Effects of Slope Stability Evaluation on Highway Bridge Design

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Introduction

Highway Bridge ends on either slopes (embankment slope or cut slope) or retaining walls

Overall stability evaluation is required for design of both slopes and retaining walls.

Owner specifies factor of safety (FS) for stability evaluation

Introduction

AASHTO LRFD 2012 6th ED 11.6.2.3

- Where the geotechnical parameters are well defined, **and** the slope does not support or contain a structural element .... RF=0.75 (FS=1.33)
- Where the geotechnical parameters are based on limited information, **or** the slope contains or supports a structural element ....RF=0.65 (FS=1.54)

FS=1.5 in general accepted for Overall Stability of Bridge Slopes or Retaining Walls

Introduction

For Design of Highway Bridge Support Slopes

Existing Slopes:

- Flatten (Cut) Slope
- Stabilization
- Avoid slope (stride over slope)

Embankment Slopes:

- Slope Design (2H:1V, 3H:1V)
- Lightweight Fills (Tire Shreds, EPS)
- Strong Materials (Sandy Fills, fiber reinforced fill)
- Soil Improvement (inclusions, surcharge, stone columns….)
- Stage Construction

Case River Crossing Bridge

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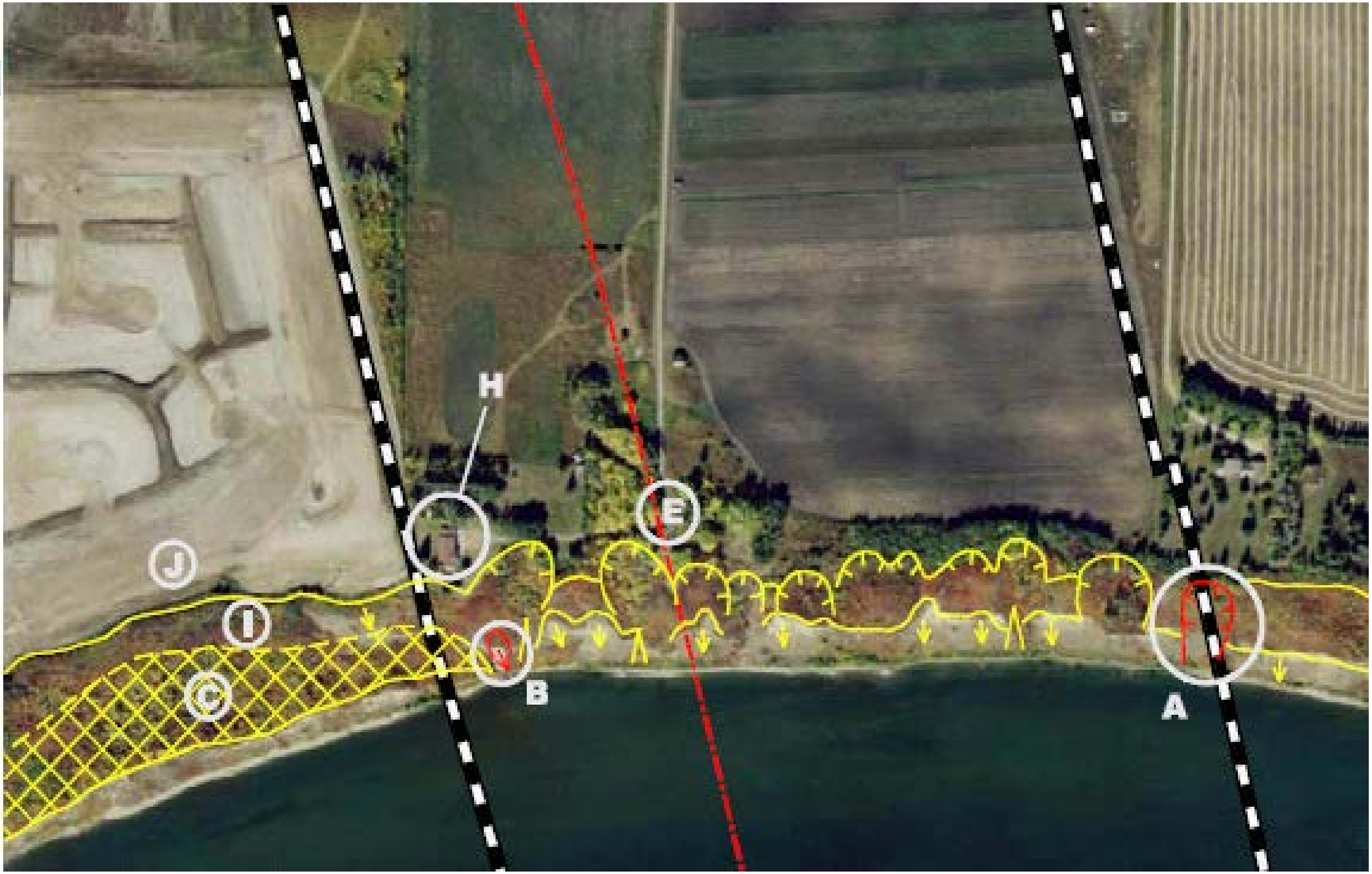
Historical Slope Failures



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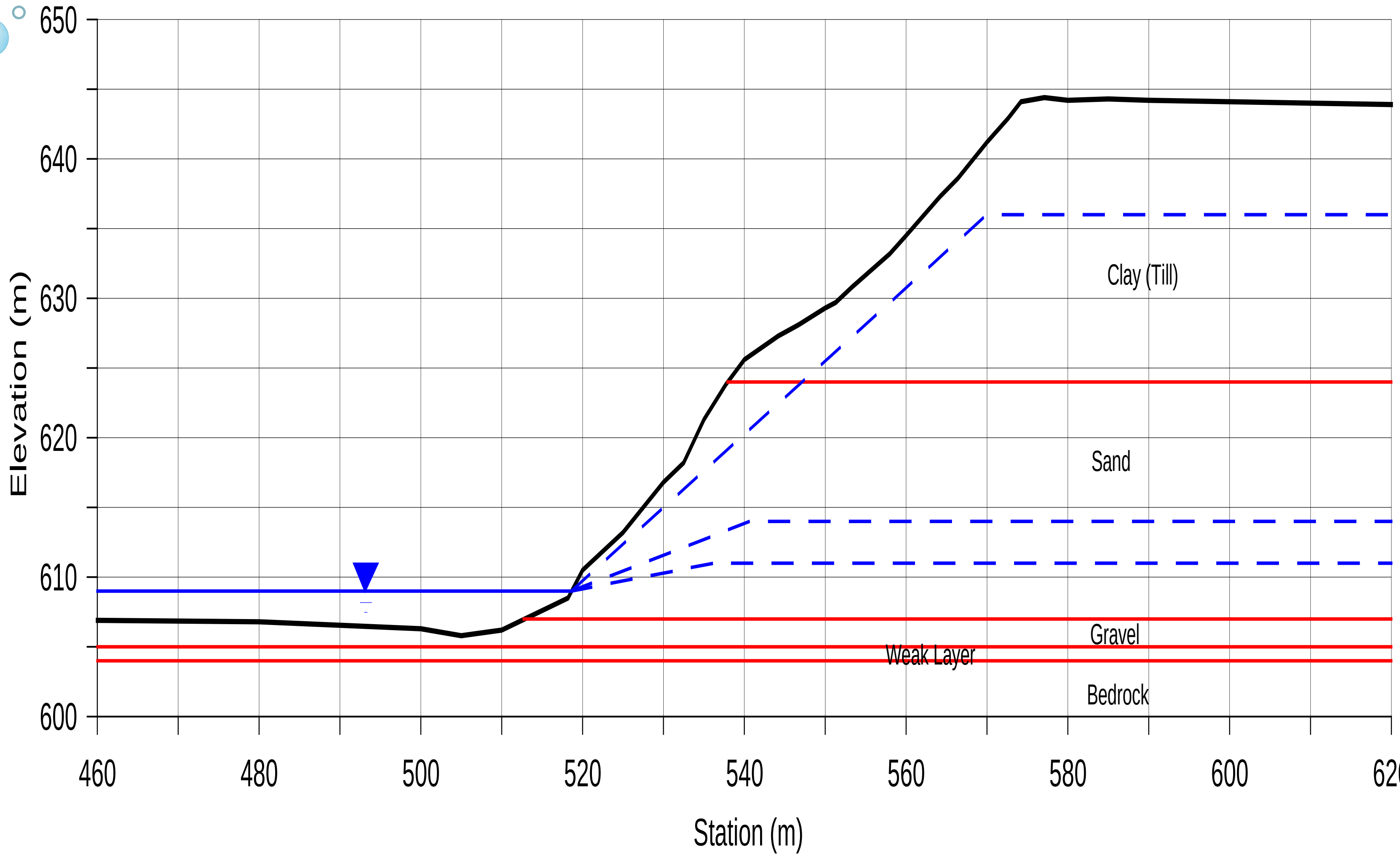
North Bank Slope Profile of Conceptual Design Study



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Slope Profile Strata

Layer 1: Clay Till -Elev. 644m to 624m

Layer 2: Pre-Glacial Sand - Elev. 624m to 607m

Layer 3: Pre-Glacial Gravel – Elev. 607m to 605m

Layer 4: Weathered Bedrock – Elev. 605m to 604
Clay Shale with bentonite.

Layer 5: Bedrock – under Elev. 604m
Clay shale and sandstone with lenses of coal and seams of bentonite

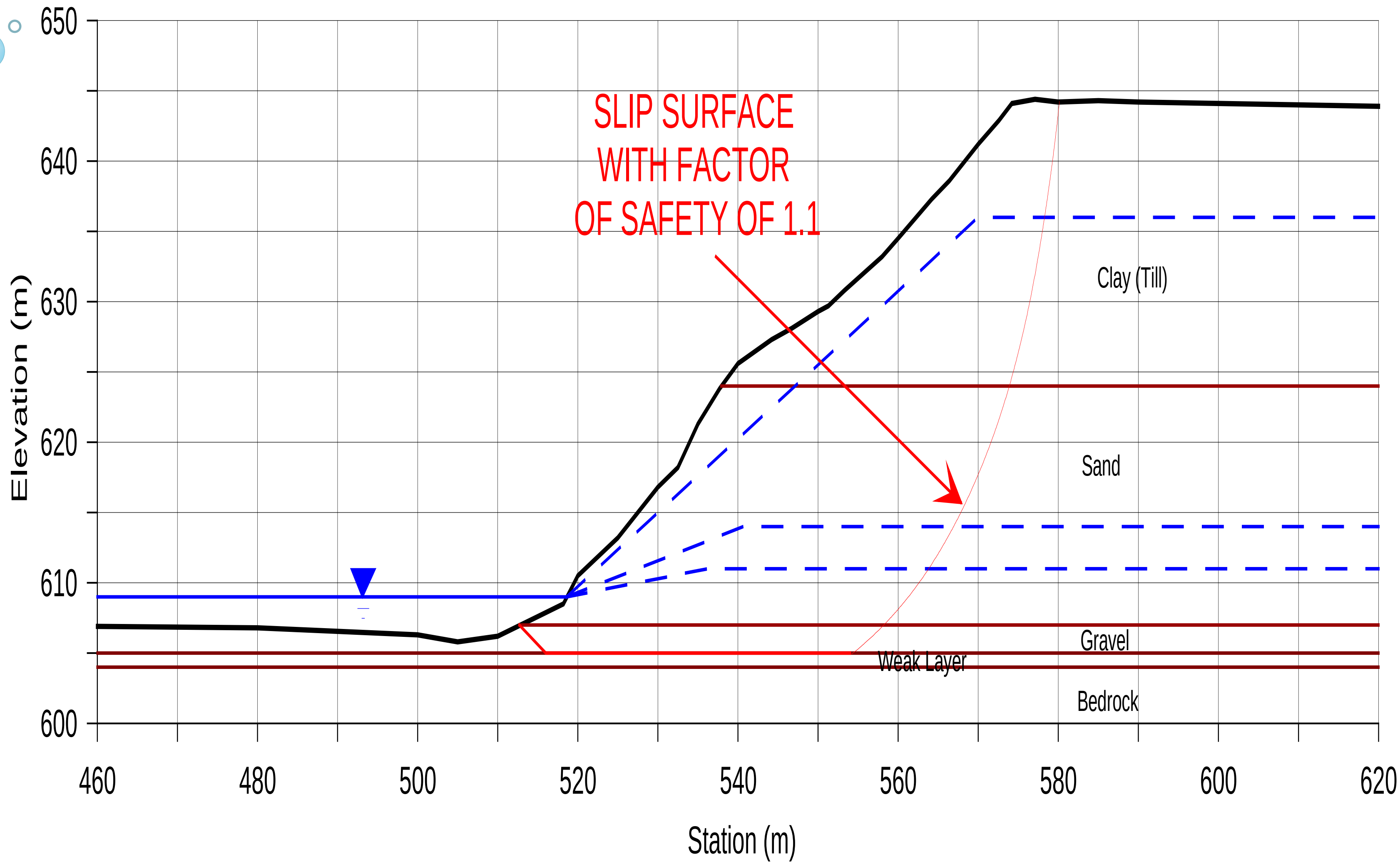
Three Water Levels:

Clay - Elev. 636m Sand & Gravel: Elev. 614m
Bedrock: - Elev. 611m

North Bank Slope Soil Properties of Conceptual Design Study

Layer	Unit Weight (kN/m^3)	Friction Angle (^{0})	Cohesion (kPa)
Clay (Till)	20	24	5
Sand	19	40	0
Gravel	21	35	0
Weak Layer	17	14	0

Most Critical Slip Surface and Factor of Safety in Conceptual Design



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Slope Stability Evaluation (North Bank Slope)

Assumptions:

- Existing North Bank Slope was marginally stable (FS≈1.0);
- Soil Profile (strata and water levels) developed based on conceptual design;
- Most of soils properties were based on Conceptual design, friction angle of the weak layer was developed based on back analyses

Methods:

- Conventional Limited Equilibrium Method (LEM);
- 2-D Shear Strength Reduction Method (SSR) – FLAC2D;
- 3-D SSR – FLAC3D

Shear Strength Reduction Method (SSR)

• No need to assume a region and shape of the most critical slip surface.

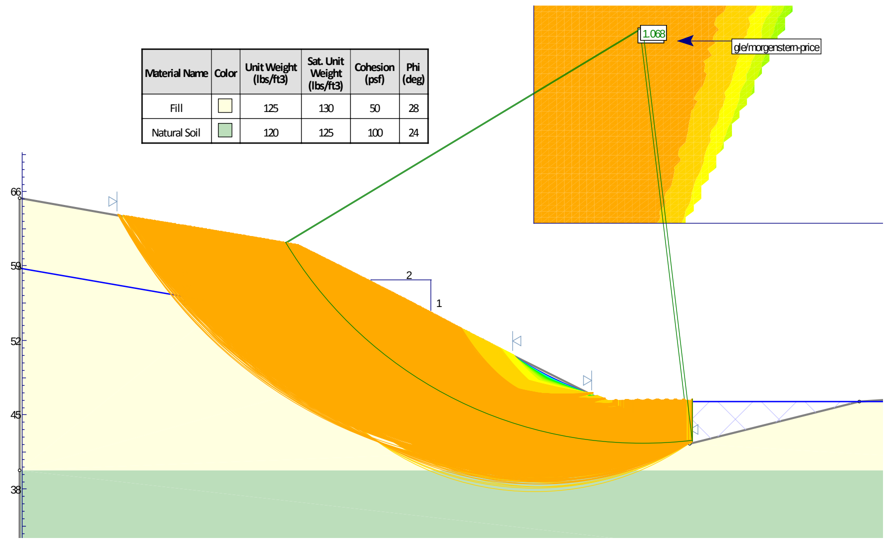
• No assumptions for interslice forces, which could potentially lead to significant differences in calculated FOS. the SSR method gives a unique solution.

• SSR method is able to simulate and thus account for the spreading effect of external stresses/forces applied beyond the most critical slip surface; the LEM considers the applied external stresses/forces only within the most critical slip surface.

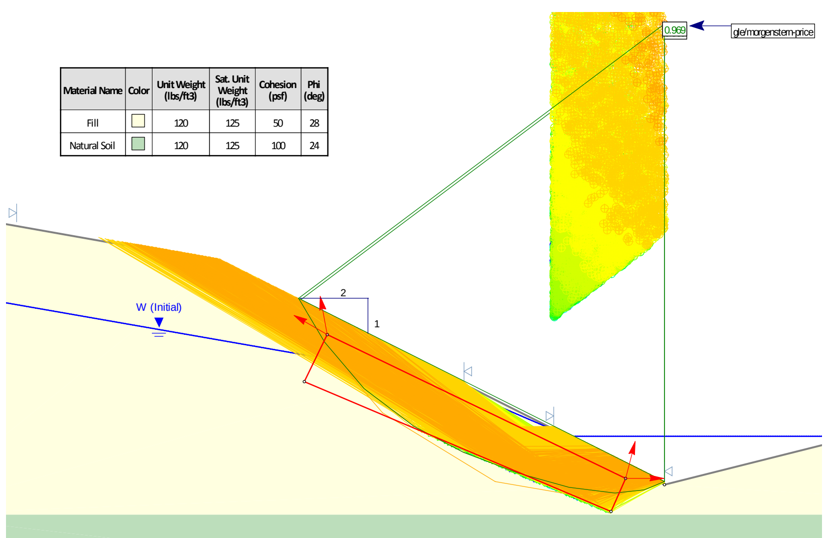
• SSR method can provide the user with slope deformation information as an output option.

Shear Strength Reduction Method (SSR)

- No need to assume a region and shape of the most critical slip surface.



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
Fill		125	130	50	28
Natural Soil		120	125	100	24



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Shear Strength Reduction Method (SSR)

- No assumptions needed, which could potentially lead to significant differences in calculated FOS. the SSR method gives a unique solution.

Table 2.5 Assumptions used in various methods of analysis (× means not satisfied and √ means satisfied)

Method	Assumptions	Force equilibrium X	Force equilibrium Y	Moment equilibrium
1 Swedish	$P = V = 0$	×	×	√
2 Bishop simplified	$V = 0$ or $\Phi = 0$	×	√	√
3 Janbu simplified	$V = 0$ or $\Phi = 0$	√	√	×
4 Lowe and Karafiath	$\Phi = (\alpha + \beta)/2$	√	√	×
5 Corps of Engineers	$\Phi = \beta$ or $\Phi_{i-1,i} = \frac{\alpha_{i-1} + \alpha_i}{2}$	√	√	×
6 Load transfer	$\Phi = \alpha$	√	√	×
7 Wedge	$\Phi = \phi$	√	√	×
8 Spencer	$\Phi =$ constant	√	√	√
9 Morgernstern–Price and GLE	$\Phi = \lambda f(x)$	√	√	√
10 Janbu rigorous	Line of thrust (Xp)	√	√	√
11 Leshchinsky	Magnitude and distribution of N	√	√	√

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Shear Strength Reduction Method (SSR)

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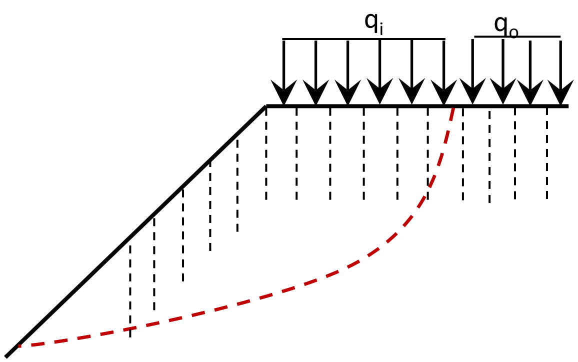
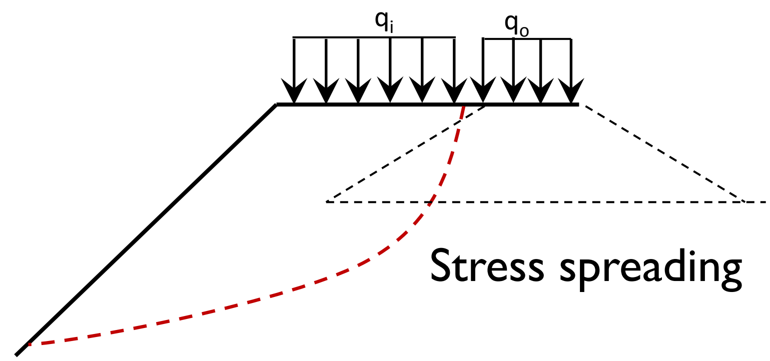


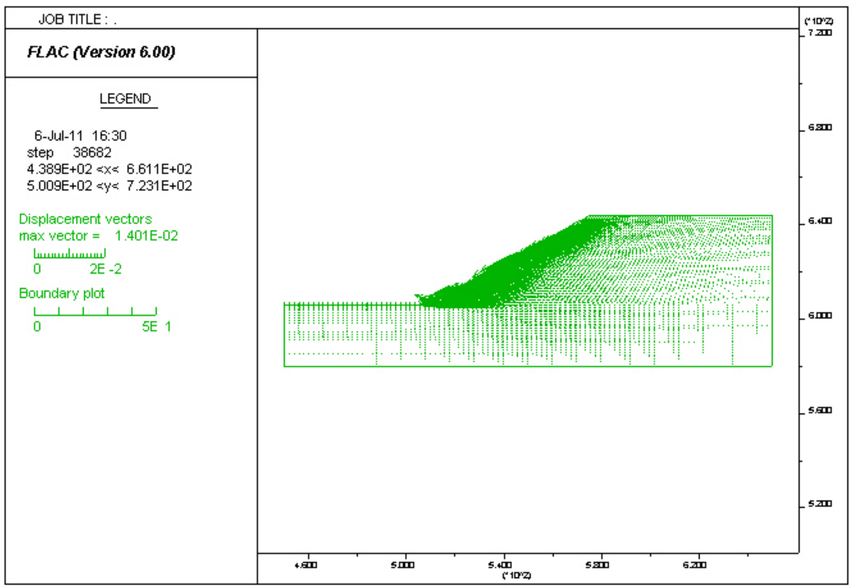
LEM

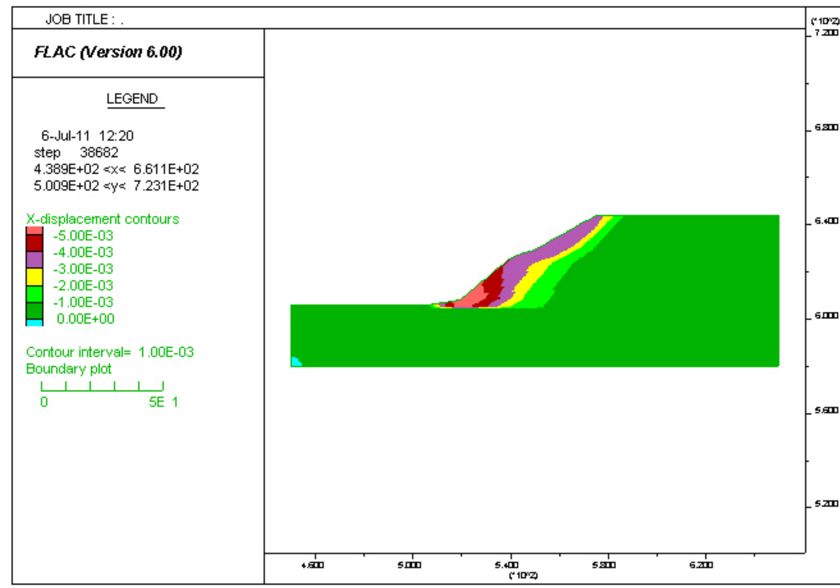


SSR

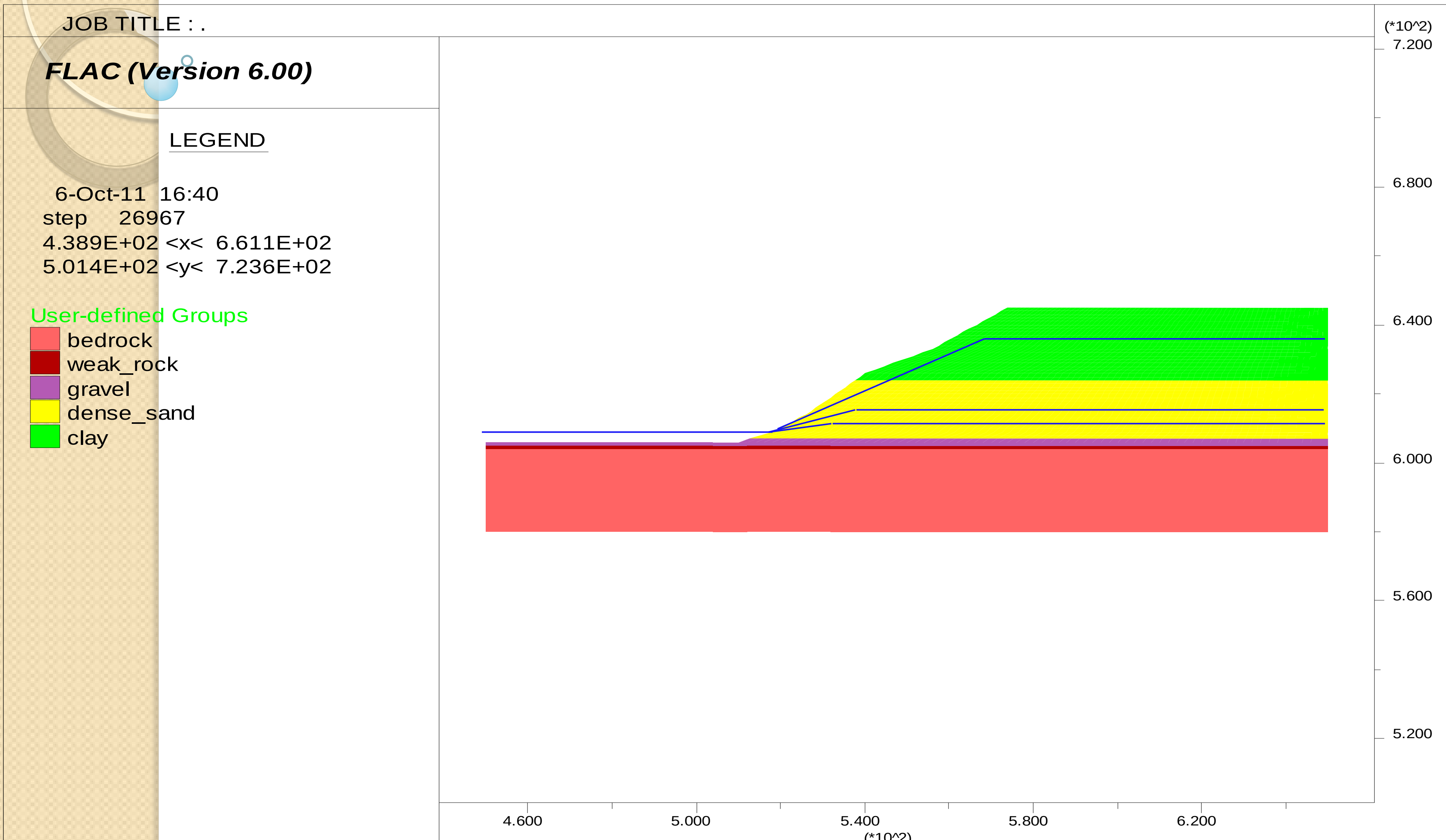
Shear Strength Reduction Method (SSR)

- SSR method can provide the user with slope deformation information as an output option.





FLAC2D Model



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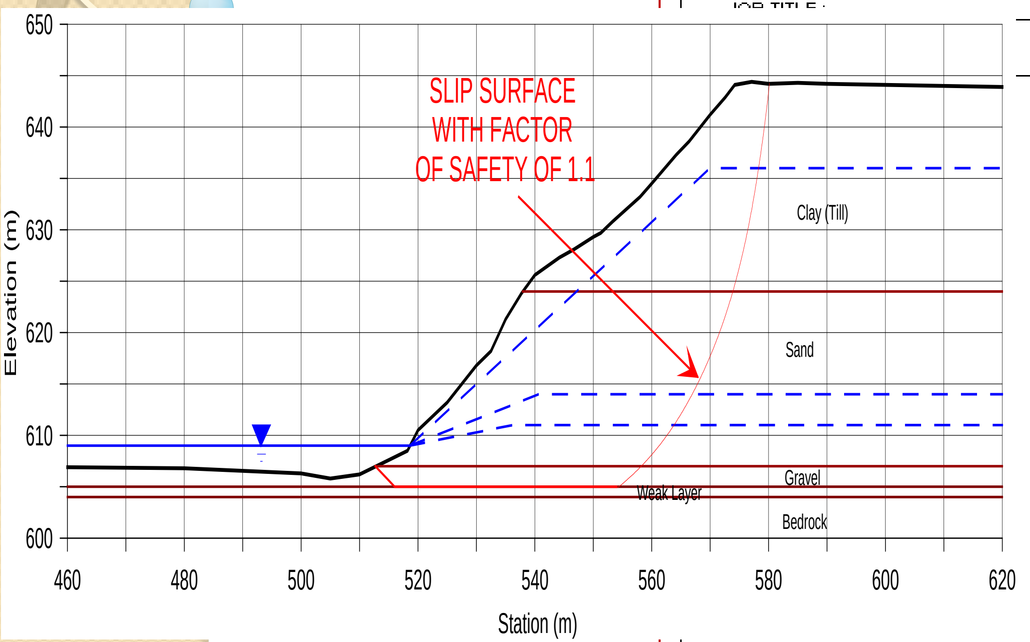
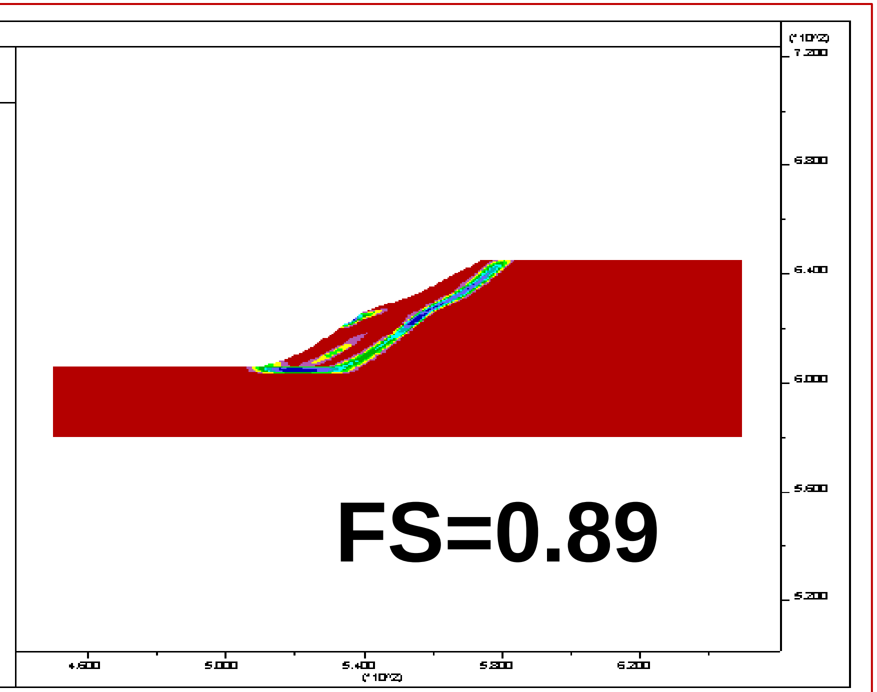
Comparison of FLAC2D & Conceptual Study





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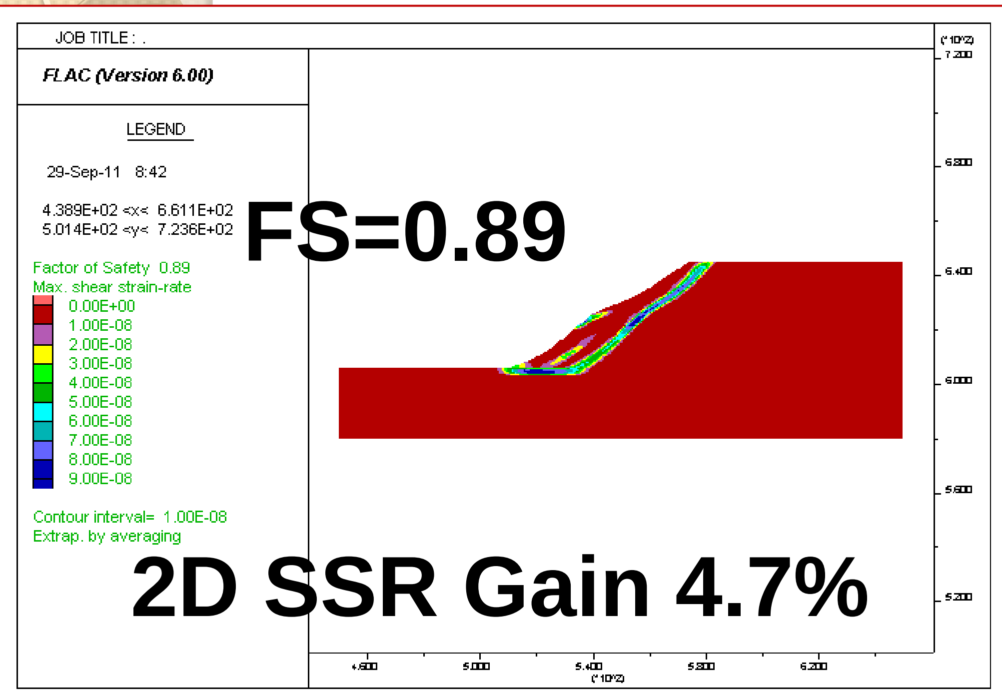
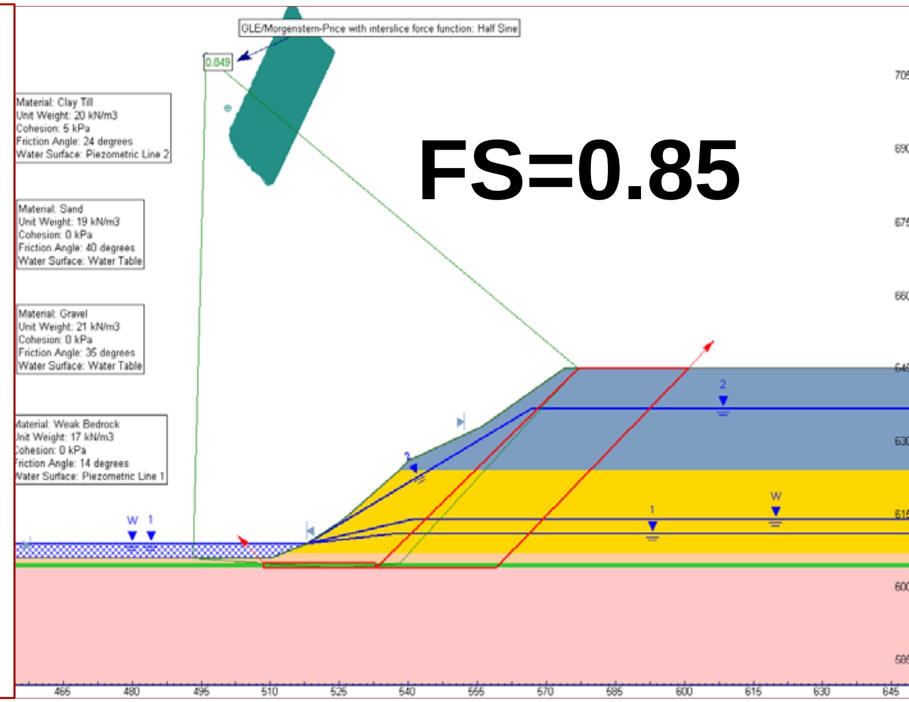


FS=0.89

2D SSR Gain 4.7%



FS=0.85

$\phi_{\text{weak layer}} = 14^0$

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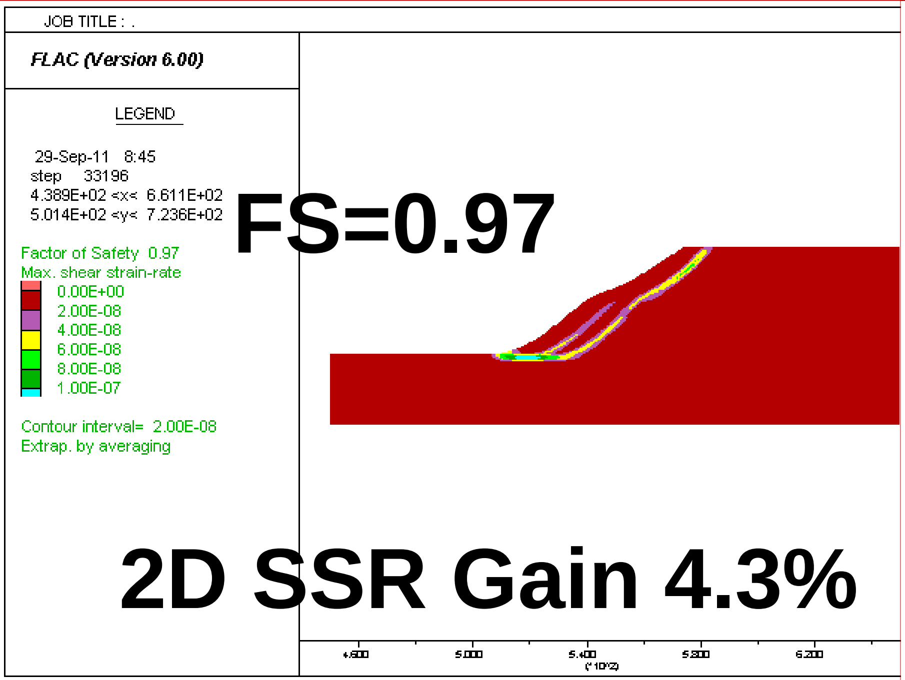
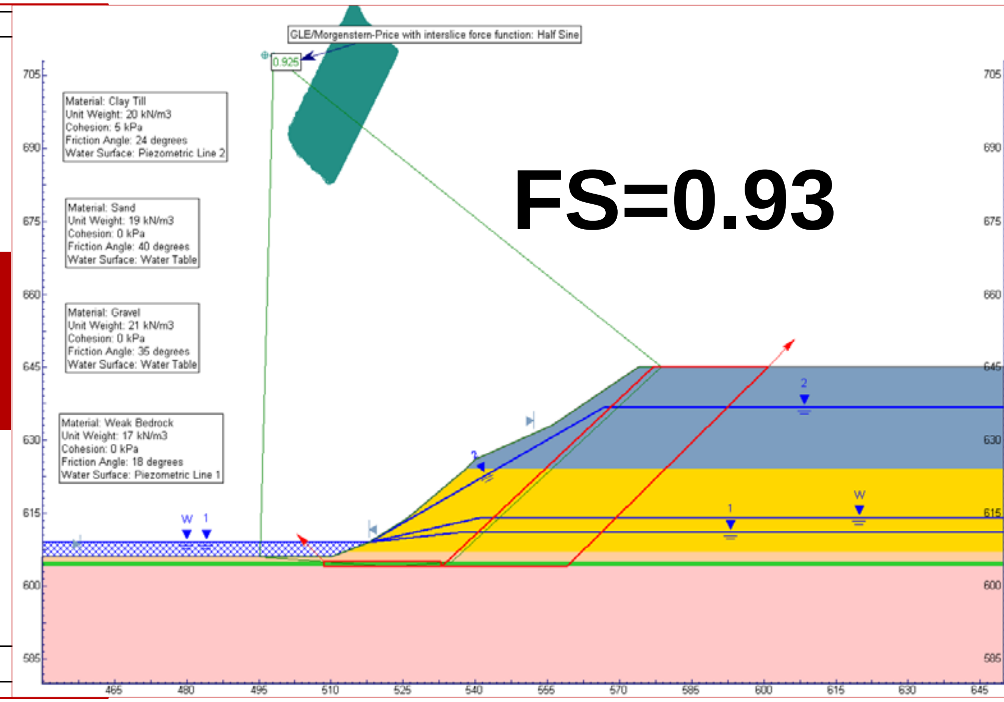


FS=0.97

2D SSR Gain 4.3%



FS=0.93

$\phi_{\text{weak layer}} = 18^{0}$

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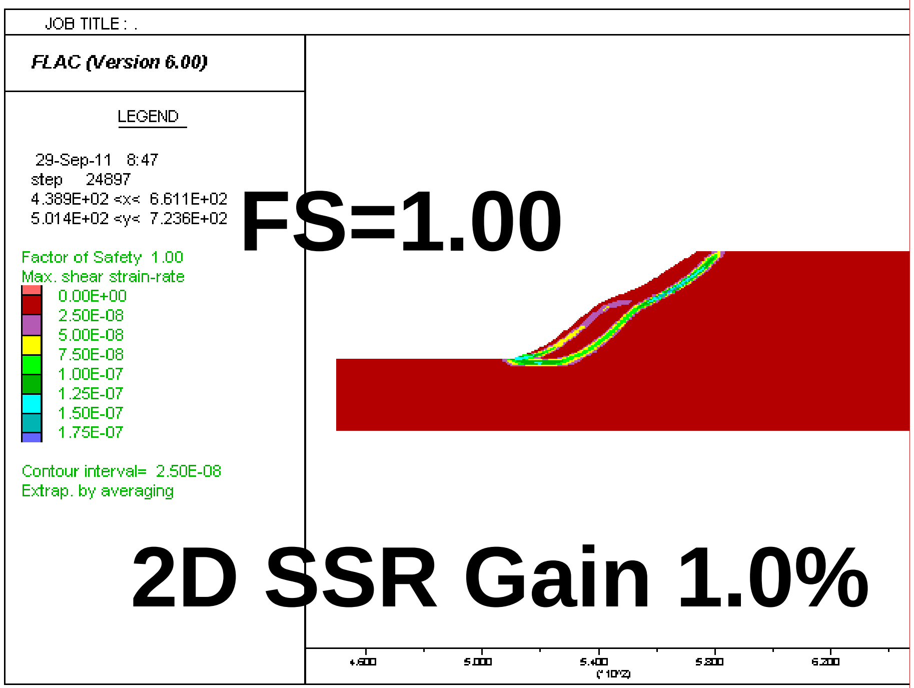
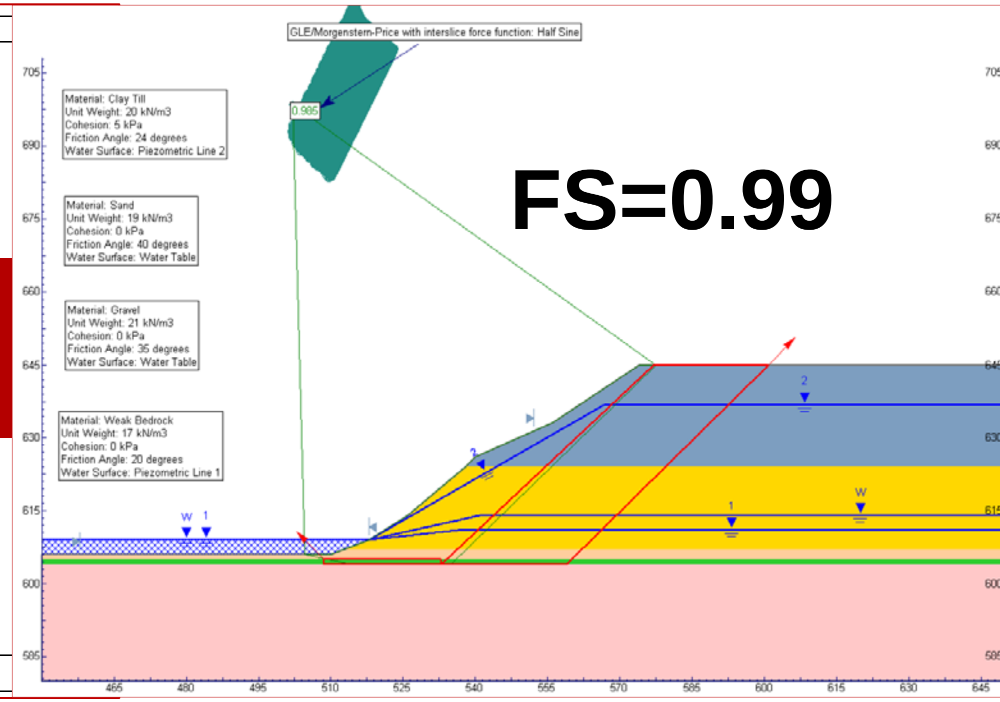
Comparison of FLAC2D & Conceptual Study



FS=1.00



FS=0.99

2D SSR Gain 1.0%

$\phi_{\text{weak layer}}=20^0$

2D SSR Versus LEM

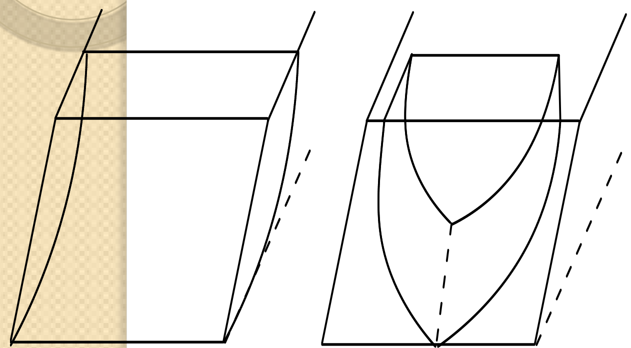
- LEM in conceptual design missed the most critical slip surface resulting in lower friction of the weak layer back analyzed;

- In this study, 2D SSR achieved slight gain of Factor of Safety (less than 5%) compared to 2D LEM;

- SSR is more reliable to identify the most critical slip surface for complicated slopes.

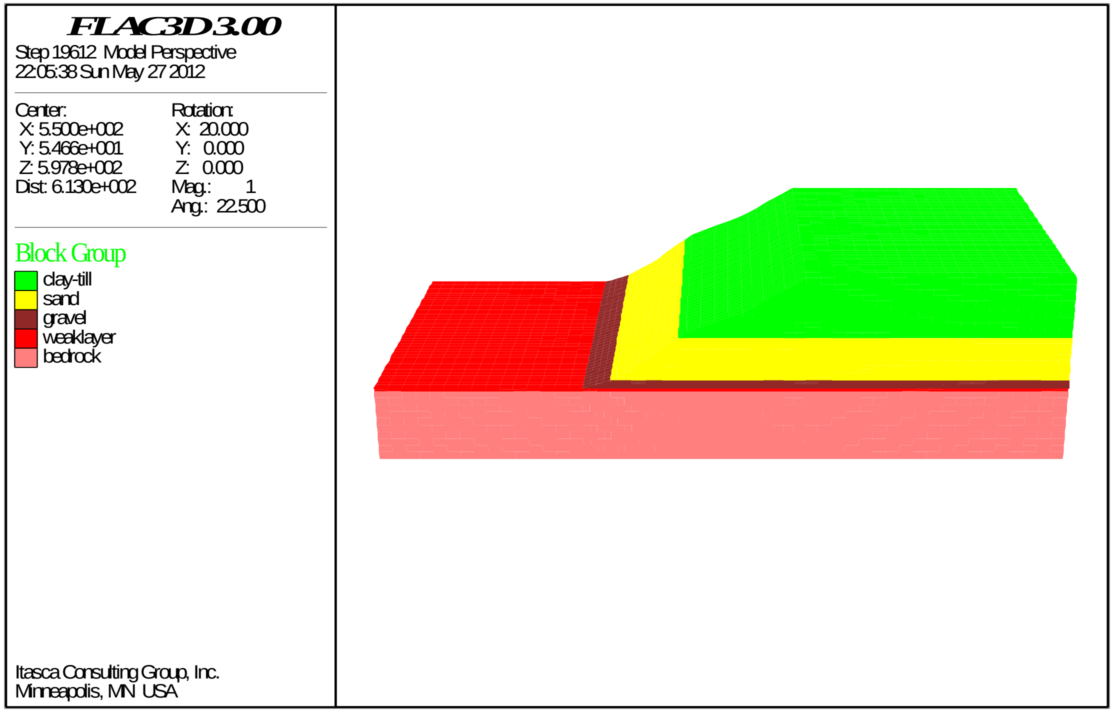
- Based on SSR back analyses, friction angle of the weak layer was increased from 14^0 to 20^0.

FLAC3D Model by 2D Model Extension



a. Two-Dimensional Slip Surface

b. Three-Dimensional Slip Surface



$\phi_{weak\ layer}=20^0$

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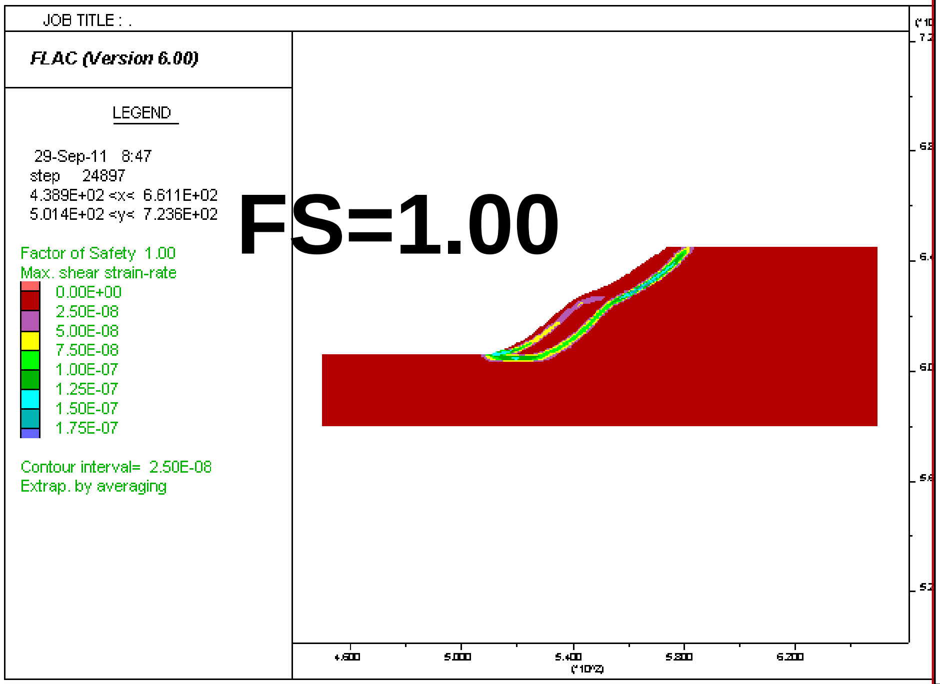
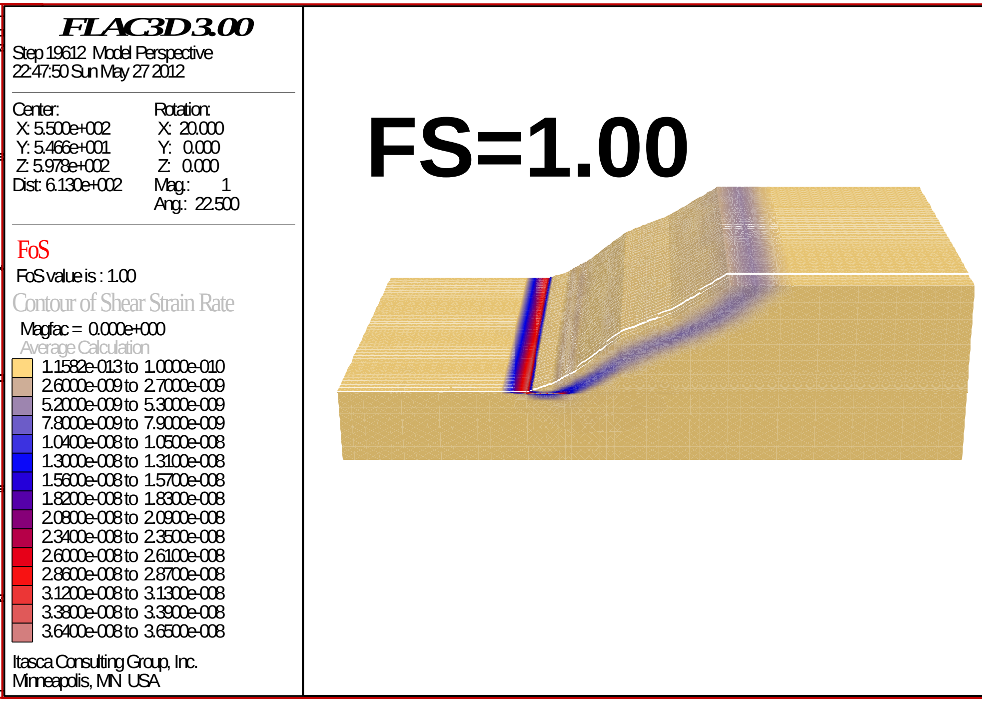
2D versus 3D Stability Evaluation





$\phi_{\text{weak layer}}=20^0$

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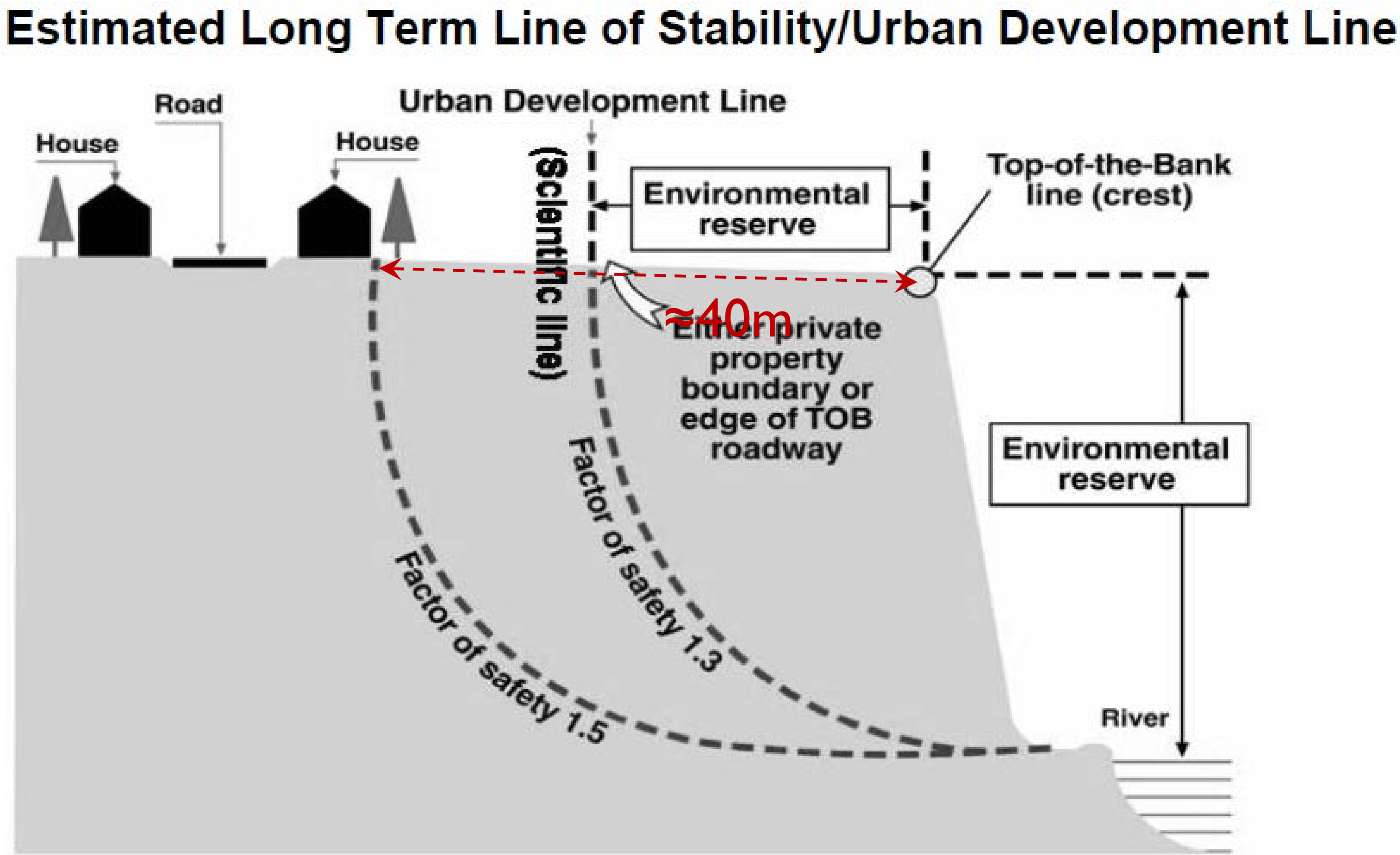
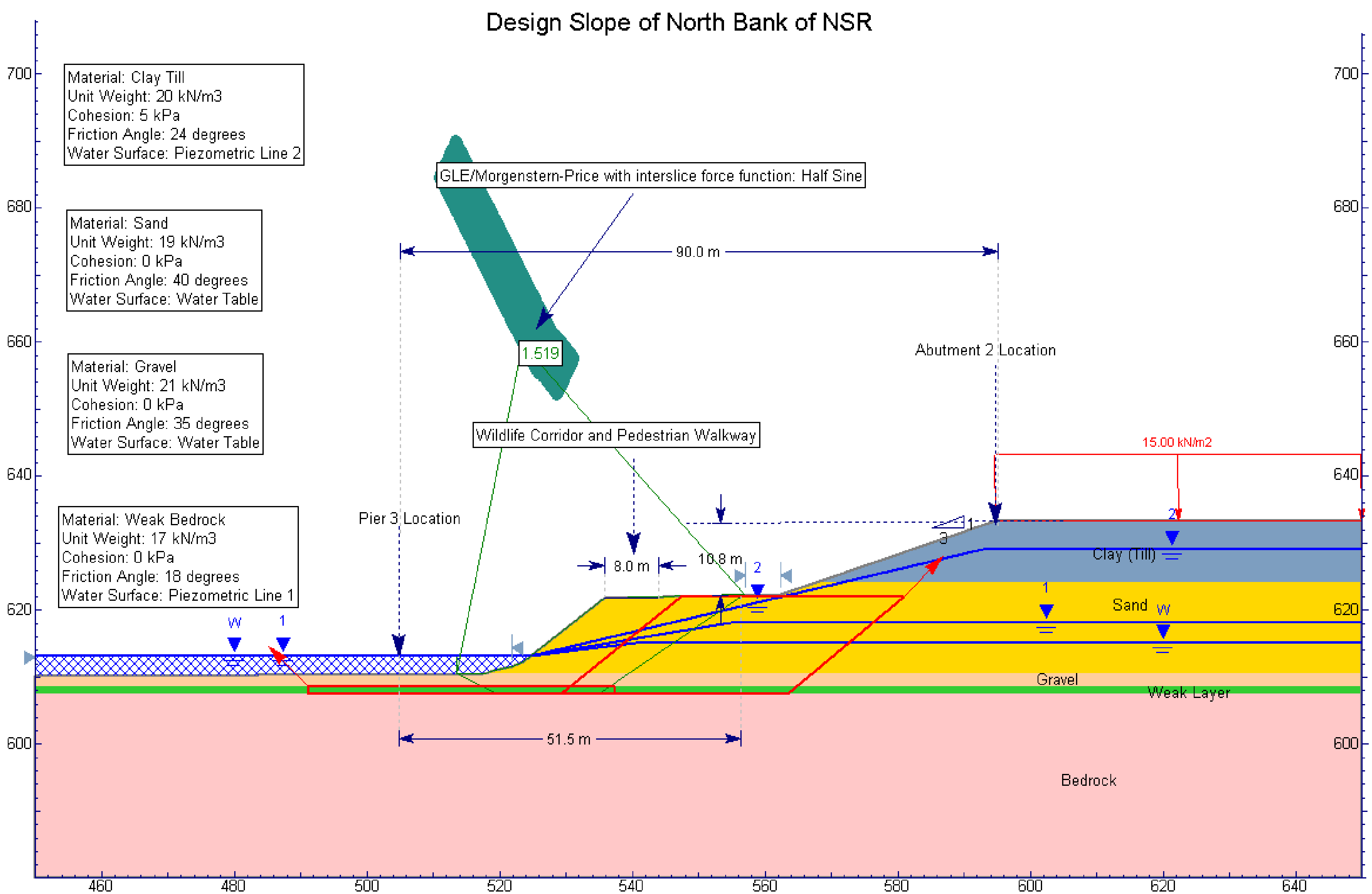
2D Versus 3D Slope Stability Evaluation

- 2D is a simplified 3D model by assuming plane strain condition.
- Both 2D and 3D models generated same factor of safety and the most critical slip surface were very similar.
- If there is no survey data and exploration data to produce real 3D model, 2D analysis is sufficient to obtain the accurate results.
- Higher accuracy can be achieved through setup of three-dimensional model based on survey data and geotechnical exploration.

North Bank Slope Design Option 1



North Bank Slope Design Option 2



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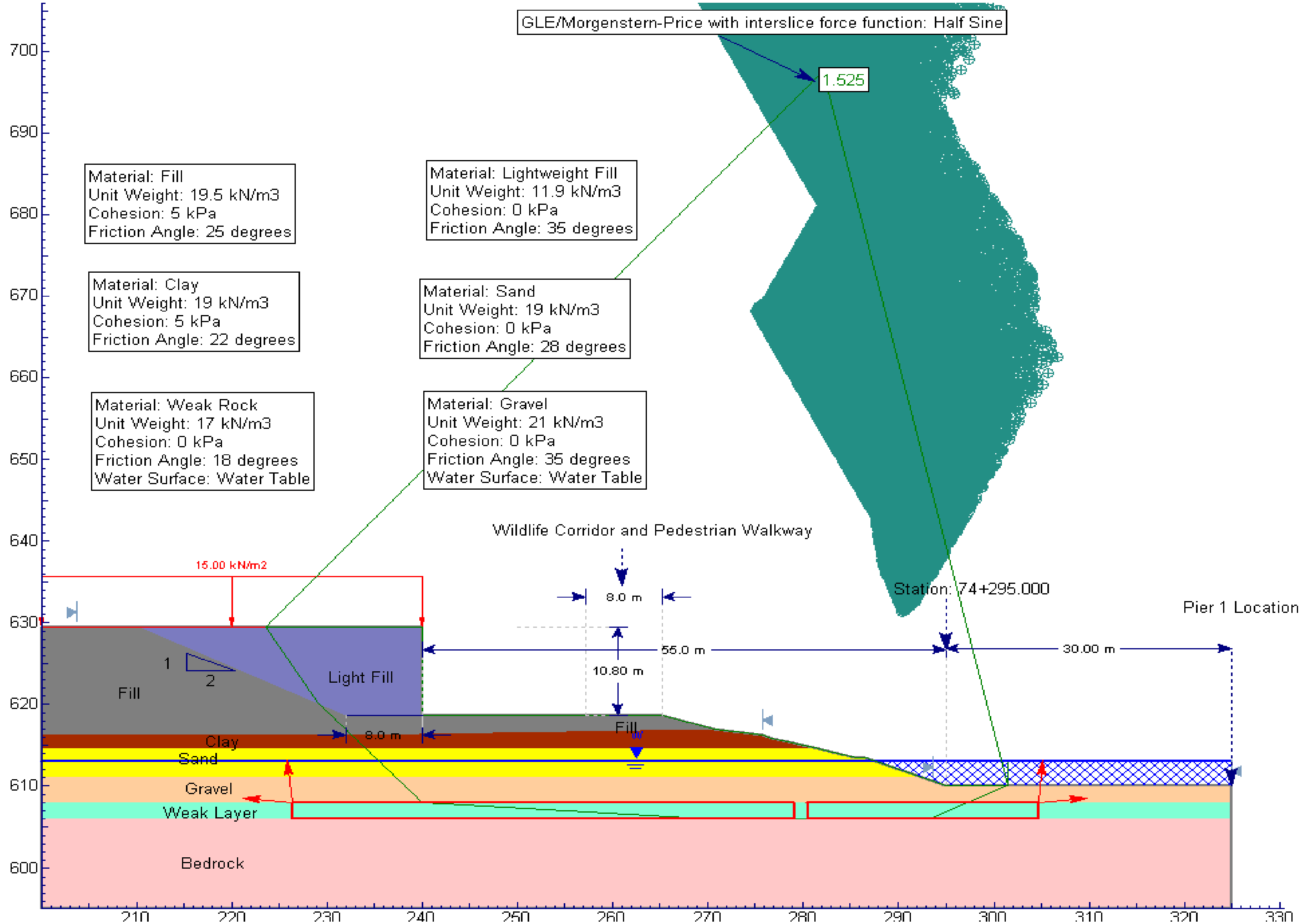
South Bank Slope Design



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QUESTIONS?