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SUBJECT: CDOT Project Code 22420 – US 550/160 Connection South D-B
Retaining Wall Design Recommendations

This memo presents a summary of subsurface conditions, geotechnical considerations and design recommendations for proposed retaining wall structures as shown on preliminary plans provided by Wood on September 14, 2018. The recommendations are intended for use in developing Reference Design Plans for the US 550/160 Connection South Design-Build project.

General Wall Recommendations

The preliminary plans show all retaining walls having full-height concrete panel facing. The recommended wall types are suitable for full height facing consisting of pre-cast or cast-in-place panels. All walls should include suitable subsurface drainage systems that prevent excess hydrostatic pressures behind the walls. The proposed walls do not support critical structures and the recommended designs achieve a global stability Factor of Safety (FoS) greater than 1.30 as required by the AASHTO 2017 LRFD design specifications. Typical section plans for the recommended wall types are provided in Appendix B.

Cut Walls

The retaining walls to support cuts are proposed to reduce excavation volumes, provide stabilization to claystone bedrock and constrain the excavation to the Right-of-Way limits shown on the plans. We recommend ground nail walls as the preferred option to achieve these goals at the proposed cut wall locations. The top-down construction methods used for ground nail walls allow construction to take place under stabilized slopes and avoid temporary excavation beyond the ultimate cut for the roadway. Constructing ground nail walls in the terrace alluvium will be difficult due to the coarse and variable nature of the deposit. Drill holes through the alluvium will likely encounter cobbles and boulders and may require casing to maintain an open hole for nail insertion. Grout containment devices may be needed to prevent excessive grout loss.

Ground nail wall designs were prepared in accordance with the Federal Highway Administration, Geotechnical Engineering Circular No. 7, *Soil Nail Walls*, published in 2003. Global stability was evaluated using the limiting-equilibrium method assisted by the SLIDE computer software.

Mechanically Stabilized Earth (MSE) walls in cut areas will require additional excavation beyond that shown for roadway construction. Where cut wall heights exceed about 15 feet, the excavation and backfill volumes necessary for placement of the MSE reinforcing and to create stable temporary slopes for construction, approach the volume of excavation required to excavate the entire slope to a stable configuration.

Cast-in-place (CIP) cantilevered concrete walls were eliminated as an option at the cut wall locations because the cost of CIP walls at the proposed wall heights is expected to be excessive. The CIP walls would also require temporary excavation to nearly the same limits as MSE walls.

Tieback anchors may also be appropriate for support of the cut slopes. Tieback construction is typically from the top of cut down, similar to ground nail wall construction. The advantage of tiebacks is that they are post-tensioned to support high earth pressures so that the number of anchors needed is less than for ground nails. However, the drilled length needed to achieve the required anchor capacity could make installation more costly than a ground nail system.

Fill Walls

The proposed fill walls will be constructed to support new embankments for a frontage road and roundabout. MSE walls are recommended at these locations because the walls can be constructed concurrent with the embankment and the volume of excavation necessary to place reinforcing is low. MSE walls are more tolerant of long-term differential settlement than CIP walls and can be constructed to perform well on compressible or expansive foundation soils. The proposed fill wall heights are near the limit where CIP walls are cost-effective and it is expected that MSE construction will be less expensive.

Fill wall designs follow the AASHTO LRFD methods, aided by use of the MSEW computer software. MSE wall global stability was evaluated by limiting-equilibrium methods, aided by the SLIDE software.

Estimated Quantities

The estimated pay item quantities for the cut and fill walls are presented in Appendix C. Estimates are for the walls as shown on the plans currently proposed and with the height of the cut walls reduced by excavating the cut slopes above bedrock to stable grades.

CUT SLOPE RETAINING WALLS A, B AND C

Post-FIR plans, dated December 5, 2016, were prepared prior to our subsurface investigation, and the conceptual designs for retaining walls were based on assumptions regarding the depth to bedrock and the thickness of the terrace alluvium deposit. The conceptual design for the cut walls A, B and C assumed the walls would be retaining claystone bedrock using ground nail reinforcing, and that the alluvium and surficial soil above would be excavated to a 3H:1V cut slope. The current preliminary plans provided by Wood represent a change in the configuration of walls A, B and C. Rather than laying back the slopes above the walls, retaining walls are currently planned for the entire height of cut. The proposed configuration will reduce the amount of excavation that will be required for the project.

Exploratory borings drilled for these walls in the winter of 2017-2018 encountered a significantly greater thickness of terrace alluvium than had been assumed at the Post-FIR planning stage. The results of our subsurface investigation indicate that excavation to the proposed roadway

grade will expose a lesser height of bedrock and a greater height of alluvium than was originally assumed.

The claystone/sandstone/shale bedrock of the Animas Formation is a weak rock and classifies as an Intermediate Geo Material (IGM) in accordance with the American Association of State Highway and Transportation Officials (AASHTO) 2017 LRFD Bridge Design Specifications. This material has engineering properties that more closely resemble a very stiff clay rather than competent rock. The IGM will be prone to deterioration and raveling when exposed to weather. This can result in loss of support for the overlying materials and can eventually cause slope failures.

Retaining structures are recommended to support near-vertical cuts in the IGM and to protect the face from deterioration. Based on the results of our subsurface exploration, cut slopes in the alluvium can be graded at 2H:1V and remain stable over the long term. Using the proposed Right-of-Way limits shown on the plans, it appears that if the bedrock is retained by walls; the cut slopes in the alluvial deposit are graded at 2H:1V; and cut slopes in the overlying surficial soils are graded at 3H:1V, the resulting excavation will not extend beyond the proposed Right-of-Way. Laying back the cut slopes would eliminate the need for Wall A and reduce the heights of Walls B and C from those shown on the Post-FIR plans and the currently proposed configurations.

Wall A – US 550 Station 1018+85 to Station 1023+32, 75.5' Lt.

Wall A, as shown on the plans from Wood, is 441 feet in length and reaches a maximum exposed height of approximately 40 feet. The wall is separated into two tiers with the lower tier having a height of 30 feet for the entire 441 feet of length and the upper tier having a maximum height of 10 feet and a length of 290 feet. The setback from face of the lower tier to the face of the second tier is 15 feet. The bottom of the wall is shown approximately 6 feet below the ground surface at the face of the wall.

Three borings were advanced along the proposed alignment using ODEX, HQ coring, and air-rotary drilling methods. Boring locations and logs are shown on the Engineering Geology plan sheet for Wall A in Appendix A.

The borings encountered 2 to 6 feet of surficial soil, consisting of a non-uniform mixture of sand, silt and clay. The soil overlies the terrace alluvium deposit, consisting of 46 to 49 feet of medium dense to very dense sandy gravel with cobbles and boulders. Claystone/sandstone/shale bedrock of the Animas Formation was encountered beneath the alluvium. A summary of the subsurface conditions encountered is provided in the table below.

Summary of Wall A Subsurface Conditions

Boring	Station	Offset	Depth of Boring (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Top of Bedrock (ft)	Elevation Bottom of Wall (ft)*	Bedrock Above (+) / Below (-) Wall (ft)**
WA-01	1019+74	92' LT	64.0	6761.5	6759.5	6711.8	6719.2	-7.4
WA-02	1020+97	86' LT	67.0	6766.5	6760.5	6714.5	6719.9	-5.4
WA-03	1022+07	84' LT	69.5	6765.7	6762.7	6713.7	6720.6	-6.9

*Approximate, as shown on Engineering Geology Plan Sheet – Wall A
**Difference between Bottom of Wall and Top of Bedrock elevations

Laboratory test results show samples of the terrace alluvium deposit have an AASHTO classification of A-1-a. AASHTO classifications based on laboratory tests performed on the terrace alluvium may not be representative of the in-place deposit. The tested samples were recovered from drill cuttings and consist of fragments of the gravel, cobbles and boulders. Core samples were collected from the bedrock at borings WA-01 and WA-02.

Wall A Design Recommendations

Results of the subsurface exploration indicate that the terrace alluvium deposit continues to a depth well below the anticipated limits of roadway and wall excavation at Wall A. The elevation of the bedrock surface is estimated to lie approximately 5 to 7 feet below the proposed bottom of wall for the full length of Wall A; therefore, bedrock is not anticipated to be exposed during construction.

Ground Nail Wall

A ground nail spacing of 5 feet vertical by 5 feet horizontal is recommended at Wall A. Ground nail holes with a diameter of 5.25 inches are expected to have a bond strength of 9.63 pounds per square inch (psi) in the alluvium and 6.26 psi in the surficial soil. Ground nails of 25 feet in length will provide a global FoS of 1.33 for Wall A.

Material Properties for Ground Nail Wall A Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Surficial Soil	28	50	100
Terrace Alluvium	38	0	130

No Walls

Grading the alluvium to a 2H:1V cut slope would eliminate the need for a wall at this location, as there is no bedrock which must be retained and protected from weathering. The global stability FoS for an unsupported 2H:1V cut slope at this location was found to be greater than 1.50.

Wall B – US 550 Station 1019+45 to Station 1029+42, 75.5' Rt.

Proposed Wall B is 995 feet in length and reaches a maximum exposed height of approximately 68 feet. Wall B is separated into three tiers. The lower tier (Tier 1) is 30 feet in height and 995 feet in length; the middle tier (Tier 2) is 855 feet long and 30 feet high; and the upper tier (Tier 3) is 87 feet in length and reaches a maximum height of 7.5 feet. The setbacks for Tiers 2 and 3 are 15 feet. The bottom of the wall is shown approximately 6 feet below the ground surface at the face of the lower tier.

Ten exploratory borings were drilled using ODEX, HQ and NQ coring, and air rotary drilling methods. The borings were located generally along the proposed alignment of Wall B in order to characterize the subsurface conditions, and are shown on the Engineering Geology plan sheets for Wall B in Appendix A.

The borings encountered a layer of surficial soil between 4 and 26 feet thick. The underlying terrace alluvium deposit ranged in thickness from 24 to 51 feet. Bedrock was encountered at

depths of 44 to 57 feet below the surface. The bedrock surface gains an estimated 40 feet in elevation from south to north along the proposed length of Wall B. The bedrock surface is lower than the proposed bottom of wall for the southern 300 feet of the wall. Boring WB-10 was located down the slope of Gulch "B". Here, the bedrock was directly overlain by approximately 4 feet of colluvium, with no Alluvium being present. A table summarizing the subsurface conditions encountered in the borings is provided below.

Summary of Wall B Subsurface Conditions

Boring	Station	Offset	Depth of Boring (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Top of Bedrock (ft)	Elevation Bottom of Wall (ft)*	Bedrock Above (+) / Below (-) Wall (ft)**
WB-01	1020+41	67' RT	69.8	6,762.7	6759.2	6708.7	6719.7	-11.0
WB-02	1021+09	96' RT	71.0	6,765.0	6758.5	6713.5	6720.0	-6.5
WB-03	1021+81	71' RT	70.0	6,771.1	6760.1	6717.1	6720.8	-3.7
WB-04	1023+08	100'RT	70.0	6,775.7	6759.7	6719.2	6721.5	-2.3
WB-05	1024+06	82' RT	69.9	6,782.0	6761.0	6727.0	6721.7	5.3
WB-06	1025+09	108' RT	69.0	6,787.0	6762.5	6731.0	6722.1	8.9
WB-07	1026+08	90' RT	69.2	6,780.7	6763.2	6736.7	6722.5	14.2
WB-08	1026+99	93' RT	69.8	6,789.2	6764.2	6737.2	6722.2	15.0
WB-09	1027+88	65' RT	68.2	6,790.0	6764.5	6740.2	6720.6	19.6
WB-10	1029+10	72' RT	50.0	6,741.8	n/a	6737.3	6718.9	18.4

*Approximate, as shown on Engineering Geology Plan Sheets – Wall B
**Difference between Top of Bedrock and Bottom of Wall elevations

Laboratory test results show the surficial soil for Wall B has AASHTO Classifications of A-7-6 with group indices of (22) to (35) and A-6 with group indices of (10) to (11). In the Unified Soil Classification System (USCS), the soils generally fall within the category of CL, although one sample classified as CH, a high plasticity clay. Swell/consolidation values for four samples tested ranged from -1.0 percent (consolidation) to +1.5 percent (swell).

Samples of the terrace alluvium deposit generally have an AASHTO classification of A-1-a. Two of 11 samples were classified as A-2-4 and A-2-6. AASHTO classifications based on laboratory tests performed on the terrace alluvium may not be representative of the in-place deposit. The tested samples were recovered from drill cuttings and consist of fragments of the gravel, cobbles and boulders. One sample from WB-01 was tested for chemical properties that contribute to soil corrosivity. The results were pH of 8.5, water soluble sulfate of 0.002 percent, and resistivity of 14,000 Ohm-cm. No water-soluble Chloride was detected.

Core samples were collected from the bedrock at borings WB-02, WB-03, WB-06, WB-07, WB-09 and WB-10. Unconfined compressive strengths for four samples tested ranged from 263 to 3728 psi with an average of 2052 psi. One remolded sample produced a swell of +0.6 percent. Corrosive property test results included pH from 8.3 to 8.6, water-soluble sulfate between 0.010 and 0.018 percent, and resistivity from 1100 to 1600 Ohm-cm. Water-soluble chloride was detected in only 1 of 5 samples tested, at 0.00623 percent.

Wall B Design Recommendations

Results of the borings indicate that excavation activities for the roadway template are not likely to encounter bedrock until approximate US 550 Station 1023+50, and that bedrock exposure on

the cut slope may not occur until approximate Station 1024+50. The maximum exposed height of bedrock is estimated to be approximately 19 feet, rather than 32 feet as was shown on the Post-FIR plans. The balance of the proposed wall height will retain the alluvium deposit and some surficial soil.

Ground Nail Walls – In Bedrock, Alluvium and Surficial Soil

Ground nail walls are recommended for Wall B where the material to be retained consists of claystone/sandstone/shale bedrock of the Animas Formation, and elsewhere if the goal is to minimize the amount of excavation required. Construction of ground nail walls in the terrace alluvium layer will be difficult due to the coarse and variable nature of the deposit. Ground nails in the surficial soil will be easier to install. Using a ground nail spacing of 5 feet by 5 feet, hole diameter of 5.25 inches, and bond strengths of 7.22 psi in bedrock; 9.63 psi in the alluvium; and 6.26 psi in the surficial soil, ground nail lengths of 35 feet in Tier 1 and 40 feet in Tier 2 will provide a Factor of Safety (FoS) of 1.34. Where Tier 3 is present, ground nails 25 feet in length will be required for that level, with a computed FoS of 1.40.

Material Properties for Ground Nail Wall B Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Surficial Soil	28	50	100
Terrace Alluvium	38	0	130
Bedrock	33	500	135

No Walls – In Alluvium and Surficial Soil

Grading the alluvium to a 2H:1V cut slope and the surficial soil to 3H:1V would significantly reduce the need for retaining wall(s) at this location. The overall length can be reduced to approximately 500 feet, with a single tier of maximum exposed height of 19 feet. The resulting wall surface area would be an estimated 86 percent less than what is described in the paragraphs above. Ground nail lengths of 15 feet would be sufficient to provide the required FoS of at least 1.30.

Wall C – US 550 Station 1025+14 to Station 1029+46, 75.5' Lt.

Proposed Wall C is 439 feet in length and reaches a maximum exposed height of approximately 43 feet. The wall is separated into two tiers, with the lower tier (Tier 1) having a height of 30 feet for the entire 439 feet of length and the upper tier (Tier 2), 299 feet in length, having a maximum height of 13 feet. The setback to the second tier is 15 feet. The bottom of the wall is shown approximately 6 feet below the grade at the face of the wall.

Three borings were advanced along the proposed wall alignment using ODEX and HQ coring methods in order to characterize the subsurface conditions. Boring locations and logs are shown on the Engineering Geology plan sheet for Wall C in Appendix A.

The layer of surficial soil encountered at Wall C was thin, less than 2 feet in thickness. Immediately beneath the soil was 28 to 32 feet of terrace alluvium. Bedrock of the Animas Formation was encountered at 33 feet below the surface in Boring WC-01, at 30 feet in WC-02, and at 29 feet in WC-03. The bedrock surface gains an estimated 11 feet in elevation from

south to north along the length of proposed Wall C. A table summarizing the subsurface conditions encountered in the borings is provided below.

Summary of Wall C Subsurface Conditions

Boring	Station	Offset	Depth of Boring (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Top of Bedrock (ft)	Elevation Bottom of Wall (ft)*	Bedrock Above (+) / Below (-) Wall (ft)**
WC-01	1026+24	84' LT	61.8	6,766.0	6765.0	6733.0	6722.0	11.0
WC-02	1027+61	84' LT	53.5	6,767.2	6766.2	6736.9	6720.9	16.0
WC-03	1028+50	74' LT	67.6	6,768.6	6767.1	6739.6	6719.4	20.2

*Approximate, as shown on Engineering Geology Plan Sheet – Wall C
**Difference between Top of Bedrock and Bottom of Wall elevations

Laboratory test results for the alluvium deposit were similar to those from Walls A and B; the AASHTO classification was A-1-a. For bedrock, unconfined compressive strength was measured for two cores. Results ranged from 1675 psi to 7224 psi. Chemical properties were measured for one sample of bedrock. The pH was 8.5, water-soluble sulfate was 0.002 percent, and resistivity was 2000 Ohm-cm. No water-soluble chloride was detected.

Wall C Design Recommendations

As with Walls A and B, the subsurface investigation showed the alluvium layer to be thicker than anticipated, with the result that the bedrock surface lies deeper than assumed for the Post-FIR plans. Results of the borings indicate that the maximum retained height of bedrock is estimated to be approximately 25 feet rather than 49 feet as was shown on the plans. The balance of proposed wall height will retain the alluvium deposit.

Ground Nail Walls – In Bedrock and Alluvium

Ground nail walls are recommended for Wall C where the material to be retained consists of claystone/sandstone/shale bedrock of the Animas Formation, and in the overlying alluvium and surficial soils to achieve the goal of minimizing the volume of excavation required. Construction of ground nail walls in the terrace alluvium layer will be difficult due to the coarse and variable nature of the deposit. Using a ground nail spacing of 5 feet by 5 feet, hole diameter of 5.25 inches, and bond strengths of 1429 lb/ft in bedrock and 1905 lb/ft in the alluvium, ground nail lengths of 30 feet in Tier 1, and 10 feet in Tier 2 will provide a Factor of Safety (FoS) of 1.46.

Material Properties for Ground Nail Wall C Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Terrace Alluvium	38	0	130
Bedrock	33	500	135

No Walls – In Alluvium

Grading the alluvium to a 2H:1V cut slope would significantly reduce the need for a retaining wall at this location. While the wall length would remain constant at 439 feet, a single tier with maximum exposed height of approximately 19 feet would be required. The surface area of the wall resulting from this change would be approximately 62 percent less than that described in

the paragraphs above. The required length of ground nails will be 15 feet to achieve a global stability FoS of at least 1.30.

CUT SLOPE RETAINING WALL G

Wall G – US 550 Station 1007+82 to Station 1011+25, 75.5' Rt.

Proposed Wall G will retain a cut slope on US 550 beneath an existing well pad on the Webb property. The proposed length of Wall G is 345 feet, and the wall height ranges from approximately 20 to 26.7 feet. The bottom of the wall is shown as being 5 feet below the finished grade at the front face.

Borings R-10, R-11 and R-12 were advanced in the vicinity of the proposed wall alignment using hollow-stem auger drilling methods. Boring locations and logs are shown in Appendix A on the Engineering Geology plan sheet for Wall G.

The borings encountered 5 to 20 feet of surficial soil, a non-uniform combination of sand, silt and clay. Below the surficial soil, the borings encountered the terrace alluvium deposit, consisting of very dense sandy gravel with cobbles and boulders, to the full depth of exploration. Bedrock was not encountered in the borings. A summary of the subsurface conditions encountered near Wall G is provided in the table below.

Summary of Wall G Subsurface Conditions

Boring	Station	Offset	Depth of Boring (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Bottom of Wall (ft)*	Alluvium Above Bottom of Wall (ft)**
R-10	1008+72	129' RT	35.0	6732.0	6712.0	6702.6	9.4
R-11	1009+60	127' RT	35.0	6734.1	6714.1	6704.1	10.0
R-12	1009+68	19' LT	30.5	6718.0	6713.0	6704.2	8.8

*Approximate, as shown on Engineering Geology Plan Sheet – Wall G
**Difference between Bottom of Wall and Top of Alluvium elevations

Laboratory test results show the surficial soil for Wall G has AASHTO Classifications of A-2-4 and A-4 with group indices of (0). In the Unified Soil Classification System (USCS), the soils fall with the categories of SM and SM-SC, ranging from non-plastic (NP) to a Plasticity Index (PI) of 4. No Swell/consolidation testing was performed.

Laboratory test results for boring R-12 assign the upper zone of the terrace alluvium deposit an AASHTO classification of A-2-6 (0), and a USCS classification of GC. The PI for this sample was 20. The presence of cobbles and boulders was noted beginning at 14.5 feet (Elev. 6703.5) in R-12.

Wall G Design Recommendations

The lower 9 to 10 feet of Wall G will be constructed within the terrace alluvium layer, while the upper portion will retain surficial soil. A ground nail wall system is recommended for Wall G to reduce the volume of excavation needed for construction. Using a ground nail spacing of 5 feet by 5 feet, hole diameter of 5.25 inches, and bond strengths of 6.26 psi in soil and 9.63 psi in the alluvium, ground nail lengths of 20 feet will extend beyond the estimated slope failure surface and provide a Factor of Safety (FoS) of 1.70.

Material Properties for Ground Nail Wall G Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Surficial Soil	28	50	100
Terrace Alluvium	38	0	130

EMBANKMENT FILL RETAINING WALLS D, E AND F

Preliminary designs for MSE walls recommended to retain embankment fill were evaluated using the wall design software MSEW. Global stability of the walls was checked using the SLIDE software. Design procedures were consistent with CDOT guidelines and AASHTO LRFD specifications. The preliminary wall designs have a FoS for global stability of at least 1.30.

Wall D – US 550 Station 1040+00 (Roundabout), Lt.

Wall D is proposed to retain fill on US 550 near the roundabout planned at the northern limit of the project. Preliminary plans indicate that Wall D will be 140 feet in length with a maximum height of approximately 15 feet. One boring was drilled to evaluate the subsurface conditions, as shown on the Engineering Geology plan sheet for Wall D in Appendix A. Claystone bedrock of the Animas Formation was encountered at 2.5 feet below the ground surface. The claystone was predominantly decomposed to moderately weathered. At 26.5 feet, the bedrock became interbedded sandstone and shale with some conglomeratic sandstone. A summary of the subsurface investigation results is provided in the table below.

Summary of Wall D Subsurface Conditions

Boring	Station	Offset	Total Depth (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Top of Bedrock (ft)	Elevation Bottom of Wall (ft)*	Bedrock Above (+) / Below (-) Wall (ft)**
WD-01	1039+79	94' LT	39.9	6688.1	n/a	6685.6	6675.0	10.6

*Approximate, as shown on Engineering Geology Plan Sheet – Wall D
**Difference between Top of Bedrock and Bottom of Wall elevations

Wall D Design Recommendations

Based on the preliminary plans and the results of subsurface exploration, it appears that Wall D will be constructed on bedrock of the Animas Formation throughout its length. Structure excavation in the bedrock will be required to embed the bottom (heel) of the wall into the slope. The material strength properties used to characterize the bedrock are conservative and apply to weathered bedrock conditions. Material properties used in the reference design calculations are presented in the table below.

Material Properties for MSE Wall D Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Structure Backfill (Class 1)	34	0	135
Weathered Bedrock	33	500	135

Traffic live loads on the wall were considered as a 250 psf Uniform Surcharge representing traffic loading. The minimum reinforcing geotextile length is 12 feet (approximately 0.7 times maximum wall height of 15 feet). At 2 foot vertical spacing between layers, a geotextile Long Term Design Strength (LTDS) of 2000 lb/ft is required to meet the AASHTO LRFD Design Specifications using the MSEW design tool.

Wall E – Frontage Rd. Station 584+49 to Station 586+89, 22' Lt.

Wall E is shown on the Post-FIR plans as retaining the Frontage Road fill section where it abuts the Eagle Block private parcel west of the County Road 220 intersection. The maximum proposed wall height is 16.7 feet including an embedment of 1.5 feet. Two borings were drilled for Wall E. The borings encountered 14 to 16 feet of surficial soil underlain by the terrace alluvium deposit. The Wall E borings are summarized in the table below. The Engineering Geology plan sheet for Wall E is included in Appendix A.

Summary of Wall E Subsurface Conditions

Boring	Station	Offset	Total Depth (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Top of Bedrock (ft)	Elevation Bottom of Wall (ft)*	Alluvium Above (+) / Below (-) Wall (ft)**
WE-01	985+25	125' LT	29.5	6707.6	6693.1	n/a	6701.0	-7.9
WE-02	985+72	125' LT	30.5	6706.2	6690.2	n/a	6701.0	-10.8

*Approximate, as shown on Engineering Geology Plan Sheet – Wall E
**Difference between Top of Alluvium and Bottom of Wall elevations

Laboratory test results show the surficial soil at Wall E has AASHTO Classifications of A-4, with group indices of (4) to (7), and A-6 (11). In the Unified Soil Classification System (USCS), the soils are classified as CL, lean clay. Gradation results show sand content between 16 and 18 percent, and fines of 72 to 84 percent. Atterberg Limits test results show a Liquid Limit (LL) ranging from 26 to 33 percent and a Plasticity Index (PI) ranging from 8 to 18 percent. The Swell/consolidation result for the one sample tested was -0.2 percent (Consolidation). The corresponding natural moisture content of the sample was 14.8 percent, with a natural dry density of 107.4 pounds per cubic foot (pcf). Chemical property test results were pH = 8.5, water-soluble sulfate of 0.054 percent, water-soluble chloride of 0.00784 percent, and resistivity of 1000 Ohm-cm.

Wall E Design Recommendations

Wall E will be constructed on the surficial soil throughout its length. Structure excavation will be required to embed the heel of the wall into the existing slope. The material properties used in the reference design calculations and input for the MSEW software are presented in the table below.

Material Properties for MSE Wall E Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Structure Backfill (Class 1)	34	0	135
Surficial Soil	30	50	120

A traffic live load expressed as a 250 psf Uniform Surcharge for the roadway at the top of the wall was considered in the preliminary design. The minimum reinforcing geotextile length is 12 feet (0.7 times maximum wall height of 17 feet). At a vertical reinforcing spacing of 2 feet, a geotextile with a Long Term Design Strength (LTDS) of 2200 lb/ft is required.

Wall F – Frontage Rd. Station 579+75 to Station 581+25, 150' Lt.

Wall F is shown in the Post-FIR plans as retaining the Frontage Road fill section where it abuts a private parcel west of the County Road 220 intersection. The maximum proposed wall height is approximately 12.5 feet, including 1.5 feet of embedment. Two borings were drilled for Wall F. Boring WF-01 encountered 24 feet of surficial soil; and at Boring WF-02 the surficial soil was 16 feet thick. Beneath the soil layer was the terrace alluvium deposit. The conditions encountered in the Wall F borings are summarized in the table below. The Engineering Geology plan sheet for Wall F is included in Appendix A.

Summary of Wall F Subsurface Conditions

Boring	Station	Offset	Total Depth (ft)	Elevation Top of Boring (ft)	Elevation Top of Alluvium (ft)	Elevation Top of Bedrock (ft)	Elevation Bottom of Wall (ft)*	Alluvium Above (+) / Below (-) Wall (ft)**
WF-01	979+74	214' LT	33.2	6714.5	6690.5	n/a	6695.95	-5.5
WF-02	981+74	195' LT	29.3	6706.9	6690.9	n/a	6695.95	-5.1

*Approximate, as shown on Engineering Geology Plan Sheet – Wall F
**Difference between Top of Alluvium and Bottom of Wall elevations

Laboratory test results show the surficial soil for Wall F to wide ranging properties. At WF-01, the AASHTO Classification was A-7-6 (32), while WF-02 was classified as A-4 (5). In the Unified Soil Classification System (USCS), the soils fall within CH (high-plasticity clay) and CL (lean clay) categories, respectively. Gradation results show sand content ranging between 15 and 24 percent, and fines of ranging from 85 and 76 percent. Atterberg Limits test results show Liquid Limits (LL) ranging from 50 to 31 percent and Plasticity Indices (PI) ranging from 38 to 8 percent. The Swell/consolidation results for two samples tested were +4.3 percent (swell) at WF-01 and -0.8 percent (consolidation) at WF-02. The corresponding natural moisture contents were 13,1 and 13.8 percent, with natural dry densities of 116.6 and 101.7 pounds per cubic foot (pcf). Soil corrosive potential was not evaluated using Wall F samples.

Wall F Design Recommendations

The preliminary design of Wall F indicates it will be constructed on surficial soil throughout its length. Structure excavation will be required to embed the bottom of the wall into the existing slope. The material properties used to characterize the surficial soil for the MSEW wall design model are presented in the table below.

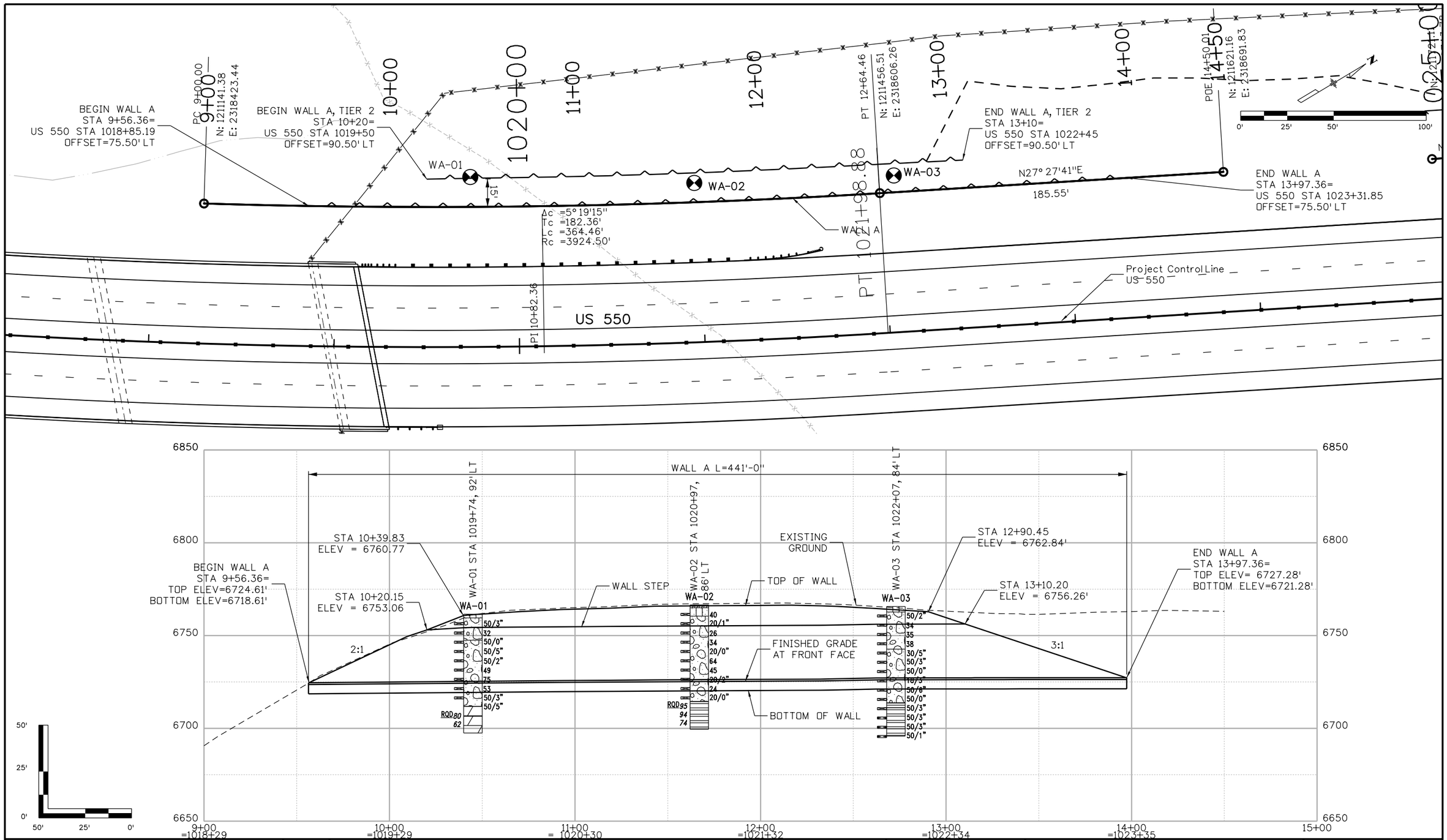
Material Properties for MSE Wall F Design

Description	Soil Properties		
	Friction, φ (deg)	Cohesion, c (psf)	Unit Weight, γ (pcf)
Structure Backfill (Class 1)	34	0	135
Surficial Soil	30	50	120

Traffic live loads were included as a 250 psf Uniform Surcharge over the paved portion of roadways above the wall. A wall design with minimum reinforcing geotextile length of 9 feet (0.7 times maximum wall height of 12 feet), and a 2 foot vertical spacing between reinforcing layers, will require a geosynthetic reinforcing material with a Long Term Design Strength (LTDS) of 1800 lb/ft.

Appendix A

ENGINEERING GEOLOGY PLAN SHEETS



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Unit Information Unit Leader Initials			
Yeh and Associates, Inc. Consulting Engineers & Scientists			

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

As Constructed
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STRUCTURE ENGINEERING GEOLOGY
WALL A

Designer:
Detailer:
Sheet Subset: WALLS
Structure Numbers
Subset Sheets: 1 of 8

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

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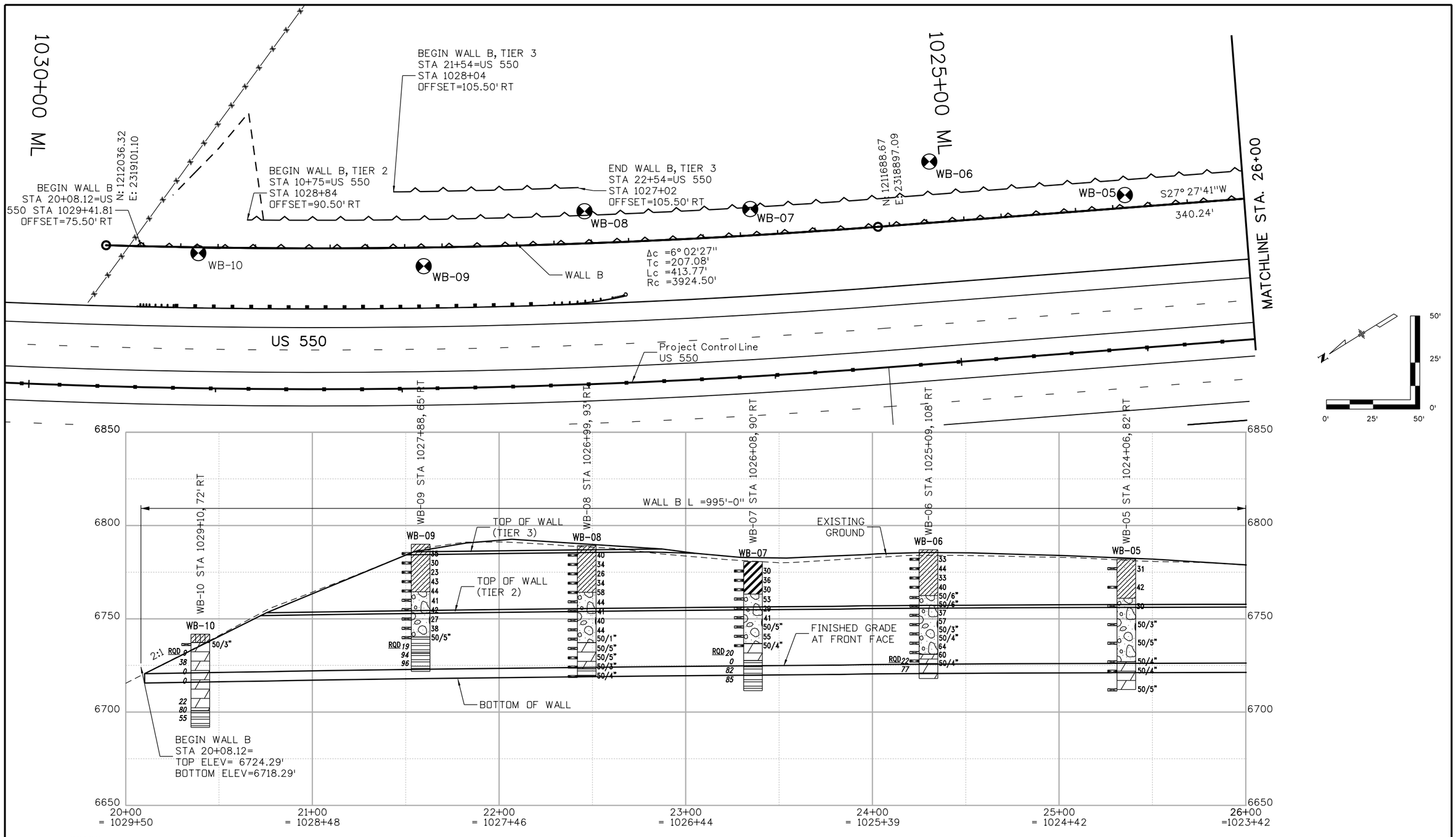

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Unit Information Unit Leader Initials		Region 5 DRV	Void:
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STRUCTURE ENGINEERING GEOLOGY WALL B		Project No./Code
Designer:	Structure Numbers:	NHPP 5501-029
Detailer:		22420
Sheet Subset: WALLS	Subset Sheets: 2 of 8	Sheet Number

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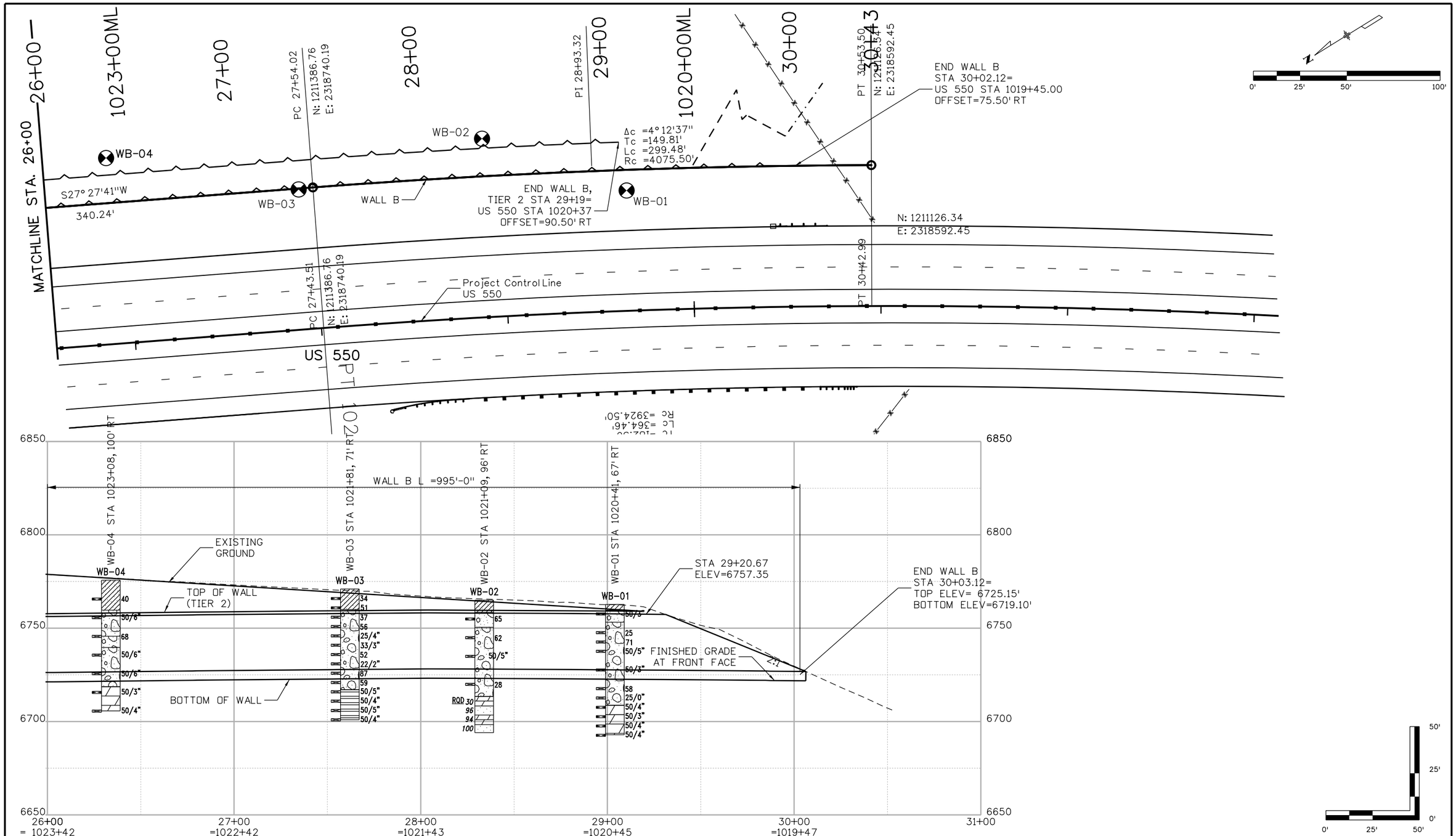

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Revised:
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STRUCTURE ENGINEERING GEOLOGY
WALL B

Designer:
Detailer:
Sheet Subset: WALLS
Structure Numbers
Subset Sheets: 3 of 8

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

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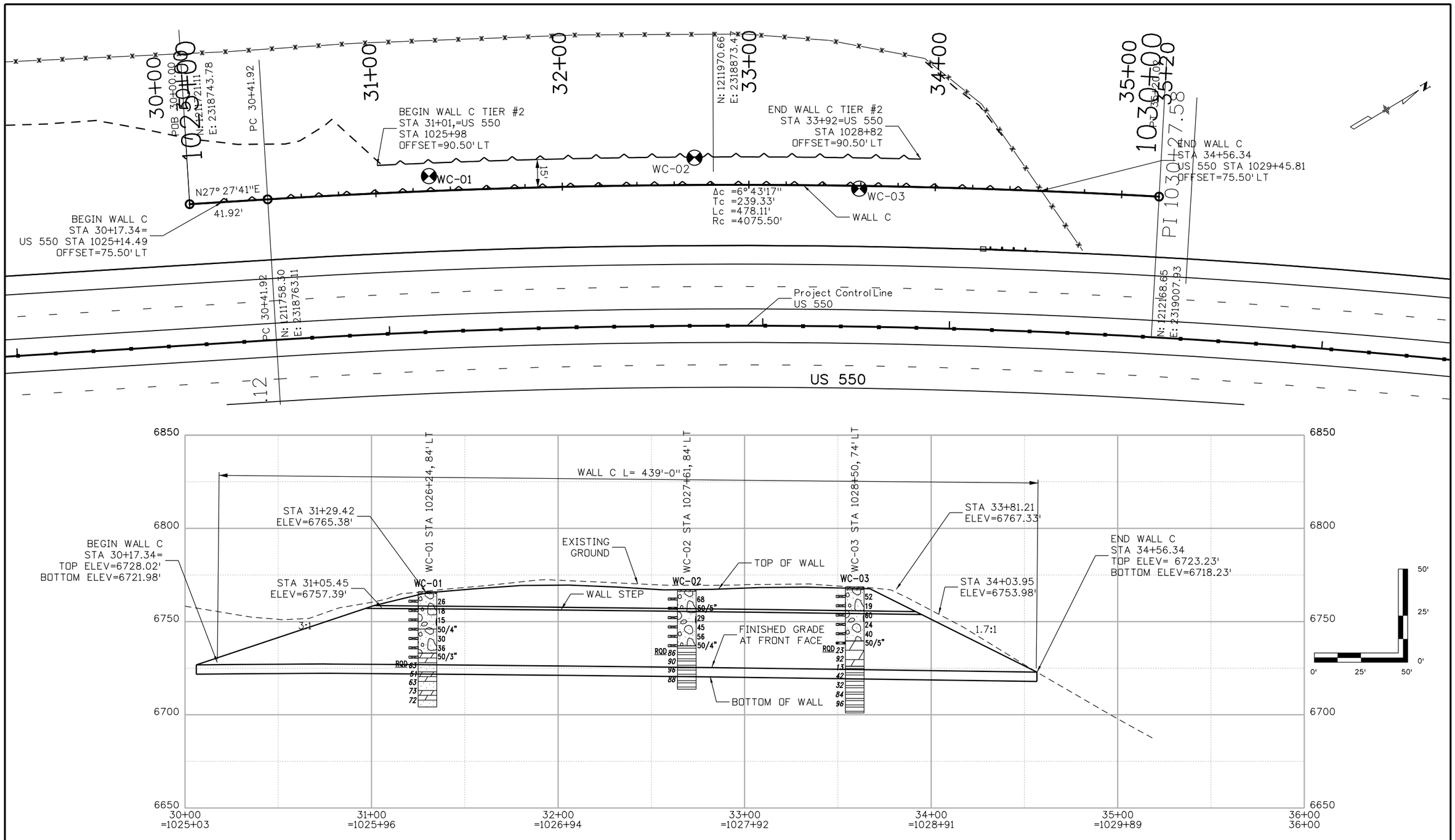

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Unit Information Unit Leader Initials		Region 5 DRV	Void:
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STRUCTURE ENGINEERING GEOLOGY WALL C			Project No./Code
			NHPP 5501-029
Designer:	Structure Numbers		22420
Detailer:			
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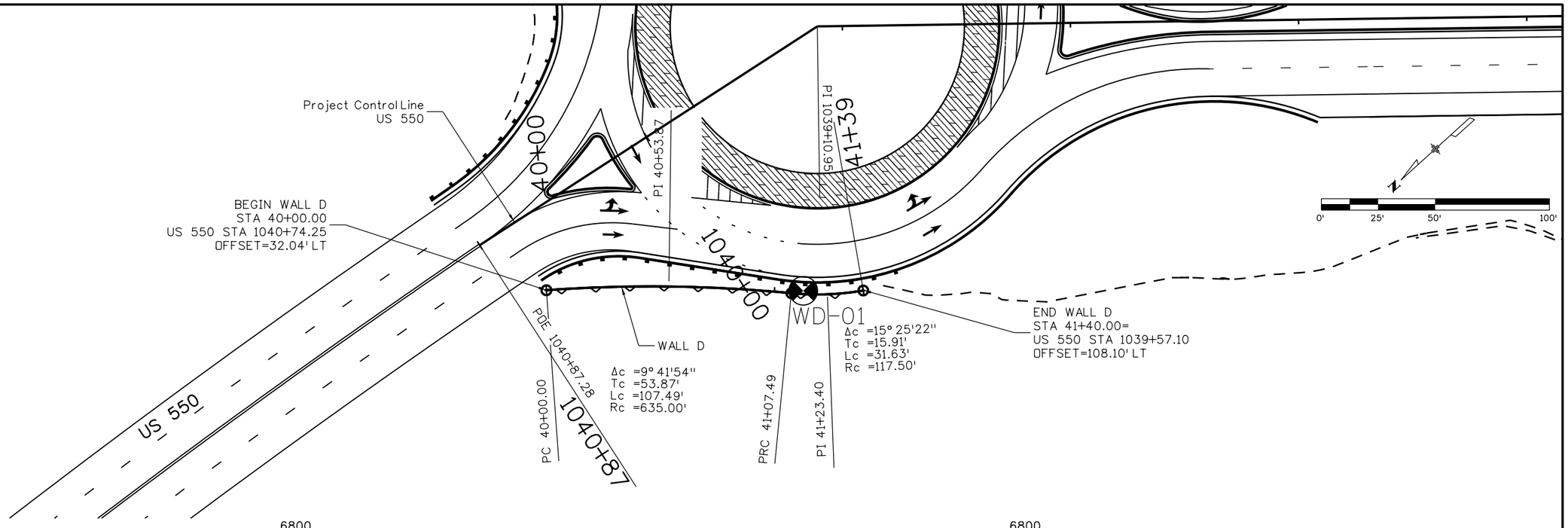

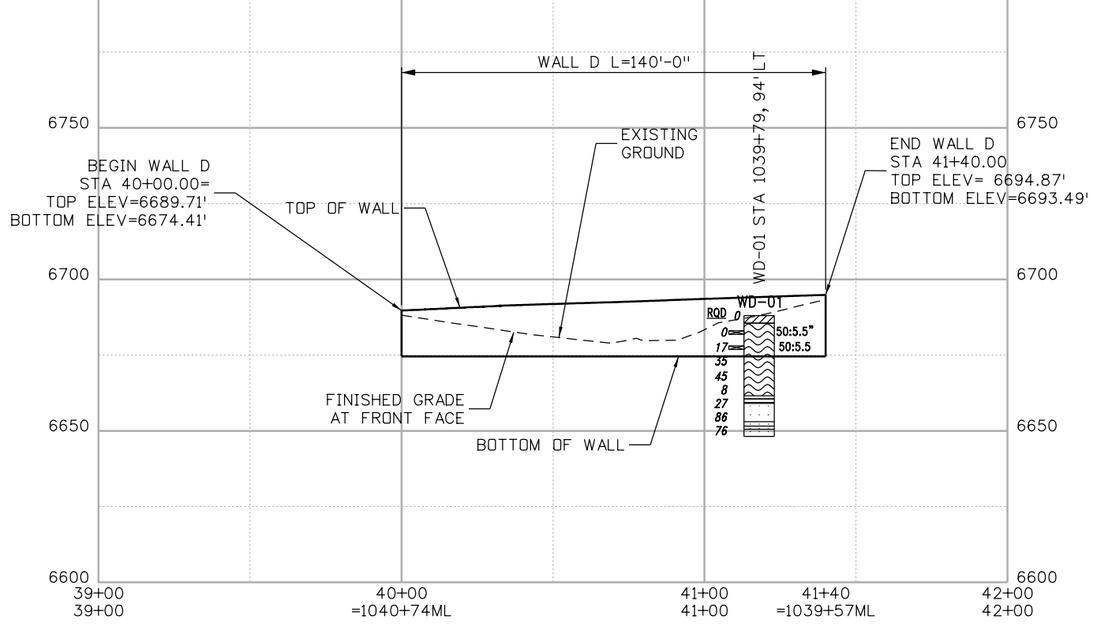

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Unit Information Unit Leader Initials			
Yeh and Associates, Inc. Consulting Engineers & Scientists			

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Region 5 DRV

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Revised:
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STRUCTURE ENGINEERING GEOLOGY
WALL D

Designer:
Detailer:
Sheet Subset: WALLS
Structure Numbers
Subset Sheets: 5 of 8

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

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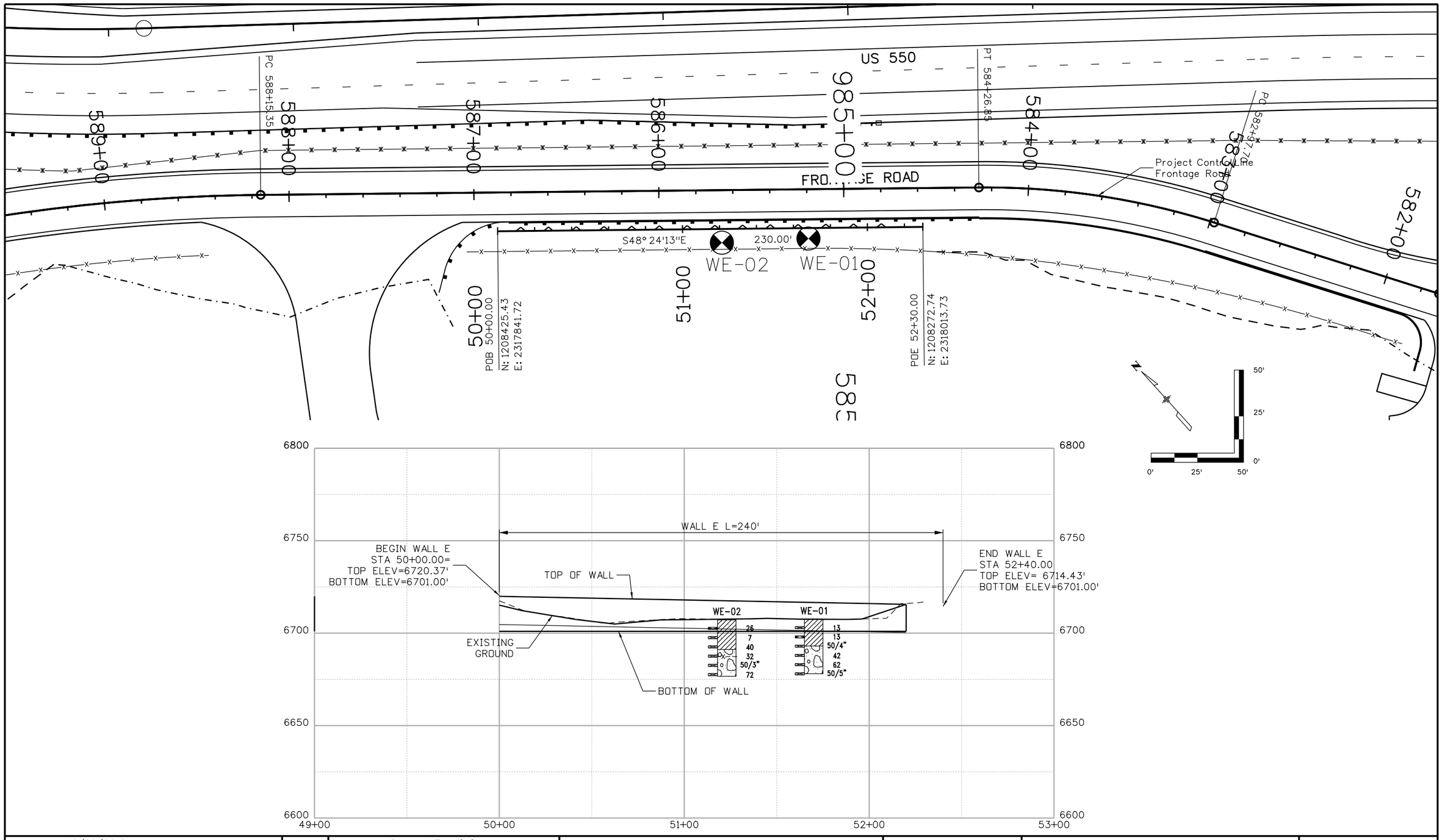

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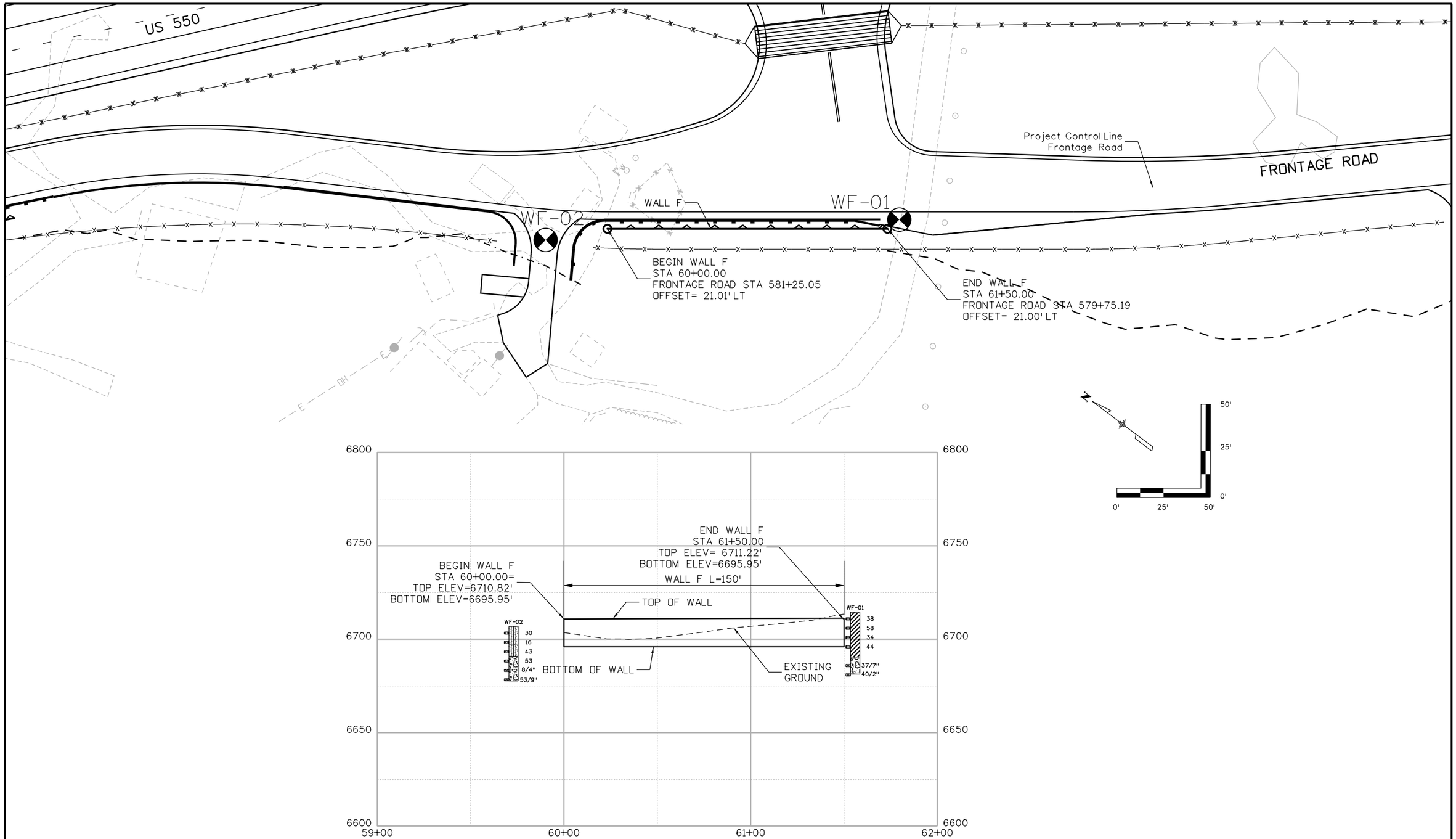
Yeh and Associates, Inc. Consulting Engineers & Scientists						Project No./Code: NHPP 5501-029; 22420; Sheet Number



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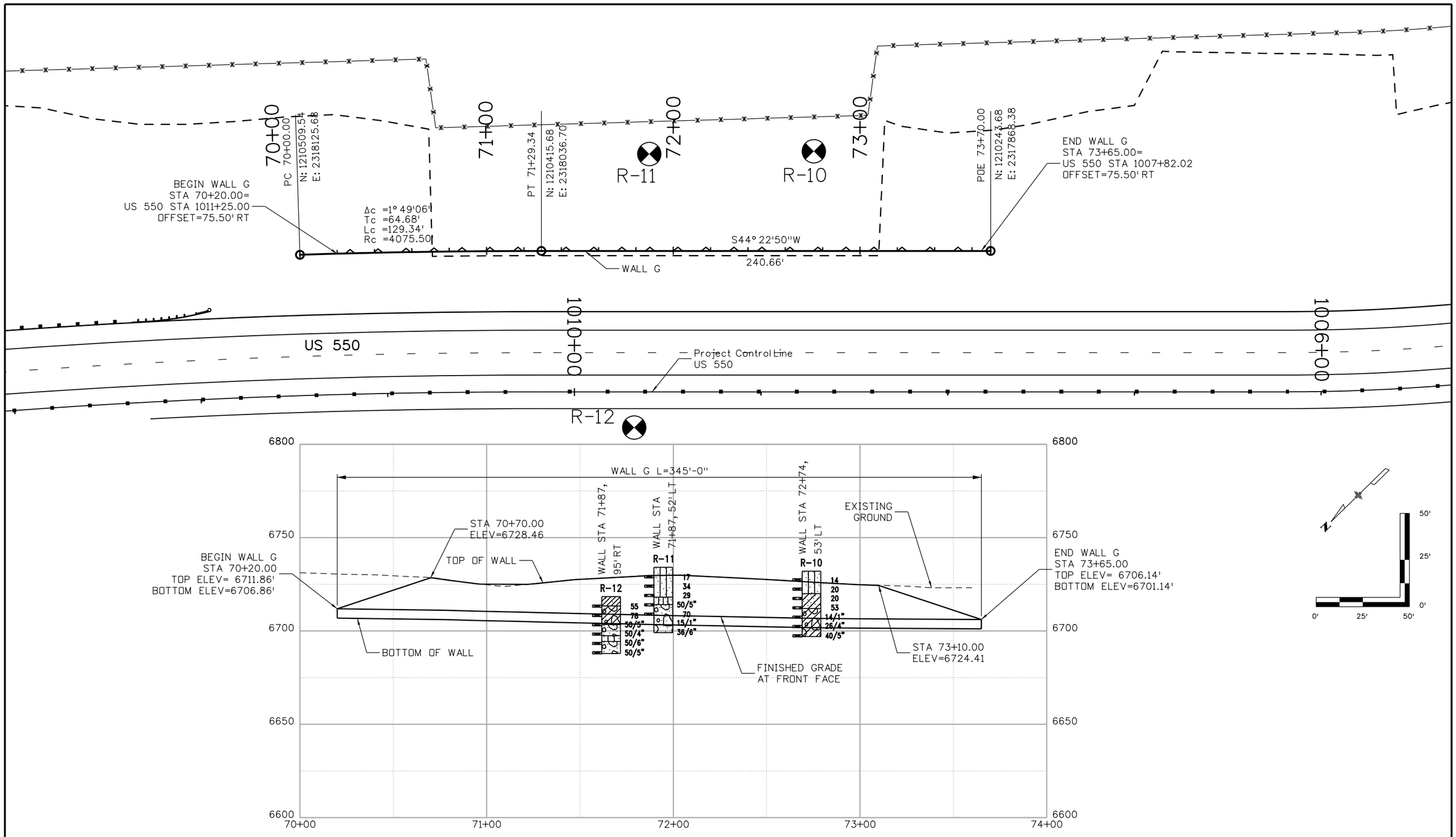
Yeh and Associates, Inc. Consulting Engineers & Scientists					Region 5 DRV	Void:	Sheet Subset: EGWALLS	Subset Sheets:	7 of 8	Sheet Number



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Unit Information Unit Leader Initials					Void:
Yeh and Associates, Inc. Consulting Engineers & Scientists					

WALL G PLAN AND PROFILE				Project No./Code
				NHPP 5501-029
Designer: KB	Structure Numbers			22420
Detailer: KB				
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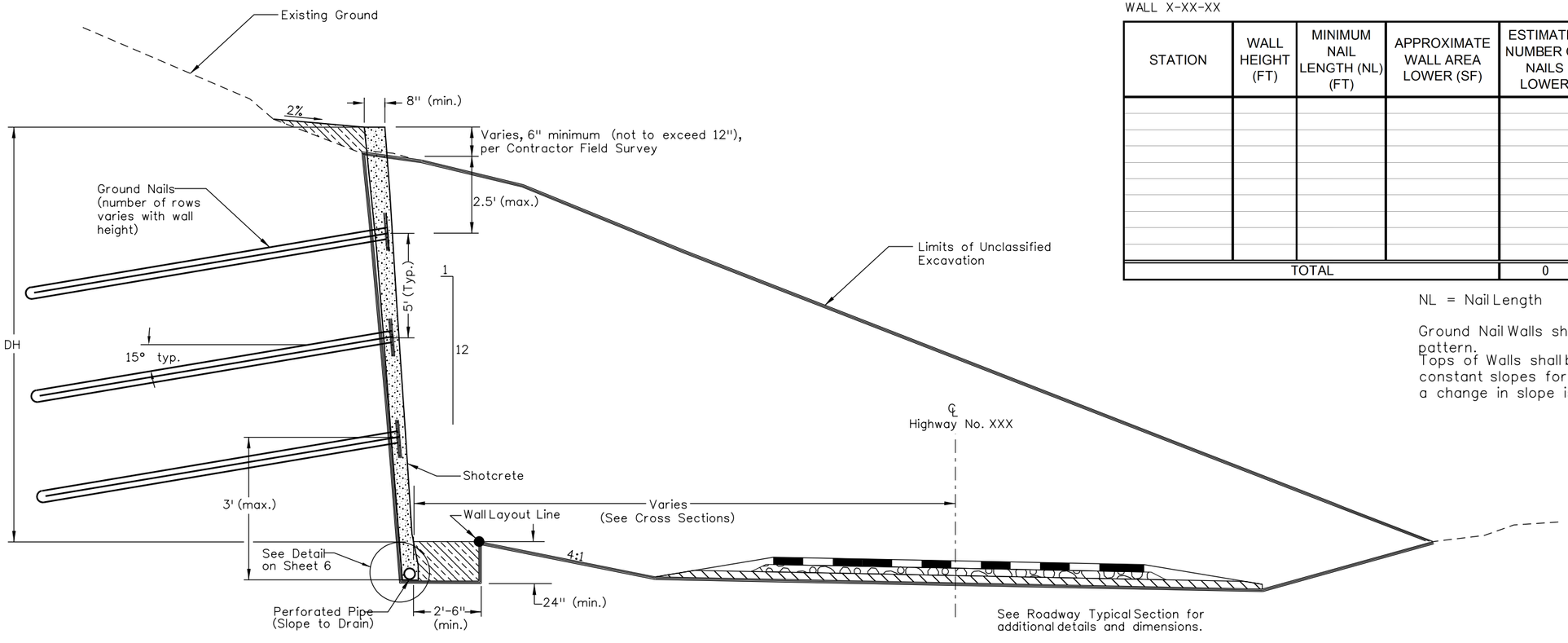
Appendix B

TYPICAL SECTION PLAN SHEETS

GROUND NAIL WALL TYPICAL SECTION

WALL X-XX-XX
STATION X+XX TO STATION X+XX

WALL X-XX-XX
STATION X+XX TO STATION X+XX
STATION X+XX TO STATION X+XX



SUMMARY OF APPROXIMATE QUANTITIES (FOR INFORMATION ONLY)

WALL X-XX-XX

STATION	WALL HEIGHT (FT)	MINIMUM NAIL LENGTH (NL) (FT)	APPROXIMATE WALL AREA LOWER (SF)	ESTIMATED NUMBER OF NAILS LOWER	APPROXIMATE WALL AREA UPPER (SF)	ESTIMATED NUMBER OF NAILS UPPER
TOTAL				0		0

WALL X-XX-XX

STATION	WALL HEIGHT (FT)	MINIMUM NAIL LENGTH (NL) (FT)	APPROXIMATE WALL AREA LOWER (SF)	ESTIMATED NUMBER OF NAILS LOWER	APPROXIMATE WALL AREA UPPER (SF)	ESTIMATED NUMBER OF NAILS UPPER
TOTAL				0		0

NL = Nail Length

Ground Nail Walls shall use a 5ft v x 5ft h nail pattern.
Tops of Walls shall be constructed to have constant slopes for a minimum of 30 feet before a change in slope is allowed.

Print Date: 10/4/2018	Sheet Revisions		
File Name: 040_22420 Typical GNW Section.dgn	Date:	Comments	Init.
Horiz. Scale: 1:10 Vert. Scale: As Noted			
Unit Information Unit Leader Initials			
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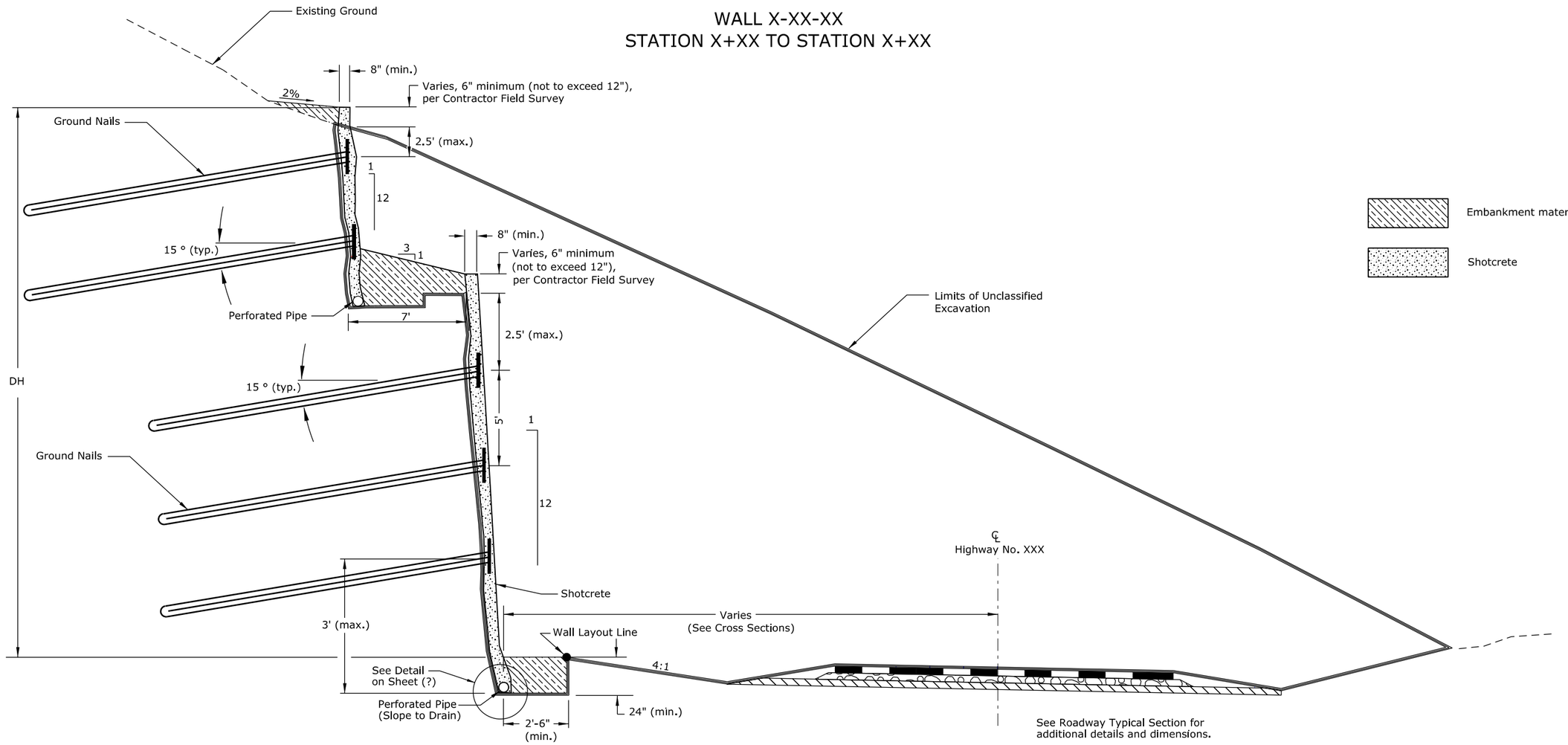
As Constructed	GROUND NAIL WALL TYPICAL SECTION			Project No./Code
No Revisions:				NHPP 5501-029
Revised:	Designer: XXXXXXXX	Structure Numbers	X-XX-XX	22420
Void:	Detailer: XXXXXXXX		X-XX-XX	Sheet Number
	Sheet Subset: XXXXXXX	Subset Sheets: XXX of XXX		

LRuiz 11:23:17 AM W:\2017 Projects\217-376 ES US 550 South Connection to US 160 Geotech\7. Drawings\040_22420 Typical GNW Section.dgn

GROUND NAIL WALL TIERED TYPICAL SECTION

WALL X-XX-XX
STATION X+XX TO STATION X+XX

WALL X-XX-XX
STATION X+XX TO STATION X+XX



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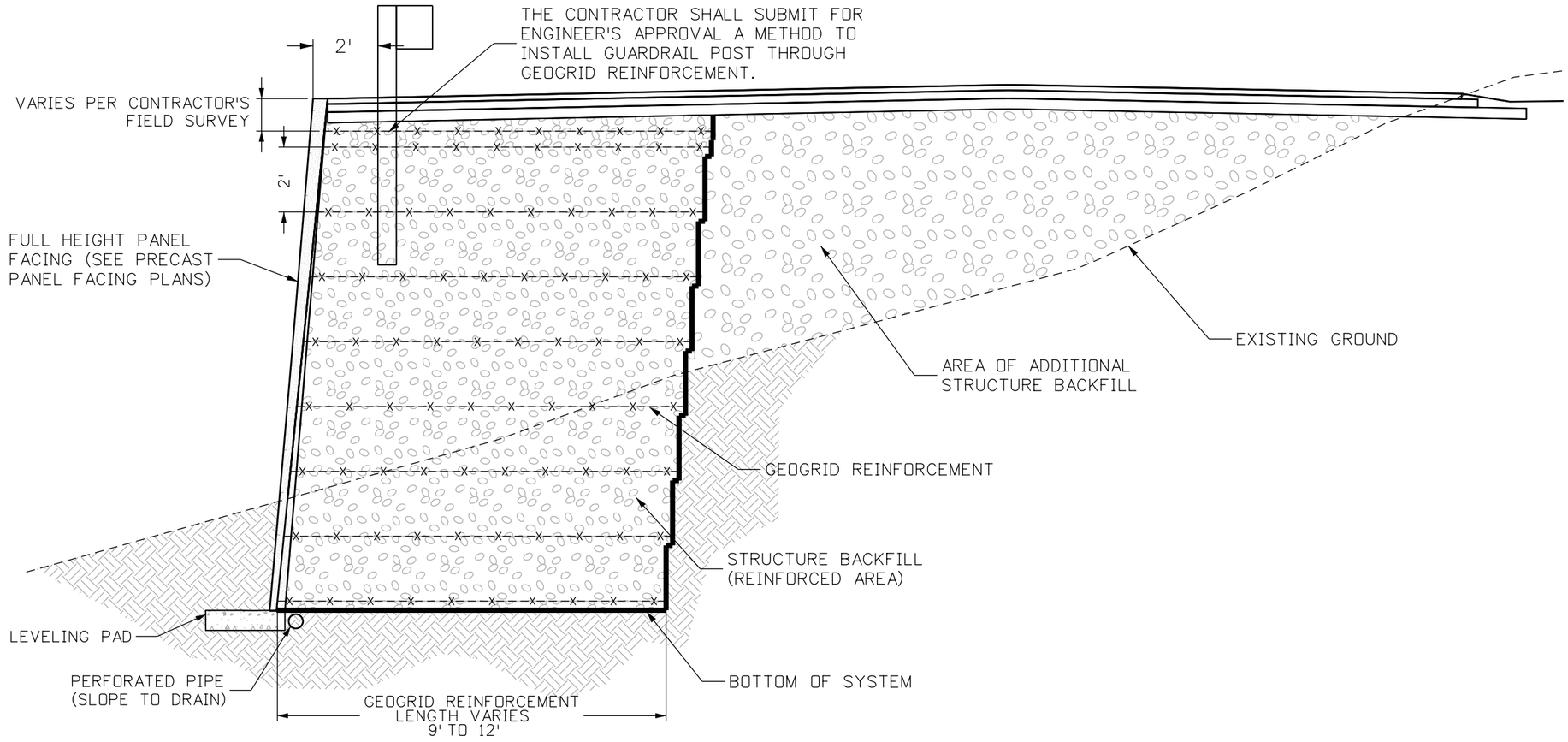

TYPICAL SECTION
WALLS E, F, AND D

STRUCTURE BACKFILL

8"x12" W4.5xW3.5 WELDED WIRE FABRIC (WWF)

Print Date: 10/4/2018	Sheet Revisions			Colorado Department of Transportation	As Constructed
File Name: 042_22420 TypicalMSE Wall.dgn	Date:	Comments	Init.	3803 North Main Avenue, Suite 200, Durango, CO 81301, Phone: 970-385-1440 FAX: 970-385-8365	No Revisions:
Horiz. Scale: 1:4 Vert. Scale: As Noted				Region 5 DRV	Revised:
Unit Information Unit Leader Initials					Void:
Yeh and Associates, Inc. Consulting Engineers & Scientists					

US 550/160 CONNECTION MSE WALL TYPICAL			Project No./Code
			NHPP 5501-029
Designer: XXXXXXXX	Structure Numbers	X-XX-XX	22420
Detailer: XXXXXXXX		X-XX-XX	
Sheet Subset: XXXXXXX	Subset Sheets: XXX of XXX		Sheet Number XXX

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Appendix C

ESTIMATED WALL QUANTITES

22420 Cut Wall Estimated Quantities 10/11/2018

Wall	Tier	Base Length	Surface Area		Soil Nails, in feet (EA)							Soil Nails (LF)	Shotcrete (SY)	Panel Facing (SF)	Underdrain (LF)
		LF	SF	SY	40	35	30	25	20	15	10				
A	Tier 1	441	13,319	1,480				533				13,325	1,480	13,319	441
	Tier 2	290	2,565	285				112				2,800	285	2,565	290
	Sub-Total	731	15,884	1,765	0	0	0	645	0	0	0	16,125	1,765	15,884	731
B	Tier 1	995	33,033	3,670		1,321						46,246	3,670	33,033	995
	Tier 2	855	17,902	1,989	719							28,760	1,989	17,902	855
	Tier 3	87	475	53				27				675	53	475	87
	Sub-Total	1,937	51,410	5,712	719	1,321	0	27	0	0	0	75,681	5,712	51,410	1,937
C	Tier 1	439	13,428	1,492			537					16,110	1,492	13,428	439
	Tier 2	299	3,340	371							161	1,610	371	3,340	299
	Sub-Total	738	16,768	1,863	0	0	537	0	0	0	161	17,720	1,863	16,768	738
G	Tier 1	345	6,995						280			5,596	0	6,995	345
	Sub-Total	345	6,995	777	0	0	0	0	280	0	0	5,596	0	6,995	345
Project Total Quantities					719	1,321	537	672	280	0	161	115,122	9,340	91,057	3,751

Bedrock Only - B	Tier 1	500	6,975	775						279		4,185	775	6,975	500
	Sub-Total	500	6,975	775						279		4,185	775	6,975	500
	% of original	26%	14%	14%								6%	14%	14%	26%

Bedrock Only - C	Tier 1	439	6,434	715						257		3,855	715	6,434	439
	Sub-Total	439	6,434	715						257		3,855	715	6,434	439
	% of original	60%	38%	38%								22%	38%	38%	60%

22420 Fill Wall Estimated Quantities 10/01/18

Wall	MaximumHeight	Base Length	Face Area		Reinforcement Length	Reinforcement Vertical Spacing	Reinforcement Area	Structure Excavation	Reinforced Fill	Structure Backfill	Panel Facing
	FT	LF	SF	SY	FT	FT	SY	CY	CY	CY	SF
D	19	140	2,660	296	14	2	436				2,660
E	17	240	3,126	347	12	2	2,347	989	1,182	927	3,126
F	12	150	1,504	167	9	2	796	624	474	678	1,504
Project Total Quantities							3,579	1,613	1,656	1,605	7,290