Stability of the Meninting Diversion-Spillway Tunnel Constructed into Weak Volcanic Rock Masses Influenced by the Lombok Earthquake 2018

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Abstract. The Meninting diversion-spillway tunnel is a part of the Meninting dam project located in West Lombok District. The construction commenced in 2017; then, a series of severe Lombok earthquakes halted the construction for a while in 2018, where some landslides occurred around the site. This possibly caused rock masses around the tunnel to be sheared off during the earthquake events. The last earthquake events increased seismic parameters, increasing stresses around the tunnel. Thus, the stability of the tunnel decreased in terms of a strength factor. Although, the overall stability of the tunnel was still fine with a strength factor of around 2.5; the tunnel certainly requires more stability improvements for future similar earthquake events.

Keywords: Lombok Earthquake · Meninting Tunnel · Stress around Tunnel · Strength Factor · Stability Improvement

1 Introduction

The Mininting diversion-spillway tunnel was a part of the dam project constructed in the West Lombok District in Lombok Island since 2017. The location of the project was only at 50 km distance from the epicenter of the 5th August 2018 Lombok earthquake [1–3]. The intensity of the earthquake event was reported of MMI VII at the project site [4], which caused some collapsed area around the site [2].

The Lombok earthquakes have increased seismic parameters for Nusa Tenggara region [5], including higher peak ground acceleration, spectral accelerations S_S and S_1, compared to those of the SNI 1726:2019 [6]. These seismic conditions should increase the risk of instability of the tunnel, since it was designed before the Lombok earthquake events [7]. Therefore, this paper recalculated the stability of the Meninting diversion-spillway tunnel according to the current seismic parameters.

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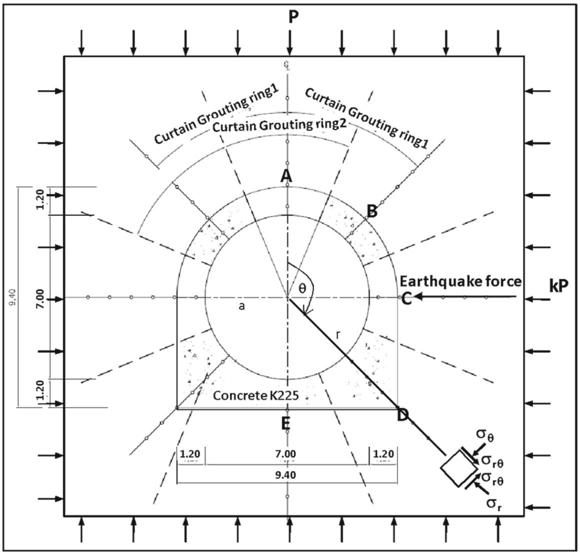

Fig. 1. Typical type 2 of diversion tunnel with stresses working around tunnel where earthquake forces acted horizontally perpendicular to the tunnel axis [7].

2 Tunnel Design

The Meninting diversion-spillway tunnel design had two types: Type 1 diversion tunnel, and Type 2 spillway tunnel. Both types were connected with a connecting shaft to become a diversion-spillway tunnel. The type 2 of a shoe-shape tunnel had a dimension of 9.40 × 9.40 × 252.5 m (Fig. 1). The elevation of the tunnel base would be at + 147.8 m above the MSL, while the top surface of the tunnel would be at + 211.9 m above the MSL. Fully support systems have been installed, including shotcreted wiremesh with a 0.15 m thickness, steel H-beams with a spacing of 1 m, a concrete lining of 0.6 m thickness, and consolidation and curtain grouts. The far field stresses, P on vertical and kP on horizontal directions, were estimated on each part of the tunnel: A, B, C, D, E; and additional earthquake stresses worked horizontally perpendicular to the tunnel axis.

3 Method

The New Austrian Tunneling Method (NATM) was applied in the construction of the Meninting tunnel [8]. The support systems followed the geomechanics classification [9, 10]. Then, the stability analysis applied the non-linear Hoek-Brown criterion (HB) [11, 12]:

$$\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b\frac{\sigma_3}{\sigma_{ci}} + s\right)^a \tag{1}$$

According to Eq. (1), the strength of rock masses will depend on parameters m_b, s and a, which can be obtained from the rock mass rating (RMR) [11]. Earthquake forces work horizontally on rock perpendicular to the tunnel axis, so the kP stress was added with earthquake stresses. Then the estimation of stresses around the tunnel followed the Kirsch solutions [11].

However, the Indonesian standards for tunnels have not yet been updated for current seismic conditions, for particular the Nusa Tenggara region. The available national standards were the SNI 1726–2019 and Pd T-14–2004-A [6, 14]. The adaptation of these two standards was applied to the Meninting diversion-spillway tunnel. Equation (2) is adapted to estimate earthquake forces from peak ground acceleration (PGA) on the surface and weight of rocks around the tunnel, which was obtained from the coefficient Z [14].

$$F = \alpha_1 \times \frac{\alpha_d}{g} \times W \tag{2}$$

F = horizontal earthquake force
a_1 = correction factor for construction type
a_d = peak ground acceleration on the surface
$= Z \times a_c \times V$
Z = earthquake zone coefficient
a_c = peak ground acceleration
V = correction factor for rock/soil type
g = gravity
W = weight

In order to gain peak ground acceleration values, the updated seismic parameters from [5]: PGA, short and long spectral accelerations (Ss, and S1) were therefore applied for the current stability analysis of the Meninting tunnel.

4 Results

4.1 Rock Mass Strength

The Meninting diversion-spillway tunnel was mainly excavated into volcanic breccias. The rocks were included into poor rock mass quality with an RMR of 40. The stand up time for the tunnel was one week without any support [11]. Using this RMR value, m_i of 19 and confining pressures of 0.06 MPa, the rock mass strength was within the range of 0.32 - 0.41 MPa, depending on the rock position on the tunnel (Table 1). These low σ_1 values were influenced by low confining pressures of 0.06 MPa. In this estimation, the RMR of 40 did not really increase the rock mass strength [13].

4.2 Stresses Around the Tunnel

The tunnel had a different stress concentration working on each part. On the boundary when the radius a equals the distance r, the radial stress σ_r and the shear stress $\sigma_{r\theta}$ were zero, so the only tangential stress σ_θ had a non-zero value. When r = a + 1 m, stress values on each part of the tunnel can be seen in Table 2.

The tangential stresses worked significantly on the Crown B, Wall C and Base D; shear stress concentrations should be on the Crown B and Base D; while, the Crown A should be tensioned, and some heave might occur on the Base E.

Table 1. Results of the rock mass strength of the Menința tunnel type 2

Parameter	Crown A	Crown B	Wall C	Base D	Base E
Rock	Breccia	Breccia	Breccia	Breccia	Breccia
Unit weight, γ (MN/m^3)	0.021	0.021	0.021	0.021	0.021
Depth of axis, H (m)	26.6	26.6	26.6	26.6	26.6
σ_{ci}, (MPa)	5.9	5.9	5.9	5.9	5.9
σ_3, (MPa)	0.06	0.05	0.06	0.07	0.07
m_i	19	19	19	19	19
RMR	40	40	40	40	40
σ_1 (1), (MPa)	0.36	0.32	0.36	0.41	0.39

Table 2. Stresses working on each part of the tunnel for r = a+1 m.

Stress (MPa)	Crown A	Crown B	Wall C	Base D	Base E
σ_r	0.01	0.08	0.18	0.07	0.01
σ_θ	-0.09	0.22	0.63	0.29	-0.09
$\sigma_{r\theta}$	0.00	-0.20	0.00	0.20	0.00

4.3 Strength Factor

The stability of the tunnel was described in terms of a strength factor (SF) of each part of the tunnel. The SF of the tunnel after excavation influenced by earthquakes was calculated in terms of a ratio between rock mass strength and forces working around the tunnel subject to Kirsch formulations [11]. The Crown B, Wall C and Base D of the tunnel were influenced by earthquakes, where stress concentrations were found.

The most deformed part of the tunnel was the Wall C, where earthquake forces worked on the horizontal line perpendicular to the tunnel axis. This part of the tunnel had only an SF of 0.52 against the σ_θ stress. This SF value was higher for about 27% from that of [14], which was 0.41 (Table 3).

The tunnel might have a stand-up time of up to 1 week prior to the installation of tunnel supports [11]; but it would shorten, probably down to be 25 min, under the influence of earthquakes. Thus, supports should be immediately installed as primary and secondary supports [8, 15].

After the completion of the construction, the tunnel had an increased SF to become over 2.0; although, the Wall C had still a lower value than other parts of the tunnel (Table 4). The SF value for the Wall C was slightly lower than those estimations of older PGA values [6]. The reduction was about 7%.

Overall SF values may still be relevant to the tunnel, since all tunnel supports were fully installed, and the underground structure had fairly stability under earthquakes. The overall SF of the structure was about 2.5.

Table 3. Strength factor after earthquake working on each part of the tunnel for r = a+1 m.

Strength factor	Crown B	Wall C	Base D
Estimations from [14]			
σ_1/σ_r	3.04	1.78	5.10
σ_1/σ_θ	1.10	0.52	1.30
Estimations from [5, 14]			
σ_1/σ_r	2.57	1.42	4.31
σ_1/σ_θ	0.93	0.41	1.09

Table 4. Strength factor for fully constructed Meninting tunnel.

Strength factor	Crown B	Wall C	Base D
Estimations from [5]			
σ_1/σ_r	3.65	1.93	6.01
σ_1/σ_θ	1.32	0.56	1.52
Estimations from [6]			
σ_1/σ_r	3.84	2.06	6.32
σ_1/σ_θ	1.39	0.60	1.60

5 Discussion

The Meninting tunnel was influenced by earthquake forces, for which the SF of the tunnel reduced significantly, particularly on the tangential directions of stresses. The estimations of rock mass strength of the HB criterion were less sensitive to the influence of earthquakes forces. One suggested stability improvement of many suggestions [16] would be the application of grouting and rock bolting [17], which could increase the shear strength, and reduce deformation of rock masses [18, 19].

The Meninting tunnel construction might be sufficient to stand earthquake stresses, but since it was excavated into a hill of various volcanic rock materials, the stability of rock masses would be a problem [20, 21]. On the top of the tunnel, loose bouldery agglomerates and colluviums had low strength [22], particularly with a high coefficient of permeability; they could be easily to lose their shear strength under earthquake forces.

The Lombok earthquakes in 2018 caused rock failures within the area of the dam project, where many landslides occurred during the events [2]. Considering the upper tunnel, it could be more vulnerable than the lower part due to earthquakes [21]. Thus, the stability of the tunnel would not only depend on the support systems installed to the tunnel; but it also could depend on the stability of residual rock mass strength around the tunnel. The residual shear strength of the rocks could drop 41% after the Lombok earthquake 2018 [3], this should be problems for the tunnel stability in future [23–25].

6 Conclusions

The stability of Meninting diversion-spillway tunnel has been recalculated using new seismic parameters for Lombok Island. The recalculations resulted in the reductions of the strength factor of 35%. But, overall stability of the tunnel should be fine for an overall SF of 2.5. The stability of the tunnel requires some improvements for severe earthquakes in future.

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