PERFORMANCE OF SHORT PILED RAFT FOUNDATION SYSTEM ON PEAT SOIL UNDER STATIC LOAD

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For my beloved family, especially my dearest wife Tuty Handayani, as well as the three my beloved sons, Herolistra Baskoroputro, Elgodwistra Kartikoputro and Paripurna Bawonoputro, also the three my dearest grandchildren and my two daughters in law

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ABSTRACT

Peat is known as problematic soil, because has low shear strength and high compressibility characteristics. Particular attention should be paid, when building a construction on it. In recent years, there is no special established foundation structure for peat yet, without any treatment of soil. Thus, notably for a depth of 3 to 10 m of the peat layer, there is a challenge to develop a foundation system on peat without any stabilization nor remove and replace, especially for foundation under static point load. This research was conducted to explore a proposed Short Piled Raft (SPR) foundation system, which is a combination of a pile foundation and raft foundation, with a pile length short enough. The objectives of this research were to optimize pile spacing of SPR foundation system related to its stability, especially immediate settlement. The optimization was carried out by comparing some results of simulation using Plaxis 3D Foundation software for numerical modelling. The software was also used for another simulation series with some different soil parameters and site conditions. The selected results of numerical modelling were verified by using the full scale model. Optimum pile spacing of the SPR foundation system with the pile length of 3.0 m and pile outer diameter of 0.32 m is 1.0 m. It was found that SPR foundation system has superiority than other previous methods (Chicken Claw and Nailed Slab). The main reason is that SPR has weight relatively lighter than others, caused by utilizing the uplift force to closed end pipe as pile and the thin concrete slab. While for loading test of full scale model of 3.0 m x 3.0 m concrete slab with the thickness of 0.15 m and 9 closed end short piles, the result shown a good performance. The SPR was able to support 100% design load of 100 kN, with maximum immediate settlement was 19 mm and for 160% design load, maximum immediate settlement was 34 mm. The knowledge contribution of this research is a proposed chart for basic step to design SPR. With these findings, it is hoped that the next research is recommended to research stability of the SPR on peat under static load in the long term and also for dynamic load.

ABSTRAK

Gambut dikenali sebagai tanah bermasalah, kerana mempunyai kekuatan ricih rendah dan ciri-ciri mampatan yang tinggi. Perhatian khusus harus diberikan, ketika membina bangunan di atasnya. Hingga masa ini, belum ada struktur asas khas untuk gambut, tanpa rawatan tanah. Oleh itu, terutama untuk kedalaman 3 hingga 10 m lapisan gambut, ada cabaran untuk mengembangkan sistem asas pada gambut tanpa penstabilan atau pembuangan dan penggantian, terutama untuk asas di bawah beban titik statik.. Penyelidikan ini dijalankan untuk meneroka sistem asas Rakit Cerucuk Pendek (RCP), yang merupakan gabungan asas cerucuk dan asas rakit, dengan panjang cerucuk cukup pendek. Objektif penyelidikan ini adalah untuk mengoptimumkan jarak cerucuk sistem asas RCP yang berkaitan dengan kestabilannya, terutama penurunan segera. Pengoptimuman itu dilakukan dengan membandingkan beberapa hasil simulasi menggunakan perisian Plaxis 3D Foundation untuk pemodelan berangka. Perisian ini juga digunakan untuk siri simulasi lain dengan beberapa parameter yang berbeda. Hasil pemodelan berangka yang dipilih disahkan dengan menggunakan model skala penuh. Jarak cerucuk optimum sistem asas RCP dengan panjang cerucuk 3.0 m dan diameter luar cerucuk 0.32 m ialah 1.0 m. Didapati bahawa sistem asas RCP mempunyai kelebihan berbanding kaedah sebelumnya yang lain (Chicken Claw dan Nailed Slab). Sebab utama adalah bahawa RCP mempunyai berat yang relatif lebih ringan daripada yang lain, disebabkan oleh penggunaan daya angkat ke paip hujung tertutup sebagai cerucuk dan papak konkrit tipis. Sedangkan untuk ujian beban model skala penuh papak konkrit 3.0 m x 3.0 m dengan ketebalan 0.15 m dan 9 cerucuk pendek hujung tertutup, hasilnya menunjukkan prestasi yang baik. RCP mampu menyokong beban jangkaan 100% 100 kN, dengan penurunan segera maksimum adalah 19 mm dan untuk beban jangkaan 160%, penurunan segera maksimum adalah 34 mm. Sumbangan pengetahuan penyelidikan ini adalah anjuran carta untuk langkah awal untuk merancang RCP. Dengan penemuan ini, diharapkan penyelidikan seterusnya disarankan untuk meneliti kestabilan RCP pada gambut di bawah beban statik dalam jangka panjang dan juga beban dinamik.

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LIST OF SYMBOLS AND ABBREVIATIONS

C	Cohesion
D	Pile outer diameter
d	Diameter of cylindrical specimen
E	Elastic modulus
G_s	Specific gravity of soil
g	Acceleration due to gravity
H	Height of retaining wall
I	Moment of inertia
L	Pile depth/pile length
LL	Liquid Limit
l	Length of cylindrical specimen
M	Mass of soil
M_s	Weight of solid particle
PL	Plastic Limit
S	Pile spacing
S_c	Primary consolidation settlement
S_e	Elastic or immediate settlement
SL	Shrinkage Limit
S_s	Secondary consolidation settlement
S_T	Total settlement
$S_{T(max)}$	Maximum of total settlement
T	Raft or concrete slab thickness
V	Total volume of soil
V_s	Volume of solid particle
W	Total weight of soil
w	Water content
w_s	Weight of dry soil
w_w	Weight of water

ΔH	Retaining wall movement
$\Delta S_{T(max)}$	Maximum of difference in total settlement between any two points
γ	Unit weight
γ_d	Dry unit weight of soil
γ_s	Unit weight of soil solids
γ_{sat}	Saturated unit weight of soil
γ_{unsat}	Unsaturated unit weight of soil
γ_w	Unit weight of water
ρ	Density
ρ_d	Dry density
ρ_w	Density of water
σ	Normal stress
τ	Shear strength
φ	Internal friction angle

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CHAPTER 1

INTRODUCTION

1.1 Background

Peat generally has much greater moisture content rather than inorganic soils which has exceeded 100% and it even can reach 3000% (Zainorabidin & Wijeyesekera, 2007). More over Bakar (2014) emphasised that peat was often regarded as problematic soils and was known as soft soils with organic matter content more than 75%. Recently, because the available land is very limited, as a result many construction projects have penetrated challenging soil areas, with some problems faced (Patil, Vasanvala & Solanki, 2013). As an example among several similar projects was Sedenak Factory Park Project in Johor Malaysia. Figure 1.1 shows a construction project at a peatland area as a challenging soil area, located at Sedenak, as mentioned above.

Figure 1.1: Sedenak Factory Park Project, Sedenak, Johor, Malaysia.

Completion of construction on peatland area by implementing a conventional foundation system such as pile foundation system is still considered unsatisfactory (Effendi, 2013). Therefore, some attempts in geotechnical and foundation engineering are still needed to be developed for overcoming those problems.

1.2 Problem Statements

In Geotechnical Engineering, peat has always attracted special attention because of the challenges and problems that should be faced when building a construction on it. These problems rise a trend to avoid the construction on these areas, or if impossible, to simply remove or replace them, which can cause to uneconomic alternative of design and construction (Huat, 2004).

The method of construction on peat is different, depending on the depth of peat (Bakar, 2014). The removal and replacement method are usually used for peat with depth less than 3 m, While for the depth 3 m to 10 m, engineers normally used sand drain, lightweight fills and stone column. The use of sand drain may encounter some difficulties, when making vertical holes in peat with shallow ground water level, because the hole will soon be closed again, As for the use of lightweight fill is highly dependent on the availability of materials suitable for that purpose, so it is not always easy to implement it technically. While the use of stone column is not recommended, because of the very small lateral strength of the peat. Finally, for the depth more than 10 m, the suitable method is deep stabilization techniques such as pile and dynamic compaction. Figure 1.2 shows removal and replacement method was used at Sedenak Factory Park Project, Sedenak, Johor, Malaysia.

By remembering the difficulties encountered even before, during and after construction on peat, especially with a layer thickness of 3 m to 10 meters, then an opportunity is open to develop a suitable foundation system which can be applied on peat. In addition, until now, there is no foundation structure system that is being specially developed, applied to peat soils. However, it is necessary to pay attention to the problems that arise related to the performance of the stability of the foundation that will be developed, namely the bearing capacity and settlement that will occur. Besides, the use of what materials are appropriate and how to build them should be paid more attention.

Figure 1.2: Removal and replacement method of peat at Sedenak Factory Park Project, Sedenak, Johor, Malaysia.

1.3 Aims

This research was conducted to explore a proposed Short Piled Raft (hereinafter abbreviated as SPR only) foundation system, which is expected suitable to be applied on peat. The SPR foundation system is a modified piled raft foundation system, which is a combination of pile foundation and raft foundation, with a pile length relatively short enough, $\frac{L}{D} \leq 20$ (Das and Sivakugan, 2017) and considered as a reinforced concrete slab floating on a number of piles. By understanding the stability performance of SPR foundation system, it can be ensured that this foundation system is suitable or not to be implemented on peat.

1.4 Objectives

The objectives of this research were:

i. To optimize pile spacing of SPR foundation system related to its stability, by using numerical model Plaxis 3-D Foundation software.

ii. To conduct a sensitivity analysis of stability of the SPR foundation system with optimum pile spacing, based on different parameter (φ, C, γ), pile length, ground water level fluctuation, peat layer thickness and eccentric load.

iii. To verify stability of the SPR foundation system by using full scale model related to immediate settlement.

iv. To develop design chart for the SPR foundation system.

1.5 Scopes and Limitations

This research focused on experimental research and verify the results accordingly.

i. Numerical Modelling of SPR foundation system on peat for static load by using Plaxis 3-D Foundation software. Typical model was concrete slab with the thickness of 0.15 m and outer diameter of steel galvanized pipe as pile of 0.32 m. For optimizing pile spacing, the concrete slab model size was 7.0 m x 7.0 m, and pile length was 3.0 m. While for simulations, the concrete slab model size was 3.0 m x 3.0 m. Different parameters were used for simuation and pipe length were 1.0 m, 2.0 m and 3.0 m. The different parameters used for the simulation were pile length, internal friction angle $\boldsymbol{\varphi}$, cohesion C, unit weight $\boldsymbol{\gamma}$, ground water level fluctuation, peat layer thickness and slope of peat layer.

ii. Full Scale Model Testing of selected SPR foundation system on peat for static load at REPEATS (Research on Peat Station) area, Parit Nipah Darat, Johor, Malaysia. The concrete slab model size was 3.0 m x 3.0 m, pile length 3.0 m and outer diameter 0.32 m. Static load varied from 20 kN to 160 kN with the increment of 20 kN. The load acted on the centre of concrete slab, with the step of loading, unloading, reloading, remain, unloading and final rebound.

1.6 Significant Knowledge Contributions

After conducting this research, some knowledge contributions were found as follows.

i. There is an optimum pile spacing of SPR in order to achieve minimum settlement. With the pile length of 3.0 m, outer diameter 0.32 m and concrete slab thickness of 0.15 m, the optimum pile spacing is 1.0 m.

ii. Conducting erection of the pile on peat during the rainy season turns out to be technically unprofitable. It is caused the ground water level is very high, the bearing capacity at the ground level is to be very low and therefore the verticality of the pile being erected is difficult to be maintained, The use of wooden pattern for erecting the pile is very effective to assist adjusting verticality of the pile and to ensure the precision of piling at the specified point.

iii. Deduction of reading duration for vertical movements by up to 50% on the loading test of full scale model of SPR on peat, shows that the reading results do not significantly differ from the reading results with full duration based on ASTM D 1143 - 81, so it can reduce the duration of the loading test. However, this step is not fulfil the standard of test procedure.

iv. A chart for basic step to design SPR has been developed. This chart is limited to typical of SPR foundation system, with 0.15 m thickness of concrete slab, pile spacing of 1,0 m, with the dimensionless L/D of 4, 8 and 12, and thickness of peat layer is 3.0 m to 10.0 m.

1.7 Outline of Thesis

Short explanation of this thesis which contains six chapters is conceived as follows:

Chapter 1 : Background in general, that peat is known a problematic soil, difficulties to build a construction on it, therefore the needs to conduct this research related to develop a foundation system, problem statements, aims of the research, objectives of the research, and scope and limitation.

Chapter 2 : Literatures review of peat, distribution of peatland, settlement of peat, construction method on peat, suitability to apply foundation system on peat, especially for raft foundation, piled raft foundation, chicken claw foundation system, nailed slab foundation system, previous researches to solve soft soil problem, modelling in geotechnics, full scale model and Plaxis 3-D Application Software for numerical modelling.

Chapter 3 : Methodology to conduct the entire works of this research project, mainly regarding to set-up and explore numerical modelling and full scale model testing.

Chapter 4 : Data analysis and results, related to numerical modelling, presents of the documented whole works, from the desk works, project site and material selection, numerical modelling for pile spacing optimization, simulation with different parameters and conditions, compared to other previous methods numerically and discussed the results.

Chapter 5 : Data analysis and results, related to full scale model testing, presents of the documented whole works implementation of full scale model construction, loading test and discussed the results.

Chapter 6 : Conclusions and recommendations, highlight the results of this research and suggests recommendation for future research projects.

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