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Behavior of Piled Raft Foundation in Soft Clay Layer with Geo-Foam Application

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Abstract

Piled raft system proves to be more effective on such problematic soft soil conditions. It takes the high vertical load and used to bring the settlement, differential settlement and tilting of structure within the permissible limit. Piled raft system proves to be cost effective than the conventional pile foundation system. Piled raft foundation accounts for complex soil-structure interaction, which needs interaction between structural engineer and geotechnical engineer. Geo-foam application is introduced below the footing to enhance floating resistance. The performance behavior of piled raft foundation in clayey soil and layered soil is carried out using laboratory experimental and then verified by 2D PLAXIS. There is a significant relationship between the decreases in settlement of the piled raft due to hydrostatic uplift.

Keywords
behavior; piled raft foundation; soft clay

I. Introduction

The raft foundation is a foundation system that include three elements: piles, raft and soil. Its design procedure differs from the traditional methods for the design of foundation systems. Usually, the loads are assumed to be carried either by the raft or by the piles. More exactly, the design of piled raft should take into consideration the actual load share between the piles and the raft. The reduction in uniform and differential deformations, increase in stability of foundation, reduction in number of piles compared to pile foundation and reduction in bending stress for the raft are considered as the major advantage of using a pile raft foundation. Tom and Sindhu (2016) conducted experimental and numerical models to compare the load-settlement response of raft and piled raft. At the same settlement value, the load causing this settlement in piled raft case is higher than in the case of raft. The investigated the best piled raft configuration and the settlement ratio showing that the settlement ratio with increasing the number of piles.

Due to the high shear force and bending moment, which generated in traditional piled raft system, Wong., et al. (2000) suggested unconnected piled raft system. In this case, the piles disconnected from the raft and considered it as soil reinforcement to increase the soil bearing capacity. The gap between the raft and pile can be filled with a cushion of structural material. Liang., et al. (2003) developed the concept of piled raft to new system called composite piled raft system, using short pile to strength the shallow soft soil, long pile to reduce the settlement and cushion to redistribute the stress to subsoil. Sharma., et al. (20150 studied the effect of cushion on composite piled that the short piles made of flexible materials were used to strengthen the shallow soft soil, while the long piles made of relatively rigid materials were used to reduce the settlements and the cushion beneath the raft was used to redistribute and adjust the stress ratio of piles to subsoil. El-Gendy et. al. (2018), determined unconnected piled raft foundation with EPS as cushion (EPS-UCPR) provides much better alternative for a connected piled raft foundation, especially under dynamic load effect. Solanki and Sorte (2016) overviewed the connected and unconnected piled raft foundations. The maximum lateral load in the connected system occurs at pile head and then decreases along the length of the pile, however, when unconnected system is provided, the location of maximum axial load is shifted downwards to a certain length belthe pile head. Situmorang et.al. (2109) carried out a lateral loading test to the nailed slab, a pavement method that uses a pile as a support plate for pavement. This method can be applied to land that has a lot of soft soil, with a certain depth limit. A lateral loading was applied as a result of braking the vehicle. The results showed that there was an effect due to lateral loading on the decrease in pavement. where the road pavement decreases when lateral loading is applied. Khan (2018) conducted experimentl testing that shear test results on geofoam monoblocks showed that the increase in density results in an increase in the material cohesion, which is associated with a decrease in the internal friction angle. Most of the interface resistance was found to develop at small displacements. For geofoam–PVC interface, both the adhesion and angle of interface friction slightly increased with the increase in geofoam density. The measured geofoam–sand interface strength revealed a consistent increase in the angle of interface friction as the density of geofoam material increased.

The more rigorous methods of piled raft analysis began with the contributions of Kuwabara (1989), and extended by Poulos (2003) with further contributions from Clancy (2003), Ta and Small (1996) and Zhang and Small (2000). Notably, Prakoso and Kulhawy (2001) used the PLAXIS software in the 2-D analysis of piled raft foundations.

Here is an illustration of the comparison of the use pile under foundation with the conventional box culvert on soft soil. where, on conventional pavement is not resistant to loading and easily damaged because the soil is essentially soft soil, while the pile under slab system with geo-foam application beneath for reducing settlement is fixed resistant to loading because there is a pile as a support slab so that it can be increased the strength of the slab, the illustration as shown in Figure 1.

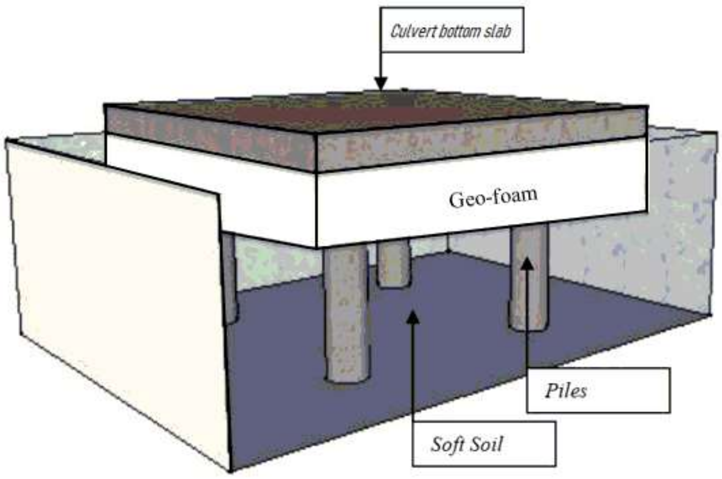


Figure 1. *Illustration Raft Foundation Model*

Piled Raft Foundation

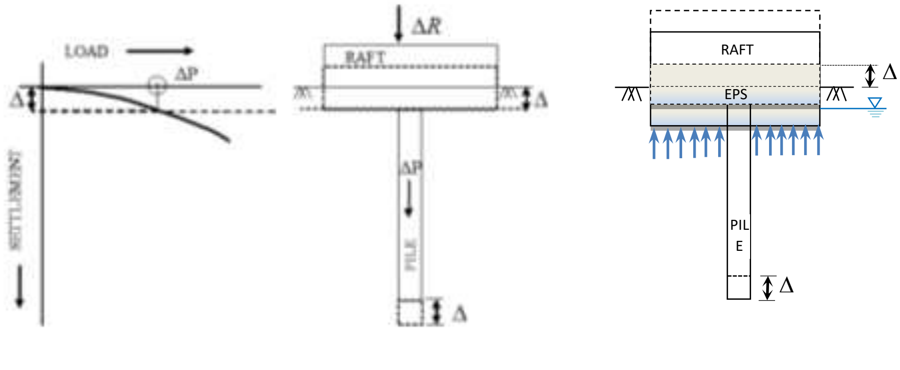
Time effects in soil structure analysis was first considered by Wood et al. (1975) on the basis of 1D Terzaghi‟s model of consolidation by virtue of finite difference method. Then the time dependent response of the piled-raft-soil interaction system under vertical loading was analysed by Cheng et al. (2004) using 2D FEM based on Biot's theory of consolidation.

The linear creep model was incorporated by Viladkar et al. (1993) into FEM in interaction analysis and it is found that bending moment, contact pressure and differential settlement vary with time. A simplified rheologic element model was used by Xia (1994) to evaluate the distribution of raft contact pressure on visco-elasto plastic soil. A three dimensional FEM is proposed by An et al. (2001) to predict the creep settlement of foundation on elasto visco plastic soil. The interaction analysis considering time effects induced by both viscosity and consolidation was conducted by Wang et al. (2001) in which a closed form fundamental solution of stresses of saturated visco elastic soil underlying raft under vertical loading is derived. However, a critical study of Poulos (2011) showed that results from such models shows large scatter from each other. The analyses of piled rafts using finite element method to investigate the performance of piled rafts have been done. This method can yield good results for piled raft analyses. The literature survey on piled raft foundation design discussed above shows that, most of the previously formulated design cases overlook time-dependency of soil deformation and may give rise to inaccuracy in evaluation of interaction behaviour and unreliability in design of structures. Till date no approach has been made to formulate a relatively simple and accurate method for designing a piled raft foundation in consolidating foundation bed. Actual site conditions are to some extent simulated as isotropic. Settlement oriented design methodologies are also limited. According to (Razanajatovo, 2020) to the soil engineer, the word "soil" means a material which is used in any kind of civil engineering job, either as foundation material to support the load exerted by structures, or as construction material itself, as in the case of highway constructions. However, the best growth was obtained in the mixture of top-soil and saw dusts medium (Saani, 2020). Such mining mechanisms can lead to different problems such as polluting the soil, water, and air of the mining sites, recycling of hazardous metals/chemicals through the food chain, falling adjacent residences to different health risks (Gebru, 2020).

For a raft, proposed design approach starts with evaluation determination of its bearing capacity from both the shear failure criteria and permissible settlement limits for existing subsoil profile. The safe load for the raft is finalized following the most critical condition of the above two criteria. Now from the routine pile load tests the load that could be safely taken by the pile is evaluated through load settlement curves. In the presence of geo-foam is functioned as reducing settlement if water table persist between top and bottom part of EPS. Thus for a chosen settlement of' 'Δ', if raft carries a load, ΔR and pile carries a load, ΔP, then the capacity of piled raft foundation, ΔPR can be expressed as

(1) $\Delta_{PR} = \Delta_R + \Delta_P - \Delta_{GF}$

Here settlement 'Δ' takes care of both immediate and consolidation settlement of the subsoil profile. Figure 2 illustrates the schematic presentation of pile load test result and piled raft load sharing.



(a) (b) (c)

Figure 2. *Schematic Diagram (a) Load Settlement Curve of Routine Pile Load Test; (b) Load Taken by Raft and Pile at Chosen Settlement, Δ, from Pile Load test Curve; (c) Hydrostatic Up-lift Provided by Geofoam EPS*

II. Research Methods

The equipment used is a thin steel plate formed in the form of a box with dimensions of 2 x 1.5 x 1.5 m, where a raft foundation with geo-foam prototype is placed inside the box, which is connected to a device that is all connected to the computer. The research will be conducted in the Unissula Soil Mechanics Laboratory. The test procedure suggested by ASTM D [22] was employed. The clay was consolidated by applying a static vertical load gradually on a steel plate to get soil bearing capacities of 2.5, 5.0, 7.5, 10.0 and 12.5 kN, under time sub-step of 30 seconds up to last sub-step of 150 seconds. The measurement of actual displacement was recorded by strain gauge automatic reading.

Numerical Modelling

In this research, the finite element analysis of a piled raft system is performed by PLAXIS 2D software. The behavior of a strip foundation is analyzed under dynamic loading of constant amplitude and varying frequency. Piles as well as the raft are modeled as elastic material. The clay and EPS are modeled with elastic ideally plastic constitutive model that obey the Mohr-Coulomb yield criteria. Due to consideration the soil is over consolidated clay, a perfectly-plastic constitutive model used with a fixed yield surface without account the stress -time effect.

Plane strain 15-noded triangular isoperimetric elements are used to represent the soil. The boundaries of the finite element model, both in horizontal and vertical directions, are set as far as 5-times the raft width, to minimize the boundary effect. To investigate the excess pore water pressure, build up under machine foundation due to harmonic excitation, saturated soil conditions with water table coinciding with the ground surface is presumed. All displacements are restricted at the base of finite element model, whereas horizontal fixities are applied at the extreme vertical side boundaries. Absorbent boundaries are applied along vertical and horizontal boundaries to avoid the reflection of stress waves back to the soil domain. To ensure the validity of the proposed numerical model for static analysis of piled raft, an experimental data set was selected for the verification under static loading. Regarding the soil technical report for this area tested by consolidated undrained triaxial.

Each load step on the footing is keep up for around 15 minutes in all the case studies until the settlement stops relatively. An elastic material model is assumed for the plate in the analysis, whereas the Mohr-Coulomb constitutive model is adopted for clay and EPS. The underlying soil dimension are 20.0 x 20.0 m and 10.0 m deep, as shown in Figure 3.

Results of the finite element analysis for the maximum cases of settlement obtained by PLAXIS 2D and compared to the experimental results under different position of ground water level (GWL) for the following case study:

a) Case 1: GWL far below the piles
b) Case 2: GWL on the EPS base
c) Case 3: GWL on the top of EPS

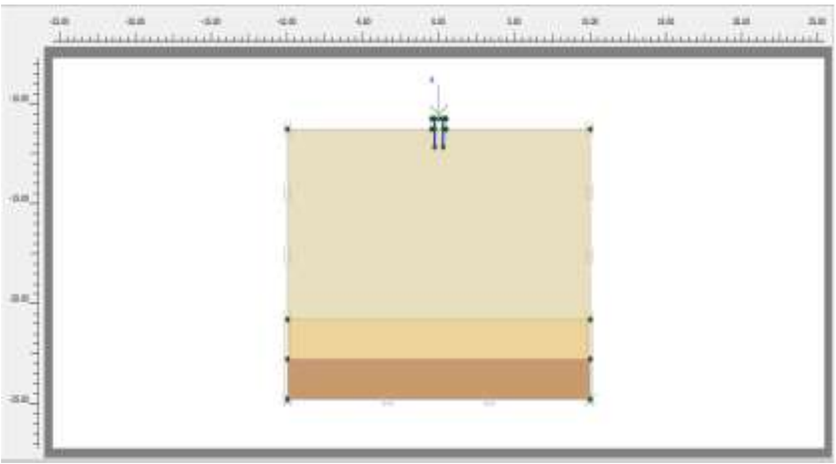


Figure 3. *Model for PLAXIS*

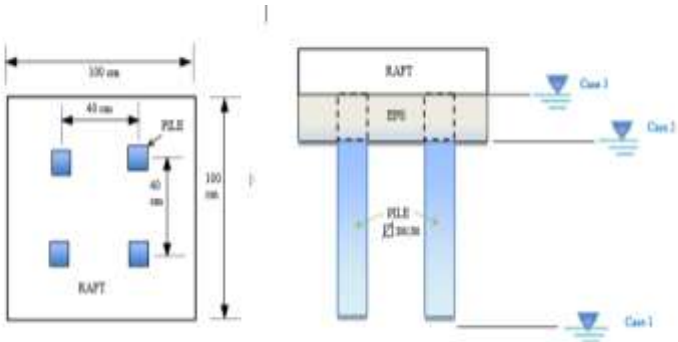


Figure 4. *Adopted Piled-Raft Geometry*

III. Discussion

These results of the experimental study (Figure 1) show that geofoam application is very influential on the deflection of the pile, where the GWL position is in between the height of geofoam. Bare piled raft foundation under the ultimate static load of 3.00 kN produces a vertical deformation of 11.5 cm, but for the ultimate static load of 3.75 kN, the deformation increases significntly by 69 mm or 6 times, as reached 80.5 mm. By using geofoam application, the raft in the dry conditions (Case 1) deformed, □C1, of 6.0 cm under 10 kN loading. The presence of hydrostatic uplift significantly decreases the settlement by 50% or about 3.0 cm with the condition of GWL on the EPS base (Case 2). The pile raft foundation with EPS in fully wet condition (Case 3) shows slightly reducing in the settlement by 20% of □C3 2.5 cm. By comparison the EPS with 50 cm and 90 cm thick, it can be affected on the soil layer charactersitic and uplift response. The thickness of EPS is slightly not significantly difference in the foundation behaviour of reducing settlement. Figure 5 below shows the plotting of load-displacement response of the piled raft foundation with

50cm thick EPS under condition of above GWL (Case 2). The result shows the FEM analysis using Plaxis is well validated against the experimental testing response.

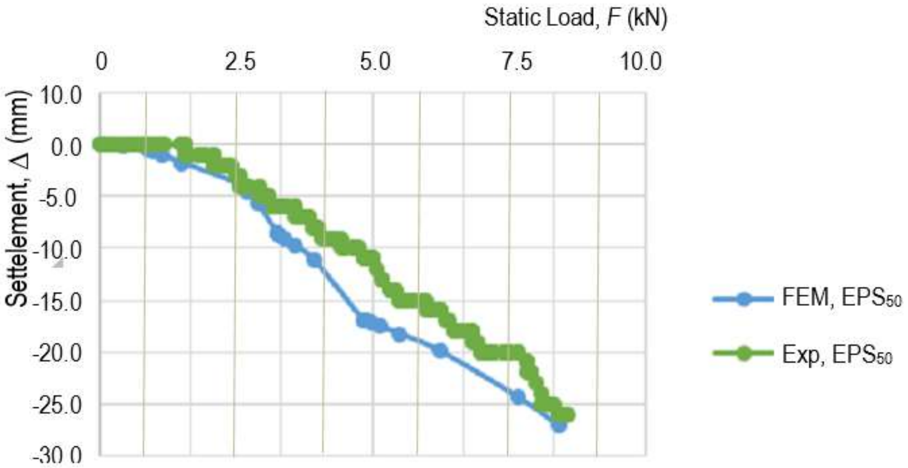
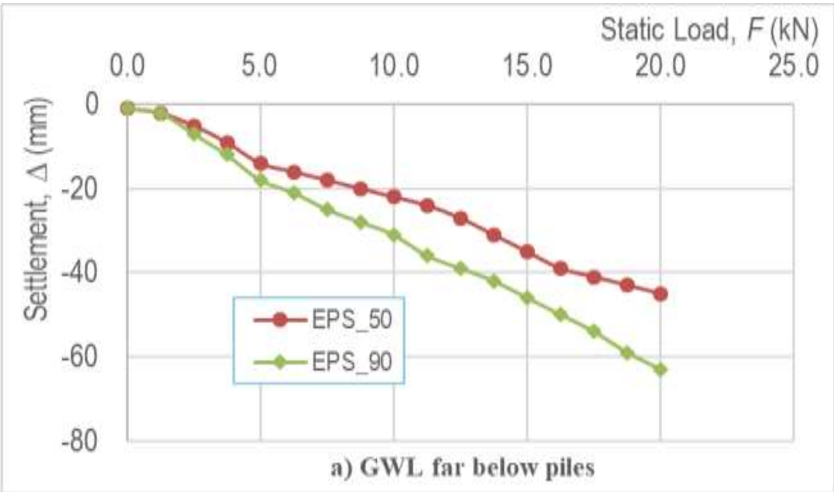


Figure 5. *Load-displacement – GWL on the 50cm Thick EPS Base*

Displacements of Piled Raft Foundation under Static Load

Analysis for 1.0 m piled raft foundation application was carried out at the groundwater level of -1.0 m and -3.0 m using Model 1. The vertical displacements obtained as a result of the analysis were shown in Figure 6. It was seen from the figure that the deformation decreases with the raising of the ground water level. Vertical displacements at the GWL of -3.0 were determined between 42 mm and 62 mm. Vertical displacements at the GWL of -1.0 were determined between 28 mm and 37 mm. Settlement at the GWL above EPS were determined between 26 mm and 28 mm. At both the GWL, the lowest displacement value found in Model 2 and 3 and the highest displacement value was observed in Model 1.



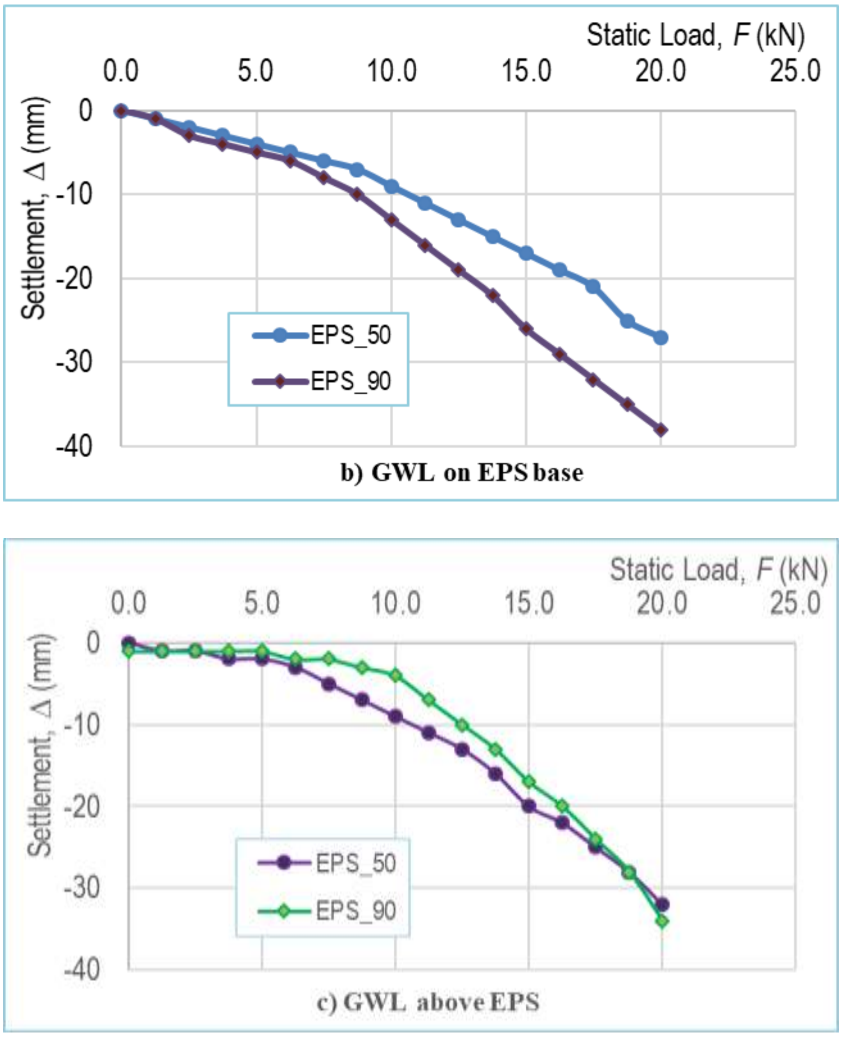


Figure 6. *Plaxis Modelling of Piled Raft Foundation*

IV. Conclusion

From the review of literature on and analysis of pile raft foundation using cuishoned geofoam, the following conclusions are drawn:

1. The results of the above research, the addition of geofoam will result in the reduction of settlement of piled raft significantly.
2. For the static load 20 kN, there is a settlement addition 4.0 mm, this is likely because the friction of pile does not function properly.
3. Proving and analyzing that there is a significant relationship between the decrease in settlement of the piled raft due to hydrostatic uplift.
4. From the results of the pile deformation analysis in dry condition concluded that there is a gap between the pile and the ground which can reduce the bearing capacity of pile friction with no supported action of the EPS
5. Analyzes the behavior of the pile raft foundation system due to the influence of vertical loads, varying ground water level and geofoam thickness.

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