Earthquake Hazard Analysis Use Vs30 Data In Palu

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Abstract. Palu City is an area passed by Palu-Koro fault and some small faults around it, causing the Palu of city often hit by earthquake. Therefore, this study is intended to mapped the earthquake hazard zones. Determination of this zone is one of aspect that can be used to reducing risk of earthquake disaster. This research was conducted by integrating Vs30 data from USGS with Vs30 from mikrotremor data. Vs30 data from microtremor used to correction Vs30 from USGS. This Results are then used to determine PeakGround Acceleration (PGA) can be used to calculate the impact of earthquake disaster. Results of the study shows that Palu City is in high danger class. Eight sub-districts in Palu City, there are 7 sub-districts that have high danger level, namely Palu Barat, PaluTimur, Palu Selatan, Palu Utara, Tatanga, Mantikulore and Tawaeli.

1. Background
One of the cities that often hit by the earthquake is Palu City. This is caused by an active fault that crosses this region. The fault is known as the Palu-Koro Fault (figure 1). Based on earthquake history since 1927 in this region, shows that there have been 9 (nine) times destructive earthquake events in Palu valley. The eighth earthquake caused the death toll not less than 250 people and property damage [1]. A study on the level of earthquake hazard that is interpreted in the form of zoning area of earthquake disaster hazard has been done. Determination of seismic hazard level is done by analyzing the response of geological characteristics through Determination of Vs30 and peak ground acceleration [2].
Figure 1. Points of earthquakes destructive and tectonic of Sulawesi Island [3].

Vs30 is one of the most commonly used parameters in predicting shear wave velocity in sedimentary layers at a depth of 30 meters[4]. This parameter is very significant in identifying the characteristics of rocks for earthquake resistant building design[5, 6]. One classification is often used in decrypt geological conditions that experience earthquake vibration effects, namely Site Class (SC) introduced National Earthquake Hazard Reduction Program (NEHRP) which is defined by the Building Seismic Safety Council [7, 8].

The natural period is estimated to be four times the speed of shear wave propagation in each soil layer, assuming that each part is represented by a soil layer with a constant shear wave velocity[8]. There are four classes in this classification, namely SC I, II, III and IV, which means, I, instead of rock, II hard soil, III medium soil and IV soft soil. The class determination based on shear wave (Vs30) can be seen in table 1:

| Site Classes       | Site Natural Period (s) | Vs30   | NEHRP class |
|--------------------|-------------------------|--------|-------------|
| SC I: (Rock/Stiff Soil) | T_G < 0.2s             | V_s30 > 600 m/s | A + B       |
| SC II: (Hard Soil)   | 0.2s ≤ T_G < 0.4s      | 300 < V_s30 ≤ 600 m/s | C           |
| SC III: (Medium Soil) | 0.4s ≤ T_G < 0.6s      | 200 < V_s30 ≤ 300 m/s | D           |
| SC IV: (Soft soil)   | T_G ≥ 0.6s             | V_s30 ≤ 200 m/s    | E           |
One of methods that commonly used in determining shear wave velocity is the HVSR, this method uses microtremor observations that can display subsurface profile [9, 10]. The results obtained are the horizontal-to-vertical (HVSR) spectrum ratio that can estimate the shear wave velocity Vs. This value is then used to predict Vs30.

2. Geological Conditions
Palu is one of the cities on the island of Sulawesi which has various geological conditions, this is caused the island of Sulawesi is a collision of three plates, the Indian-Australian Plate, the Pacific Ocean Plate and the Eurasia Plate. As a result of the collision Sulawesi has many active faults, one of which is the active Palu-Koro fault located in Palu City[11]. In addition to its unique geological structure, Palu City is composed of alluvial deposits in the Valley, while in the northwest part it consists of granite fragments. In the western to north part it consists of granite and granodiorite rocks, to the south composed of schistophyllitic rocks and to the east consisting of mollasses[12]. Distribution of geological rocks of Palu City can be seen in figure 2.

Figure 2. Geological conditions of Palu city.

3. Method
The research begins by analyzing the global Vs30 data. Further correction is done using microtremor field measurement results. This is done to improve unfamiliar data on global data. The result of this improvement yields a corrected Vs30 value and can be considered as the wave propagation velocity at the study site. Vs30 measurements in the field using a portable microtremor set of tools consisting of Portable Digital Seismograph 3 component (2 horizontal components: EW-NS and 1 vertical components) short-period Taurus (Canada) brand with type of Feedback Short Period Seismometer type DS-4A sensor and equipped with digitizer (Data logger). Measurement of microtremor done at 6 point of Palu City. The flow of this study is more fully shown in figure 3.
Microtremor data processing is done by designing the concept of field acquisition, so that obtained a detailed description related to the acquisition will be done. The next stage is the retrieval of microtremor data at the point of measurement that has been designed previously. The next microtremor data is processed to obtain natural frequency and amplification values. Data processing is used to analyze the data HVSR (Horizontal to Vertical Spectral Ratio). Furthermore the HVSR curve of the HVSR analysis is converted to obtain a VS value which is then used to estimate the value of Vs30 [13].

Knowledge of the elastic properties of material near the surface and its effect on seismic wave enlargement is essential in the design of earthquake resistant buildings for disaster risk reduction. The most important factor that causes the amplification of the earthquake movement is the increase in amplitude in soft sediments [14]. The VS30 value can be determined from the formulation:

\[ V_{s30} = \frac{30}{\sum_{i=1}^{N} \left( \frac{d_i}{V_i} \right) } \]  

(1)

With, \( d_i \) is thickness of the sediment layer (m), \( V_i \) is the shear wave velocity (m / s) and \( N \) is the number of layers above 30 m depth. Vs30 value is used to determine rock classification based on vibration strength of earthquake due to local effect and used for purposes in earthquake resistant building design. Basically the Vs30 value alone can not represent the site effect because the shear wave velocity is only at a depth of 30 meters from the surface, where the bedrock depth and the impedance ratio between the soil and bedrock layers all contribute significantly to the site response. However, only layers of rock to a depth of 30 m only can determine the magnification of earthquake waves. This wave magnification effect on earthquake hazard assessment as recommendation material for earthquake resistant building construction.

To produce an accurate picture of the distribution of Vs30 values, sampling should be done at each geological condition. Since some regions can not be measured because of unreachable location factors, to obtain the value, it is done by using Vs30 data from USGS then corrected with VS30 data on field measurements. Correction value of \( V_{s30} \) is done with the following formula:

\[ V_{s30 \text{ USGS} } - V_{s30 \text{ Ukur} } = \Delta V \]  

(2)
\[ \Delta V = \frac{v_i}{n} \]  
(3)

\[ V_{s30} \text{ terkoreksi} = V_{s30} \text{ USGS} - \Delta V \]  
(4)

where the value \( \Delta V \) is difference of shear wave velocity (m/s), \( \overline{V} \) is average shear wave velocity (m/s) with \( v_i \) is the shear wave velocity at point \( i \) (m/s) and \( n \) is point of measurement at \( i \). and then the \( V_{s30} \) value is then converted to get the PGA value. The value of PGA is used to determine the area of earthquake hazard according to Perka BNPB No. 3 Year 2012. The PGA formulation according to Takahashi in 2000 [15], as follows:

\[ \log_{10}[y] = aM - bx - \log_{10}(x + c10^{4M}) + e(h - h_c)\delta_h + S_k \]  
(5)

\( y \) is the value PGA (cm/s²), \( a = 0.446, b = 0.00350, c = 0.012, d = 0.446, e = 0.00665, S = 0.941, S_r = 0.751, S_m = 1.003, S_s = 0.995

4. Results and Discussion

The analysis \( V_{s30} \) - USGS shows that the value of \( V_{s30} \) distribution in Palu City is in the range of 268-760 m/s². After corrected with \( V_{s30} \) microtremor data shows a lower \( V_{s30} \) value, with a range of values from 137 - 456 m/s². Referring from the NEHRP site class, indicates that Palu City is located on SC II (hard ground) SC III (moderate ground) and SC IV (Soil Soil). Earthquakes that occur tend to have an enlarged amplitude in soft soil. While on hard soil amplitude decreases. This incident greatly affects the condition of the building above the ground, where the building located on soft soil will experience a greater degree of damage than the building located on hard soil[12].

4.1. Integration \( V_{s30} \) Microtremor and \( V_{s30} \) USGS

Palu City has a topographic shape of basin or valley so that most of the land in Palu Valley area is alluvial soil. This is in line with the \( V_{s30} \) correction results indicating that almost all sub-districts in Palu City are located in soft soil, especially in the Palu Valley area. The area of Site Class \( V_{s30} \) in each sub-district in Palu City can be seen in table 2.

| No | Sub district | SCV \( V_{s30} \) | Area (Ha) | No | Sub district | SCVs30 | Area(Ha) |
|----|--------------|----------------|---------|----|--------------|--------|---------|
| 1  | Mantikulore  | 2 12265        | 5       | 2  | Palu Utara   | 0      | 0       |
|    |              | 3 4583         |         | 3  | Palu Barat   | 918    |         |
|    |              | 4 2393         |         | 4  | Tatanga      | 2077   | 250     |
| 2  | Palu Barat   | 56             | 6       | 2  | Taweli       | 358    | 918     |
|    |              | 3 73           |         | 3  | Taweli       | 918    |         |
|    |              | 4 610          |         | 4  | 1969         | 2119   | 2786    |
| 3  | Palu Selatan | 0              | 7       | 2  | Ulujadi      | 1163   | 5884    |
|    |              | 3 0            |         | 3  | Ulujadi      | 429    |         |
|    |              | 4 601          |         | 4  |              | 55     |         |
Figure 4. Percentage Chart \( \text{Site Class} V_{s30} \) in Palu City each sub district

Figure 4 shows a diagram illustrating the site class of each sub-district in Palu City. This diagram shows the percentage of site class of each sub-district in Palu City. District of South Palu and District of East Palu 100% of its territory is in SC IV. Furthermore, sub-districts with a significant percentage of SC IV are Palu Barat District 82% followed by Palu Utara sub-district 69%, then Tatanga District 60% and Kecamatan Tawaeli 46%. Kecamatan kecamatan which dominant region SC IV is sub-district with rock dominated by soft soil. Ulujadi sub district has 92% area located on site class II, while Mantikulore District has SC big enough that is 64%. This picture shows that these two sub-districts are dominated by hard rocks such as granite and granodiorite rocks that belong to intrusive rocks. This condition resulted in shrinking earthquakes tend to shrink in the District Ulujadi and Matikulore Subdistrict. Distribution of \( V_{s30} \) showing site class in each region in Palu City can be seen in figure 5:
Figure 5. Vs30 from USGS (a) Vs30 Correction of microtremor (b).

Figure 5 shows the distribution of Vs30 both uncorrected (a), as well as those already in Correction (b). The results show that most of Palu City is hard land. This is inversely proportional to the results of research conducted by Nurahmi, where research conducted by using microtremor shows that in the lowland areas into the category of soft soil [16]. Since the Vs30 value of the USGS is considered not to reflect the real condition of the field, a Vs30 value correction is made using microtremor data taken at some point which is considered to represent the geological condition of the local area.

This spatial data illustrates that the valley area, in Palu City has a low shear wave velocity, ie the average value is < 200 m/s. This data illustrates that the valley area, in Palu City is a location with soft soil class. While in the east and west side shows that the more toward the hill speed of shear wave propagation has increased 200-600 m / s, which correlates with the level of hardness of the rock toward the hills.

Associated with the carrying capacity of rocks against the building in case of earthquake, then the lowland area or the valley area is the area with the most low its carrying capacity increases the carrying capacity to the hills.

Taking into account this condition, the area experiencing retrofitting in case of an earthquake is a lowland or valley area, while hilly areas in the west, as well as in the eastern part, will not experience significant reinforcement. This can be seen from the low shear wave velocity in the valley area whereas in the hilly region the wave velocity is quite high.

Unfortunately, the inhabitants of Palu City mostly live in the lowlands or Palu valleys, where this location is an area with a very low velocity of Vs30 shear wave propagation, which means the rocks in this location are soft rocks. The condition of soft rock locations like this carries the consequences of propagation of the waves will undergo high amplification so that the buildings on it are more shaken than the buildings located in hard rock [14]. This figure shows that the level of risk in the Valley or in the lowlands in Palu City is higher than in the hills from the threat of earthquake disaster.
4.2. Earthquake Hazard analysis

Vs30 data processing results are then processed using the Takahashi equation to obtain the Peak Ground Acceleration (PGA) value. The analysis was performed on earthquake occurrence on January 24, 2005 with magnitude 6.3 Mw and obtained 3 classes showing the increase of spectral peak value from SC II to SC IV (figure 6). The highest PGA value obtained is 73.8 cm/sec² in SC IV indicating that this region is categorized as dangerous if it refers to BNPB PERKA No.2, (2012)[17]. The distribution of PGA values in Palu City shows results that are not much different from the distribution of Vs30. The highest PGA values are in the Valley area, and decrease toward the hill, either towards the West, or to the east. The higher the PGA value, the higher the dangers of earthquakes and can result in large losses for the buildings in the area.

![Graphic PGA](a) ![Graphic PGA](b) ![Graphic PGA](c)

**Figure 6.** Graphic PGA by magnitude 6.3 Mw at SC II-hard soil (a), for SC III-medium soil (b), and SC IV-soft soil (c).

The picture above shows the relationship of pseudo speed with PGA value. The points depicted on the graph show the maximum value of PGA. The results obtained in three geological conditions show the value of pseudo speed on hard soil below 10 cm / s, whereas on medium soil 10 cm / s and in soft soil are at the apparent speed above 10 cm / s. Based on the hazard class published by BNPB by referring to the guideline published by National Geological Agency[17]. Palu City is divided into two classes of earthquake hazard indices: moderate hazard class with PGA 25-70 cm/sec² and high hazard class with PGA value greater than 70 cm/sec². In line with the division of the class, then the eight districts in Palu City can be divided into, seven districts are in areas with high hazard and one districts level of moderate hazard. The sub-districts located in the high hazard are Palu Barat, Palu Timur, Palu...
Selatan, Palu Utara, Tatanga, Mantikulore and Taweli sub-districts, while sub-districts entering the dangers are districts Ulujadi (figure 7b).

Figure 7. Distribution of PGA value in di Kota Palu (a) Map of Earthquake hazard in Kota Palu (b)

5. Conclusion
The use of the USGS Vs30 can be used properly when corrected with Vs30 microtremor measurements in the field. The results obtained are lower, with a range of values from 137 - 456 m / s² corresponding to actual field conditions, where Palu City is located on SC II (hard soil) SC III (medium soil) and SC IV (Soil Soil). Palu City has a topographic shape of basin or valley so that most of the land in Palu Valley area is alluvial soil. This is in line with the Vs30 results indicating that almost all sub-districts in Palu City are located in soft soil, especially in the Palu Valley area.

Palu city is one of the areas that have high threat of earthquake. From eight sub-districts in Palu City, there are 7 sub-districts that have high danger level, namely Palu Barat, Palu Timur, Palu Selatan, Palu Utara, Tatanga, Mantikulore and Taweli sub-districts while Ulujadi District is in moderate danger class.

Peack Ground Acceleration (PGA) or maximum ground motion acceleration is one of the parameters that become the reference in earthquake resistant building planning. Analysis of these parameters is important especially in areas where the threat of earthquakes is quite high. Particularly for Palu City which passes by active fault of Palu Koro, where most of its area is categorized as high hazard, the building should be built with earthquake resistant construction.

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