Technical Memorandum

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To:	Will Smith	**CC:**	Scott Golbek, P.E.
From:	Dave Walker, P.E. Cris Castro, P.E. Suren Balendra	**Date:**	March 22, 2011
RE:	I-90 Snoqualmie Pass East, Task Order AC – Analysis of Overburden Slopes Above Soil Nail Wall		

WSDOT is evaluating two options for increasing the stability of the existing cut slope between approximately LW 1349+00 and the west end of the proposed snowshed at approximately LW1352+40:

- Option 1: Slope Reinforcement
- Option 2: Slope Regrade

This memorandum presents information to support the selection of a preferred stabilization option, including the results of preliminary stability analyses and planning-level cost estimates. This memorandum was prepared by URS under Contract Y-10847, Task Order AC.

OPTION 1: SLOPE REINFORCEMENT

Option 1 is to reinforce the slope by installing soil nails and a wire reinforcement material (GeoBrugg TECCO® steel wire mesh). The work was assumed to include:

1. **Mobilization:** This work item includes transporting a crane, Spyder excavator, and wagon drill to the site. A combination of a crane-mounted drill, Spyder excavator, and wagon drill will be used to install the soil nails.
2. **Soil Nail Installation:** This work item includes the installation of soil nails using a combination of a drill-on-crane, Spyder excavator, and wagon drill to drill the grout hole, install the soil nails and casing, and grout the hole. Based on discussion with several contractors, it was concluded that soil nail installation at the site is feasible. Minor tree removal may be required before beginning this work.
3. **Wire Reinforcement Material Installation:** This work item involves the installation of the wire reinforcement material, specifically GeoBrugg TECCO® steel wire mesh, on the reinforced slope. The soil nails will be used as anchors for the wire mesh system. The wire mesh system includes: TECCO G65-3 millimeter mesh; T3 clips; border rope; and spike plates.

4. **Revegetation Matting:** This work item involves stabilizing the face of the reinforced slope using jute mesh erosion control mat that will be installed below the wire mesh.

ANALYSIS AND RESULTS

Material properties used for the stability analyses are summarized in Table 1. Strength properties for the Gravel/Sand that comprises the existing overburden slope were taken from Allen and Badger (2009), who back-analyzed the properties using a limit equilibrium stability analysis and assumed that the existing slope factor of safety (FS) under static loading is equal to approximately 1.05.

Table 1. Soil and Rock Properties

Layer	Unit Weight (pcf)	Friction Angle (deg)	Cohesion (psf)
Gravel/Sand (Overburden Soil)	135	40	100
Bedrock	Assumed No Failure		

Slope reinforcement requirements were analyzed at LW 1350+00, 1351+00, and 1352+00. The snow surcharges included in the analyses were 520 pounds per square foot (psf) (LW 1351+00 and 1352+00) and 730 psf (LW 1350+00).

The reinforced slope considered in our analyses includes the use of #9 bars (75 kips per square inch (ksi) bar grade) as the soil nail and GeoBrugg TECCO® steel wire mesh (TECCO G65-3 millimeter mesh) for the final facing.

URS evaluated reinforcement requirements for both shallow and deep failure surfaces, as described below.

1. Shallow failure - Shallow failure stability analyses were performed using RUVOLUM-7 software. Based on the cross sections for LW 1349+00 to 1352+00, the existing slopes above the overburden soil nail wall and proposed snow catchment cut vary between 40 and 60 degrees; therefore, URS performed the analyses from 40 to 60 degrees at 5-degree increments. Note that there is no option to include surcharge loads in RUVOLUM-7 software; therefore, URS incorporated the surcharge load by increasing the unit weight of the soil, as presented in Table 2.

Table 2. Equivalent Modified Unit Weight for Surcharge Loads

Surcharge (psf)	Modified Unit Weight (pcf)
260	168
520	200
730	226

- Modified Unit Weight= Surcharge/t + Unit Weight, where t = 8 feet and Unit Weight = 135 pounds per cubic foot (pcf).
- The following assumptions were made for the analysis above:
    a. Layer thickness (t) = 8 feet; and
    b. Pretensioning of the system (V) = 7 kips

2. Deep failure (Global failure) - Global stability analyses were performed using the computer program Slide (V6) and Spencer's Method. The minimum FS for the reinforced slope under static and seismic loading required by the Washington State Department of Transportation (WSDOT, 2010) are 1.33 and 1.1, respectively. Parameters used for the reinforced slope analyses are summarized in Tables 1 and 3.

Table 3. Global Stability Analysis Parameters

Parameters	Static	Seismic
Allowable Tensile Force (kips) (for #9 bar)	40	55
Allowable Nail Head Force[1] (kips)	25	35
Allowable Bond Strength (kips/ft)	3.15	4.2

[1]Source: GeoBrugg specifications for TECCO® G65-3 millimeter mesh

Based on the results of both shallow and deep failure analyses, URS has developed the following preliminary design criteria:

Table 4. Soil Nail Spacing Requirements

Station	Slope (deg)	Spacing (ft)
LW 1350+00	40	8
	45	7.5
	50	6
	55	5.5
	60	5
LW 1351+00	40	6
	45	6
	50	6
	55	6
	60	5.5
LW 1352+00	40	8
	45	8
	50	6.5
	55	6
	60	5.5

- Minimum grout hole diameter = 6 inches
- Minimum bar size/bar grade = #9 / 75 ksi
- Nail inclination = 15 degrees
- Allowable design load transfer for soil = 3.15 kips per foot
- Pretensioning of the system (V) = 7 kips

- Final Facing: GeoBrugg TECCO® steel wire mesh (TECCO G65-3 millimeter mesh)

Note that, at this preliminary analysis phase, the soil nail reinforcements have not been optimized. During the design phase, additional analyses can be performed to optimize the soil nail lengths and soil nail spacing.

PLANNING-LEVEL COST ESTIMATE

A planning-level cost estimate was developed for Option 1: Slope Reinforcement and is presented as Exhibit 1. The planning-level estimated construction cost, exclusive of tax and contingency, is $1.3 million. The total planning-level estimated construction cost, including 8.6% state sales tax and a 20% contingency, is $1.7 million.

Based on the results of the analyses described above, URS used the soil nail quantities in Table 5 for the planning-level cost estimate.

Table 5. Soil Nail Quantities

LW Station Range	Soil Nail Length (ft)	Soil Nail Spacing (ft)	Soil Nail Wall Vertical Surface Area (ft^2)	Number of Soil Nails	Total Soil Nail Length (ft)
1349+34 to 1350+37.5	20	7.5	3,804	68	1,360
1350+37.5 to 1351+62.5	40	6	9,543	266	10,640
1351+62.5 to 1352+00	30	6.5	2,400	57	1,710
Totals			**15,747**	**391**	**13,710**
Average Nail Length =				**35**	**feet**
Rounded Up Number of Nails =				**400**	**each**
Rounded Up Total Nail Length =				**14,000**	**feet**

The wire reinforcement material quantity was determined using the average end area method, at cross sections representing LW 1349+34, 1349+50, 1349+75, 1350+00, 1350+25, 1350+50, 1350+75, 1351+00, 1351+25, 1351+50, 1351+75, and 1352+00, where the wire mesh is to be installed on the slope surface, starting at the top of the overburden soil nail wall and ending at a point on the slope where there is a grade break to a shallower slope. The quantity includes a contingency of approximately 9% for overlapping and wire mesh quantity required to go over the crest of the reinforced slope.

The revegetation matting quantity was determined using the average end area method, where the area of jute mesh required is equal to the surface area of the slope that will be covered with wire mesh.

When reinforcing the slope (soil nails and wire mesh), tree removal will be required at all stations, except LW 1349+34 and 1349+50. Based on preliminary drawings, the required reinforced slope area appears to stay within the right-of-way line, as defined on the WSDOT-provided cross sections.

OPTION 2: SLOPE REGRADE

Option 2 is to regrade the slope to a stable configuration (a slope of 1.25H:1V) using a Spyder excavator and install cable net slope protection. The work was assumed to include:

1. **Mobilization:** This work item includes transporting a crane, Spyder excavator, tracked excavator, loader, dozer, and steel plates to the site.
2. **Accessing the Slope:** The Spyder excavator is assumed to access the slope by being lifted and placed on the slope using a crane that will be based at the roadside level. The selected contractor for this project will determine if it is feasible to access the slope by alternative methods, such as walking/climbing up the slope or constructing a temporary bench. Ultimately, the construction means and methods for slope access will be determined by the contractor.
3. **Tree Removal:** Tree removal for this option becomes a cost consideration, because the target slope of 1.25H:1V extends beyond the tree line between LW 1349+50 and LW 1352+40. Tree removal should be performed prior to excavation of the slope.
4. **Excavation:** This work item includes the use of the Spyder excavator to perform most of the excavation required to regrade the slope to achieve a stable slope. Prior to the start of the work, tree removal will be required. The Spyder excavator will push the excavated spoils downslope to the roadside level. Areas that are flatter than the target slope of 1.25H:1V will not be filled. If there is an opportunity to work from a temporary bench, some of this excavation may be performed by a tracked excavator working from this temporary bench. Blasting is not expected or assumed to be required to achieve the target slope.
5. **Excavation Spoils Loading:** This work item involves consolidating and loading the excavated spoils into haul trucks using a tracked excavator, dozer, and front end loader working at the roadside level.
6. **Haul:** This work item involves hauling the excavation spoils a round-trip distance of approximately 20 miles to the Crystal Springs Sno-Park for stockpiling.
7. **Cable Net Slope Protection Installation:** This work item involves the installation of the cable net on the slope. The cable net is to be secured at the top of the slope cut, with the net draped down the slope. No interior/pattern anchors are assumed required for this project.
8. **Revegetation Matting:** This work item involves stabilizing the face of the newly excavated slope using jute mesh erosion control mat.

ANALYSIS AND RESULTS

Slope stability analyses were performed using the computer program SLOPE/W (2007) and Spencer's Method. The minimum FS for a cut slope under static loading required by WSDOT (WSDOT, 2010) is 1.25. Since WSDOT does not normally mitigate potential slope instabilities under seismic loading, seismic stability was not analyzed.

Stability was analyzed both with and without a snow surcharge. The snow surcharges included in the analyses were 520 psf (LW 1351+00 and 1352+00) and 730 psf (LW 1350+00). However, there are no code requirements or recommendations that require the inclusion of the snow surcharge. The results of the global stability analyses for the regraded slope are summarized in Table 6. The analyses with no snow surcharge indicate that slopes ranging from approximately

1.1H:1V to 1.25H:1V are needed to achieve a calculated FS of 1.25. The calculated FSs for a 1.25H:1V slope without the snow surcharge are 1.25 or slightly less than 1.25. Since relatively small changes in the steepness of the slope can have significant effects on the catch points and volumes of material to be excavated, calculated FSs at steeper slopes are also presented in Table 6.

Table 6. Summary of Calculated Factors of Safety, Option 2

Station	Snow Surcharge	Slope	Calculated Factor of Safety
LW 1350+00	No	1.1H:1V	1.24
	Yes	1.1H:1V	1.14
	Yes	1.15H:1V	1.17
	Yes	1.25H:1V	1.25
LW 1351+00	No	1.25H:1V	1.22
	Yes	1.25H:1V	1.20
	Yes	1.3H:1V	1.23
	Yes	1.35H:1V	1.27
LW 1352+00	No	1.2:1V	1.25
	Yes	1.2H:1V	1.19
	Yes	1.25H:1V	1.23
	Yes	1.3H:1V	1.26

Based on the results of the analyses, WSDOT selected a regraded slope of 1.25H:1V. Additional global stability analyses for a 1.25H:1V slope were performed at LW 1351+75 and LW 1352+00 and are summarized in Table 7. At these stations, the slope immediately upslope of the planned rock cut is approximately 1.25H:1V, or very close to 1.25H:1V, and becomes steeper further upslope. The additional analyses consider regrading only the steepest parts of the existing slope, between approximately 95 and 170 feet left of the LW line at LW 1351+75 and between approximately 105 and 160 feet left of the LW line at LW 1352+00.

Table 7. Additional Calculated Factors of Safety, Option 2

Station	Snow Surcharge	Slope	Calculated Factor of Safety
LW 1351+75	No	1.25H:1V	1.23
LW 1352+00	No	1.25H:1V	1.22

The calculated FSs for the 1.25H:1V slope are as low as 1.22 at LW 1351+00 and 1352+00. WSDOT determined that these FSs are acceptable considering the hard till within the lower portion of the cut and the use of the cable net slope drape (Badger 2011).

PLANNING-LEVEL COST ESTIMATE

A planning-level cost estimate was developed for Option 2: Slope Regrade and is presented as Exhibit 2. The planning-level estimated construction cost, exclusive of tax and contingency, is $992,000. The total planning-level estimated construction cost, including 8.6% state sales tax and a 20% contingency, is $1.3 million.

The excavation quantity was determined using the average end area method. At cross sections representing LW 1349+34, 1349+50, 1349+75, 1350+00, 1350+25, 1350+50, 1350+75,

1351+00, 1351+25, and 1351+50, the target slope (1.25H:1V) was drawn starting at the top of the overburden soil nail wall on the downslope end and ending at the point where the target slope catches the existing slope. At LW 1351+75, 1352+00, and 1352+40, the quantities were estimated assuming regrading of only the steepest parts of the existing slope, as described in the preceding section. It was assumed that areas where the existing slope is flatter than the target slope would not be filled.

The revegetation matting quantity was determined using the average end area method, where the area of jute mesh required is the surface area of the slope, once it is cut to the target cut slopes.

At all stations except LW 1349+34 and 1349+50, the target slopes catch the existing slopes beyond the right-of-way line, as defined in the WSDOT-provided cross sections. Also, at all stations except LW 1349+34, the target slopes catch the existing slopes beyond the tree line, as defined in the WSDOT-provided cross sections. As a result, tree clearing will be needed at all stations, except Station LW 1349+34, to achieve the target regrade slope. For the purpose of the cost estimate, it was assumed that trees requiring removal are spaced 20 feet apart for a tree density of one tree per 400 square feet.

CONCLUSIONS

Based on preliminary analyses and correspondence with experienced contractors, URS concludes that the two options are both feasible and would provide a stable slope. The estimated cost of Option 2 is $440,000 less than Option 1. Implementation of Option 2 would require that permits for work beyond the right-of-way be obtained. A comparison of the two options is presented in Table 8.

Table 8. Comparison Factors

Factor	Option 1: Slope Reinforcement	Option 2: Slope Regrade
Estimated Construction Cost	$1,730,000	$1,290,000
Tree Removal	Yes, less than Option 2 (LW 1349+75 to 1352+00)	Yes, more than Option 1 (LW 1349+50 to 1352+40)
Beyond Right-of-Way	No	Yes (LW 1349+75 to LW 1352+40)
Static Stability	Yes Calculated FS ≥ 1.33	Yes Calculated FS = 1.25 or slightly less
Seismic Stability	Yes Calculated FS ≥ 1.1	Not evaluated
Excavation Depth	Minimal	10 to 20 feet (LW 1350+50 and LW 1351+50)

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REFERENCES

Allen, T.M. and Badger, T.C. 2009. *Memorandum: SR-90, MP 57 to 58 Vicinity*. *Snoqualmie Pass East – Phase 1B. Overburden Thickness and Cut Slope. Recommendations*. August 31, 2009.

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FHWA. 2003. *Geotechnical Engineering Circular No 7 (Soil Nail Wall), FHWA0-IF-03-017*,

GeoBrugg. 2006. RUVOLUM-7 Manual for the software to dimension the TECCO slope stabilization system.

GEO-SLOPE International Ltd. 2007. Slope/W by GEO-SLOPE International Ltd., Calgary, Alberta.

Rocscience. 2010. Slide (version 6) by Rocscience, Toronto, Ontario M4E 3B5.

WSDOT. 2010. *Geotechnical Design Manual, M 46-03*. November 2010.

ATTACHMENTS

Exhibit 1. Planning-Level Cost Estimate. Option 1 – Slope Reinforcement
Exhibit 2. Planning-Level Cost Estimate. Option 2 – Slope Regrade
Figure 1. Option 1 – Slope Reinforcement. Typical Cross Section
Figure 2. Option 2 – Slope Regrade. Typical Cross Section

I-90 SNOQUALMIE PASS EAST

ANALYSIS OF OVERBURDEN SLOPES ABOVE SOIL NAIL WALL
EXHIBIT 1. PLANNING-LEVEL COST ESTIMATE
OPTION 1: SLOPE REINFORCEMENT

Item	Description	Unit	Unit Rate	Quantity	Cost	Source/Justification
	Mobilization/Demobilization					
1	Mobilization/Demobilization	LS	95,000.00	1	$ 95,000	Lump sum rate based on budgetary costs from AIS Construction Company. Lump sum rate includes the mobilization/demobilization of the Spyder excavator, crane, and wagon drill.
	Mobilization/Demobilization Subtotal				**$ 95,000**	
	Soil Nail Wall and Erosion Control					
2	Soil Nail Installation	LF	75.00	14,000	$ 1,050,000	Unit rate based on budgetary costs from AIS Construction Company. Unit rate assumes the use of the combination of a crane, spyder excavator, and wagon drill to install the soil nails. The unit rate includes drilling the grout hole, installing the soil nail/casing, and grouting the hole. Refer to Table 5. Soil Nail Quantities for a breakdown of the soil nail count. The cross sections used were provided by WSDOT and are from September 2010.
3	Wire Reinforcement Material Installation	SF	7.00	25,000	$ 175,000	Unit rate based on budgetary costs from AIS Construction Company and Geobrugg and assumes the use of the Geobrugg TECCO wire mesh. The unit rate is an installed cost and includes: TECCO G65-3 mm wire mesh, spike plates, border rope system, and aesthetic coloring. Quantity includes the slope surface area with the bottom at the top of the overburden soil nail wall and the top at a point on the slope where there is a grade break to a shallower slope. The quantity includes a contingency of approximately 9% for overlapping and wire mesh quantity required to go over the assumed crest of the SNW. The cross sections used were provided by WSDOT and are from September 2010.
4	Revegetation Matting	SY	3.09	2,778	$ 8,575	Unit rate based on 2011 RS Means Site Work & Landscape Cost Data (31 25 14.16 0010) for jute mesh (materials and installation). Unit rate includes location factor of 1.05 and a factor of 2 for complex project site. Quantity is based on the slope surface area following regrade of the slope.
	Soil Nail Wall and Erosion Control Subtotal				**$ 1,233,575**	
	Subtotal				$ 1,328,575	
	State Taxes @8.6%				$ 114,257	
	Total with State Taxes				$ 1,442,832	
	Contingency @20%				$ 288,566	Minimal tree removal, safety considerations, miscellaneous items
	Total Estimated Project Cost				**$ 1,731,399**	

I-90 SNOQUALMIE PASS EAST

ANALYSIS OF OVERBURDEN SLOPES ABOVE SOIL NAIL WALL
EXHIBIT 2. PLANNING-LEVEL COST ESTIMATE
OPTION 2: SLOPE REGRADE

Item	Description	Unit	Unit Rate	Quantity	Cost	Source/Justification
	Mobilization/Demobilization					
1	Mobilization/Demobilization	LS	80,000.00	1	$ 80,000	Lump sum rate based on budgetary costs from AIS Construction Company. Lump sum rate includes the mobilization/demobilization of the Spyder excavator, excavator, loader, dozer, and steel plates.
	Mobilization/Demobilization Subtotal				**$ 80,000**	
	Earthwork and Erosion Control					
2	Tree Removal	EA	230.00	54	$ 12,420	Unit rate based on WSDOT-provided cost information for tree removal from Phase 1B. Quantity is based on the area upgradient from the tree line to the point 15 feet upslope from where the 1.25H:1V line catches the existing slope, which is approximately 2,386 SY. Tree spacing assumed is 20 feet, resulting in a tree density of approximately 1 tree per 400 SF.
3	Excavation	CY	93.05	5,404	$ 502,836	Unit rate based on budgetary costs from AIS Construction Company. Unit rate assumes the use of a Spyder Excavator on the slope. The work involves the Spyder Excavator excavating to the target slope grade and then dumping it downslope for retrieval at the roadside level. Quantity is based on URS drawing target slope grades, starting at the top of the soil nail wall and ending where it daylights with the existing slope surface. The cross sections used were provided by WSDOT and are from September 2010. If a temporary work bench can be establish, some of the excavation may be performed by the excavator.
4	Excavation Spoils Loading	CY	3.41	5,674	$ 19,363	Unit rate based on 2011 RS Means Heavy Construction Cost Data (31 23 16.42 0260 and -1600) for 2-CY capacity excavator to consolidate excavated spoils and 2 1/4-CY capacity wheel-mounted front end loader to load haul truck. Unit rate also includes a location factor of 1.05 for Seattle (source: RS Means). Quantity is based on the volume excavated by the Spyder Excavator and includes a bulk factor of 5%.
5	Haul	CY	8.51	5,674	$ 48,259	Unit rate based on 2011 RS Means Heavy Construction Cost Data 31 23 23.20 1078 for 20-mile round trip haul (40 mph, 12-cy truck, 15 min. wait time). Unit rate also includes a location factor of 1.05 for Seattle (source: RS Means). Quantity is based on the volume excavated by the Spyder Excavator and includes a bulk factor of 5%.
6	Cable Net Slope Protection Installation	SF	7.00	45,000	$ 315,000	Unit rate based on WSDOT-provided cost information for cable net slope protection from Phase 1B and assumes the cable net will be secured at the top of the cut and the net draped down the slope. No interior/pattern anchors are assumed in the unit rate. Quantity includes the slope surface area with the bottom at the top of the overburden soil nail wall and the top at a point on the slope where there is a grade break to a shallower slope. The quantity includes a contingency of approximately 9% for overlapping and wire mesh quantity required to go over the assumed crest of the regraded slope. The cross sections used were provided by WSDOT and are from September 2010.
7	Revegetation Matting	SY	3.09	4,594	$ 14,182	Unit rate based on 2011 RS Means Site Work & Landscape Cost Data (31 25 14.16 0010) for jute mesh (materials and installation). Unit rate includes location factor of 1.05 and a factor of 2 for complex project site. Quantity is based on the slope surface area following regrade of the slope.
	Earthwork and Erosion Control Subtotal				**$ 912,060**	
	Subtotal				$ 992,060	
	State Taxes @8.6%				$ 85,317	
	Total with State Taxes				$ 1,077,377	
	Contingency @20%				$ 215,475	Safety considerations, miscellaneous items
	Total Estimated Project Cost				**$ 1,292,852**	

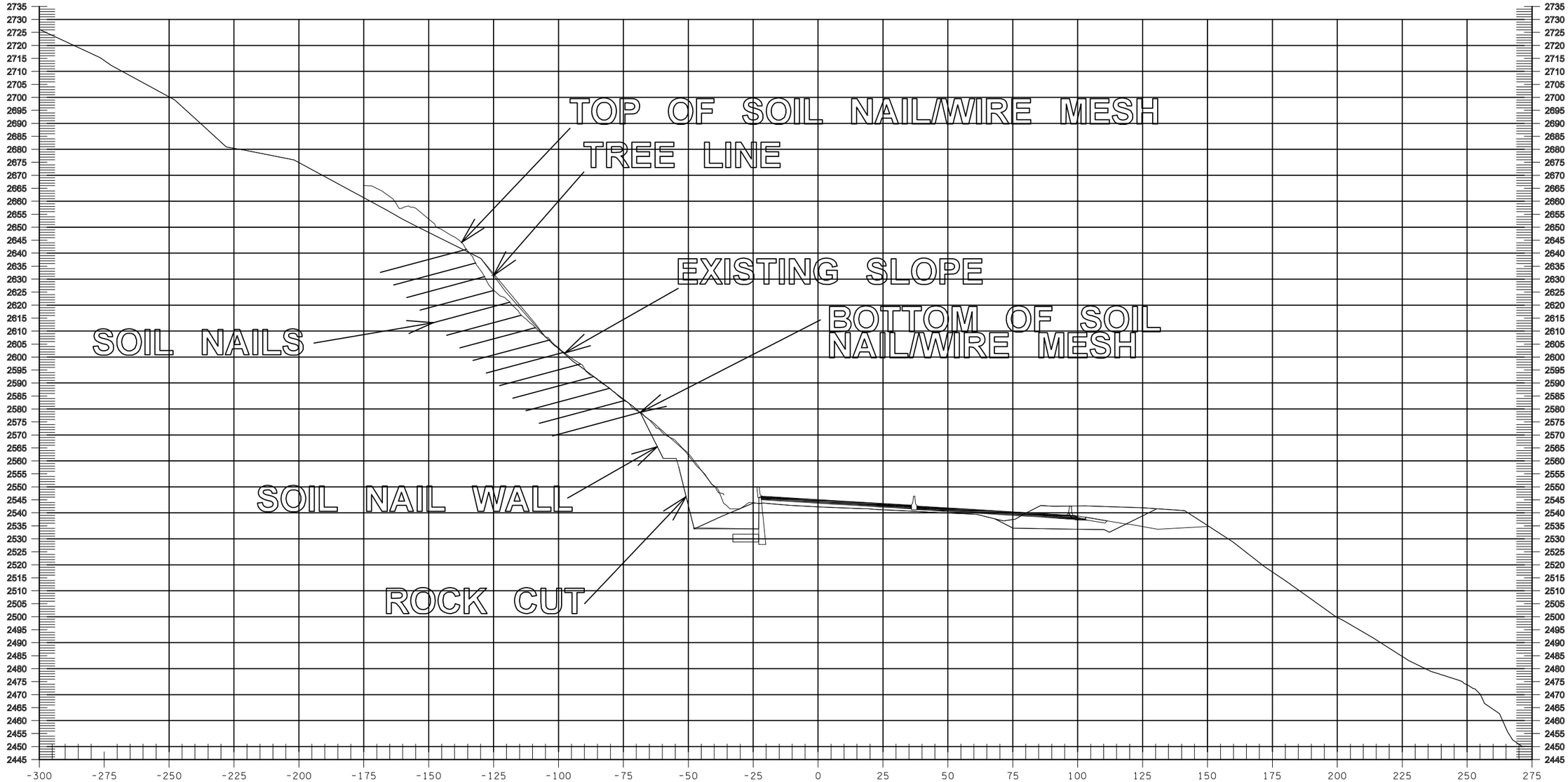

Figure 1. Option 1 - Slope Reinforcement Typical Cross Section

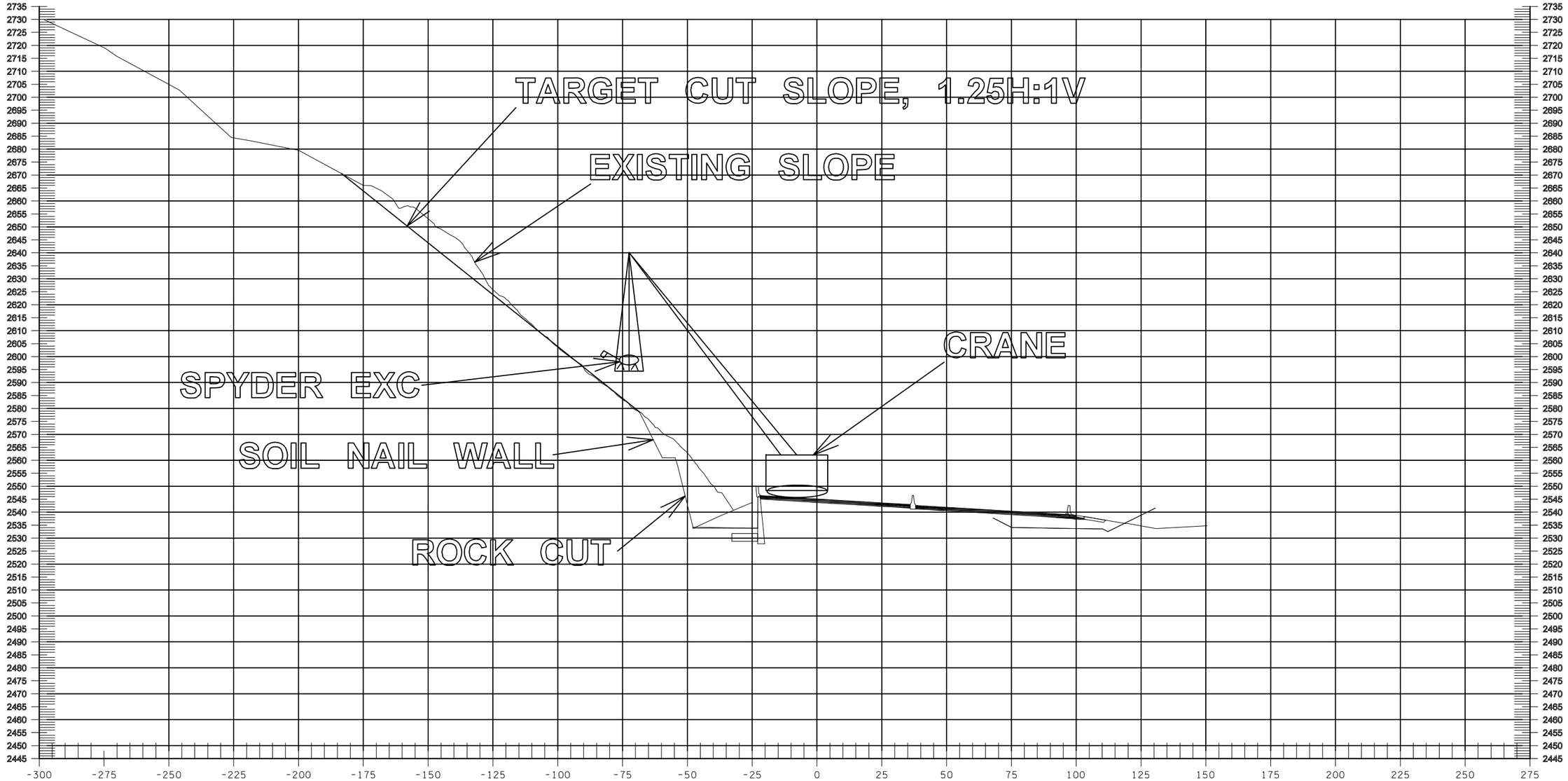

Figure 2. Option 2 - Slope Regrade Typical Cross Section