# Study of Slope Failure and Reinforcement Analysis to Restore and Increase the Slope Stability in Flores, East Nusa Tenggara Using Plaxis 2D and 3D

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**ABSTRACT:** The steeper modification of a natural slope due to construction demand required additional reinforcement to minimize the slope failure potential. The excavation and removing of sloping soil create new internal instability which means slope failure potential increase and must anticipated with additional reinforcement. The reinforcement as internally stabilized systems intended to decrease the stress release during and after excavation activity. Steeper modification of natural slope does need proper geotechnical design and construction method as well post construction monitoring. In Flores, East Nusa Tenggara, the slope fails after end of excavation with a height of about 20m and a slope angle of 60o without reinforcement. Internally stress release of slopes increases gradually and causing slope failures and cracks in the around of collapsing area. To restore the modification slope is required the reinforcement of the slope such as ground anchor, soil nailing and crib wall as additional support the slope stability. Comprehensive analysis of slope reinforcement is done using finite element method in Plaxis 2D and 3D program. The design parameters were obtained from the results of the soil investigation in the study area and field observation. According to slope analysis model for slope failure condition with crack around the collapsing area, safety factor is less than 1. The process of analysis is done by back fill slope which serves as counter weight then done excavating gradually and follow by installing the combination of ground anchor, soil nailing, and crib wall. The length of ground anchor and soil nailing is designed to exceed the slope failure pattern that occurs and ends in the rock layer so that the final SF obtained is more than 1.5 or is in a safe condition. The stage of construction should be implemented based on the on engineering design of slope stabilization to avoid failure.
**Keywords:** Slope stability, finite element method, ground anchor, soil nailing.

## 1. INTRODUCTION

The study location is located Flores - East Nusa Tenggara with existing steep slope about 30$^{\circ}$ to 45$^{\circ}$ (Van Zuidam, 1983). To achieve the elevation level of the plan, the existing slopes are excavated at about 20 m with an angle of 60$^{\circ}$. Based on preliminary study and field observation, slope conditions are unstable. This is shown to be found some signs of deformation of the slope, including initial crack above the site, repaired road and tilted electric pole due to sliding, and road rectified due to slope deformation. So that in the construction Stage of stripping required reinforcement of slopes in the form of crib wall, soil nailing, and drainage at the edge of the highway to stabilize the slope and reduce erosion on the slope.

In the construction Stage, the initial work undertaken is stripping existing slopes to the elevation level of the planned buildings with temporary road below the main road. High excavation slopes about 20 m with an angle reaching 60$^{\circ}$. During the slope stripping process, the planned slope reinforcement is not carried out. These conditions make the slope becomes prone to slope failures. Finally, the potential slope failure becomes true. The deformation of the slopes is caused by the slope loss the axial and lateral extension (stress release) due to the excavation, so it is easy to be triggered for slope failures.

From the slope failure pattern it can be classified into Multiple Rotational Debris Slides. This is because the slope failure geometry consists of one crown and scrap but there is also a fracture that forms a crown behind the avalanche. Therefore, the situation is very dangerous around the location if the construction activity is continued without any mitigation to the collapsing area. Response to the slope failure slope should be done by restore the slope before the construction continued. During the process of restoring the slope, it is necessary to observe periodically on the fractures formed by slope failures. The Slope reinforcement that can be done, such as backfilling and gabion installation at the bottom of the slope to the collapsing area serving as counterweight, installing an anchor at the top of slope, and installing soil nailing on the slope to the elevation of the plan.

## 2. PREMILINARY STUDIES

### 2.1 Regional Geology

Based on the geographical position, the study location is in the Physiographic Zone of the Lesser Sunda Islands, where the Small Islands physiographic zone includes Bali, West Nusa Tenggara and East Nusa Tenggara (Van Bemmelen, 1949). These zones are small islands formed by tectonic activity of the Indo-Australian plate that moves northward, urging the Eurasian plate. The deformation resulted in the basement of the continent which was originally below the average surface of the land to be raised and formed a group of Lesser Sunda Islands. In addition, increased volcanic activity contributed to the formation in some parts of the archipelago because of its position on the Sunda Volcanic Arc.

The study location is composed by Tertiary Volcanic Rock Formation. The stratigraphic aspect of the project area is structured by one formation, the Dacitic Tuff Unit, based on the Geological Sheet Map of Komodo, Nusa Tenggara (Ratman et al., 1978). The Dacitic Tuff Unit (Tmdt) generally consists of volcanic sediment material, composed by the dacitic tuff mostly bedded and partly massive, contain intercalations of green tuff, calcareous tuff, limestone, tuffaceous sandstone, breccia, and lava. The composition of the lava is partly dacite and partly andesite. This unit is estimated to be middle Miocene with the marine deposition environment. The Dacitic Tuff (Tmdt) unit is deposited not aligned with the volcanic rock units (Tmv) composed of lava and the dacitic breccia and the laminated Limestone (Tml) units composed by layered limestone with intercalations tuffaceous limestone, quartz sandstone, tuffs, and conglomerates.

### 2.2 Site Observations

Based on field observations before constructions phase started, the slope conditions are unstable. This is shown by several signs of slope deformation, including initial crack above the site, repaired road and tilted electric pole due to sliding, and road rectified due to slope deformation. So that in the stage of stripping construction need slope reinforcement such as crib wall, soil nailing, and drainage on the edge of the highway to stabilize the slope and reduce erosion on the slope.

Figure 1: Site condition from Google Earth observation (Source: Street View of Google Earth)

Figure 2: Initial crack above the site project

## 3. POST-SLOPE FAILURE OBSERVATION

After the excavated slope collapsed, there are appear cracks in some location around the crown. This is an indication that the slope is still in unstable condition and there is a possibility of further slope failure potential. So that it is necessary to conduct intensive observation of slope deformation during the process of slope reinforcement until the construction phase is complete.

Figure 3: Post-Slope failure Condition.

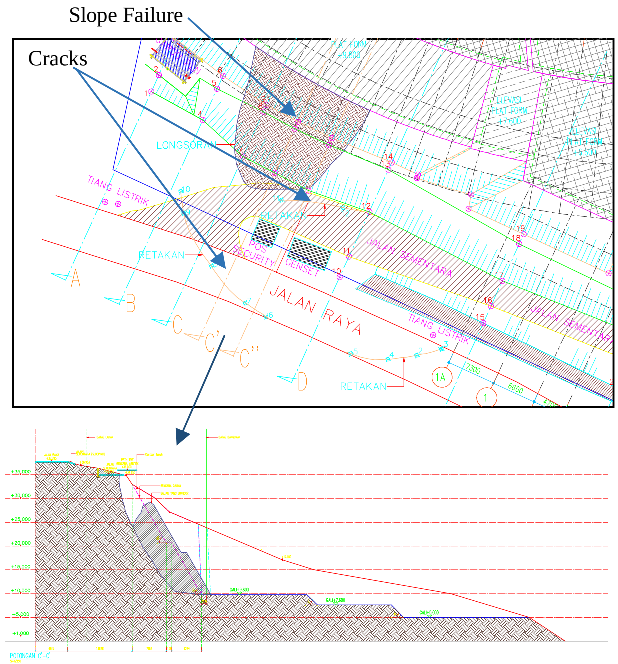


Figure 4: Land Situation and vertical cross section.

Based on the result of monitoring the slope deformation carried out at 6 monitoring point, it can be seen that the slope deformation in the cracks has decreased. The slope deformation observation for 9 days after the slope failure shows a downward trend until it stops. From the result of slope deformation, it can be concluded to be classified as Extremely Slow, with an average deformation speed of $9.65 \times 10^{-9}$ mm/sec ≈ 0.3 mm/year.

| Velocity Class | Description | Velocity (mm/sec) | Typical Velocity | Probable Destructive Significance |
|---|---|---|---|---|
| 7 | Extremely Rapid | | | Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely |
| | | $5 \times 10^{3}$ | 5 m/sec | |
| 6 | Very Rapid | | | Some lives lost; velocity too great to permit all persons to escape |
| | | $5 \times 10^{1}$ | 3 m/min | |
| 5 | Rapid | | | Escape evacuation possible; structures; possessions, and equipment destroyed |
| | | $5 \times 10^{-1}$ | 1.8 m/hr | |
| 4 | Moderate | | | Some temporary and insensitive structures can be temporarily maintained |
| | | $5 \times 10^{-3}$ | 13 m/month | |
| 3 | Slow | | | Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase |
| | | $5 \times 10^{-5}$ | 1.6 m/year | |
| 2 | Very Slow | | | Some permanent structures undamaged by movement |
| | | $5 \times 10^{-7}$ | 15 mm/year | |
| 1 | Extremely SLOW | | | Imperceptible without instruments; construction POSSIBLE WITH PRECAUTIONS |

(Cruden and Varnes, 1996)

Figure 5: Classification of sliding deformation rate (Cruden and Varnes, 1996)

## 4. DATA AND METHOD

Approximate soil parameter and cross section for slope stability analysis assumed from the geotechnical investigation, consists of 11 deep boring and laboratory test. The slope stability analysis is based on finite element method, which is performed on the Plaxis 2D and Plaxis 3D program.

To calculate the reinforcement for the slope stability design, the soil parameter required as input into the program for analysis. The soil parameters are interpreted based on the result of the geotechnical investigation. The analysis carried out by considering one condition, is a long term or drained condition in Plaxis 2D and Plaxis 3D, and uses the main parameters such as (c ', φ', E ', ν') for cohesive soil and uses drained material for non-cohesive soils with parameters (c ', φ', E ', ν') for the modulus value in the excavation are used unload-reload modulus whose value is assumed to be three to four times the effective modulus.

Table 1. Soil Parameter

| | *Soil Layer* | $\gamma_{unsat}$ [kN/m³] | E'ref [kN/m²] | v [-] | $c_{ref}$ [kN/m²] | ϕ [°] |
|---|---|---|---|---|---|---|
| 1 | **Layer-1** | 18.00 | 52700 | 0.30 | 20 | 35 |
| 2 | **Layer-2** | 20.00 | 90000 | 0.30 | 44 | 38 |

With the local collapsing of the slope in the field, then the back analysis of the soil parameters is reduced on the deformation plane by adding an interface line on the layer based on the slope failure and crown patterns that occur around it. The existing safety factor obtained will be lower than the equilibrium condition (SF = 1).

The reinforcement alternatives used in slope back analysis are fill material, Ground Anchor, Soil Nailing, Crib Wall, and Gabion.

Table 2. Reinforcement Parameter

| | *Mohr-Coulomb* | $\gamma_{unsat}$ [kN/m³] | E'ref [kN/m²] | v [-] | $c_{ref}$ [kN/m²] | ϕ [°] | ψ [-] |
|---|---|---|---|---|---|---|---|
| 1 | **Fill Material** | 13.00 | 37000 | 0.30 | 20 | 35 | - |

| **Structure** | **Length** [m] | **L** Spasi [m] | **Type** | $E_A$ [kN/m] | $F_{max}$, Tens [kN] | $F_{max}$, Comp [kN] |
|---|---|---|---|---|---|---|
| **Ground Anchor** | 23 | 2 | Elastic | 1.399E+05 | - | - |
| **Soil Nailing** | 20 | 2 | Elastoplastic | 8.042E+04 | 314 | 1 |

| **Structure** | **d** [m] | **Type** | **EA** [kN/m] | **EI** [kNm²/m] | **v** |
|---|---|---|---|---|---|
| **Crib Wall** | 0.201 | Elastic | 1.990E+06 | 6729.89 | 0.15 |

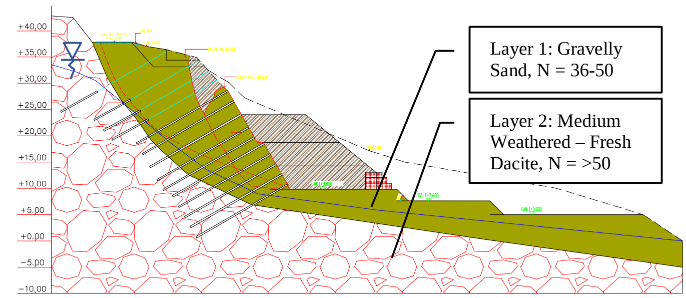


Figure 6: Slope profile and cross section.

The Slope stability improvement analysis shall meet the requirement for the safety factor condition with a factor value of **1.5**.

## 5. RESULT AND DISCUSSION

### 5.1 Back Analysis Result

The back analysis in Plaxis programs is done in various phases. The phases are the construction stage that will be done in the field if the analysis results have been qualified. The slope geometry is based on post-slope failure cross section.

1. In the early phase is the initial load or gravity load stage in the post-slope failure condition. This stage still includes the traffic load of main road and the temporary road to the location.

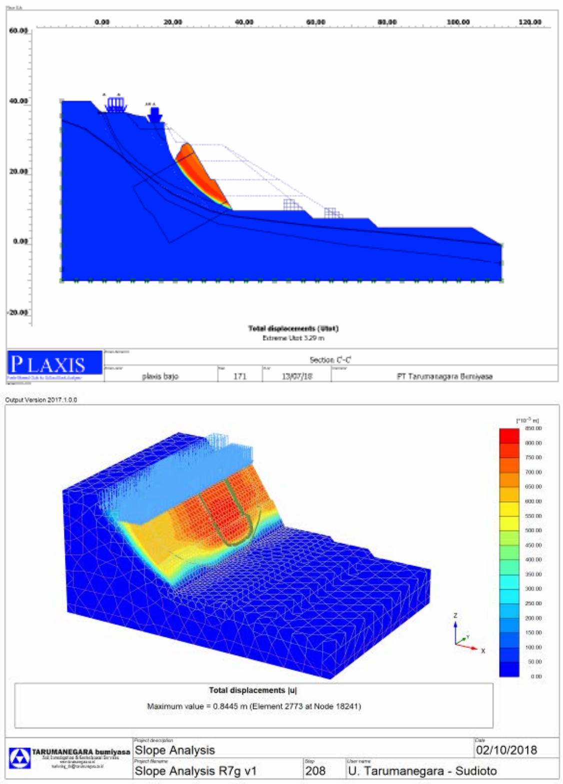


Figure 7: Back analysis of post-slope failure phase, Top: Plaxis 2D, Bottom: 3D

2. The second phase is the early treatment phase where to backfill the fill material that serves as counterweight up to +28.7m and installation of gabion on the toe of counterweight. At this stage the main road is shifted and the road temporarily stopped.

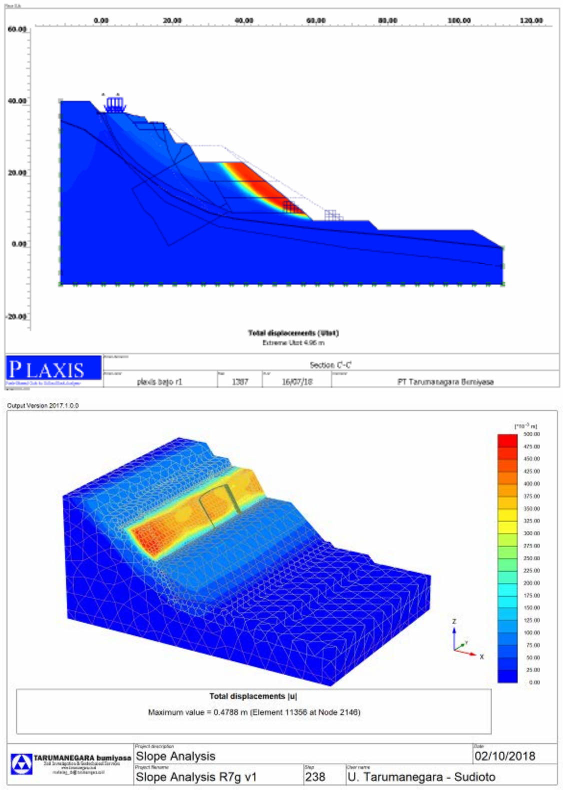


Figure 8: Early treatment phase, add fill material for counterweight and gabion, Top: Plaxis 2D, Bottom: 3D

3. The Slope reinforcement phase 1. The installation of ground anchor and crib wall for slopes close to the main road.

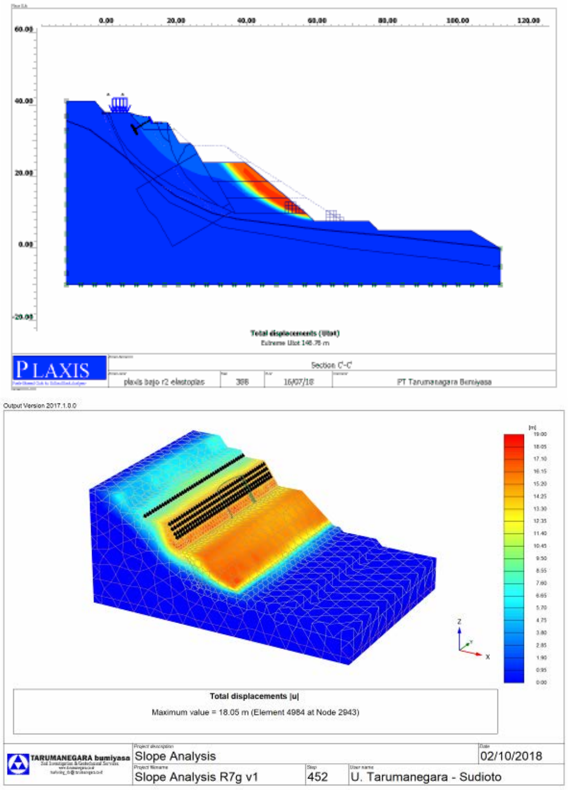


Figure 9: Slope Reinforcement Phase 1, Top: Plaxis 2D, Bottom: 3D.

4. Slope reinforcement phase 2, the installation of soil nailing and crib wall down to +18.5m elevation. In the installation of soil nailing and crib wall, counterweight excavated gradually then follow by installing the soil nailing and crib wall.

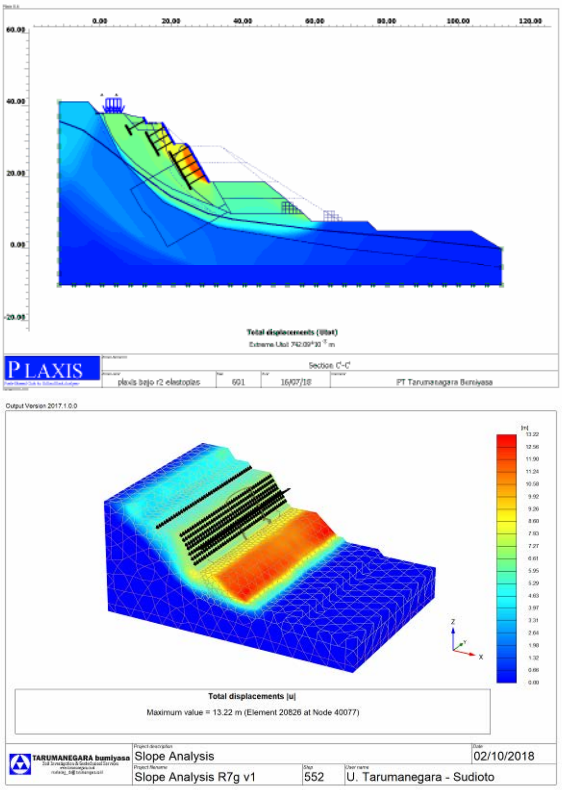


Figure 10: Slope Reinforcement Phase 2, Top: Plaxis 2D, Bottom: 3D.

5. Slope reinforcement phase 3, the installation of soil nailing and crib wall down to +9.8m elevation and external load (traffic on the main road has been running normally).

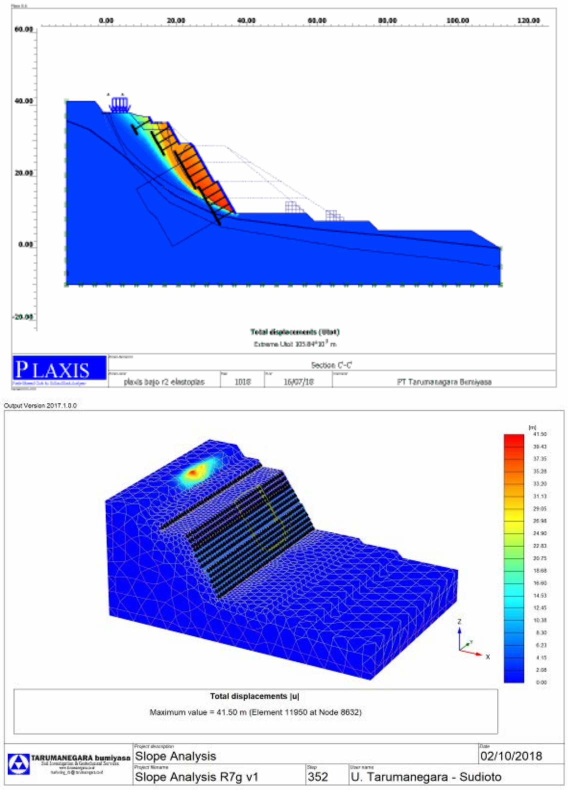


Figure 11: Slope Reinforcement Phase 3, Top: Plaxis 2D, Bottom: 3D.

6. The final phase is applying earthquake load $a_h$= 0.288g.

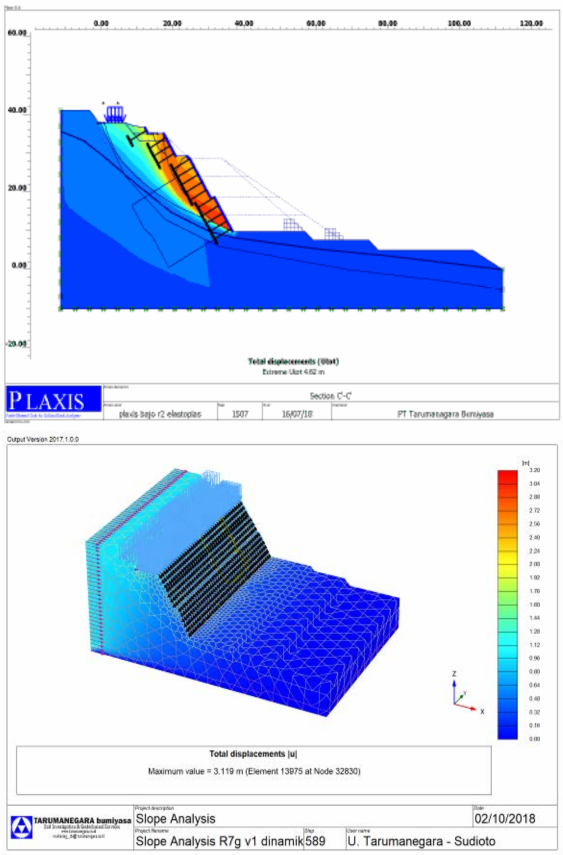


Figure 12: Earthquake load phase, Top: Plaxis 2D, Bottom: 3D.

### 5.2 Early Warning System

For Further construction and post-construction, it need to install early warning system (EWS) for slope failure hazard mitigation. The Early warning system instrument consists of crackmeter, extensometer, tiltmeter, potensiometer, and accelerometer which can be monitored remotely anytime. The installation of Early Warning system (EWS) on the slopes as early warning and can minimize the risk in case of significant slope deformation or failure.

## 6. CONCLUSION

The slope failure that has occurred in site, caused by the slope loss the axial and lateral extension (stress release) due to the excavation without installing additional reinforcement to the slope. According the analysis of restoring collapsed slope need backfill serves as counter weight, excavating gradually, and follow by installing combination of ground anchor, soil nailing, and crib wall. The result of back analysis with Plaxis 2D and Plaxis 3D, the safety factor of back analysis of various phases is as below.

Table 3. Safety Factor Result

| **Phase** | **Safety Factor (2D)** | **Safety Factor (3D)** |
|---|---|---|
| Post-Slope failure | 0.99 | 1.07 |
| Early Treatment | 1.70 | 1.62 |
| Slope Reinforcement 1 | 1.67 | 1.94 |
| Slope Reinforcement 2 | 1.96 | 2.37 |
| Final: Slope Reinforcement 3 | 1.62 | 3.22 |
| Earthquake load | 1.08 | 1.47 |

The result of safety factor from Plaxis 2D and Plaxis 3D, the safety factors meet the requirements SF=1.5 in final condition, and for dynamic condition (earthquake load), safety factor of Plaxis 2D close to the safety factor requirement, SF=1.15, but safety factor of Plaxis 3D meets the requirement. The difference between the safety factor result of Plaxis 2D and Plaxis 3D is SF of Plaxis 3D larger than SF of Plaxis 2D.

Based on the result of back analysis, we can conclude that the additional reinforcement can restore the collapsing area and increase the slope stability. The synchronization between geotechnical slope stability design and construction activity is needed to minimize the slope failure potential.

In addition, the installation of Early Warning system (EWS) on the slopes as an early warning and can minimize the risk in case of significant slope deformation or failure.

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