International Journal of Advanced and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

Special Issue

STRENGTH OF EXPANDED POLYSTYRENE (EPS)-SAND AS LIGHTWEIGHT MATERIAL IN GEOTECHNICAL ENGINEERING

A. Ibrahim*, F. Ahmad, Z. A. Hassan and F. Ali

Department of Civil Engineering, Faculty of Engineering, UniversitiPertahananNasional Malaysia, Sungai Besi Camp, 57000 Kuala Lumpur, Malaysia

Published online: 10 September 2017

ABSTRACT

This paper aims to introduce the uses of waste expanded polystyrene (EPS) as an option of lightweight soil especially for the buried structures such as tunnel and bunker for military uses, which is threatened to the impact of blast loading. This paper focuses on the strength of EPS-sand mixture, damping ration and pressure produced due to blasting effect on the material. The EPS-sand mixed proportion used for this study were 10%, 20%, 30%, 40%, 50% and 60% of EPS and also 100% sand. Shear strength and damping ratio were measured through shear box test and cyclic loading test respectively. Other than that, numerical simulation using ANSYS AUTODYN was use to obtain pressure due to the blast loading. Results indicated that 40% EPS-sand mixture gave optimum strength and also the highest damping ratio for all pressures applied.

Keywords: EPS-sand; shear strength; damping ratio; blast loading.

Author Correspondence, e-mail: aniza@upnm.edu.my

doi: http://dx.doi.org/10.4314/jfas.v9i3s.44

1. INTRODUCTION

Most of critical infrastructure such as tunnel, pipeline or even electric and telecommunication cables and gas mains are located underground and their fate is closely related to the surrounding ground. Underground structures for example, can be affected by the vibration due to vehicles movements, earthquake and ground impact caused by explosion. The soil-structure interaction of a buried structure is affected by the structure's material, size and stiffness; by the method of construction in the field (e.g., trench, embankment or tunnel); by the type and placement of the soil backfill material and by the external loading. While external loading can be static loads or dynamic loads, soil that is subjected to these loads must be capable to reduce the amount of pressure to the underlying structures. As for backfill material, lightweight soil of high shear resistance and damping capacity may be considered as a layer of shield to buried structures. Lightweight materials have been used extensively in civil engineering application. The use of lightweight soil material is used to reduce vertical earth pressure and lateral earth pressure, also to prevent excessive settlement, to increase factor of safety for slope and other applications [9].

There have been various studies on lightweight materials for construction purposes such as rubber-sand mixture, rubber-gravel mixture, rubber tire and others. A study using rubber-sand mixture and rubber-gravel mixture was done by [1] on the determination of the small-strain shear modulus and damping ratio of rubber-sand and rubber-gravel mixture. Results from the study indicated that response of the mixtures is significantly affected by the content of rubber and the relative size of rubber to soil particles. It is mentioned in the result that the percentage of rubber should not exceed 50% for the mixture. Other than that, the study also found that higher percentage of rubber in the mixtures will increase the damping ratio.

Other lightweight soil material research that used fill material for highway embankment, bridge abutments and backfill behind retaining structures especially involving weak foundation soils with low bearing capacity and high settlement problems was done by [8]. This study has used waste rubber tire in the form of chips in lightweight soil that includes the geotechnical properties of rubber tire chips-cohesive clayey soil.

In [6] also studied the use of tire chips as lightweight inclusion for the purpose of improving the bearing capacity and to control the settlement of sandy soil. The result revealed that the ultimate bearing capacity of the mixture of tire chips and sandy soil showed a noticeable increase up to 7 times its value compare to control sand samples.

Expanded polystyrene (EPS) is a thermoplastic, lightweight, rigid-foam plastic with low thermal conductivity, high compression, strength and excellent shock absorption that makes it an ideal material for application demand [3]. In Malaysia, recycle program of EPS waste has not yet been very successful, waste EPS products from packaging materials to food containers are disposed together with domestic waste, creating a huge problem at dumping sites. Approximately, 8 kilograms of waste EPS would take up a volume of 1 cubic meter of the dumping site space. In average, Malaysia produces not less than 300,000 tons of waste EPS every year, a number which is not a huge different with the UK's.

The use of waste EPS is an option in the development of sustainable geometrical, especially in the development of lightweight soil. EPS can reduce overburden pressure on underground structure that may subjected to vibration, explosion or seismic load. Since EPS is also known for its high damping capacity, this may permit consideration of EPS-soil mixture as part of damping system to reduce vibration, thus can be useful in explosive impact absorption and earthquake mitigation. EPS is considered to be very low in density which is almost 100 times lesser than soil, but high in compressibility with good flexural strength and high rupture strength in shear [8]. The usage of EPS as recycled material does not only provide lightweight fill solution, but also its usage would save the environment [4].

There are few studies have been conducted using EPS bead as a lightweight material. In [7] carried out investigation on the mechanical characteristics of the EPS bead mixture for lightweight soil as the filling material of highway embankments. The result showed that the uses of EPS bead is adequate to be used as the filling material in order to decrease the damage potential of the bridge-head jumping and to control the post-construction settlement. Moreover, in [5] found that the inclusion of EPS granules has significantly reduced the potential volume change of the soils when subjected to one-dimensional free swell conditions. In other words, the recycled EPS granules is proven to be able to reduce the volumetric shrinkage potential of the expansive soils. In [2] has conducted a study shear strength of EPS beads-sand mixture. The study comprised of 0.5%, 1.5% and 2.5% EPS bead and were employed and tested with 4 different cell pressure of 100kPa, 200kPa, 300kPa and 400kPa respectively. The results indicated that the shear strength of the EPS bead-sand mixture decrease with the EPS percentage increase. The study also suggested the mixture of 0.5% of EPS bead- sand for the industrial usage.

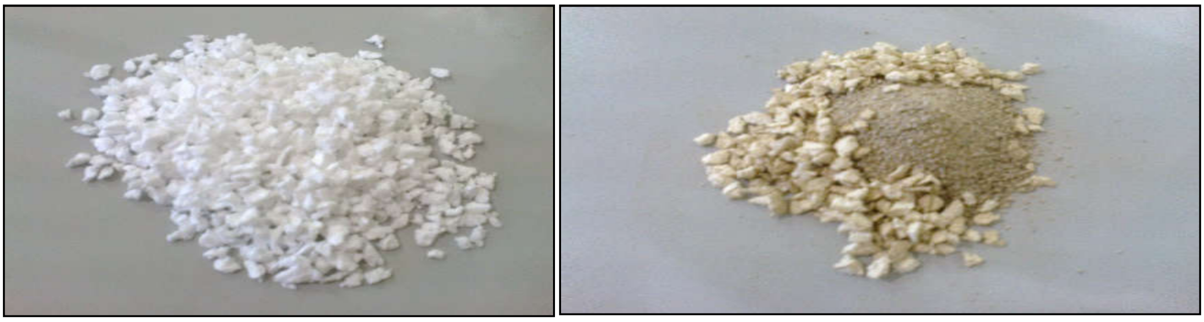
In another study, EPS geofoam was tested by [12] as lightweight filling material to observe long term durability and performance for road construction purposes. It is recommended that EPS geofoam to be used as the life cycle up to 100 years. But, it should be noted that the material should be properly protected from spills of dissolving agent and the dead load should be kept below 30-50% of stress level. In addition, there are other researchers that studied on the mixed EPS particulates with sand to create a lightweight fill. The stress-strain characteristics of the modified soils in the laboratory using direct shear and triaxial compression tests are obtained by [2-4, 10-11, 14].

Apart from the aforementioned researches, there are still many areas in lightweight soil where information is still inadequate especially on its dynamic properties and soil-structure interaction. The objectives of this paper are to determine the shear strength of the shredded EPS-sand mixture, its damping ratio and pressure produced due to the blast-loading when the shredded EPS-sand mixture are used as lightweight material for ammunition concrete bunker. The explosion created the intensive shock waves that propagate the outward at supersonic velocity followed by heat and light that can produce pressure which can cause damage on the structures.

2. METHODOLOGY

2.1. Material

This research was using waste EPS that has been manually cut and shredded. Then the shredded EPS was mixed with commercially obtained sand with the volume percentage of 10%, 20%, 30%, 40%, 50% and 60% of EPS. Other than that, this research is also using sample of 100% sand for control purposes. The volume percentage were determined by using 54.75 mm diameter with 43 mm height cup and 1 cup of EPS represent 10% of EPS. Sample of EPS-sand mixture is shown in Fig. 1.



(a) (b)

Fig.1. Samples of (a) raw shredded EPS (b) EPSsand mixture

2.2. Properties of Soil

Basic soil properties test for the samples were conducted in laboratory. The tests included sieve analysis, optimum moisture content, specific gravity and dry unit weight for each of the sample.

2.2.1. Shear Box Test

Shear box test was conducted to determine shear strength of each EPS-mixture sample. For this test, each sample was mixed with the optimum moisture content value which was obtained from the soil properties test. Five layers of mixture were placed in the shear box apparatus and compacted for 25 blows for each layer (Fig. 2). In this test, three loadings were used for the test; 2, 3 and 4 kilogram (kg) respectively and displacement of horizontal were measured. The tests were done with three samples of loading for each to all EPS-sand mixtures and control sand samples.

Fig.2. Shear box test for EPS-sand mixture

2.2.2. Dynamic Cyclic Test

Dynamic cyclic test is used to determine damping ratio for each of the EPS-sand mixture, which is the behaviour of soil under dynamics loading. In this research, GDS Enterprise Level Dynamic Triaxial Testing System (ELDYN) apparatus were used in the laboratory. The sample of the EPS-sand mixture was prepared by mixing it with the optimum level of water content. Then, the sample was placed in the rubber membrane of the apparatus with five layers and compacted for 25 blows for each layer. The samples were placed in the triaxial apparatus and tested by 1Hz frequency for 50 cycles (Fig. 3). The pressure used for dynamic cyclic test are 56, 83 and 112 kPa respectively, which were the same as the loading for shear box test. The tests were done with three samples of each to all EPS-sand mixtures and control sand samples.

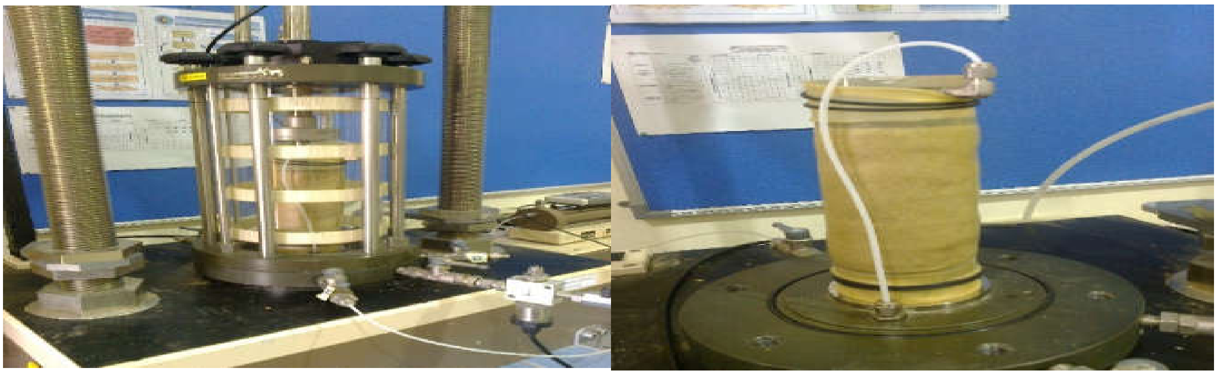


Fig.3. Dynamic cyclic test

Damping ratio λ can be determined from the hysteresis loops using the following equation, which is based energy loss coefficienton the Fig. 4 [13].

$$\lambda = \frac{A_1}{4\pi A_2} \tag{1}$$

where A_1 is the area enclosed by hysteresis loop ACBDA and A_2 is the area of ΔAOE.

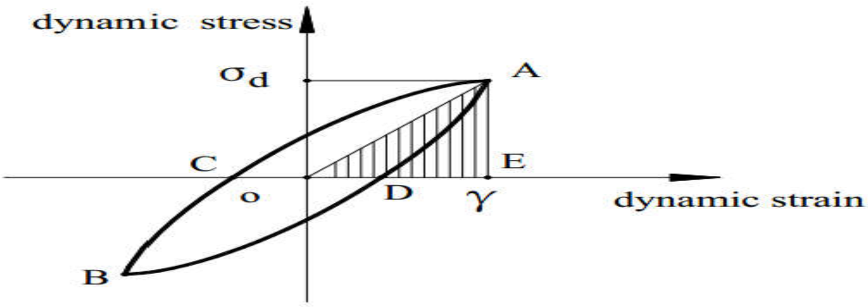
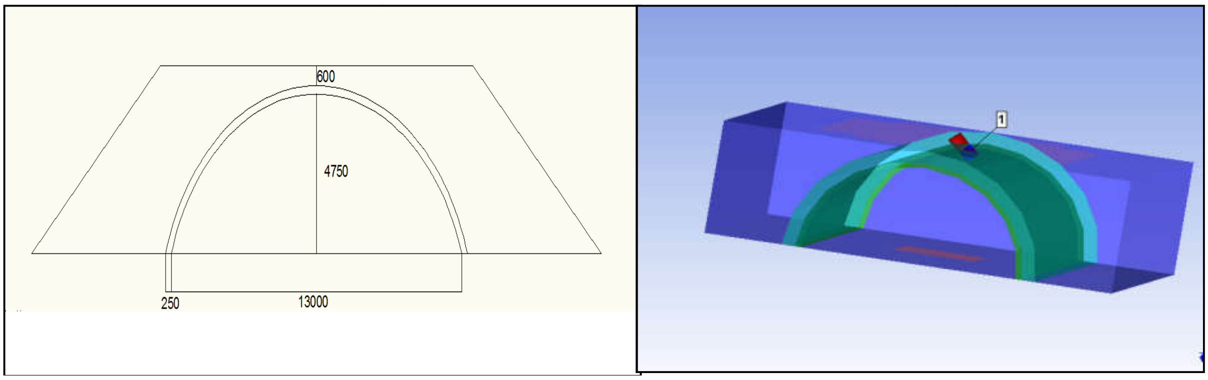


Fig.4. Dynamic stress and strain for damping ratio [13]

2.2.3. Numerical Simulation

In this study, numerical simulation using ANSYS AUTODYN software is used to simulate the effect of overpressure induced due to the blast loading to the EPS-sand mixture. In this simulation, the EPS-sand mixture was tested whereby the material is used as lightweight material for the bunker for military purposes. Therefore, in this software, the EPS-sand mixture was filled on top of the bunker and the blast loading using explosive material is produced by trinitrotoluene (TNT) weighing 227kg. The weight of TNT is obtained by the actual weight of Mark 82 (Mk 82) bomb used and dropped to the ground by armed air force. The concrete bunker size is 13 m x 13 m with 250 mm thickness, while the EPS-sand mixture filled on top of it is 600 mm thick. For the simulation of overpressure purposes, a gauge is placed on the middle top of the EPS-sand mixture. The schematic diagram of the bunker is illustrated in Fig. 5. The effect of the blast loading was simulated for all of the EPS-sand mixture percentage including 100% sand.



(a) (b)

Fig.5. (a) Schematic diagram of the bunker (b) Location of gauge at ANSYS AUTODYN software

3. RESULTS AND DISCUSSION

3.1. Basic Soil Properties

The result of dry unit weight, specific gravity, and moisture content of all samples EPS-sand mixture and 100% sand are shown in Table 1.

Table 1. Soil properties of sample

	Dry Unit Weight	Specific Gravity	Moisture Content
Sand	18.80	2.62	5%
10% EPS	18.33	2.5	6%
20% EPS	18.03	2.32	6%
30% EPS	17.06	2.06	6%
40% EPS	15.23	1.83	6%
50% EPS	14.32	1.66	6%
60% EPS	14.19	1.42	6%

3.2. Shear Strength

Shear strength of the EPS-sand mixture were obtained from shear box text. Horizontal displacement results are as in Fig. 6 (a) to (c). The results show that 40% EPS sand mixture achieved highest strength for all 56, 83 and 112 kPa of loading respectively for both horizontal and vertical stresses. It can also be seen from the results that the highest loading of 112 kPa obtained the highest displacement for 40% EPS-sand mixture. In addition, this experiment also indicates that all EPS-sand mixture has achieved higher shear stresses, τ compared to 100% sand mixture. This has proven that the EPS has increased the shear strength of soil and with 40% mixture has given it the optimum shear strength.

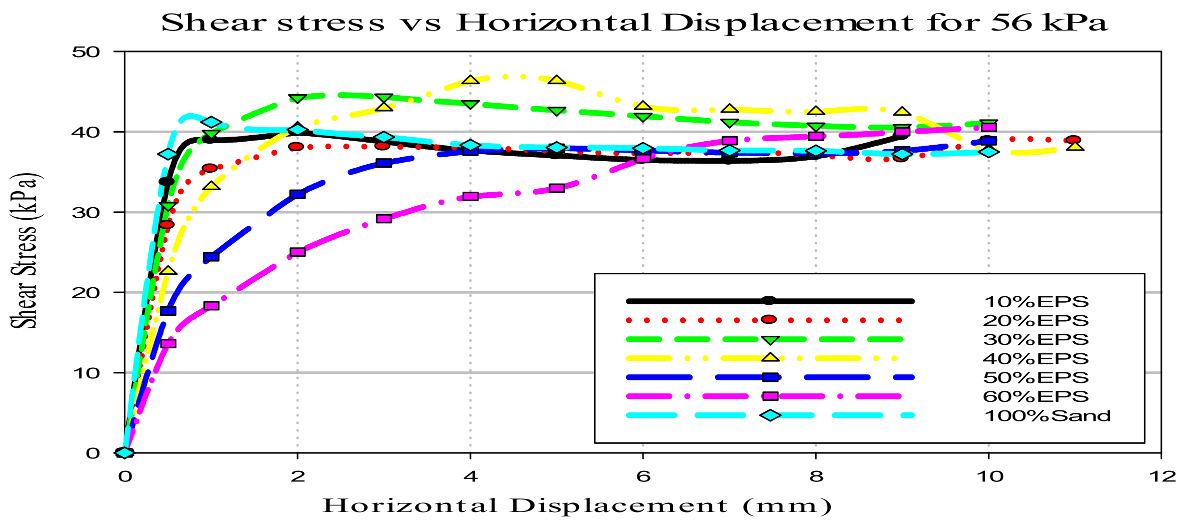
3.3.Damping Ratio

Mixture has the highest ability to damping ratio for the EPS-sand mixtures were determined by the dynamic cyclic loading test. The result from Fig. 7 shows that 40% EPS-sand mixture gives highest damping ratio for all loadings that were applied to the samples. It also shows the increase of damping ratio compared to 100% sand. Higher value of damping ratio gives lower impact of vibration to the EPS-sand mixture, which will reduce any damage to the structures below the mixture. From dynamic cyclic test, the damping ratio of the mixture was affected by cell pressure where lower cell pressure increased the damping ratio. Numerical simulation shows that 40% EPS-sand absorbs pressure in comparison to other mixtures.

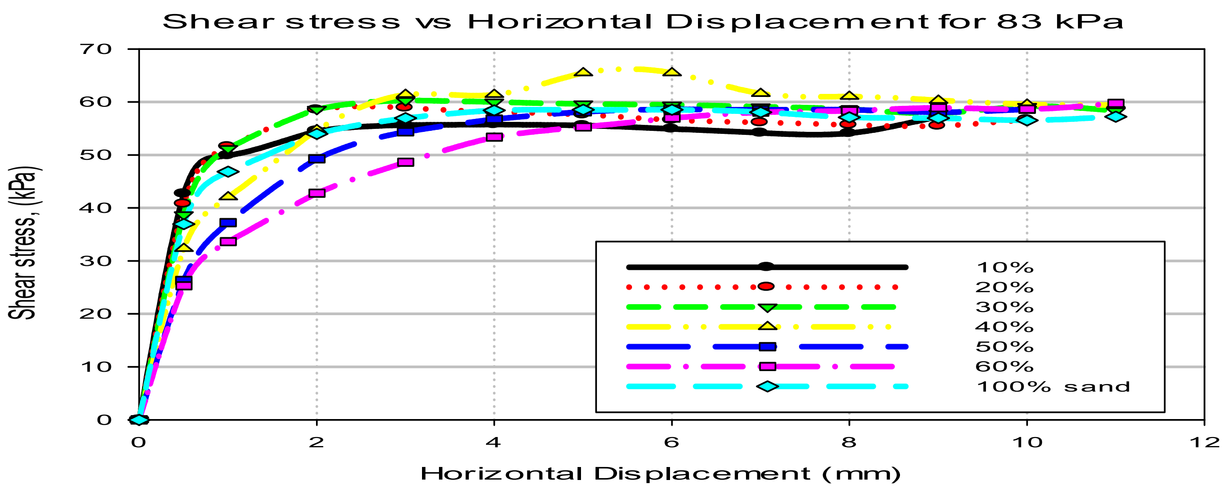
3.4. Overpressure

Overpressure for the EPS-mixtures were determined by the numerical simulation using

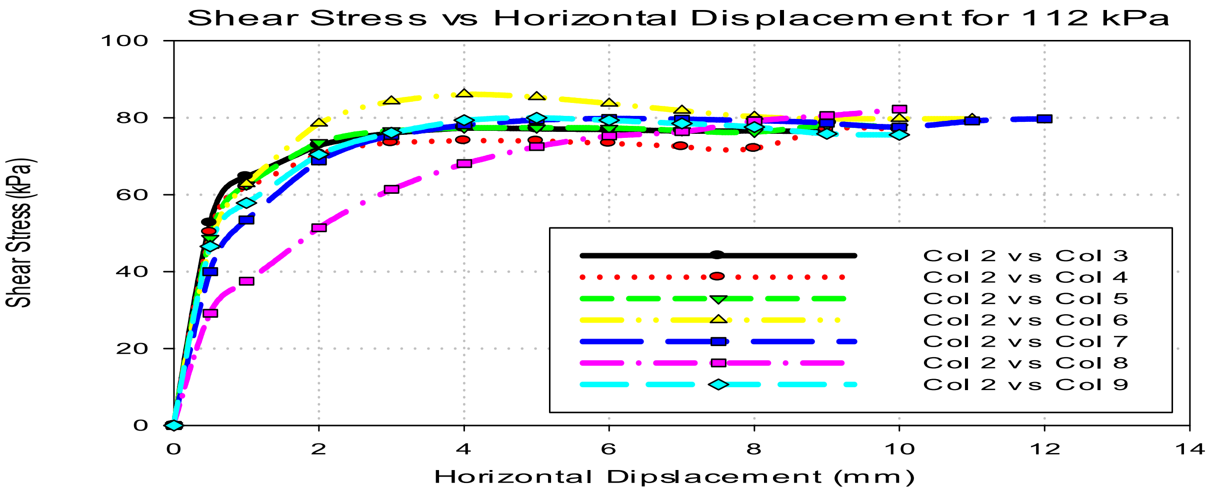
ANSYS AUTODYN, which simulates the blasting effect to a concrete military bunker. By using the same loading applied to shear box tests, the simulation result of overpressure is shown in Fig. 8. The result which is based on the highest peak shows that 40% EPS-sand mixture gives the lowest overpressure to the mixtures. The result also indicated that 40% EPS-sand mixture experienced the longest time for the peak overpressure value. This result shows that with 40% EPS-sand mixture not only will produce highest endurance to protect the structures beneath it, but it also takes the longest time to produce the peak overpressure. In contrast, the sample with 100% sand experienced highest peak overpressure compared to all EPS-sand mixtures which support the claim that the addition of EPS will increase soil strength against the effect of blast loading.



(a)



(b)



(c)

Fig.6. Shear stress versus horizontal displacement graph of (a) 56 kPa (b) 83 kPa (c) 112 kPa

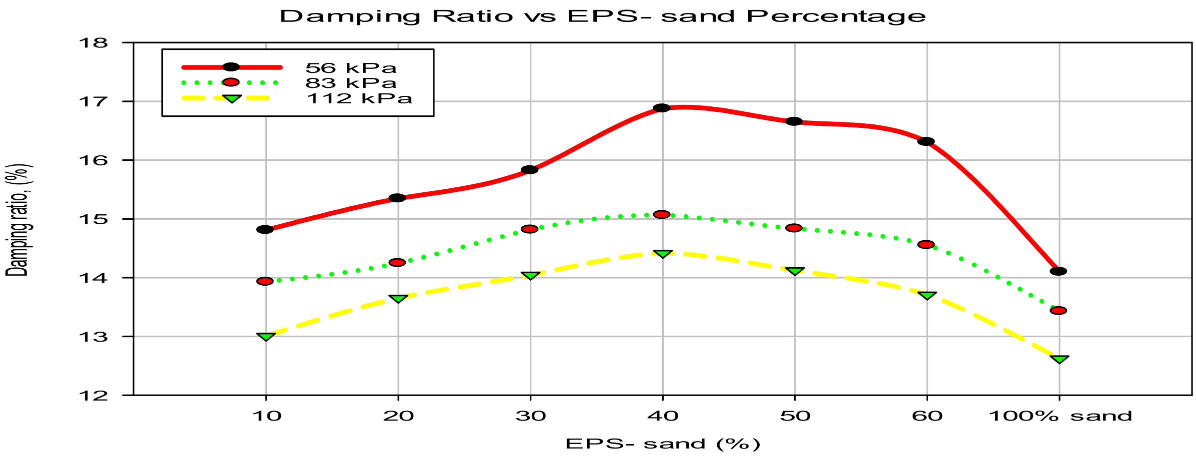


Fig.7. Damping ratio of EPS-sand mixtures and control sand sample

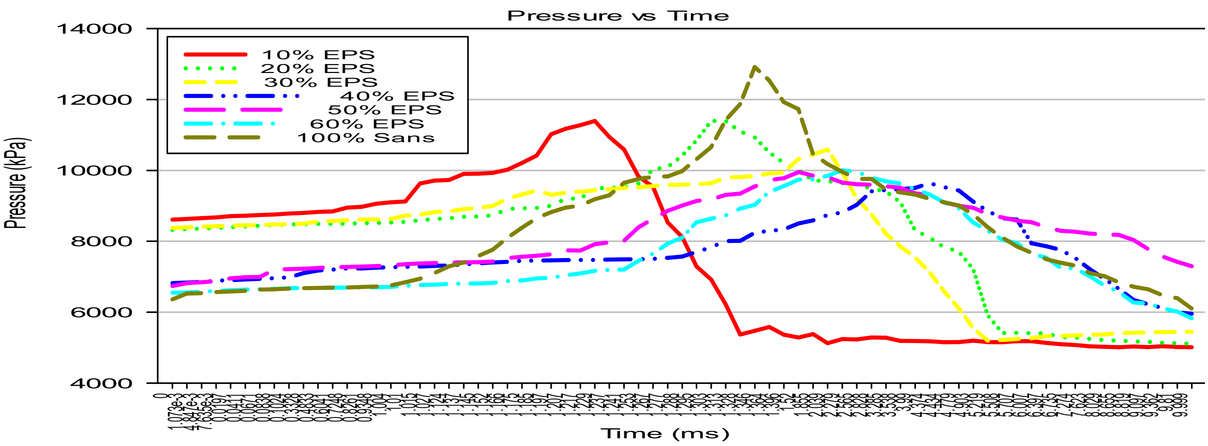


Fig.8. Overpressure versus time of EPS-sand mixtures and control sand sample

4. CONCLUSION

This paper has discussed on the strength of EPS-sand mixtures using shear box apparatus and numerical simulation of its application for the effect of blast loading. Shear strength of soils using shear box test has proved that EPS sand mixtures achieved better results than the control sand sample. The results also revealed that the 40% EPS-sand mixtures achieve the optimum strength compared to other mixtures. In term of damping ratio against vibration, the result indicated that 40% EPS-sand mixture also gives the highest value for all pressures applied including the control sand sample. Furthermore, numerical simulation also proved that 40% EPS-sand mixture produces the lowest overpressure which can sustain better than other mixtures including control sand sample for the effect of blast loading. In future, it is recommended that the research of EPS-sand mixture lightweight material to be extended by investigating the transfer of heat wave by due to the effect of explosive material.

5. ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the financial supports provided by UniversitiPertahananNasional Malaysia (UPNM) through RAGS/2013/UPNM/TL/03/1.

6. REFERENCES

[1] Anastasiadis A, Senetakis K, Pitilakis K. Small strain shear modulus and damping ratio of sand- rubber and gravel-rubber mixtures. Journal Article of Geotechnical and Geological Engineering,2012, 30(2):363-382

[2] Deng A, Yang X.Modeling stress-strain behavior of sand-EPS beads lightweight fills based on cam-clay models. In GeoHunan International Conference, 2009, pp. 55-61

[3] Deng A, Xiao Y. Measuring and modelling proportion-dependent stress-strain behaviour of EPS-sand mixture. International Journal of Geomechanics, 2010, 10(6):214-222

[4] Edinçliler A, OzerA T. Effects of EPS bead inclusions on stress–strain behaviour of sand. Geosynthetics International, 2014, 212(2):89-102

[5] Nataatmadja A, Illuri H K. Sustainable backfill materials made of clay and recycled EPS. In 3rd CIB International Conference on Smart and Sustainable Built Environments, 2009, pp. 1-8

[6] AbdrabboF M, Abouseeda H M, Gaaver K E, El-Marassi M A.Behavior of strip footings

resting on sand reinforced with tire-chips.In GSP 140 Slopes and Retaining Structures under Seismic and Static Conditions-Geo-Frontiers Congress, 2005, pp. 1-14

[7] Wang F, Miao L.A proposed lightweight fill for embankments using cement-treated Yangzi River sand and expanded polystyrene (EPS) beads. Bulletin of Engineering Geology and the Environment,2009, 68(4):517-524

[8] Cetina H, Fenerb M, Gunaydinb O. Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. Engineering Geology, 2006, 88(11):110-120

[9] Fard K, Chenari R. Shear strength characteristics of sand mixed with EPS beads using large direct shear apparatus. Electric Journal of Geotechnical Engineering, 2015, 20(8):2205-2220

[10] Han-Long L, Deng A, Jian C. Effect of different mixing ratios of polystyrene pre-puff beads and cement on the mechanical behaviour of lightweight fill. Geotextiles and Geomembranes, 2006, 24(6):331-338

[11] Linchang M, Wang F, Han J, Weihua L, Jing L. Properties and applications of cement-treated sand-expanded polystyrene bead lightweight fill. Journal of Materials in Civil Engineering, 2012, 25(1):86-93

[12] Frydenlund T E, Aaboe R. Long term performance and durability of EPS as a lightweight filling material. In 3rd International ConferenceEPS Geofoam, 2001, pp. 1-15

[13] Chen W, Kong L W, Zhu J Q. A simple method to approximately determine the damping ratio of soils. Rock and Soil Mechanics, 28(S1):789-801

[14] Zhu W, Mingdong L, Chunlei Z, Gan Z. Density and strength properties of sand-expanded polystyrene beads mixture. In GeoCongress 2008: Characterization, Monitoring, and Modeling of GeoSystems, 2008, pp. 36-43

How to cite this article:
Ibrahim A, Ahmad F, Hassan Z A, Ali F. Strength of expanded polystyrene (eps)-sand as lightweight material in geotechnical engineering. J. Fundam. Appl. Sci., 2017, *9(3S), 566-577*