Yeh and Associates, Inc.
Consulting Engineers & Scientists

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FROM: Thomas L. Allen, P.E. TLA
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DATE: October 8, 2018

SUBJECT: CDOT Project Code 22420 – US 550 S Connection to US 160 D-B
Gulch A Landslide Mitigation

This memo presents a summary of subsurface conditions, geotechnical considerations and evaluation of alternatives to stabilize the existing unstable slope (landslide) below the south abutment (Abutment 1) of proposed Bridge Structure P-05-AZ (Bridge 1). The structure is shown on preliminary plans provided by CDOT for Project 19378 (Post-FIR dated 12-05-16). The landslide is identified on the Geologic Map included in the Draft Geotechnical Data Report (GDR) for CDOT Project 19378, prepared by Yeh and Associates (YA) and dated July 17, 2018. The recommendations are intended for use to develop Reference Design Plans for the Design-Build project.

Landslide Description

The landslide on the south side of Gulch A, at the proposed bridge abutment, is one of several that were identified along the side slopes of Gulches A and B during early geologic reconnaissance for development of the Supplemental Environmental Impact Statement (SEIS) prepared in 2014. These unstable slopes are prevalent on the side slopes of the gulches and along the edges of the mesa. They generally consist of colluvium derived from surficial soils and terrace gravel deposits that overly the Animas Formation bedrock. The relatively shallow colluvium is gradually creeping down the sides of the drainages as evidenced by headscarps that have formed near the upper ends of the deposits. Seepage has been observed near the toes of the unstable slopes, indicating groundwater from the upper alluvial gravels has migrated along the colluvium/bedrock contact. High groundwater levels, occurring during wet years or seasonal irrigation, appear to trigger slope movement.

This memo addresses the landslide below the proposed Abutment 1 of Bridge P-05-AZ. The Abutment 1 and Pier 2 foundations will be located in the landslide and the mitigation alternatives discussed herein are proposed to stabilize the slope and support the foundation elements as shown in the Reference Design Plans. The mitigation alternatives are not intended for design options other than the Reference Design. Mitigation may be required at other landslide locations where unstable slopes could affect proposed structures or grading that differ from the Reference Design.

Additional geologic mapping and subsurface exploration, performed as part of the geotechnical investigation for preparation of the GDR, further identified the limits of the landslide below Abutment 1 of Structure P-05-AZ. The horizontal limits are shown on the Geologic Map included in the GDR. A head scarp feature that crosses the proposed alignment was identified during the field investigation at approximate Station 1013+80. The location for the proposed spread footing foundation of Abutment 1 is near the top of the landslide at Station 1014+23. Landslide mitigation is required for long term stabilization of the slope below the abutment such that the slope will support the abutment loads over the design life of the bridge structure.

Proposed Bridge Structure

The proposed bridge P-05-AZ will be a four span structure with 2 abutments and 3 piers. Abutment foundations will be spread footing and the pier foundation will be drilled caissons. It appears the Abutment 1 footing will be founded on the landslide deposit with a maximum bearing pressure of approximately 6.0 ksf. The pier foundations will penetrate the colluvial gravel deposit and bear in the underlying bedrock. Pier 2 will be located on the unstable slope and will require a design that resists the lateral loads imposed by the landslide. The bridge layout is shown on the attached Structure Engineering Geology plan sheet. The upper portion of the materials that form the landslide is expected to be removed during grading for the roadway. The removal will reduce the potential for landslide activation by decreasing the forces that drive movement.

Subsurface Conditions

Fifteen (15) borings were drilled to investigate subsurface conditions at Bridge 1. The boring locations and logs are shown on the attached Structure Engineering Geology plan sheet. The conditions encountered in the borings generally consist of 5 to 20 feet of clayey sand soil or clayey sand and gravel over dense alluvial terrace gravel or claystone/shale bedrock. A summary of the conditions encountered in each boring at Bridge 1 is provided in Table 1.

Borings B1-01 and B1-02 were drilled at the proposed location of Abutment 1 as shown on the plans. These borings encountered silty sand soil over sandy gravel with cobbles and boulders. Bedrock was encountered at depths of 89 feet and 88 feet respectively. The bedrock surface elevation is, in general, lower in these borings than in other nearby borings.

Table 1 Summary of Bridge 1 Borings

Boring	Station	Offset	Total Depth (ft)	Approx. Cut (ft)	Depth to Gravel (ft)	Depth to Bedrock (ft)
B1-01B	1013+18	36’ LT	79.1	20	16.5	66.5
B1-02A	1013+38	31’ RT	89.2	30	27	79.0
B1-01A	1013+80	17’ RT	122.0	17	18	100.4
B1-01	1013+94	24’ LT	106.0	9	9	89.0
B1-02	1014+08	29’ RT	101.0	7	0	88.0
B1-03	1014+68	24' RT	48.5	n/a	0	35.0
B1-04	1015+09	1' RT	55.0	n/a	0	1.5
B1-05	1015+39	20' LT	45.0	n/a	0	9.0
B1-06	1015+60	24' RT	32.7	n/a	0	10.3

B1-07	1015+72	41' LT	40.0	n/a	0	21.0
B1-08	1016+11	0'	70.0	n/a	0	7.0
B1-09	1016+55	0'	70.0	n/a	0	5.0
B1-10	1017+80	1' LT	70.0	n/a	0	6.7
B1-11	1019+17	21' LT	70.2	n/a	0	15.2
B1-12	1019+20	25' RT	70.4	n/a	0	13.0

We believe irregular erosion of the bedrock near the proposed location of Abutment 1 has resulted in a bedrock surface depression that was subsequently infilled with colluvium that consists of a mixture of clayey soils and terrace deposits, and contains cobbles and boulders (referred to as slope wash deposits in the GDR). The materials were transported by erosion and gravity from their original alluvial deposit and are believed to be unstable and the source of the landslide. Boring B1-01A was drilled south of the abutment location to identify the extent of the bedrock depression and colluvial materials. This boring encountered conditions similar to those in Borings B1-01 and B1-02, with bedrock at a depth of approximately 100 feet. Borings B1-01B and B1-02A were drilled approximately 80 feet south of the planned location of Abutment 1. These borings encountered clayey surficial soils overlying terrace alluvium that appears to be unaltered by recent erosion. These in-place alluvial materials are expected to have good foundation support characteristics.

Inclinometers were installed in Borings B1-03, B1-05, B1-06 and B1-07 to measure the rate, direction and depth of slope movement. Data collection from the instrumentation began in early April 2018 and no significant movement had been observed as of August 20, 2018. The absence of measurable slope movement may be due to the extreme drought conditions in the area over the past year.

Analysis

Yeh and Associates modeled the global stability of the landslide using the limiting equilibrium method of slices. Using this technique, the slope profile is geometrically divided into many vertical “slices,” driving and resisting forces are calculated for each slice, the forces are summed, and then a factor of safety is calculated as the ratio of the sum of resisting forces to the sum of driving forces. Thus, a factor of safety (FS) of 1.0 can be interpreted as resisting forces equal to driving forces, or a slope that exists just at equilibrium, which would indicate continual creeping of the landslide are likely. A FS less than 1.0 indicates resisting forces less than driving forces, or a slope below the limit of equilibrium (the slope is actively failing at a moderate rate). A FS more than 1.0, for example a FS of 1.50, indicates total resisting forces are 50 percent higher than total driving forces.

The AASHTO 7th Edition LRFD Bridge Design Specifications (2014) indicate the overall (global) stability of earth slopes with or without a foundation unit should be investigated using a resistance factor of:

- 0.75 where the slope does not support or contain a structural element
- 0.65 where the slope contains or supports a structural element

For overall (global) stability, resistance factors are inverted to get a factor of safety corresponding to that calculated by limiting equilibrium. Thus, a resistance factor of 0.75 is equivalent to a FS of 1.3 and a resistance factor of 0.65 is equivalent to a FS of 1.5. A FS of at least 1.50 is required for the landslide stabilization below the abutment. We recommend mitigating from below the entire width of the bridge and at least 20 feet either side of the abutment, a total of approximately 120 feet across the slope, to stabilize the landslide.
YA evaluated global stability of the landslide with the aid of the computer software SLIDE (Version 7, Rocscience, 2016) at a cross-section through the bridge centerline within the unstable slope section. The global stability analysis results presented in this report include:

- Existing conditions
- Four rows of ground anchor tieback anchors
- Four rows of ground anchor tieback anchors with a toe buttress

Existing Conditions

As the first step of our analysis, YA modeled the global stability of the existing condition to match approximately the existing location of the headscarp at approximate Station 1013+80. A FS near 1.0 was back calculated to represent the marginal stability of the existing slope. The SLIDE output for the existing conditions is included as an attachment.

It appears that the slope failure shear zone is located within the colluvial materials and above the approximate bedrock surface as measured in the borings. Water infiltration through the alluvial terrace gravel from precipitation during wet years and from irrigation likely contributes to the slope failure.

Based on the subsurface materials encountered in the borings, laboratory testing, and a parametric stability analysis, YA chose the following strength parameters to represent the soil and bedrock materials present at the subject site:

Table 1 – Strength Parameters used in Slope Stability Models

Material Type	Dry Unit Weight (pcf)	Residual Cohesion (psf)	Residual Friction (deg)
Clayey Sand Surficial Soil	120	50	28
Alluvial Terrace Gravel	135	0	35
Colluvium	130	0	32
Bedrock	140	2000	45
Buttress	135	0	36

These strength parameters are intended to represent the residual (i.e. after movement has initiated) strength of the soil along the existing failure surface. The evaluation of mitigation options included the anticipated loads from the bridge abutment and traffic loads at the bridge approach.

Alternative 1-Tieback Anchors

The tieback anchor mitigation alternative consists of installing several rows of ground anchors into the landslide, constructed from a series of working benches. A wall would not be required, and each row of tieback anchors would be connected with a row of concrete or shotcrete structural panels. Preliminary analysis indicates that four (4) rows of tiebacks anchored in the Animas Formation bedrock would be required to reach a FS of 1.5 or greater. Tieback anchors would be installed 8.5 feet on center horizontally within each row, and each anchor would be tensioned to 175 to 200 kips. The tieback anchors would be approximately 130 to 150 feet long including bond length, depending on the location, in order to reach stable bedrock material for the bond length of the anchors. Approximately 56 anchors would be required. The SLIDE analysis output for this option is attached.

Alternative 2 - Tieback Anchors and Toe Buttress

This alternative would consist of four rows of tiebacks and a stabilization buttress near the toe of the unstable slope. The tieback configuration would be the same as for the alternative above, except that the minimum anchor tension would be 140 kips. This will reduce the required bond length in the bedrock. A typical section for Alternative 2 is provided in the Appendix. Preliminary global stability analysis of this alternative indicates a minimum FS of 1.54, and an example of the SLIDE analysis performed is attached.

Multiple Rows of Tieback Anchors Option Advantages:

1. Long-term stabilization of the landslide for support of the bridge abutment.
2. Stabilization of the slope for temporary access to pier foundations.
3. Can be buried after construction to reduce visual impacts.

Multiple Rows of Tieback Anchors Disadvantages:

1. Temporary work platform required on side of existing slope.
2. Requires comprehensive testing of tiebacks during installation and construction.
3. Installation through colluvium and alluvium with boulders and cobbles to design depths will be difficult.

Tieback Anchor Design

The tieback anchor system designs assume an ultimate bond stress of 0.2 Mpa (30 psi) based on values for gravity grouted anchors in soft shale as shown in Table 7 of the FHWA publication GEC 7, *Ground Anchors and Anchored Systems*. An anchor installed in a 7-inch diameter drill hole will have an ultimate bond capacity of approximately 7900 pounds per foot of bond length. Using a Factor of Safety of 2.0 for the bond stress, the allowable bond capacity is 3950 lb/ft of bond length. Minimum bond lengths are 35 feet for a 140 kip capacity anchor and 43 feet for a 170 kip capacity anchor. Proposed anchor panels consist of 8-foot by 8-foot reinforced concrete. Anchors are spaced at 8.5 feet O.C. across the slope.

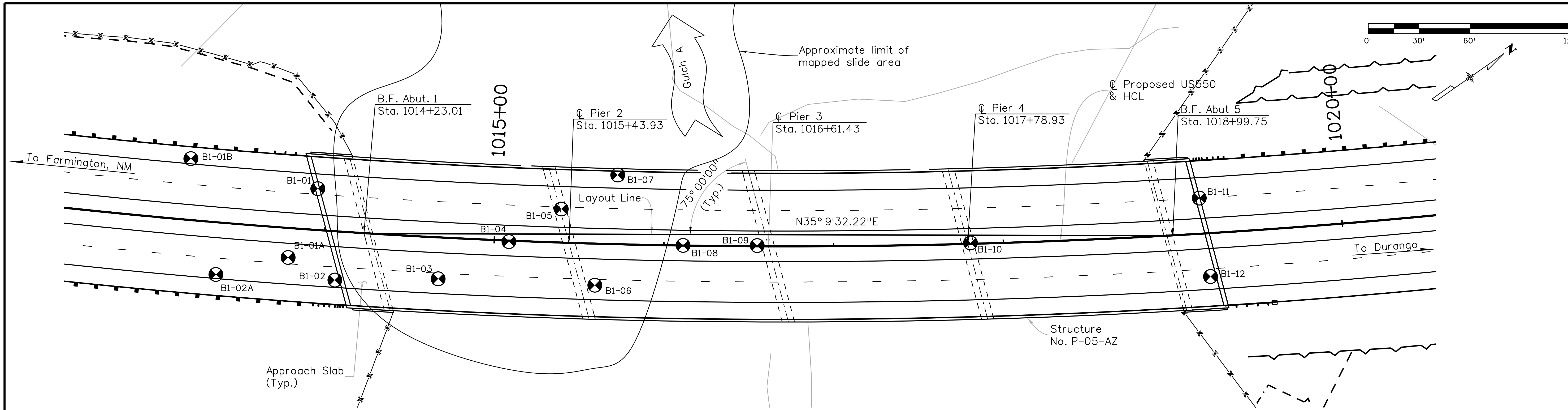
Tieback Anchors and Buttress Alternative - Estimated Cost

Table 2 summarizes the estimated costs for the tieback anchor and buttress alternative. The estimate includes landslide mitigation items only and does not include mobilization, construction engineering, or other costs. The estimated unit costs reflect the difficult access and drilling conditions expected at the site.

Table 2 – Estimated Cost of Multiple Rows of Tieback Anchors with Buttress Option

Item No.	Item Description	Unit	Est. Quantity	Est. Unit Cost	Est. Total Item Cost
203-00060	Embankment - Buttress	CY	1700	$22.00	$37,400
206-00000	Structure Excavation	CY	900	$30.00	$27,000
504-04430	Reinforced Concrete Facing	SF	3600	$30.00	$108,000
618-08900	Ground Anchor	LF	7980	$90.00	$718,200
				Est. Total Cost	$890,600

Attachments: Engineering Geology Plan Sheet (Bridge 1), SLIDE Analysis Results (3), Mitigation Alternative Plan Sheet



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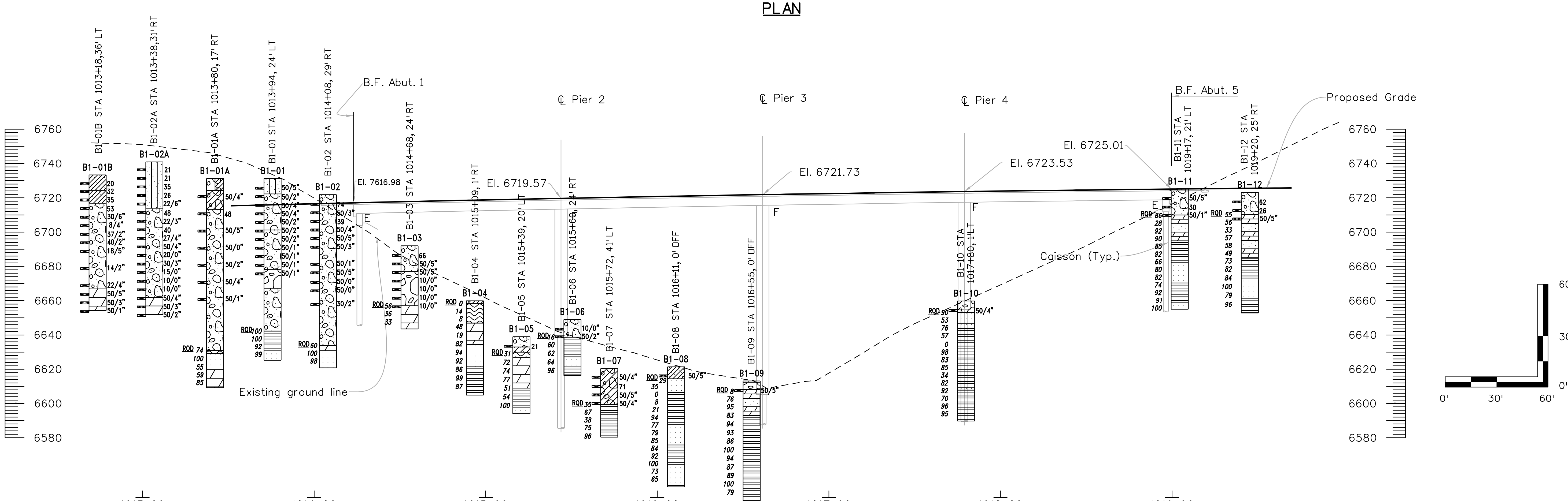

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File Name: 019_22420_Bridge 1_PnP (Eng Geol).DGN			
Horiz. Scale: 1:60	Vert. Scale: As Noted		
Unit Information	Unit Leader Initials		
Yeh and Associates, Inc. Consulting Engineers & Scientists			

Sheet Revisions

Date:	Comments	Init.

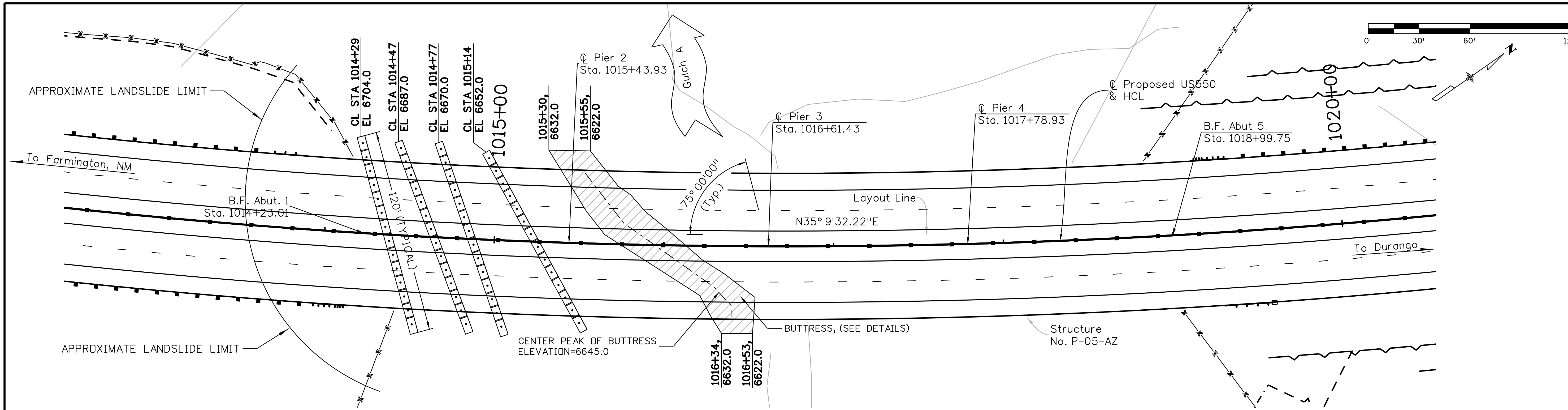
Colorado Department of Transportation
CDOT
3803 North Main Avenue
Suite 200
Durango, CO 81301
Phone: 970-385-1440 FAX: 970-385-8365
Region 5 DRV

As Constructed
No Revisions:
Revised:
Void:

STRUCTURE ENGINEERING GEOLOGY
BRIDGE 1 (GULCH A)

Designer:		Structure Numbers	P-05-AZ
Detailer:			
Sheet Subset: EG-BRIDGES		Subset Sheets:	1 OF 2

Project No./Code
NHPP 5501-029
22420
Sheet Number



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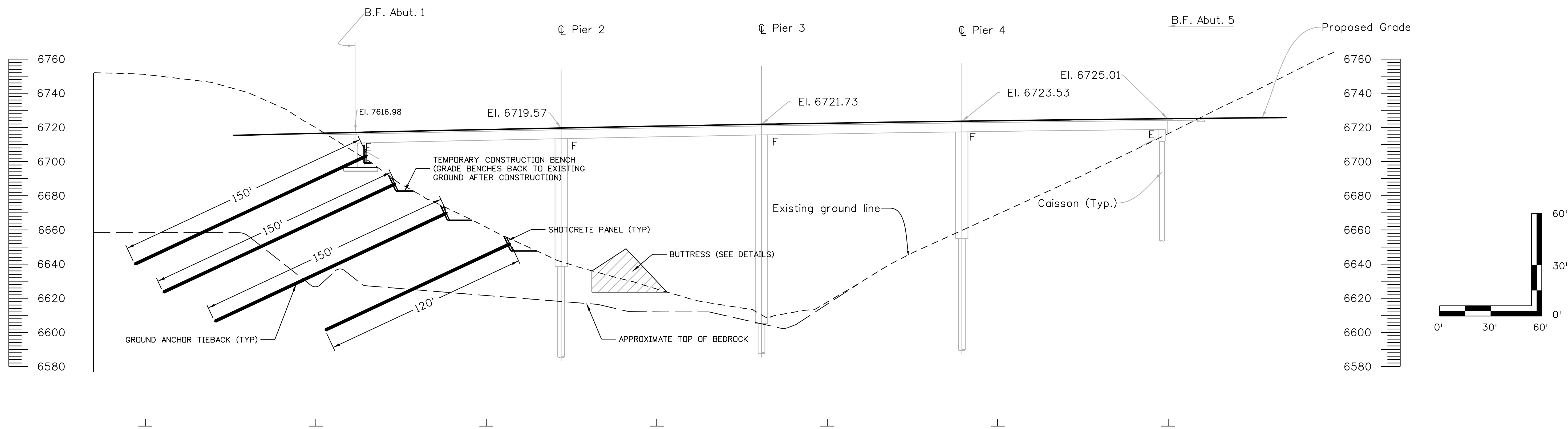

Print Date: 10/4/2018	Sheet Revisions	Colorado Department of Transportation	As Constructed
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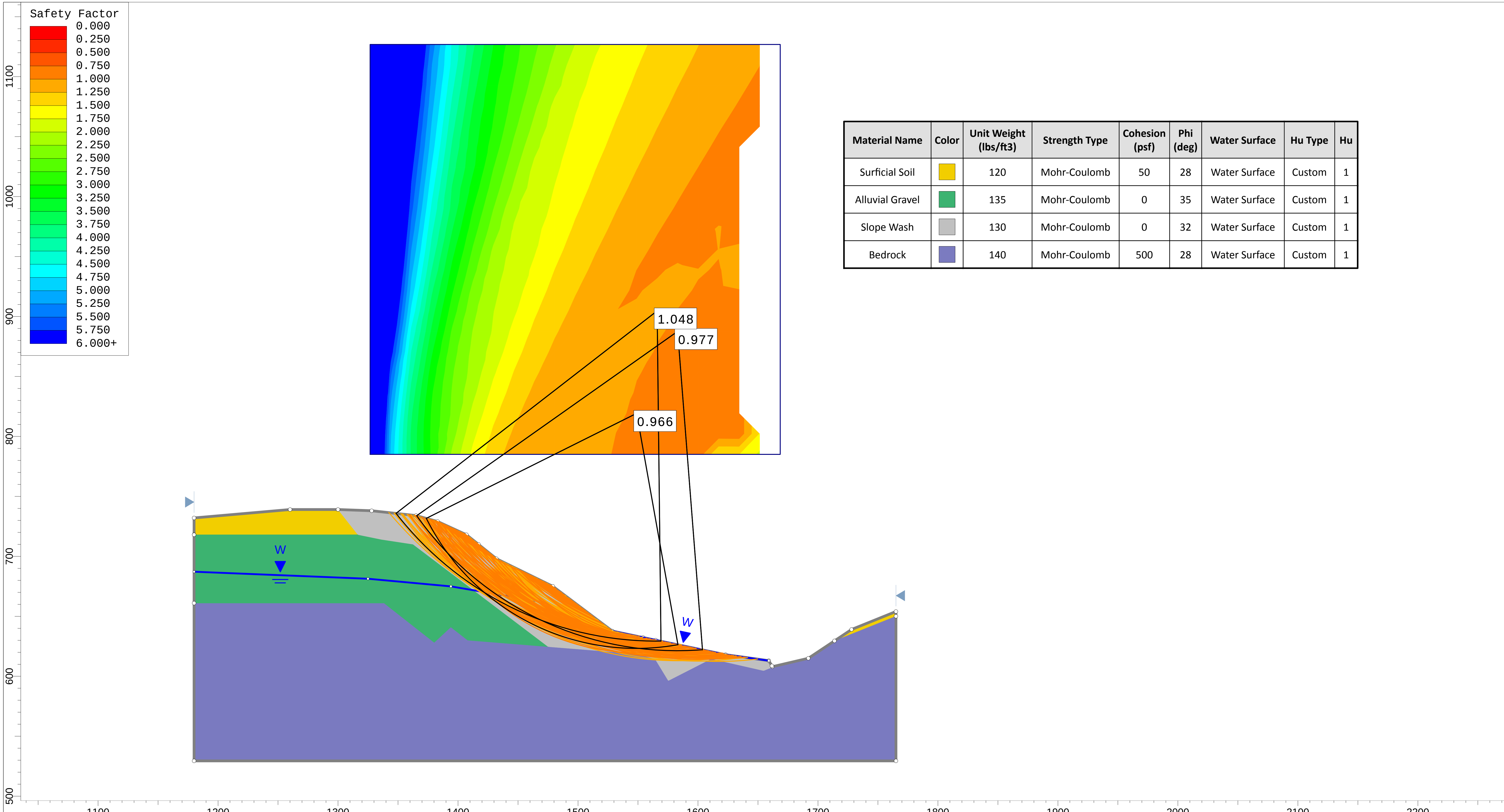
Horiz. Scale: 1:60 Vert. Scale: As Noted		Region 5 DRV	Revised:
Unit Information Unit Leader Initials			Void:
Yeh and Associates, Inc. Consulting Engineers & Scientists			

LANDSLIDE MITIGATION ALTERNATIVE 2 BRIDGE 1 (GULCH A)		Project No./Code
Designer:	Structure Numbers P-05-AZ	NHPP 5501-029
Detailer:		22420
Sheet Subset: EG-BRIDGES	Subset Sheets: 1 OF 2	Sheet Number



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Surficial Soil		120	Mohr-Coulomb	50	28	Water Surface	Custom	1
Alluvial Gravel		135	Mohr-Coulomb	0	35	Water Surface	Custom	1
Slope Wash		130	Mohr-Coulomb	0	32	Water Surface	Custom	1
Bedrock		140	Mohr-Coulomb	500	28	Water Surface	Custom	1

SLIDEINTERPRET 7.031

Project	Colonial Drive Ground Nail Wall		
Analysis Description	10-foot Nails - No External Loads		
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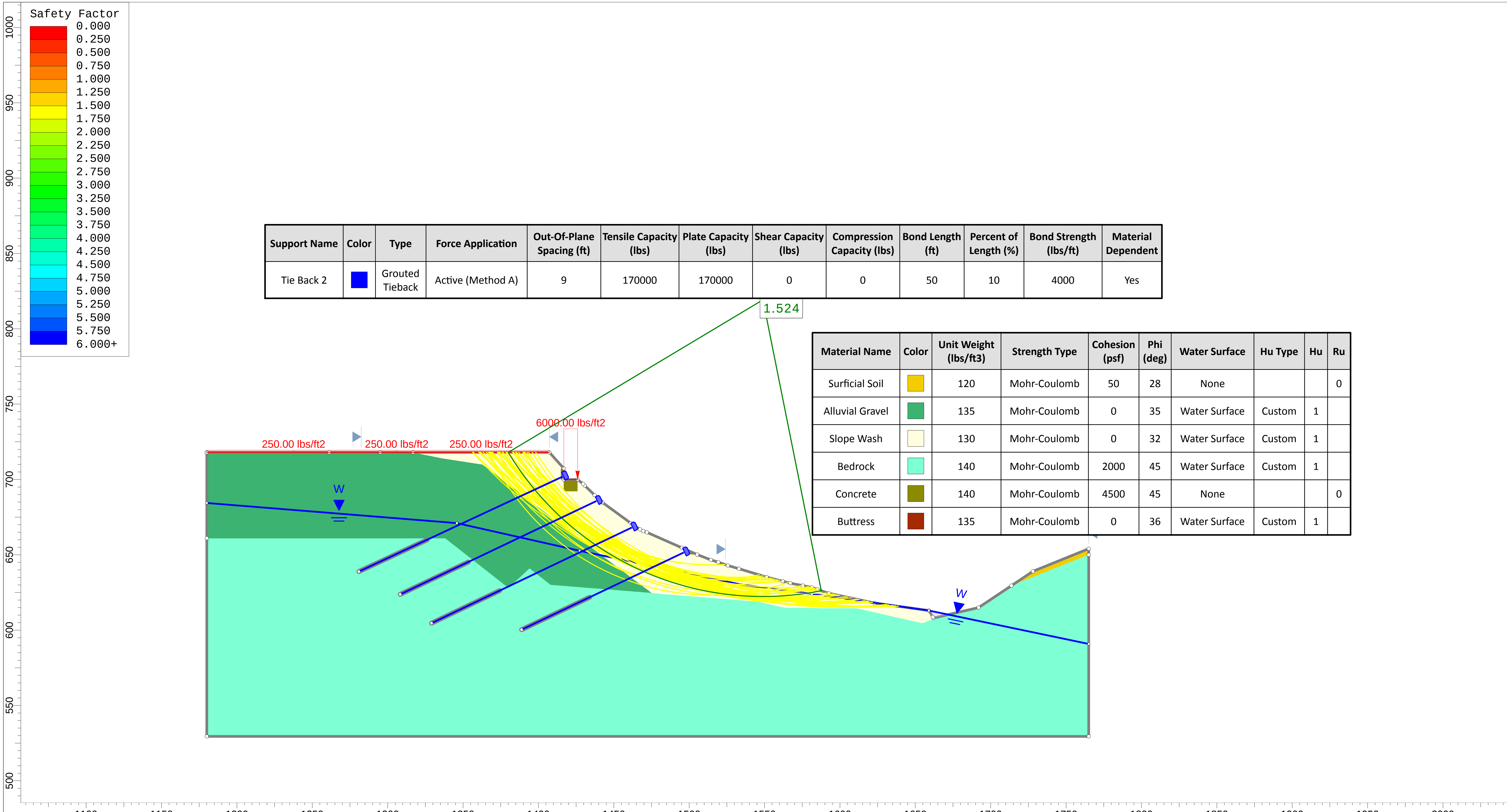
Company	Yeh Yeh and Associates, Inc.		
Date	8/6/2018, 4:02:32 PM	*File Name*	22420 B1A1 Existing Cond.slim



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Tensile Capacity (lbs)	Plate Capacity (lbs)	Shear Capacity (lbs)	Compression Capacity (lbs)	Bond Length (ft)	Percent of Length (%)	Bond Strength (lbs/ft)	Material Dependent
Tie Back 2		Grouted Tieback	Active (Method A)	9	170000	170000	0	0	50	10	4000	Yes

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu	Ru
Surficial Soil		120	Mohr-Coulomb	50	28	None			0
Alluvial Gravel		135	Mohr-Coulomb	0	35	Water Surface	Custom	1	
Slope Wash		130	Mohr-Coulomb	0	32	Water Surface	Custom	1	
Bedrock		140	Mohr-Coulomb	2000	45	Water Surface	Custom	1	
Concrete		140	Mohr-Coulomb	4500	45	None			0
Buttress		135	Mohr-Coulomb	0	36	Water Surface	Custom	1	

SLIDEINTERPRET 7.031

Project	Colonial Drive Ground Nail Wall
Analysis Description	10-foot Nails - No External Loads
Drawn By	TLA
Scale	1:732
Company	Yeh Yeh and Associates, Inc.
Date	8/6/2018, 4:02:32 PM
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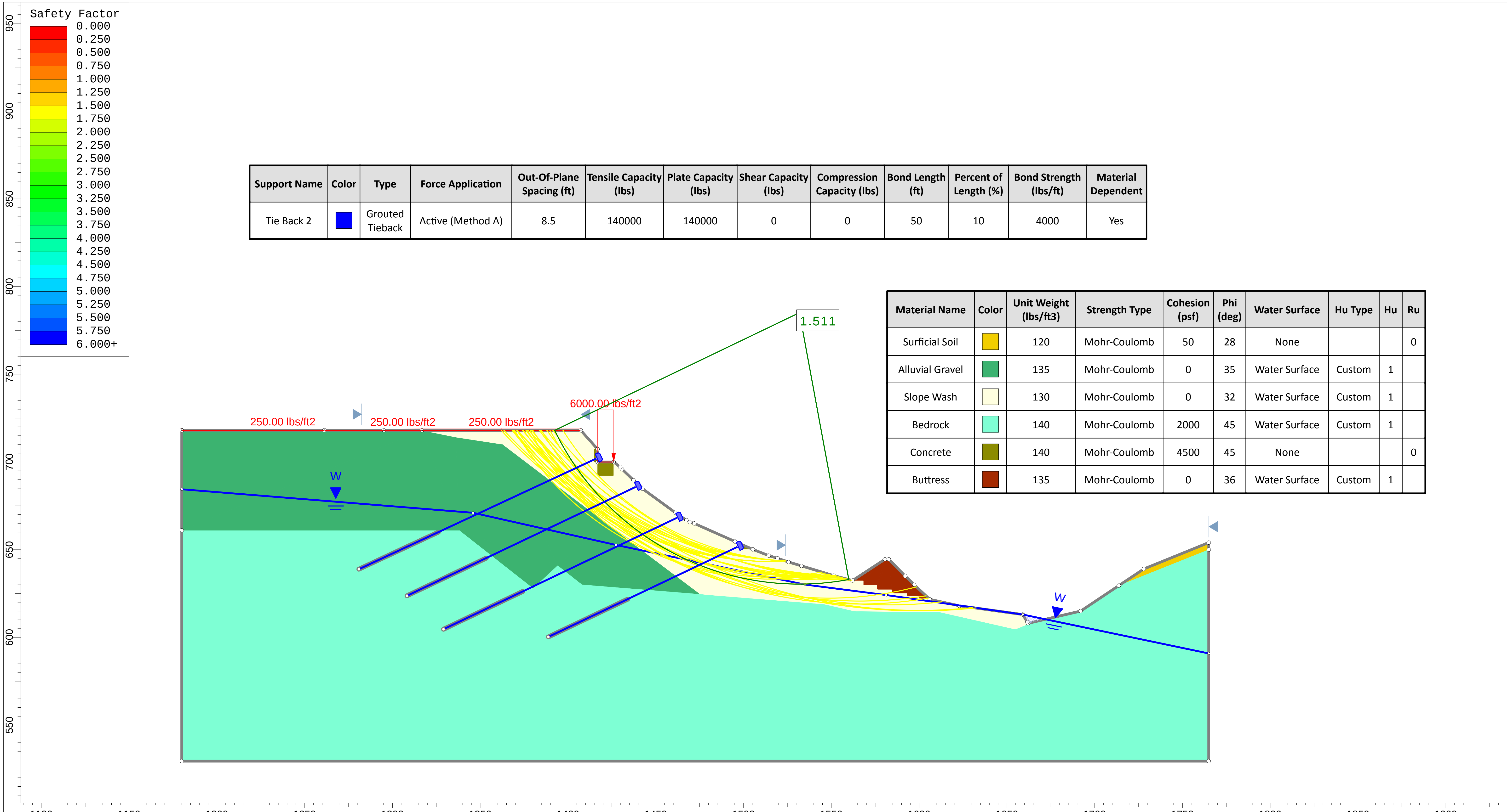

Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Tensile Capacity (lbs)	Plate Capacity (lbs)	Shear Capacity (lbs)	Compression Capacity (lbs)	Bond Length (ft)	Percent of Length (%)	Bond Strength (lbs/ft)	Material Dependent
Tie Back 2		Grouted Tieback	Active (Method A)	8.5	140000	140000	0	0	50	10	4000	Yes

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu	Ru
Surficial Soil		120	Mohr-Coulomb	50	28	None			0
Alluvial Gravel		135	Mohr-Coulomb	0	35	Water Surface	Custom	1	
Slope Wash		130	Mohr-Coulomb	0	32	Water Surface	Custom	1	
Bedrock		140	Mohr-Coulomb	2000	45	Water Surface	Custom	1	
Concrete		140	Mohr-Coulomb	4500	45	None			0
Buttress		135	Mohr-Coulomb	0	36	Water Surface	Custom	1	

SLIDEINTERPRET 7.031

Project	Colonial Drive Ground Nail Wall
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