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February 3, 2021

Project No. 220-063

Mr. Ron Gibson, P.E.
Stanley Consultants
8000 South Chester Street, Suite 500
Centennial, Colorado 80112

Subject: Preliminary Geotechnical Study
Structure M-22-U
23558/23559 Region 2 Bridge Bundle
CDOT Region 2, Colorado

Dear Mr. Gibson:

This memorandum presents the results of Yeh and Associates, Inc.'s (Yeh) preliminary geotechnical engineering study for the proposed replacement of Structure M-22-U as part of the CDOT Region 2 Bridge Bundle Design-Build Project.

The CDOT Region 2 Bridge Bundle Design-Build Project consists of the replacement of a total of 19 structures bundled together as a single project. These structures are rural bridges on essential highway corridors (US 350, US 24, CO 239, and CO 9) in southeastern and central Colorado. These key corridors provide rural mobility, intra- and interstate commerce, movement of agricultural products and supplies, and access to tourist destinations. The design-build project consists of 17 bridges and two Additionally Requested Elements (ARE) structures.

This design-build project is jointly funded by the USDOT FHWA Competitive Highway Bridge Program grant (14 structures, Project No. 23558) and the Colorado Bridge Enterprise (five structures, Project No. 23559). These projects are combined to form one design-build project. The two ARE structures are part of the five bridges funded by the Colorado Bridge Enterprise.

The 19 bridges identified to be included in the Region 2 Bridge Bundle were selected based on similarities in the bridge conditions, risk factors, site characteristics, and probable replacement type, with the goal of achieving economy of scale. Seventeen of the bridges being replaced are at least 80 years old. Five of the bridges are load-restricted, limiting trucking routes through major sections of the US 24 and US 350 corridors. The bundle includes nine timber bridges, four concrete box culverts, one corrugated metal pipe (CMP), four concrete I-beam bridges, and one I-beam bridge with corrugated metal deck.

1 PROJECT UNDERSTANDING

Bridge M-22-U is part of the Region 2 Bridge Bundle project that will be delivered as a design-build project. Our preliminary geotechnical study was completed to support the 30% design level that will be included in the design build bid package. We understand the existing structure will be replaced with either a concrete box culvert (CBC) or a bridge structure. The new structure will be constructed along the current roadway alignment and existing roadway grade will be maintained. No significant cut or fills are required for construction of the proposed replacement structure.

2 SUBSURFACE CONDITIONS

Two bridge borings, M-22-U-B-1 and M-22-U-B-2, were drilled by Yeh in the vicinity of the existing bridge, and two pavement borings, M-22-U-P-1 and M-22-U-P-2, were drilled along the existing pavement approximately 250 feet from the bridge. The approximate boring locations are shown on the engineering geology sheet in Appendix A. The legend and boring logs are included in Appendix B. Laboratory test results are provided in Appendix C and are shown on the boring logs.

The bridge borings encountered lean clays with sand and gravel and clayey gravel soils overlying limestone bedrock. Table 1 provides a summary of the bedrock and groundwater conditions for the bridge borings. The surface elevations, approximate bedrock depths/elevations, and approximate groundwater depths/elevations are presented to the nearest 0.5 feet. The groundwater depths and elevations are based on observations during drilling.

Table 1. Summary of Bedrock and Groundwater Conditions

Boring ID	Location[1] (Northing, Easting)	Ground Surface Elevation at Time of Drilling[1] (feet)	Approx. Depth to Top of Competent Bedrock[1] (feet)	Approx. Elevation to Top of Competent Bedrock[1] (feet)	Approx. Groundwater Depth[1, 2] (feet)	Approx. Groundwater Elevation [1, 2] (feet)
M-22-U-B-1	475060.335, 551591.579	4232.0	18.0	4214.0	Not Encountered	Not Encountered
M-22-U-B-2	475012.354, 551541.265	4232.0	16.5	4215.5	Not Encountered	Not Encountered

Notes:

(1) Surface elevations, approximate bedrock depths/elevations, and approximate groundwater depths/elevations are presented to the nearest 0.5 feet. Location and elevation are provided by project surveyor.

(2) Groundwater depths and elevations are based on observations during drilling.

3 BRIDGE FOUNDATION RECOMMENDATIONS

We understand that the replacement structure will consist of either a new bridge structure or a concrete box culvert structure (CBC). If a bridge structure is selected, then the abutments and piers will be supported on driven H-piles, drilled shafts, or shallow foundations. If a CBC structure is selected, then the structure will be founded on a shallow mat foundation. Wing walls for the bridge and CBC structures will be founded on shallow strip foundations.

Based on the subsurface conditions encountered during our preliminary study, our engineering analysis, and our experience with similar projects, it is our opinion that driven H-pile and drilled shaft foundations are suitable for support of the bridge structure. Shallow foundations are suitable for support of the CBC and wing wall structures and may be suitable for the support of the bridge structure. Recommendations for shallow foundations are presented in Section 3.1, drilled shaft recommendations are presented in Section 3.2, driven H-pile recommendations are provided in Section 3.3, and CBC foundation recommendations are presented in Section 3.4.

The soil and bedrock properties were estimated from penetration resistance, material descriptions, and laboratory data. The design and construction of the foundation elements should comply with all applicable requirements and guidelines listed in AASHTO (2020) and the CDOT Standard Specifications (CDOT 2019).

3.1 Shallow Foundation Recommendations

Based on the depth to bedrock and the anticipated loading requirements, shallow foundations such as reinforced concrete strip footings may be suitable to support the bridge structure. Alternatively, a Geosynthetic Reinforced Soil – Integrated Bridge System (GRS-IBS) may be considered. We recommend the FHWA GRS-IBS Implementation guide (FHWA-HRT -11-026) and Synthesis report (FHWA-HRT-11-027) be followed for the design and construction of the GRS-IBS system. Design and construction for the shallow foundation or GRS-IBS system should take into consideration the scour potential at the proposed bridge site.

We anticipate that the bearing resistance of the shallow foundations will meet the project loading requirements provided that the shallow foundations are founded on competent bedrock. The bottom of GRS-IBS structures should be founded directly on competent bedrock. Existing surficial soils and weathered bedrock should be over-excavated to the top of competent bedrock prior to placement of shallow foundations or GRS-IBS.

Visual inspection of the foundation excavations should be performed by a qualified representative of the Geotechnical Engineer of record to identify the quality of the foundation materials prior to construction of the foundation. Groundwater may be encountered during excavation for the subgrade preparation. Groundwater control systems may be required to prevent seepage migrating into the construction zone by creating groundwater cut-off and/or dewatering systems.

3.2 Drilled Shaft Recommendations

3.2.1 Drilled Shaft Nominal Axial Resistance

The estimated bearing resistance should be developed from the side and tip resistance in the underlying competent bedrock. The resistance from the overburden soil should be neglected. We used unconfined compressive strength (UCS) and Standard Penetration Test (SPT) values to evaluate side and tip resistances in accordance with AASTHO LRFD (2020). The design approach in Abu-Hejleh et al. (2003) provides recommendations for the use of an updated Colorado SPT-based (UCSB) design method. In this design method, the nominal side and tip resistance of a drilled shaft in bedrock is proportional to the driven sampler penetration resistance. This approach was generally used to estimate the axial resistance in the bedrock where UCS test results were unavailable. Based on local practice, the modified California penetration resistance is considered to be equivalent to SPT penetration resistance, i.e. N value, in bedrock.

Table 2 contains the recommended values for the nominal side and tip resistance for drilled shafts founded in the underlying competent bedrock. The upper three feet of competent bedrock penetration shall not be used for drilled shaft resistance due to the likelihood of construction disturbance and possible additional weathering. To account for axial group effects, the minimum spacing requirements between drilled shafts should be three diameters from center-to-center.

Table 2. Recommended Drilled Shaft Axial Resistance

Reference Boring	Approximate Top of Competent Bedrock Elevation (feet)	Tip Resistance (ksf)		Side Resistance, (ksf)	
		Nominal	Factored (Φ=0.5)	Nominal	Factored (Φ=0.55)
M-22-U-B-1	4214.0	150	75	15	8.2
M-22-U-B-2	4215.5	150	75	15	8.2

3.2.2 Drilled Shaft Lateral Resistance

The input parameters provided in Table 3 are recommended for use with the computer program LPILE to develop the soil models used to evaluate the drilled shaft response to lateral loading. Table 3 provides the estimated values associated with the soil types encountered in the borings. They can also be used for driven H-piles, which will be described in Section 3.3. The nature and type of loading should be considered carefully. Individual soil layers and their extent can be averaged or distinguished by referring to the boring logs at the locations of the proposed bridge. The soils and/or bedrock materials prone to future disturbance, such as from utility excavations or frost heave, should be neglected in the lateral load analyses to the depth of disturbance, which may require more than but should not be less than three feet.

Recommendations for p-y multiplier values (P_m values) to account for the reduction in lateral capacity due to group effects are provided in Section 10.7.3.12 of AASHTO (2020). The P_m value will depend on the direction of the applied load, center-to-center spacing, and location of the foundation element within the group.

Table 3. LPILE Parameters

Material Type	LPILE Soil Criteria	Effective Unit Weight (pcf)		Friction Angle, (deg.)	Undrained Cohesion, (psf)	Unconfined Compressive Strength (psi)	Strain Factor, ε50	p-y modulus kstatic (pci)	
		AGT[1]	BGT[2]					AGT[1]	BGT[2]
Class 1 Structure Backfill	Sand (Reese)	130	67.5	34	-	-	-	90	60
Clay (Fill)	Stiff Clay w/o Free Water (Reese)	120	57.5	-	600	-	0.01	-	-
Clayey Gravel (Fill)	Sand (Reese)	125	62.5	30	-	-	-	25	20
Limestone Bedrock	Strong Rock (Vuggy Limestone)	130	130	-	-	4,000	0.002	-	-

Note: [1]Above Groundwater Table
[2]Below Groundwater Table

3.2.3 General Drilled Shaft Recommendations

The following recommendations can be used in the design and construction of the drilled shafts.

- Groundwater and potentially caving soils may be encountered during drilling depending on the time of year and location. The Contractor shall construct the drilled shafts using means and methods that maintain a stable hole.

- Bedrock may be very hard at various elevations. The contractor should mobilize equipment of sufficient size and operating condition to achieve the required design bedrock penetration.
- Drilled shaft construction shall not disturb previously installed drilled shafts. The drilled shaft concrete should have sufficient time to cure before construction on a drilled shaft within three shaft diameters (center to center spacing) begins to prevent interaction between shafts during excavation and concrete placement.
- Based on the results of the field investigation and experience with similar properly constructed drilled shaft foundations, it is estimated that foundation settlement will be less than approximately ½ inch when designed according to the criteria presented in this report.
- A representative of the Contractor's engineer should observe drilled shaft installation operations on a full-time basis.

3.3 Driven H-Pile Recommendations

3.3.1 Driven H-Pile Axial Resistance

Steel H-piles driven into bedrock may be designed for a nominal axial resistance equal to 34 kips per square inch (ksi) multiplied by the cross-sectional area of the pile for piles composed of Grade 50 ksi steel for use with LRFD Strength Limit State design. Piles should be driven to refusal into the underlying bedrock as defined in Section 502.05 of CDOT (2019). A wave equation analysis using the Contractor's pile driving equipment is necessary to estimate pile drivability.

Based on the strength of the limestone bedrock encountered during our investigation, it is likely that refusal will be met within the upper 1 to 2 feet of bedrock. Holes may need to be pre-drilled to meet the requirement for pile design tip elevations.

3.3.2 Driven H-Pile Axial Resistance Factors

Assuming a pile driving analyzer (PDA) is used to monitor pile driving per Section 502 of CDOT (2019), a resistance factor of 0.65 may be used per AASHTO (2020) Table 10.5.5.2.3-1. Section 502.05 of CDOT (2019) stipulates that if PDA is used, a minimum of one PDA monitoring per bridge bent be performed to determine the condition of the pile, efficiency of the hammer, static bearing resistance of the pile, and to establish pile driving criteria. Per AASHTO (2020) recommendations, a resistance factor of 0.5 can be used for wave equation analysis only without pile dynamic measurements such as PDA monitoring. Per AASHTO (2020) recommendations, a resistance factor of 0.75 may be used if a successful static load test is conducted per site condition.

3.3.3 Driven H-Pile Lateral Resistance

The information provided previously in Section 3.2.2 may be used to evaluate H-pile lateral resistance.

3.3.4 General Driven H-Pile Recommendations

The following recommendations are for the design and construction of driven H-piles.

1. Based on the results of the field exploration and our experience with similar properly constructed driven pile foundations, it is estimated that settlement will be less than approximately ½ inch when designed according to the criteria presented in this report.

2. A minimum spacing requirement for the piles should be three diameters (equivalent) center to center.

3. Driven piles should be driven with protective cast steel pile points or equivalent to provide better pile tip seating and to prevent potential damage from coarse soil particles, which may be present at the site.

4. A qualified representative of the Contractor's engineer should observe pile-driving activities on a full-time basis. Piles should be observed and checked for crimping, buckling, and alignment. A record should be kept of embedment depths and penetration resistances for each pile.

5. It is estimated that the piles will penetrate approximately 1 to 2 feet into competent bedrock (see Table 1 for the estimated elevation for the top of competent bedrock). The final tip elevations will depend on bedrock conditions encountered during driving.

6. If the pile penetration extends below the estimated pile penetration into bedrock by 10 feet or more, the pile driving operations should be temporarily suspended for dynamic monitoring with PDA. We recommend that the subject pile be allowed to rest overnight or longer before restriking and monitoring the beginning-of-restrike with a PDA. The data collected with the PDA shall then be reduced using the software CAPWAP to determine the final nominal pile resistance. The pile driving criteria may be modified by CDOT's or the Contractor's engineer based on the PDA/CAPWAP results.

3.4 CBC Foundation Recommendations

To assure adequate foundation support and to minimize the potential for differential settlement, we recommend that the exposed subgrade soils should be scarified a minimum of 6 inches, moisture conditioned, and re-compacted in accordance with Section 203.07 of the CDOT Standard Specifications (2019) before the placement of structural elements or structural backfill. If unsuitable or soft materials are encountered after the excavation, the materials may be removed and replaced with CDOT Class 1 Structure Backfill in accordance with Section 203.07 of the CDOT Standard Specifications (2019). Visual inspection of the foundation excavations should be performed by a qualified representative of the Geotechnical Engineer of record to identify the quality of the foundation materials prior to placement of backfill and the CBC. Groundwater may be encountered during excavation for the subgrade preparation. Groundwater control systems may be required to prevent seepage migrating into the construction zone by creating groundwater cut-off and/or dewatering systems.

The recommended nominal bearing resistance using Strength Limit State for the CBC and associated wing walls for both moist and saturated conditions are provided in Table 4. We assume the materials in contact with the bottom of the proposed CBC and wing walls will consist of native clay or clayey gravel, or CDOT Class 1 Structure Backfill placed in accordance with Section 203.07 of the CDOT Standard Specifications (2019). The reduced footing width due to eccentricity can be calculated based on the recommendations in Sections 11.6.3.2 and 11.10.5.4 of AASHTO (2020). A bearing resistance factor of 0.45 may be used for shallow foundations based on the recommendations in Table 10.5.5.2.2-1 of AASHTO (2020).

Table 4. Bearing Resistance for CBC and Wing Walls on Shallow Foundation

Soil Conditions	Nominal Bearing Resistance (ksf) [1, 2]
Moist	2.0 + 1.0 * B'
Saturated	1.0 + 0.5 * B'

[1] B' is the footing width in feet reduced for eccentricity (e). B' = B - 2e, where B is the nominal foundation width.
[2] The calculated nominal bearing resistance is based on a minimum 12 inches of embedment and shall be limited to 10 ksf.

The proposed CBC will be at the location of the existing CBC, and as needed, a portion of the CBC will be in a cut area, therefore it is estimated that the total settlement of the structure will be minimal and will occur during construction. The structure settlement is partially controlled by the weight of the adjacent embankment fill.

Thus, it is recommended that the embankment fill on both sides of the CBC be placed at a relatively uniform elevation.

Resistance to sliding at the bottom of foundations can be calculated based on a coefficient of friction at the interface between the pre-cast concrete and the existing native soils or compacted CDOT Class 1 Structure Backfill. The recommended nominal coefficients of friction and the corresponding resistance factors for Class 1 Structure Backfill and native soils are provided in Table 5.

Table 5. Coefficients of Friction for CBC and Wing Walls on Shallow Foundation

Foundation Soil Type	Coefficient of Friction	Resistance Factor
Class 1 Structure Backfill	0.53	0.9
Native Clay	0.30	0.8

Backfill adjacent to the CBC should be Class 1 Structure Backfill, compacted with moisture density control. Backfill materials shall have a Class 0 for severity of sulfate exposure. Fill should be tested for severity of sulfate exposure prior to acceptance.

The passive pressure against the sides of the foundation is typically ignored; however, passive resistance can be used if long-term protection from disturbance, such as frost heave, future excavations, etc., is assured. Table 6 presents recommendations for the passive soil resistances for the encountered soil conditions. The passive resistance estimates are calculated from Figure 3.11.5.4-1 in AASHTO (2020) where a portion of the slip surface is modeled as a logarithmic spiral, the backslope is horizontal and the passive soil/concrete interface friction angle is equal to 60 percent of the soil's friction angle.

The recommended passive earth pressure resistances are presented in terms of an equivalent fluid unit weight for moist and saturated conditions. The recommended passive earth pressure values assume mobilization of the nominal soil/concrete foundation interface shear strength. A suitable resistance factor should be included in the design to limit the strain, which will occur at the nominal shear strength, particularly in the case of passive resistance. The resultant passive earth force, calculated from the equivalent fluid unit weight, should be applied at a point located 1/3 of the height of the soil (in contact with the foundation) above the base of the foundation, directed upward at an angle of 20 degrees from the horizontal.

Table 6. Passive Soil Resistance for CBC

	Soil Type	Nominal Resistance	Resistance Factor
Passive Soil Resistance	Moist	332 psf/ft	0.50
	Saturated	159 psf/ft	0.50

3.5 Lateral Earth Pressures

External loads used in the analyses of the bridge abutments and wing walls should include earth pressure loads, traffic loads, and any other potential surcharge loads. Typical drainage details consisting of inlets near the abutments, geocomposite strip drains, and perforated pipes shall be included in the design to properly contain and transfer surface and subsurface water without saturating the soil around the abutments.

All abutment and wing wall backfill materials should meet the requirements for CDOT Structure Backfill Class 1 in accordance with CDOT (2019). All backfill adjacent to the abutments and walls shall be placed and compacted in accordance with CDOT (2019). It is recommended that compaction of backfill materials be observed and evaluated by an experienced Contractor's engineer or Contractor's engineer's representative.

A lateral wall movement or rotation of approximately 0.1 to 0.2 percent of the wall height may be required to mobilize active earth pressure for the recommended backfill materials. If the estimated wall movement is less than this amount, an at-rest soil pressure should be used in design. In order to mobilize passive earth pressure, lateral wall movement or rotation of approximately 1.0 to 2.0 percent of the wall height may be required for the recommended backfill materials. It should be carefully considered if this amount of movement can be accepted before passive earth pressure is used in the design.

Earth pressure loading within and along the back of the bridge abutments and wing walls shall be controlled by the structural backfill. We recommend that active, at-rest, and passive lateral earth pressures used for the design of the structures be based on an effective angle of internal friction of 34 degrees, and a unit weight of 135 pounds per cubic foot (pcf) for CDOT Structure Backfill Class 1. The following can be used for design assuming a horizontal backslope:

- Active earth pressure coefficient (k_a) of 0.28
- Passive earth pressure coefficient (k_p) of 3.53
- At-rest earth pressure coefficient (k_0) of 0.44

Lateral earth pressures for a non-horizontal backslope can be estimated using section 3.11 in AASHTO (2020).

3.6 Bridge Scour Parameters

A bulk sample of the creek bed soils/rock below the existing bridge was collected for gradation analysis. The results of the grain size analysis are presented in Appendix C.

4 BRIDGE APPROACH PAVEMENT

Pavement borings were located approximately 250 feet beyond the existing bridge abutments on each side. Prior to drilling, the existing pavement was cored with a 4-inch nominal diameter core barrel. Photos of the pavement core, logs of the subsurface soils/rock, and results of geotechnical and analytical laboratory testing are presented in the appendices. Bulk soil samples were collected from the pavement borings and combined for classification, strength (R-value), and analytical testing. The asphalt pavement thicknesses, aggregate base thicknesses (if present), subgrade soil classifications, and subgrade R-values are presented in Table 7. Analytical test results are presented in Table 8. Preliminary pavement design will be completed by CDOT Staff Materials.

Table 7. Existing Pavement Section and Subgrade Properties

Boring ID	Existing Asphalt Concrete Thickness (in)	Aggregate Base Thickness (in)	Subgrade Soil Classification (AASHTO)[1]	R-Value[1]
M-22-U-P-1	8.0	Not Encountered	A-6 (11)	15
M-22-U-P-2	10.0	Not Encountered		

1. Subgrade Classification and R-value test results based on combined bulk sample from each pavement boring.

5 ANALYTICAL TEST RESULTS

Analytical testing was completed on representative samples of soils encountered in the borings. The test results can be found in Appendix C and are summarized in Table 8. The Analytical results should be used to select the proper concrete type for the project in accordance with CDOT Standard Specifications (2019). A qualified corrosion engineer should review the laboratory data and boring logs to determine the appropriate level of corrosion protection for materials in contact with these soils.

Table 8. Analytical Test Results

Boring ID	Material	Water Soluble Sulfates, %	Water Soluble Chlorides, %	pH	Resistivity, ohm-cm
M-22-U-P-1/P-2	Lean Clay (Fill)	1.534	0.0026	-	-
M-22-U-B-1	Clayey Sand	0.654	0.0065	7.7	1119

6 SEISMIC CONSIDERATIONS

No active faults are known to exist in the immediate vicinity of the proposed bridge location. Based on the site class definitions provided in Table 3.10.3.1-1 of AASHTO LRFD (2020), the site can be categorized as Site Class E. Also based on the recommendations in Table 3.10.6-1 of AASHTO LRFD (2020), the bridge site can be classified as Seismic Zone 1.

The peak ground acceleration (PGA) and the short- and long- period spectral acceleration coefficients (S_s and S_1, respectively) for Site Class B (reference site class) were determined using the seismic design maps from the USGS website. The seismic design parameters for Site Class E are shown in Table 9.

Table 9. Seismic Design Parameters

PGA (0.0 sec)	S_S (0.2 sec)	S_1 (1.0 sec)
0.040 g	0.089 g	0.030 g
A_s (0.0 sec)	S_{DS} (0.2 sec)	S_{D1} (1.0 sec)
0.099 g	0.222 g	0.103 g

7 LIMITATIONS

Our scope of services was performed, and this report was prepared in accordance with generally accepted principles and practices in this area at the time this report was prepared. We make no other warranty, either express or implied.

The classifications, conclusions, and recommendations submitted in this report are based on the data obtained from published and unpublished maps, reports, and geotechnical analyses. Our conclusions and recommendations are based on our understanding of the project as described in this report and the site conditions as interpreted from the explorations. This data may not necessarily reflect variations in the subsurface conditions and water levels occurring at other locations.

The nature and extent of subsurface variations may not become evident until excavation is performed. Variations in the data may also occur with the passage of time. If during construction, fill, soil, rock, or groundwater conditions appear to be different from those described in this report, this office should be advised immediately so we could review these conditions and reconsider our recommendations. If there is a substantial lapse of time between the submission of this report and the start of work at the site, or if conditions have changed because of natural forces or construction operations at or adjacent to the site, we recommend that this report be reviewed to determine the applicability of the conclusions and recommendations concerning the changed conditions or time lapse. We recommend on-site observation of foundation excavations and foundation subgrade conditions by an experienced geotechnical engineer or engineer's representative.

The scope of services of this study did not include hazardous materials sampling or environmental sampling, investigation, or analyses. In addition, we did not evaluate the site for potential impacts to natural resources, including wetlands, endangered species, or environmentally critical areas.

8 REFERENCES

AASHTO LRFD, 9th Edition. AASHTO Load Resistance Factor Design (LRFD) Bridge Design Specifications, Eight Edition. Washington, DC: American Association of State Highway and Transportation Officials. 2020.

Abu-Hejleh, N., O'Neill, M.W., Hanneman, Dennis, Atwooll, W.J., 2003. Improvement of the Geotechnical Axial Design Methodology for Colorado's Drilled Shafts Socketed in Weak Rocks, Final Report: Colorado Department of Transportation Research Branch, July 2003, Report No. CDOT-DTD-R-2003-6.

Colorado Department of Transportation, 2019. CDOT Standard Specifications for Road and Bridge Construction. 2019 Edition.

Federal Highway Administration (FHWA) publications, Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide, Publication No. FHWA-HRT-11-026, June 2012.

Federal Highway Administration (FHWA) publications, Geosynthetic Reinforced Soil Integrated Bridge System Synthesis Report, Publication No. FHWA-HRT-11-027, January 2011.

Respectfully Submitted,
YEH AND ASSOCIATES, INC.

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Independent Technical Review by:

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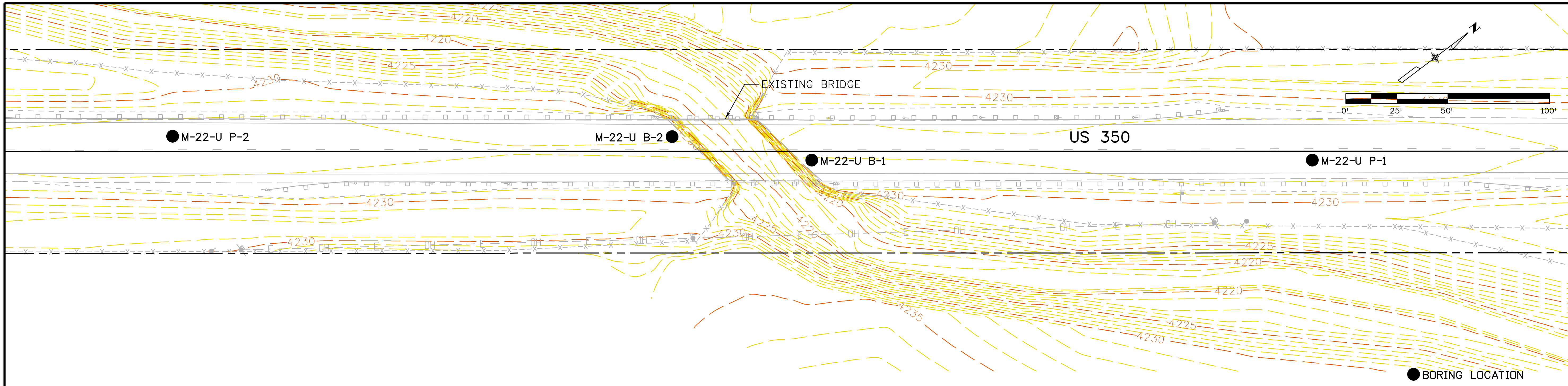
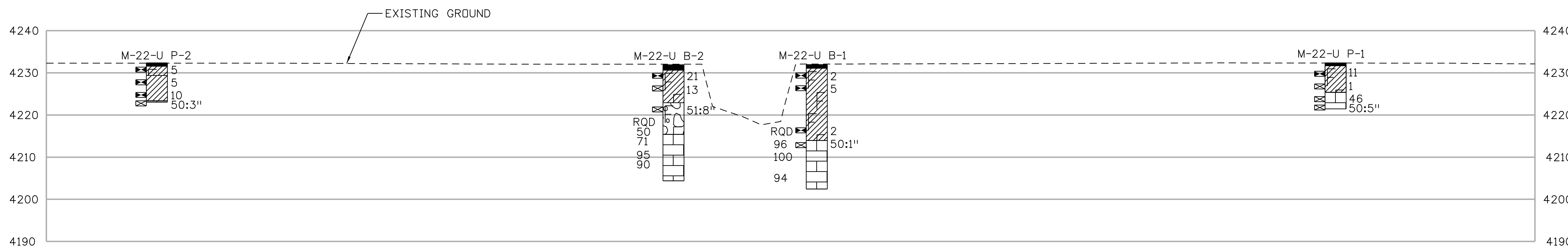
Attachments:
Appendix A
Appendix B
Appendix C

APPENDIX A

ENGINEERING GEOLOGY SHEET

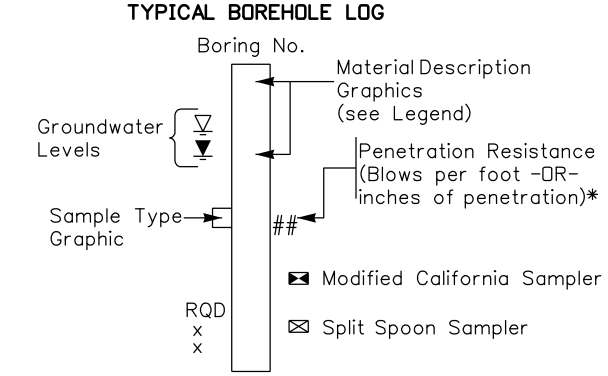




LEGEND

- Asphalt
- Low Plasticity Sandy Clay
- Fill
- USCS Clayey Gravel
- Limestone

TYPICAL BOREHOLE LOG



*e.g. A value of 50/3 or 50:3" indicates that 50 blows were applied to the sampler, with a penetration of 3 inches.

Print Date: 11/20/2020	
File Name: 23558GEOT_Engineering Geology M-22-U.dgn	
Horiz. Scale: 1:50	Vert. Scale: As Noted
Unit Information	Unit Leader Initials

Yeh and Associates, Inc.
Geotechnical · Geological · Construction Services

Sheet Revisions

Date:	Comments	Init.

Colorado Department of Transportation
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Region 2

As Constructed
No Revisions:
Revised:
Void:

R2 BRIDGE BUNDLE
ENGINEERING GEOLOGY

Designer:	JTM	Structure Numbers	M-22-U
Detailer:	MJW		
Sheet Subset:	Geology	Subset Sheets:	1 of 1

Project No./Code
STM R200-262
23558
Sheet Number

APPENDIX B

KEY TO BORING LOGS

BORING LOGS

PAVEMENT CORE PHOTOS

ROCK CORE PHOTOS

Yeh and Associates, Inc.
Geotechnical • Geological • Construction Services

Project:	CDOT Region 2 Bridge Bundle
Project Number:	220-063

Legend for Symbols Used on Borehole Logs

Sample Types

- Bulk Sample of auger/odex cuttings
- Rock core
- Modified California Sampler (2.5 inch OD, 2.0 inch ID)
- Standard Penetration Test (ASTM D1586)

Drilling Methods

- CORING
- HOLLOW-STEM AUGER

Lithology Symbols (see Boring Logs for complete descriptions)

Asphalt	Cobbles and gravel	USCS Fat/High Plasticity Clay	USCS Lean/Low Plasticity Clay
Fill with Clay as major soil	Fill with Gravel as major soil	USCS Clayey Gravel	USCS Silty, Clayey Gravel
USCS Poorly-graded Gravel	USCS Poorly-graded Gravel with Clay	Low Plasticity Gravelly Clay	USCS Silt
USCS Low Plasticity Organic silt or clay	High Plasticity Sandy Clay	Poorly-graded Sandy Gravel	Low Plasticity Sandy Clay
USCS Clayey Sand	USCS Silty Sand	USCS Poorly-graded Sand	USCS Poorly-graded Sand with Clay
Cobbles and gravel	Diorite	Gneiss	Granite
Limestone	Sandstone	Shale	Weathered Bedrock

Lab Test Standards

Moisture Content	ASTM D2216
Dry Density	ASTM D7263
Sand/Fines Content	ASTM D421, ASTM C136, ASTM D1140
Atterberg Limits	ASTM D4318
AASHTO Class.	AASHTO M145, ASTM D3282
USCS Class.	ASTM D2487

(Fines = % Passing #200 Sieve
Sand = % Passing #4 Sieve, but not passing #200 Sieve)

Other Lab Test Abbreviations

pH	Soil pH (AASHTO T289-91)
S	Water-Soluble Sulfate Content (AASHTO T290-91, ASTM D4327)
Chl	Water-Soluble Chloride Content (AASHTO T291-91, ASTM D4327)
S/C	Swell/Collapse (ASTM D4546)
UCCS	Unconfined Compressive Strength (Soil - ASTM D2166, Rock - ASTM D7012)
R-Value	Resistance R-Value (ASTM D2844)
DS (C)	Direct Shear cohesion (ASTM D3080)
DS (phi)	Direct Shear friction angle (ASTM D3080)
Re	Electrical Resistivity (AASHTO T288-91)
PtL	Point Load Strength Index (ASTM D5731)

Notes

1. Visual classifications are in general accordance with ASTM D2488, "Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)".
2. "Penetration Resistance" on the Boring Logs refers to the uncorrected N value for SPT samples only, as per ASTM D1586. For samples obtained with a Modified California (MC) sampler, drive depth is 12 inches, and "Penetration Resistance" refers to the sum of all blows. Where blow counts were > 50 for the 3rd increment (SPT) or 2nd increment (MC), "Penetration Resistance" combines the last and 2nd-to-last blows and lengths; for other increments with > 50 blows, the blows for the last increment are reported.
3. The Modified California sampler used to obtain samples is a 2.5-inch OD, 2.0-inch ID (1.95-inch ID with liners), split-barrel sampler with internal liners, as per ASTM D3550. Sampler is driven with a 140-pound hammer, dropped 30 inches per blow.
4. "ER" for the hammer is the Reported Calibrated Energy Transfer Ratio for that specific hammer, as provided by the drilling company.

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services	Project Name: CDOT Region 2 Bridge Bundle	PAGE 1 of 1
	Project Number: 220-063	Boring No.: **M-22-U-P-1**

Boring Began: 8/24/2020
Boring Completed: 8/24/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 55 Truck
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.9 ft
Ground Elevation: 4232.36
Coordinates: N: 475257.1 E: 551738.8
Location: US 350, northbound outside lane
Logged By: R. Desterhouse
Final By: J. McCall

Weather Notes: Clear, hot
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Liquid Limit	Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
				0.0 - 0.7 ft. ASPHALT (8 inches).									
				0.7 - 7.0 ft. Lean CLAY with sand (CL) (Fill), brown, moist, very soft to stiff.									
4230		6-5	11		*9.5*		*6.0*	*22.8*	*71.2*	*32*	*16*	*A-6 (9) CL*	
	5	2-0-1	1										
4225				**7.0 - 10.9 ft. LIMESTONE**, light gray to light brown, slightly weathered, medium hard to very hard.									
		31-12-34	46										
	10	45-50:5"	50:5"										
				Bottom of Hole at 10.9 ft.									
4220													
4215													
4210													

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services	Project Name: CDOT Region 2 Bridge Bundle	PAGE 1 of 1
	Project Number: 220-063	Boring No.: **M-22-U-P-2**

Boring Began: 8/27/2020
Boring Completed: 8/27/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 55/300 Track
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 9.3 ft
Ground Elevation: 4232.35
Coordinates: N: 474816.2 E: 551394.1
Location: US 350, southbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 80s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
							0.0 - 0.8 ft. ASPHALT (10 inches).									
				2-3	5		**0.8 - 3.0 ft. Lean CLAY with sand (CL) (Fill)**, light brown to gray, moist, medium stiff.									
4230																
				3-2	5		**3.0 - 9.0 ft. Lean CLAY with sand (CL)**, light brown to light gray, moist, stiff, abundant calcite crystals, rock structure apparent (residuum).	16.5	104.5	0.0	20.1	79.9	36	21	A-6 (15) CL	S/C=0.4%
	5															
4225				3-7	10											
				50:3"	50:3"		**9.0 - 9.3 ft. LIMESTONE**, light brown, slightly weathered, very hard.									
4220							Bottom of Hole at 9.3 ft.									
4215																
4210																

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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 | Boring No.: **M-22-U-B-1**

Boring Began: 8/24/2020
Boring Completed: 8/28/2020
Drilling Method(s): Hollow-Stem Auger / Wireline Coring
Driller: Vine Laboratories
Drill Rig: CME 55 Truck
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 29.5 ft
Ground Elevation: 4231.95
Coordinates: N: 475060.3 E: 551591.6
Location: US 350, northbound outside lane
Logged By: R. Desterhouse
Final By: J. McCall

Weather Notes: Hot, 100F
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Rock Recovery (%)	Rock RQD (%)	Soil Samples Blows per 6 in	Soil Samples Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Liquid Limit	Atterberg Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
						0.0 - 0.9 ft. ASPHALT (11 inches).									
4230				1-1	2	**0.9 - 18.0 ft. Lean CLAY with sand (CL) and gravel (Fill)**, light brown to yellowish brown, soft to medium stiff.									
	5			2-3	5		15.0	109.6	22.0	29.5	48.5	34	19	A-6 (5) SC	pH=7.7 S=0.654% Chl=0.0065% Re=1119ohm·cm
4225															
	10														
4220															
	15			1-1	2										
4215															
				50:1"	50:1"	**18.0 - 29.5 ft. LIMESTONE**, white to light gray, very hard, subvertical fractures wtih oxide staining, fresh to slightly weathered with local decomposed zones, fossiliferous, gypsum in fractures.									
		97	97												
	20														UCCS=5740 psi
4210															
		100	100												

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Rock: Recovery (%)	Rock: RQD (%)	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
4205				100	94													

Bottom of Hole at 29.5 ft.

Elevation (feet)
4200
4195
4190
4185
4180

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services	*Project Name:* CDOT Region 2 Bridge Bundle	*PAGE 1 of 2*
	Project Number: 220-063	*Boring No.:* **M-22-U-B-2**

Boring Began: 8/27/2020
Boring Completed: 8/27/2020
Drilling Method(s): Hollow-Stem Auger / Wireline Coring
Driller: Vine Laboratories
Drill Rig: CME 55/300 Track
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 27.5 ft
Ground Elevation: 4231.9
Coordinates: N: 475012.4 E: 551541.3
Location: US 350, southbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 80s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Rock: Recovery (%)	Rock: RQD (%)	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
	0					**0.0 - 1.3 ft. ASPHALT** (15 inches).									
4230				3-18	21	**1.3 - 9.0 ft. Sandy lean CLAY with gravel (CL) (Fill)**, light brown to gray, moist, very stiff, limestone gravels.									
	5			3-5-8	13										
4225															
	10			1-1-50:2"	51:8"	**9.0 - 16.5 ft. Clayey GRAVEL with sand (GC) (Fill)**, light brown and light gray, moist, very loose, limestone gravels.	3.7		49.0	20.3	30.7				
4220															
	15	65	50												
4215		83	71			**16.5 - 27.5 ft. LIMESTONE**, light gray, predominantly decomposed to slightly weathered, very hard, irregularly spaced and oriented fractures, oxide staining, clay infilling.									UCCS=12490 psi
	20														
4210		95	95												

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Project Name:	CDOT Region 2 Bridge Bundle	PAGE 2 of 2
Project Number: 220-063	Boring No.: **M-22-U-B-2**	

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Rock: Recovery (%)	Rock: RQD (%)	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
4205				90	90													
									Bottom of Hole at 27.5 ft.									
4200																		
4195																		
4190																		
4185																		
4180																		

Boring:	**B-1**	AC:	**10.5"**
Roadway:	**US 350**	PCC:	**-**
Direction:	**Northbound**	Base:	**-**
Lane:	**Outside**	Notes:	P-1 core crumbled. B-1 core shown.

Boring:	**P-2**	AC:	**10"**
Roadway:	**US 350**	PCC:	**-**
Direction:	**Southbound**	Base:	**-**
Lane:	**Outside**	Notes:	-

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Pavement Core Photographs

FIGURE **B-1**

PROJECT NO.	220-063	DATE:	11/16/2020
FIGURE BY:	BHL	YEH OFFICE:	Colorado Springs
CHECKED BY:	JTM		

CDOT Region 2 Bridge Bundle
Structure M-22-U

Yeh and Associates, Inc.
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Rock Core Photos
Boring: B-1
Depth: 18' - 26'

FIGURE

B-2

PROJECT NO.	220-063	DATE:	11/16/2020
FIGURE BY:	BHL	YEH OFFICE:	Colorado Springs
CHECKED BY:	JTM		

CDOT Region 2 Bridge Bundle
Structure M-22-U

Yeh and Associates, Inc.
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Rock Core Photos
Boring: B-1
Depth: 26' - 29'

FIGURE

B-3

PROJECT NO.	220-063	DATE:	11/16/2020
FIGURE BY:	BHL	YEH OFFICE:	Colorado Springs
CHECKED BY:	JTM		

CDOT Region 2 Bridge Bundle
Structure M-22-U

Yeh and Associates, Inc.
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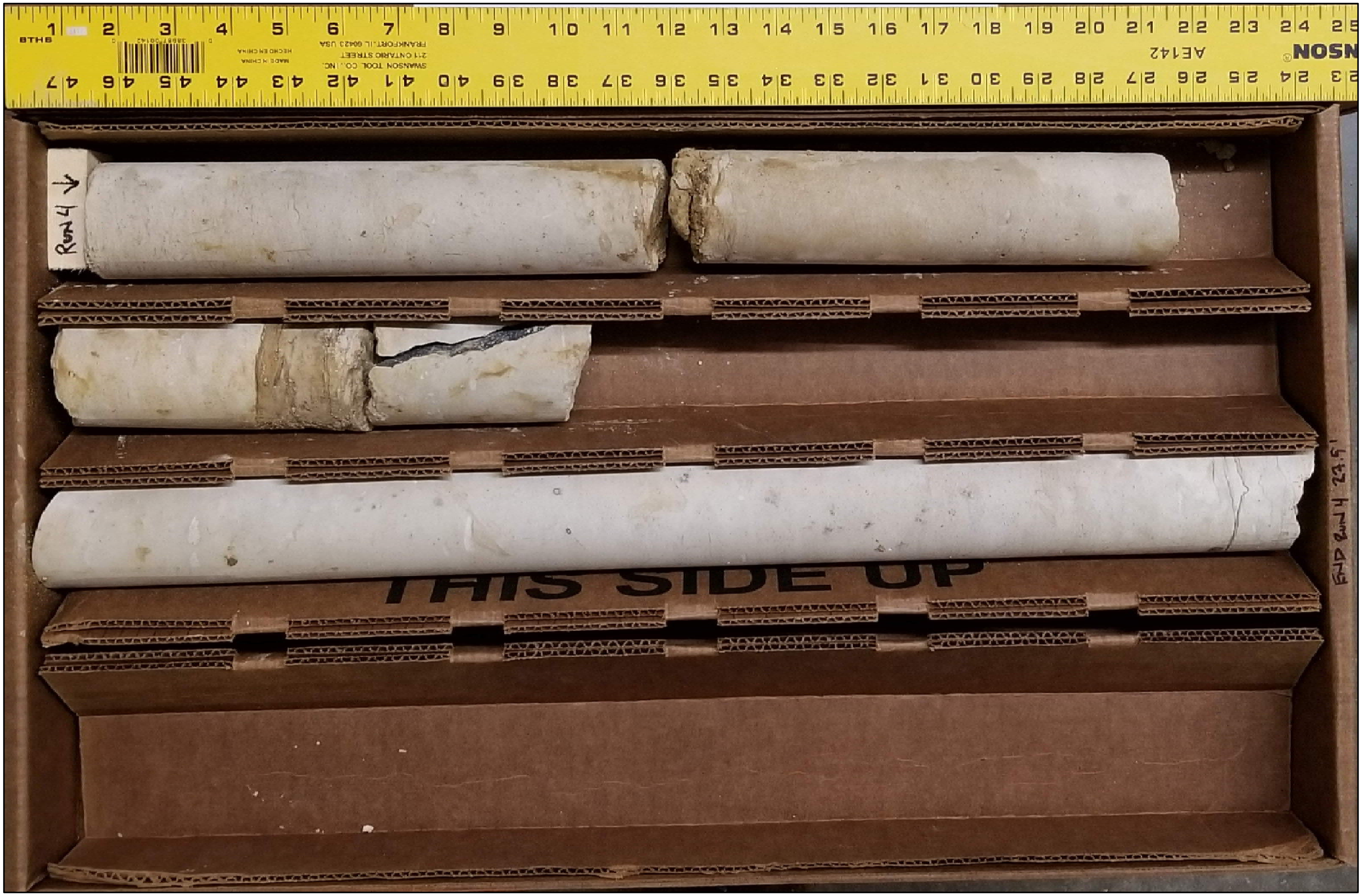
Rock Core Photos
Boring: B-2
Depth: 15' - 22.5'

FIGURE
B-4

PROJECT NO.	220-063	DATE:	11/16/2020
FIGURE BY:	BHL	YEH OFFICE:	Colorado Springs
CHECKED BY:	JTM		

CDOT Region 2 Bridge Bundle
Structure M-22-U



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Rock Core Photos
Boring: B-2
Depth: 22.5' - 27.5'

PROJECT NO.	220-063	DATE:	11/16/2020
FIGURE BY:	BHL	YEH OFFICE:	Colorado Springs
CHECKED BY:	JTM		

CDOT Region 2 Bridge Bundle
Structure M-22-U

FIGURE

B-5

APPENDIX C

SUMMARY OF LABORATORY TEST RESULTS

Yeh and Associates, Inc.
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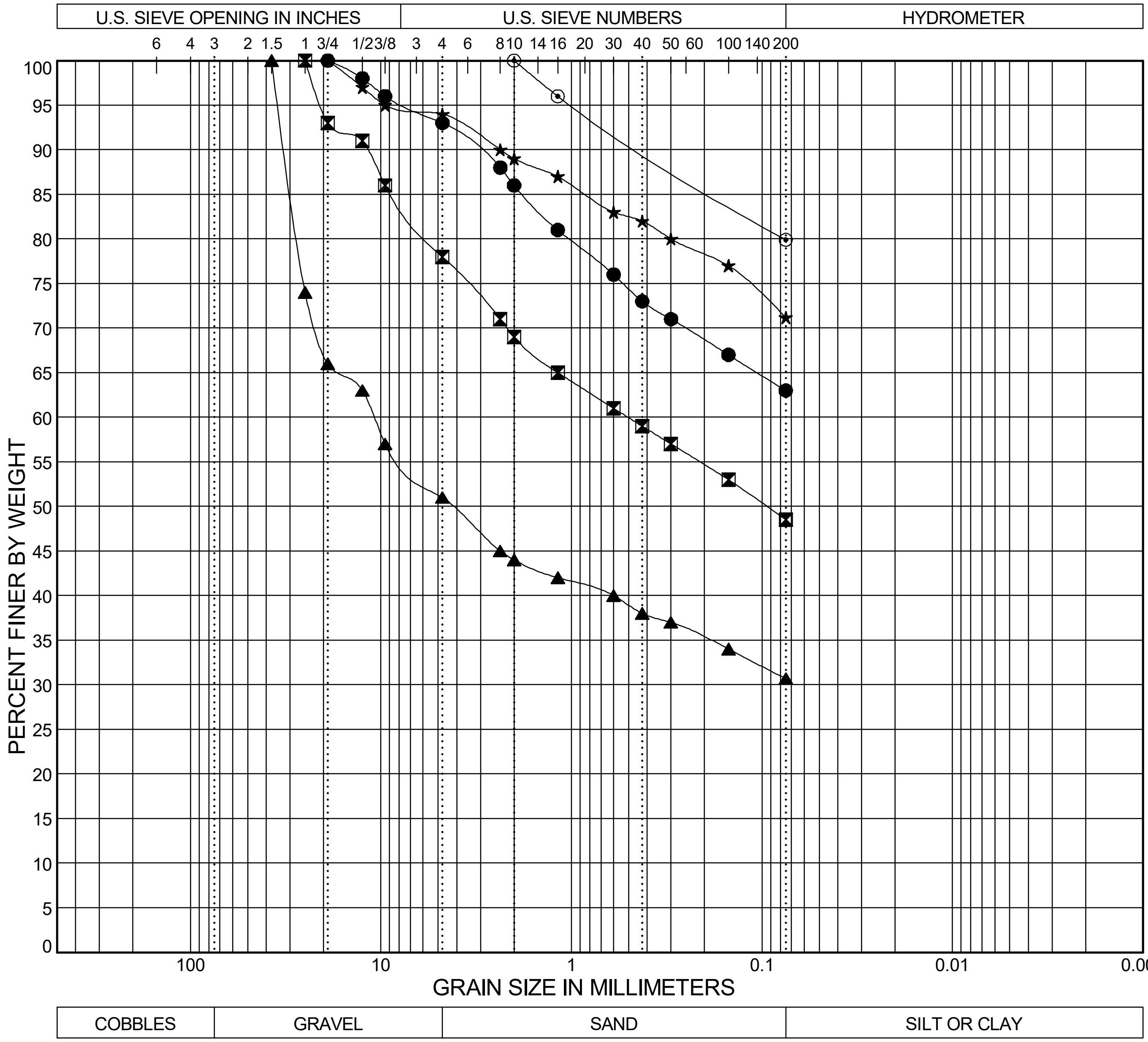
Colorado Springs Lab

Summary of Laboratory Test Results

Project No: 220-063 Project Name: CDOT Region 2 Bridge Bundle Date: 11-19-2020

Sample Location			Natural Moisture Content (%)	Natural Dry Density (pcf)	Gradation			Atterberg			pH	Water Soluble Sulfate (%)	Water Soluble Chloride (%)	Resistivity (ohm-cm)	Swell (+) / Collapse (-) (% at Load in psf)	Unconf. Comp. Strength (psi)	R-Value	Classification	
Boring No.	Depth (ft)	Sample Type			Gravel > #4 (%)	Sand (%)	Fines < #200 (%)	LL	PL	PI								AASHTO	USCS
M-22-U P-1/P-2	2.5	BULK	13.8		7.0	30.0	63.0	36	14	22		1.534	0.0026				15	A-6 (11)	CL
M-22-U Scour	0	BULK	5.9		31.0	24.3	44.7												
M-22-U-B-1	5.0	MC	15	109.6	22.0	29.5	48.5	34	15	19	7.7	0.654	0.0065	1119				A-6 (5)	SC
M-22-U-B-1	21.0	CORE														5740			
M-22-U-B-2	10.0	SPT	3.7		49.0	20.3	30.7												
M-22-U-B-2	18.0	CORE														12490			
M-22-U-P-1	2.0	BULK	9.5		6.0	22.8	71.2	32	16	16								A-6 (9)	CL
M-22-U-P-2	4.0	MC	16.5	104.5	0.0	20.1	79.9	36	15	21					0.4 @ 200			A-6 (15)	CL



BOREHOLE		DEPTH (ft)	AASHTO Classification	USCS Classification	LL	PL	PI	%Gravel	%Sand	%Fines %Silt	%Fines %Clay
●	**M-22-U P-1/P-2**	**2.5**	**A-6 (11)**	**CL**	**36**	**14**	**22**	**7.0**	**30.0**	**63.0**	
⊠	**M-22-U-B-1**	**5.0**	**A-6 (5)**	**SC**	**34**	**15**	**19**	**22.0**	**29.5**	**48.5**	
▲	**M-22-U-B-2**	**10.0**						**49.0**	**20.3**	**30.7**	
★	**M-22-U-P-1**	**2.0**	**A-6 (9)**	**CL**	**32**	**16**	**16**	**6.0**	**22.8**	**71.2**	
⊙	**M-22-U-P-2**	**4.0**	**A-6 (15)**	**CL**	**36**	**15**	**21**	**0.0**	**20.1**	**79.9**	

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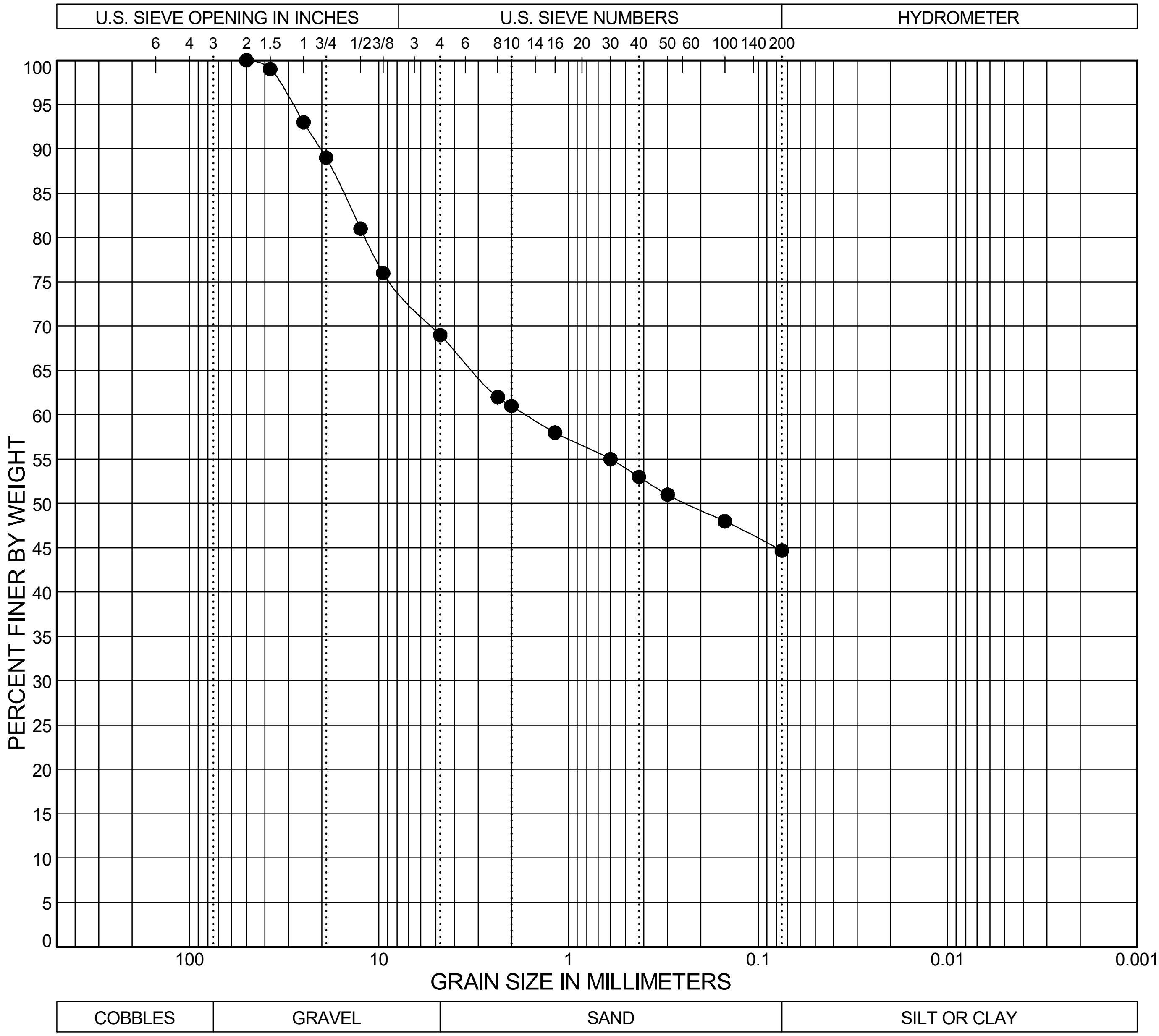
SIEVE ANALYSIS

FIGURE C- 1

Project No.	220-063	Date:	11-19-2020
Report By:	D. Gruenwald	Yeh Lab:	Colorado Springs
Checked By:	J. McCall		

CDOT Region 2 Bridge Bundle
Structure M-22-U



	BOREHOLE	DEPTH (ft)	AASHTO Classification	USCS Classification	LL	PL	PI	%Gravel	%Sand	%Fines: %Silt	%Fines: %Clay
●	**M-22-U Scour**	**0.0**						**31.0**	**24.3**	**44.7**	

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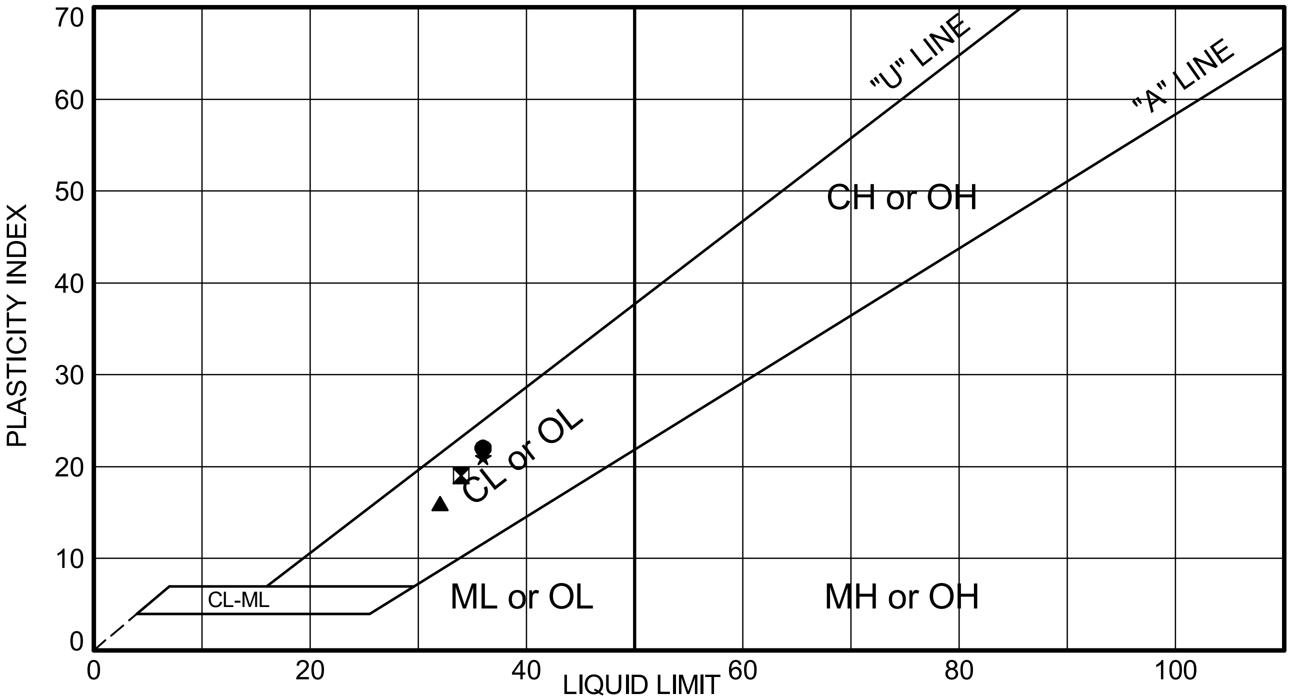
SIEVE ANALYSIS

FIGURE

C- 2

Project No.	220-063	Date:	11-19-2020
Report By:	D. Gruenwald	Yeh Lab:	Colorado Springs
Checked By:	J. McCall		

CDOT Region 2 Bridge Bundle
Structure M-22-U



	BOREHOLE	DEPTH (ft)	LL	PL	PI	Passing #200	USCS Sample Description and Symbol	AASHTO Class.
●	**M-22-U P-1/P-2**	**2.5**	**36**	**14**	**22**	**63.0**	**SANDY LEAN CLAY (CL)**	**A-6 (11)**
⧗	**M-22-U-B-1**	**5.0**	**34**	**15**	**19**	**48.5**	**CLAYEY SAND with GRAVEL (SC)**	**A-6 (5)**
▲	**M-22-U-P-1**	**2.0**	**32**	**16**	**16**	**71.2**	**LEAN CLAY with SAND (CL)**	**A-6 (9)**
★	**M-22-U-P-2**	**4.0**	**36**	**15**	**21**	**79.9**	**LEAN CLAY with SAND (CL)**	**A-6 (15)**

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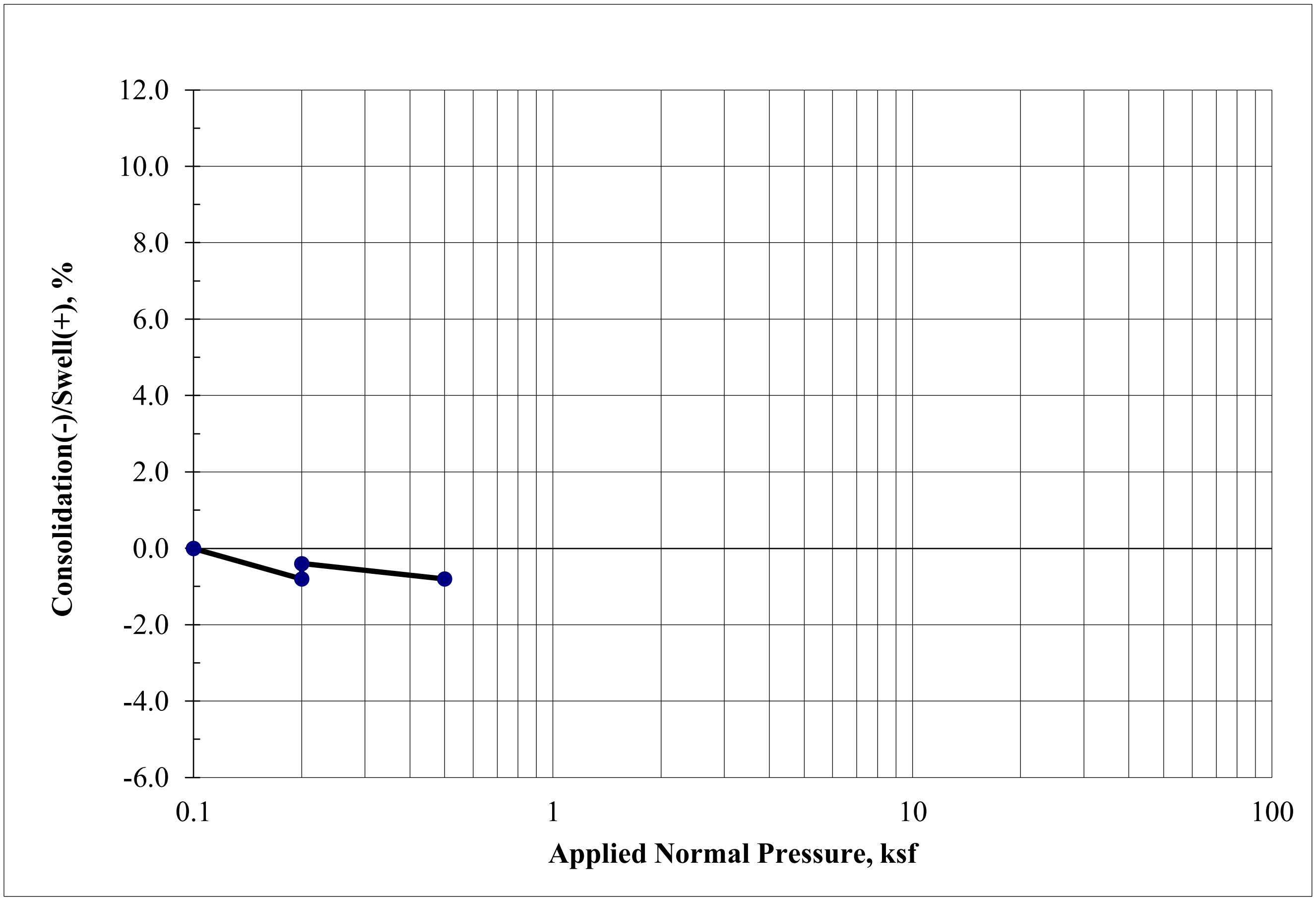
ATTERBERG LIMITS

FIGURE C - 3

Project No. 220-063 Date: 11-19-2020
Report By: D. Gruenwald Yeh Lab: Colorado Springs
Checked By: J. McCall

CDOT Region 2 Bridge Bundle
Structure M-22-U

SWELL/CONSOLIDATION TEST - ASTM D 4546



Boring ID	P-2
Sample Depth (ft)	4.0
Date Sampled	8/24/2020

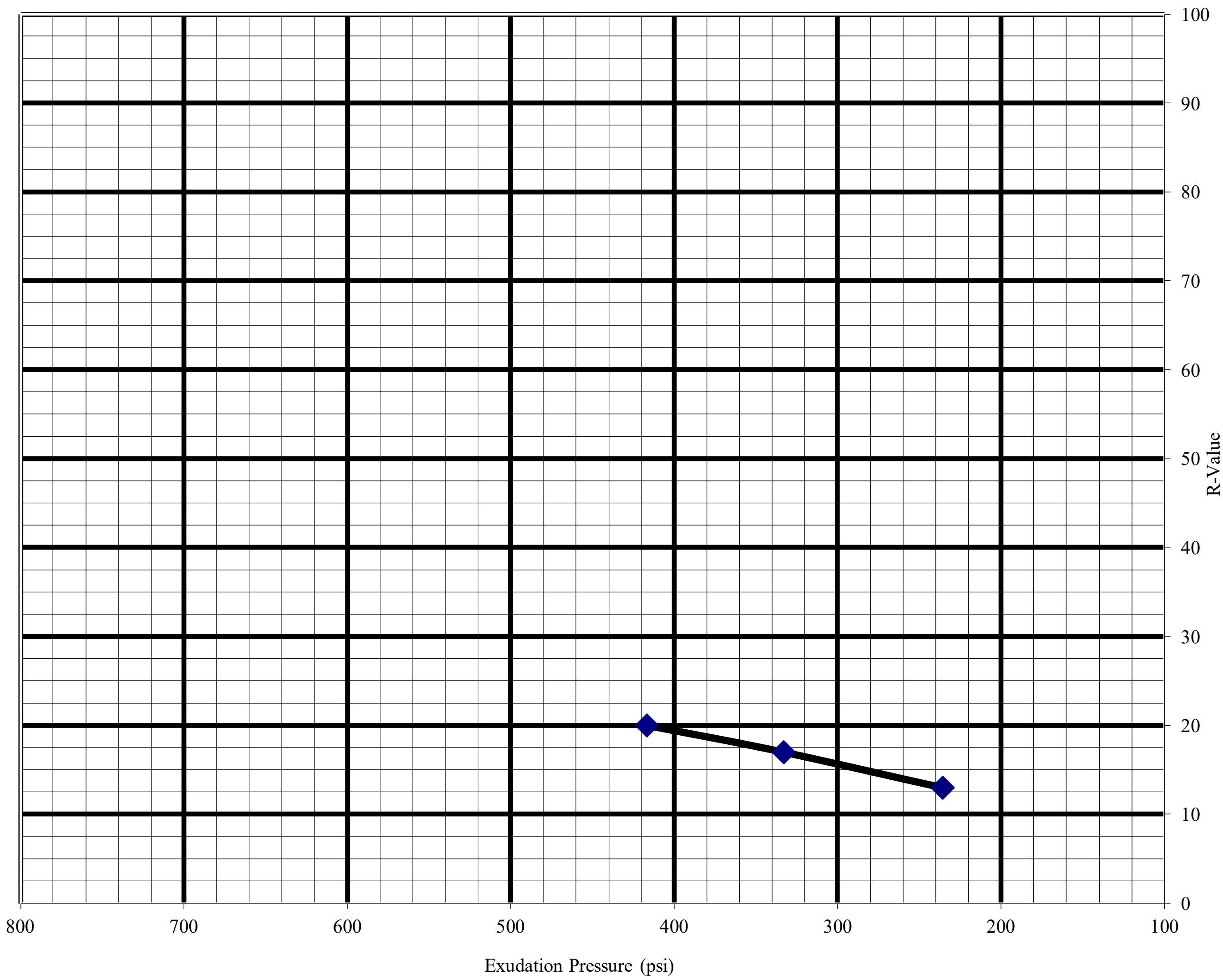
Swell/ Consolidation (%)	0.4
Natural Moisture Content (%)	16.5
Saturated Moisture Content (%)	20.6
Dry Density (pcf)	104.5

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services				**SWELL/ CONSOLIDATION TEST RESULTS**	**FIGURE**
Project No.	220-063	Date:	11/19/2020	CDOT Region 2 Bridge Bundle Structure M-22-U	**C-4**
Report By:	DG	Yeh Lab:	Colorado Springs		
Checked By:	JTM				

YEH AND ASSOCIATES, INC
R-Value Test Report

Project Number: 220-063
Project Name: CDOT Region 2 Bridge Bundle
Sample Id: P-1 / P-2
Depth (ft): 2.5
Location: M-22-U
Station:
Date Sampled: 8/24/2020
Date Tested: 11/13/2020

R-Value at 300 psi exudation pressure = 15



Test No.	Compact. Press. (psi)	Density (pcf)	Moist. (%)	Horizont. Pressure (psi)'@ 160 psi	Sample Height (in).	Exud. Pressure (psi)	R Value	R Value Correct.
1	350	123.8	13.0	121	2.51	417	20	20
2	350	120.2	14.0	124	2.46	333	17	17
3	350	120.4	15.0	130	2.50	236	13	13

Sampled by: RD
Tested by: Kyle Lyons
Checked by: M.A

Rev. 08-16-2018