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Investigation of Subgrade Particles Acceleration due to Dynamic Loading

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Abstract - Detail investigation on flexible pavement due to of vehicles traversed was presented in this paper. The behavior of subgrade particles acceleration on flexible pavement was investigated and is explained in order to obtain the comprehensive understanding about pavement. Investigation was conducted in the highway which has a yearly construction problem. The data collected from field investigation represents the correlation between soil particles acceleration (*a*) depends to time (*t*) in three axis main principal direction (*x, y and z axis*) movements. The main objective of this work is to evaluating the effects of vehicle traverse on the pavement to several parameters, such as soil particles acceleration and the thickness of subgrade. The results revealed that the soil particles acceleration due to of motorcycles traversers loading recorded at 0.0002 – 0.0005 m/s^2. Furthermore, due to of car and truck loading traverses are 0.0006 – 0.00085 m/s^2 and 0.0012 – 0.0045 m/s^2 respectively. The subgrade thickness has an influenced on the level of soil particles accelerations. Soil particles acceleration in the middle of subgrade reaches the maximum value for both types of vehicles.
Keywords: soil articles acceleration, subgrade, vehicles, flexible pavements

Introduction

In Indonesia, the problems concerning on highway resistance occurred every year. The physical damage was found on the highway, such as surface cracking, bumpy and pothole. Some practices indicated the weather and overloaded vehicles traversed as triggering factors of the highway damage. Many researchers for three decades have been exploring various methods of modeling and sensing a dynamic traffic loading to predict the behavior of subgrade when subjected the vehicles loading (Junhua, 2016; Sergio, 2016; Shuang, 2015; Nugroho, 2016).)

A reasonable description of the ground motion is thus necessary to predict the behavior of pavement and comprehensive results could be reached in order to design the suitable highway structure. The effect of vehicle motion on the road embankment was examined by many researchers (Aung, 2011; Boroweic, 2013; Olmsted, 2009; Raper, 1995). Olmstead (2009) was detailed an estimation of vertical stress subjected to vehicular loading to the subgrade pavement. From his analysis depicted that soil types and soil moisture as factors initiating the differences of vertical loading due to of vehicles motion and it pointed out that the combination between pressure pads embedded on the soil have a great contribute to the difference subgrade behavior by the increasing the vertical loading on the sand with higher moisture. Furthermore, Yang (2011) and Boroweic (2014) discussed a failure of pavement and road embankment due to water level and soil moisture. Their study revealed that a failure on pavement trigger by an increasing pore water pressure under vibratory traffic load with the presence of water on soil pores. Furthermore, Kusumawardani (2016) discussed the dynamics behavior of clean sand under low frequency of dynamic loading. From his research, it depicted that soil particles under repetition of dynamic loading have surprising behavior with indication soil tends to liquefy.

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Furthermore, Kusumawardani (2016) discussed the dynamics behavior of clean sand under low frequency of dynamic loading. From his research, it depicted that soil particles under repetition of dynamic loading have surprising behavior with indication soil tends to liquefy. Previous research on behavior of soil particles caused by traffic loading also was observed by Kusumawardani (2014; 2015). From the geotechnical dynamical engineering point of view, the vibration due to of vehicles traverses could be classified as repetitive cyclic loading. Vibration due to vehicles motion on soil could reach various levels depend on types of vehicles, soil and thickness pavement. A higher level of vibration may not be acceptable to the pavement structure

Materials and Methods

Study Area

Soil subgrade sample were taken from Gunungpati district, Semarang city and a flexible pavement was chosen as the subject of research. Detail location of study area can be seen in Figure 1. A degradation quality of pavement was indicated by cracking in the asphalt surface and it a sign that soil sub grade could not support vehicle movement as a repetitive load subjected to the pavement. A set of laboratory testing soil parameter were conducted in soil subgrade sample in order to obtain the physical soil sub grade characteristic in detail. This area was mainly dominated by clay and silt with local sand and gravel through the visible and physical preliminary field investigation.

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Method of testing

An accelerometer was employed during the testing. This equipment is a set of field vibration investigation which used to record various types of vibration such as earthquakes, strong vibration or forced oscillation vibrations. The advantage of this equipment system is it consists of accelerometer which could calculate the particles displacements in 3 axis instruments, with a standard measuring range of ± 2g, bandwidth up 100 Hz and dynamic range up to > 120 dB. Furthermore, the data from field investigation delivered through serial communication channel directly to the portable computer. This accelerometer can produce real time function of time and velocity data because it was equipped with an automatic data acquisition. Many researchers widely used this equipment in seismic research and to monitor the behavior of seismic or the dynamic response of technical works and constructions.

This study was conducted in two stages. Firstly, installing the accelerometer embedded the various levels of depths. Secondly, set up a portable computer in the other side in order to obtain computerized results of vibration. The aim of installation of accelerometer at various depths from soil surface was conducted to obtain a vibration of sub grade material caused by vehicles motion which traverses a pavement. An instrument of data acquisition system was completed for recorded soil particle motion in 3 directions axes. Description of installation seismic monitoring testing during field investigation could be seen in Figure.2.

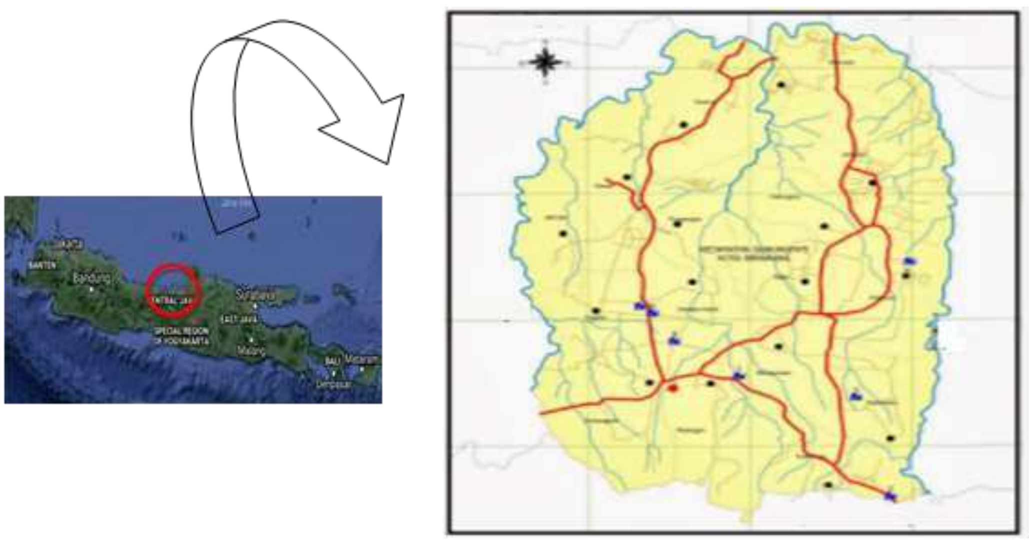

Figure 1. Location of Study area

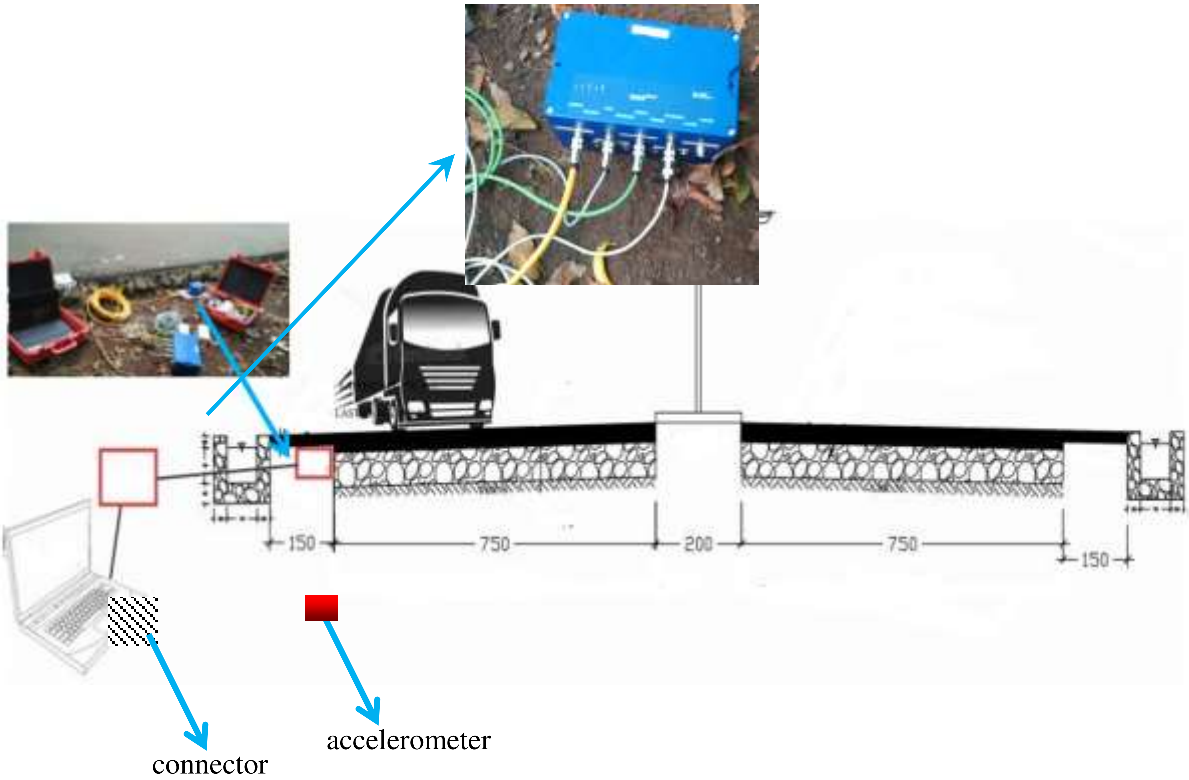

Figure 2. Installation of seismic monitoring unit during field investigation

Results and Discussion

Materials properties

A series of laboratory testing was conducted on sub grade materials in order to get a comprehensive result of soil physical characteristics. In this study, a unified soil classification systems (USCS) was chosen as a method of soil type determination. The test results of soil properties of subgrade are presented in Table 1. The soil samples are brown to dark brown, loosely to medium density, mainly composed of clay and silt size fraction with little sand and gravel. Disturbed soil samples were identified their soil properties by using Atterberg limit, soil moisture testing and combination of sieve and hydrometer methods for particle size distribution. The distribution of grain size of the soil sample is presented in Figure 3. According to Unified Soil Classification System (USCS), the soil sample was classified as MH or OH. Physical properties of soils demonstrate that the sub grade has specific gravity 2,59

Table 1. Soil properties of sample

Variables	Unity	Results
Moisture content (w)	%	31.60
Specific volume (G_s)	gr/cm³	2.59
Degree of saturation (S_r)	°	69.91
Porosity (n)	-	46.24
Void ratio (e)	-	0.86
Cohesion (c)	gr/cm²	0.8
Internal soil friction (φ)	°	25.11
Coefficient of uniformity (C_u)	-	20
Coefficient of gradation (C_c)	-	7

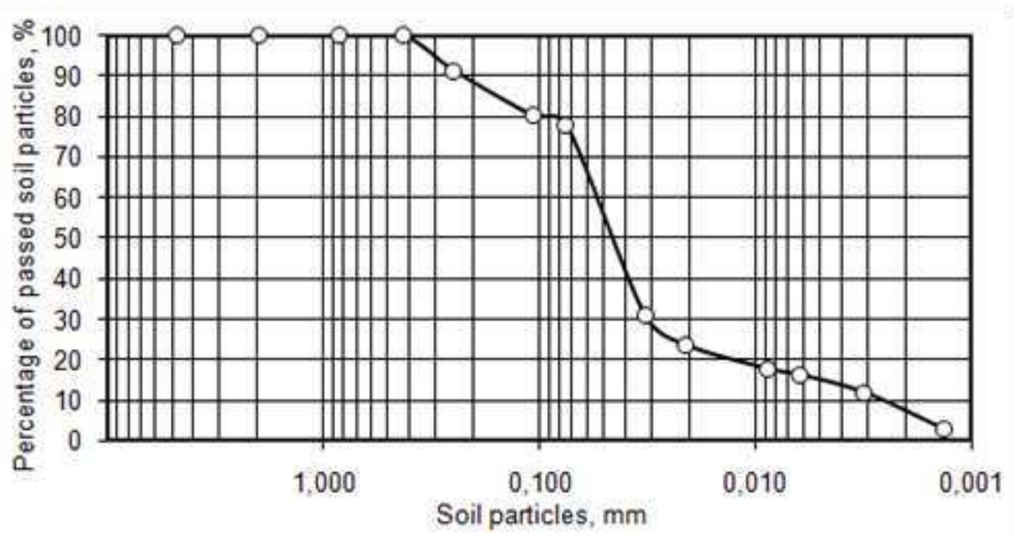

Figure 3. Soil grain size analysis of soil sample

Acceleration of subgrade soil particles

An acceleration of soil particles in three axes directions (x, y and z) dependent with time was measured by using a field investigation monitoring system as described above. From this system, the magnitude of acceleration could be identified in every second of real time monitoring. From Figure. 5, it pointed out the type of vehicles traverse contribute an influence of soil acceleration particles magnitude. The *y*-direction revealed the most valuable of acceleration and *x*-direction reached the smallest value. This result revealed due of the vehicles traverses on the pavement, it triggers the displacement of soil particles in the three directions. It is noteworthy that the acceleration in the *y*-direction (vertical) reached almost two times of acceleration in *x* (horizontal) and *z* (perpendicular) – direction.

Figure 4. GeoSig accelerometer and its direction

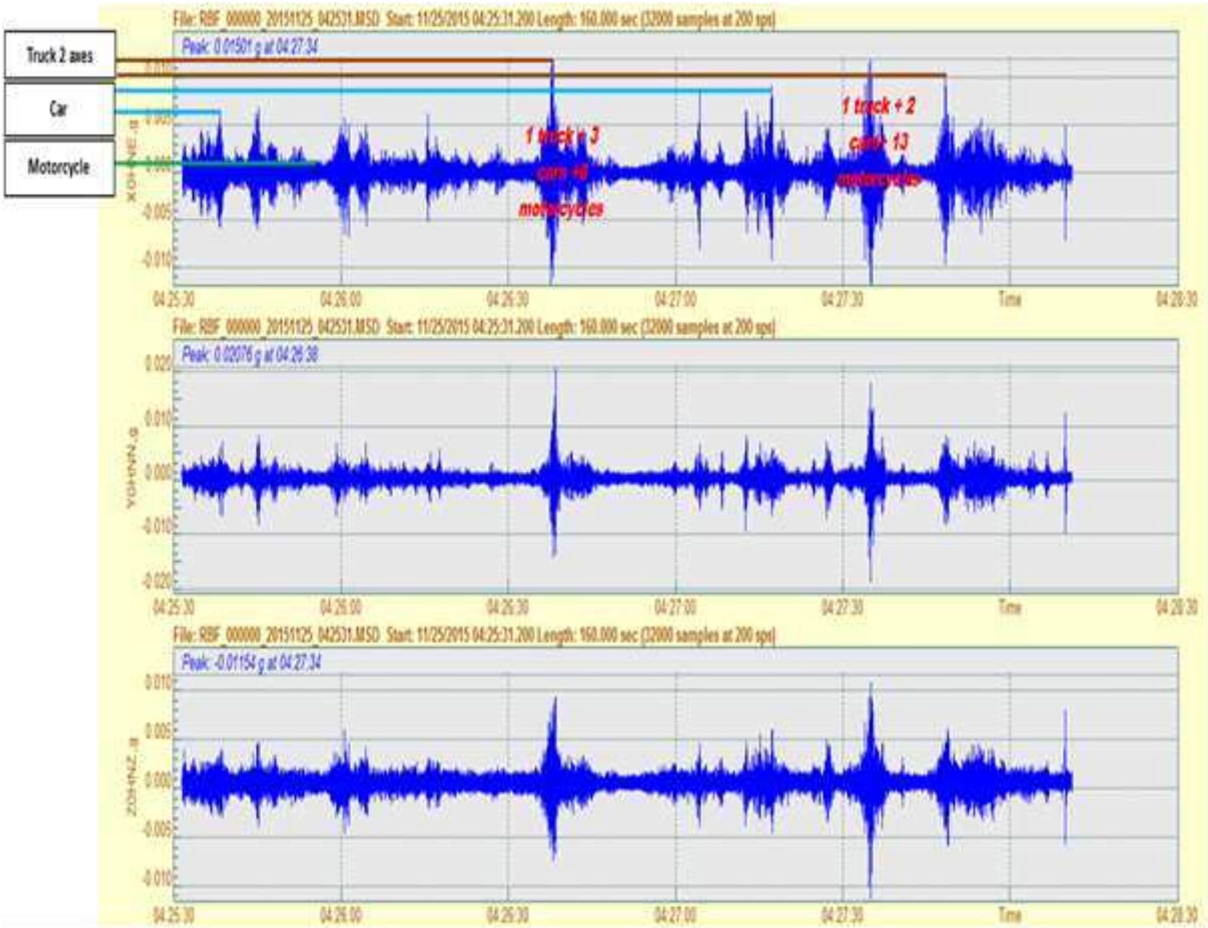

Figure 5. Soil vibration motion in three axis direction

Effect of vehicles type

Soil particles acceleration was induced by types of vehicles and number of passed. From Figure .6 below, it illustrated that an acceleration of soil particles for motorcycles ranged at 0.0002 – 0.0005 m/s^2. The acceleration soil particle was caused by type vehicles of car and truck within the range of 0.0006 – 0.00085 m/s^2 and 0.0012 – 0.0045 m/s^2. In this case, the accelerometer was embedded 30 cm from pavement surface (top of soil surface). The results of investigation revealed both have a same trend line which concluded that each type of vehicles have a range of value acceleration even though the number of vehicles passed increasing. This phenomenon explained that the traffic load which described vehicles traverse subjected to the pavement. Thus, it converged to the subgrade. It also could be said that the traffic loading trigger contribute the acceleration of soil particles displacement. The results of three different locations also reach the similar magnitude soil particles acceleration. This result is depicted in Table 2 below

Table 2 Soil particle acceleration due to of traffic load

Research site	Type of vehicle	a_s (m/s^2)
Patemon street	Motorcycle	0.00020-0.00054
	Car	0.00070-0.00098
	Truck 2 axes	0.00120-0.00440
Cangkiran street	Motorcycle	0.00020-0.00049
	Car	0.00068-0.00090
	Truck 2 axes	0.00140-0.00440
Gunungpati street	Motorcycle	0.00020-0.00045
	Car	0.00060-0.00080
	Truck 2 axes	0.00100-0.00263

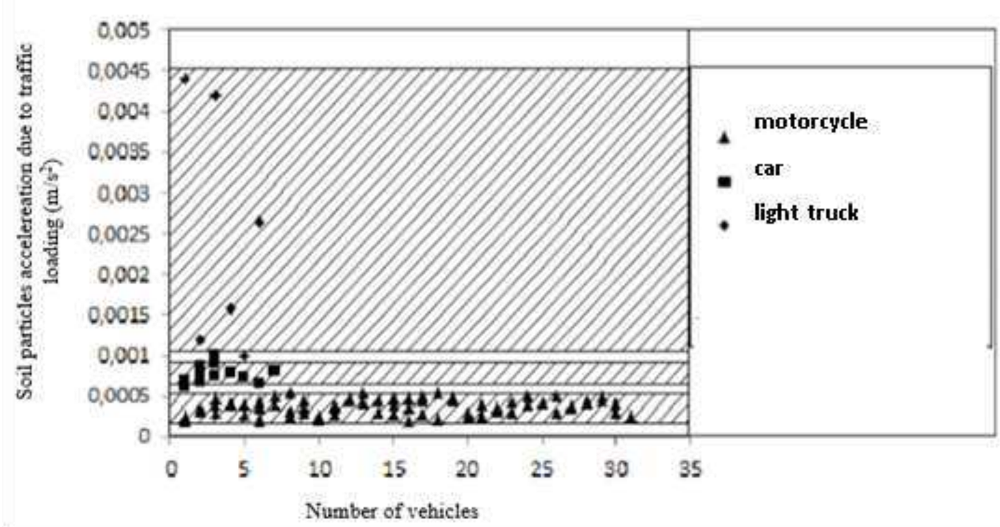

Figure 6. Soil particles acceleration due to traffic load based on type of vehicles

Effect of depth

During the investigation, three types of installation of accelerometer were conducted. It embedded on surface of pavement (model A), in the middle of subgrade (model B) and at the bottom of subgrade (model C). The illustration of installation of equipment is described in Figure. 7 and the results are shown in Table 3

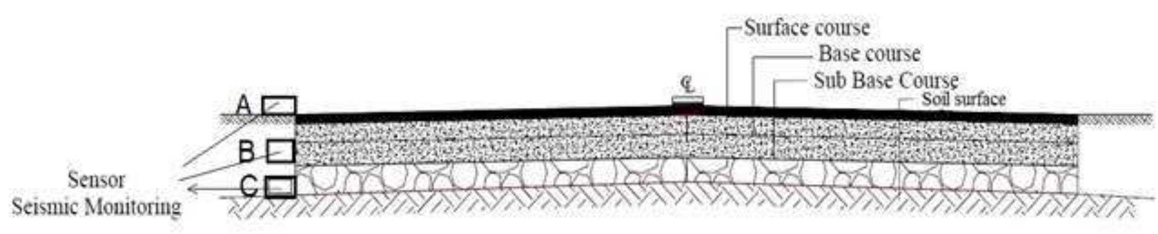

Figure 7. Soil particles acceleration due to traffic load based on type of vehicles

Table 3 Soil particles acceleration based to installation of embedded the accelerometer

Types of vehicles	**Soil particles acceleration (m/s^2)**		
	Model A	**Model B**	**Model C**
Motorcycle	0.001 – 0.003	0.0012 – 0.004	0.002 – 0.0059
Car	0.004 – 0.006	0.00477– 0.00855	0.006 – 0.01
Light truck	0.006 – 0.01	0.009 – 0.017	0.015 – 0.028

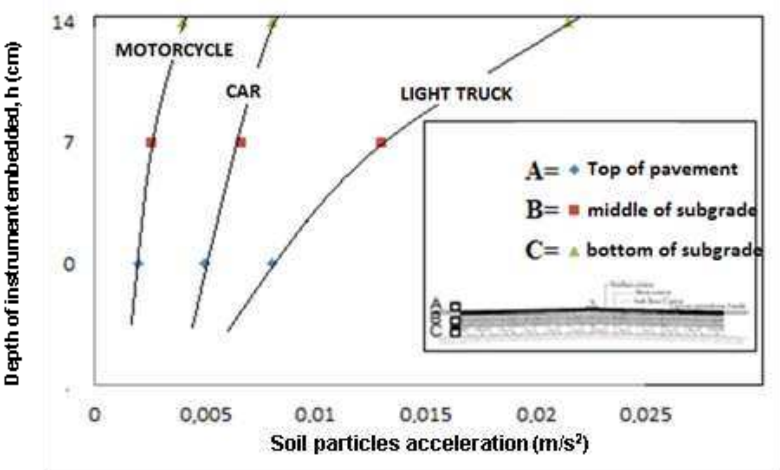

Figure 8. Soil particles acceleration due to traffic load based on type of vehicles

Conclusions

The dynamic source loading from vehicles traverses trigger the acceleration deformation of particles. Field investigation data indicated the magnitude soil particles acceleration (*a*) in –*y* direction (verticals) mostly reached two times compared to other direction (-*x* and –*z* direction. For motorcycles, the magnitude of a_x (in -*x* direction), a_y (in -*y* direction) and a_z (in -*z* direction) are 0.1*g*, 0.2*g* and 0.8*g* respectively. If the soil subgrade of highway composed mostly from sand and dynamic loading subjected on it, its particles moves in order to obtain its stability. The types of the vehicles also contributed to the magnitude of soil particles acceleration. The soil particles acceleration due to of motorcycles, car and truck traversers loading recorded were 0.0002 – 0.0005 m/s^2, 0.0006 – 0.00085 m/s^2 and 0.0012 – 0.0045 m/s^2 respectively

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