International Journal of GEOMATE, Dec., 2023 Vol.25, Issue 112, pp.40-47
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.112.4108
Geotechnique, Construction Materials and Environment

INVESTIGATION OF SEDIMENT THICKNESS BENEATH THE MANDALIKA CIRCUIT AND ITS SURROUNDINGS BASED ON MICROTREMOR DATA

*Suhayat Minardi[1], Teguh Ardianto[1], Alfina Taurida Alaydrus[1,2], Moh. Iqbal Tawakal[3], and Agustya Adi Martha[4]

[1]Department of Physics, Faculty of Mathematics and Natural Sciences, University of Mataram, Indonesia
[2]Student of Doctoral Program, Department of Physics, Brawijaya University, Indonesia
[3]Regional Earthquake Center 2, Meteorological Climatological and Geophysical Agency, Indonesia
[4]Research Center for Geospatial, National Research and Innovation Agency, Indonesia

*Corresponding Author, Received: 31 Aug. 2023, Revised: 02 Oct. 2023, Accepted: 04 Nov. 2023

ABSTRACT: The Mandalika Circuit, now one of the icons of Indonesian pride, is located on the south coast of Lombok Island. The south coast of Lombok Island is an area where the Indo-Australian plate subducts into the Eurasian plate, known as the subduction zone. Coastal areas dominated by sediment deposits (alluvial) and adjacent to subduction zones are disaster-prone areas, such as damage from earthquakes and liquefaction. The objective of this research is centered on the analysis of the potential damage due to geological conditions and liquefaction caused by the earthquake. This microseismic method with a total of 51 measuring points scattered around the Mandalika circuit was employed in this research. The microseismic data were measured using a portable three-component seismograph and processed using the horizontal-to-vertical spectral ratio (HVSR) method. HVSR analysis results are presented in terms of natural frequency (f_0), amplification factor (A_0), seismic vulnerability index (K_g), shear wave velocity profile at 30m depth (Vs_{30}), and sediment thickness. Groundwater level data was used to support the potential liquefaction analysis. Based on the Vs_{30} soil type classification, soft and medium soils dominate the Mandalika International Circuit. Estimates of sediment thickness range from 5 to 90 meters. The Mandalika Circuit and its surrounding area are vulnerable to earthquakes and liquefaction hazards that may potentially decrease to the north or away from the coastline.

Keywords: HVSR, Liquefaction, Mandalika circuit, Seismic vulnerability

1. INTRODUCTION

The Mandalika Circuit is located within the Special Economic Zone (SEZ) of Mandalika, an area currently being developed within the framework of ecotourism in response to the demand for sustainability and consideration of environmental issues in the tourism industry [1].

Located in the southern part of Lombok Island, the Komodo Ecotourism Development Area (KEK) Mandalika is dedicated to promoting sustainable tourism practices through the development of eco-friendly tourist sites and attractions that prioritize the preservation of the surrounding environment [2]. The location of the study area is presented in Figure. 1.

Based on the geological map, the rock formations found in the Mandalika Tourism Area comprise Alluvial Deposits and Penggulung Formation. The oldest exposed formation is the Penggulung Formation, comprising breccias, lava, and tuff with limestone lenses. The formation is estimated to be of late Oligocene to early Miocene age. It intersects with the Kawengan formation, comprising alternating quartz sandstones, claystones, and breccias. Alluvial deposits are distributed unevenly on older rocks, specifically the (Baturape-Cindako Volcanic rocks, and have a vast distribution, especially in the area surrounding the project site. The rocks present in this location were formed during the Quaternary period and belong to the Alluvium geological group, which encompasses river swamps, and coastal alluvial deposits (Qac). By evaluating the physical properties of the lithology and its location, it can be concluded that the alluvial deposits are the most recent rocks in this area. Typically, this rock unit is composed of coarse sand, fine sand, clay, and some marine animal fragments [3, 4].

Potential hazards such as seawater intrusion, subsidence, and other earthquake-related hazards such as tsunamis and liquefaction are present in most coastal areas dominated by sedimentary rocks [5]. The potential disasters associated with seawater intrusion in the study area have been investigated using gravity and geoelectric methods [6, 7, 8]. Using the Microtremor method, this research investigates the potential hazards associated with earthquakes in the Mandalika Circuit and its surroundings, which are included in the Mandalika SEZ area. This potential is reflected in the value of the Seismic Vulnerability Index, which is related to the degree of vulnerability of an area to the threat of earthquakes causing damage. The greater the value of the Seismic Vulnerability Index, the higher the risk of damage.

All these potential disasters can be detected by the Microtremor method. The analysis technique used is the horizontal-to-vertical spectral ratio (HVSR) method.

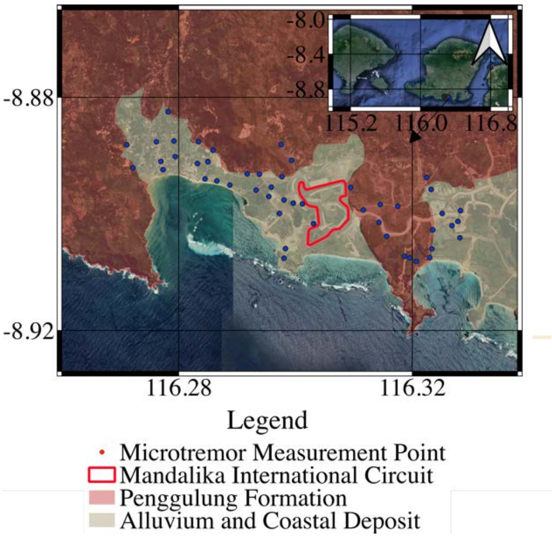

Fig.1 Microtremor seismic measurement points and Geological map of the study area (modified from [3]).

One post-earthquake hazard is liquefaction. When an earthquake strikes, the soil may no longer be able to withstand the load on it resulting from the sudden release of the soil's shear strength and an increase in pore water pressure due to dynamic loads [9], leading to liquefaction. Two factors that can increase liquefaction potential are sand density and earthquake intensity [10]. In addition to the aforementioned factors, the groundwater level is a critical factor in liquefaction vulnerability. The surface area near the groundwater level is particularly susceptible to liquefaction. This is because unsaturated soil above the groundwater level does not undergo liquefaction. [11].

Microtremor measurements are similar to seismic ones. The signal obtained from the measurements can provide information, such as wave source, wave attenuation, and the condition of the measurement point [12]. For instance, monitoring unconventional reservoirs, such as shale gas, requires the microtremor to accurately characterize the cracks. This information is crucial in determining the potential for future oil and gas production wells. [13]. Microtremor studies have been widely used in assessing earthquake damage. This technique is highly accurate in estimating the degree of seismic risk concerning the local geological conditions [14, 15]. In seismic engineering studies, softer lithologies pose a greater risk of earthquake shaking as they undergo higher wave amplification than more compact rocks [16]. Meanwhile, microtremor microzonation involves dividing zones based on characteristic parameters such as ground vibration, amplification (strengthening), dominant frequency, and dominant period. The characteristics of microtremors depend on the type of soil (sediment) in the study area. Utilized for identifying earthquake-prone areas, microzonation determines their potential impact [17]. Several recommended criteria exist within the HVSR technique to aid in interpreting each resulting curve. These include criteria for a reliable H/V curve and criteria for peak H/V [18]. Several conducted studies show that a significant H/V amplitude corresponds to a large impedance contrast between sediment (soft soil) and bedrock, whereas a small H/V amplitude indicates a small impedance contrast indicating the presence of thick soil (hard soil) [19].

The main objective of this study is to present an earthquake risk map and soil type classification for the Mandalika SEZ area. Disaster risk consists of natural frequency, amplification factor, vulnerability index and assessment of shear wave velocity at a depth of 30 meters (Vs30). Microtremor measurements for earthquake mitigation have been carried out by many previous researchers. However, the assessment of the earthquake hazard in the SEZ Mandalika area is still limited. To obtain comprehensive results, we compared the microtremor measurement data with Spontaneous Potential (SP) data, and Normal Resistivity Logs in the Mandalika SEZ area.

2. RESEARCH SIGNIFICANCE

The specific benefits of this research are intended for scientific development and the benefit of stakeholders. The results will serve as reference material on the geological conditions of the Mandalika SEZ area for scientific advancement. Additionally, stakeholders will benefit from the microzonation of potential disasters. This will allow for the avoidance of developing residential and hotel areas in high earthquake vulnerability index zones.

The significance of this research is to assist the government in building and developing the Mandalika SEZ as an ecologically responsible tourist attraction that prioritizes the preservation of the surrounding environment and its value to the community.

3. DATA AND METHOD

The direct measurement of microtremors was conducted at 50 measurement sites in Mandalika.

The distribution of measurement sites is presented in Figure 1. The equipment used in this research was a portable three-component seismograph. Data were recorded for approximately 30 minutes at each site. The measurement procedures followed the recommendations guidelines in The Site Effects Assessment using Ambient Excitations operational standards.

The Horizontal-to-Vertical Spectral Ratio (HVSR) is a method calculated by comparing the horizontal and vertical Fourier spectrum components. This method can investigate the local response characteristics of certain sites. HVSR produces dominant frequency and amplification factor values. The process of analyzing microtremor data to obtain dominant frequency and amplification data is performed using the Geopsy software [20]. Subsequently, to determine the dynamic characteristics of soil in the research area, the authors conducted seismic vulnerability index calculations.

$$K_g = A^2/f \quad (1)$$

Where soil resistance to ground shaking is represented by Kg, the amplification factor by A, and the dominant frequency by f.

The shear wave velocity at a depth of 30 meters is acquired by inverting the HVSR curve using Geopsy Software's Dinver program. Each measurement location yields a 1D ground profile. Furthermore, the categorization of soil types according to the Vs30 values adheres to the criteria specified in the Indonesian National Standard SNI 1726:2019 [21].

4. RESULTS AND DISCUSSION

Natural frequency refers to the number of vibrations or waves occurring per unit of time. This natural frequency is affected by the average wave velocity and bedrock thickness [14]. Sedimentary deposits are commonly linked with low natural frequency values, while rock sites are associated with higher natural frequencies. Geomorphologically, hilly areas have a higher natural frequency than those transitional areas between hills and plains, while, the alluvial plains are characterized by a lower natural frequency.

The horizontal spectral ratio technique obtained natural frequencies from the ambient microtremor spectrum. This method produces a curve showing the natural frequency and amplification. The natural frequency is determined from the frequency at the curve peak of the curve. High natural frequencies indicate the presence of bedrock layers, while low natural frequencies suggest sediment thickness.

The Mandalika International Circuit area and its surroundings are dominated by low frequencies ranging from 1.0 to 2.5 Hz, marked with red gradations in Figure 2. Based on the classification of soil types, the site includes soft soil (Site Class IV) and medium soil (Site Class III) [22]. The Mandalika SEZ poses a significant earthquake disaster risk. When an earthquake occurs, the risk of disaster is high if the natural frequency value is similar or almost similar to the earthquake wave frequency, causing frequency resonance. Similar natural frequencies or close matches to earthquake wave frequencies create a higher risk of disaster occurrence due to frequency resonance. The buildings in that area exhibit a high level of vulnerability.

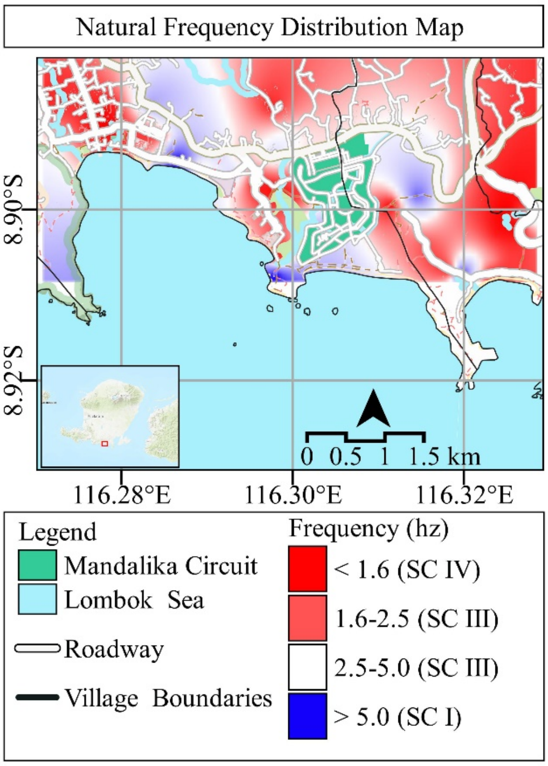

Fig.2 Natural Frequency Distribution Map in Research Area.

The amplification factor indicates the variation in rock layers dynamic characteristics upon receiving earthquake wave propagation. During an earthquake, the sediment layer undergoes wave amplification resulting from multiple reflections of earthquake waves between the bedrock and sediment layer surface. The amplification factor can also be caused by the significant impedance contrast between the sediment layers and the rock layers. The relationship between the amplification factor and the impedance contrast is that the higher the amplification factor value indicates, the higher the impedance contrast between the sediment and rock layers.

Based on Figure 3, the amplification factor values in the study area range from 1 to 9. The

Mandalika International Circuit has a higher amplification factor than the surrounding area, ranging around 7 to 9 magnification of the earthquake waves. A high amplification factor is associated with a low natural frequency (see Fig.3). Improper disaster mitigation results in greater damage to buildings in areas with an amplification factor of more than 9.

The seismic vulnerability index (K_g) parameter relates to the natural frequency and amplification factor. This parameter can be used as a reference for micro zonation, namely mapping an area based on the level of vulnerability. K_g obtained the seismic vulnerability index by squaring the amplification factor divided by the natural frequency [23].

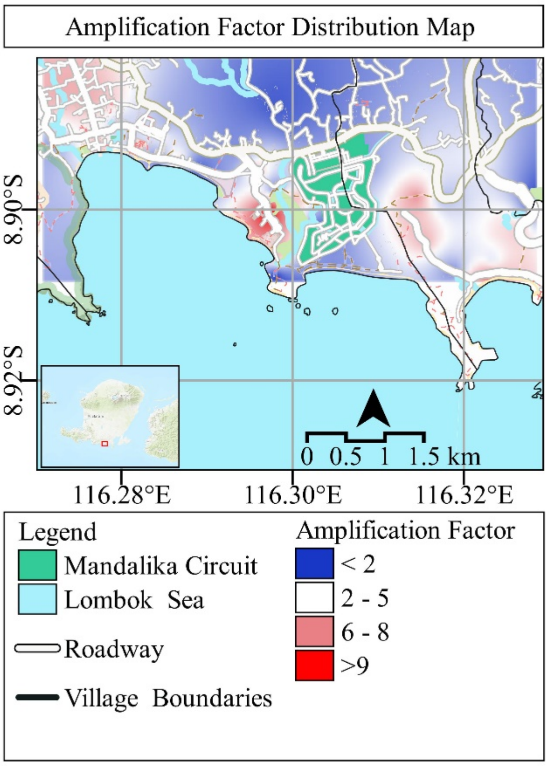

Fig.3 Amplification Factor Distribution Map in Research Area.

The seismic vulnerability index of the study area ranges from 1 to 17 (see Fig.4). The southern part of the study area is dominated by a high seismic vulnerability index of 7 to 17. This area is a coastal area composed of alluvial material. In contrast, the hilly northern region displays a lower seismic vulnerability index.

This research employed an assessment to classify soil types by analyzing the shear wave velocity at a depth of 30 m (Vs30) with HVSR inversion. The classification of layer types for bedrock determination based on shear wave velocity (Vs30) aligns with the guidelines of the National Standardization Agency SNI 1726:2019 for earthquake-resistant buildings and non-building structures.

Generally, the scattering of Vs30 in the Mandalika International Circuit area varies from 140 m/s to 787 m/s. The distribution of Vs30 reveals that the circuit is primarily composed of stiff soil layers, with Vs30 values ranging between 175-350 m/s (indicated by orange to light green colors). However, the southern part of the Mandalika International Circuit is characterized by a soft soil layer with a Vs30 value lower than 175 m/s (indicated by the red color). The distribution of Vs30 in the study area is presented in Figure 5.

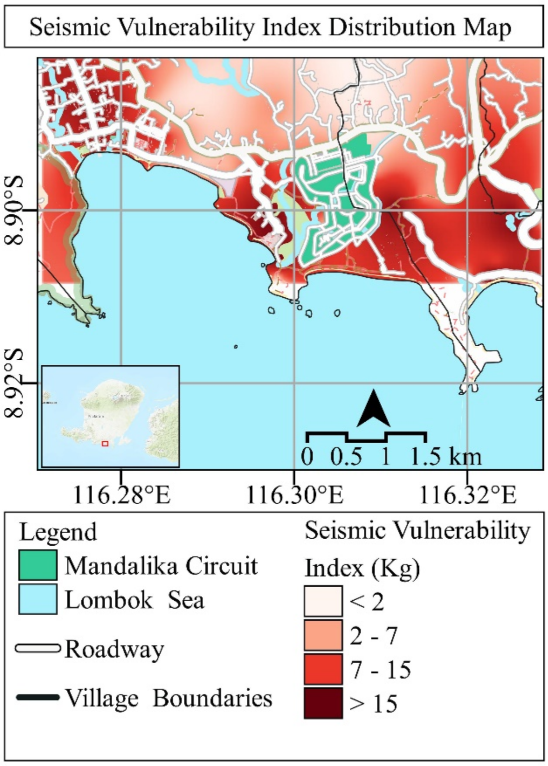

Fig.4 Seismic Vulnerability Index Distribution Map in Research Area.

The h/v curve inversion method is used to obtain cross-sectional information on the subsurface Vs of the study area. The h/v curve inversion method begins by inputting the amplification and natural frequency data obtained from the h/v curve. This is then combined with other model parameters such as P-wave velocity, S-wave velocity, Poisson ratio, and density. The modeling process is performed by iteration method. The iteration process is employed to determine a model space founded on Monte Carlo to minimize the misfit function. This method results in a shear wave velocity model at each measurement point. The application of this method at all measurement points produces a ground profile as shown in Figure 6.

The result of h/v curve inversion indicates a variation in Vs down to a depth of 150 meters.

Specifically, the Vs value at point G49 located in the southwestern part of the Mandalika Circuit suggests the presence of a sediment layer with a thickness of approximately 90 meters. The results of Vs inversion of the depth at the G55 station in the Penggulung formation confirmed that the G55 point area had a sedimentation thickness ~18 meters thinner than the G49 point.

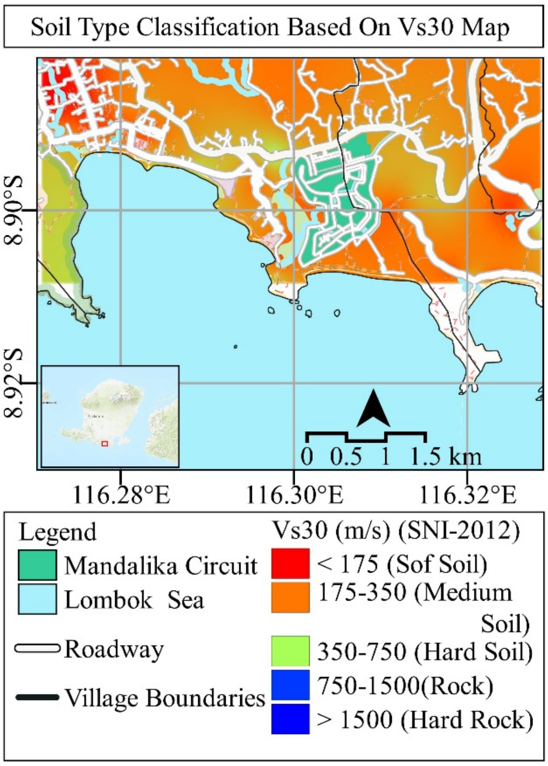

Fig.5 Classification of Soil Type based on Vs30 Map in Research Area.

To enhance the certainty of the results of the inversion level, the authors compare the results at the G18 point to the Spontaneous Potential (SP) data, as well as the Long and Short Normal Resistivity Log in the Sekarkuning area, which is around 1 kilometer away from the G18 point (Fig.7). Based on the findings at a depth of approximately 5 meters, there has been an upward trend in SP values and resistivity, indicating that rocks at the same depth have a decreased level of porosity. These conclusionsis is are drawn from inversion results of the G18 point revealing a rise in Vs values between depths of 4 to 6 meters. An increase in resistivity values was observed at depths ranging from about 8 to 12 meters, which corresponded to an increase in the Vs values between 400 and 650 km/s. Additionally, permeable zones were found at a depth of around 36 meters from the SP results, which were linked to structures with Vs values of around 800 meters.

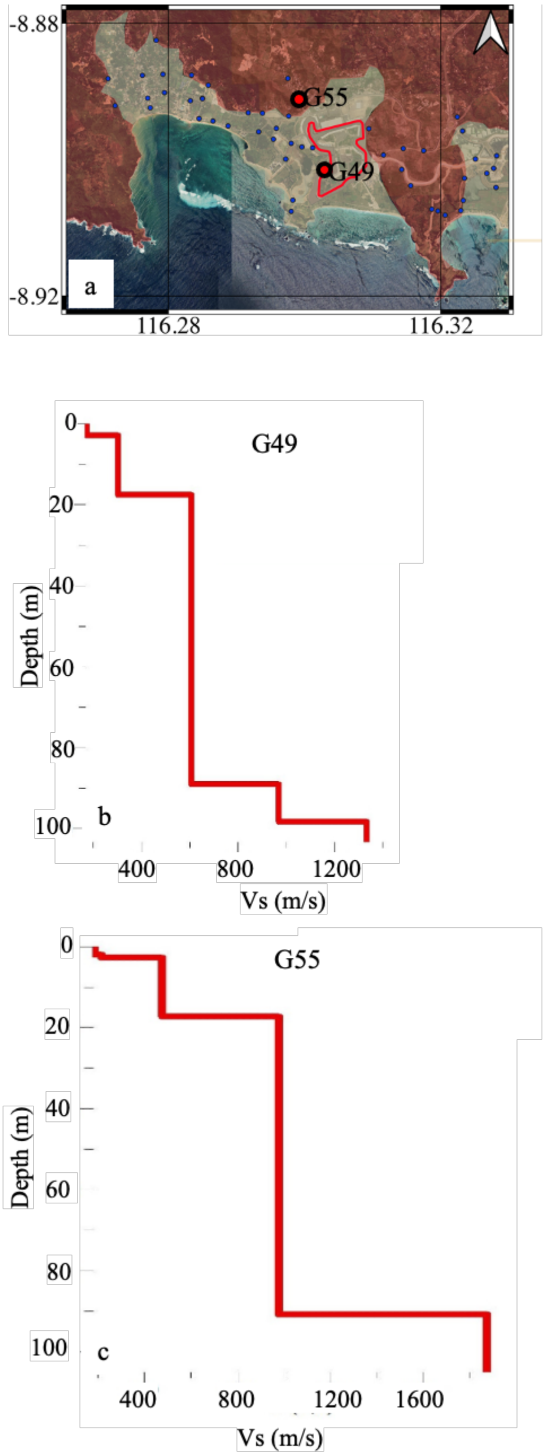

Fig.6 (a) Map of the location of observation points G49 and G55; (b) Ground profile results of the ellipticity method in G49; and (c) G55.

The results of the cross-section on the A-A' trajectory through points G8, G10, G25, and G21 in the western part of the study area showed that the trajectory was associated with sedimentation with a thickness of 20 to 40 m (Fig.8). The sedimentation layer was identified as a rock associated with a low Vs (<700 m/s). The past location is in the transitional zone between alluvium geological formations and scavengers. Trajectories passing through points G62 and G63 in the Pengulung formation, despite a relatively thick sediment layer, revealed structures with higher Vs values (>1200 km/s) at a shallower depth of around 100 meters.

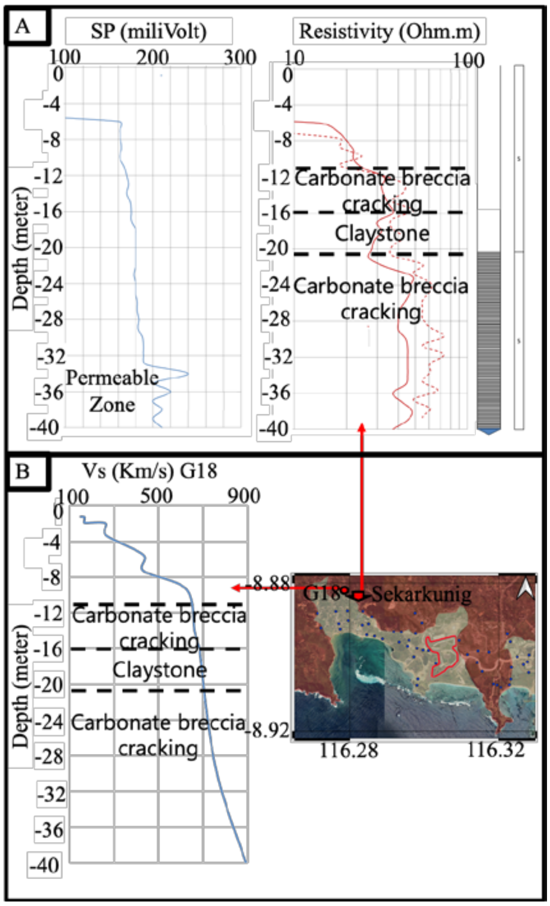

Fig. 7 Comparison between Log SP, Resistivity (Top), and Vs G18 (bottom) measurements.

Cross-section findings on the B-B track located in the Peng formation reveal sedimentation layers with thicknesses ranging from approximately 10 to 40 meters (see Figure 8). Rocks with high Vs are are located at relatively shallower depths of around 80 meters along trajectories in the Pengulung formation. At the end of the southern track, situated east of the Mandalika circuit area, this structure with a high Vs value occurs at a deeper depth of around 125 meters.

The trajectory of C-C' passes through points G41, G49, G63, G62, and G75 (see Fig.8). Notably, G41 lies in the coastal area, while G49 lies in the Mandalika circuit area characterized by sedimentation layers measuring around ~20 to 40 meters. Trajectories passing through the spooling formation reveal structures with high Vs values at a shallower depth compared to those trajectories passing through the Alluvium formation. Along this track, sedimentation on the Mandalika circuit has a thickness of around ~20 to 25 meters.

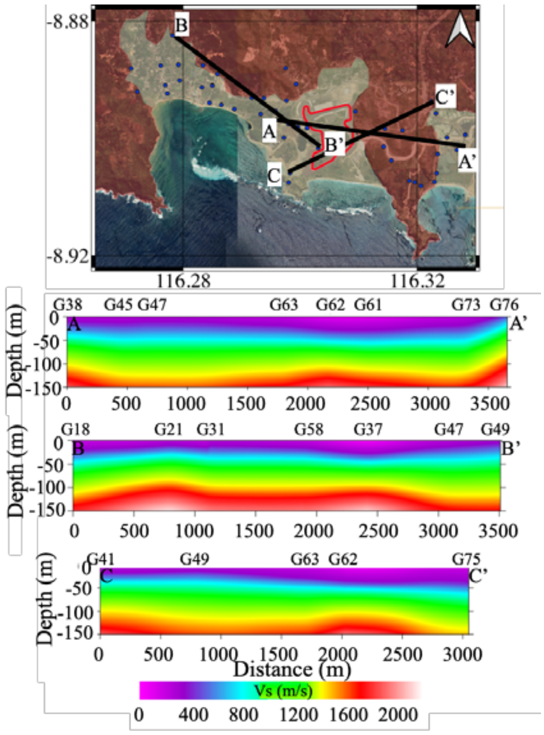

Fig. 8 Cross section Vs trajectories A-A', B-B' and C-C'

5. CONCLUSION

The results of the spatial distribution of natural frequencies and Vs30 values in the study area indicate that the natural frequency values range from 1 to 17 Hz, and Vs30 ranges from 140 m/s to 780 m/s. Low natural frequency and Vs30 values are observed in The Mandalika International Circuit area, specifically between 1 - 7 Hz and 140 - 350 m/s. These results suggest that The Mandalika International Circuit is situated above soft to medium soil layers.

Based on the inversion of the h/v curve, the sediment thickness in the study area varies between 5 and 90 meters, with an estimated sediment thickness in The Mandalika International Circuit area ranging from 20 to 25 meters. These results show a pattern similarity with the SP and Log resistivity data. The Mandalika International Circuit area and its surroundings are vulnerable to earthquake and liquefaction hazards that may potentially decrease to the north or away from the coastline, as indicated by the relatively thick sediment layer and a high seismic vulnerability index.

6. ACKNOWLEDGMENT

The authors express their gratitude to the Research and Community Service Institute (LPPM) of Mataram University for financially supporting this research with a letter of agreement number: 1232/UN18.L1/PP/2022. The authors also thank the Meteorology, Geophysics and Climatology Agency (BMKG), especially Mataram Geophysics Station for providing equipment and personnel for Microtremor data acquisition, and all parties involved for their support of this research.

7. REFERENCES

[1] Estriani H. N., Kawasan Ekonomi Khusus (KEK) Mandalika Dalam Implementasi Konsep Pariwisata Berbasis Ecotourism: Peluang Dan Tantangan, Mandala Jurnal Hubungan Internasional, Vol.2 No.1, 2019, pp. 64 – 79.

[2] Peraturan dewan nasional kawasan ekonomi khusus nomor 2 tahun 2021 tentang perubahan atas peraturan dewan nasional kawasan ekonomi khusus nomor 1 tahun 2021 tentang kegiatan utama kawasan ekonomi khusus, Dewan Nasional Kawasan ekonomi khusus, Republik Indonesia, 2021, pp. 24 – 26.

[3] Suratno N., Geological and mineral potential map of West Nusa Tenggara-Lombok and Sumbawa quadrangles, Baranc office of Department of Mines and Energy West Nusa Tenggara Province, 1994.

[4] Alaydrus A. T., Susilo A., Naba A., and Minardi S., Identification of the constraints of physical properties on the fluid flow rate (as a preliminary study for analysis of changes in subsurface conditions in the KEK Mandalika Lombok), Journal of Physics: Conference Series 1816, 2021, doi:10.1088/1742-6596/1816/1/012100

[5] Owen G., and Moretti M., Identifying triggers for liquefaction-induced soft-sediment deformation in sands, Vol. 235, Issue 3–4, 2011, pp.141-147.

[6] Alaydrus A. T., Susilo A., Minardi S., Naba A., and Wahid A., Analysis the Effect of Physical Parameters on Groundwater Salinity in the KEK Mandalika Lombok, Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram, Vol. 9, No. 2, 2021, pp. 316-324 .

[7] Alaydrus A. T., Susilo A., Minardi S., Naba A., and Mudyanto A., Identification Of Seawater Intrusion Using Geophysical Methods In The Mandalika, Lombok, Indonesia. International Journal of GEOMATE, Vol.23, Issue 97, 2022, pp.12-21.

[8] Alaydrus A. T., Susilo A., Minardi S., Naba A., and Abraham T. P., 3D inversion modeling of gravity and geomagnetic in the coastal aquifer of the Mandalika Lombok, IOP Conf. Series: Earth and Environmental Science 1175 (2023) 012018, 2023.

[9] Youd T. L., and Idriss I. M., Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 4, 2001, pp. 297-313.

[10] Ishihara K., and Ansal A., Dynamic Behaviour of Soil-Soil Amplification and Soil-Structure Interaction, Final Report for Working Group D, UNDP/UNESCO Project on Earthquake Risk Reduction in the Balkan Region, available at https://unesdoc.unesco.org/ark:/48223/pf0000 060371, 1984.

[11] Day R. W., Geotechnical Earthquake Engineering Handbook: McGraw-Hill, 2002, pp. 6.6 – 6.10.

[12] Bouranta E., Vallianatos F., Hatzopoulos J., Papadopoulos I., and Gaganis P., Microtremor HVSR study of site effects in the urban area of the town of Mytilene, Lesvos (Greece) - Preliminary results. Bulletin of the Geological Society of Greece, 47, 2013, pp. 1081-1089.

[13] Zheng Y., Wang Y., and Chang X., Wave Equation Based Microtremor Source Location and Velocity Inversion. Physics of the Earth and Planetary Interiors, 2016, http://doi.org/10.1016/j.pepi.2016.07.003

[14] Nakamura Y., On The H/V Spectrum. Proceedings of 14th World Conference on Earthquake Engineering October 12-17, Beijing, China, 2008, Paper No.07-0033, 8p.

[15] Tawakal M. I, Haris A., and Martha, A. A, Estimating shear wave velocity (Vs30) of East Java, Indonesia, using ambient noise inversion of horizontal to vertical spectral ratio (HVSR), IOP Conf. Series: Earth and Environmental Science 538 (2020) 012012, 2020, doi:10.1088/1755-1315/538/1/012012

[16] Kanai K., Seismology in Engineering. Japan: University of Tokyo Press, 1983, pp.251.

[17] Walling M. Y., and Mohanty W. K., Earth-Science Reviews an Overview on the Seismic

Zonation and Microzonation Studies in India. Earth Science Reviews, 96(1-2), 2009, pp. 67–91.

[18] SESAME European Research Project, Guidelines for The Implementation of the H/VSpectral Ratio Technique on Ambient Vibrations, available at ftp://ftp.geo.uib.no/pub/seismo/SOFTWARE/SESAME/USER-GUIDELINES/SESAME-HV-User-Guidelines.pdf, 2004.

[19] Leyton F., Ruiz S., Sepúlveda S. A., Contreras J. P., Rebolledo S., and Astroza M., 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, 2013, pp. 26–33.

[20] Geopsy Software for Geophysical Research and Applications Geopsy 2018 available at http://www.geopsy.org.

[21] SNI 1726:2019. Procedures on Earthquake Resistance Planning for Building and NonBuilding Structures. Badan Standarisasi Nasional, Jakarta, 2019.

[22] Zhao J. X., Irikura K., Zhang J., Fukushima Y., Sommerville P. G., Asano A., and Ogawa H., An Empirical Site-Classification Method for Strong Motion Stations in Japan Using H/V Response Spectral Ratio, Bulletin of the Seismological Society of America, Vol. 96, No. 3, 2006, pp. 914-925.

[23] Nakamura, Y., Clear Identification of the Fundamental Idea of Nakamura’s Technique and Its Applications. 12th World Conference on Earthquake Engineering, New Zealand (CD-ROM), 2000, Paper No. 2656, 8 p.