Ground shear strain value based on microseismic data in Oebelo, Kupang NTT

H U Mala1*, H F Lalus2, P Nanlohy1 and A Y Elake1

1Physics department, Faculty of Mathematics and Natural Sciences, Universitas Pattimura, Kota Ambon, Indonesia
2Physics department, Faculty of Teacher Training and Education, Universitas Nusa Cendana, Kupang, Indonesia

Abstract. Information the ground shear strain in an area are very important. Quantitatively, this characteristic is reflected in the value of shear strain. This value provides an illustration of the ability of the soil layer to vibrate, stretch or shift even broken during an earthquake. The potential of vibrating and stretching of the soil is not only influenced by the magnitude and hypocenter but also the geological conditions of the local area. Geological characteristics in the form of dominant frequency values and amplification factors were obtained through the HVSR method using microseismic waves. The study was conducted in Oebelo, Kupang with a distribution of 52 points of microseismic measuring. Its parameters are used to calculate the seismic vulnerability index value and PGA value. These two values are used to determine the shear strain value at each measuring point. The results showed the magnitude of shear strain values was range from $1.5 \times 10^{-2}$ to $1.6 \times 10^{-1}$. The highest is located at coordinates 10.11128° S and 123.7418° E, while the area with the lowest at the coordinates 10.11578° S and 123.7396° E. Areas with shear strain values in the range $10^{-2}$ to $10^{-1}$ above, have dynamic properties are collapse, repeat-effects and speed-effects of loading. Phenomena that will occur are landslides, soil compaction and liquefaction during an earthquake. In the context of risk reduction, it is necessary to avoid areas with high shear strain values for human activities and infrastructure development.

1. Introduction
Nusa Tenggara Timur (NTT) is geographically Flores Sea in the north, and Indonesia Ocean and Australia South section. NTT and its surroundings are part of the framework of Indonesian tectonic system. The area are included in the path of the Mediterranean mountains (Trans-Asiatic) and are in the meeting zone plates. The meeting of these two plates is convergent, where both collide and one of them, namely the Indo-Australian plate that infiltrated the Eurasian plate. This plate boundary is marked by the presence of an oceanic trough, as evidenced by the discovery of a trough to the south of Timor Island known as the Timor Trench [1].

Timor Island is one of the islands in NTT that has high seismic activity. It is located right on the edge of tectonic plates Indo-Australia. This has led to complex geological conditions, marked by a variety of jumbled rocks that are often touched by the structure. The presence of mixed rock on the island is a result of the usual deposition process and also as a result of tectonic processes. Tectonic development of the island of Timor allegedly lasted from the Late Cretaceous to Eocene.
Disaster mitigation efforts in areas with high levels of seismicity should be a serious concern for all components of society, especially the government as policy makers. If an error occurs in the policy, then it certainly will affect the emergency response efforts in the field. Before formulating the regulations related to disaster mitigation, there needs to be an academic study in the form of research in the field of disaster. One of them is seismic research that specifically examines the impact of earthquakes on a region.

Passive seismic methods that take advantage of microseismic waves have been introduced to estimate the dynamic characteristics of the surface layer. This technique was first introduced by Nakamura. Nakamura had characterized microseismic waves using Horizontal to Vertical Spectral Ratio (HVSR) then popular with the term method of Nakamura. The information obtained through this technique is the dynamic characteristics of the soil and structure. This technique is very popular today and is easy to do because it provides clear and reliable information and is very simple and inexpensive in its use [2].

HVSR method has been widely used to estimate the characteristic of sediment layers by using microseismic waves. Through this technique, the physical characteristics of the sediment obtained are in the form of the dominant frequency of the soil and the amplification factor. Both of these parameters are used to calculate the value of seismic vulnerability index and maximum ground acceleration which are used in determining the value of Shear Strain in an area.

Ground shear strain (GSS) is a value that states the potential for sediment layer movement in an area due to earthquake shaking. The potential for land movement in East Island is quite large considering the high level of seismicity. BMKG recorded the total earthquake incidence in NTT in 1911-2008 as many as 4176 events, for the territory of Timor Island, especially Kupang region in the years 1936-2013 as many as 446 events, the average type of shallow earthquake with a depth of 8 km-243 km and magnitude ranging from 3.3 SR-7.3 SR. While the earthquake with magnitude ≥ 5 SR was 98 events, depth of 8 km-190 km [3]. It is very necessary and important to map of dynamic properties of sediments in a region in order to reduce the impact that occurred at the time of the earthquake.

2. Theory

2.1. HVSR method

One of the most widely used matrices for estimating soil response is a Nakamura technique where the spectral ratio between vertical and horizontal components provides a good estimate of the basic frequency. This is a cheap and fast technique that allows detailed mapping of frequencies in urban areas [4].

Mikrotremor processing was first introduced by Nagishi and Igarashi 1971 and subsequently distributed by Nakamura in 1989. HVSR technique is a technique of estimating the ratio between horizontal and vertical components of the Fourier amplitude spectrum of ambient vibration recorded at the station. At present, HVSR has been widely used in estimating the value of the dominant frequency of ground vibration, especially for microzonal purposes [5]. This method can be used to indicate the dominant frequency and peak value of HVSR (A0) which represent the dynamic characteristics of the sediment layer. From the relationship between the two can be seen seismic vulnerability index (Kg).

The dominant frequency of soil is an index of soil conditions at the time of vibration. In frequency analysis of ground motion as long as the vehicle is running, usually one to several maximum peaks can be achieved, but it has been found that the maximum peak frequency is not much affected by the distance from the vibration source or the magnitude of the vibration, but that the ground vibrates at the closest vibration. The frequency that identifies this maximum peak is called the dominant frequency of the soil.

Three main hypotheses in formulating this method are:

- Ambient noise or natural vibration is caused by reflection and refraction of shear waves in shallow soil layers and by surface waves.
- Local noise sources do not affect ambient noise at the bottom of the unconsolidated structure.
- The fragile / soft soil layer does not strengthen the vertical component of ambient noise.
2.2. PGA

Empirical equations that use historical data of earthquakes and data on the dominant period of land which are the results of measurements in the field using seismographs are Kanai empirical equations [6]. In the method of calculating the PGA value with the Kanai method not only perform calculations based on earthquake parameters, but also required observational data carried out in the field in the form of a dominant period of soil that describes the characteristics of the local sedimentary layer. This method combines earthquake parameters and soil characteristics somewhere. Seismic vibration depends on the propagation of seismic waves and the characteristics of the soil layer in a place that causes the acceleration of surface soil.

Earthquake parameters required in the calculation of this method is the magnitude of the earthquake and the epicenter distance, while the value of a dominant period soil obtained from microseismic measurements in the field. With the parameters needed in the calculation, the peak ground acceleration value can be calculated using the Kanai method:

\[
\alpha_g = G(T)\alpha_0
\]

(1)

\[
\alpha_0 = \frac{1}{T} 10^{0.61 M - \left(1.66 + \frac{3.6}{R}\right) \log R + 0.167 + \frac{1.83}{R}}
\]

(2)

\[
G(T) = \frac{1}{\sqrt{1 - \left(\frac{T}{T_0}\right)^2 + \left(\frac{T}{\sqrt{T_0}}\right)^2}}
\]

(3)

with, T = earthquake wave period (s), T₀ = dominant period of land measuring point (s) and G(T) = magnification factor.

If resonance occurs (T=T₀) then the value of G(T) becomes the maximum. This resonance is caused by waves passing through the sedimentary layer caused by earthquake waves that have a wide spectrum, so that only the same earthquake waves with the dominant period of soil from the sedimentary layer will be strengthened. The ground acceleration on the surface becomes maximum with the magnification price of G(T) then equation (1) can be written:

\[
\alpha_g = 5\sqrt{T_0} 10^{0.61 M - \left(1.66 + \frac{3.6}{R}\right) \log R + 0.167 + \frac{1.83}{R}}
\]

(4)

\(\alpha_g\) = value of peak ground acceleration (gal), \(T_0\) = dominant period of soil (s), \(M\) = moment magnitude and \(R\) = hypocenter distance (km).

2.3. Ground Shear Strain (GSS)

GSS is a value that describes the ability of the sediment layer material to stretch and shift during a shock caused by an earthquake [2]. This value information is very useful for disaster mitigation in the risk reduction context that might occur during an earthquake event.

According to Ishihara, the sediment layer will become plastic if the shear strain value is in the range of 1,000 x 10⁻⁶ and there will be logging or stretching on shear strain values of 10,000 x 10⁻⁶ [2]. The table below shows the shear strain values that depend on the dynamic nature of the sediment layer and the phenomena that occur.

| Size of Strain γ | 10⁻⁶ | 10⁻⁵ | 10⁻⁴ | 10⁻³ | 10⁻² | 10⁻¹ |
|-----------------|------|------|------|------|------|------|
| Phenomena       | Wave, Crack, Landslide, Soil Compaction, Vibration Settlement Liquefaction Elasto-Plasticity Collapse Repeat-Effect, Speed-Effect of Loading |

To calculate shear strain values can be estimated by equation [8]:

Table 1. GSS values based on dynamic properties of the sediment layer [7].
\[ \gamma = K_g \times \alpha_g \]  
\[ K_g = \frac{A_0^2}{\pi^2 f_0 V_b} \]

where, \( \gamma \) = shear strain value, \( K_g \) = seismic vulnerability index \( (s^2/cm) \), \( \alpha_g \) = peak ground acceleration \( \text{gal} \), \( A_0 \) = amplification factor, \( V_b \) = Velocity of S wave in the basement and \( f_0 \) = dominant frequency of ground \( \text{Hz} \).

3. Methods
   - Microseismic data retrieval with seismometer Portable tool with the number of measuring points 52
   - Ground vibration data processing from seismometer recording in trace (trc) form should be changed in the form of MiniSeeD (MSD) so that it can be processed in Geopsy software, then obtained the dominant frequency value and amplification factor of each measurement point.
   - PGA value calculation using the Kanai method according to Equation (4)
   - Seismic vulnerability index calculations using Equation (6) with the input parameters of the dominant frequency of the land and the amplification factor of each measuring point of the microseismic.
   - Calculation of shear strain values using equation (5)

4. Results and discussion
Geologically, Timor Island is dominated by clay which is part of the Bobonaro formation. The sedimentation process mainly occurs in lowland areas and around the coast. Oebelo village is one area that is located on the gulf coast of Kupang with surface soil conditions in the form of black clay and alluvium (Figure 1). Clay and alluvium as a top soil sediment with an average thickness of \( \pm 10 \text{ m} - 60 \text{ m} \). This cover is supported by limestone rocks as bedrock at a depth of 60 m [3].

![Figure 1. Geological map of microseismic measurement area [9].](image)

The following is the distribution of shear-strain values in the study area shown in Figure 2 below.
Based on the shear strain distribution Map, the highest value is at coordinates 10.1128°S and 123.7418°E with blue index, while the lowest is at coordinates 10.11578°S and 123.7396°E with gray colors index. High value indicates that the area has a high potential for landslides in the event of an earthquake while areas with low values are areas that have the potential to cause cracks or settlement when an earthquake occurs. Regional geological conditions with the highest values are areas dominated by alluvium, while areas with low values are black clay mixing with coral limestone formation. This value is directly proportional to the value of seismic vulnerability and PGA value, meaning that regions with high shear strain distribution are areas with high vulnerability index and ground acceleration values. As it is known that the seismic vulnerability index shows the physical magnitude of the vulnerability of an area affected by shocks or movement of rock layers. The greater the value of the seismic vulnerability index, the more vulnerable the area is affected by shocks.

Table 2. Shear strain value at Oebelo.

| Size of Strain $\gamma$ | $10^{-2}$ | $10^{-1}$ |
|-------------------------|----------|----------|
| Total Points            | 43       | 9        |
| Phenomena               | Settlement | Landslide, Soil Compaction, Liquefaction |
| Dynamic Properties      | Plasticity, Repeat-Effect, Speed-Effect of Loading | Collapse |

Table 2 provides information on the number of measuring points with shear strain values along with their phenomena and dynamic properties. Based on the table, it can be seen that the location of the study was dominated by the shear strain value at $10^{-2}$ with the phenomenon that has the potential to occur is landslide. Meanwhile there are 43 measuring points with slightly lower shear strain values, potentially settlement with dynamic properties plasticity, repeat-effect, speed-effect of loading.

The ground motion parameters that contribute greatly to the shear strain value are the amplification factors and the dominant frequency of the soil. The amplification factor and frequency of soil movements have long been recognized as parameters used in estimating the severity that is significantly dependent on soil characteristics of the subsurface layer [10].
5. **Conclusion**

The research to estimate the shear strain values in the Oebelo area obtained the following conclusions:

1. The highest shear strain value at coordinates 10.11128° S and 123.7418° E while the area with the lowest is at the coordinates 10.11578° S and 123.7396° E.

2. Areas with shear strain values in the range $10^{-2}$ to $10^{-1}$ above, have dynamic properties are collapse, repeat-effects and speed-effects of loading. Phenomena that will occur are landslides, settlement, soil compaction and liquefaction during an earthquake.

**References**

[1] BMKG 2015 Earthquake Bulletin *Class I Geophysical Station Kampung Baru: Kupang*

[2] Nakamura Y 2000 ON The H/V Spectrum *The 14th World Conference on Earthquake Engineering, Beijing, China*

[3] Mala H U, Susilo A, and Sunaryo 2015 Study of Microtremor and Resistivity Geoelectric Around Trans Timor Primary Arterial Road for Disaster Mitigation *Natural B* 3(2015) 24-34

[4] Mahajan A K, Mundepi A K, Chauhan N, Jasrotia A S, Rai N, and Gachhayat T K 2012 Active seismic and passive microtremor HVSR for assessing site effects in Jammu city, NW Himalaya, India-A case study *Journal of Applied Geophysics* 77 51–62

[5] Leyton E, Ruiz S, Sepúlveda S A, Contreras J P, Rebolloso S, and Astroza M 2013 Microtremors’ HVSR and its correlation with surface geology and damage observed after the 2010 Maule earthquake (Mw 8.8) at Talca and Curicó, Central Chile *Engineering Geology* 161 26–33

[6] Douglas J 2011 Ground Motion Prediction equations 1964-2010 *Pacific Earthquake Engineering Research Center College of Engineering University of California, Berkeley*

[7] Nakamura Y 1997 Seismic Vulnerability Indices for Ground and Structures Using Microtremor *World Congress on Railway Research, Florence*

[8] Nakamura Y 2000 Clear Identification of Fundamental Idea of Nakamura’s Technique and Its Applications *System and data research Co Ltd, 3-25-3 Fujimidai, Kunitachi-shi, Tokyo, Japan 12WCCE*

[9] Rosidi H M D, Tjokrosapoetro S, and Gafoer S 1996 Geology Map of Kupang-Atambua, Timor *Geological Research and Development Center, Bandung*

[10] Bazzurro P and Cornell C A 2004 Ground-Motion Amplification in Nonlinear Soil Sites with Uncertain Properties *Bulletin of the Seismological Society of America* 94(6) 2090–2109