Estimation of landslide prone zones around the Semarang Fault based on by combining the slope stability analysis and HVSR microtremor methods

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Abstract. Morphologically the City of Semarang consists of Downtown and Uptown Semarang. Downtown Semarang which is composed of alluvial deposits and sandstone of the Damar Formation. Uptown Semarang composed of conglomerate of the Damar Formation, claystone of the Kalibiuk Formation, volcanic breccia of the Kaligetas Formation, volcanic breccia of Ungaran Volcano, Andesite igneous rock, and Basalt igneous rocks. Upper Semarang is hilly, some of which have steep slopes, especially on the Semarang Fault Zone. This condition makes the area frequent landslides. To find out the zone that is prone to landslides in the area around the Semarang Fault, slope stability analysis and microtremor measurements were performed. Slope stability analysis was carried out at 7 points using the bishop method based on slope, specific gravity, internal shear angle and soil cohesion. The acquisition by microtremor method was carried out at 9 trajectories that were estimated to pass through the Semarang Fault, then from the Horizontal to Vertical Spectral Ratio (HVSR) curves obtained was carried out an inversion to obtain the shear wave velocity profile on the trajectory. From the two methods of analysis found several locations with potential landslides, namely in the area of Mangun Harjo in the east of the study area, Karangrejo in the middle of the study area and Sadeng in the west of the study area.

1. Introduction
The existence of faults in the city of Semarang has been studied geologically and the results are outlined in the Geological map sheet Semarang [1]. The fault area causes land instability and road damage as found in Sekaran, Gombel, Sigarbencah to damage to the Semarang-Ungaran toll road in Gedawang. At the beginning of 2014, there was a landslide on half of the Sekaran-Sampangan road that was lost due to landslides [2]. Landslides in Gombel also caused several houses to be damaged and one person was killed and several residents of Trangkil housing had to be relocated because their house was heavily damaged by landslides. Many people call this fault the Gombel Fault, but because of its stretch that almost separates upper and lower Semarang, it is more accurately referred to as the Semarang Fault [2]. The Semarang fault stretches from west to east starting from the north of Jatirejo, north of Sekaran, Gombel, curves and turns southeast through Sigar Bencah, Keramas, and Gedawang. Active faults in Semarang are the result of pressure in the north-south direction [1]. Upward faults that actively cut rocks of Late Plistocene and younger age [3].
The area of Semarang and its surroundings is an area with a complex geological structure, mainly dominated by downward faults. Shear faults are also found that traverse northeast - southwest through the Keji area to Mount Serangkong and faults that traverse north and south through Mount Genting to Rowosari [2,4]. The existence of the Semarang Fault has been mapped using gravity and magnetic methods [5,6]. The Semarang Fault in the southeast passes the Pengkol River between Kalikayen and Jabung Hamlet then to the north through Bukit Kencana Jaya, Bulusan Village, Kramas Village, continues north to the Jurang Blimbing and Sendang Kenogo hamlets. From Sendang Kenongo, turn west through Trangkil Hamlet, Ngesrep Village, towards the west a little to the north through Karangrejo Selatan Hamlet and then west until Ngelosari Hamlet, Sadeng Village. Relatively small descending faults were found in Kaligarang, Sroondol and Gadjah Mungkur [5,6].

Research related to soil stability around the Semarang Fault has not been done much, although the impact of faults has long been felt, especially in relation to soil stability. Research on the details of the distribution, position and type of Semarang Fault has not been widely carried out. This study aims to find out the zone that is prone to landslides in the area around the Semarang Fault Zone based on slope stability and HVSR analysis. Slope stability analysis is carried out based on the physical and technical properties data of local soil samples.

2. Geology research area

The geology of the research area is contained in the geological map of Semarang-Magelang sheet shown in Figure 1 [1]. There are two types of rock in the study area, namely sedimentary rock and igneous rock. The sedimentary rock groups from the old to the young can be grouped into several rock formations, namely Kerek Formation (Tmk), Kalibeng Formation (Tmpk), Kaligetas Formation (Qpkg), Damar Formation (Qtd) and alluvium deposits (Qa). Igneous rock or Rock group results of volcanic activity consist of several units of Kaligesic volcano rock (Qpk), Gadjah Mungkur Volcano rock (Qhg) and Andesite Rock (Tma) [1,2].

![Figure 1. Geological map of the research area [1]](image)

3. Methods

The research was conducted with the HVSR micro tremor method to determine the subsurface conditions based on the seismic wave velocity Vs and its density. This research was conducted in the Semarang Fault zone which has been mapped in the previous study [1,5,6]. The procedure for data collection and processing of HVSR data follows standard procedures [7]. In this study, 9 measurement points were selected, namely at locations that have a slope of more than 30°. The 9 locations are Kalikayen (L1),
Bukit Kencana (L2), Mangunharjo (L3), Jangli (L4), Gombel (L5), Karangrejo (L6), Tinjomoyo (L7), Bendan Ngisor (L8), dan Sadeng (L9). The location of HVSR measurement and soil sampling in this study is as shown in Figure 2 and Figure 3.

4. Result and discussion
The data obtained from the HVSR measurement in the field is then processed and then inversion is carried out to determine the Shear wave velocity (Vs) in the study area. Shear wave (S wave) is a seismic body wave that shakes the ground back and forth perpendicular to the direction the wave is moving. HVSR inversion is carried out on the forward principle modeling (FWD). FWD calculates the theoretical transfer function of the layers layered bottom based on Tsai and Housner's approach [8], where the subsurface layer is assumed as a stack of a viscoelastic homogeneous layer on top half space and is depicted in terms of thickness (H), density (Rho), compression wave velocity and shear (Vp, Vs). Inversion is done with the Dinver open software. The S wave velocity data was made contour for each path using Surfer software. Areas with relatively low S wave velocities (less than 400 m / s) are less stable zones [9]. The profiles of the S wave velocity modeling results in a lateral and vertical direction for each path are shown in Figure 4a-i. Areas that are less stable and are estimated to be prone to landslides are marked with a red line. The results of field observations show that these locations are composed of clay stone which is easily destroyed when exposed on the ground. The rock condition is prone to landslides because it is located on a steep topography on the Semarang Fault Line.

The results of slope stability analysis using the Bishop method using Geoslope software obtained a safety factor value (FS) which can be summarized as shown in Figure 5a-g. The limitation of a stable slope is if the FS value is greater than 1.5, and it is unstable if the F value is less than 1.5. If FS is at a value of about 1.5 it is said that the slope is in critical condition [10].
Figure 4. S-wave velocity profile
Based on the results of the slope stability analysis as outlined in Figure 5a-g, it is found that several locations with a safety factor value of less than 1.5 are on trails 3 and 6, while locations with a value of 1.52 are in location 2.

Based on the results of the inversion of S wave velocity and slope stability analysis, it can be interpreted that the locations that are prone to landslides are in three places, namely in Sadeng in the west, Karangrejo in the middle and Mangunharjo in the eastern part of the Semarang Fault as shown by the yellow circle in Figure 6.
5. Conclusion
Based on HVSR data inversion and slope stability analysis, the area around the Semarang Fault has 3 potential landslide locations, namely the area around Sadeng in the west, Karangrejo in the middle and Mangunharjo in the eastern part of the Semarang Fault.

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