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by Rini Kusumawardani

THE ANALYSIS OF LIQUEFACTION PHENOMENON OF THE FLEXIBLE PAVEMENT USING SEISMIC MONITORING EQUIPMENT

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ABSTRACT: Liquefaction phenomenon is generally caused by high dynamic vibrations in a very short duration. This article investigated the behavior of dynamic vibrations caused by vehicles on the road. This study employed the HVSR (Horizontal Vertical Spectral Ratio) with an accelerometer. The result of dynamic vibration generated by the passing vehicle or the micro tremor / micro seismic vibration was recorded by seismic monitoring devices. This seismic monitoring equipment converted vibration into natural frequency (f_0) and amplification (A_0) using Geopsy software. The result of HVSR (Horizontal Vertical Spectral Ratio) was the soil vulnerability index (K_g). The results of this study indicated that the three parameters above were then analyzed with the assumption that if the amplification value (A_0) was higher and associated with a lower natural frequency value (f_0) with a high vulnerability index (K_g), then the area had potential liquefaction, with laboratory research results in the form of granular gradation testing as the supporting data. Therefore, the results of the analysis and the laboratory work lead to the conclusion that the study area of Majapahit street has potential for liquefaction.

ABSTRAK: Fenomena pencairan umumnya disebabkan oleh getaran dinamik tinggi dalam tempoh singkat. Artikel ini mengkaji fenomena getaran dinamik yang disebabkan oleh kenderaan di jalan raya. Kajian ini menggunakan HVSR (Nisbah Spektral Menegak Mendatar) dengan alat pengukur pecutan. Hasil getaran dinamik yang dihasilkan oleh kenderaan yang lalu-lalang atau gegaran mikro / getaran seismik mikro telah direkodkan oleh alat pemantauan seismik. Alat pemantauan seismik ini mengubah getaran kepada frekuensi semula jadi (f_0) dan amplifikasi (A_0) menggunakan perisian Geopsy. Hasil HVSR (Nisbah Spektral Menegak Mendatar) ini adalah indeks kelemahan tanah. Keputusan kajian ini menunjukkan bahawa tiga parameter di atas kemudiannya dianalisa dengan anggapan bahawa jika nilai amplifikasi (A_0) adalah lebih tinggi dan nilai frekuensi semulajadi (f_0) lebih rendah dengan indeks kelemahan yang tinggi (K_g), maka kawasan ini mempunyai potensi pencairan. Penyelidikan makmal yang dilakukan pada kajian ini berupa ujian tingkatan granular sebagai data sokongan. Oleh itu, hasil analisis dan ujian makmal menunjukkan lokasi penyelidikan ini iaitu Jalan Majapahit mempunyai potensi pencairan akibat lalu lintas kenderaan.

KEYWORDS: *liquefaction; flexible pavement; soil vulnerability index (K_g); seismic monitoring; HVSR (Horizontal Vertical Spectral Ratio) method*

1. INTRODUCTION

The liquefaction phenomenon is the behavior of collapsed soil that occurs over a short period of time that is caused by dynamic load [1]. According to Legrans [2], liquefaction is a condition where the soil experiences continuous deformation at residual stresses or low residual resistance caused by the formation of high pore pressure that decreases effective pressure. The increase in pore water pressure that causes liquefaction can be caused by static or cyclic stresses, and the possibility of liquefaction depends on the number of pores, the relative density, and total pressure. Soil mass suddenly experiences a transition from a solid state to a liquid state or has a major consistency like a liquid. One of the main requirements for liquefaction includes the presence of dynamic load on loose sandy soil (not dense) that is saturated with water. However, some studies assume that liquefaction is only triggered by earthquakes [3-5]. The impact of liquefaction itself could trigger a problem in the structure of single- or multi-storey buildings and also the pavement structure. The liquefaction phenomenon, as illustrated on Fig. 1, occurred in 2011 as the result of the earthquake in Christchurch, New Zealand. The liquefaction phenomenon caused all pavements to be submerged by water and sand boiling to occur.

Fig. 1: The impact of liquefaction in Christchurch, New Zealand [6].

Kusumawardani [7,8] argues that the liquefaction potential can also occur in vibrations that have a low frequency but occur repeatedly over a long time. Her study was continued in the following year by analyzing the behavior of soil particle vibrations due to vehicle types [9] and thickness of the pavement [10]. The acceleration of soil particles in subgrade was examined by 3-way review (x, y and z). The analysis results showed positive correlation between vehicle type, pavement thickness and acceleration. These parameters have contributed to the behavior of the soil particle acceleration that it passes through. Changes in the behavior of particle acceleration caused the load of passing vehicles affected the performance of the flexible pavement system. The flexible pavement system resisted the load of the passing vehicle and then transmitted the load from the top layer to the layer below. The soil vibrations caused by traffic, industry, and human activity on the earth's surface are called micro tremor vibrations. Micro tremor data can be analyzed using the HVSR (Horizontal to Vertical Spectral Ratio) method [19]. When the vehicle passed, the soil particles under the pavement moved from their original position to find their stability. The illustration of particle movements under the pavement is contained in Fig. 2. The loading from the vehicle passage is assumed to be dynamic loading. Soil, as a propagation medium for a dynamic wave, has dynamic properties that show the ability of the soil to support a dynamic load. The soil could collapse when the effective soil decreases as an effect of dynamic load to the soil mass particles. This raises the assumption that liquefaction can be caused by the load of passing vehicles.

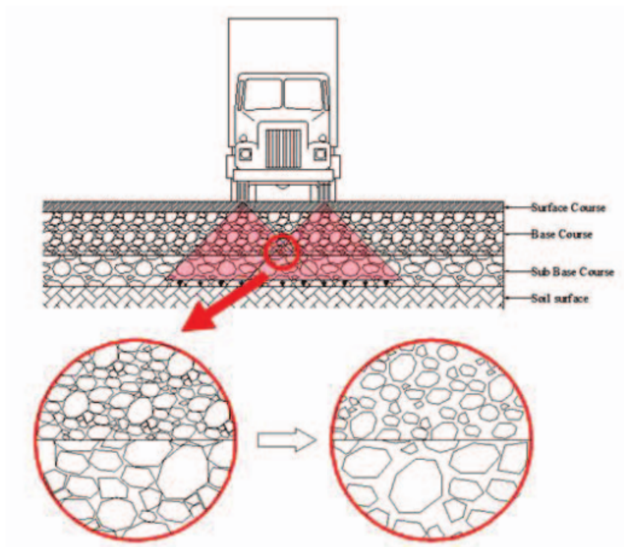


Fig. 2: Illustration of soil particle movement due to vehicle load passed [9].

2. STUDY OF LITERATURE

2.1 The Soil Vulnerability Index (Kg)

The soil vulnerability index is a parameter used in identifying a vulnerable area against strong soil motion [11]. This parameter shows the soil resistance index against deformation for receiving seismic and dynamic loads. To figure out the index, the Horizontal to Vertical Spectral Ratio (HVSR) method is generally used [12]. This method compares the ratio of the horizontal components to the vertical components of the micro tremor signal spectrum [13]. The micro tremor signal is obtained from the accelerometer data installed in the field that consists of three components: vertical (z), horizontal x (North-South) and horizontal y (East-West). The Fast Fourier Transform (FFT) algorithm was used to analyze the results of field measurement. The comparison value of horizontal and vertical components (H/V) was obtained using HVSR analysis. The result was represented in the H/V amplitude versus frequency curve (Fig. 3).

The curve in Fig. 3 shows the predominant frequency value and amplification factor, which was then used to calculate the soil vulnerability index (Kg) using the following equation:

$$K_g = \left(\frac{{A_g}^2}{\pi^2 f_g v_b}\right) \quad (1)$$

where, K_g is soil vulnerability index, A_g is soil amplification, f_0 is natural frequency (Hz) and v_b is wave velocity (m/s^2).

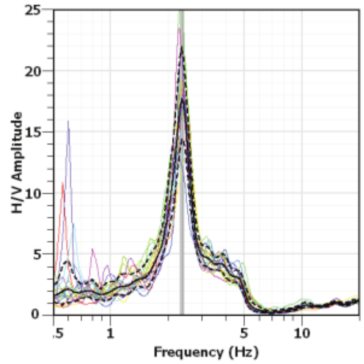


Fig. 3: The H/V amplitude versus frequency curve was obtained by using HVSR analysis [14].

2.2 Micro-Seismic Data

A load that occurs repeatedly that can cause liquefaction is also called a micro seismic vibration. Micro seismic vibration itself is soil vibration caused by traffic, industry, and human activity on the earth's surface. Sources of soil vibrations caused by natural factors such as the interaction of wind and building structures, earthquakes, currents, and long period ocean waves can also affect micro seismic vibrations [15]. Micro seismic vibration is a natural vibration (ambient vibration) that could come from two main sources: natural and human factors [13]. Records of soil motion always contain ambient vibration (micro seismic). It shows that the soil is never really in a state of silence without vibration. All energy sources generate seismic waves such as the sea and continuous meteorological disturbances. Therefore, they become a background of noise at all times [16].

3. METHODOLOGY OF RESEARCH

3.1 Study Area

The location of the study was Majapahit Street, Semarang, Central Java which can be seen in Fig. 4. In this location, the occurrence of road damage was detected annually. This area is known as busy area traffic in Semarang city. The numbers of passing vehicles, variations in the type of vehicles passing and the type of pavement are the parameters in this study. Some field investigation was conducted during the research, there was manual traffic counting and installation of a set of acceleration equipment. The study area was selected considering the ease of access, heavy traffic flow, and ease of data retrieval.

3.2 Field Investigation

Field investigation at the location of the study was aimed at looking at the pavement condition of the road to be examined and determining the position of seismic monitoring equipment. The equipment placement model was based on previous research, where the sensor devices were embedded under the pavement. Variations in the placement of sensor devices and the thickness of pavement were carried out to determine the behavior of particles caused by traffic loads [7,17]. During the testing, the accelerometer was placed beneath the pavement. The illustration of the investigation field can be seen in Fig. 5(a).

The peak traffic hour was selected for the equipment installed during data retrieval. By combining with a set of video cameras to capture the type of passing vehicle, the correlation of the passing vehicle type and the micro tremor data was obtained.

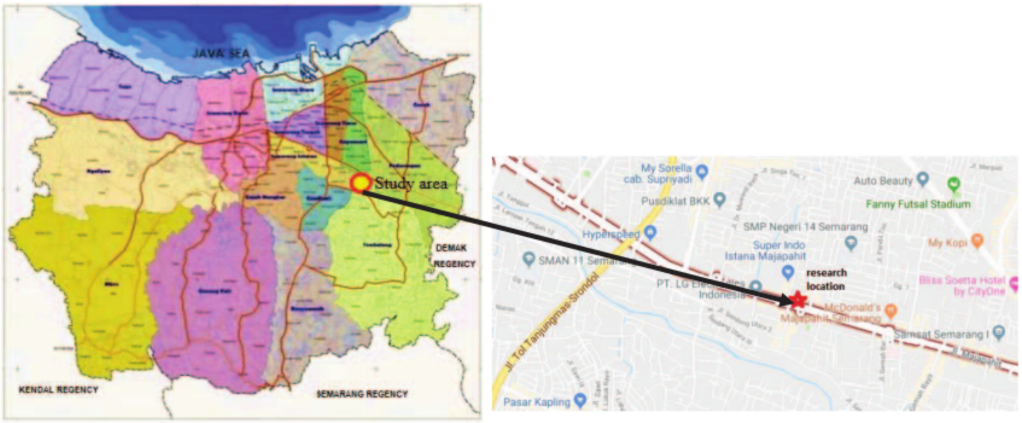
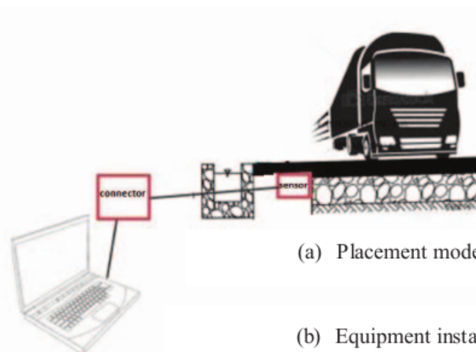


Fig. 4: Map of the study location.



(a) Placement model for equipment

(b) Equipment installation during the research

Fig. 5: Installation of the accelerometer in the field.

3.3 Geopsy

This software, which is popular in the geophysics field, processes the field investigation data obtained from acceleration recording. When the data processing is running, several windows appeared that indicated the three-directional signal obtained

(Fig. 6). The information suggested by geopsy is recording time, number of signals, and frequency. After finished the analysis process, the result of the geopsy is the spectrum that described the natural frequency (f_0) and soil amplitude (A_0) of the study area.

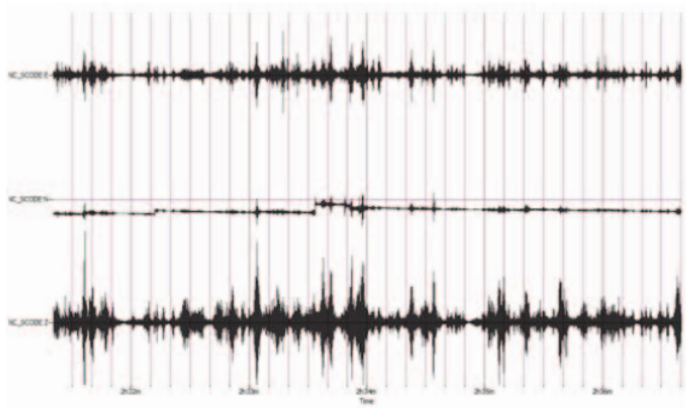


Fig. 6: Geopsy result data.

4. RESULTS AND DISCUSSION

4.1 Average Daily Traffic

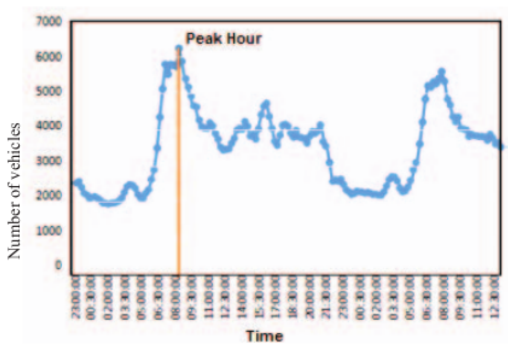


Fig. 7: Number of vehicles during peak hours at Majapahit Street.

In order to obtain the vehicle's average daily traffic data on Majapahit Street, a three-day survey was conducted to obtain the traffic characteristics in the study area. This preliminary investigation was carried out to determine the estimated peak hours on the study area. The data of numbers of vehicles during peak hours was obtained by an observation for 48 hours with a 15 minute observation interval. From Fig. 7, it can be concluded that the peak hours on Majapahit Street usually occurred in the morning hours, (08.00-09.00). Data was gathered for 1 hour by preparing seismic monitoring sensor equipment to record waves every 5 minutes.

4.2 Natural Frequency (f_0), Amplification (A_0) and Soil Vulnerability Index (K_g)

The natural frequency is the frequency that often appears or the frequency of the rock layer. It indicates the type and characteristics of the rock in the study area. High frequency values reflect more massive rock material such as andesite breccia rock, while low frequency values indicate sediment at the location of study where there is topsoil or clay on the surface. The low frequency value confirms that the location experiences damage caused by severe vibration [12].

The value of soil amplification can increase if the rock has experienced deformation (weathering, folding or faulting) that changes the physical properties of the rock. In the same area, the amplification value varies according to the level of deformation and weathering of the rock [18]. In Nakamura [13], the value of soil amplification is related to the ratio of the contrast impedance of the surface layer to the layer below. Figures 8 and 9 are micro tremor data and H/V graphs obtained at the location of the study. Recapitulation of the results of natural frequency analysis, amplification, and vulnerability of soil at the location of the study can be seen in Table 1.

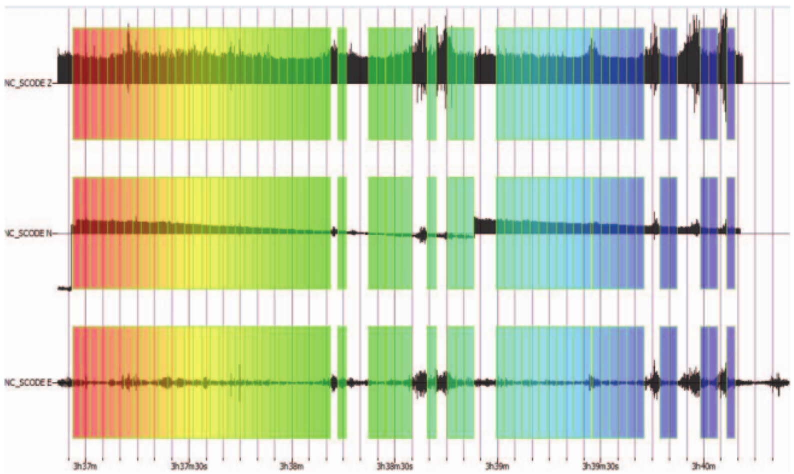


Fig. 8: The micro tremor data display at Majapahit Street after being processed using Geopsy software.

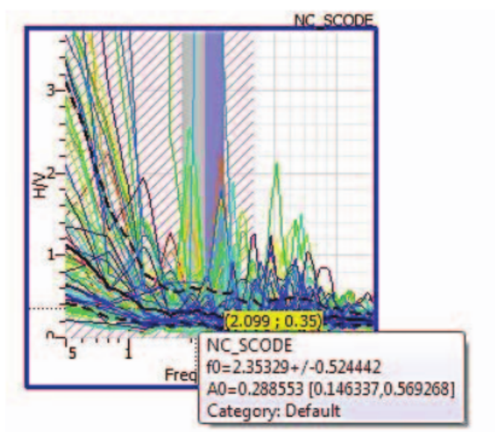


Fig. 9: The display of H/V graph at Majapahit Street with the results of natural frequency (f_0) 2,35329 and amplification (A_0) 0,288553.

5. CONCLUSION

The study of the analysis of liquefaction potential on flexible pavement using seismic monitoring equipment concluded these following results:

a) The results of the micro tremor data from seismic monitoring equipment were in the form of natural frequency (f_0) and amplification (A_0). The two parameters were processed using the HVSR (Horizontal to Vertical Spectral Ratio) method to generate the soil vulnerability index of each location of the study.

b) To analyze the liquefaction potential at the location of the study, it is assumed that the higher amplification value (A_0) leads to the greater value of the soil vulnerability index (K_g) in the location associated with the low natural frequency value (f_0). These parameters indicated liquefaction potential.

c) From the location of the study, the results of 1 hour of data collection using seismic monitoring equipment were then processed and analyzed. It was concluded that the location of the study had the potential for liquefaction.

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PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9