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SEISMIC HAZARD AND MICROZONATION STUDY OF TANJUNG REGION, NORTH LOMBOK (INDONESIA) USING MICROTREMOR MEASUREMENT

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ABSTRACT

Tanjung Region is one of the severely damaged areas by the Lombok earthquake on June 22, 2013. Therefore, to anticipate the similar events, it is necessary to perform microzonation in this region. Objective of this study is to map the distribution of the physical quantities related to the vulnerability of area included the frequency characteristics, amplification factor, and soil vulnerability index. The results showed that the value of the resonant frequency in this region ranged from 0.401 to 16.92 Hz. In general, the lower frequency was 0.40 to 5.91 Hz contained 87 data (71%) were located in the north of the region, which meant that that area has a high vulnerability. While based on the H/V amplitude and vulnerability index, the zone that suffered severe damage on the earthquake of June 22, 2013, showed a different uncertainty of amplification and vulnerability index value.

ABSTRAK

Wilayah Tanjung adalah salah satu daerah yang mengalami rusak parah akibat gempa Lombok pada tanggal 22 Juni 2013. Oleh karena itu, untuk mengantisipasi kejadian serupa, maka perlu untuk melakukan mikrozonasi di daerah tersebut. Tujuan dari penelitian ini adalah untuk memetakan distribusi besaran fisis yang terkait dengan kerentanan suatu daerah terhadap gempa bumi yang meliputi frekuensi respon, amplitudo getaran tanah dan indeks kerentanan tanah. Hasil penelitian menunjukkan bahwa nilai frekuensi resonansi di wilayah ini berkisar antara 0,401-16,92 Hz. Secara umum, frekuensi respon di daerah ini rendah yaitu 0,40-5,91 Hz dengan jumlah 87 data (71%) yang terletak di utara dari wilayah tersebut, yang berarti bahwa bagian utara wilayah memiliki kerentanan yang tinggi. Meskipun berdasarkan nilai amplitudo H/V dan indeks kerentanan, daerah yang mengalami kerusakan parah saat gempa 22 Juni 2013 menunjukkan pola amplifikasi dan indeks kerentanan yang sangat tidak biasa.

Keywords: Microtremor; HVSR; Nakamura; Seismic hazard; Microzonation; Tanjung; Lombok

INTRODUCTION

It has been observed that the damage as the result of the earthquake, is not only associated to a magnitude of the earthquake and its epicentral distance but also caused by the effect of the topographic and geological condition of the site. The reaction of the local geological conditions to the incoming seismic energy is known as the site response or local site effects (Fernandez & Brandt, 2000). For seismic hazard assessment, the site effect is typically represented by frequency of resonance and the associated ground motion amplification. Several methods such as array data analysis and horizontal to vertical spectral ratio (HVSR) refer to the site in estimating such parameters. On the other hand, the use of ambient vibration records for determining the fundamental resonant frequency has recently gained worldwide acceptance. It is well known that soil deposits amplify ground motion. The amplification depends on several factors including layer's thickness, the degree of compaction and age (Bonnefoy-Claudet, et al., 2006), (Syamsud-

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din, Probopuspito, Sartohadi, Suryanto, & Adhi, 2014). One of the many reasons for choosing the ambient noise as widely accepted method by several researchers is that it allows the quick and reliable estimation of site characteristics of any area. Apart from being a cost-effective measure, it reduces time compared to evaluating site characteristics from an earthquake which has always been a time-consuming as well as an expensive process so far as the maintenance of equipment and human resources is concerned.

So many research in utilizing this H/V ratio estimation the fundamental frequency of ambient vibrations in urban environments (Lebrun, Hatzfeld, & Bard, 2001), (Guillier, Chatelain, Claudet, & Haghshenas, 2007), (Garcia-Jerez, et al., 2007). The proximity of fundamental frequency for resonance effects causes damages to a site of the existing man-made structures. Therefore, investigation of each site condition is an important step towards earthquake hazard mitigation (Rusilowati, Supriyadi, & Mulyani, 2012).

Indonesian Lesser Sunda, where Lombok Island is located has been proclaimed as one of the most tectonically active regions in the world. Two recent destructive earthquakes were one in 2004 and the other in 2013 had already ripped through this region. One of the most striking features of Lombok Island Region, Indonesia that most of its cities and densely populated settlements are located in the valley, sedimentary basins or hills, etc. The objective of this research is site characterization of Tanjung Region regarding resonant frequency, site amplification, etc. using H/V spectral ratio methodology (Nakamura Y. , 1989), (Nakamura Y. , 2000) as modified by (Bard, 1999).

Geology and Seismicity of the Study Area

Lombok Island is one of a small island in the archipelago of Nusa tenggara, Indonesia, tectonically is an area with very high seismic activity level. This is due to its position as the adjacent of the collision zone between the Eurasian and Indo-Australian Plate in the Indian Ocean where the Indo-Australian plate subduction rate is under the Eurasian plate of about 71 mm/year. As a result of the collision of the two plates, appear back arc thrust in the North of Lombok Island which is an active shallow earthquake generator from Bali to Flores and is very powerful and destructive. Based on the data from USGS, since 1973 to 2015 there has been more than 2400 earthquakes, and some of them are destructive earthquakes (Fig. 1).

There were two recent destructive earthquake which occurred in the Lombok Island. First was the West Lombok earthquake on January 24, 2004, with the epicentre at 8.26°S and 115.79°E and depth of 33 km and 6.2 SR scale (IV MMI scale), this earthquake causing victims 30 people injured and 2,241 houses were damaged. The second one was North Lombok earthquake which occurred on June 22, 2013, with the epicentre at 8.43°S and 116.04°E (about 14 km north-west of Lombok Island) and depth of 10 km and 5.4 SR scale (III-IV MMI scale) with victims 44 people injured and 5,370 houses were damaged (Anonym, 2013).

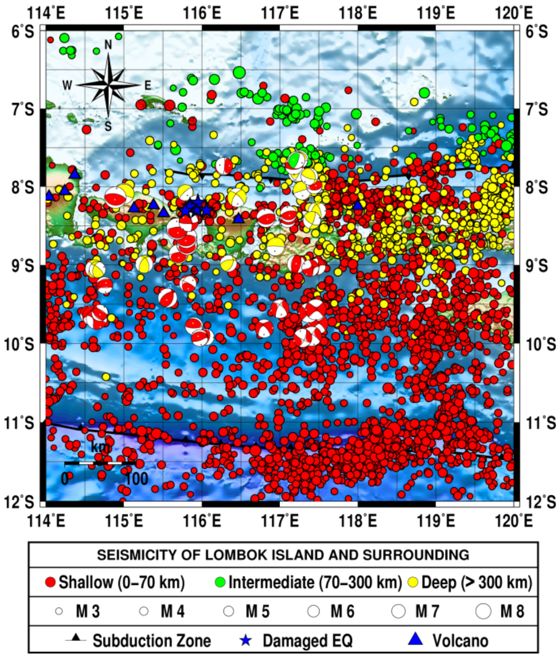

Figure 1. Seismicity map of Lombok Island and surrounding region.

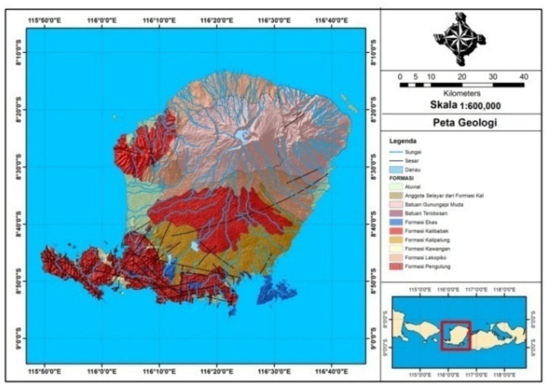

Figure 2. Geological map of Lombok Island.

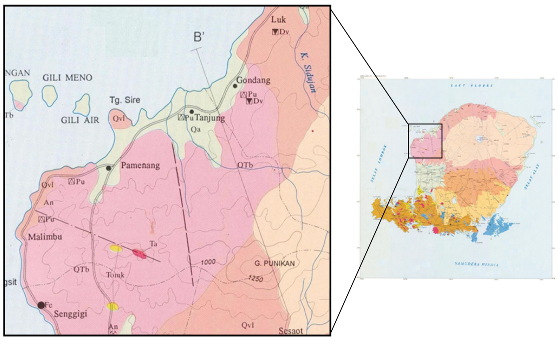

Figure 3. Location of survey.

The lithology of Lombok Island is composed of sediment which is relatively young with Tertiary to Quaternary age (Manga, Atmawinata, Hermanto, & Amin, 1994). Rocks in Lombok island are dominated by volcanic rocks, consisting of volcanic breccia, lava, and sandstone. Some places are covered by sediment quarter which is relatively young and unconsolidated (Fig. 2). In the eastern part of Lombok Island, the tertiary rocks forms are composed of breccias, lavas, tuffs, etc. In the west, which is an alluvial area, the rock arrangement is composed of alluvial or loose rock such as sand, gravel, and mud, where in the northern part of the rock area, consists of Quaternary volcanic rocks precipitated from Rinjani volcano. The rocks are loose, especially around Rinjani Volcanic area. The sediment layer is quite thick, which cover nearly two-thirds of the Lombok island (Agustawijaya & Syamsuddin, 2012).

METHOD

Microtremor Survey

In this study, microtremor measurements was carried out in the Tanjung Region, North Lombok District (Fig. 3). Measurements were made for 15 days (June 25 to July 9, 2015) with the number of points as much as 123 point of measurement. The model of Seismometers used was the LE-3D/20s with three components of speed sensor (Lennartz Electronic) connected to data logger series DI-710 (Data Instruments) along with Windaq Professional software as the acquisition partner. The utilized speed sensors had a natural frequency of 0.05 Hz and could measure the vibration of the three components of one vertical and two horizontal directions. The frequency response to the tool was 0.05 to 40 Hz. Data recording was performed with a sampling rate of 100 samples per second with a duration measurement of 20 to 60 minutes. The survey area on-gird with a spacing of 500 meters. The position of each measuring point was determined by GPS.

The seismometer was placed on a concrete or tar-sealed surface, but in cases where only grass or soft surface soil was available, a removable concrete pad was used as a base to remove any resonance involving the seismometer and the ground (see fig. 4).

Figure 4. Setting of seismometer at ground surface

To ensure the reliability of noise recording, the guidelines proposed by (Koller, et al., 2004) was used as guidance in the framework of SESAME. Besides, quiet environment & good weather condition had been the prime requisite for executing this data acquisition process. At each field measurements location, the sheet was filled in which described the time, date, operator name, coordinates, etc. of the area onset and the duration of the measurement.

Microtremor H/V analysis

Data were processed by applying the horizontal to vertical (H/V) spectral ratio method, using the GEOPSY software package (www.geopsy.org). In pre-processing, all data were converted to SAF format (SESAME ASCII Format). HVSR at each site was computed with the following steps (Duval, et al., 2004): (1) Offset removal (baseline correction). Since similar sensors are used for all the three components, therefore no instrumental correction has been applied; (2) filtering the band-pass with a frequency ranging from 0,02 to 20 Hz; (3) Determining the stable time windows in the 20 s length and removing time windows contaminated by transients using an anti-trigger algorithm. This assured that only the coherent constituent of microtremors were included and the transient was discarded. This was performed to obtain the comparation between short term average ('STA', the average level of signal amplitude over a short period of time, 1 s) and long-term average 'LTA' (the average level of signal over a much longer period of time, 30 s). Only windows with threshold ratio STA/LTA from 0.3 to 2.5 was used for computing the H/V. (4) For each time window, a 5% cosine taper function was applied on both sides of the window signal of the Vertical (V), North-South (NS) and East-West (EW) components; (5) The Fourier spectra were calculated for each time windows of the three components to obtain the three spectral amplitudes using the Fast Fourier Transform (FFT) and smoothed with using Konno-Ohmachi filter with constant bandwidth of b=40 (Konno & Ohmachi, 1998). (6) Finally, the Fourier amplitude ratio of the two horizontal Fourier spectra and one vertical Fourier spectrum were obtained using Equation (1):

$$r(f) = \frac{\sqrt{S_{NS}(f) \times S_{EW}(f)}}{S_Z(f)} \tag{1}$$

Where r(f) is the horizontal to vertical (H/V) spectrum ratio, SNS(f) , SEW(f) and SZ(f) are the Fourier amplitude spectra in the NS, EW and Vertical directions, respectively.

After obtaining the H/V spectra for the selected segments of the signal, the average of the spectra was obtained as the H/V spectrum for a particular site. The same procedure was repeated at all locations. The peak of the H/V spectral plot showed the predominant frequency of the site and the H/V amplitude. Additionally, calculation of standard deviation for each point was performed earlier.

RESULTS AND DISCUSSION

The main results obtained in this study is the resonance frequencies (f_0) of the site-sedimentary geology (site-soil columns) and the correspondence of relative site-amplification factor (A_0) derived from the amplitude of spectral ratio values.

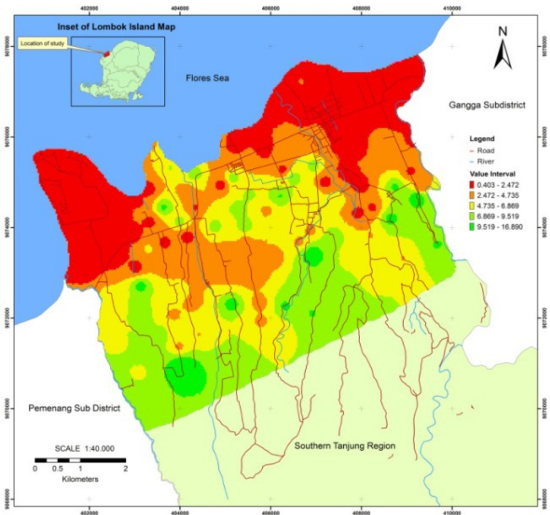

Figure 5. Map of the resonance frequency (f_0) for Tanjung Region.

Figure 5 shows a map of the resonance frequency of land vibration in the of Tanjung Region, North Lombok. The ground vibration frequency values was corresponded with the thickness of sediment constituent in the region. Based on the map showed that the value of the vibration frequency of the soil ranged from 0.403 Hz to 16.890 Hz.

The vibration frequency in low land was f0= 0.403-2.471 Hz, symbolized by the red color. Therefore, the value of the frequency was inversely proportional to the value of the ground vibration period, as it could also be regarded as ground vibrations with a very long period, the very low vibration frequency of the soil was generally associated with very thick sediment. The low vibration frequency with f0 = 2.471-4.735 Hz, which was symbolized by the brown color, associated with long periods of vibration, which could be interpreted as a thick sediment. The frequency of the vibration to the value of f0 = 4.735-6.869 Hz, symbolized by the yellow color, associated with periods of moderate ground shaking, interpreted as a rather thick layer of sediment. High-frequency vibration to the value f0 = 6.869-9.519 Hz, which was symbolized by the light green color, associated with short periods of ground vibrations, which could be interpreted as a thin sediment. The very high vibration frequency with a value f0 = 9.519-16.890 Hz, which was symbolized by the green color, it is associated with a very short period of vibration, which could be interpreted as a very thin sediment.

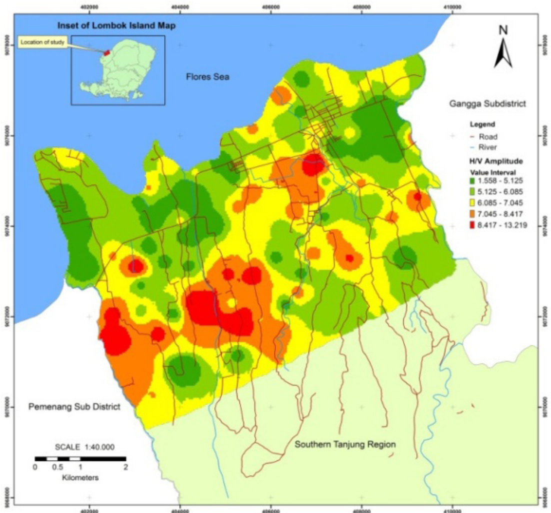

Figure 6. Map of the amplification factor (A_0) for Tanjung Region.

Figure 6 showed the map of the ground-shaking amplification in the Tanjung Region, North Lombok. The amount of vibration was related to the nature of the soil compaction or hard-soft sediments that made up the region. The amount of ground vibration amplification ranged from 1.558 to 13.219. To simplify the analysis and interpretation, the vibration amplification value of land in this map was divided into five classes as follow: very low Amplification of ground vibrations with A0 = 1.558-5.124 represented by the green color, associated with very compact sediment. Lower amplification of ground vibrations with A0 = 5.124-6.085, depicted with light green color, was associated with hard sediment. Amplification of ground vibrations with A0 = 6.085-7.045, represented by the yellow color was associated with soft to hard sediment. High amplification of ground vibrations with A0 = 7.045-8.417, illustrated by a brown color, associated with soft sediments. Very high amplification ground vibrations with A0 = 8.417-13.219, which was depicted in red, associated with a very soft sediments that generally consist of soft clay.

Figure 7 showed the map of the vulnerability index in the surface in the Tanjung Region, North Lombok. The value of land vulnerability index was related to sediment thickness and compacting properties or hard-soft sediments in the region. The value of this land vulnerability index ranged from 0.169 to 95.873. To simplify the analysis and interpretation, the vulnerability index value of land in this map was divided into five classes as follow: (a) The value of vulnerability index of very low with Kg = 0.169-12.226, represented by the green color, was generally associated with very thick and very hard sediments. (b) The values of vulnerability index of lower land with Kg = 12.226-23.907, were depicted with light green color, generally associated with thick and hard sedimentary. (c) The value of vulnerability index of land with Kg = 23.907-39.732, which was depicted in yellow, associated with thick and hard sediment. (d) The value of vulnerability index of land with Kg = 39.732-59.701, which was depicted with a brown color, associated with thin and soft sediments. (e) The value of vulnerability index of land with Kg = 59.701-95.873, which was depicted in red, associated with very thin and soft sediments.

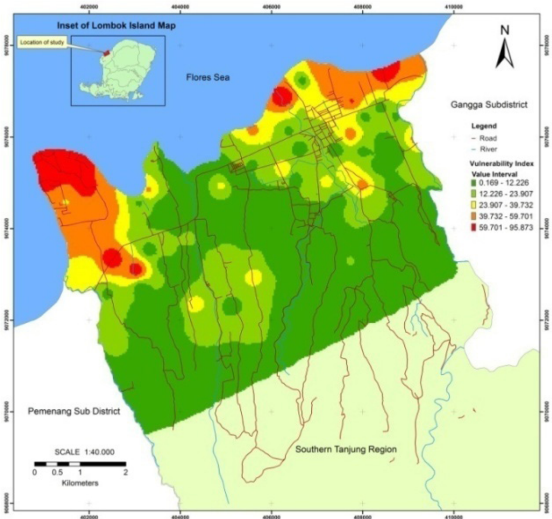

Figure 7. Map of the seismic vulnerability index (K_0) for Tanjung Region.

CONCLUSION

Based on the description of the results and discussion above, some conclusions can be state that the values of the natural ground frequency ranged between 0.403 Hz to 16.890 Hz. The distribution pattern of the natural frequency value of ground in of Tanjung Region tend to have a regular pattern where the northern part of the zone has the lower value and in the southern area has a high-frequency value.

The value of amplification of land in Tanjung Region ranged from 1.558 to 13.219. The distribution of the value of the amplification tend to have a regular pattern where the northern zone had a lower value (safer to be occupied), while the southern part of the area has a higher value of amplification (less safe for occupancy).

High amplification – very high regions zones that suffered severe damage when an earthquake ocurred in Lombok on June 22, 2013, namely Gol Village and Orong Kopang Village in Desa Medana and Karang Nangka village, Tanjung.

The value of vulnerability index of the land in Tanjung Region ranged from 0.169 to 95.873. The value distribution of the vulnerability index of the land tend to have a regular pattern similar to the map of northern part where the amplification value in this zone was low, while the southern part of the region had a higher ground vulnerability index. When compared to the building's damage pattern caused by the earthquake in Lombok on June 22, 2013 to, the vulnerability index map also had a positive correlation.

There was a positive correlation between the map of ground shaking amplification and ground susceptibility index with a pattern of damage caused by the earthquake of Lombok on June 22, 2013.

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