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PROBABILISTIC SEISMIC HAZARD ASSESSMENT OF TIMOR-LESTE

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ABSTRACT

This dissertation examines the purpose of defining the seismic hazard level in Timor-Leste for seismic building codes based on past earthquakes and tectonic settings. The historical earthquake occurrences from 1960 to 2021 were collected from the United States Geological Survey (USGS) and the Institute of Geology and Petroleum (IPG) with a magnitude between 2 and 8.1 Richter Scala. Earthquake source zoning was based on the occurrences of historical earthquakes surrounding Timor-Leste, and the frequency magnitude distribution by using the Gutenberg-Richter recurrence law was estimated. The kernel density function has been used to modulate the probability distribution of hypocenter distance from different source zones. The simulation procedure was to determine peak ground acceleration using the Ground Motion Prediction equation adapted from Si et al, 1999. The result gave the seismic hazard curves, and a seismic hazard map plotted for the return period of 475 and 2500 years (10% and 2% exceedance in 50 years, respectively). The highest total hazard observed in the Atauro site was a very high hazard level with a PGA value of 440 gals and 209 gals, which was included in class V and class III, corresponding to a 2% and 10% probability of exceedance in 50 years. However, the smallest total hazard observed in the southern part of the Viqueque site was a low hazard level with a PGA value of 171 gals for a 2% probability of exceedance for 50 years also for 10% probability of exceedance for 50 years discovered in Viqueque, Lautem and RAEOA sites with the PGA value less than 100 gals.

Keywords: Timor-Leste, Earthquake Source Zones, Earthquake Parameters, PGA, Seismic Hazards

1. INTRODUCTION

Timor-Leste is a young independent country situated in the eastern half of the island of Timor, between Indonesia and Australia. It consists of 13 municipalities, one special administrative region, Oe-Cusse, and the islands of Atauro and Jaco. Timor-Leste is approximately 14, 874 sq km, with about 70% of its land mass covered by mountains or hills.

Timor-Leste is vulnerable to several natural hazards and disasters, including tropical cyclones, flooding, drought, landslides, earthquakes, and tsunamis. Fortunately, these events are relatively localized with no historical widespread devasting impacts. This notwithstanding, the country does not have a seismic building code or formulated policies.

Tectonically, the island of Timor lies in the outer arc region between the Timor Trough and the Banda Arc. It is the most mature part of the transition from subduction to the collision of the Australian plate with the Banda Arc and is the orogenic product of that collision [Carter et al., 1976; Hamilton, 1979]. The subsidence of Banda Trench has rollbacked southeastwards about 30 km from 4 to 0 Ma. This subducted slab is traceable by earthquake seismology to depths beyond 600 km [Engdahl et al., 1998]. Therefore, the collision creates the area surrounding Timor Island, which is prone to earthquakes.

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Regarding the seismicity on Timor Island, the shallow earthquakes are in the northern and eastern parts of Timor Island, and the intermediate and deep earthquakes are located in the western part of Timor Island. The purpose of this study is to define seismic hazard levels in Timor-Leste for building code by determining peak ground acceleration with the Probabilistic Seismic Hazard Assessment method (PSHA)

2. DATA

The data was obtained from The United States Geological Survey (USGS) and the Institute of Geology and Petroleum (IPG) seismic catalog. The composite catalog of this study area spanned from 1960 to 2021 and was used for the seismicity of the Timor-Leste region and the surrounding area between coordinates 0° - 18° South Latitude and 114° - 135° East with a total of 11237 earthquakes events. The earthquake catalog considered completeness with ranges of magnitude from 2 SR to 8.1 Ritcher Scale. The background earthquake model is employed in this study since information about the individual fault is not identifiable in Timor-Leste.

3. METHODOLOGY

3.1. Identification of Earthquake Source Zones

Identifying the earthquake source zone is based on observing the distribution of past earthquakes and tectonic settings in the region and considering all earthquakes surrounding Timor-Leste. Because the individual faults are not identifiable, we assumed that the frequency of earthquake events that occurred in the past would happen in the future. The target area focuses on 14 points that cover 14 municipalities in Timor-Leste, such as Dili, Atauro, Manatuto, Baucau, Lautem, Covalima, Ainaro, Aileu, Ermera, Liquisa, Bobonaro, Manufahi, Viqueque and RAEOA.

3.2 Processing Earthquake Data

3.2.1 Conversion of Magnitude

Earthquake data collected from the USGS and IPG catalogs have different magnitude types, such as body-wave magnitude (m_b), surface-wave magnitude (M_s), and local magnitude (M_L). Meanwhile, in the a-value and b-value analysis, one type of magnitude is required, namely moment magnitude (M_w), which for this reason is needed to convert all magnitude types from the catalog to moment magnitude (M_w), which were derived by Badan Meteorologi, Klimatologi dan Geofisika (BMKG), 2017:

$$M_w = 1{,}0107 m_b + 0{,}0801 \quad (1)$$

$$M_w = 0{,}6016 M_s + 2{,}476 \text{ for } M_s \leq 6.1 \quad (2)$$

$$M_w = 0{,}9239 M_s + 0{,}5671 \text{ for } M_s \geq 6.2 \quad (3)$$

3.2.2 De-Clustering

De-clustering is to separate mainshocks, foreshocks, and aftershocks in the catalog and remove dependent events to get the accuracy of the poison model. The process of separating the main and background earthquakes from foreshocks and aftershocks uses the empirical method proposed by Gardner and Knopoff (1974) to find out the sensitivity of the results to changes in the use of the empirical approach. The process of the separation uses ZMAP7 software (Wiemar, 2001).

3.3 Estimation of Earthquake Parameters

3.3.1 a and b Value Parameters

Determination of a and b values is chosen from Guttenberg & Richter's (1944) first study of observation of earthquake magnitudes:

$$log_{10}\lambda_m = a\text{-}bm \quad (4)$$

Where λ_m is, the rate of earthquakes with magnitudes greater than m; a is the constant of the overall rate of the earthquake in a region, and *b* indicates the relative likelihood of large and small earthquakes (typical b values are approximately equal to 1).

The cumulative distribution function (CDF) for the magnitudes of earthquakes that are larger than some minimum magnitude m_{min} Eq. (4) can be used for (Baker, 2008) equation if a maximum magnitude can be determined as:

$$F_M(m) = P\ (M \leq m|M > m_{min}$$

$$= \frac{Rate\ of\ earthquakes\ with\ m_{min} < M \leq m}{Rate\ of\ earthquakes\ with\ m_{min} < M}$$

$$= \frac{\lambda m_{min} - \lambda m}{\lambda m_{min}}$$

$$= \frac{10^{a-bm_{min}} - 10^{a-bm}}{10^{a-bm_{min}}}$$

$$= 1 - 10^{-b(m-m_{min})}, \quad m > m_{min} \quad (5)$$

Where F_M (m) is the cumulative distribution function for M, the probability density function (PDF) for M can also be computed by taking the derivative of the CDF.

$$f_M(m) = \frac{d}{dm}F_M(m)$$

$$= \frac{d}{dm}\left[1 - 10^{-b(m-m_{min})}\right]$$

$$= bln(10)10^{-b(m-m_{min})}, \quad m > m_{min} \quad (6)$$

Where $f_M(m)$ is a probability density function for *M*, m_{max} is a maximum magnitude earthquake. For continuous distribution of magnitudes into a discrete set of magnitude for a and b values can be used:

$$P(M = M_j) = F_M(m_{j+1}) - F_M(m_j) \quad (7)$$

Where m_j is a discrete set of magnitude, order that $m_j < m_{j+1}$. We can calculate the probabilities associated with all magnitudes between m_j and m_{j+1} to discrete value m_j. If the discrete magnitude is closely spaced, the approximation will not affect the numerical result.

3.4 Estimation of Ground Motion Parameters

The selection of the GMPE equation in this study is based on the similarity of the region's tectonics and the individual fault, not identifying where the new attenuation relationship for peak ground acceleration is adapted from (Si et al.,1999).

$$\log \overline{PGA} = 0.5*Mw+0.0043*D+di+0.61-Log10(X+0.0055*10^{0.5Mw})-0.003X \quad (8)$$

Where M_w is moment magnitude, D is a depth, and di is a constant depending on earthquake types, 0.00 is for shallow crustal, 0.22 is for intra-plate, the standard deviation σ for log PGA is 0.27.

The natural logarithm of PGA is seen to be normally distributed. So, we can determine the probability of exceeding any PGA level using mean and standard deviation (G&R)

$$P\ (PGA > a|M_w,\ X, D)\ = 1 - \Phi\left(\frac{a - \log \overline{PGA}}{\sigma}\right) \quad (9)$$

Where Φ () is the standard normal cumulative distribution function, $P(PGA) > a|M_w$, X, D is the probabilistic distribution function.

We also assumed the fault distance X according to (Tjanima & Hayashida, 2018):

$$X = H_D - 10^{0.5Mw-1.85}/2 \quad (10)$$

3.5 Hazard Curve

With all information above, we can now combine it, using the probabilistic seismic hazard assessment equation, to get the annual probabilistic of exceedance.

$$\nu(PGA > a) = \Sigma\Sigma\Sigma P\ (PGA > a|M_w,\ X, D)\nu(M_w)P(X)P(D) \quad (11)$$

Where ν(PGA >a) is the Annual frequency, that PGA is larger than a.

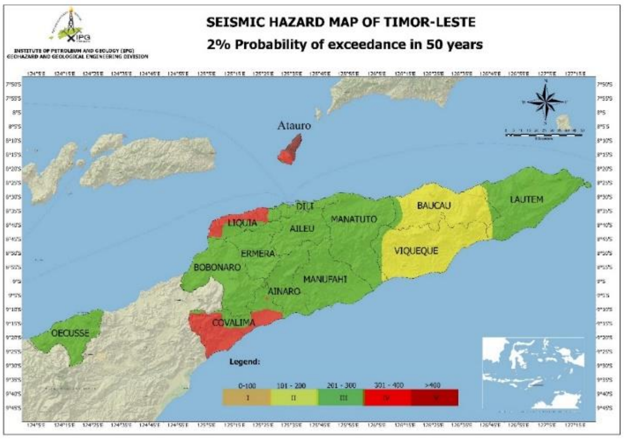
The result of this hazard analysis includes a hazard map for 10% probability of exceedance of peak ground acceleration of 10% in 50 years and 2% probability of exceedance in 50 years.

4. RESULTS AND DISCUSSION

We have obtained evidence of the seismicity in the observed area between 1960 and 2021, ranging from 2 to 8.1 Richter scale with depths from shallow to deep. Since the distances between the earthquake source zones and the sites are very close with a range of less than 400 km and the complexity of the tectonic setting, it is therefore suggested that the cumulative earthquake that occurred in Timor-Leste has increased over the years, although until now there has been no destructive earthquake. We identify the earthquake source zones into six zones.

The highest *a* and *b* values are represented in Zone 2 (intra-plate), Zone 3 (shallow crustal and intra-plate), Zone 4 (shallow crustal) and Zone 6 (intra-plate), while the lowest *a* and *b* values are represented in Zone 1 (intra-plate and shallow crustal), Zone 2 (shallow crustal), Zone 4 (intra-plate), Zone 5 (shallow crustal), and Zone 6 (shallow crustal), respectively. The fix of depths used for the ground motion prediction equation is generated using MATLAB software.

In this study, the probability target for the seismic hazard and structural performance design limit state for engineering approaches divides into two parts, such as the ultimate limit state and the collapse limit state. According to ACI (American Concrete Institute) 318-02 Standard, the corresponding probability of the incipient collapse is less than 2%/50 years, or 4×10^{-4}/year and the probability of the ultimate is less than 10%/50 years, or 2×10^{-3}/year.



The results for the PSHA analysis for Timor-Leste can be appreciated in figure 1, for a 10% probability of exceedance in 50 years, the PGA ranges from 80-209 gall.

Based on the peak ground acceleration classification that the PGA value of 0 to 100 gals belongs to class I by category of low hazard level for Lautem, Viqueque, and RAEOA sites. PGA goes from 101 to 200 gals is observed around the southern part of the Atauro, Dili, Aileu, Manufahi, Manatuto, Ermera, Liquisa, Covalima, Ainaro, and Bobonaro sites with the class II and categorized as moderate low hazard level.

However, for a 2% probabilistic exceedance in 50 years, the PGA varies from 171 to 440 gals. The highest PGA is observed in the northern part of the Atauro site, and the PGA value is 440 gals which correspond to class V with a very high hazard level. PGA value of 303 to 304 gals is observed around the southern part of Atauro, the northern part of Liquisa and Covalima sites which belong to class IV by categorized as high hazard levels. PGA value of 207 to 287 gals is observed in the southern part of Liquisa, Dili, Lautem, and Aileu, Manufahi, Manatuto, Ermera, Ainaro, Bobonaro, RAEOA, which belongs to class III with moderate-high hazard level, and sites Viqueque and Baucau, the ranges of PGA are from 171 to 192 gals which include class II with Moderate low hazard levels.

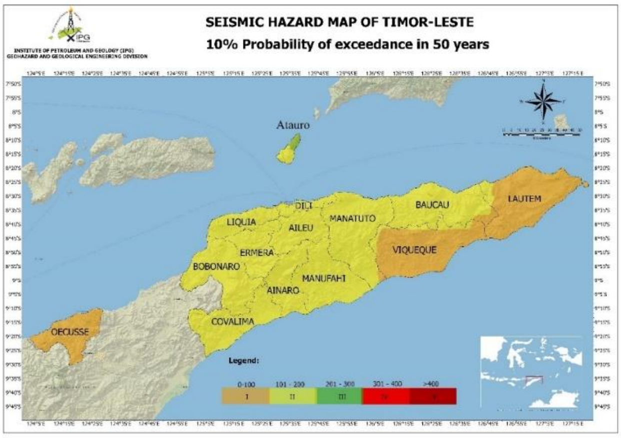


Figure 1.Peak ground acceleration for 2% and 10% probability of exceedance in 50 years.

On the other hand, the hazard level is higher in site Atauro, due to the hypocenter distance of less than 400 km from the respective site and produced a PGA value the estimated the maximum value and also Atauro is formed from uplifting pressure of tectonic plates.

5. CONCLUSIONS

The seismic hazard level in Timor-Leste was successfully obtained for future building code purposes.

For comparison between 14 sites of the target area, the very high risk categorized as class V is observed in the northern part of Timor-Leste, the Atauro Municipality for 2% probability of exceedance in 50 years (which corresponds to a return period of 2500 years), and the lowest hazard level is observed in the southern part of Viqueque Municipality.

Furthermore, for the 10% probability of exceedance in 50 years (which corresponds to a return period of 457 years), the ranges of hazard levels are from low up to Moderately high.

The highest hazard level is observed in Atauro and the lowest hazard level is observed in Lautem, Viqueque, and RAEOA.

The hazard level is high in Atauro, due to the hypocenter distance of less than 400 km from the respective site and produced an increase in PGA. However, Zone 2 and 3 affected the most to the observed site because based on the tectonic setting of Timor-Leste is located in the subduction zone, and Atauro is formed from the uplifting of the tectonic setting.

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