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Assesment to the Local Site Effects during Earthquake Induced Landslide Using Microtremor Measurement (Case Study: Kemuning Lor, Jember Regency- Indonesia)

Ria Asih Aryani Soemitro[1], Dwa Desa Warnana[1,2], Widya Utama[3], Runi Asmaranto[1,3]

[1)] Lecturer of Civil Engineering Department, Faculty of Engineering and Planning, Sepuluh Nopember Institute of Technology Surabaya, (INDONESIA 60111)
[2)] Lecturer of Geophysic Department, Faculty of Mathematic and Natual Science, Sepuluh Nopember Institute of Technology Surabaya. (INDONESIA 60111)
[3)] Lecturer of Water Resources Engineering Department, Faculty of Engineering, University of Brawijaya, Malang (INDONESIA 65145)

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ABSTRACT

In Kemuning Lor village – Jember regency – East Java, The local site of geology and topographic on ground motion during earthquake induced landslide were investigated using Horizontal to Vertical Spectra Ratio (HVSR). The microtremor measurements were performed at the landslide area on 82 free-field measurement having 20 x 20 m dense grid. The amplification factor (A_m) in 2-7 range and the soil natural frequency (f_o) in 1-3 Hz were obtained from the HVSR analysis. The f_o value had changed with the topographic pattern. The bedrock surface might be estimated using the f_o value. The A_m highest value was found at the main scarp landslide and at the slope area having high topographic gradient. Variations of f_o and Am parameters were indicated as surface soil parameter's variations.
In general, the local geology effects is more dominant than the topography effect. The level of soil damage due to the local site effects at the landslide location was indicated by the vulnerability index (kg) and the effective shear strain (γ). Generaly, vulnerability index (kg) varied from 2.6 to 34.6 and the γ values varied from 500 $x10^{-6}$ to 6700 x 10^{-6}. This paper illustrates how the vulnerability index and the effective shear strain could be used to make preliminary assessment of the main scarp area failed during the earthquake.

KEY WORDS: local site effects, amplification factor, natural frequency, soil vulnerability index, landslide, HVSR, Kemuning Lor-Jember Regency.

INTRODUCTION

According to Bolt (1988), one of the catastrophic effects associated to an earthquake is the landsliding, which is the cause of significant economic and human losses. Landslide occurs when the tangential stress is greater than the shear strength of soil, and the slope soil mass to move down along the sliding surface. The formation of a sliding surface is preceded by more or less long stress concentration in its vicinity associated with numerous micro and medium-scale changes to strained soil. [1]
These changes include forming and healing of cracks accompanied by release of microseismic energy (called acoustic or seismoacoustic emission). Seismoacoustic emission makes up a great portion of the microseismic field on active slopes, and its parameters (intensity, energy and spectral patterns) have been broadly used in landslide monitoring. [1] [2] [3] [4] [5].

***Corresponding Author:** Dr. Ria Asih Aryani Soemitro, Lecturer of Civil Engineering Department, Faculty of Engineering and Planning, Sepuluh Nopember Institute of Technology Surabaya, (INDONESIA 60111)

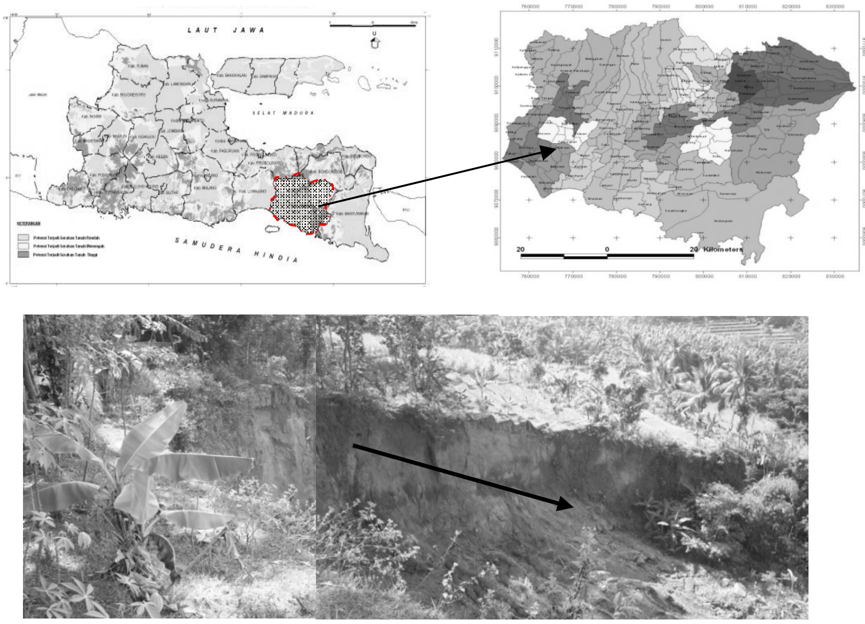
Topographic site effects i.e. the height and, angle, of slope, the presence of breaks and convexity on its surface and the effects of geological site (the geometry of the layers and a strong contrast of impedance between the layers and the bedrock) led to modification the characteristics of seismic parameters. The combined effect is known as a local site effects.

It is now well known that local site characteristics may produce large ground motion amplifications during earthquakes. This issue can be investigated by means of the analysis of actual seismic records and the study of synthetic seismogram as well. By last century's middle years, effects of local soil and geological condition were studied mainly in terms of peak accelerations or peak velocities. The effects of topography on surface ground motion have been observed and studied from field experiments. Trifunac and Hudson (1971), David and West (1973), Wong et.al (1977), Grifiths and Bollinger (1979), and Tucker *et. al* (1984) among others, recorded significant amplifications. [6]

In fact, even though the knowledge on local site effects have been historically improved, the understanding of seismic slope response is still limited due to of the scarcity of ground motion recordings on landslide-prone slopes. Furthermore, numerical modeling of slope behavior under earthquake shaking is not easy because the acquisition of relevant geotechnical parameters of slope materials is difficult in sites characterized by rough topography and sharp lateral lithological and/or physical heterogeneities. The assessment of subsurface geology through borehole or "active" geophysical surveying is expensive and is typically limited to post-factum (post-failure) local scale investigations. Then, exploring the capability of microtremor is interesting as it is considered as cheaper and quicker geophysical. [7]

The present paper is attempted to assess the local site effects of landslide in the village of Kemuning Lor, Jember Regency, East Java Indonesia. The local site effects characterized by high levels of seismicity and steep topography are vulnerable to slope instabilities (Figure 1). This can be identified from the Peaks Ground Accelaration (PGA) ranges from 0.2 to 0.25 g and 6^{th} level earthquake hazard. [8]. During the period from 2001 to 2008, a large number of houses were destructed by five large sized mass movements in the research area; though a delayed indirect seismic effect might be responsible for the landslides.

The microtremor investigation was use to determine the characteristics of surface ground in the landslide areas. The Nakamura technique has been adopted for the microtremor measurements analysis (HVSR) (e.g. Nakamura, 1989; 1997) to estimated the natural frequency (f_0), amplification factor (A_m), vulnerability index ($kg = A^2/F$) and effective shear strain (γ The parameters were combined to determine the relationship between the local site effects and the landslides. [9],[10],[11]



(a)

(b)

Fig 1. **(a)** Location of site investigation. **(b)** Landslide direction

MATERIALS AND METHODS

Geological and Geotechnical Setting

Based on the Jember Regency geological map, the location of site investigation is an area of Argopuro breccias sedimentary. The surface ground is dominated by the volcanic breccias distribution with the insertion of lava. Generally, volcanic breccias is mild-high weathering, gray, with the base rock consisted of andesite and tuff. The rocks of this formation generally have a low to high rock strength. [12]

The geotechnical investigation were drilling and standard penetration test (SPT) to 30 m depth. The drilling data indicated that the soil is brown and mainly consisted of sandy silt-clayey and silty sand-clayey. There was no ground water level to 30 m depth. The soil is relatively soft indicated by the SPT value (N) from 10 to 30 and the relatively density from 40 to 60. The stiff soil was found at the depth below 26 m having SPT value greater than 50. [13]

Microtremor Investigation and Data Processing

The microtremor investigation was conducted on 24 to 28 October 2009, on 20 x 20 m grid around of the main landslide area having 82 points. The location of geotechnical and microtremor investigation is shown on Figure 2.

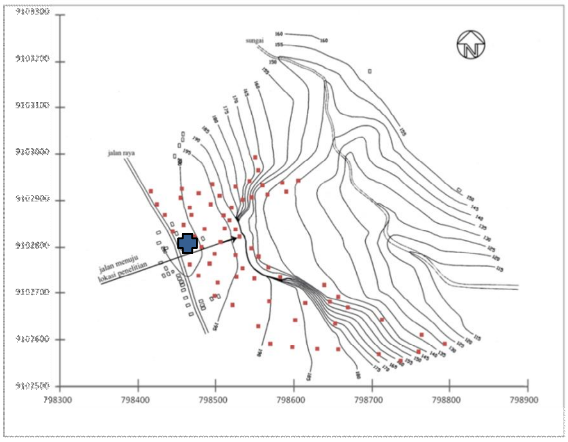


Fig 2. The location of microtremor investigation (red dots). Geotechnical investigation (Blue dots)

For each point of microtremor measurement, 15 minutes of ambient noise were recorded at the sampling rate of 100 Hz. The data processing to obtain the HVSR at each site was performed in the following way: the data was filtered between 0.2 and 25 Hz by a band-pass 4 poles Butterworth filter after the mean and a linear trend were removed; then each component of the recorded signal was windowed in a time series of 20 sec length (cosine taper 5%) and for each time window an FFT was calculated and smoothed using the Konno and Ohmachi (1998) window (b=40). For each time window the spectral ratio between the root-mean square average spectrums of the horizontal components over the spectrum of the vertical component was calculated and, finally, the average HVSR and the standard deviation were computed. Overall HVSR analysis performed using GEOPSY Software (2007).

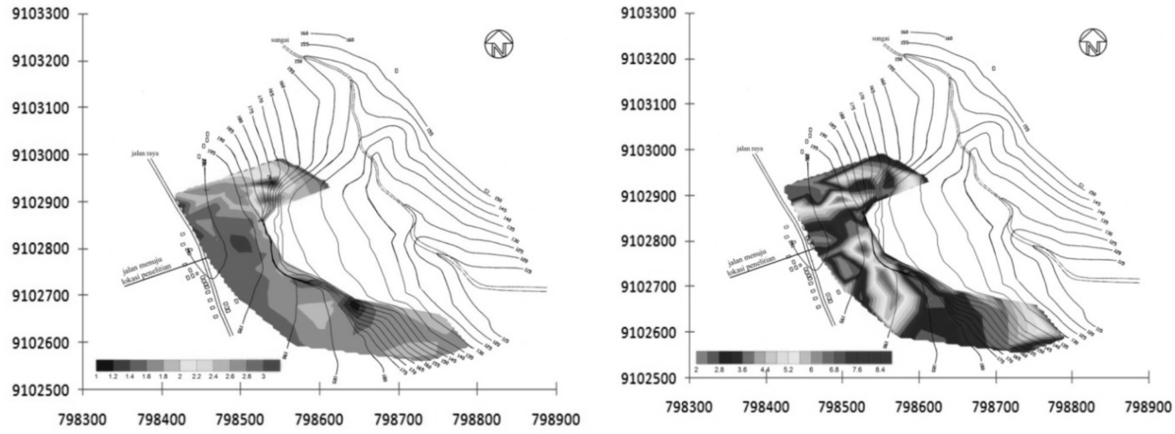
RESULTS AND DISCUSSION

At each point of microtremor measurement, the natural frequency (f_0), amplification factor (A_m), vulnerability index (Kg) and effective shear strain (γ) were determined.

Distribution of soil natural frequency (f_0) and amplification factor (A_m)

Figure 3a shows the distribution of f_0 where the distribution of natural frequencies is relatively uniform, ranging from 1-3 Hz. The topographic patterrn is associated with the f_o value. The soil thicknes (h) is possibly estimated using the formula $f_0 = V/4h$, where V is shear wave velocity.[14] Ghalandarzadeh (2006) in

Towhata Ikuo (2008) is also empirically determined the sandy soil layer thickness using the formula of (h) = 96 x $f_0^{-1.388}$. It could be noted that the f_0 is associated with the the depth of bedrock. The smaler of f_0 value, the greater of depth of bedrock.



(a) (b)

Fig 3. **(a)** Distribution of soil natural frequency (f_0). **(b)** Distribution of amplification factor (Am) on study area

Figure 3b represents the amplification factor (A_m) or peak ratio HVSR spectrum in investigation sites ranging from 2 to 7. High amplification factor (A_m>4) are found in several main scarp areas and in slope areas having high topographic gradients. The previous investigators (Bovckovalas & A.G Papadimitriov, 2005) using the numerical analysis of seismic wave propagation due to topographic effects found the similar results. An important remark should be made upon similar findings of the site investigation results and numerical analysis results.

The large amplification factor (A_m) was found not only on the high topographic gradient slope but also on the terrain topographic slope. On the other hand, small amplification factor was found on the part of main scarp. Thus the topographic effects is not the only one factor controlling the amplification factor. [15]

Different value of A_m might be found in the same value of the natural frequency. It can be noted that the variation of Am value is not strongly effected by the soil depth. She Wang and Hong Hao (2002) explained that the variation of soil parameters (shear modulus, damping ratio and density) influenced the amplification factor. Yang, Jun (2006) explained that the influence of the saturation state of the bedrock is insignificant; a change of the saturation state of the soil layer may have a marked impact on the amplification factor. [16]. It can be clearly stated that the geological factors are more dominant to the A_m variation.

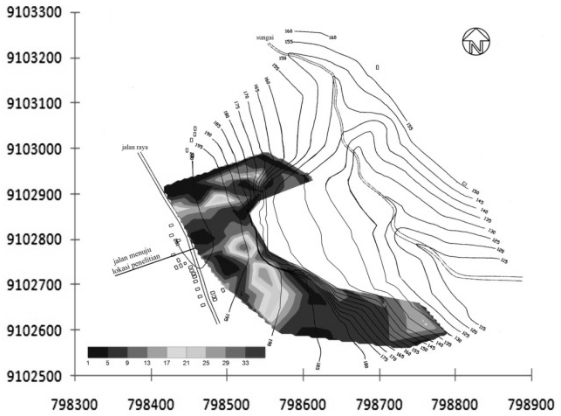
At present, using the A_m to assess the local site effects is still a hot debate among the experts [17]. Some investigators insisted that natural frequency (f_0) had to be considered.

Distribution of Soil Vulnerability Index (kg) and Effective Shear Strain (γ)

Nakamura (1996) introduced a Vulnerability Index Parameter (kg), which combined A_m and f_o to determine soil damage level due to the local site effects. [10] Thus, Kg can be considered as an index to indicate easiness of deformation of measured points which is expected useful to detect weak points of the ground. To estimate soil vulnerability index (kg), the value of shear strain (γ) need to be considered. [17]. According to Ishihara (1982) ground soil becomes plastic state at about $\gamma \cong 1000 \times 10^{-6}$; and for $\gamma > 10{,}000 \times 10^{-6}$ catastrophic landslide or very large deformation will be occured. Nakamura (1997) had outlined the formulation in detail, but in summary it can be written as follows: [11]

$$\gamma = \frac{A_m^2}{f_0}\frac{a}{\pi^2 v_b}$$

In this equation, $(A_m)^2/f_0$ is called soil vulnerability index (kg), a is the ground acceleration and v_b is the shear wave velocity of bedrock. Figure 4a, shows the distribution of vulnerability index (kg) having values ranging from 2.6 to 34.6. Nakamura (2008) stated that kg greater than 20 represented that ground deform much. Large values of kg (kg > 20) were found all along the main scrap; these zones were considered as weak zones which may fail during the earthquake.



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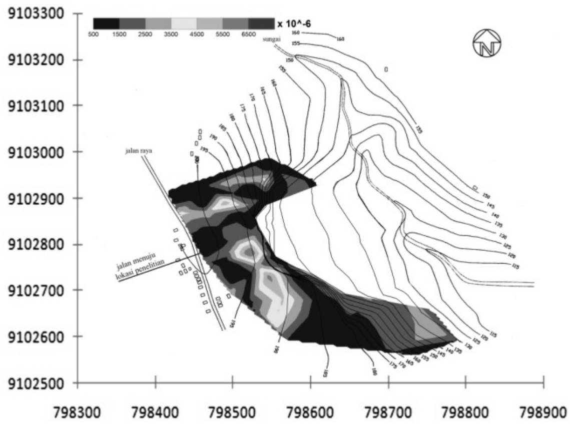

(b)

Fig 4.(a) Distribution of soil vulnerability index (kg), (b) Distribution of value of shear strain (γ) on study area

To better understand that an increase of kg value resulted in a greater possibility landslide, the effective shear strain calculation may be used. For a = 0.25 g and vb = 500 m/s it can be determined that effective shear strain varied from 500 $\times10^{-6}$ to 6700 $\times 10^{-6}$ during an earthquake (Figure 4b). Large values of γ were found all along the main scrap; these zone were considered as weak zones which may failed during the earthquake.

CONCLUSIONS

The distribution of f_0 is relatively uniform, ranging from 1-3 Hz, where the topographic patterrn is associated with the f_o value. The amplification factor (A_m) is ranging from 2 to 7. High amplification factor (A_m>4) are found in several main scarp areas and in slope areas having high topographic gradients. An important remark should be made upon similar findings of the site investigation results and numerical analysis results.
The topographic effects is not the only one factor controlling the amplification factor and It can be clearly stated that the geological factors are more dominant to the A_m variation.
Large values of kg and γ were found all along the main scrap; these zone were considered as weak zones which may failed during the earthquake.

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