http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 8 No 4 2023

RESEARCH ARTICLE

# Identification Of Shear Strain On The Surface Ground Of Wangi-Wangi Island, Southeast Sulawesi, Indonesia, Using Nakamura's Technique and The Possibility Of Its Impacts

Abdul Manan [1,*], Cindy Puspitafuri[2], Rani Chahyani[3], Irawati[1], Imanuela Indah Pertiwi[4]

[1] *Department of Geophysical Engineering, Universitas Halu Oleo, Kampus Hijau Bumi Tridharma, Kendari City, Indonesia*
[2] *Research and Development Agency (BALITBANG), Southeast Sulawesi Provincial Government, Kendari City, Indonesia*
[3] *Study Program of Physical Education, Institut Agama Islam Negeri (IAIN) Kendari, Kendari City, Indonesia*
[4] *BMKG Stasiun Geofisika Kendari, Kendari City, Indonesia*

* Corresponding author : amanan.geophysics@gmail.com, amanan@uho.ac.id
Tel.:+62-82-4709-3388
Received: Jan 14, 2023; Accepted: Nov 1, 2023.
DOI: 10.25299/jgeet.2023.8.4.11780

**Abstract**

This research was conducted to determine the possible impact of an earthquake on the mainland of Wangi-Wangi Island based on the presence of shear strain on the surface ground ($\gamma$). The size of $\gamma$ is obtained by multiplying the ground susceptibility index and the acceleration of basement ground or PGA using Nakamura's technique. The data used are microtremor data and earthquake data from 1920 to 2020 sourced from the USGS. Microtremor data are obtained from the results of filtering ground vibration signals using a Band Pass Filter in the frequency range between 0.5 to 25 Hz. Ground vibration signals were recorded at 47 measurement points spread over the surface of Wangi-Wangi Island within 29.25 to 48.16 minutes. Furthermore, the microtremor data were processed using the HVSR (Horizontal to Vertical Spectral Ratio) method. The use of earthquake data must meet the requirements for a surface magnitude ($M_S$) $\geq$ 5.0 SR and an earthquake epicenter depth ($h$) $\leq$ 45 km. The results obtained are the $\gamma$ sizes of Wangi-Wangi Island in the order of $10^{-06}$ to $10^{-03}$. Based on the size distribution, it is known that the majority of the Wangi-Wangi Island area has the potential to experience cracks and land subsidence due to settlements if an earthquake occurs, and only a portion of the area is vibrating. In addition, it is also known that the mainland of Wangi-Wangi Island is not prone to landslides and liquefaction because $\gamma<10^{-2}$.

**Keywords:** Shear strain, Nakamura's technique, PGA, HVSR, Microtremor, Ground Vibration Signal

## 1. Introduction

An earthquake is a natural event that will always occur. This natural event is felt as a shaking on the earth's surface. Tectonically, earthquakes occur due to the activity of the earth's crust which produces a sudden burst of energy with a certain magnitude and propagates in all directions randomly in the form of waves. The earthquake that occurs will leave seismic traces along its propagation path. These seismic traces can be identified from the presence of shear strains formed on the ground surface.

The presence of shear strain in the surface ground layer in an area illustrates the ability of the materials that make up the ground layer in that area to stretch or shift against each other during an earthquake occurs. Damage caused by an earthquake occurs when the earthquake force exceeds the threshold of the strain that is formed. Under this circumstance, the surface ground layer will experience a deformation process. Therefore, the presence of shear strains can indicate that certain ground dynamics have occurred in an area along with the accompanying phenomena on the surface.

By identifying the distribution of shear strain on the surface, it is possible to know the impact that may be experienced by the mainland of Wangi-Wangi Island if an earthquake occurs, particularly the potential for liquefaction, soil compaction, and landslides. To determine the shear strain on the surface in this study using Nakamura's technique. In this technique, the shear strain size at the ground surface is obtained by multiplying the ground vulnerability index and the acceleration of the basement ground. In Nakamura (1997), Nakamura (2000) and Nakamura (2008), it is stated that the ground vulnerability index is an index that can describe the ability of the ground in an area to experience deformation, so it can be useful to know the weakest points on the ground surface when an earthquake occurs. Data on the distribution of the ground vulnerability index on the mainland of Wangi-Wangi Island has been published by Manan et al. (2021). While the acceleration of the basement ground in question is the greatest ground acceleration that has ever occurred to the basement in an area within a certain period and is hereinafter known as Peak Ground Acceleration (PGA). For the surface of Wangi-Wangi Island, the PGA distribution has been studied by Manan et al. (2023). Several researchers who have used the Nakamura's technique in determining shear strains include Kurniawan et al. (2023), Jalil et al. (2021), Mala et al. (2021), Farid and Mase (2020), Farid and Hadi (2018), Farid and Suryanto (2016), and Soemitro et al. (2011).

Many PGA formulas have been published, each with its own set of parameters. A summary of these formulations can be found in Douglas (2022). In this study, the calculation of basement PGA used the empirical equation proposed by Fukushima and Tanaka (1990). The effect of basement PGA on surface shear strain is also strongly influenced by the depth of the basement from the surface. Research on the depth of the mainland surface layer of Wangi-Wangi Island has been carried out by Chahyani et al. (2020) by assuming that the Wangi-Wangi Island area is composed of only 2 main layers, namely the surface layer and the basement, as Nakamura did in Nakamura (1997), Nakamura (2000), and Nakamura (2008).

The application of Nakamura's technique in this study involved Ishihara's approach (Ishihara, 1986). This approach provides a description of the dynamics and soil phenomena that may occur in an area based on the shear strain conditions that have formed in that area. Using this approach, it is possible to predict the potential impact that might be experienced on the mainland of Wangi-Wangi Island if an earthquake occurs.

Geographically, Wangi-Wangi Island is located in the Wakatobi Regency of Indonesia's Southeast Sulawesi Province. There are numerous water-filled caves on Wangi-Wangi Island. These caves are formed as a result of water dissolving in the limestone that forms the mainland of the island. It is uncommon to hear about the impact of earthquake events that are destructive to infrastructure on the mainland of the island, with only minor damage to people's homes and local government buildings being reported. As a result, this situation raises the question of how the shear strain that becomes a seismic trace on the mainland of the island creates this situation.

## 2. Nakamura’s Technique

In the Nakamura’s technique (Nakamura, 1997; Nakamura, 2000; Nakamura, 2008), the approach used is that the subsurface layer is divided into 2 layers, namely the surface layer and the basement layer (Fig 1). In this case, the effective shear strain $\gamma$ at the ground surface is estimated using the formula:

$$\gamma = A \times \delta / H \tag{1}$$

or

$$\gamma = \alpha \times K(e) \tag{2}$$

where $\alpha$ is an acceleration of basement ground, and

$$K(e) = e \times \left(\frac{A^2}{F^2}\right) / \left(\frac{\pi^2 V_b}{100}\right) \tag{3}$$

where $K(e)$ is the ground vulnerability index when the efficiency of the seismic force is $e$% of the static force, $\delta$ is the seismic shift of the basement layer, $A$ is the amplification factor, $F$ is the predominant frequency of the surface ground, and $V_b$ is the velocity of the S wave in the basement. If it is assumed that the efficiency of the seismic force is 60% and $V_b$ = 600 m/s, then the approach described in equation (3) applies:

$$K = \frac{A^2}{F^2} \tag{4}$$

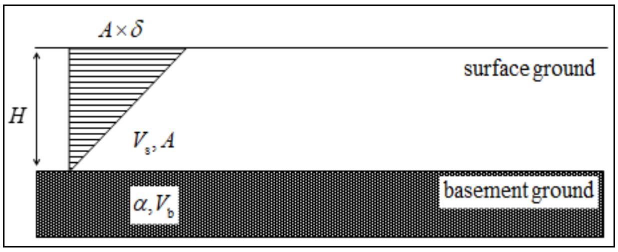


Fig 1. Shear deformation on the surface ground (Nakamura, 1997; Nakamura, 2000; Nakamura, 2008).

In the Nakamura’s technique, parameters $A$ and $F$ are obtained from a graph of the Horizontal to Vertical spectral ratio. Currently this technique is known as the HVSR method. Many studies have used the HVSR method with data sourced from microtremors, some of which can be found in Yulianto and Yuliyanto (2023), Arintalofa et al. (2020) and Putti and Satyam (2020).

Molnar et al. (2022) have conducted a review of the HVSR method using microtremor data (MHVSR) sourced from several previous studies. This HVSR method is one way to obtain input parameters in the Nakamura’s technique. These two parameters are used in microtremor data processing to determine shear strains on surface ground.

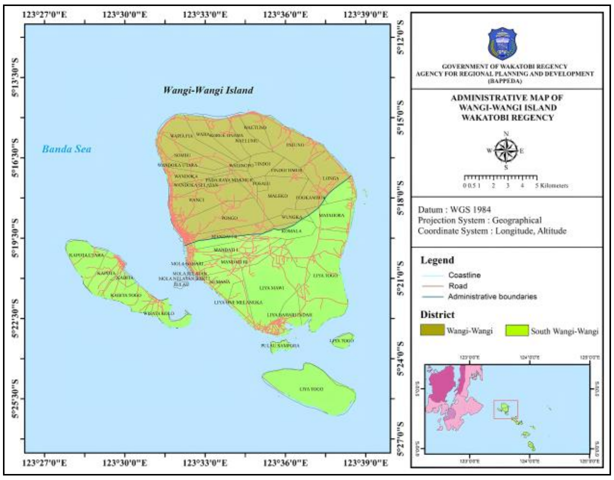


Fig 2. Administrative map of Wangi-Wangi Island

## 3. Research Method

### 3.1 Data Acquisition

This research is located on Wangi-Wangi Island (Fig 2), which is administratively within the archipelago of Wakatobi Regency, Southeast Sulawesi Province, Indonesia. The Wakatobi Islands are formed by 4 large islands, namely Wangi-Wangi Island, Kaledupa Island, Tomia Island, and Binongko Island. Data acquisition on the island was carried out by recording ground vibration signals using 1 set of TDL 303S portable Seismograph from June 28 to July 4, 2020. The recorded data is stored in .MSD (minisheed) format on the TDL 303S digitizer. Further data processing is carried out by first changing the format of the recorded data into .trc (trace) form. In recording ground vibration signals in the field, it takes time between 29.25 to 48.16 minutes, and in practice it is carried out following the guidelines from the SESAME European Research Project (SESAME, 2004). There are 47 recording points with a distance of ±1.9 km between each recording point. The recording points are spread from T1.1 to T7.4 as shown in Fig 3.


Fig 3. Distribution of ground vibration signals recording points on Wangi-Wangi Island.

### 3.2 Data Processing

In this research, to identify the shear strain on the surface ground, Nakamura's technique (Nakamura, 1997; Nakamura, 2000; Nakamura, 2008) was used as formulated in equation (2). The $K(e)$ value in the equation is calculated using the approach formulated in equation (4). The distribution of $K(e)$ values on the mainland of Wangi-Wangi Island has been published by Manan et al. (2021). The values of $A$ and $F$ used in equation (4) were obtained from the HVSR (Horizontal to Vertical Spectral Ratio) graphs of microtremor signals generated from microtremor data processing using Geopsy 3.2.2 software. To obtain microtremor data, ground vibration signals recorded at 47 measurement points on Wangi-Wangi Island were filtered using a Band Pass Filter in the frequency range of 0.5 to 25 Hz.

Parameter $\alpha$ in equation (2) is calculated using the empirical equation that has been published by Fukushima and Tanaka (1990). The equation is:

$$\log_{10}\alpha = 0.41M_S - \log_{10}\left(R_h + 0.032\times 10^{0.41M_S}\right) - 0.0034R_h + 1.30 \qquad (5)$$

where $\alpha$ is the peak ground acceleration at the basement (gal), $M_S$ is the surface magnitude of the earthquake (Richter Scale) and $R_h$ is the hypocenter distance of the earthquake (km). $M_S$ and $R_h$ values use earthquake data from 1920 to 2020 obtained from the USGS (United States Geological Survey) catalog for earthquakes with epicenters in the Southeast Sulawesi Province, Banda Sea, and Flores Sea. Fig 4 shows the distribution of earthquake epicenters from the catalog.

In data processing, only earthquake data with depth $\leq 45$ km and surface magnitude ($M_S$) $\geq 5.0$ Richter Scale are used in calculating the $\alpha$ parameter. In addition, if the known earthquake magnitude data is local magnitude ($M_L$), body magnitude ($M_B$), or moment magnitude ($M_W$), then the conversion process is carried out first to surface magnitude ($M_S$). In the conversion process, pay attention to the approach table proposed by Heaton et al. (1986). The table for this approach can also be seen in Idriss (1985) and Kramer (1996).

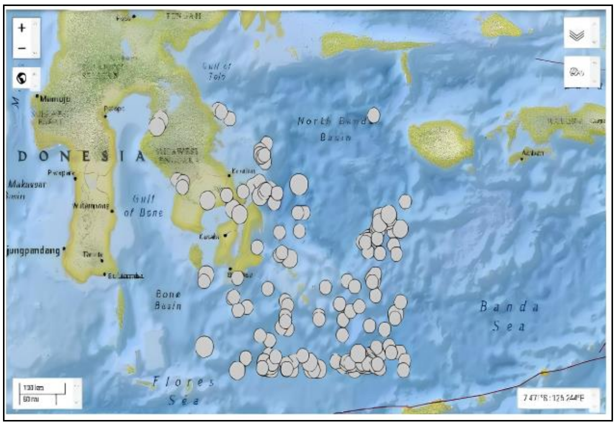


Fig 4. Map of the distribution of earthquake epicenters in the area of 7°6'43.20" – 2°53'16.80" South Latitude and 120°47'42.00" – 125°59'27.60" East Longitude for $M \geq 5.0$ Richter Scale from 1920 to 2020 (USGS – United States Geological Survey).

Knowledge of traces of shear strain on the surface ground can be used to determine the possibility of ground movement on the surface when an earthquake occurs. This possibility is predicted qualitatively using Table 1. This table was published by Ishihara (1986).

Table 1. Relationship of strain and soil dynamic properties (Ishihara, 1986).

| Size of strain $\gamma$ | $10^{-6}$ | $10^{-5}$ | $10^{-4}$ | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ |
|---|---|---|---|---|---|---|
| Phenomena | Wave, vibration | | Crack, settlement | | Landslide, soil compaction, liquefaction | |
| Dynamic Properties | Elasticity | | Elasto-plasticity | | Collapse | |
| | | | | | Repeat-effect, speed-effect of loading | |

The final stage in this research is to identify the possible effects of shear strain on the surface ground on the mainland of Wangi-Wangi Island, Wakatobi Regency, Southeast Sulawesi, Indonesia.

### 4. Results and Discussion

Two important parameters used in determining the shear strain on the mainland of Wangi-Wangi Island are the ground vulnerability index and the acceleration of basement ground or PGA. The distribution of the ground vulnerability indexes on Wangi-Wangi Island has been published in Manan et al. (2021), and Fig 6 shows a graph of the ground vulnerability indexes. The indexes were calculated using equation (4). The values of $F$ and $A$ in equation (4) used by Manan et al. (2021) are sourced from microtremor data which is processed using the Horizontal to Vertical Spectral Ratio (HVSR) method. While the microtremor itself is obtained from the results of filtering ground vibration signals recorded at 47 measurement points spread over the mainland of Wangi-Wangi Island using a Band Pass Filter in the frequency range of 0.5 to 25 Hz.

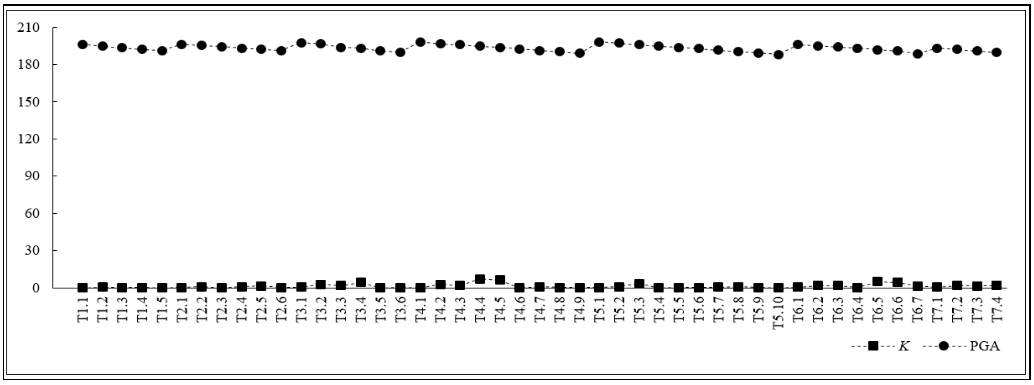


Fig 6. Ground vulnerability indexes ($K$) (Manan et al., 2021) and basement PGAs of Wangi-Wangi Island.

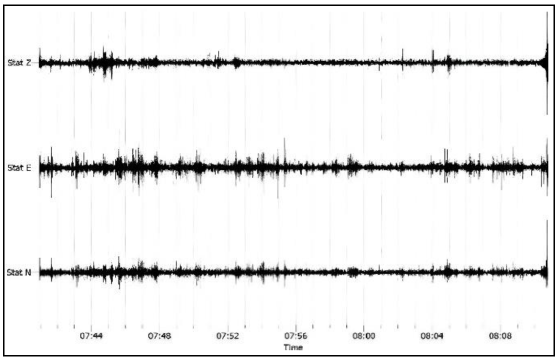


Fig 7. Ground vibration signals at T3.2 recording point.

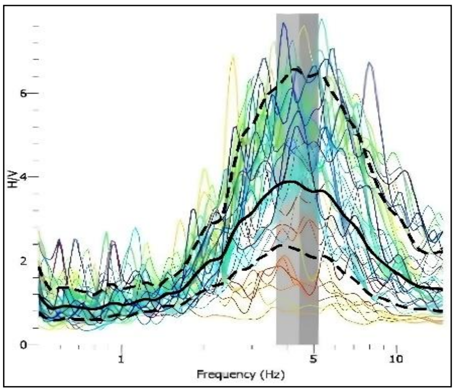


Fig 8. HVSR of microtremor at T3.2 recording point.

Fig 7 shows the ground vibration signals recorded on Wangi-Wangi Island which consist of 3 components, namely 1 vertical (V) or Z-component, 1 North-South horizontal component (NS), and 1 East-West horizontal component (EW). This figure is only an example of the results of recording at one measurement point, namely at T3.2 point. Ground vibration signals in the field were recorded using 1 set of TDL 303S portable Seismograph. Furthermore, the ground vibration signals for the two horizontal components are processed into 1 single component (H) using the *Squared-Average* method to produce a Fourier H/V spectrum in the frequency domain (HVSR). The HVSR for the recording point at T3.2 can be seen in Fig 8. Records of ground vibrations and HVSR ($f$) of microtremor for the mainland of Wangi-Wangi Island can also be seen in Chahyani et al. (2020) and Manan et al. (2021).

To determine the shear strain on the surface ground of Wangi-Wangi Island, calculations were carried out using Nakamura's technique as in equation (2). The $\alpha$ parameter or acceleration of basement ground or PGA in the equation is calculated using equation (5), and the results can also be seen in Fig 6. Meanwhile, the shear strain sizes can be seen in Fig 9. Fig 9 shows a graph of the shear strain sizes on the mainland of Wangi-Wangi Island, which vary based on the locations of the recording points. The largest size of shear strain on Wangi-Wangi Island is 1.448 $x$ $10^{-03}$ at the T4.4 recording point, and the lowest size is 9.652 $x$ $10^{-06}$ at the T1.5 recording point.

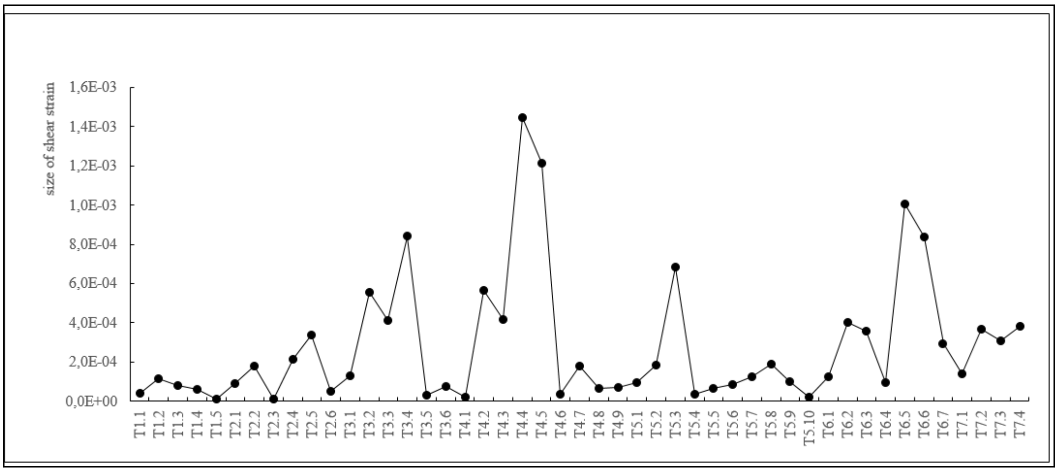


Fig 9. Sizes of shear strain on the surface ground of Wangi-Wangi Island.

The shear strain on the surface ground is seismic traces that formed on the surface. The existence of shear strain can provide an outlook on the possible state of the ground layers if the event of an earthquake occurs. This is because an earthquake can cause straining or shifting of the ground layers against one another. Thus, the sizes of shear strain can be used to identify impacts that could potentially arise as a result of an earthquake.

To identify the possible impact of an earthquake based on shear strain on the mainland of Wangi-Wangi Island, a qualitative approach was carried out using Table 1 published by Ishihara (1986). This table contains the relationship between shear strain sizes and ground dynamic properties (and its phenomena). According to Ishihara (1986), the surface ground only vibrates during an earthquake when $\gamma<100x10^{-6}$ or $10^{-4}$ which indicates the ground is still within its elastic limit, but the surface ground becomes elasto-plasticity when the value $\gamma=1000x10^{-6}$ or $10^{-3}$ which indicates the character of the ground begins to be nonlinear (cracks occur, land subsidence due to settlement), and when $\gamma>10{,}000x10^{-6}$ or $10^{-2}$ the surface ground will begin to experience major deformation, for example in the form of landslides, soil compaction or liquefaction. In other words, the damage caused by earthquakes due to ground deformation occurs when the earthquake force exceeds the limit of this strain.

Referring to the graph in Fig 9 and Table 1, the possibility of the potential impact of an earthquake on Wangi-Wangi Island is that several areas only experience cracks in buildings until land subsidence, but no serious damage occurs because the $\gamma$ limit that can cause deformation is not exceeded, which is still $\gamma<10^{-2}$. In this state, the ground layer is still elasto-plasticity. Whereas in some other areas nothing happens because the surface ground is still within its elastic limit when responding to earthquake shocks. In this situation, the surface ground only vibrates with the occurrence of an earthquake. The zoning map showing the possible impacts that could potentially exist if an earthquake occurs on the mainland of Wangi-Wangi Island can be seen in Fig 10. This figure is a map of the phenomena of ground movement on Wangi-Wangi Island.

Based on Fig 10, areas that are estimated to be prone to cracking to land subsidence due to settlement are experienced by most of the Wangi-Wangi Island region. While the areas that only vibrate when an earthquake occurs are most of the Liya Togo, Mahahora, Longa, Komala, and Waetuno areas, and in parts of the Patuno, Waelumu, Tindoi, East Tindoi, Waha, Wapia pia, Sombu, South Wandoka, Wanci, Pongo, Wungka, Mandati I, Mandati II, Mandati III, Liya Mawi, and Liya Bahari Indah areas. The surface ground layer only vibrates when responding to earthquake vibrations because the ground shear strain is still at its level of elasticity or $\gamma<10^{-4}$.

When looking at the map of the surface layer thickness of Wangi-Wangi Island in Chahyani et al. (2020), it can be seen that most of the Wangi-Wangi Island region has a surface layer thickness of <140 meters, and only a small portion or only around 10.64% of the Wangi-Wangi Island region with a surface layer thickness of > 140 meters. This condition of the surface layer has an influence on the formation of the zoning map pattern in Fig 10. In other words, the thickness of the surface layer affects the size of shear strain, so it will affect the level of vulnerability of an area to be affected by an earthquake event.

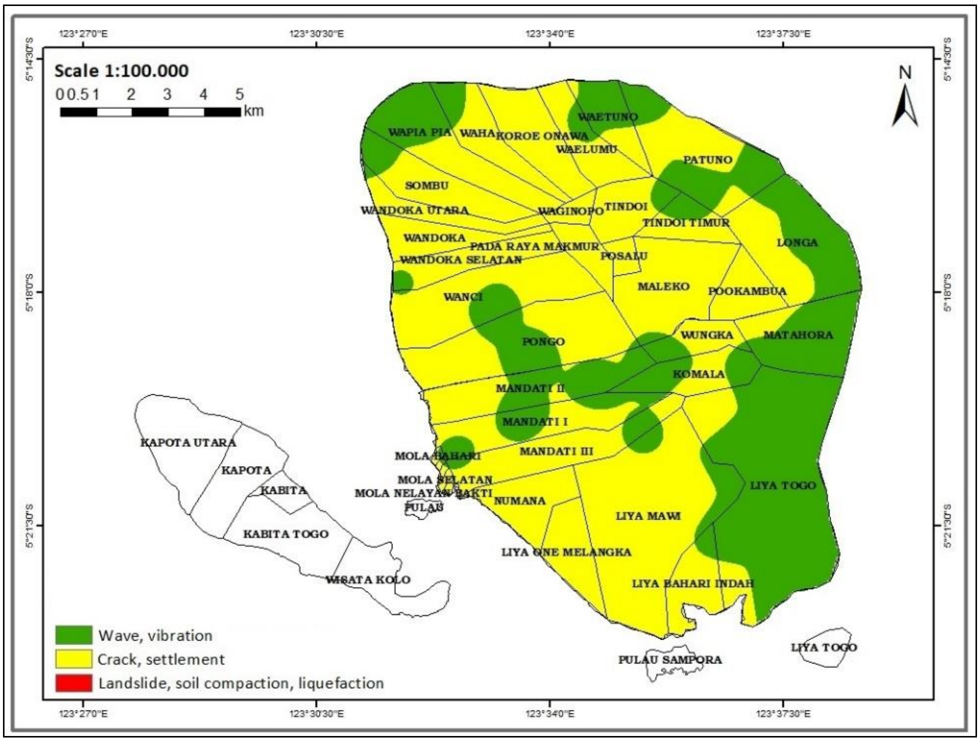


Fig 10. Map of the phenomena of ground movement on Wangi-Wangi Island using the sizes of shear strain on the surface ground.

Based on this research, it is also known that Wangi-Wangi Island is not prone to landslides and liquefaction due to earthquake activity because the size of $\gamma>10^{-2}$ is not fulfilled. For liquefaction, these results resemble the liquefaction zone map of Southeast Sulawesi Province published by the Geological Agency, the Ministry of Energy and Mineral Resources, Republic of Indonesia in 2019 (Buana et al., 2019).

## 5. Conclusion

The sizes of shear strain on the surface ground of Wangi-Wangi Island are in the range of 1.448 $x$ $10^{-03}$ to 9.652 $x$ $10^{-06}$. Within this size range, the possible impact that could potentially be experienced on Wangi-Wangi Island if an earthquake occurs is that most of the Wangi-Wangi Island region is prone to cracks to land subsidence due to settlement and only a portion of it has the potential to vibrate. The areas that only vibrate include most of the Liya Togo, Mahahora, Longa, Komala, and Waetuno areas, and in parts of the Patuno, Waelumu, Tindoi, East Tindoi, Waha, Wapia pia, Sombu, South Wandoka, Wanci, Pongo, Wungka, Mandati I, Mandati II, Mandati III, Liya Mawi, and Liya Bahari Indah areas. These areas only vibrate because $\gamma<10^{-4}$. Besides that, it is also known that Wangi-Wangi Island is not prone to landslides and liquefaction because $\gamma>10^{-2}$ is not fulfilled.

## Acknowledgements

We hereby express our gratitude to the Research and Development Agency (BALITBANG) of the Southeast Sulawesi Provincial Government which has provided funds for microtremor research on Wangi-Wangi Island through the Decree of the Governor of Southeast Sulawesi Province, Republic of Indonesia, Number 7 of 2020 dated 5 February 2020. In addition, we also express our grateful thanks to BMKG Stasiun Geofisika Kendari for permission and assistance in using its TDL 303S Seismograph for data collection in the field.

## References

Arintalofa, V., Yuliyanto, G., and Harmoko, U., 2020. Subsurface characterization of Diwak-Derekan geothermal field by HVSR analysis method based on mictrotremor data. *AIP Conf. Proc.*, 1–9. doi: 10.1063/5.0030356

Buana, T.W., Hermawan, W., Rahdiana, R.N., Widyaningrum, R., Wahyudin, Hasibuan, G., Wiyono, and Sollu, W.P., 2019. Atlas Zona Kerentanan Likuefaksi Indonesia.

Badan Geologi, Kementerian Energi dan Sumber Daya Mineral, Bandung.
Chahyani, R., Manan, A., Puspitafuri, C., and Kasmawati, 2020. Identification of surface-basement layer distribution of Wangi-Wangi Island based on HVSR method of microtremor data. *J. Phys.: Theor. Appl.* 4(2), 94–101. doi: 10.20961/jphystheor-appl.v4i2.48727
Douglas, J., 2022. Ground Motion Prediction Equations 1964-2021. http://www.gmpe.org.uk., University of Strathclyde, Glasgow.
Farid, M., and Mase, L.Z., 2020. Implementation of seismic hazard mitigation on the basis of ground shear strain indicator for spatial plan of Bengkulu city Indonesia. *GEOMATE Journal* 18(69), 199–207. doi: 10.21660/2020.69.24759
Farid, M., and Hadi, A.I., 2018. Measurement of shear strain in map liquefaction area for earthquake mitigation in Bengkulu city. *TELKOMNIKA* 16(4), 1597–1606. doi: 10.12928/telkomnika.v16i4.8043
Farid, M., and Suryanto, W., 2016. Microseismic wave measurements to detect landslides in Bengkulu shore with attenuation coefficient and shear strain indicator. *KnE Engineering*, 1–7. doi: 10.18502/keg.v1i1.477
Fukushima, Y., and Tanaka, T., 1990. A new attenuation relation for peak horizontal acceleration of strong earthquake ground motion in Japan. *Bull. Seism. Soc. Am.* 80(4), 757–783. doi: 10.1785/BSSA0800040757
Heaton, T.H., Tajima, F., and Mori, A.W., 1986. Estimating ground motions using recorded accelerograms. *Surveys in Geophysics* 8, 25–83. doi: 10.1007/BF01904051
Idriss, I.M., 1985. Evaluating seismic risk in engineering practice. *Proc. the 11th International Conference on Soil Mechanics and Foundation Engineering*, 255–320.
Ishihara, K., 1986. Geomechanical Modelling in Engineering Practice, 1st ed. CRC Press, Devon.
Jalil, A., Fathani, T.F., Satyarno, I., and Wilopo, W., 2021. Liquefaction in Palu: the cause of massive mudflows. *Geoenvironmental Disasters* 8, 1-14. doi: 10.1186/s40677-021-00194-y
Kramer, S.L., 1996. Geotechnical Earthquake Engineering. Prentice-Hall Inc., New Jersey.
Kurniawan, C.W., Yatini, Y., and Pramono, S., 2023. Application of Ground Shear Strain (GSS) for mapping liquefaction potential in Palu, Central Sulawesi, Indonesia. *International Journal of Scientific and Research Publications* 13(2), 64–71. doi: 10.29322/IJSRP.13.02.2023.p13407
Mala, H.U., Lalus, H.F., Nanlohy, P., and Elake, A.Y., 2021. Ground shear strain value based on microseismic data in Oebelo, Kupang NTT. *J. Phys.: Conf. Ser.*, 1–6. doi: 10.1088/1742-6596/2017/1/012007
Manan, A., Puspitafuri, C., Pertiwi, I.I., and Chahyani, R., 2023. Identification of Peak Ground Acceleration and hazard potency of earthquake disaster on the mainland surface of Wangi-Wangi Island, Wakatobi Regency, Southeast Sulawesi, Indonesia. *J. Phys.: Conf. Ser.*, 1–9. doi: 10.1088/1742-6596/2498/1/012040
Manan, A., Puspitafury, C., Kasmawati, and Pertiwi, I.I., 2021. Identifikasi potensi kerusakan akibat gempabumi berdasarkan Indeks Kerentanan Seismik data mikrotremor di Pulau Wangi-Wangi. *Jurnal Formasi* 6(2), 01–11.
Molnar, S., Sirohey, A., Assaf, J., Bard, P.Y., Castellaro, S., Cornou, C., Cox, B., Guillier, B., Hassani, B., Kawase, H., Matsushima, S., Sanchez-Sesma, F.J., and Yong, A., 2022. A review of the microtremor horizontal‐to‐vertical spectral ratio (MHVSR) method. *J Seismol* 26(4), 1–33. doi: 10.1007/s10950-021-10062-9
Nakamura, Y., 1997. Seismic vulnerability indices for ground and structures using microtremor. *Proc. World Congress on Railway Research*, 1–7.
Nakamura, Y., 2000. Clear identification of fundamental idea of Nakamura's technique and its applications. *Proc. The 12th World Conf. on Earthquake Engineering* (*12WCEE*), 1–8.
Nakamura, Y., 2008. On the H/V spectrum. *Proc. The 14th World Conf. on Earthquake Engineering*, 1–10.
Putti, S.P., and Satyam, N., 2020. Evaluation of site effects using HVSR microtremor measurements in Vishakhapatnam (India). *Earth Syst Environ* 4, 439–454. doi: 10.1007/s41748-020-00158-6
SESAME, 2004. Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: Measurements, Processing and Interpretation. http://sesame.geopsy.org/Papers/HV_User_Guidelines.pdf, SESAME European Research Project WP12.
Soemitro, R.A.A., Warnana, D.D., Utama, W., and Asmaranto, R., 2011. Assesment to the local site effects during earthquake induced landslide using microtremor measurement. *J. Basic. Appl. Sci. Res.* 1(5), 412–417.
Yulianto, T., and Yuliyanto, G., 2023. Microtremor data and HVSR method in the Kaligarang fault zone Semarang, Indonesia. *Data in Brief* 49, 1–6. doi: 10.1016/j.dib.2023.109428