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Stability analysis of Saka Dam diversion tunnel portal slope, South Ogan Komering Ulu, South Sumatra

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ABSTRACT. The Saka Dam has a channel in the form of a diversion tunnel. This paper presents the results of rock mass characterization using the Geological Strength Index (GSI) classification and evaluation of the stability of the tunnel portal slope with earthquake loads using numerical methods. Based on the GSI classification, the Saka Dam tunnel portal slope is composed of rock masses that are poor quality, fair, and good. The calculation results show that the Saka Dam can experience earthquake loads with an acceleration of 0.4g. Earthquake loads can cause a decrease in the safety value strength reduction factor (SRF) of the tunnel portal slope based on the results of numerical analysis. SRF value of the natural portal slope without earthquake effect is 10.23 (inlet) and 1.5 (outlet). SRF value of the design slope portal without earthquake effect is 6.64 (inlet) and 1.76 (outlet), whereas if the earthquake effect is taken into account, the SRF value obtained is 20.31 (inlet) and 0.99 (outlet). This shows that the condition of the natural portal slope and the portal slope design planner section of the Saka Dam inlet diversion tunnel is safe. Meanwhile, modification is needed for the portal slope excavated from the outlet section to obtain a safe slope condition. The modified geometry of the slopes at the outlet section resulted in an SRF value of 1.47, indicating that the slope is stable.

Keywords: Strength Reduction Factor · GSI · Slope stability.

1 INTRODUCTION

The Saka Dam is in Simpang Saga Village, Buay Runjung Sub-district, South Ogan Komering Ulu Regency, South Sumatra Province (Figure 1). In the construction of dams, there is an important part of its construction, namely the diversion tunnel. The Saka Dam diversion tunnel has a geometrical design of the inlet and outlet portal slopes that BBWS Sumatra VIII Palembang has made. Still, stability analysis has not been conducted on the tunnel portal slopes. The design of the slope geometry is based on core samples and laboratory results. In the implementation of construction, excavation of tunnels and dynamic loads in the form of earthquakes can disrupt the tunnel slope during the tunnel construction, so the potential for landslides on the slopes of the portal can cause fatalities.

The Geological Strength Index (GSI) classification method is used to determine the rock mass quality in this study. In this GSI-based determination, the rock mass observed is cored in the area around the tunnel construction site. The assessment results based on the GSI are used to determine the value of material properties in the index and mechanical properties. These are then needed when analyzing the tunnel slope portal using RS2 software (Rocscience, Inc.). The analysis results are expected to show a safe FS value on the slope of the inlet por-

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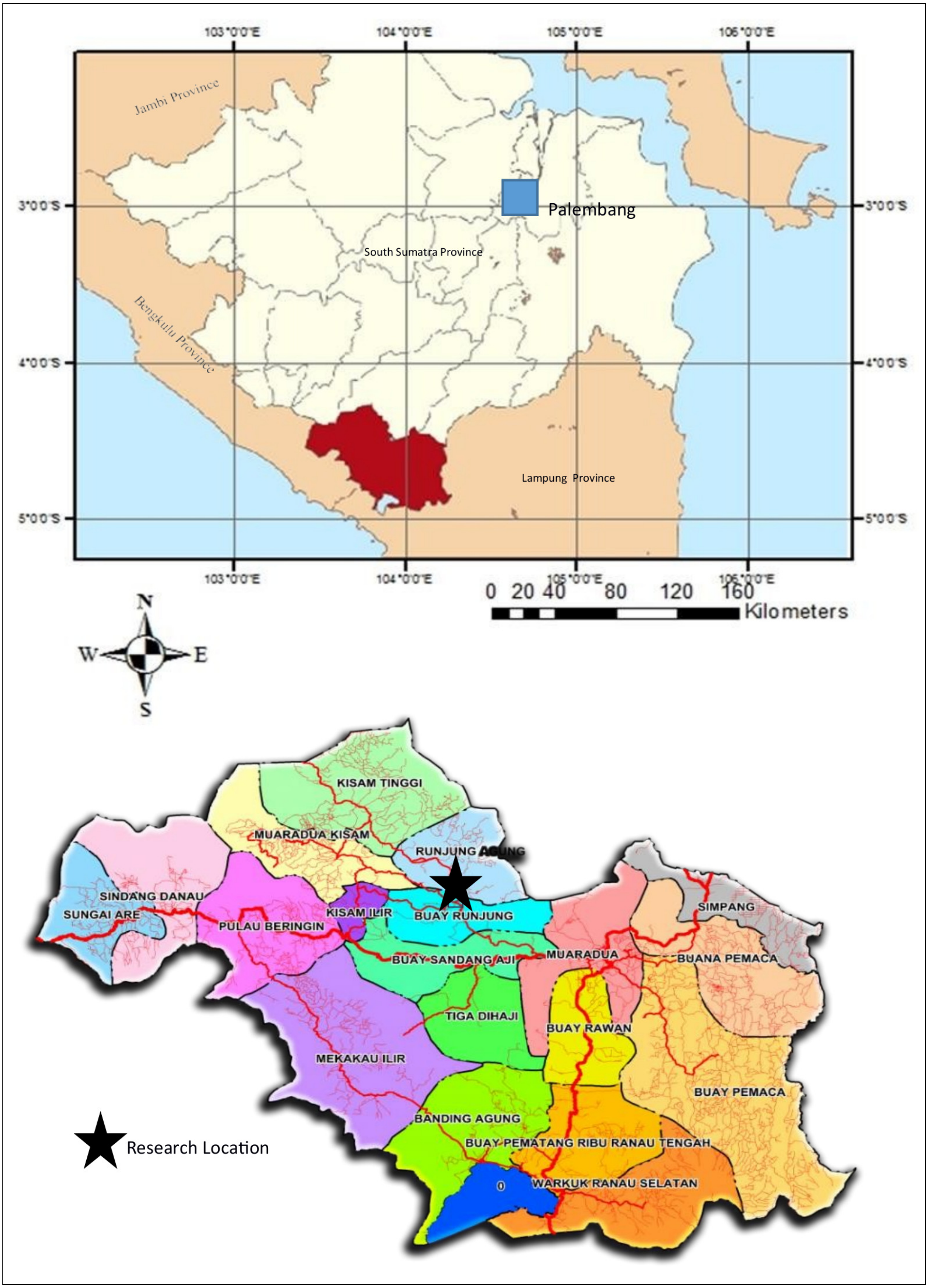


FIGURE 1. Location of the research area (source: Wikipedia.com and Okuselatankab.go.id.

tal and the outlet diversion tunnel so that the construction work process can be carried out on time and provide a sense of security during construction.

Several studies that have been carried out relating to the use of finite elements in the analysis of slope stability include Sunardi (2019) conducting a stability study on the portal slope stability of the Leuwikeris Dam diversion tunnel, West Java. This study performs a slope stability analysis to find a safe Strength Reduction Factor value using RS2 software. Besides, Dinata (2019) conducted a study on the stability of the portal slope diversion tunnel deflection Pasuruhan Dam, Central Java. This study performs a slope stability analysis to find a safe SRF value using RS2 software. As for the comparison, the boundary equilibrium method and the finite element method have been conducted by Nuryanto (2017) in slope stability analysis with the boundary and finite element equilibrium method. Nuryanto (2017) study compares static, equivalent static, and dynamic analysis in a pile and excavation model in hard, medium, and soft soils. Furthermore, Ramadhani (2019) studied the stability of slopes and metamorphic rock tunnels at the Poboya gold mine in Palu. This study aims to determine the mechanism of slope collapse and stability based on several methods and types of mining that are the most optimal and safe and disaster mitigation.

2 GEOLOGICAL CONDITION

Based on the Regional Geological Map of the Baturaja Sheet (Gafoer et al., 1993, see Figure 2), the tunnel construction site is located in the Baturaja Formation (Tmb), resulting from tertiary sedimentation and Miocene age. According to the surface geological mapping and core results, the study area is divided into two lithology types: polymict breccia lithology and quartz sand deposits.

3 RESEARCH METHOD

In this study, the first thing to do is collect data consisting of primary data collection and secondary data collection. The input parameters in material properties were obtained by observing the geological condition and surface and subsurface engineering geology and some testing of the rock index properties and mechanical properties in the laboratory. The rock mass quality was observed using the Geological Strength Index (GSI), according to Marinos & Hoek (2007). Also, subsurface rock and soil sampling are needed for laboratory research. Secondary data was obtained from BBWS Sumatra VIII and PT Global Parasindo Jaya through portal slope geometry inlet, outlet tunnels, and bore logs. Data analysis is then performed to obtain material properties that will be used in analyzing the stability of the tunnel portal slope using RS2 software. The resulting material properties include Geological Strength Index (GSI) and Uniaxial Compressive Strength (UCS), according to Marinos & Hoek (2007). After entering the values of the properties, then determine the earthquake coefficient in the horizontal direction (kh) of the study area. Based on SNI 8460 (BSN, 2017), a slope is stable (safe) if the critical SRF value is 1.5 on permanent conditions without earthquake load and 1.1 on conditions with earthquake load.

4 RESULTS AND DISCUSSION

4.1 Lithology

Based on the results of direct surface rock observations and subsurface rock observations from the core box, an overview of the overburden condition to the tunnel's depth composed of residual soil, quartz sand deposits, and polymict breccias is obtained. At the construction site of the diversion tunnel, no structure was found at the study site.

4.2 Analysis of rock mass quality

GSI values of subsurface rocks were obtained from observations at 3 drill point locations based on RQD values and joint condition values. It was concluded that at the study site, it could be divided into 4 units of rock quality, namely good quality rocks (GSI values of 56–75), fair quality rocks (GSI values of 41–55), poor quality rocks (GSI values of 21–40) and very poor quality rocks (GSI values of 0–20).

As shown in Figure 3 and Figure 4, the slope of the inlet tunnel section is composed of residual soil and polymict breccias in good condition. In contrast, the outlet comprises quartz sand deposits and polymict breccias with poor, fair, and good conditions. At the inlet, the

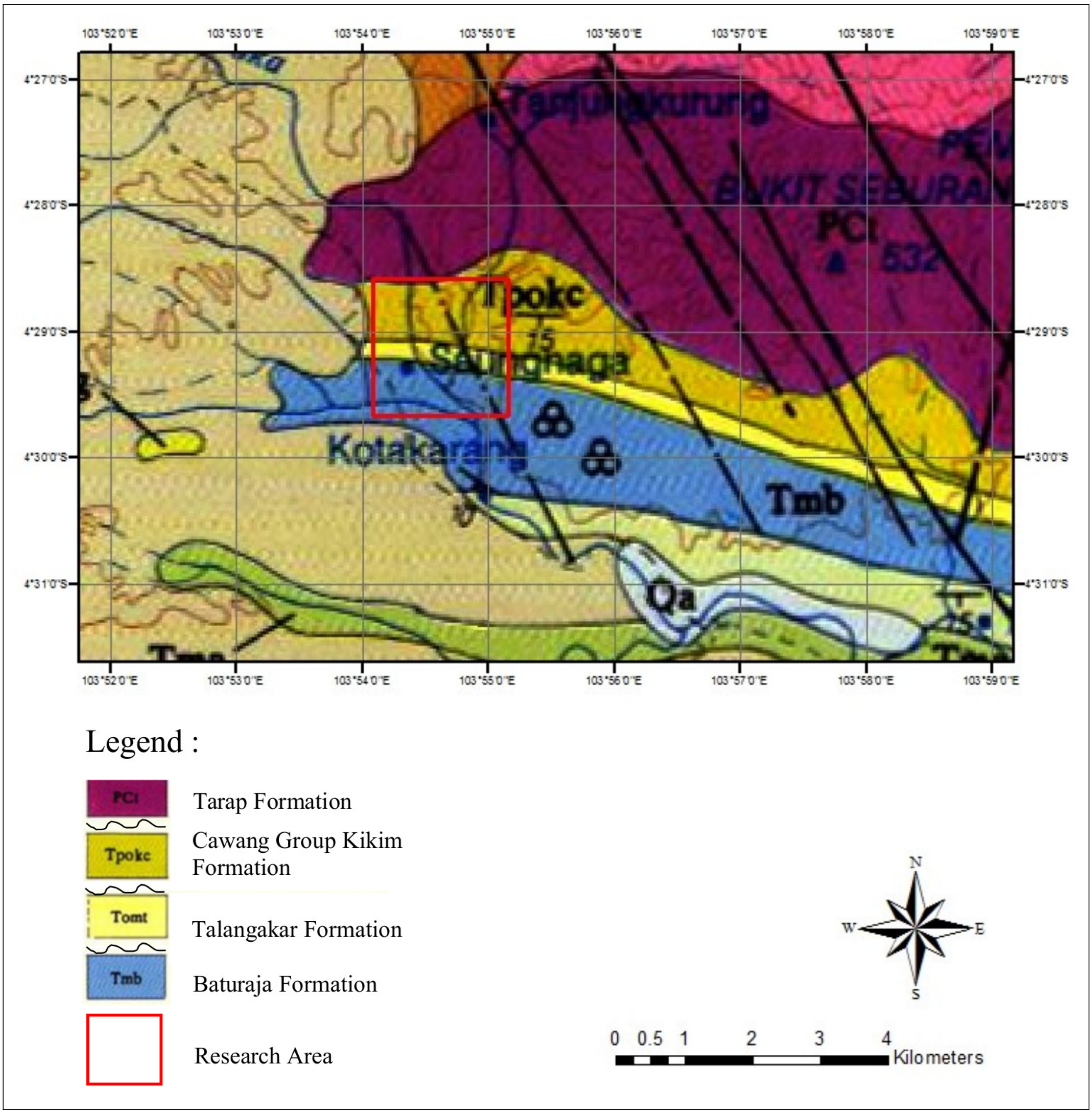


FIGURE 2. Geological Map (source: Gafoer et al., 1993).

groundwater level is approximately 1.8 meters from the ground surface, and at the outlet of the tunnel is at a depth of approximately 8 meters.

4.3 Earthquake analysis

Earthquake coefficient horizontal direction (kh) of the study area. This determination uses earthquake acceleration maps on bedrock (PUSGEN, 2017) to obtain PGA values. Based on the map, the PGA value = 0.35 is obtained for the determination of site classification of the average value of SPT at BS-03 and BS-04 drill points to a depth of 30 meters range between 20-40 so that the study area is included in the classification of medium soil sites (SD) was used to calculate the value of the horizontal earthquake coefficient (kh) in the analysis of the portal slope stability is 0.4025 g.

4.4 Slope stability analysis

Stable diversion tunnel slope of portal slope analysis is performed on natural conditions and the planned portal slope condition regardless of earthquake load or earthquake load calculation. In the stability analysis of this portal, RS2 software (Rocscience, Inc.) is used with the parameters shown in Table 1 below.

Based on numerical analysis using RS2 software (Rocscience, Inc.) on the tunnel portal slope at the inlet and outlet of the diversion tunnel, the portal slope results in the natural condition of the inlet has a slope of 15° and has a safety value (SRF) of 10.23. After excavation of the slope with a slope of 63° based on the planner's design, it is obtained that a safety value (SRF) is 6.64 without earthquake load and 20.31 with the effect of earthquake load. Based on the results of the analysis shows that the slope is in a safe condition, both conditions without earthquake effects or with earthquake effects. The natural slope of the outlet has a slope of 24° and has a safety number (SRF) of 1.5. After excavation of the slope with a slope of 63° based on the design of the planner, then obtained a safety number (SRF) of 1.76 without earthquake load and 0.99 with earthquake load. Detailed FS values for these conditions can be seen in Table 2. The numerical modeling output of slope stability analysis under these conditions is shown in Figure 5 through Figure 7 below.

Based on the results of the analysis, the safety

TABLE 1. Material parameters of the portal tunnel slope properties.

		Lithology	GSI	Unit Weight (MN/m^3)	Saturated Unit (MN/m^3)	UCS (MPa)	Young's Modulus	Poison Ratio	c (MPa)	ϕ (°)
Inlet	Layer 1	Soil	-	0.0169	0.0179	-	10.5	0.2	0.301	14.74
	Layer 2	Soil Saturated	-	0.0169	0.0179	-	10.5	0.2	0.301	14.74
	Layer 3	Breccia Good	64	0.0236	0.0245	2.75	7620.62	0.15	-	-
	Layer 4	Breccia Good Saturated	64	0.0236	0.0245	2.75	7620.62	0.15	-	-
Outlet	Layer 1	Sand Deposit	-	0.0079	0.0139	-	10.35	0.2	0.005	17.80
	Layer 2	Soil	-	0.0169	0.0179	-	10.5	0.2	0.301	14.74
	Layer 4	Breccia Good	59	0.0115	0.0165	2.40	1213.61	0.05	-	-
	Layer 5	Breccia Good Saturated	59	0.0115	0.0165	2.40	1213.61	0.05	-	-
	Layer 6	Breccia Poor Saturated	30	0.01	0.015	0.02	218.22	0.11	-	-
	Layer 7	Breccia Fair Saturated	41	0.0091	0.0152	0.45	207.34	0.16	-	-
	Layer 8	Breccia Good Saturated	64	0.0236	0.0245	2.75	7620.62	0.15	-	-

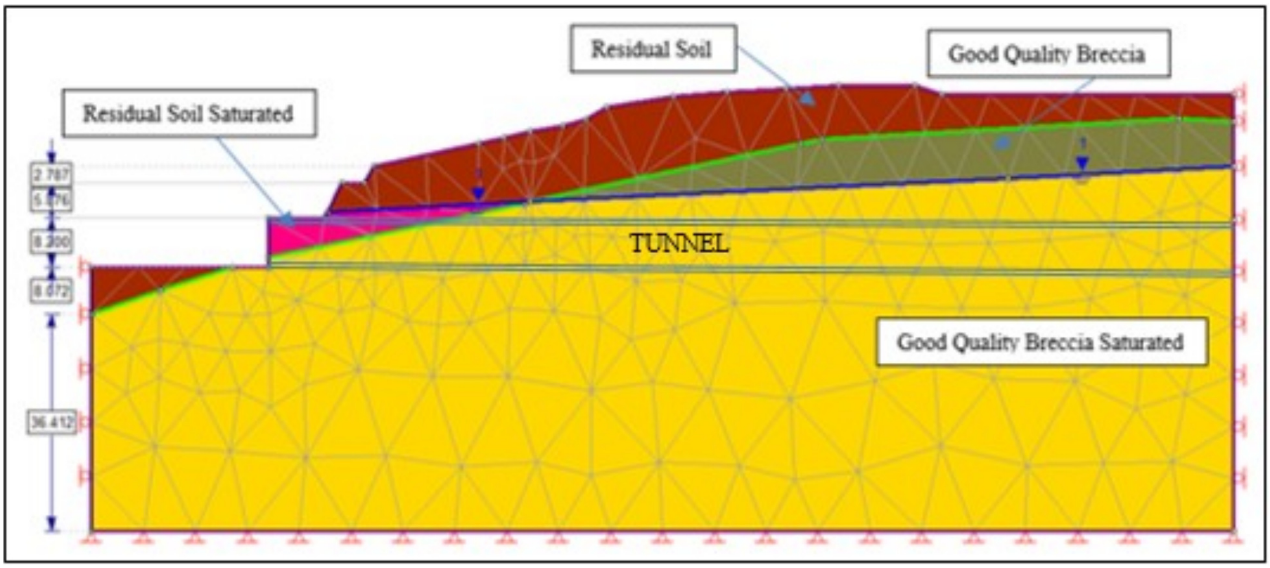


FIGURE 3. GSI incision profile of the tunnel inlet portal slope.

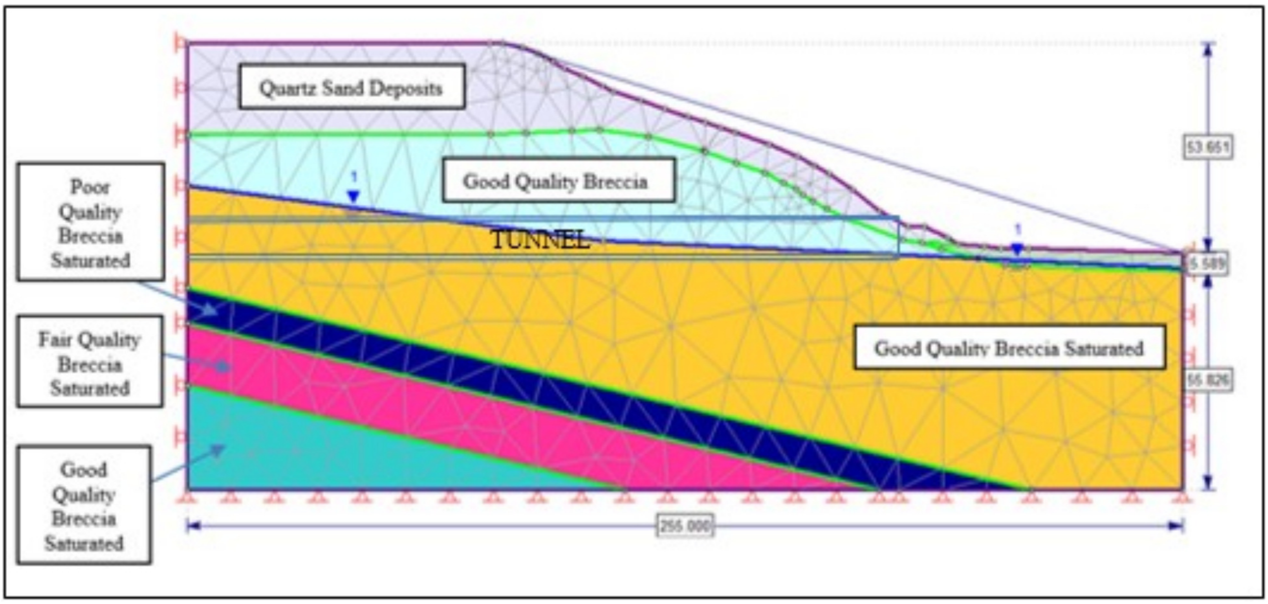
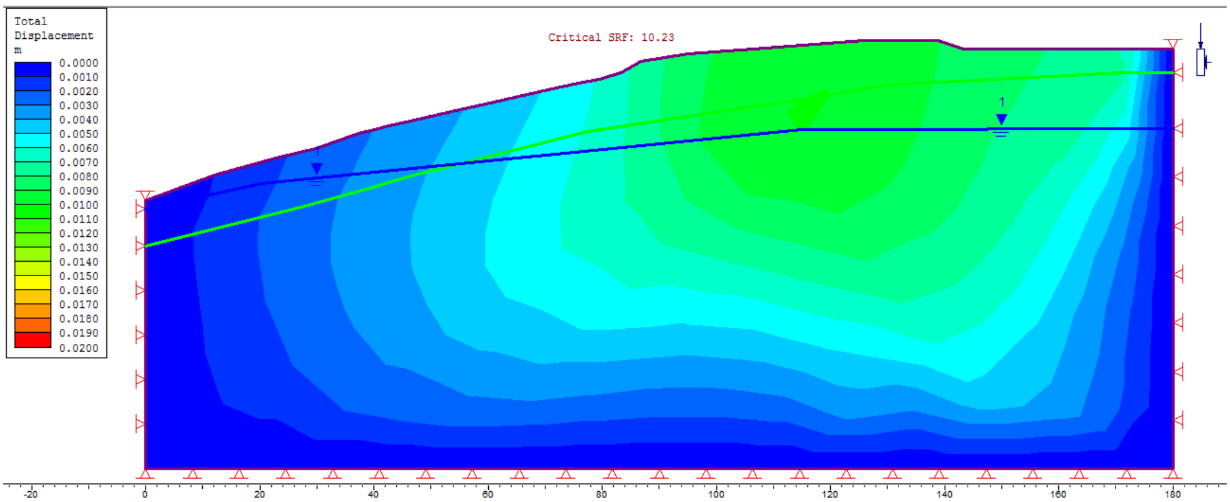


FIGURE 4. GSI incision profile of the tunnel outlet portal slope.

TABLE 2. The safety figure (SRF) results from the calculation of the stability analysis of the portal slope.

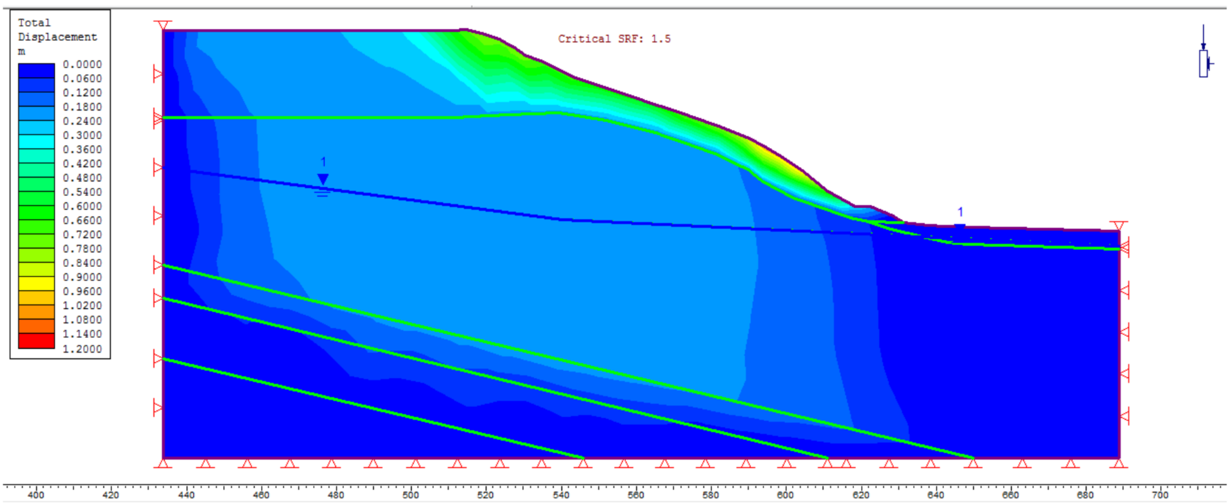
Slope	Condition	SRF		Description
		No Earthquake Effect	With Earthquake Effect	
Inlet	Natural	10.23	-	Tilt ± 15°
	Design	6.64	20.31	Tilt 63°
Outlet	Natural	1.5	-	Tilt ± 24°
	Design	1.76	0.99	Tilt 63°

Inlet



FS = 10,23

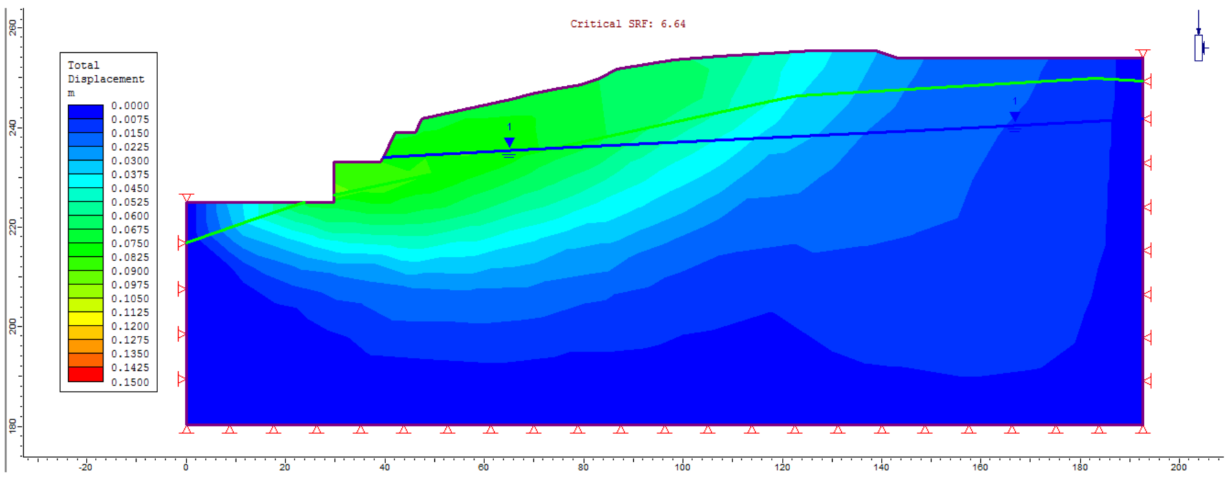
Outlet



FS = 1,5

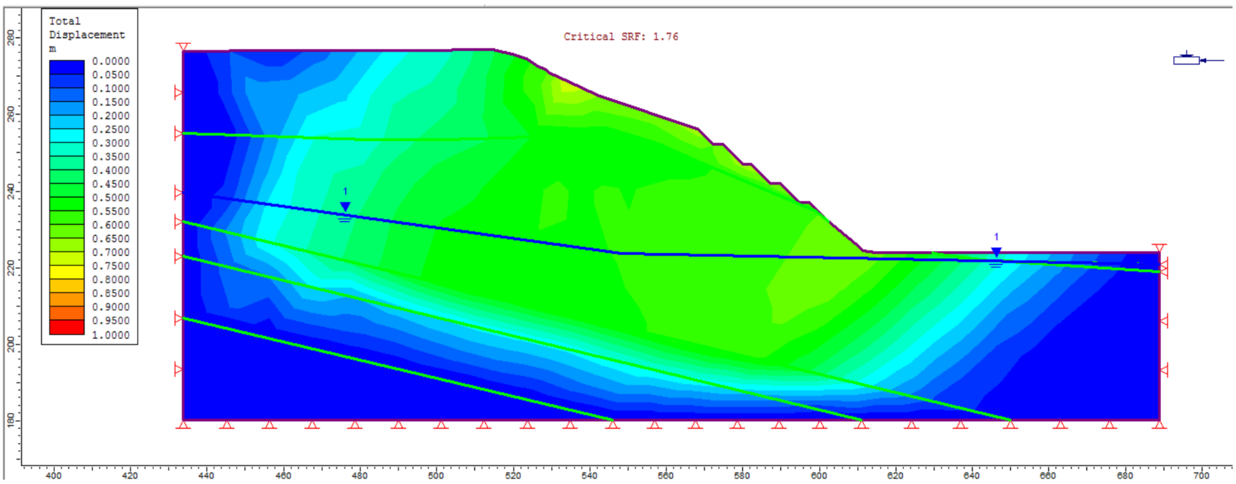
FIGURE 5. The output of natural slope modeling in the Inlet and Outlet sections.

Inlet



FS = 6,64

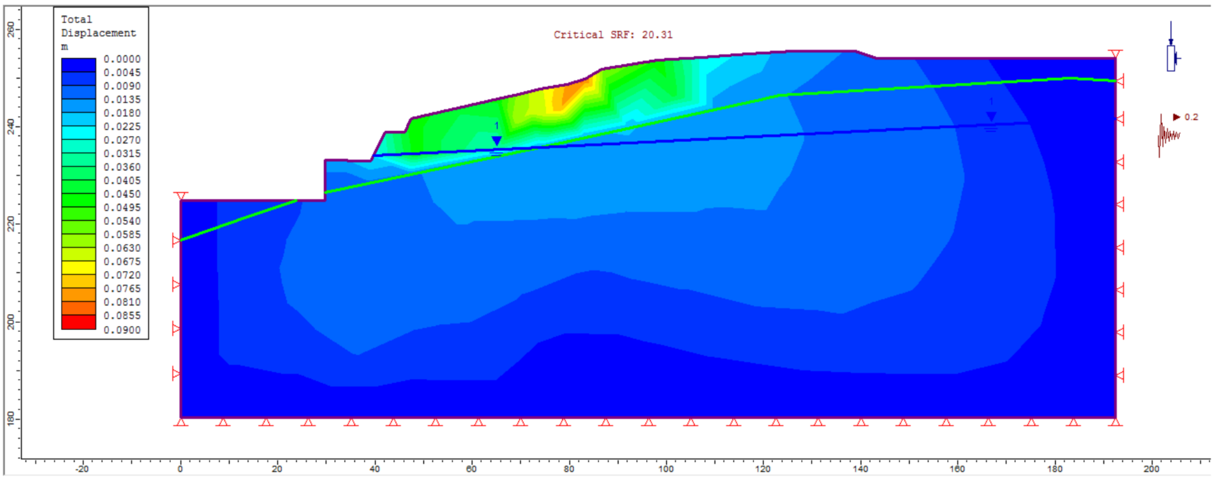
Outlet



FS = 1,76

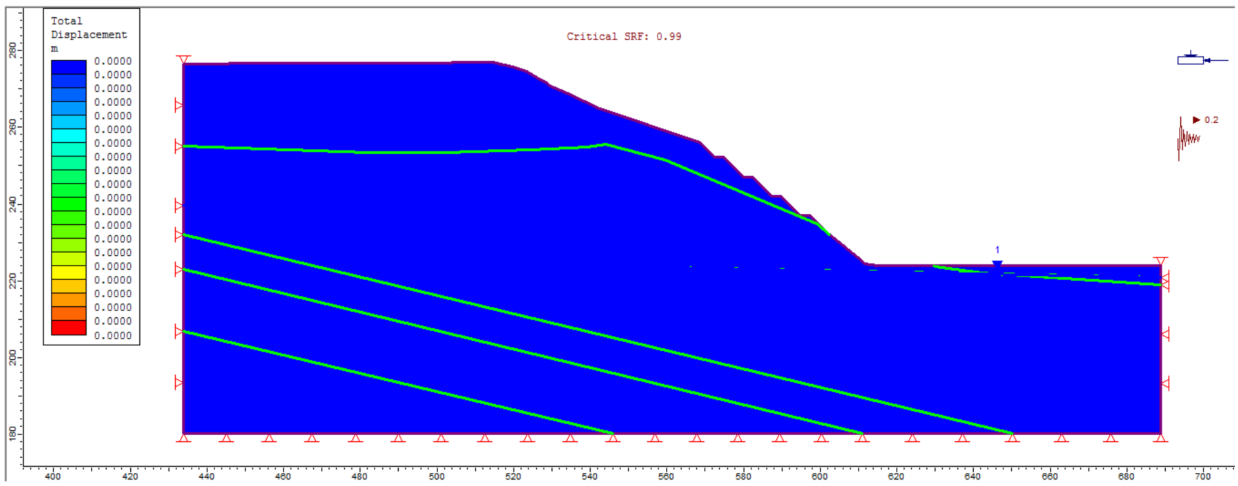
FIGURE 6. The output of slope modeling design of Inlet and Outlet sections without earthquake load.

Inlet



FS = 20,31

Outlet



FS = 0,99

FIGURE 7. The output of slope modeling design of Inlet and Outlet sections with earthquake loads.

figures on the tunnel slope portal outlet section are in unsafe conditions (SRF < 1.1), so it was modified with a slope of 1V:2H (26°) to a slope of 1V:1H (45°), resulting in a safety number (SRF) of 4.06 without calculating earthquake load and 1.47 taking into account earthquake load. The modified output outlet of the portal tunnel slope is shown in Figure 8.

5 CONCLUSION

The research area consists of residual soil, quartz sand deposits, and polymict breccias with GSI values that vary from very poor (GSI values of 0–20), poor (GSI values of 21–40), fair (GSI values of 41–55), and good (GSI values of 56–75) rock mass. The portal slopes of the inlet section are composed of rocks with good mass quality, while the outlet section comprises rocks with poor, fair, and good mass quality. The inlet and outlet planning is a natural slope, and the slope design is stable if the slope stability analysis does not consider the earthquake load. This is indicated by the value of natural slope safety figures of 10.23 (inlet) and 1.5 (outlet). At the same time, the value of excavated slope safety figures is 6.64 (inlet) and 1.76 (outlet). The design slope at the outlet is unstable if the earthquake load is considered in the analysis. This is shown from the FS value obtained at 0.99, so it is necessary to modify the slope. After changing the slope of the FS, the value obtained is higher at 1.47 and is greater than the required FS> 1.1.

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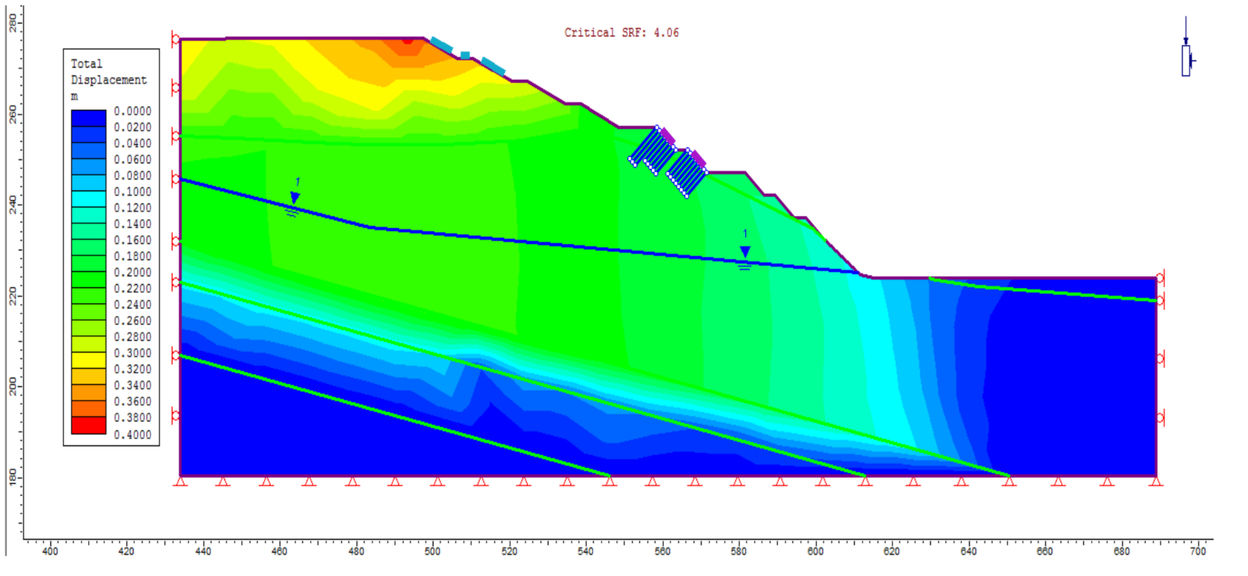
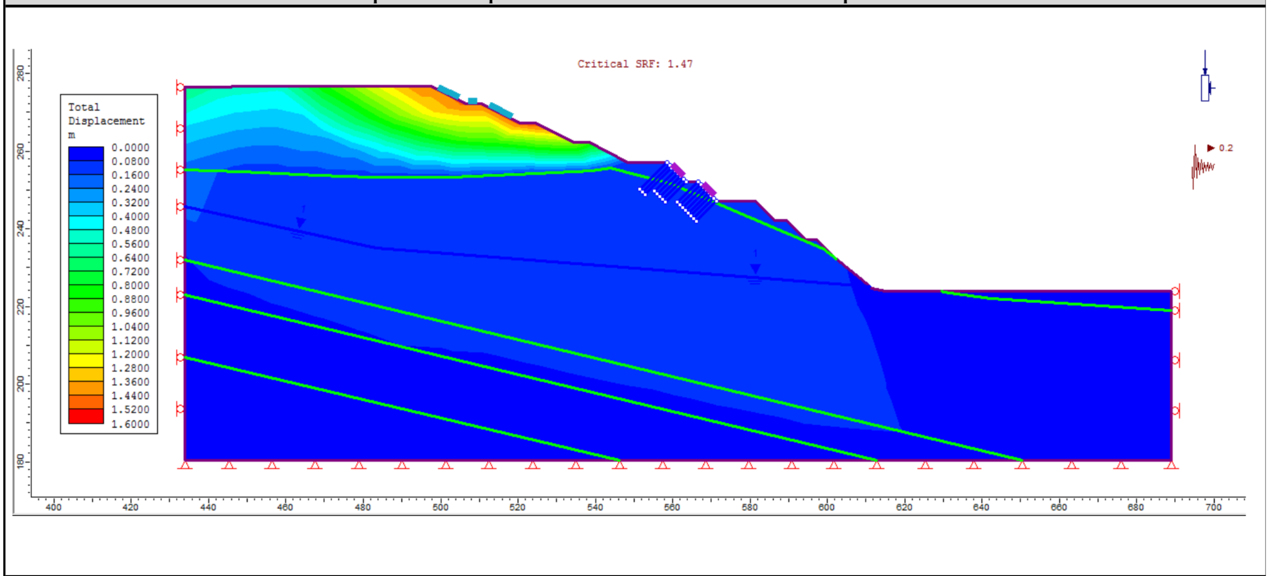
Tunnel portal slope outlet section with no earthquake effect



FS = 4,06

Tunnel portal slope outlet section with earthquake effect



FS = 1,47

FIGURE 8. Output Modelling of the tunnel outlet portal slope with modification influenced by earthquake load and not affected by earthquake load.