Indonesian Geotechnical Journal, December 2023, Vol 2 (3). Page 85 - 94
DOI: https://doi.org/10.56144/igj.v2i3.64
E-ISSN:2829-7520
https://indonesian-geotechnical-journal.org/index.php/JGI/issue/archive

In-Peat Geomechanical Monitoring Method under Actual Road Embankment

Alsidqi Hasan[1,*], Jeffery Tay[2], Jye Lee[3]
[1]Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Kota Samarahan, Malaysia, 94300; halsidqi@unimas.my
[2]Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Kota Samarahan, Malaysia, 94300; jeffery@geospec.com.my
[3]Sarawak Public Works Department, Kuching, Malaysia, 934582; leelj@sarawak.gov.my
*Correspondence: halsidqi@unimas.my

SUBMITTED 09 August 2023 **REVISED** 26 August 2023 **ACCEPTED** 01 September 2023

ABSTRACT This paper presents an ongoing 'in-peat' geomechanical monitoring exercise under an actual road embankment being constructed in Sarawak State of Malaysia. The road embankment will serve as part of 236km second trunk road, which is expected to be completed in 2 years. The road embankment measures about 24m wide and 2m high, overlies about 5m thick of peat and a soft clay. The peat classification varies from H2 (fibric) to H6 (hemic) with undrained shear strength values ranges from 5.3 to 6.8 kPa. The 'in-peat' monitoring method uses a burial technique that can monitor the vertical stress, the horizontal stress, the pore water pressure, and the settlement from within the peat layer. This monitoring will provide a complete set of data that are valuable to back analyze the phenomena takes place during and post construction, using the state-of-the-art concept in soil mechanics. The detail site information, the installation method and the preliminary data are discussed. The installation exercise has been finished and the in-peat monitoring has been started. A professional service was appointed to install and monitor the sensors, which was supervised by the academic and the department of public works. To date, all sensors have been successfully registering the data continuously, at which the readings showed corresponding actual loading condition at site. The 'in-peat' monitoring is a critical milestone to better understand the geomechanical behavior of peat under actual road embankment and to verify the current peat conceptual model.

KEYWORDS Peat; In-situ; Monitoring; Soft Soil; Road Embankment; Instrumentation

1 INTRODUCTION

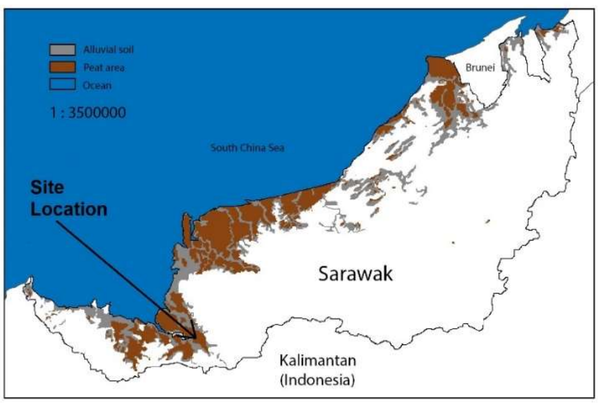
A road infrastructure project passing soft soils is currently being constructed in Sarawak state of Malaysia, where about 80% of the entire length is underlain by deep peat layer. The total road length is approximately 236 km, which is to be built in accordance with R5 Malaysian Ministry of Public Works standard highway. The highway allows a maximum speed limit of 100 km/h with partial access control (JKR 2015). The road infrastructure is known as the second trunk road, which is expected to provide a faster access in connecting major towns than the primary one (Pan Borneo highway) after the next 2 years.

The current design uses surcharging and counter berms method combined with geo-reinforcement (geotextile) in order to provide stability during construction and to satisfy strength-deformation criteria. Prefabricated vertical drain (PVD) is also employed in some locations to expedite the consolidation of the peat and the soft clay layer. PVD and geo-reinforcement was effective in constructing a stable embankment and to improve its performance (Hayashi et al. 2011, Rowe and Soderman 1985). Lack of prior experience in constructing road on deep peat is the challenge. Limited available literatures also generate lack of confidence in the design. Most literatures reported restricted information to on-ground measurement such as settlement (Forsman et al. 2016, Ong et al. 2009, Susila & Apoji 2012). The current design is solely based on computational and analytical methods using textbook theories, guidelines and the limited past literatures. Therefore, the Sarawak Ministry of Public Works and the Universiti Malaysia Sarawak took the initiative to carry out a comprehensive instrumentation program in order to monitor the long term geomechanical performance of peat under the actual road embankment.

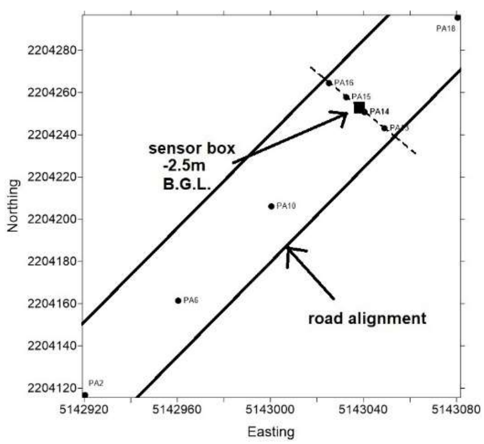
This paper presents the ongoing instrumentation monitoring program, which focuses on the method and the preliminary outcome of the monitoring. The information in this paper will provide engineers and academic a benchmark and learning experience for the future instrumentation program.

2 SITE INFORMATION

The instrumentation monitoring program is conducted at second trunk road section B4 near Betong town of Sarawak with the Easting and Northing coordinates of 5143040 and 2204250, respectively and the global coordinate of 1°17'37.0"N 111°31'31.5"E (Figure 1a). The site is located within sedimentary/alluvial region (grey color in map). This region comprises about 15% of Sarawak state land. Peat covers the vast majority of the alluvial region (brown color in map). Peat and alluvial soil from tropical region are unique compared to subtropical or temperate regions due their different origin and high number of weathering cycles (Andriesse 1988; Edelman & van der Voorde, 1963; Buringh, 1979).



(a)



(b) (c)

Figure 1. Site information: (a) map of site location, (b) site layout (c) site condition

Figure 1b shows the site layout and the road alignment. There were eight peat auger tests carried out nearby the site, at which the instrumentation sensors to be located, namely PA2, PA6, PA10, PA13, PA14, PA15, PA16 and PA18. The dashed line in Figure 1b is the cross section to be instrumented, which passes PA13-PA14-PA15-PA16. Figure 1c illustrates the site condition prior to instrumentations. The site was originally a tropical forest and was not accessible. The original water table was found at the ground level. Sandy material (orange color material in Figure 1c) is not the residual soil, but it was transported to site as temporary road access. The temporary road access was located beyond the proposed road alignment.

3 METHODS

3.1 Selection of Monitoring Point

In order to determine the monitoring point within the proposed site, we analyzed peat auger test results. Two important aspects were considered, namely: depth and the obstruction. For the first aspect, the monitoring point was proposed to be located at peat depth around 5-6m. Peat with this depth is considered deep peat, where the conventional technique “remove and replace” is normally not a viable option due to cost constraint. Installing sensors at 5-6m was practically possible using the available machinery at the site. For the second aspect, we tried to avoid the existing structure/infrastructure that might obstruct the installation and might influence the reading of the sensors. In the proposed site, there are two obstructions were found, namely an electrical transmission tower and an existing road diagonally crossing PA2. These two obstructions were avoided.

Figure 2a and 2b show the cross section and long section soil profiles from peat auger tests, respectively. The water table was found to be located at the ground level. The extracted soils from the auger tests were visually assessed. The peat varies from H2 (fibric) to H6 (hemic) according to Von-Post classification method. The peat depth ranges from 4m to 6m, underlain by a soft clay layer. Peat layer was distinguishable from the underlying layer. The peat color is medium to dark brown, while the soft clay color is grey. Traces of woods was found in peat, which indicates that the peat might be originally derived from woods. This agrees with the general findings that peat in the tropical region primarily composes of lignin, a major constituent of wood (Hasan and Janting 2023, Andriesse 1988). The peat augering was terminated at a few meters after the soft clay layer was found. Note that extending the investigation to the underlying soil is important. This is due to the failure plane might take place at the boundary between peat and underlying soil (Zwanenburg et al. 2012).

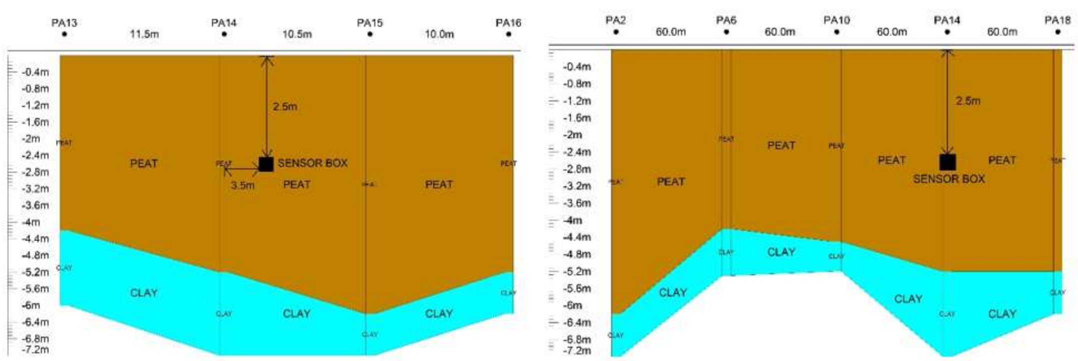


Figure 2. Soil profile: (a) cross section, (b) long section

Considering the above aspects and the soil profile, we decided the monitoring point to be located at the centerline of the road alignment on the cross section PA13-PA14-PA15-PA16, i.e. 3.5 m from the PA14 to PA15 (Figure 1b). The average depth of peat at the decided monitoring point was about 5m. Therefore, the depth of monitoring point was chosen at 2.5 m below ground level (B.G.L.), i.e. the middle of the peat layer.

3.2 Sensors Installation

In order to monitor the vertical stress, the horizontal stress, the pore water pressure, and the settlement, the following sensors were installed: two units of earth pressure cells (vertical, V-EPC and horizontal, H-EPC), one unit of piezometer and one unit of settlement gauge, respectively.

Besides these sensors, a biaxial tilt meter and a magnetic compass were incorporated to detect if any rotation or tilt of the sensor box occurs during the monitoring. All sensors (except for tilt meter and magnetic compass) use vibrating wire principle that is suitable for the field geotechnical applications due to its stability, accuracy, and durability. They were attached (screwed or cable tied) in a special sensor box, that consist of a light aluminum frame weighing about 10kg (Figure 3a). The frame measures 500mm wide, 450mm thick and 940mm high. The total weight of the sensor box (aluminum frame with all sensors) was approximately 28kg, which gives a self-weight stress of about 1.2kPa. This stress is considered minimum compared to the stress exerted from the road embankment.

The vertical earth pressure cell (V-EPC) is of a jackout type, while the horizontal earth pressure cell (H-EPC) is of a standard type. They measure the stress within the peat by measuring the pressure on the surface of their circular plates. The face of the circular plates oriented to the direction of the measured stress. The piezometer measures the actual pore water pressure within the peat that include both excess and hydrostatic. The tip the piezometer sensors has a filter to allow only water to enter the diaphragm. The settlement gauge has similar principle to the piezometer. It measures the pressure of water from a reference tank above ground via tubing (small hose). The reference tank is placed on a pile that was driven and rest on the hard layer (Figure 3b). The settlement is calculated by dividing the water pressure with the unit weight of water.

All sensors were calibrated and checked prior to the deployment individually. Note that, each vibrating wire sensor has an internal thermistor used to measure the temperature as well as to correct the measurement due to the temperature fluctuation. The pre-deployment checking was conducted in order to ensure all sensors works properly as expected. A 6m tall PVC cylinder was made and filled with water (Figure 3c). Each sensor was dipped into the cylinder from the top until various depths. The reading from the data logger was confirmed with the actual stress calculated from the depths, i.e. unit weight multiplied by the depth.

Once all sensors were calibrated and checked, they were re-attached to the sensor box and immersed in peat in a big tank (Figure 1d). This step was done to double check the measurement of the sensors in similar environment to the fields. The immersion was continued until the actual deployment at the monitoring point.

At the monitoring point, the sensor box was placed at the designated depth through a hole. A steel casing measuring 800mm in diameter was inserted into the peat ground (Figure 3e and 3f). The peat inside the casing was excavated. The sensor box was lowered down and placed correctly 2.5m B.G.L. measured from the ground level to the settlement gauge. After placement, the excavated peat was backfilled entirely into the casing (Figure 3g). Once the peat was backfilled, the casing was extracted/pulled out by an excavator (Figure 3h). During the extraction, all sensors cables and tubing were pulled out and placed above the excavated peat to prevent damage. After the casing was successfully extracted, the cable was embedded properly on peat ground. The cables were made loose (slacked) to allow settlement of the sensor box without snapping the cables. A special trench was made to secure the cable on peat ground (Figure 3i).

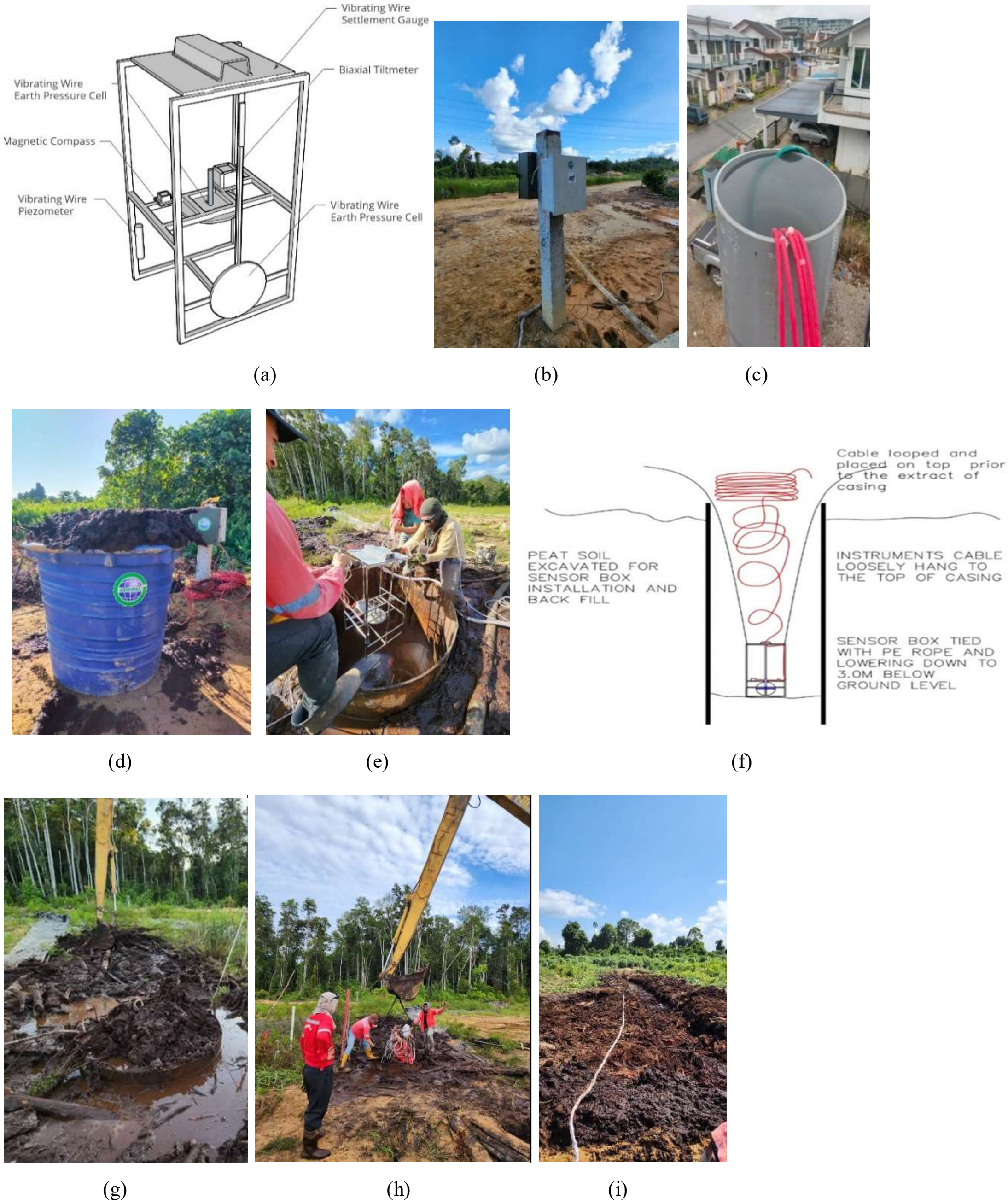


Figure 3 Sensors: (a) Sensor box, (b) Sensor reference tank and data logger placed on pile (c) Calibration cylinder, (d) Peat tank, (e) Burial of the sensors, (f) Schematic of burial process, (g) Backfilling the excavated peat, (h) Extracting the casing (i) Cable trench

The last step was to connect all cables and to the data logger, and the tubing of the settlement gauge to the reference tank (Figure 3b). The data logger registered the measurement from the sensors after the installation.

4 PRELIMINARY DATA ANALYSIS

4.1 Strength Properties

Shear strength data of the peat and clay has been collected. Field vane shear gives a direct measurement of field undrained shear strength and is capable of measuring low shear strength of soil such as peat. It is the most used tool to estimate undrained shear strength of soft soils (Almeida and Marques 2018). Figure 4 shows the undrained shear strength, s_u (kPa) with depth down to 7.2m from Field vane shear tests conducted at PA14. The solid and dashed lines represent the undisturbed and remolded shear strength, respectively. The s_u mostly ranges between 6-8 kPa. The shear strength of the surface peat, i.e. 1-2m is relatively stronger than the deeper one. This is understandable since the peat surface has been slightly desiccated and compacted due to the clearing activities at the surface. At the depth between 4-6m is the weakest location, where the peat is not affected by the desiccation and compaction and the peat remains in its natural state. The shear strength found is apparently too soft to support the future road embankment to be constructed on it. A significant settlement is to be expected.

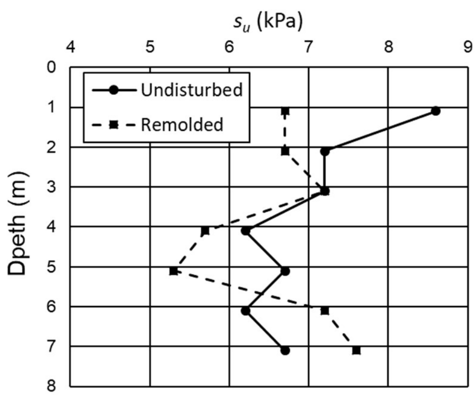


Figure 4. Undrained shear strength vs depth at PA14

The sensitivity, i.e. the ratio between the undisturbed and remolded is plotted in Figure 5. It reduces as the depth increases, which indicate that the peat fabric structure does not significantly contribute to the shear strength especially at the deeper layer. The average sensitivity across the depth is 1.1. This finding suggest further investigation on the geotechnical characteristic of the peat can be done using remolded sample in the laboratory, i.e. getting undisturbed sample is not that critical. At the moment, getting undisturbed sample in the field is not possible due to high water content of peat.

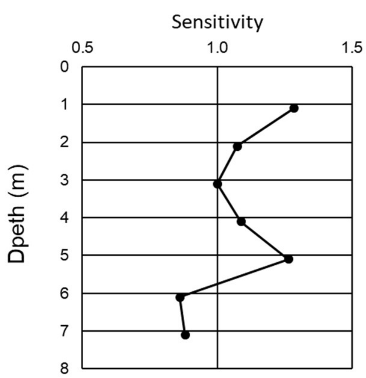


Figure 5. Sensitivity vs depth at PA14

4.2 On-going Measurement

Currently, the road embankment construction has not been yet been started since the installation. It is expected that the sensors will record during construction stages and post construction. Figure 6 shows the road embankment to be built, the location of the sensor box and the peat augering points. The road has width of about 24m shoulder to shoulder with counter berms at both sides to improve the stability during construction. The stages of the construction will be conducted as the following stages:

a. Constructing the embankment and counter berms until finished road level (FRL) +2.0m and to 1.m above ground level, respectively. The filling rate will be 300mm per week with 2 weeks rest period in between filling.
b. Waiting the soil to consolidate due to filling.
c. Topping up of the fill to the surcharge level and counter berms above ground level, respectively. It will be carried out when the fill has settled more the 0.3m.
d. Trimming the excess materials from the surcharge and counter berms when consolidation has terminated to the appropriate levels to facilitate the roadway construction.
e. Constructing the pavement and turf accordingly.
f. Installing close turfing on slope and spot turfing on shoulders.

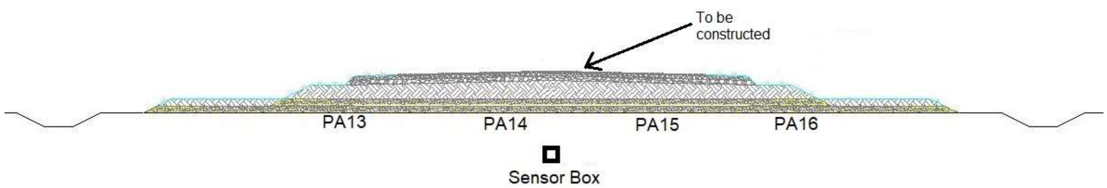
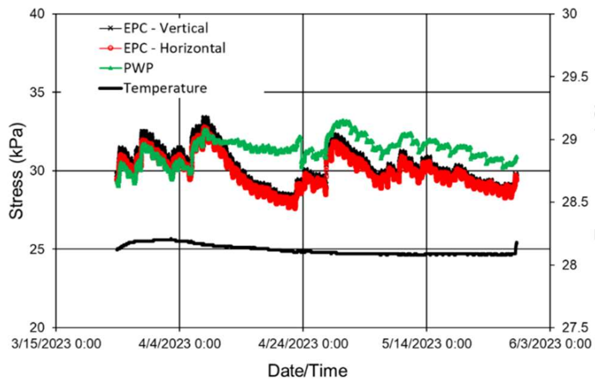


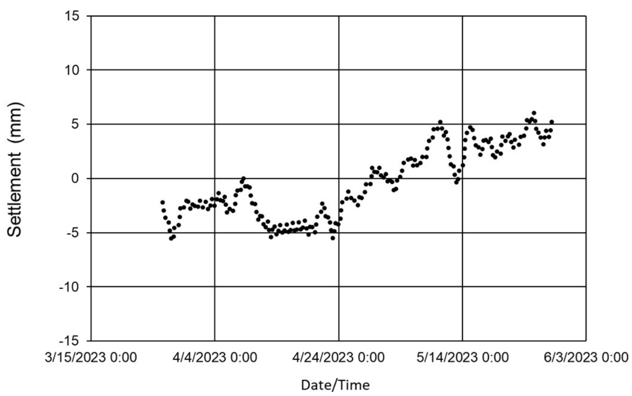
Figure 6. Road embankment and roadway to be constructed on top of peat

The sensor box has been placed 2.5m B.G.L under the ground level and buried completely. The current readings of the sensors are shown in Figure 7a and 7b. Figure 7a show the reading of the two EPCs, piezometer and temperature. There is not much difference in temperature since the instrumentation has been started on the 24th of March 2023. The temperature of the peat shows around 25°C. The EPCs and piezometer readings show a fluctuation (up and down measurement) around 30kPa. The vertical and horizontal EPC show almost equal in values, which indicate that the peat is in liquid state, i.e. the peat has not gained any effective stress. The coefficient of lateral earth pressure at rest, K_o is almost equal to 1. This finding is an agreement with the Field vane shear test (Figure 4). The fluctuation of the EPCs are thought due to the temporary activities above ground. The reading of the two EPC corresponds with the reading of pore water pressure reading from the piezometer. The piezometer shows equal values with EPCs until 9th of April 2023. The 2.5m B.G.L position of the sensors should give around 30 kPa of geostatic pressure (liquid soil) with the saturated unit weight of peat around 12 kN/m^3.

It is interesting to see that the pore water pressure reading is maintained after 9th of April 2023 while the two EPCs reading decreases until 24th of April 2023. This might indicate that when high temporal load from the activities above ground (on the 9th of April 2023) was reduced, the excess pore water pressure does not decrease as much as the stress reading from the EPCs. The reduction of the temporal load which caused the stress to decrease did not follow by the reduction of the pore water pressure. This phenomenon might be associated with the low permeability of the soil. The peat permeability is very low at the steadier state (Hasan and Janting, 2023 in-press). The pore water pressure only shows very small dissipation until 24th of April 2023. After this period, the EPCs show another increase in stress, which is also followed by the piezometer. The readings from EPCs and piezometer after 24th of April 2023 are qualitatively showing similar behavior. However, the reading from the piezometer still show higher than the two EPCs, which means the excess pore water pressure that was initially developed on the 9th of April 2023 has not entirely dissipated.



(a)



(b)

Figure 7. Current reading of sensors: (a) stress and temperature, and (b) settlement

The settlement gauge reading does not show significant increase or decrease (Figure 7b). It fluctuates around value of 0mm, which means the sensor box has been moved yet. Note that the plus (+) sign of settlement in Figure 7b indicates downward and the minus (–) sign indicates vice versa, i.e. heaves upward. The small fluctuation is very negligible to be interpreted at the moment. The current location of the sensor box was confirmed by manual checking. A steel rod was inserted from the above ground to check the depth the sensor box. It was confirmed that the sensor box still stays in place until the last reading was taken.

Monitoring of the sensors will be conducted regularly by the University and local department of public works. The back analysis will be conducted after the construction will be done in the near future. The data from the monitoring will be useful for academic and geotechnical engineering to better understand the geomechanical behavior of peat under actual road embankment.

5 CONCLUSIONS

This paper discusses about the ongoing ‘in-peat’ geomechanical monitoring method under an actual road embankment (to be constructed soon) and the preliminary analyses of the measurement from the installed sensors. The following conclusions are made:

1. The sensor burial method has been successfully implemented using methods as described in this paper.
2. The sensors have indicated good working condition and are capable of monitoring the actual site condition.
3. Field vane shear tests of peat showed undrained shear strength values 5.3 to 6.8 kPa. There is insignificant different between undisturbed and remolded results.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author upon reasonable request.

ACKNOWLEDGMENTS

Authors would like to acknowledge financial support from the Sarawak Ministry of Public Works under a grant title: Desktop Study for Instrumentation of Road Embankment on Peat, grant no. RG/F02/JKRS/02/2021(registered in Universiti Malaysia Sarawak) as well as facilitating the instrumentation program. Authors also would like to thank stakeholders including consultant and contractors.

REFERENCES

Almeida, M., & Marques, M., 2018. *Design and Performance of Embankments on Very Soft Soils*. CRC Press, Taylor & Francis Group.

Andriesse, J., 1988. *Nature and Management of Tropical Peat Soils. Rome: Soil Resources, Management and Conservation Service, FAO Land and Water Development Division*. Food and Agriculture Organization of the United Nations, Soils Bulletin.

Buringh, P., 1979. *Introduction to the study of soils in tropical and subtropical regions*: Centre for Agricultural Publications and Documentation, Wageningen, The Netherlands.

Edelman, C. H. and van der Voorde, P. K. J., 1963. Important characteristics of alluvial soils in the tropics: *Soil Science*, 95(4), pp. 258–263.

Forsman, J., Dattenborn, T., Skepast, P., Mets, M., Olep, M., Ellmann, A., Vallas, I., Tonts, T., & Konston, K., 2016. Full scale reinforced road embankment test sections over soft peat layer, Voobu, Estonia. *In Proceedings of the 17th Nordic Geotechnical Meeting Challenges in Nordic Geotechnical* 25th-28th of May.

Hasan, A., & Janting, W. 2023. Permeability Behavior of Tropical Sapric Peat Under Isotropic Compression. *Geotechnical and Geological Engineering*, Springer Nature. https://doi.org/10.1007/s10706-023-02612-4

Hayashi, H., Nishimoto, S., & Takahashi, M., 2011. Field Performance of PVD Combined with Reinforced Embankment on Peaty Ground. *Soils and Foundations* 51 (1), pp. 191-201

JKR (Jabatan Kerja Raya), 2015. *Arahan Teknik (J) 8 / 86: A Guide On Geometric Design Of Roads*. Public Works Department Malaysia. Kuala Lumpur.

Ong, D., Kho, K., Danial, A., & Tau, L., 2009. Effective Road Embankment Construction on Fibrous Peat using Hydraulic Sand-Fill. *In Proceedings of Ground Improvement Technologies and Case Histories.* pp. 663-670.

Rowe, R., & Soderman, K., 1985. Geotextile Reinforcement of Embankments on Peat. *Geotextiles and Geomembranes*, 2, pp. 277-298.

Susila, E., & Apoji, D. 2012. Settlement of a Full-Scale Trial Embankment on Peat in Kalimantan: Field Measurements and Finite Element Simulations. *Jurnal Teknik Sipil*, 19(3), ISSN 0853-2982

Zwanenburg, C., Den-Haan, E., Kruse, J., & Koelewijn, A., 2012. Failure of a trial embankment on peat in Booneschans, the Netherlands. *Geotechnique*, 62(6). Pp. 479-490.

- This page is intentionally left blank -