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# Numerical Analyses of Tunnel Outlet Slope at Leuwikeris Dam, West Java, Indonesia

Sunardi, Ardian Baroto Murti, and I Gde Budi Indrawan*

*Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia*

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ABSTRACT. The excavated slope of the diversion tunnel outlet at the Leuwikeris Dam was designed based on core test data and the Circular Failure Chart (CFC) method. The stability of the excavated slope under static and seismic loads has not been verified using a different method. The objective of this research was to evaluate the performance of the excavated slope under static and seismic loads using the finite element method (FEM). Stability analyses of the natural slope were also carried out to assess the improved stability of the slope after excavation. Geological mapping, examinations of drill cores and borehole logs, and laboratory tests were conducted to characterize the soils and rocks comprising the tunnel outlet slope. The rock masses were characterized using the Geological Strength Index (GSI) for the input parameters of the Generalised Hoek-Brown criterion. The slope stability analyses under static and seismic loads were performed using the finite element-based computer package RS2. The results show that the diversion tunnel construction site consists of residual soil and very poor to fair quality andesite breccia rock and tuff breccia with thin claystone intercalation. The groundwater table was located approximately 40 m below the ground surface. In general, the seismic load reduced the stability of the slopes. The critical strength reduction factor (SRF) values of the natural portal slope, which had a 40° inclination, were 3.6 and 1.45 under static and seismic loads, respectively. Meanwhile, the SRF values of the excavated slope, which had seven benches and 55 to 74° inclinations, were 3.83 and 1.78 under static and seismic loads, respectively. The natural and excavated slopes were considered stable under static and seismic loads and met the stability criteria determined by the National Standardization Agency of Indonesia (2017). The slope design increased the slope FS values by 6% and 20% under static and seismic loads.

**Keywords:** Finite element · Leuwikeris Dam · Seismic load · Slope stability · Tunnel outlet.

## 1 INTRODUCTION

The process of river water diversion in order not to inundate a construction site is an essential stage in constructing a dam. A twin diversion tunnel was constructed for river water diversion during the construction of the Leuwikeris Dam (Figure 1). The Leuwikeris Dam is administratively located in Cimaragas and Cijeungjing Districts, Ciamis Regency, West Jawa Province, Indonesia. Regional Geological Map of Tasikmalaya Sheet (Budhitrisna, 1986) indicates that the twin tunnel site consists of Old Volcanic Rock Formation (Qtvs), Quartenary sediment of Pleistocene age.

Excavation of the diversion tunnel at the Leuwikeris Dam may affect the stability of slopes, especially around the tunnel portals. In addition to tunnel excavation by blasting, the factor that may affect slope stability in the research area is a dynamic load than can be

*Corresponding author: I G. B. INDRAWAN, Department of Geological Engineering, Universitas Gadjah Mada. Jl. Grafika 2 Yogyakarta, Indonesia. E-mail: igbindrawan@ugm.ac.id

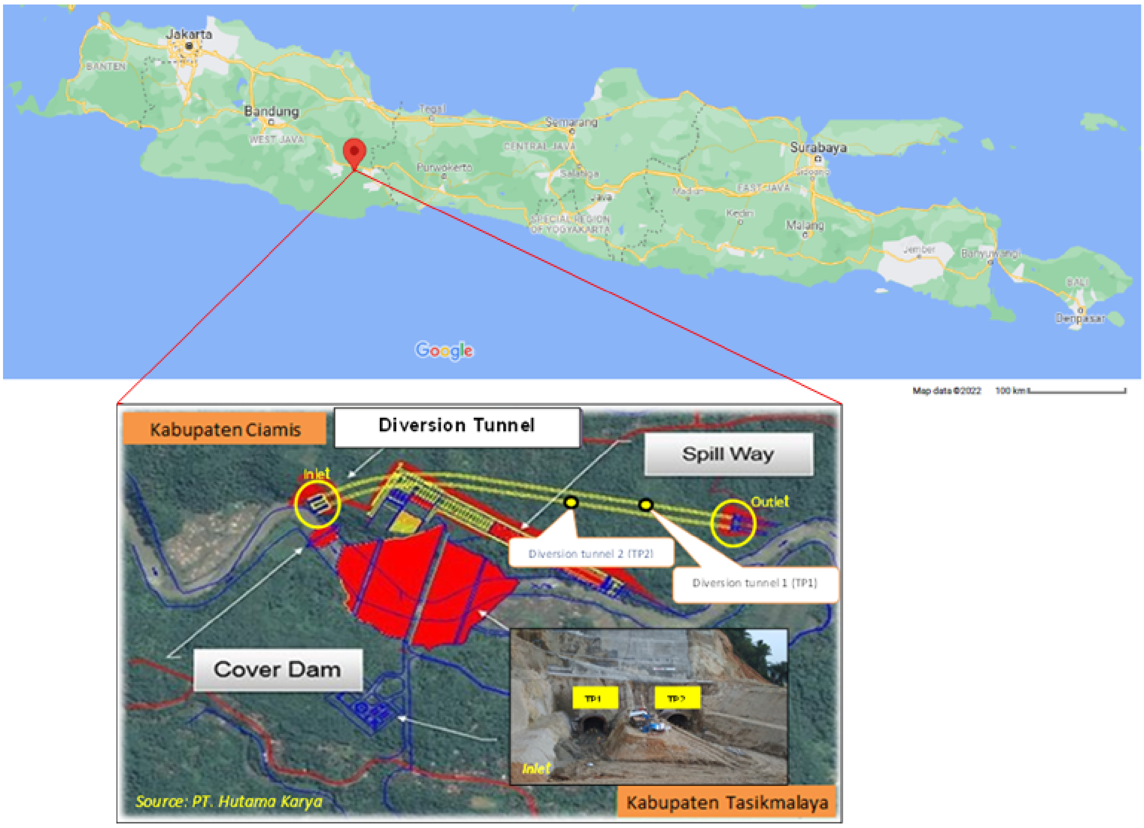


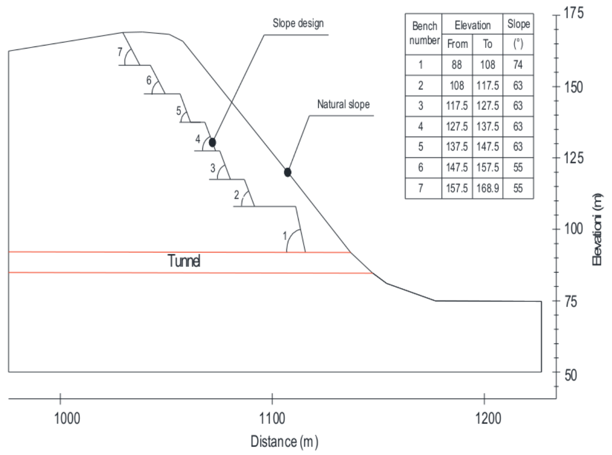

FIGURE 1. Research location.

in the form of seismic. Indonesia is located at four main tectonic plates, namely the Indo-Australia, Eurasia, Pacific, and Philippine Sea plates. Interaction between the four tectonic plates makes Indonesia one of the countries with high seismic activity and is susceptible to seismic. The tremor from a seismic will be distributed from the center to all directions through delivery media, such as soil and rocks. Stability analyses of tunnel portal slopes under seismic load are essential as several reported cases indicate that ground failures, including slope failures at portals, are common during seismic events (*e.g.*, Jaramillo, 2017).

PT. Hutama Karya (2018) has designed the geometry of the tunnel outlet slope at the Leuwikeris Dam. The slope design was based on laboratory tests of core samples and the Circular Failure Chart (CFC) method (Hoek and Bray, 1981) without calculating the potentially occurring earthquake load. This paper presented the stability analyses of the natural (pre-excavated) and excavated tunnel outlet slopes at the Leuwikeris Dam under static and seismic loads using the FEM. The FEM was used in this research because the method typically produces safety factor values similar to the conventional and widely used limit equilibrium method (LEM). One of the significant advantages of the FEM over the LEM is that the FEM does not require assumed slip surfaces, which are required in the LEM.

## 2 METHOD

Geometries of the natural and designed slopes are shown in Figure 2. The excavated slope of the diversion tunnel outlet was designed to have seven benches and 55 to 74° inclinations. Types of materials comprising the tunnel outlet slope were determined by surface geological mapping and examination of drill cores collected by PT Hutama Karya (2018). The drilling locations near the diversion tunnel outlet are shown in Figure 6. Rock mass characterizations of drill cores were carried out using the GSI proposed by Hoek *et al.* (2013). The GSI combines two main parameters, namely joint condition (JCond89), which was defined by Bieniawski (1989), and RQD, defined by Deere (1963). Rock mass quality of the portal slopes was determined based on the Rock Mass Rating (RMR) using the GSI–RMR correlation de-




| Bench number | Elevation | | Slope |
|---|---|---|---|
| | From | To | (°) |
| 1 | 88 | 108 | 74 |
| 2 | 108 | 117.5 | 63 |
| 3 | 117.5 | 127.5 | 63 |
| 4 | 127.5 | 137.5 | 63 |
| 5 | 137.5 | 147.5 | 63 |
| 6 | 147.5 | 157.5 | 55 |
| 7 | 157.5 | 168.9 | 55 |

FIGURE 2. Natural and designed tunnel portal slopes.

scribed in Shivakugan *et al.* (2013). Laboratory tests were conducted to determine the unit weight values of the soil and rock samples based on the ASTM D7263-09 (ASTM International, 2009). Soil shear strength was determined based on the ASTM D3080-98 (ASTM International, 1998), and uniaxial compressive strength (UCS) values of intact rocks were determined based on the ISRM (1981).

The slope stability analyses under static and seismic loads were performed using the finite element-based computer package RS2 developed by Rocscience Inc. Soil shear strength was modeled using the Mohr-Coulomb failure criterion, while the rock mass strength was modeled using the Generalised Hoek-Brown failure criterion (Hoek et al., 2002). A disturbance factor (D) of 0.7 was assumed due to the mechanical method of the slope excavation. The excavated slope was designed to have reinforcements of a 0.1 m thick shotcrete and 4-mm diameter wire mesh. Borehole logs indicated that the groundwater table at the tunnel outlet slope was approximately 40 m below the ground surface. However, the slope stability analyses using the FEM were performed under a dry slope condition to obtain results comparable to the slope design using the CFC method. A 0.4 horizontal seismic load coefficient, determined from a response spectrum analysis of seismic acceleration at the Leuwikeris Dam site provided by the National Center for Earthquake Studies (2017), was assigned to simulate the seismic load imposed on the tunnel outlet slopes. The determination of the horizontal seismic coefficient is described in Sunardi (2019). The slope stability level is represented by the critical strength reduction factor (SRF) value, also called the factor of safety (FS). As stipulated in the SNI 8460:2017 (National Standardization Agency of Indonesia, 2017), the allowed FS for permanent slope conditions is 1.5. If the seismic load is considered, the required minimum FS is more than 1.1.

## 3 RESULTS AND DISCUSSION

### 3.1 Material types and properties

The surface geological mapping results show that the diversion tunnel construction site consisted of andesite breccia and tuff breccia. Photographs of the weathered andesite breccia and tuff breccia outcrops are shown in Figures 3 and 4, and the geological map of the diversion tunnel construction area is shown in Figure 5. The andesite breccia and tuff breccia had a massive structure, poor sortation, and open fabric (matrix-supported). The andesite breccia consisted of angular-subangular shape, gravel-size andesite fragments, and fine to a coarse sand matrix. Meanwhile, the tuff breccia consisted of a tuff-dominated fragment and matrix. The twin diversion tunnel outlets are located near the sinistral strike-slip fault. The evaluation of drill cores showed that the tunnel portal slope consisted of residual soil, andesite breccia rock, and tuff breccia with thin claystone intercalation (Figure 6). The andesite breccia had very poor to poor quality, the tuff breccia had poor to fair quality, while the thin claystone intercalation had poor quality. The materials and shotcrete properties used for input parameters in the slope stability analyses are presented in Table 1 and Table 2. The constants mi for each material and the wire mesh properties used the default values provided in the RS2 software package. The corresponding values of mb, s, and constants were calculated automatically.

### 3.2 Slope stability

The stability analysis results of the natural and excavated slopes under static and seismic loads are shown in Figure 7 and Figure 8 and summarized in Table 3. Figure 7 shows that the maximum strains developed below the residual soil layers of the natural slopes under static and seismic loads. In the natural slopes, the maxi-

FIGURE 3. Outcrop of andesite breccia.

FIGURE 4. Outcrop of tuff breccia.

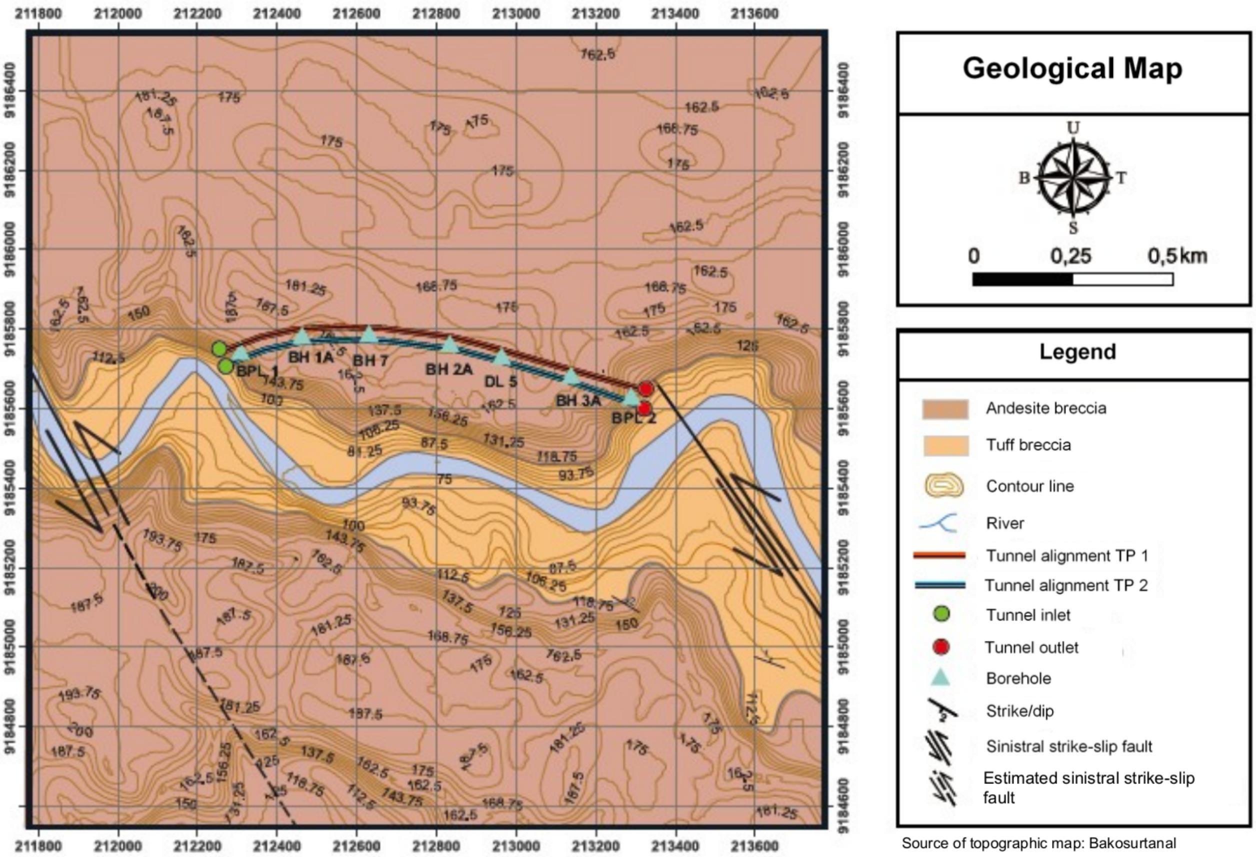
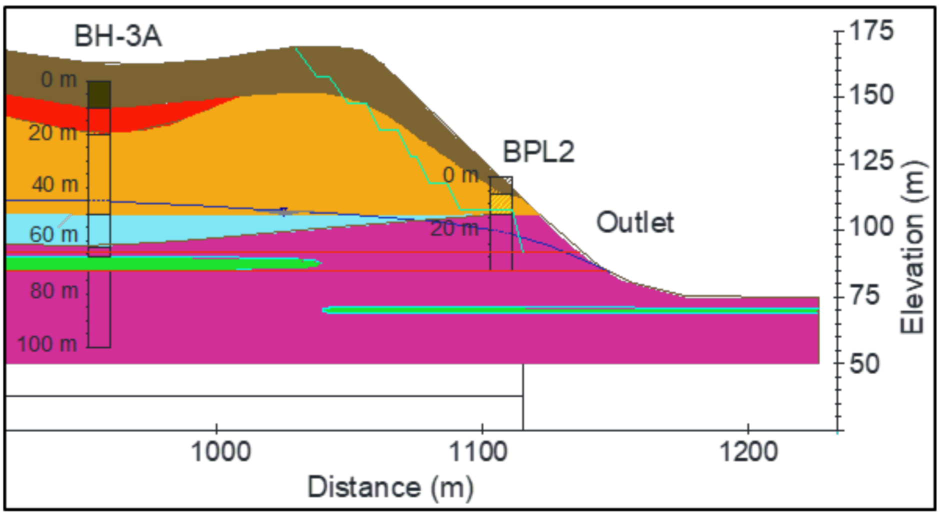



FIGURE 5. Geological map of the research area (Murti, 2019).




| | | | | | |
|---|---|---|---|---|---|
| | Residual soil | | Tuff breccia (poor) | | Tunnel |
| | Andesite breccia (very poor) | | Tuff breccia (fair) | | Groundwater table |
| | Andesite breccia (poor) | | Claystone (poor) | | Designed slope |

FIGURE 6. Materials comprising the portal slope.

TABLE 1. Material properties.

| Material | GSI | $\rho_b$ | $\rho_{sat}$ | $\rho_d$ | $\rho_{ci}$ | $E_i$ | $v$ | Constants | | | | $c$ | $\phi$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (MN/m$^3$) | (MN/m$^3$) | (MN/m$^3$) | (MPa) | (MPa) | | $m_i$ | $m_b$ | $s$ | $a$ | (MPa) | (°) |
| Residual soil | | 0.013 | 0.016 | 0.01 | | 8.826 | 0.3 | | | | | 0.064 | 15.6 |
| Andesite breccia (very poor) | 16 | 0.012 | 0.017 | 0.012 | 31.8 | 350.7 | 0.38 | 14 | 0.95 | 0 | 0.557 | | |
| Andesite breccia (poor) | 35 | 0.018 | 0.021 | 0.008 | 31.8 | 1047 | 0.35 | 14 | 1.87 | 0.001 | 0.516 | | |
| Tuff breccia (poor) | 32 | 0.018 | 0.02 | 0.016 | 2.3 | 61.2 | 0.35 | 14 | 1.68 | 0.001 | 0.52 | | |
| Tuff breccia (fair) | 49 | 0.02 | 0.021 | 0.019 | 19 | 1593 | 0.3 | 19 | 3.07 | 0.003 | 0.506 | | |
| Claystone (poor) | 28 | 0.017 | 0.018 | 0.014 | 4.3 | 77.9 | 0.39 | 2 | 0.31 | 0 | 0.526 | | |
| Lining Tunnel (Concrete) | | 0.024 | | | | 23500 | 0.15 | | | | | 0.5 | 35 |

Note: $\rho_b$ = total density; $\rho_{sat}$ = saturated density; $\rho_d$ = dry density; $\rho_{ci}$ = UCS intact rock; $E_i$ = modulus Young's of intact rock; $v$ = Poisson's ratio; $m_i$ = intact rock constant; $m_b$, $s$, and $a$ = rock mass constants; $c$ = cohesion; and $\phi$ = internal friction angle.

TABLE 2. Shotcrete properties.

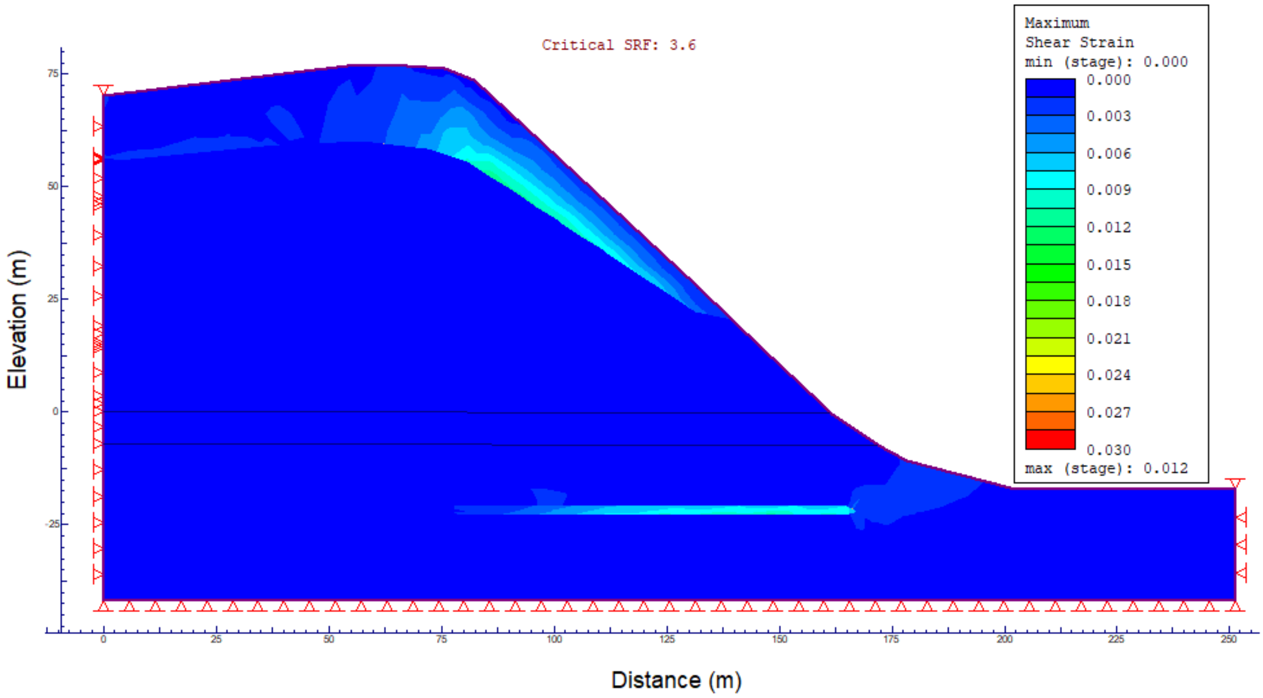
| Thick-ness | Young Modu-lus | Poisson Ratio | Com-pressive Strength | Tensile Strength |
|---|---|---|---|---|
| (m) | (MPa) | | (MPa) | (MPa) |
| 0.1 | 23453 | 0.15 | 24.9 | 1.25 |

TABLE 3. Summary of slope stability analysis results.

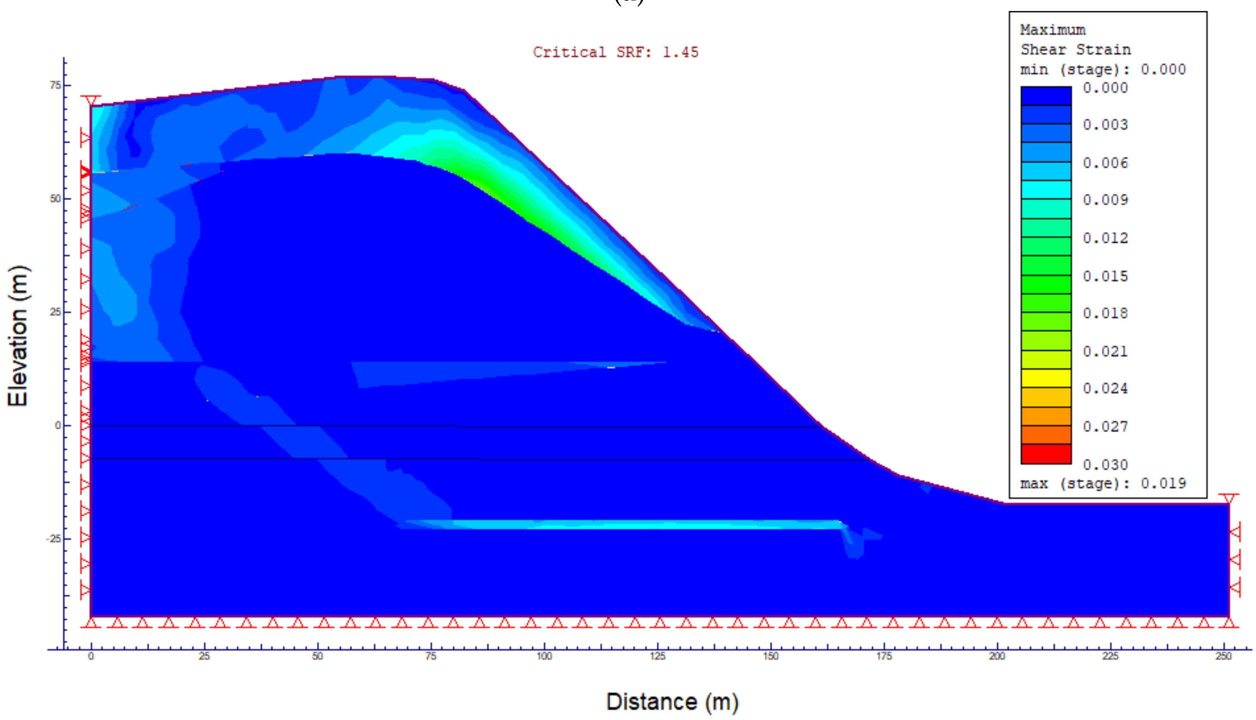
| Slope | Critical SRF | |
|---|---|---|
| | Static load | Seismic load |
| Natural slope | 3.6 | 1.45 |
| Excavated slope | 3.83 | 1.78 |

mum shear strains of 1.2 % and 1.9 % developed in the residual soil under static and seismic loads, respectively. This is because the residual soil was a relatively weak material compared to the other materials. In general, it is shown that the seismic load reduced the stability of the slopes. Figure 7 and Table 3 show the critical SRF values that the natural slopes were 3.6 and 1.45 under the static seismic loads, respectively. Because the critical SRF values of the slope were higher than 1.5 and 1.1, the natural slopes were considered in stable conditions based on the stability criteria specified by the National Standardization Agency of Indonesia (2017).

Figure 8 shows that the slope design reduces the potential instability zone in the tunnel outlet slopes, causing the maximum shear strains to develop only in the thin layers of poor quality tuff breccia. Under the static and seismic loads, the maximum shear strains developed in the poor quality tuff breccia were 2.1% and 2.7 %, respectively. Although the maximum shear strains increased, Figure 8 and Table 3 show that critical SRF values of the excavated slopes under static and seismic loads were 3.83 and 1.78, respectively. The critical SRF values indicate that the excavated slope is in stable conditions under static and seismic loads and meets the stability criteria specified by the National Standardization Agency of Indonesia (2017). The stability analysis results also indicate that the slope design increased the slope FS




(a)




(b)

FIGURE 7. Critical SRF values and maximum shear strain contours in the natural slopes under (a) static load; (b) seismic load.

values by 6 % and 20 % under static and seismic loads.

Although the critical SRF values of the tunnel outlet slope were relatively high and met the stability criteria specified by the National Standardization Agency of Indonesia (2017), the slope stability analyses in this research were performed under several assumptions, such as each of the materials was assumed to have homogenous and isotropic properties and plastic behavior. The stability analyses were also conducted under static pore-water pressure. Further studies are recommended to evaluate the impacts of groundwater level fluctuation due to rainwater infiltration and increased river water elevation on slope performance.

## 4 CONCLUSION

Slope stability analyses using the FEM were performed on the natural and excavated tunnel outlet slopes at the Leuwikeris Dam to evaluate the performance of the excavated slope designed using the CFC method. Geological mapping, examinations of drill cores and borehole logs, and laboratory tests were conducted to characterize the soils and rocks comprising the tunnel outlet slope. The rock masses were characterized using the GSI for the input parameters of the Generalised Hoek-Brown criterion. The slope stability analyses under static and seismic loads were performed using the computer package RS2. The results show that the diversion tunnel construction site consists of residual soil and very poor to fair quality andesite breccia rock and tuff breccia with thin claystone intercalation. The groundwater table was located approximately 40 m below the ground surface. In general, it is demonstrated that the seismic load reduced the stability of the slopes. The critical strength reduction factor (SRF) values of the natural portal slope, which had a 40° inclination, were 3.6 and 1.45 under static and seismic loads, respectively. Meanwhile, the SRF values of the excavated slope, which had seven benches and 55 to 74° inclinations, were 3.83 and 1.78 under static and seismic loads, respectively. The natural and excavated slopes were considered stable under static and seismic loads and met the stability criteria specified by the National Standardization Agency of Indonesia (2017). The slope design increased the slope FS values by 6% and 20% under static and seismic loads.

## ACKNOWLEDGEMENTS

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## REFERENCES

ASTM International (1998). ASTM D3080-98: Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. West Conshohocken, PA.

ASTM International (2009). ASTM D7263-09: Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens. West Conshohocken, PA.

Bieniawski, Z. T. (1989). Engineering Rock Mass Classification Mining and Mineral Resources Research Institute. Pennsylvania State University.

Budhitrisna, T. (1986). Geological Map of Tasikmalaya Sheet, West Java. Geological Research and Development Centre. Bandung. Deere, D.U. 1963. Technical description of rock cores for engineering purposes. Felsmechanik und Ingenieurgeologie 1, pp. 16–22.

Hoek, E., & Bray, J. W. (1981). Rock slope engineering. 3rd ed. Institute of Mining and Metallurgy, London.

Hoek, E., Carranza-Torres, C., & Corkum, B. (2002). Hoek-Brown criterion – 2002 edition. In: Hammah R, Bawden W, Curran J, Telesnicki M, editors. Mining and tunneling innovation and opportunity, proceedings of the 5th North American rock mechanics symposium and 17th tunneling Association of Canada conference. Toronto, Canada. Toronto: University of Toronto.

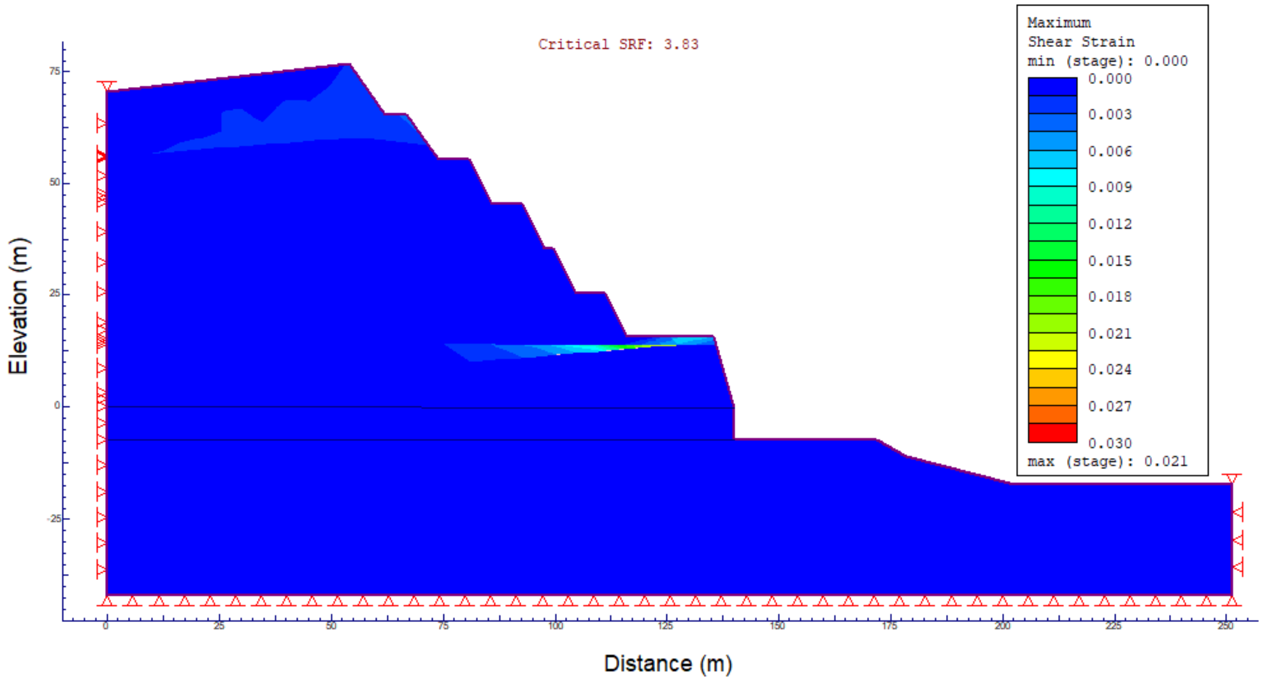
Hoek E., Carter T. G., & Diederichs M. S. (2013). Quantification of the Geological Strength Index Chart. US Rock Mechanics/Geomechanics Symposium), San Fransisco.

ISRM (1981). The Complete ISRM Suggested Methods for Rock Characterization, Testing, Monitoring, Ankara, ISRM Turkish National Group.

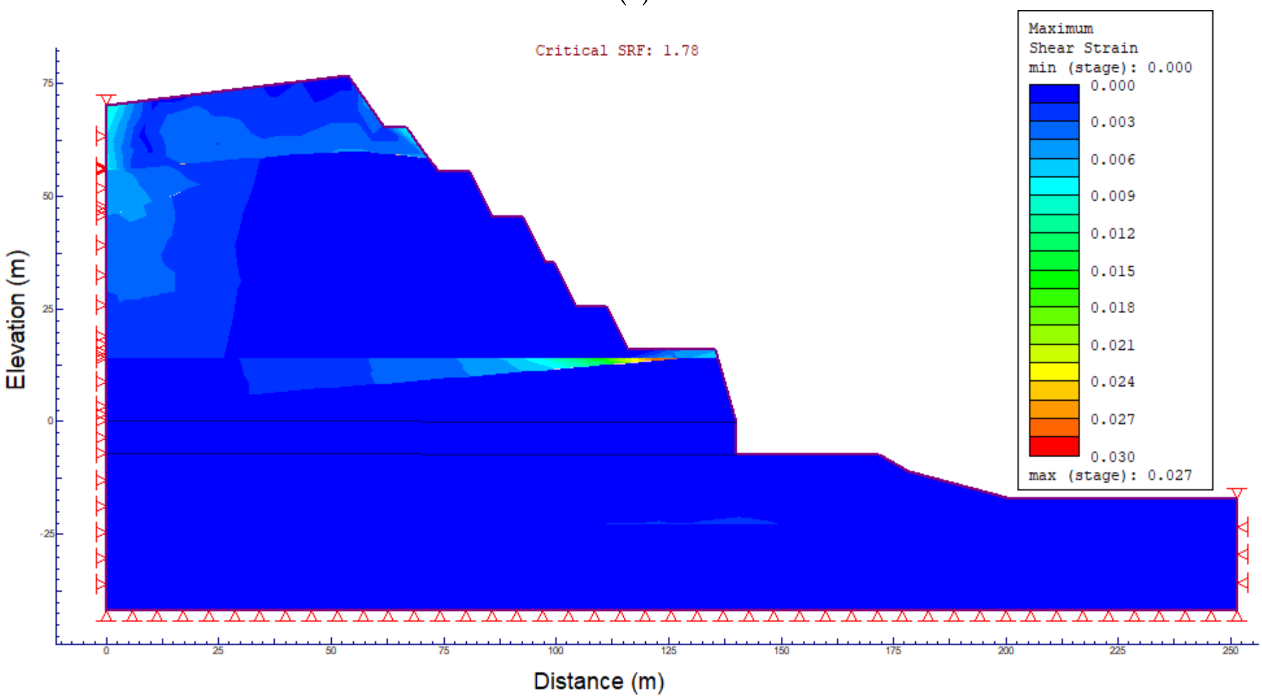
Jaramillo, C. A. (2017). Impact of seismic design on tunnels in rock – Case histories. Underground Space 2, pp. 106–114.

Murti, A. B. (2019). Engineering geological characteristics of diversion tunnel at Leuwikeris Dam, Ciamis, West Java. Unpublished undergraduate thesis. Department of Geological Engineering, Universitas Gadjah Mada. Indonesia.

National Center for Earthquake Studies. (2017). Indonesian seismic sources and seismic hazard




(a)




(b)

FIGURE 8. Critical SRF values and maximum shear strain contours in the excavated slopes under (a) static load; (b) seismic load.

maps 2017—Center for Research and Development of Housing and Resettlement, Ministry of Public Works and Housing, Indonesia.

National Standardization Agency of Indonesia. (2017). SNI 8460:2017: Geotechnical design requirements. Jakarta. Indonesia.

PT Hutama Karya (Persero) (2018). Report on the 2D pole-dipole electrical resistivity survey to support rock investigation. Bandung. Indonesia.

Shivakugan, N., Shukla, S. K., & Das, B. (2013). Rock Mechanic An Introduction. New York: CRC Press.

Sunardi (2019). Evaluation of engineering geological conditions and stability analysis of diversion tunnel excavation at Leukeris Dam, Ciamis, West Java. Unpublished Master of Engineering Thesis. Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada. Indonesia.