BYU | CIVIL & ENVIRONMENTAL ENGINEERING
IRA A. FULTON COLLEGE

Temporary Slope Repair for Highway Expansion
Project ID: CEEn_2017CPST_006

by

SAMM Engineering
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Mary Ririe

A Capstone Project Final Report

Submitted to

Matt Hawley
Kiewit

Department of Civil and Environmental Engineering
Brigham Young University

April 2018

Executive Summary

PROJECT TITLE: Temporary Slope Repair for Highway Expansion
PROJECT ID: CEEn-2016CPST-006
PROJECT SPONSOR: Kiewit
TEAM NAME: SAMM Engineering

This project included the design of a slope repair in Irving, TX. During a highway expansion project, the slope which had been cut into began to fail. The scope of this project was to discover the cause of failure and propose a solution that would be cost effective and will have a design life of two years. The deliverables of this project include: CAD drawings of the final proposed design, a cost estimate, and a construction schedule and relevant calculations. Kiewit provided SAMM engineering with relevant CAD drawings and boring logs of the failed slope.

SAMM Engineering analyzed the data provided in UTexas and discovered the failure plane to be the worst at station 489+50 which had a safety factor of 0.87. A simple cost analysis was performed comparing three different methods of slope stability: drill shafts, driven piles and soil nails with a shotcrete façade. Different characteristics were weighted such as cost, ease of construction, capacity design load, design life and aesthetics. Shotcrete with steel nails had the highest weighted score so design continued. Further analysis of feasible soil nail design was conducted using UTexas as well as design equations from FHWA. Using UTexas, the proposed layout of soil nails increased the Factor of Safety to 1.36 at our target station. Supporting calculations were made using Mathcad to ensure that all the limit states were considered.

Our proposed design includes drilling and grouting 952 soil nails 4 ft. o-c. horizontally and 5ft o-c. vertically. These nails are 20 ft. long with 1 in diameter and grade 60 steel, inserted at 15° from the horizontal. Each will be grouted with 6 in of grout and topped with an 8x 8 x ¾ steel plate. Initial shotcrete covering will be 4 in and final covering will be 6 in which corresponds with the required minimums in FHWA.

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Introduction

The purpose of this report is to submit the design for the temporary slope repair for highway expansion in Irving, TX. The slope in question failed during a temporary road widening in order to make room for a detour lane. Due to the temporary nature of this project, the design life is two years. This slope consists of alternating layers of clay and sand, with the failure plane located in the steepest portion of the slope in the clay layer. The proposed design includes CAD drawings, calculations, cost estimates and a construction schedule. Calculations were completed using UTexas, FHWA and Mathcad. The resumes of each team member is located in Appendix A. The CAD drawings are shown in Appendix B.

Schedule

Figure 1 shows the schedule SAMM Engineering followed during the semester. The UTexas analysis took longer than expected to complete and therefore, our schedule was different than estimated, but everything else was completed on schedule.

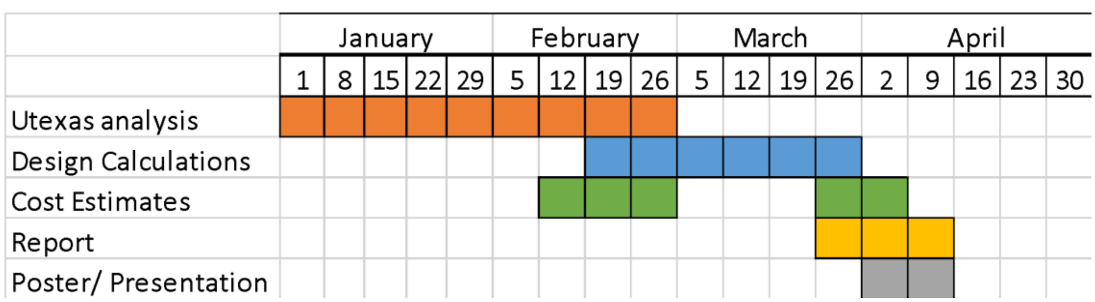

Figure 1. Design Schedule

Assumptions & Limitations

The boring logs provided were from three stations along the location of the slope. Although these stations were far apart, a linear profile was interpolated and these values were used to calculate the cohesion and friction angles for each estimated layer of soil. It must also be noted that correlations were used to obtain the soil properties from the boring logs. This is not as accurate as conducting laboratory tests, so further soil testing is recommended before proceeding with the design.

Design, Analysis & Results

Approach

The team was given boring logs and slope CAD drawings to analyze the failure planes. To investigate the possible causes of failure the team proceeded as follows:

- Researched slope failures and probable causes
- Analyzed boring logs
- Researched soil properties
- Researched Texas Cone Penetrometer and SPT conversions
- Added soil layering to slope CAD drawings via boring logs and interpolation
- Studied UTexas manual
- Entered soil layering into UTexas along with soil properties
- Investigated failure planes by using UTexas
- Iterated all stations to understand how the different variables affected the soil failure plane
- Contacted professors to clarify UTexas concepts and properties
- Researched several slope stability methods as well as most cost effective options
- Created a spreadsheet to compare costs
- Finalized slope stability method option

Failure Findings

The failure plane is on the top clay layer of the slope; it daylights on the interface between the sand and clay layer, in the same area of the water level. Figure 2 below illustrates the failure plane, along with the factor of safety. The lowest factor of safety found was 0.874. The UTexas analysis at each station is shown in Figures C.1-C.10 in Appendix C.

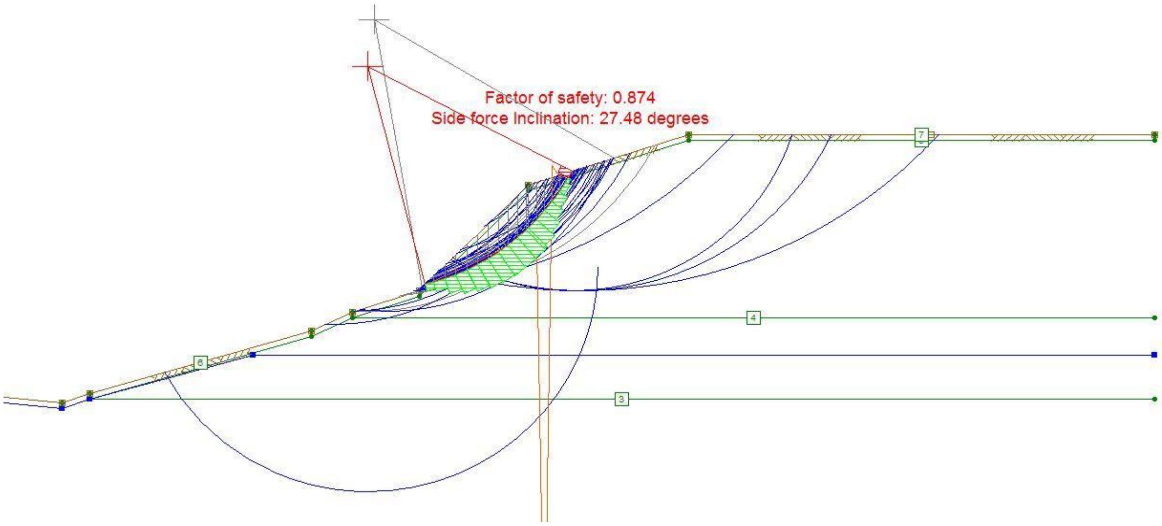

Figure 2. Slope Failure

Scope of Possible Solutions

Three different possible solutions were investigated as part of this project:

1. Soil Nails extending through the problem area to provide stability with a wire mesh cover on the surface of the slope to prevent shallow slides.
2. Soil Nails extending through the problem area to provide stability with a shotcrete facing over the surface of the slope
3. Reinforcing driven piles / drilled shafts into the slope to provide stability.

These possible solutions were briefly analyzed according to several criteria in order to determine their feasibility. This analysis also assisted in determining which solution to move forward with for the stability design. The criteria used in the preliminary comparison are as follows:

1. Cost
2. Ease of Construction / Feasibility / Accessibility
3. Capacity to Carry the Design Load
4. Meets Design Life / Corrosion
5. Aesthetically Pleasing / Environmentally Friendly

Each solution was given a rating based on its performance in the above criteria, with cost being the criteria with the highest weight.

Table 1. Cost Comparison Analysis

Ratings Table: 1 = lowest (worst), 4 = highest (best)	Drill Shafts	Driven Piles	Shotcrete	Steel Mesh
Cost (Weighting = 0.85)	1	2	3	4
Ease of Construction (Weighting = 0.3)	1	4	3	2
Capacity Design Load (Weighting = 0.5)	4	2	3	1
Meets Design Life (Weighting = (0.25)	1	2	3	4
Aesthetic/Environment (Weighting = 0.15)	1	3	2	4
Sum of (Rating Times Weighting)	3.55	4.85	6	6.1

Steel Mesh was given the highest overall rating at 6.1 for our design criteria weights. (See explanation and analysis below for more details.)

EXPLANATION OF KEY ITEMS ON THE TABLE:

The cost determination was very simple. We made some brief preliminary cost estimates based on similar job sites total project cost, and experience of our engineering advisors. The costliest method received a rating of 1, with the least costly a rating of 4.

Ease of construction was determined considering standard procedures used for each method. Since our failure is on a moderately steep slope, accessibility and the feasibility of construction were taken into consideration. Drilled shafts require heavy equipment, a large amount of work, and might be difficult to access on a slope. Wire mesh also requires a lot of work and more precision and consideration of the terrain than other methods. Shotcrete requires almost the same amount of work, but less precision is needed, as long as the thickness of the concrete slab meets the minimum requirement. Finally driven piles requires minimal effort providing access is easily obtainable on site.

Capacity to carry design loads. This parameter varies with time. Steel mesh is considered a passive solution and may need extra structural consideration depending on the abnormalities in the site. It may fail at a later date when initially secure, thus lowering the rating. Driven piles require very high soil cohesive values. This project has median soil values and would require extra tying to the slope and other structural considerations. Shotcrete has been proven to perform very well on most types of similar slope projects. Driven Piles are immovable and very structurally sound. The higher diameter increases the force it can resist.

The design life is 2 years. We want our project to exceed this parameter, but not become a burden to remove in the future. Drilled shafts, driven piles, and shotcrete all meet the requirements but may be difficult to remove in the future. Methods of corrosion may help speed the process, but ultimately Steel Wire Mesh meets the design life the most efficiently.

Aesthetic / Environmentally Friendly. Drilled shafts disturb the environment the most, by heaving up great amounts of dirt, and permanently adding multiple concrete structures. Shotcrete also adds a more permanent structure and can be aesthetically displeasing unless properly treated for corrosion resistance. Driven Piles are much less visible (if at all) than Drilled Shafts but would still disturb the surrounding soils. Wire mesh is removable and compatible with surrounding foliage if a corrosive retardant is applied at installment.

Selected Design

The preferred slope stability design will use soil nails and steel mesh over the slope. This method has the greatest design score based on the criteria above, and is the most viable solution for the problem at hand. It is a cheap, but effective solution to slope failure and is widely used around the world.

Soil nails are placed into slopes to prevent and remediate slope failure. They are a passive design, meaning that resistance along the nails is developed through movement of the soil around the nail. These nails serve to anchor the slope and prevent deep-seated slides. The mesh is anchored to the surface of the slope by the nails, and provides a retaining force to the surface of the soil, preventing shallow sloughing of the soil at the surface. Often, a layer of shotcrete is also applied over the surface as an aesthetic cover, but there are organic mats which may be placed under the mesh which promote plant growth and may be used as an alternative aesthetic element of design.

Design Parameters

The results from the UTEXAS modeling program indicated that 952 soil nails spaced at four feet by five feet and at a length of 20 feet deep would give an acceptable factor of safety for our design.
The final design parameters of the shotcrete layer are calculated per "Soil Nail Walls Reference Manual - AASHTO LRFD Bridge Design Specifications, 7th Edition" as shown in the appendix. The overall thickness of the shotcrete is ten inches. It has a four-inch initial sub layer to resist bearing pressure of the soil, and provide a barrier between the soil and the wire mesh reinforcement. The wire mesh reinforcement was chosen from table A.5 and from "Design Guidelines for Wire Mesh Net Slope Protection" to distribute the load from each soil nail to the shotcrete facing, and the final facing of six inches to protect the wire-mesh reinforcement from environmental corrosion and add significant weight to reduce punching shear of the soil nails. The facing calculations are located in Appendix D.

Cost Estimate

Table 2 contains the estimated cost of the proposed design. The calculations and sources of the material costs are located in Figure D.1 in Appendix D.

Table 2. Cost Estimation

Cost Estimation	
6x6x.105 Wire Mesh:	$1,675
Grade 60 Rebar (#6):	$20,000
8x8x3/4 Steel Plates:	$10,710
Shotcrete:	$3,031
Material Subtotal:	$35,416
Installation:	$121,584
Contingency:	$10,000
Project Total:	$167,000

Cost Estimate Summary

An initial preliminary cost analysis estimate was determined for each possible solution. Shotcrete / Wire Mesh was selected for design and a more detailed cost analysis was made. Total material costs and labor were estimated to be approximately $35,500.00 and $124,500.00, respectively. Material costs were referenced in the calculations and are accurate as of 04-05-18 and were considered dependent upon availability costs near current site in Texas. Labor costs may vary and were determined based upon a time constituent estimate from similar projects.

Lessons Learned

A huge challenge was to find time where the group could meet as well as meeting with our sponsor and Project Manager. Each of us had very different schedules which made it difficult to plan the ideal time to meet together. Another challenge that relates to this was making sure each person knew what was expected of them making sure we were able to use our time efficiently and not overlap on any of our responsibilities. Technology has been a huge help with this, through text, email, google docs and a group folder on through CAEDM, we have been able to collaborate and share even though we can only meet once a week.

Other challenges have included learning how to use new programs such as UTexas and knowing which equations to use for our analysis. There are many resources available, but with each of us being new to this process, we often weren't sure we were choosing the best options

Conclusions

This report covers the analysis and solution of the temporary slope repair for a highway expansion in Irving, TX. With the boring logs from a Texas Cone Penetrometer Test, we performed interpolations to achieve a soil profile for the repair area. UTexas and AutoCAD were the main software used to perform several iterations to define the slope failure, where it was found to be on the upper clay layer, due to low cohesion factor. Once that was determined, possible solutions were analyzed until the combination of soil nails with shotcrete facing was chosen to be the most effective and feasible option. The soil nail length was determined to be 20 feet long, using a #6 bar. The nails were spaced 5 ft. from vertical and 4 ft. from horizontal, with a total of 952 nails over the project area. The nails are covered with an initial (4”) and final (6”) shotcrete facings. The cost was estimated at $167,000 with a completion time of 4 weeks. The final factor of safety is 1.308.

Recommendations

It is recommended that further testing on the soils be completed before implementing the design in order to confirm the results obtained within this study. Drainage was also not considered in the study, so further design should consider drainage the drainage needs of the soil nail wall.

Appendix A

SJI

Architecture / Civil Engineering B.S.

Determined / Honest / Reliable

Stephen J Isaacson

IsaacsonStephen@gmail.com
www.linkedin.com/in/isaacsonstephen

801.921.1216

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Why you should hire me

In short, I am an all-around great guy! I work hard, and will get everything you need done, done. If you want work to be efficient, successful, and far too enjoyable, hire me.

Achievements

- February 16, 2013, I married my sweetheart, Kaisha Marie Beatty, for time and all eternity in the Mt. Timpanogos Temple.
- June 17, 2014, My Son, Nathanael James Isaacson, was born into our family.
- March 2009 to March 2011, I served a full-time mission for the Church of Jesus Christ of Latter Day Saints in the California Santa Rosa Mission.

Goals

I will graduate from BYU spring of 2018 in the Civil Engineering program, with a focus on Structures, and go on to the University of Utah to obtain a Master's degree in Architecture. My ultimate career goal is to build churches and temples for the Church of Jesus Christ of Latter Day Saints.

Education

Brigham Young University | BS Civil Engineering 2018
Utah Valley University | Associate in Pre-Engineering 2013
American Fork High School | Graduate 2007

Skills

Professionally used Revit Architecture 2016, 2015,2012,2010,2009, Basic Hand Drafting, Basic knowledge of AutoCad, Pro-E, and Solid Works.

Experience

Company Name: Architectural Coalition- Guil Rand
Job Title: Project Manager / Architectural Drafter
Start Date: May 2014
End Date: Currently Employed

Amanda Correa McFarland

amanda.cc.mcfarland@gmail.com
801.654.3616
3074 Davencourt Loop, Lehi, UT 84043

EDUCATION

Candidate, Bachelor of Science, Civil Engineering, Brigham Young University, Provo, Utah. Summer 2013 – Spring 2018, GPA: 3.47/4.00
Relevant Courses: Traffic Engineering, Urban Transportation Planning

Associate of Applied Sciences, Interior Design, LDS Business College, Salt Lake City, Utah. Winter 2010 – Fall 2011

Student in the Architecture Program, Federal University of Campinas, Sao Paulo, Brazil. 2009

EXPERIENCE

Interior Design Assistant, Leslie Schofield Design, Salt Lake City, UT
January 2013 – Present
Efficient AutoCAD and Revit drawings, renderings, presentations, helps designer with installs and site visits, quality aid in every step of the design process

Interior Design Assistant, Brigham Young University, Provo, UT
May 2014 – December 2014
Detail work in commercial design, space planning, met with clients, presented ideas and products

Design Associate, Restoration Hardware, Salt Lake City, UT
February 2012 – October 2013
Competent works with clients helping them with their design needs, implemented high quality visual standards

Registration Assistant, LDS Business College, Salt Lake City, UT
August 2010 – February 2012
Quality customer service improving 80% of the efficiency

Interior Design Intern, Imbue Design, Salt Lake City, UT
August 2011 – November 2011
Developed 3D models; researched furniture, materials, and design fixtures; using Photoshop

SKILLS

- Proficient in AutoCAD, and SketchUp
- Intermediate in Revit and beginner in GIS
- Passion for engineering and continuous learner
- Work well under deadlines and pressure
- Detail oriented to perform quality tasks
- Leadership and team work through collaboration in college projects
- Knowledge in using Microsoft Office, Excel VBA primer, and Internet use
- Portuguese speaking

REFERENCES Upon request

MARY RIRIE

66 W 300 S #1 Springville, UT 84663 • 972.589.4211 • ririe.mary@gmail.com

EDUCATION

BS IN CIVIL ENGINEERING, *BRIGHAM YOUNG UNIVERSITY*, PROVO, UT
Graduation Date: June 2018
GPA: 3.44/4.0

SOFTWARE: AutoCAD, Civil 3D, MathCAD, RAM Steel, UTexas and Microsoft Office Suite

WORK EXPERIENCE

INTERN, *KELLER ASSOCIATES, INC.*, IDAHO FALLS, ID — JAN 2017 TO AUG 2017

- Analyzed data and created graphs and tables to present to clients
- Attended meetings to consult with clients
- Compiled bid documents
- Worked as a field engineer including site observation and reviewing submittals
- Aided in pump and pipe design
- Compiled quotes to help estimate the total project cost
- Worked extensively with coworkers to complete projects

TEACHERS ASSISTANT FOR STRUCTURAL ANALYSIS, *BYU*, PROVO, UT — AUG 2017 TO DEC 2017

- Assist students in learning principles of structural analysis
- Grade papers

RESEARCH ASSISTANT, *BYU*, PROVO, UT — OCT 2017 TO PRESENT

- Conduct experiments to measure the air content of mortar
- Statistically analyze the results
- Write a technical report

VOLUNTEER EXPERIENCE

EERI SECRETARY, *BYU*, PROVO, UT — JAN 2018 TO PRESENT

- Email reminders to all interested parties
- Keep track of budget
- Keep club organized

ASCE MEMBER, *BYU CHAPTER*, PROVO, UT — JAN 2010 TO PRESENT

- Member of the BYU chapter of the American Society of Civil Engineers
- Participated in a minimum of 5 hours of service per semester. Previous service programs include Habitat for Humanity and Math Counts.
- Attend presentations from various fields of engineering weekly

WE@BYU MENTOR, PROVO, UT — AUG 2017 TO PRESENT

- Assigned to meet with a few freshmen to aid them in getting adjusted to school and engineering

McKay Parkinson

438 N 700 E, Provo UT 84604 | (505) 660-4405 | mckayparkinson@gmail.com

Education

UNDERGRADUATE – BRIGHAM YOUNG UNIVERSITY — **EXPECTED GRADUATION: DECEMBER 2018**

- Major: Civil Engineering
- Major Courses: Geometric Highway Design, Foundation Design
- GPA: 3.04

Experience

HORROCKS ENGINEERS — **MAY 2017 - PRESENT**

- Perform turning movement, approach, and average daily traffic counts using count-boards, pneumatic tubes, etc.
- Author Traffic Impact Studies
- Assisted with creating Impact Fee Facilities Plans for American Fork and Orem

RESEARCH ASSISTANT — **JANUARY 2017 - PRESENT**

- Created reports on UDOT roads using the Roadway Safety Analysis Method developed at BYU

TEACHING ASSISTANT – BRIGHAM YOUNG UNIVERSITY — **JANUARY 2016 - MAY 2017**

- Graded assignments, answered students' questions, and trained co-worker on various responsibilities

BYU STEEL BRIDGE TEAM — **AUGUST 2015 - JUNE 2017**

- Designed, fabricated, and built a steel bridge for the AISC Steel Bridge competition
  - 2017 Rocky Mountain Conference champions – Competed at the National Steel Bridge Competition at Oregon State

Volunteer Work and Professional Associations

BYU AREMA STUDENT CHAPTER – ACTIVITIES COORDINATOR — **APRIL 2017 - PRESENT**

- Plan bi-monthly Professional Forums on campus

BYU ITE STUDENT CHAPTER – SECRETARY/TREASURER — **DECEMBER 2016 - PRESENT**

- Manage chapter website, maintain lists of current membership, and manage chapter funds

THE CHURCH OF JESUS CHRIST OF LATTER DAY SAINTS — **MAY 2013 - MAY 2015**

- Served a proselyting mission for two years in Germany and Austria training single missionaries and leading groups of 8-12 missionaries

Skills & Abilities

COMPUTER SKILLS

- Synchro 10 & Vistro 5.0
- ArcGIS
- Visual Basic Programming

LANGUAGES

- English (native), German (proficient)

KAYLEE BATEMAN

15 E 200 N Apt. 3, Orem, Utah 84057 ♦ (208)390-4544 ♦ kayleedeebateman@gmail.com

EDUCATION

Masters of Science, Structural Enginering — **Estimated Apr 2018**
Brigham Young University — *Provo, UT*
- Master's Thesis: Relationship between delaminations of steel reinforcement and chloride concentrations in concrete bridge decks

Bachelors of Science, Civil Engineering — **Aug 2017**
Brigham Young University — *Provo, UT*
- Member of national and student chapter of American Society of Civil Engineers

RELATED WORK EXPERIENCE

Graduate Research Assistant — **Feb 2017 – Present**
Brigham Young University — *Provo, UT*
- Performed chloride testing on bridge decks to determine structural integrity of the bridge
- Carried out a unique process preparing, diluting, and titrating chloride samples
- Communicated amongst peers and the research professor to define problems, collect data, establish facts, and draw conclusions

Undergraduate Researcher — **Oct – Dec 2016**
Brigham Young University — *Provo, UT*
- Tested and developed grout mixtures with specified compressive strengths
- Reviewed calculations and analytical data to maintain accuracy during testing

Civil Engineering Structural Intern — **Apr – Aug 2016**
Engineering Systems Solutions (ES^2) — *Idaho Falls, ID*
- Created concrete design spreadsheets for concrete shear, column interaction diagrams/ loadings and beam moment analysis
- Utilized proprietary software from ES^2 to check company designs with reinforced concrete
- Coordinated with other project engineers to review projects for construction

ACTIVITIES AND INVOLVEMENT

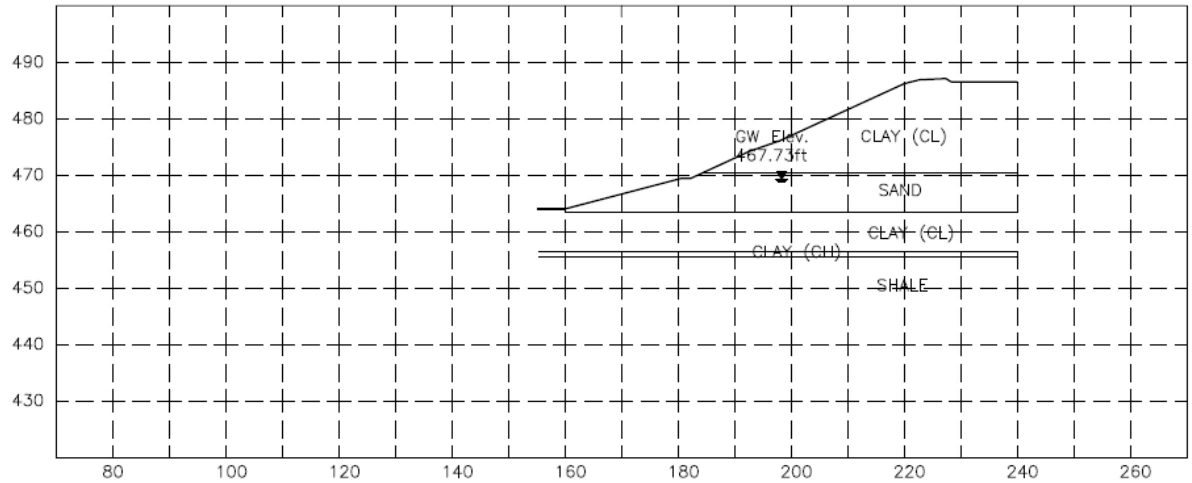
Analyst — **Sep 2016 – Apr 2017**
City of Orem Transportation — *Orem, UT*
- Analyzed effect of changing an intersection control system through a traffic corridor
- Collaborated with eight city engineers and capstone team members

Mentor — **Sep 2016– Dec 2016**
Brigham Young University — *Provo, UT*
- Assisted incoming female freshman in engineering navigate their first semester by helping them coordinate schedules and build relationships with peers

Leadership Study — **May – June 2015**
Brigham Young University — *Guangzhou, China*
- Studied engineering leadership at Sun Yat Sen University

Student Volunteer — **Aug – Dec 2013**
Westerstede Elementary — *Westerstede, Germany*
- Volunteered 15 hours a week assisting German students with English

Appendix B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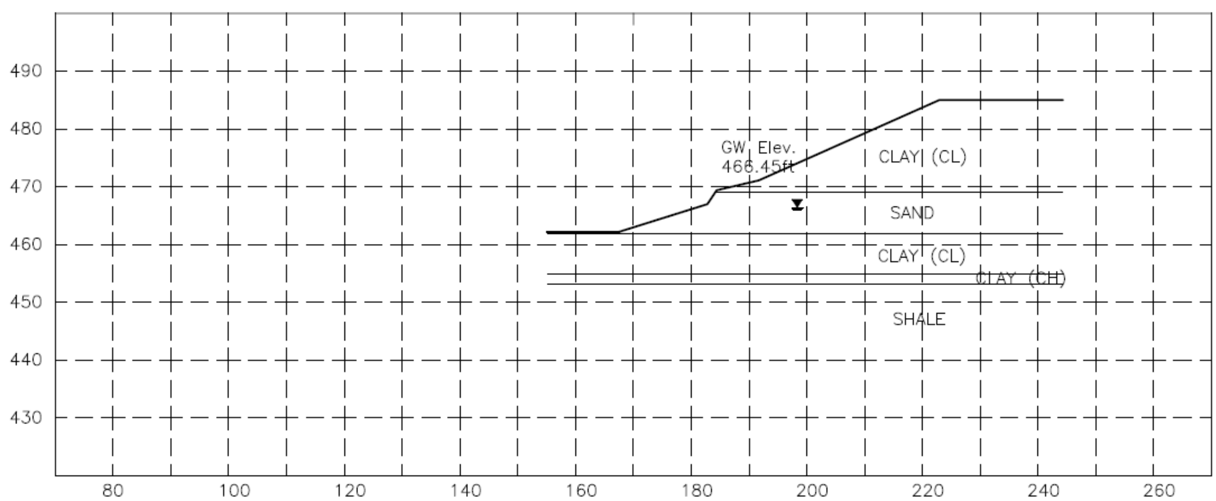
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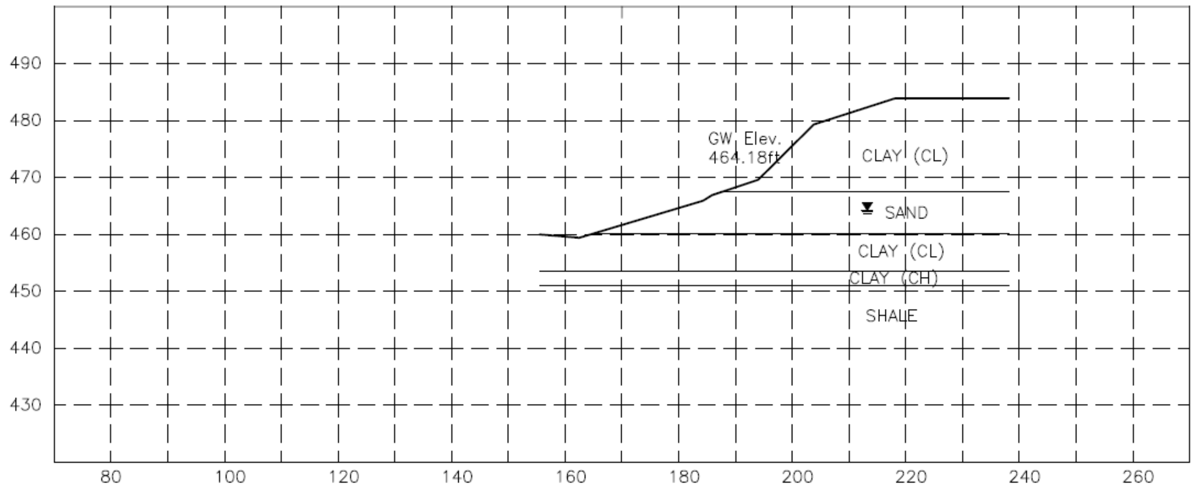
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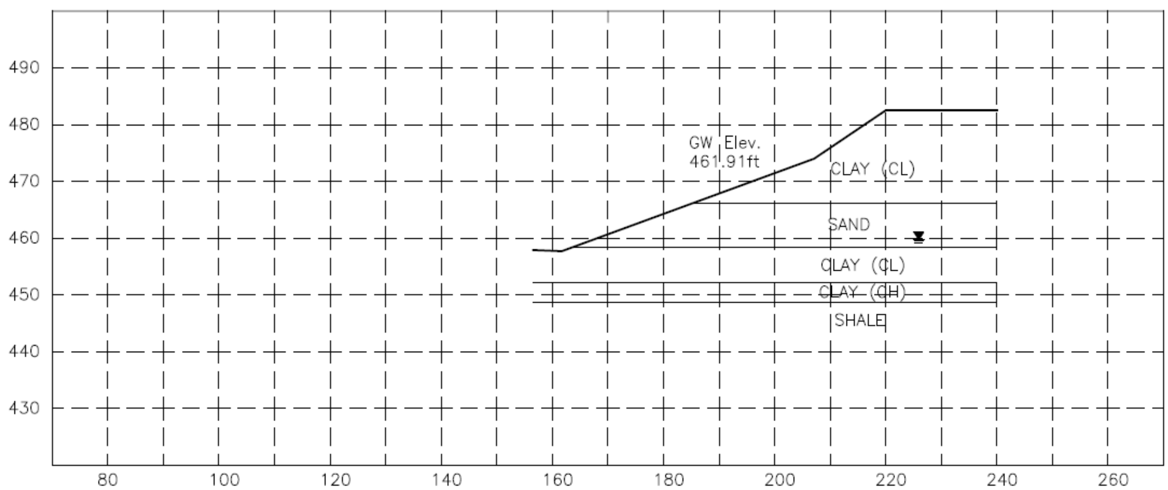
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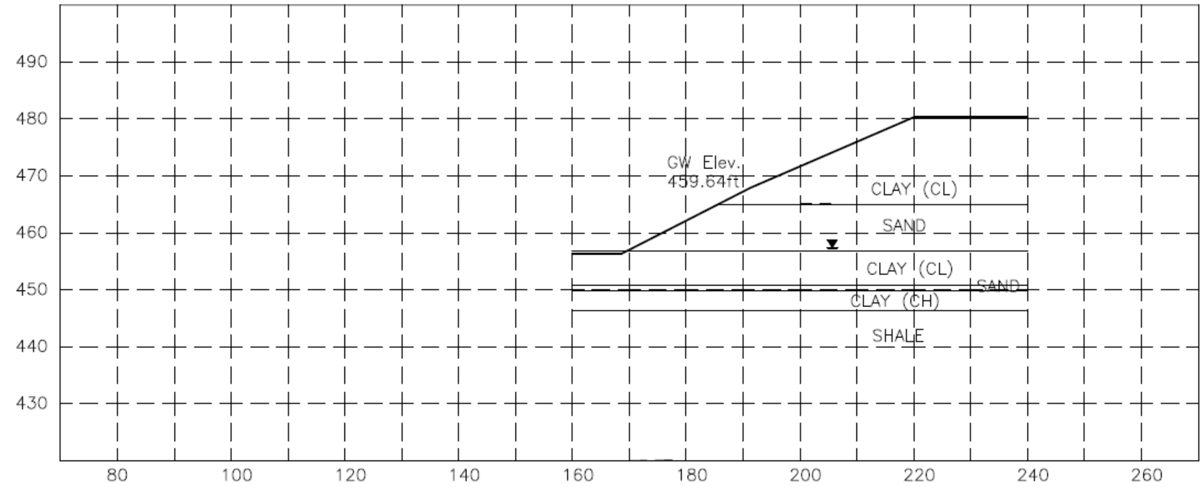
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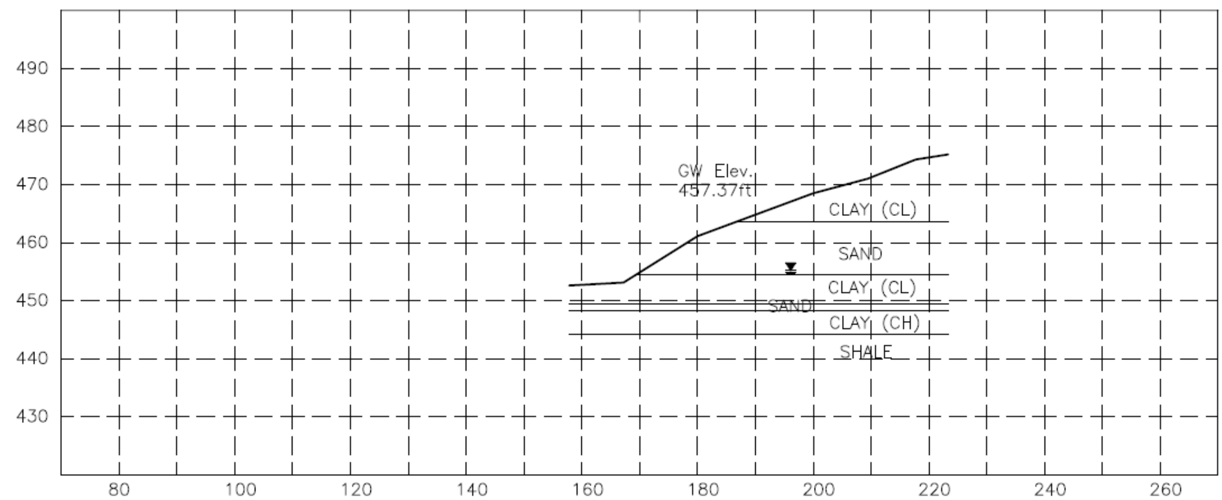
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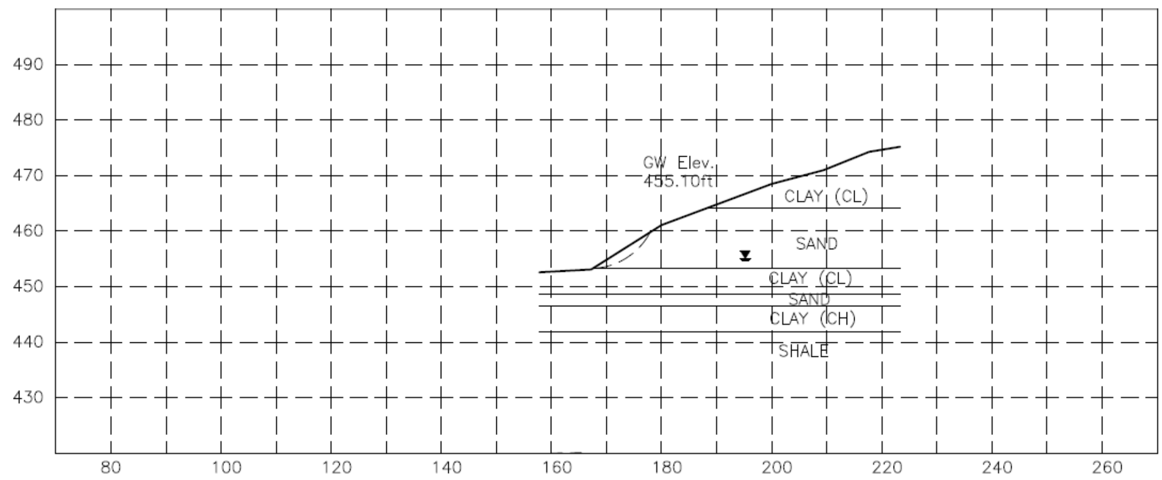
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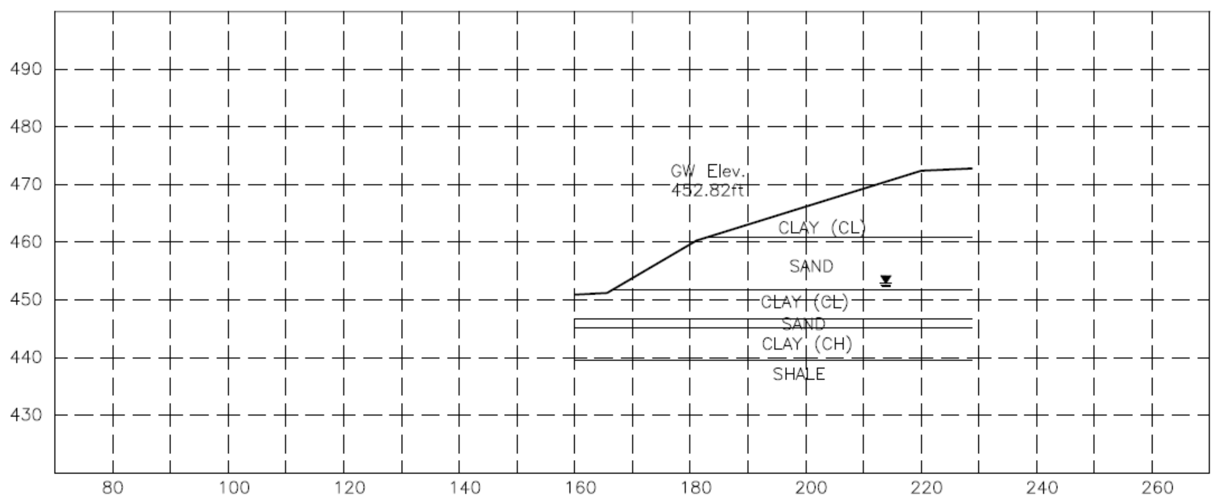
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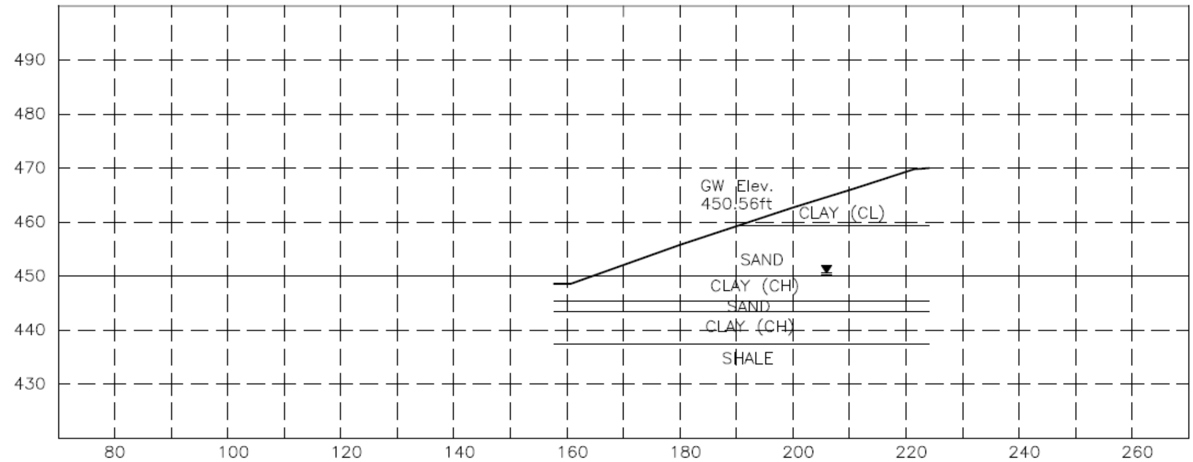
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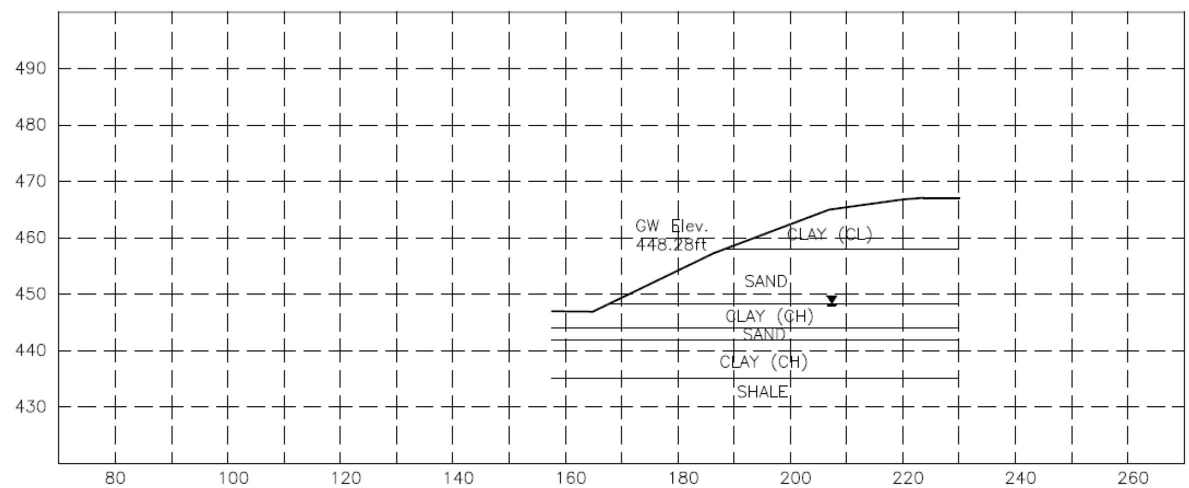
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Appendix C

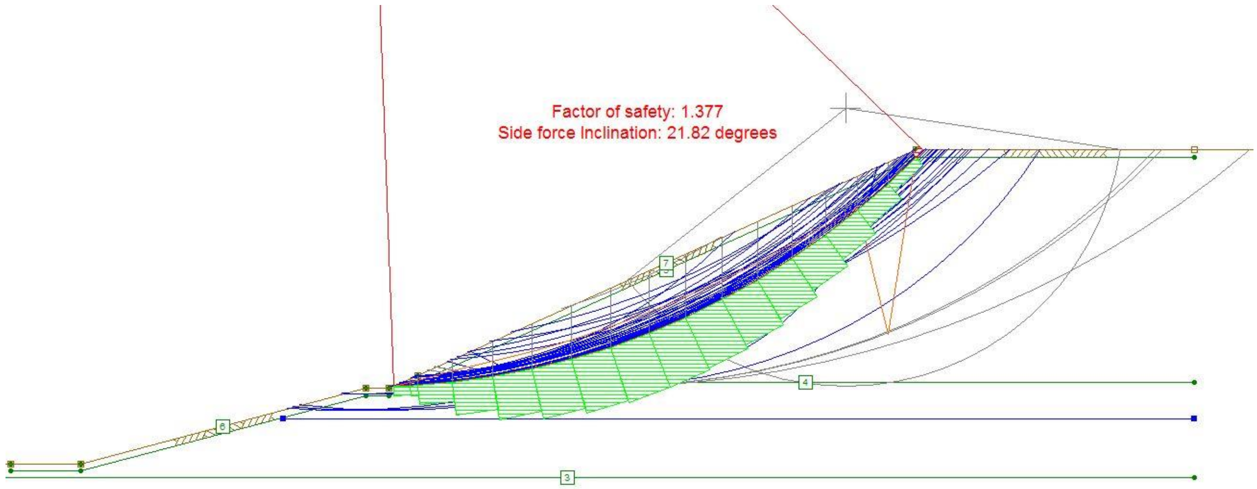


Figure C.3: Station 488+50 with FS of 1.377

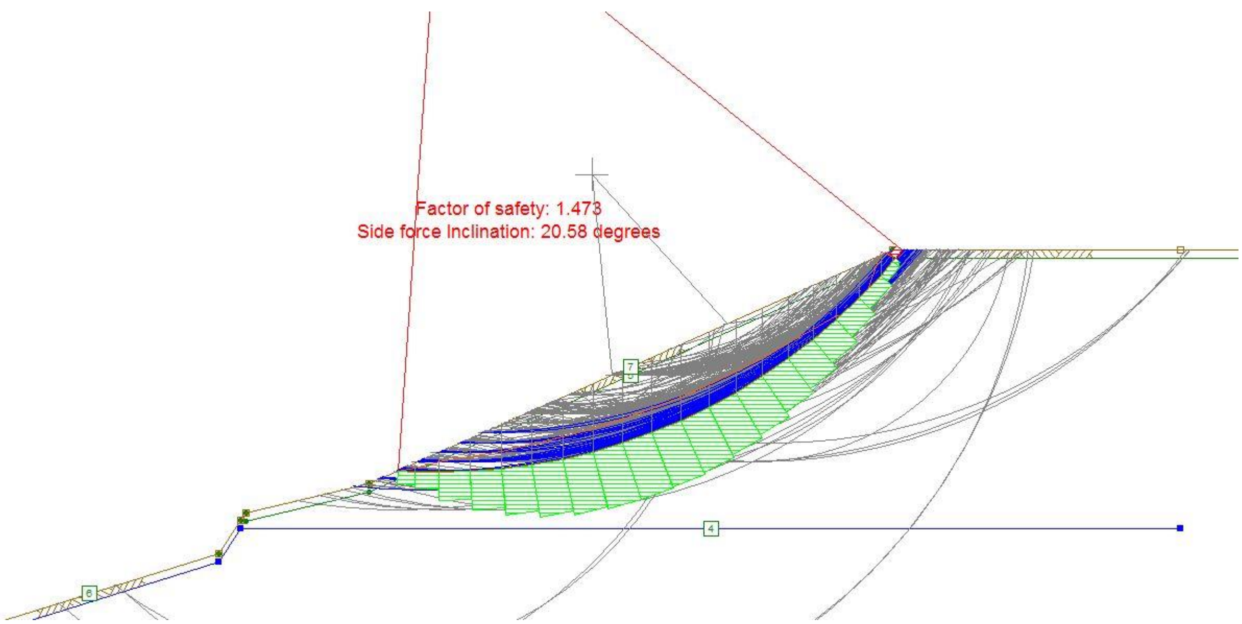


Figure C.4: Station 489+00 with FS of 1.473

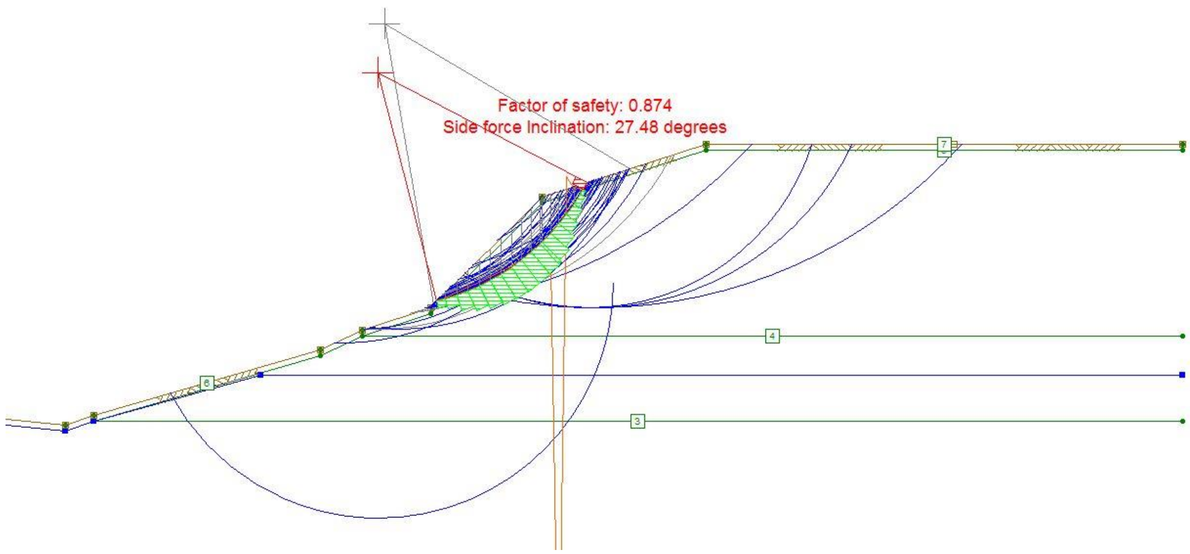


Figure C.5: Station 489+50 with FS of 0.874

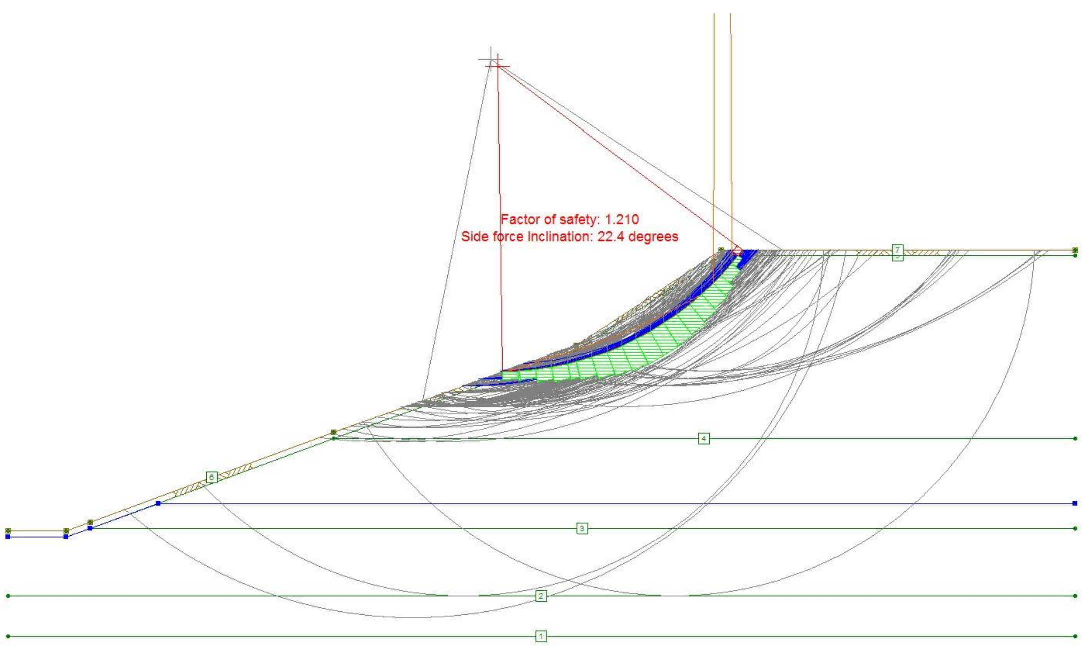


Figure C.6: Station 490+00 with FS of 1.210

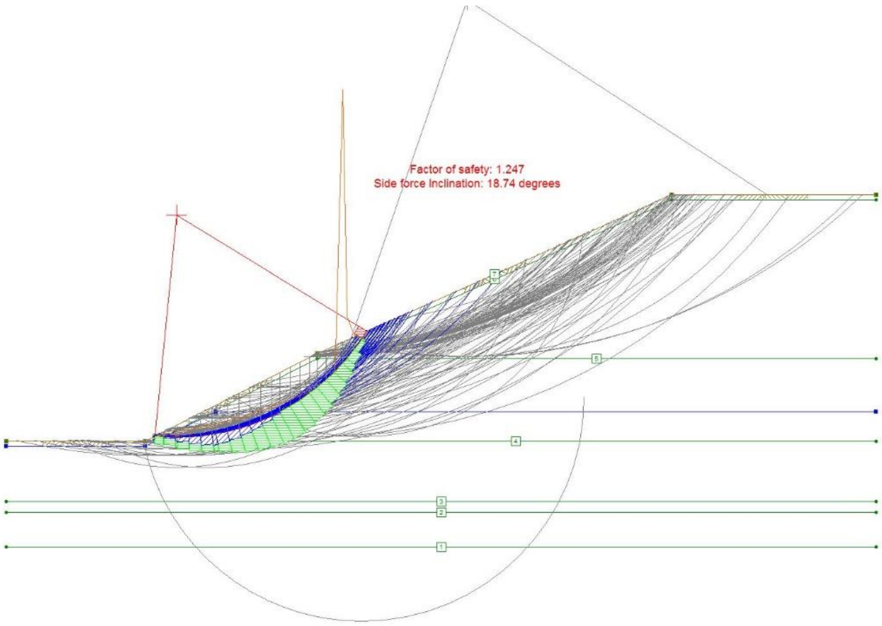


Figure C.7: Station 490+50 with FS of 1.247

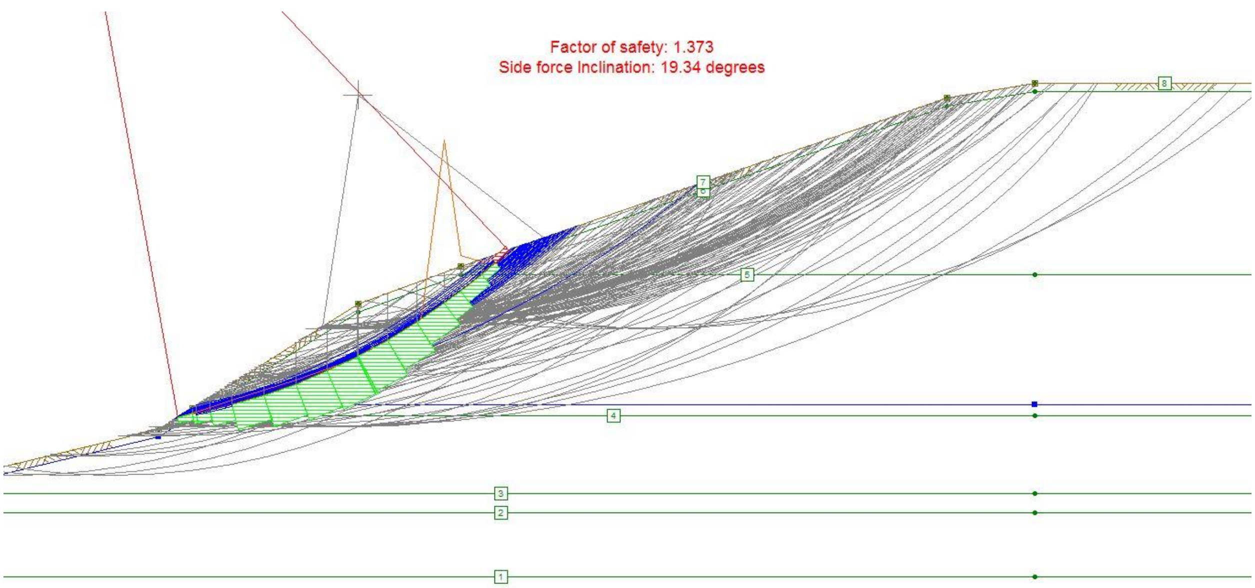


Figure C.8: Station 491+00 with FS of 1.373

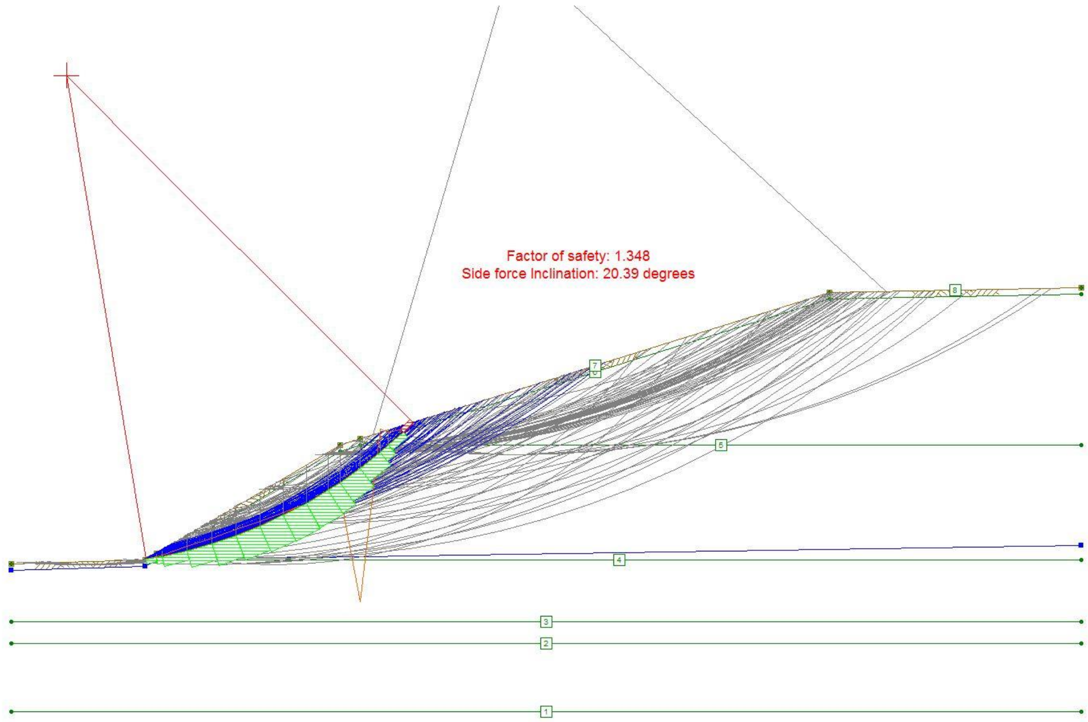


Figure C.7: Station 491+50 with FS of 1.299

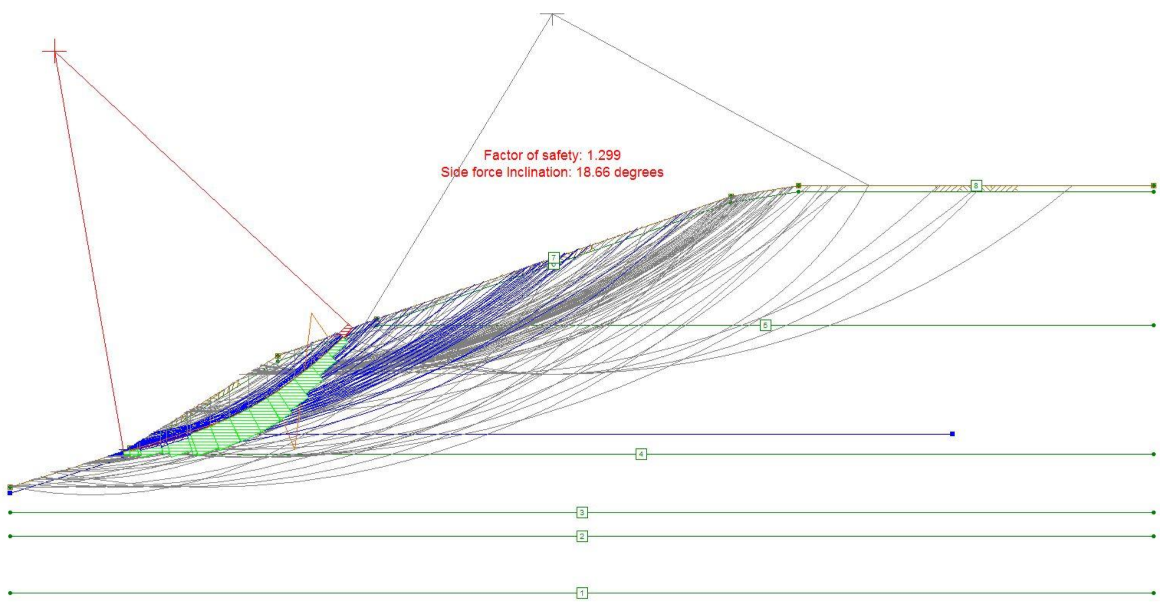


Figure C.8: Station 492+00 with FS of 1.348

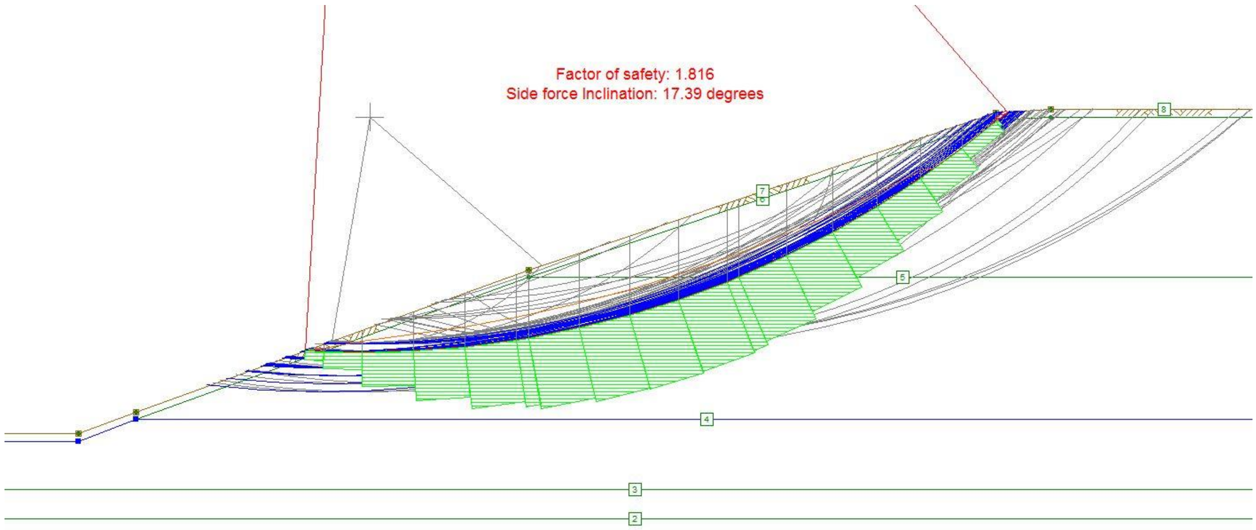


Figure C.9: Station 492+50 with FS of 1.816

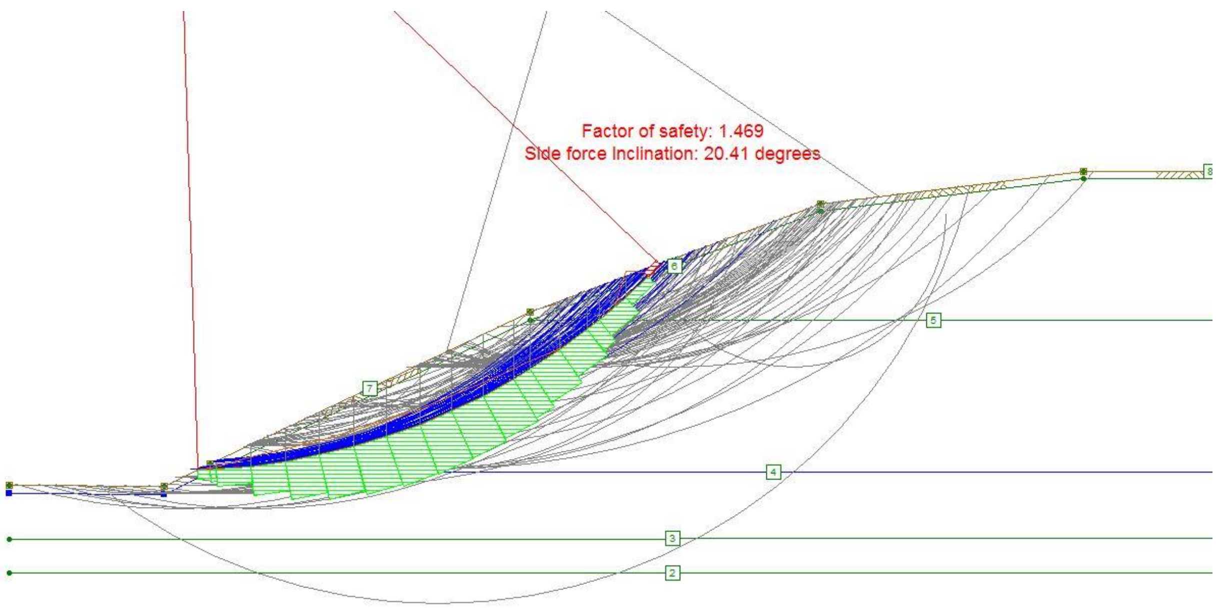


Figure C.10: Station 493+00 with FS of 1.469

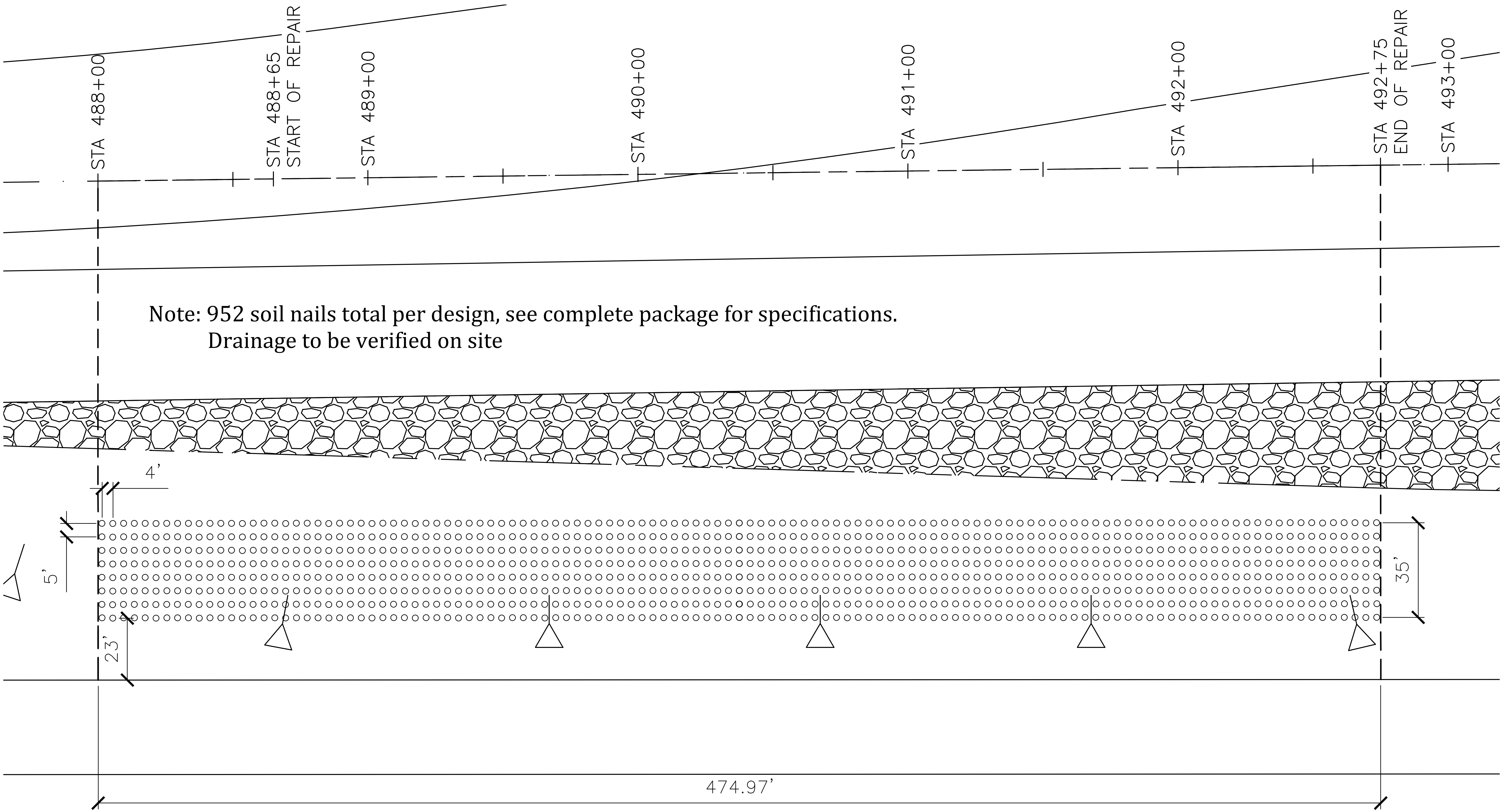
Appendix D

Cost Calculation - (with sources)

6" by 6" by 0.105" Wire mesh (500sq ft)	$1,675.00	(Source: https://www.twpinc.com/6-mesh)
Grade 60 Rebar #8 sold by weight = 2.67 lbs per foot		
2.67*952*20 = 50836.8 = 50837 lbs		
50837 lbs / 2000 lbs = 25.4184 tons		
Cost = $770 per ton		
25.4184 * 770 = $19572.168 =	$20,000.00	(Source: http://wcrebar.com/rebar-prices/)
8" by 8" by 3/4" steel plates w/ 1" hole		
11.25 each * 952 = $10710.00	$10,710.00	(Source: https://www.midweststeelsupply.com/store/a36steelplate)
Shotcrete (can vary)		
Must meet all standards of AASHTO T334		
See attached document for specific selection =>		(Source: http://www.wsdot.wa.gov/research/reports/fullreports/870-1.pdf)
(10" / 12") * 474 ft^2 = 395 ft^3 = 400 ft^3		
395 ft^3 =11.1852 M^3		
Avereage Price per M^3 Shotcrete = $271		(Source: http://oceanconcrete.com/price-list)
Concrete Material Cost = 11.1852*271.00 =	$3,031.19	
Portland Cement Type I-II		
Silica Fume		
Blast-Furnice Slag		
Aggregate / Fines		
Total Facing Material Price =	$35,416.19	

Figure D.1: Cost Calculations for the final product

Appendix E

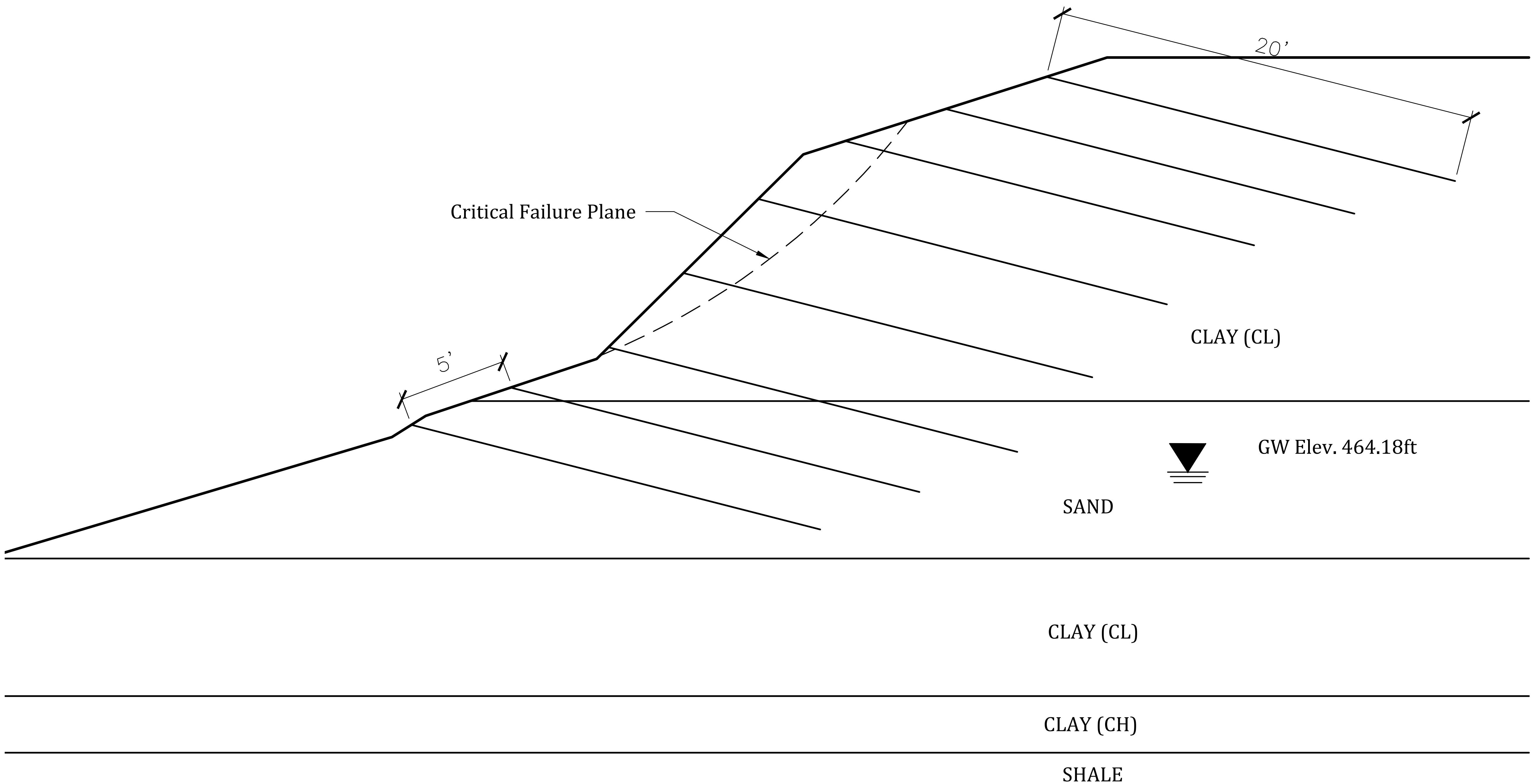


SAMM ENGINEERING

SOIL NAILS LOCATION PLAN

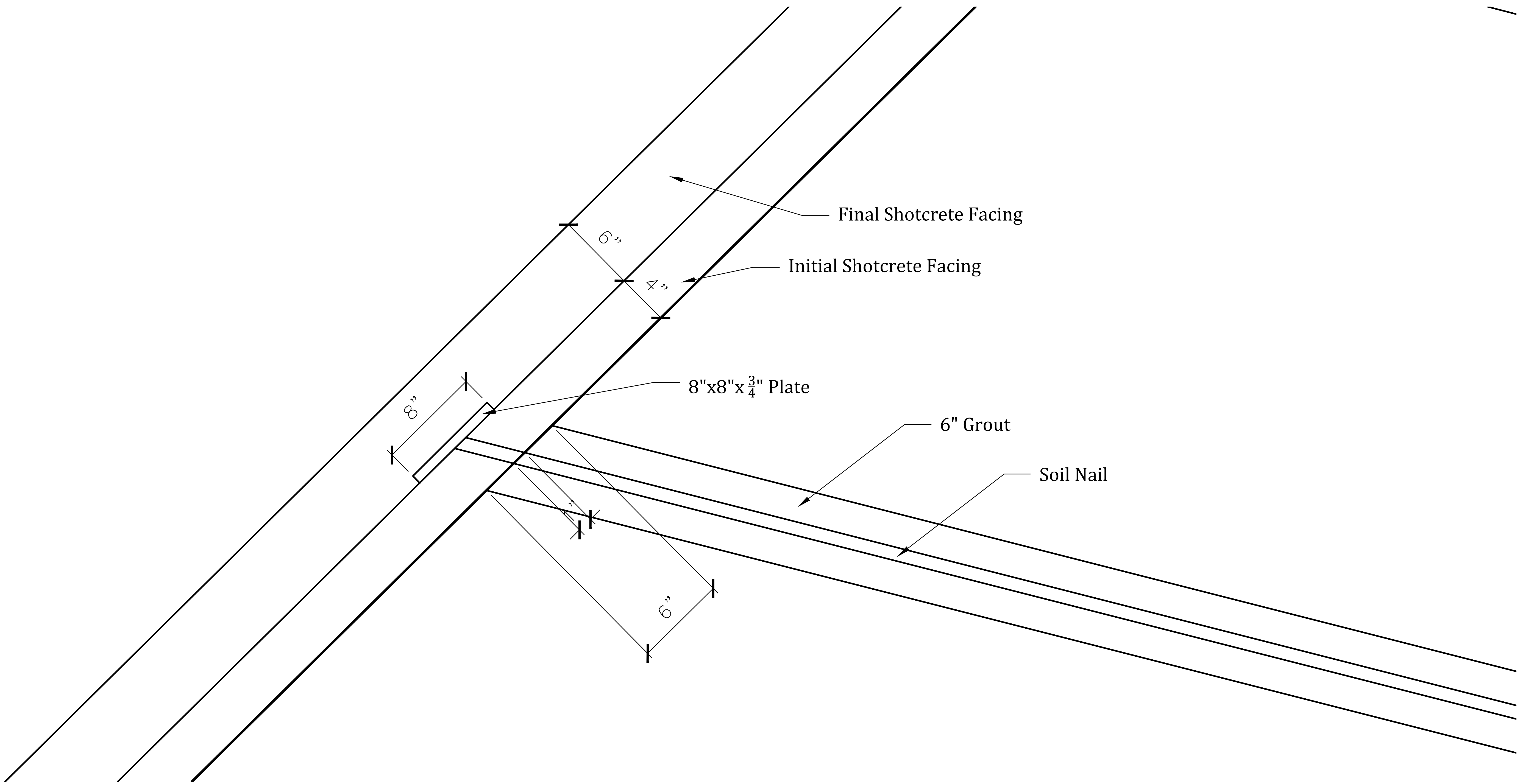
03.24.18

SCALE: 1" = 3'



SAMM ENGINEERING

SOIL NAILS ELEVATION, STATION 489+50
03.24.18
SCALE: 3/16" = 1'



SAMM
ENGINEERING

SLOPE STABILITY DESIGN DETAIL
03.24.18
SCALE: 1 1/2" = 1'