Peat modification integrating Geopolymer and fly ash

I B Mohamed Jais¹, N Abdullah¹, M A Md Ali², M A Johar²

¹Geotechnical Forensic Specialised Initiative Group (GeoForenSIG), Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor Darul Ehsan, 40450 Malaysia
²Geocon Engineering Sdn Bhd, Shah Alam, Selangor Darul Ehsan, 40300 Malaysia

*Corresponding author e-mail: ismac821@uitm.edu.my

Abstract. Peat is known of its high compressibility, low shear strength, natural moisture content and long-term settlement. This indicates that peat is problematic, and it is necessary to improve the soil so that it can be used for supporting foundations. Fly ash is one of the source materials for geopolymer binders and available abundantly worldwide. It is considered as eco-friendly when it is used in the construction industry since it is a recycled material. A geopolymer mix known as Geopolymer Flexible Activator (GeoFlexA) and fly ash is used as an alternative solution to solve ground settlement issues related to soft soils. The purpose of this research is to modify peat by binding GeoFlexA and fly ash together. This research is carried out to determine the effect of GeoFlexA admixture and fly ash to the strength of peat. The index property tests include moisture content, organic content, fibre content, specific gravity and pH test only. Compaction test and Unconfined Compressive Test (UCT) is used to prepare samples and to analyse the strength respectively. The UCT was conducted after the samples were prepared in the mould and allowed to cure under 0, 7, 14, 28 and 56 days. Various percentages of fly ash used are 5%, 10%, 15% and 20% while a constant GeoFlexA admixture is used at 40% of the soil weight. The experimental results demonstrated that the compressive strength of the modified peat increases significantly with the fly ash content and curing time. These indicated that the mixture of GeoFlexA and fly ash can promote to an enhanced compressive strength of peat, hence, become a potential admixture for modifying peat.

1. Introduction

In Malaysia, peat is found in many places in Sarawak including the capital city of Kuching and the largest percentage of peat in the country covering approximately 1.66 million hectares [1]. Construction on this problematic soil is difficult to avoid since there is an increasing demand of land for development. In the construction industry, when the peat is subjected to moderate loads, long term consolidation settlement might happen and cause further problems to structures and roadways [2]. Hence, it is mandatory to modify peat for any future development.

There is a way to construct highway or any structures on a problematic soil by removing it and replacing it with a stronger material such as crushed rock, however, replacement of suitable material is costly, therefore, alternative methods of construction on problematic soils were devised thus finding new stabilization techniques [3]. Several case histories were reported where chemical stabilization methods were applied to stabilise the peat [1]. One of the proposed method is to utilize fly ash as a stabilizing agent. As an alternative for subgrade improvement, fly ash stabilization shows that the
unconfined compressive strength and the California Bearing Ratio (CBR) value have increased as well as the durability [4].

1.1. Modification of Peat

Nowadays, with the high demand of land for housing developments, industrial sites and the construction of roadways, it is not possible to avoid construction on problematic soils, especially in Sarawak where peat deposits are scattered in many places. Construction of highways over soft soils are one of the most common civil engineering problems faced since soft soils have low strength and high compressibility [3]. Peat is classified as highly organic because it exists due to the decomposition of plants and produced a composition of fibrous organic matters [5].

A number of researchers have studied the stabilization of soft soil by cement, cement-ground granulated blast furnace slag and lime-cement and only a few studies discussed on the stabilization by using recycled waste like fly ash [1]. The presence of moisture in fly ash will react chemically and forms cementitious compounds since fly ash has little cementitious agents which will assist to improve the strength and compressibility characteristics of soils [6]. Geopolymer or synthetic alkali aluminosilicate material gives advantage to significantly reduce greenhouse emissions while providing a comparable performance to traditional cementitious binders in various application [7]. Therefore, in this paper, a geopolymer known as Geopolymer Flexible Activator (GeoFlexA) together with fly ash is integrated to bind and strengthen peat. The new chemical does not need cement as the hardening agent since fly ash is used as an alternative to reduce waste hazards surrounding electrical power plants. The objectives of this research are (i) To characterize the physical and engineering properties of peat used for modification; (ii) To determine the modified strength and durability of peat mixed with GeoFlexA and fly ash; and (iii) to evaluate the strength and durability characteristics of natural and modified peat.

1.2. Scope of Work

The soil sample was extracted at Kampung Johan Setia, Klang Selangor while GeoFlexA is supplied by Geocon Engineering Sdn Bhd and fly ash was collected at Kapar Energy Venture, Sultan Salahudin Abdul Aziz Power Plant. In the first part of this research, the natural state of peat is determined in terms of its physical and engineering properties. Several physical tests executed are Moisture Content, Organic Content, Fibre Content, Specific Gravity, pH test and compaction test. Hence, Unconfined Compression Test (UCT) is performed on an undisturbed sample and the shear strength parameters will be obtained. In the second part of this research, GeoFlexA and fly ash were introduced and mixed with peat to evaluate the modified strength. The sample was cured underwater for the period of 7, 14, 28 and 56 days. The UCT are then tested after the samples were mixed and cured for 0, 7, 14, 28 and 56 days.

2. Distribution and Characteristics of Peat in Malaysia

Peat is a common deposit obtained close to the mangrove area with low bearing capacity, low shear strength and highly compressible. In civil engineering viewpoint, peat is usually acidic which has low pH, medium to low hydraulic conductivity, relatively low plasticity, and varies in particle size distribution. In its natural state, peat has a low bulk density, high porosity and is extremely soft and compressible due to high water content and organic matter. It is essential to determine its physical, chemical and engineering properties of peat to understand how peat will behave in connection with construction works [8].

Index properties are the physical properties of the soils, which are used to classify soil for various engineering applications. Kalantari [9] demonstrated a classification for organic soils, which can be integrated with the based on unified soil classification system (USCS) to bridge the gap between peat, and purely inorganic soils shown in Table 1.
Based on the study by Zainorabidin and Wijeyesekera [10] the Malaysian Soil Classification System (MSCS) introduced that, after organic content, the second important parameter needs to be considered is the state of decomposition or the degree of humidification shown in Table 2, thus, explains the state of decomposition or decay of organic matter increase in peats and organic soils. The percentage of fibre content has been considered in MSCS and in the classifications for Malaysian peat, there are three scales for the fibre content. These categories are fibrous, hemic and sapric shown in Table 3. Figure 1 shows the distribution of peat in Malaysia and Table 4 provides geotechnical properties of soft soil in Malaysia.

| Soil Group | Organic Content | Group symbol | Degree of Humidification | Subgroup Name | Field Identification |
|------------|----------------|--------------|--------------------------|---------------|----------------------|
| Peat       | >75%           | Pt           | H1-H3                    | Fibric or Fibrous Peat | Dark brown to black in color. Material has low density so seems light. Majority of mass is organic so if fibrous the whole mass will be recognized plant remains. More likely to smell strongly if highly humidified. |
|            |                |              | H4-H6                    | Hemic or Moderately Decomposed Peat | |
|            |                |              | H7-H10                   | Sapric or Amorphous Peat | |

**Table 3. Classification of peat. [9]**

| Type of Peat   | Fiber Content | Von Post Scale |
|----------------|---------------|----------------|
| Fibric peat    | Over 66%      | H4 or less      |
| Hemic peat     | 33-66%        | H5 or H6        |
| Sapric peat    | Less than 33% | H7 or more      |

2.1 Fly Ash
Ozdemir [3] described fly ash as finely graded residue that comes from the combustion of pulverized coal in a coal fires boiler and transported by flue gases to generate electricity for thermal power plants. Fly ashes are divided into two classes, that are class F and class C. Class C fly ash has pozzolanic and cementitious properties while class F fly ash has pozzolanic properties only. Pozzolanic activity is initiated by the addition of water, and resulting in the formation of cementitious compounds while modifying the engineering properties of soil. Class C fly ash also referred to as high calcium fly ash since it contains more than 10 percent CaO. The high CaO content will contributes more in self-cementing property in the presence of water.
2.2 Geopolymer as an Activator

Geopolymer is a material that is produced by the reaction of solid aluminosilicate with a highly concentrated aqueous alkali hydroxide or silicate solution. These materials can provide improvement performance to traditional cementitious binders in a range of applications, but with added advantage of significantly reduced greenhouse emission. The effect of raw material selection on the properties of geopolymer composites are from the fundamental chemical and structural characteristics of geopolymers that derived from metakaolin, fly ash and slag. Figure 2 presents a highly simplified reaction mechanism of geopolymerization and shows the key processes occurring in the transformation of a solid aluminosilicate source into synthetic alkali aluminosilicate. [7]

![Figure 1. Distribution of peat lands in Malaysia. [10]](image)

| Soil deposit                  | Carey Island Marine Clay | West Malaysia Peat and Organic Soil | East Malaysia Peat and Organic Soil | Johore Hemic Peat |
|-------------------------------|--------------------------|------------------------------------|------------------------------------|-------------------|
| Natural water content, W (%)  | 28-93                    | 200-700                            | 200-2207                           | 230-500           |
| Liquid Limit, LL (%)          | 33-104                   | 190-360                            | 210-550                            | 220-250           |
| Plastic Limit, PL (%)         | 24-41                    | 100-200                            | 125-297                            | -                 |
| Plasticity Index, PI (%)      | 21-63                    | 90-160                             | 85-297                             | -                 |
| Specific gravity (G_s)        | 2.55-2.68                | 1.38-1.70                          | 1.07-1.63                          | 1.48-1.8          |
| Organic content (%)           | -                        | 65-97                              | 50-95                              | 80-96             |
| Unit weight (kN/m³)           | 13-16.9                  | 8.3-11.5                           | 8.0-12.0                           | 7.5-10.2          |
| Undrained shear strength (kPa)| -                        | 8-17                               | 8-10                               | 7-11              |
| Compression index, C_c        | 0.5-1.25                 | 1.0-2.6                            | 0.5-2.5                            | 0.9-1.5           |
Abdullah et al. [11] studied the comparison of the chemical compositions of the original fly ash and the foamed geopolymer concrete. This foam was added to the geopolymeric mixture to produce lightweight concrete. The chemical composition has a reaction between fly ash and the alkaline activator which is known as geopolymerization. This process occurs through a mechanism involving the dissolution of the aluminum and silicon species from the surfaces of waste material (fly ash) as well as the surface hydration of undissolved waste particles, followed by the polymerization of active surface groups and soluble species to form a gel and, subsequently, a hardened geopolymer structure. Figure 3 shows the compressive strengths at days 1, 7, and 28 for the foamed geopolymer concretes that were cured at room temperature and at 60 °C for the average of 3 samples. For each of the test days, the maximum compressive strength was observed in the samples that had been cured in the oven (LW2).

![Conceptual Model for Geopolymerization](image)

**Figure 2.** Conceptual Model for Geopolymerization. [7]

2.3 Strength Characteristics of Peat Stabilized with Various Percentage of Fly Ash

Research from Ozdemir [3] showed that the maximum dry density of soft soil decreases slightly with the addition of fly ash due to its lightweight and fine material properties since it is in the form of powder. On the other hand, with the addition of fly ash up to 10 percent, the optimum moisture content varies between 7.20 and 8.34 percent. To obtain the optimum moisture content for soft soil, 3 percent fly ash and 5 percent fly ash samples are close to each other. For 7 percent fly ash and 10 percent fly ash samples, the optimum moisture content increased as shown in Table 5.
Based on the values given in Table 6, curing for zero-day condition, there is slight increase in UCS values up to 5 percent fly ash. But it has decreased for 7 percent and 10 percent fly ash. This is related to high compaction water content and low compaction characteristics. For 7 days cured sample, strength gain was observed for 10 percent fly ash sample whereby the UCS value increases up to 389 kPa.

**Table 5.** Fines Percentage, Atterberg Limits, Soil Class and Compaction Characteristics of Samples. [3]. LL – liquid limit, PL – plastic limit, PI – plasticity index, MDD - maximum dry density, OMC – Optimum moisture content.

| Sample | Fines (%) | LL (%) | PL (%) | PI (%) | Soil Class | MDD (g/cm³) | OMC(%) |
|--------|-----------|--------|--------|--------|------------|-------------|--------|
| SOS    | 65.9      | 23     | 11     | 12     | CL         | 2.188       | 7.63   |
| 3%FA   | 60.8      | 25     | 12     | 13     | CL         | 2.172       | 7.42   |
| 5%FA   | 55.3      | 26     | 12     | 14     | CL         | 2.157       | 7.20   |
| 7%FA   | 51.6      | 30     | 14     | 16     | CL         | 2.145       | 7.80   |
| 10%FA  | 50.2      | 29     | 14     | 15     | CL         | 2.100       | 8.34   |

**Table 6.** Average UCS of Samples. [3]

| Curing  | 0 day | 7 days | 28 days |
|---------|-------|--------|---------|
| Sample  | Wₜₙₜₑₜₙ (%) | Cₕₑₜ (%) | UCSₕₑₜ (kPa) | Wₜₙₜₑₜₙ (%) | Cₕₑₜ (%) | UCSₕₑₜ (kPa) | Wₜₙₜₑₜₙ (%) | Cₕₑₜ (%) | UCSₕₑₜ (kPa) |
| SOS     | 15    | 88     | 47      | N/A     | N/A     | N/A       | N/A     | N/A     | N/A       |
| 3%FA    | 16    | 84     | 51      | 15       | 85      | 73        | 15       | 87      | 112       |
| 5%FA    | 17    | 84     | 55      | 15       | 87      | 85        | 15       | 88      | 134       |
| 7%FA    | 21    | 79     | 24      | 16       | 86      | 95        | 13       | 88      | 333       |
| 10%FA   | 26    | 75     | 6       | 15       | 87      | 389       | 14       | 88      | 642       |

Wₜₙₜₑₜₙ: Design water content obtained from soaked CBR tests for stabilized and unstabilized samples
Cₕₑₜ: Average percent of compaction.
3. Testing Programme
The soil sample was taken from Kampung Johan Setia, Klang Selangor, Malaysia which is classified as peat shown in Figure 4. The samples were collected using thin wall sampler for undisturbed soil while hand auger is used to take the disturbed soil. For undisturbed samples, the entire samples were wrapped with plastic after collection to maintain the moisture content. The location area for this particular study is situated at Kampung Johan Setia, Klang Selangor as shown in Figure 5. The behaviours of peat can be determined by conducting laboratory works in order to complete the study and to compare the strength of peat before and after GeoFlexA together with fly ash added. Laboratory tests are divided into two categories which are physical properties and engineering properties shown in Table 7.

![Figure 4. Disturbed and undisturbed peat sample taken from Kampung Johan Setia, Klang Selangor.](image)

![Figure 5. Study Location at Kampung Johan Setia, Klang Selangor.](image)

The samples were prepared in the mould with size 50 mm x 100 mm that allow constant compaction using tamping rod. Then, the sample will be cure for 0 day, 7 days, 14 days, 28 days and 56 days in the water bath to resemble the condition of the peat below the water table before testing for UCT. Table 8 shows the sample preparation mix for GeoFlexA and fly ash.
Table 7. Summary of laboratory tests executed.

| Test                      | Method                  | Purpose                                                                 |
|---------------------------|-------------------------|-------------------------------------------------------------------------|
| Physical Properties Test  |                         |                                                                         |
| Moisture content          | BS 1377-2:1990          | Determination of moisture content of a specimen of soil as a percentage of its dry mass. |
| Specific Gravity          | BS 1377-2:1990          | Determination of the density of the soil solids                         |
| Organic Content           | ASTM D2974-07a          | Determination of the percentage by dry mass of organic matter present in soil. |
| Fiber Content             | ASTM D1997-91           | Determination of fiber content of samples of peat by dry mass.          |
| pH Test                   | BS 1377-3:1990          | Determination of pH value by electrometric method.                      |
| Engineering Properties Test|                         |                                                                         |
| Unconfined Compression test (UCT) | BS 1377-7:1990   | Determination of unconfined compressive strength                        |

4. Test Results and Discussions
The results of the physical properties tests show that the peat obtained from Kampung Johan Setia is categorized as hemic since the value of fibre content is 46.46 % which is semi fibrous and intermediate decomposed with organic content of 84.15 %. The specific gravity is low which is 1.38 with a moisture content of 59.920 %. The peat obtained is highly acidic with a pH value of 3.02. Table 9 summarizes the peat of Kampung Johan Setia, Klang, Selangor.

Table 8. Sample preparation mix for GeoFlexA and fly ash.

| No. | Percentage of fly ash by weight of soil (%) | Percentage of GeoFlexA by weight of soil (%) |
|-----|--------------------------------------------|---------------------------------------------|
| 1   | 5                                          | 40                                          |
| 2   | 10                                         | 40                                          |
| 3   | 15                                         | 40                                          |
| 4   | 20                                         | 40                                          |
### Table 9. Summary of peat properties at Kampung Johan Setia, Klang.

| Properties                        | Value  |
|-----------------------------------|--------|
| Moisture Content (%)              | 599.20 |
| Specific Gravity (G_s)            | 1.38   |
| Organic Content (%)               | 84.15  |
| Fibre Content (%)                 | 46.46  |
| pH value                          | 3.02   |
| Category                          | Hemic  |
| Undrained shear strength (kPa)    | 6      |

### 4.1 Unconfined Compressive Strength

For sample without curing, Unconfined Compression Test was conducted for natural and stabilized peat. Figure 6 shows the stress-strain relationship immediately tested after mixing with GeoFlexA and fly ash. The maximum compressive strength for natural peat is 12 kPa. The highest value of the compressive strength for stabilized peat is at 10% fly ash content which is 172.3 kPa while the lowest value is at 5% fly ash content of 132.1 kPa.

For 7, 14, 28 and 56 days curing, the Unconfined Compression Test was conducted for modified peat with GeoFlexA and fly ash content at 5, 10, 15 and 20%. Figure 7 shows stress-strain curve when it is tested after 7 days curing. The highest value of the compressive strength for modified peat is at 20% fly ash content which is 38 kPa while the lowest value is at 5% fly ash content which is 19.5 kPa. Figure 8 shows stress-strain curve when it is tested after 14 days curing. The highest value of the compressive strength for modified peat is at 20% fly ash content which is 44.5 kPa while the lowest value is at 5% fly ash which is 23.7 kPa. Figure 9 shows stress-strain curve when it is tested after 28 days curing. The highest value of the compressive strength for modified peat is at 20% fly ash content which is 78.6 kPa while the lowest value is at 5% fly ash which is 34.8 kPa. Figure 10 shows stress-strain curve when it is tested after 56 days curing. The highest value of the compressive strength for modified peat is at 20% fly ash content which is 63.9 kPa while the lowest value is at 5% fly ash content which is 44.5 kPa.

The results given in Figure 11 shows that the unconfined compressive strength of natural peat is low at 12 kPa. Based on research conducted by Hashim and Islam [2], the unconfined compressive strength is lower which is 6.9 kPa. Thus, the values of natural peat before modification with GeoFlexA and fly ash are very poor in comparison to the modified peat. The modified peat shows a positive outcome where the unconfined compressive strength of peat has increased from its natural state.
Figure 6. Stress strain response of natural and modified peat soil immediately after mixing.

Figure 7. Stress strain response of modified peat after 7 days curing.

Figure 8. Stress strain response of modified peat soil after 14 days curing.
Figure 9. Stress strain response of modified peat after 28 days curing.

Figure 10. Stress strain response of modified peat after 56 days curing.

Figure 11. Summarized of UCT test results on natural and modified peat.
4.2 Undrained Shear Strength and Stiffness

From the results shown in Figure 12, for samples without curing, the undrained shear strength, $Cu$ increased when the fly ash content increases which are 66.05 kPa, 86.15 kPa and 70.05 kPa, respectively. However, after 56 days of curing, there is a reduction in the undrained shear strength whereby the value decreased to 66.95 kPa. It is clearly seen that the strength increase was due to the presence of chemical composition of GeoFlexA and fly ash. Kolay et al. [1] stated that, the moisture content of stabilized peat decreases because the air void of natural peat was filled up by small particles of the admixture material. As shown in the summary results for UCT of each modified sample, the percentage moisture content was reduced by half from the natural moisture content of the peat.

When the curing days started there is a clear trend of decreasing strength of stabilized peat. This is because the samples have lost their strength due to the curing process, whereby it is submerged in the water bath. Even though the samples without curing present an enhanced modified strength, but the presence of high ground water level in peatland area needs to be handled and simulated accordingly.

Md. Yusof et al. [12] highlighted that the hydration process is still incomplete during short curing duration. Hence, for a better strength, longer curing duration is needed to promote the reaction of the geopolymer stabilizer.

Therefore, at 28 days curing period, there is increment in strength especially for peat modified with GeoFlexA and 20% fly ash, followed by GeoFlexA and 15% fly ash which are 32 kPa and 39.3 kPa, respectively. At 56 days curing period, it shows the increment strength for peat modified with 5% fly ash and 10% fly ash which are 22.25 kPa and 24.05 kPa. While the strength value for peat modified with 15% fly ash and 20% fly ash decreased which are 27.55 kPa and 31.95 kPa, respectively. Table 10 shows the modified unconfined compressive strength, $qu$ and the relating moisture content to show the reduction of moisture content when GeoFlexA and fly ash was added into the peat.

Immediately after mixing, the stiffness is high due to the reaction of admixture but did not represent the initial peat condition at site location which is fully saturated as shown in Figure 13. According to Mesri and Ajlouni, [13], based on the undrained triaxial compression tests on fibrous peat, the ratio of $Eu/Su$ are in the range of 20 to 80. Modified samples for 20% fly ash gave a higher value of stiffness among the curing period at 28 days. The results indicated that the efficiency of adding GeoFlexA and fly ash to modify peat gives improvement of strength and the stiffness of the peat.

![Figure 12. Undrained shear strength of modified peat from immediately after mixing to different curing time.](image-url)
Figure 13. Undrained stiffness of modified peat at different curing time.

Table 10. Summary of unconfined compressive strength and moisture content.

| Curing Time | Admixture Mixing | Unconfined Compressive Strength, $q_u$ | Moisture Content |
|-------------|------------------|----------------------------------------|-----------------|
| Days        | Fly Ash (%)      | GeoFlexa (%)                          | kPa             | %   |
| 7           | 5                | 40                                     | 19.5            | 345.2 |
| 14          | 5                | 40                                     | 23.7            | 376.4 |
| 28          | 5                | 40                                     | 34.8            | 385.3 |
| 56          | 5                | 40                                     | 44.5            | 375.1 |
| 7           | 10               | 40                                     | 29.6            | 336.1 |
| 14          | 10               | 40                                     | 27.7            | 364.8 |
| 28          | 10               | 40                                     | 40.3            | 375.1 |
| 56          | 10               | 40                                     | 48.1            | 384.6 |
| 7           | 15               | 40                                     | 31.3            | 339.4 |
| 14          | 15               | 40                                     | 32.3            | 347.5 |
| 28          | 15               | 40                                     | 64              | 369.7 |
| 56          | 15               | 40                                     | 55.1            | 362.8 |
| 7           | 20               | 40                                     | 38              | 325.7 |
| 14          | 20               | 40                                     | 44.5            | 338.2 |
5. Conclusions

This research was designed to determine the modified strength and durability of peat modified with GeoFlexA and fly ash, hence evaluate the strength and durability of natural and modified engineering properties of the peat. It can be concluded that:

- The physical properties of peat based on its organic content, moisture content, fibre content, specific gravity and pH test confirmed that the soil sample taken is organic peat. For engineering properties, compaction test was conducted to determine its maximum dry density and optimum moisture content in preparing samples. UCT have been conducted to know the compressive strength and shows that the natural peat has a low undrained shear strength of 6 kPa.

- Peat was modified with GeoFlexA (40%) and fly ash at various percentage (5%, 10%, 15% and 20%), and shows increase in strength. Immediately after mixing, the highest value of undrained shear strength for stabilized peat is 86.15 kPa at 10% fly ash while the lowest is 66.05 kPa at 5% fly ash. For natural peat, the shear strength is 6 kPa. Durability of the soil have been tested when the samples were cured for 7, 14, 28 and 56 days.

- Peat modified with 20% fly ash and GeoFlexA and then cured for 28 days showed an increase of six times the unconfined compressive strength of the natural peat which is from 12 kPa to 78.6 kPa. The modified peat also becomes more stiff as the percentage of fly ash increased. in general, therefore the longer curing period is allowed, the peat becomes more stable due to pozzolanic reaction and hydration process. The durability of the modified peat also increases at 56 days curing for peat stabilised with 5% and 10% fly ash.

6. References

[1] Kolay, P.K., Sii, H.Y. & Taib, S.N.L. (2011). Tropical Peat Soil Stabilization using Class F Pond Ash from Coal Fired Power Plant. International Science Index, Civil and Environmental Engineering, 5(2), 79–83.

[2] Hashim, R., & Islam, S. (2008). Engineering properties of peat soils in Peninsular, Malaysia. Journal of Applied Sciences. https://doi.org/10.3923/jas.2008.4215.4219

[3] Ozdemir, M. A. (2016). Improvement in Bearing Capacity of a Soft Soil by Addition of Fly Ash. Procedia Engineering, 143(Ictg), 498–505. https://doi.org/10.1016/j.proeng.2016.06.063

[4] Khalid, N., Mukri, M., Awang, H., Kamarudin, F., Halim, A., Ghani, A. & Hashim, S. (2016). Compaction Characteristics of Baniting Soft Soil Subgrade Stabilized Using Waste Paper Sludge Ash (WPSA), 30008. https://doi.org/10.1063/1.4965064

[5] Deboucha, S., Hashim, R., & Alwi, A. (2008). Engineering properties of stabilized tropical peat soils. Journal of Geotechnical Engineering, 13, 1–9. https://doi.org/10.3923/jas.2008.4215.4219

[6] Bhuvaneshwari, S., Robinson, R. G., & Gandhi, S. R. (2005). Stabilization of Expansive Soils Using Flyash. Fly Ash India, (1), 1–10.

[7] Duxson, P., Fernández-Jiménez, A., Provis, J. L., Lukey, G. C., Palomo, A., & Van Deventer, J. S. J. (2007). Geopolymer technology: The current state of the art. Journal of Materials Science, 42(9), 2917–2933. https://doi.org/10.1007/s10853-006-0637-z

[8] Rahgozar, M. A., & Saberian, M. (2016). Physical and chemical properties of two Iranian peat types, (September).

[9] Kalantari, B. (2013). Civil Engineering Significant of Peat. Global Journal of Researches in Engineering, 13(2).
[10] Zainorabidin, A. & Wijeyesekera, D. C. (2007). Geotechnical Challenges with Malaysian Peat. Advances in Computing and Technology, The School of Computing and Technology 2nd Annual Conference, 2007. 252 – 261.

[11] Abdullah, M. M. A. B., Hussin, K., Bnhussain, M., Ismail, K. N., Yahya, Z., & Razak, R. A. (2012). Fly ash-based geopolymer lightweight concrete using foaming agent. International Journal of Molecular Sciences, 13(6), 7186–7198. https://doi.org/10.3390/ijms13067186

[12] Md Yusof, Z. & Mohd Harris, S. N. & Mohamed, K. (2015). Compressive Strength Improvement of Stabilized Peat Soil by Pond Ash - Hydrated Lime Admixture. Applied Mechanics and Materials. 747. 242-245.

[13] Mesri, G., & Ajlouni, M. (2007). Engineering Properties of Fibrous Peats. Journal of Geotechnical and Geoenvironmental Engineering, 133(7), 850–866. https://doi.org/10.1061/(ASCE)1090-0241(2007)133:7(850)

7. Acknowledgements
The author would like to acknowledge Geocon Engineering Sdn Bhd for the financial support and platform to embark on this research. The authors would also like to extend their gratitude to the Faculty of Civil Engineering, Universiti Teknologi MARA for the full cooperation and collaborative industrial research initiatives provided.