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SEISMICITY ANALYSIS BASED ON THE INTEGRATION OF EARTHQUAKE VULNERABILITY INDEX (KG) THROUGH POLYGON DISTRIBUTION IN BENGKULU CITY AREA

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Abstract

Bengkulu Province is an area with a very high level of earthquake susceptibility, this is due to the confluence of large tectonic plates, covering Indo-Australia, Eurasia, and the Pacific. This is the fundamental reason for the need for micro-zoning mapping as a basis for spatial planning evaluation and sustainable development, especially in the city of Bengkulu which is the heart of the province where it is the center of regional social and economic activities. This concept is by applying the Horizontal to Vertical Spectral Ratio (HVSR) method and inversion of the microtremor curve as a result of obtaining shear wave velocity data at a depth of 30 meters as many as 30 measurement points covering the distributed Bengkulu City that forms polygons. The HVSR parameters reviewed include dominant frequency (f_0), amplification (A_0), and seismic vulnerability index (Kg) show that Bengkulu City has very heterogeneous sediment characteristics from soft to hard where the value of the earthquake susceptibility index is in the range of 0.25-8 and the shear wave speed range at a depth of 30 meters, namely in the range of 240 m/s - 520 m/s. This study concludes that Bengkulu City has a very complex level of seismic vulnerability with specific conditions that divide the area into 3 large zones which include the risk zone, conditional zone, and safe zone. The division of the zone is an illustration of the response behavior to the area in Bengkulu City, both actions of managing the area wisely through improving the design of earthquake-resistant building structures so that the basis of regional planning recommendations for the direction of spatial planning in Bengkulu Province can minimize disaster risk. Keywords: HVSR, Microtremor, Vs30, Earthquake vulnerability index, Microzoning, spatial planning.

Keywords: Vehicle Load, Transceiver nRF24L01, Fiber Optic, Sensor.

INTRODUCTION

Geographically, Bengkulu City is located in a zone adjacent to the interaction of the Indo-Australian and Eurasian Plates, which is also accompanied by activity in the Sumatran Fault. The combination of these two earthquake sources causes the region to experience higher levels of seismicity compared to other areas, both provincially and regionally, including areas on the island of Sumatra. Referring to the national earthquake hazard map, which also contributes to indications of relatively high ground acceleration values in this region, Bengkulu is prone to receiving strong shocks from various earthquake mechanisms. Subsurface seismic response is based not only on the quantity of earthquake sources but also on the properties of subsurface materials, known as local footprint effects. This background emphasizes the need for detailed mapping of soil characteristics to understand how an area responds to seismic waves. At the local scale, this understanding is called microzoning, and the implementation of this research covers the research area that forms the regional scale area in Bengkulu City. Reaching for the previous statement, Litman et al. (2021) emphasized that physical development in Bengkulu City closely considers the surrounding seismic conditions, which emphasize a significant quantity of shocks. It can be said that urban spatial planning and building permits are highly dependent on local seismic data, one of which is the microzonation results covering the Bengkulu City area categorized based on vulnerability levels so that urban spatial planning can be used as a pinpoint for areas requiring development restrictions that are publicly recommended. Local hazard analysis also shows differences between zones. PSHA was used to calculate the PGA of bedrock in each sub-district of Bengkulu City and found maximum values of ~0.7-1.2 g with a probability of reaching 10% and 2% in the 50-year decade. Spectral acceleration values were relatively high, especially in coastal areas adjacent to subduction sources, with short periods (0.2-0.3 seconds) showing higher values than in the city center. This spatial pattern confirms that coastal areas require different mitigation approaches, such as strengthening coastal infrastructure and securing port facilities.

These findings, supported by historical seismic data and hazard analysis results, indicate that microzoning mapping in Bengkulu City is highly necessary, especially in zones with high vibration amplification and liquefaction potential.

This research study uses a microtremor analysis method based on spectral comparison between horizontal and vertical components. This approach utilizes natural ground surface vibrations to obtain resonance at the study site. The HVSR curve obtains the dominant frequency (f_0) and amplification (A_0), which are correlated with the thickness of bedrock sediments, and then correlated with the shear wave velocity parameter (Vs30) as a standardization in classifying earthquake site classes. One reference is the study by Sugianto & Refrizon (2021) who mapped the Vs structure on the Tengah-Kepahiang route with the hinterland. The use of this method is very dominant in geophysical research because it provides a comprehensive picture of how the soil responds to seismic waves. The output of the HVSR method application in this study, with the acquisition of Vs30 mapping and the earthquake vulnerability index, is integrated to obtain a classification of the soil site zone as a description of the sensitivity of the study area to shocks, or can be said to be a comprehensive interpretation of low to high seismic vulnerability zones that can be directly used as a guideline for development evaluation in Bengkulu City.

METHOD

To achieve the objectives of this research, a systematic, measurable, and appropriate methodological approach is required, in accordance with the characteristics of the raw data obtained at the research location. Based on the classification of this type of research, it is a quantitative research with a geophysical observation approach that includes the range of natural frequency parameters (fo), amplification (A_0), and shear wave velocity (Vs30) which produces objective and measurable visualization of seismic vulnerability in the research area. By using the concept of single station microtremor research using a tool called a three-component seismometer, where this method is a non-invasive, efficient, inexpensive method, and is able to visualize the dynamic response of shallow subsurface layers without requiring rock waves that tend to be destructive. The data obtained were then analyzed using geopsy software and then analyzed using Horizontal-to-Vertical Spectral Ratio (HVSR) developed by Nakamura and became an international standard in identifying local resonance, sediment thickness, and amplification zones which include natural frequency parameters (f_0), amplification (A_0), earthquake vulnerability index (Kg), and average shear wave velocity at a depth of 30 meters obtained at the final stage of research data processing by validating the HVSR curve where the previous processing curve is a curve with a clear, stable resonance peak, with consistency between windows and if not then a separation or iteration of data processing will be carried out on the geopsy software itself even recording iterations at the research location which are then inverted in the software's default program to produce a Vs30 profile. The final results of this research were then integrated between the earthquake vulnerability index (Kg) parameters and the shear wave velocity (Vs30) which is the basis for classification followed up with visualization which is the result of research using the deterministic interpolation concept which covers the research area in Bengkulu City.

A. Earthquake Vulnerability Index (Kg)

The curve graph that has been obtained from the data processing process in the software that has been explained previously is filtered by maximizing the Konno-ohmachi smoothing action with a bandwidth of 40. This will then attach the basic parameters of natural frequency (f_0), amplification (A_0), to produce the earthquake vulnerability index parameter (Kg) which is obtained from the following equation formulation:

$$K_g = (A_0^2)/f_0 \qquad (1)$$

To obtain the seismic vulnerability index value, the A_0 value is needed, which is the amplification factor or a symbol of the seismic wave magnification factor and fo which is a natural parameter which is a symbol of the resonance frequency of the soil layer.

B. HVSR Curve Inversion on Vs30 Profile

At this stage, it is a crucial process in obtaining a shear wave velocity model (Vs30) which is the classification of seismic sites in the research area using Dinver software which is part of the Geopsy package, which is an application of the Neighborhood Algorithm (NA). With a working system that produces a number of initial models and then refines the model iteratively based on the suitability between the HVSR curves of the research results which are very effective in modeling complex sedimentary subsurface structures, especially in coastal and alluvial areas such as Bengkulu City. The results of the inversion include the Vs profile of each layer to a depth of 30 meters, this is one of the standard parameters in earthquake hazard classification. The results of the inversion include the Vs profile of each layer to a depth of more than 30 meters, as well as the Vs30 value which is a standard parameter in earthquake hazard classification. Mathematically, the Vs30 value is calculated using equation (2)

$$Vs_{30} = 30/\left(\sum(^{i} = 1)^{n}(h_i/Vs_i)(2)\right.$$

Where Vs_30 shows that the average harmonic shear wave velocity at a depth of 30 meters of the top soil layer is formulated along with, h_i = thickness of the i-th layer (meters), is the thickness of the i-th layer (meters), Vs_i = shear wave velocity in the i-th layer (m / s), and the number 30 is the distance of the layer to a depth of 30 meters where the international standard is meters, where the low reflects softer soil conditions and is susceptible to earthquake shock amplification. Site classification based on Vs_30 refers to the NEHRP standard or national classification, with SC / SD class for soft soil (Vs_30 <200 m / s) and SB class for stiff sediment (Vs_30 = 300-500 m / s). In visualizing the HVSR parameters (f $_0$, A $_0$, and Kg) and the inversion of the HVSR curve to obtain the Vs30 value as the basis for site classification, it is continued by mapping using Qgis software, which is an open-source platform that is widely used in geospatial studies and geophysical mapping in Indonesia.

The interpolation method used in this study is Inverse Distance Weighting (IDW). The selection of the IDW method is based on the consideration that the measurement points in this study are moderately distributed and relatively uniformly spaced for soft soil (Vs30 < 200 m/s) and class SB for stiff sediment (Vs30 = 300-500 m/s). In visualizing the HVSR parameters (f_0, A_0, and Kg) and inverting the HVSR curve to obtain the Vs30 value as the basis for site classification, mapping is continued using Qgis software, which is an open-source platform widely used in geospatial studies and geophysical mapping in Indonesia. The interpolation method used in this study is Inverse Distance Weighting (IDW). The selection of the IDW method is based on the consideration that the measurement points in this study are moderately distributed and relatively uniformly spaced at the city and district scales. IDW is a deterministic interpolation technique commonly used in shallow geophysical mapping because it produces stable results, does not require specific statistical distribution assumptions, and is easy to apply to medium- sized datasets . Mathematically, IDW is calculated using the formula:

$$Z(x) = \left(\sum(^{i} = 1\right)^{n} w_i \cdot Z_i / \left(\sum(^{i} = 1\right)^{n} w_i$$

With the weight calculated as:

$$w_i = 1/d_i^p$$

With, Z(x) the interpolation value at location x,, = the parameter value at the i-th measurement point, = is the distance between location x and the i-th point = the power parameter which is usually 2 to give greater weight to closer points. After the interpolation is carried out, the results are presented in several types of thematic maps. Frequency maps (f_0) are used to identify areas with thick sediments or shallow rocks. The lower the f_0 value , the thicker the sediment layer and the higher the potential for seismic wave amplification. Amplification maps (A_0) show the level of earthquake shock amplification that can occur on the ground surface.

RESULTS AND DISCUSSION

The results of microtremor analysis at 30 measurement points spread across Bengkulu City show quite significant variations in seismic characteristics that reflect heterogeneity between locations reflected through a combination of natural frequency parameters (f_0), amplification (A_0), and earthquake susceptibility index (Kg) obtained from the HVSR curve which is an initial picture of the local soil response to the received resonance waves consistently different with complex increases and decreases. The research area shows variations in Kg values ranging from 0.25 to 8 which are attached to Figure 3. The range of values describes a relatively low level of seismic vulnerability indicating that conditions. Conversely, higher values indicate a soft bedrock layer or can be said to have minimal compactness so that the potential for seismic wave amplification is much greater when the wave propagates in this layer, for example during an earthquake. The shear wave propagation value at a depth of 30 meters can be seen in Figure 3, which is the result of inversion based on the detailed site classification basis, also shows a range of values of 240 m/s -520 m/s, which then integrates the earthquake vulnerability index parameters along with the shear wave velocity as far as 30 meters, indicating that the seismic vulnerability level of the research area is divided into 3 large classification zones as an outline of the interpretation of Bengkulu City, which has characteristics dominated by soft to hard layers.

A. Earthquake Vulnerability Index Map (Kg)

a) Earthquake Vulnerability Index Map (Kg)

Mapping was conducted to determine the level of earthquake vulnerability that occurred in the research location based on field surveys and data processing in geopsy software using both the HVSR method and inversion. The visualization of this study shows from dark blue representing the lowest range <0.25 to dark red representing the highest range, namely 8, which is visible to the west and northeast of the research area.

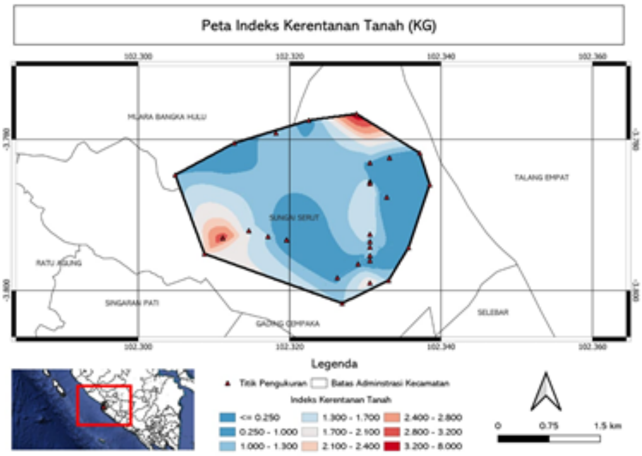

Figure 3 (a) Earthquake Vulnerability Index

b) Vs30 Distribution Map

It has been explained previously that the characteristics of the subsurface structure of the research area can be interpolated through the shear wave velocity parameter at a maximum depth of 30 meters (Vs30). It can be seen that the range of the smallest recorded value is <240 m/s to the largest at <520 m/s.

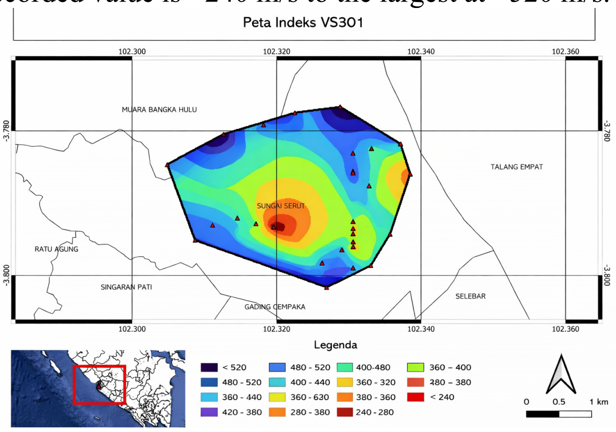

Figure 3 (b) Distribution map of Vs30

c) Research Table

A low seismic vulnerability index value indicates that an area has a relatively high level of seismic wave amplification, thus its vulnerability to earthquake shocks tends to be lower. Conversely, a higher vulnerability index value indicates that the soil layer has the potential for greater seismic wave amplification. Meanwhile, the shear wave velocity (Vs) value ranges from 240 m/s to 520 m/s, indicating that the soil conditions in the previous study area were categorized as medium to hard soil according to the shear wave velocity classification, as shown in the table below.

Table 1 Research Zone Classification

Research Zone Classification	Earthquake Vulnerability Index Value	Shear wave value at a depth of 30 meters
Retriski Zone	2.4-8	240m/s-360m/s
Conditional Zone	1.3-2.4	360 m/s- 440 m/s
Safe Zone	0.25-1.3	440 m/s-520 m/s

CONCLUSION

This study divides 3 areas of Bengkulu City into areas based on the integration of the two parameters which include the earthquake vulnerability index parameter (Kg) & Shear wave velocity at a depth of 30 meters (Vs30) namely the retrieval zone indicated by the earthquake vulnerability index parameter in the range of 240 m/s -360 m/s which interprets the subsurface structure with maximum thickness with a dominance of coastal sediment content and alluvial deposits. Furthermore, the earthquake vulnerability index parameter value (Kg) is confirmed in the range of 1.3-2.4 with shear wave velocity in the range of 360 m/s-440 m/s which interprets the subsurface structure with the dominance of coastal sediment content and alluvial deposits that are close to the classification of SD sites which causes amplification in this area is not as significant as the retriski area so that the development of the application of geotechnical standards & earthquake-resistant land structure design and finally called a safe zone with confirmation of the earthquake vulnerability index parameter (Kg) which is 0.25-1.3 with shear wave velocity in the highest range of 440 m/s-520 m/s which interprets the subsurface structure in the SC classification where the condition of the bedrock is stiffer and responsive to good seismic vibrations. Geologically, this area is dominated by old sedimentary rocks and altered volcanic materials with a relatively shallow bedrock depth, so that the potential for amplification of earthquake shocks is lower. With these characteristics, safe zones are suitable for long-term development and can function as the best expansion areas in disaster mitigation-based spatial planning strategies.

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