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DESIGN MEMORANDUM

Date: September 7, 2023

To: Mr. Paul Durham, Stantec.

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

RE: **Geotechnical Design Memorandum**
Project HAM-LMST Extension to Elstun, PID 113602
Retaining Wall 1
City of Cincinnati, Hamilton County, Ohio

INTRODUCTION

Per your request, this memorandum presents design information for the proposed retaining wall (RW1) as part of the overall Ohio Department of Transportation (ODOT), Little Miami Scenic Trail (LMST) extension to Elstun Road (Rd) project located in the City of Cincinnati, Hamilton County, Ohio. A summary of: 1) the proposed retaining wall structure; 2) the existing site conditions; 3) the surficial and subsurface conditions via project borings; and, 4) our recommendations for retaining wall foundation design, are presented below.

NEAS's 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), ODOT's 2021 LRFD Bridge Design Manual (BDM) (ODOT, 2023) and ODOT's 2023 Geotechnical Design Manual (GDM).

To date NEAS has performed the subsurface exploration for the project's proposed two-span pedestrian bridge over Clough Creek (Bridge HAM-LMST ELSTUN-0.09) and provided the Structure Foundation Exploration (SFE) Report for the proposed bridge on December 15, 2022. As the proposed retaining wall will be located within new embankment fill associated with the bridge and immediately adjacent to the referenced bridge structure's abutments, the existing site conditions, site exploration and findings presented with the referenced SFE are generally representative of the proposed retaining wall location.

PROPOSED/EXISTING SITE CONDITIONS

Proposed Construction

NEAS understands that Stantec is developing construction plans for the LMST extension to Elstun Rd project. As part of the project, it is our understanding that to support the referenced trail extension new embankment fill is proposed along segments of the project as well as a new two span bridge to carry the LMST over Clough Creek (Bridge HAM-LMST ELSTUN-0.09). During the early design stages of the project and after discussions with Duke Energy regarding an existing utility easement, it was identified that a new retaining wall will be required to facilitate the construction of the newly proposed bridge structure and its associated new embankment.

It is our understanding that the proposed RW1 will be approximately 235 ft in length and about 9 to 11.5 ft in height. The proposed RW1 will be located along the western edge of the LMST from approximate STA. 73+75 to approximate STA. 76+25. For analysis purposes, RW1 and bearing elevations are anticipated to range from about 485.5 ft amsl to about 491.5 ft amsl. The proposed retaining wall will be constructed following a bottom-up construction sequence, and the likely wall type will be a modular block retaining wall, bearing on the existing natural cohesive soils or new embankment fill.

GEOLOGY AND OBSERVATIONS OF THE PROJECT

A summary of the geology, hydrogeology, site records and site reconnaissance representative to the proposed retaining wall location can be found in the referenced SFE report submitted by NEAS on December 15, 2022

FIELD EXPLORATION AND LABORATORY TESTING PROGRAM

The exploration for the project was conducted between July 6, 2022 and August 11, 2022 and included 4 borings drilled to depths between 33.3 and 41.0 ft bgs. The boring locations were selected and performed by NEAS with the intent to evaluate subsurface soil and groundwater conditions along the Elstun Connection alignment as well as the existing embankment soils of the adjacent ramp from State Route 32 (SR-32) Southbound (SB) to SR-125 eastbound (EB).

The laboratory testing program implemented for the project included classification testing, moisture content streambed grain size distribution, unconfined compressive strength of soil, consolidation testing, and unconfined compressive strength of bedrock. A summary of the field and laboratory programs as well as their results are presented in the referenced SFE report submitted by NEAS on December 15, 2022.

GEOTECHNICAL FINDINGS / SUBSURFACE CONDTIONS

The subsurface conditions encountered during NEAS's explorations are described in the referenced SFE report submitted by NEAS on December 15, 2022, as well as on the attached boring logs. The boring logs represent NEAS's interpretation of the subsurface conditions encountered at each boring location based on our site observations, field logs, visual review of the soil samples by NEAS's geologist, and laboratory test results. The lines designating the interfaces between various soil strata on the boring logs represent the approximate interface location; the actual transition between strata may be gradual and indistinct. The subsurface soil and groundwater characterizations, including summary test data, are based on the subsurface findings from the geotechnical explorations performed by NEAS as part of the referenced project, results of historical explorations, and consideration of the geological history of the site.

ANALYSIS AND RECOMMENDATIONS

We understand that the construction of a retaining wall (RW1) will be required as part of the HAM-LMST Extension to Elstun project (PID 113602) within the City of Cincinnati, Hamilton County, Ohio. During the early design stages of the overall project and after discussions with Duke Energy regarding an existing utility easement, it was identified that a new retaining wall will be required to facilitate the construction of the newly proposed bridge structure planned to carry the LMST over Clough Creek and its associated new embankment atop the easement. It is our understanding that the proposed RW1 will be approximately 235 ft in length and about 9 to 11.5 ft in height. The proposed RW1 will be located along the western edge of the LMST from approximate STA. 73+75 to approximate STA. 76+25. For analysis purposes, RW1 and bearing elevations are anticipated to range from about 485.5 ft amsl to about 491.5 ft amsl. Retained soil grades will generally be level or slightly slope upwards away from the back of wall to proposed trail grades behind the wall. The proposed retaining wall will be constructed following a bottom-up construction sequence, and the likely wall type will be a modular block retaining wall, bearing on the existing natural cohesive soils or new embankment fill.

Based on the above information in addition to: 1) the soil characteristics gathered during the subsurface exploration (i.e., SPT results, laboratory test results, etc.); 2) the developed generalized soil profile and estimated engineering properties and other design assumptions presented in subsequent sections of this memo; and, 3) the proposed Retaining Wall 1 plans provided by Stantec via email on August 17, 2023, geotechnical analyses consisting of evaluation of bearing resistance, global stability, and settlement were performed for the proposed wall.

The geotechnical engineering analyses were performed in accordance with ODOT's BDM (ODOT, 2023) and AASHTO's LRFD BDS (AASHTO, 2020). Based on the results of the analysis, it is our opinion that the subsurface conditions encountered are generally satisfactory and will provide adequate resistance to bearing and global stability assuming the proposed RW1 is constructed in accordance with the recommendations provided within this report, as well as all applicable standards and specifications (i.e., ODOT, manufacture, etc.) for modular block wall construction.

Retaining Wall Design Assumptions

As the proposed RW1 is to be designed as gravity modular block type walls, ODOT recognizes that these wall systems may employ unique design and construction requirements that are specific to a particular wall type. Therefore; a Prefabricated Retaining Wall System Evaluation Report shall be submitted to ODOT in order to identify all unique features of the wall system and highlight exceptions to the ODOT BDM and AASHTO LRFD Bridge Design Specifications. Based on this information; it is assumed that NEAS's analyses responsibilities include: 1) bearing capacity recommendations at the proposed bearing wall elevation within the plans, 2) perform a settlement analysis based on the anticipated bearing and retained earth loads; and, 3) perform a review of global stability based on the plan indicated exposed wall heights and finished grades.

With respect to RW1 specific design constraints and assumptions, the geometry of the proposed walls (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 Retaining Wall 1 plans provided by Stantec via email on August 17, 2023. The soil parameters of the new embankment fill were assumed to be consistent with those recommended in Table 500-2 of the ODOT GDM for "Assumed Embankment Fill Properties" and are presented in Table 1 below.

Table 1: Design Soil Parameters for Fill Materials

Type of Soil	Soil Unit Weight (pcf)	Undrained Shear Strength (psf)	Effective Cohesion (psf)	Effective Friction Angle (°)
On-site soil (A-7-6)	125	2,000	200	26

Notes:
1. Per Table 500-2 of the 2023 ODOT GDM.

Generalized Soil Profile for Analysis

For analysis purposes, each boring log within the area of the proposed wall was reviewed and a generalized material profile was developed for analysis. Utilizing the generalized soil profile, engineering properties for each soil strata were estimated based on the field (i.e., SPT N_{60} Values, hand penetrometer values, etc.) and laboratory (i.e., Atterberg Limits, grain size, etc.) test results using correlations provided in published engineering manuals, research reports and guidance documents. The developed soil profile and estimated engineering soil properties for use in analysis (with sited correlation/reference material) is summarized within Tables 2 and 3 below.

Table 2: Soil Profile and Estimated Engineering Properties - At Boring B-001-0-20

Retaining Wall: B-001-0-20				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Silty Clay Elevation (499.5 ft - 463 ft)	125	2100	200	24

Notes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if N160<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 3: Soil Profile and Estimated Engineering Properties - At Boring B-002-0-20

Retaining Wall: B-002-0-20				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Silt and Clay Elevation (477.6 ft - 473.1 ft)	125	1100	250	25
Silty Clay Elevation (473.1 ft - 468.4 ft)	108	1000	100	22
Gravel with Sand Elevation (468.4 ft - 465.6 ft)	125	-	-	36
Gravel Elevation (465.6 ft - 463.8 ft)	128	-	-	37
Silt and Clay Elevation (463.8 ft - 456.6 ft)	118	1100	100	22
Coarse and Fine Sand Elevation (456.6 ft - 454.8 ft)	122	-	-	30
Silt and Clay Elevation (454.8 ft - 453.1 ft)	122	2100	200	24
Gravel with Sand and Silt Elevation (453.1 ft - 449.3 ft)	130	-	-	38
Silt and Clay Elevation (449.3 ft - 446.6 ft)	135	5500	400	27

Notes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if N160<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Bearing Resistance

A shallow foundation bearing analysis was performed for the proposed retaining wall (RW1) in general accordance with the *LRFD Bridge Design Specifications*, *9th Edition*, Section 10.6.3.1.2a, utilizing the information provided within Tables 1 through 3. Based on: 1) the developed generalized profile; 2) estimated engineering soil properties; 3) retaining wall design assumptions provided in the above sections of this memo; and, 4) an estimated minimum embedment depth of 3 ft, bearing resistance analyses were performed for each wall under effective and total stress conditions. As each of the wall's configuration and associated bearing elevation is anticipated to change along the alignment, bearing resistance was reviewed and broken down by possible bearing strata into separate segments along the length of the wall.

Based on our review, RW1 was broken down in to two (2) separate bearing strata segments. Each segment (bearing soil) was evaluated for resistance to bearing pressure at the Strength Limit State in accordance with Section 11.10.5.4 of the AASHTO's LRFD BDS. Table 4 below summarizes the estimated bearing resistance for various block widths within each segment for RW1. The table also summarizes the segment (bearing soil) station range, estimated bearing elevation range, and the boring data used in analysis. Bearing Resistance Calculation Results are attached.

Table 4: Bearing Resistance Summary for Retaining Wall 1

Station Range	Bearing Elevation Range (ft amsl)(1)	Boring Data Used in Calculations	Width (ft)	Nominal Bearing Resistance (psf)	Factored Bearing Resistance (psf)
BEGIN (0+00) to STA 1+70	484 - 487	B-001-0-21	2.0	8,600	4,300
			3.0	9,200	4,600
			4.0	9,800	4,900
			5.0	10,400	5,200
STA 1+70 to END (STA 2+35)	488 - 492	New Fill	2.0	10,400	5,200
			3.0	11,200	5,600
			4.0	12,000	6,000
			5.0	12,800	6,400

Notes:
1. *Assumed Bearing Elevations based on Stage 1 Site Plan and embedment depth of 3 ft.*
2. *Resistance Factor of 0.5 Per LRFD Bridge Design Specifications Article 10.5.5.2.2-1.*

Global Stability

For purposes of evaluating the stability of the proposed retaining wall site (RW1), NEAS reviewed multiple cross-sections within the wall's limits that were interpreted to represent conditions that posed the greatest potential for slope instability. In general, cross-sections along the proposed wall alignment were reviewed to determine if the section 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 cut into existing embankment slopes, weak soil layer, etc.). Based on our review of the available information at the referenced location and the associated soil properties, the cross-section estimated to be most "critical" was analyzed for global stability. The two cross-sections analyzed for global stability included approximate STA. 75+00 (proposed LMST alignment) and approximate STA. 75+50 (proposed LMST alignment) along RW1's alignment. The cross-sections analyzed were determined to be the portion of the wall with the tallest exposed wall face and the steepest slope in front of the wall.

For these cross-sections, NEAS developed a representative cross-sectional model to use as the basis for global stability analyses. The model was developed from NEAS's interpretation of the available information which included: 1) the proposed Retaining Wall 1 plans provided by Stantec via email on August 17, 2023; 2) a live load surcharge of 250 psf, accounting for traffic induced loads and 100 psf for pedestrian induced loads; and, 3) test borings and laboratory data developed as part of this report. With respect to the soil's engineering properties, the provided Soil Profile and Estimated Engineering Properties presented in the referenced section of this memo were used in our analyses. The estimated engineering soil properties determined for Boring B-001-0-20 and Boring B-002-0-20 were utilized in the development of the cross-sectional model for RW1. It should also be noted that as specific wall design and dimensions information was not available at the time of this report, a wall width of 3 ft was assumed for global stability analysis purposes.

The above referenced slope 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

Modified Bishop and Spencer analysis methods were used to calculate a factor of safety (FOS) for circular type slope failures. The FOS is the ratio of the resisting forces and the driving forces, with the desired safety factor being more than about 1.33 which equates to an AASHTO resistance factor less than 0.75 (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 0.75 or lower is targeted as the slope does not contain or support a structural element.

Based on our slope stability analyses for the referenced retaining wall sections, the minimum slope stability safety factor is about 1.838 (0.54 resistance factor). The graphical outputs of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) are attached.

Settlement

A settlement analysis was performed as part of the provided SFE report for the Bridge HAM-LMST ELSTUN-0.09 submitted on December 15, 2022. Based on that analysis it was determined the estimated maximum total settlement associated with the loads induced by the proposed new embankment at the rear and forward abutment locations is about 3.4 inches. This settlement will begin as the embankment load is applied and will dissipate with time. However, the amount of settlement and the time required for the settlement to occur is mostly dependent on the thickness of the underlying compressible soil, the uniformity and properties of these layers (i.e., compaction, material type, compressibility, etc.), and the proposed embankment fill height/surcharge load. Of the total settlement, about 0.7 inches is expected to be elastic (immediate) and take place during construction. The remaining 2.7 inches of settlement is anticipated to be long-term with the majority (i.e., 90 percent) of long-term settlement anticipated to take place in the first 70 days following construction at the rear abutment and 170 days following construction at the forward abutment.

Therefore; based on our discussions with the design team and our understanding that the project can tolerate a delay between substantial completion of the site earthwork and bridge pile installation, NEAS recommends that site earthwork be performed at both the rear and forward abutments and that a settlement monitoring program be implemented at these locations. The monitoring program should be designed and implemented to verify that the settlements have dissipated to a level acceptable by the Geotechnical Engineer as well as to determine the time when pile installation/abutment construction may begin.

For the proposed RW1, NEAS recommends that the RW1 supporting new embankment soils follow the same phasing and waiting periods as bridge abutment embankment fills. Provided that the project schedule can tolerate a delay between substantial completion of the site earthwork in this area and the commencement of retaining wall construction, postponing construction of the wall and allowing the potentially damaging settlements to take place is recommended.

Temporary Excavations

It is recommended that all temporary excavations comply with the most recent Occupational Safety and Health Administration (OSHA) Excavating and Trenching Standard, Title 29 of the Code of Federal Regulation (CFR) Part 1926, Subpart P. The contractor is responsible for designing and constructing stable, temporary excavations and should shore, slope, or bench the sides of the excavations as required to maintain stability of both the excavation sides and bottom. Per Title 29 CFR Part 1926, the contractor's competent person should evaluate the soil exposed in the excavations as part of the their safety procedures. In no case should slope height, slope inclination, or excavation depth, including utility trench excavation depth, exceed those specified in local, state, and federal safety regulations. Based on the natural soils encountered at the site (Type B Soil), it is recommended that temporary excavation slopes (exceeding a depth of 3 ft and less than 20 ft) be laid back to at least 1H:1V and these slopes should be braced or backfilled if the excavation slope will be maintained for more than a day.

Drainage Considerations

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

It is recommended that internal drainage of the retaining wall be designed to provide positive drainage behind the wall and limit the buildup of hydrostatic pressure. Furthermore, it is recommended that the barrier or curb at the roadway extend at least 25 ft beyond wall limits, and outlet to a piped collection system (i.e., collection basin/inlet) located beyond the extents of the wall. Where a barrier or curb is not present, it is recommended that a paved channel (swale) be placed directly behind the top of the wall. The paved channel should be designed to intercept surface water and direct it to an outlet as well as reduce the potential for surface water from overtopping the wall. The designer should anticipate and address in design and detailing the possibility of water runoff from extreme events which will overtop the drainage swale and run down the wall face.

SOIL BORING LOGS

PROJECT: HAM-LMST EXT	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 55X	STATION / OFFSET: 76+65, 34' LT.	EXPLORATION ID B-001-0-20
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: ELSTUN CONNECTION	
PID: 113602 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/24/22	ELEVATION: 499.5 (MSL) EOB: 36.5 ft.	PAGE 1 OF 2
START: 8/11/22 END: 8/11/22	SAMPLING METHOD: SPT	ENERGY RATIO (%): 79	LAT / LONG: 39.106434, -84.400284	

MATERIAL DESCRIPTION AND NOTES	ELEV. 499.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY STIFF, BROWN AND LIGHT BROWN, **SILTY CLAY**, LITTLE SAND, TRACE TO LITTLE GRAVEL, DAMP TO MOIST		0 - 9.5																
		2.5 - 4	2 3 5	11	56	SS-1	3.25	13	7	10	35	35	39	21	18	17	A-6b (10)	
		5 - 6.5	2 3 2	7	39	SS-2	3.00	5	5	13	39	38	39	20	19	20	A-6b (12)	
		7.5 - 9	2 4 9	17	33	SS-3	2.50	-	-	-	-	-	-	-	-	21	A-6b (V)	
HARD, GRAYISH BROWN, **SILTY CLAY**, TRACE SAND, TRACE GRAVEL, DAMP	490.0	9.5 - 14.5																
		10 - 11.5	3 6 9	20	100	SS-4	4.25	-	-	-	-	-	-	-	-	18	A-6b (V)	
		12.5 - 14	3 6 11	22	67	SS-5	4.25	-	-	-	-	-	-	-	-	18	A-6b (V)	
HARD, GRAYISH BROWN AND BROWN, **SILTY CLAY**, SOME GRAVEL AND STONE FRAGMENTS, SOME SAND, DAMP	485.0	14.5 - 22																
		15 - 16.5	3 14 8	29	100	SS-6	4.25	24	14	9	30	23	35	19	16	15	A-6b (6)	
		17.5 - 19	5 6 7	17	44	SS-7	4.50	-	-	-	-	-	-	-	-	16	A-6b (V)	
		20 - 21.5	7 7 8	20	28	SS-8	4.25	-	-	-	-	-	-	-	-	14	A-6b (V)	
HARD, BROWN AND BROWNISH GRAY, **SILTY CLAY**, TRACE TO LITTLE SAND, TRACE GRAVEL, DAMP	477.5	22 -																
		22.5 - 24	5 5 6	14	39	SS-9	4.25	-	-	-	-	-	-	-	-	19	A-6b (V)	
		25 - 26.5	3 4 6	13	56	SS-10	4.25	4	6	8	44	38	39	21	18	19	A-6b (11)	
		27.5 - 29	4 6 8	18	28	SS-11	4.25	-	-	-	-	-	-	-	-	19	A-6b (V)	

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 12/15/22 11:49 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\HAM LMST EXT\GINT FILES\HAM-LMST EXT.GPJ

MATERIAL DESCRIPTION AND NOTES	ELEV. 469.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
HARD, BROWN AND BROWNISH GRAY, **SILTY CLAY**, TRACE TO LITTLE SAND, TRACE GRAVEL, DAMP *(continued)*		31	5 7 8	20	50	SS-12	4.25	-	-	-	-	-	-	-	-	21	A-6b (V)	
	467.5	32																
VERY STIFF TO HARD, GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP		33	4 6 7	17	44	SS-13	4.25	4	5	10	49	32	35	20	15	20	A-6a (10)	
		34																
		35																
	463.0	36 EOB	4 5 6	14	39	SS-14	4.00	-	-	-	-	-	-	-	-	13	A-6a (V)	

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

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

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 12/15/22 11:49 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\HAM LMST EXT\GINT FILES\HAM-LMST EXT.GPJ

PROJECT: HAM-LMST EXT	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 55X	STATION / OFFSET: 76+68, 36' RT.	EXPLORATION ID B-002-0-20
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: ELSTUN CONNECTION	
PID: 113602 SFN:	DRILLING METHOD: 3.25" HSA / NQ2	CALIBRATION DATE: 1/24/22	ELEVATION: 477.6 (MSL) EOB: 41.0 ft.	PAGE 1 OF 2
START: 7/7/22 END: 7/8/22	SAMPLING METHOD: SPT / ST / NQ2	ENERGY RATIO (%): 79	LAT / LONG: 39.106323, -84.400483	

MATERIAL DESCRIPTION AND NOTES	ELEV. 477.6	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
HARD, BROWN, **SILT AND CLAY**, SOME GRAVEL, LITTLE SAND, CONTAINS ROOTS, DAMP	473.1	1 2 3 4	3 7 8	20	61	SS-1	4.50	24	11	9	36	20	34	20	14	14	A-6a (6)	
STIFF TO VERY STIFF, BROWN AND BROWNISH GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, CONTAINS IRON STAINING, MOIST TO DAMP		5 6 7	2 3 3	8	100	SS-2	3.25	-	-	-	-	-	-	-	-	22	A-6b (V)	
@7.9' TO 8.4'; Qu = 2271 PSF @ 15.0%	468.4	8 9			83	ST-1	2.00	9	6	9	41	35	38	20	18	20	A-6b (11)	
MEDIUM DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP	465.6	10 11	10 8 9	22	50	SS-3	-	-	-	-	-	-	-	-	-	5	A-1-b (V)	
MEDIUM DENSE, GRAY, **STONE FRAGMENTS**, LITTLE SAND, TRACE SILT, TRACE CLAY, ENCOUNTER WITH COBBLE, MOIST	463.8	W 465.1 12 13 14	4 9 12	28	44	SS-4	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
SOFT TO STIFF, GRAY, **SILT AND CLAY**, TRACE TO LITTLE SAND, TRACE GRAVEL, MOIST TO WET		15 16 17	1 2 3	7	100	SS-5	1.75	3	2	6	56	33	32	20	12	26	A-6a (9)	
		18 19	3 4 4	11	39	SS-6	0.75	-	-	-	-	-	-	-	-	31	A-6a (V)	
	456.6	20 21	4 4 3	9	100	SS-7A	0.50	-	-	-	-	-	-	-	-	29	A-6a (V)	
LOOSE TO MEDIUM DENSE, GRAY, **COARSE AND FINE SAND**, SOME GRAVEL, TRACE SILT, TRACE CLAY, WET	454.8	22				SS-7B	-	-	-	-	-	-	-	-	-	16	A-3a (V)	
STIFF, GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST		23	3 5 8	17	100	SS-8A	-	-	-	-	-	-	-	-	-	13	A-3a (V)	
	453.1	24				SS-8B	1.50	-	-	-	-	-	-	-	-	23	A-6a (V)	
DENSE, GRAY, **STONE FRAGMENTS WITH SAND AND SILT**, TRACE CLAY, WET	449.3	25 26 27 28	7 10 18	37	44	SS-9	-	-	-	-	-	-	-	-	-	15	A-2-4 (V)	
VERY STIFF, GRAY, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, RELIC ROCK STRUCTURE, DAMP		29																

PID: 113602	SFN:	PROJECT: HAM-LMST EXT	STATION / OFFSET: 76+68, 36' RT.	START: 7/7/22	END: 7/8/22	PG 2 OF 2	B-002-0-20

MATERIAL DESCRIPTION AND NOTES	ELEV. 447.6	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
	446.6	TR 31	17 50/3"	-	89	SS-10	3.50	-	-	-	-	-	-	-	-	12	A-6a (V)	
INTERBEDDED LIMESTONE (51%) AND SHALE (49%), CONTAINS MANY INTERBEDDED 1/8" - 1/2" CLAY SEAMS, BEDDING DISCONTINUITIES: LOW ANGLE, HIGHLY FRACTURED TO MODERATELY FRACTURED, OPEN TO NARROW, SLIGHTLY ROUGH TO VERY ROUGH, BLOCKY/DISTURBED/SEAMY, GOOD TO FAIR SURFACE CONDITION, RQD 24%, REC. 90%; **LIMESTONE**, GRAY AND LIGHT GRAY, UNWEATHERED TO SLIGHTLY WEATHERED, MODERATELY STRONG TO STRONG, FINE TO COARSE GRAINED, LAMINATED TO THIN BEDDED, FOSSILIFEROUS, STYLOLITIC; **SHALE**, GRAY, SEVERELY TO HIGHLY WEATHERED, VERY WEAK TO WEAK, FISSILE.	436.6	32 33 34 35 36 37 38 39 40 EOB 41	24		90	NQ2-1											CORE	

NOTES: GROUNDWATER ENCOUNTERED AT 12.5' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 100 GAL. BENTONITE GROUT

OHIO DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING

Office of Geotechnical Engineering

B-002-0-20

Run #:	Depth		Recovery		RQD	
NQ2-1	31.0’	41.0’	108”/120”	90%	28.5”/120”	24%

HAM-LMST Extension to Ranchvale (PID #113602)

NEAS
National Engineering & Architectural Services Inc.

5710 Westbourne Avenue
Columbus, OH 43213
614-892-0162

Unconfined Compressive Strength of Cohesive Soil (ASTM D2166)

(Project: HAM-LMST Ext, Boring Location: B-002-0-20, ST-1, Depth: 7.9 - 8.4ft)

Tested Date: 7/11/2022

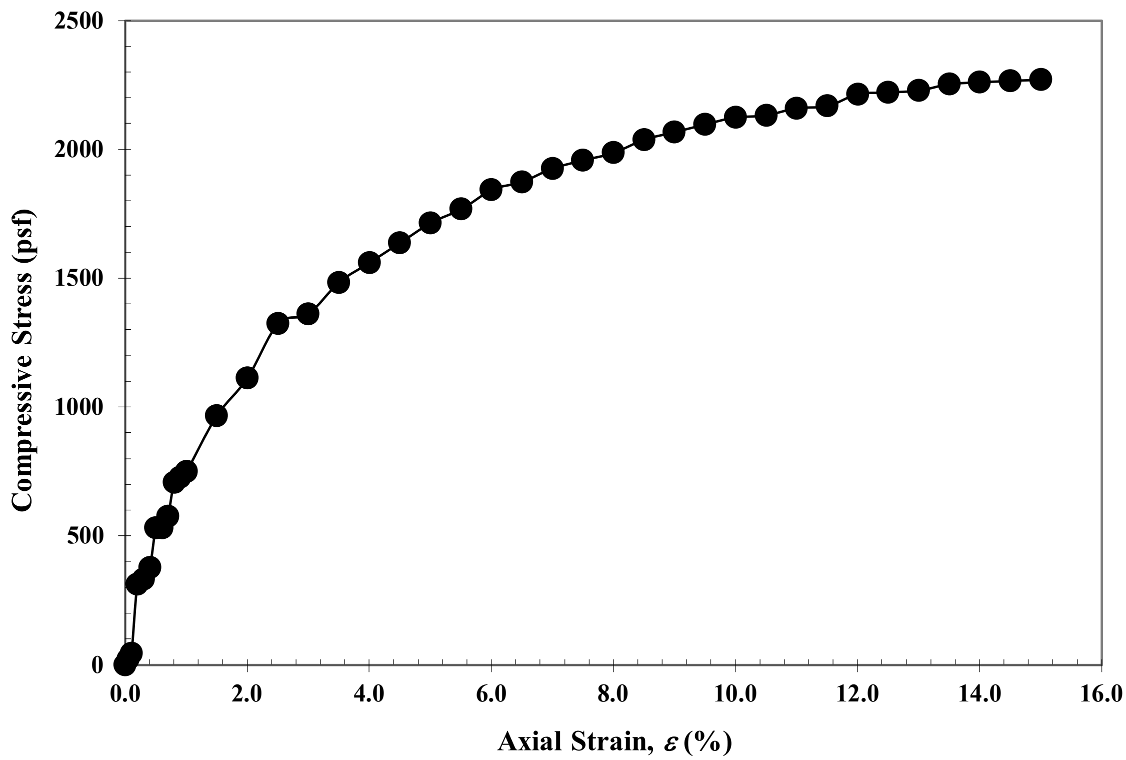
Specimen Properties

Average Dia., D_{avg} (in):	2.87
Average Height, H_{avg} (in):	5.75
Area, A (in^2):	6.47
Volume, V (in^3):	37.21
Wet Mass of Specimen (lb):	2.8
Moisture Content (%):	21.9
Dry Mass of Specimen (lb):	2.3
Wet Unit Weight, γ (lb/ft^3):	129.1
Dry Unit Weight, γ_d (lb/ft^3):	105.9

Final Specimen Figure

Results

Unconfined Compressive Strength (psf):	**2271**
Strain (%):	**15.0**



Notes: Stiff, brownish gray, SILTY CLAY, little sand, trace gravel, damp. Specimen contains gravel >1/6 specimen diameter. Results reported may differ from a specimen that meets the maximum particle size allowance of D2166. Specimen exceeded strain limitations of 15.0%.

NEAS
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Columbus, OH 43213
614.892.0162

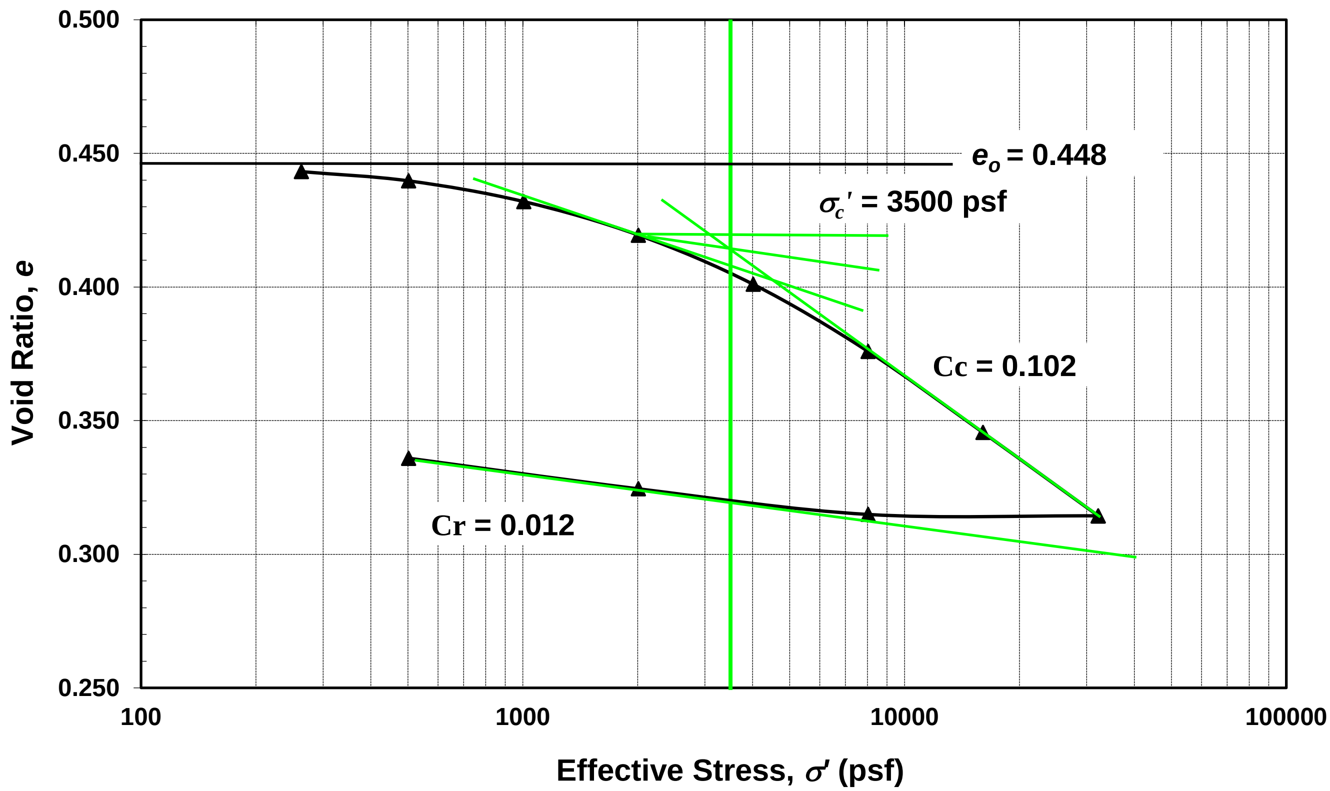
Consolidation Test

Project Name:	HAM-LMST Ext	Prepared by:	LR
Source:	B-002-0-20 ST-1 (8.4' - 8.5')	Checked by:	ZM
Description:	Stiff to very stiff, gray, SILTY CLAY, little sand, trace gravel, damp. After testing, a 7/16" gravel piece was found within the specimen.	Date:	7/29/2022
Test Specification:	ASTM D 2435		
Initial Void Ratio:	0.448	Initial Bulk Unit Weight (lb/ft^3):	135
In-situ Vertical Effective Stress (psf):	1100	Dry Unit Weight (lb/ft^3):	116

Compression and Swelling Index

Compression Index (*Cc*):	0.102	Preconsolidation Pressure (σ_c')(psf):	**3500**
Recompression Index (*Cr*):	0.012	Over-Consolidation Ratio (*OCR*):	**3.18**

Consolidation Curve



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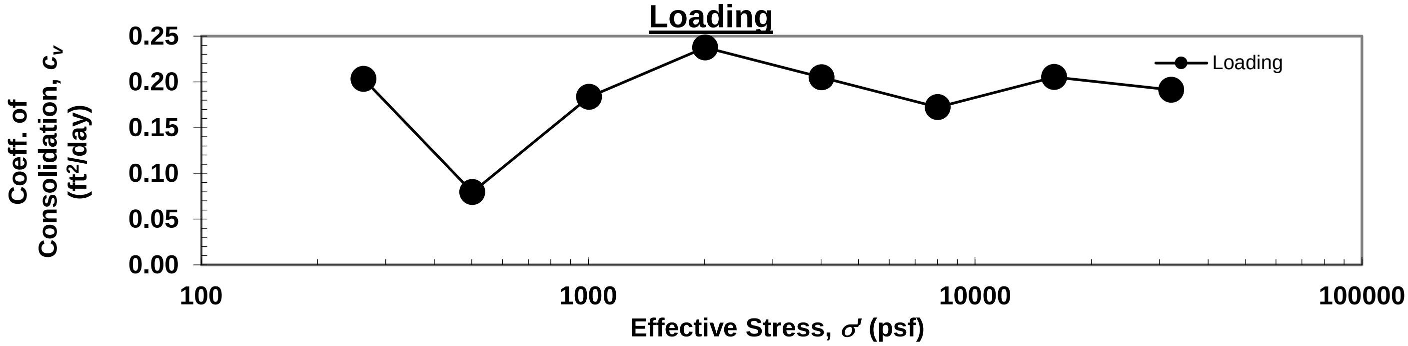


BEARING ANALYSIS

Approx. Bearing Ele. = 487 ft amsl and below

Objective: To determine the nominal bearing capacity of foundation soil for modular block wall design.
Method: In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].
Assumptions:

- **Modular block wall treated as continuous footing with breadth (B).**
- **Depth of footing (D_f).**
- **Depth correction factor (d_q) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 ($D_f / B \le 1$) or the soils above the footing are not as adequate as the bearing soils. Can change d_q below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 2\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 24\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

$$N_q := \text{if}\left(\phi_{fd} > 0, e^{\pi \cdot \tan(\phi_{fd})} \cdot \tan\left(45\ deg + \frac{\phi_{fd}}{2}\right)^2, 1.0\right) \qquad N_c := \text{if}\left(\phi_{fd} > 0, \frac{N_q - 1}{\tan(\phi_{fd})}, 5.14\right) \qquad N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fd})$$

$N_q = 9.6$ $\qquad N_c = 19.3$ $\qquad N_\gamma = 9.4$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $\qquad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$ — Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 8646\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\qquad q_R = 4.32\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 487 ft amsl and below

Objective: To determine the nominal bearing capacity of foundation soil for modular block wall design.
Method: In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].
Assumptions:

- **Modular block wall treated as continuous footing with breadth (B).**
- **Depth of footing (D_f).**
- **Depth correction factor (d_q) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 ($D_f/B \le 1$) or the soils above the footing are not as adequate as the bearing soils. Can change d_q below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 3\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 24\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

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

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

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

$N_q = 9.6$ $\quad N_c = 19.3$ $\quad N_\gamma = 9.4$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $\quad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$$

Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 9236\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\quad q_R = 4.62\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 487 ft amsl and below

Objective: **To determine the nominal bearing capacity of foundation soil for modular block wall design.**
Method: **In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].**
Assumptions:

- **Modular block wall treated as continuous footing with breadth (B).**
- **Depth of footing (D_f).**
- **Depth correction factor (d_q) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 ($D_f / B \le 1$) or the soils above the footing are not as adequate as the bearing soils. Can change d_q below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 4\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 24\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

$N_q := \text{if}\left(\phi_{fd} > 0, e^{\pi \cdot \tan(\phi_{fd})} \cdot \tan\left(45\ deg + \frac{\phi_{fd}}{2}\right)^2, 1.0\right)$ $\quad N_c := \text{if}\left(\phi_{fd} > 0, \frac{N_q - 1}{\tan(\phi_{fd})}, 5.14\right)$ $\quad N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fd})$

$N_q = 9.6$ $\quad N_c = 19.3$ $\quad N_\gamma = 9.4$

$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5)$ $\quad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$

$C_{wq} = 1$ $\quad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$ — Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 9826\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\quad q_R = 4.91\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 487 ft amsl and below

Objective: **To determine the nominal bearing capacity of foundation soil for modular block wall design.**
Method: **In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].**
Assumptions:

- **Modular block wall treated as continuous footing with breadth (** B **).**
- **Depth of footing (** D_f **).**
- **Depth correction factor (** d_q **) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 (** $D_f / B \le 1$ **) or the soils above the footing are not as adequate as the bearing soils. Can change** d_q **below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 5\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 24\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

$$N_q := \text{if}\left(\phi_{fd} > 0, e^{\pi \cdot \tan(\phi_{fd})} \cdot \tan\left(45\ deg + \frac{\phi_{fd}}{2}\right)^2, 1.0\right) \qquad N_c := \text{if}\left(\phi_{fd} > 0, \frac{N_q - 1}{\tan(\phi_{fd})}, 5.14\right) \qquad N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fd})$$

$N_q = 9.6$ $\qquad N_c = 19.3$ $\qquad N_\gamma = 9.4$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $\qquad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$ — Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 10417\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\qquad q_R = 5.21\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 488 ft amsl and above

Objective: **To determine the nominal bearing capacity of foundation soil for modular block wall design.**
Method: **In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].**
Assumptions:

- **Modular block wall treated as continuous footing with breadth (B).**
- **Depth of footing (D_f).**
- **Depth correction factor (d_q) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 ($D_f / B \le 1$) or the soils above the footing are not as adequate as the bearing soils. Can change d_q below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 2\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 26\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

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

$N_q = 11.9$

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

$N_c = 22.3$

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

$N_\gamma = 12.5$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $\quad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$$

Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 10464\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\quad q_R = 5.23\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 488 ft amsl and above

Objective: **To determine the nominal bearing capacity of foundation soil for modular block wall design.**
Method: **In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].**
Assumptions:

- **Modular block wall treated as continuous footing with breadth (** B **).**
- **Depth of footing (** D_f **).**
- **Depth correction factor (** d_q **) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 (** $D_f / B \le 1$ **) or the soils above the footing are not as adequate as the bearing soils. Can change** d_q **below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 3\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 26\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

$$N_q := \text{if}\left(\phi_{fd} > 0, e^{\pi \cdot \tan(\phi_{fd})} \cdot \tan\left(45\ deg + \frac{\phi_{fd}}{2}\right)^2, 1.0\right) \qquad N_c := \text{if}\left(\phi_{fd} > 0, \frac{N_q - 1}{\tan(\phi_{fd})}, 5.14\right) \qquad N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fd})$$

$N_q = 11.9$ $\quad N_c = 22.3$ $\quad N_\gamma = 12.5$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $\quad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$$

Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 11247\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\quad q_R = 5.62\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 488 ft amsl and above

Objective: To determine the nominal bearing capacity of foundation soil for modular block wall design.
Method: In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].
Assumptions:

- **Modular block wall treated as continuous footing with breadth (B).**
- **Depth of footing (D_f).**
- **Depth correction factor (d_q) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 ($D_f/B \le 1$) or the soils above the footing are not as adequate as the bearing soils. Can change d_q below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 4\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 26\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

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

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

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

$N_q = 11.9$ $N_c = 22.3$ $N_\gamma = 12.5$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

$$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$$

Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 12031\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $q_R = 6.02\ ksf$ — Factored bearing resistance

Approx. Bearing Ele. = 488 ft amsl and above

Objective: To determine the nominal bearing capacity of foundation soil for modular block wall design.
Method: In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].
Assumptions:

- **Modular block wall treated as continuous footing with breadth (B).**
- **Depth of footing (D_f).**
- **Depth correction factor (d_q) is equal to 1. Due to the foundation depth to breadth ratio assumed to be less than or equal to 1 ($D_f / B \le 1$) or the soils above the footing are not as adequate as the bearing soils. Can change d_q below for differing conditions.**

Givens:

Wall Geometry:

$D_f := 3\ ft$ — Depth to base of modular block wall

$B := 5\ ft$ — Width/Breadth of modular block wall

Foundation Soil Design Parameters:

$\phi_{fd} := 26\ deg$ — Angle of internal friction

$\gamma_{fd} := 125\ \frac{lbf}{ft^3}$ — Unit weight

$c_{fd} := 200\ \frac{lbf}{ft^2}$ — Cohesion (Undrained Shear Strength)

$d_w := 20\ ft$ — Depth of Groundwater below bottom of Bearing Elevation.

Bearing Resistance Calculation:

$$N_q := \text{if}\left(\phi_{fd} > 0, e^{\pi \cdot \tan(\phi_{fd})} \cdot \tan\left(45\ deg + \frac{\phi_{fd}}{2}\right)^2, 1.0\right) \qquad N_c := \text{if}\left(\phi_{fd} > 0, \frac{N_q - 1}{\tan(\phi_{fd})}, 5.14\right) \qquad N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fd})$$

$N_q = 11.9$ $\qquad N_c = 22.3$ $\qquad N_\gamma = 12.5$

$$C_{wq} := \text{if}(d_w \ge 0, 1, 0.5) \qquad C_{w\gamma} := \text{if}(d_w > 1.5 \cdot B, 1, 0.5)$$

$C_{wq} = 1$ $\qquad C_{w\gamma} = 1$ — Groundwater Factors

$d_q := 1.0$ — Depth Correction Factor

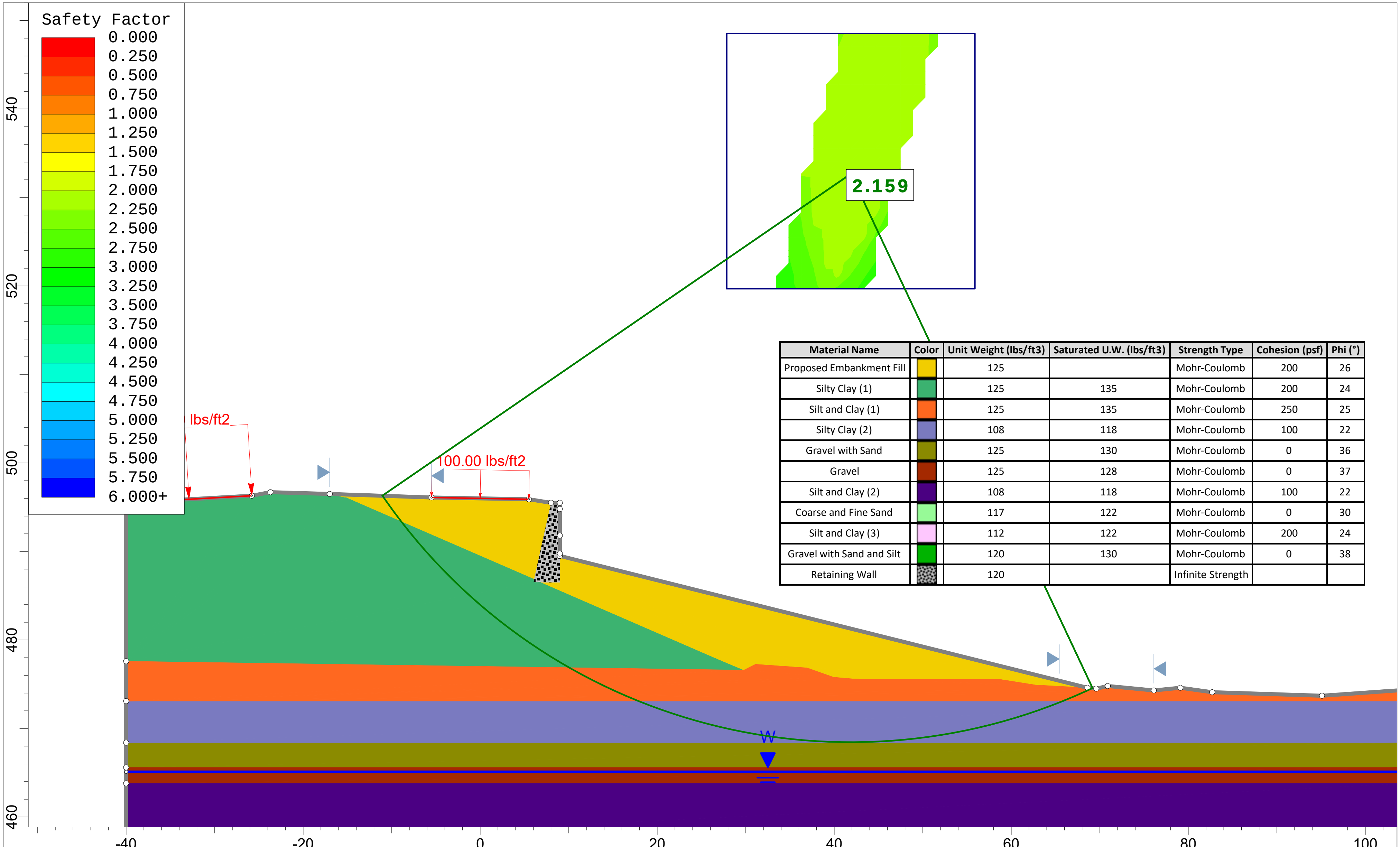
$q_n := c_{fd} \cdot N_c + \gamma_{fd} \cdot D_f \cdot N_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B \cdot N_\gamma \cdot C_{w\gamma}$ — Nominal bearing resistance (LRFD [Eq. 10.6.3.1.2a-1]

$q_n = 12815\ \frac{lbf}{ft^2}$

$\phi_b := 0.5$ — Bearing resistance factor (LRFD 10.5.5.2.2-1]

$q_R := \phi_b \cdot q_n$ $\qquad q_R = 6.41\ ksf$ — Factored bearing resistance

GLOBAL STABILITY



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	200	26
Silty Clay (1)		125	135	Mohr-Coulomb	200	24
Silt and Clay (1)		125	135	Mohr-Coulomb	250	25
Silty Clay (2)		108	118	Mohr-Coulomb	100	22
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	100	22
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	200	24
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

Project	HAM-Little Miami Scenic Trail to Elstun		
Analysis Description	RW1 Stability Analysis - Near STA. 75+00 (LMST) - Effective Stress - Circular Failure		
Drawn By	BPA	*Company*	NEAS Inc.
Date	9/7/2023	*File Name*	LMST-RW1_75+00_EffCirc_090723.slim

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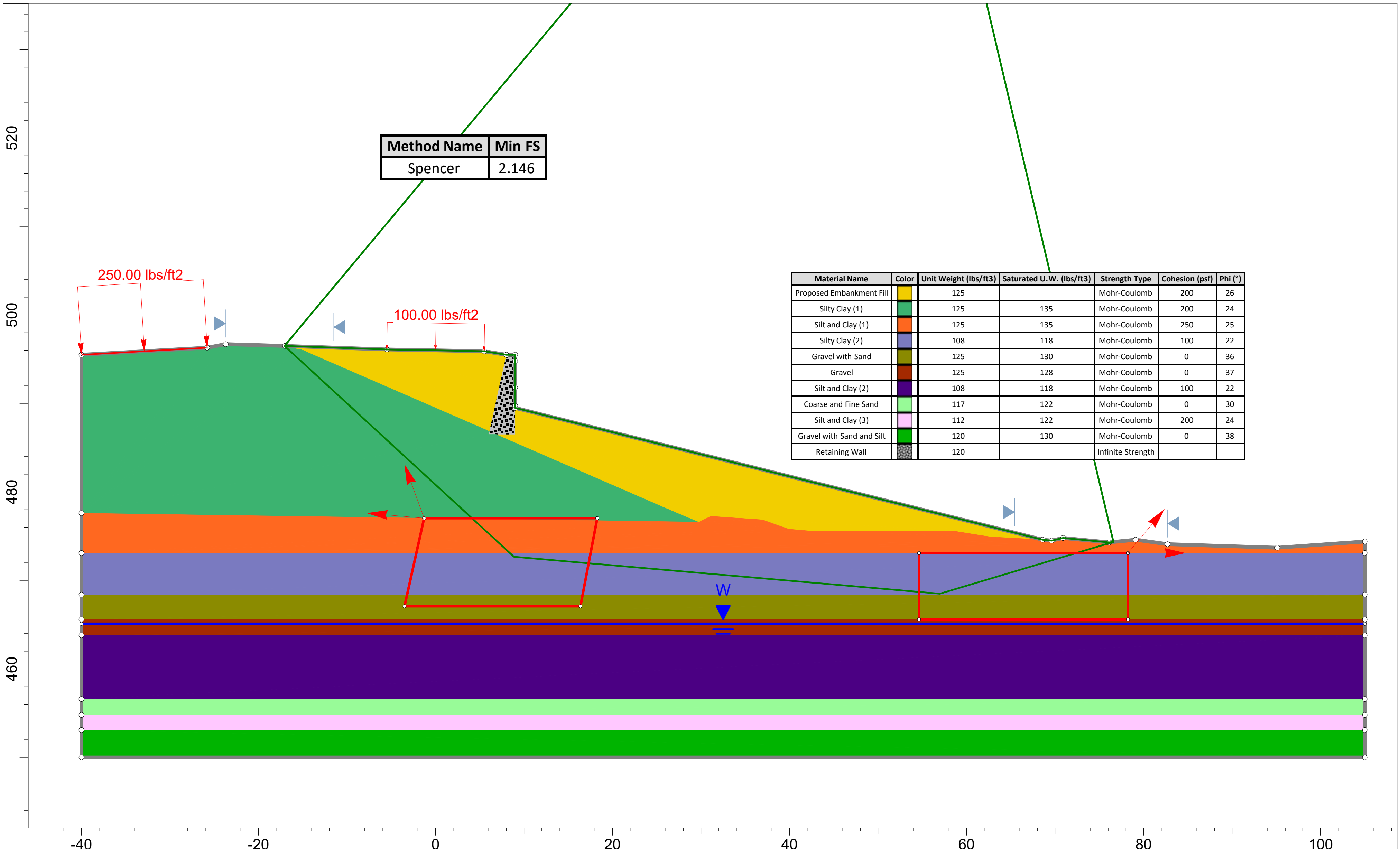
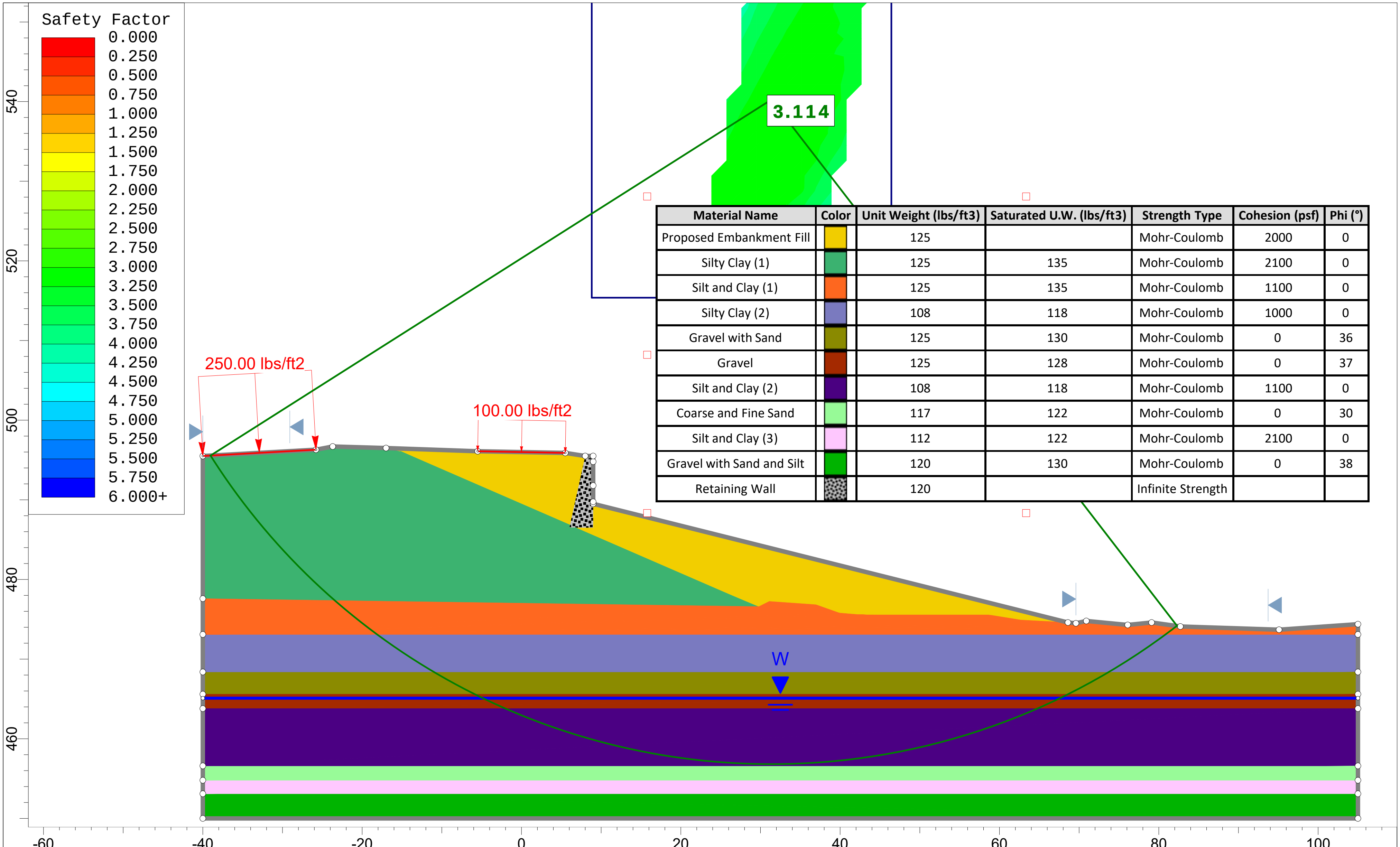


Method Name	Min FS
Spencer	2.146

Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	200	26
Silty Clay (1)		125	135	Mohr-Coulomb	200	24
Silt and Clay (1)		125	135	Mohr-Coulomb	250	25
Silty Clay (2)		108	118	Mohr-Coulomb	100	22
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	100	22
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	200	24
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

Project	HAM-Little Miami Scenic Trail to Elstun		
Analysis Description	RW1 Stability Analysis - Near STA. 75+00 (LMST) - Effective Stress - Block Failure		
Drawn By	BPA	*Company*	NEAS Inc.
Date	9/7/2023	*File Name*	LMST-RW1_75+00_EffBlock_090723.slim

SLIDEINTERPRET 9.028



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	2000	0
Silty Clay (1)		125	135	Mohr-Coulomb	2100	0
Silt and Clay (1)		125	135	Mohr-Coulomb	1100	0
Silty Clay (2)		108	118	Mohr-Coulomb	1000	0
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	1100	0
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	2100	0
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

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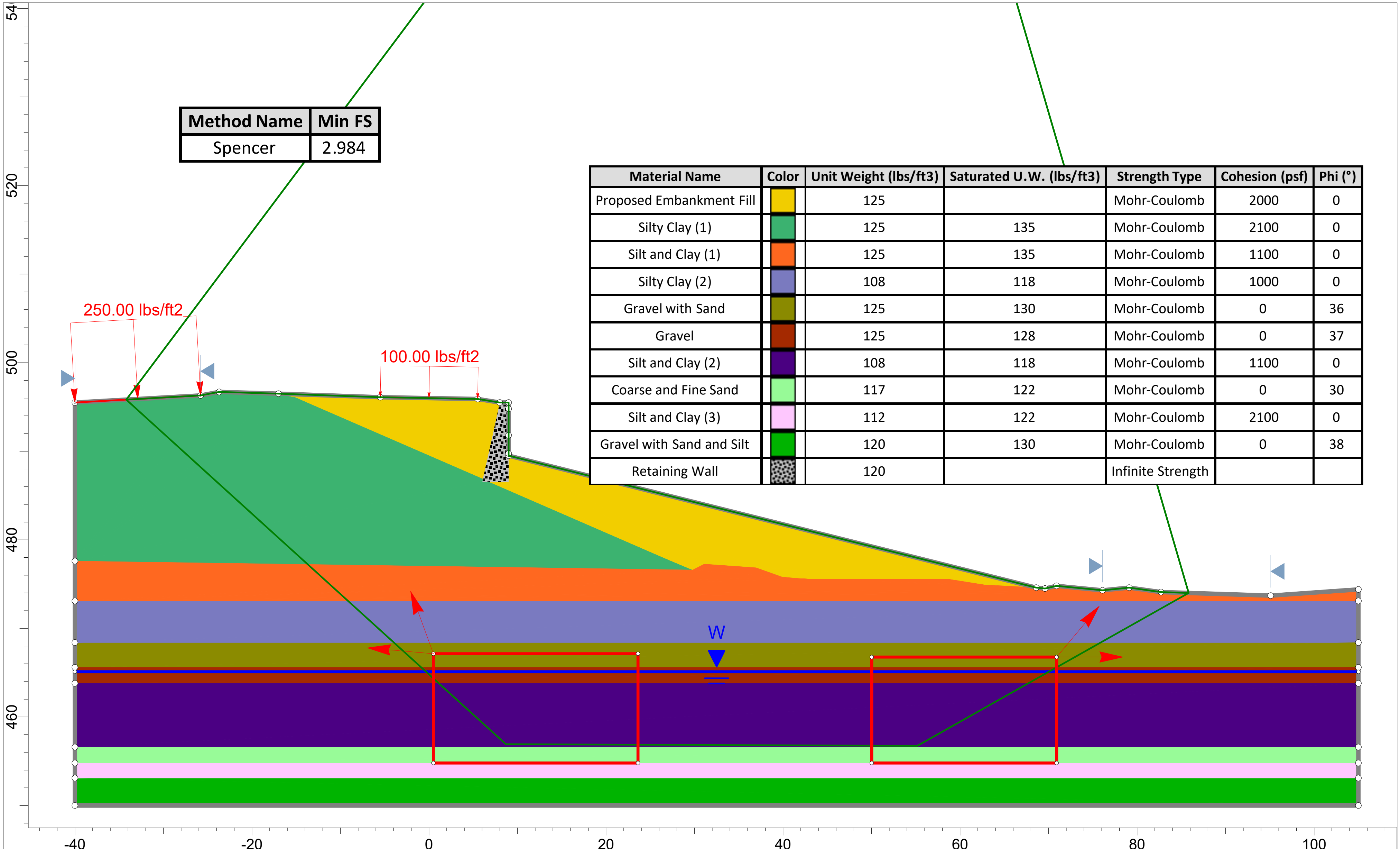
SLIDEINTERPRET 9.028

Project	HAM-Little Miami Scenic Trail to Elstun		
Analysis Description	RW1 Stability Analysis - Near STA. 75+00 (LMST) - Total Stress - Circular Failure		
Drawn By	BPA	*Company*	NEAS Inc.
Date	9/7/2023	*File Name*	LMST-RW1_75+00_TotCirc_090723.slim



Method Name	Min FS
Spencer	2.984

Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	2000	0
Silty Clay (1)		125	135	Mohr-Coulomb	2100	0
Silt and Clay (1)		125	135	Mohr-Coulomb	1100	0
Silty Clay (2)		108	118	Mohr-Coulomb	1000	0
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	1100	0
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	2100	0
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

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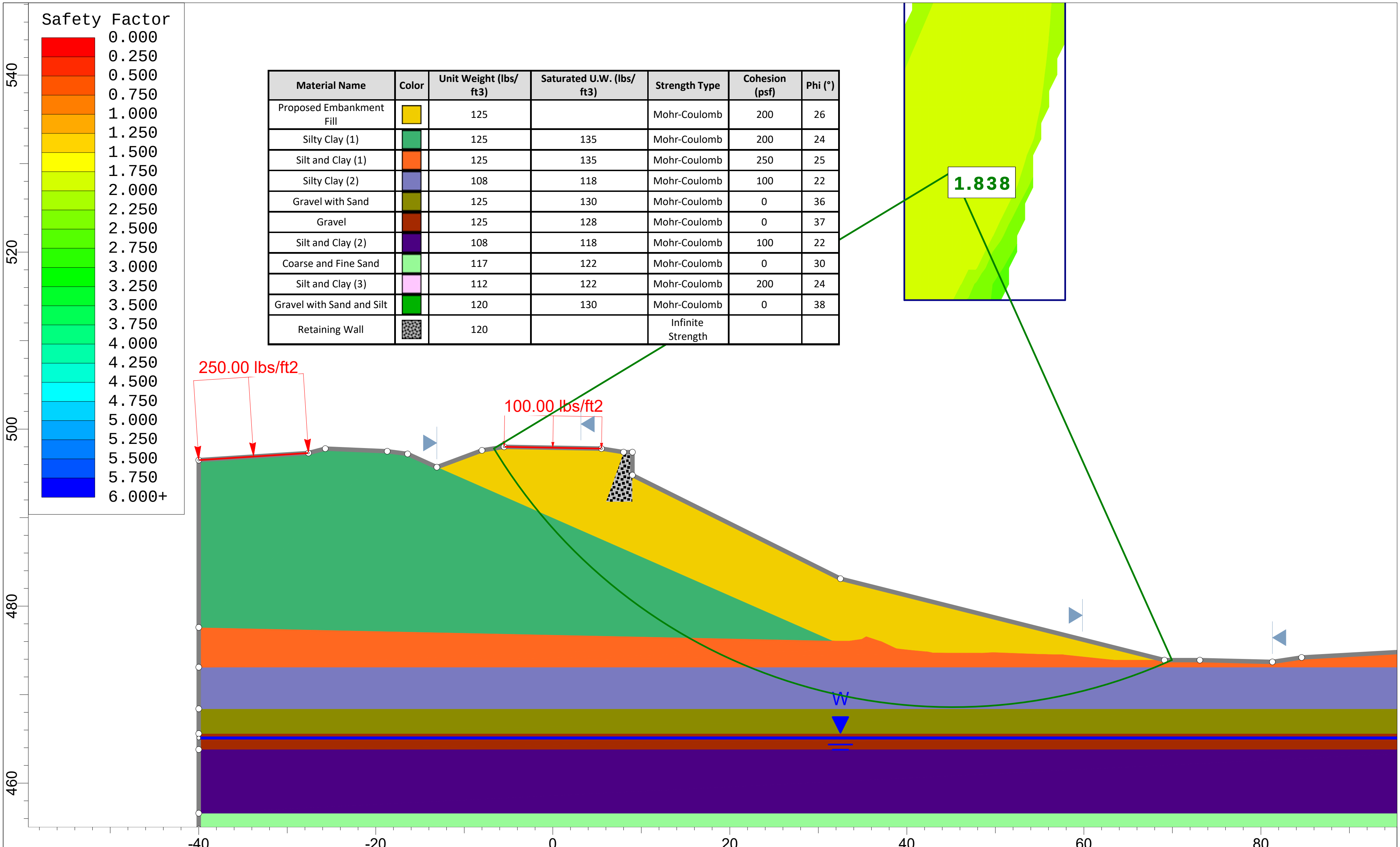
SLIDEINTERPRET 9.028

Project	HAM-Little Miami Scenic Trail to Elstun		
Analysis Description	RW1 Stability Analysis - Near STA. 75+00 (LMST) - Total Stress - Block Failure		
Drawn By	BPA	*Company*	NEAS Inc.
Date	9/7/2023	*File Name*	LMST-RW1_75+00_TotBlock_090723.slim



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	200	26
Silty Clay (1)		125	135	Mohr-Coulomb	200	24
Silt and Clay (1)		125	135	Mohr-Coulomb	250	25
Silty Clay (2)		108	118	Mohr-Coulomb	100	22
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	100	22
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	200	24
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

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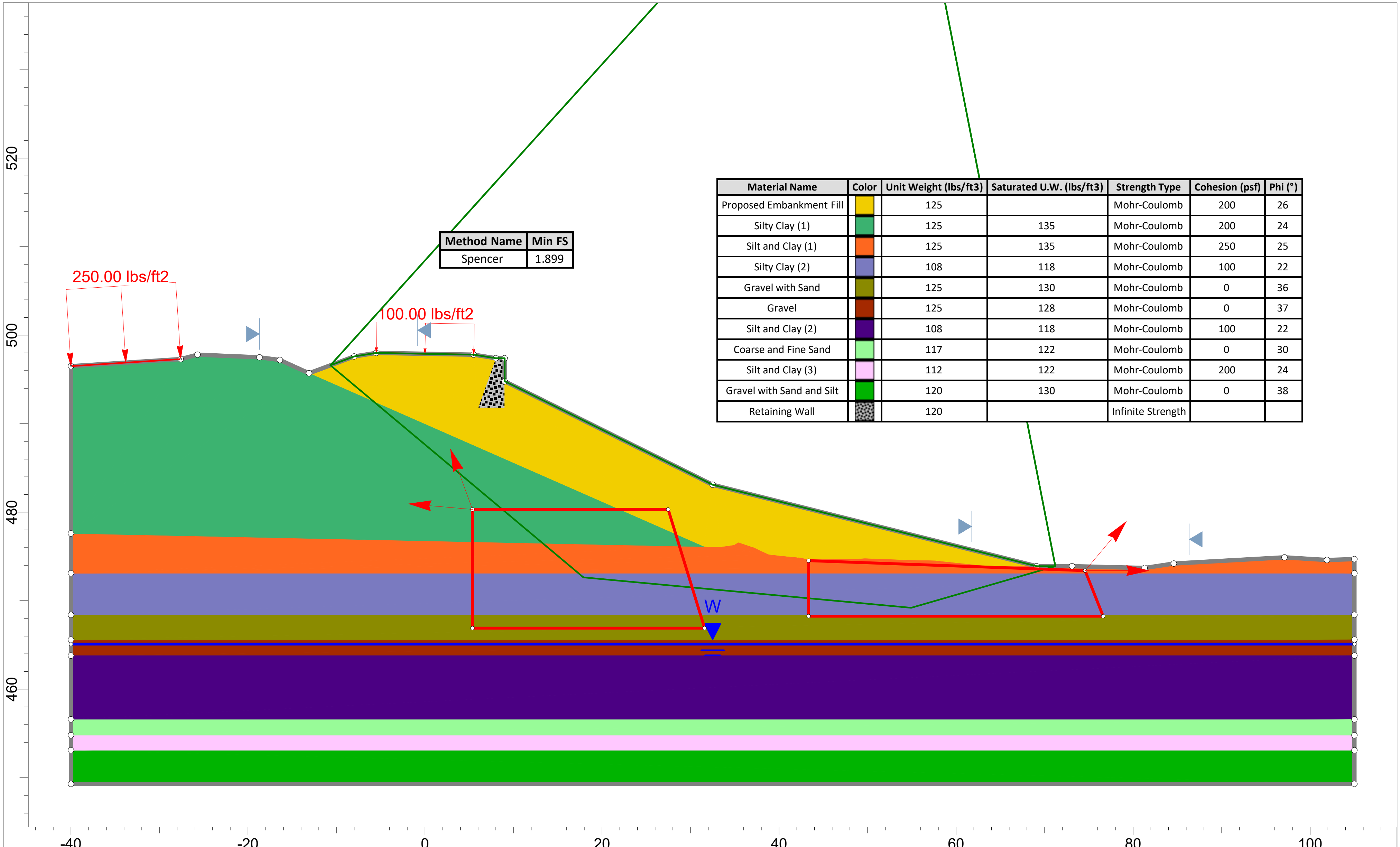
SLIDEINTERPRET 9.028

Project	HAM-Little Miami Scenic Trail to Elstun
Analysis Description	RW1 Stability Analysis - Near STA. 75+50 (LMST) - Effective Stress - Circular Failure
Drawn By	BPA
Company	NEAS Inc.
Date	8/31/23
File Name	LMST-RW1_75+50_EffCirc_083123.slim



Method Name	Min FS
Spencer	1.899

Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	200	26
Silty Clay (1)		125	135	Mohr-Coulomb	200	24
Silt and Clay (1)		125	135	Mohr-Coulomb	250	25
Silty Clay (2)		108	118	Mohr-Coulomb	100	22
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	100	22
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	200	24
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

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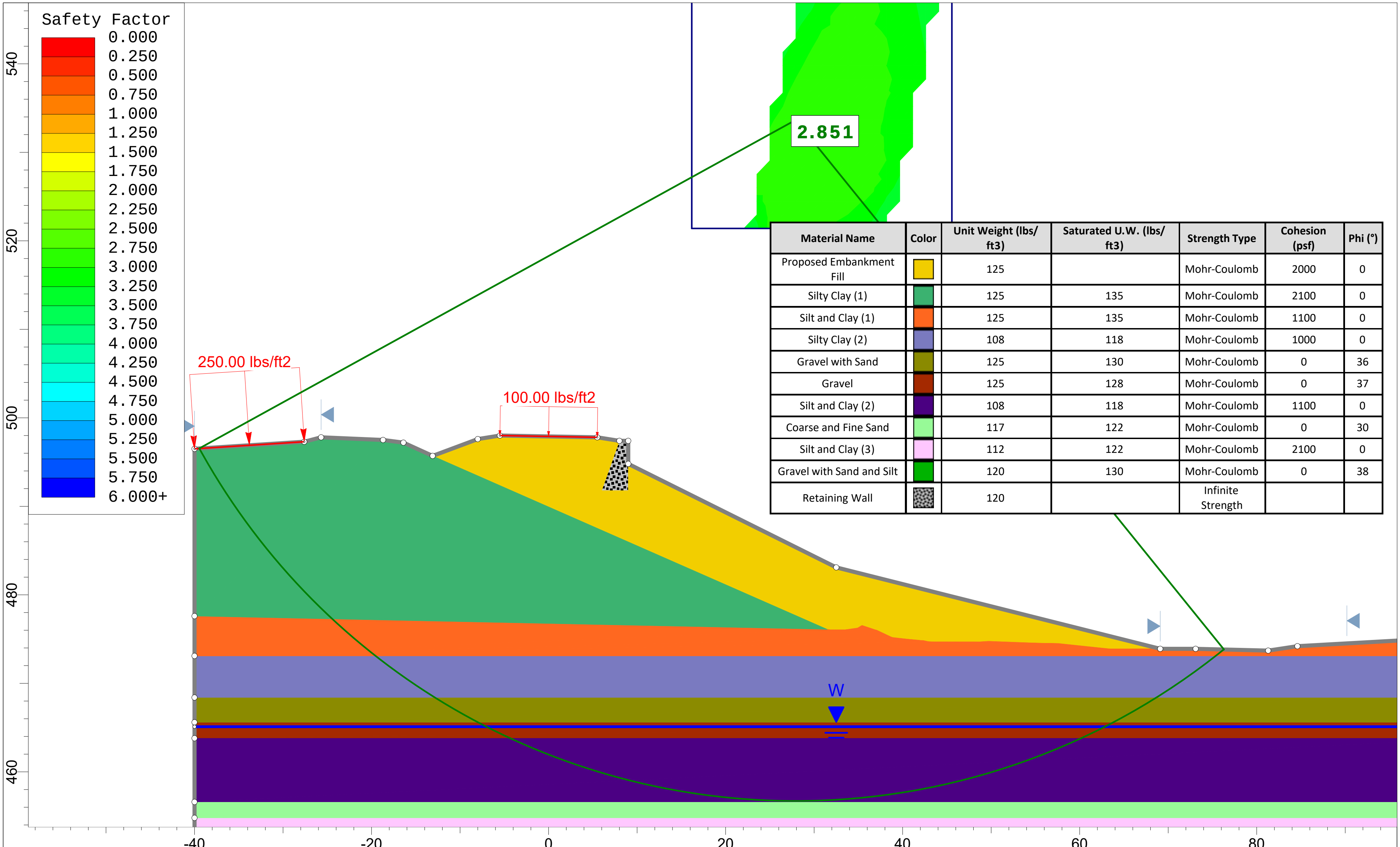
SLIDEINTERPRET 9.028

Project	HAM-Little Miami Scenic Trail to Elstun
Analysis Description	RW1 Stability Analysis - Near STA. 75+50 (LMST) - Effective Stress - Block Failure
Drawn By	BPA
Company	NEAS Inc.
Date	8/31/23
File Name	LMST-RW1_75+50_EffBlock_083123.slim



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	2000	0
Silty Clay (1)		125	135	Mohr-Coulomb	2100	0
Silt and Clay (1)		125	135	Mohr-Coulomb	1100	0
Silty Clay (2)		108	118	Mohr-Coulomb	1000	0
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	1100	0
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	2100	0
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

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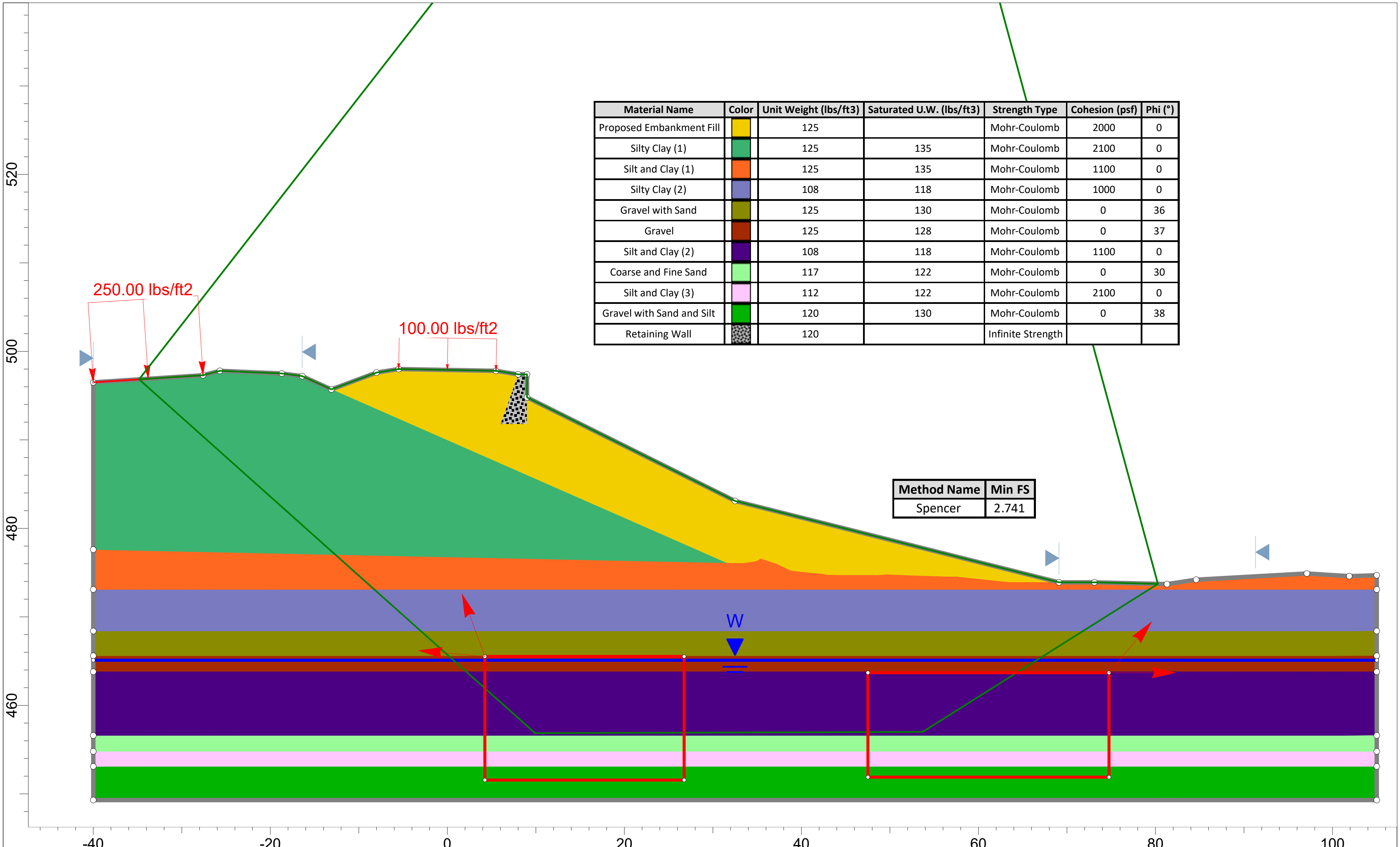
SLIDEINTERPRET 9.028

Project	HAM-Little Miami Scenic Trail to Elstun		
Analysis Description	RW1 Stability Analysis - Near STA. 75+50 (LMST) - Total Stress - Circular Failure		
Drawn By	BPA	*Company*	NEAS Inc.
Date	8/31/23	*File Name*	LMST-RW1_75+50_TotCirc_083123.slim



Material Name	Color	Unit Weight (lbs/ft3)	Saturated U.W. (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)
Proposed Embankment Fill		125		Mohr-Coulomb	2000	0
Silty Clay (1)		125	135	Mohr-Coulomb	2100	0
Silt and Clay (1)		125	135	Mohr-Coulomb	1100	0
Silty Clay (2)		108	118	Mohr-Coulomb	1000	0
Gravel with Sand		125	130	Mohr-Coulomb	0	36
Gravel		125	128	Mohr-Coulomb	0	37
Silt and Clay (2)		108	118	Mohr-Coulomb	1100	0
Coarse and Fine Sand		117	122	Mohr-Coulomb	0	30
Silt and Clay (3)		112	122	Mohr-Coulomb	2100	0
Gravel with Sand and Silt		120	130	Mohr-Coulomb	0	38
Retaining Wall		120		Infinite Strength		

Method Name	Min FS
Spencer	2.741

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SLIDEINTERPRET 9.028

Project	HAM-Little Miami Scenic Trail to Elstun		
Analysis Description	RW1 Stability Analysis - Near STA. 75+50 (LMST) - Total Stress - Block Failure		
Drawn By	BPA	*Company*	NEAS Inc.
Date	8/31/23	*File Name*	LMST-RW1_75+50_TotBlock_083123.slim