study of Initial liquefaction

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The Analysis of Liquefaction phenomenon on the Flexible Pavement using Seismic Monitoring Equipment

Abstract: Liquefaction phenomenon is generally caused by high dynamic vibrations in a very fast 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 (f0) and amplification (A0) using Geopsy software. The result of HVSR (Horizontal Vertical Spectral Ratio) was the soil vulnerability index (Kg). The results of this study indicated that the three parameters above were then analyzed with the assumption that if the amplification value (A0) was higher and associated with a lower natural frequency value ($f0$) with a high vulnerability index (Kg), then the area had the 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 can concluded that the three research locations have the potential liquefaction.

Keywords: liquefaction, flexible pavement, soil vulnerability index (Kg), seismic monitoring, HVSR (Horizontal Vertical Spectral Ratio) method

1. INTRODUCTION

The liquefaction phenomenon is the behavior of collapsed soil that occurs in a short period of time which is caused by dynamic load (Kusumawardani, 2016). According to Seed (1979) in Legrans (2016), 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 the static or cyclic stresses, and the possibility of liquefaction depends on the number of the pores, 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 (Warman, 2013). One of the main requirements for liquefaction includes the presence of dynamic load on loose sandy soil (not dense) and saturated with water. Howevter, some studies assume that liquefaction is only triggered by earthquakes (Seed, 1968; Oshaki, 1966; Seed and Idriss, 1982). While, the impact of liquefaction itself can occur on the structure of buildings / multi-storey buildings and also the pavement structure. Liquefaction phenomenon as illustrated on Figure 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 occurs (Oetomo, 2013).

Figure 1 The Impact of Liquefaction in Christchurch, New Zealand

Kusumawardani (2014, 2016) argues that the liquefaction potential can also occur in vibrations that have a low frequency but occur repeatedly in a long time. Her study was continued in the following year by analyzing the behavior of soil particle vibrations due to vehicle types (Kusumawardani, 2017) and thickness of the pavement (Kusumawardani, 2018). 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 (Lestari 2016). This raises the assumption that liquefaction can be caused by the load of passing vehicles.

2. STUDY OF LITERATURE

a. The soil vulnerability index (Kg)

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 (HSVR) method is generally used (Kurniawati, 2017). This method compares between the ratio of the horizontal components to the vertical components of the micro tremor signal spectrum (Nakamura, 1989). The micro tremor signal is obtained from the accelerometer data installed in the field which 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 by using HVSR analysis. The curve shows the predominant frequency value and amplification factor, which was then used to calculate the soil vulnerability index (Kg) by using the following equation:

$$K_g = (\frac{{A_g}^2}{\pi^2 f_g v_b})$$

Where A_g is amplification factor, f_g is predominant frequency and v_b is shear wave velocity beneath of soil (m/s).

b. Micro seismic data

The load that occurs repeatedly which can cause liquefaction is also called micro seismic vibration. Micro seismic itself is soil vibration caused by traffic, industry, and human activity on the earth's surface (Lestari, 2016). 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 (Petermans, 2006).

Micro seismic is a natural vibration (ambient vibration) which comes from two main sources: natural and human factors (Nakamura, 2000). 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 of energy sources generate seismic waves such as the sea and continuous meteorological disturbances. Therefore, they become the background of noise at all times (Febriani, 2013).

3. METHODOLOGY OF RESEARCH

a. Area of the Study

This research was carried out on several roads in Semarang, Central Java, Indonesia. The location of the study was Komodor Laut Yos Sudarso, Majapahit Road, and Semarang - Solo Road which can be seen in Figure 2. The number of passing vehicles, variations in the type of vehicles passing and the type of pavement used in the three roads which is flexible pavement are the parameters in this study.

Figure 2. The Map of the Location of the Study (Source: penataanruangjateng.info, 2011)

b. 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 determine the point of seismic monitoring equipment. The placement model of the equipment was based on previous research (Nugroho, 2016; Kusumawardani, 2016a; 2016b). Variations in the placement of sensor devices and thickness of pavement were carried out to determine the behavior of particles caused by traffic loads. The illustration of the investigation field can be seen in Figure 3.

Figure 3. The Location of the Accelerometer placement at the field

4. RESULTS AND DISCUSSION

a. (Average Daily Traffic)

The vehicle's average daily traffic data on Majapahit Street which can be seen on Figure 4 was obtained using a three-day survey: on Sunday April 19 2015, Monday April 20 2015, and Tuesday April 21, 2015. The data were obtained by observation for 48 hours with a 15 minute observation interval. From Figure 4.1, it can be concluded that the peak hours on Jalan Komdor Yos Sudarso usually occurred in the morning hours, which are around 08.00-09.00. Data were gathered for 1 hour by preparing a seismic monitoring sensor equipment to record waves every 5 minutes.

Figure 4. The Graph of Peak Hours at Jalan Majapahit

b. Natural Frequency (f0), amplification (A0) and soil vulnerability index (Kg)

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 the sediment at the location of the study where there are topsoil or clay on the surface. The low frequency value confirms that the location experiences damage caused by severe vibration (Putri, 2017).

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. At the same area, the amplification value varies according to the level of deformation and weathering of the rock (Arifin, 2014). In Nakamura (2000), the value of soil amplification is related to the ratio of the contrast impedance of the surface layer to the layer below. The soil vulnerability index is a parameter used in identifying a vulnerable area against strong soil motion (Karyono, 2016). Figures 5 and 6 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 on Table 1

Figure 5 The Micro Tremor Data Display at Jalan Komdor Laut Yos Sudarso after being processed using Geopsy Software

Figure 6 The Display of H/V Graph at Jalan Komdor Laut Yos Sudarso with the Results of Natural Frequency (f_0) 2,35329 and amplification (A0) 0,288553

Table 1. The Recapitulation of Analysis on Natural Frequency and Amplification at Yos Sudarso Road

No	Natural frequency (f_n)	Amplification (A_0)	Vulnerability Index (Kg)
1	2.35329	0.288553	0.035381459
2	1.98380	0.282897	0.040342128
3	2.00005	0.295896	0.043776127
4	1.60213	0.299765	0.056087243
5	2.17203	0.299776	0.041374037
6	1.48574	0.282801	0.039649202
7	2.06225	0.414651	0.115723782
8	2.38107	0.258215	0.032331185
9	1.58632	0.271363	0.030926381
10	2.06523	0.284753	0.0511147
11	1.58490	0.304858	0.045001477
12	1.98380	0.303641	0.045001477
Range	**1.48574 - 2.38107**	**0.258215-0.414651**	**0.030926-0.11572**

3. Identification of Liquefaction Potential

The analysis of the liquefaction potential identification was conducted after obtaining the amplification value (A0) and natural frequency (f0). The equation (1) was used to obtain the value of the soil vulnerability index (Kg) at each point of the location of the study. The smallest data on natural frequency data (f0) and the highest value of Amplification (A0) and the value of the soil vulnerability index (Kg) were used. If the three parameters in one data were related to the assumptions used to determine the liquefaction potential in flexible pavement, then it can be concluded that the liquefaction potential could occur at the location. Based on Table 1, it can be seen that data number 7 shows a high amplification value and a low natural frequency value. As a consequence, the high soil vulnerability index value is obtained. This result indicate the liquefaction potential. The results of the analysis are illustrated in the micro zonation map on Figure 7.

Figure 4.7 Micro zonation Map of Liquefaction Potential

From Figure 4.7, it can be seen that the high amplification (A0) value is associated with a low natural frequency value (f0) so that a high vulnerability index (Kg) is obtained. It can be concluded that liquefaction can potentially occur on Jalan Komdor Laut Yos Sudarso.

5. CONCLUSION

The study on 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 (f0) and amplification (A0), then 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 (A0) lead to the greater value of the soil vulnerability index (Kg) in the location associated with the low natural frequency value (f0). These parameters indicated liquefaction potential.

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

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