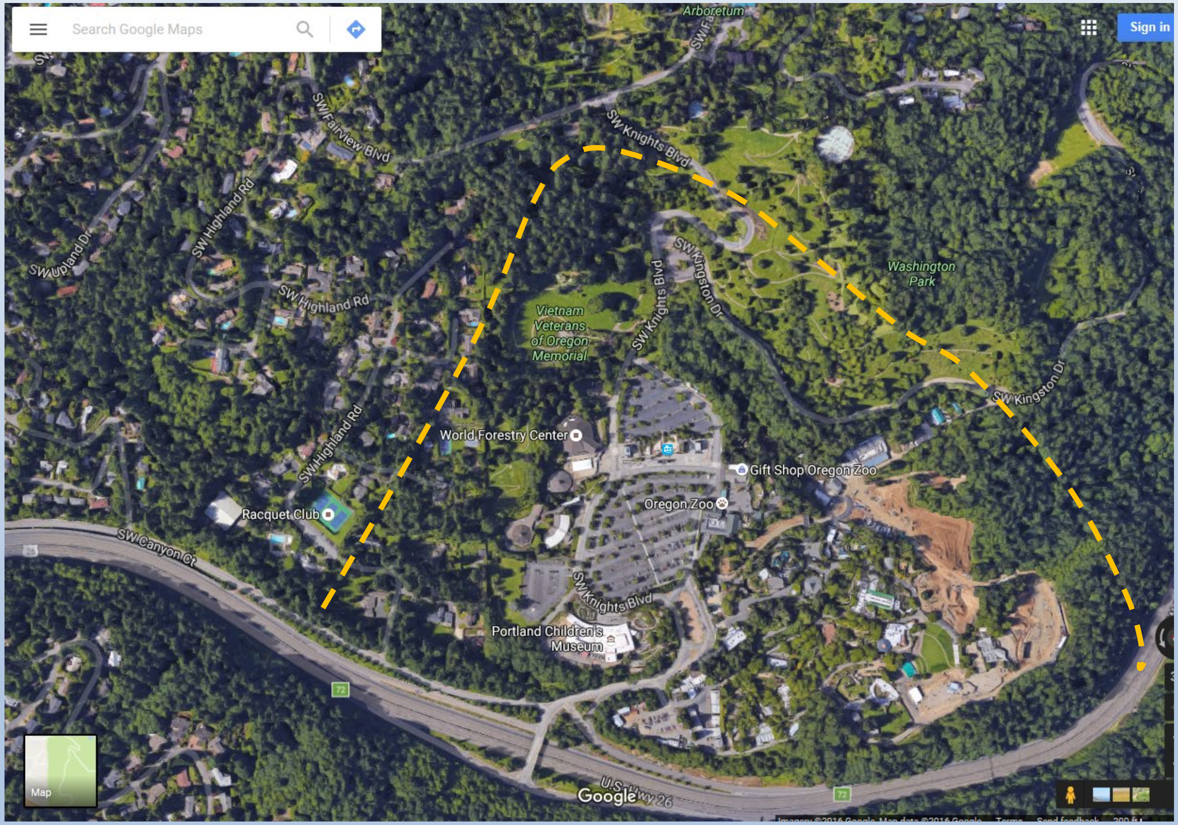
Slope Stabilization Case Studies

Learning Objectives

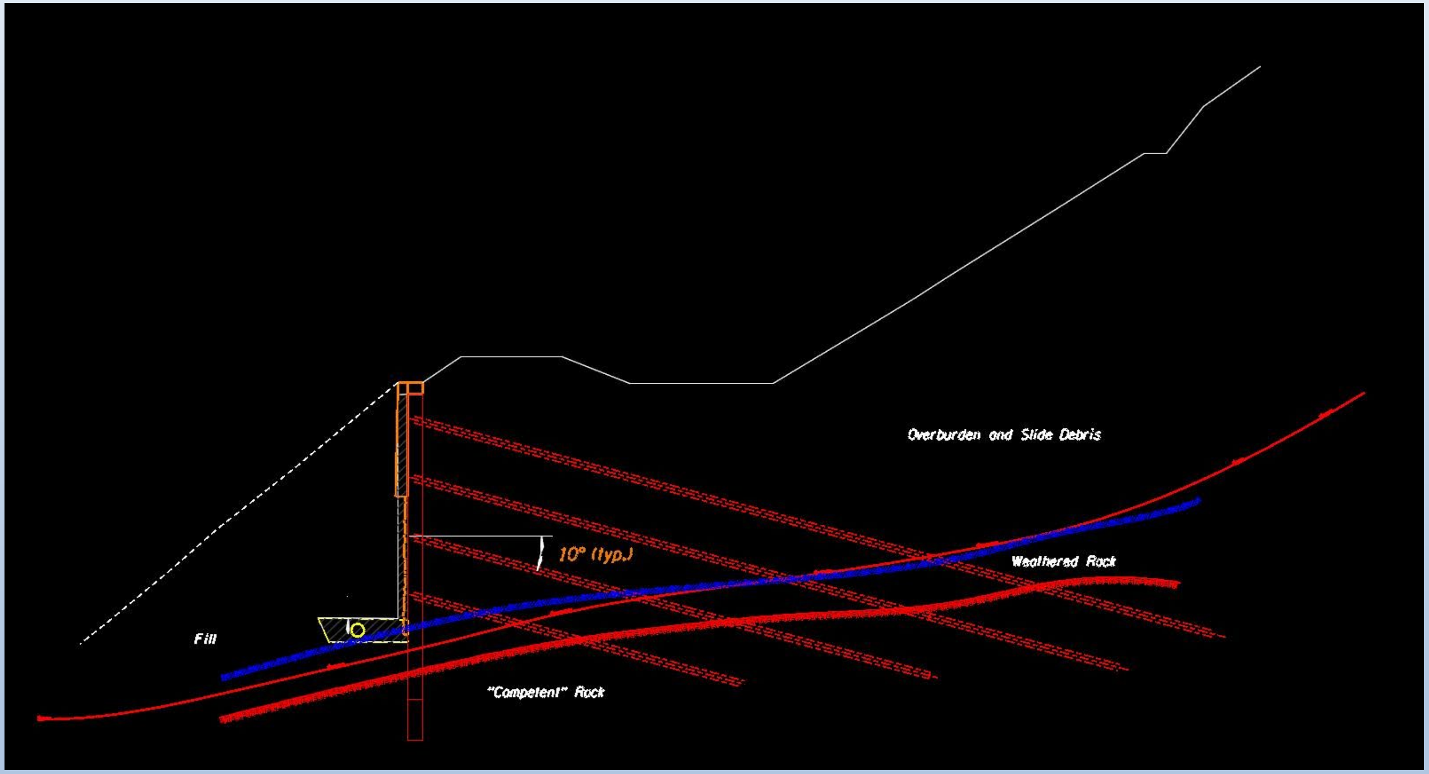
- Introduce several instructive case studies that illustrate the concepts of landslide repair.

Zoo-Highlands Slide

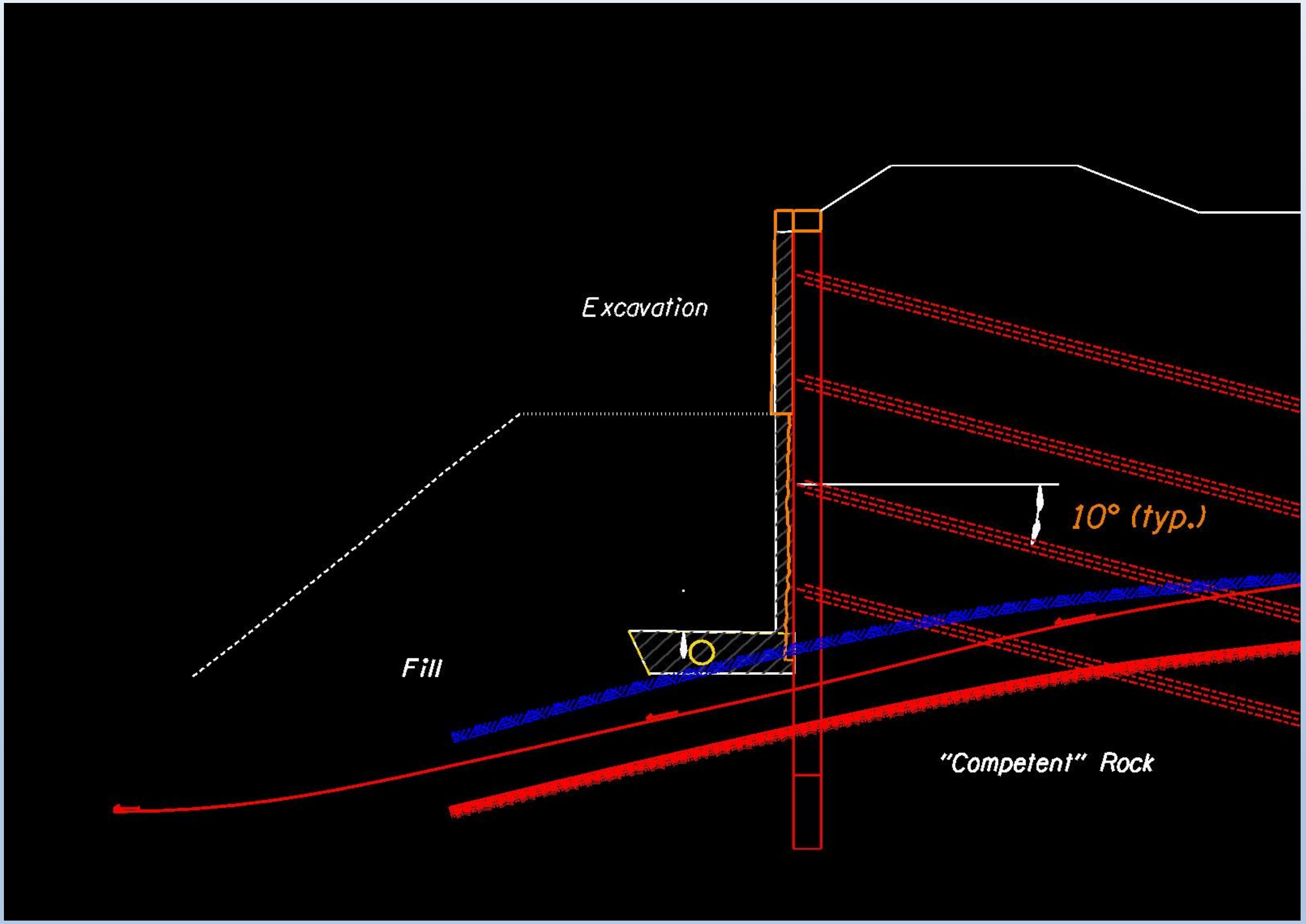


Exploration Program

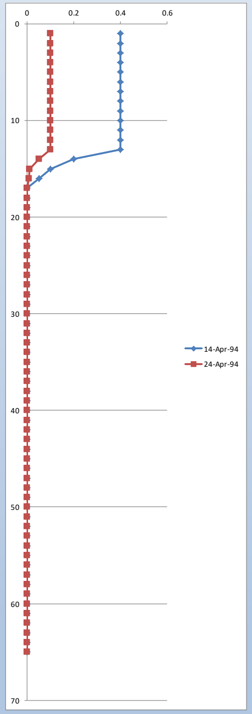
Tieback Wall (General Plan)



Over-Excavation/Out-of-Sequence



Cautionary Results of Over-Excavation



Soldier Pile Drilling & Installation

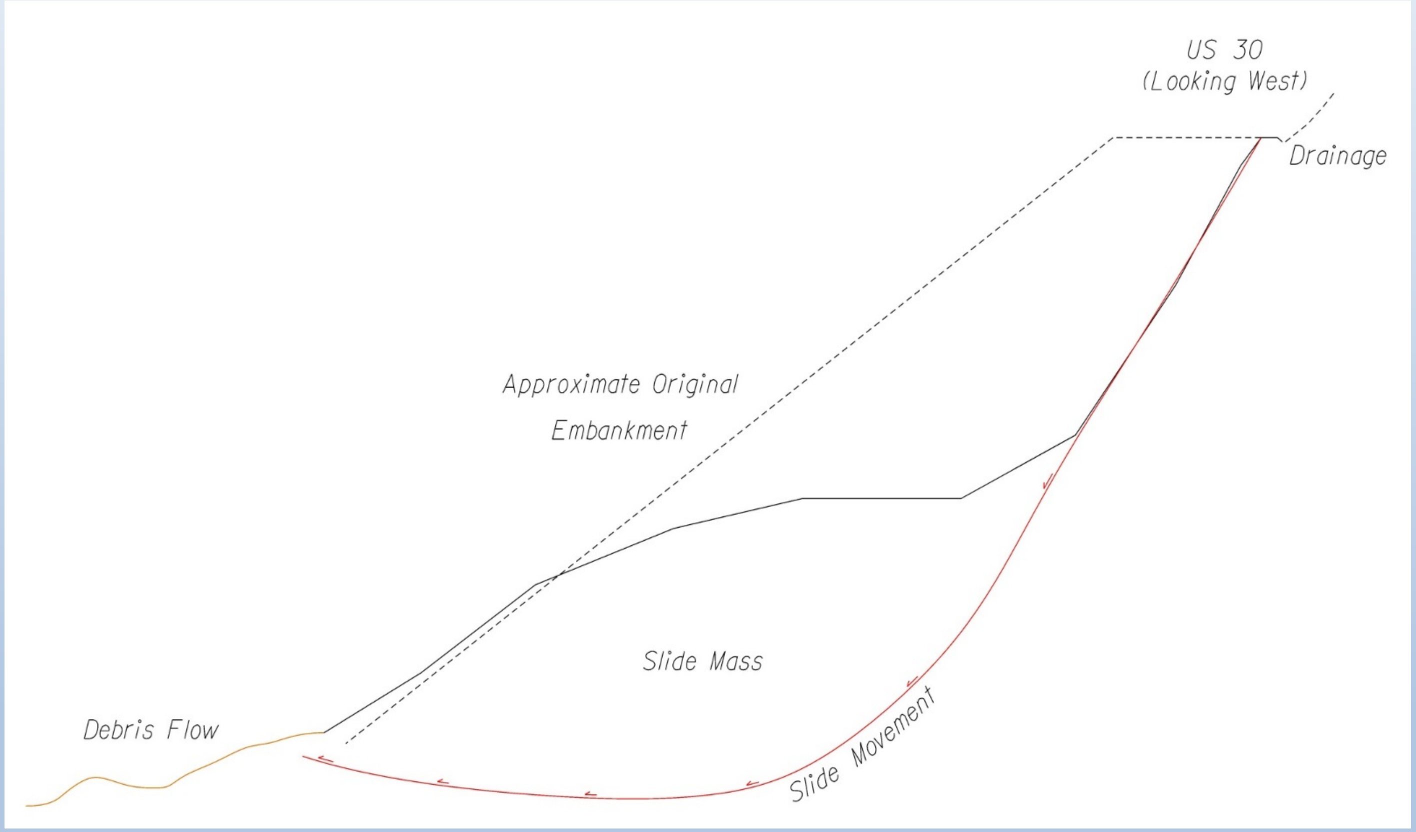
Tieback Drilling

Tieback Installation

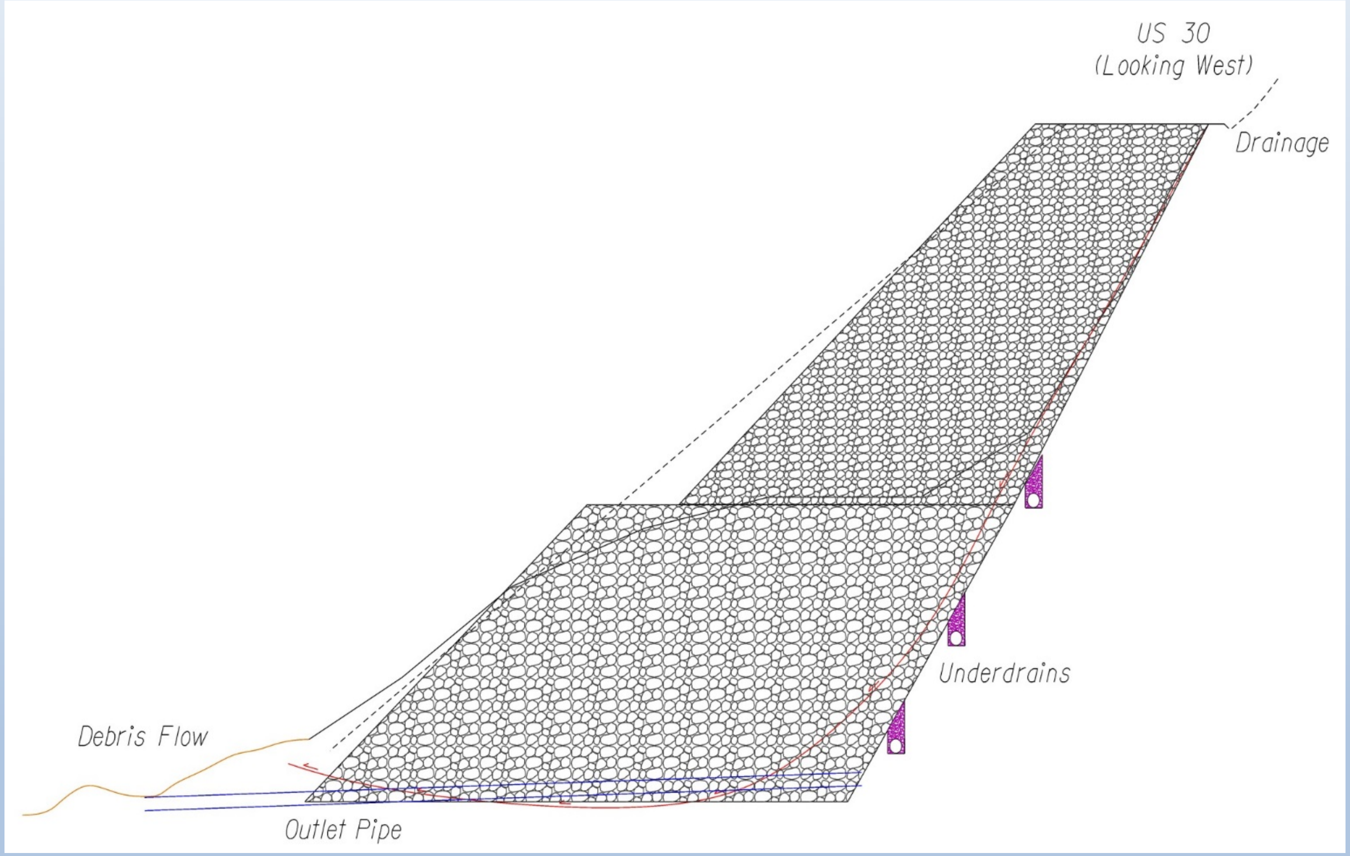
Near-Completion

US 30 @ Clatskanie

Initial Failure



Repair Schematic



Buttress/Shear Key Excavation

Underdrains

Finished Embankment

SLOPE STABILIZATION CASE STUDIES IN A FOREST ENVIRONMENT

WFCA April 11-12, 2019 RAR

“Typical Landslide, Cut/Fill Slope Problems Encountered on Low Volume Roads in Steep Mountainous Terrain and Their Solutions”

Courtesy of: Ed Rose (Retired)
R1 Geotechnical Engineer

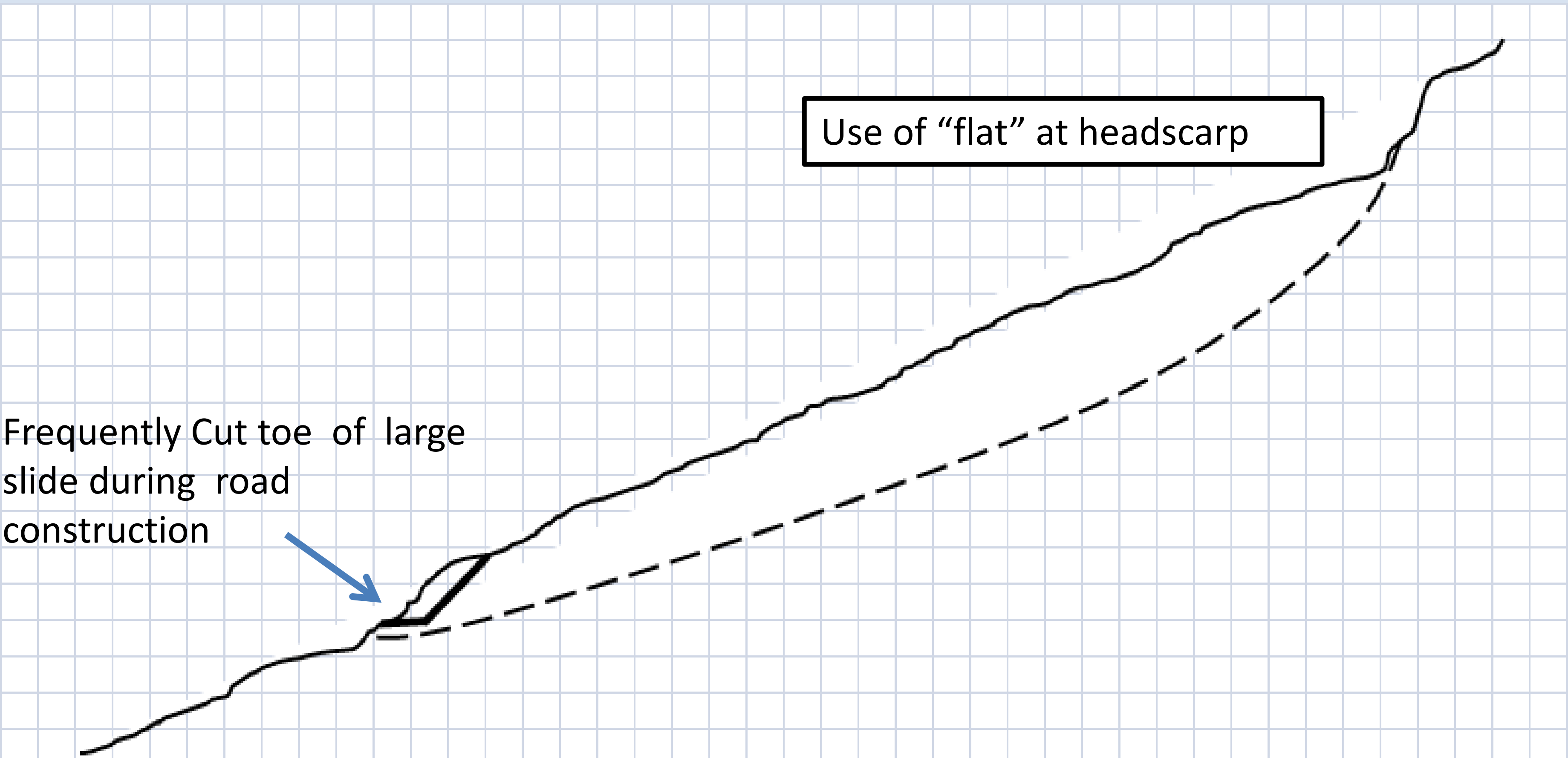
General Categories of Problems Created by Road Building

- Large ancient landslides disturbed by cutting or filling
- Smaller deposits of colluvium, residual soil, fault zones or glacial deposits disturbed
  - Cutting creating unstable cutslopes
  - Filling creating unstable fill/ground
  - Altering natural hydrology/groundwater (increased groundwater under fill)
- Side-cast fill with organics remaining

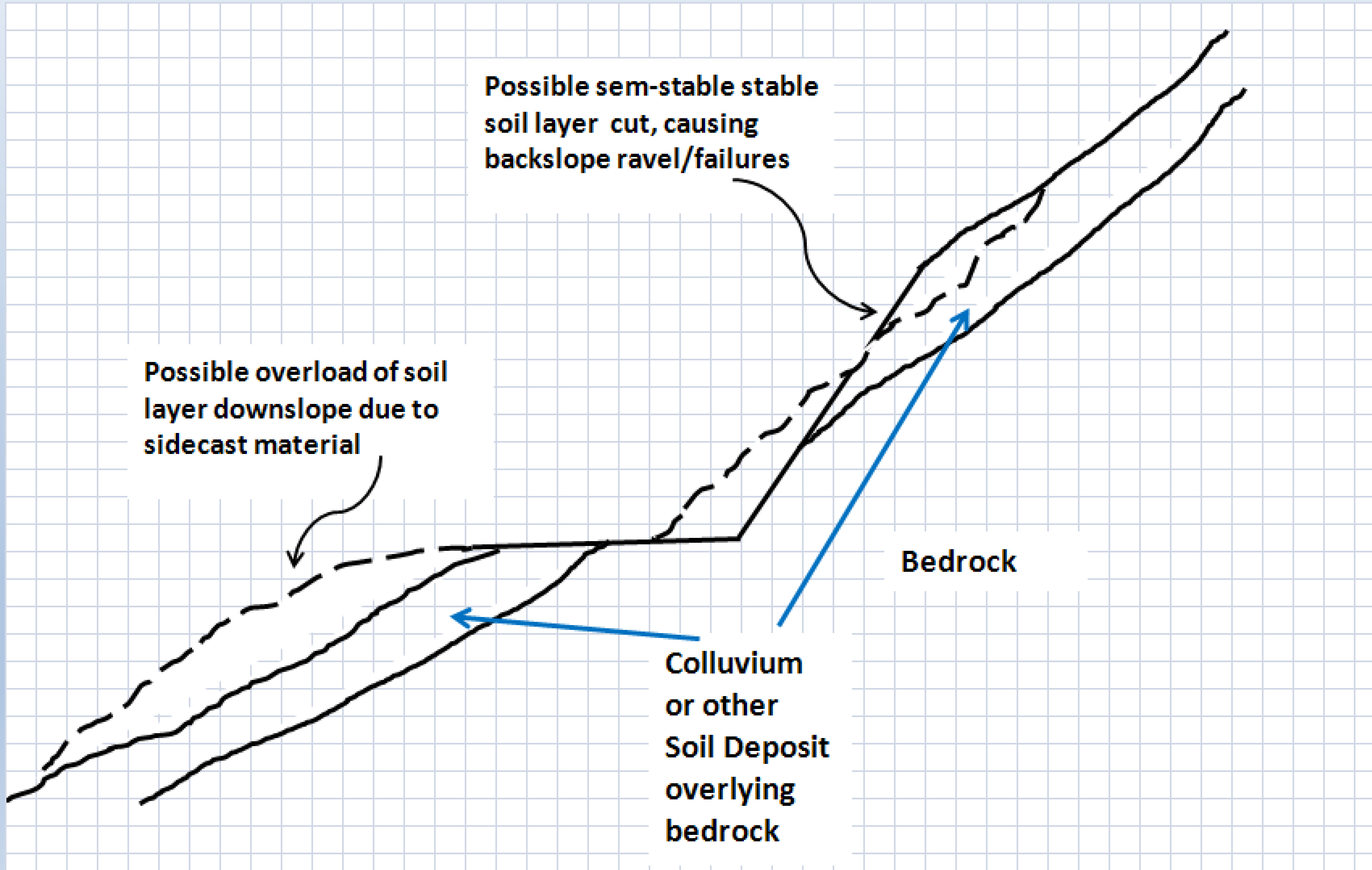
Legacy Forest Service Road -1964

Typical Side –Cast Construction

Ancient Landslide Terrain



Frequent Full-Bench Road Construction Impacts



Implement Cost Effective Solution 3-Step process

- Investigate and define problem-
  - Establish boundary conditions
  - Establish materials parameters
  - Establish water table
- Geotechnical Engineering Analysis-
  - Analyze existing condition
  - Analyze possible solutions
  - Select most cost effective solution
- Prepare Design, Plans and Specifications

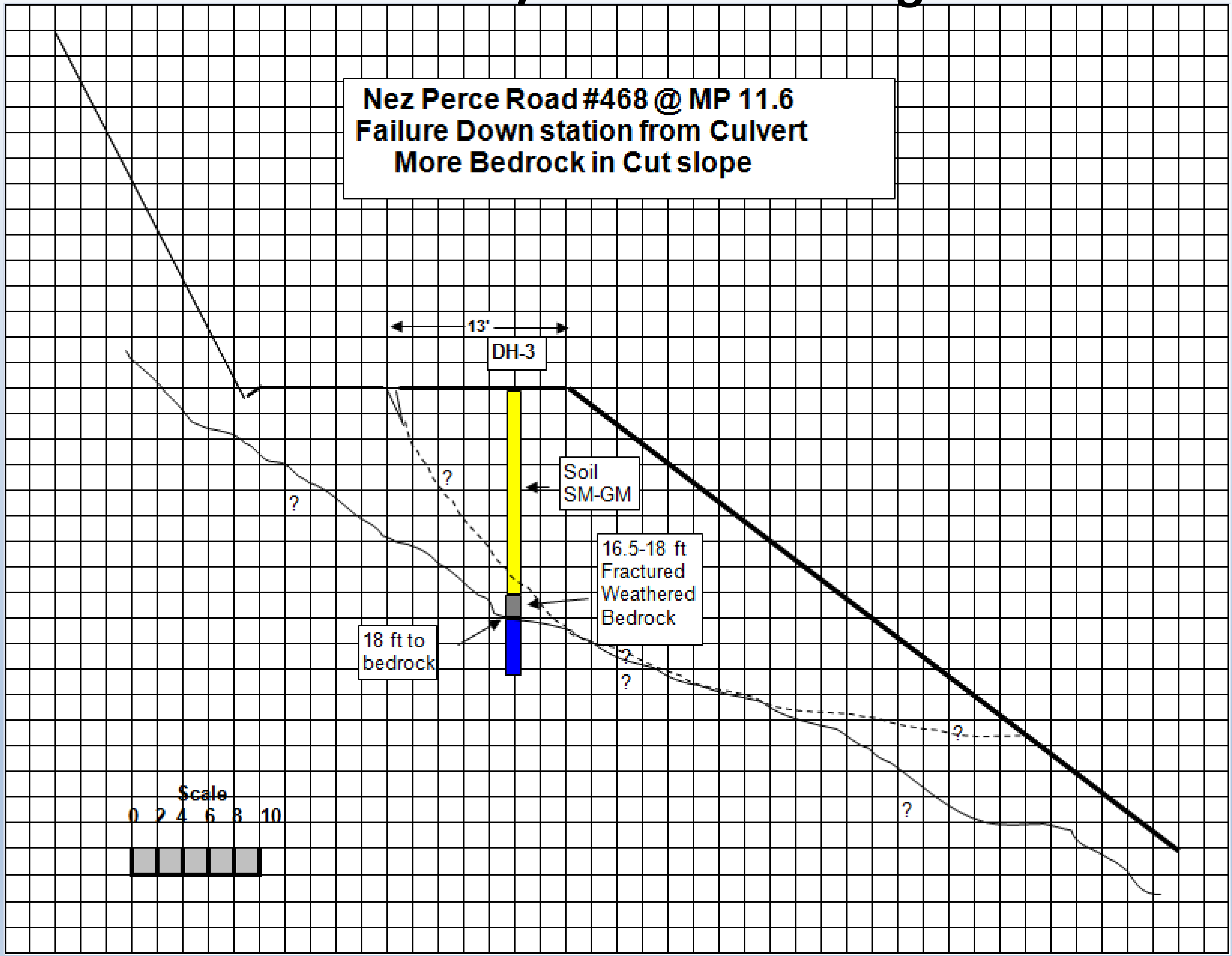
Investigate and Define Problem

- Define boundary conditions and materials parameters
  - Reconnaissance- establish landform, strata and deposits, and identify any discontinuities (Geologist)
  - Investigation (Geologist and Engineer)
    - Surficial –Shallow hand excavations
    - At Depth – Backhoe or Drill
    - Testing Field
      - Portable Triggs SPT, seismograph survey, vane shear, tube densities.
      - Slope Inclinometer
      - SPT, splitspoon samples, shelby tube samples
    - Laboratory tests
      - Classification, moisture, density
      - Shear strength- direct shear/ triaxial shear
      - Permeability
  - Establish X-Section for Analysis

Establish Critical X-Section For Analysis

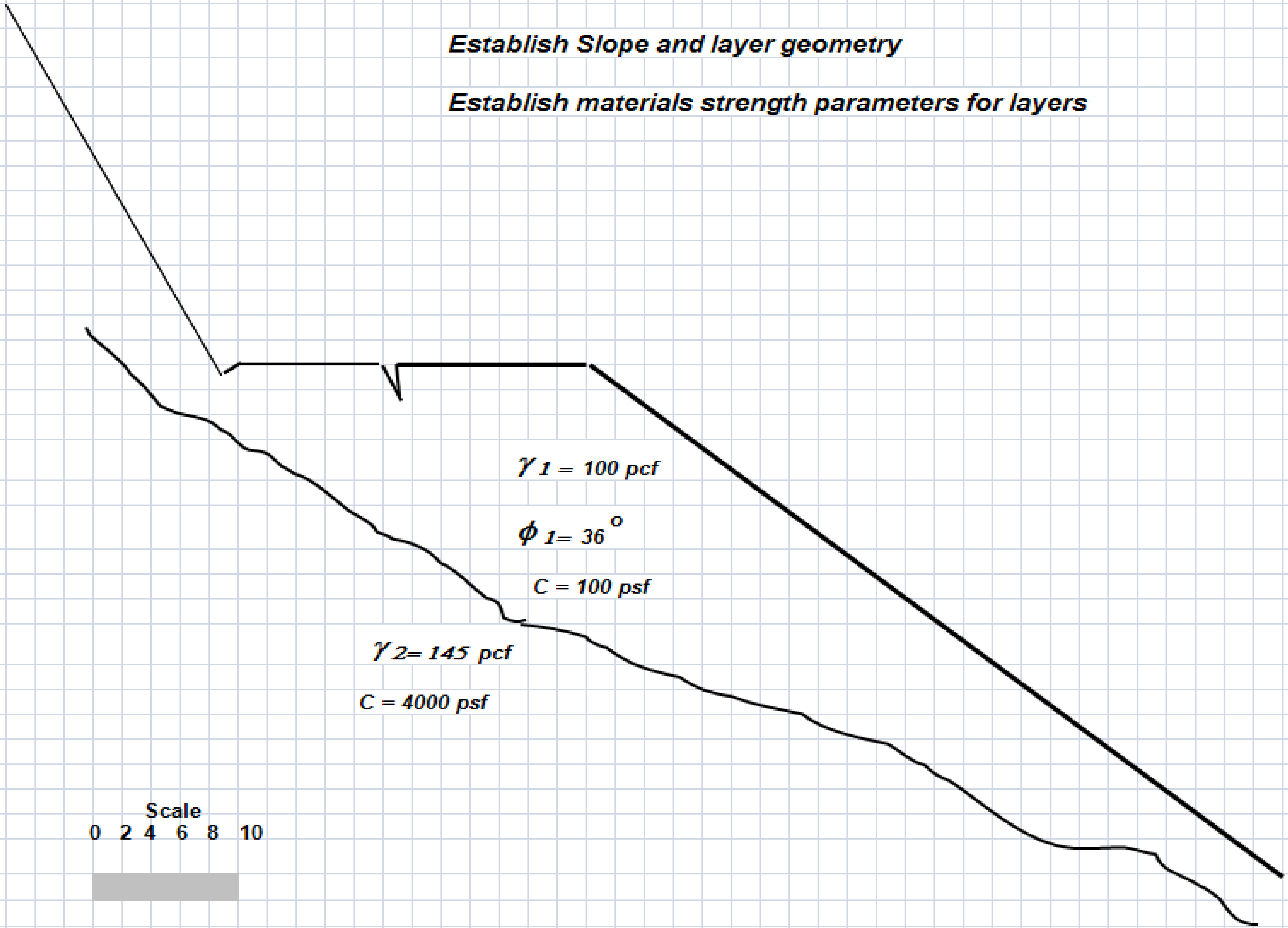
- Geometry and Layering
  - depth/thickness of various strata or deposits
- Materials parameters of each layer
  - Unit weight – γ_{moist} pcf
  - Friction Angle- ϕ degrees
  - Cohesion- c psf
- Define Water table if present
  - Unit weight s– $\gamma_{sat.}$ and γ_{water}

From Drill Hole and/or other Investigations

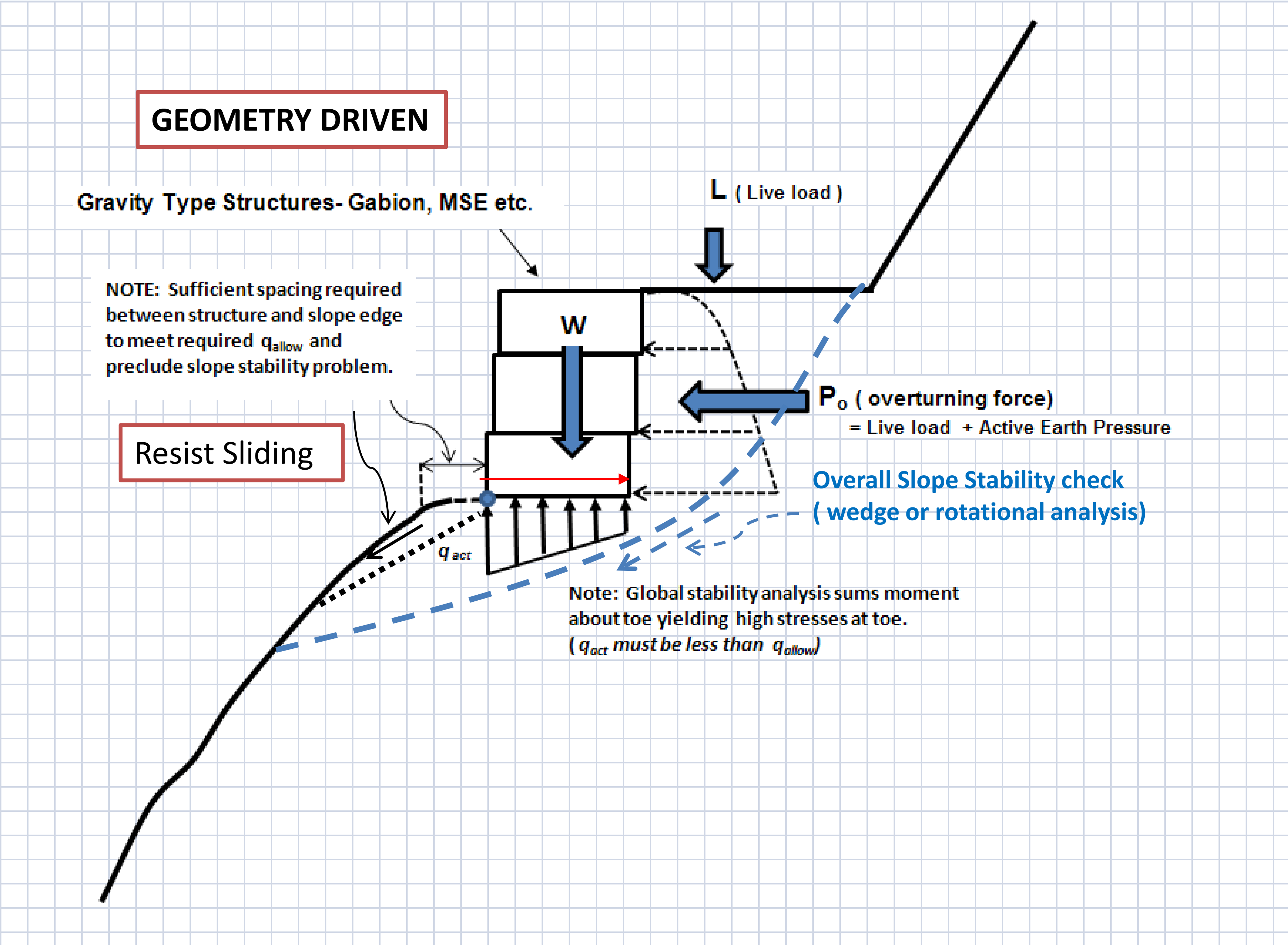


Establish Slope and layer geometry

Establish materials strength parameters for layers



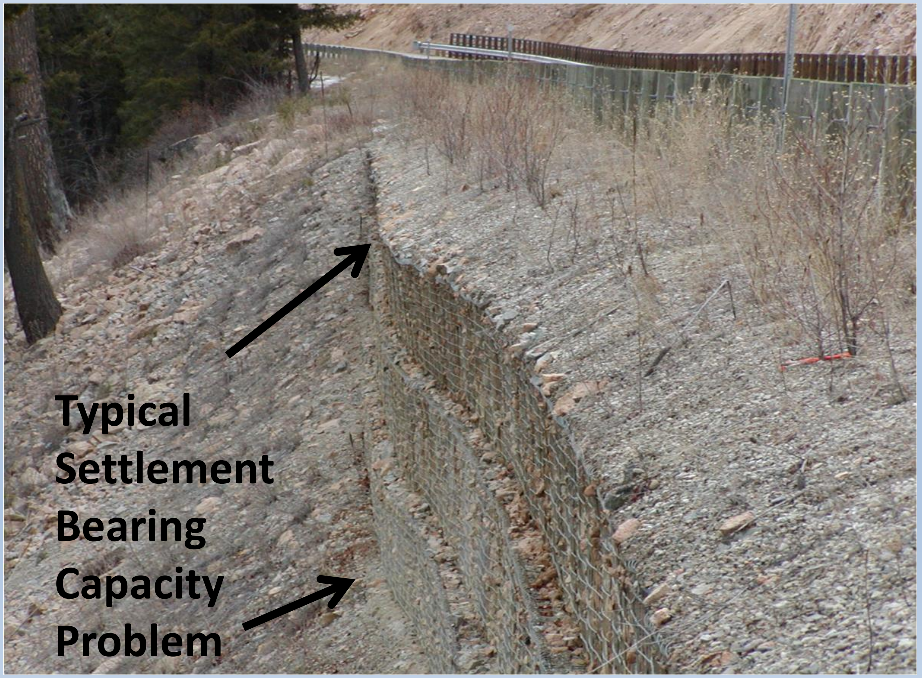
RETAINING WALLS


GEOMETRY DRIVEN
Gravity Type Structures- Gabion, MSE etc.
L (Live load)
NOTE: Sufficient spacing required between structure and slope edge to meet required q_{allow} and preclude slope stability problem.
W
P_o (overturning force)
= Live load + Active Earth Pressure
Resist Sliding
Overall Slope Stability check
(wedge or rotational analysis)
q_{act}
Note: Global stability analysis sums moment about toe yielding high stresses at toe.
(q_{act} must be less than q_{allow})

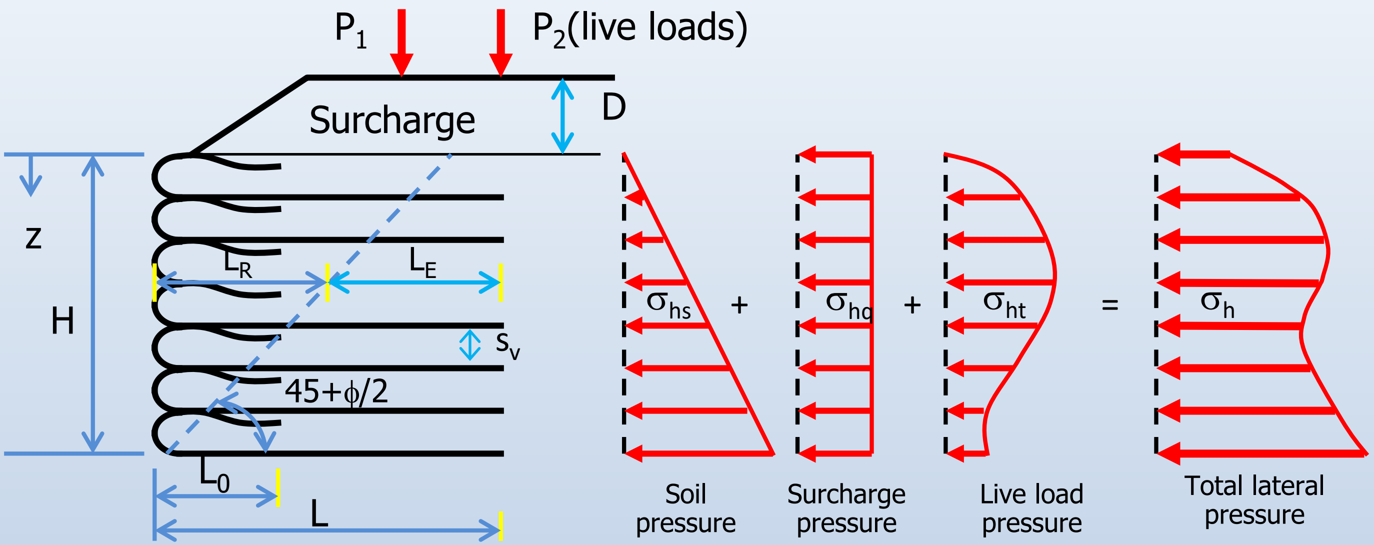
Gravity Type Walls

Rock Gabions

Gabion wall at reclaimed mine site on Klamath N.F. Region 5



Elements of Basic Mechanically Stabilized Earth Wall Design



Hilfiker Welded Wire Wall-Mendocino N.F. Region 5

Angeles N.F. Region 5 Geogrid Reinforced Modular Block Wall

MSE Walls-Layered Construction

Timber Faced Geogrid Reinforced Wall, Happy Camp R.D. Klamath N.F.

Timber Faced Geogrid Reinforced MSE Wall

MSE Wall Just after Completion

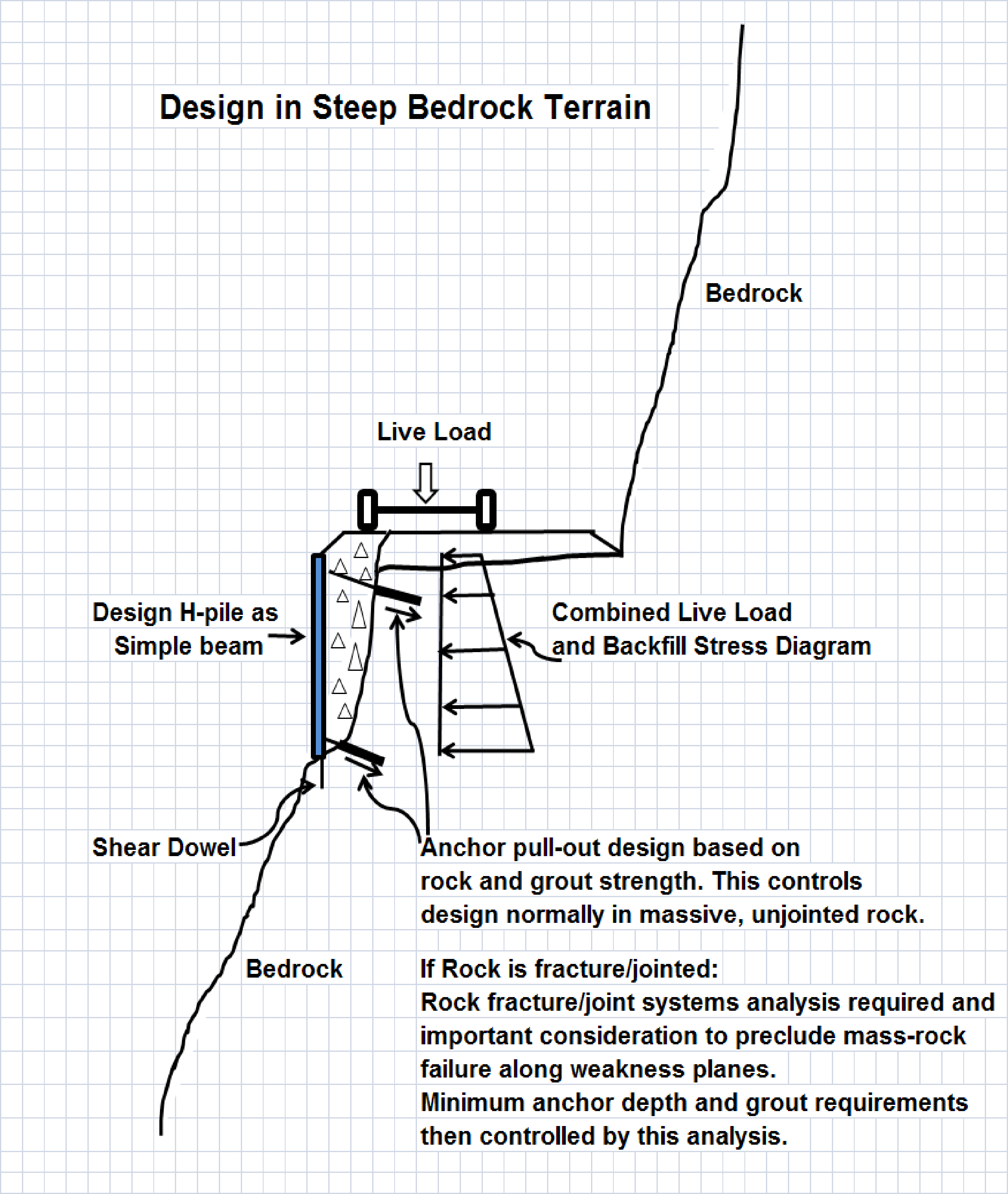
MSE Wall 3 Years after Construction. Happy Camp R.D. averages between 60 and 80 inches of precipitation per year

Pile/Lagging Tie-back Component Design Ideal in Steep Bedrock Terrain

- Allows one to fit component design to terrain rather than try to modify terrain to fit structure.
- Quit often try to fit MSE wall or other gravity type structure in to bedrock
  - Needless rock excavation because of base width requirement
  - Environmental impact!

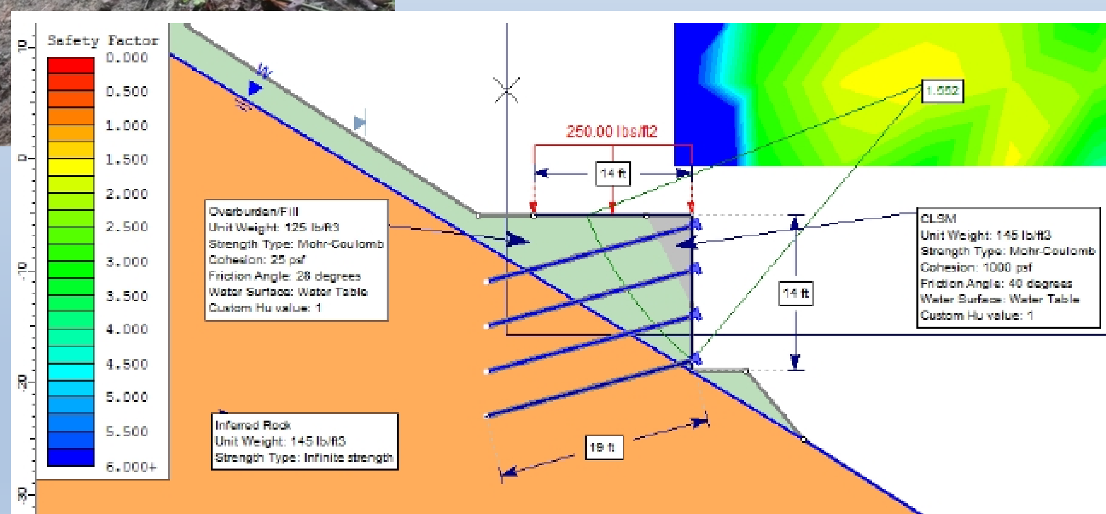
Tie-Back, H-Pile Retaining Wall

Basic Design Procedure

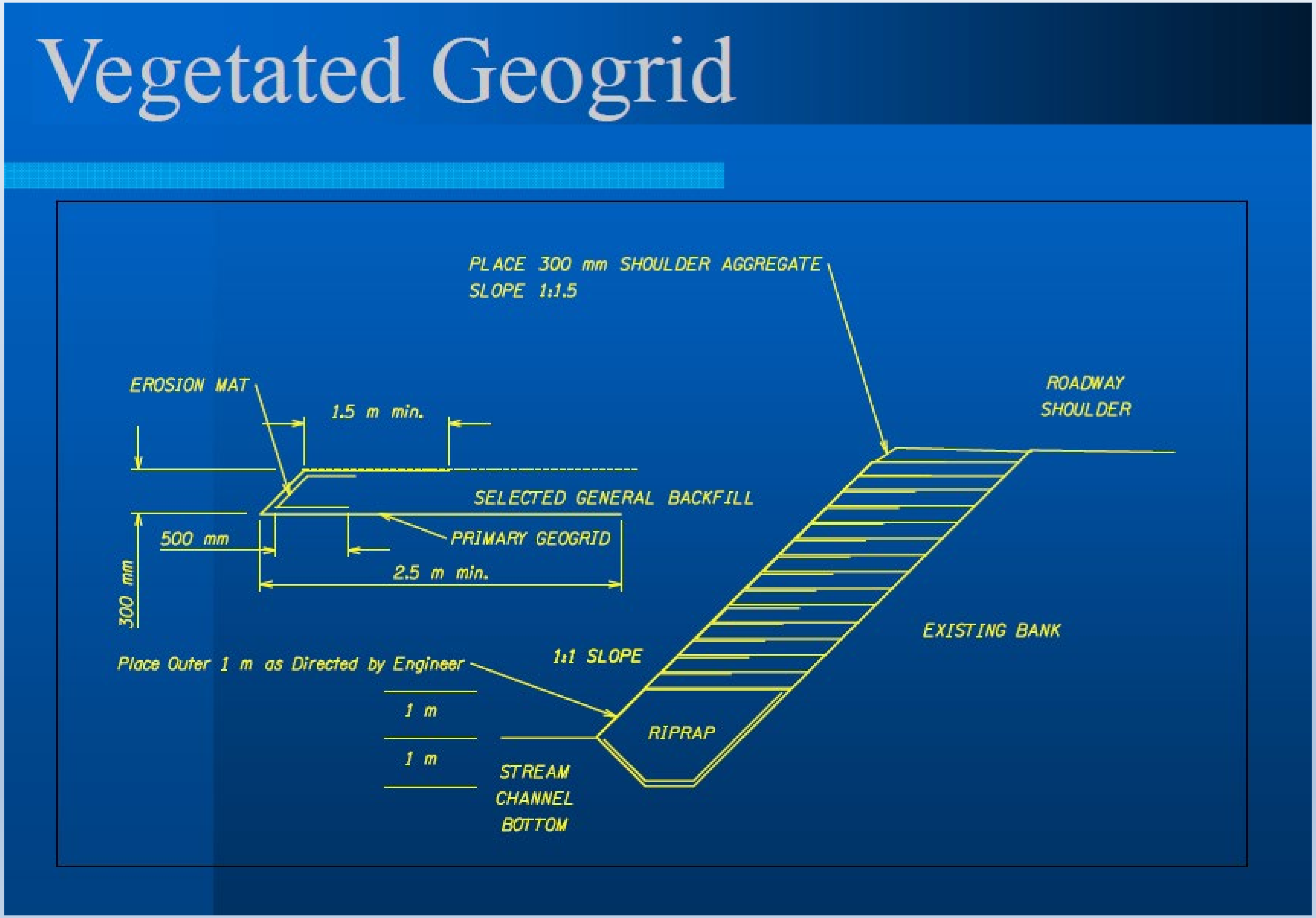



"Component" Tie-back H-pile wall
– allows for fitting Structure to
the Terrain.
Insignificant excavation and
environmental damage!

Soil Nail Anchored Wall
(Built from remaining roadway - GSI)



STABILIZATION W/GEOSYNTHETICS



Variety of Geogrid products used in MSE (Mechanically Stabilized Earth) Walls and RSS (Reinforced Soil Slopes) A.KA. Reinforced Fills.

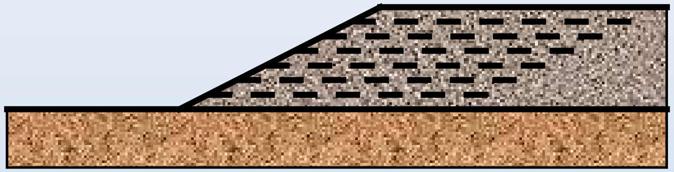
Tensar BX 1100 + Typical used in MSE Wall Construction

Typical Over Steepened Fill Failures - Klamath N.F. Region 5

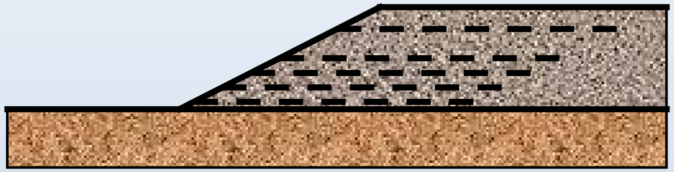
Ukonom Ranger District

Oak Knoll Ranger District

Placement Patterns Reinforced Fill Designs



(a) Even spaced-even length



(b) Uneven spaced-even length

Primary Geogrid Reinforced Fill Layer

Secondary Geogrid Reinforced Fill Layer.
Essential compaction of Soil for Strength

45 ft High Reinforced Fill Ukonom R.D. Klamath N.F. Region 5

Completed reinforced fill before erosion control mat placed on slope

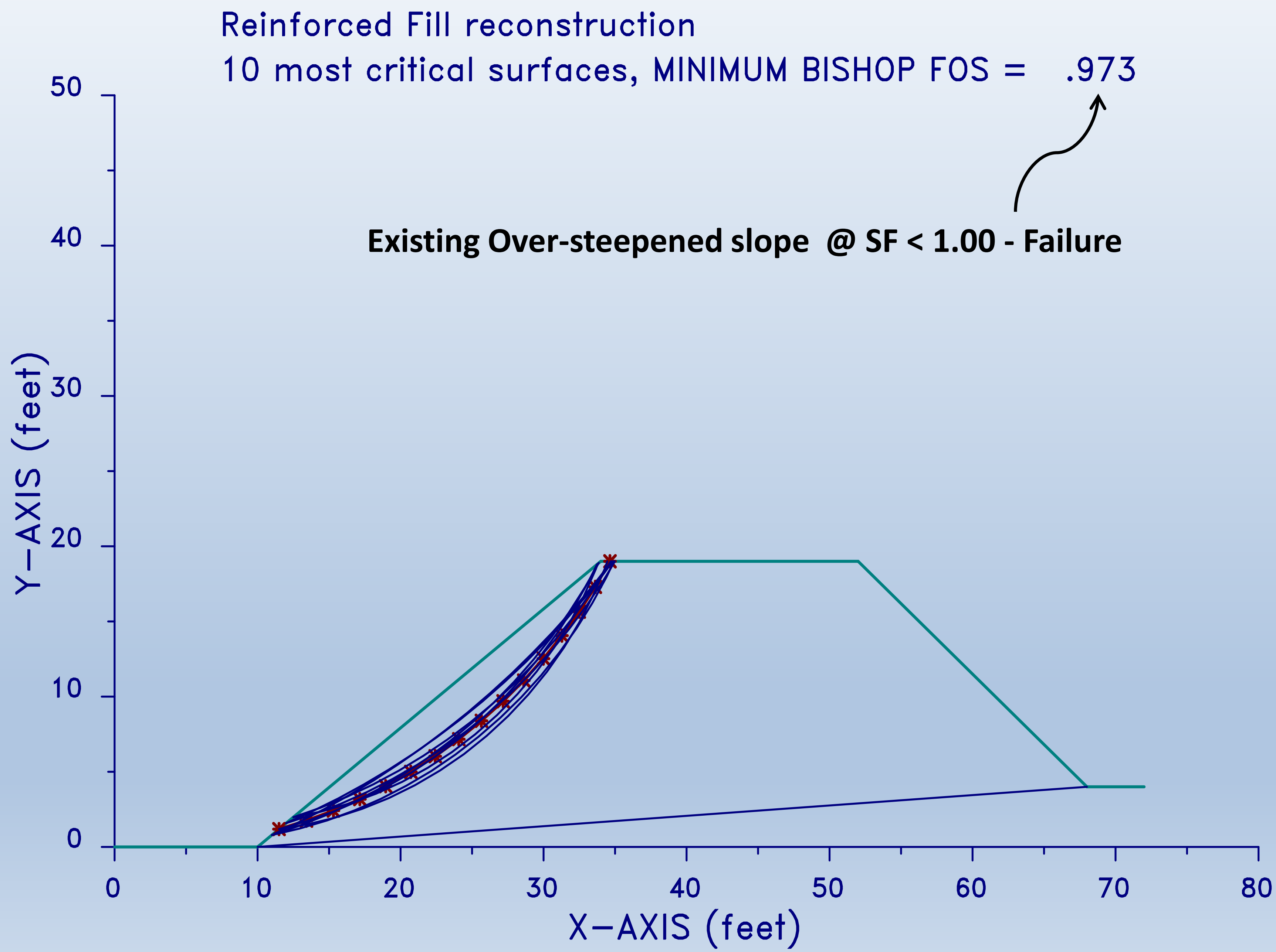
Reinforced fill 2 years after completion.

20 Ft. High Reinforced Fill, Oak Knoll Ranger District, Klamath N.F.

Reinforced Fill Just Completed and Before Erosion Control Mat Placed on Slope.

Reinforced Fill 3 years after Construction

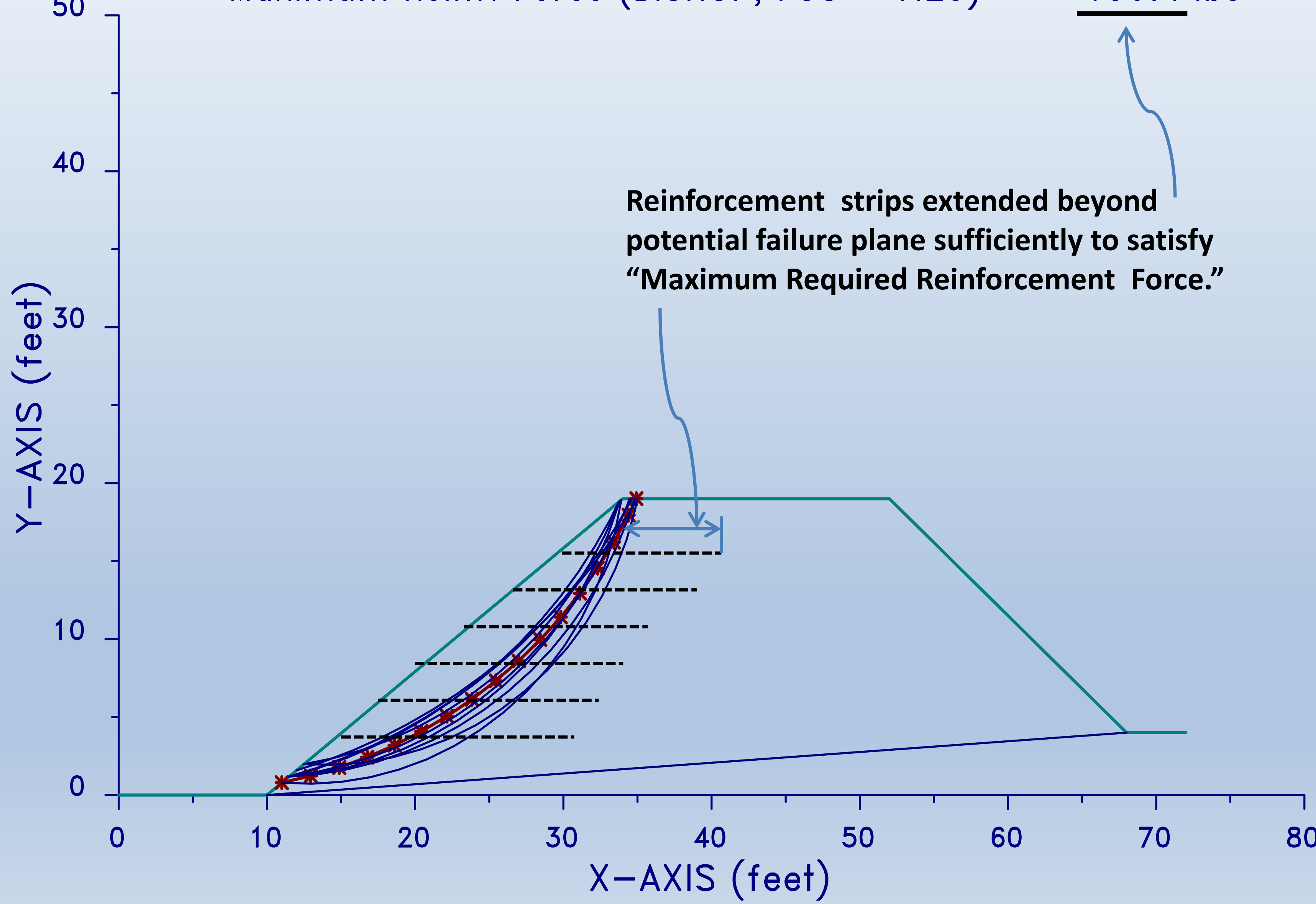
RYECRK1R 3-24-10 16:40

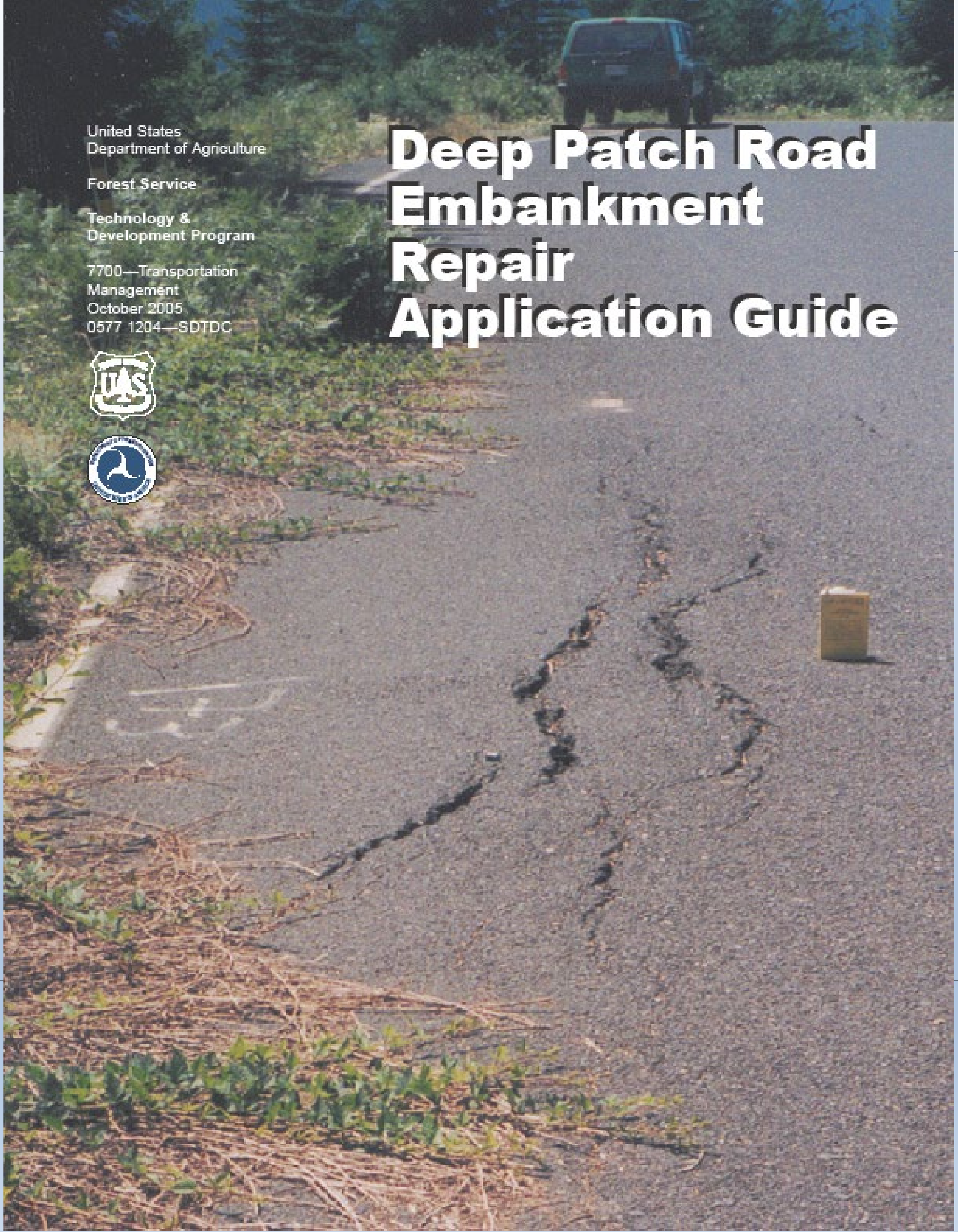


RYECRK1X 3-24-10 16:41

Reinforced Fill reconstruction

Maximum Reinf. Force (BISHOP, FOS = 1.25) = 1307. lbs



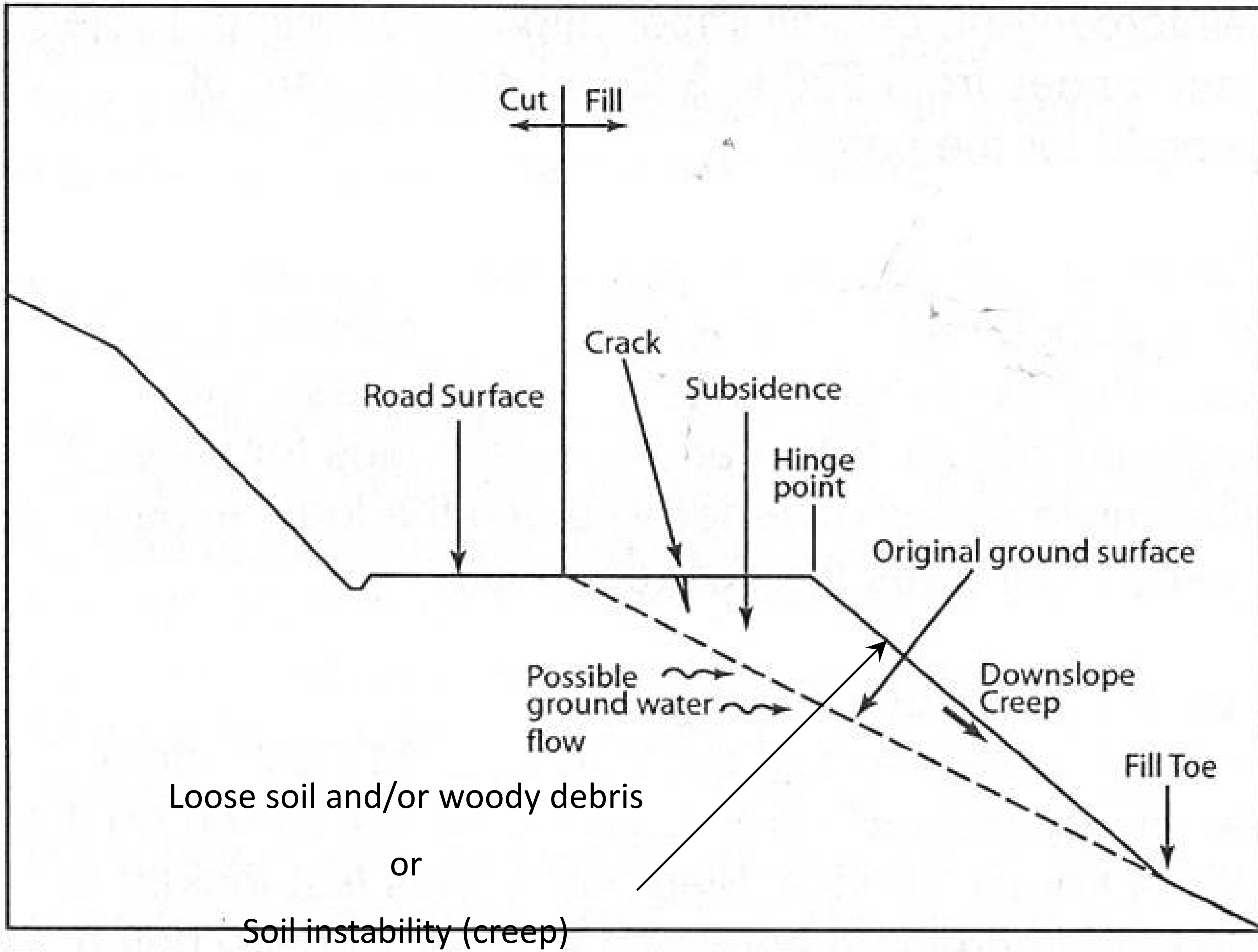

United States
Department of Agriculture

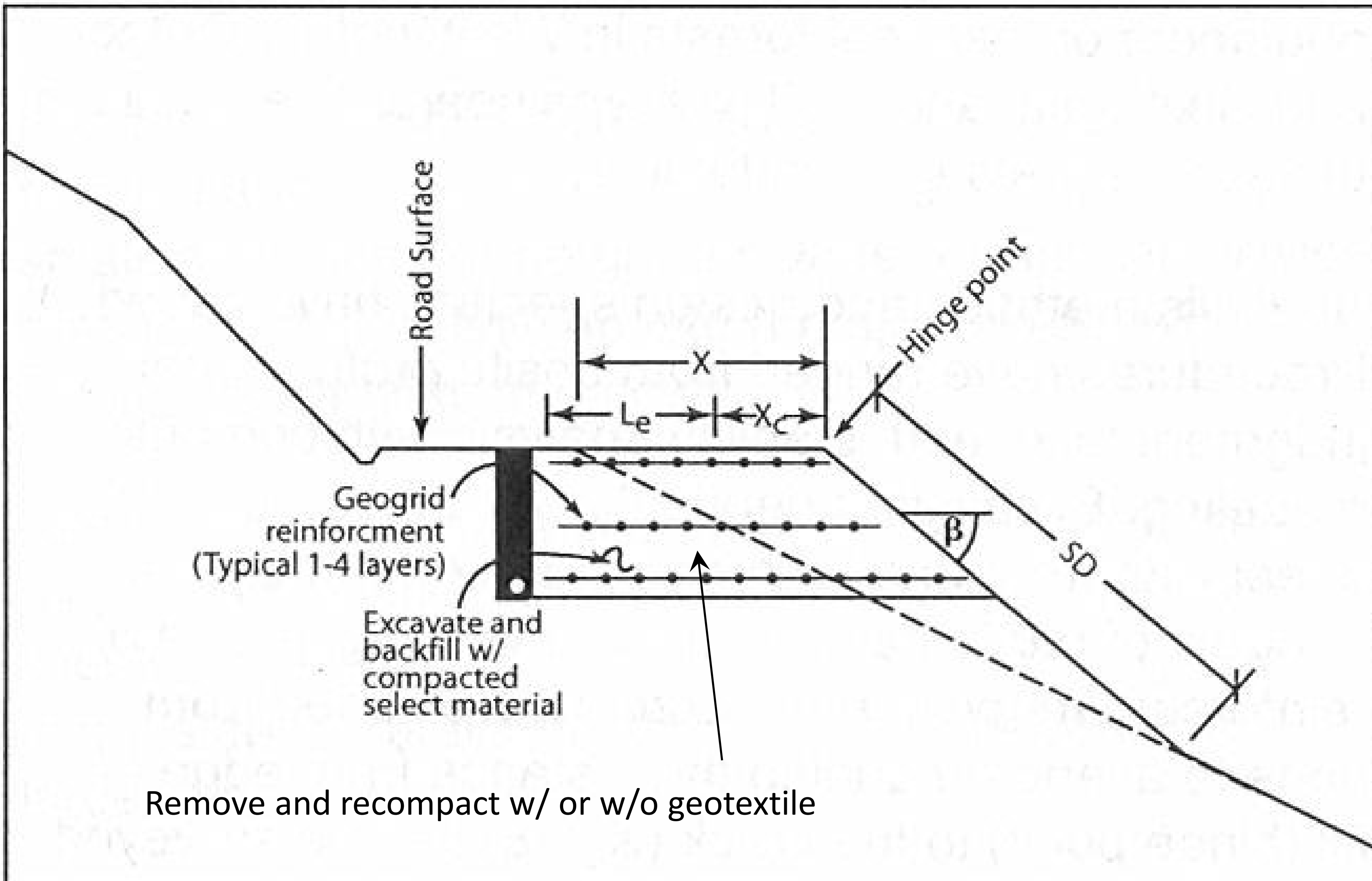
Forest Service

Technology &
Development Program

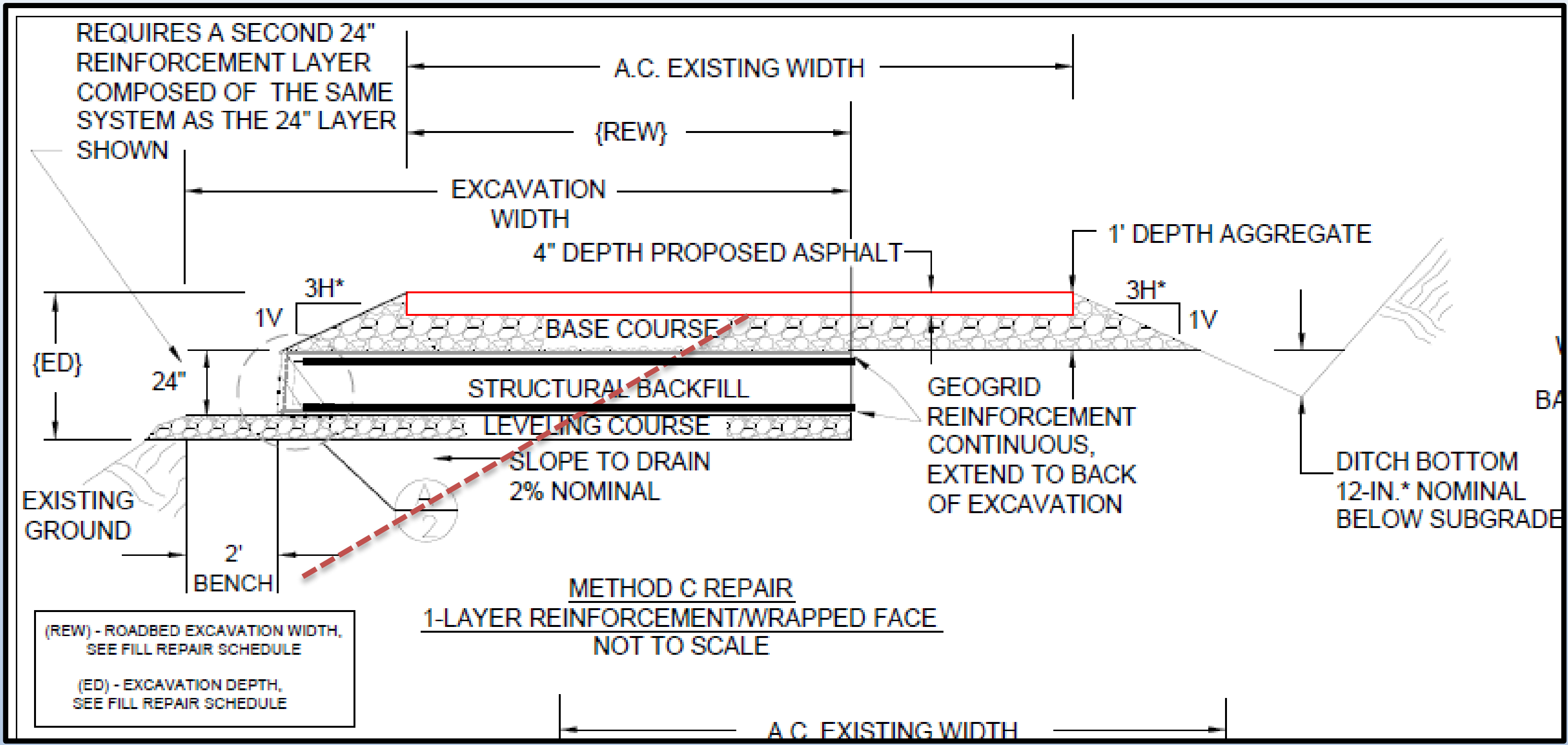
7700—Transportation
Management
October 2005
0577 1204—SDTDC

Deep Patch Road Embankment Repair Application Guide


Cut
Fill
Crack
Road Surface
Subsidence
Hinge point
Original ground surface
Possible ground water flow
Downslope Creep
Fill Toe
Loose soil and/or woody debris
or
Soil instability (creep)



Remove and recompact w/ or w/o geotextile


REQUIRES A SECOND 24" REINFORCEMENT LAYER COMPOSED OF THE SAME SYSTEM AS THE 24" LAYER SHOWN
A.C. EXISTING WIDTH
{REW}
EXCAVATION WIDTH
4" DEPTH PROPOSED ASPHALT
1' DEPTH AGGREGATE
3H*
1V
3H*
1V
{ED}
24"
BASE COURSE
STRUCTURAL BACKFILL
LEVELING COURSE
GEOGRID REINFORCEMENT CONTINUOUS, EXTEND TO BACK OF EXCAVATION
SLOPE TO DRAIN 2% NOMINAL
DITCH BOTTOM 12-IN.* NOMINAL BELOW SUBGRADE
EXISTING GROUND
2' BENCH
METHOD C REPAIR
1-LAYER REINFORCEMENT/WRAPPED FACE
NOT TO SCALE
(REW) - ROADBED EXCAVATION WIDTH, SEE FILL REPAIR SCHEDULE
(ED) - EXCAVATION DEPTH, SEE FILL REPAIR SCHEDULE
A.C. EXISTING WIDTH

STABILIZATION W/EARTHWORKS

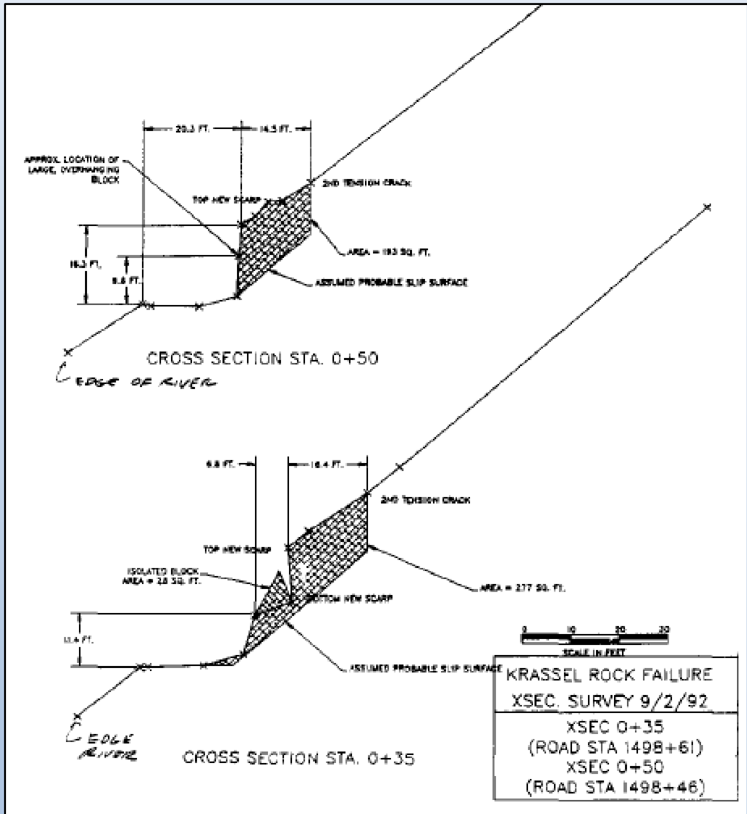
(REMOVAL - photo from Jigsaw Enterprises)

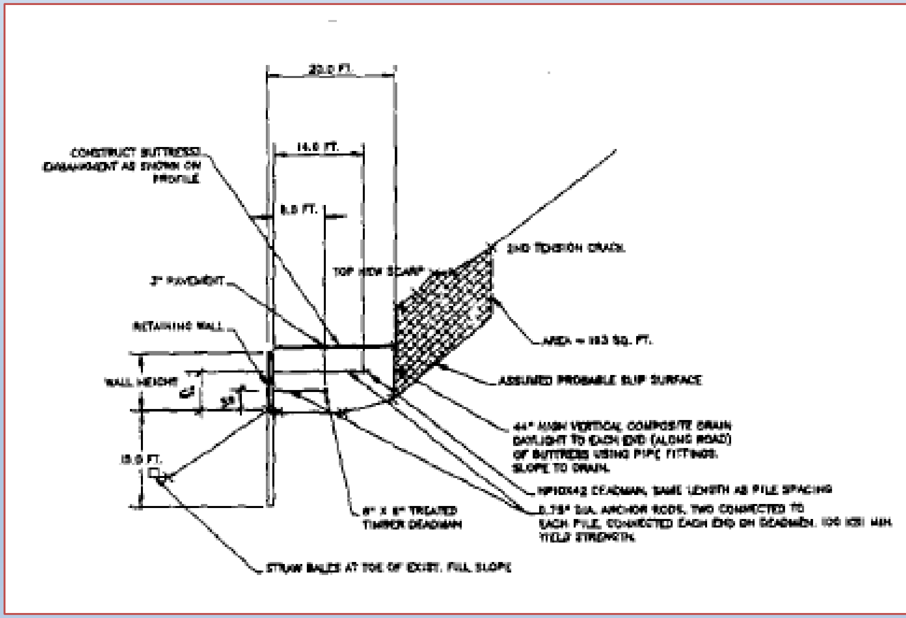
Typical Buttresses

Buttress in Failed Cut-Slope
Shasta Trinity N.F. Region 5

Toe Buttress at Base of Reinforced
Fill Slope, Klamath N. F. Region 5

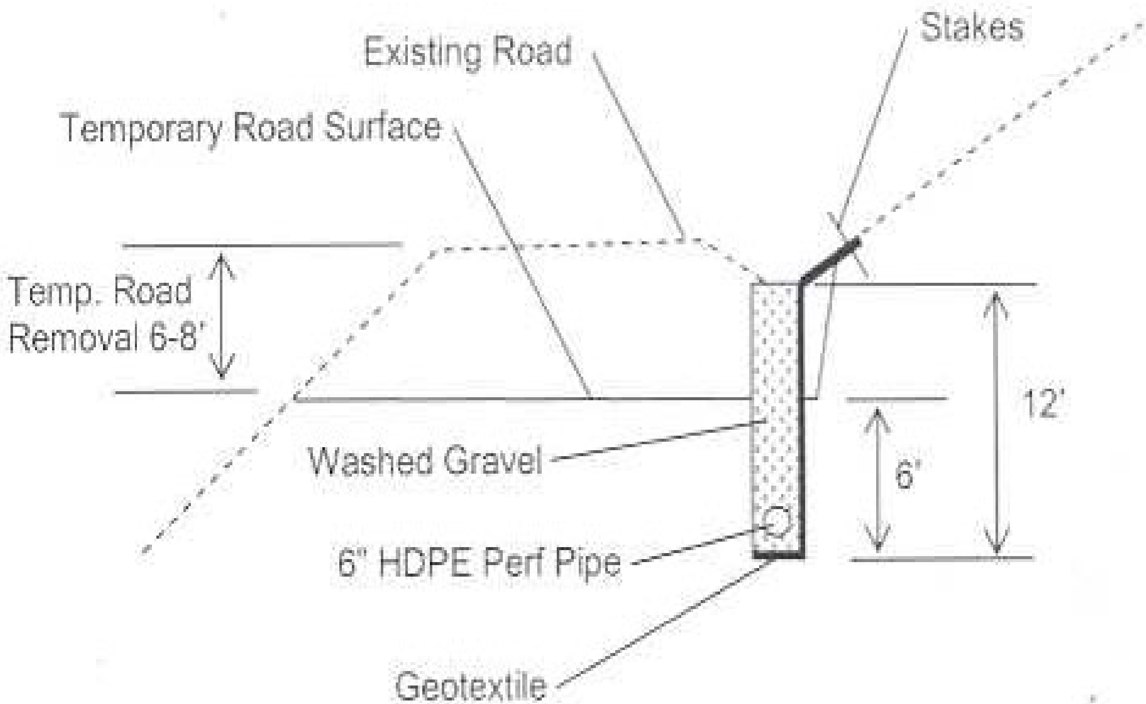
Road as Buttress





STABILIZATION W/DRAINAGE

Cut-Off Drainage Trench Solution



Non-Woven
Water Flow Rate (ASTM D-4491): 80 gpm/sq ft (min)
AOS (ASTM D-4751): 80 (min)
Puncture Strength (ASTM D-48833): 110 lb (min)
Mullen Burst (ASTM D-3786) 350 psi

Coal Creek Landslide Failure

- Seasonal Long Term Creep Failure
- Large amounts of subsurface water
- Previous cross-drain solutions didn't slow movement
- Maintenance crews would add more gravel as a leveling course but over time added load.
- State DNRC wanted to have a timber which required a route on this road.
- Concern about loading on current fill.


10.04.2011

Monitoring Wells

From existing ground surface

Soil Boring/ DCP		Date	
	10-11-2007	5-30-2008	9-2-2010
CC-1	21.1	7.9	16.3
CC-2	27.8	9.8	11.7
CC-3	NG	NG	-
DPS-1	-	0.25	-
DPS-2b	-	0.10	-
DPS-1a	-	NG	-
DPS-2a	-	NG	-

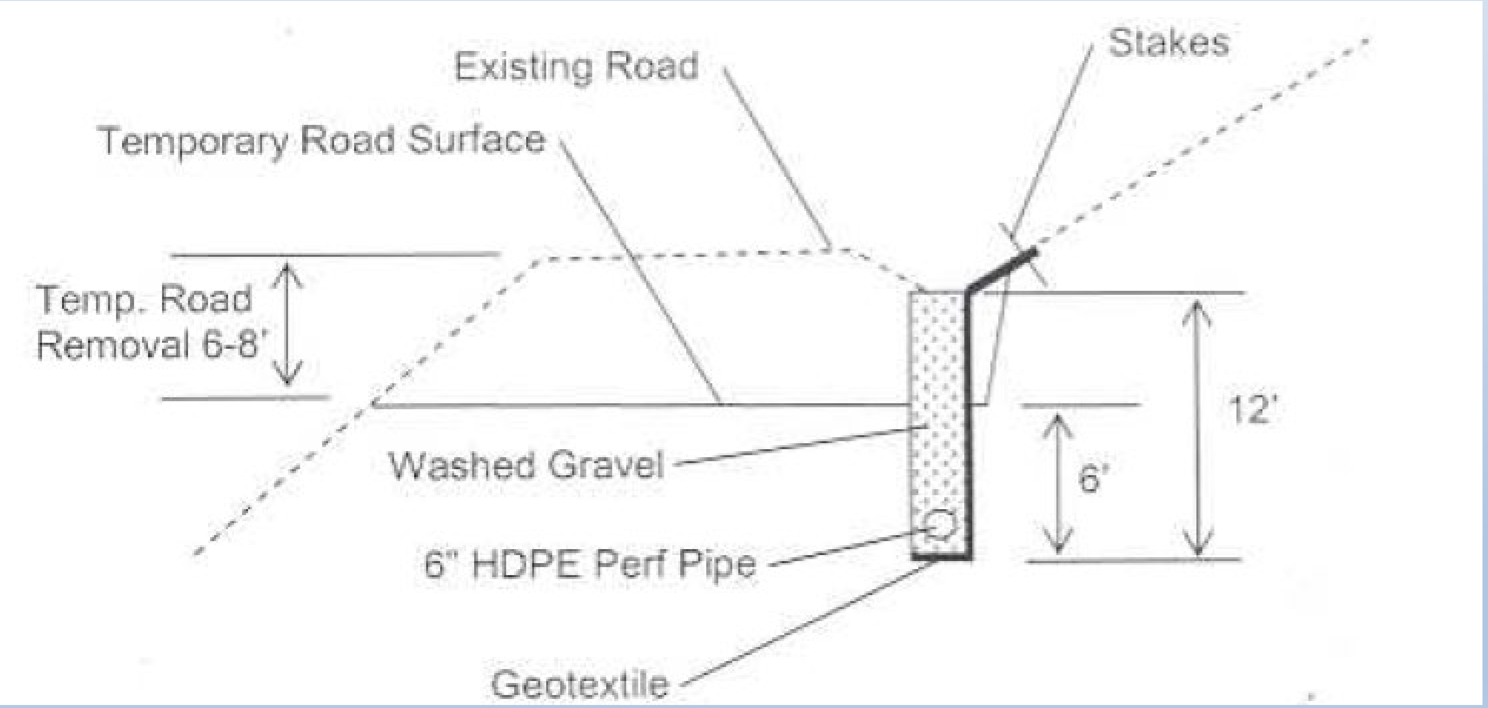
Findings

- High water contents and saturation
- A large presence of fine grained cohesive soils mixed with gravels
- Possible water lenses
- High subsurface water table

Conceptual Design

- Needed to stabilize slope by facilitating drainage given the saturated conditions
- Needed to rebuild the road fill
- Curtain drain was the desired option given no structural stabilizing was needed

Early Conceptual Design

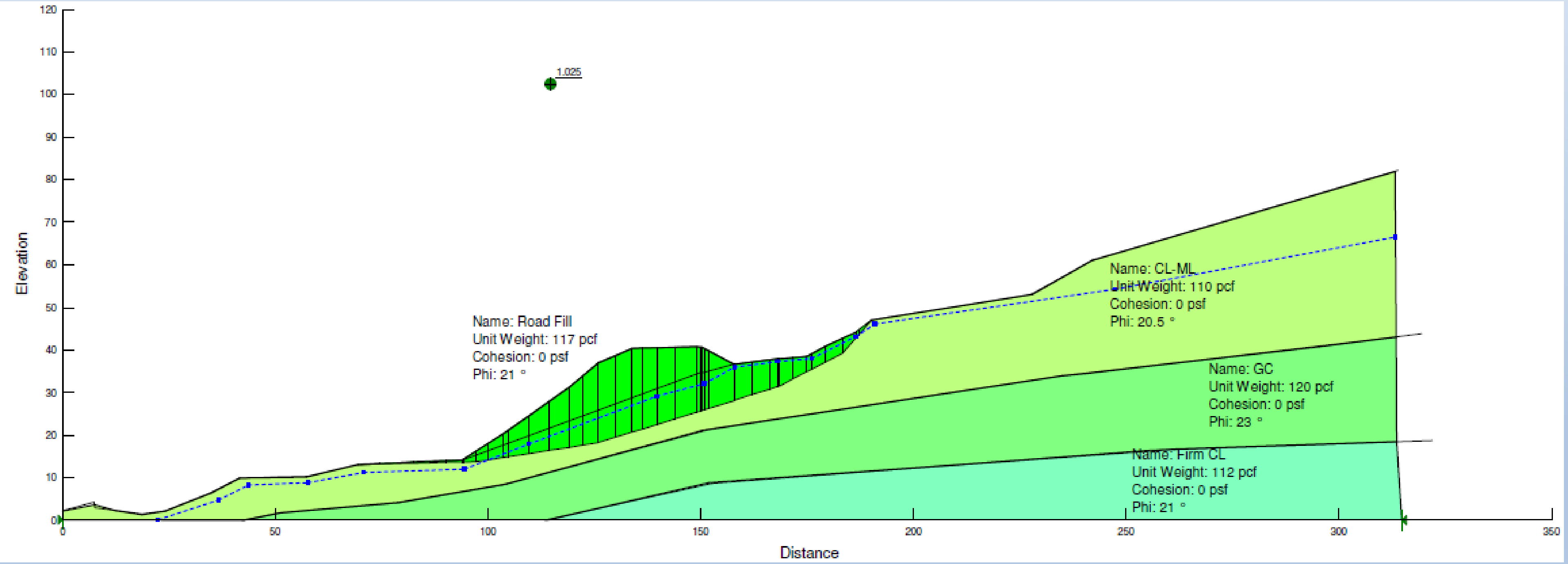


Slope Stability Modeling

- Using field data
  - Come up with a layering system
  - Determine appropriate phreatic surface
  - Failure scarps to tie in a reasonable failure plane
  - Failure plane used to refine soil properties at FS~1 for an existing ground model

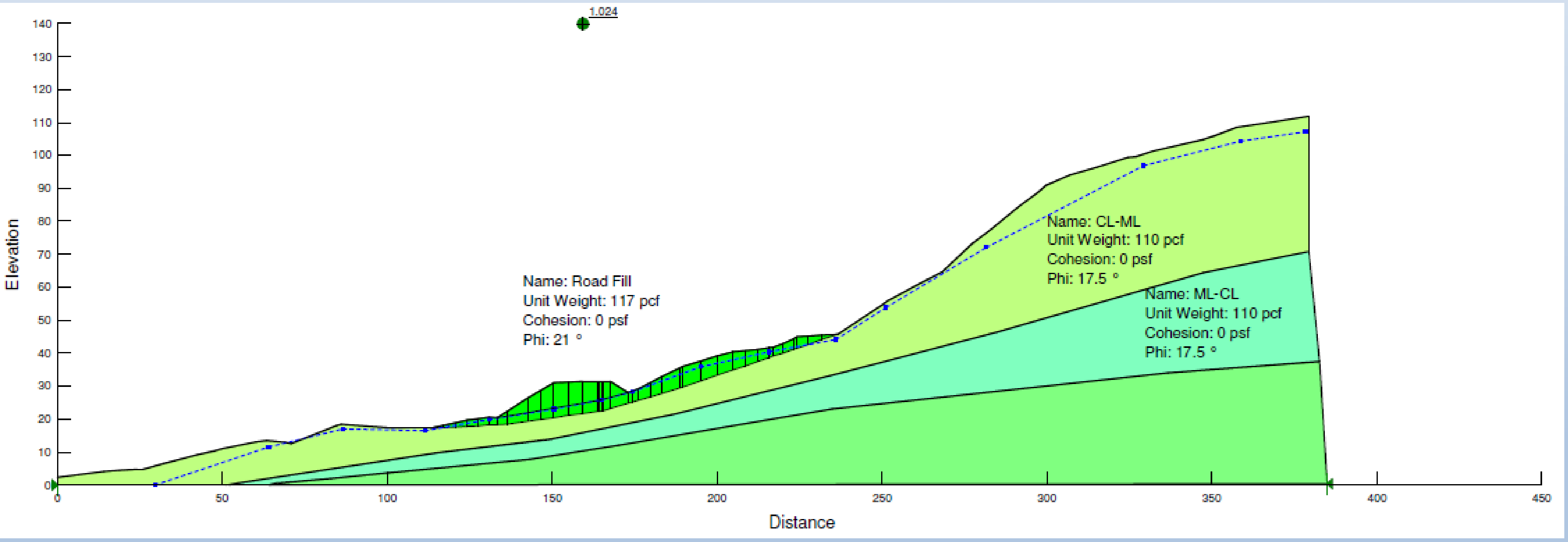
Existing Ground

Station 1+20 – first failure

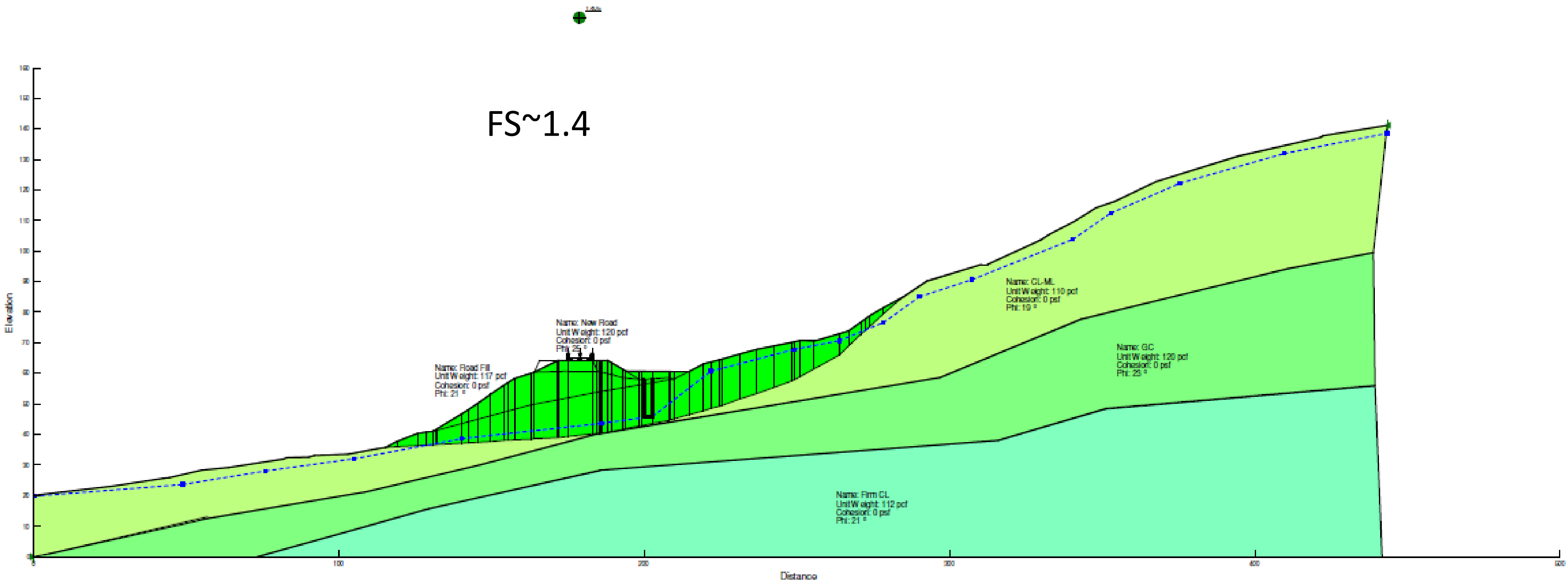


Existing Ground

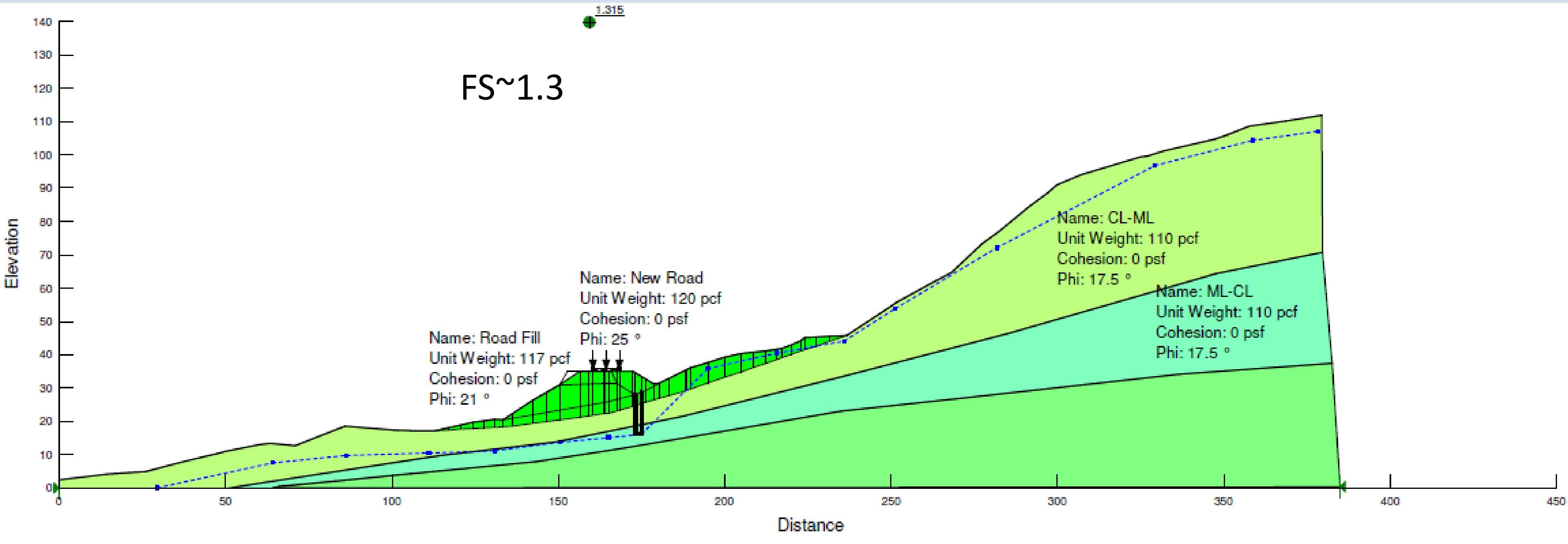
Station 3+00 – second failure



Curtain Drain Analysis



Curtain Drain Analysis

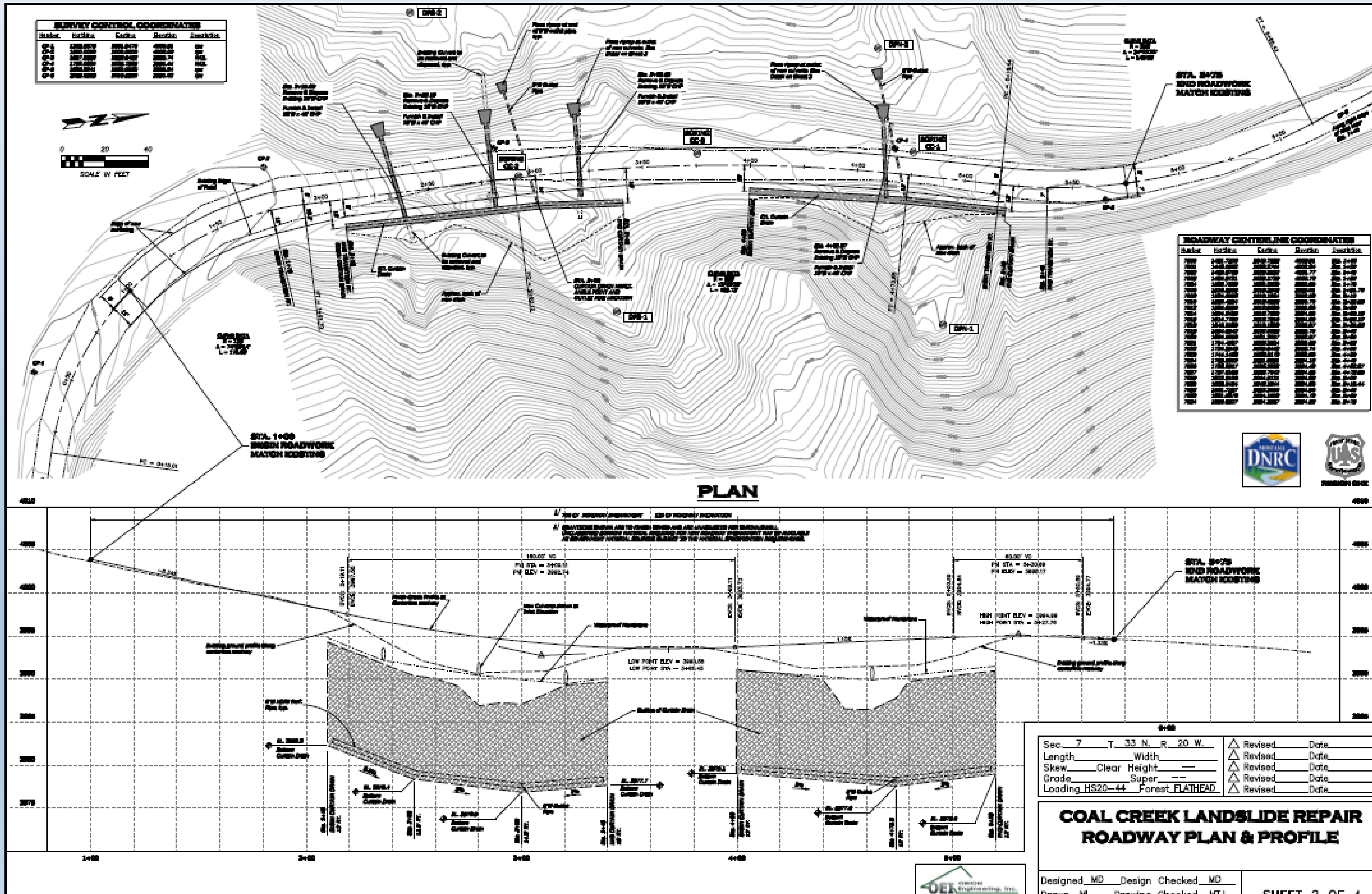


Alternative

Modeled a 14 foot curtain drain to determine increase in factor of safety

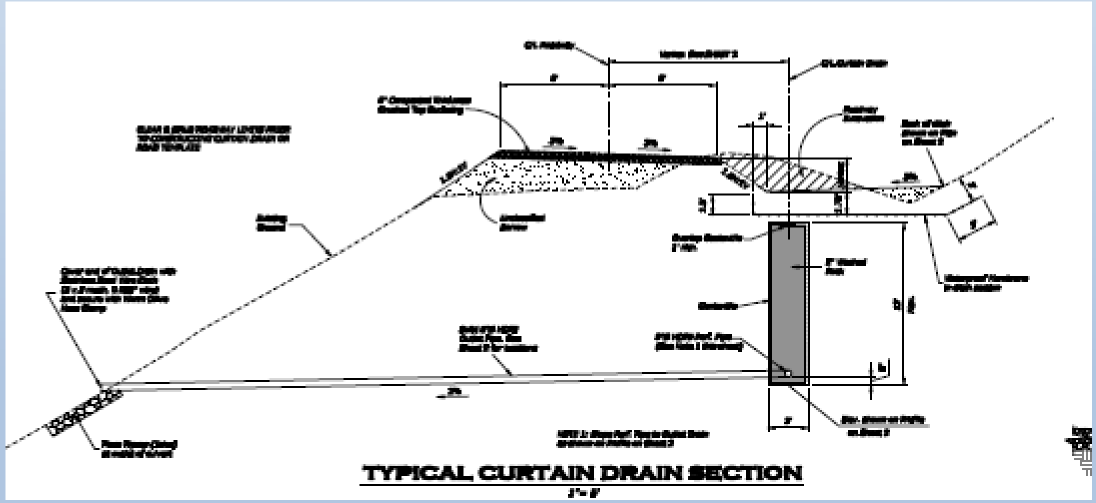
- This increased the factor of safety only 0.02
- Opted for the 12 ft depth given the extra cost of excavating an extra two feet

Plans



SCALE IN FEET
0
20
40
PLAN
DNRC
Sec. 7 T. 33 N. R. 20 W.
Length Width
Skew Clear Height —
Grade Super --
Loading HS20-44 Forest FLATHEAD
Revised Date
Revised Date
Revised Date
Revised Date
Revised Date
COAL CREEK LANDSLIDE REPAIR
ROADWAY PLAN & PROFILE
Designed MD Design Checked MD
Drawn ML Drawing Checked MTJ
SHEET 2 OF 4

Section

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10. 13. 2011


10. 13. 2011

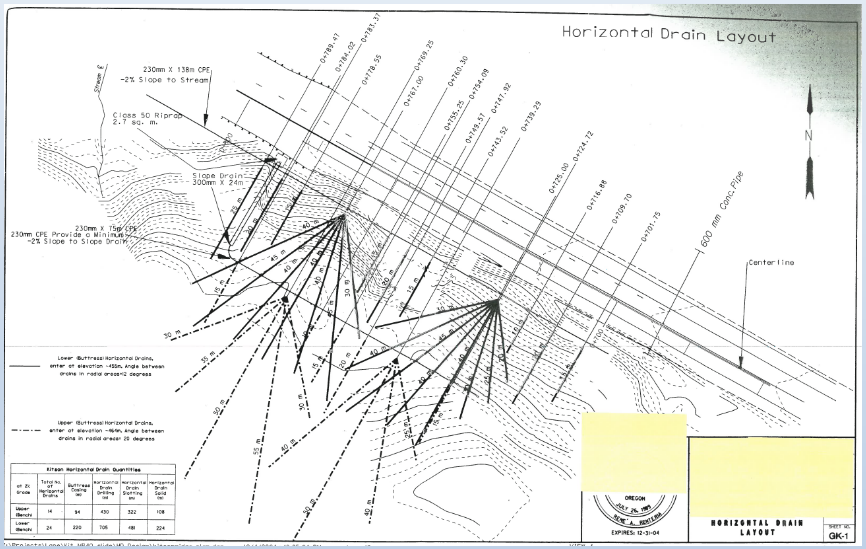

10. 13. 2011

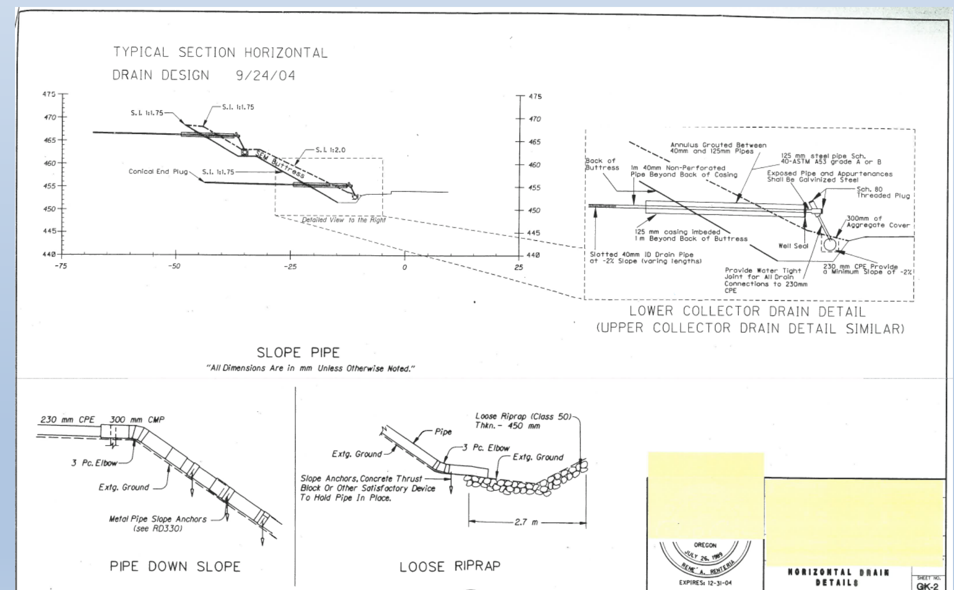
Slide Plane!


25D

Drill & Install Horizontal Drains

Horizontal Drain Details





COMBINATION METHODS


R1 North Fork Teton Slide
Drainage & Support
(Courtesy Chud Lundgreen, USFS R1)


N Fork Teton -Typical Large Natural Slide

North Fork Teton Slide

- Ancient slide first disturbed by cutting toe for road during early logging activities.
- Consists of glacial outwash deposit overlaying bedrock in large drainage.
- Disturbed years back and some shallow drainage measures implemented.
- Area burned in 2007 and following Spring run-off, slide re-activated

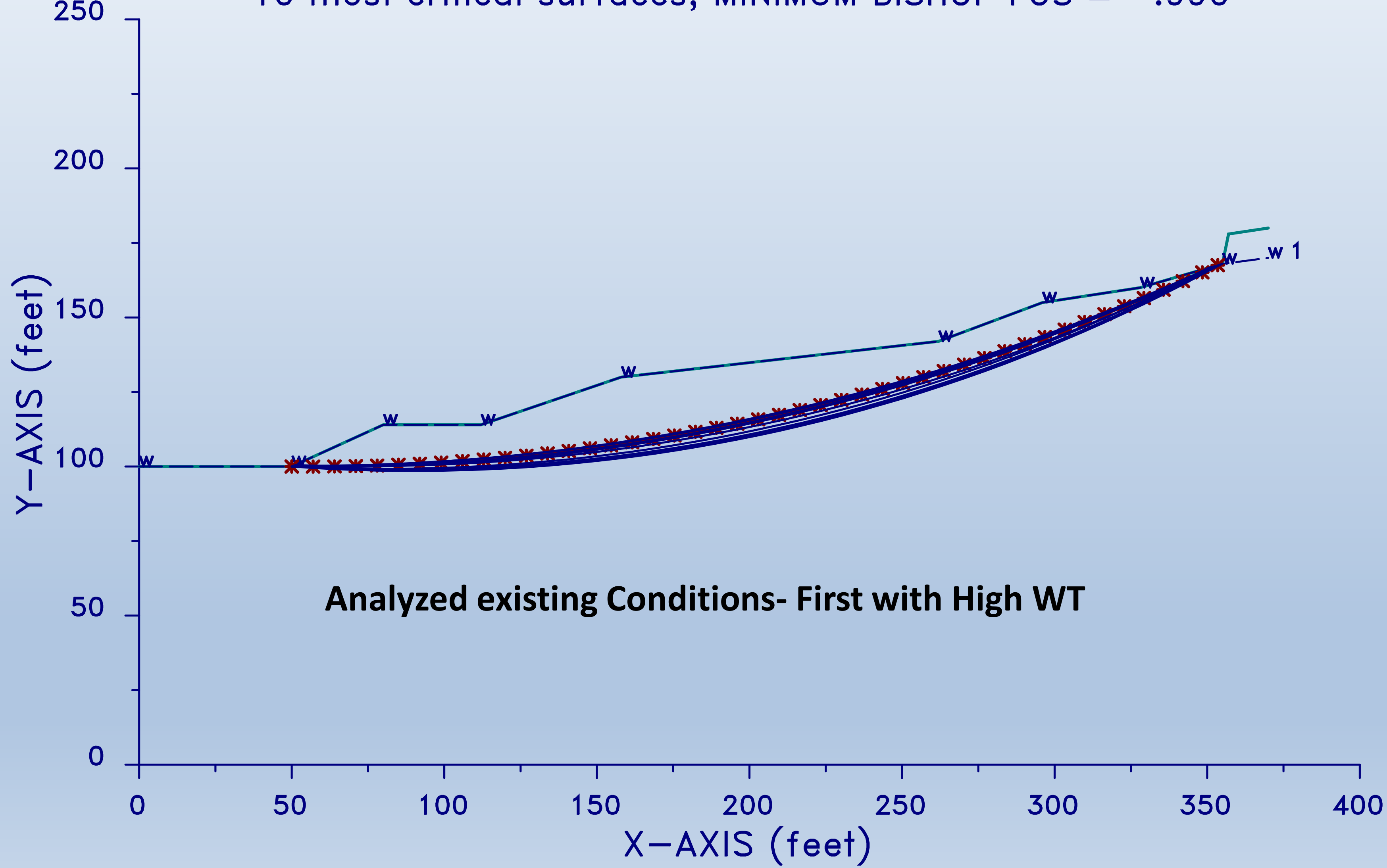
NF Teton Slide

- Size-300 feet long and 150 feet wide
- Sandy Clay/Gravelly Soil
- Very High Water Table
- Contractor in area and pit-run rock readily available
- Quickest Solution- Rock Buttress and surface drainage.

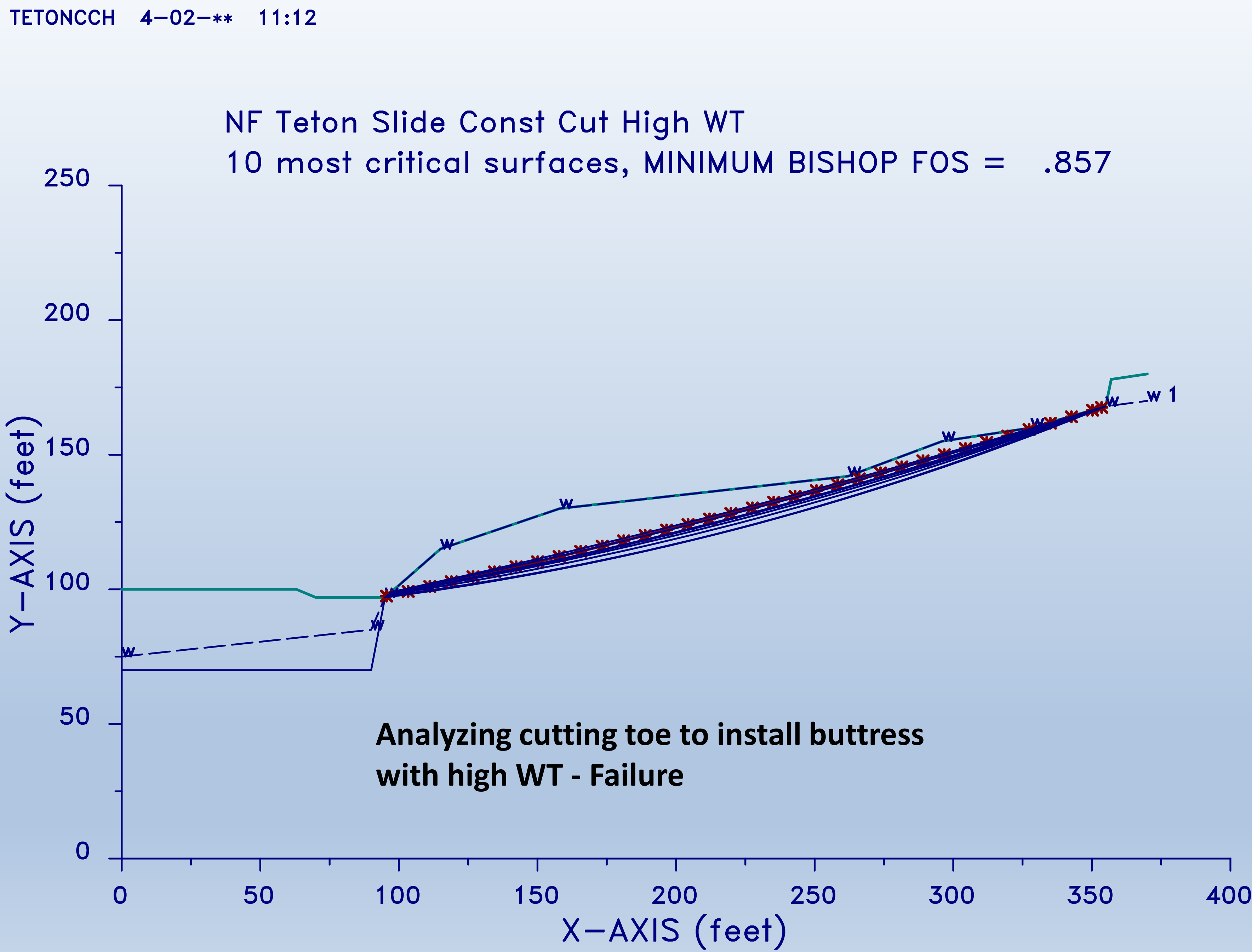
TETONWT1 8-14-** 10:21

Teton Slump Orig Failure with WT

10 most critical surfaces, MINIMUM BISHOP FOS = .990

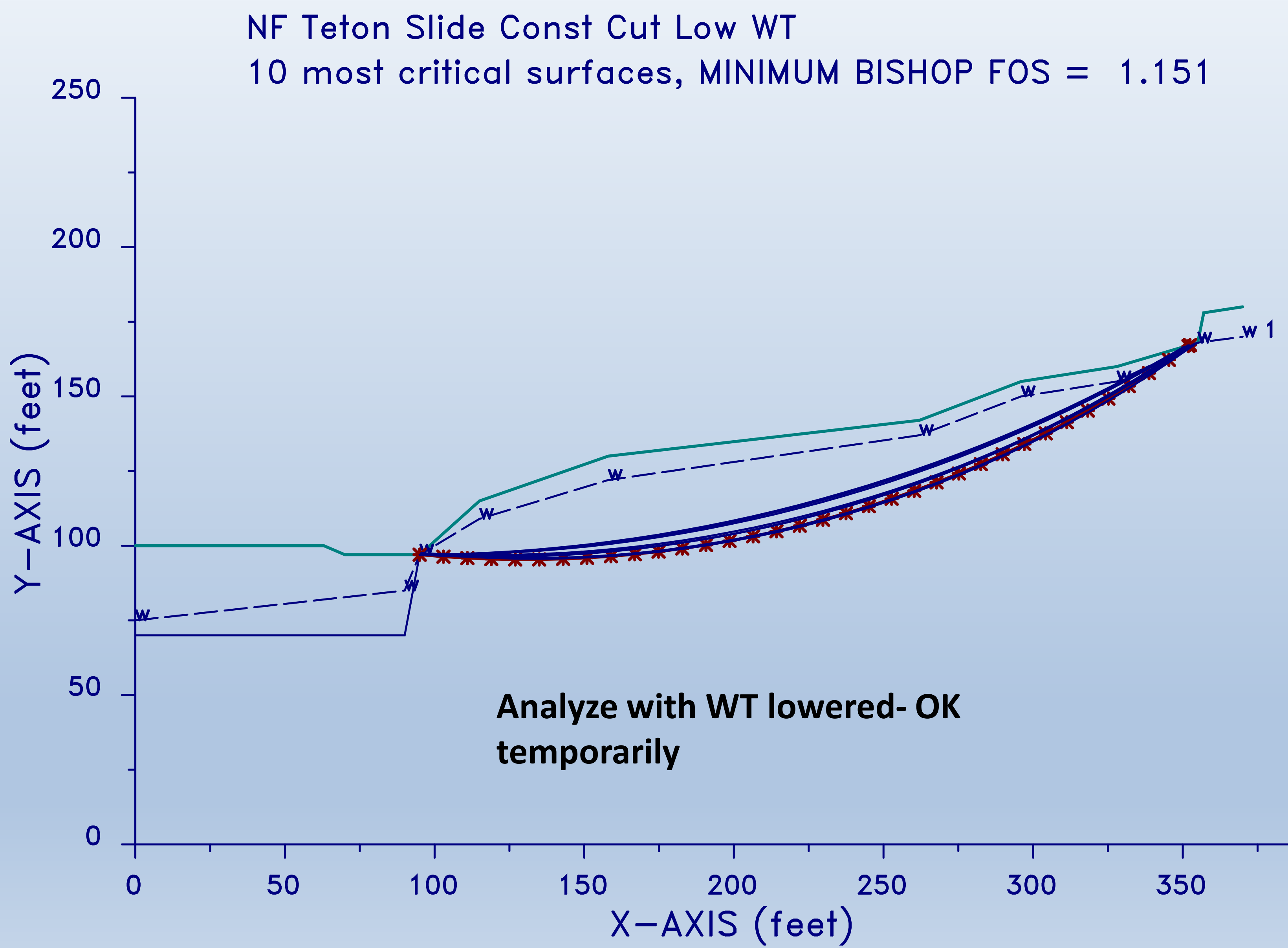


Analyzed existing Conditions- First with High WT

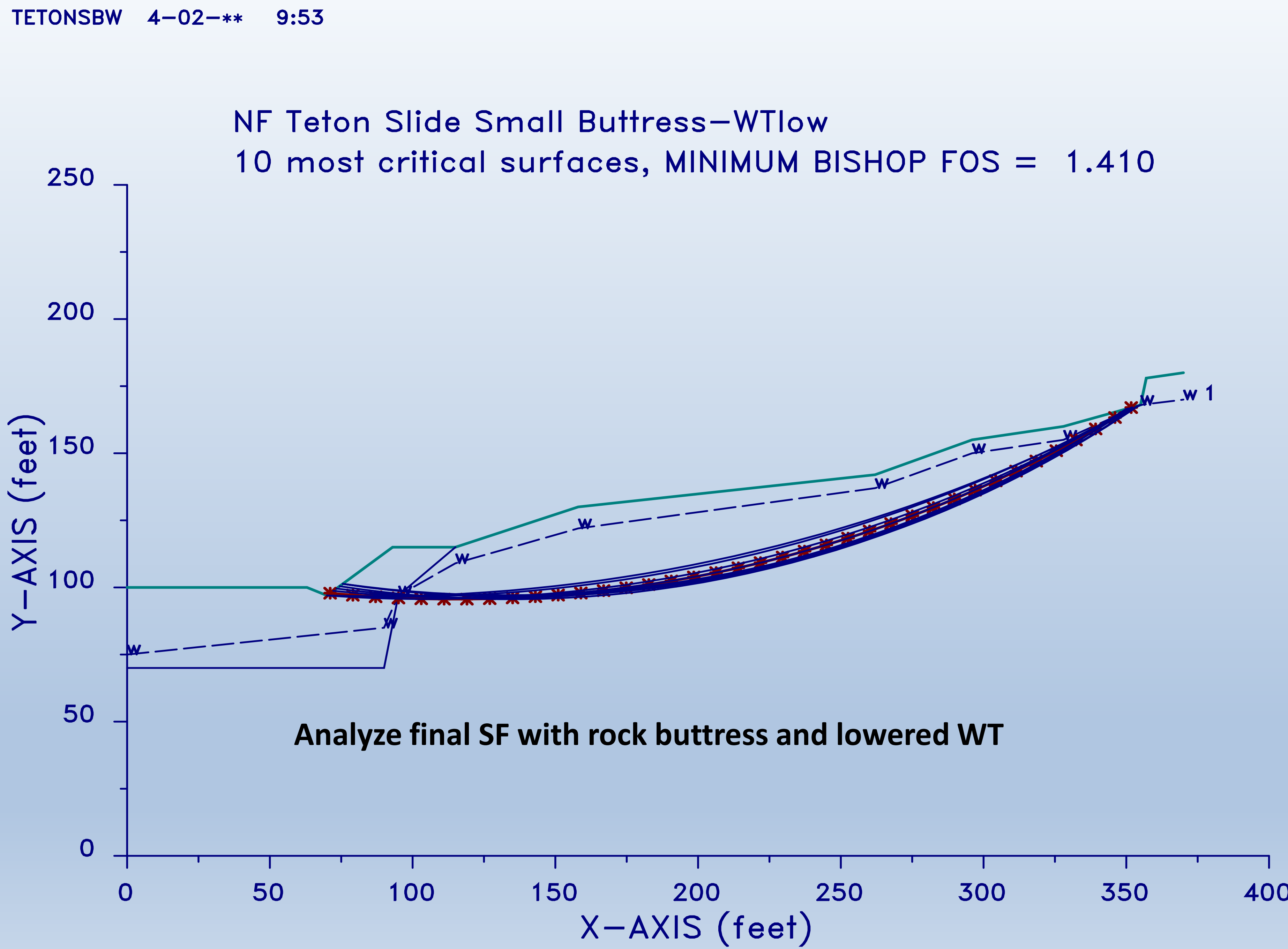


Analyzing cutting toe to install buttress with high WT - Failure

TETONCCL 4-02-** 10:32

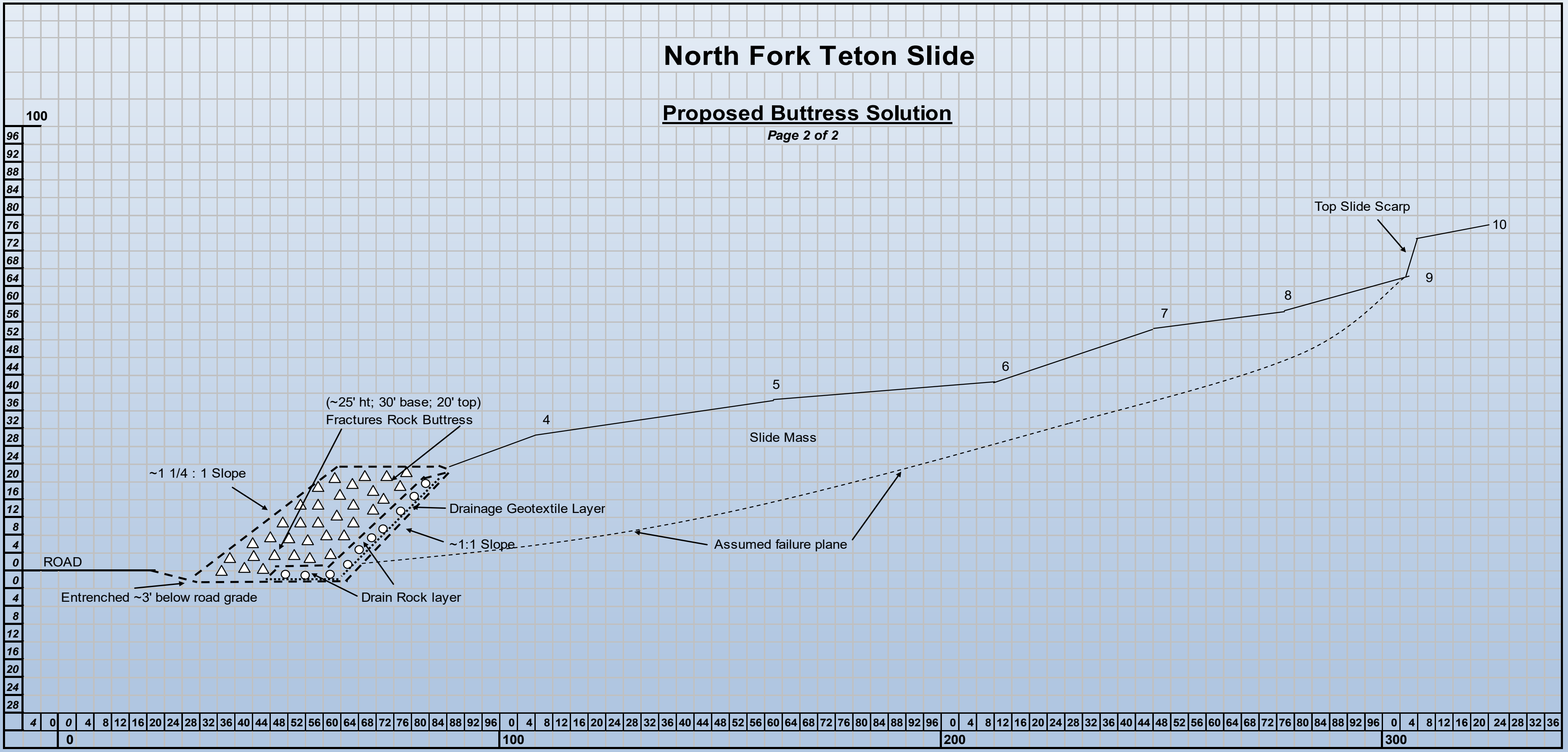


Analyze with WT lowered- OK temporarily



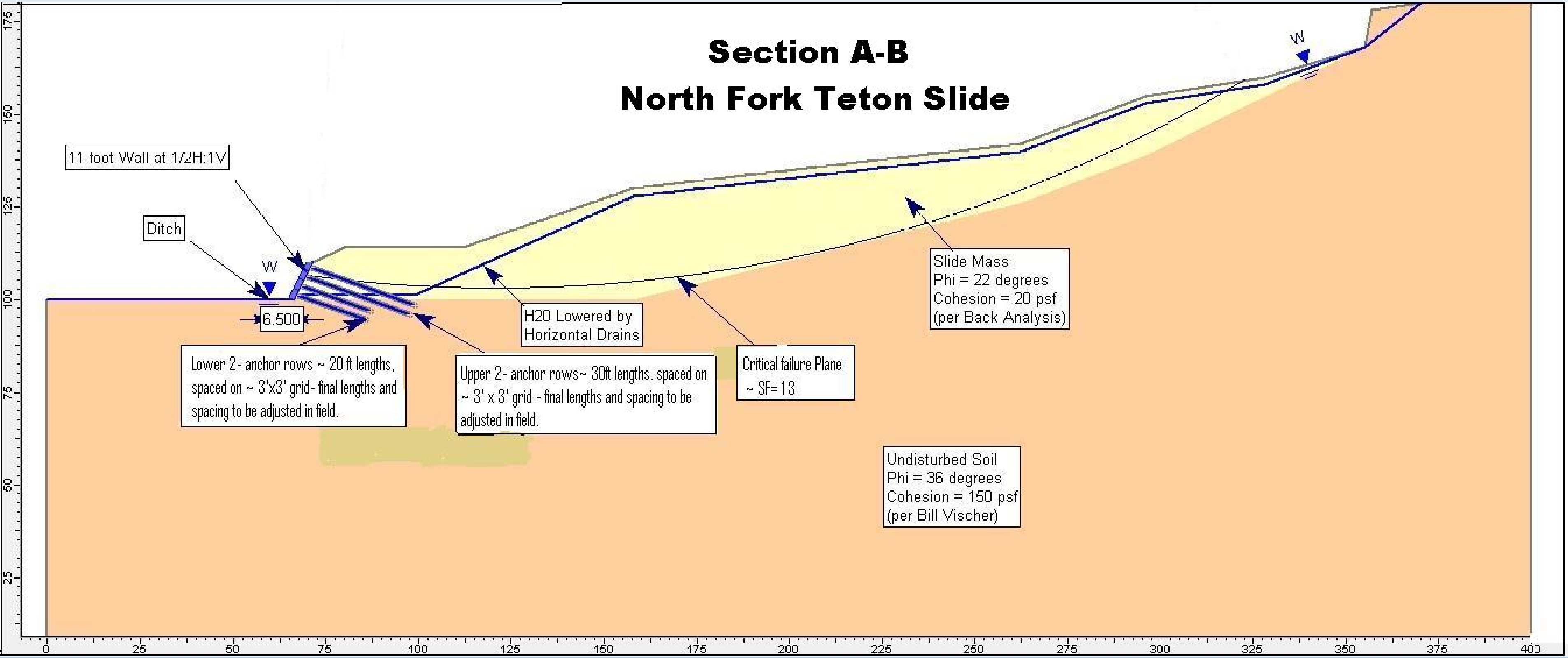
Analyze final SF with rock buttress and lowered WT

Preliminary Design Proposal Buttress with Surface Trench Drainage



Problem- Surface drainage not lowering WT ???

Final North Fork Teton Design- Soil Nail Buttress Wall at Toe of Slide with Horizontal Drains



Flathead NF Region 1- “Coal Creek” Slides

(Courtesy Chud Lundgreen, USFS R1)

Rebuild the Fill & Drainage

(courtesy Peter Bolander USFS WNF retired)



Field Developed Cross-Section

- **Obtain the following**
  - **Slope**
  - **Relief**
  - **Landforms**
  - **Changes in soil and rock units**
  - **Changes in vegetation**
  - **Changes in surface water distribution**

- **Purpose**
  - **3D model**
  - **Ability to project known data points**

Field Developed Cross Section

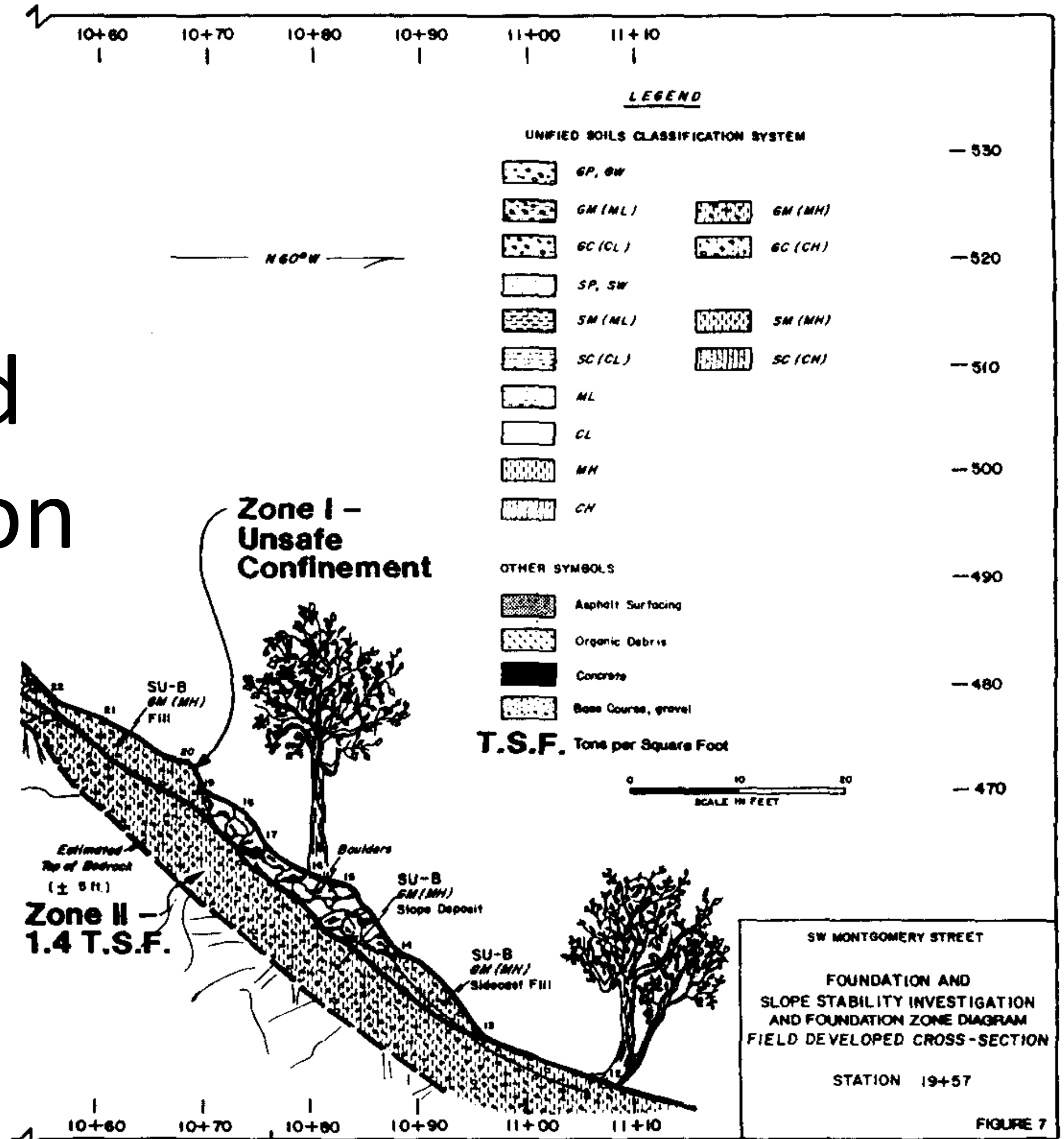
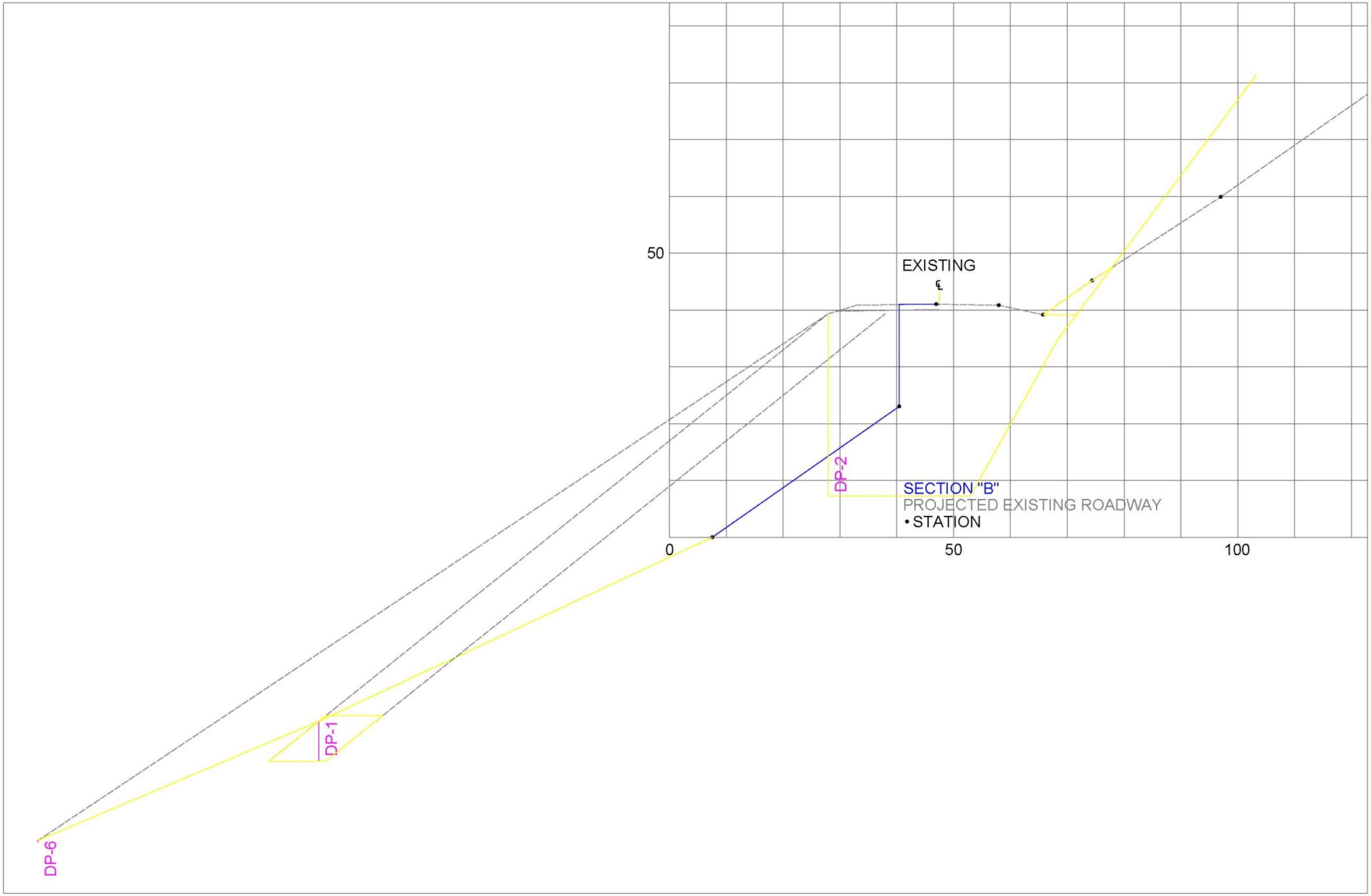


Figure 7. (Continued)

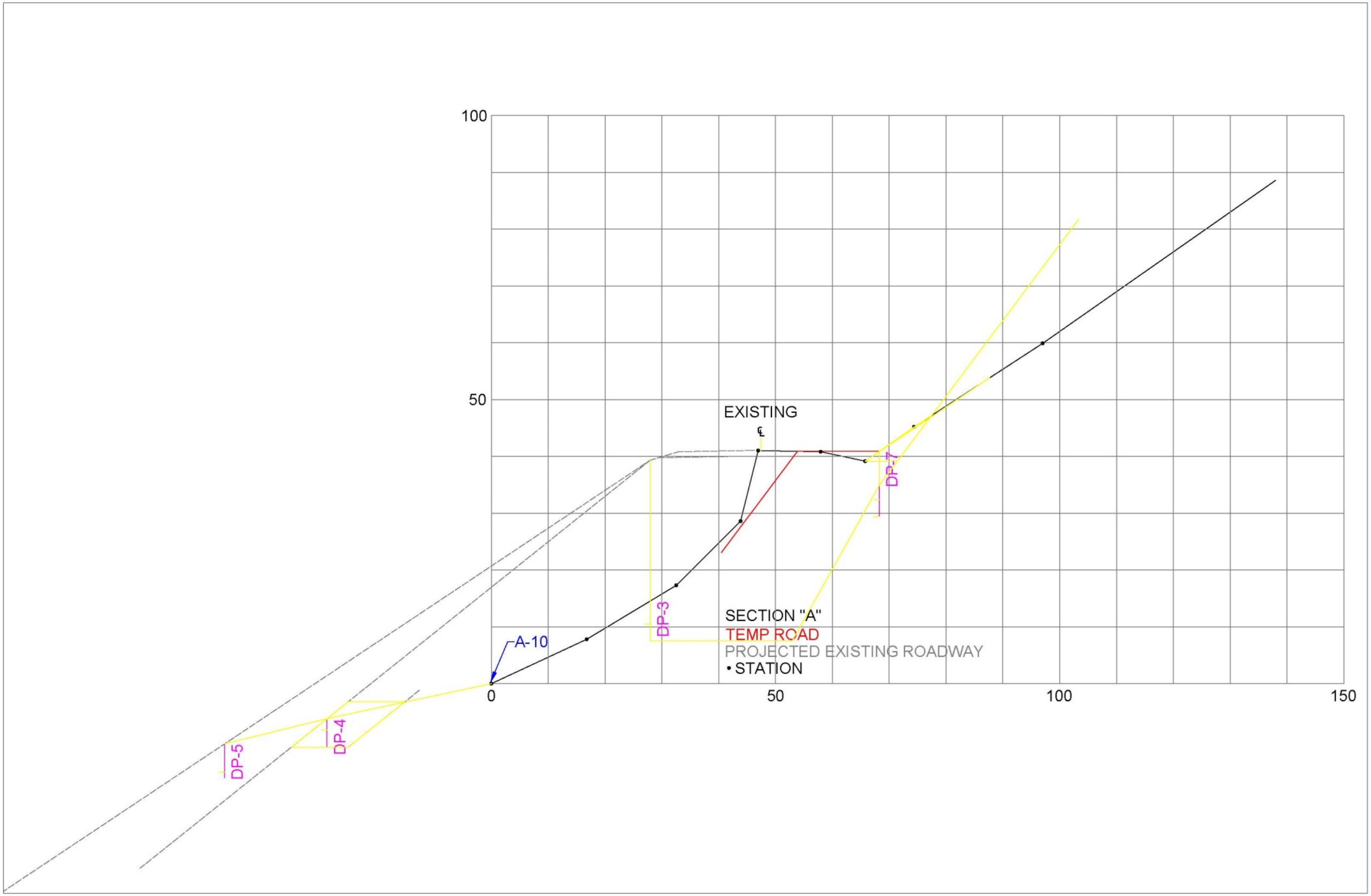
Subsurface Investigation

Final Subsurface Interpretation

- **Based on surface and drive probe information only**
- **See following “Geologic Cross-Sections”**



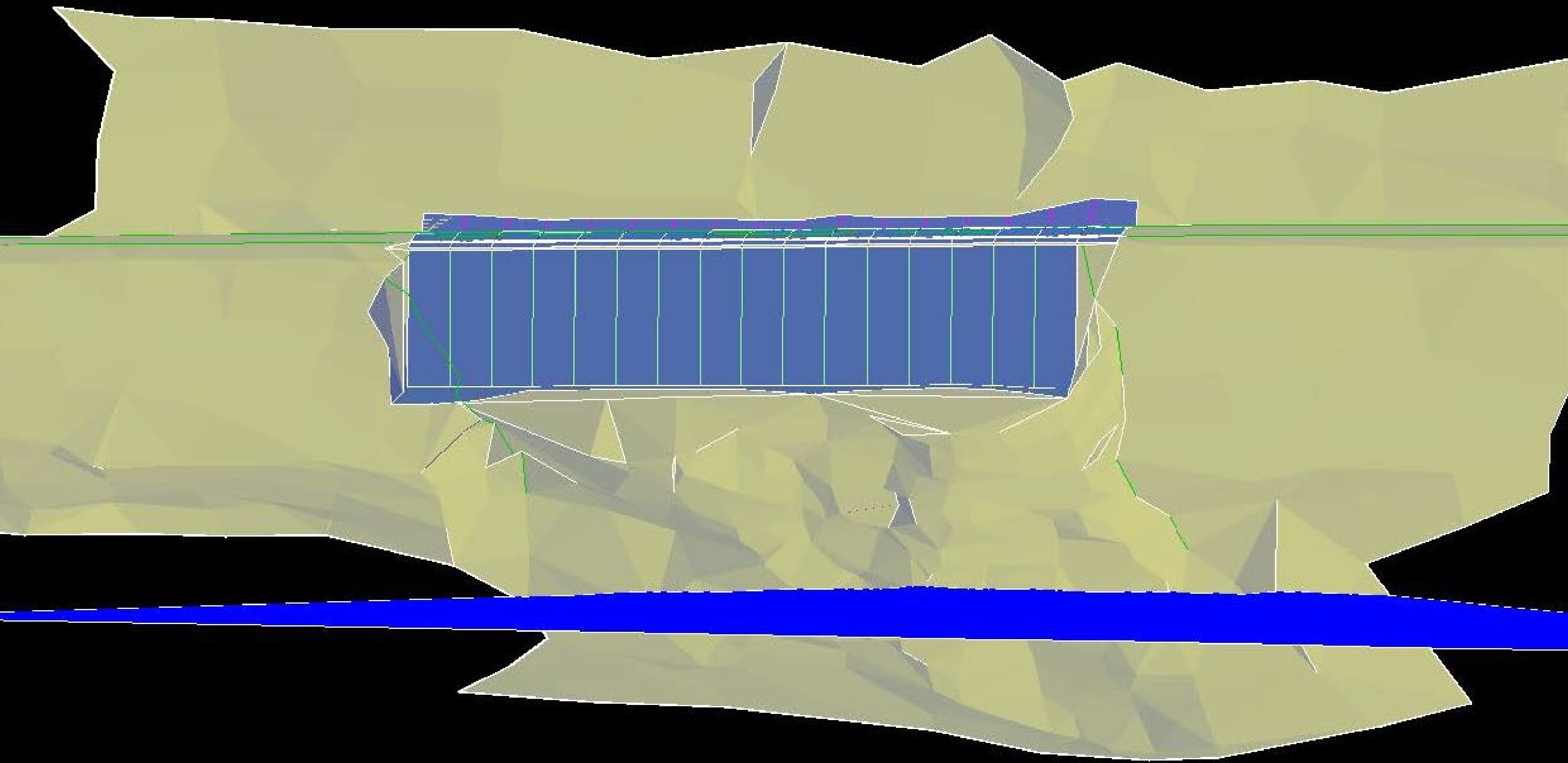
50
EXISTING
℄
DP-2
SECTION "B"
PROJECTED EXISTING ROADWAY
• STATION
0
50
100
DP-1
DP-6

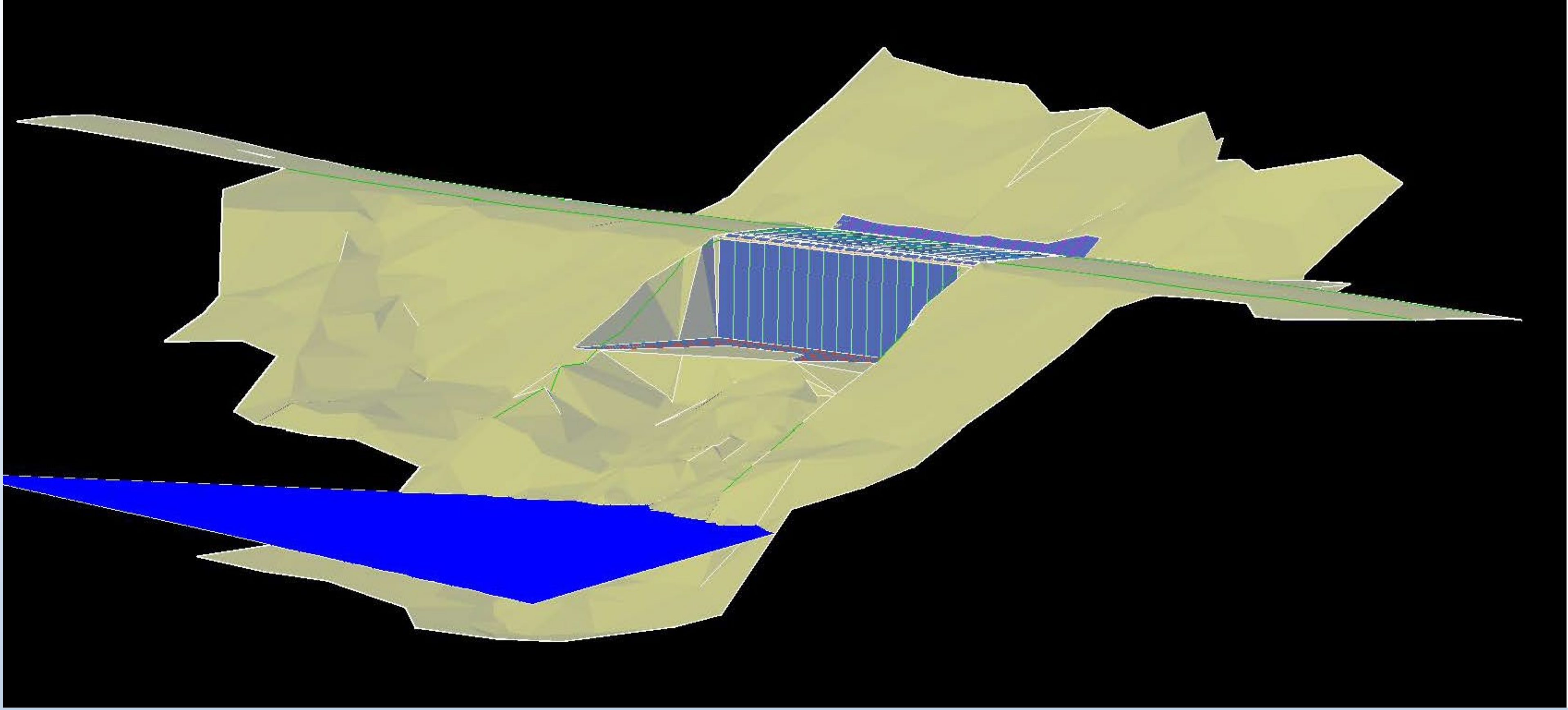


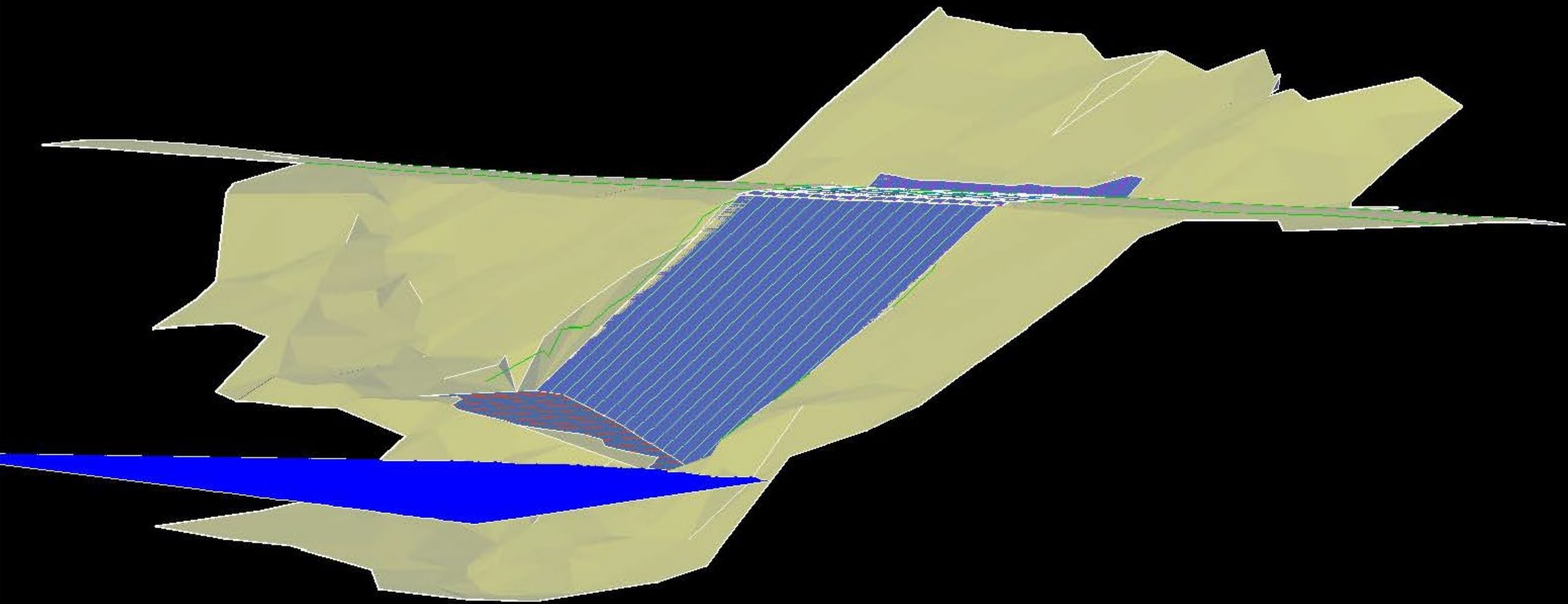
100
50
0
50
100
150
EXISTING
℄
SECTION "A"
TEMP ROAD
PROJECTED EXISTING ROADWAY
• STATION
A-10
DP-3
DP-4
DP-5
DP-7

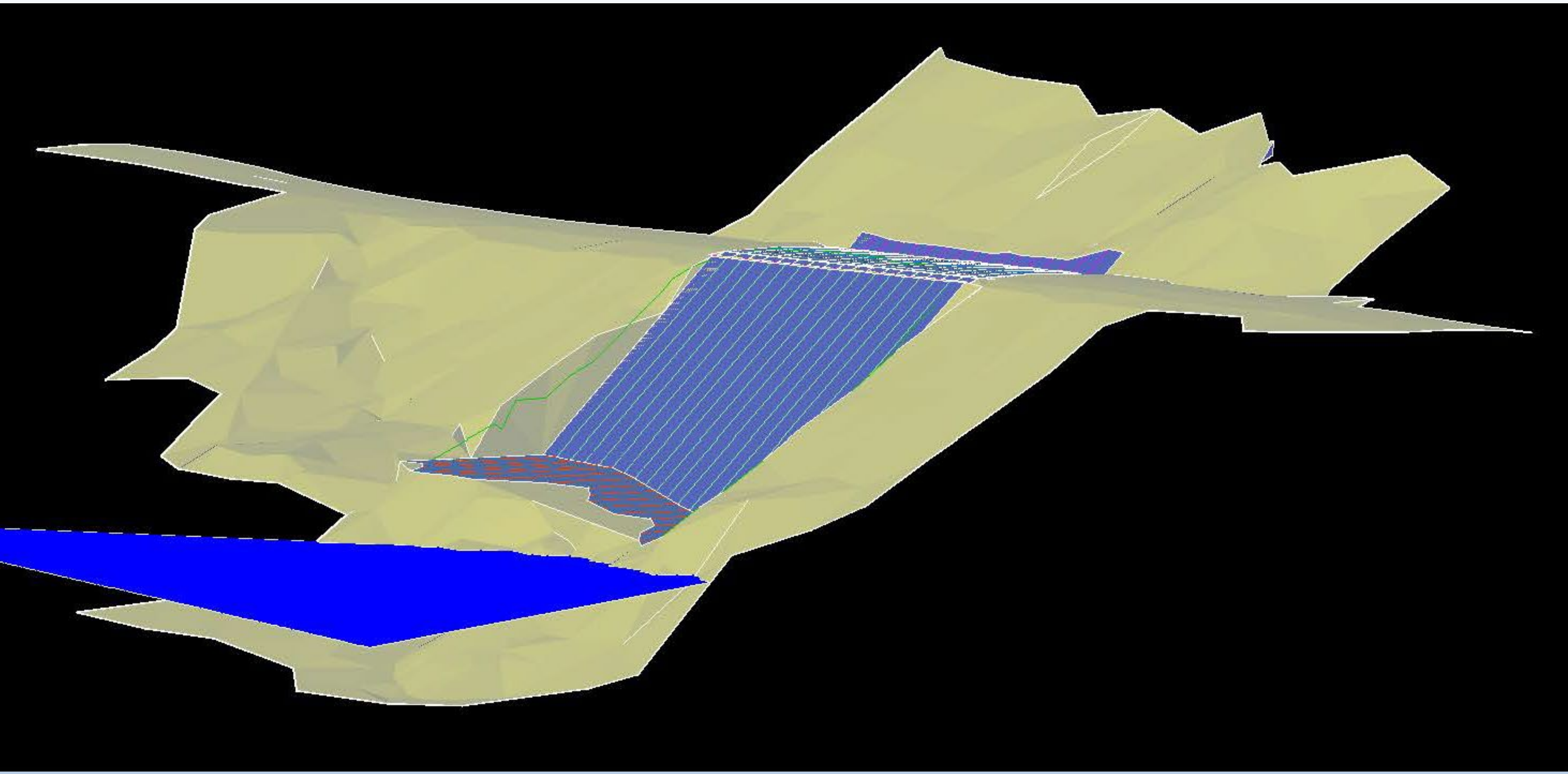
Repair Alternatives

- **Road Closure/Alternate Route**
- **Realignment**
- **Earth Embankment**
- **Rip Rap Embankment**
- **Reinforced Soil Slope**
- **Retaining Wall**







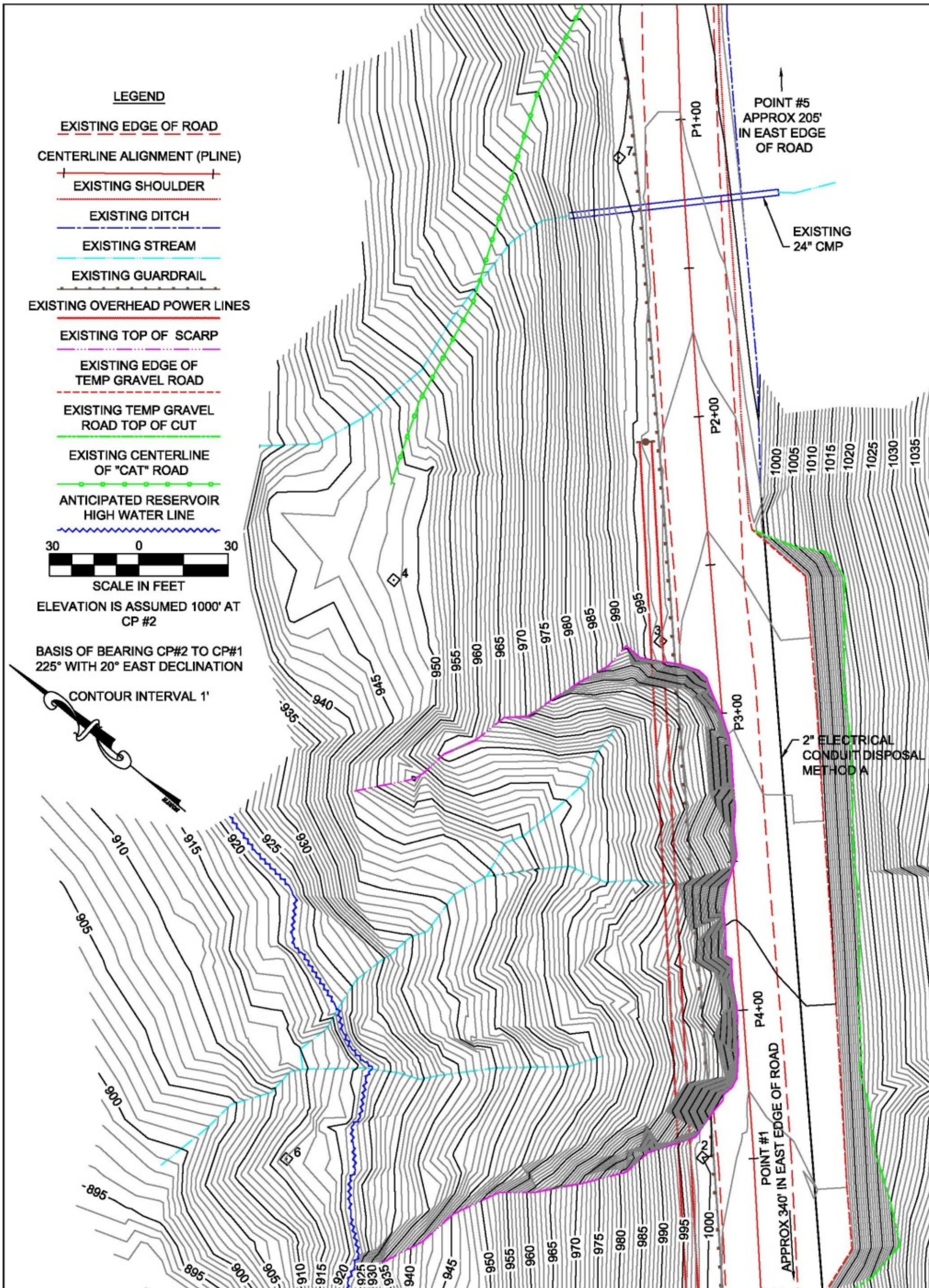


Repair Alternatives

Alternative	Pro	Con	Relative Costs
1.25H to 1V Rip Rap Embankment	* Stay out of Reservoir		Low
1H to 1V Rip Rap Embankment		* Toe within Reservoir	Low
Retaining Wall	* Stay out of reservoir	* Could not provide temporary access during construction	High
Reinforced Soil Slope	* Stay out of reservoir	* Could not use excavated material	Medium
Full Alignment Shift Into the Hillside		* Unsure if would encounter additional subsurface water	Low
Partial Alignment Shift into the Hillside and either one of the above Fillslope Repairs Options	* Stay out of reservoir	* Difficult to provide temporary access during construction	Medium

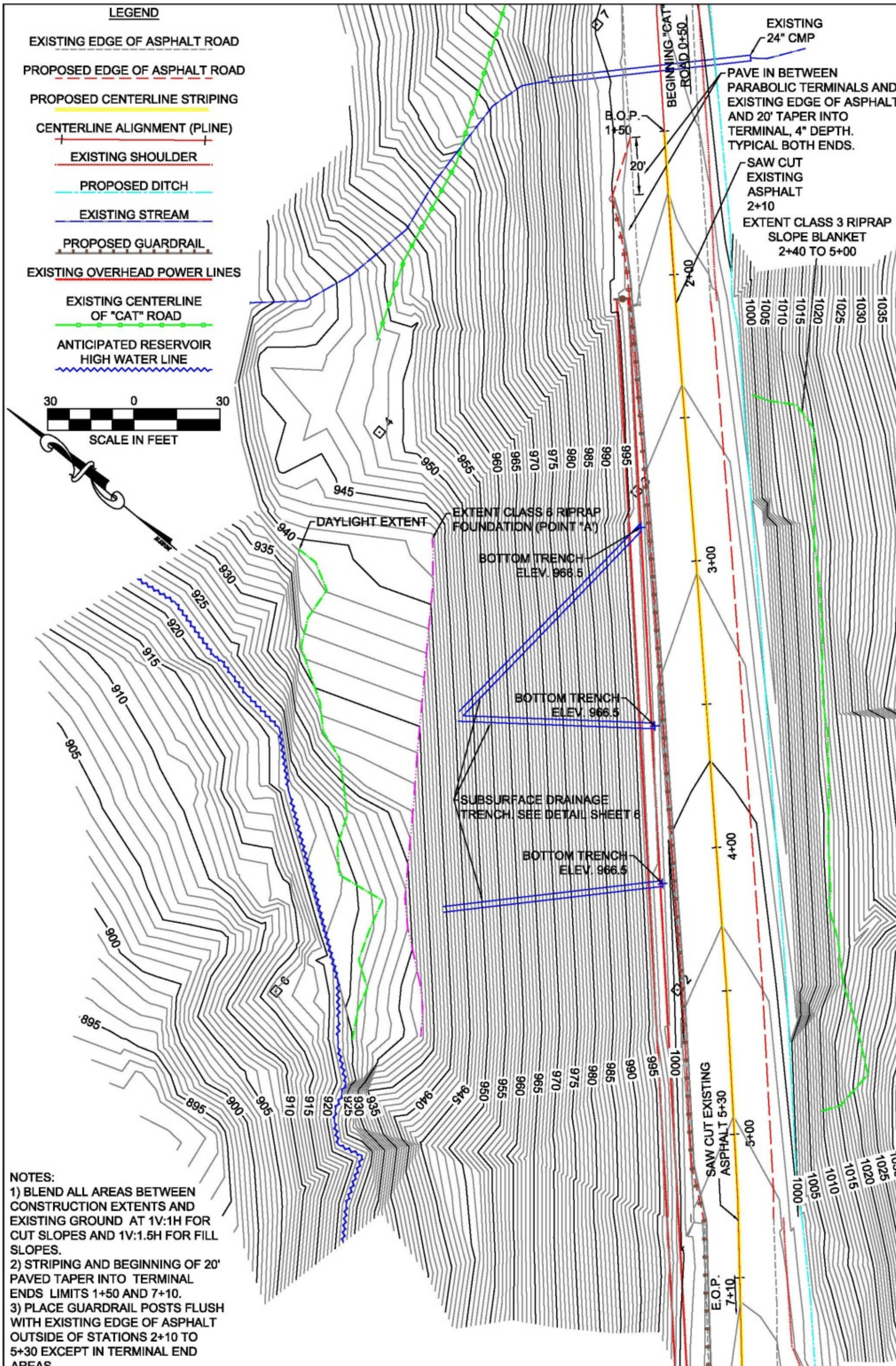
Design

- **Stable Foundation**
- **Drainage**
- **Stable Embankment**
- **Access During Construction**
- **Recreation Traffic Considerations**



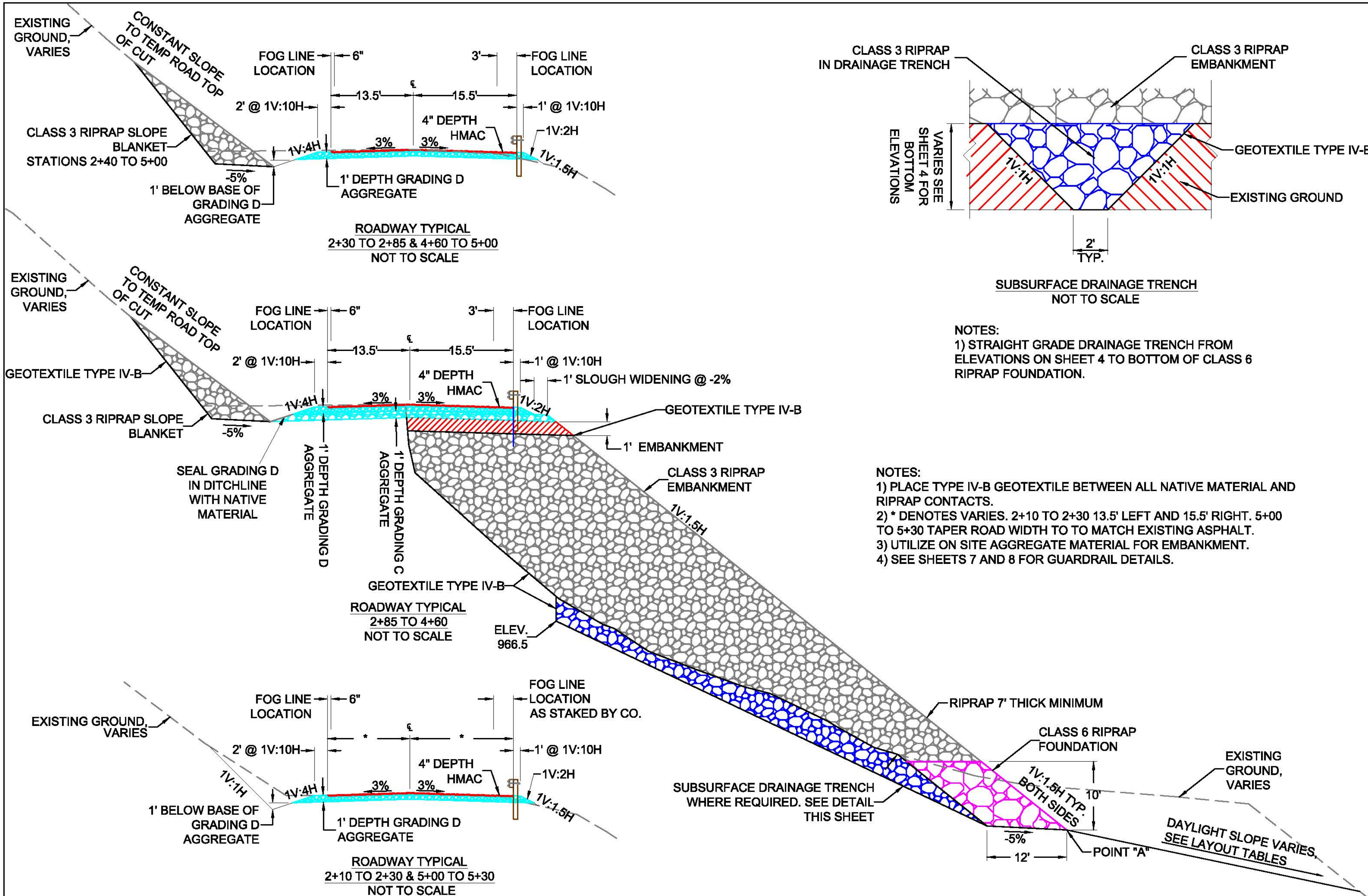
CP #	NORTHING	EASTING	ELEVATION	DESCRIPTION
1	4755.88	9755.88	1006.84	PK NAIL
2	5000.00	10000.00	1000.00	HUB
3	5122.38	10123.76	997.08	HUB
4	5204.24	10082	948.58	HUB
5	5341.72	10420.94	993	PK NAIL
6	5106.78	9909.82	917.24	HUB
7	5237.48	10239.36	995.29	HUB

SHEET 03
SHEETS 09
SHEET NAME
EXISTING SITE PLAN
PROJECT
ROAD 15 M.P. 2.25 ERFO



NOTES:
1) BLEND ALL AREAS BETWEEN CONSTRUCTION EXTENTS AND EXISTING GROUND AT 1V:1H FOR CUT SLOPES AND 1V:1.5H FOR FILL SLOPES.
2) STRIPING AND BEGINNING OF 20' PAVED TAPER INTO TERMINAL ENDS LIMITS 1+50 AND 7+10.
3) PLACE GUARDRAIL POSTS FLUSH WITH EXISTING EDGE OF ASPHALT OUTSIDE OF STATIONS 2+10 TO 5+30 EXCEPT IN TERMINAL END AREAS.

SHEET	SHEETS	SHEET NAME	PROJECT
04	09	PROPOSED SITE PLAN	ROAD 15 M.P. 2.25 ERFO



NOTES:
1) STRAIGHT GRADE DRAINAGE TRENCH FROM ELEVATIONS ON SHEET 4 TO BOTTOM OF CLASS 6 RIPRAP FOUNDATION.

NOTES:
1) PLACE TYPE IV-B GEOTEXTILE BETWEEN ALL NATIVE MATERIAL AND RIPRAP CONTACTS.
2) * DENOTES VARIES. 2+10 TO 2+30 13.5' LEFT AND 15.5' RIGHT. 5+00 TO 5+30 TAPER ROAD WIDTH TO TO MATCH EXISTING ASPHALT.
3) UTILIZE ON SITE AGGREGATE MATERIAL FOR EMBANKMENT.
4) SEE SHEETS 7 AND 8 FOR GUARDRAIL DETAILS.

PROJECT: ROAD 15 M.P. 2.25 ERFO

SHEET NAME: ROADWAY AND DRAINAGE DETAILS

SHEETS: 09

SHEET: 06

Construction

- **Confirm Foundation Assumptions**

- **Drainage Considerations**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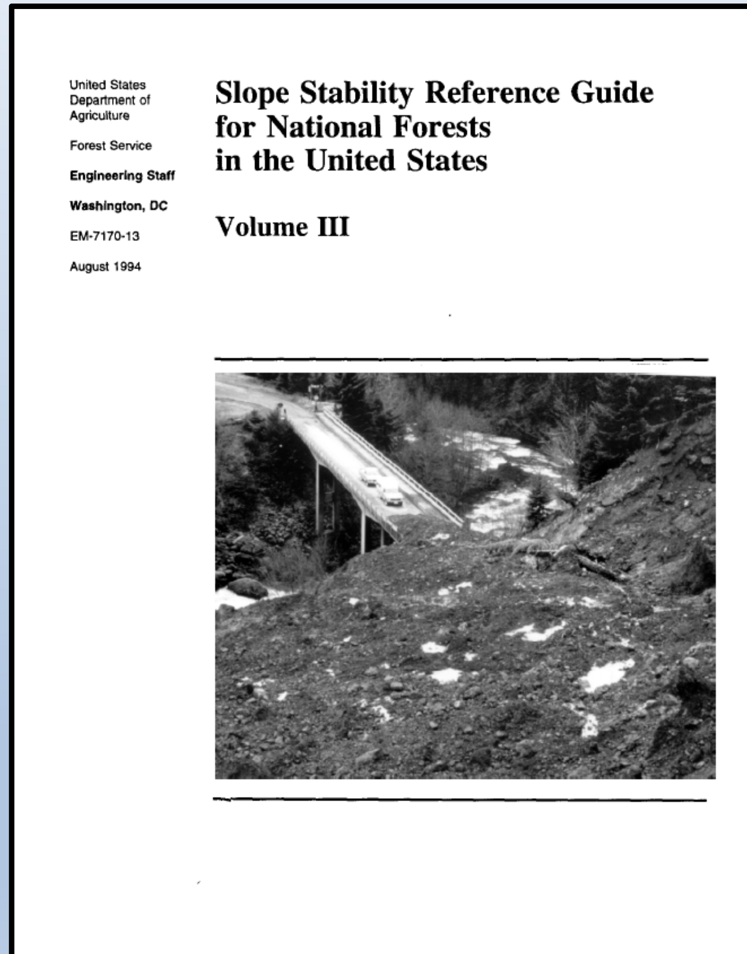
Lessons Learned

- **Creating 3-D subsurface models improve the selection of alternatives with higher degree of confidence and fewer design modifications**
- **Team effort between geotech and designer leads to quick contract package and award**
- **For critical designed slopes check the contractor for accuracy**
- **Can use same process for evaluation of retaining walls and initial rock source evaluation**

More Info and Examples…



United States
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Agriculture

Forest Service

Engineering Staff

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Volume III