Environmentally friendly foundation for the sustainability development of infrastructures in swamp area

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Abstract. Infrastructure development in Indonesia, especially, has moved into swamp areas. Swamps are usually associated with saturated clay and peat soils that are soft and highly compressible. The low bearing capacity and the high excessive settlement are usually solved with piles and pre-consolidation. The remove and replace method with new and better material is sometimes also used. Those methods have really changed the characteristics of the soils and are not friendly to the environment. Some foundation constructions for soft soils have also been proposed, but, in their application, there are technical constraints which are difficult to overcome. Research on the light foundation in soft soils has been carried out to support the light load with a satisfactory settlement. Further studies are carried out to obtain a foundation construction that can support larger loads, but which are still friendly to the swamp environment. The bearing capacity and settlement of foundation is plotted in the graph to formulate the satisfaction indicators of the foundation. In addition, the simple formulation procedures for practical application requirements will be also provided since it is the target of this research for general applications. This foundation is very useful for the sustainability of infrastructure developments that is environmentally friendly.

1. Introduction

In many islands in Indonesia there are many difficult soils, including very soft clay and highly organic peat soils with varying thicknesses as a result of weathering of vegetation [1]. Swamps are strongly associated with saturated clay and/or peat soils that are usually very soft to soft and highly compressible. The fast development of infrastructures in Indonesia has moved into swamp areas (figure 1). The low bearing capacity of the soils and the high excessive settlement are usually solved with long piles and pre-consolidation constructions. However, such constructions are generally very expensive and not a good choice for light buildings or constructions. Many buildings on soft soils have experience failure, ranging from minor to severe damage or collapse. On the other hand, the civil engineer’s responsibility has increased over the decades in terms of functional and safety after the construction has been submitted to the building owner [2].
Figure 1. Road development in very soft soil [3].

The other very popular alternative method to make any constructions in soft soil is 'remove and replace'. This method is done by removing bad soil and replacing it with new and better material from another site. This method has really changed the characteristics of the soil, but is not friendly to the environment. Sometimes synthetic materials for separating the original and new soil are used (figure 2). This method also can be used for mitigation of expansive soils where the expansive soil with its negative effects is removed and then replaced with non-expansive soil [4].

Figure 2. Remove and replace.

Some special constructions for soft soils have also been proposed, but there are technical constraints in the application which are difficult to overcome. Several construction failure case histories in soft soil in Indonesia have been summarized in [5]. The improvement of those kinds of soils using vertical drain and vacuum equipment has been discussed in [6].

This paper presents preliminary results of research on the light foundation in soft soils. The light foundation here means that the foundation's bearing capacity is sufficient to support the light load of the upper structures with a satisfactory settlement. Further studies are carried out to obtain a foundation construction that can support larger loads, but are still friendly to the swamp environment. This foundation will be very useful for the sustainability of infrastructure developments that is environmentally friendly in swamp areas, especially for light load construction such as the neighborhood passways. Further, the simple formulation procedures for practical application requirements are also provided.

The structures which can be supported by this foundation must be categorized lightweight constructions, such as neighborhood pathways, single floor houses and other simple facilities. In the
application of the foundation, the soil investigation on-site must be carried out prior to the design. The essential laboratory test must, at least, give information on the undrained shear strength of the soil.

2. Laboratory experiment
In order to gain the important behavior information of the purposed foundation, a series of laboratory tests of foundations were carried out on four different diameters of foundation models (figure 3). The foundation models are made of PVC pipe with closed pile cap so that there is air trapped inside the foundations. Initially, each foundation was embedded in the soil and left for a week before load tests were carried out. The foundation models then were loaded on the tip. The loads were recorded for every 0.7mm of tip settlement. The load test stopped after 30mm of settlement for every model.

![Figure 3. Detail of the laboratory test (unit in cm).](image)

The soil for laboratory test is made up clay particles passed through sieve no 200. The soil was put in the transparent 40cm x 60m box. The soil samples were then tested to obtain the basic engineering properties, as shown in table 1. The compressive strength test (UCS) according to the ASTM D2165 was performed to the soil as well. The undrained shear strength (Su) from the UCS test was 0.03kN/m², which is very small. These values indicate that the soil can be categorized to very soft soil. The water content of the soil after the test was 98.8%, which is larger that its liquid limit. This type of soil is recognized as an ultra-soft soil [7] in which the liquidity index is above unity and the soil strength is very low. This soil also may still be under process self-weight consolidation.

| Table 1. Soil properties. |
|----------------------------|
| Type of parameter       | Value | Unit   |
| Specific gravity        | 2.50  |        |
| Unit volume             | 16.3  | kN/m³  |
| Liquid limit            | 52.9  | %      |
| Plastic limit           | 31.1  | %      |
| Plastic Index           | 21.8  | %      |
3. Test results
In the laboratory, the foundations were loaded axially for several series. During the test, the applied load and settlement on the top of foundation were recorded. The applied load and settlement on the each foundation was then plotted in the graph. For the foundation model with the diameter 1/2", the load settlement graph is shown in figure 4. It can be seen that the load is increasing gradually with the settlement of the foundation. The load then jumped suddenly at the settlement between 15 to 20mm.

![Load - settlement for diameter 1/2".](image)

The load-settlement graphs for the others foundation model were also plotted, as shown in figures 5, 6 and 7 for the model size of 1", 2" and 2.5", respectively. Almost similar load settlement relationships are shown from those figures where the applied loads are increased with the settlement. The maximum load of each graph is then taken for settlement of 20 mm where the jump load is begun.

| Model type: | 1/2" | 1" | 2" | 2.5" |
|-------------|------|----|----|-----|
| Dia. (cm)   | 1.27 | 2.54 | 5.08 | 6.35 |
| Length (cm) | 30   | 30  | 30  | 30  |
| Skin Area (cm²) | 59.8 | 119.7 | 239.4 | 299.2 |
| Air (kg)    | 0.02 | 0.08 | 0.30 | 0.48 |
| Load (kg)   | 0.25 | 0.60 | 1.02 | 1.18 |
| P<sub>net</sub> (kg) | 0.23 | 0.52 | 0.72 | 0.70 |
| P<sub>net</sub>/Dia. | 0.18 | 0.21 | 0.14 | 0.11 |

Table 2. Test results summary.
In order to have relation between the dimension of the model with the bearing capacity, the netto applied load ($P_{\text{net}}$) is calculated by the maximum load minus the air trapped. Each netto load is then divided by the diameter of the model as shown in table 2. The relation of the diameter of the model and the maximum load is then plotted in figure 8. It can be seen that it has quite linear relationship between maximum load and the diameter of the foundation. However, bigger diameter will linearly increase the maximum load, but it reduces the load diameter ratio. The load-diameter ratio is very important in applying this foundation on-site, especially in determining the number of piles for each unit area of the foundation.

**Figure 5.** Load - settlement for diameter 1".

**Figure 6.** Load - settlement for diameter 2".
4. Conclusions
The need of infrastructure development in Indonesia has moved into swamp areas which may consist of saturated clay and/or peat soils that are very soft and highly compressible. The low bearing capacity and the high excessive settlement of soil need engineering solution for better constructions. The available methods may sometimes solve the problems, but usually are not friendly to the environment. This research proposes a friendly environmental solution in terms of the light foundation to be applied in soft soils. The test results show that the foundations can have bearing capacity which may be sufficient to support the light load with a satisfactory settlement. The maximum loads and settlements of foundations are plotted in the graph to see the satisfaction indicators of the foundation. It is preliminary concluded that the bigger diameter of the foundation model gives higher support, but decreases linearly in terms of load-diameter ratio. Further studies to obtain a bearing capacity formulation of foundation for supporting larger loads are still ongoing. The preliminary results of this study are very useful for future environmentally friendly infrastructure developments.
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