



GeoStudio Example File Maccaferri 37 m High MSE Wall

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Introduction

Maccaferri S.p.A. designed and built a mechanically stabilized earth (MSE) wall reaching a height of 40 m in Albania. The large height was achieved using rock-faced reinforced soil walls in combination with geogrid reinforcement. This example demonstrates the use of SLOPE/W to check the global and internal stability of the MSE wall. Specifically, the objectives of this case study are to: 1) demonstrate the usage of the Maccaferri reinforcement library in SLOPE/W; 2) illustrate the method for analyzing a two-component MSE wall (i.e. rock wall with geogrid); and, 3) systematically analyze different modes of failure.

Note that this example is for demonstration purposes only as no attempt is made to verify the analysis against real-world behaviour. Maccaferri conducted the actual analysis and design, and the presented SLOPE/W results were not compared to the original design report.

Background

The MSE wall was constructed to accommodate a roadway along the perimeter of a steep slope (Figure 1). Figure 2 shows a detailed view of the Maccaferri Terramesh rock wall system, which is a gabion structure comprised of a steel wire mesh filled with stones. Specifically, the Terramesh system consists of pre-assembled wire mesh units (cells) used to confine the stone (Figure 3). The cell is constructed using a continuous panel of mesh that comprises a base, fascia, lid, and diaphragm (dividing wall). The length of the base behind the gabion is project-specific.



Figure 1. View MSE Wall and roadway.

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Figure 2. Detailed view of the Maccaferri Terramesh rock wall.

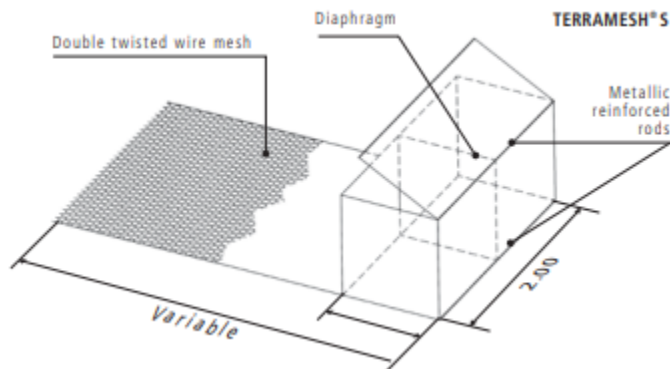


Figure 3. Details of Terramesh system (www.maccaferri.com).

Figure 4 presents a typical cross section at the site. The overall slope angle is about 34° from vertical. The stratigraphy comprises foundation soil, backfill, and structural soil, which is used as backfill behind the gabions. The MSE wall was constructed in four benches with battered walls having a face inclination of 5.7° from vertical. Construction commences with the placement of the gabion system (Figure 3). Each gabion had a height and width of 1 m and 2 m, respectively. The steel wire mesh base extended to a length of 10 m behind the face of the wall. The gabion portion is filled with stone and the lid securely fastened. Structural soil was placed behind the wall up to grade with the top of the gabion. A Maccaferri Paralink 300 geogrid was then installed prior to construction of the next layer. The length of each Paralink geogrid was governed by the distance from the wall to the face of the hillslope.

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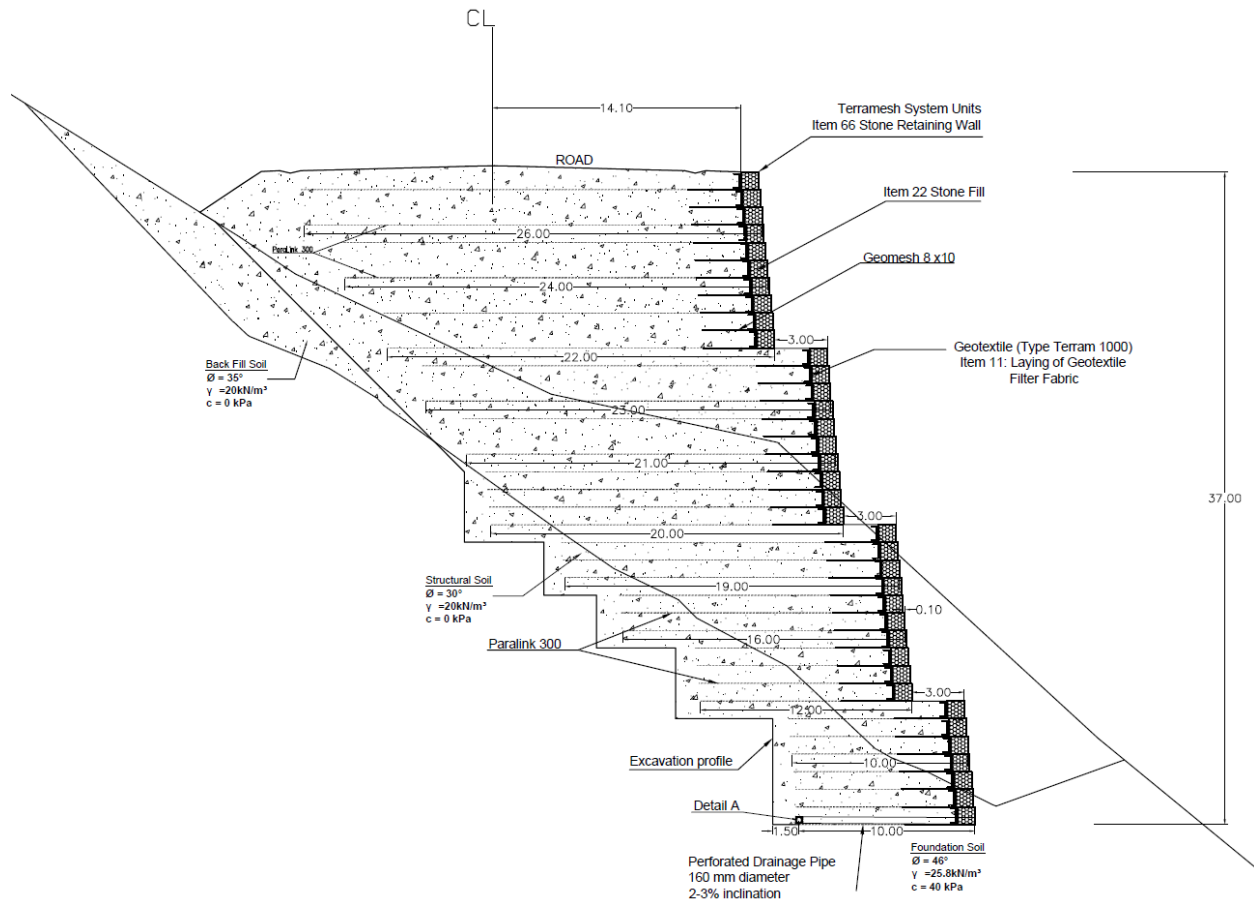


Figure 4. Typical cross-section at the site.

Numerical Simulation

The numerical simulation considers a 37-m high portion of the MSE wall (Figure 5). All of the soils were modeled using a Mohr-Coulomb material model. The GeoStudio file includes a single geometry and six SLOPE/W analyses (Figure 6). The first analysis represents the base case without reinforcement. The Paralink 300 reinforcement is included in the remaining five analyses.

Horizontal and vertical seismic coefficients of 0.062 and 0.03, respectively, are included in analyses 3 to 6. A surcharge load is applied to all analyses to account for road traffic. Analysis 4 considers the global stability of the slope, while analyses 5 and 6 assess sliding stability at the toe of benches 2 and 3. All stability calculations were conducted using the Morgenstern-Price method with the entry-exit slip surface definition. Pore water pressures are not defined in this project.

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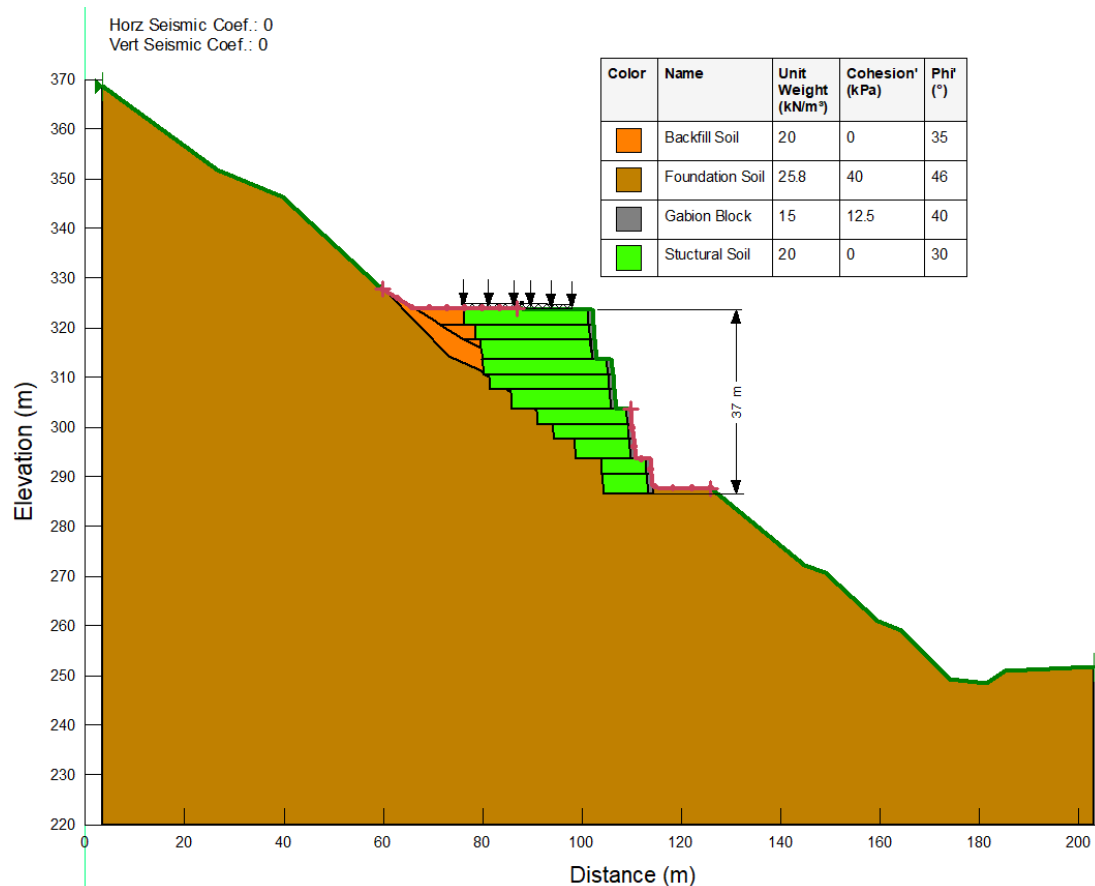


Figure 5. Geometry and material properties for SLOPE/W analyses.

Analyses

Cross Section A

- 1 No Reinforcement
- 2 Reinforcement w/o seismic
- 3 Reinforcement with seismic
- 4 Global stability
- 5 Internal Stability TMS02
- 6 Internal Stability TMS03

Figure 6. Project analysis tree.

It is good practice to analyze each mode of failure independently. This is generally accomplished by adjusting the location of the slip surface search zones. Equally important, however, is making assumptions about the influence of certain reinforcement components on the stability of the system. In this case study, the additional shear resistance of the gabion basket steel mesh is not considered. Only the shear resistance mobilized by the rock within the gabion basket is considered. An active wedge mode of failure located near the face of the slope is also not considered (Figure 7). This mode of failure would be stabilized via the Terramesh

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system. As such, the 10 m long reinforcement steel wire mesh base is not included in the analyses.

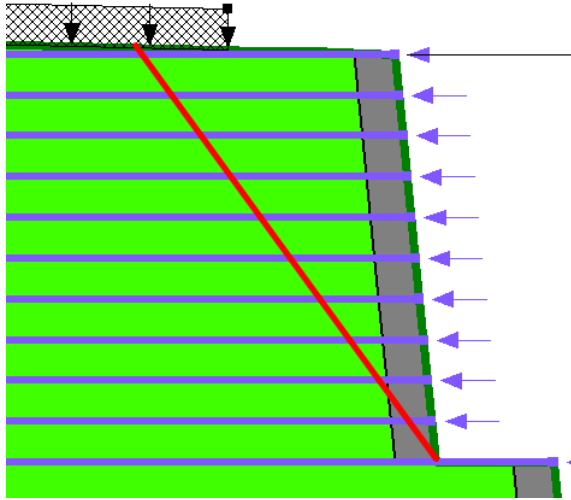


Figure 7. Active wedge failure not considered in this case study.

The Paralink 300 reinforcements were created in eleven sets using the Draw Reinforcement Set command (Figure 8). Each reinforcement set is installed horizontally, with a vertical spacing of 1 m. The reinforcement sets are named PMS01, PMS02, and so on, to associate with the Paramesh Systems (PMS; Terramesh System combined with Paralink) installed on benches 1 to 4. A reinforcement set is a convenient approach for drawing groups of reinforcements with similar geometric configurations (i.e., length, angle, and spacing).

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The screenshot shows the 'Define Reinforcement Sets' dialog box. At the top, there's a list of reinforcement sets: TMS01-1, TMS01-2, TMS02-01, and TMS02-02. 'TMS01-1' is selected. To the right of the list are 'Add' and 'Delete' buttons. Below the list, the 'Name' field is filled with 'TMS01-1'. The 'Reinforcement' dropdown menu is set to 'Maccaferri Paralink 300'. The 'Set Range' section has a checkbox for 'Lock to ground surface' which is unchecked. Below it, 'Start Point' is defined by two input fields: '114.44 m' and '286.558 m'. 'End Point' is defined by two input fields: '114.13707 m' and '289.558 m'. The 'Orientation and Length' section has 'Orientation' set to 'Horizontal' and 'Left', and 'Length' set to '10 m'. The 'Spacing' section has 'Spaced' set to 'Vertically'. Below that, there are two radio buttons: 'Number of Reinforcements' (unchecked) and 'Distance Between Reinforcements' (checked). The 'Distance Between Reinforcements' is set to '1 m'. At the bottom right, there is an 'Ungroup' button.

Figure 8. Dialogue box for reinforcement sets.

Table 1 summarizes the inputs, calculated outputs, and selections used for the Maccaferri Paralink reinforcement. The reinforcement is created by adding a new reinforcement into the list, changing the Type to Maccaferri, selecting the model, and then choosing the product from the drop-down menu. The Paralink 300 geogrid has a tensile capacity of 301 kN/m. The factored tensile capacity, FTC , is calculated as:

$$FTC = \frac{\text{Tensile Capacity}}{RF_{ID} \times RF_W \times RF_{CH} \times f_s \times RF_{CR}} = \frac{\text{Tensile Capacity}}{\text{Overall Reduction Factor}} \quad \text{Equation 1}$$

where RF_{ID} is the reduction factor for installation damage, RF_W is the reduction factor for weathering, RF_{CH} is the reduction factor for chemical/environmental effects, RF_{CR} is the reduction factor for creep, and f_s is the reduction factor for extrapolation of the data. Selection of the D50 particle size of the fill material, the analysis type (static or seismic), operating temperature, design life, and pH conditions affects the Overall Reduction Factor according to the manufacturer's specifications. Given the selections presented in Table 1, the Overall Reduction Factor is 1.0924. The factored tensile capacity is therefore 275.54 kN/m (301 kN/m/1.0924).

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Table 1. Summary of inputs, calculated outputs, and the selection for the Maccaferri reinforcements.

Input	Calculated Output	Selection
Maccaferri Product	Tensile Capacity	Paralink 300
D50 Particle Size	Overall Reduction Factor	13 mm (coarse gravel)
Fill Material	Pullout Coefficient	Gravel
Internal Friction Angle Soil Structure	Interface Shear Angle	30°
Resistance Reduction Factor	Factored Pullout Resistance	1
Analysis	Overall Reduction Factor	Seismic
Temperature	Overall Reduction Factor	20°C
Design Life	Overall Reduction Factor	60 yr
pH	Overall Reduction Factor	4 <pH <9

The magnitude of the reinforcement load used in the analysis at solve-time is governed by either: (1) the pull-out resistance of the geogrid; or, (2) the factored tensile capacity. The pull-out resistance, PR , is calculated for each reinforcement as:

$$PR = (\sigma_v' \cdot \tan \delta) \cdot SAF \quad \text{Equation 2}$$

where σ_v' is the effective overburden stress, δ is the internal friction angle of the soil structure (i.e. interface shear angle), and SAF is a surface area factor, which accounts for the mobilized pull-out resistance on the top and bottom of the geogrid. For Maccaferri reinforcement, the SAF is generally set to 2. The interface adhesion is defaulted to zero for Maccaferri reinforcement. The interface shear angle is calculated as:

$$\text{Interface Shear Angle} = \tan^{-1} (\alpha \cdot \tan \delta) \quad \text{Equation 3}$$

where α is the pullout coefficient. The pullout coefficient varies from 0.7 to 0.9, depending on the selection for the backfill material. The factored pull-out resistance, FPR , is calculated at solve time as:

$$FPR = \frac{PR}{RF_R} \quad \text{Equation 4}$$

where RF_R is the resistance reduction factor, which can be used to account for a variety of issues such as non-linear stress reduction over the embedded length, or installation damage

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and deterioration. This value is generally set to 1.0 for Maccaferri reinforcement. In the case of a Partial Factor analysis (e.g. Eurocode 7), the factor is automatically applied.

The face anchorage option was set to true, assuming that the connection strength of the reinforcement to the gabion is not less than the tensile capacity of the reinforcement. The reinforcement load used in the analysis is determined at solve time. The reinforcement load is calculated as the FPR multiplied by the length of reinforcement behind the slip surface. The lesser of the reinforcement load and the factored tensile capacity is used in the Factor of Safety calculations.

Finally, it should also be noted that SLOPE/W can only be used to analyze the stability of a sliding mass. Slip surfaces that pass through the reinforced zone benefit from the reinforcement behind the slip surface, however, the results cannot be used to evaluate rupture and pullout. Internal stability related to these modes of failure can be evaluated according to the FHWA Simplified Method (2001). An example entitled 'Stability of a Mechanically Stabilized Earth Wall' discusses this issue and is available on the Seequent website.

Results and Discussion

The unsupported slope has a factor of safety < 1.0 (Figure 9). As expected, the critical mode of failure is an active wedge-like failure with the exit point located at the toe of the MSE wall. The slip surface colour map, and the associated legend, indicate that the FOS is less than 1.0 for all slip surfaces located within the backfill and structural soil. Introduction of the Maccaferri Paralink reinforcement causes the FOS to increase to 1.52 (Figure 10), while inclusion of the horizontal and vertical seismic loads of 0.062 and 0.03, respectively, causes the FOS to decrease marginally to 1.45 (Figure 11). The critical slip surface for both Analyses 2 and 3 is located toward the back of the reinforcement because all shallower slip surface have greater reinforcement load and a higher FOS.

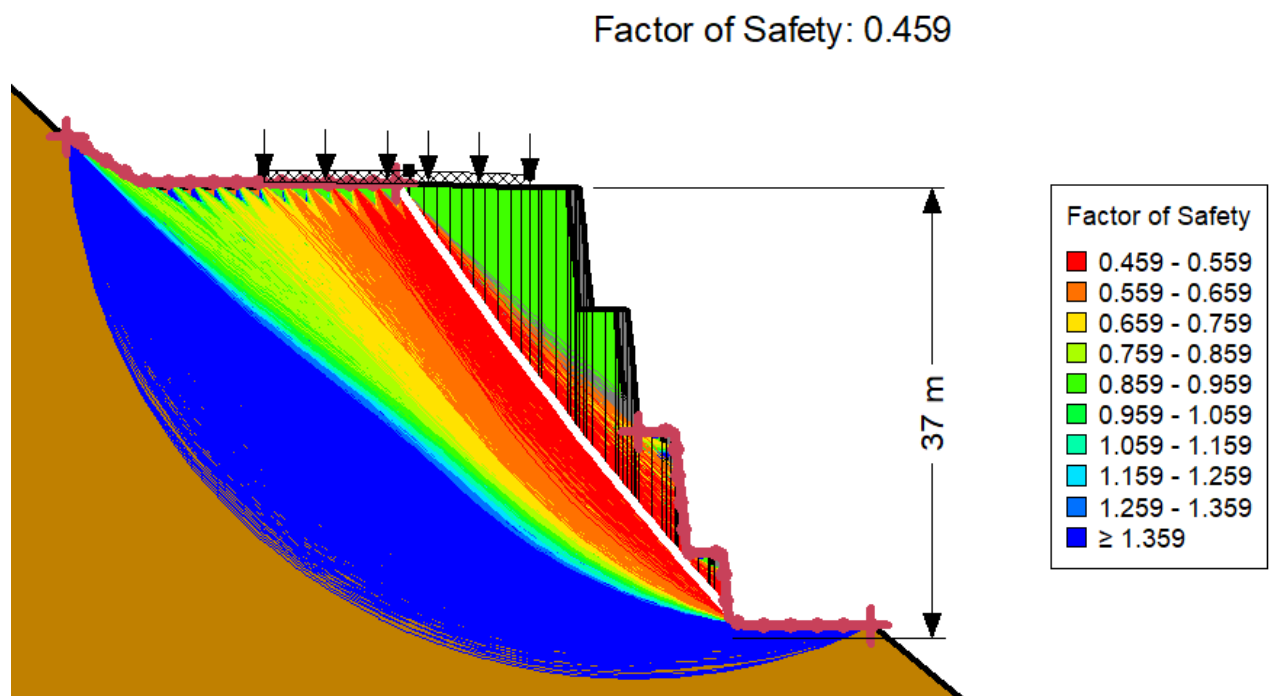


Figure 9. Stability results for the base case (Analysis 1).

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Factor of Safety: 1.523

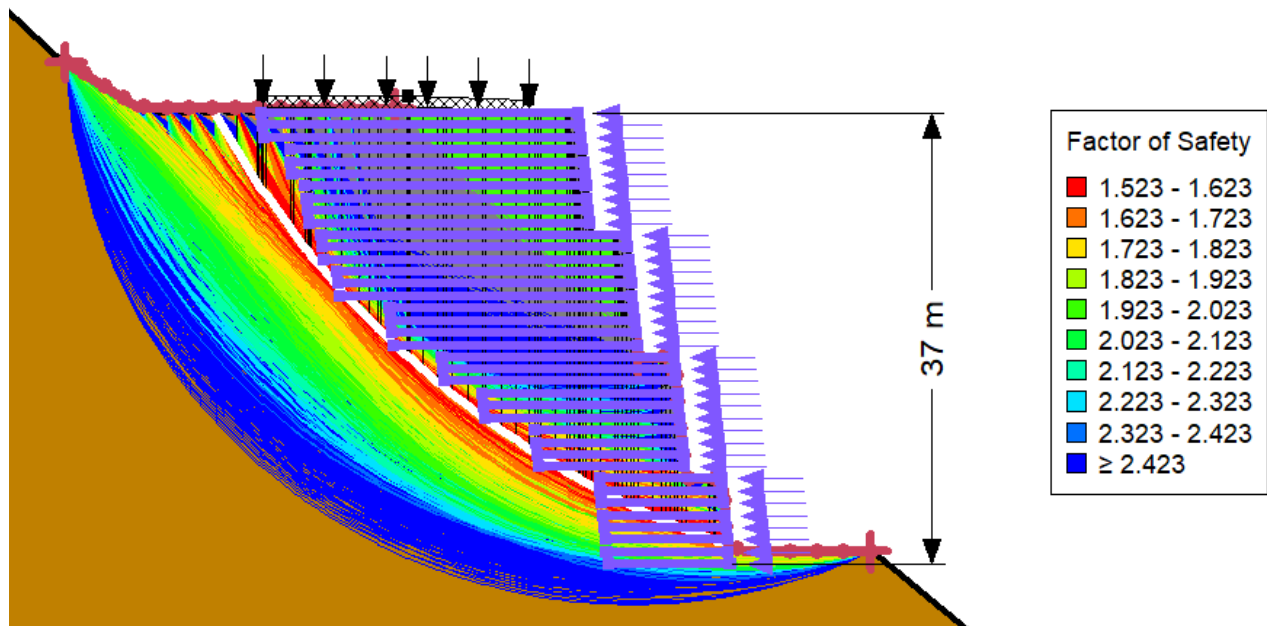


Figure 10. Stability results for analysis with reinforcement and no seismic load (Analysis 2).

Factor of Safety: 1.454

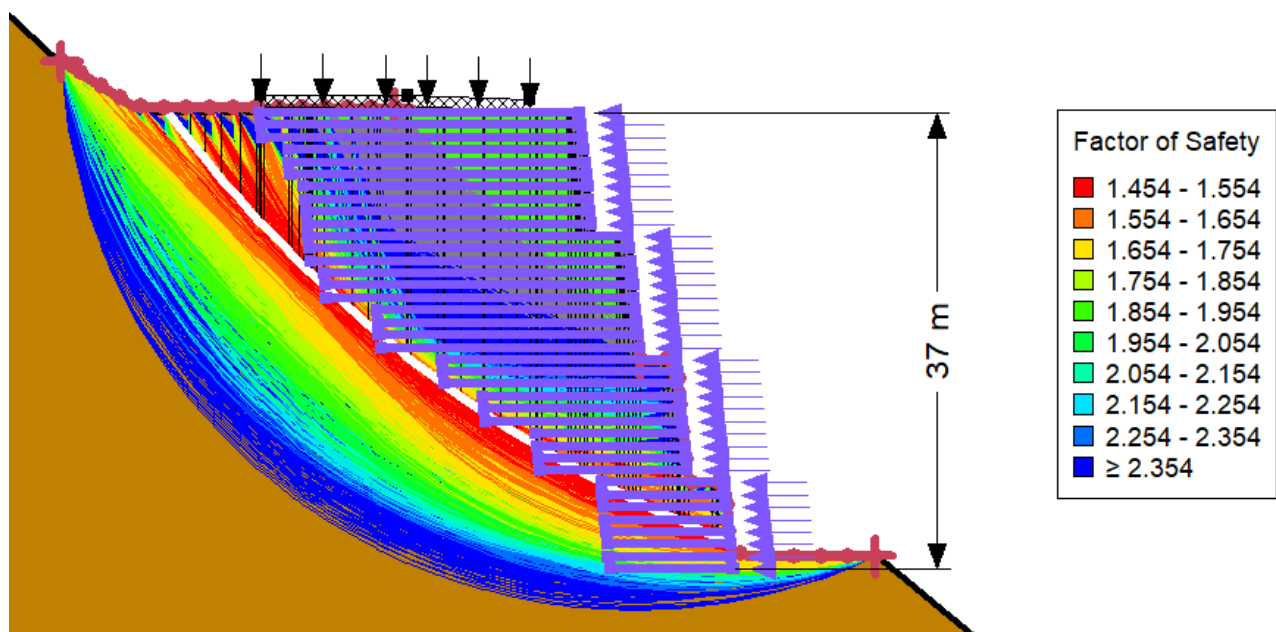


Figure 11. Stability results for analysis with reinforcement and seismic load (Analysis 3).

Figure 12 presents the FOS vs Lambda convergence plot for Analysis 3. The cross-over between the FOS-moment and FOS-force lines is unambiguous, indicating acceptable convergence. Moreover, the majority of slip surfaces in the zone of interest exhibit clean

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convergence. Most of the non-converged slip surfaces or invalid slip surface (e.g. exiting above the defined zone) are shallow. Convergence problems are common for slip surfaces with large point loads due to reinforcement. Regardless, Figure 11 demonstrates wide coverage and convergence for the key mode of failure: deep-seated movement located near the back of the reinforcement.

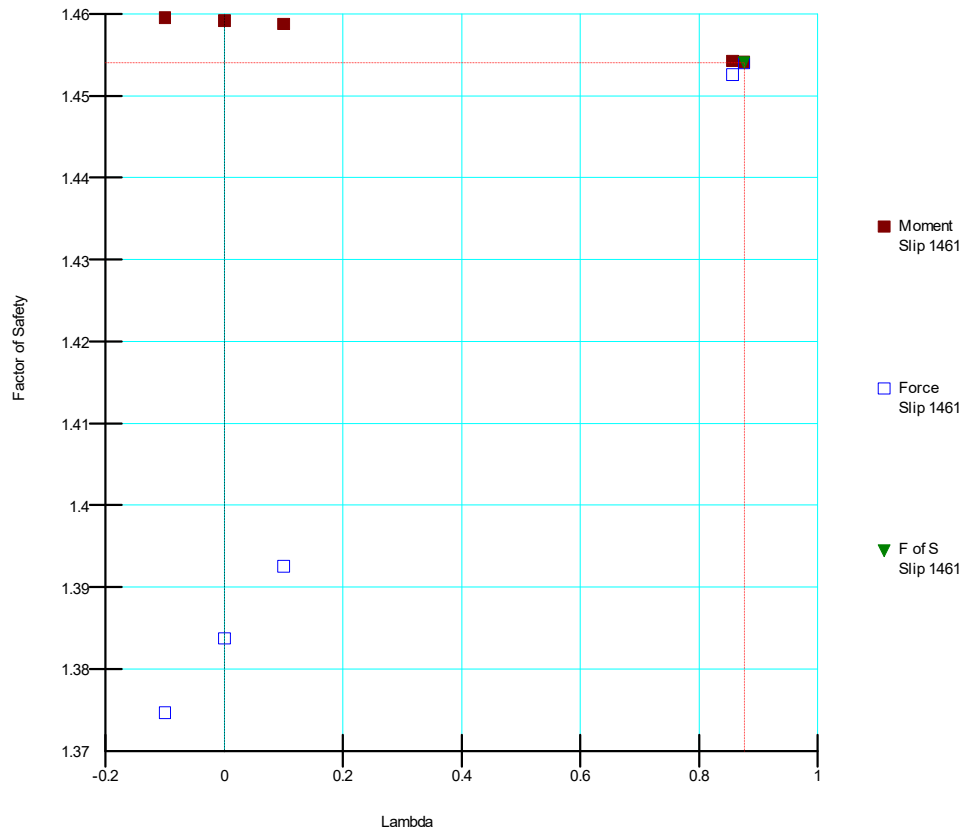


Figure 12. FOS vs lambda convergence plot for Analysis 3.

Figure 13 presents the stability results for Analysis 4. The deep-seated, global, mode of failure was investigated by moving the entry and exit zones further upslope and downslope, respectively. The critical slip surface sits directly behind the reinforcement, which means that reinforcement has no effect on stability. The factor of safety color map indicates that most of the slip surfaces have a factor of safety between 1.53 and 1.63. There is a wide shear band governing stability, as opposed to one specific slip surface.

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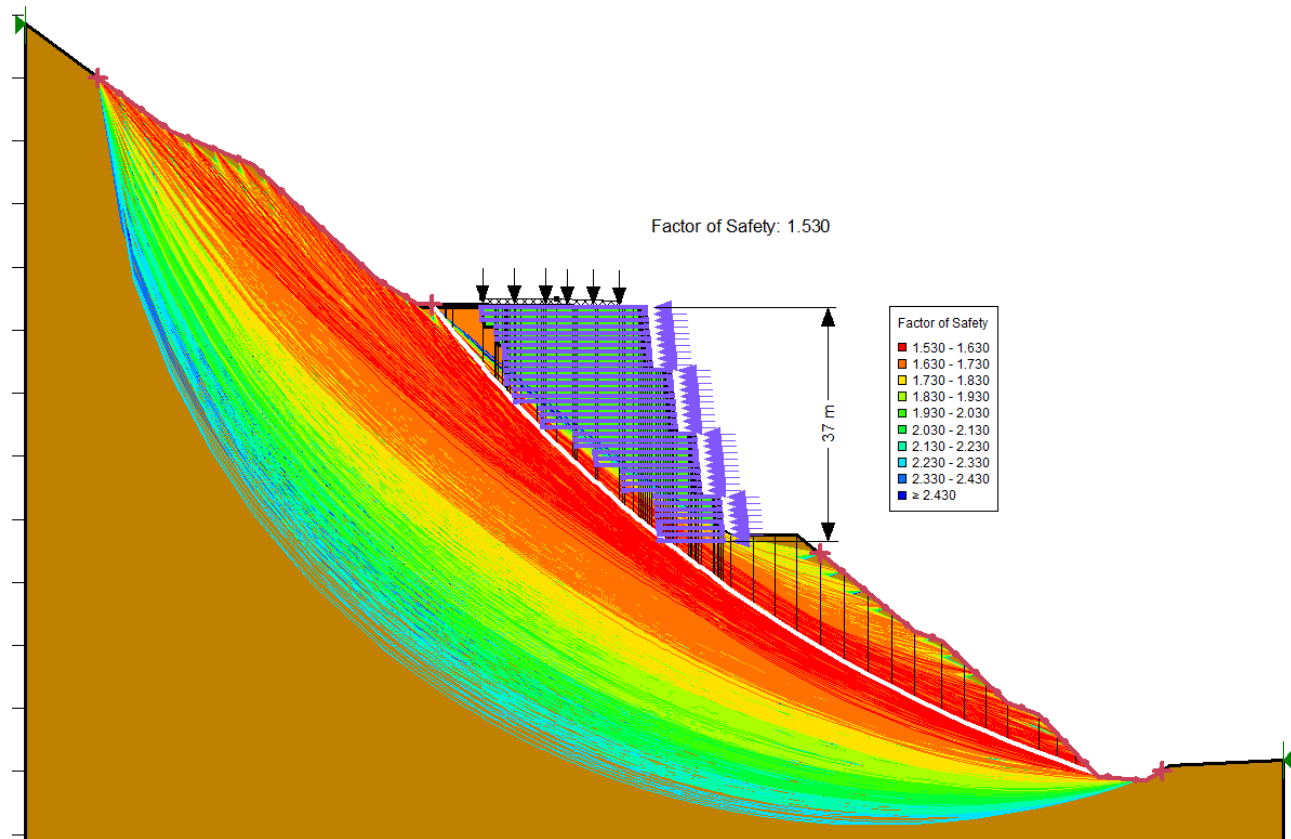


Figure 13. Stability results for the global stability analysis (Analysis 4).

Summary and Conclusions

This example analyzes the stability of a 37 m tall mechanically stabilized earth wall built using the Maccaferri Terramesh system and Paralink geogrid. One of the most challenging aspects of simulating MSE walls is determining the appropriate pull-out characteristics and tensile capacities for the reinforcement. The SLOPE/W manufacturer library for Maccaferri products simplifies this process considerably. The Overall Reduction Factor applied to the characteristic tensile capacity is determined through a number of design selections, including selection of the D50 particle size of the fill material, the analysis type (static or seismic), operating temperature, design life, and pH conditions. The pullout coefficient applied to the internal friction angle of the soil structure is populated automatically via the selection of the fill material.

References

Federal Highway Administration (FHWA), 2001, "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes—Design and Construction Guidelines," FHWA-NHI-00-043, V. Elias, B. R. Christopher, and R. R. Berg, Eds., Federal Highway Administration, Washington D.C., USA.