Peat soil stabilization using electrokinetic stabilization (EKS) treatment at Parit Lapis Kadir, Batu Pahat, Johor, Malaysia

Abdul Wahab\textsuperscript{1,2,a}, Zaidi Embong\textsuperscript{1,2}, Abbas Ali Naseem\textsuperscript{3}, Saiful Azhar Bin Ahmad Tajudin\textsuperscript{4}, Qamar Uz Zaman\textsuperscript{5},

\textsuperscript{1}Research Centre for Soft Soil, Universiti Tun Hussein Onn Malaysia.
\textsuperscript{2}Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia.
\textsuperscript{3}Department of Earth Science, Quaid-E-Azam University, Islamabad, Pakistan.
\textsuperscript{4}Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia.
\textsuperscript{5}Department of Geology, Northwest University Xian PR China.

\textsuperscript{a}wahab.dir555@gmail.com

Abstract. Peat is found all over the world, which covered about 4.5% of the total world land and considered one of the most challenging soil, it creates many problems in constructions projects due to its characteristics like low shear strength, high water content and high compressibility. Hence, buildings and roads construction on peat has become more complex and differential settlements, slope failures, global instabilities, and long-term excessive settlements have occurred. Developing countries such as Malaysia, also facing such type of problems in building and road constructions. To overcome this problem, several matters related to soft soil strength, its essential to be resolved in proper way. This can be done by performing soil treatment to enhance its strength and physical properties. The application of soil improvement by using the electrokinetic stabilization (EKS) method has the potential to overcome problems such as low shear strength, high moisture content and high compressibility of the low permeable soil. The principles of EKS method involve applying a low potential gradient through electrodes which are inserted in the low permeable soil that cannot readily be drained. The voltage gradient of 110 V and 150 V was applied to the peat soil with the help of aluminium electrodes for the operational period of 3 and 6 hours. The peat sample was collected from Parit Lapis Kadir, Batu Pahat, Johor state, Malaysia. Some soil parameters like shear strength ($\tau$) moisture content (WN), liquid limit (WL), maximum dry density (MDD), optimum moisture content (OMC) and dynamic properties were examined for pre and post EK. The result shows that shear strength was improved from 10.7 to 58 and 64 kPa, moisture content was reduced from 476.84 to 336.22 and 306.38%, the liquid limit was improved from 152.33 to 198.10 and 213.96%, maximum dry density was increased from $7.97 \times 10^{-7}$ to $7.29 \times 10^{-7}$ and $8.39 \times 10^{-7}$ kg/m$^3$ and optimum moisture content was improved from 27.56 to 114.01 and 125.25%. The shear wave velocity (SWV) was increased from 75.5 m/s to 109.5 m/s. The experimental results suggest the potential of developing EKS technique to stabilize shear strength of soft peat is effectively and efficiently.
1. Introduction

Peat has been considered as an organic remnant that suffers decomposition process throughout times under overburden pressure. The composition of peat normally consists of organic matters and it’s exceeded sometimes up to 75% especially when the woods grows in marshes places in conditions where deficiencies of oxygen exist [1]. Peat consists of high moisture content about 250% to 985.40% and high compressibility [2], with the low shear strength of 5 to 20 kPa, which often results in creates difficulties when construction work is undertaken on peat deposit [3]. In comparison with other soft soils, peat is often viewed as problematic soil, mainly because of their inferior poor construction [4]. Peat is considered as one of the most challenging soil for the construction projects due to its characteristics in the result instability problems such as excessive settlement, local sinking, and long-term settlement occurred, if some moderate load is subjected to it or when buildings or roads are constructed on it [5].

In recent years, major settling or tilting of buildings, bridges, and road embankments have been occurred due to low shear strength and high compressibility of soil. In this regard, it is necessary to determine the soil improvement alternatives, technically and economically, from the ultimate state design in accordance with geotechnical categories. To stabilize and remediate the existing peat soil prior to the commencement of any construction activities the distortion under stress, reduce compressibility, control shrinking and swelling, control permeability and reduce water pressure [6].

Peatland is found in all parts of the world which covered about 4.5% of the whole world land [5]. Malaysia is considered 9th country in the world with highest amount total area of peat [7]. In entire country peat covers about 8% or 3 million hectares of the total land. Out of this land, 6300 hectares of the peatland is found in Batu Pahat, Pontian, and Muar districts in West Johor state as tabulated in Table 1. Sarawak state is the largest peatland area in the country, consisting about 13% of the peatland or 1.66 million hectares of the total peatland in Malaysia [8].

| State       | Peatland (ha) |
|-------------|--------------|
| Sarawak     | 1,697,847    |
| Selangor    | 164,708      |
| Pahang      | 164,113      |
| Johor       | 143,974      |
| Sabah       | 116,965      |
| Terengganu  | 84,693       |
| Perak       | 69,597       |
| Kelantan    | 9,146        |
| Negeri Sembilan | 6,245 |
| Federal Territory | 381 |
| Total Peat Land | 2,457,669 |

Many construction projects and coastal high-rise buildings whose basics are frequently supported by peat, are facing issues when not given physical existence. Likewise, in Malaysia, the construction industry is facing many challenges related to peat stabilization and major economic activities; and social developments focusing on the coastal area. One of the major problems for the construction industry is the settlement of peat foundation for the development of highways and buildings during or after construction when the soil is not properly treated. To ensure the solution of these problems or at least minimizing their overall negative impact on the industry, electrokinetic stabilization methods should be applied for the peat stabilization [9].

Some previous researchers [10] have applied EKS treatment for the improvement of low permeable soil. The clay samples were collected from East Java, Indonesia. Calcium chloride was used as an electrolyte solution while aluminum was used as an electrode with the electric gradient of 13 V for the operational period of 12 hours to 3 days, intervalley. The authors concluded that the shear strength was improved up to 56% while the liquid limit was increased. The authors Moayedi in 2014 performed a laboratory experiment to improve the shear strength of peat soil by using EK method. The peat samples were collected from Selangor, Malaysia. Graphite was used as an electrode with the electric gradient of
60 V for the operational period of 7 days. The results show the strength of peat soil was improved up to 29 kPa [11]. Keykha in 2014 conducted electrokinetic stabilization laboratory-based method, for the determination of improving the strength and reduce the moisture content of the soft soil. Two graphite laminate were used as electrode and calcium carbonate used as electrolyte solution with the electric gradient of 60 V, for the period of 4 days, which shows the shear strength was improved from 6 kPa to 60 kPa [12].

Amnart Rittirong conducted the laboratory-based electrokinetic technique for the assessment of electrokinetic strengthening of soft clays. The clay soil was collected from Ankara, Turkey. Circular electrokinetic experimental setup was arranged with multiple electrodes were used, while C₆Cl₂ was used as a stabilizing agent (electrolyte solution) with a voltage gradient of 10 V for the operational period of 10 days, the authors concluded that shear strength was increased up to 36, 50, 58 and 85 kPa respectively in different phases [13].

2. Method and material
There were twenty different peat locations were investigated at Parit Botak area, Batu Pahat, Johor, Malaysia, which was based on low shear strength. The peat sample was collected from Parit Botak area. The shear strength was measured with the help of (field vane shear) at the depth of 20 cm, 30 cm and 40 cm, respectively, according to EK cell size as shown in Figure 2. The in-situ measurement of water content was not possible so, accordingly, the sample was carefully transferred to the laboratory. Where some standardized laboratory tests such as shear strength, moisture content, liquid limit and bender element test exist for observing the physical, chemical and dynamic properties of peat.

![Shear strength test (vane shear apparatus)](image)

**Figure 1.** In-situ shear strength measurement.

3. Electrokinetic stabilization (EK) treatment
The EK experiments were carried out at the Research Center for Soft Soil (RECESS), UTHM. The Electrokinetic experiment was conducted in a laboratory environment at an ambient temperature of 27 °C. The EK cell designed for this research was made up of the transparent acrylic plate with rectangle shape open at the top with 40 cm of depth and 42 cm of width while the thickness of the acrylic plate was 1.5 cm. Further it was divided into 3 major slots which as an anode, cathode and untreated peat compartment. The two outside slots were reserved for the anode and cathode while the middle section was reserved for the untreated peat sample. The anode and cathode sections were 10 cm while contaminated soil compartment was 17 cm as shown in Figure 2.

The electrodes were inserted vertically into the untreated peat. The two aluminum passive electrodes were placed at the extreme edges of the peat specimen. The post-EK treatment was divided into two phases, where in phase I, the voltage gradient of 150 V was applied for the operational period of 6 hours as shown in Figure 4, while in phase II, the voltage gradient of 110 V was applied with load of 50 kg for the operational period of 3 hours as shown in Figure 3.
Figure 2. EK stabilization compartments and its dimensions.

Figure 3. Load test inside the EK compartment for post-EK.
Figure 4. A complete set of EKS treatment (with voltage gradient of 150 V)

4. Result and discussion

4.1. Physical and dynamic properties of untreated peat
The physical and dynamic properties tests were conducted for pre EK (untreated peat), to examine the physical and dynamic properties of peat. The physical properties tests include shear strength test, moisture content test, liquid limit test and compaction test while dynamic properties test shows the shear wave velocity in peat sample as tabulated in Table 2.

Table 2. The physical and dynamic properties for untreated peat.

| Properties                          | Parit Lapis Kadir | Value and Reference |
|-------------------------------------|-------------------|---------------------|
| Shear strength (kPa)                | 10.7              | 3-17                |
| Organic Content (%)                 | 97.286            | 96.64               |
| Moisture Content (%)                | 476.849           | 200-700             |
| Liquid limit (%)                    | 152.333           | 173.75              |
| Maximum Dry Density (kg/m³)         | $7.79 \times 10^{-7}$ | $4.90 - 8.12 \times 10^{-7}$ |
| Shear wave velocity (m/s)           | 75.5              | 26.02 - 96.89       |

4.2. Physical and dynamic properties of treated peat (Phase I)
The physical and dynamic properties of peat were observed after applied the load of 150 V for the operational period of 6 hours. The soil parameters i.e. shear strength, moisture content, liquid limit, maximum dry density, optimum moisture constant and shear wave velocity were observed improved as compared to pre-EK as tabulated in Table 3.
4.3. Physical and dynamic properties of treated peat (Phase II)

The physical and dynamic properties of peat were observed after applying the voltage gradient of 110 V with a load of 50 kg for the operational period of 3 hours. The load was applied before applying the current. After removing the load, the current of 110 V was applied for 3 hours. The properties i.e. shear strength, moisture content, liquid limit, maximum dry density and shear wave velocity were observed improved as compared to phase I as shown in Table 4.

4.3.1. Shear strength (kPa) of treated peat. The load of 50 kg was applied before providing the voltage gradient. After removing the load from EK cell, the peat was observed compacted. The electric gradient of 110 V was applied through Aluminium electrode for the operational period of 3 hours. The shear strength was measured with the help of (field vane shear apparatus) inside EK cell in various positions. The results show that shear strength was improved from 10.7 kPa to 64 kPa as shown in Figure 5.

![Figure 5. Shear strength (kPa) for pre and post EK.](image)

Table 3. The physical and dynamic properties for pre and post EK (phase I)

| Parameters                              | Parit Lapis Kadir |
|-----------------------------------------|-------------------|
| Shear strength ($\tau$) (kPa)           | Pre EK            |
|                                         | Post EK (Phase I) |
| Moisture content ($W_N$), (%)           | 476.849           |
| Liquid Limit ($W_L$), (%)               | 152.333           |
| Maximum dry density $\rho_d$ (kg/cm$^3$)| 7.79 x 10$^{-7}$  |
| Optimum moisture content (%)            | 27.569            |
| Shear wave velocity (m/s)              | 75.5              |

4.3.2. Moisture content of treated peat. The moisture content was reduced with an applied load of 50 kg along with the voltage gradient of 110 V for the operational period of 3 hours. The peat was observed compacted, moisture content and compressibility were reduced due to a load of 50 kg, the contaminations was moved from cathode to anode. The initial moisture content of untreated peat soil was observed 476.849% while applying the voltage gradient of 110 V for the operational period of 3 hours continuously, the moisture content was reduced up to 306.384%. Figure 6 shows moisture content for post EK (treated soil).
4.3.3. Liquid Limit (LL) of treated peat. The liquid limit was increased with an applied load of 50 kg along with a voltage gradient of 110 V for the operational period of 3 hours respectively. Here, the initial liquid limit of untreated peat was observed 152.333%, while after treatment the liquid limit was observed improved up to 213.965%. Figure 7 shows that the liquid limit was increased for post EK.

4.3.4. Compaction behaviour of treated peat. The maximum dry density and optimum moisture content were observed increased with an applied load of 50 kg along with a voltage gradient of 110 V for the operational period of 3 hours. The result shows that MDD was increased up to 8.39 kg/m$^3$ while OMC was increased to 125.253%.

4.3.5. Shear wave velocity for treated peat. The bender element test was performed for treated peat samples after applied the load of 50 kg with the voltage gradient of 110 V for the operational period of 3 hours. As observed in pre-EK, that shear wave velocity for Parit Lapis Kadir untreated peat was 75.5 m/s while it was increased up to 109.5 m/s as shown in Figure 7.
4.4. Compression between pre and post-EK
The pre and post result shows, that physical properties of peat were more observed in post-EK phase II, with the voltage gradient of 110 V with an applied load of 50 kg for the operational period of 3 hours.

(i) The shear strength was improved from 10.7 to 58 kPa in phase I, with applied voltage of 150 V for the operational period of 6 hours, while up to 64 kPa in phase II, with applied voltage 110 V with applied load of 50 kg for the operational period of 3 hours as shown in Figure 8.

![Figure 8](image_url)

**Figure 8.** Shear strength of peat between pre and post-EK.

(ii) Similarly, moisture content also improved in post-EK phase II, with voltage gradient of 110 V with load of 50 kg for the operational period of 3 hours, the moisture content was reduced from 476.849 to 306.384%, while it was reduced to 370.942% with applied voltage gradient of 150 V for the operational period of 6 hours as shown in Figure 9.
Figure 9. The moisture content of peat for pre and post-EK

(iii) The liquid limit was observed increased in phase II, with a voltage gradient of 110 V with a load of 50 kg for the operational period of 3 hours, LL was improved from 152.333 to 213.965 %, while it was improved up to 198.106 % with applied voltage gradient of 150 V for the operational period of 6 hours as shown in Figure 9.

(iv) Maximum dry density (kg/cm$^3$) was observed 7.79×10$^{-7}$ for pre EK, while it was decreased to 7.29×10$^{-7}$ (kg/m$^3$) in phase I, while increased up to 8.39×10$^{-7}$ (kg/m$^3$) in phase II. The optimum moisture content was recorded 27.569 % for re-EK, while for post-EK phase I, it was observed 114.011 % and 125.253 % in phase II.

(v) The shear wave velocity was observed 75.5 m/s for untreated peat soil (Pre-EK), where it was increased up to 88.5 m/s in phase I post-EK, while in phase II, it was increased up to 109.5 m/s.

5. Conclusions and recommendations
The result shows improvement when the voltage gradient of 110 V was applied for an operational period of 3 hours with the help of the aluminium electrode. As tabulated in Table 5, It was observed that shear strength was improved when the electric gradient was applied to the peat soil. The moisture content was decreased because the contaminations was moved outside. The liquid limit was found increased due to high particle compactness. The shear wave velocity was found increased which is directly reflect the strength. The outcome of this study potential may contribute toward the selective properties of particular soil in order to support a specific infrastructure and construction.
6. References

[1] Moayedi H, Nazir R 2018 Malaysian experiences of peat stabilization, state of the art. Geotech. and Geol. Eng. 36(1) p 1-11.

[2] Zainorabidin A, Mohamad H M 2017 Engineering properties of integrated tropical peat soil in Malaysia. Electr. J. of Geotech. Eng. 22 p 457-466.

[3] Razali S N M, Bakar I, Zainorabidin A 2013 Behaviour of peat soil in instrumented physical model studies. Procedia Eng. 53 p 145-155.

[4] Mesri G, Ajlouni M 2007 Engineering properties of fibrous peat. J. of Geotech. and Geoenviron. Eng. 133(7) p 850-866.

[5] Abdel-Salam A E 2017 Stabilization of peat soil using locally admixture HBRC J.

[6] Mosavat N, Oh E, Chai G 2012 A review of electrokinetic treatment technique for improving the engineering characteristics of low permeable problematic soils Int. J. of GÉOMATE, 2(2) p 266-272.

[7] Mohamad H M 2015 Post cyclic behaviour of Malaysian peat soil (Universiti Tun Hussein Onn Malaysia).

[8] Melling L 2016 Peatland in Malaysia Trop. Peatland Ecosys (Springer) p 59-73.

[9] Hua L J, Mohd S, Tajudin S A A, Mohamad S N A, Bakar I, Masirin M I M, Mahmoud A A-W 2016 Construction of infrastructure on peat: case studies and lessons learned MATEC Web of Conf.

[10] Thuy T T T, Putra D P E, Budianta W, Hazarika H 2013 Improvement of expansive soil by electro-kinetic method J. of Appl. Geol. 5(1) p 50 – 59.

[11] Moayedi H, Kassim K A, Kazemian S, Raftari M, Mokhberi M 2014 Improvement of peat using Portland cement and electrokinetic injection technique Arabian J. for Sci. and Eng. 39(10) p 6851-6862.

[12] Keykha H A, Huat B, Asad A 2014 Electrokinetic stabilization of soft soil using carbonate-producing bacteria Geotech and Geological. Eng. 32(4) p 739-747.

[13] Aski, T, Turer D 2016 Effect of electrode configuration on electrokinetic stabilization of soft clays. Quart. J. of Eng. Geol. and Hydrogeol. y, 49(4), 322-326.

[14] Zainorabidin A, Zolkefle S N A 2014 Dynamic behaviour of western Johore peat, Malaysia.

[15] Deboucha S, Hashim R, Alwi A 2008 Engineering properties of stabilized tropical peat soils

(i) For all types of soft soil, by applying the voltage gradient EKS, that may increase the shear strength easily and can be beneficial to improve their physical properties.

(ii) If the high voltage gradient (>150 V) is to be applied on soft soil, it may easily enhance the physical, chemical as well as dynamic properties of soil.

(iii) In context, if the high load (>50 kg) it can result to achieve maximum stabilization at very less cost.

---

### Table 5. The physical properties for treated peat

| Parameters                  | Pre EK Phase I | Post EK Phase II |
|-----------------------------|----------------|------------------|
| SS (kPa)                    |                |                  |
| 10.7                        | 58 (54%↑)      | 64 (59%↑)        |
| MC (%)                      | 478.849        | 306.384 (64%↑)   |
| LL (%)                      | 152.333        | 213.965 (14%↑)   |
| MDD ρ_d (kg/cm³)            | 7.79×10⁻⁷      | 8.39×10⁻⁷ (1%↑)  |
| OMC (%)                     | 27.569         | 125.253 (45%↑)   |
| SWV (m/s)                   | 75.5           | 109.5 (14%↑)     |

---

For all types of soft soil, by applying the voltage gradient EKS, that may increase the shear strength easily and can be beneficial to improve their physical properties. If the high voltage gradient (>150 V) is to be applied on soft soil, it may easily enhance the physical, chemical as well as dynamic properties of soil. In context, if the high load (>50 kg) it can result to achieve maximum stabilization at very less cost.
[16] Boulanger R W, Arulnathan R, Harder Jr L F Torres R A Driller MW 1998 Dynamic Properties of Sherman Island Peat J. of Geotech. and Geoenviron. Eng. 124(1) p 12-20.

Acknowledgement
The authors would like to express his gratitude to Research Centre for Soft Soil (RECESS), UTHM that provides all the facilities to ensure the success of this research and thanks also goes to those who assist directly and indirectly.