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Deformable unsaturated laterite soil under vibration impact with dissimilar moisture content

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Abstract. Vibrations from vehicle traffic, machinery and operations from construction activities such as blasting are examples of some natural and man-made vibration phenomenon's that can cause dynamic stress when imposed onto soils. In order to ensure sustainability of the geo-environment, the impacts caused by these vibrations as well as the changes in moisture content needs to be addressed. To achieve this, the behaviour of vibrated deformable double-porosity under dissimilar moisture content in non-repeated vibration was assessed and characterized through laboratory experiments. Investigation of deformable unsaturated laterite soil by aggregating laterite soil using 29%, 30%, 32% and 34% moisture content was carried out and presented in this paper. An acrylic soil column, accelerometer and vibrating table were used to conduct the experiments. The acrylic columns were filled with each aggregated soil and the soil was then compressed to a height of 10 cm, which had been pre-determined beforehand. Accelerometers were installed to a vibrating table where each soil column was tested to measure the time histories of high-frequency acceleration on the surfaces of both the laterite soil and vibrating table. Acceleration was observed at two points, namely; (1) the surface of the soil sample and (2) the surface of the vibrating table. The amplitude of the vibrating table was increased in order to test for repeated vibration. Maximum amplitudes were recorded by collecting the acceleration time histories and the amplitude of displacement was increased in order to carry out the tests. The outcome of the tests demonstrated that there was an increase of the acceleration response in non-repeated vibration when moisture contents were also increased. For the vibrated samples that were used, it was found that there was a rearrangement of the soils structure and as expected, the porosity characteristics that were identified had influenced the liquid penetrations' speed.

1. Introduction
In the practice of engineering, the volumetric deformation of soil aggregate structures, rearrangement of soil macro structure, unstable soil structures and cracked soil are the aftermath caused by earthquakes. Due to this natural disaster the characteristics and condition of pore sizes are affected. According to [1] underground liquid tanks and drainage pipes have been found to be damaged and leaking from the incident of earthquakes. Figure 1 illustrates an example of ground failure in Ranau, Sabah after an

earthquake had hit the area. Vibration phenomenon that has been described in [2] include earthquakes, wind and wave loading, machinery and operations from construction activities such as blasting as well as vehicle traffic vibrations. However, the behaviour of soil strength during vibration is not merely dependant on the soils' physical properties such as mineralogy soil particles, grain size distribution, cohesion, density, internal friction angle, moisture content and void ratio or dry density, but it is also dependant on vibration characteristics such as acceleration, frequency and amplitude. Fractured soil lessens the shear strength of the intact soil and increases hydraulic conductivity [3]. The pattern and speed of fluid migration is ultimately affected by soil structure. It had been found in [4] that in the water flow through problematic soil, an influential role is played by cracked soil. Likewise, [3] had found significant changes of hydrological behaviour and mechanical properties in fractured porous media. Double porosity media is described at a soil that exhibits two detailed scales of porosity media. Thus, in order to provide geo-environment sustainability, attention and focus towards the problem of vibration and liquid leakages is needed.

Figure 1. Ground failure after an earthquake hit Ranau, Sabah.

2. Experimental Theory

Vibrations with different moisture content affects soil structure. Previous studies have proven that characteristics of soils are not completely homogenous and demonstrate several different structures at different scales. Cohesion and suction affect the strength of soil bonding without any external load, the civil and structural will change when the saturation value of soil changed, 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 [5] Double-porosity media in its usual condition is described as soils that exhibit two specific scales of porous media [6]. Characterization of double-porosity media is determined by the difference of pore sizes and hydraulic properties focusing on the soils two specific sub-regions. Pore-size bimodal distribution that is displayed in soils with intra-aggregate and inter-aggregate pores for aggregated innate soil can be found in agricultural tops-soils and compacted soils [7], [8]. As described by [9] deformation of double-porosity soil is caused by effects from vibration, where when a strong earthquake occurs it shakes water-saturated granular soils such as soil and sand which may cause them to liquefy and cause deformations. Changes in permeability will ultimately lead to the weakening of soil structure and brings the effects of great destructive power as changes to the grain arrangement and fluid movement have occurred. According to [10], the characterization of fractured porosity formations is based on water-bearing formations or fractures are caused by tectonic force from the breakage of the rock masses. In the past decades, studies of double-porosity media mainly used numerical and computational methods and the media used by researchers were mostly , [11]–[16]. The hydraulic condition (fully permeable or impermeable) at the contact surface affects the vertical vibrations at higher frequencies[17] also

according to [18], soil particles under repetition of dynamic loading tend to liquefy. Soil types and soil moisture content initiate the differences of vertical loading [19]. Additionally, it was discovered that initially, with double-porosity for one-dimensional infiltration experiments, the soil used in the laboratory can be used to create double-porosity characteristics performed under constant pressure head [20]. In earthquake engineering, Peak Ground Acceleration (PGA) and Peak Surface Acceleration (PSA) have been used to evaluate structures or ground responses by means of utilizing laboratory equipment. Amplification is demonstrated when the value of PSA is higher than PGA while dis-amplification is established when the value of PGA is higher than PSA. For the purpose of this laboratory study, the terms PSA and PGA were renamed to better suit the experiment conditions and thus were changed to Peak Table Acceleration (PTA) and Peak Specimen Surface Acceleration (PSSA). Finding large fractured rock was a challenge as the actual samples on site required a large amount of budget in order to relocate it into the laboratory. This made the actual physical experiments very difficult to be conducted in the laboratory. Shortage of practical equipment that was available also posed a problem to the researchers of this study. It has been found that there has been substantial progress since the last fifty years, in understanding the effects of vibration towards the strength and deformation properties of soils [21]–[23]. Discoveries of important conclusions have been generated from valuable data thanks to the numerous experiments of vibration application that have been conducted on cohesive and cohesion-less soils [24]–[26]. Essentially, this study created a physical laboratory experiment model where a vibrating table was used to vibrate aggregated soil samples which involved a specific experimental setup in order to analyse the double-porosity soil characteristics and ground response. As [16] had mentioned, there is still a gap in literature of immiscible fluid movement in double-porosity soils with specific consideration of investigations via experiments. Therefore, to enable this study to achieve its aim, based on the literature review that had been carried out, to investigate inter-aggregate and intra-aggregate of double-porosity soil using the acceleration response on non-repeated vibration with different water content.

3. Material and Methods

The materials and methods of the laboratory experiment setup and procedure which include the physical apparatus, soil samples and aggregation are briefly discussed in the following subsequent sections.

3.1. Preparation of the Soil Sample

The soil samples were collected from the School of Electrical, Faculty of Engineering at Universiti Teknologi Latitude 1'33'39' N Longitude 103' 28' 44' E Malaysia and were prepared as double-porosity soil with the laboratory soil characteristics properties. Based on the British Standard BS1377-2:1990, the liquid limit = 66%, plastic limit = 33%, plasticity index = 33% and particle density = 2.74 Mg/m3. It was classified as clay with high plasticity (CH) according to the Unified Soil Classification System (USCS). In order to prepare the aggregated soil sample, the method expressed in [27] was adopted. The reason that different water content was prepared for each soil sample, set at 29%, 30%, 32% and 34% respectively, was to identify the properties of granular soil sample. To achieve this, dried laterite soil was mixed with 29%, 30%, 32% and 34% of water content for all the samples (namely as Sample 1, Sample 2, Sample 3 and Sample 4). For a minimum of 24 hours, the samples were kept in cool conditions to prevent the evaporation of the moisture content and thus the mixed sample was cured and kept in a re-sealable plastic bag. For all the samples, dried aggregate soil that passed through the 2.36mm sieve was then placed in the circular acrylic column and compressed using a simple compression machine until it reached a height of 100mm. Any changes occurring to whole area and inside the circular acrylic column was observed as shown in Figure 2.

(a) Compressed Soil
    Sample

(b) Surface View / Sample
    from Top View

(c) Front view

Figure 2. Soil Sample.

3.2. Laboratory Experiment Setup and Procedures

A specifically designed acrylic soil column with a sealed base and dimensions of 300mm high x 100mm outer and 94mm inner diameter was used to execute the experiments. Soil samples were vibrated using a vibrating table with application of different vibration amplitudes for the process of deformation. In order to avoid any movement of the acrylic soil column, the acrylic soil column was fixed onto the vibratory table and locked in placed by using bolts and nuts. Visualization of the whole area of the acrylic soil column was very important for the best results from this experiment. Recordings of the PTA, PSSA and observations of the inter-aggregate and intra-aggregate were observed for all Samples throughout the vibration process. This experimental setup was developed to accomplish the objectives of this study effectively and economically. The view of the 3D laboratory setup is shown in Figure 3.
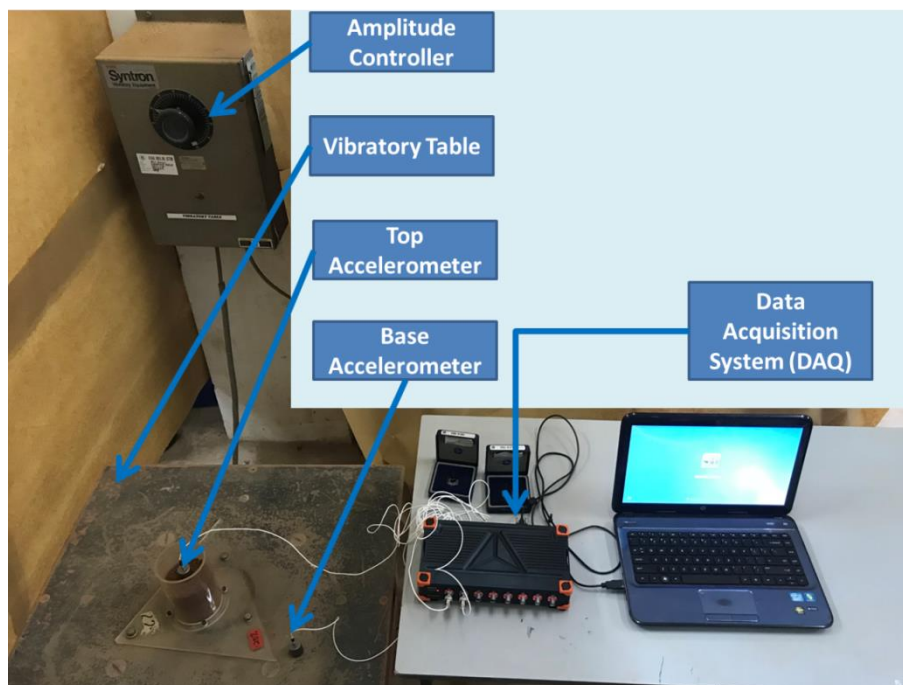
(b) 3D Actual experimental setup.

Figure 3. Experimental setup.

4. Results and Analysis

4.1. Acceleration Response on Non-Repeated Vibration for Double-Porosity Soil.

Based on the objectives of this study, the calibrated vibrating table natural amplitude and results of the Sample testing for PSSA and PTA are shown in Table 1. As mentioned earlier, for referencing purposes, the vibrating table control panel amplitude was separated from the calibrated vibrating table indicator. Thus, since the amplitude was obtained from the calibrated seismic accelerometers with high sensitivity, the calibrated amplitude value was used as the vibrating table indicator. According to Table 1, the observations made during the experiments had found that shaking amplified at the amplitude of 2.45 A, where the values of PSSA/PTA was recorded at (1.86/1.85), (2.48/1.91), (2.44/2.24) and (2.6/1.33) respectively for Sample1, Sample 2, Sample 3 and Sample 4, therefore increasing the gap between PSSA and PTA. Sample 4 was determined to have a higher shaking amplification, and the value of PTA (1.33) was recorded to be lower than the value of PSSA (2.6) at 2.450 Amplitude of vibratory table, meaning that the shaking of the surface is higher than the shaking of the ground. In order to better analyse the acceleration response, graphs of amplitude (acceleration) versus PTA and PSSA values were necessary to be produced and the results gathered are as portrayed in Table 1. Based on Figure 4, Figure 5, Figure 6, and Figure 7 it shows the amplification of laterite soil become bigger with higher moisture content due to its plasticity [28].

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)	Sample 4 (PSSA/PTA)
1.240	1.56 / 1.13	1.47 / 1.16	2.1 / 1.4	1.49 / 0.82
2.450	1.86 / 1.85	2.48 / 1.91	2.44 / 2.24	2.6 / 1.33
2.690	2.43 / 2.42	2.74 / 2.44	2.79 / 2.55	3.36 / 1.72
3.320	3.13 / 3.06	3.35 / 3.00	3.22 / 2.94	3.78 / 1.99
3.610	3.43 / 3.36	3.59 / 3.23	3.44 / 3.03	4.22 / 2.37
3.990	3.85 / 3.71	4.06 / 3.47	3.64 / 3.39	4.08 / 2.59

Figures 4, 5, 6 and 7 show the graphs of non-repeated vibration versus PTA and PSSA for Sample 1 with 29% water content, Sample 2 with 30% moisture content, Sample 3 with 32% water content and Sample 4 with 34% water content respectively.
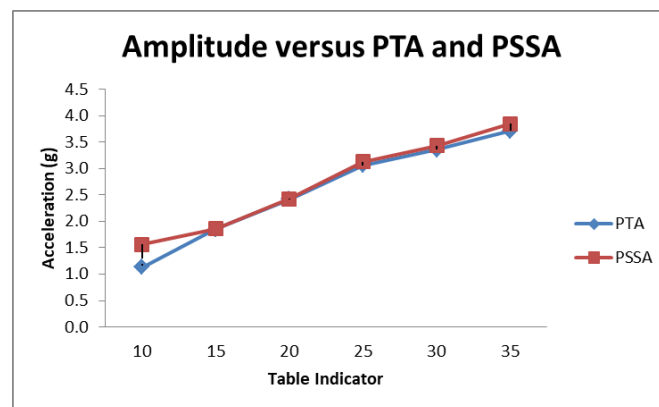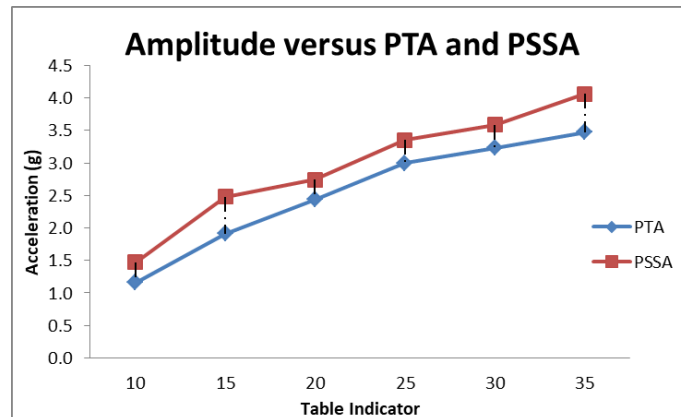

Figure 4. Sample 1 with 29 % Moisture Content.

Figure 5. Sample 2 with 30 % Moisture Content.
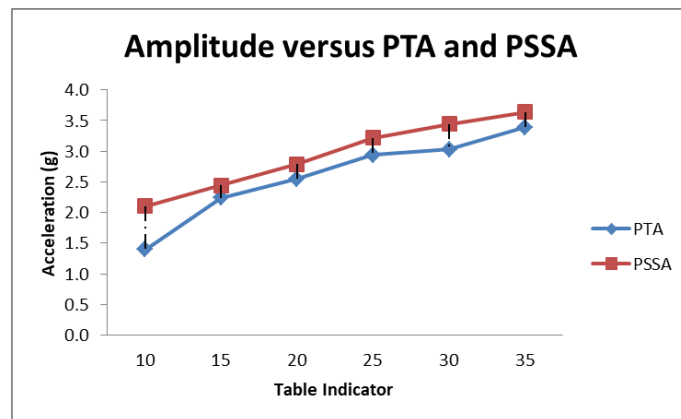

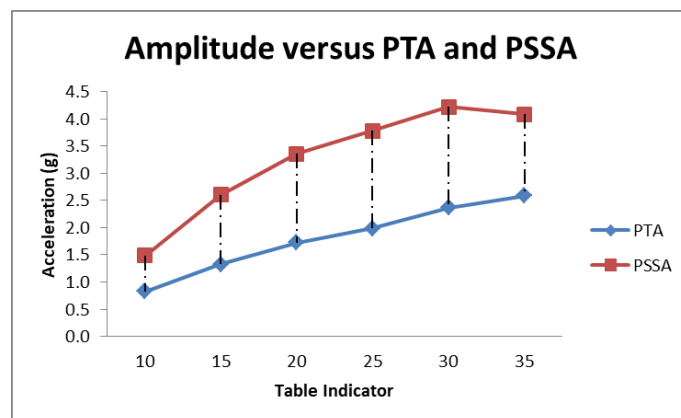**Figure 6.** Sample 3 with 32 % Moisture Content.

Figure 7. Sample 4 with 34 % Moisture Content.

4.2 Validation on The Characteristic of Double-Porosity Soil
Figure 8 displays the images using depth zoom results, of vibrated double-porosity for 29%, 30%, 32% and 34% moisture content at the magnification of 180-fold, 1000-fold and 3000-fold. Crack and failure at the surface of the soil sample is shown when the resultant of SEM test is at 180-fold magnification,

whereas the resultant SEM test at 1000-fold magnification shows the inter-aggregate pores. The inter-aggregate pores and individual laterite granules were examined to have split up among themselves when the FESEM test at 180-fold magnification was carried out. Intra-aggregate pores were indicated when soil samples were examined using further magnification of 3000-fold. Based on the non-repeated vibration on soil sample, it was verified through the SEM test double-porosity laterite soil formation was created by the deformable characteristics of intra-aggregate and inter-aggregate pores aggregate pores. The SEM test result also illustrated that soil Sample 4 has more porosity compared to the Samples 1, 2 and 3. A similarity that all the Samples have to that the soil was seen to be coated by a liquid layer that gave off a shining image when viewed using the SEM image zoom in. All the Samples were also found to have a coarse granule structure and characteristics of moisture content in the soil Sample was also displayed. Therefore, the speed of liquid penetration and migration is expected to be contributed by the vibrated double-porosity characteristics with multi-porosity.
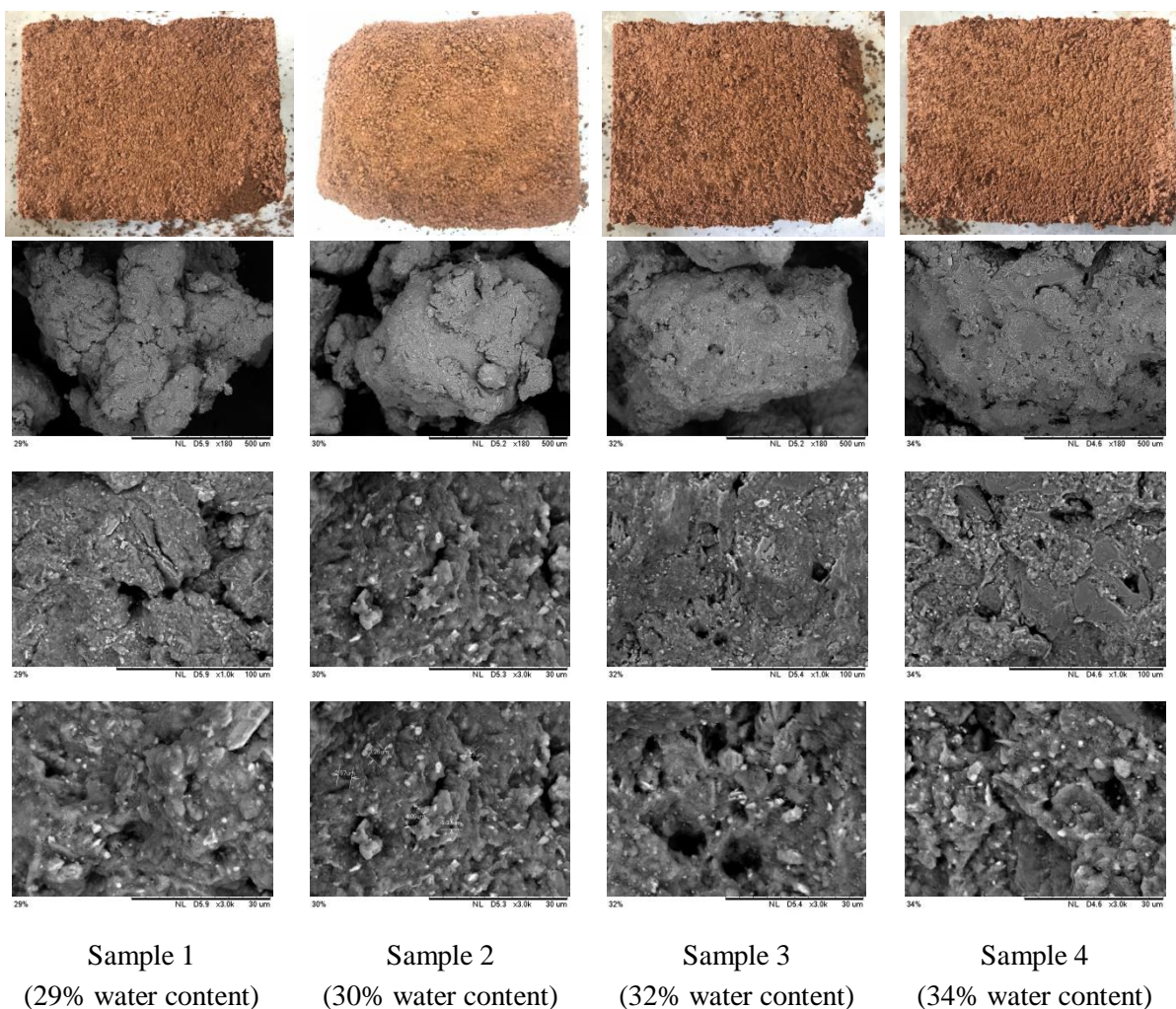
Sample 1	Sample 2	Sample 3	Sample 4
(29% water content)	(30% water content)	(32% water content)	(34% water content)

Figure 8. SEM image with 180, 1000 and 3000-fold magnification.

5. Conclusion

The results of acceleration responses on the impact of non-repeated vibration on double-porosity laterite soil with distinct water were recorded from the physical laboratory experiments that had been conducted. It was verified and confirmed that the deformable double-porosity soil had inter-aggregated and intra-aggregated through the scanning electron microscopy (SEM) test. When all the four samples were

compared, it had been found that due to the weakened rearrangement of the soil structure and changes in the content of moisture, the biggest amplification shaking was Sample 4. Sample 1, on the other hand, had the smallest amplification shaking as it consisted of stiff soil. Since multi-porosity characteristics have been found in the soil samples due to the pore holes between the structure soils it has been identified as problematic double-porosity soil. Based on the experiments performed by [8], [21] that had excluded the vibration effect, it had been found that non-repeated vibrated double-porosity laterite soil has different behaviour characteristics on wettability and permeability as compared to an experiment of non-repeated double-porosity kaolin soil. It had been proven that seismic acceleration response values were different for each Sample and that the effect of moisture content towards the laterite soil granule was significant. Additionally, it was anticipated that an influential factor in the movement of fluid in the subsurface system would be the high permeability value.

6. References

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