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COMPARISONS ON THE RESPONSE OF SHALLOW GEOTHERMAL ENERGY PILE EMBEDDED IN SOFT AND FIRM SOILS

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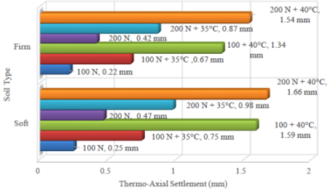
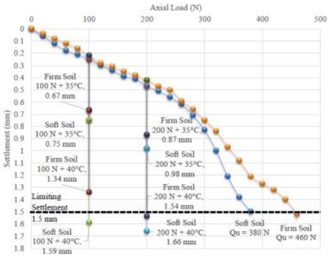
Aminaton Marto[a], Ahmad Mahir Makhtar[b], Adriana Amaludin[c]*

[a]Soft Soil Engineering Research Group, Department of Geotechnics and Transportation, Faculty of Civil Engineering Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Industrialised Construction System Research Group, Innovative Engineering Research Alliance, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Civil Engineering Programme, Faculty of Engineering, Universiti Malaysia Sabah, Sabah, Malaysia

*Corresponding author
adriana@ums.edu.my

Graphical abstract





Abstract

Shallow geothermal energy pile, particularly the one used in tropical countries, is a sustainable geostructure system that transforms the soil surrounding the geostructure as a heat sink, for building cooling purposes. Thermal loads stored in the soil will cause thermally induced settlement. A series of laboratory tests were performed to study the behaviour of model energy piles installed in kaolin soil with soft and firm consistencies. Twelve tests which included thermal load tests (35˚C and 40˚C) and thermo-axial load tests (100 N and 200 N, combined with thermal loads) were performed. The pile response to thermal and thermo-axial loads were attributed to the soil consistency and the magnitude of the loads applied to the pile head. Firm soils produce lower thermally induced settlement, due to higher level of restraint compared to soft soils. To ensure that the thermo-axial settlement does not exceed the limiting settlement, the recommended global factor of safety used for soft soil and firm soils subjected to 40˚C thermal load should be more than 4.0 and 2.5, respectively.

Keywords: Shallow geothermal energy pile; thermal settlement; cohesive soil

Abstrak

Sistem cerucuk tenaga geoterma, khasnya yang digunakan di negara tropika, adalah satu sistem geostruktur lestari yang menukarkan tanah disekeliling geostruktur kepada sinki haba untuk penyejukan bangunan. Beban haba yang disimpan di dalam tanah akan menyebabkan enapan terma. Satu siri ujikaji makmal telah dilakukan untuk mengkaji kelakuan model cerucuk di dalam tanah kaolin yang mempunyai kekonsistenan lembut dan kukuh. Sebanyak dua belas ujikaji yang merangkumi ujian beban terma (35˚C dan 40˚C) dan ujian beban terma-paksi (100 N dan 200 N, dengan beban terma) telah dikenakan kepada model cerucuk tenaga. Tindak balas cerucuk kepada beban terma dan beban terma-paksi bergantung kepada kekonsistenan tanah serta magnitud beban terma yang dikenakan kepada cerucuk. Tanah kukuh akan menghasilkan enapan terma teraruh yang lebih rendah disebabkan oleh tahap kekangan yang tinggi daripada tanah lembut. Untuk memastikan bahawa nilai enapan terma-paksi tidak melebihi enapan penghad, nilai faktor keselamatan global yang disarankan bagi tanah lembut dan tanah kukuh yang dikenakan beban terma 40˚C, masing-masing harus melebihi nilai 4.0 dan 2.5.

Kata kunci: cerucuk tenaga geoterma cetek; enapan terma; tanah jeleket

1.0 INTRODUCTION

The energy pile system is designed to achieve energy efficient space heating and cooling for residential and commercial buildings of various sizes; while satisfying load bearing requirements of the underlying foundation [1]. It uses the embedded structural elements e.g. piles in soil as a medium to transfer thermal energy between the building and the soil directly underneath it. Heat exchanger piles transport the ground thermal energy to buildings via heat exchanger fluids that circulate in heat exchanger pipes embedded in the piles. [2]

Nowadays, geothermal energy pile systems have been implemented throughout the world, for example in countries such as Austria, Switzerland, United Kingdom, Japan, China and Hong Kong. However, the engineering community has addressed concerns regarding the effect of thermal loads on the performance of energy piles during its operation. Therefore, there is a need to gain a better understanding of the effect of these thermal loads on the energy pile to justify its use on a large scale, particularly in Malaysia. Recently, the behaviour of the geothermal energy piles under the coupled axial and thermal loads (otherwise known as thermo-axial load) has generated substantial attention amongst researchers in the field of energy geotechnics. This is evident since there were several full-scale in-situ tests on energy pile systems that were commissioned by Laloui *et al.* [3] in Switzerland, Bourne-Webb *et al.* [4] in United Kingdom, Wang *et al*. [5] in Australia and Murphy *et al.* [6] in United States, despite the technology being in the nascent stage.

The geothermal energy foundation system is an element of "sustainable structure" that has been developed in recent years. Hence, the published data on long-term performance are scarce. Therefore, experimental investigations on shallow geothermal energy piles are able to provide significant information with regards to their long-term performance. There are only six known laboratory experimental studies conducted to observe the behaviour of these energy piles. Three studies on single gravity energy piles embedded in sand were conducted by Wang *et al.* [7], Kalantidou *et al.* [8], and Yavari *et al.* [9], and three centrifuge studies were carried out by Rosenberg [10], Stewart and McCartney [11], and Loria *et al.* [12] on energy piles in silt have been carried out to date. Accordingly, additional testing and new analyses are required to obtain a better understanding of the mechanisms of thermal soil-structure interaction in energy piles. It is paramount to analyze the thermal behavior of a foundation, since it governs the bearing response for the superstructure [13].

Even though geothermal energy pile systems have gained recognition and acceptance in other countries, the technology has not been widely implemented in other countries, including Malaysia. Very little is known about the performance of the geothermal energy pile system in tropical countries, e.g. Malaysia, which will mostly require the system to perform under cooling conditions. As such, this study aims to address the need for further understanding of the energy pile performance in tropical weather conditions. More specifically, this paper presents the findings of the study conducted to quantify thermally-induced settlements for model energy piles embedded in firm and soft kaolin soils.

2.0 MATERIAL AND TESTING PROGRAMME

2.1 Material

In order to investigate the behaviour of energy piles using laboratory model, commercially available kaolin soil was used. Prior to the start of the main testing stage, relevant standard laboratory tests were conducted to obtain the basic properties and undrained shear strength of the compacted kaolin soil. The soil sample in this study was obtained from Kaolin Malaysia Sdn. Bhd., available in the market as S300. The laboratory tests were conducted based on the British Standard [14] and the American Society of Testing Material [15]. The laboratory test results are shown in Table 1.

Table 1 Physical Indices of S300 Kaolin Soil

PROPERTY	VALUES
Particle Density	2.66 Mg/m^3
Grain Size	
Sand (0.075-2.0 mm)	14 %
Silt (2-75 μm)	70 %
Clay (< 2μm)	16 %
Atterberg Limit	
Liquid Limit	38 %
Plastic Limit	27 %
Plasticity Index	11 %
Standard Proctor Compaction Parameters	
Maximum Dry Density	1.63 Mg/m^3
Optimum Moisture Content	17 %
Soil Classification (USCS)	ML

Based on the Unified Soil Classification System (USCS), the soil sample was classified as ML (low plasticity silt). For the liquid limit and plasticity index results, the obtained values for S300 soil falls within the range of typical kaolinite material. Marto [16],[17] stated that liquid limit range for typical kaolinite material is 40-60% and the plasticity index range is 10-25%, both criterias that were met based on the results of this study. The kaolin soil used for this study was similar to that used by Rosenberg [10] and Stewart and McCartney [11]. Both researchers had used the soil that was classified also as ML. The S300 kaolin soil was chosen for this study because it possesses a high fines content to enable the observation of thermal consolidation and low plasticity to prevent changes in soil-pore water interactions due to temperature changes [11].

2.2 Experimental Setup

For this study, a physical model representing a shallow geothermal energy pile system was developed to characterize the soil-structure interaction mechanism. More specifically, this model allows the evaluation of the model energy pile behavior in a controlled environment [11]. The physical model design was derived from previous studies conducted by Wang *et al.* [7], Kalantidou *et al.* [8], and Yavari *et al.* [9], with some minor design improvisation. This is due to the fact that all three models were designed to be tested using cohesionless materials, while this study focuses on cohesive material instead.

The physical model consists of four (4) main components, which includes the axial load control system, thermal load control system, soil container and the model pile. First, the axial load system was designed to provide axial load to the model energy pile head via a stress-controlled system. The amount of axial load applied to the model pile head was controlled using a pneumatic control valve, and the resultant axial load was observed using a load cell.

Next, the thermal load system was designed to emulate the thermal load transfer from the building via the energy pile to the surrounding soil. To achieve this, the thermal load system consisting of a metallic U-tube was installed within the model pile to distribute the thermal load evenly along the pile length. The thermal load input was provided using a temperature bath equipped with a thermostat to allow precise temperature control.

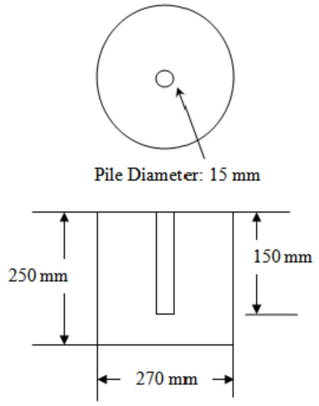


Figure 1 Dimension of model energy pile and soil container

The soil container and model pile design was done by scaling down the typical dimensions of an energy pile found in-situ. According to Brandl [2], energy piles diameters typically range from 0.6 to 1.5 m, while having 10-25 m length. As such, the chosen model energy pile dimension was 15 mm diameter and 150 mm embedded length. Meanwhile, the soil container's dimension was set at 270 mm diameter with a maximum height of 450 mm. Figure 1 shows the dimensions of the model energy pile and model soil.

2.3 Experimental Method

To prepare the soil model, the S300 kaolin powder was oven dried at 105°C for 24 hours to prevent any biological activity within the sample, as explained by Effendi [18]. The model pile was fixed in the centre of a 270 mm inner diameter cylindrical acrylic plexiglass, while the model soil was compacted around the pile by using a steel tamper. For firm soil, The chosen target dry density was 1.47 Mg/m^3 (corresponding to a relative density of 90%), while for soft soil the target dry density was 1.3 Mg/m^3 (for a relative density of 80%). In this study, the model pile installation method was carried out in a similar manner to that of the installation of non-displacement piles [2].

Prior to the commencement of the pile tests, the ultimate bearing load of the model energy piles were determined to define the actual factor of safety of the chosen initial axial loads used for this study. The initial axial loads were 100 N and 200 N. Kalantidou *et al.* [8] has defined that bearing capacity of the model energy pile as the value of axial load, obtained when the pile settlement value reaches ten (10) percent of the diameter (D) of the pile. Therefore, the designated settlement value at which the model pile presumably fails is approximately 1.5 mm. In firm soil, the ultimate load capacity obtained was 460 N while for soft soil the value was 380 N. Table 2 shows the calculated factor of safety for the chosen initial axial loads.

Table 2 Factor of safety (FOS) for imposed axial loads

SOIL TYPE	ULTIMATE LOAD CAPACITY	AXIAL LOAD	
		100 N	200 N
Firm	460 N	4.6	2.3
Soft	380 N	3.8	1.9

Next, to ensure uniformity of the model soil samples, the average undrained shear strength values for both firm and soft soil samples were determined. Standard unconfined compression tests were carried out on samples of 38 mm diameter and 76 mm height. In the case of firm soil, the average undrained shear strength value was 37 kPa, while for soft soil the value was 25 kPa. Both samples had the same average moisture content value of 17%. The distinction between firm and soft soils were made based on Le Tirant and Meunier [19], where soft soils were classified as having an undrained shear strength of 25 kPa or less.

To initialize the main testing phase, the laboratory equipments consisting of the temperature bath, load cell and linear variable displacement transducer (LVDT) were setup. For the thermal load testing phase, the model pile was subjected to one thermal load cycle, followed by a cooling down period. As recommended by Brandl [2], the values of 35˚C and 40˚C were chosen based on the typical operating temperatures of energy pile systems. Temperature values exceeding 50˚C must not be used since this value is not applicable for actual operating conditions of the energy pile system.

On the other hand, for thermo-axial load tests the initial axial load of 100 N or 200 N was applied first. After no further pile head displacement was observed due to the applied axial load, the model pile was then subjected to one thermal load cycle, and a cooling cycle right thereafter. More specifically, the thermal load cycle comprises of increasing the model pile temperature from ambient temperature of 27˚C to 35˚C or 40˚C, and followed by the reduction of the thermal load until the pile temperature reaches the ambient temperature.

3.0 RESULTS AND DISCUSSION

In this section, the results of the conducted tests carried out to determine the thermal and thermo-axial characteristics of the model energy pile behavior are presented and analyzed.

3.1 Thermal Load Test

In order to replicate the thermal loading effect that occurs during the heat transfer of the energy pile, the thermal load test was carried out. The test examines the amount of thermal settlement that develops at the soil underneath the model pile as a result of the temperature increase in the soil sample. For the case of thermal load test carried out on soft soil sample, Figure 2 presents the thermal settlement data obtained by applying two types of thermal load, 35˚C and 40˚C to the model pile.

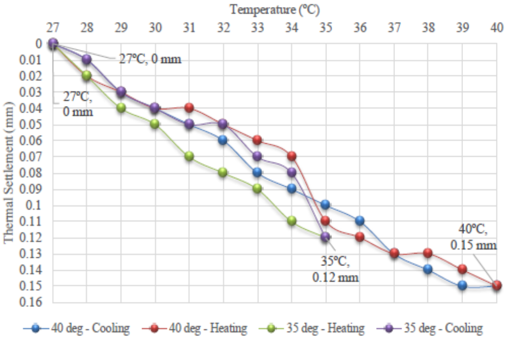


Figure 2 Pile head settlement due to thermal load at 35˚C and 40 ˚C for soft soil

The observed maximum settlement for the model pile heated at 40˚C reached a value of 0.15 mm (or equal to 10 % of the settlement at ultimate bearing capacity), while the maximum settlement for the model pile heated at 35˚C had a value of 0.12 mm. At the maximum thermal load of 40˚C, it was found that the thermal displacement is relatively small (about 0.15 mm or 1% of pile diameter). According to Laloui and Di Donna [20], in their study the thermal load test without any axial loads applied to the pile head also produced small thermal displacement values that did not exceed 1% of the pile diameter.

Moreover, a hysteresis phenomenon that denotes the distinct heating and cooling paths was observed in the cycle, similar to the conclusion made by Kalantidou *et al.* [8]. After the model pile has been cooled back to ambient temperature, no irreversible thermal settlement of the pile was observed for both 35°C and 40°C thermal load tests. Furthermore, the cooling path follows the same slope as that of the heating path. However, contrary to the findings of Kalantidou *et al.* [8], there was no sign of heaving of the model pile head found in this case. This may be attributed to the different type of soil encountered for the thermal load test, where Kalantidou *et al.* [8] used dry Fontainbleau sand, while for this study cohesive soil of soft and firm consistency at optimum moisture content was used instead.

Furthermore, this study uses a pneumatic axial load system to apply the load to the pile head, while the former uses the dead load system for applying the axial load. As such, the level of restraint for both pile models are also different, where the level of restraint in this study is higher. The level of restraint is one of the three factors that affects the amount of thermal strain and settlement found in energy piles [21]. Since the study conducted by Kalantidou *et al.* [8] used a loading system that had a lower level of restraint, this permits the pile head heave to occur.

On the other hand, for the case of the firm soil sample, Figure 3 shows the thermal settlement obtained by applying two types of thermal load, 35˚C and 40˚C to the model pile. The maximum settlement for the model pile heated at 40˚C reached a value of 0.14 mm, while the maximum settlement for the model pile heated at 35˚C had a value of 0.1 mm. Furthermore, the maximum thermal displacement is also relatively small, where the value of 0.14 mm is less than 0.15 mm or 1% of pile diameter. As seen in the previous section, a similar hysteresis phenomenon was also observed in this test, where the heating and cooling paths are well defined. However, the thermal load test that is conducted at 40˚C shows an irreversible thermal settlement of 0.01 mm after being cooled.

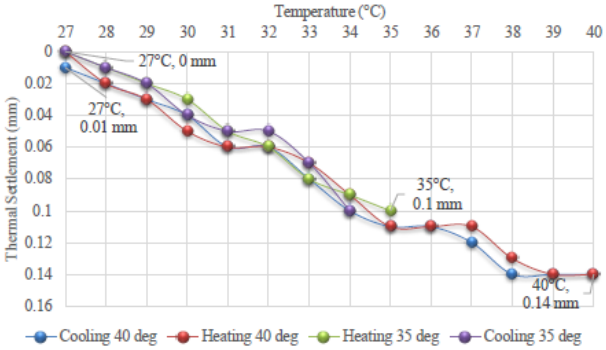


Figure 3 Pile head settlement due to thermal load at 35˚C and 40 ˚C for firm soil

Consequently, the irreversible thermal settlement phenomenon that was observed was in line with the finding of Bourne-Webb *et al.* [4].While the model pile undergoes heating, the pile dilates in response to the heating process. As such, the soil has a tendency to restrain the dilation of the pile, and that additional stresses may be developed at the pile toe [10], [11]. Apparently, the additional stresses developed at the pile toe that was induced by heating leads to the development of irreversible strains on the pile, hence irreversible settlement was observed [8].

Mitchell and Soga [22] found that denser soil has higher composite thermal conductivity, which means that more thermal loads are stored within the firm soil surrounding the model pile compared to soft soil. Consequently, soft soils have a higher void content which reduced the thermal conductivity. Hence the amount of thermal load received by the soft soil surrounding the model pile is less than that found in firm soils [23]. Higher void content also means that the pile deformation process is less restricted, which is reflected in the higher thermal settlement values in soft soil. On the other hand, Di Donna and Laloui [24] reported that clay soil response to thermal load is complex as a consequence of their microstructure and the electrochemical equilibrium between clay particles.

3.2 Thermo-Axial Load Test

In Figure 4, the thermo-axial settlement values for tests conducted in soft soil are plotted against the settlement at ultimate load. An observation that can be made here is that at 40ºC thermal load, the thermo-axial settlement value is greater than the value of settlement at ultimate load, valued at 1.5 mm. This means that at 100 N and 200 N axial load values (equal to factors of safety of 3.8 and 1.9), the pile could not withstand the effect of additional thermal load. In this case, a higher factor of safety should be used in order to take into consideration the effects of thermal loading. It is important to note that the starting point of all the thermo-axial load-settlement curves do not start at zero; the readings start from the initial settlement caused by the initial axial loads (100 N and 200 N respectively).

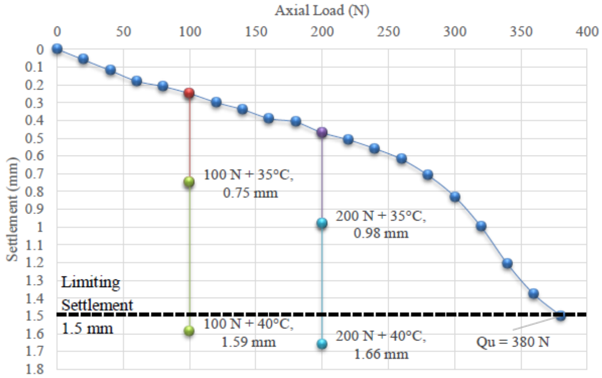


Figure 4 Thermo-axial settlement in soft soil with respect to limiting settlement

From Figure 4, at 35˚C thermal load, the lower axial load produces a lower value of thermo-axial settlement where the 100 N axial load only gave a settlement of 0.75 mm, while a settlement of 0.98 mm was observed when 200 N axial load was used. The same trend is observed in Figure 5 for 40˚C thermal load, where a thermo-axial settlement of 1.59 mm was recorded for an axial load of 100 N and 1.66 mm for an axial load of 200 N.

In Figure 5, the thermo-axial settlement values for tests conducted in firm soil are plotted against the settlement at ultimate load. It was found that only one thermo-axial settlement that had exceeded the limiting settlement (1.5 mm), which was the 200 N axial load combined with 40ºC thermal load. In firm soil, the value of axial load of 200 N yields a factor of safety of 2.3. Nevertheless, for a factor of safety of 2.3, it is deemed not adequate to withstand the effect of the thermo-axial load. Again, to ensure that the thermo-axial load does not adversely affect the pile performance, the recommended step to take is by choosing a higher factor of safety, meaning lowering the working load.

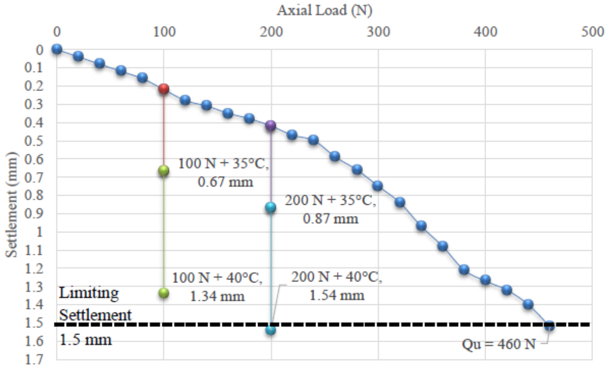


Figure 5 Thermo-axial settlement in soft soil with respect to limiting settlement

In general, as the model soil is dried upon each cycle of heating and cooling, the corresponding change in soil-foundation interface brings about a cumulative change in the thermo-mechanical settlement within the foundation, leading to a cumulative movement of the foundation [25]. Amatya *et al.* [21] stated that the pile response to thermal loads and thermo-axial loads are attributed mainly to ground conditions, end restraint conditions and the magnitude of thermal load applied to the pile. Based on Di Donna and Laloui [24], the overconsolidation ratio of soil maybe less than 2 as it contract during heating, causing negative skin friction to the pile. It then cause a down-drag to the pile, resulting with settlement to the pile head. Figure 6 shows the comparison of thermo-axial settlements in firm and soft soil, while Figure 7 shows the thermo-axial settlement values with respect to the ultimate load in both types of soil consistency.

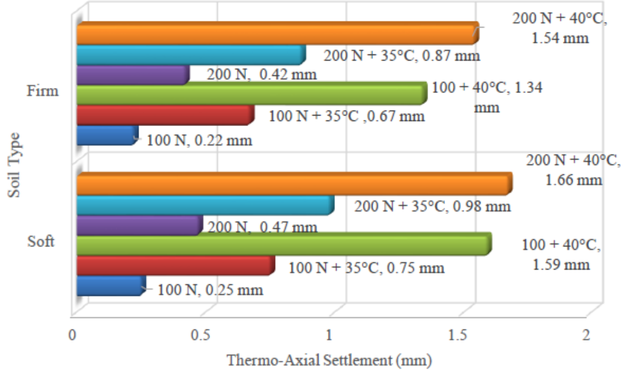


Figure 6 Thermo-axial settlements in firm and soft soil

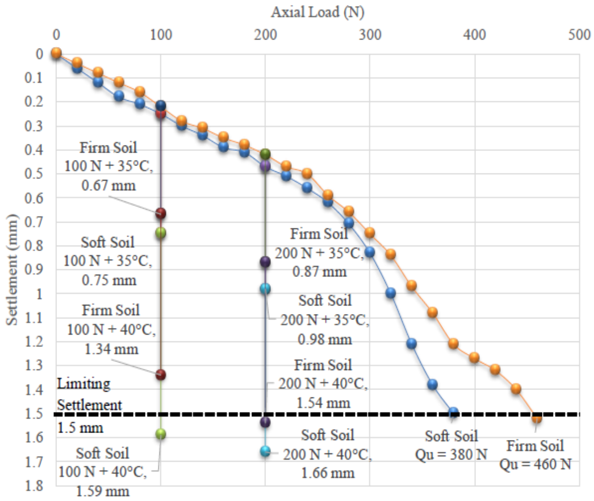


Figure 7 Thermo-axial settlements with respect to settlement at ultimate load

It can be said that firm soils consistently produce smaller thermo-axial settlement values compared to soft soils, due to higher density and is therefore less likely to yield to thermally-induced settlement [4]. Therefore, it could be recommended that for softer soils and at higher thermal loads (40˚C), the working load or initial axial load should be reduced, hence giving a higher factor of safety in order to accommodate the effects of thermally induced settlements, which are observed to give a greater effect when combined with axial loads.

However for in-situ cases, it is unlikely that the thermally induced settlement, strains and stresses will adversely affect the energy pile as seen in this study. This is because of the limitations of this study, whereby heat dissipation in a small scale model pile is not similar to the heat dissipation in a full-scale model [10], [24]. In full-scale tests, the thermal loads are evenly distributed along the pile length, and therefore this results in much lower thermo-axial settlements compared to the small scale model.

4.0 CONCLUSION

In this study, the behaviour of geothermal energy pile model embedded in firm and soft cohesive soils, subjected to varying thermal load and thermo-axial loads were determined using a single gravity laboratory model tests. The obtained results could provide an insight on the behavior of energy piles, since the current state of knowledge in Malaysia is limited. A total of twelve tests were performed on kaolin clay with firm and soft consistencies to evaluate the behavior of the energy pile model under different thermo-axial loads. The thermal loads of up to 40˚C induced very small values of thermal settlement, whereby it was less than 1% of the pile diameter. The irreversible thermal settlement phenomenon was also observed during the cooling cycle of the 40°C thermal load. Also, firm soils produces lower thermal settlement values due to higher level of restraint, despite having a higher thermal conductivity value compared to soft soils.

For 35˚C thermal loads, the resulting settlement did not exceed the limiting settlement. Meanwhile, the highest thermo-axial settlement obtained was 1.66 mm for thermo-axial load of 40°C and 200 N (global factor of safety (FOS) of 1.9) in soft soil, and the settlement at thermo-axial load of 40°C and 100 N axial load (global FOS of 3.8) amounts to 1.59 mm. Consequently, in firm soil and for thermo-axial load of 40˚C and 200 N (global FOS of 2.3), the thermo-axial settlement is 1.54 mm. As a conclusion, the global FOS to be applied for soft soil should be more than 4.0, while for firm soil the value should be more than 2.5 to ensure that the thermo-axial settlement does not exceed the limiting settlement if subjected to thermo-axial up to 40°C.

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References

[1] Gao J., Zhang X., Liu J., Li K. and Yang J. 2008. Numerical and experimental assessment of thermal performance of vertical energy piles: An application. *Applied Energy* 85(10): 901-10.

[2] Brandl, H. 2009. "Energy Piles Concepts", *Deep Foundations on Bored and Auger Piles* - Van Impe and Van Impe, Taylor & Francis Group, London, ISBN 978-0-415-47556-3, 77 – 95.

[3] Laloui, L., Nuth, M. and Vulliet, L. 2006. Experimental and numerical investigations of the behaviour of a heat exchanger pile. *International Journal for Numerical and Analytical Methods in Geomechanics* 30 (8): 763–81.

[4] Bourne-Webb, P. J., Amatya, B., Soga, K., Amis, T., Davidson, C. and Payne, P. 2009. Energy Pile Test at Lambeth College, London: Geotechnical and Thermodynamic Aspects of Pile Response to Heat Cycles. *Géotechnique* 59(3): 237–48.

[5] Wang, B., Bouazza, A., Singh, R. M., Barry-Macaulay, D., Haberfield, C., Chapman, G., and Baycan, S. 2013. *Field investigation of a geothermal energy pile: initial observations. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering. Paris, France*. 3415-3418.

[6] Murphy, K. D., McCartney, J. S., and Henry, K. H. 2014. Thermo-mechanical characterization of full-scale energy foundations. *Proceedings of the GeoCongress ASCE*. 617-628.

[7] Wang, B., Bouazza, A. and Haberfield, C. 2011. Preliminary Observations from Laboratory Scale Model Geothermal Pile Subjected to Thermo-Mechanical Loading. *Geo-Frontiers 2011*. Dallas, TX. 430-39.

[8] Kalantidou, A., Tang, A. M., Pereira, J.-M. and Hassen,. G. 2012. Preliminary Study on the Mechanical Behavior of Heat Exchanger Pile in Physical Model (Technical Note). *Géotechnique* 62 (11): 1047 –51.

[9] Yavari, N., Tang, A. M., Pereira, J. M., & Hassen, G. 2014. Experimental study on the mechanical behaviour of a heat exchanger pile using physical modelling. *Acta Geotechnica* 9(3): 385-398.

[10] Rosenberg, J. E. 2010. *Centrifuge Modeling of Soil-Structure Interaction in Thermo-Active Foundations*. MSc Thesis, University of Colorado Boulder.

[11] Stewart, M. A. and McCartney, J. S. 2012 Strain Distribution in Centrifuge Model Energy Foundations. *GeoCongress 2012. Oakland, CA*. 4376-85.

[12] Loria, A. F. R., Gunawan, A., Shi, C., Laloui, L., and Ng, C. W.W. 2015. Numerical modelling of energy piles in saturated sand subjected to thermo-mechanical loads. *Geomechanics for Energy and the Environment* 1: 1-15.

[13] Batini, N., Loria, A. F. R., Conti, P., Testi, D., Grassi, W., and Laloui, L. 2015. Energy and geotechnical behaviour of energy piles for different design solutions. *Applied Thermal Engineering* 86: 199-213.

[14] British Standard 1377-1. 1990. Methods of Test for Soils for Civil Engineering Purposes. General Requirements and Sample Preparation. BSI Group

[15] ASTM D2487-11.2011 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM International.

[16] Marto, A. 1996. Critical state of Keuper marl silt. *Jurnal Kejuruteraan Awam* 9(2): 34-58.

[17] Marto, A. 1999. Pore pressure response of undrained two-way cyclic loading of silt. *Jurnal Kejuruteraan Awam* 11(1): 35-62.

[18] Effendi, R. 2007. *Modelling of the settlement interaction of neighbouring buildings on soft ground*. PhD Thesis, University of Sheffield.

[19] Le Tirant, P., and Meunier, J. 1990. Anchoring of Floating Structures (Design Guides for Offshore Structures), Editions Technip.

[20] Laloui, L. and Di Donna, A. 2013. *Energy Geostructures: Innovation in Underground Engineering*, ISTE-Wiley Publishing, United Kingdom.

[21] Amatya, B.L., Soga, K., Bourne-Webb, P.J., Amis, T., Laloui, L. 2012. Thermo-mechanical Behaviour of Energy Piles. *Géotechnique* 62(6): 503 –519.

[22] Mitchell, J.K., and Soga, K. 2005. Fundamentals of Soil Behavior, 3rd Edition, John Wiley and Sons, Inc., United Kingdom.

[23] Abuel-Naga, H.M., Bergado, D.T., Bouazza A., and Pender, M.J. 2009. Thermal conductivity of soft Bangkok clay from laboratory and field measurements. *Engineering Geology* 105 (3): 211-219.

[24] Di Donna, A. and Laloui, L. 2013. Soil Response under Thermomechanical Conditions Imposed by Energy Geostructures. *Energy Geostructures*, John Wiley and Sons, 3-18.

[25] Stewart, M.A. 2012. *Centrifuge Modeling of Strain Distributions in Energy Foundations*. M.S. Thesis, University of Colorado at Boulder.