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Evaluation of engineering geological conditions for slope stability analysis of diversion tunnel portal of Jlantah Dam, Karanganyar, Central Java

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ABSTRACT. This paper presents the research results to analyze the slope stability of the diversion tunnel portal of Jlantah Dam based on the rock mass quality. The classification of the rock mass quality at the tunnel location refers to the Geological Strength Index (GSI) method. At the same time, the analysis of portal slope stability is modeled numerically with the element method using RS2 software. The tunnel portal slope design was modeled with and without earthquake load to obtain the safety factor (SF) value. The results showed that the study area consists of residual soil, andesite breccia, and lapilli tuff rocks with rock mass quality based on the GSI value ranging from poor to fair. The inlet portal slope comprises rocks with poor and fair mass quality, while the inlet section comprises rocks with poor mass quality. The selection of the slope design 1V:2H (alternative 2) with a face height of 3 meters and a bench length of 2 meters shows the slope in a safe condition both without earthquake (SF > 1.3) or earthquake (SF > 1.1) without additional reinforcement. The SRF value at the portal outlet location is greater than the SRF value at the portal inlet location for the same slope design conditions indicating that the rock mass quality at the portal outlet location is better than the rock mass quality at the portal inlet location.

Keywords: Diversion tunnel · Earthquake coefficient · GSI · Rock mass quality · Slope stability.

1 INTRODUCTION

In dam construction, several methods can be applied to divert the river flow (Komisi Keamanan Bendungan, 2003). Considering all aspects of tunnel design requirements, from the study work to the detailed design work, the construction of the Jlantah Dam carried out by the Bengawan Solo River Basin Research Station (BBWS) was designed using tunnels combined with conduit channels. According to the design, it has a horseshoe shape with a total tunnel length of 374.50 m, a combination of a 223.7 m tunnel and a 150.8 m conduit.

The diversion tunnel of Jlantah Dam is located geographically in Tlobo Village, Jatiyoso District, Karanganyar Regency, Province of Central Java, Indonesia (Figure 1). Based on the Regional Geological Map of the Ponorogo Sheet, Java (1508-1) defined by Sampurno et al., 1997, in general, the lithology at the tunnel location and its surroundings is Lava Lawu (Qlla) rock, some part of it is Jobolarang Lava (Qvjl) and the rest is Sidoramping Lava (Qvsl).

In the existing design details, tunnel portals are designed with wire mesh, shotcrete, and rock bolt reinforcement systems with ambient slope. Therefore, it is necessary to conduct further geological engineering investigations to determine the rock mass quality in the tunnel portal plan area. In the implementa-

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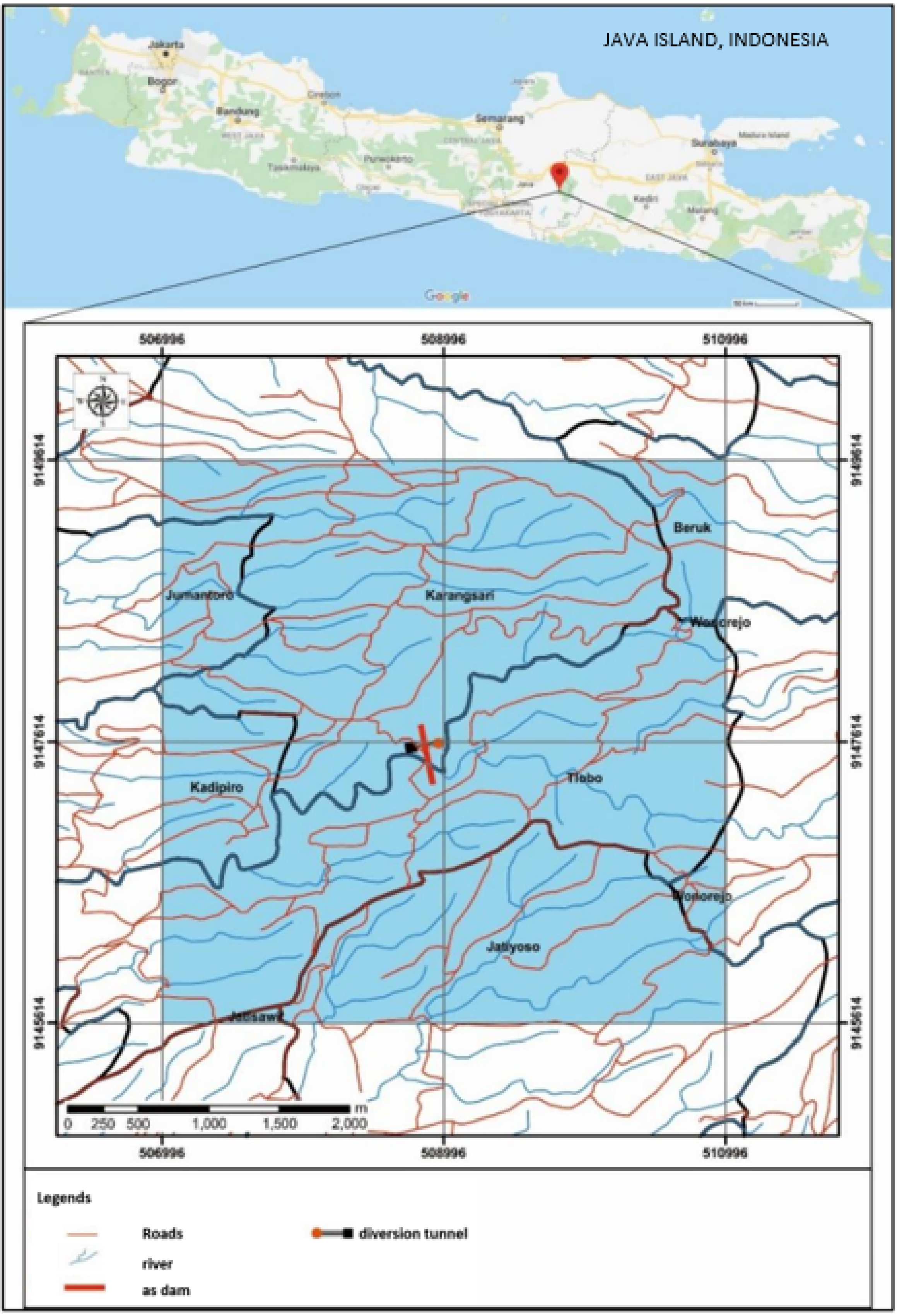

FIGURE 1. Map of the planned location of the Jlantah Dam tunnel, Karanganyar Regency, Province of Central Java, Indonesia (Triatmojo, 2019).

tion method, the portal slope is a temporary building that will be backfilled at the next stage of work after completing the conduit structure work. Based on this consideration, it is necessary to analyze the slope design that is precise and appropriate.

The value of rock mass quality obtained is used as one of the slope design parameters. This paper discusses the qualification of rock mass using the Geological Strength Index (GSI) method on the slope location of the conduit-tunnel portal so that it can be used in designing the slope reinforcement system in the form of slope design with the value of the safety factor (SF) of the portal slope stability.

2 METHODOLOGY

2.1 Classification of rock mass

The Geological Strength Index (GSI) is used to determine the classification of the quality of subsurface rock masses by combining 2 (two) main parameters, namely joint condition (JCond89) defined by Bieniawski (1989) and RQD defined by Deere & Miller (1966) in autoreffig2 (Hoek et al., 2013).

From the classification of the RQD and joint condition assessment, the calculation of GSI for subsurface measurements (Hoek et al., 2013) uses the Equation 1.

$$GSI = 1.5JCond_{89} + \frac{RQD}{2} \tag{1}$$

in which: GSI = Geological Strength Index; $JCond$ = Joint Condition; RQD = Rock Quality Designation.

The GSI value was then used in determining the quality of rock mass based on the classification of Sivakugan (2013) in Table 1.

2.2 Laboratory tests

The index properties, direct shear, and UCS are laboratory tests of soil dan rocks. The index properties tests were conducted to obtain water content, density, specific gravity, void ratio, porosity, saturation, shrinkage limit, plastic limit, and plasticity index. The direct shear tests were carried out on undisturbed soil samples, while the UCS tests were carried out on samples of fresh rock conditions.

2.3 Portal slope stability

Based on SNI 8460:2017, earthquake design criteria based on infrastructure designation, especially in dam supplementary buildings, use a 50-year plan life with a probability of exceeding 2% and a 2500-year return period. This standard explains the procedure for determining the design response spectrum to be used as input data for the earthquake coefficient values in tunnel design analysis.

2.3.1 Parameters for portal slope stability analysis

The soil shear strength parameters are the basis for conducting slope stability analysis. Based on SNI 8460:2017(BSN, 2017), rock shear strength parameters are obtained from intact rock (α_{ci}) strength, Hoek-Brown constant mi, GSI (Geological Strength Index), and rock unit weight (γ_b) of rock.

2.3.2 Safety factor value

The slope safety factor (SF) value required in the slope stability analysis refers to SNI 8460:2017 (BSN, 2017), which equals 1.3 for temporary rock slope conditions. Slope design with earthquake effect must have a safety factor value greater than 1.1.

2.3.3 Earthquake coefficient

Based on the 2017 Earthquake Source and Hazard Map, the study location is in the PGA of 0.253g (bedrock PGA). The average SPT value taken from the secondary data from the core drill at the tunnel location is 25, so it is included in the SD site class (medium ground), and with the amplification factor at the study site, the surface PGA value is 0.33g. Based on SNI 8460:2017 (BSN, 2017), it can be determined that the horizontal seismic coefficient, kh, is 0.5 from the surface PGA which is equal to 0.164.

2.3.4 Analysis method

The analysis of portal slope stability used in this study area uses the element method with RS2 (Phase2 9.0) software (Rocscience, Inc) through the SRF value approach. SRF or Strength Reduction Factor is a quantity in the "shear strength reduction method", wherein the method is reduced to rock shear strength parameters. Input parameters used in modeling based on lithology and shear strength of

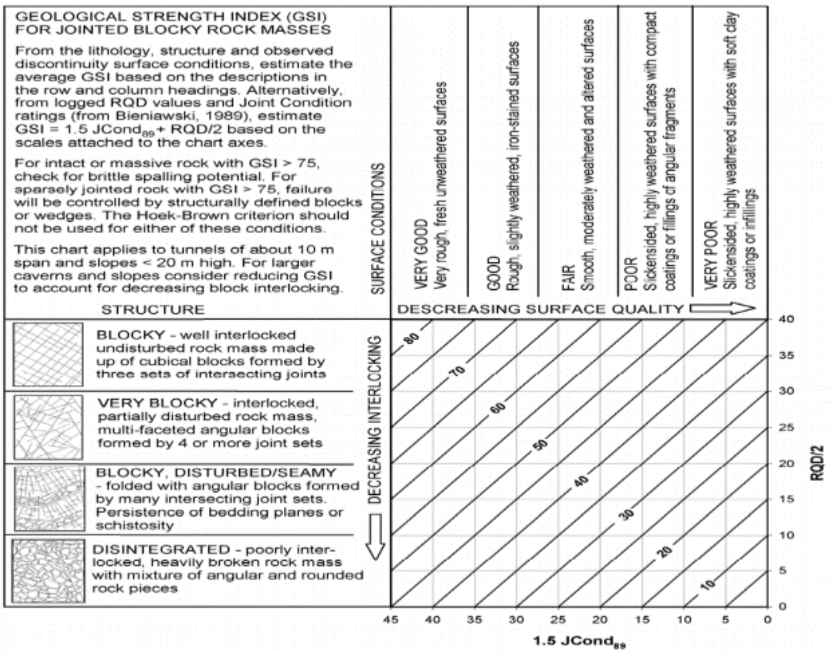

FIGURE 2. Chart of GSI score estimation (Hoek et al., 2013).

TABLE 1. GSI quality of rock mass (Sivakugan, 2013).

GSI Value	95–76	75–56	55–41	40–21	>20
Rock mass quality	Very good	Good	Fair	Poor	Very poor

rock mass. To obtain the right SRF, iteration is needed until the slope collapses (iteration becomes non-convergent). The approach of the SRF value in the slope stability analysis will show the value of the safety factor (SF).

3 RESULTS AND DISCUSSION

The lithology of the study area is determined from the correlation results between surface rocks from field observations and core data. Surface rock mapping was carried out in 57 stations in the study area (Triatmojo, 2019), while the core data was obtained from BBWS Bengawan Solo and PT. Aditya Engineering Consultants. The borehole position is shown in Figure 3.

The correlation results show that the research area comprises 4 rock units: pyroclastic breccia, tuff breccia, lapilli tuff, and andesitic breccia (as a subsurface rock unit). The lithology of the research area is shown in Figure 4.

According to the direct observations, the surface rock mass in the study area was dominated by rocks with slightly weathered to moderately weathered conditions with disintegrated structural conditions. The sample of rock unit outcrops can be shown in Figure 5.

According to the direct observations, the surface rock mass in the study area was dominated by rocks with slightly weathered to moderately weathered conditions with disintegrated structural conditions. The sample of rock unit outcrops can be shown in Figure 6.

The quality of subsurface rock mass at the portal location was analyzed by describing observations on drill point BJ04 in the tunnel outlet section and drill point BJ06 in the inlet section of the tunnel. The long section of tunnel traces describes the rock mass quality, shown in Figure 7.

The soil and rock parameters obtained from laboratory tests used in modeling portal slope stability are shown in Table 2.

Based on the Earthquake Source and Hazard Map in 2017, the study location was in the PGA of 0.253g, so the horizontal peak acceleration value was 0.33 from the SD site class (medium soil) and amplification factors at the study location. A horizontal seismic coefficient, kh, of

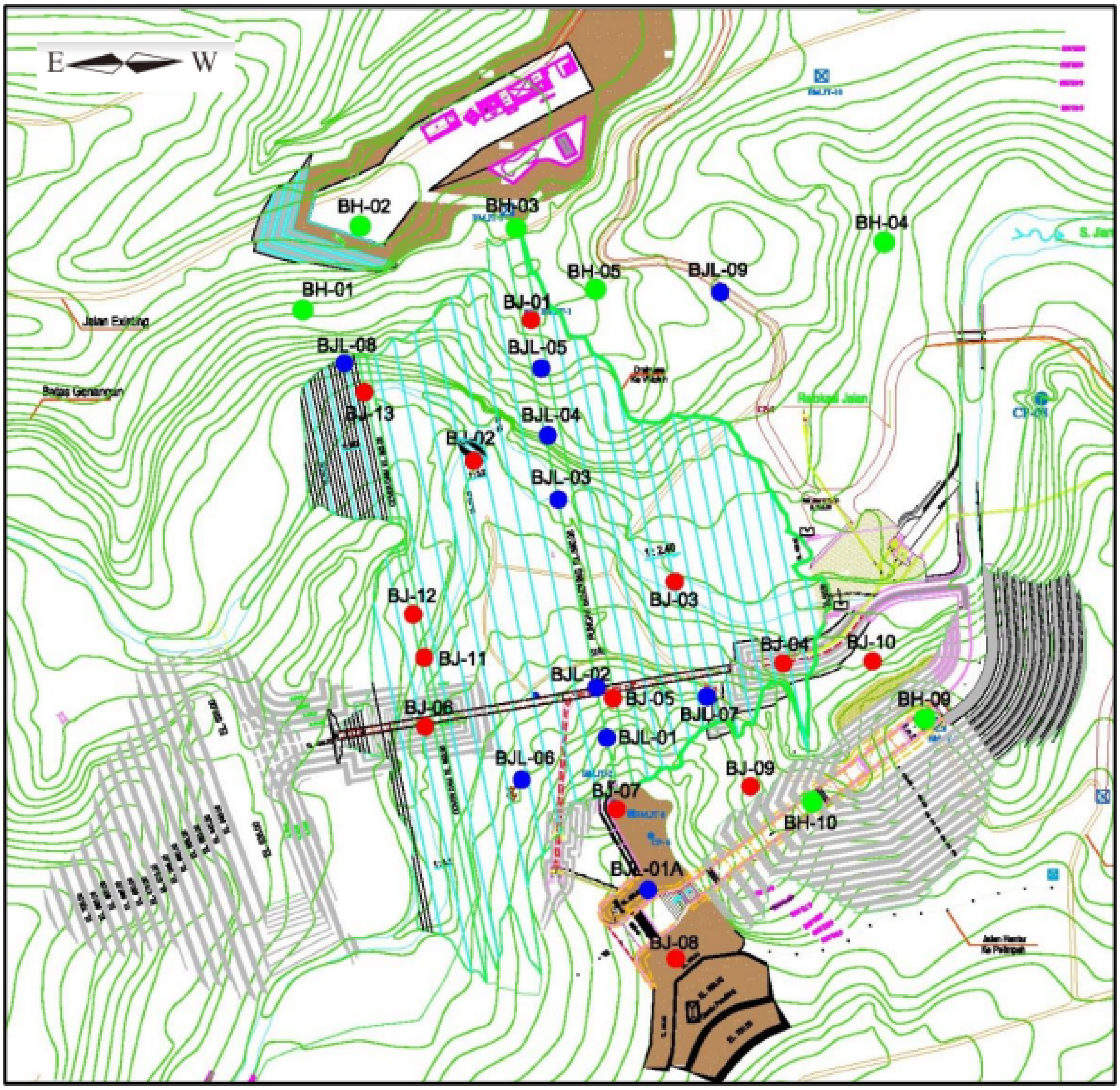

FIGURE 3. The borehole position (PT. Aditya Engineering Consultant, 2017).

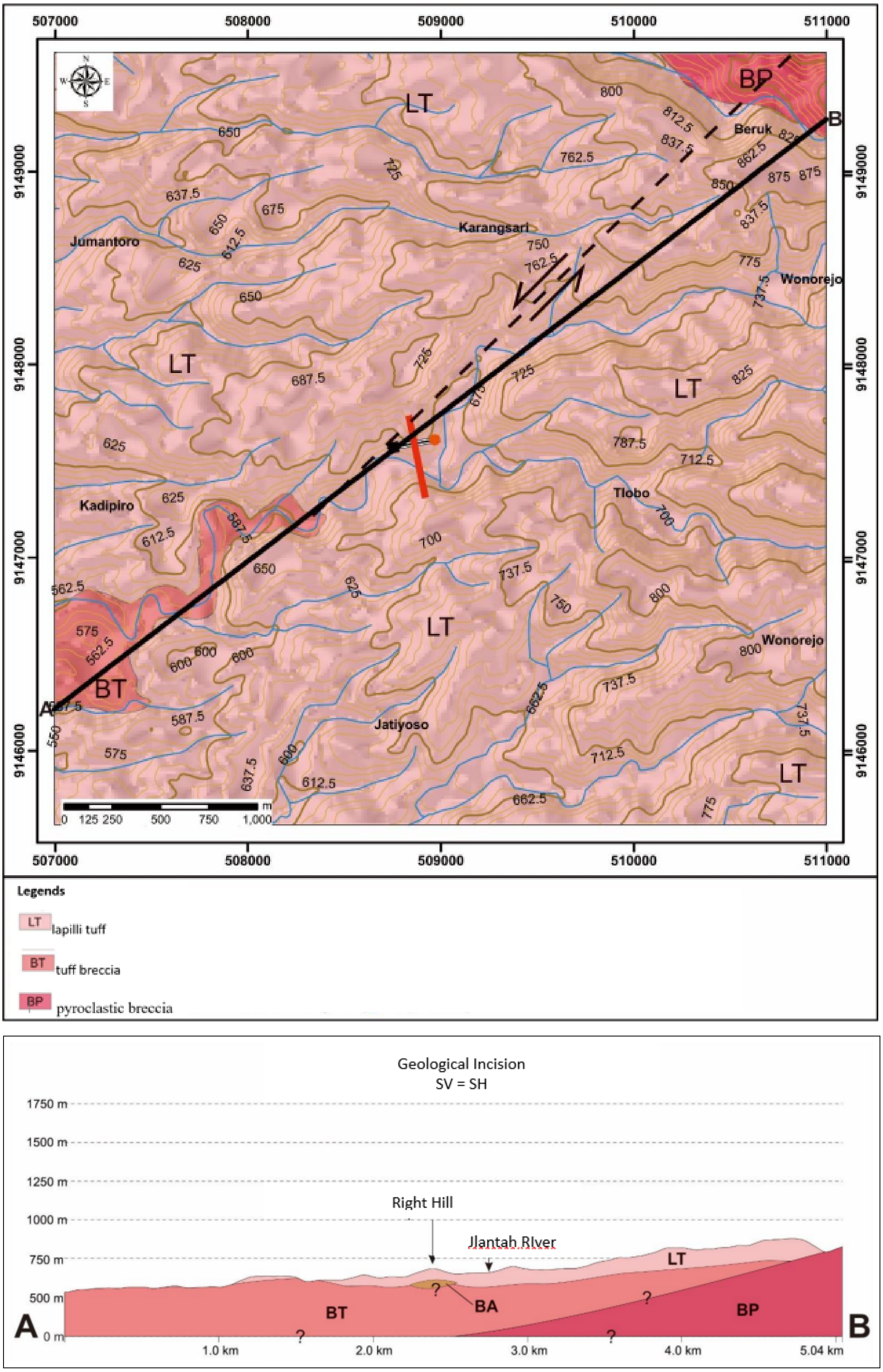

FIGURE 4. Geological map and geological incision in the research area (Triatmojo, 2019).

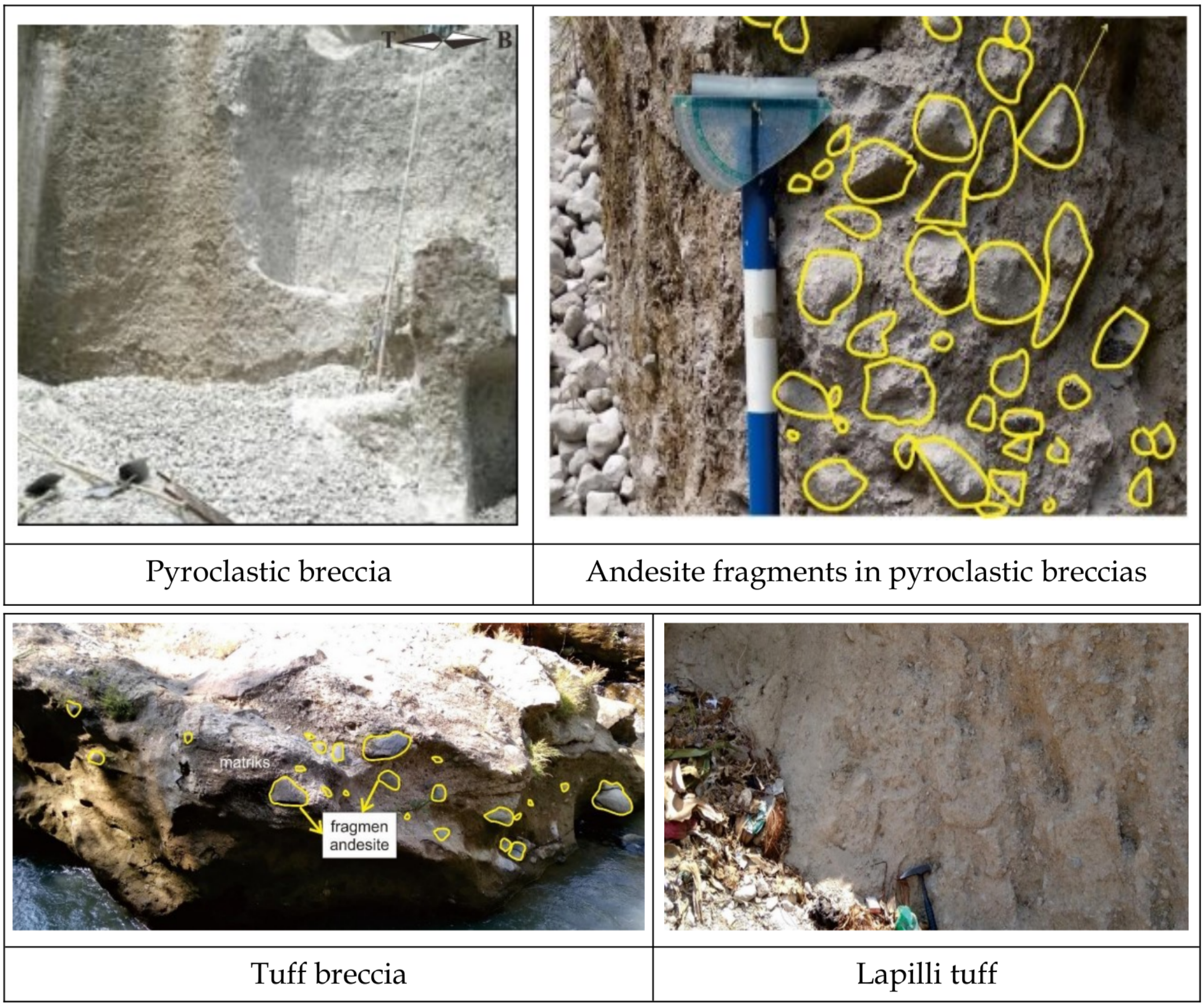

FIGURE 5. The sample of rock unit outcrops in the research area.

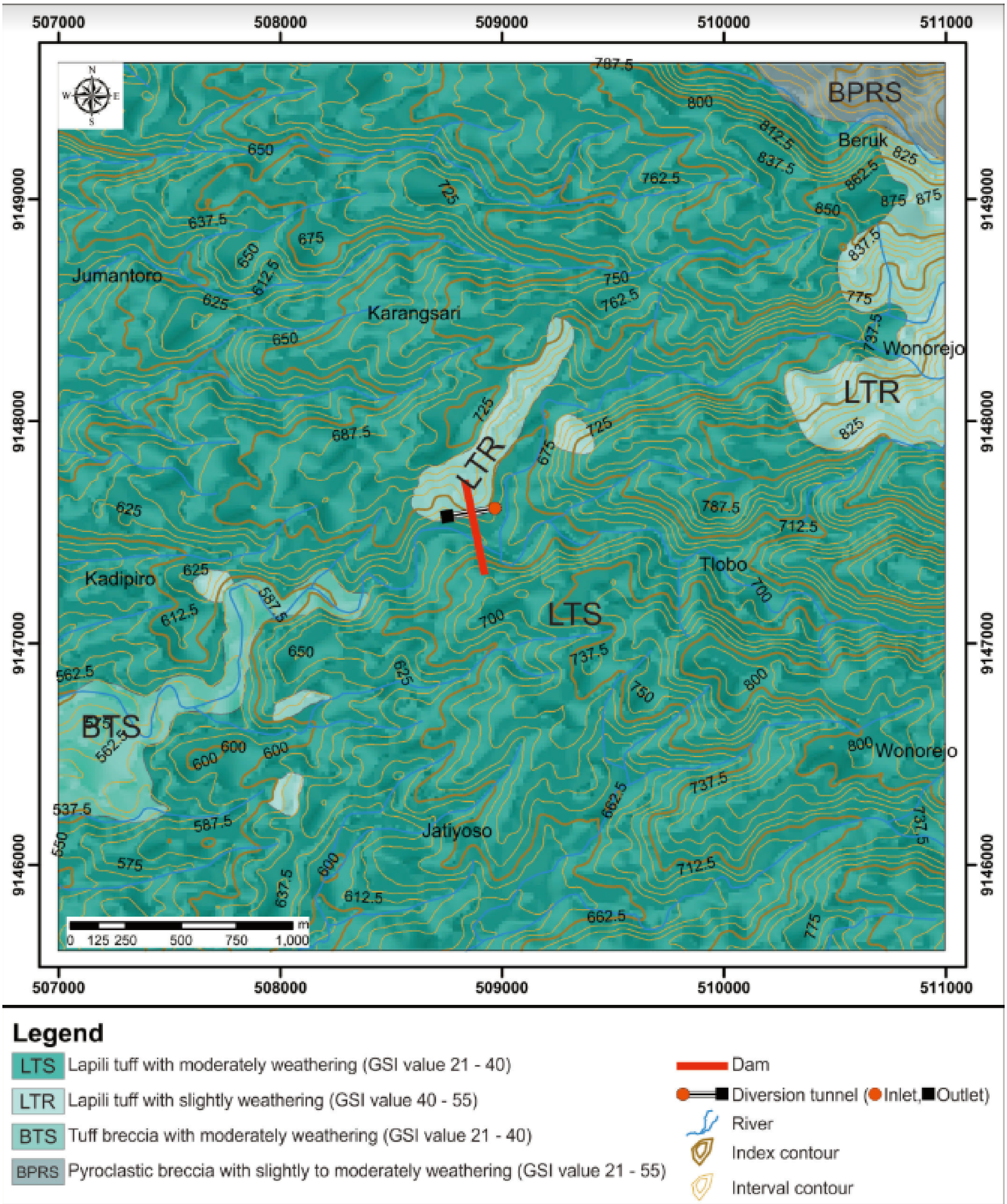

FIGURE 6. Weathering degree map of surface rock mass (Triatmojo 2019).

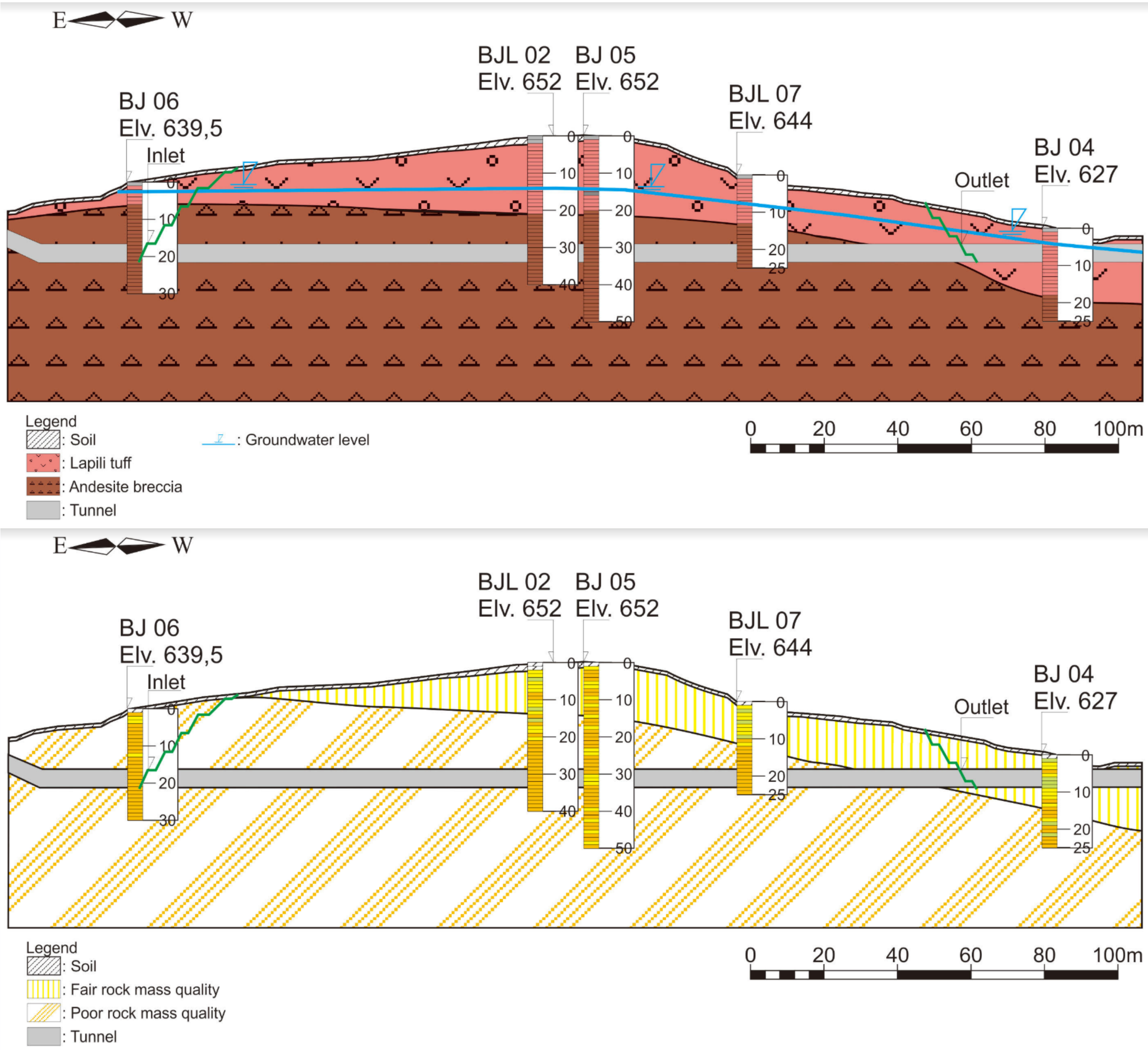

FIGURE 7. Profiles of soil and rock type (top) and rock mass quality (bottom) along the tunnel.

0.164 was used in the modeling, with 0.5 of the horizontal peak acceleration.

Slope modeling was carried out according to the blueprint and several alternatives, various slope designs, namely 1V:1.5H and 1V:2H, with a face slope height of 3 meters and a bench length of 2 meters. The results of the calculation of portal slope modeling are shown in Table 3 in the form of SRF values, which show the value of slope safety factors with and without the influence of the earthquake.

Table 3 shows that the plan design without the influence of the earthquake on the inlet and outlet slope locations resulted in unsafe conditions because of low safety factors (SRF<1.3). In the next model, the SRF value can reach a safe threshold (SRF>1.3) after changing the slope to 1V:1.5H. However, in the condition of alternative 1 (1V:1.5H) with the influence of the earthquake on the inlet position offered, the portal SRF value is still below the threshold (SRF=0.98 or SRF<1.1). Alternative 2 (1V:2H) produces an SRF value of 1.17 or SRF>1.1 for conditions with earthquake influence, so the portal inlet slope is safe. Likewise, the alternative modeling 2 (1V:2H) at the portal outlet location increased the SRF value's safety rate from 1.12 to 1.24. The modeling results with RS2 software (Rocscience, Inc) in each condition can be seen in Figure 8 and Figure 9.

SRF value at the portal outlet location is greater than the SRF value at the portal inlet location for the same slope design conditions in terms of the overall relative slope height. This is because the quality of rock mass at the portal outlet location is better than that of rock mass at the portal inlet location, as shown in Figure 7.

Regarding global safety, when the re-sloping was conducted, the SRF value increased with and without earthquake influence. However, regarding local safety, the results showed that some slope parts must be treated, especially on the surface area. It was red in the lower bench area (Figure 8). This is in accordance with the characteristics of andesitic breccia rocks with poor rock mass quality at location BJ06 (inlet) and fair rock mass quality lapilli tuff rocks at location BJ04 (outlet) (Figure 7). The recommended treatments as the slope surface protections are shotcrete combined with wire mesh and rock-bolt. However, from an economic per-

TABLE 2. The input of rock parameters for portal slope stability modeling.

Lithology	Bulk Unit Weight (γ) MN/m^3	Dry Unit Weight (γ) MN/m^3	Saturated Unit Weight (γ) MN/m^3	Modulus Young MPa	Poisson Ratio	UCS MPa	c MPa	ϕ (°)	GSI
Soil outlet	0.0162	0.0103	0.0164	6.00	0.30		0.068	8.112	
Soil Inlet	0.0166	0.0112	0.0168	10.00	0.30		0.069	10.852	
Lapilli tuff	0.017	0.0154	0.0195	88.57	0.40	0.77			Inlet = 37.5 outlet = 46
Andesite breccia	0.025	0.0245	0.0268	125.93	0.35	0.92			Inlet = 37.5 outlet = 37.5

Note: UCS = uniaxial compression strength; c = cohesion; ϕ = internal friction angle

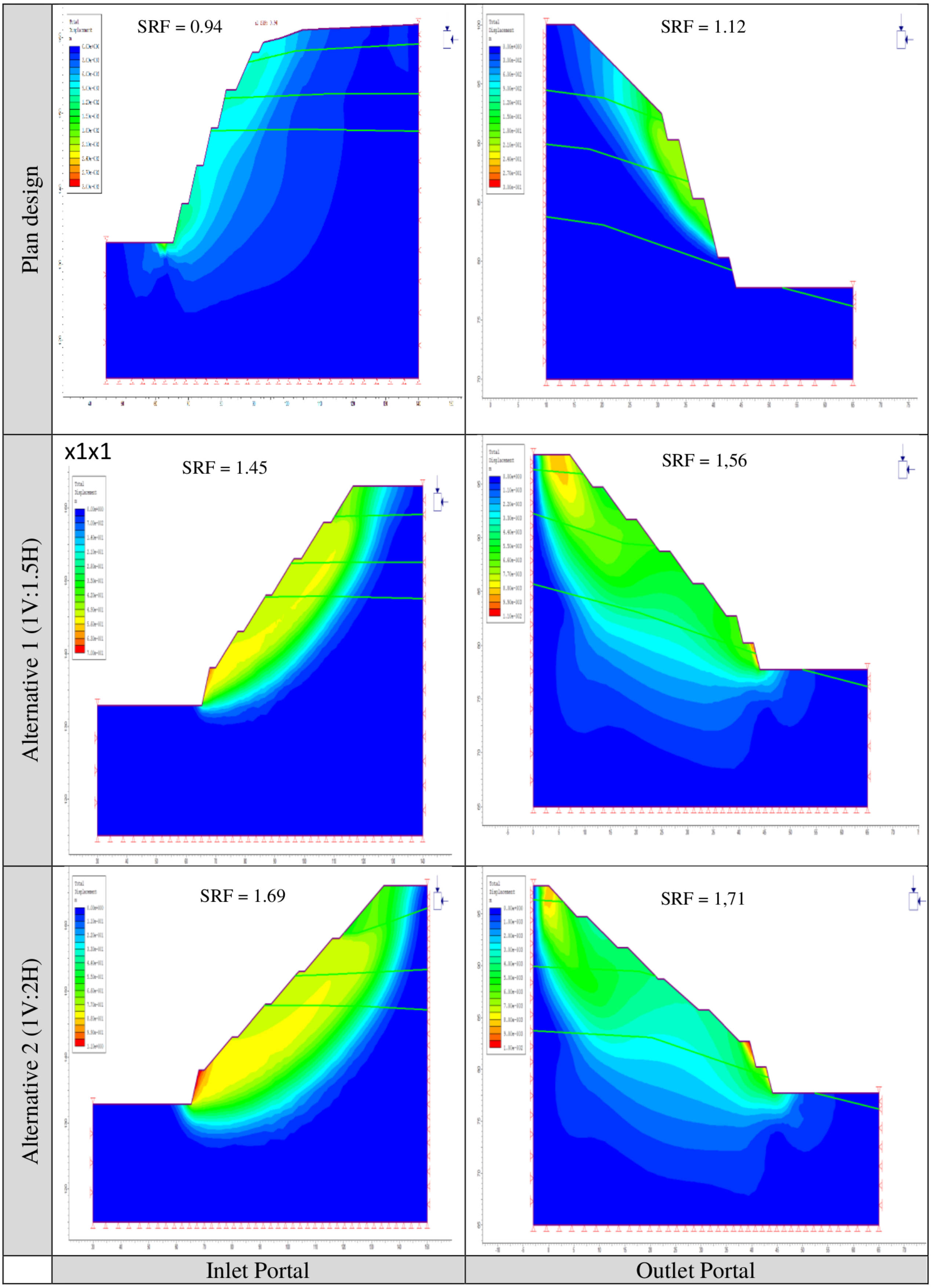

FIGURE 8. Modelling results of portal slope stability without earthquake influence.

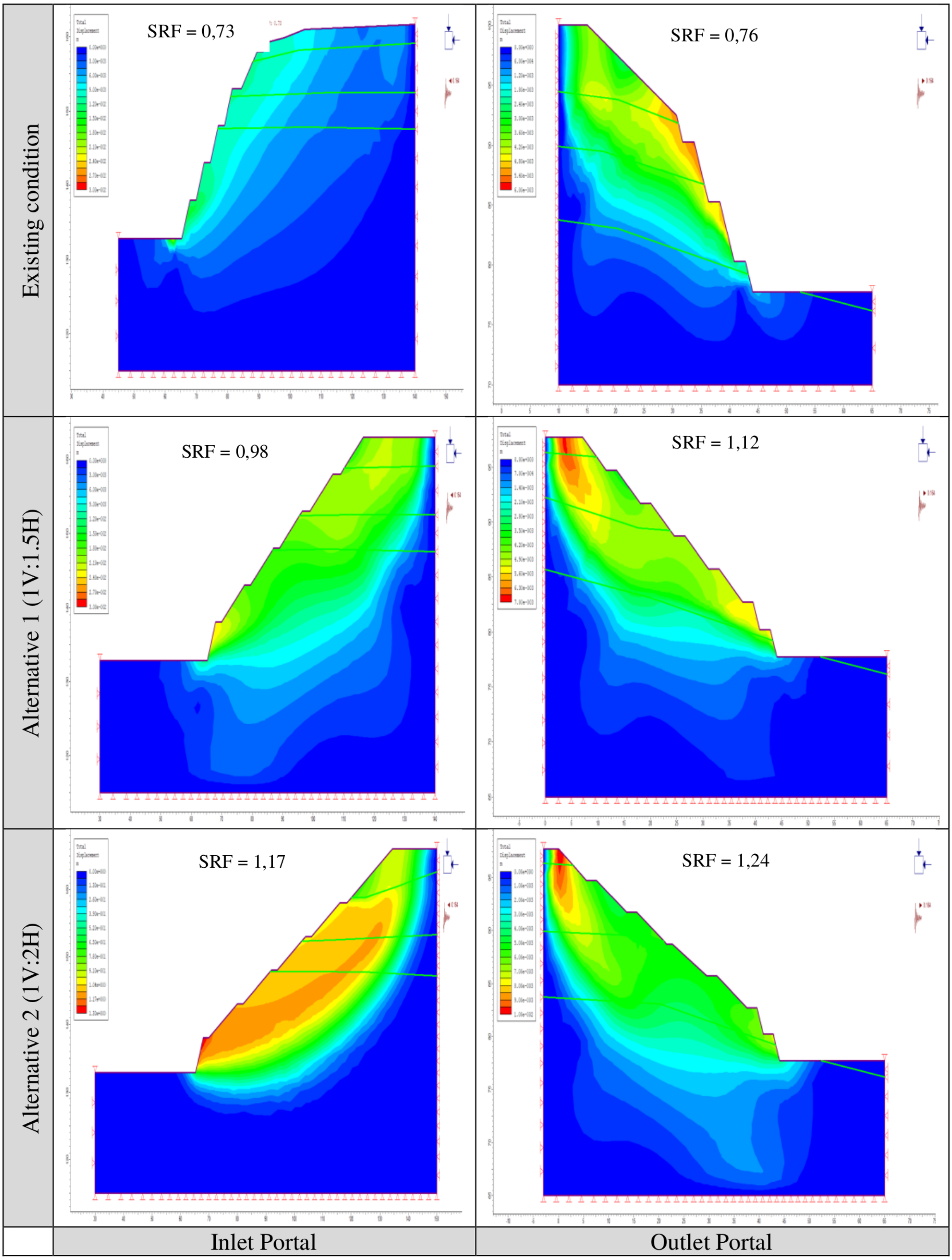

FIGURE 9. Modelling results of portal slope stability with earthquake influence (kh = 0.164).

TABLE 3. Calculation results of portal slope stability analysis.

Condition	Slope Design	Loading	SRF	
			Inlet Portal	Outlet Portal
Plan Design	1 V : 0.5 H	without earthquake influence	0.94	1.12
		with earthquake influence	0.73	0.76
Alternative 1	1 V : 1.5 H	without earthquake influence	1.45	1.56
		with earthquake influence	0.98	1.12
Alternative 2	1 V : 2 H	without earthquake influence	1.69	1.71
		with earthquake influence	1.17	1.24

spective, the treatments may not be necessary because the conduit tunnel will be backfilled after the dam's construction. The greater SRF values than required are considered sufficient for non-permanent buildings. According to the comparison of the re-sloping alternatives design, alternative 2 was appointed as the recommended design to be applied.

4 CONCLUSION

The study area consists of residual soil, andesite breccia, and lapilli tuff rocks with rock mass quality based on the GSI value ranging from poor to fair. The inlet portal slope comprises rocks with poor and fair mass quality, while the inlet section comprises rocks with poor mass quality. The design of a 1V:2H slope with each face slope height of 3 meters and the length of each bench of 2 meters produces an SRF value of 1.69 in conditions without the influence of earthquake load and an SRF of 1.17 in conditions with the influence of earthquake load on the portal inlet location. At the portal outlet, the SRF value generated is 1.71 in conditions without the influence of earthquake load and SRF of 1.24 in conditions with the influence of earthquake load. So it can be concluded that the selection of the slope design 1V:2H (alternative 2) with a face height of 3 meters and a bench length of 2 meters shows the slope in a safe condition both without earthquake (SF > 1.3) or earthquake (SF > 1.1) without additional reinforcement. The rock mass quality strongly influences portal slope stability. The better the rock mass's quality, the higher the safety factor's value.

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