Identification ground layer structure of land subsidence sensitive area in Semarang city with horizontal to vertical spectral ratio method

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Abstract. Semarang City is located in the northern coastal plain of Java which is geologically composed of alluvial deposits and the land subsidence sensitive area. The drilling data and various research indicates that not all layers of lithology are soft layers supporting the land subsidence. However, vertical distribution of the soft layer is still unclear. One the other side, an analysis regarding this kind of research can be done based on microtremor by using Horizontal to Vertical Spectral Ratio (HVSR). The goals of this research are to determine the layer which contribute to land subsidence based on Vs and Vp/Vs profile in Semarang City. Based Vs and Vp/Vs profile can be obtained some conclusion that the lithology layer with Vs less than 1000 meter/second and Vp/Vs less than 1.7 is the dominant lithology in high rate of land subsidence. Compare to drilling data, this lithology is composed by clay, silt and sandy clay that has the low bearing capacity.

1. Introduction
Semarang is the capital of Central Java located 6°58’S and 110°25’E on the northern coast of Java. Land subsidence in Semarang is a severe hazard threatening people and urban infrastructure. As the effect of the land subsidence, some areas have been in below the sea level so it will be flooded with coastal flooding (rob) [1]. It results in disturbing the activity of the people and several infrastructures facing a fast defect. The handling of this situation has been managed to be conducted by arranging the function of the area by paying attention to all behaviors of land subsidence, but it is not completely succeed yet.

The evolution of land subsidence has been monitored and indicated that it was varied between one place and another, and the biggest one reached 16 cm/year [1]. The measurement of land subsidence in Semarang City based on Levelling, Interferometric Synthetic Aperture Radar (InSAR) methods, Microgravity and survey using Global Positioning System (GPS) method, showed that the rate of land subsidence in Semarang City is more than 19 cm/year in period of 1999 to 2011 [2]. The rate of land subsidence was supposed to be caused by compaction in marine and alluvial sediments containing clay. Compaction is a natural process but can also be caused by uncontrolled usage and over-exploitation of ground water, and the building construction in some points [3],[4]. Tectonic activity is not related to the land subsidence so that the bedrock does not decrease [5]. The effect of land subsidence was coastal flooding (it is called rob by the locals) that its coverage tends to enlarge by times. It was predicted to cause the flooded area increases from 2,162.5 Ha (5.6%) to 3,896.3 Ha (10.1%) in the next 10 years [6]. The weak or soft lithology layer can be determine by Vs and Vp/Vs profile analysis using HVSR (Horizontal to Vertical Spectral Ratio) method [7].

This research aimed to map the lithology soft layer which resulting in the land subsidence by identifying thickness of the soft lithology layer and mapping the spread spatially according to the data of Vs and VP/Vs profile.
2. Research Method

The method of Horizontal to Vertical Spectral Ratio (HVSR) is used to know the value of natural frequency and amplification value so that it can be calculated soil susceptibility value [8]. The HVSR method is a method of comparing the spectrum of the horizontal component to the vertical component of the microtremor wave. Mikrotremor consists of a variety of Rayleigh wave base, it is assumed that the peak period of the H/V ratio of microtremor provides the basis of the wave period S. The H/V ratio in microtremor is the ratio of the two components that theoretically yield a value. The dominant period of a site can be approximated from a peak period of H/V microtremor ratio. [9] tried to separate the geological effects by normalizing the spectrum of horizontal components with vertical components at the same measuring point. The observation results show that the recording at the station located on hard rock, the maximum value of the horizontal component spectrum ratio to the vertical approaches the value of one. At the station located in soft rocks, the ratio of the maximum value to magnification (amplification), which is greater than 1. Based on these conditions, Nakamura formulated a microtremor HVSR transfer function. The effect of wave gain on horizontal component can be expressed by Eq. (1), that is:

\[ SE(w) = H_s(w) H_B(w) \]  

with the notation Hs (w) is the horizontal component's microtremor spectrum on the surface and HB (w) is the horizontal component's microtremor spectrum in the bedrock. Reinforcement of waves in vertical components can be expressed as the ratio of the vertical component spectrum on the surface and in the bedrock given by Eq. (2), ie :

\[ AS(w) = V_s(w) V_B(w) \]  

with the notation Vs (w) is the spectrum of the vertical component microtremor at the surface and VB (w) is the spectrum of the vertical component microtremor in the bedrock. To reduce the effect of the source, the horizontal reinforcement spectrum SE (w) is normalized to the source spectrum AS (w) written as:

\[ SM(w) = SE, \]  
\[ (w) AS(w) = [H_s(w)V_s(W)]/[H_B(w)V_B(w)] \]  

with the SM (w) notation is the transfer function for the soil layer. If HB(w) VB(w) = 1, then the soil transfer function will be the same as the value of the comparison of the microtremor spectrum value on the horizontal component surface with the vertical component written by :

\[ SM(w) = H_s(w)V_s(W) \]
Figure 1. Microtremor measurement map. Data source: Base map of Indonesia 1:25,000; ASTER GDEM V2 Image; and Field Survey. Projection system: UTM Zone 49S. Datum: World Geodetic System 1984.

In the field observation there are two horizontal components measured that the northsouth component and the west-east component so that the Eq. (4) becomes:

$$SM(w) = \sqrt{(HSN(w)^2 + HWE(w)^2)/2} V s.$$  (5)
With the $HSN(w)$ notation is the microtremor spectrum of the north-south horizontal component and $HWE(w)$ is the spectrum of the east-west microtremor component.

For the making of the Vs and Vp/Vs profile, the HVSR curve elipticity is then processed to obtain the Vs and Vp value to depth profile. Furthermore, using surfer program the Vs data from each measurement point then contoured Vs to depth for a given path. Inversion is carried out by using algorithm proposed by [10]. The locations of the HVSR measurement points are distribute on Semarang coastal plain as given in Figure 1.

3. Result and Discussion

Based on Semarang and Magelang Geological Map [11], the Semarang coastal plain is composed of alluvial deposits consisting of clay, silt, sand and granule. The layer of clay and silt will prone to have smaller Vs than the sand, especially if it contains water [12]. Vs and Vp/Vs profile along Tanjung Emas (measurement point 10) to the south was shown in Figure 2. Tanjung Emas has soft lithology about 41 – 82 m soft layer which results in the largest land subsidence in this area [12]. Based on the figure, can be identified that this area has Vs less than 1000 meter/second and Vp/Vs less than 1.7. This is a little different from the previous research which states that lithology with Vs 750 – 1500 meter/second includes hard rock types [13]. This is very possible because the speed of seismic waves is strongly influenced by various rock factors such as elasticity, density, porosity, saturation, pressure, and temperature. The thickness of lithology which Vs less than 1000 meter/second and Vp/Vs less than 1.7 in each measurement was presented in Table 1.

![Figure 2. Vs and VP/Vs profile along Tanjung Emas to the south](image)

| Point No. | East | North | Lithology thickness with Vs < 1000 meter/second (m) | Lithology thickness with Vp/Vs < 1.7 |
|-----------|------|-------|---------------------------------|---------------------------------|
|           |      |       |                                 |                                 |

Table 1. The Depth of soft lithology layer, clay-silt to sand ratio based on the resistivity data and the rate of land subsidence in Semarang City.
The map of land subsidence overlayed by the map of thickness of lithology with Vs less than 1000 meter/second is presented on the Figure 3. Based on the figure, it can be seen that the rate of land subsidence in the location around Tanah Mas, Tanjung Emas Port and Terboyo are higher than another areas (brown and red color). In this area, thickness of lithology with Vs less than 1000 m are thicker than another areas (shaded diagonal line). This pattern indicates that the layer with low Vs are the soft lithology layer that contributes to subsidence. This is in line with previous research that the softer the rock, the Vs will be smaller according to the class of rock sites as stipulated in surface soil classification based on SNI 1726-2012 [13]. Research on several landslide areas shows that the slip surface is at a difference in Vs, which large Vs is hard rock and low Vs above it is soft soil resulting from weathering of bedrock [7].

The location around Tanjung Emas Port and Tanah Mas in North Semarang Sub-district had the higher land subsidence than the other areas at 9.4 - 10.08 cm/year. In that location, it was found that thickness of soft layer was thicker than another areas at 16 – 20 m in Tanah Mas and 12 – 18 m in around Tanjung Mas Port. In the point 23 of microtremor measurement located in Krobokan with the land subsidence of 10.69 cm/year also had the thickness of soft layer about 15 m. The location with a slightly higher rate of land subsidence was also found in around Terboyo, at 8.58 cm/year, and it actually had the thickness soft layer for 14 m. The spread of soft layer can be found in all research areas with the thickness of soft layer varied about 2.0 m to 21.0 m.
Figure 3. Map of the land subsidence and the thickness of lithology with Vs < 1000 meter/second in Semarang City. Data source: Base map of Indonesia 1:25,000; ASTER GDEM V2 Image; and Field Survey. Projection system: UTM Zone 49S. Datum: World Geodetic System 1984.
Figure 4. Map of the land subsidence and thickness of lithology with Vp/Vs < 1.7 in Semarang City. Data source: Base map of Indonesia 1:25,000; ASTER GDEM V2 Image; and Field Survey. Projection system: UTM Zone 49S. Datum: World Geodetic System 1984.
The map of land subsidence overlayed by thickness of lithology with Vp/Vs less than 1.7 is presented on the Figure 4. Based on the figure, it can be seen that the rate of land subsidence in the location around Tanah Mas, Tanjung Emas Port and Terboyo are higher than another areas (brown and red color). In Tanah Mas, thickness of lithology with Vp/Vs < 1.7 was varied large (shaded diagonal line) to small (shaded horizontal line). High land subsidence in Tanjung Emas and Tambak Lorok area, the thickness of lithology with Vp/Vs Less than 1.7 also was mostly small (shaded horizontal line). Refering to Figure 4, even in areas with small land subsidies (yellow color), the thickness of rock layers with Vp <1.7 is actually large. This shows that lithology with Vp / Vs <1.7 does not show a relationship with lithology which contributes to the subsidence of the land.

4. Conclusion
The rate of land subsidence in Semarang City is generally greater in areas with a thick soft layer which is indicated by lithology layer with Vs less than 1000 meter/second. The thick soft layer in Tanah Mas, Tanjung Emas Port and the area around Terboyo were about 12 -20 m, and the rate of land subsidence was about 9.4 - 10.08, higher than other areas. On the other hand, the thickness of lithology with VP/Vs less than 1.7 does not correlate with the land subsidence rate, although the Vp / Vs section shown Vp/Vs less than 1.7 coincides with the location of the high land subsidence rate in Tanjung Emas area.

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