Vibration Vulnerability Identification in Kota Lama Semarang using Microtremor Method

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ABSTRACT

Kota Lama is one of the landmarks in Semarang Central Java that is located on young alluvial sediment. This area is prone to vibrations stemming from tectonic activities around Semarang. Therefore, measurements were carried out to identify this vibration vulnerability using the microtremor method. These were aimed at obtaining a spatial distribution of vibration vulnerability. There were 29 measurement points each separated by a sampling interval of 50 ms and a duration of 10 minutes. Ground vibration amplification in this area was found to range from 0.74 to 4.9 with the highest being on the outskirts of Kota Lama. The predominant frequency was found to range from 0.02 to 1.1 Hz. These patterns of high predominant frequency and ground vibration amplification suggest that the central area of Kota Lama needs more attention. High ground shear strain that ranges from 0.02 to 0.86 means that possible event to occur in Kota Lama include landslide, soil compaction, and liquefaction, as is also evident with existing dynamic properties of repeated collapse effect and loading speed effect. Meanwhile, structure of vibration amplification against predominant frequency underneath Kota Lama revealed lateral subsurface discontinuity on its southwest side. It was also found that the contour of ground vibration amplification resembles the shape of Vifjhoek fort.

Keywords: Vibration Vulnerability, Microtremor, Ground Shear Strain, Vifjhoek Fort

INTRODUCTION

Kota Lama is one of the many landmarks in Semarang and it is certainly one of the most iconic. It was established on top of very young alluvial sedimentation that stems from estuary mud sedimentation from the rivers of Kali Kreo, Kali Garang, and Kali Kripik. The geology of Kota Lama is dominated by quarterly alluvial sediments with the lithology made up of clay, slit, and sand, and the other layers, each with 50 m thickness or more [1]. As a cultural heritage site, Kota Lama is of important and authentic values in the form of colonial style buildings that represent an era, and hence, has to be preserved. The existence of an old fort in the area has drawn archaeological interests, but physical evidence proves hard to trace. According to Purwanto (2005), Vifjhoek fort was constructed in 1705 to replace an old fort that was built in 1600 on the western side of Kota Lama to protect Dutch interests after the VOC (Dutch East India Company) helped the Mataram kingdom crushed the Trunojoyo rebellion [2].

One aspect to consider in preserving this area is vulnerability to vibration that correlates to the condition of buildings, infrastructure, and construction, where are largely affected by the ground layers where the buildings and constructions stand. Vibration vulnerability, especially due to activities, is inversely proportional to material density of surrounding rocks. The lower the material density of surrounding rocks, the higher the vulnerability is [3]. Historical records suggest that Kota Lama has been rocked by earthquakes of high magnitudes in 1856, 1958, 1959, and 1966, which were triggered by activities of the Lasem fault. Tectonic activities around Semarang that have the potential to cause damaging vibration include from Kendeng fault of Semarang section, and reactivated Kaligarang fault that completely splits Semarang from the north to south [4]. Active hanging and sliding faults control the rocks that make up the city of Semarang [5].

Those facts emphasize the need for a study on the vulnerability of Kota Lama to vibration, as to find out the response of ground layers against mainly earthquake induced vibration. Layers thickness and hardness in the study area are resonance function that describes the effect of ground vibration amplification. Sediments with low resonance frequency has high index of seismic vulnerability [6]. Seismic vulnerability index is the index that describes vulnerability of upper ground layers to deformation in the event of an earthquake [3]. The higher the seismic vulnerability index of a sediment, the more incapable the sediment is in withstanding deformation. Deformation includes ground fracture, liquefaction, and landslide that can be predicted from the value of ground shear strain of an area. This research compared horizontal spectra against vertical spectra of microtremors recorded by portable 3-component seismometers to identify the distribution of seismic vulnerability index.

HVSR Method

Microtremor or ambient vibration is ground movement of micrometer magnitude that may be caused by both natural phenomena and human activities such as the wind, ocean wave, and vehicles that describe the geological condition of adjacent near surface areas [7]. According to Mirzaoglu & Dykmen (2003), microtremor is ground vibration of around 0.1-1 μm amplitude [8]. Mircrotremors are classified into two types based on their periods: The first is short period microtremor of less than 1 second. This relates to shallow upper surface structure of a few tens of meters of thickness. The second is long period microtremor of more than 1 second. This relates to deeper ground structure, which includes bases of hard rocks. Microtremor surveys can be used to figure ground layer characteristics based on the parameters of predominant periods and wave amplification factors. Predominant frequencies are the most often detected frequencies that are then recognized as the frequencies of the rocks in certain areas. These frequencies reveal the types and characteristics of rocks in those areas. Predominant period is the time required by a microtremor wave to have one deflection on a deflection plane to the surface. Predominant periods also indicate the characteristics of rock layers in an area.

HVSR (Horizontal-to-Vertical Spectral Ratio) is a method based on the assumption that the ratio of horizontal and vertical surface vibration is a transfer function. This method also helps to show that the dynamic characteristics of a surface layer can be deduced from observation points of seismic microtremor waves using three components; two horizontal components and one vertical component [6]. These components are given as:

$$HVSR = \frac{\sqrt{(S_{north-south})^2+(S_{east-west})^2}}{S_v} \tag{1}$$

where $S_{north-south}$ is the spectrum of the north-south, $S_{east-west}$ is the spectrum of east-west component, and S_v is the vertical component.

Ground Shear Strain

Ground Shear Strain **(**GSS) on the ground surface depicts the ability of surface layer materials to move during an earthquake. The value of Ground Shear Strain (γ) can be calculated using the following equation [9]:

$$\gamma = (K_g a_g) \tag{2}$$

where K_g is the seismic vulnerability index, and a_g is the subsurface seismic wave acceleration. Seismic vulnerability index is given as:

$$K_g = (A_g/f_0)/(\pi^2 V_s) \tag{3}$$

where A_g is amplification factor, f_0 is the predominant frequency, and V_s is the sliding wave velocity. Relationships of ground shear strain values and soil dynamic properties are given in Table 1.

Table 1. Strain dependence of soil dynamic properties [9]

Strain Magnitude γ	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}
Phenomena	Wave vibration		Crack, Settlement		Landslide,Soil compaction, liquefaction	
Dynamic properties	Elasticity		Elasto-plasticity		Collapse Repeated effect, loading speed effect	

METHOD

Microtremor data to figure out site response effect of Kota Lama were taken from 29 locations (Figure 1) using the grid system with a 10-minute measurement duration for each point with sampling interval of 50 ms. The gridding system, as represented by dotted lines, was aimed at obtaining the profile of vibration cross-section in the research area. These microtremor data were then processed to obtain predominant frequencies and vibration amplitudes of the ground layers in the research area. Calculation for seismic vulnerability index and ground shear strain was the performed, followed by lateral contouring to find out lateral distribution of predominant frequencies, ground vibration amplifications, seismic vulnerability, and ground shear strain. Vertical contouring or profiling was also carried out to find out the sensitivity of predominant frequencies against ground amplifications at certain lines in the research area.

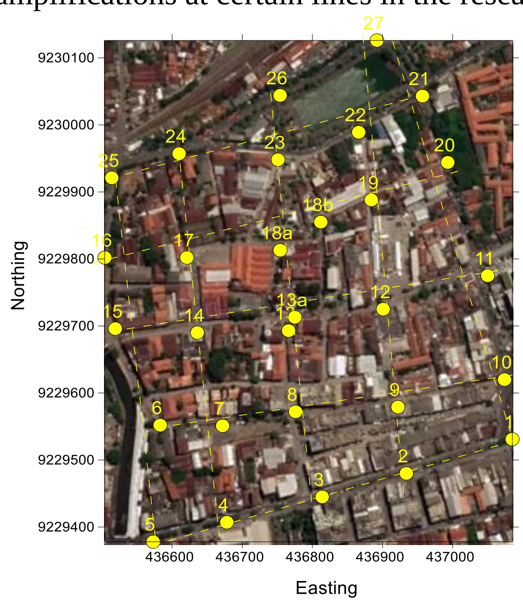
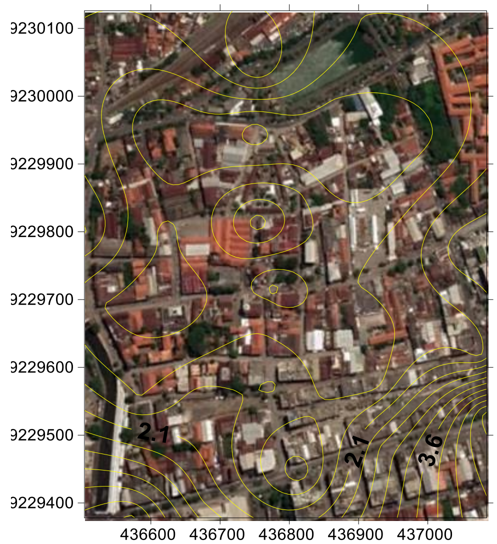


Figure 1. Research location with dotted lines at which a profile of vibration amplifications against predominant frequencies of the ground layers was made

RESULTS AND DISCUSSION

Predominant frequencies contour shows values in the range of 0.02 - 1.1 Hz, while ground vibration amplifications contour shows a minimum of 0.74 and a maximum of 4.94 (Figure 2). The ground layers beneath Immanuel Church belong to the area having high predominant frequencies. Predominant frequencies have increasing closure that is centered on the central part of Kota Lama. Meanwhile, areas that border this area have relatively lower predominant frequencies. In terms of ground vibration, a decreasing closure is detected around the central part of Kota Lama. In the southern area of Jl. Agus Salim, a contour of higher ground vibration amplification was identified.

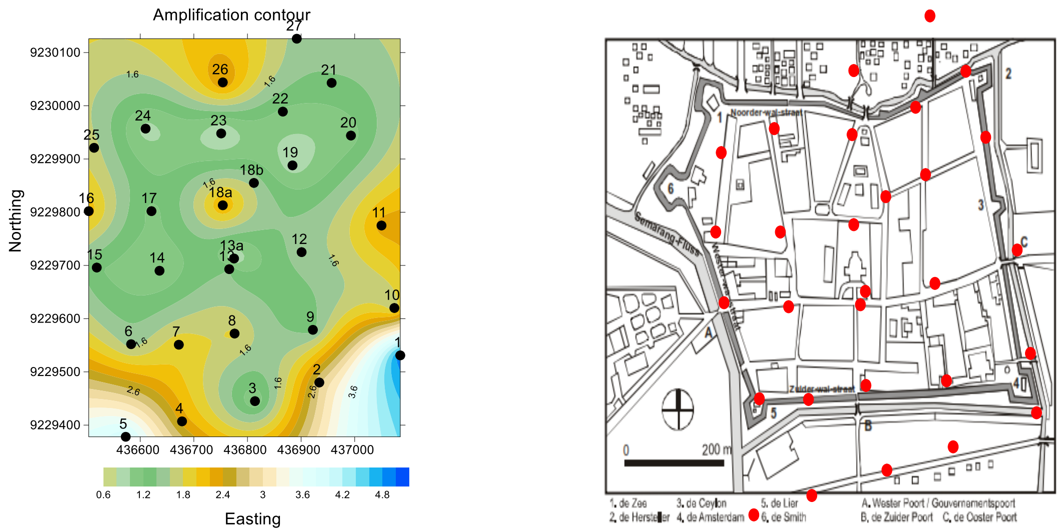
(a)



(b)

Figure 2. Predominant frequency contour (a) and amplification contour (b)

This result is associated with Vifjhoek fort in Kota Lama and a diagram depicting the fort outlined by [2]. A contour of amplification in the research area shows values in the range of 0.9 - 4.0 (Figure 4) showing a pattern resembling Vifjhoek fort that is estimated to be at the same location. The southern wall of the fort is now Jl. Kepodang. If it was true that the gate and walls of the fort were torn down in 1824, then there would have been 119 years of soil consolidation and compaction due construction of settlements and activities within the fort. The line making up point 6 to 10 (Jl. Sendowo) has different ground layer amplification value compared to its northern area or the fort complex, because this area was a fort canal back then.

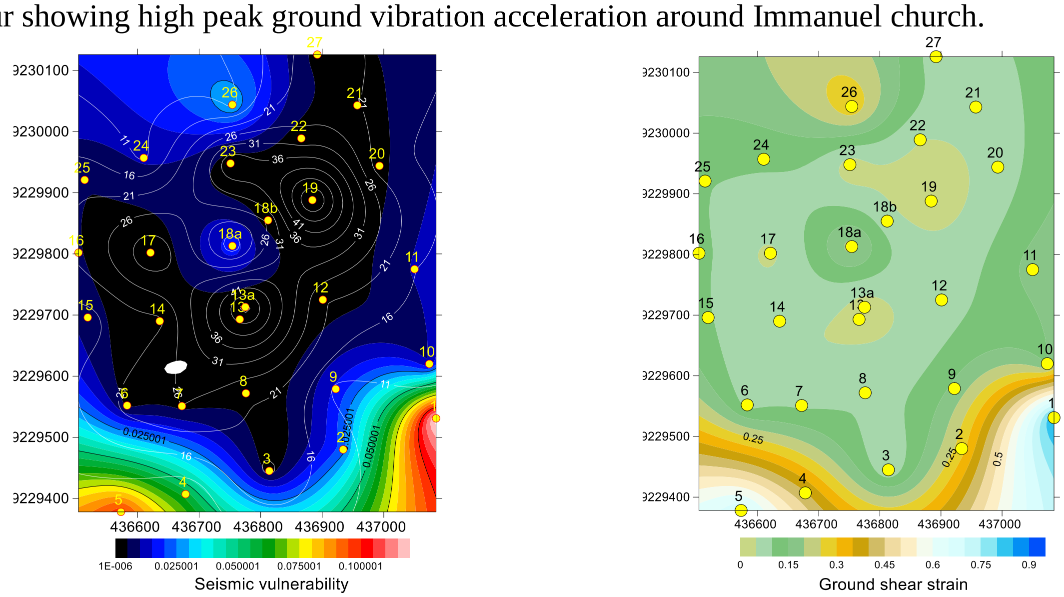


(a) (b)

Figure 3. Ground amplification contour of the research area (a) with a pattern resembling fort Vifjhoek's diagram of 1766 [2] (b).

A contour of seismic vulnerability that is overlain with contours of peak ground acceleration and ground shear strain (Figure 4) reveals lower seismic vulnerability around the central part of Kota Lama. The ground shear strain values in this area are also relatively lower. Meanwhile, higher seismic vulnerability and ground shear strain are observed in the southern side of Kota Lama. In general, possible events to occur in Kota Lama include landslide, soil compaction, and liquefaction, as is also evident with existing dynamic properties of repeated collapse effect and loading speed effect.

In terms of peak ground vibration acceleration, the contour obtained is similar to the frequency contour showing high peak ground vibration acceleration around Immanuel church.



(a) (b)

Figure 4. Seismic vulnerability contour overlaid with PGA contour (a) and Ground shear strain contour (b)

Based on cross-section of amplifications against predominant frequencies for each line (Figure 5), a pattern of discontinuity is observed in the east at Point 6, in the north at Point 4 down to the middle of the line at Point 14, and in the north at Point 3 to the middle of the line or Point 13 (Immanuel church). A structure of high vibration amplification is found to vertically cut through the ground layer adjacent to it. Further research has to be carried out to explain this phenomenon in terms of its geophysics and geology.

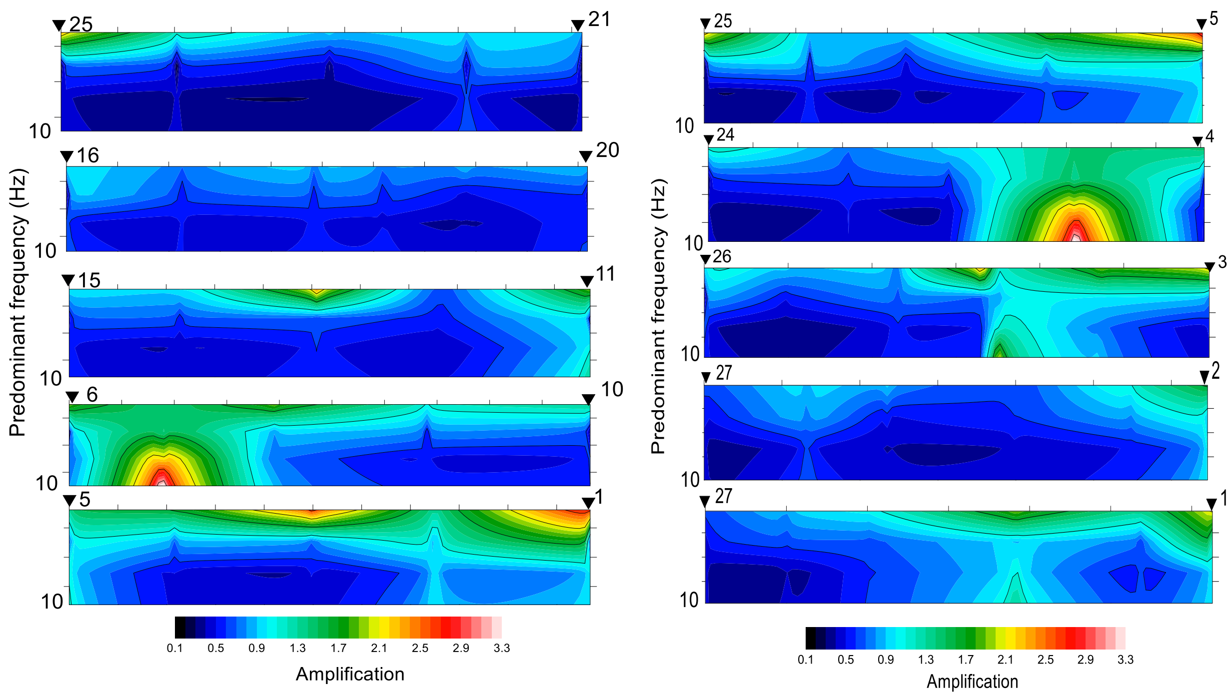


Figure 5. Amplification and frequency cross-section of the line depicted in Figure 1

Correlation graph of average spectrum and average profile curves in Kota Lama (Figure 6) shows negative values. This means that the peak of vibration spectrum from anthropogenic activities and natural sources is not amplified by the predominant frequency of the ground. HVSR profile of Kota Lama indicates the presence of massive underlying rocks underneath the alluvial layer that makes up the area.

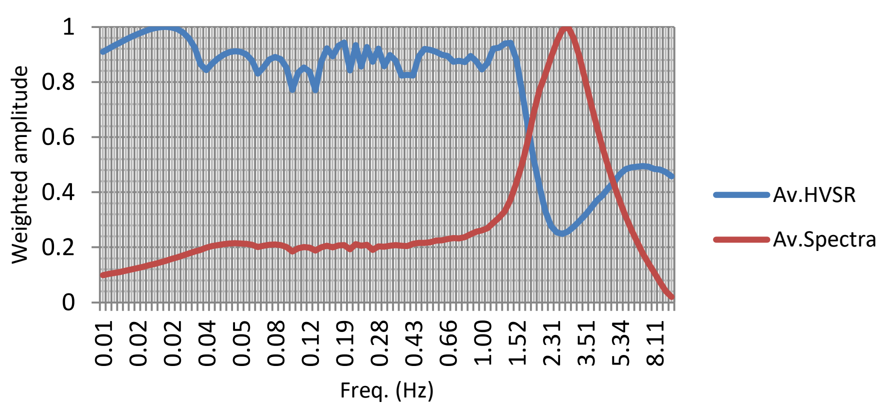


Figure 6. Correlation of weighted ambient vibration spectra and HVSR profile from all observation points

CONCLUSION

Results of microtremor analysis to identify vibration vulnerability of Kota Lama Semarang show that ground amplification of the area is in the range of 0.74 - 4.94 with the highest values found to be on the outskirts, whereas high predominant frequency and ground vibration acceleration values detected also suggest the need to pay more attention to central part of this area. With ground shear strain values in the range of 0.02 - 0,86, the most probable event to occur in the area of Kota Lama Semarang are landslide, soil compaction, and liquefaction, as evident with the dynamic properties of repeated collapse effect and loading sped effect. Meanwhile, structure of vibration amplification against predominant frequency underneath Kota Lama revealed lateral subsurface discontinuity on its southwest side. It was also found that the contour of ground vibration amplification resembles the shape of Vifjhoek fort.

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