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RESEARCH ARTICLE

The Soft Layer Thickness Estimation using Microtremor Measurement to Identify Landside Potential in Watukumpul, Central Java, Indonesia.

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Abstract

Watukumpul is an area that is prone to landslides, so determining the soft layer thickness is very important to identify the landslide potential. The soft layer thickness can be estimated using microtremor signal measurements which analyzed using the Horizontal to Vertical Spectral Ratio (HVSR). In this study,we measured microtremor signal of 33location around Watukumpul, Pemalang, Central Java area to determine soft layer thickness. Micretremor signal was analyzed based on theHVSR method using Geopsy software and follow the standard of the Sesame Europan Project. The results of the HVSR method are the HVSR curve that fulfills the reliable curve standard. HVSR curve shows that the dominant frequency of soft layer ranges from 1.36 – 7.62 Hz and the amplification values ranges from 9.00 – 41.45. The soft layer thickness value in the study area ranges from 17.58 - 103.60 meters. The high landslide potential area are located at W7, W8, W18, W30 and W32 where has thin soft layer and high soil slope.

Keywords: Microtremor, HVSR, Soft layer thickness

1. Introduction

Watukumpul is an area in the south of Pemalang Regency, Central Java. Watukumpul is an area that has the potential to experience landslides because it is a hilly area with a high soil slope (Prabowo et al., 2019), so a sustainable mitigation effort is needed. Landslidewas a process of soil or rock movement due to disturbing slope equilibrium (Suhendra et al., 2018). Several parameters that influence the occurrence of landslides are soil type, volume of unstable soil / soft layer (Firmansyah et al., 2016), landslide slip surface (Darsono et al., 2016), and other parameter. In this study, we conducted preliminary survey to determine location where has a high potential volume of unstable soilbased on the soft layer thickness estimation in Watukumpul.However, the soft layer thickness also reflect the depth of landslide slip surface.

The geotechnical and geophysical method can be used to estimatethe soft layer thickness,i.e borehole drilling, geoelectricitymethod (Islami, 2019), SASW method (Naing et al., 2015), array-microtremor (Koesuma et al., 2017; Liu et al., 2014) and Microtremor measurement (Seht and Wohlenberg, 1999; Supriyadi et al., 2019). In this study, we estimate the soft layer thicknessusing microtremor measurement which analyzed using Horizontal to Vertical Spectral Ratio (HVSR) method. Microtremor measurement was proven beneficial to give a wider picture of subsurface ground investigationdue to non-destructive, reliable, and cost-effectivemethod (Kamarudin et al., 2016). Microtremor measurement also useful to get a subsurface information of the shallow and deep soil layer (Kyaw et al., 2015)

Microtremor is the constant vibrations of the earth with a very small amplitude, and the displacements are inthe order of 10^{-4} to 10^{-2} mm (Okada, 2003). The microtremor signal analysis using the HVSR method was developed by Nakamura in 1989. This method calculated the spectrum ratio of the microtremor signal in a horizontal component to its vertical component. The results of the HVSR method analysisare the HVSR curve, which the curve peak related to the dominant frequency and amplification values that describe the site response characteristic or local site effect (Anggono et al., 2016; Nakamura, 2008). Dominant frequency and amplification can also be used to determine the weak zone of an area that has the potential to experience damage during an earthquake (Sulistiawan et al., 2017) and the response of soft surface surfaces when experiencing an earthquake (Yulianto et al., 2016). Besides that, the dominant frequency value describes the thickness of the surface sediment layer (Zulfakriza et al., 2019). Other research states that the HVSR method is

efficiently used in determining the contact boundary between stable and unstable material in landslides (Méric et al., 2007)

2. The Study Area

The study area is located in the south of Pemalang regency and near the Slamet Mountain. Watukumpul is a downhill area with high soil slope. Fig 1 of the Watukumpul geological map, which shows that the study area consists of Rambatan formation and Halang formation with some diorite intrusion. Halang formation consists of andesitic sandstone, tuffaceous conglomerate, and marl intercalates with sandstone. While Rambatan formation consists of shale, marl, and calcareous sandstone (Djuri et al., 1996).

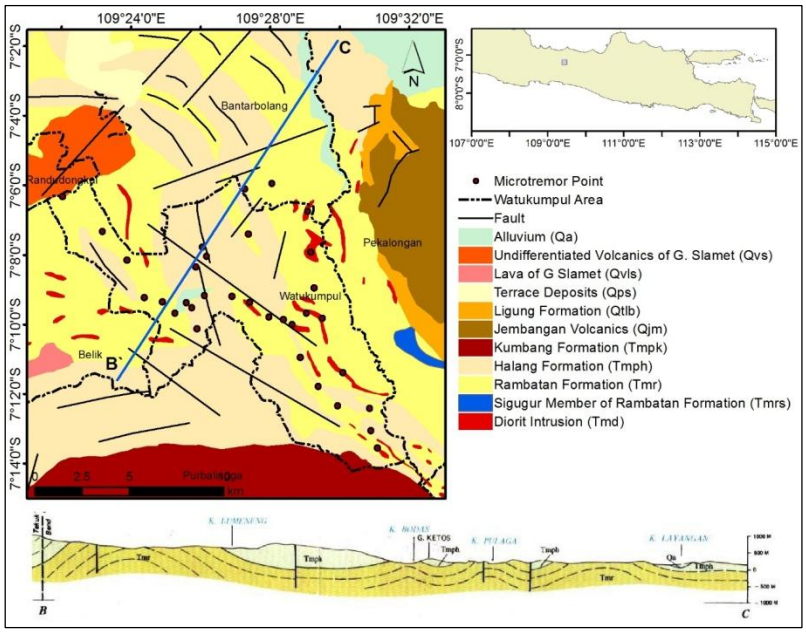

Fig. 1. Geological map of the study area (black dotted is microtremor measurement location) (Modified after Djuri et al., 1996).

3. Methodology

3.1 Data Acquisition

Microtremor signals were recorded at 33 locations in Watukumpul Pemalang (Fig 1). The microtremor signal was recorded using a three-component seismometer type of MAE with a sampling rate of 100 Hz. Measurement was carried out in a quiet location to minimize noise. The measurement duration, for each point was about 20 minutes.

In this research, we also used shear wave velocity at a depth of 30 meters (V_{s30}), which was obtained from the United States Geological Survey (USGS).

3.2Horizontal to Vertical Spectral Ratio (HVSR)

Horizontal to Vertical Spectral Ratio (HVSR) is a 3-component microtremor data analysis method. In this study, the microtremor signal processing useing Geopsy software, and the standard criteria for data processing according to the Sesame European Project.

The HVSR method begins with manually selected the stationary signal by windowing the signal with a window width of the 20s. Then, the microtremor signal in the time domain was transformed into the frequency domain through the Fast Fourier Transform (FFT) process with a tapering value of 5% and subsequently smoothen using the Konno-Omaching method with a constant value of b = 40 (SESAME European Research Project, 2004). The result of the spectrum on the horizontal component ($H(f)$) divided by the vertical component($V(f)$) based on Equation (1) to obtain the HVSR curve (Nakamura, 2008).

$$HV-ratio = \frac{H(f)}{V(f)} = \frac{\sqrt{H_{EW}^2(f)+H_{NS}^2(f)}}{V(f)} \quad (1)$$

Where $H_{EW}(f)$ is a spectrum of the horizontal component in the east-west direction, and $H_{NS}(f)$ is a spectrum of horizontal components in the north-south direction

The peak of the HVSR curve shows the dominant frequency and amplification values.

3.3The Soft Layer Thickness

The soft layer thickness is related to the dominant frequency, which is the resonant frequency of the surface sediment layer when it reaches the maximum amplification value. The relationship between thickness and dominant frequency can be determined based on the closed Organa pipe rule. The maximum amplitude in close Organa pipe occurs when the thickness is a quarter of the wavelength (Seht and Wohlenberg, 1999). So the soft layer thickness can be determined using equation (2)

$$f_0 = \frac{V_S}{4H} \quad (2)$$

where f_0 is dominat frequency, V_s is shear wave velocity of soft layer and H is the thickness of soft layer. In this study we used V_{s30} data as the input of V_s parameter

4. Result and Discussion

4.1 HVSR Results

The result of microtremor signal analysis using the HVSR method is the HVSR spectrum curve. The HVSR curves of some locations showstwo curve peaks (Fig 2) which means there are two dominant frequencies. The two peaks of the HVSR curve show that the microtremor signal at the time of measurement captured two subsurfaces impedance contrasts from the deep and shallow soil layers (Kyaw et al., 2015). The dominant frequency of microtremor measurements does not necessarily indicate the characteristics of a single layer due to the complex ground vibration motion (Thein et al., 2013).

Further analysis was carried out on the HVSR curve which met the criteria for a reliable curve, as follows in Figure 3. Based on criteria in Fig 3, we can conclude that all the HVSR spectrum curve fullfill the criteria for a reliable curve. The fulfilment of first criteria based on the dominant frequency value of the first peak (1.36 – 7.62 Hz) which higher than the criteria $\frac{10}{I_w} = 0.5$(window length is 20 s). The second criteria was fullfil by all the HVSR curve because all the point has more than 10 number of windows so the significant number of cycles were than 200. The third criteria is fulfill because no HVSR curve has standard deviation of amplitide more than 2.

Table 1. HVSR Result and the soft layer thicknes from HVSR first peak (*H*)

No	Microtremor Point	Long (deg)	Lat (deg)	*First Peak*		*Second Peak*		Vs_{30}	*H (m) (from first peak)*	*Geological formation*
				A_0	f_0	A_i	f_1			
1	W1	109.37	-7.11	15.94	1.60	-	-	438.58	68.40	Rambatan Formation
2	W2	109.39	-7.12	15.98	2.92	-	-	715.23	61.28	Rambatan Formation
3	W3	109.40	-7.14	16.87	2.62	-	-	693.03	66.10	Rambatan Formation
4	W4	109.41	-7.15	21.61	1.90	15.82	7.65	609.06	79.97	Rambatan Formation
5	W5	109.41	-7.16	11.63	2.14	11.82	6.50	569.81	66.47	Rambatan Formation
6	W6	109.42	-7.16	12.73	1.64	26.10	7.25	579.81	88.22	Rambatan Formation
7	W7	109.43	-7.17	11.81	3.40	19.64	5.84	649.75	47.82	Rambatan Formation
8	W8	109.43	-7.13	21.17	6.90	-	-	606.30	21.97	Halang Formation
9	W9	109.44	-7.13	14.68	3.35	18.25	7.27	583.38	43.57	Halang Formation
10	W10	109.43	-7.14	31.04	7.62	-	-	536.25	17.58	Halang Formation
11	W11	109.43	-7.15	34.65	2.63	-	-	540.53	51.30	Halang Formation
12	W12	109.43	-7.16	12.34	1.36	-	-	563.19	103.60	Alluvium
13	W13	109.43	-7.16	41.45	4.11	-	-	570.62	34.69	Alluvium
14	W14	109.47	-7.10	14.84	6.04	-	-	508.60	21.04	Halang Formation
15	W15	109.45	-7.10	20.93	6.48	-	-	496.39	19.15	Rambatan Formation
16	W16	109.46	-7.12	15.43	3.44	-	-	639.23	46.40	Halang Formation
17	W17	109.45	-7.15	35.53	5.25	17.50	15.42	565.52	26.91	Rambatan Formation
18	W18	109.46	-7.16	36.13	6.87	-	-	583.28	21.23	Rambatan Formation
19	W19	109.47	-7.16	23.45	6.57	-	-	598.59	22.78	Diorit Intrusion
20	W20	109.47	-7.16	12.86	6.85	-	-	589.90	21.53	Rambatan Formation
21	W21	109.48	-7.16	32.87	2.65	-	-	548.26	51.74	Rambatan Formation
22	W22	109.48	-7.17	11.67	3.04	60.78	18.09	587.20	48.32	Rambatan Formation
23	W23	109.48	-7.18	15.35	3.24	-	-	609.86	47.03	Diorit Intrusion
24	W24	109.49	-7.20	13.37	2.61	14.77	5.61	653.75	62.64	Rambatan Formation
25	W25	109.50	-7.21	19.38	2.46	18.62	5.75	632.91	64.43	Rambatan Formation
26	W26	109.48	-7.11	23.57	1.91	-	-	514.28	67.49	Rambatan Formation
27	W27	109.49	-7.13	14.84	2.23	-	-	461.15	51.70	Diorit Intrusion
28	W28	109.49	-7.15	23.75	2.30	29.75	7.25	490.77	53.44	Diorit Intrusion
29	W29	109.49	-7.16	20.40	4.24	-	-	547.10	32.26	Rambatan Formation
30	W30	109.50	-7.19	11.59	2.47	10.36	5.92	629.12	63.60	Rambatan Formation
31	W31	109.51	-7.21	19.68	2.57	20.84	11.82	657.49	63.86	Diorit Intrusion
32	W32	109.51	-7.22	14.46	2.24	18.47	5.39	683.85	76.43	Halang Formation
33	W33	109.52	-7.23	9.00	2.18	-	-	665.65	76.41	Halang Formation

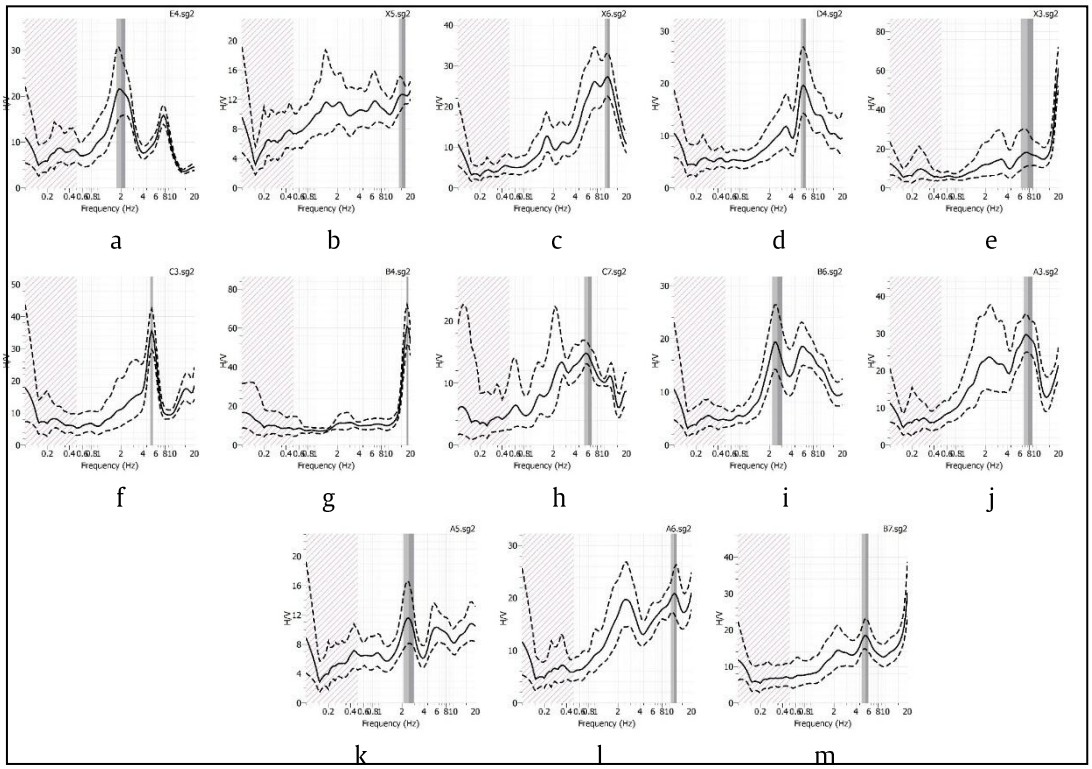

Fig 2. HVSR curve with 2 peaks (a) W4; (b) W5; (c) W6; (d) W7; (e) W9; (f) W17;(g) W22; (h) W24; (i) W25; (j) W28; (k) W30; (l) W31; (m) W32

Criteria for a reliable HVSR curve

1. $f_0 > \frac{10}{I_w}$
2. $n_c(f_0) > 200$; $n_c(f_0) = I_w . n_w . f_0$
3. $\sigma_A(f) < 2$ for $0{,}5 f_0 < f < 2 f_0$ if $f_0 > 0.5$
   or
   $\sigma_A(f) < 2$ for $0{,}5 f_0 < f < 2 f_0$ if $f_0 > 0.5$
   with
   f = frequency f_0 = dominant frequency
   I_w = window length n_w = number of windows
   n_c = number of significant cycles
   σ_A = standard deviation of HVSR dominant frequency

Fig 3. Criteria for a reliable HVSR curve (SESAME European Research Project, 2004)

Table 1 showed the dominant frequency and amplification value of reliable HVSR curve. The HVSR results used for further analysis were the dominant frequency at the first peak, which reflected the deep soft layer andpresent at all measurement points.The amplification value of the first peak ranged from 9.00 – 41.45 (Fig. 4). Amplification value provides information about the potential effect of earthquake vibration resonance on buildings so it can correlate with local ground shaking characteristics (Stanko et al., 2019). The high amplification value located at central of watukumpul so this area has the higher potential of earthquake vibration resonance effect. The treshold of amplification and frequency value (seismic vulnerability index) which caused eartquake damage can be determined by corellate the value with the earthquake damage map (Daryono et al., 2009). But in this study, we couldnot determined the treshold because there are no data about earthquake damage history.

The amplification value describes the geological conditions between the sediment layer and the hard rock which beneath it and does not correlate with the dominant frequency or thickness of the soft layers(Prabowo et al., 2018).The high amplification value is located in the middle of the study area, dominated by sandstone of the Halang formation with an age ranged between late Miocene and pliosen. The high amplification value caused by younger and softer rocks in the Halang formation than rocks layer below from Rambatan formation (middle miocene age) (Fig. 1). In other areas where consisted of rock from Rambatan formation, the amplification value is relatively small because the soft layer formed from weathered rock of the Rambatanformation so the difference conditions between the sediment layer and the hard rock is small.

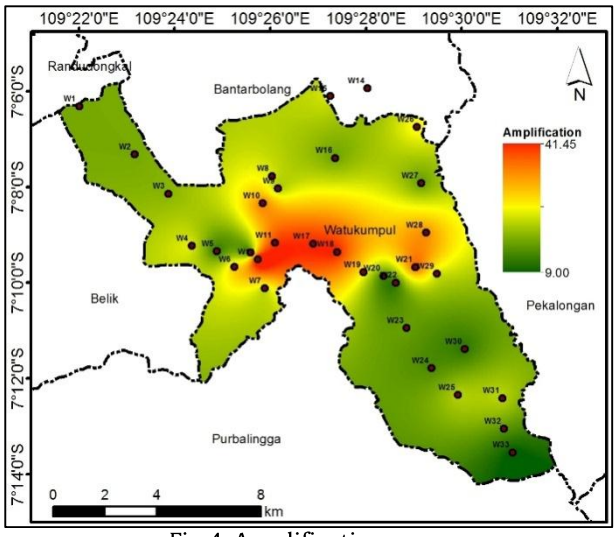

Fig 4. Amplification map

The dominant frequency of HVSR curve first peak ranged from 1.36 7.62 Hz (Fig. 5). The frequency value is proportional to the thickness of the soft sediment layer. A high dominant frequency value is located in the middle of the study site which is composed of rocks from the Halang formation and little part of the Rambatan formation. This high frequency value indicates a thinner sediment layer in the middle of the study area than the other measurement areas.

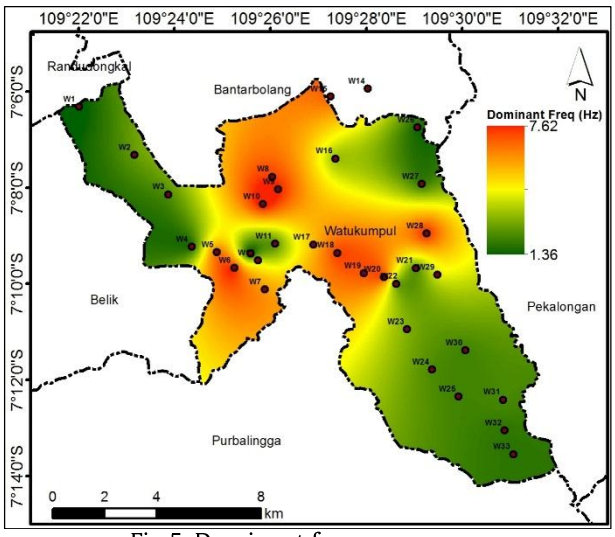

Fig 5. Dominant frequency map

4.2 The Soft Layer Thickness of Study Area

The soft layer thickness in the study area is determined based on equation (2) with the calculation results shown in Table 1 and Fig 6. The thickness of the soft layer in the Watukumpul area ranges from 17.58 - 103.60 meters.

Fig 3 shows the distribution of location and the thickness of the soft layer in the study area. The thicker soft sediment layer is located in the west of the study area at point W1 - W6, which ranges from 61.28 - 88.22 meters, and the largest value is at point W12 which is 103.60 meters. Thicker soft layer is also located in the southern area of the area at points W30 - W31, which ranges from 63.60 - 76.43 meters.

Figure 7 shows that point W12 has the largest thickness of the sediment layer composed of alluvium deposits with quarter age. The thick accumulation of alluvium probably originates from a higher area at the west of point W12. Point W12 is in an area with low elevation and tends to be flat so that the soft soil tends to be stable. This indicates that the potential for landslides is very small even though the thickness of the sediment is the largest.

In Figure 7, points W4 and W5 have the potential for landslides. This is due to the high elevation with a large soil slope and slip surface. The rocks at this location are dominated by sandstone from Halang formation with a large soft soil thickness ranging from 66 - 80 m

Figure 8 shows a cross section of the thickness of the sediment layer from north to south. In the northern area, it tends to have an even thickness of soft soil and a relatively small slope, so the potential for landslides is low. The southern area has a large enough soil elevation and slope with a thickness of soft soil between 63 - 76 m. This causes the southern area to have the potential for landslides. At point W32 it is composed of rocks from the Halang formation which are between the tougher Rambat formations. This allows the geometry of the slip plane in the form of curves under the Halang formation which can trigger rotational landslides.

Figures 7 and 8 show that the thickness of the soft soil can provide a preliminary picture of the volume of soft soils and the morphology of the slip plane. The potential for large landslides is in locations with thick soft soil and large soil slopes. Based on land slope data in previous studies, locations with large soil slopes and thickness of sediment layers shown in Fig9.There were 5 point; W7, W8, W18, W30, and W32 which has land slide potential. These point has soil slope more than 20^0 andthe soft soil thichness ranged between 21.2 -76.4 m. The highest soil slope is $29,14^0$ which located in W8. The landslide potential assestment in this study was limited in 33 measurement point location. There another location with higher soil slope that have not measure yet caused by our limitation in time, transportation acces and facilities.

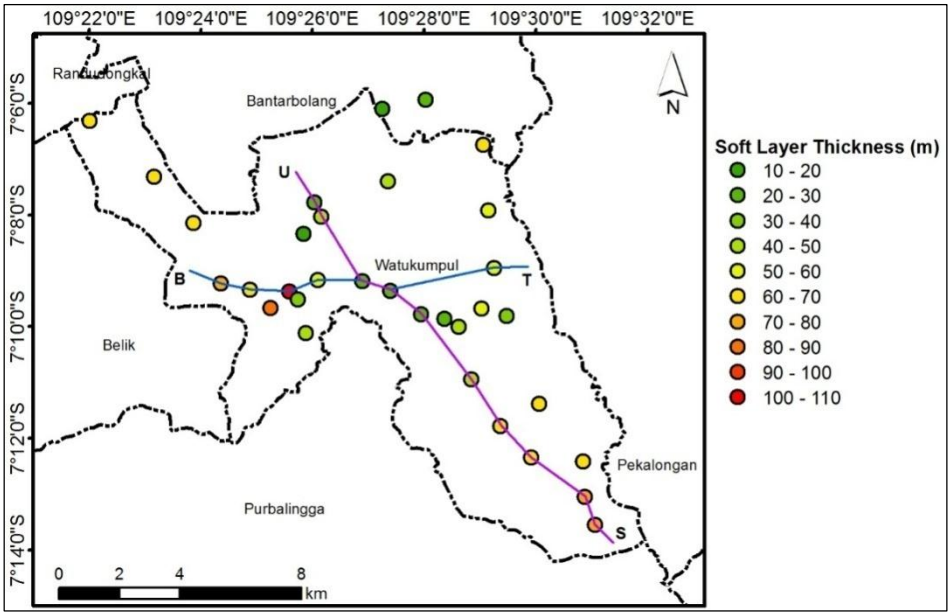

Fig. 6. Map of the Soft layer thickness

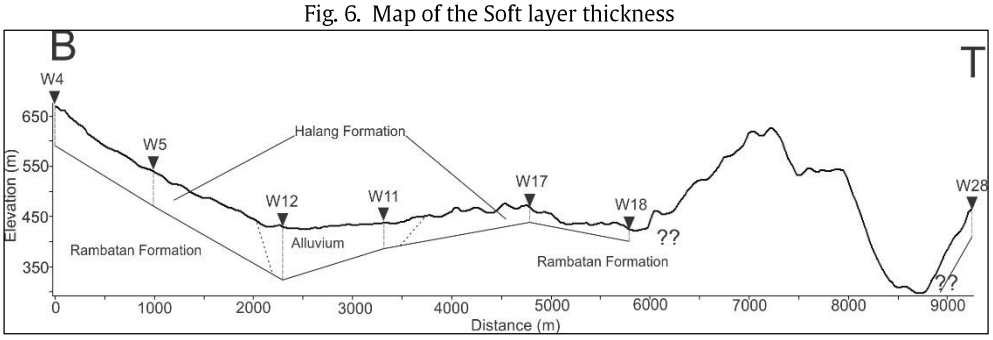

Fig. 7. B-T cross section

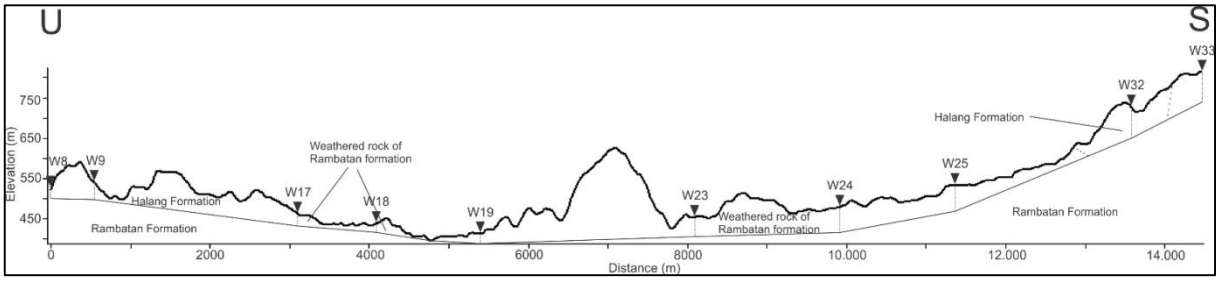

Fig. 8. U-S cross section

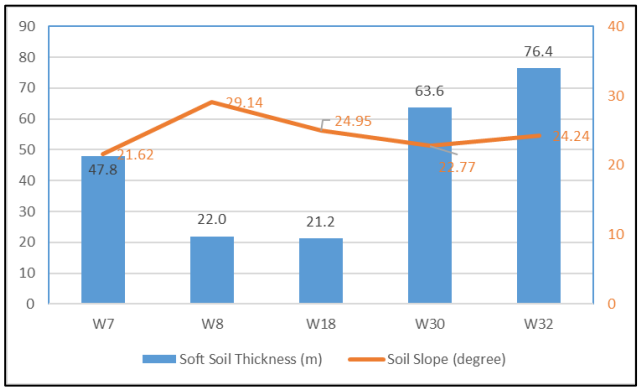

Fig. 9. Soft soil thicknes and soil slope (> 20^0)

5. Conclussion

The microtremor can be used to determine the thickness of the soft soil which can provide a preliminary picture of the volume of the soft soil and the morphology of the slip plane. The potential landslide area is an area with thick soft soil and a large soil slope.

The soft layer thickness value in this study is calculated based on the first peak HVSR curve which describes the thick soft layer, which ranges from 17.58 - 103.60 meters. Areas that have the potential for landslides are located at W7, W8, W18, W30 and W32.

In further research, it is necessary to measure using other geophysical methods such as geoelectricity or masw to map the morphology of the slip plane in more detail. In addition, research on soft

soil types is also important so that it can explain the mechanism of landslides that can occur.

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