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GEOTECHNICAL EVALUATION REPORT

PROPOSED GRS-IBS BRIDGE

Route 6460 over Laguna Creek
Dennehotso, Arizona

WT Reference No. 2123JA038/3127JS001

PREPARED FOR:

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February 1, 2024

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ROUTE 6460 OVER LAGUNA CREEK
DENNEHOTSO, ARIZONA

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1.0 PURPOSE

This report contains the results of our geotechnical evaluation for the proposed bridge over Laguna Creek. The purpose of these services is to provide information and recommendations regarding bridge design and construction. The results of the field exploration and laboratory tests are presented in the Appendix.

2.0 PROJECT DESCRIPTION

The project will consist of constructing a bridge over Laguna Creek in Dennehotso, Arizona. The approximate bridge location is shown on the attached Site Location Diagram (Plate 1). The bridge will consist of a Geosynthetic Reinforced Soil - Integrated Bridge System (GRS-IBS) structure with a total span of 110 feet. The bridge plan and profile is shown on the attached Plate 2. The design details for the bridge are presented in greater detail in Section 5.2 of this report.

3.0 SCOPE OF SERVICES

3.1 Field Exploration

Four borings were drilled at the abutment locations for this project. The borings were advanced to depth of 25 to 38 feet. The borings were drilled at the approximate locations indicated on the attached Boring Location Diagram (Plate 3).

A WT engineer monitored the drilling operations and prepared a field log for each boring. These logs contain visual classifications of the materials encountered during drilling as well as interpolation of the subsurface conditions between samples.

The final boring logs, included in Appendix A, represent our interpretation of the field logs and may include modifications based on laboratory observations of the recovered samples. The final logs describe the materials encountered, their thicknesses, and the depths at which samples were obtained.

The Unified Soil Classification System was used to classify the soil. The soil classification symbols appear on the boring logs and are briefly described in Appendix A.

3.2 Laboratory Testing

Laboratory tests were performed on representative samples to aid in material classification and to estimate the pertinent engineering properties of the soil. Testing was performed in general accordance with applicable ASTM methodologies. The following tests were performed and the results are presented in Appendix B.

- Water Content
- Percent Passing the No. 200 Sieve
- Liquid and Plastic Limits
- Compression
- Sulfates, Chlorides, and pH

The laboratory test results were used in the development of the recommendations contained in this report.

3.3 Analyses and Report

Analyses were performed and this report was prepared for the exclusive purpose of providing geotechnical engineering information and recommendations. The scope of services for this project does not include, either specifically or by implication, any environmental assessment of the site or identification of contaminated or hazardous materials or conditions. If the owner is concerned about the potential for such contamination, other studies should be undertaken. We are available to discuss the scope of such studies with you.

This geotechnical engineering report includes a description of the project, a discussion of the field exploration and laboratory testing programs, a discussion of the subsurface conditions, and design recommendations as required to satisfy the purpose previously described.

4.0 SITE CONDITIONS

4.1 Surface

The bridge will be located in an undeveloped area east of an unimproved low-water crossing over Laguna Creek. The base of the low-water crossing is sandstone bedrock. The ground surface in the area of the bridge slopes down toward Laguna Creek. The banks of Laguna Creek are near vertical and are approximately 10 feet high. Groundcover generally consist of desert grasses and brush.

4.2 Subsurface

Very loose to medium dense Silty SAND (SM) was encountered in the borings to depths of about 9 to 13 feet. The Silty SAND was underlain by Sandstone bedrock that extended to the boring termination depths. The upper portion of the Sandstone was weathered and therefore it was not possible to core the rock until the boring was advanced several feet into the Sandstone.

4.3 Groundwater

Groundwater was encountered in the borings at depths of about 9 to 13 feet during drilling. The level of the groundwater table will fluctuate seasonally with variations in the amount of precipitation, evaporation, and the water level in Laguna Creek. The observations made during this investigation must be interpreted carefully because they are short-term and do not constitute a groundwater study.

5.0 RECOMMENDATIONS

5.1 General

The recommendations contained in this report are based on our understanding of the project criteria described in Section 2.0, **Project Description**, and the assumption that the subsurface conditions are those disclosed by the test borings. Others may change the plans, final elevations, number and type of structures, foundation loads, and floor levels during design or construction. Substantially different subsurface conditions from those described herein may be encountered or become known. Any changes in the project criteria or subsurface conditions shall be brought to our attention in writing.

5.2 General GRS-IBS Information

The Geosynthetic Reinforced Soil - Integrated Bridge System (GRS-IBS) provides an economical solution to accelerated bridge construction. It is a fast, cost-effective method of bridge support that blends the roadway into the superstructure to create a jointless interface between the bridge and the approach. It consists of three main components: 1) the reinforced soil foundation (RSF), 2) the abutment, and 3) the integrated approach.

The RSF is composed of granular fill that is compacted and encapsulated with a geotextile fabric. It provides embedment and increases the bearing width and capacity of the GRS abutment. It also prevents water from infiltrating underneath and into the GRS mass from a river or stream crossing. The abutment uses alternating layers of compacted fill and closely spaced geosynthetic reinforcement to provide support for the bridge, which is placed directly on the GRS abutment without a joint and without cast-in-place (CIP) concrete. GRS is also used to construct the integrated approach to transition to the superstructure. This bridge system therefore alleviates the “bump at the bridge” problem caused by differential settlement between bridge abutments and approach roadways.

This geotechnical design of the GRS-IBS for the Dennehotso Bridge is based on the following FHWA publications:

- FHWA-HRT-11-027 “Geosynthetic Reinforced Soil Integrated Bridge System Synthesis Report” (January 2011)
- FHWA-HRT-17-080 “Design and Construction Guidelines for Geosynthetic Reinforced Soil Abutments and Integrated Bridge Systems” (June 2018)
- GRS-IBS Design Spreadsheet (LRFD), 05-20-2021.xlsx

Some of the current limits on GRS-IBS are for the span of the bridge with maximum spans in the range of 100 ft up to 140 ft; maximum height of the abutments of about 30 ft, and bearing stress on the abutments less than or equal to 4,000 pounds per square foot (psf). It is recommended that if the bearing stresses on the abutments are greater than 4,000 psf, the performance criteria must be checked against the applicable stress-strain curve resulting from a performance test. The performance criteria for GRS-IBS consists of a tolerable vertical strain of 0.5 percent and lateral strain of 1 percent.

GRS-IBS abutment capacities are dependent on a combination of the strength of the fill and the strength of the reinforcement when built in accordance with the two rules of GRS construction: 1) sufficient compaction (95 percent of maximum dry unit weight, according to AASHTO T99) of high-quality granular fill and 2) closely spaced layers of reinforcement (12 inches or less).

The geotechnical design of GRS-IBS includes checking the internal and external stability of the structure. The external stability analysis checks for the direct sliding, bearing capacity, global stability and overturning. The internal stability analysis checks for vertical capacity either by the empirical method or by the analytical method, deformations (both vertical and lateral deformations) and the required reinforcement strength.

5.3 Bridge Details

Based on the proposed bridge details provided by Client, the following geometric information was obtained for the geotechnical analysis:

- Span Length = 110 feet
- Maximum Wall Height = 20 feet
- Base Width of Wall = 10 feet
- Clear Space = 5 inches

The maximum wall height was based upon raising the site grades approximately 10 feet in order to develop the finish site grades and bearing the abutments 2 feet into the sandstone. The sandstone was encountered at depths of approximately 9 to 13 feet at the boring locations. A total wall height of 20 feet was therefore used for design.

The minimum clear space (d_e) is defined as the distance from the top of the uppermost facing block to the bottom of the superstructure, should be 3 inches of 2 percent of the abutment height, whichever is greater. The gap is to ensure that the superstructure does not bear on the facing block due to an unforeseen event. For this particular project, an abutment height of 20 ft (240 inches), the clear space is about 4.8 inches (2 percent of abutment height).

5.4 Bridge Loading

The structural loads, as provided by Client, are presented in the following table.

TABLE 1 - BRIDGE LOADING

Maximum Applied Structural Loads		
Location	**Service I**	**Strength I**
Abutment 1	728 Kips	1,020 Kips
Abutment 2	728 Kips	1,020 Kips

The FHWA design methodology uses the Dead Load and Live Load as input parameters. It was assumed that the Dead Load would be about 75 percent of the Total Loads presented in Table 1. This translates into a Dead Load of 546 kips per abutment under the Service I condition. The Live Loads were estimated as about 25 percent of the Total Loads on Table 1. The Live Loads consider bridge's geometric information (Approach Roadway Live Load) and Bridge Live Load, which is based on applying the HL-93 LL model. A Live Load of 182 Kips was used for the analysis.

5.5 Soil and Reinforcement Parameters

Three different soil zones must be considered in the analysis of GRS-IBS structures: (1) reinforced soil zone, (2) retained soil zone (the zone right behind the reinforced soil zone), and (3) foundation soil zone. The following properties were used in the analysis/design of the GRS-IBS structure:

TABLE 2 - DESIGN SOIL PROPERTIES

Soil Property	Reinforced Soil	Retained Soil	Foundation Soil
Unit Weight	110 pcf	100 pcf	110 pcf
Cohesion	0 psf	0 psf	0 psf
Angle of Internal Friction	45°	32°	45°

The retained soil properties correspond to the properties of the native material determined in the laboratory by the direct shear test. Due to the granular nature and relatively low moisture content of the collected ring samples, no direct shear tests could be performed on the samples. The properties for the Reinforced Soil and Foundation Soil zones must satisfy the requirements of one of the two rules of a successful GRS construction, that is, to provide sufficient compaction (95 percent of maximum dry unit weight, according to AASHTO T99) of a high-quality granular fill.

The global stability analysis was performed using commercial software Slope/W *v23.1.2* developed by SeeQuent's GeoSlope. The analysis was based upon the GRS-IBS being supported by the Sandstone formation. The following design parameters were conservatively assumed for the sandstone in the ReSSA analysis:

- Unit Weight: 125 pcf
- Cohesion: 4,000 psf

The GRS-IBS design methodology requires the reinforcement elements to consist of geosynthetic material with an ultimate strength of at least 4,800 lbs/ft, and a strength at 2% of deformation of at least 1,370 lbs/ft. Geosynthetic materials used in all in-service GRS-IBSs structures have been a biaxial, woven polypropylene (PP) geotextiles. These material properties were used in the analysis.

5.6 Load Resistance Factors

The load and resistance factors used in the analysis and design of the GRS-IBS structure were the default values presented in the FHWA Excel spreadsheet which are based on AASHTO LRFD Bridge Design Specifications Manual, 2010. The following load factors were used in the analysis:

TABLE 4 - LOAD FACTORS

Type of Load	Load Factor	
	Maximum	Minimum
Dead Load	1.25	0.90
Horizontal Active Earth Pressure	1.50	0.90
Vertical Earth Pressure	1.35	1.00
Earth Surcharge	1.50	0.75
Live Load Surcharge	1.75	----

The following resistance factors were used in the analysis/design:

TABLE 5 - RESISTANCE FACTORS

Resistance	Factor
Capacity Resistance	0.45
Reinforcement Resistance	0.40
Soil-Sliding Resistance	1.00
Bearing Capacity Resistance	0.65

5.7 Analysis and Design

The analysis and design was performed utilizing FHWA Excel Spreadsheet GRS-IBS Design Spreadsheet (LRFD), 05-20-2021.xlsx using the information presented above.

The initial analysis and design considered a Bridge Beam Seat Width (Bearing Seat) of 6 ft as indicated on Foundation Plan sheet 3/10 and a Reinforcement Spacing of 8 inches but the analysis indicated that this configuration FAILED on the Ultimate Capacity check and on the Reinforcement Strength Check indicating that the reinforcement spacing should be decreased. It was also cautioned that the applied vertical stress should be limited it 4,000 psf; the analysis resulted on an applied vertical stress of 4,507 psf. A final flag was issued in the analysis indicating that a bearing bed reinforcement was needed. The bearing bed reinforcement are the short length reinforcement layers placed in between the primary reinforcement layers under the Bearing Seat of the box girders for up to a depth of 6.67 ft or adding 10 short length reinforcement layers.

In order to improve the design the length of the Beam Seat Width was increased to 6.5 ft and the Reinforcement Spacing was reduced to 6 inches. This configuration reduced the Applied Vertical Stress to 4,268 psf (still issuing a CAUTION because the Applied Vertical Stress was higher than 4,000 psf) and indicating that Bearing Bed Reinforcements were needed up to a depth of 2.25 ft or adding 5 short length intermediate reinforcement layers. In order to reduce the applied vertical stress to a value equal to or less than 4,000 psf it would be necessary to increase the length of the Beam Seat Width but then an issue regarding a negative eccentricity on the Bearing Capacity analysis is raised causing a red flag in the analysis. As mentioned at the beginning of this section, if the bearing stresses on the abutments are greater than 4,000 psf, a performance criteria consisting of checking the tolerable vertical strain of 0.5 percent and lateral strain of 1 percent must be performed; Figure 20 on FHWA-HRT-11-026 shows a design envelope for vertical capacity and strain at 8-inch reinforcement spacing indicating that for applied vertical stress of about 4,300 psf the vertical strain is approximately 0.45% or slightly less than the tolerable 0.5%. It should be noted that for a smaller reinforcing spacing the vertical strain should also be smaller value. The results of the Internal Stability analysis/design indicates that the performance criteria is OK.

The results of the global stability analysis performed using the Slope/W Version 23.1.2 software by SeeQuent's GeoSlope yielded a Factor of Safety of 2.92 which is a much greater value than the minimum required of 1.5. The analysis considered the Dead Load (DL) pressure plus the Live Load (LL) pressure at the abutments plus the surcharge loads dur to the Road Basse Surcharge and the Approach Roadway Live Load. The output sheets of this analysis are presented in the appendices (Appendix D).

The output sheets for the Excel GRS-IBS Design Spreadsheet_05-20-2021.xlsx are presented in the appendices (Appendix C).

5.8 Recommendations

A review of the set of drawings provided by Client and results of the analysis/design performed with the FHWA Excel spreadsheet indicates that the proposed design is acceptable with the modification of increasing the Beam Seat Width from 6 ft to 6.5 ft in order to reduce the applied vertical stress on the abutments, and using a Reinforcement Spacing of 6 inches and the addition of Bearing Bed Reinforcement within the upper 2.25 ft in between the primary reinforcing layers.

5.9 Seismic Considerations

Based on a study completed for the Arizona Department of Transportation (1992), the maximum anticipated horizontal accelerations of bedrock for the site are 0.02 and 0.05. These values assume a 90 percent probability of non-exceedance within 50 and 250 years, respectively.

6.0 EARTHWORK

6.1 General

The conclusions contained in this report for the proposed construction are contingent upon compliance with recommendations presented in this section. Any excavating, trenching, or disturbance which occurs after completion of the earthwork must be backfilled, compacted, and tested in accordance with the recommendations contained herein. It is not reasonable to rely upon our conclusions and recommendations if any unobserved and untested trenching, grading or backfilling occurs.

6.2 Site Clearing

Site clearing may involve removal of existing structure, base course, earth embankment, temporary drainage structures, utility lines, guard rail fences and some other small features. Areas disturbed by the removal of these items should be excavated down to dense, undisturbed soil, and backfilled with native materials compacted to the appropriate densities indicated below. All exposed surfaces after clearing should be free of mounds and depressions which could prevent uniform compaction.

6.3 Excavation

The excavations for the GRS-IBS structure should conform to Section 203-5.03(A) of ADOT Standard Specifications and OSHA Construction Standards for Excavations.

We anticipate that excavations in the overburden material for the proposed construction can be accomplished with conventional equipment. Once the underlying bedrock is encountered, heavy duty, specialized equipment such as hoe rams or jack hammers, possibly together with drilling and blasting, may be required to achieve the required foundation depth.

6.4 Temporary Slopes on Soils (back of reinforced soil zone)

The overburden soils in this area consist mostly of very loose to medium dense (low blow counts and consequently low shear strength) sands, Silty SAND. They classify as Type C soils according to OSHA and the maximum allowable slopes for cuts up to 20 ft high is 1 1/2H:1V.

6.5 Materials

Based on the tests performed on samples from native material, it is recommended that this material not be used as backfill material in the reinforced zones.

Based on FHWA-HRT-12-051 "Sample Guide Specifications for Construction of Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS)" it is recommended that select material (from borrow sources) conforming to the following gradation requirements be used as backfill material in the reinforced zones.

Description	Values	
	Well-Graded Material	Open-Graded Material
Maximum Grain Size (inches)	0.5 - 2	0.5 – 2
Percent Passing the No. 200 Sieve	≤ 12	≤ 5

- Plasticity Index (PI) ....6 Max.
- Angle of Internal Friction .... 45° Min.
- Backfill material for the reinforced soil zones shall be substantially free of shale or any other poor durability particles.

- Backfill material for the reinforced soil zones shall have a magnesium sulfate loss of less than 30 percent after four cycles or a sodium sulfate soundness loss of less than 15 percent after five cycles.

If imported material is required to backfill within the retained soil zone, we recommend the follow gradation:

- Gradation (ASTM C136):

	percent finer by weight
6"	100
4"	70-100
No. 4 Sieve	50-100
No. 200 Sieve	50 (max)

- Maximum expansive potential(%)* 1.5

- Maximum soluble sulfates(%) 0.10

* Measured on a sample compacted to approximately 95 percent of the ASTM D698 maximum dry density at about 3 percent below optimum water content. The sample is confined under a 100 psf surcharge and submerged.

Geosynthetics material may be manufactured from polypropylene, high-density polyethylene, or polyester. It can be either uniaxial or biaxial. When a uniaxial type is used, higher-strength axis must be placed perpendicular to the wall face. It must have a minimum ultimate tensile strength of 4,800 lbs/ft and a reinforcement strength at 2% strain greater than the unfactored required reinforcement strength (1,370 lbs/ft).

6.6 Placement and Compaction

a. Place and compact fill in horizontal lifts, using equipment and procedures that will produce recommended water contents and densities throughout the lift. Hand-held or hand-guided equipment should be used to compact backfill material within 3 feet of the facing members.

b. Uncompacted fill lifts, other than reinforced zone backfill, should not exceed 10 inches. For the reinforced soil zone backfill, uncompacted fill lifts should not exceed 6 inches or the required reinforcement spacing by design.

c. Materials should be compacted a minimum of 95% of the maximum dry density as determined in accordance with the requirements of Arizona Test Method 225 or ASTM Test Method D698. The top five (5) feet of the abutment shall be compacted to 100% of the maximum dry density as determined in accordance with the requirements of Arizona Test Method 225 or ASTM Test Method D698.

d. Placement and compaction of backfill should generally comply with Sections 203-5.03(B)(3) and 203-5.03(B)(4) of the ADOT Standard Specifications with some appropriate modifications for the placement and compaction of backfill material for the MSE walls.

e. Jetting should not be allowed as a method of soil densification.

6.7 Compliance

The retained backfill around and behind the reinforced zones, within the reinforced zone of the GRS-IBSs should be tested to verify that the material is adequately compacted. The testing should generally comply with appropriate ASTM or AASHTO procedures.

7.0 LIMITATIONS

This report has been prepared assuming the project criteria described in Section 2.0. If changes in the project criteria occur, or if different subsurface conditions are encountered or become known, the conclusions and recommendations presented herein shall become invalid. In any such event, contact WT to assess the effect that such variations may have on our conclusions and recommendations. If WT is not retained for the construction observation and testing services to determine compliance with this report, our professional responsibility is accordingly limited.

The recommendations presented are based entirely upon data derived from a limited number of samples obtained from widely spaced borings. The attached logs are indicators of subsurface conditions only at the specific locations and times noted. This report assumes the uniformity of the geology and soil structure between borings, however variations can and often do exist. Whenever any deviation, difference or change is encountered or becomes known, WT should be contacted.

This report is for the exclusive benefit of our client alone. There are no intended third-party beneficiaries of our contract with the client or this report, and nothing contained in the contract or this report shall create any express or implied contractual or any other relationship with, or claim or cause of action for, any third party against WT.

This report is valid until the earlier of one year from the date of issuance, a change in circumstances, or discovered variations. After expiration, no person or entity shall have any right to rely on this report without the express written authorization of WT.

8.0 CLOSURE

We prepared this report as an aid to the designers of the proposed project. The comments, statements, recommendations and conclusions set forth in this report reflect the opinions of the authors. These opinions are based upon data obtained at the boring locations. Work on your project was performed in accordance with generally accepted standards and practices utilized by professionals providing similar services in this locality. No other warranty, express or implied, is made.

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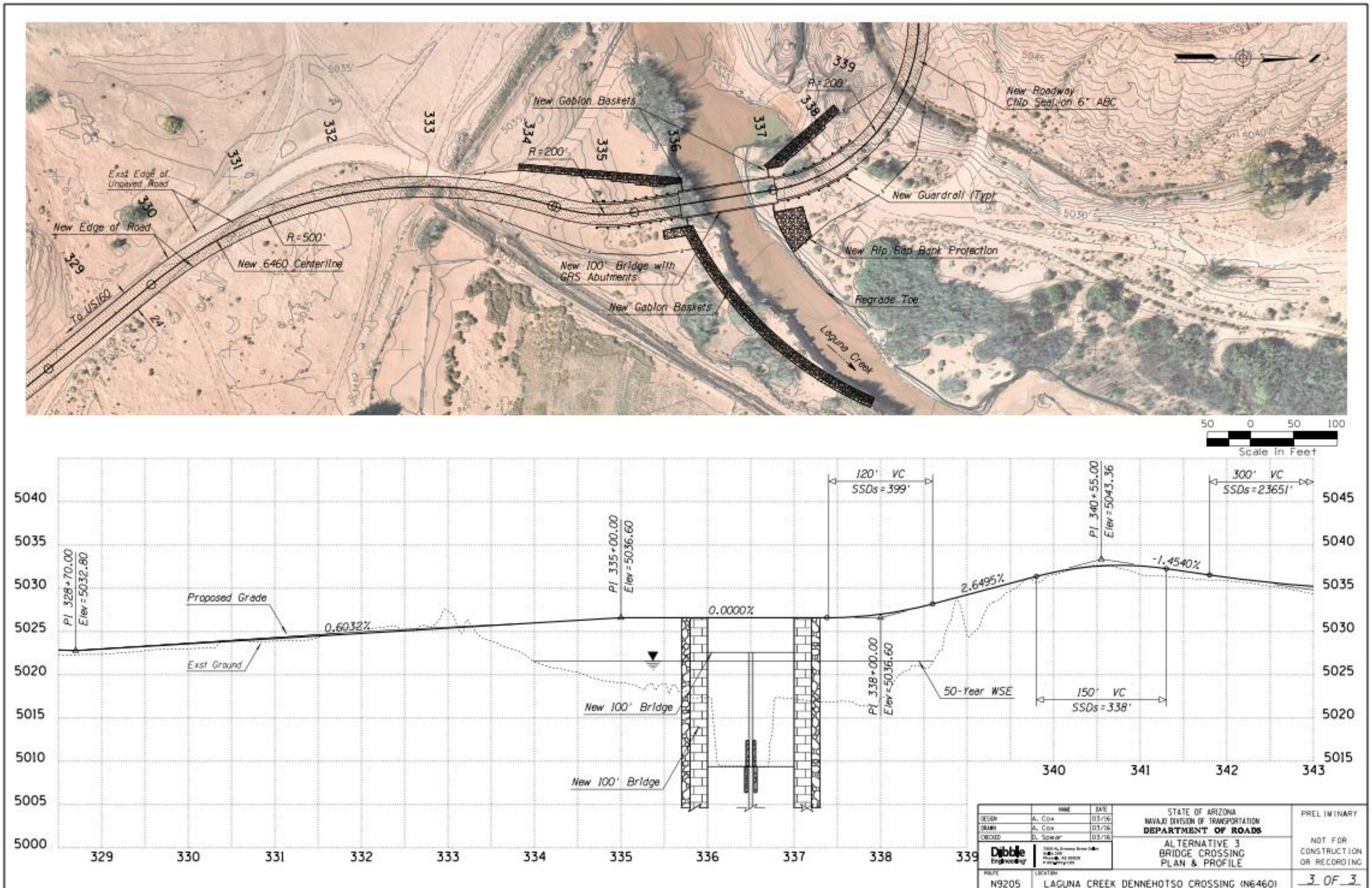
PROJECT: PROPOSED LAGUNA CREEK DENNEHOTSO CROSSING

JOB NO.: 3127JS001

SITE LOCATION DIAGRAM

PLATE: 1



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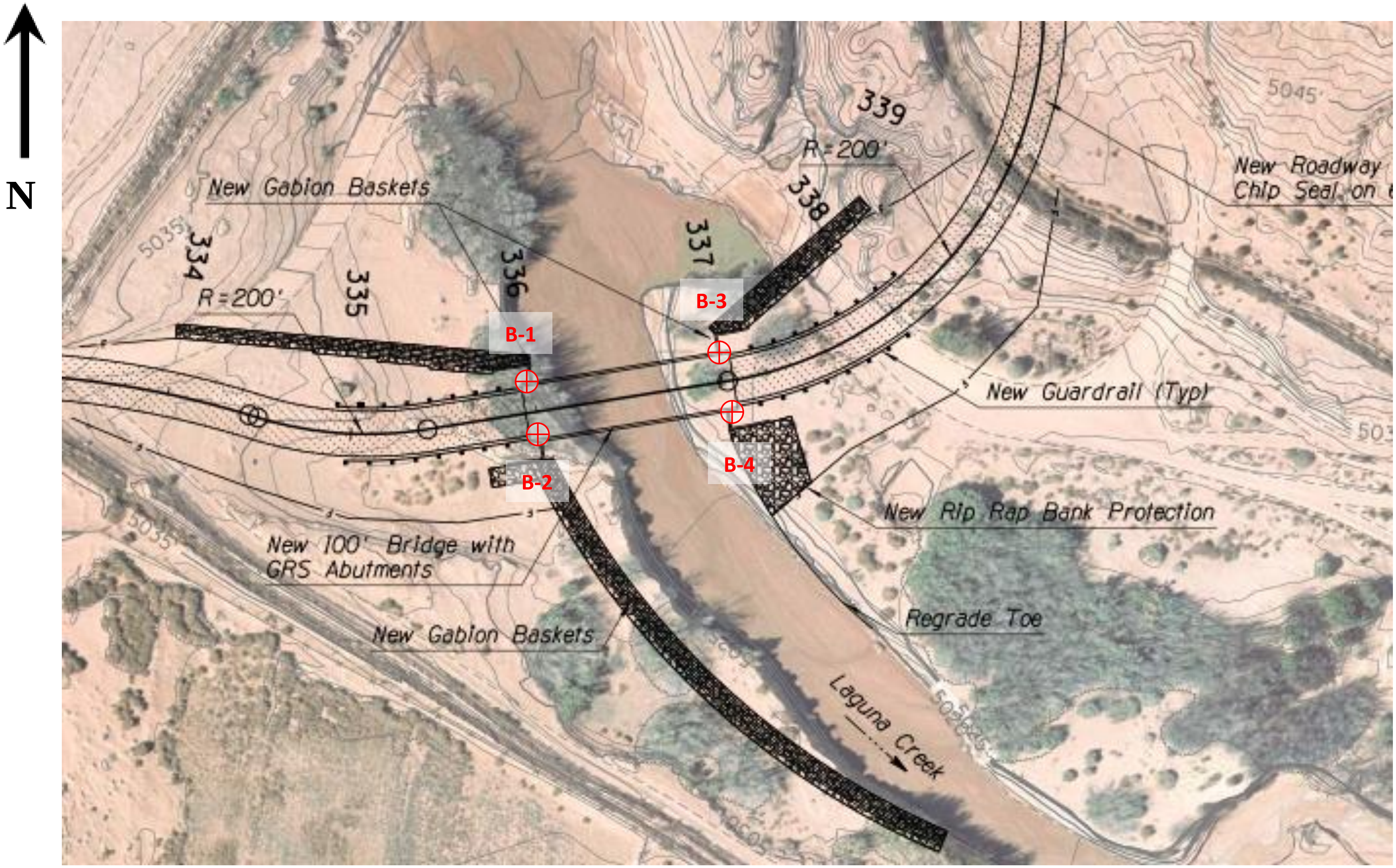
BRIDGE PLAN AND PROFILE

PLATE: 2



⊕ APPROXIMATE BORING LOCATION

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BORING LOCATION DIAGRAM

PLATE: 3

APPENDIX A
BORING LOGS

Allowable Soil Bearing Capacity	The recommended maximum contact stress developed at the interface of the foundation element and the supporting material.
Backfill	A specified material placed and compacted in a confined area.
Base Course	A layer of specified aggregate material placed on a subgrade or subbase.
Base Course Grade	Top of base course.
Bench	A horizontal surface in a sloped deposit.
Caisson/Drilled Shaft	A concrete foundation element cast in a circular excavation which may have an enlarged base (or belled caisson).
Concrete Slabs-On-Grade	A concrete surface layer cast directly upon base course, subbase or subgrade.
Crushed Rock Base Course	A base course composed of crushed rock of a specified gradation.
Differential Settlement	Unequal settlement between or within foundation elements of a structure.
Engineered Fill	Specified soil or aggregate material placed and compacted to specified density and/or moisture conditions under observations of a representative of a soil engineer.
Existing Fill	Materials deposited through the action of man prior to exploration of the site.
Existing Grade	The ground surface at the time of field exploration.
Expansive Potential	The potential of a soil to expand (increase in volume) due to absorption of moisture.
Fill	Materials deposited by the actions of man.
Finished Grade	The final grade created as a part of the project.
Gravel Base Course	A base course composed of naturally occurring gravel with a specified gradation.
Heave	Upward movement.
Native Grade	The naturally occurring ground surface.
Native Soil	Naturally occurring on-site soil.
Rock	A natural aggregate of mineral grains connected by strong and permanent cohesive forces. Usually requires drilling, wedging, blasting or other methods of extraordinary force for excavation.
Sand and Gravel Base Course	A base course of sand and gravel of a specified gradation.
Sand Base Course	A base course composed primarily of sand of a specified gradation.
Scarify	To mechanically loosen soil or break down existing soil structure.
Settlement	Downward movement.
Soil	Any unconsolidated material composed of discrete solid particles, derived from the physical and/or chemical disintegration of vegetable or mineral matter, which can be separated by gentle mechanical means such as agitation in water.
Strip	To remove from present location.
Subbase	A layer of specified material placed to form a layer between the subgrade and base course.
Subbase Grade	Top of subbase.
Subgrade	Prepared native soil surface.

COARSE-GRAINED SOILS
LESS THAN 50% FINES

GROUP SYMBOLS	DESCRIPTION	MAJOR DIVISIONS
GW	WELL-GRADED GRAVEL OR WELL-GRADED GRAVEL WITH SAND, LESS THAN 5% FINES	GRAVELS MORE THAN HALF OF COARSE FRACTION IS LARGER THAN NO. 4 SIEVE SIZE
GP	POORLY-GRADED GRAVEL OR POORLY-GRADED GRAVEL WITH SAND, LESS THAN 5% FINES	
GM	SILTY GRAVEL OR SILTY GRAVEL WITH SAND, MORE THAN 12% FINES	
GC	CLAYEY GRAVEL OR CLAYEY GRAVEL WITH SAND, MORE THAN 12% FINES	
SW	WELL-GRADED SAND OR WELL-GRADED SAND WITH GRAVEL, LESS THAN 5% FINES	SANDS MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE
SP	POORLY-GRADED SAND OR POORLY-GRADED SAND WITH GRAVEL, LESS THAN 5% FINES	
SM	SILTY SAND OR SILTY SAND WITH GRAVEL, MORE THAN 12% FINES	
SC	CLAYEY SAND OR CLAYEY SAND WITH GRAVEL, MORE THAN 12% FINES	

NOTE: Coarse-grained soils receive dual symbols if they contain 5% to 12% fines (e.g., SW-SM, GP-GC).

FINE-GRAINED SOILS
MORE THAN 50% FINES

GROUP SYMBOLS	DESCRIPTION	MAJOR DIVISIONS
ML	SILT, SILT WITH SAND OR GRAVEL, SANDY SILT, OR GRAVELLY SILT	SILTS AND CLAYS LIQUID LIMIT LESS THAN 50
CL	LEAN CLAY OF LOW TO MEDIUM PLASTICITY, SANDY CLAY, OR GRAVELLY CLAY	
OL	ORGANIC SILT OR ORGANIC CLAY OF LOW TO MEDIUM PLASTICITY	
MH	ELASTIC SILT, SANDY ELASTIC SILT, OR GRAVELLY ELASTIC SILT	SILTS AND CLAYS LIQUID LIMIT MORE THAN 50
CH	FAT CLAY OF HIGH PLASTICITY, SANDY FAT CLAY, OR GRAVELLY FAT CLAY	
OH	ORGANIC SILT OR ORGANIC CLAY OF HIGH PLASTICITY	
PT	PEAT AND OTHER HIGHLY ORGANIC SOILS	HIGHLY ORGANIC SOILS

NOTE: Fine-grained soils may receive dual classification based upon plasticity characteristics (e.g. CL-ML).

SOIL SIZES

COMPONENT	SIZE RANGE
BOULDERS	Above 12 in.
COBBLES	3 in. – 12 in.
GRAVEL	No. 4 – 3 in.
Coarse	¾ in. – 3 in.
Fine	No. 4 – ¾ in.
SAND	No. 200 – No. 4
Coarse	No. 10 – No. 4
Medium	No. 40 – No. 10
Fine	No. 200 – No. 40
Fines (Silt or Clay)	Below No. 200

NOTE: Only sizes smaller than three inches are used to classify soils

CONSISTENCY

CLAYS & SILTS	BLOWS PER FOOT
VERY SOFT	0 – 2
SOFT	3 – 4
FIRM	5 – 8
STIFF	9 – 15
VERY STIFF	16 – 30
HARD	OVER 30

RELATIVE DENSITY

SANDS & GRAVELS	BLOWS PER FOOT
VERY LOOSE	0 – 4
LOOSE	5 – 10
MEDIUM DENSE	11 – 30
DENSE	31 – 50
VERY DENSE	OVER 50

NOTE: Number of blows using 140-pound hammer falling 30 inches to drive a 2-inch-OD (1⅜-inch ID) split-barrel sampler (ASTM D1586).

PLASTICITY OF FINE GRAINED SOILS

PLASTICITY INDEX	TERM
0	NON-PLASTIC
1 – 7	LOW
8 – 20	MEDIUM
Over 20	HIGH

DEFINITION OF WATER CONTENT

DRY
SLIGHTLY DAMP
DAMP
MOIST
WET
SATURATED

METHOD OF CLASSIFICATION

The number shown in **"BORING NO."** refers to the approximate location of the same number indicated on the "Boring Location Diagram" as positioned in the field by pacing or measurement from property lines and/or existing features, or through the use of Global Positioning System (GPS) devices. The accuracy of GPS devices is somewhat variable.

"DRILLING TYPE" refers to the exploratory equipment used in the boring wherein **HSA = hollow stem auger**, and the dimension presented is the outside diameter of the HSA used.

"N" in "BLOW COUNTS" refers to a 2-inch outside diameter split-barrel sampler driven into the ground with a 140 pound drop-hammer dropped 30 inches repeatedly until a penetration of 18 inches is achieved or until refusal. The number of blows, or "blow count", of the hammer is recorded for each of three 6-inch increments totaling 18 inches. The number of blows required for advancing the sampler for the last 12 inches (2nd and 3rd increments) is defined as the Standard Penetration Test (SPT) "**N**"-Value. Refusal to penetration is considered more than 50 blows per 6 inches. (Ref. ASTM D1586).

"R" in "BLOW COUNTS" refers to a 3-inch outside diameter ring-lined split barrel sampler driven into the ground with a 140 pound drop-hammer dropped 30 inches repeatedly until a penetration of 12 inch is achieved or until refusal. The number of blows required to advance the sampler 12 inches is defined as the "**R**" blow count. The "**R**" blow count requires an engineered conversion to an equivalent SPT N-Value. Refusal to penetration is considered more than 50 blows per foot. (Ref. ASTM D3550).

"CS" in "BLOWS/FT." refers to a 2½-in. outside diameter California style split-barrel sampler, lined with brass sleeves, driven into the ground with a 140-pound hammer dropped 30 inches repeatedly until a penetration of 18 inches is achieved or until refusal. The number of blows of the hammer is recorded for each of the three 6-inch increments totaling 18 inches. The number of blows required for advancing the sampler for the last 12 inches (2nd and 3rd increments) is defined as the "CS" blow count. The "CS" blow count requires an engineered conversion to an equivalent SPT N-Value. Refusal to penetration is considered more than 50 blows for a 6-inch increment. (Ref. ASTM D 3550)

"SAMPLE TYPE" refers to the form of sample recovery, in which **N** = Split-barrel sample, **R** = Ring-lined sample, **"CS"** = California style split-barrel sample, **G** = Grab sample, **B** = Bucket sample, **C** = Core sample (ex. diamond bit rock coring).

"DRY DENSITY (LBS/CU FT)" refers to the laboratory-determined dry density in pounds per cubic foot. The symbol **"NR"** indicates that no sample was recovered.

"WATER (MOISTURE) CONTENT" (% of Dry Wt.) refers to the laboratory-determined water content in percent using the standard test method ASTM D2216.

"USCS" refers to the "Unified Soil Classification System" Group Symbol for the soil type as defined by ASTM D2487 and D2488. The soils were classified visually in the field, and where appropriate, classifications were modified by visual examination of samples in the laboratory and/or by appropriate tests.

These notes and boring logs are intended for use in conjunction with the purposes of our services defined in the text. Boring log data should not be construed as part of the construction plans nor as defining construction conditions.

Boring logs depict our interpretations of subsurface conditions at the locations and on the date(s) noted. Variations in subsurface conditions and characteristics may occur between borings. Groundwater levels may fluctuate due to seasonal variations and other factors.

The stratification lines shown on the boring logs represent our interpretation of the approximate boundary between soil or rock types based upon visual field classification at the boring location. The transition between materials is approximate and may be more or less gradual than indicated.

BORING NO. B-1

DATE DRILLED: **1-17-17**
LOCATION: **See Boring Location Diagram**
ELEVATION: **Not determined**

EQUIPMENT TYPE: **CME-75**
DRILLING TYPE: **7" HSA**
FIELD ENGINEER: **C. Dumrtru**

WATER CONTENT (%)	POCKET PENETROMETER (tsf)	SAMPLE TYPE	BLOWS/FT.	DEPTH (FEET)	USCS	SOIL DESCRIPTION
		G		0	SP-SM	POORLY GRADED SAND; with silt, orange-brown, medium dense, damp
		R	27			
6.2		R	6	5		changing to very loose
19.6		R	10		SM	SILTY SAND; orange-brown, loose, moist
		N	50/6"	10		SANDSTONE; orange-brown, soft to moderately hard
		N	50/6"	15		
		N	50/4"	20		
		N	50/4"	25		
		C		28–38		
				38		**Boring terminated at 38 feet**

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE
BN- BLUNT NOSE PENETROMETER

NOTES: **Groundwater encountered at 9 feet during drilling**

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

WESTERN TECHNOLOGIES INC.

PROJECT: **PROPOSED DENNEHOTSO BRIDGE**
REF. NO.: **3127JS001**

BORING LOG

PLATE **A-4**

DATE DRILLED: **1-17-17**
LOCATION: **See Boring Location Diagram**
ELEVATION: **Not determined**

BORING NO. B-2

EQUIPMENT TYPE: **CME-75**
DRILLING TYPE: **7" HSA**
FIELD ENGINEER: **C. Dumrtru**

WATER CONTENT (%)	POCKET PENETROMETER (tsf)	SAMPLE TYPE	SAMPLE	BLOWS/FT.	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
		G			0	SM		SILTY SAND; orange-brown, loose to medium dense, damp
2.7		R		16				
3.6		R		14	5			
8.1		R		21				
					9			SANDSTONE; orange-brown, soft to moderately hard
		N		50/4"	10			
		N		50/4"	15			
		N		50/4"	20			
		N C		50/2"	25			
					30			
					35			**Boring terminated at 35 feet**

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE
BN- BLUNT NOSE PENETROMETER

NOTES: **Groundwater encountered at 9 feet during drilling**

WESTERN TECHNOLOGIES INC.

PROJECT: **PROPOSED DENNEHOTSO BRIDGE**
REF. NO.: **3127JS001**

PLATE **A-5**

BORING LOG

BORING NO. B-3

DATE DRILLED: **1-18-17**
LOCATION: **See Boring Location Diagram**
ELEVATION: **Not determined**

EQUIPMENT TYPE: **CME-75**
DRILLING TYPE: **7" HSA**
FIELD ENGINEER: **C. Dumrtru**

WATER CONTENT (%)	POCKET PENETROMETER (tsf)	SAMPLE TYPE	BLOWS/FT.	DEPTH (FEET)	USCS	SOIL DESCRIPTION
		G		0	SP-SM	POORLY GRADED SAND; with silt, orange-brown, loose, damp
0.6		R	16			
1.0		R	12	5		
3.1		R	10			
		N	10	10		changing to medium dense
				13		SANDSTONE; orange-brown, soft to moderately hard
		N C	50/1"	15		
				20		
				25		**Boring terminated at 25 feet**
				30		
				35		

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE
BN- BLUNT NOSE PENETROMETER

NOTES: **Groundwater encountered at 13 feet during drilling**

WESTERN TECHNOLOGIES INC.

PROJECT: **PROPOSED DENNEHOTSO BRIDGE**
REF. NO.: **3127JS001**

PLATE **A-6**

BORING LOG

DATE DRILLED: **1-18-17**
LOCATION: **See Boring Location Diagram**
ELEVATION: **Not determined**

BORING NO. B-4

EQUIPMENT TYPE: **CME-75**
DRILLING TYPE: **7" HSA**
FIELD ENGINEER: **C. Dumrtru**

WATER CONTENT (%)	POCKET PENETROMETER (tsf)	SAMPLE TYPE	SAMPLE	BLOWS/FT.	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
		G				SM		SILTY SAND; orange-brown, loose, damp
0.9		R		14				
		R		14	5			
5.5		R		12				
					9			SANDSTONE; orange-brown, soft to moderately hard
		N		50/4'	10			
		N C		50/2"	15			
					20			
					25			**Boring terminated at 25 feet**
					30			
					35			

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE
BN- BLUNT NOSE PENETROMETER

NOTES: **Groundwater encountered at 9 feet during drilling**

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

WESTERN TECHNOLOGIES INC.

PROJECT: **PROPOSED DENNEHOTSO BRIDGE**
REF. NO.: **3127JS001**

PLATE **A-7**

BORING LOG

APPENDIX B
LABORATORY TEST RESULTS

Boring No.	Depth (ft.)	USCS Class.	Dry Density (pcf)	Water Content (%)	Compression Properties			Plasticity		Percent Passing #200	Remarks
					Surcharge (ksf)	Total Compression (%)		Liquid Limit	Plasticity Index		
						In-Situ	After Saturation				
B-1	5 - 6	SP-SM	97	6.2						7.2	
B-1	7 - 8	SM	102	19.6						14.4	
B-2	2 - 3	SM	96	2.7	0.69	0.8				35.9	1
					1.38	2.7	3.5				2
B-2	5 - 6	SM	101	3.6						29.6	
B-2	7 - 8	SM	108	8.1						16.8	
B-3	2 - 3	SP-SM	105	0.6	0.69	0.9				11.9	1
					1.38	2.2	3.2				2
B-3	5 - 6	SP-SM		1.0						8.1	
B-3	7 - 8	SP-SM	104	3.1						11.3	
B-4	2 - 3	SM		0.9						13.7	
B-4	7 - 8	SM	98	5.5						14.8	

Note: Initial Dry Density and Initial Water Content are in-situ values unless otherwise noted.
NP = Non-Plastic

Remarks

1. Test performed on undisturbed sample
2. Submerged to approximate saturation.

Geotechnical
Environmental
Inspections
Materials

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PROJECT: PROPOSED GRS-IBS BRIDGE
JOB NO.: 3127JS001

SOIL PROPERTIES

PLATE
B-1

APPENDIX C

GRS-IBS EXCEL SPREADSHEET OUTPUT RESULTS

Abutment Geometry:			
Abutment Height	H	20.0	ft
Base Width of Wall (including wall facing)	B_{wf}	10.0	ft
Reinforcement Spacing	S_v	6.0	in
Base Width of Wall (not including wall facing)	B	9.33	ft
Setback from facing	a_b	0.67	ft
Bridge Seat Width	b	8.0	ft
Width of Bridge Beam	B_b	28.0	ft
Structure depth (road surface to top of block)	H_{bridge}	3.50	ft
Width of Traffic and Roadbase Load Behind Wall	$b_{rb,t}$	0.67	ft
Footing Area		224.0	SF
Block Parameter:			
Height	H_{block}	8.0	in
Length (along face)	L_{block}	16.0	in
Depth (front to back)	b_{block}	8.0	in
Block Weight	W_{block}	44	lbs
Number of Reinforcement Layers	N_{Sv}	30	
Reinforced Soil Foundation			
Is there an RSF? (yes,no)		yes	
Depth of Reinforced Soil Foundation	D_{RSF}	1.5	ft
Distance of RSF in front of Abutment	x_{RSF}	1.5	ft
Base Width of Reinforced Soil Foundation	B_{RSF}	11.5	ft
Load and Resistance Factors			
Dead Load Max	$\gamma_{DC\ MAX}$	1.25	
Dead Load Min	$\gamma_{DC\ MIN}$	0.9	
Horizontal Active Earth Pressure Max	$\gamma_{EH\ MAX}$	1.5	
Horizontal Active Earth Pressure Min	$\gamma_{EH\ MIN}$	0.9	
Vertical Earth Pressure Max	$\gamma_{EV\ MAX}$	1.35	
Vertical Earth Pressure Min	$\gamma_{EV\ MIN}$	1	
Live Load Surcharge	γ_{LS}	1.75	
Horizontal Active Earth Pressure Min	$\gamma_{passive\ MIN}$	0.5	
Capacity Resistance	ϕ_{cap}	0.45	
Reinforcement Resistance	ϕ_{reinf}	0.40	
Soil-Sliding Resistance	ϕ_{τ}	1.00	
Bearing Capacity Resistance	ϕ_{bc}	0.65	

Soil Parameters			
Foundation Soils, Friction Angle	ϕ_f'	45	degree
Foundation Soils, Cohesion	c'_f	-	psf
Foundation Soils, Unit weight	γ_f	110	pcf
Does GW impact foundation capacity? (yes,no)		yes	
Foundation Soil Effective Unit Weight	γ'_f	48	lb/ft^3
$K_{a,f}$		0.17	
$K_{p,f}$		5.83	
Bearing Capacity Factors (Table 10.6.3.1.2a-1, AASHTO LF	N_c	133.9	
	N_γ	271.8	
	N_q	134.9	
Retained Soils, Friction Angle	ϕ_b'	32	degree
Retained Soils, Cohesion	c'_b	-	psf
Retained Soils, Unit weight	γ_b	100	pcf
$K_{a,b}$		0.31	
Reinforced Soils, Friction Angle	ϕ_r'	45	degree
Reinforced Soils, Cohesion	c'_r	-	psf
Reinforced Soils, Unit weight	γ_r	110	pcf
Maximum Diameter of Reinforced Fill	d_{max}	0.50	in
$K_{a,r}$		0.17	
$K_{p,r}$		5.83	
Road Base Unit Weight	γ_{rb}	140	pcf
Reinforced Soil Foundation, Friction Angle	ϕ_{rsf}'	45	degree
Reinforced Soil Foundation, Cohesion	c'_{rsf}	-	psf
Reinforced Soil Foundation Unit Weight	γ_{rsf}	110	pcf
Bridge Loads			
Bridge dead load per abutment	Q_{DL}	546,000	lbs
Bridge live load per abutment	Q_{LL}	182,000	lbs
Dead load pressure per abutment	$q_{DL,b}$	2,438	psf
Live load pressure per abutment	$q_{LL,b}$	813	psf
Geosynthetic Reinforcement			
Ultimate Reinforcement Strength	T_f	4,800	lb/ft
Ultimate Reinforcement Strength, Factored	$T_{f,f}$	1,920	lb/ft
Reinforcement Strength at 2%	$T_{@\varepsilon=2\%}$	617	lb/ft
Number of bearing bed reinforcement (3 min)		5	layers
Length of bearing bed reinforcement (min)		9.33	ft

[redacted]

Calculate weights (unfactored)			
Weight of GRS Abutment	W_{GRS}	20,533	lb/ft

Road Base			
Height ($H + H_{bridge}$)		20.00	ft

Weight of Wall Face	W_{face}	990	lb/ft
Weight of RSF	W_{RSF}	1,898	lb/ft
Weight of Road Base	W_{RB}	327	lb/ft
Weight of Traffic	W_{T}	133	lb/ft
Wight of Bridge DL	$W_{b,DL}$	19,500	lb/ft
Wight of Bridge LL	$W_{b,LL}$	6,500	lb/ft

Factord Weights

	Max	Min	
Weight of GRS Abutment	27,720	20,533	lb/ft
Weight of Wall Face	1,238	891	lb/ft
Weight of RSF	2,562	1,898	lb/ft
Weight of Road Base	441	327	lb/ft
Weight of Traffic	233		lb/ft
Weight of Bridge DL	24,375	17,550	lb/ft
Weight of Bridge LL	11,375		lb/ft

Driving Moments - Factored

Moment from Road Base	$M_{D,RB}$	52,196	ft * lbs/ft
Moment from Traffic	$M_{D,T}$	24,855	ft * lbs/ft
Moment form earth pressure	$M_{D,Pa}$	76,341	ft * lbs/ft
Moment from facing	$M_{D,B}$	4,847	ft * lbs/ft
Total driving moments	$M_{D,Total}$	158,240	ft * lbs/ft

Resisting Moments - Factored

Moments from abutment fill	$M_{R,W1}$	30,030	ft * lbs/ft
Moment from road base above GRS	$M_{R,WRB}$	2,389	ft * lbs/ft
Moment from Traffic above GRS	$M_{R,WT}$	1,264	ft * lbs/ft
Moments from bridge Dead Load	$M_{R,DL}$	26,406	ft * lbs/ft
Moments from bridge Live Load	$M_{R,LL}$	12,323	ft * lbs/ft
Total Resisting Moments	$M_{R,Total}$	72,412	ft * lbs/ft

Equivalent Height for Traffic	$H_{t,eq}$	2.00	ft
Road Base Surcharge	q_{rb}	490	psf
Approach Roadway Live Load	q_{t}	200	psf

Calculate Lateral Forces at top of RSF

Lateral Load from Retained Soil	P_{a}	6,145	lb/ft
Lateral Load from Road Base	P_{rb}	3,011	lb/ft
Lateral Load from Traffic Surcharge	P_{t}	1,229	lb/ft

Factored Lateral Forces at top of RSF

	Max	Min	
Lateral Load from Retained Soil	9,218	5,531	lb/ft
Lateral Load from Road Base	4,517	2,710	lb/ft
Lateral Load from Traffic Surcharge	2,151		lb/ft

Calculate Lateral Forces at bottom of RSF

Lateral Load from Retained Soil	P_{a}	7,102	lb/ft
Lateral Load from Road Base	P_{rb}	3,237	lb/ft
Lateral Load from Traffic Surcharge	P_{t}	1,321	lb/ft
Passive Resistance in front of RSF	P_{p}	312	lb/ft

Factored Lateral Forces at bottom of RSF

	Max	Min	
Lateral Load from Retained Soil	10,652	6,391	lb/ft
Lateral Load from Road Base	4,855	2,913	lb/ft
Lateral Load from Traffic Surcharge	2,312		lb/ft
Passive Resistance in front of RSF	156		lb/ft

Applied Bearing Pressure

Total Vertical loads - Factored	V_{Total}	67,943	ft * lbs/ft
Eccentricity	e	1.26	ft
Bearing width	B'	8.97	ft
Bearing Pressure - Factored	σ_{V}	7,564	psf

[redacted]

Sliding Stability at bottom of reinforced fill to RSF or Foundation

Total Driving Force	F_{n}	10,385	lb/ft
Factored Driving Force	F_{R}	15,885	lb/ft
Resisting Weight	$W_{t,R}$	39,301	lb/ft

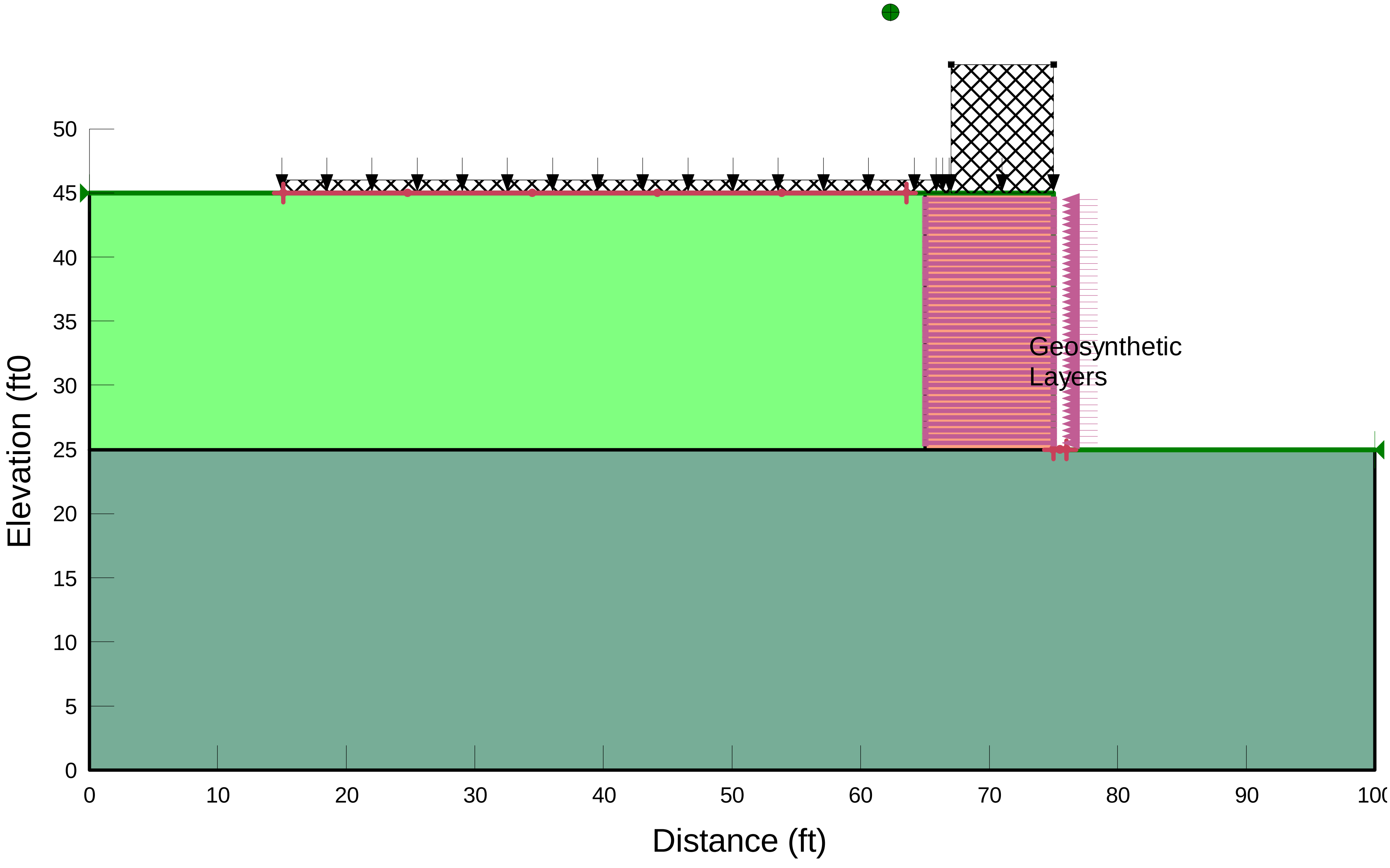
Sliding Stability at bottom of RSF/foundation

Total Driving Force	F_{n}	11,660	lb/ft
Factored Driving Force	F_{R}	17,820	lb/ft
Resisting Weight	$W_{t,R}$	41,199	lb/ft

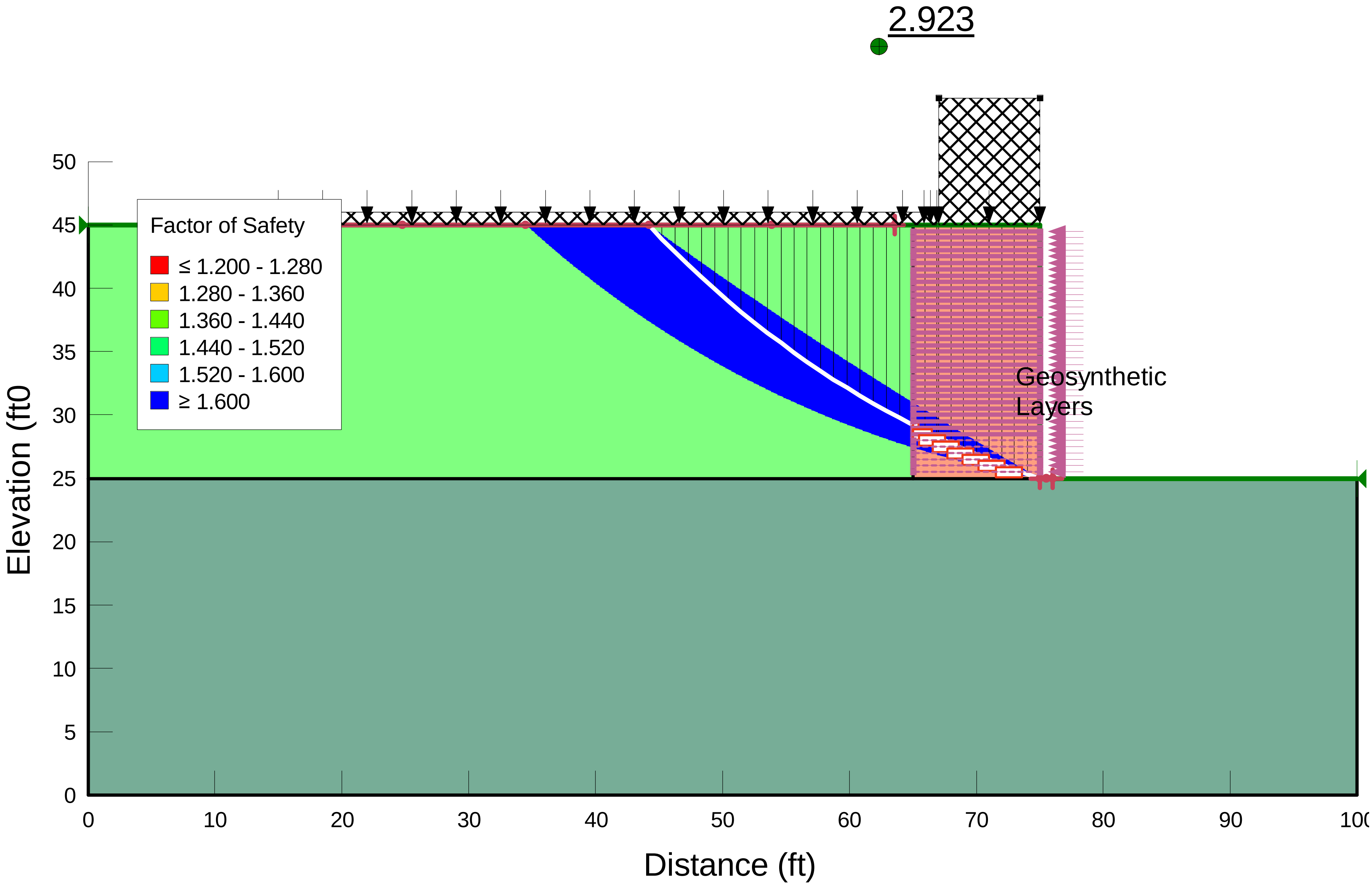
Critical Friction Angle	ϕ_{crit}	33.7	deg	Critical Friction Angle	ϕ_{crit}	33.7	deg
Sliding Friction	μ	0.67		Sliding Friction	μ	0.67	
Assumed Adhesion Resistance of Foundation Soil	$R_{af,R}$	0	lb/ft	Assumed Adhesion Resistance of Foundation Soil	$R_{af,R}$	0	lb/ft
Factored Resisting Force	R_R	26,201	lb/ft	Factored Resisting Force	R_R	27,621	lb/ft
Direct Slide Check		**OK**		**Direct Slide Check**		**OK**	
CDR		1.65		CDR		1.55	
Bearing Capacity				Internal Bearing Capacity			
Nominal Bearing Capacity	q_{Nom}	67,680	psf	Nominal Capacity (empirical)	$q_{n,an}$	27,417	psf
Factored Bearing Resistance	q_R	43,992	psf	Factored Resistance Capacity	$q_{n,an,f}$	12,338	psf
Bearing Pressure - Factored	σ_V	7,564	psf	Factored Bridge Bearing Pressure	$Q_{b,factored}$	4,469	psf
Bearing Capacity		**OK**		**Capacity Check**		**OK**	
CDR		5.82		CDR		2.76	
Reinforcement Strength							
Reinforcement Strength at 2%	$T_{@\varepsilon=2\%}$	617	lb/ft	Ultimate Reinforcement Strength, Factored	$T_{f,f}$	1,920	lb/ft
Maximum unFactored Required Reinforcement Strength	$T_{req,f}$	617	lb/ft	Maximum Factored Required Reinforcement Strength	$T_{req,f}$	847	lb/ft
Reinforceemnt Serviceability Check		**OK**		**Reinforcement Strength Check**		**OK**	
CDR		1.00		CDR		2.27	

APPENDIX D

GLOBAL STABILITY ANALYSIS



Geosynthetic
Layers
Elevation (ft0
Distance (ft)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100



2.923
Factor of Safety
≤ 1.200 - 1.280
1.280 - 1.360
1.360 - 1.440
1.440 - 1.520
1.520 - 1.600
≥ 1.600
Geosynthetic
Layers
Elevation (ft0
Distance (ft)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100

1 - Base Case

File Information

File Version: 11.05
Title: Reinforcement with Geosynthetics
Comments: This example demonstrates the use of reinforcment functionality in SLOPE/W to simulate the internal stability of reinforced earth walls, such as geosynthetic materials.
Created By: Seequent Ltd.
Last Edited By: Armando del la Rocha
Revision Number: 163
Date: 01/27/2024
Time: 02:15:56 PM
Tool Version: 23.1.2.11
File Name: Revised Dennehotso 2023 Reinforcement with Geosynthetics.gsz
Directory: G:\2023\2123JA038-DIBBLE E-Dennehotso Brid\DOCUMENTS\

Project Settings

Unit System: International System of Units (SI)

Analysis Settings

1 - Base Case

Kind: SLOPE/W
Analysis Type: Spencer
Settings
  PWP Conditions from: (none)
  Unit Weight of Water: 62.430189 pcf
Slip Surface
  Direction of movement: Left to Right
  Use Passive Mode: No
  Slip Surface Option: Entry and Exit
  Critical slip surfaces saved: 1
  Optimize Critical Slip Surface Location: No
  Tension Crack Option: (none)
Distribution
  F of S Calculation Option: Constant
Convergence
  Geometry Settings
    Minimum Slip Surface Depth: 0.32808399 ft
    Number of Columns: 30
  Factor of Safety Convergence Settings
    Maximum Number of Iterations: 100

Tolerable difference in F of S: 0.001
Solution Settings
Search Method: Linear Search
Must Obtain at Lambda Factor of Safety: 0.2
Lambda
Lambda 1: -0.8
Lambda 2: -0.6
Lambda 3: -0.4
Lambda 4: -0.2
Lambda 5: 0
Lambda 6: 0.2
Lambda 7: 0.4
Lambda 8: 0.6
Lambda 9: 0.8

Materials

Original Material

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 4,000 psf
Effective Friction Angle: 45 °
Phi-B: 0 °

Engineered Material

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 110 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 45 °
Phi-B: 0 °

Retained Material

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 100 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 32 °
Phi-B: 0 °

Reinforcements

New Reinforcement

Type: Geosynthetic
Pullout Resistance: 1,566.4076 psf
Pullout Resistance Reduction Factor: 1.5
Tensile Capacity: 15,748.031 lbf
Tensile Capacity Reduction Factor: 2.24

F of S Dependent: No
Force Distribution: Distributed
Face Anchorage: Yes
Factored Pullout Resistance: 1,044.3 psf
Factored Tensile Capacity: 2,142.9 lbf/ft

Slip Surface Entry and Exit

Left Type: Range
Left-Zone Left Coordinate: (15.099167, 45) ft
Left-Zone Right Coordinate: (63.576923, 45) ft
Left-Zone Increment: 5
Right Type: Range
Right-Zone Left Coordinate: (75, 25) ft
Right-Zone Right Coordinate: (76, 25) ft
Right-Zone Increment: 2
Radius Increments: 5

Slip Surface Limits

Left Coordinate: (0, 45) ft
Right Coordinate: (100, 25) ft

Seismic Coefficients

Horz Seismic Coef.: 0
Vert Seismic Coef.: 0

Reinforcement Lines

Reinforcement Line 1

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 44.5) ft
Inside Point: (65, 44.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 2

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 39) ft
Inside Point: (65, 39) ft
Length: 10 ft
Orientation: 180 °

Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 3

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 33.5) ft
Inside Point: (65, 33.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 4

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 29) ft
Inside Point: (65, 29) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 5

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 28.5) ft
Inside Point: (65, 28.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 6

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 28) ft
Inside Point: (65, 28) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 7

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 27.5) ft
Inside Point: (65, 27.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 8

Reinforcement: New Reinforcement

Lock to Ground Surface: No
Outside Point: (75, 27) ft
Inside Point: (65, 27) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 9

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 26.5) ft
Inside Point: (65, 26.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 10

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 44) ft
Inside Point: (65, 44) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 11

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 43.5) ft
Inside Point: (65, 43.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 12

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 43) ft
Inside Point: (65, 43) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 13

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 42.5) ft
Inside Point: (65, 42.5) ft

Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 14

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 42) ft
Inside Point: (65, 42) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 15

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 41.5) ft
Inside Point: (65, 41.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 16

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 41) ft
Inside Point: (65, 41) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 17

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 40.5) ft
Inside Point: (65, 40.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 18

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 40) ft
Inside Point: (65, 40) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 19

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 39.5) ft
Inside Point: (65, 39.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 20

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 38.5) ft
Inside Point: (65, 38.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 21

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 38) ft
Inside Point: (65, 38) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 22

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 37.5) ft
Inside Point: (65, 37.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 23

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 37) ft
Inside Point: (65, 37) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 24

Reinforcement: New Reinforcement
Lock to Ground Surface: No

Outside Point: (75, 36.5) ft
Inside Point: (65, 36.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 25

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 36) ft
Inside Point: (65, 36) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 26

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 35.5) ft
Inside Point: (65, 35.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 27

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 35) ft
Inside Point: (65, 35) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 28

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 34.5) ft
Inside Point: (65, 34.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 29

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 34) ft
Inside Point: (65, 34) ft
Length: 10 ft
Orientation: 180 °

Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 30

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 33) ft
Inside Point: (65, 33) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 31

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 32.5) ft
Inside Point: (65, 32.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 32

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 32) ft
Inside Point: (65, 32) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 33

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 31.5) ft
Inside Point: (65, 31.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 34

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 31) ft
Inside Point: (65, 31) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 35

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 30.5) ft
Inside Point: (65, 30.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 36

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 30) ft
Inside Point: (65, 30) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 37

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 29.5) ft
Inside Point: (65, 29.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 38

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 26) ft
Inside Point: (65, 26) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Reinforcement Line 39

Reinforcement: New Reinforcement
Lock to Ground Surface: No
Outside Point: (75, 25.5) ft
Inside Point: (65, 25.5) ft
Length: 10 ft
Orientation: 180 °
Max. Pullout Force: 7,030.3712 lbf

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 394 pcf
Direction: Vertical

Coordinates

	X	Y
	67 ft	55 ft
	75 ft	55 ft

Surcharge Load 2

Surcharge (Unit Weight): 690 pcf
Direction: Vertical

Coordinates

	X	Y
	15 ft	46 ft
	66.9 ft	46 ft

Geometry

Name: Default Geometry

Settings

View: 2D
Element Thickness: 3.2808399 ft

Points

	X	Y
Point 1	0 ft	45 ft
Point 2	65 ft	25 ft
Point 3	75 ft	25 ft
Point 4	75 ft	70 ft
Point 5	65 ft	45 ft
Point 6	75 ft	45 ft
Point 7	0 ft	25 ft
Point 8	100 ft	25 ft
Point 9	100 ft	0 ft
Point 10	0 ft	0 ft

Regions

	Material	Points	Area
Region 1	Retained Material	1,5,2,7	1,300 ft²
Region 2	Engineered Material	5,2,3,6	200 ft²
Region 3	Original Material	7,2,3,8,9,10	2,500 ft²