Effects of Shear Box Size on Shear Strength between Modified Sand-Column (PFA-Sand Mixture) and Soft Soil

Shakri M. S.[1,2], Md. Noor M. J.[2], Nazaruddin A. T.[2], and Hafez M. A.[3]
[1]Department of Civil Engineering, SEGi University, Kota Damansara Selangor, Malaysia
[2]Faculty of Civil Engineering, University Teknologi Mara, Shah Alam Selangor, Malaysia
[3]Faculty of Engineering, University Tenaga Nasional, Bangi Selangor, Malaysia
Email: {shagamy2, mohdjamaludinmdnoor, nazaruddin23858}@yahoo.com, egypt8@gmail.com

***Abstract*—Shear Box or direct shear test is widely used in the study of shear strength characteristics. Many researchers done their studies on many aspects of test including effect of shear box sizes. In this study, by implementing the different size of shear box, the shear strength of soft soil sample with modified sand column will be determined. Pulverized fuel ash (PFA) has been selected to improve the mechanical properties of sand column including shear strength. PFA can be classified as hazardous Coal Combustion by-Product (CCP), which can contributes to the environmental pollution. According to (ACAA 2009), USA itself has produced approximately 125.5 million tons per annual of CCP which merely 56 million tons of these waste by-products has been successfully employed in applications and others still remain untreated. Therefore, this study is conducted to implement PFA to solve the issue regarding environmental and at the same time benefit the engineering. 40 samples with various proportion of materials (cement, PFA and sand) were prepared. Shear box tests were performed of two shear box sizes (60 x 60 mm and 300 x 300 mm). The results shown that the shear strength decreases as the size of shear box increase.**

***Index Terms*—shear box, PFA, shear strength, ground improvement and sand column**

I. Introduction

Sustainable development is a vital concept to be considered in substitution of ground improvement methods in conventional construction practices. Inter-dependence of economy and environment factors are significantly important in regards to formulate policies and legislations in global aspect decisions, especially in terms of projects that impose massive impact on environment [1]. It is imperative to study concurrent status of construction site prior to geotechnical design, especially in cases involving larger infrastructures. Most of construction practices use raw materials insted of recycling of waste materials and at the end of the day, it produces waste and resulting in an increase of waste collected. It becomes worst if the wastes are harmful to the environment and human health [2].

Reduction of environmental pollution and move towards sustainable development should not be merely regarded as effort to reduce the negative effects of human activities but also as an effort to save resources for the future generation. In order to achieve this, one of the easiest scheme would be to salvage the way advances in reduction and saving resources is to replace the new material rather than conventional sources of construction materials. Ref. [3] reported that fly ash can be successfully used to improve the geotechnical parameters such as bearing capacity and shear strength. Ref. [4] conducted a research on the impact of tire chips mixed with lime, gysum, and fly ash composites for quantification of unconfined compressive strength. Research has found that the use of the mixture can increase the potential for implementation of road sub-base medium with light traffic. Ref. [5] showed through their research, the use of pulverized fuel ash (PFA) can improve the shear strength, bearing capacity and at the same time solve the problems of settlement under the road embankment clay.

Pulverized Fuel Ash (PFA) was categorized as one of the fly ash. According to [6], PFA is a fly ash that can be classified under Class C in Coal Combustion By-Products (CCP) As such, PFA can be regarded as dangerous. PFA contains higher ratio of Al, Si and it also contains Ca and therefore it exhibits pozzolanic behaviour that produces self-hardening case, although a degree of self-cementing can vary in accordance with the source material and the type of coal [7]. Thus this study conducted to implementing PFA as a waste material into one of the ground improvement technique; sand column. Sand column is one of the ground improvement techniques by installing the reinforcement column into the weak soil. Most of projects such as construction of road, highway, embankment and also runway (Kuala Lumpur International Airport 2, Malaysia) are the examples of use of reinforcement column to improve the ground [8]. With reference on shear strength development, the effect on the addition of PFA can be observed and analysed in order to determine the optimum mix design for sand column. Therefore, it is important to study the interrelation between optimum mix design and its corresponded shear

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strength, because the role of sand column can be implemented effectively.

Shear Box or direct shear test is widely used in study the shear strength characteristics. The result from shear box test can be considered as straightforward and some insignificant errors while conducting the test. Ref. [9] mentioned that the insignificant errors caused by apparatus inherent errors while measuring the applied normal stress and errors made by rigidity condition of top loading platen, or the peak frictional angle mobilized in horizontal shear plane that leads to smaller values than the frictional angle in the plane which contains minor and major principal stresses.

Other than errors issues, previous studies showed that the size of sample that being tested also played major effect on the outcome of experiment. Ref. [10] conducted a test on few samples of sand by using different sizes and concluded that friction angle of sand was slight decrease with increasing the size of shear box. Ref. [11] tested on Leighton Buzzard Sand showed no difference in frictional angle with increasing shear box size. Ref. [12] conducted a set of test on sand and sandy gravel samples and concluded that the specimen size and shape give effect on the shear zone. By increasing the size, the shear strength slightly decrease. They also suggested using rectangular cross section for more accurate data on shear box test. Ref. [9] conducted test on Firuzkuh sand with different silt percentages by using different sizes of direct shear box. The results showed that peak shear strength and friction angle are decreased as the shear box size increased. So the tests indicated that the scale effect can be seen in silty sands but the rate of its effect reduces with increasing the silt percentages. Thus this study conducted to investigate the effect of different size of shear box on the shear strength between modified sand column (PFA-Sand column) and soft soil sample.

II. Experimental Program

A. Material Selected

Pulverized Fuel Ash (PFA), cement, sand and natural soft soil were used for the experimental investigations. PFA is a solid waste from the combustion of coal with a high temperature (about 10000℃) in coal based power stations coal. For this study, the source of the PFA has been taken from Power-plant Station of Sultan Salahuddin Abdul Aziz at Kapar Selangor Malaysia. Portland cement has been used as a type of cement based on the availability of this product and according to [13] this type of cement has an ideal ratio of material properties needed. Sand particles passing through 4.75 mm sieve were used to mix with other materials. The moisture content of sand used are ranged between 5.28% and 6.7% when it is in a natural state. The particle density of sand has been obtained and recorded as 2.45 Mg/m^3. Thus, the soil classification of sand used is Well Graded SAND. Summary of the chemical composition of PFA and cement have been presented in Table I. While for natural soft soil also has been used as a second layer of direct shear test. It has been used to study the effects between samples of mixture with natural of soil. Table II shows the properties of soft soil used in this study

TABLE I. Chemical Composition of PFA and Cement

Component	PFA (%)	Cement (%)
Silica (SiO_2)	40-60	20.65
Alumina (Al_2O_3)	20-30	5.87
Iron Oxide (Fe_2O_3)	4-10	2.52
Calcium Oxide (CaO)	5-30	63.55
Magnesium Oxide (MgO)	1-6	2.75
Sulphur Trioxide (SO_3)	0-2	1.63
Sodium Oxide (Na_2O)	0-2	0.85
Potassium Oxide (K_2O)	0-4	0.63
Loss on Ignition (LOI)	0-3	1.54

TABLE II. Type Sizes for Camera-Ready Papers

Properties	Ratio
Moisture content, w_c (%)	58-60
Plastic limit, w_p (%)	30.83
Liquid limit, w_L (%)	50.52
Plastic index, I_P (%)	19.69
Partical density (Mg/m^3)	2.23

B. Sample Preparation

Samples were prepared differently by using various percentage of PFA, cement and sand. 40%, 50%, 60% 70 % and 80% of PFA were used while for cement 4%, 8%, 12% and 16% were used. As for the sand, percentage is added to each mixture through make up of 100% mixture of calculation, for example with 4% of cement mixed with 40% PFA bringing the total of 44%, so over 56% of the mixture is sand. After the samples were prepared, it will be cured based on 28 days curing time period before tested with natural soft soil collected from site.

C. Shear Box Test

Direct shear box tests were performed on various mixture of samples in general accordance [14] standard test method for direct shear tests of soils under consolidated drained conditions. According to [14] the direct shear box test has several particle-size to box size requirements when preparing specimens for testing. It is recommended that the minimum specimen width should not be less than ten times the maximum particle-size diameter and the minimum initial specimen thickness should not be less than six times the maximum particle diameter. Therefore, 60 mm x 60 mm size of shear box test for both PFA-sand mixture and soft soil sample were used for small shear box test and 275 mm x 275 mm size of PFA-sand mixture, 300 mm x 300 mm size of soft soil sample were used for big shear box test. While for loading rate, the average loading rate for small shear box used is 0.85 mm/min and big shear box is 1 mm/min

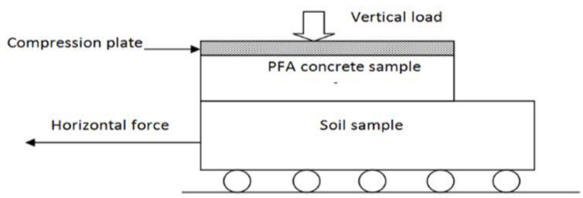


Figure 1. Note how the caption is centered in the column.

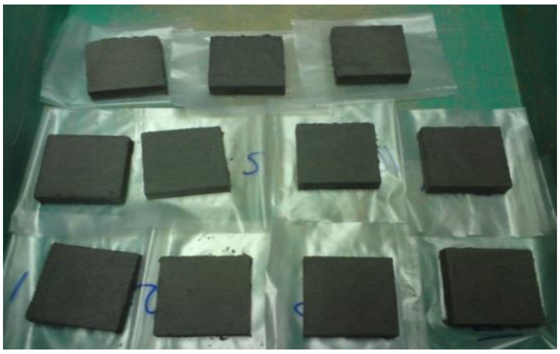


Figure 2. Speciments for small shear box after 28 days curing

Fig. 1 shows the illustration of shear box test conducted. While Fig. 2 and 3 show the sample for big shear box and small shear box after 28 days curing process.

III. Experimental Program

A. Shear Strength Comparison between Small Shear Box (SSB) and Big Shear Box (BSB) Test

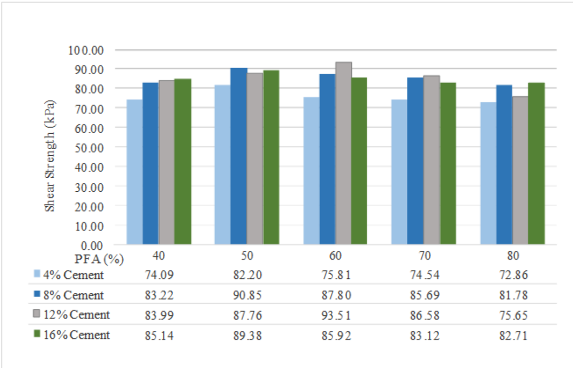
The output data obtained from both type of shear box test were analyzed based on previous and main menthod and theory. Results obtained have been presented in the form of table and graph to make it easily to understood. For small shear box test, the values of normal stress used were 30 kPa, 60 kPa and 120 kPa, while for big shear box test, 5 Psi (34.474 kPa), 10 Psi (68.948 kPa) and 20 Psi (137.896 kPa) have een selected. The test conducted based on unsaturated sample because for natural soil used, natural moisture content been prefered to apply the real condition of site. For stabilized material, 20% to 30% of water ratio were used respectively. Thus, for the sample results, the failure envelope did not go through zero because tests were done under unsaturated condition, so that little amount of apparent cohesion might occur [15]. This phenomenon happens even in some cohesionless soils, in unsaturated condition that particles bound together by capillary attractive forces. Accordingly, the friction angles were computed from peak shear strength. Friction angles may show curvature dependence with relatively density over a large range of normal stresses, as noted is some triaxial compression tests [16].

Figure 3. Speciments for big shear box after 28 days curing

In shear test, each specimens are subjected to normal stress σ› to bedding plane. The test also subjected to the shear stress τ that cause the displacement. The shear stress will increase rapidly until the peak strength is reached. This corresponds to the sum of the strength of the cementing material bonding the two halves of the bedding plane together and the frictional resistance of the matching surfaces. As the displacement continues, the shear stress will fall to some residual value that will then remain constant, even for large shear displacements. For planar discontinuity surfaces the experimental points will generally fall along straight lines. The peak strength line has a slope of Ø and an intercept of *c'* on the shear strength axis. The relationship between the peak shear strength and the normal stress can be represented by the Terzaghi equation [17]:

$$\tau = c' + \sigma' tan\emptyset \tag{1}$$

where c' is the cohesive strength between soft soil and specimens of PFA-Cement-Sand (modified sand column) and Ø is the angle of friction. The output raw data from shear box test have been analysed, where the peak stresses from stress-strain curve are determined and based on Formula (1), shear strengths are calculated and summarized in Fig. 4 and Fig. 5.



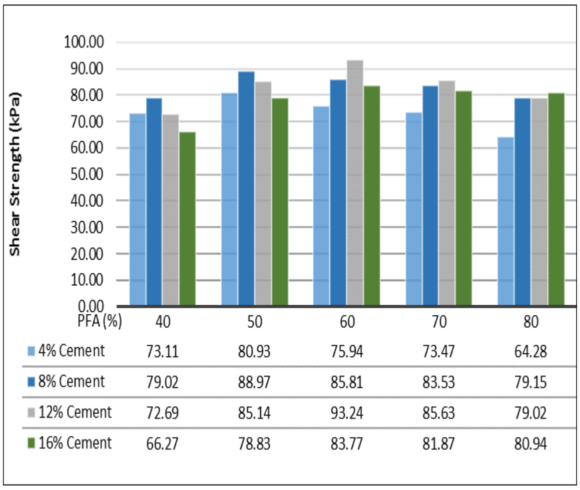
PFA (%)	40	50	60	70	80
4% Cement	74.09	82.20	75.81	74.54	72.86
8% Cement	83.22	90.85	87.80	85.69	81.78
12% Cement	83.99	87.76	93.51	86.58	75.65
16% Cement	85.14	89.38	85.92	83.12	82.71

Figure 4. Summary of the shear strength of SSB for sample after 28 days curing process

Fig. 4 shows a summary of small shear box (SSB) data of shear strength for all the samples that been tested after curing process. For all samples, the shear strength are in range above 70 kPa with the highest was recorded is 93.51 kPa where the proportion of materials is 12%:60:28% (cement: PFA: sand).

By using PFA 60%, the value of shear strength almost the highest compared with the other percentage of PFA. For cement used is 4%, the value of shear strength recorded is 75.81 kPa, cement 8%, the value of shear strength recorded is 87.80 kPa and for cement 14%, the value of shear strength recorded is 85.92 kPa. For PFA used is 50% also giving the high value of shear strength where recorded that by using 8% cement and 42% of sand, the shear strength obtained is 90.85%. By using 4% cement, the shear strength recorded is 82.20 kPa where slightly highest compared with 60% PFA. This patent also same for cement used 12% and 16% that recorded shear strength 87.76 kPa and 89.38 kPa that also highest compared with 60% PFA. Thus it can be concluded that by using percentage of PFA between 50% to 60%, and cement between 8% to 12%, give the highest value of shear strength compared with the other proportion of materials for test that conducted by using small shear box.

While Fig. 5 shows a summary for big shear box data of shear strength for all the samples that been tested after curing process. By comparing with graph Fig. 4, the value of shear strength recorded slightly different with the range between 60 kPa with the highest was recorded is 93.24 kPa for the proportion of materials is 12%:60:28% (cement: PFA: sand). Although slightly different with small shear box, the highest shear strength for big shear box recorded in the proportion of materials that are used that same with smaller shear box that also had great value for shear strength. Thus it can be concluded that by using 60% of PFA with the percentage of cement used in range of 8% to 12%, highest of shear strength can be recorded even different of shear box sizes. However, for PFA 50%, also giving high value of shear strength. By using 4% of cement, shear strength was recorded is 80.93 kPa, 8% cement, shear strength was recorded is 88.97 kPa and 12% cement shear strength was recorded is 85.14 kPa. Same as small shear box, for big shear box suggested that by obtaining highest of shear strength value, the percentage of PFA is suggested to be used are 50% to 60% with percentage of cement, 8% to 12%.



PFA (%)	40	50	60	70	80
4% Cement	73.11	80.93	75.94	73.47	64.28
8% Cement	79.02	88.97	85.81	83.53	79.15
12% Cement	72.69	85.14	93.24	85.63	79.02
16% Cement	66.27	78.83	83.77	81.87	80.94

Figure 5. Summary of the shear strength of BSB for sample after 28 days curing process

B. *Comparison of Small Shear Box (SSB) and Big Shear Box (BSB)*

Although it has been concluded that to have the highest shear strength value, the percentage of PFA suggested to be used are 50% to 60% with percentage of cement 8% to 12% for both SSB test and BSB test, the main objective is to compare the shear strength values between SSB and BSB test. Thus Fig. 6 till Fig. 9 show the comparison of shear strength values for those tests.

Fig. 6 till Fig. 9 show the comparison of shear strength between SSB and BSB based on different percentage of cement used. All the graphs show the same pattern where the line increasing by increasing percentage of PFA till it reaches at the optimum point before it starts decreasing even percentage of PFA still increasing. Based on this pattern, it can be concluded that PFA is a binder that can increase the shear strength of mixture. However percentage of PFA has optimum level that can providing maximum shear strength, when PFA still be added till beyond the optimum value, shear strength starts falling. Fig. 6 is a comparison of shear strength between SSB and BSB with cement used is 4%.

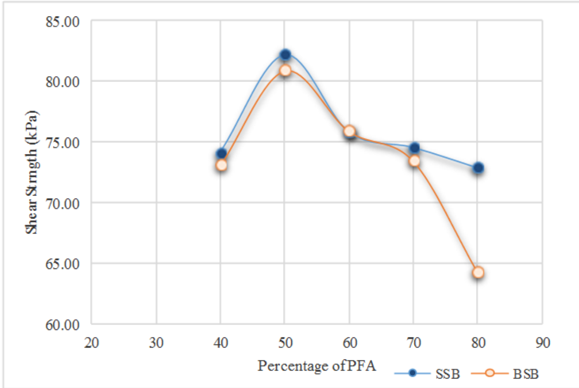


Figure 6. Comparison of shear strength for SSB and BSB with percentage cement used 4%

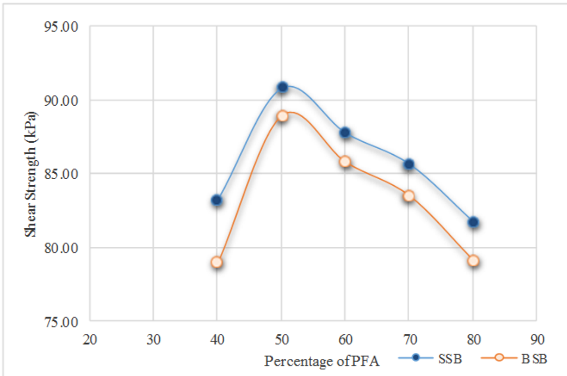


Figure 7. Comparison of shear strength for SSB and BSB with percentage cement used 8%

Result showed readings for shear strength will increase parallel with rising percentage of PFA. For SSB, the highest value of shear strength recorded at 75.94 kPa and BSB is 80.93 kPa. Based on these value, it shows that with percentage cement is 4%, SSB gave the highest value of shear strength. This pattern keep continues for percentage cement used is 8% as shown in Fig. 7 where the highest shear strength was recorded at 90.85 kPa for SSB and 85.81 kPa for BSB. In Fig. 8, the value of shear strength between SSB and BSB almost same where for SSB recorded at 93.51 kPa and BSB at 93.24 kPa, the different between SSB and BSB is below 1 kPa with percentage of cement used is 12%. However in Fig. 9, the pattern return as Fig. 6 and 7 where the different between SSB and BSB is highest than 1 kPa with the shear strength for SSB recorded at 82.71 and BSB recorded at 80.94 with percentage of cement used is 16%. Based on Fig. 6 till Fig. 9, it can be concluded that by conducting small shear box test, the value of shear strength recorded slightly high compare if using big shear box test. By calculating average, the different between SSB and BSB, is around 2.9 kPa or in percentage, the different is 25.8% and the comparison between the highest value of shear strength for both SSB and BSB concluded and shown in Fig. 10.

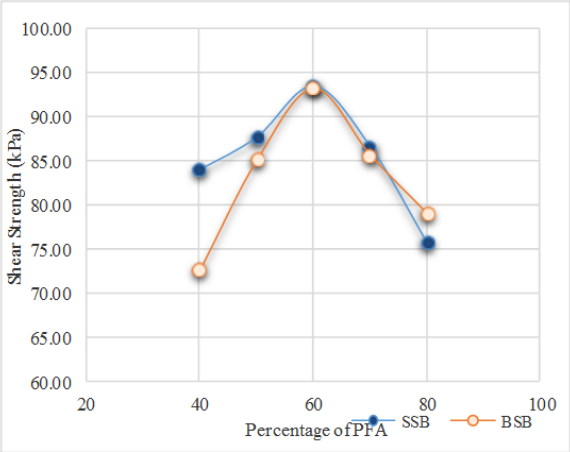


Figure 8. Comparison of shear strength for SSB and BSB with percentage cement used 12%

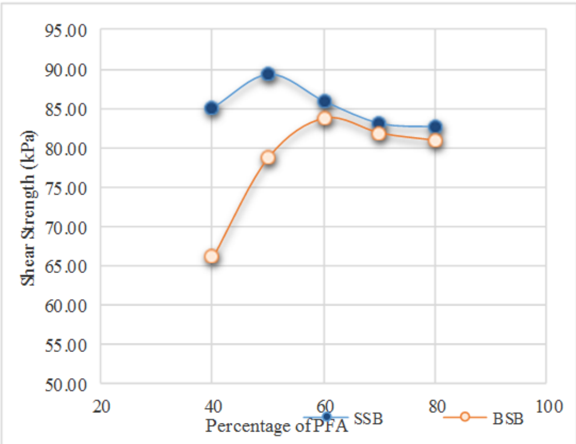


Figure 9. Comparison of shear strength for SSB and BSB with percentage cement used 16%

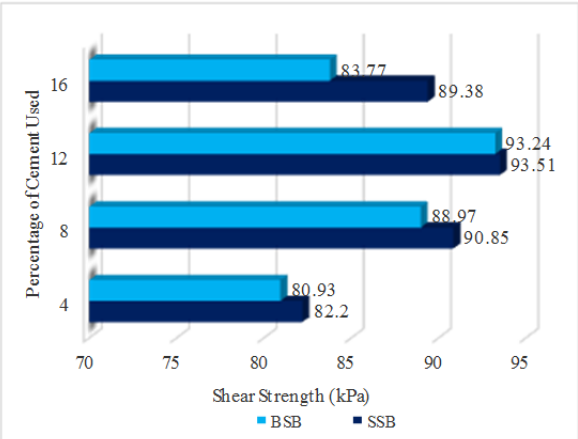


Figure 10. Comparison between the highest value of shear strength for both SSB and BSB

In Fig. 10 shows the summary of comparison between SSB and BSB. As mentioned before, other than percentage of PFA used is one of the main factor that will effect on the shear strength, percentage of cement and size of shear box also the other factors that affect shear strength. Based on Fig. 10, it shows that cement also has optimum value that can provide highest value of shear strength. In Fig. 10, can be concluded that optimum percentage of cement between 8% and 12% and when percentage of cement still be added till beyond the optimum value, shear strength starts falling as shown in Figure when the cement used is 16%, the shear strength for both SSB and BSB decrease. In Fig. 10 also shows the different value of shear strength recorded for SSB and BSB. All four different percentage of cement used showed that the highest of shear strength recorded when test conducted by using SSB. However between SSB and BSB have slight different and when cement used is 12%, the different of shear strength between SSB and BSB almost zero.

IV. Conclusion and Discussion

Sustainable development is a vital concept to be considered in substitution of ground improvement methods in conventional construction practices. Inter-In this study, a series of direct shear tests with different sizes of shear box were conducted to measure the shear strength between mixture of PFA-Cement-Sand and soft soil. For this purpose and in order to observe the scale effects or specimen size effects on shear strength value several of proportion of materials (PFA, cement and sand) have been used. From the tests results and analysis presented above, the following conclusions were derived: The results showed that peak shear strength decreased as the shear box size increased.

However SSB and BSB just showed slight different and when cement used is 12%, the different of shear strength between SSB and BSB almost zero. Other than size of shear box as the main factor that affect shear strength, percentage cement and PFA also the other factors. Both of materials show that the same pattern of the graph. For both materials, the line of shear strength was showing increasing by increasing the percentage of cement and PFA. However both of materials have optimum value, thus if the percentage of materials continue increase until beyond the optimum value, graph will start decreasing even the percentage of these materials keep increasing.

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Mr. Shakri M. S. was born in 1985 in Perak Malaysia. He currently is a lecturer in Faculty of Engineering and The Built Environment under Department of Civil Engineering in SEGi University Malaysia. He also currently is a Ph.D candidate in Faculty of Civil Engineering, University Teknologi Mara Malaysia. He obtained his Master's degree and Bachelor's degree from the same university that he currently doing his PhD. His research interest is ground improvement, foundation and slope stability. He has supervised more than 10 undergraduate students and has published/presented more than 15 journal/proceeding papers in international journals and conferences. He also won awards from international exhibition, innovation and exhibition events, local and international.

Md. Noor M. J. was born in 1962 in Malaysia. He currently working as an Assc. Prof in Faculty of Civil Engineering, University Teknologi Mara Malaysia. He received his Ph.D degree from Faculty of Civil Engineering, Sheffield University, United Kingdom. His research areas includes rainfall induced slope failure, wetting settlement and slope stabilization using hybrid anchor. He has more than 10 years of teaching experience and has published more than 30 papers in international journals.

Nazaruddin A. T. was born in 1985 in Sabah Malaysia. He currently is a Ph.D candidate in Faculty of Civil Engineering, University Teknologi Mara Malaysia. He obtained his Master's degree and Bachelor's degree from the same university that he currently doing his PhD. His research interest is ground improvement and foundation. He and has published more than 3 journal papers in international journals

Hafez M. A. was born in 1961 in Egypt. He currently working as an Assc. Prof in Faculty of Engineering, University Tenaga Nasional Malaysia. He received his Ph.D degree from Faculty of Civil Engineering University Malaya in 2007. He areas interest include ground improvement, foundation and dam. He has more than 10 years of teaching experience and has published more than 30 papers in international journals