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THE IMPACT OF VEHICLE LOAD INDUCING VIBRATIONS ON THE SUBGRADE SOIL PARTICLE ACCELERATION

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Abstract

This paper revealed the description of subgrade soil particles vibration induced by vehicles. A field investigation has been conducted to obtain the comprehensive understanding about the behaviour of soil particles vibration by analyzing the interaction between the problem of the frequency and time vibration analysis to the type and technical condition of the road and dynamic vehicle loads caused by traversing vehicles. This paper presents the effects of vehicles movement on the pavement to the soil particles acceleration of subgrade. The field investigation measurements utilized a package accelerometer with velocity triaxial sensors. Soil movement particles were recorded in three axes main principal direction (*x*, *y* and *z*-axis). The results represented the natural frequency of vibrations and the relationship between acceleration (*a*) and time (*t*) of soil particles subgrade in different depth of soil caused by passing vehicles. The findings during the research represent the soil type in the research study was dominated by clay and silt with sand and gravel. When soil particles were in the bottom of subgrade, it reached the maximum acceleration value due to of dynamic traffic loading. A positive correlation was depicted in this paper between parameters of the depth of soil, type of vehicles and soil particles acceleration. The results could develop a new design pavement formulation and predict parameter of pavement destruction such as initial piping of pavement due to dynamic traffic loading.

Keywords: Accelerometer, Dynamic traffic loading, Natural frequency, Soil particles vibration,

Abbreviation

CL	Center Line
EAF	Federal Aviation Administration's Layered Elastic
ESAL	Equivalent Single Axle Load
L	Longitudinal
LEAF	Federal Aviation Administration's Layered Elastic
T	Traverse
USCS	Unified Soil Classification System
V	Vertical
VL	Vertical Longitudinal

1. Introduction

For three decades, many researchers have explored various methods of modelling and sensing a dynamic traffic loading. A reasonable description of the ground motion is necessary to predict the behaviour of pavement and soil settlements [1-3]. Many researchers examined the effect of vehicle motion on the road embankment [4-8]. An estimation of vertical stress subjected to vehicular loading was detailed by Olmstead and Fischer [6]. The combination of pressure pads embedded in soil and LEAF analysis depicted soil types and soil moisture as factors initiating the differences of vertical loading caused by vehicles motion. Sand with higher moisture represented an increasing vertical loading compared to dry sand. A failure of pavement and road embankment caused by water level and/or soil moisture was discussed in [5, 9]. Their studies argued that an increasing pore water pressure under vibratory traffic load was caused by the presence of water on soil pores.

Therefore, it triggered a failure on soil structure to support various loading on it. Furthermore, Kusumawardani et al. [10] discussed the dynamics behaviour of clean sand under the low frequency of dynamic loading. His study revealed that soil particles under repetition of dynamic loading tend to liquefy. The estimation of vehicles speed was observed by Obertov et al. [11]. A single of node sensor which consisted accelerometer was placed on the pavements. The results showed that the vehicles speed accuracy almost reached 90% compared to field investigations. Furthermore, Obertov et al. [11] indicated the estimation of axle distance contributed an impact to the transferred energy of vibrations. The behaviour of soil ground motion was observed by Kusumawardani et al. [12] which revealed that the impact of traversing vehicles as a traffic loading by using study case of Weleri ring road. Furthermore, Nugroho et al. [13] analyzed the ESAL factors of vehicles, which affected the performance of pavements in the similar study area.

From the geotechnical dynamical engineering point of view, this vibration could be classified as repetitive cyclic loading. A higher level of vibration may not be acceptable to the pavement structure and may have an effect such as surface cracking, bumpy and pothole. The effect of vehicles motion on soil on the flexible pavement was being investigated in this study. The objective of this paper is to predict the vibration due to vehicles motion on soil subgrade. The types of vehicles and soil subgrade, the thickness of various pavements were considered as factors influencing the levels of vibrations of soil particles of the subgrade. For this purpose, three types of accelerometer placement were selected be investigated. The detailed was illustrated in Fig. 1. The results of field investigation were recorded to analyze the structural response performance on the flexible pavement under vehicles motion. Secondly, to determine the level of repetitive cyclic induced by vehicle motion on the flexible pavement.

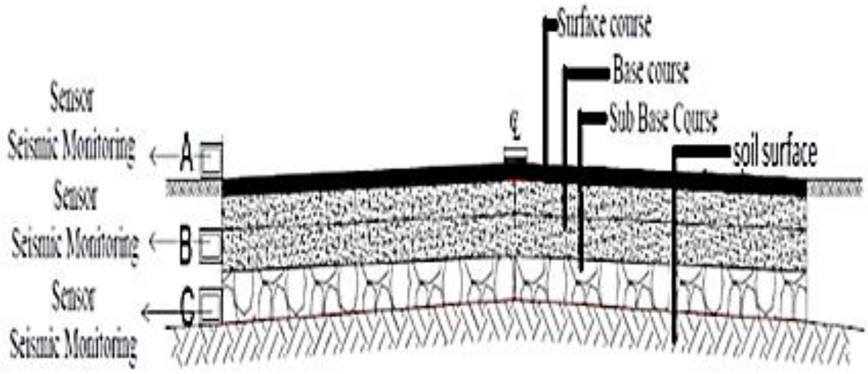

Fig. 1. The placement of accelerometer measurement for recorded the soil particles subgrade vibrations.

2. Methodology

2.1. Study area

The study area was located in Gunungpati district, Semarang city, Java Island, Indonesia. The flexible pavement selected as the subject area was located at Trangkil Street (Location 1), Cangkiran Street (Location 2) and Patemon Street (Location 3). The location of the study area can be seen in Fig. 2. Trangkil and Patemon Street connect the centre of Semarang city to the suburban in the Gunungpati. Thus, the Ungaran-Gunungpati highway has an important function as the connector from one district to another district in Semarang city.

These roads have been selected for reason there are various vehicles passes on those roads such as motorcycle, car and various type of truck. A traffic survey was conducted in order to obtain of average volume data traffic in the research location. During sixteen hours of investigations, it concluded more than 24,490 numbers of vehicles pass. A peak hour of traffic was 9-10 a.m., which the vehicles numbers was reached more than 1,600. Thus, at this certain hours was used as data collecting period with the reason was a huge traffic as a largest dynamic load on the pavements. The hypothesis was a different behaviour of soil particles acceleration induced by various types of vehicles. A soil particle acceleration was observed in the different depth of subgrade by placed the accelerometer instruments beneath of pavement.

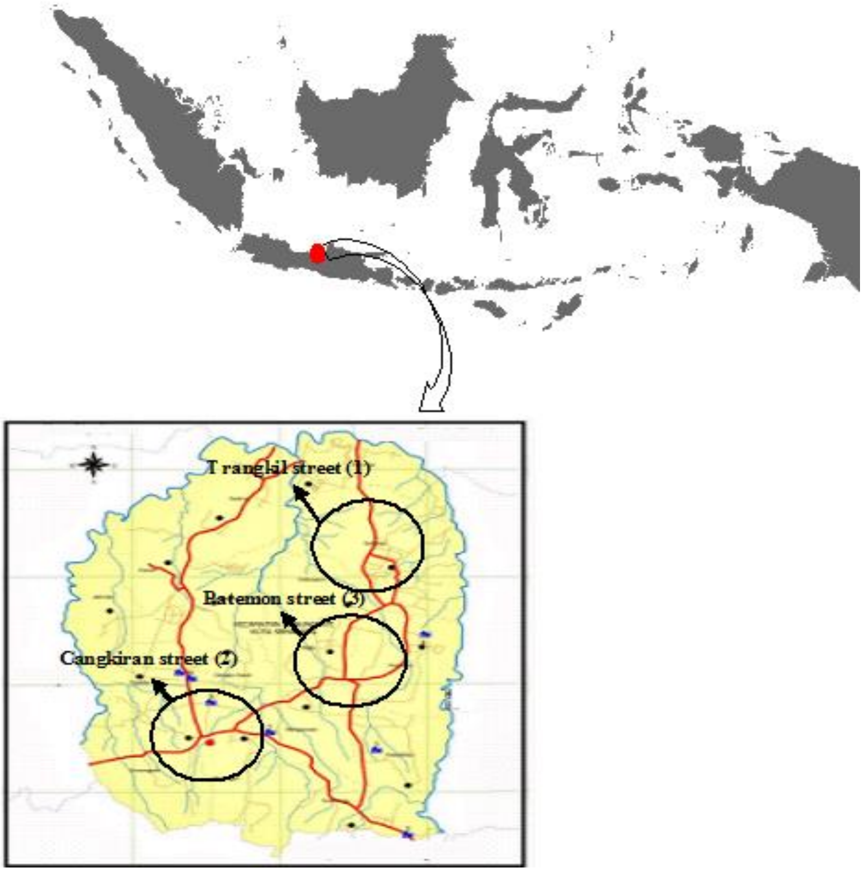

Fig. 2. The placement of accelerometer measurement for recorded the soil particles subgrade vibrations.

2.2. Material properties

Subgrade materials, which supported soil, were investigated by a series of laboratory testing. In this study, type of soil was determined by unified soil classification systems. A series of laboratory testing was conducted to obtain a physical soil parameter. The test results of soil from three locations are presented in Table 1. The soil samples for all study area are brown to dark brown, loosely to medium density, mainly composed of clay and silt size fraction with little sand and gravel. Furthermore, the disturbed soil samples were identified their soil properties by using Atterberg limit, soil moisture testing and the combination of sieve and hydrometer methods for particle size distribution. The soil subgrade as the subject of the study was collected from Trangkil highway, which connected the centre of Semarang city to the suburban in the Gunungpati district. Figure 3 illustrated the grain size of the soil sample. According to Unified Soil Classification System [14], the soil sample was classified as MH or OH. Physical properties of soils demonstrate that the subgrade has specific gravity 2.59. This area was mainly dominated by clay and silt with local sand and gravel.

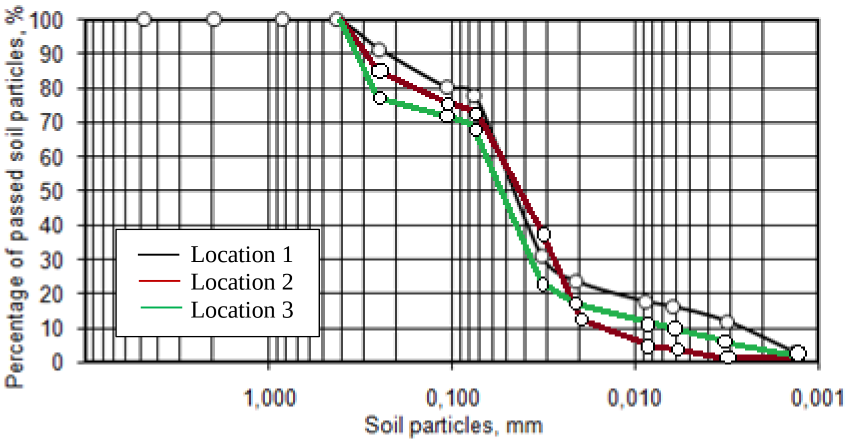

Fig. 3. Soil grain size analysis of soil sample.

Table 1. Soil properties of sample

Variables	**Unity**	**Location of research**		
		1	**2**	**3**
Moisture content (*w*)	%	31.60	27.56	28.33
Specific volume (G_s)	gr/cm^3	2.59	2.63	2.71
Degree of saturation (S_r)	°	69.91	50.28	55,21
Porosity (*n*)	-	46.24	45.34	45.78
Void ratio (*e*)	-	0.86	0.79	0.81
Cohesion (*c*)	gr/cm^2	0.8	0.75	0.8
Internal soil friction (φ)	°	25.11	27.03	26.54
Coefficient of uniformity (C_u)	-	2.0	2.8	6.5
Coefficient of gradation (C_c)	-	7	2.11	6.15

2.3. Method of testing

A set of the accelerometer was employed during the field investigation. This study utilized the accelerometer tri-axis instrument, which is a sensor, which can detect vibration induced wave motion beneath the pavement. This accelerometer produced by GeoSig type AC-7x is a sensor package which has an electro-mechanical triaxial downhole accelerometer designed for broadband vibration monitoring such as earthquake, strong vibration or forced oscillation vibrations.

The triaxial accelerometer detected vibration waves induced by traversing vehicles from three directions, longitudinal (L), vertical (V) and traverse (T). Each direction had a single sensor, which recorded a feedback amplifier in consideration of the stability of the sensor output. The illustration of instrument working system as illustrated in Fig. 4.

In this study, the accelerometer was installed in three different depths; 0 cm, 7 cm and 14 cm below from soil surface respectively. The vibration of subgrade material caused by vehicles motion was observed to obtain a comprehensive behaviour of soil particles acceleration. Three directions of soil particle motion were recorded by utilizing an instrument of data acquisition system. Furthermore, on another side, a set of the portable computer was prepared to obtain computerized results of vibration. The acceleration of soil particle vibration produced by vehicles motion was measured during the certain time of observation. Description of installation seismic monitoring testing during field investigation could be seen in Fig. 5.

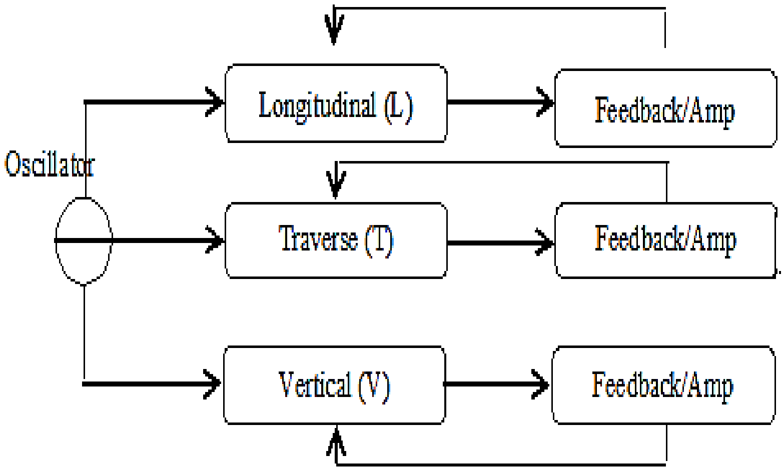

Fig. 4. Concept of tri-axial accelerometer.

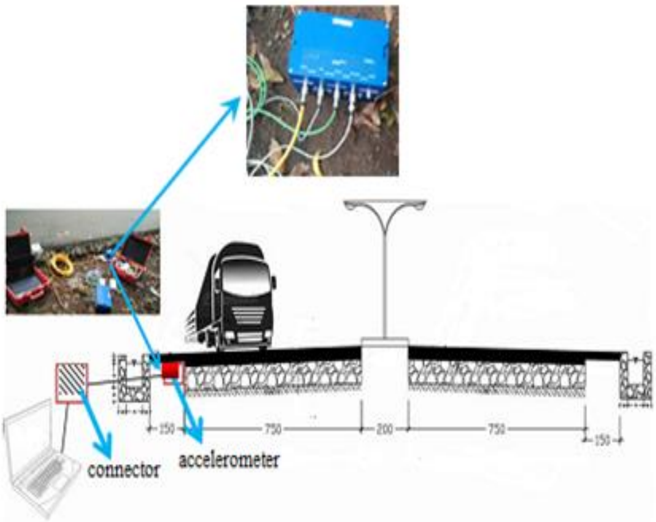

Fig. 5. Installation of seismic monitoring unit during field investigation.

3. Results and Discussion

The soil behaviour induced by passing vehicles during time observation could be analyzed. Alias (1984) stated that passing vehicles influence a low-frequency dynamic load (up to 15 Hz) and the low frequency was transmitted to the ground when a ground natural frequency was reached by the wheel contact dynamic load. The field investigation was conducted in three locations of the study area, there are Trangkil Street (1), Cangkiran Street (2), Patemon and Street (3). The various data obtained from this testing were the soil particles acceleration (*a*) and depth of pavement (*h*) corresponding to the time (*t*). The correlation between depth and soil particles acceleration was concluded from all data.

3.1. The effect of vehicle loading on soil particles acceleration

The accelerometer was installed below the subgrade. The results of soil particles acceleration were illustrated in Fig. 6 and it was recorded in three axes direction (*x*, *y* and *z*). The illustration of placement equipment testing can be seen in Fig. 6.

The results of the field investigation showed that the *x*-direction reached the maximum value in the three-study area. The *x*-direction or the value of soil particles acceleration was almost 1.5 times of -*y* and -*z*-direction. Furthermore, it also indicated that the soil particle acceleration was induced by the type of vehicles. The most and the least triggering types of vehicles on the level of soil particles acceleration are (*a*) are light truck, car, and motorcycle respectively. The soil particles acceleration (a) data obtained from recorded field investigation was illustrated in Fig. 7.

Furthermore, the effect of depth on soil particles acceleration (a) was investigated at Trangkil Street and it was detailed in Fig. 8. The accelerometer was installed on these following depths: 0 cm, 7 cm, and 10 cm respectively from the surface of the subgrade.

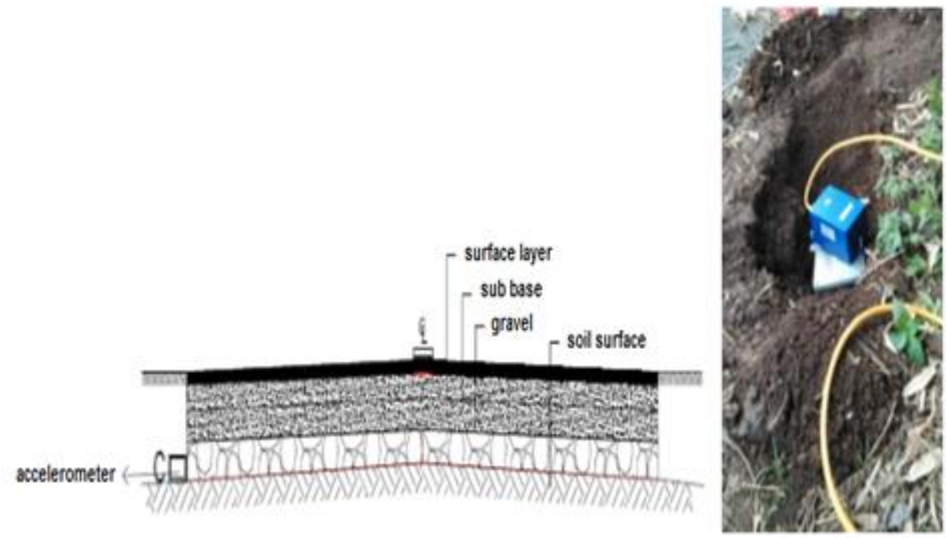

Fig. 6. Installation of seismic monitoring unit during field investigation.

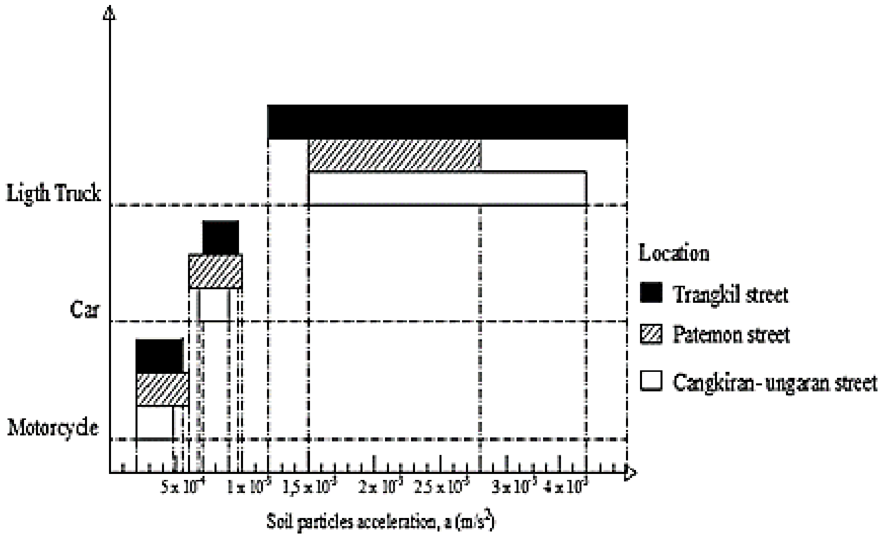

Fig. 7. Soil particles acceleration due to different types of vehicles types.

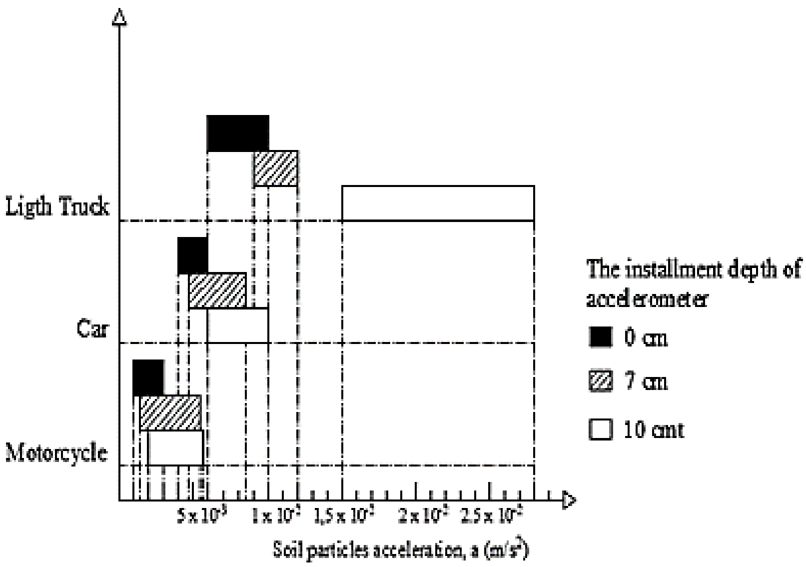

Fig. 8. Soil particles acceleration in different depth due to different types of vehicles types.

3.2. Curvature of soil particles acceleration and depth of subgrade graphic

When the accelerometer was installed in different depths of soil, it has a specific behaviour and revealed in the graphic, which illustrated in Fig. 9. This figure described a correlation of three parameters, which were the type of vehicles, the depth of subgrade and soil particles acceleration. All of the graphics depicted a positive correlation between the increase of slope inclination and vehicle load. The acceleration of soil particles was caused by car and motorcycle loading, the slope inclination smoothly increased the correlation with the soil depth. Furthermore, the soil particles acceleration were subjected by a light truck, it depicted a significant increase of soil particles acceleration when the depth of soil increased.

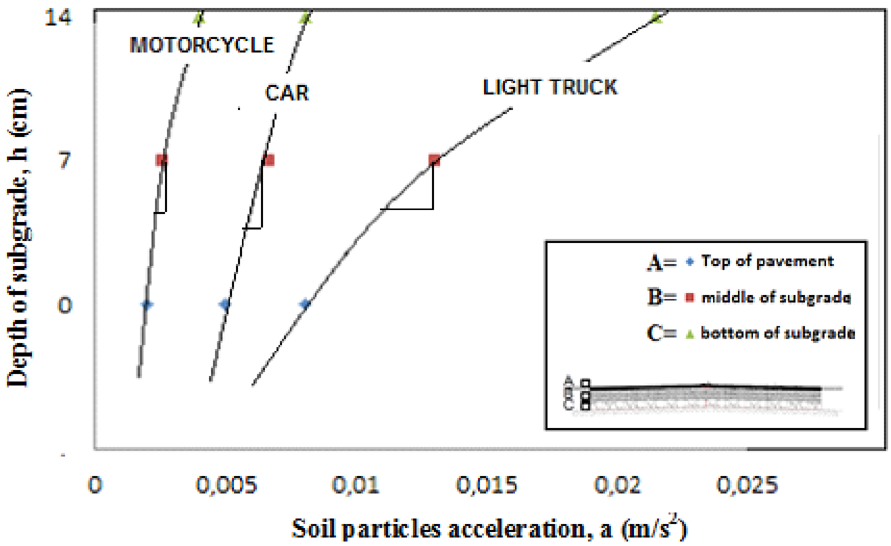

Fig. 9. The curvature of the correlation between soil particles acceleration and depth.

3.3. Soil particles interaction

In a soil medium, there were grains, which bind to each other. In the existing condition without any external load, the bond strength between the soil grains was influenced by cohesion and suction. The value of cohesion and suction could change when the saturation value of the soil changed. The bond strength of these particles actually supported the working load on a soil mass. When there were external loads such as the passing vehicle loads, then the load propagated into the ground. The magnitude of the propagating wave caused by the load can be measured in terms of the particle acceleration parameter. Acceleration value that occurred did not have the same magnitude at each depth because it depended on the soil types when it passed on.

When the soil elements were exposed to a continuous load, it affected the behaviour of the bond between the soil grains. The bonds were weakened for a long time because the soil grain automatically moved to find its stability. In the field, the sub-base course layer was formed from gravel aggregate, which almost had a uniform diameter. Meanwhile, the sub-base course layer was supposed to consist of coarse aggregates that had a larger diameter. The use of uniform diameter caused the faster soil particles acceleration because there was nothing to reduce it. The deeper layer triggered the acceleration because the diameter was bigger. This explains the phenomenon in Fig. 10.

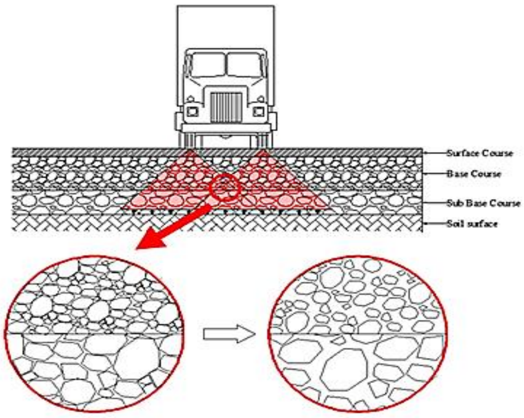

Fig. 10. Illustration of soil particles bonding due to of vehicles loading.

4. Conclusions

A field investigation has been conducted on the vehicles load effects on soil particles acceleration behaviour on subgrade of flexible pavement. During the observation, an accelerometer was placed in different depth. Some concluding from the field investigation is as follows.

- Each type of vehicle will have different effects on soil particles acceleration. This is caused by several factors, including vehicle weight and vehicle speed when passing. Increases in the value of acceleration that occurs for vehicles of motorcycles, cars and light trucks reach 2 to 3 times.
- A positive correlation between depth of soil and soil particles acceleration was depicted in this paper. The aggregate type, which used in sub-base layer, triggers an increase of soil particles acceleration.

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