	0	0.5
Hydroconsolidation Settlement [in]	0	0
Average Degree of Consolidation [%]	0	73.6713
Undrained Shear Strength	0	0.0690155

Stage: Stage 4 = 10000 d

Data Type	Minimum	Maximum
Total Settlement [in]	0	3.69137
Total Consolidation Settlement [in]	0	2.59787
Virgin Consolidation Settlement [in]	0	0.977903
Recompression Consolidation Settlement [in]	0	1.61997
Immediate Settlement [in]	0	1.09492
Secondary Settlement [in]	0	0
Loading Stress ZZ [ksf]	0.0220044	1.38
Loading Stress XX [ksf]	-0.0133433	1.10485
Loading Stress YY [ksf]	-0.0205296	0.930533
Effective Stress ZZ [ksf]	0.265	8.25407
Effective Stress XX [ksf]	0.488	8.25396
Effective Stress YY [ksf]	0.353491	8.25256
Total Stress ZZ [ksf]	0.265	12.8342
Total Stress XX [ksf]	0.488	12.8341
Total Stress YY [ksf]	0.353491	12.8327
Modulus of Subgrade Reaction (Total) [ksf/ft]	0	5.63136
Modulus of Subgrade Reaction (Immediate) [ksf/ft]	0	17.7207
Modulus of Subgrade Reaction (Consolidation) [ksf/ft]	0	7.85209
Total Strain	0.000224679	0.240824
Pore Water Pressure [ksf]	-1.63745e-06	4.58016
Excess Pore Water Pressure [ksf]	-1.63745e-06	4.18816e-06
Degree of Consolidation [%]	0	100
Pre-consolidation Stress [ksf]	0.267825	37.0275
Over-consolidation Ratio	1	6.17826
Void Ratio	0	0.708703
Permeability [ft/d]	0	0.557907
Coefficient of Consolidation [ft^2/d]	0	0.5
Hydroconsolidation Settlement [in]	0	0
Average Degree of Consolidation [%]	0	100
Undrained Shear Strength	0	0.0690204

Loads

1. Polygonal Load: "Polygonal Load 1"

Label	Polygonal Load 1
Load Type	Flexible
Area of Load	171.5 ft2
Load	0.53 ksf
Elevation	503 ft
Installation Stage	Stage 1 = 0 d

Coordinates

X [ft]	Y [ft]
0	141.8
0	132
17.5	132
17.5	141.8

2. Polygonal Load: "Polygonal Load 2"

Label	Polygonal Load 2
Load Type	Flexible
Area of Load	332.5 ft2
Load	1.38 ksf
Elevation	503 ft
Installation Stage	Stage 1 = 0 d

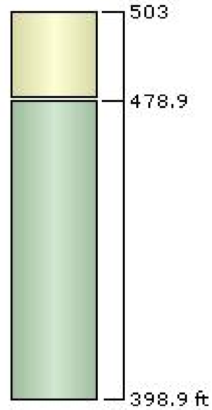
Coordinates

X [ft]	Y [ft]
0	132
0	113
17.5	113
17.5	132

Soil Layers

Ground Surface Drained: Yes

Layer #	Type	Thickness [ft]	Elevation [ft]	Drained at Bottom
1	Cohesive Soil 1	24.1	503	Yes
2	Granular Soil 1	80	478.9	No



Soil Properties

Property	Cohesive Soil 1	Granular Soil 1
Color		
Unit Weight [kips/ft3]	0.118	0.12
Saturated Unit Weight [kips/ft3]	0.128	0.125
K0	1	1
Immediate Settlement	Enabled	Enabled
Es [ksf]	640	98
Esur [ksf]	640	98
Primary Consolidation	Enabled	Disabled
Material Type	Non-Linear	
Cc	0.2	-
Cr	0.041	-
e0	0.71	-
OCR	6.5	-
Cv [ft2/d]	0.5	-
Cvr [ft2/d]	0.1	-
B-bar	1	-
Undrained Su A [kips/ft2]	0	0
Undrained Su S	0.2	0.2
Undrained Su m	0.8	0.8
Piezo Line ID	Staged	Staged

Groundwater

Groundwater method	Piezometric Lines
Water Unit Weight	0.0624 kips/ft3
Generating excess pore pressure above water table	

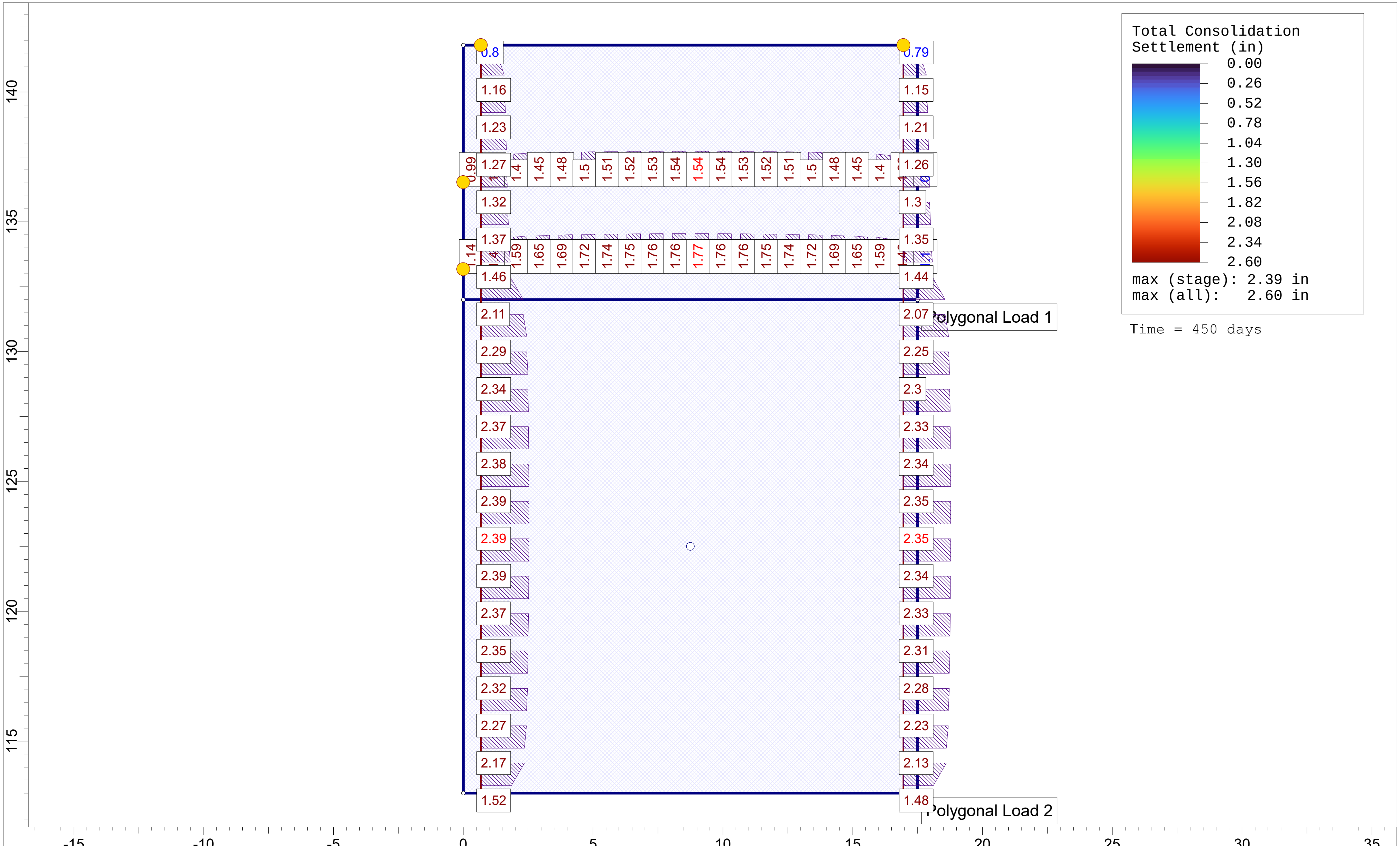
Piezometric Line Entities

ID	Elevation (ft)
1	472.3 ft

Query

Query Lines

Line #	Query Line Name	Start Location	End Location	Horizontal Divisions	Vertical Divisions
1	Query Line 1	0, 133.177	17.5, 133.177	20	Auto: 55
2	Query Line 2	0, 136.524	17.5, 136.524	20	Auto: 55
3	Query Line 3	0.67545, 141.8	0.67545, 113	20	Auto: 55
4	Query Line 4	16.9537, 141.8	16.9537, 113	20	Auto: 55



rocscience	Project	HAM-75-01.05 (PID 122048)	
	Analysis Description	Bridge HAM-75-0125E Rear Abutment	
	Drawn By	KCA	Company: NEAS Inc.
SETTLE3 5.024	Date	12/31/2024, 4:05:52 PM	File Name: HAM-75-0125E_RA.s3z

DOWNDRAG ANALYSIS

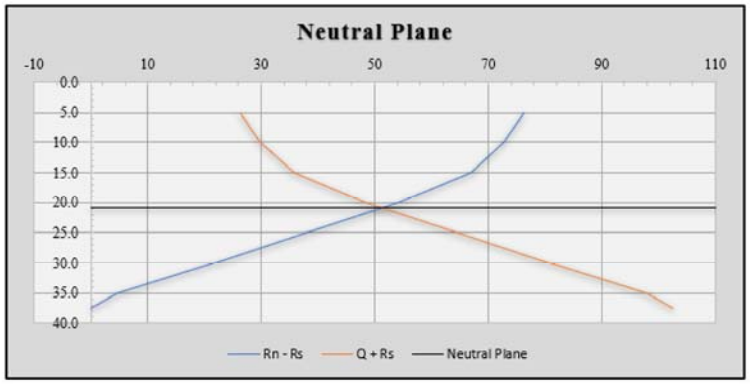
Objective: **To evaluate structural capacity of cast-in-place (CIP) closed-ended pipe piles at the Structural Strength Limit State considering downdrag loading, as well as to determine the elastic compression of the pile above the neutral plane for evaluation at the Service Limit State.**

Method: **In accordance with ODOT Bridge Design Manual, 2020 [Sect. 305.3.2.2], FHWA-NHI-16-009/010, Geotechnical Engineering Circular 12 (GEC 12), [Sect. 7.3.5, Sect. 7.3.6.1, and Sect. 11.6.3], and LRFD Bridge Design Specifications, 8th Ed., 2018, [Sect. 6.15.3.1]**

Givens:

DD Load Factor	UBV (kips)	Factored Permanent Load (kips)	Unfactored Permanent Load (kips)
1.4	77.5	31.5	25.1

Depth (ft)	Side Resistance, Rs (kips)	Nominal Resistance - Side Resistance (Rn - Rs) (kips)	Unfactored Permanent Load + Side Resistance (Q + Rs) (kips)
5.0	1.2	76.30	26.30
10.0	4.7	72.80	29.80
15.0	10.6	66.90	35.70
20.0	23.5	54.00	48.60
25.0	39.4	38.10	64.50
30.0	55.7	21.80	80.80
35.0	72.9	4.60	98.00
37.4	77.5	0.00	102.60



	Depth	Rs	Rn-Rs	Q+Rs
Lower Bound	20	23.5	54	48.6
Upper Bound	25	39.4	38.1	64.5

Depth of Neutral Plane (ft)	20.8
Q+DD @ Neutral Plane (kips)	51.3
DD @ Neutral Plane (kips)	26.2
Qp @ Neutral Plane (kips)	68.2

Rs = Nominal Side Resistance
Rn = Nominal Geotechnical Resistance (Side & End Bearing)
Q = Permanent Unfactored Load (Exclude Transient)
Qp = Total Factored Load (Permanent & Downdrag)
DD = Nominal Drag Load Per Pile

Pile Loading and Parameters:

Total Unfactored Axial Load (for the highest loaded pile at the substructure):

$Q_1 = \Sigma Q_i$ $\quad Q_1 := 40.6\ kip$ $\quad$ Permanent and transient loads

$Q_2 = \Sigma Q_i + DD$ $\quad Q_2 := 51.3\ kip$ $\quad$ Permanent and downdrag (DD) loads

$Q := \max(Q_1, Q_2)$ $\quad Q = 51.3\ kip$ $\quad$ Factored Axial Load to use in Structural Strength Limit State per **ODOT BDM [Sect. 305.3.2.2]**

Total Factored Axial Load (for the highest loaded pile at the substructure):

$Q_{P1} = \Sigma \eta_i \gamma_i Q_i$ $\quad Q_{P1} := 54.2\ kip$ $\quad$ Permanent and transient loads **ODOT BDM [Eq. C305.3.2-5]**

$Q_{P2} = \Sigma \eta_i \gamma_i Q_i + \eta_i \gamma_p DD$ $\quad Q_{P2} := 68.2\ kip$ $\quad$ Permanent and downdrag (DD) loads **ODOT BDM [Eq. C305.3.2.2-1]**

$Q_P := \max(Q_{P1}, Q_{P2})$ $\quad Q_P = 68.2\ kip$ $\quad$ Factored Axial Load to use in Structural Strength Limit State per **ODOT BDM [Sect. 305.3.2.2]**

Pile Parameters:

$D_o := 12\ in$ $\quad$ Pile Outside Diameter (ODOT Preferred: 12-in, 14-in & 16-in)

$t_w := 0.25\ in$ $\quad$ Pile Wall Thickness (minimum = UBV/900 kips)

$D_i := D_o - 2 \cdot t_w$ $\quad D_i = 11.5\ in$ $\quad$ Pile Inside Diameter

$f'_c := 4\ ksi$ $\quad$ 28-day compressive strength of concrete assumed to be 4 ksi per **ODOT BDM [Sect. C305.3.3]**

$F_y := 35\ ksi$ $\quad$ Yield strength of structural steel assumed to be 35 ksi per **ODOT BDM [Sect. C305.3.3]**

Calculations

Assumptions:

The factored axial structural resistance of the pile calculated below are calculated in accordance with **LRFD BDS [Sect. 6.9.5.1]** assuming an axially loaded pile with negligible moment; no appreciable loss of section due to deterioration throughout the life of the structure; a steel yield strength of 35-ksi; a 28-day compressive strength of concrete. 4-ksi, a structural resistance factor for pipe piles subject to damage due to severe driving conditions (φ_c = 0.60); and a pile fully braced along its length (l = 0-in). If a pile is not anticipated to be fully braced along its length (i.e., capped column type piers) see **LRFD BDS [Sect. 6.9.5.1].**

Piles under combined axial compression and flexure, should check structural Strength Limit State by determining factored structural resistance in accordance with LRFD BDS [Sect. 6.9.2.2]

Cross-sectional area of concrete

$$A_c := \frac{\pi}{4} \cdot D_i^2 \qquad A_c = 103.9\ in^2$$

Cross-sectional area of steel

$$A_s := \frac{\pi}{4} \cdot \left(D_o^2 - D_i^2\right) \qquad A_s = 9.2\ in^2$$

Nominal Compressive Resistance of Composite Members:

$$F_e := F_y + 0.85 \cdot f'_c \cdot \left(\frac{A_c}{A_s}\right) \qquad F_e = 73.3\ ksi$$

LRFD BDS [Eq. 6.9.5.1-4]

Factored Structural Resistance of Pile:

$\varphi_c := 0.6$ Structural Resistance Factor per **LRFD BDS [Sect. 6.5.4.2]** for severe driving conditions

$$P_r := \varphi_c \cdot F_e \cdot A_s \qquad P_r = 405.7\ kip$$

Structural Strength Limit State Check:

$$\text{Check} := \text{if}\left(P_r \ge Q_P, \text{"GOOD"}, \text{"FAIL"}\right)$$

$$\text{Check} = \text{"GOOD"}$$

If Check = "FAIL", consideration should be given to increased pile wall thickness or decreased load on pile (i.e., more piles, reduce downdrag effect, etc.)

Axial Compression of Pile Above the Neutral Plane:

$C_3 := 0.4$ Composite Column Constant per **LRFD BDS [Table 6.9.5.1-1]**

$E := 29000\ ksi$ Elastic Modulus of Steel

$L := 20.8\ ft$ Length of pile (above neutral plane if downdrag controls)

$A := \frac{\pi}{4} \cdot D_o^2 = 113.1\ in^2$ Total Area of the Pile

$E_c := \left(2500\ f'_c{}^{0.33}\right)\ ksi = 3950.2\ ksi$ Elastic Modulus of Concrete per **LRFD BDS [Eq. C5.4.2.4-1]**

$n := \frac{E}{E_c} = 7.3$ Modular Ratio on the Concrete per **LRFD BDS [Eq. C5.4.2.4-1]**

$E_e := E \cdot \left(1 + \left(\frac{C_3}{n}\right) \cdot \left(\frac{A_c}{A_s}\right)\right) = 46784.3\ ksi$ Elastic Modulus of Composite Column per **LRFD BDS [Eq. 6.9.5.1-5]**

$\Delta := \frac{Q \cdot L}{A \cdot E_e} = 0.002\ in$ Elastic Compression of the Pile per **GEC 12 [Eq. 7-48]**