The influence of earthquake force directions on building construction in Lombok Island: a case study of Pandanduri dam in East Lombok

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Abstract. Lombok Island is one of the regions in Indonesia that has a relatively high risk of earthquakes due to being flanked by two earthquake sources, namely from the south in the form of Indo-Australian plate thrusting (subduction mega-thrust) and north there is a north arc pressure (Flores thrust). Pandanduri Dam is located in the direction of the earthquake force N 171° E. This study aims to determine changes in dam planning using earthquake force calculations from SNI 1726-2002 to SNI 1726-2012 and the effect of the direction of earthquake strength on dam stability. The analysis results show that earthquake risk in Lombok Island is 0.34 g and 0.42 g for the possibility of exceeding 10% and 2% in 50 years. SNI changes in earthquake force calculations have decreased by 26% for 500 years and an increase of 10% for 2500 years. The percentage of the earthquake force directions is not known to be greater than the percentage the earthquake force directions known that N 171°E is influenced by the angle produced by the earthquake direction N 171° E which is 0.094° for the main force direction of the dam and 89.906° for the direction perpendicular to the dam.

1. Introduction

Lombok Island is one of the regions in Indonesia that has a relatively high risk of earthquakes because it is in the eastern part of the Sunda Bow stretching from the Sunda Strait to the east to Sumba Island and flanked by two earthquake source generators, namely from the south in the form of the Indo-Australian plate (subduction mega-thrust) and to the north there is a north arc pressure (Flores thrust)[1], as shown in the Figure 1.

Figure 1. Map of Indonesian settings that determine the boundary between the Sunda Arc and the Banda Arc [1]
This study uses the calculation of the forces acting on the dam namely dam shear force, water drag force, and earthquake forces. Pandanduri dam was built in 2011-2015, so the dam planning uses the earthquake force calculation of SNI 1726-2002. This certainly indicates a change in the procedure for calculating earthquake forces from SNI 1726-2002 to SNI 1726-2012 and the earthquake force directions are not determined in the SNI even though based on earthquake research there are earthquake force directions acting on the area under review. For the case of Lombok Island, there are earthquake force directions that are determined based on the study of a terrestrial earthquake N 171° E.

2. Method
This research was carried out in Pandanduri dam, Swangi village, Sakra district, East Lombok regency, West Nusa Tenggara province. The types of data needed include primary data and secondary data. Earthquake data is primary data obtained from BMKG and USGS from 1970 - 2016 with magnitude ≥ 4 SR, depth ≤ 300 km and distance not more than 500 km. The object of this study is located at 8 ° 10' 00" - 9 ° 05' 00" LS and 115 ° 46' 00" - 117 ° 05' 00" BT. The dam data is secondary data obtained from Waskita-Brantas, PT. Indra Karya, Hall for the testing of construction materials for the West Nusa Tenggara public works office, and book 3 of the final report on the detailed design of the Pandanduri dam. After the earthquake and dam data are obtained, data management is carried out. Data management is done manually by entering variable numbers into the existing formula and then the results were analyzed. Those formulas are described in the subsection 2.1-2.6.

Earthquake activity is in accordance with the Gutenberg-Richter relationship and is usually expressed by the following Equation [2]:

\[
\log N (M) = a - b M
\]  (1)

\( N (M) \) = the cumulative number of earthquakes magnitude greater than or equal to M
\( a \) and \( b \) = capital regression parameters

The attenuation formula used in Calculation (PGA) is attenuation Joyner and Boore [3] are:

\[
a = 10^{0.71+0.23 (Mw-6)-log(R)-0.0027R}
\]  (2)

\( a \) = earthquake acceleration (g)
\( Mw \) = Moment magnitude (SR)
\( R \) = \( R = \sqrt{(R_0^2 - 8^2)} \) (km)

The equation used according to Gumbel [4] are:

\[
G (M) = 10^{(-a.e^{-\beta M})}
\]  (3)

\( a \) = the average of earthquake
\( \beta \) = connection between earthquake with magnitude
\( M \) = earthquake magnitude (SR)

The earthquake risk determines the potential of earthquake during the life of plan where the calculation is described in the Equation 4 as follows:

\[
RN = 1 - (1-RA)^N
\]  (4)

\( RN \) = Earthquake risk during life of plan (%)
RA = Earthquake risk years (1/TR)
TR = Return period earthquake plan (year)
N = Life of plan construction (year)

The safety factor (SF) of a dam is defined as the value of the ratio between the force holding and the force that moves, namely:

$$SF = \frac{\tau_f}{\tau_d}$$

SF = Safety factor
\(\tau_f\) = Shear force on the soil or stones (kN/m2)
\(\tau_d\) = Shear stress which moves the landslide field (kN/m2)

There are three factors that play an important role associated with the dam stability. Those factors are dam shear force, water drag force, and earthquake slide with their own characteristic as described below.

The dam shear force defines the equation as follows [5]:

$$\tau = c + \sigma \tan \phi$$

\(\tau\) = Share force of soil (kg/cm2)
\(c\) = Soil cohesion (kg/cm2)
\(\sigma\) = Normal stress on the collapses field (kg/cm2)
\(\phi\) = friction angle of soil (°)

The drag force of water is the relationship between water weight, water depth and hydraulic gradient of the river [6].

$$\tau = w.h.l$$

\(\tau\) = Shear force (kg/cm2)
\(w\) = Water weight (1000 kg/cm3)
\(h\) = Water deep (m)
\(l\) = Hydraulic gradient from river

In addition, the earthquake slide has three essential parameters, namely weight, response coefficient, and factor as presented in Equation 8 [7]:

$$V = \frac{(Sps \times I_e)}{R} \times W$$

\(V\) = Earthquake slide (ton)
\(W\) = Earthquake effective weight
\(Cs\) = Earthquake response coefficient
\(Sps\) = Acceleration response spectrum design on short period
\(R\) = Modification response factor
\(I_e\) = Earthquake factor
3. Result and Discussion

3.1 Maximum earthquake acceleration
In this earthquake data study obtained from USGS and BMKG on Lombok Island from 1970 - 2016, there are 906 earthquake events that are sorted into 62 earthquake events according to the data used in this study, i.e. magnitude $\geq 4$ SR, depth $\leq 300$ km and distance not more than 500 km.

The linear regression coefficient on the Gumbel method as an earthquake risk for Lombok Island is as follows: $A = 0.8641$; $B = -20,778$. Based on linear equations with regression coefficients then the earthquake acceleration on Lombok Island with a probability exceeding 10% and 2% in 50 years is equal to 0.34 g and 0.42 g.

3.2 Earthquake force according to the earthquake force directions on the Pandanduri dam
In this study the earthquake map used is 10% and 2% in 50 years based on SNI 1726-2012 compared by calculating spectrum response based on the map of the Indonesian earthquake area based on [7], Lombok Island. There is an earthquake area 4 [7].

The ground or bedrock where the Pandanduri dam was built belongs to the hard rock class. This is based on the classification of rock types according to their formation process, i.e. volcanic breccia rocks that enter into the type of sedimentary rock. Sedimentary rock is hard rock formed from magma that comes out of the bowels of the earth and freezes because it undergoes a cooling process and then experiences erosion in a certain place and then settles and becomes hard.

In SNI-1726-2002 and SNI-1726-2012 mention the direction of the general earthquake loading there are 2 components namely 100% style for direction main (//) and 30% force for perpendicular direction (⊥). The earthquake force directions on Lombok island is N 171º E, then projected against axles Dam of 0.094º for the main force direction dam and 89,096º for perpendicular directions dam in Figure 2.

![Figure 2](image.jpg)

Figure 2. Direction of earthquake forces against Pandanduri dam in Lombok Island

From the results of this calculation, the earthquake force produced a 26% decrease for 500 years and a 10% increase for 2500 years [7]. Besides that the spectrum response curve of the second this regulation does show a difference which is quite significant (which is affected a difference an earthquake plan with return period different).

3.3 Dam safety factor
The average percentage of earthquake force directions which is not known is greater than the average percentage of the direction of the earthquake force known as N 171ºE. This is affected by the decline of the dam's safety factor caused by the direction of the earthquake force. for the reason of the safety factor in earthquake direction known as N 171ºE is smaller, because it is influenced by the angle produced by the earthquake direction of N 171ºE, which is 0.094º for the direction of force main dam and 89,906º for upright direction straight dam. To make sure the dam size is a bigger influence of the direction of
earthquake forces on the Lombok Island then the building construction should refer to the earthquake map. The earthquake map was determined from the calculation of earthquake acceleration that consider to conditions and characteristics of the seismicity of Lombok Island.

4. Conclusion

Dam planning using earthquake force calculations from SNI [7] decreased by 26% to 500 years and increased 10% to 2500 years. In addition, the spectrum response curve of the two regulations showed a significant difference (which influenced differences of earthquake plan with different return periods). The effect of the earthquake force directions on construction buildings is the reduced value of safety factors. In SNI [7], the not known earthquake direction produces a safety factor of 1.2, greater than the direction of the earthquake known of N 171ºE, which produces a safety factor of 0.3. The reason why the safety factor in the direction of the earthquake known as N 171ºE to be smaller, because it is influenced by the angle produced by the N 171ºE earthquake direction which is 0.094º for the main force direction of the dam and 89.906º for the direction perpendicular to the dam.

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