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Vibration impact towards deformable laterite soil with different moisture content

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Abstract. In engineering practice, natural and man-made vibration phenomenon can cause dynamic stress to be imposed on soils such as blasting, construction operations and machinery, and vehicle traffic vibrations. This issue need to be addressed to ensure the geo-environment is sustainably secure. Laboratory experiments were conducted to characterize the behaviour of vibrated deformable double-porosity under different moisture content in repeated vibration. This paper presents the investigation of vibrated double-porosity soil by aggregating laterite soil with 29%, 32% and 34% moisture content. The experiments were conducted by using acrylic soil column, accelerometer and vibrating table. Aggregated laterite soil is poured in acrylic soil column then compress until 10 cm height. High-frequency accelerometers were installed to observe acceleration at 2 points; (1) surface of soil sample, and (2) surface of vibrating table. The experiments for repeated vibration were conducted by increasing the amplitude of the vibrating table. The acceleration time histories at accelerometers were collected to observe maximum amplitude. The results showed that the acceleration response in non repeated vibration was increased with increasing of moisture contents. It was found that with vibrated samples, the soil structure was rearrange and porosity characteristics identified as expected influence the speed of liquid penetration.

1. Introduction
In engineering practice, earthquake causes volumetric deformation of soil aggregate structures, soil macro structure rearrangement unstable soil structures and cracked soil, which affected condition and characteristics of pore sizes. Incidents of earthquake phenomena had caused damage and leakage to underground drainage pipes and liquid tanks [1]. Figure 1 shows a ground failure after an earthquake in Ranau, Sabah. These phenomena include earthquakes, wind and wave loading, blasting, construction operations, machinery and vehicle traffic vibrations [2]. A soils' strength behaviour during vibration does not only depend on the physical properties of the soil such as cohesion, internal friction angle, mineralogy soil particles, density, grain size distribution, void ratio or dry density, and

moisture content, but also on characteristics of vibration such as amplitude, acceleration and frequency.

Therefore, vibration and leakage of liquids on the ground is a problem that requires attention and focus to provide the sustainability of the geo-environment. The soil fractured reduces the intact soil shear strength and increased the hydraulic conductivity [3]. The soil structure ultimately affects the speed and pattern of fluid migration. Existing research by [4] recognised that the cracked soil played an influential role in the water flow through problematic soil. Similarly, [3]determined the significant changes of mechanical properties and hydrological behavior in fractured porous media. Soil that displays two specific scales of porosity media is known as double porosity media [5].

Therefore, there is an urge to study the behaviour of soils due to vibrations to find the gap by determine the changes of double-porosity with different moisture content and increasing amplitude method in soil.

Figure 1. Ground failure after earthquake at Ranau, Sabah

2. Experimental Theory

The structure of the soil is affected by earthquake vibration and moisture content. It is well known that the soils display many different structures at the different scales, and that soils are not completely homogeneous in character. According to [5], the double-porosity media in usual condition termed as soil display two specific scales of porous media. Different hydraulic properties and pore sizes with two specific sub-regions in soil are used to characterize double-porosity media [6]. The soils with intra and inter-aggregate pores for aggregated innate soil display pore-size bimodal distribution that can found in compacted soils and agricultural tops-soils [7-8]. In addition, [9]discovered that soil in laboratory can be used to create double-porosity characteristics performed under constant pressure head, initially with double-porosity for one-dimensional infiltration experiments.

Generally, in earthquake engineering, laboratory equipment has been utilized to evaluate structures or ground responses using Peak Ground Acceleration (PGA) and Peak Surface Acceleration (PSA). Value of PSA higher than PGA demonstrates amplification while the value of PGA higher than PSA demonstrates dis-amplification. Furthermore, for this laboratory study, the terms PGA and PSA were changed to more suitable names based on the experiment condition, which is known as Peak Table Acceleration (PTA) and Peak Specimen Surface Acceleration (PSSA).

Double-porosity soil deformation is due to vibration effect, which, according to [10], strong earthquake shaking meet with water-saturated granular soils such as soil and sand may liquefy and cause deformations with great destructive power effect to the grain arrangement, fluid movement and changes in permeability will lead to loss strength of soil structure. Furthermore, according to [11], formations of fractured porosity are characterized by water-bearing formations, while a fracture is caused by tectonic force from a break of the rock masses. Computational and numerical methods in past decades were mainly used in studies of double-porosity media, mostly fractured rock as media by researchers such as [6], [12–16].

Recently, the physical experimental methods on double-porosity soil have begun to be used by researchers such as [6], [16–18]. Previously, researchers have mainly used computational methods for the study of double-porosity media, specifically rock as media. Meanwhile, previous researchers also used numerical models for the study of double-porosity soil media but performed real physical experiments less often. The actual physical experiments are very difficult to perform in the laboratory, especially because large fractured rock was naturally hard to find and the actual sample on site was very complicated to relocate to the laboratory and requiring large sums of money. There is also a shortage of practical equipment as few pieces of equipment are available to do the actual experiment.

Essentially, this study covers the physical laboratory experiment model where an aggregated soil sample was vibrated using a vibrating table involving a specific experimental setup to analyse ground response and double-porosity soil characteristics. Since the half of the last century, there has been significant progress in understanding the effects of vibration on the strength and deformation properties of soils [19–21]. A number of different experiments with vibration application have been conducted on cohesive and cohesion-less soils that generated valuable data that has led to discovery of important conclusions [22–24].

Double-porosity soil is used to characterize soils that consist of two specific sub-regions that display different characteristics of pore sizes due to condition of inter-aggregate and intre-aggregate, which can be found in compacted soil and agricultural top-soils [7-8] and hydraulic properties. Moreover, [6] mentioned that there were still a gap in literature with consideration to investigations via experiment on immiscible fluid movement in double-porosity soils. Therefore, to achieve the aim of this study, several objectives recognized based on the literature were (i) to investigate double-porosity soil using the acceleration response on non-repeated vibration with different water content, and (ii) to determine inter-aggregate and intra-aggregate on vibrated double-porosity soil characteristics.

3. Material and Methods
In this study, the laboratory experiment setup and procedure encompassing the physical apparatus, soil sample and aggregation are briefly discussed in subsequent sections.

3.1 Soil sample preparation
The soil sample were collected from School of Electrical, Faculty of Engineering Universiti Teknologi Malaysia and were prepared into double-porosity soil with the laboratory soil charactreristics properties. The liquid limit = 66%, plastic limit = 33%, plasticity index = 33% and particle density = 2.74Mg/m3 based on British Standard BS1377-2:1990 and based on the Unified Soil Classification System (USCS) it was classified as clay with high plasticity (ML). The method expressed in Bagherieh et al. (2009) as previously explained was used to prepare the aggregated soil sample. The preparation of soil sample used different water content such as 29%, 32% and 34%, these water content were conducted to identify the granular soil sample properties. Thus, the dried laterite soil was mixed with 29%, 32% and 34% of water content for sample 1, sample 2 and sample 3. The samples were kept in a cool condition for a minimum 24hours, the mixed sample was cured and kept in a re-sealable plastic bag for the purpose of preventing the moisture content from being evaporated. Dried aggregate soil that passed 2.36mm sieve for both sample 1, 2 and 3 were placed in a circular acrylic and compressed until 100mm height using a simple compression machine. The acrylic soil column has been chosen to detect and monitor the changes occurring whole area and inside circular column. Prepared soil samples are shown in Figure 2.

(a) Surface view
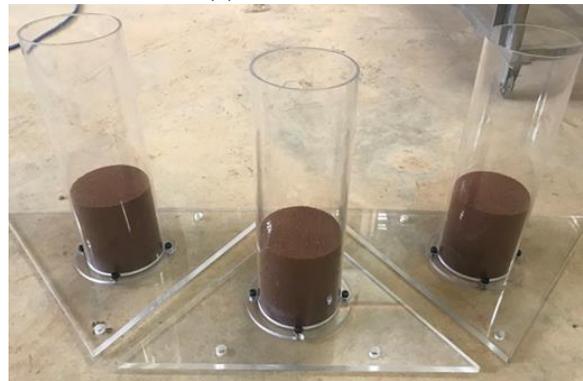
(b) Front view

Figure 2. Soil sample.

3.2 Laboratory experiment setup and procedure

The experiments were executed in an acrylic soil column sealed base designed with dimension of 300mm high x 100mm outer and 94mm inner diameter. A vibrating table was used to vibrate soil sample with different vibration amplitude for the deformation process. The acrylic soil column was placed on the vibratory table and assign properly by bolt and nut to avoid movement or spring up of the acrylic soil column. It is important to have better visualization for the whole area of acrylic soil column. During the vibration process, PTA and PSSA for all samples were recorded and the inter and intra aggregate was observed. The vibrating table and acrylic soil column with an uncomplicated experimental setup was developed to accomplish this concept economically and effectively. Figure 3(a) and 3(b) shows the view of 3D laboratory laboratory setup. The experimental procedure was arranged as shown in Figure 3(a) and 3(b).
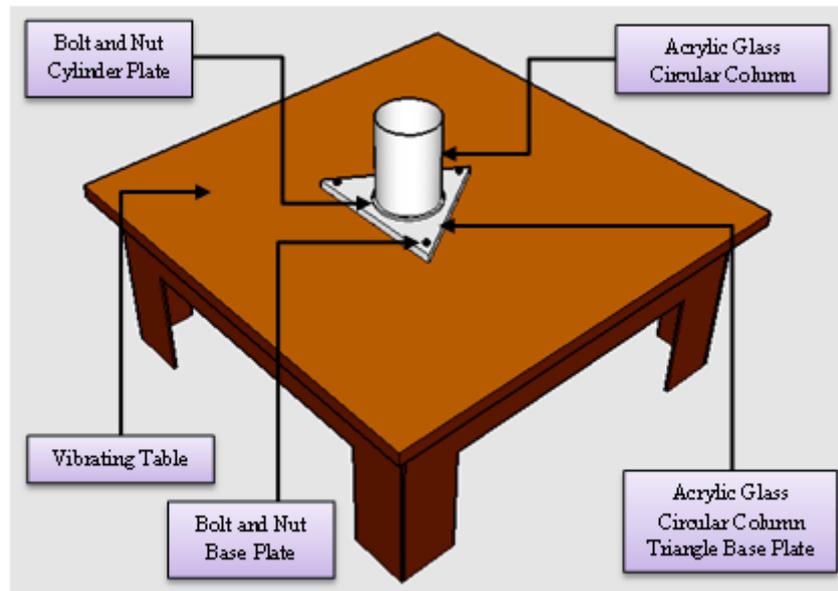
(a) 3D Laboratory experimental setup
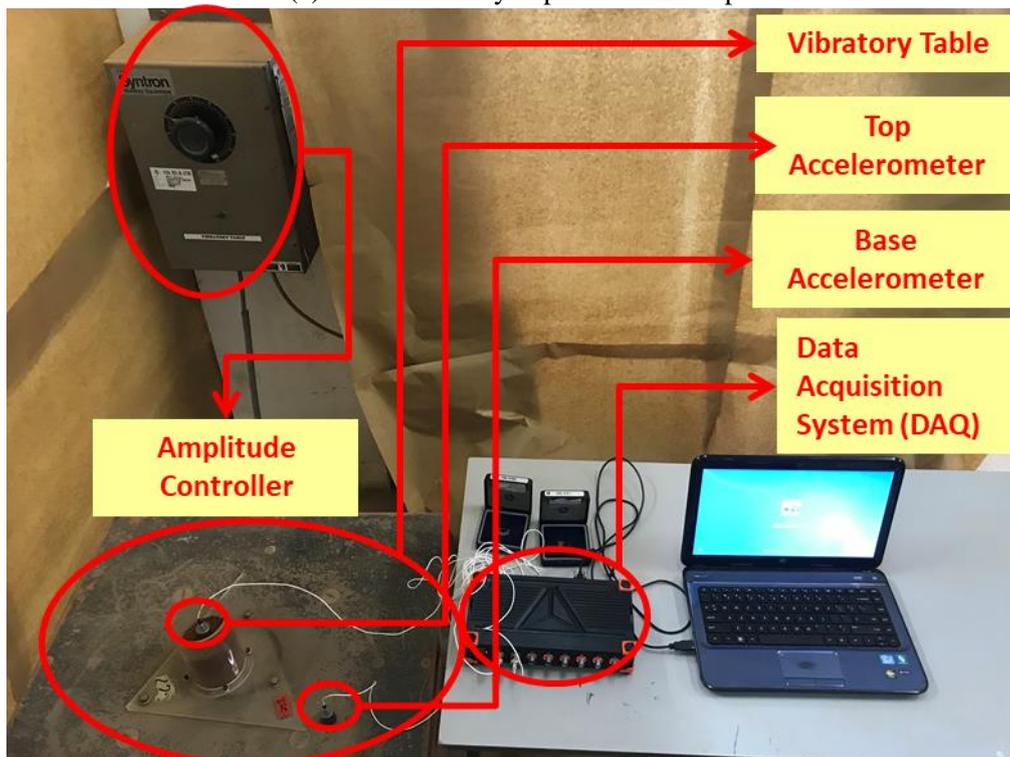
(b) 3D Actual experimental setup

Figure 3. Experimental setup.

4. Results and Analysis

4.1 Acceleration response on non-repeated vibration for double-porosity soil

Based on the study of this objectives, the results for PSSA and PTA for these samples as well as the calibrated vibrating table natural amplitude are shown in Table 1. The vibrating table control panel amplitude as mentioned earlier was differentiated from the calibrated vibrating table indicator as reference. Therefore, the calibrated amplitude value was used as vibrating table indicator since the amplitude was obtained from the calibrated seismic accelerometers with high sensitivity. Based on Table 1 and the observation during the experiment, sample 1, sample 2 and sample 3 started to amplifies shaking at the amplitude of 2.45 A, where the values of PSSA/TA (1.86/1.85), (2.44/2.24) and (2.6/1.33) increasing gap between PSSA and PTA. Sample 3 has a bigger amplification shaking, where the value of PTA (1.33) was lower than the value of PSSA (2.6) which means that the shaking of the surface is higher than the ground shaking. Therefore, to analyse the acceleration response, it was necessary to produce the graphs of amplitude(acceleration) versus PTA and PSSA value based on the result shown in Table 1.

Table 1. Calibrated non-repeated vibration and acceleration responses, PSSA and PTA results.

Vibratory Table Amplitude (A)	Acceleration Response (A)		
	Sample 1 (PSSA/PTA)	Sample 2 (PSSA/PTA)	Sample 3 (PSSA/PTA)
1.240	1.56 / 1.13	2.1 / 1.4	1.49 / 0.82
2.450	1.86 / 1.85	2.44 / 2.24	2.6 / 1.33
2.690	2.43 / 2.42	2.79 / 2.55	3.36 / 1.72
3.320	3.13 / 3.06	3.22 / 2.94	3.78 / 1.99
3.610	3.43 / 3.36	3.44 / 3.03	4.22 / 2.37
3.990	3.85 / 3.71	3.64 / 3.39	4.08 / 2.59
4.220	4.14 / 3.76	3.94 / 3.43	4.31 / 2.76

Figures 4, 5 and 6 shows the graphs of non-repeated vibration versus PTA and PSSA for sample 1 with 29% water content, sample 2 with 32% water content and sample 3 with 34% water content respectively.
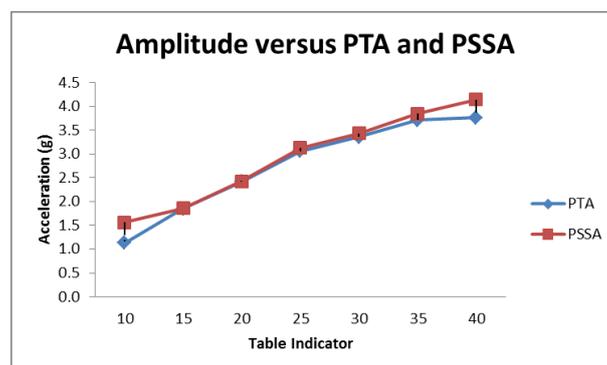
Figure 4. Graph of non-repeated vibration on amplitude (acceleration) versus PTA and PSSA for sample 1.
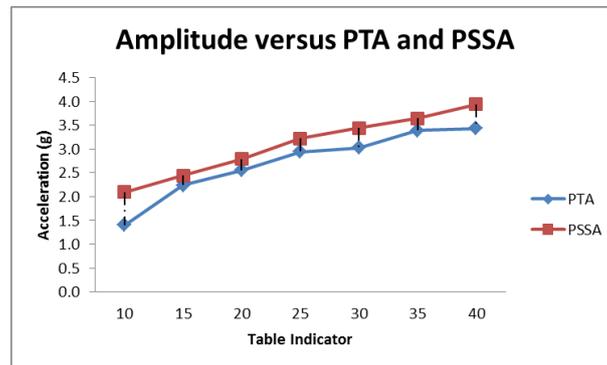
Figure 5. Graph of non-repeated vibration on amplitude (acceleration) versus PTA and PSSA for sample 2.
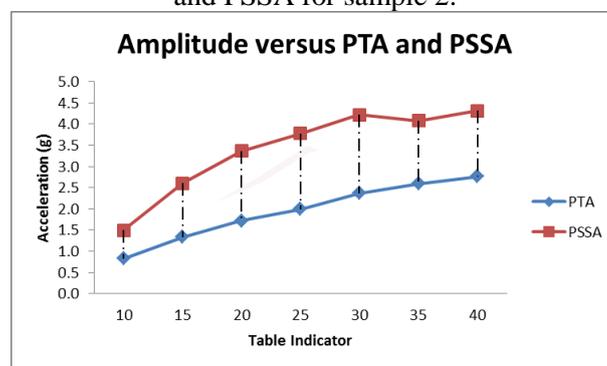
Figure 6. Graph of non-repeated vibration on amplitude (acceleration) versus PTA and PSSA for sample 3.

4.2 Validation of the double-porosity soil characteristics
Result of depth zoom in image of vibrated double-porosity for 29%, 32% and 34% moisture content at 180-fold, 1000-fold and 3000-fold magnification is shown in Figure 7. The resultant of SEM test at 180-fold magnification shows crack and fracture at the soil sample surface, while resultant SEM test at 1000-fold magnification has shown the inter-aggregate pores. The FESEM test at 180-fold magnification has also exposed that the inter-aggregate pores and individual laterite granules split up among themselves. Further magnification of both soil samples to 3000-fold indicated intra-aggregate pores. Through the SEM test, non-repeated vibration on soil sample was verified with intra-aggregate and inter-aggregate pores and aggregate pores as deformable characteristics created the double-porosity laterite soil formation. From the SEM test result, soil sample 3 has more porosity compared to sample 2 and 1. All sample have a similarity in that the soil is coated with a layer of liquid that causes a shining image when viewed by SEM zoom in image. Both samples also have a coarse granule structure and displayed the characters of moisture content soil sample. Thus, the vibrated double-porosity characteristics with multi-porosity were expected to contribute to the speed of liquid penetration and migration.

| Sample 1 | Sample 2 | Sample 3 |
| (29% water content) | (32% water content) | (34% water content) |
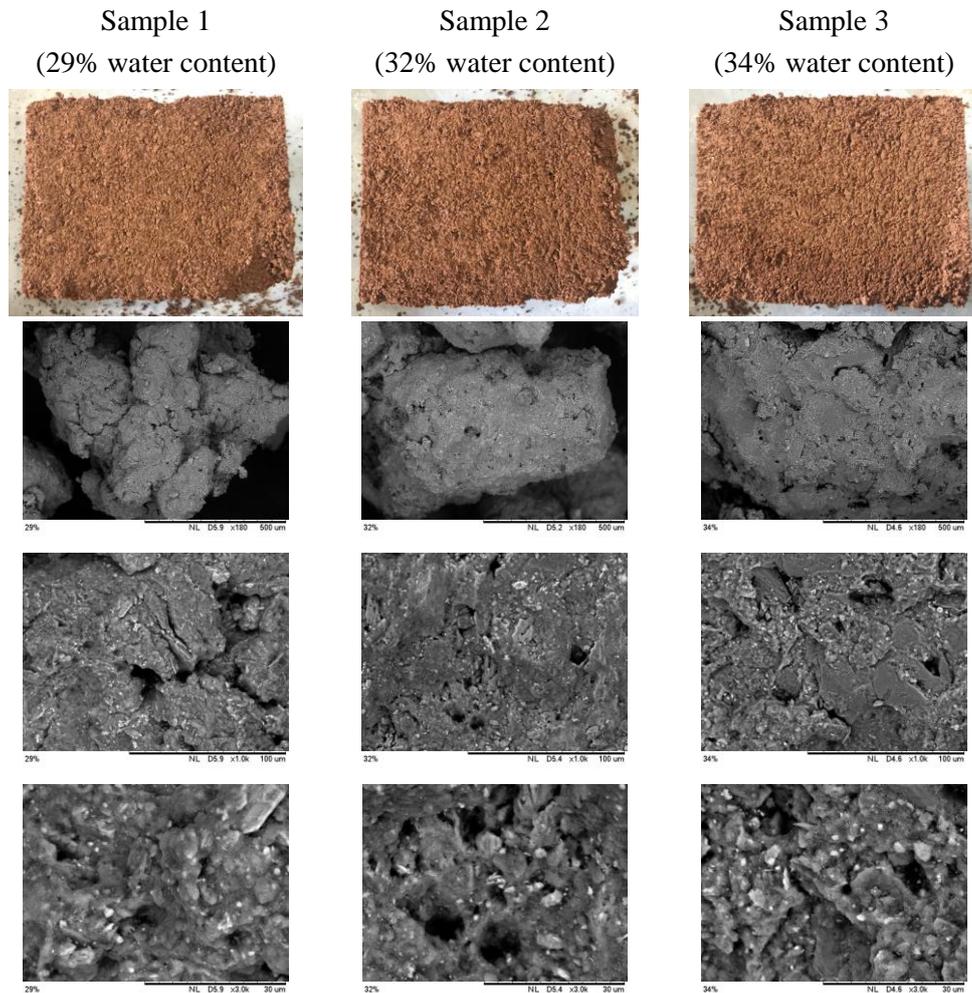
Figure 7. SEM image with 180,1000 and 3000-fold magnification.

5. Conclusion

A physical laboratory experiment acceleration responses results on impact of non-repeated vibration on double-porosity laterite soil with distinct water was conducted and recorded. Through scanning electron microscopy (SEM) test, the deformable double-porosity soil was verified and confirmed to have inter-aggregated and intra-aggregated. Sample 3 has shown bigger amplification shaking due to the weakened soil structure rearrangement and change in existing moisture content than sample 2 and sample 1, while sample 1 has smaller amplification shaking because soil sample 1 had a stiff soil. Since the soil samples have multi-porosity characteristics, it has been identified as problematic double-porosity soil due to the pore holes between the structure soil. Moreover, non-repeated vibrated double-porosity soil have different behaviour characteristics on permeability and wettability compared to a non-repeated double-porosity soil experiment. The effect of moisture content on the laterite soil granule was significant as it was proved that seismic acceleration response values were different for those samples. In addition, high permeability value was expected to be an influential factor in movement of the fluid in subsurface system.

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