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Soil response as an effect of various dynamic loading conditions at Klang Valley Area

Aniza Ibrahim[1#], Aminaton Marto[2,3], Fakhrurazi Awang Kechik[1], Ali Selamat[4]
1 Civil Engineering Department, Universiti Pertahanan Nasional Malaysia (UPNM), Kem Sg. Besi, Kuala Lumpur, Malaysia.
2 Disaster Preparedness and Prevention Centre, Malaysia Japan-International Institute of Technology, Universiti Teknologi Malaysia (UTM), Kuala Lumpur, Malaysia.
3 Research Centre for Soft Soil (RECESS), Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia
4 Malaysia Japan-International Institute of Technology, Universiti Teknologi Malaysia (UTM), Kuala Lumpur, Malaysia.
#Corresponding author. E-Mail: aniza@upnm.edu.my; Tel: +60-196-6417386; Fax: +603-90513472.

ABSTRACT Dynamic loading due to earthquake, rail transit, or machine vibration is a serious concern as these loadings reduce soil shear strength which leads to catastrophic events such as soil instability, and seismic induced loading trigger soil liquefaction. At present, there is limited information regarding the response of dynamic loading towards residual soil in Malaysia. Therefore, initial study is vital to clarify residual soil in determining the response to cyclic loading and evaluate its behavior. The residual soil sample is sourced from a depth of 1 meter from the ground at selected location within the Universiti Pertahanan Nasional Malaysia (UPNM) campus area. Basic soil properties test was performed and cyclic triaxial test with varying loading intensities was carried out. Results show that the pore pressure increases as higher amplitude was imposed on the soil and vice versa. Lower amplitude provides stable pattern of hysteresis loops while it becomes unstable towards higher amplitude. Further research needs to be conducted to evaluate the correlation of subsoil characteristics for disaster management and prevention plan for any dynamic loading leads that to disaster. This research is aligned with the Sendai Framework for Disaster Risk Reduction (2015-2030) adopted by the United Nations that was designed as a protection from catastrophe risk.

KEYWORDS: Axial Stress; Cyclic loading; Deviator stress; Hysteresis loop; Residual Soil.
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Original Article

INTRODUCTION

In Peninsular Malaysia, the possibility of an earthquake occurring along the Kuala Lumpur fault zone is a serious concern because the epicentres of ancient fault line zones have been detected within the fault lines reactivated by active tectonic plate boundaries. The immediate effects of an earthquake are ground shaking, ground rupture, and landslide. Soil liquefaction is the secondary effect of an earthquake as the dynamic response deteriorates the soil stiffness and strength (Kean *et al.*, 2015).

Numerous research has been conducted regarding soil response to cyclic loading. Research includes soil basic dynamic properties such as determination of damping ratio and shear modulus, dynamic -induced loading due to earthquake, rail transit, and machine vibration at site. In Malaysia, study for dynamic loading is mostly due to soil liquefaction.

Several researchers have investigated soil properties under dynamic loading. Dynamic modulus is a critical parameter in determining the dynamic soil properties (Luo & Miao, 2016). The two parameters of dynamic soil properties in response to dynamic loading are damping ratio and dynamic shear modulus (Lim *et al.*, 2018). The damping ratio is the ratio of the actual damping coefficient to the critical damping coefficient and soil capacity refers to disperse or to dampen the system by dynamic loading. Energy dissipation occurs when dynamic loading is applied to a soil deposit. The hysteresis loop of the stress-strain curve represents the amount of expelled energy. The increase in damping ratio corresponds with increasing cyclic shear strain. The slope of a secant line is connected to the extreme points on a hysteresis loop at a given shear strain. Shear modulus, G, is the shear stress to shear strain ratio and describes a material's propensity to deform under loading, specifically under shearing (Lim *et al.*, 2018). Energy dissipation begins with the application of dynamic loading to soil deposits. The increase in shear modulus is proportional to the increase in confining strain. Soil dynamic modulus is influenced by void, ratio, density, over consolidation ratio, structural connection, gradation, particle shape, confining pressure, average principal stress, vibration frequency, and cyclic number (Ye *et al*., 2021).

The peak ground acceleration (PGA) mapped by Vaez *et al.* (2018), Figure 1 shows that the Kuala Lumpur fault zone is an earthquake-prone area, and there is a need to put in place disaster preparedness management. An earthquake could cause soil compaction that increases pore water pressure and reduces the effective stress, which in turn cause a loss of shear strength (Othman & Marto, 2019). The inability of the liquefied soil to support building structures leads to enormous devastation. Soil liquefaction, especially within the Ring of Fire, has been occurring for a long time. In 2018, soil liquefaction caused by the 7.5 magnitude earthquake in Palu on the Indonesian island of Sulawesi destroyed buildings and caused fatalities. This shocking event underscores the need for research in this field.

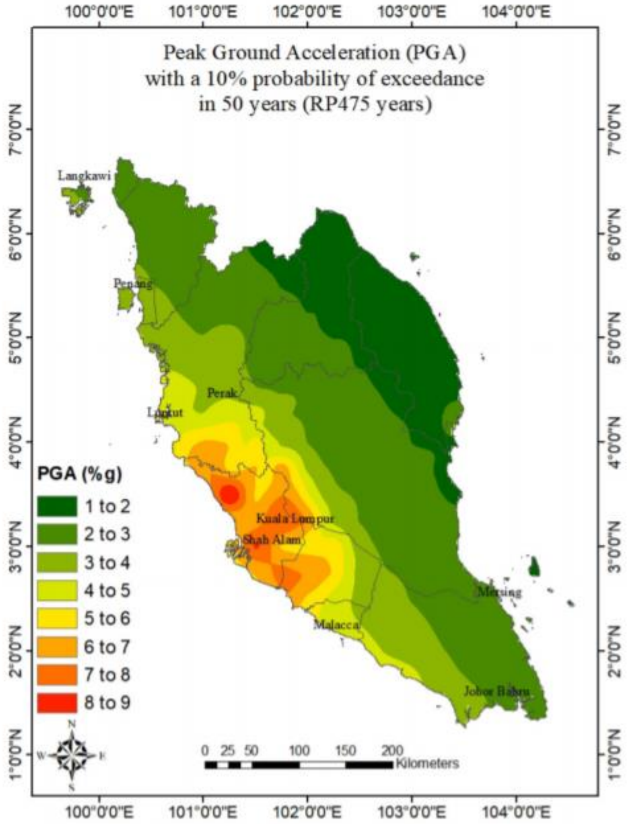

Figure 1. Peak Ground Acceleration (Vaez *et al*., 2018).

According to Othman & Marto (2019) there is a lack of research on the susceptibility to soil liquefaction due to earthquake, which accentuates the need to determine the potential of soil liquefaction within the areas. Malaysia has experienced many moderate seismic events, even though it is located not in a seismically active region. The sudden earthquake events show that Malaysia could experience earthquake events, and because of this, researchers are showing increasing interest to understand the dynamic behavior of soil in Malaysia (Yong *et al*., 2017). Hashim *et al*. (2017) have identified liquefaction potential along the east coast shoreline of Malaysia while (Marto *et al*., 2014) evaluated the possibility of soil liquefaction occurring in Nusajaya City, Johore, Malaysia. Even though the result indicated that Nusajaya City is not vulnerable to liquefaction, the researchers propose further verification and assessment. Besides, the study area is not within the fault zone and the earthquake was originated from Indonesia.

Researchers have investigated sand liquefaction, including the effects of confining pressure, particle content, cyclic shear strain, liquefaction mechanisms, and sample preparation. Some of the recent research focused on the liquefaction resistance of silt, while others studied the impact of fines content on the physical mechanism of liquefaction (Zhang *et al.*, 2018). According to Rahman & Siddiqua (2017), liquefaction resistance assessment is a critical aspect of geotechnical site characterization for the earthquake-prone area to determine the hazard risk. According to Cappellaro *et al.* (2021), there is a need to investigate soil variation in different regions since the soil reconstituted by moist tamping under cyclic response could result in different liquefaction resistance.

Given that liquefaction reduces soil strength, some researchers have been focusing on finding ways to improve the soil. One research used reconstituted materials, rubber waste and fibre, to improve soil strength; the other research explored using a sand matrix or reconstituting the original soil with different soil types. Ghadr *et al.* (2020), studied the impact of cyclic undrained behaviour of fibre-reinforced silty sand on liquefaction resistance. Higher fibre content increased the average number of contacts per particle and the excess pore water pressure making it easier for the particles to disperse. The reduced contact forces resulted in enhanced liquefaction resistance.

However, the fibre tends to immerse in the silt pellets and fill the larger pore spaces. Ding *et al.* (2021) investigated further by using granulated rubber-sand mixtures as a new railway subgrade filler under monolithic and dynamic loading. The result showed that the optimum rubber content for the new subgrade filler is about 10%. Riveros & Sadrekarimi (2020) attempted to improve soil liquefaction resistance by using environmentally friendly microbially-induced calcite precipitation (MICP). The result revealed that, relative to the untreated sand, the MICP-treated sand has up to 67% higher cyclic resistance, which improved the sample's liquefaction resistance and rigidity.

The literature revealed that most previous studies in Malaysia are focused on dynamic loading due to earthquake especially on liquefaction potential and soil improvement. Many experimental studies focused on the influence of fine and coarse content in a soil matrix and the impact of using additives to enhance soil strength under seismic loading. However, studies on residual soil response to dynamic loading is limited. The residual soil in Malaysia consists of various fine and coarse materials. High temperatures and abundant rainfall produce ideal circumstances for chemical reactions that can dissolve rock and transform it into soil, hence residual soils are frequent in tropical areas (Santos *et al.*, 2020).

According to Yong *et al.* (2017), the component of residual soils in Malaysia is dependent on the geological environment and consists of an equivalent ratio of sand, silt and clay. The residual soils have specific dynamic properties that require in-depth investigation. Meanwhile, according to Leng *et al.* (2018), several factors influence effective stress and pore water pressure, which can be divided into two categories: (1) loading conditions, such as cyclic stress level, loading frequency, and loading directions; and (2) soil characteristics, such as over-consolidation ratio, stress status, and Atterberg limits.

Therefore, the objective of this research is to investigate and present the systematic laboratory study aiming to explore the response of residual soil in Malaysia such as characteristic of stress, strain, and hysteresis loop pattern for residual subjected to cyclic loading. Residual soil samples that were subjected to cyclic loads had their dynamic response assessed, including strain development, effective stress path, and pore water pressure. The result obtained should be able to be used for further research concerning with residual soil for soil subjected to dynamic loading such as earthquake, rail trail, and machine vibration. This research project provides knowledge of residual soil behavior based on the response of soil to dynamic loading. This fundamental study delivers initial evidence for dynamic loadings imposed on the residual soils.

METHODOLOGY

Material

In this study, soil sample was obtained at UPNM campus. The location of the site is shown in Figure 2. Both disturbed and undisturbed samples were collected for laboratory experiments. Disturbed samples were collected at 1 meter depth below the ground surface for determination of soil basic properties, while undisturbed samples were collected for cyclic loading experiment.

Specimen preparation for dynamic loading experiments that used was a triaxial dynamic loading testing machine were sampled using mold size of 70 mm diameter and 140 mm height. After sampling, the mold was covered both of its ends to preserve the moisture content. Samples were carried to the laboratory and trimmed at the edge and prepared for testing.

Figure 2. Area of sampling.

Method

Disturbed soil samples were tested for soil basic properties. The laboratory experiments conducted included Particle size distribution (PSD) in according to ASTM D6913 / D6913M – 17: Standard Test Methods for Particle-Size Distribution (Gradation). Undisturbed soil samples placed in the mold are used subjected to dynamic loading experiment. This experiment was done using The GDS Enterprise Level Dynamic Triaxial Testing System (ELDYN). The experiment was conducted according to ASTM D5311-13M -Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil.

Four processes were involved for the experiment: setting up apparatus, saturation, consolidation, and cyclic loading test. For the experiment set up, the sample was placed on the cell pedestal within rubber membrane and porous disk at both sample ends. Then this system was deaired to obtain reliable data from the tests.

ELDYN apparatus consists of the following components as shown in Figure 3:

i. Triaxial cell
ii. Dynamic control and data acquisition unit
iii. Cell and back pressure/volume controllers
iv. GDSLAB control and acquisition software.

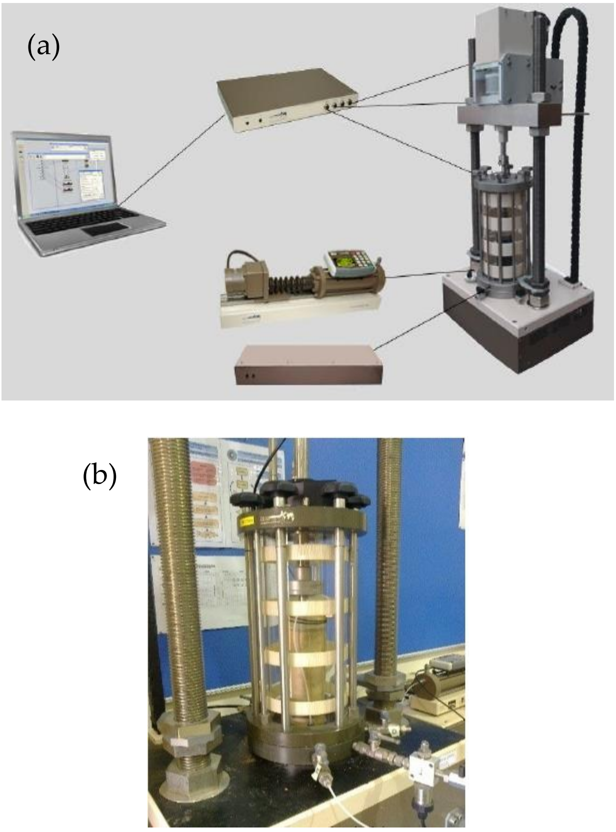

Figure 3. (a) ELDYN system [6] (b) Triaxial cell.

The saturation process then began by using consolidated undrained (CU) test. Starting at 20 kPa of back pressure, the pressure is increased at the increment of 50 kPa until full saturation is achieved. Termination of saturation process takes place when the volume change of the specimen is no longer significant and final saturation B-value of at least 0.95 or 95% of the excess pore pressure has dissipated. A consolidation process was followed, and full consolidation is considered after the specimen achieved the effective stress state required. The consolidation condition in the test is isotropic ($\sigma1 = \sigma3$).

This apparatus can conduct dynamic tests up to 5 Hz frequency and the maximum amplitude of 10kN. In this test, one-way cyclic loading varies of frequency and amplitude were applied to simulate dynamic loading. The dynamic loading is a sine wave with vibration frequencies and tests program as shown in Table 1. By using this apparatus, dynamic loading of 1 Hz, more than 1, and less than 20 represent for earthquake event, rail transit, and vibrating machine, respectively.

Table 1. Experiment Schedule for Cyclic Loading.

Type of test	Test No.	Frequency (Hz)	Amplitude (kN)
A	1	1	0.01
	2	2	
	3	3	
	4	4	
B	5	1	0.05
	6	2	
	7	3	
	8	4	

RESULTS AND DISCUSSION

Physical and mechanical properties

Particle size distribution result for the residual soil obtained is shown in Figure 4. The soil is a well graded and the moisture content is 23.5%.

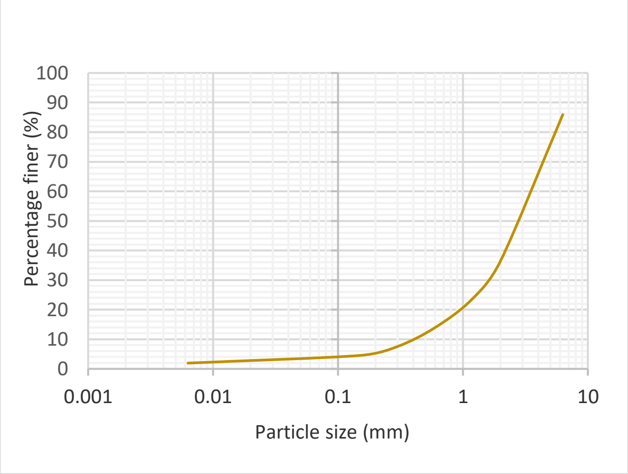

Figure 4. Particle size distribution of the sample.

Cyclic test results

The response of residual soil due to variation of cyclic loading is proved throughout the tests. A harmonically variable cyclic load was given to saturated specimens during cyclic loading, and the variation of axial stress, excess pore water pressure, and axial strain of the specimen were continually recorded.

Figures 5 to 7 show the results of a typical cyclic triaxial experiments performed on the soils. Pore pressure ratio is plotted against the stages of test of loading cycles in Figure 5. From the figure, it suggests that the rate of pore pressure generation in the soil for test type B (5 to 8) is significantly higher than test A (1 to 4). However, for each type of pore pressure, the value is gradually increased with an increasing of time of tests/ number of loading cycles. Therefore, it is indicated that higher frequency and amplitude resulted with higher pore pressure accumulation in soil. For tests with higher amplitude shows significant higher result although same frequency was imposed to the samples. It is also observed that the slow growth of pore pressure in the later stage of cyclic loading stabilized.

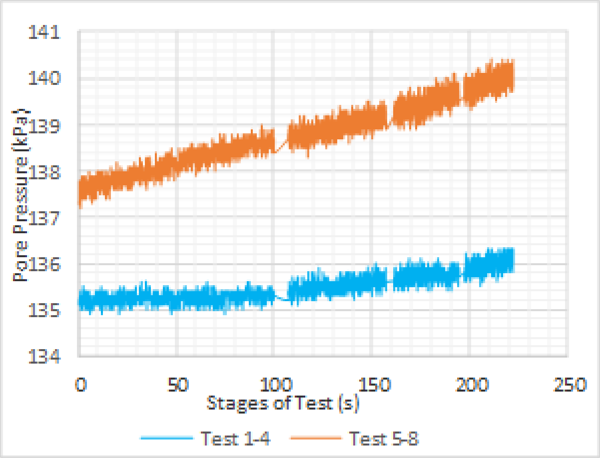

Figure 5. Pore Pressure of cyclic loading test for Test A and B.

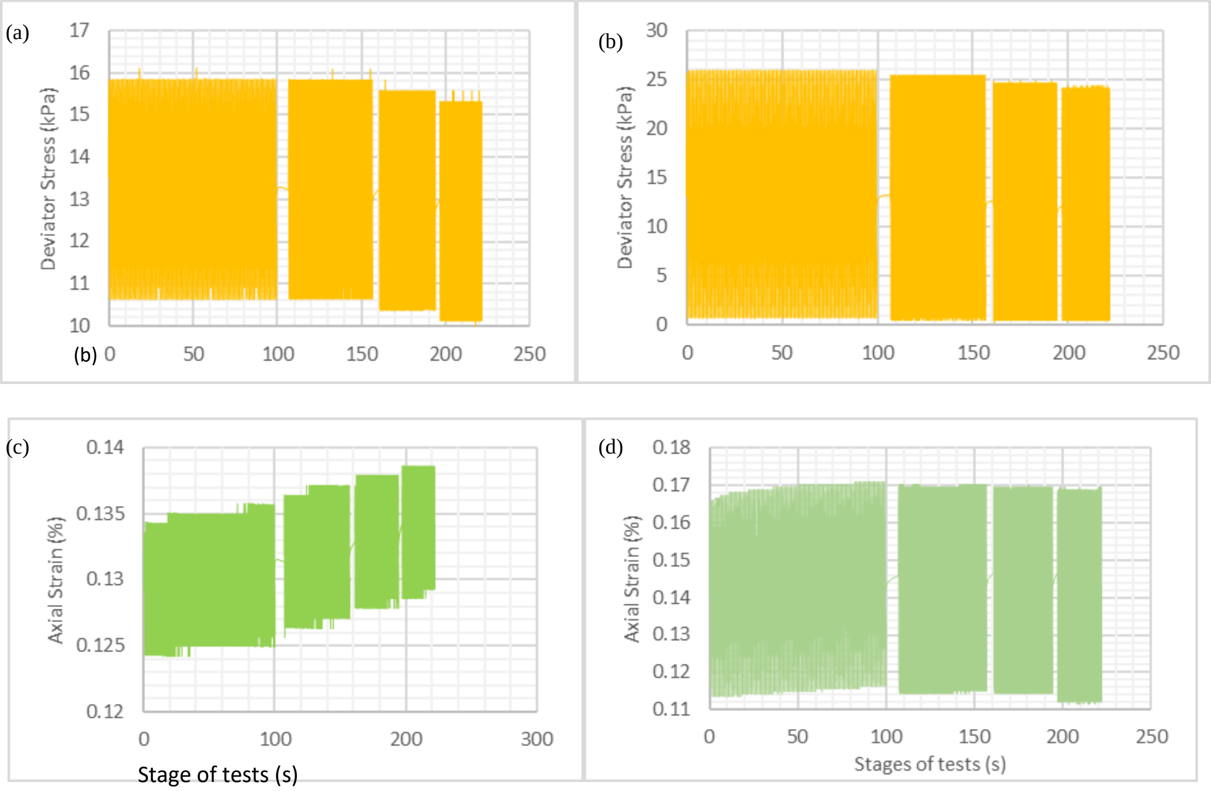

Figure 6. Deviator stress for (a) Test 1 - 4 (b) Test 5 - 8, and Axial strain for (c) Test 1 -4 (d) Test 5 – 8.

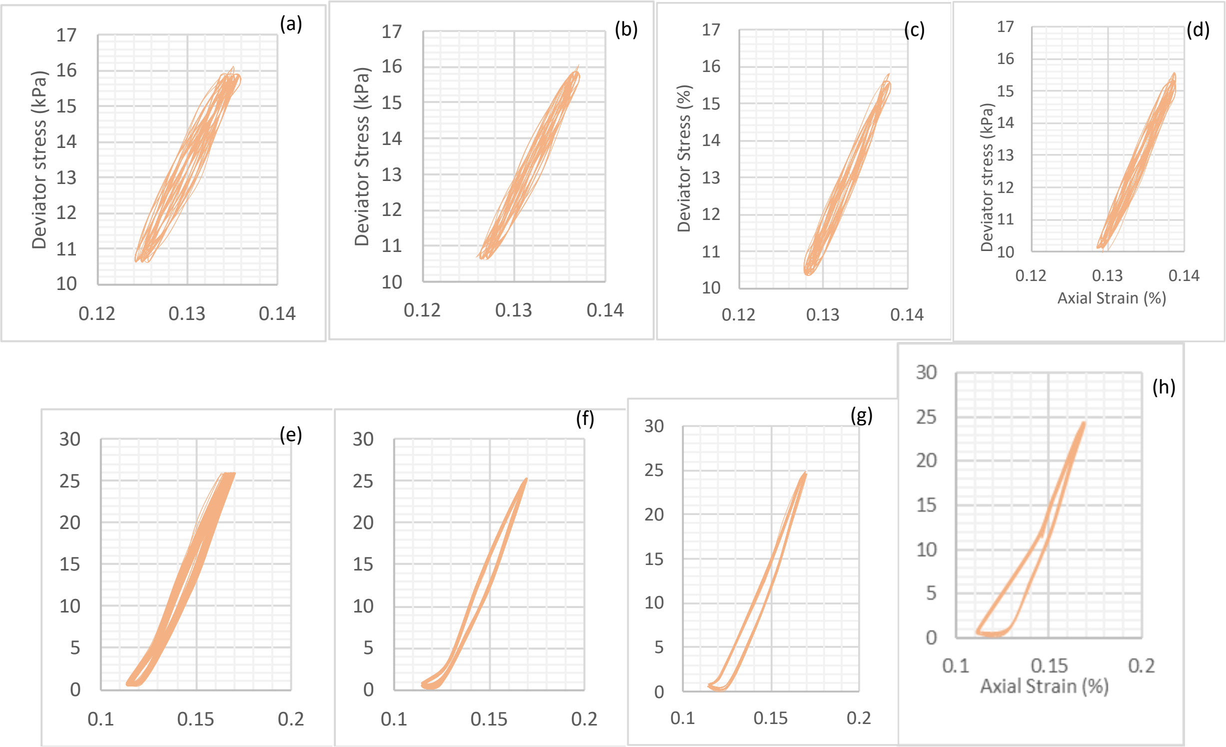

Figure 7. Stress-strain relationship for (a) - (d) Test 1 – 4 and (e)- (h) for Test 5 – 8.

Figure 6 (a) to (d) show the results of response of soil to cyclic loading through deviator stress and axial strain. It can be seen from figure 6 (a) and (b) that the pattern of stresses for both types are almost identical except higher value for test B compared to A. The variation of deviator stress is minimal during the early stages of cyclic loading throughout test 1, 2, 5 and 6. On the other hand, the decreasing of stresses can be observed starting with test 3, 4, 7, and 8, which indicated that the soils are approaching failure criteria especially the soil that was imposed with higher frequencies and amplitudes.

The axial strain pattern for both types is in contrast with deviator stress as shown in Figure 6 (e) to (h). The increasing of value from test 1 throughout test 8 for type A, but for test type B, the value increased slowly for test 5, and 6, and then gradually decreased starting at test 7 and 8 with the increased of loading cycles. Figure 7 shows the relationship between the deviator stress and axial strain for the cyclic loading tests. The establishment of stress-strain hysteresis loops for all tests shows a difference in shape of the loops for type A tests compared to type B. For type A, the loop started with lower value of strain for test 1 and 2. The hysteresis loop is then shifted towards the right side for test 3 and 4.

However, only the variation of axial strain is noticeable for test 1 to 4, but the deviator stress remains stagnant throughout the tests. For type B test, it is observed that the hysteresis loops are in different pattern compared to type A.

The peak value for the hysteresis loop is almost the same for all tests, but the shape of the loops is different which became wider at the bottom. In other words, the type A and B tests are considered as stable and unstable cycle, respectively. This can be explained by the pattern of axial strain pattern in Figure 6(d) whereby the value is increased at early tests but tends to decrease towards the last stage of tests.

Overall, the establishment of hysteresis loop due to cyclic loading shows a good agreement of result of deviator stress and axial strain. It is observed that results obtained for this study have a good agreement to the results obtained by previous researchers such as Castelli *et al.* (2019), Hashim *et al.* (2017), and Zahmatkesh & Noorzad (2018).

CONCLUSION

In this study, residual soil was tested for a series of experiment programs, subjected to cyclic loading. The response of residual soil was investigated in terms of deviator stress and axial strain establishment throughout the test. Residual soil in this research has a good response towards dynamic load imposed based on the accumulation of pore pressure obtained. With the same frequency but higher amplitude, the sample experienced higher accumulation of pore pressure. Hysteresis loops for lower amplitude achieved stable cycle throughout the tests. Unfortunately, higher amplitudes seem to be unstable cycle. This can be explained by the decreasing of axial strain starting in test B.

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REFERENCES

[1] ASTM D6913 / D6913M – 17.2017. *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*. ASTM International, West Conshohocken, PA.

[2] ASTM D5311-13M. 2021. *Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil*. ASTM International, West Conshohocken, PA.

[3] Cappellaro, C., Cubrinovski, M., Bray, J. D., Chiaro, G., Riemer, M. F. & Stringer, M. E. 2021. Liquefaction resistance of Christchurch sandy soils from direct simple shear tests. *Soil Dynamics and Earthquake Engineering*, 141, 106489.

[4] Castelli, F., Cavallaro, A., Grasso, S. & Lentini, V. 2019. Undrained cyclic laboratory behavior of sandy soils. *Geosciences*, 9(12), 512.

[5] Ding, Y., Zhang, J., Chen, X., Wang, X. & Jia, Y. 2021. Experimental investigation on static and dynamic characteristics of granulated rubber-sand mixtures as a new railway subgrade filler. *Construction and Building Materials*, 273, 121955.

[6] Ghadr, S., Samadzadeh, A., Bahadori, H. & Assadi-Langroudi, A. 2017. Liquefaction resistance of fibre-reinforced silty sands under cyclic loading. *Geotextiles and Geomembranes*, 48(6), 812–827.

[7] Hashim, H., Suhatril, M. & Hashim, R. 2017. Assessment of liquefaction hazard along shoreline areas of Peninsular Malaysia. *Geomatics, Natural Hazards and Risk*, 8(2), 1853–1868.

[8] Min Lee, L., Jianjun, Z., Yong K.K. & Li, C. Y. 2015. Overviews of Factors Affecting Dynamic Properties of Tropical Residual Soil. *International Journal of Civil and Structural Engineering*, 3(1), 17–20.

[9] Leng, J., Liao, C., Ye, G. & Jeng, D. S. 2018. Laboratory study for soil structure effect on marine clay response subjected to cyclic loads. *Ocean Engineering*, 147, 45–50.

[10] Luo,J. and Miao,L. 2016. Research on Dynamic Creep Strain and Settlement Prediction Under the Subway Vibration Loading. *SpringerPlus*, 5,1252.

[11] Lim, J. X., Lee, M. L. & Tanaka, Y. 2018. Effect of fine content on soil dynamic properties. *Journal of Engineering Science and Technology*, 13(4), 851–861.

[12] Marto, A., Tan, C. S., Esa, N. N., Pakir, F. & Jusoh, S. N. 2014. Liquefaction potential of Nusajaya city. *Electronic Journal of Geotechnical Engineering*, 19(Z5), 17231–17239.

[13] Othman, B. A. & Marto, A. 2019. A liquefaction resistance of sand-fine mixtures: short review with current research on factors influencing liquefaction resistance. *International Journal of Integrated Engineering*, 11(7), 20–30.

[14] Rahman, M. Z. & Siddiqua, S. 2017. Evaluation of liquefaction-resistance of soils using standard penetration test, cone penetration test, and shear-wave velocity data for Dhaka, Chittagong, and Sylhet cities in Bangladesh. *Environmental Earth Sciences*, 76, Article number 207.

[15] Riveros, G. A. & Sadrekarimi, A. 2020. Liquefaction resistance of Fraser River sand improved by a microbially-induced cementation. *Soil Dynamics and Earthquake Engineering*, 131,106034.

[16] Santos, O. F., Lacerda, W. A. & Ehrlich, M. 2020. Effects of Cyclic Variations of Pore Pressure on the Behaviour of a Gneiss Residual Soil. *Geotechnical and Geological Engineering*, 38(5), 5201–5212.

[17] Vaez Shoushtari, A., Adnan, A. B. & Zare, M. 2018. Incorporating the local faults effects in development of seismic ground-motion hazard mapping for the Peninsular Malaysia region. *Journal of Asian Earth Sciences*, 163, 194–211.

[18] Ye, Y., Cai, D., Yao, J., Wei, S., Yan, H. & Chen, F. 2021. Review on dynamic modulus of coarse-grained soil filling for high-speed railway subgrade. *Transportation Geotechnics*, 27,100421.

[19] Yong, K. K., Xian, L. J., Li, Y. C., Lee, L. M., Tanaka, Y. & JianJun, Z. 2017. Shaking table test on dynamic behaviours of tropical residual soils in Malaysia. *KSCE Journal of Civil Engineering*, 21(5), 1735–1746.

[20] Zahmatkesh, A. & Noorzad, R. 2018. Investigation of monotonic and cyclic behavior of sand using a bounding surface plasticity model. *Arabian Journal of Geosciences*, 11, Article number 40.

[21] Zhang, C. L., Jiang, G.L., Su, L.J., Liu, W.M. & Zhou, G. D. 2018. Effect of dry density on the liquefaction behaviour of Quaternary silt. *Journal of Mountain Science*, 15(7), 1597–1614.