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"ANALYSIS OF SEISMIC HAZARDS AND VULNERABILITY THROUGHOUT INDONESIA BASED ON 1999-2003 EARTHQUAKE DATA USING THE MICROSEISMIC METHOD"

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ABSTRACT

Indonesia is an archipelagic country that has a complex geological structure. Its location at the confluence of three plates, namely the Eurasian plate, the Indo-Australian plate, and the Pacific plate causes high tectonic activity. This seismic activity causes high seismicity levels, especially along the subduction zone. An earthquake with a large magnitude can occur and cause a high level of damage, so it is necessary to know about the language of earthquake resistance. Earthquake vulnerability is useful for mitigating earthquakes that will occur so that people are more alert to earthquake disasters that can occur anytime and anywhere. This research is a descriptive type of research, namely by collecting data on the JINSET (Japan Indonesian Seismic Network) earthquake catalog in 1999-2003 with M greater than 5 S.R. Earthquake hazard data processing using geopsy software for HVSR analysis. The horizontal component data is divided by the vertical component in the frequency domain so that the H/V value is obtained. Based on the mapping of the level of earthquake vulnerability that occurred in the territory of Indonesia, namely the islands of Sumatra and Maluku, including the vulnerable areas seen from the highest vulnerability value with an earthquake vulnerability of 77.09-85.57. Meanwhile, the lowest earthquake vulnerability areas occur on the islands of Sulawesi and Kalimantan with an earthquake vulnerability value of 0.054-9.010. The earthquake susceptibility value causes the earthquake hazard to occur.

Keywords : Earthquake, HVSR, Earthquake Vulnerability, earthquake hazard.

I. INTRODUCTION

Indonesia is an archipelago with a complex geological order because the territory of Indonesia is located at the confluence of three plates namely the Eurasian, India-Australia, and Pacific plates. The Eurasian Plate and the Australian plate collide on the west coast of Sumatra, the southern coast of Java, and the southern coast of the Nusa Tenggara Islands, and turn north towards the waters south of Maluku. The Australian and Pacific plates collide around Papua, and the encounter between the three plates occurs near Sulawesi. The meeting of the three plates resulted in high seismic activity or the territory of Indonesia. Seismic activity or high seismic activity has caused frequent earthquakes in most parts of Indonesia.

Earthquakes are events that shake the earth due to the sudden release of energy in the earth and are characterized by the rupture of rock layers in the Earth's crust, the accumulation of energy that causes earthquakes caused by the movement of tectonic plates. Energy is generated in all directions in the form of seismic waves, so that the influence of the Earth's surface can be felt (Meteorology, Climatology and Geophysics Agency). If the two plates collide with each other, then the boundary area between the two plates will experience a voltage. This tension occurs continuously and is so great that it exceeds the strength of the Earth's crust. This causes the crust to break in the weakest area. The damaged skin of the earth will release energy to return to its original state. This energy release event causes earthquakes. That the process of an earthquake occurs when the energy stored in the earth is released suddenly, usually in the form of stress on the rocks. The earth's crust has a relatively much lower temperature than the layers below it (the mantle and core of the earth) so that flow occurs. convective, i.e. mass with a high temperature flows to an area of lower temperature. This high-temperature mass resides in a very viscous, slowly flowing asthenosphere layer. As a result of these movements, the earth's crust is broken up into parts in the form of plates that move with each other, which are then called tectonic plates [1].

Seismic waves are energy propagation caused by disturbances in the Earth's crust, such as faults or explosions. This energy will spread throughout the earth and can be recorded by seismographs. The effects of these seismic waves are known as seismic phenomena.

The principle of the HVSR method is to use three-component passive seismic. Two important parameters are derived from the results of this method, namely natural frequency (fo) and magnification (Ao). These two parameters are essentially the embodiment of regional geological features. The steps of processing the HVSR method are as follows.

1) Microseismic sensors record vibrations
2) Get time-series data from each component. At this stage, the environmental signal is disconnected, so it can be processed at a later stage.
3) Gain Fourier spectrum by performing Fourier transformations on each component (N-S, E-W, and vertical components.)
4) Calculate the average of the 2 horizontal spectra, then divide the result by the vertical spectrum to get the HVSR curve and values (fo) and (Ao).

$$\alpha_g = \frac{5}{\sqrt{T0}} 10^{0,61M - (1,66 + \frac{3,6}{R}) \log R + 0.167 - \frac{1.83}{R}} \quad (1)$$

With:

α : Vibration acceleration

T : Dominant period

Ms : Magnitude of surface waves

R : Distance of the measurement station to the source of the earthquake

The natural frequency value of HVSR processing indicates the natural frequency found in the area. This states that if there is an earthquake or disturbance in the form of vibrations that have the same frequency as the natural frequency, there will be a resonance that results in the amplification of seismic waves in the area. The natural frequency value (fo) of a region according to [2] is supported by several factors, namely the thickness of the weathered layer and the average speed below the surface (Vs)

$$f = \frac{Vs}{4H} \quad (2)$$

With:

Fo : natural frequency,
Vs : the average value of the speed of shear waves at depths up to 30 meters from the surface,
H : It is the thickness of the weathered layer.

Amplification in seismic waves can be caused when an object has a self-frequency, then is disturbed by another wave with the same frequency. Amplification of earthquake waves can occur when waves propagate to the ground surface where the natural frequency (fo) of the soil has a frequency value that is almost equal to or equal to the frequency of the earthquake that comes. Amplification is the event of strengthening a wave when it passes through a certain medium. The comparison between the characteristics of a horizontal signal to a vertical signal is directly proportional to the strengthening of the wave as it goes through a medium.

The seismic vulnerability index (Kg) is an index that describes the degree of vulnerability of the surface soil layer to deformation during an earthquake. According to [3], seismic vulnerability indexes are obtained by squaring the peak values of the microtremor spectrum divided by resonance frequencies, which are formulated as:

$$K_g = \frac{A0^2}{f0} \quad (3)$$

With:

Kg= (seismic vulnerability index),
A= (the peak of the microtremor spectrum), and
Fo= Frequency

Maximum soil acceleration is one of the indicators of soil acceleration that occurs somewhere due to earthquakes that can be seen in two ways, namely using accelerometers and empirical methods to measure it [4]. Maximum soil acceleration is calculated based on magnitude and distance from the source of the earthquake to the point of calculation as well as the value of the dominant period of land in a regionSome methods that can determine the maximum soil acceleration value empirically are richter, Fukushima-Tanaka, Donovan, Esteva, Murphy-O'brein, Mc.Guirre and Kanai [5].

The method of probabilistic analysis of the level of earthquake insecurity considers the possibility of earthquakes and the sources of earthquakes and seismicity parameters that are around the research area such as the size, location and frequency of earthquake events. In this method the occurrence of an earthquake on a fault is based on the Poisson process. If the earthquake event follows the Possion model and probability then each event will produce a ground movement at a specified location point at a set rate and not depend on other events, in addition the earthquake event model follows Guttenberg and Ricther's relationship. This PSHA method can be described in 4 (four) stages of the procedure [6] as follows:

1. Identification and characterization of earthquake sources, location sources can produce significant ground movements at the location point. This stage also includes the definition of each geometry source and earthquake potential
2. Calculation of earthquake event parameters for each source. The repetition relationship that determines the average rate of an earthquake at some size will be greater used for earthquake characteristics from each area source. Calculations can be demonstrated by applying the Guttenberg and Ricther relationships that connect event frequency and magnitude, and the maximum magnitude of earthquakes at each source must be determined.
3. Development or characterization of attenuation relationships. Using predictive equations, generating ground movement at the point of location of an earthquake that is likely to measure at all possible points in each source must be determined. Ground movement can also be determined by applying the law of attenuation calculated for each region representing acceleration parameters with the distance and magnitude of a particular earthquake potential.
4. The combined uncertainty of earthquake location, magnitude and parameters ground motion.

By considering the uncertainty of the location, size of the earthquake, and the prediction of the movement of the ground by combining the effects of all earthquakes with different magnitudes and distances, the probabilities of different events in each particular place are combined, and give consequences to the probability exceeded for different degrees of acceleration for a given period of time .

II. RESEARCH METHODS

The type of research used is descriptive research. The data used in this study is secondary data obtained from JINSET (Japan Indonesian Network) data from 1999 to 2003. In this study, an earthquake analysis that had occurred using existing data was then re-examined to get the latest information. The processing in this study was carried out in several stages as follows. In data collection, the microseismic method requires a vibration source. The working principle of the microseismic method is the same as that of the seismic method in that the signal in the known time domain to generate seismic waves traveling through the subsurface is reflected or refracted back to the surface where the signal can be detected [7].

The first stage is to determine the coordinate point of the research site. Then in the second stage process and analyze the data using the Horizontal to Vertical Spectral Ratio (HVSR) method using geopsy software. The results of HVSR analysis produce dominant frequency and amplification factor. In the last stage perform the calculation of the value of the seismic vulnerability index using the formula: $K\ g = A^2/fo$ As well as mapping the level of seismic vulnerability of the Indonesian region from the results of data processing and analyzing the relationship of vulnerability and earthquake hazard for earthquake mitigation.

The data obtained is interpreted using the help of geopsy software and mapping using arcgis software 10.3. The output results in the form of data on the position of regions that experience a change in position caused by earthquakes. The earthquake analyzed was an earthquake with a magnitude of <5.0. Therefore, disaster mitigation is needed to overcome this problem. Disaster mitigation is done to reduce the risk and danger of earthquakes caused by earthquakes. Therefore, it is necessary to map the vulnerability of earthquakes in vulnerable areas in indonesia. Before mapping the daearah, first the seismic vulnerability index in the area is carried out by calculating the amplification value and natural frequency of the data processing signal output. So it is obtained how the change in position caused after and before the earthquake occurred.

III. RESULTS AND DISCUSSION

This study used data from JINSET (Japan Indonesian Network) from 1999 to 2003. Earthquake data has a magnitude of M≥5 SR with regional coordinates 6.LU-11. LS and 95.BT-141. BT. The results obtained from this study are data processing using the helper software that is Geopsy.

1. **Microseismic Processing Results**

[8] stated that based on observations made at seismic stations in Sweden found:
1) Short period (<2 seconds) microseismic waves caused by factors such as engine vibration, wind, and so on.
2) Microseismic waves of moderate period (second) caused by a storm in the sea north of Norway.
3) Long period microseismic waves (17-20 seconds), the occurrence is very rare during very large ocean waves.

The results of this study are presented in the form of maps of dominant frequency distribution, amplification factors, seismic vulnerability index, HVSR analysis of microseismic measurement data in indonesia. Based on the results of microwave processing so that 62 points are obtained spread throughout Indonesia three components of waves in the direction of NS (north-south), EW (east-west) and V (vertical). The three components of ambient wave data are then processed using the HVSR method and Geopsy software facilities. The results of the analysis with the HVSR method will produce a graph of the relationship between H / V and frequency.

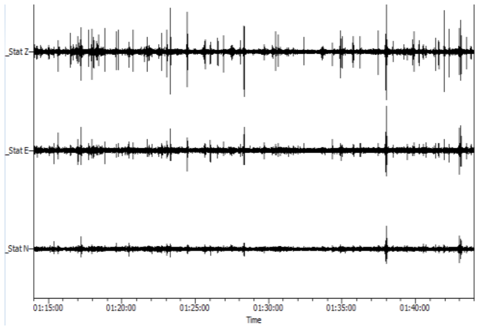

Fig.1 Microseismic Signal Components

Microtremor data processing using the HVSR method begins with the selection of stationary windows on each spectrum component, then smoothing using Konno and Ohmachi smoothing filters. Filtered data is analyzed with the HVSR method derived from the square root of the horizontal Fourier spectrum amplitude (North-South) and the horizontal Fourier spectrum (East-West) divided by the vertical Fourier spectrum, resulting in an H/V value for each window. From the anlisa HVSR obtained the HVSR curve. From the curve obtained the value of the predominant frequency and amplification factor. Then cross check is carried out by referring to the standard set by the SESAME European Research Project, which is the criteria for the reliability of the H / V curve and the criteria for the clearpeak curve H / V. Horizontal component data divided by vertical components in the frequency domain so that the value of H / V is obtained for each window. Then, the H/V value of each component for all windows is averaged so that

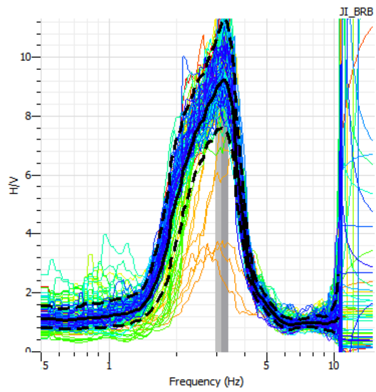

***Fig.2** Sumatra Region Processing Results*

From data processing, signal output obtained in the form of HVSR curve. The HVSR curve is used to calculate earthquake vulnerability values by comparing amplification values and natural frequencies as in the graph in figure 9. Based on the results of ambient wave analysis using the HVSR method at 62 observation points obtained a minimum amplification factor value of 0.4 which occurred on February 28, 2002 at the PTK point and a maximum amplification factor of 22.2 which occurred on June 6, 2000 at the KOTA point.

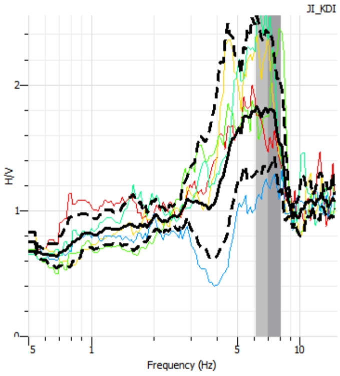

Fig.3 Maluku Region Processing Results

The Eastern Indoesia region such as the northern Maluku region is a region with a high level of tectonic activity and is influenced by regional and local tectonic conditions. The location of earthquakes that often occur on this island such as Halmahera, Maluku Sea, subduction arc Halmahera-Maluku Sea, West Halmahera, Southern Halmahera and Morotai.

2. Earthquake Vulnerability Level

Sumatra Island is an area that is prone to earthquakes, seen from the seismic vulnerability index which is quite high but requires a level of vigilance.

Table 1. The results of calculation of amplification factors using the HVSR method of sumatra island region

Titik	f0	A0	Kg= A0^/f0
JMB	0,7	2	5,714286
BRB	3	3	3
BSI	10,4	2,6	0,65
LEM	8,1	3,8	1,782716
TPN	1,8	6,4	22,75556
JMB	5	2,6	1,352
AAI	7,5	2,4	0,768
JMB	1,9	2	2,105263
KSI	10,1	11,6	13,32277
PPI	10	3,3	1,089
MNI	3,1	1,3	0,545161
MNI	10	7,6	5,776
JMB	11	1,4	0,178182
KOTA	10,5	18	30,85714
JMB	0,68	1,7	4,25
BSI	4,2	1,42	0,480095

JMB	3,3	1,4	0,593939
BKB	2	2,6	3,38
KOTA	0,68	22,5	7,4444
LEM	8,2	3,2	1,24878
BKB	5,7	2,8	1,375439
BRB	11	1,4	0,178182
JMB	7	4	2,285714
TPI	0,7	1,3	2,414286
LEM	2,6	3,4	4,446154
LEM	6	2,8	1,306667

The amplification factor value obtained at KSI, KOTA, BRB and PTK points in general is much greater than the observations at 58 other points. On one line of observation, the position of points located in Western Indonesia and Eastern Indonesia has a much greater amplification factor than the points located in Central Indonesian.

Table 2. The results of ampliwfication factor calculation using HVSR method of Maluku island and Papua

Titik	f0	A0	Kg= A0^/f0
JMB	1,6	8	40
KOTA	11	2,6	0,614545
BRB	3,1	6,8	14,91613
KOTA	1,1	2,2	4,4
KSI	10,2	12	14,11765
PPI	9	3,2	1,137778
BKB	1,7	3,78	8,404941
JMB	9,8	1,38	0,194327
PPI	11	4	1,454545
PTK	10,8	0,4	0,014815
SWH	7	6	5,142857
BRB	9	1	0,111111
KDI	6,9	2,9	1,218841
KDI	6	2,6	1,126667
PCI	0,8	1,6	3,2
TOL	11	0,17	0,002627
BRB	4	1,4	0,49
LEM	8	3	1,125

TPI	0,6	1,4	3,266667
BKB	1,8	2,8	4,355556
BRB	7,1	1,5	0,316901
BWN	8	1,2	0,18
TPN	9	1,5	0,25
JMB	0,7	3,6	18,51429
LEM	6,5	3,2	1,575385
BKB	9	2,2	0,537778
BRB	10,5	1,4	0,186667
TPI	0,9	1,6	2,844444
MNI	0,6	7,3	88,81667
LEM	8,9	4	1,797753
BKB	1,4	3	6,428571
LEM	8	3,3	1,36125
LEM	6,9	4	2,318841

3. Mapping earthquake vulnerability in Indonesian

Fig. 4 Epicenter Map of Earthquake Data of 1999-2003

In the epicenter earthquake mapping, the indonesian region is prone to earthquakes scattered in several provinces. Earthquake-prone areas such as the islands of Sumatra, Java, Sulawesi and Papua.

Fig. 5 Mapping Low Earthquake Vulnerability Levels.

In Indonesian that have the lowest level of earthquake vulnerability occurred on the island of Kalimantan. On the island of Kalimantan rarely the occurrence of earthquakes so that the area in Kalimantan is not too risky if there is an earthquake but also needs a high level of exposure.

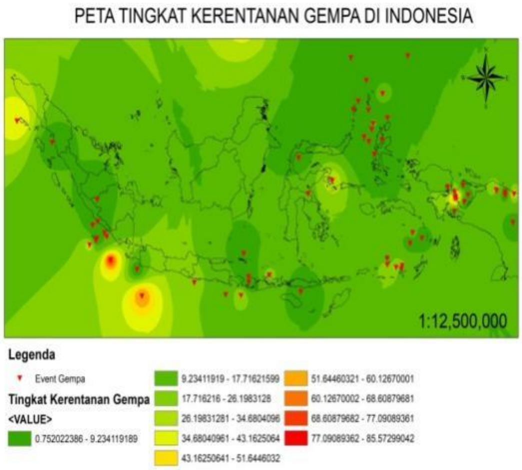

Fig. 6 Mapping High Earthquake Vulnerability Levels

In figure 6, some areas of Indonesia are prone to earthquakes. Sumetera Island is one of the earthquake-prone areas seen from the range of high earthquake vulnerability values. Therefore, the island of Sumatra needs further mitigation to reduce the danger of earthquakes that occur. Some areas of Indonesia that need to be vigilant are the island of Java.

According to [9], the energy produced is emitted in all directions in the form of seismic waves so that the effect can be felt to the earth's surface as a vibration or earth shock. Para-meter data points located in the fault zone (< 1000 m) have a high score compared to data points located far from the fault zone (> 1000 m). The spread of the indonesika region earthquake vulnerability level is presented in figure 11 with a low vulnerability level and in figure 12 with a high degree of vulnerability.

The results of the analysis obtained that the seismic vulnerability index of indonesia region ranges from 0.002 - 74.4. Areas with high seismic vulnerability index values are located on the island of Sumatra such as the west Sumatra region. Tectonics in Sumatra are controlled by the boundary between the Indo-Australian plate and the southeastern Eurasian plate which forms a subduction angle forming two faults, the mentawai fault and the Sumatran fault. The Sumatra Fault has high activity while the Mentawai Fault only partially has a fairly high activity [10]. The activity of subduction and shifts along the fault causes earthquake events that often cause casualties. West Sumatra region is one of the areas that have a high level of seismicity along with the risks it causes. The oblique convergence of the Indo-Australian plate against Eurasiae under Sumatra produces the potential for shallow and moderate earthquakes in the Sundanese fore-arc region. The potential for earthquakes is also on land along the Sumatra fault as well as in the sea along the Mentawai fault. [11] stated that shallow earthquakes have a very strong construction damaged power, due to hypocenter distance so that earthquake tremors are felt very strongly on the surface of western Indonesia, most of the area is located on the coast.

The Eastern Indoesia region such as the northern Maluku region is a region with a high level of tectonic activity and is influenced by regional and local tectonic conditions. The location of earthquakes that often occur on this island such as Halmahera, Maluku Sea, subduction arc Halmahera-Maluku Sea, West Halmahera, Southern Halmahera and Morotai. This makes the area most vulnerable to the effects of earthquakes if it continues to be rocked by earthquakes. The earthquake vulnerability index in eastern Indonesia such as Maluku and Papua ranges from 77.09-85.57. While the lowest earthquake vulnerability area occurred on the islands of Sulawesi and Kalimantan with an earthquake vulnerability value of 0.054-9.010.The lower the seismic vulnerability index value indicates that the area has solit sediments. The higher the value of a region's seismic vulnerability index, the greater the level of damage from earthquakes, the smaller the value of the seismic vulnerability index, the smaller the potential damage due to earthquakes.

Seismic vulnerability index (Kg) is an index that describes the level of vulnerability of surface soil layers to deformation during an earthquake. The seismic vulnerability index is related to geomorphological conditions. There are several factors that affect the seismic susceptibility index among them are quaternary-aged sediments that have low solidity levels that greatly affect the magnitude of amplification factors during earthquakes, whereas in tertiary-aged rocks tend to be more solid and very stable to earthquake vibrations so as not to cause amplification.

Damage caused by earthquakes to the structure of building components occurs when the earthquake force exceeds the limit of the strain of a building causing a change in the basic position of the building, and it causes the collapse of a building if the stability of the structure is low. If reviewed based on areas that have high seismic vulnerability, it shows that when there is a strong ground vibration, there is a high probability of damage in the area. The value of the seismic vulnerability index affects the danger of earthquakes that occur. If the seismic vulnerability index is low or small, then the danger of earthquakes is also small or vice versa. The seismic vulnerability index is caused by the natural frequency and amplification of the HVSR. If the natural frequency value is large then the seismic vulnerability index is also large or vice versa that affects the area prone to earthquakes and the impact they provide.

IV. CONCLUSION

Based on mapping the level of vulnerability of earthquakes that occur in indonesia, South Sumatra, North Sumatra and West Sumatra areas including vulnerable areas seen from the highest vulnerability values with earthquake vulnerability of 77.09-85.57. While the lowest earthquake vulnerability area occurred on the islands of Sulawesi and Kalimantan with an earthquake vulnerability value of 0.054-9.010. From the results of processing, the level of earthquake vulnerability is influenced by amplification values and natural frequencies. The degree of vulnerability of earthquakes also affects the seismic hazards that occur. The greater the vulnerability of the earthquake, the greater the danger posed and the area is prone to earthquakes.

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