The effect of skirt footings for road settlement on peat soil

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Abstract. The construction of peat soils is a big challenge in the construction world coupled with the very special nature of peat soil. Road construction on peat soil is a major obstacle because the deformation that occurs on the road is so large. Skirt footings are one of the shallow foundations commonly used for building offshore oil refineries. With the principle of making soil that has a low bearing capacity into a single unit to be able to withstand the burden on it. Skirt footings are placed under the embankment with a parallel position stretching to the width of the road plan. Among the skirt, footings are connected with steel straps so that during the loading process the skirt footings decrease can be controlled. The purpose of this research is to make skirt footings a shallow foundation under a road built on peat soil. Tests were also carried out on two models of shallow foundation to determine the effect produced by skirt footings on the soil. The other two types of shallow foundation models are un-skirted footings and mini piles. Comparison of the results of tests between skirt footings with un-skirted footings, it can be concluded that skirts under circular footings act as a buffer against the effective stress of the soil. While from the comparison of test results between skirt footings with mini piles, it can be concluded that circular footings play a role in reducing the effect of the differential settlement on the soil. The results of this study are that skirt footing can withstand differential settlement patterns and able to increase road stability.

1. Introduction

The Republic of Indonesia is a country located on the equator with a tropical climate, consisting of 17,504 islands with a total area of 5,455,675 km². Peat in Indonesia is spread over 8 provinces with a total area of 14.9 million hectares of peat soil. Indonesia contributes 8% of total global peat soil. Borneo island has a land area of 4.8 million hectares of peat [8]. The construction on the territory of the peat becomes quite a difficult challenge due to the nature of peat which has a high-value permeability along with major consolidation that took place very quickly. Several solutions can be applied in the handling of existing peat soil such as excavation, layer change, transferring, or pre-compression on peat soils. The use of peat soil improvement methods has grown rapidly over the past decade, starting from the use of geotextile, geogrid, to changing the composition of peat soil composition by mixing certain materials aimed at reducing the water content in peat soil pores.
Skirt Foundation or skirt footings are known to increase bearing capacity on shallow foundations on soils that have the low bearing capacity. Skirt footings are commonly used in offshore work areas. Circular skirt footings or bucket foundations or suction caissons are commonly used in the offshore oil and gas industry [2-3]. Skirts can increase the capacity of additional moments, which increases due to the suction produced by the skirt during loading. Skirt footings work system is to make the soil as a unit to channel the burden of the structure above it to the stronger ground and increase the ability to withstand overturning loads [4-6].

Pre-construction methods on peat soil include work methods with replacing peat, replacing peat methods on-site (in situ). The pre-loading method is a method that aims to accelerate the process of primary consolidation in peat soils and also to create conditions for Over-Consolidation Ratio (OCR) on peat soils. The peat soil matrix will change under load which will reduce the permeability and compressibility with the resultant value of the shear strength increasing [1]. According to the construction and building guidelines by public work service regarding the Planning for Road Embankment Construction on Peat, the Pre-Loading Method has two main functions against decrease including:

1. Adding additional weight to minimize primary degradation during life service.
2. Adding additional weight to minimize secondary settlement during life service.

2. Methods

2.1. Material properties
Material properties come from the drill log soil data of the Bukit Rawi area, Central Borneo. The drill log digging to a depth of 18 meters, but the data used in PLAXIS only the majority of soil properties. These are sand until the depth of 2 meters, peat soil until the depth of 10 meters, and the deep sand until 14 meters. The peat soil in the drill log sampling location has fibrous peat criteria with the value of cohesion is 73.89 kN/m² and the angle of friction’s value is 11.42°.

2.2. PLAXIS modeling
The research uses assistance from PLAXIS 2D software with Soft Soil Creep modeling. To find out the effect of skirt footings on the deformation that occurs, axisymmetric modeling is used in this study. Axisymmetry modeling aims to take into account the structural forces that occur at the foundation. The calculation of axisymmetric modeling is based on the existing load and not based on the displacement of forces. There are 16 variations of skirt footings with variations in size (D) and length (L) skirt footings. The variation between length (L) and diameter (D) used are (L / D) 0.25; 0.33; 0.5; 0.5; 0.67; 0.75; 1; 1; 1; 1.33; 1.5; 2; 2; 3; 4. The embankment load is changed to a static load by multiplying the
height of the embankment by the density of the soil. To help stabilize it better, a meter soil deep down under the embankment is raised in OCR value so that the foundation can work optimally withstand the load. An embankment test is carried out to determine the behavior of the soil in bearing the load, the test using a plane-strain model with all the same soil parameters. The results obtained are the amount of soil deformation that occurs and the stability factor of the embankment.

![Figure 3. Fieldwork of embankment.](image)

| Table 1. The soil condition calculation. |
|-----------------------------------------|
| U 5 days (mm)                           |
| 137                                     |
| U 365 days (mm)                         |
| 159                                     |
| SF                                      |
| 1,372                                   |

As a comparison to the function of the length of skirt footings (L) and skirt footings diameters (D), an experiment was conducted with the other type of shallow foundation. The other shallow foundations are un-skirted footings and mini pile models. To make sure that the result of all type shallow foundations can be compared properly, several adjustments are used such as, the model un-skirted footings using the diameter (D) equal to the skirt footings and mini pile models use length (L) same as the skirt footings.

1. Consolidation of 5 days, short-term consolidation.
2. Consolidation of 365 days, to see the behavior of embankment in a year.
3. Consolidation of minimum pore pressure.
4. Calculate the stability value of the embankment.

3. Results and discussion

3.1 Skirt footings
Skirt footings were tested with 4 variations in length (L) and 4 variations in diameter (D). It aims to see the effect of the length and diameter of the skirt footings on the deformation that occurs.
Table 2. The result of skirt footings fieldwork.

| D (m) | L (m) | L/D | U 5 days (mm) | U 365 days (mm) | Average U 5 days (mm) | Average U 365 days (mm) | SF |
|-------|-------|-----|---------------|----------------|----------------------|------------------------|----|
| 1     | 1     | 1   | 190           | 212            | 111,5                | 177,5                  | 2.883 |
|       | 2     | 2   | 70            | 107            |                      |                        | 2.921 |
|       | 3     | 3   | 83            | 162            |                      |                        | 2.881 |
|       | 4     | 4   | 103           | 229            |                      |                        | 2.883 |
| 2     | 1     | 0.5 | 189           | 204            | 95,75                | 122,5                  | 2.835 |
|       | 2     | 1   | 60            | 77             |                      |                        | 2.829 |
|       | 3     | 1.5 | 64            | 92             |                      |                        | 2.834 |
|       | 4     | 2   | 70            | 117            |                      |                        | 2.835 |
| 3     | 1     | 0.33| 208           | 233            | 102,75               | 143,25                 | 2.863 |
|       | 2     | 0.66| 64            | 91             |                      |                        | 2.864 |
|       | 3     | 1   | 67            | 110            |                      |                        | 2.859 |
|       | 4     | 1.33| 72            | 139            |                      |                        | 2.861 |
| 4     | 1     | 0.25| 186           | 201            | 91                   | 108,75                 | 2.874 |
|       | 2     | 0.5 | 59            | 72             |                      |                        | 2.869 |
|       | 3     | 0.75| 59            | 77             |                      |                        | 2.873 |
|       | 4     | 1   | 60            | 85             |                      |                        | 2.877 |

Table 2. shows a variety of results from skirt footings tests. The variations in the value of soil deformation resulted from each diameter of skirt footings, in general, the results obtained are the bigger the diameter of the skirt footings (D) used, the smaller the soil deformation that occurs, it is directly proportional to the fact that the smaller comparison value of the long skirt footings to the diameter of the skirt footings (L / D) then deformation results obtained are also getting smaller. If the parameters used are grouping by diameter (D) then the deformation of the skirt footings chart obtained with a different length. From the graph with the same diameter (D), it can be seen that the pattern is almost the same but looks different if the wider diameter (D) skirt footings are used, the deformation that occurs tends to be smaller. From the graph, it is found that from 4 different diameter types (D), it shows that the deformation of the soil in skirt footings with the length (L) of 2 meters is the smallest, namely 60 mm at D 2 meters and 59 mm at D 4 meters.
When seen from another viewpoint the length of the skirt footings (L), there are 4 variations in the length of the skirt footings, the deformation that occurs also changes. The length of the skirt footings influences reducing the deformation of the soil that occurs. From the 4 types of skirt footings with different diameters (D), it can be seen that skirt footings with a diameter of 4 meters have a small deformation when viewed from each different length of skirt footings. At 365 days the deformation is much more noticeable pattern changes than the deformation of 5 days at each skirt footings (L), the most obvious change is the deformation that occurs at D 1 meter with 4 meters L. In the consolidation of 5 days, the deformation was 103 mm while the consolidation 365 was deformed as far as 229 mm.
3.2 Un-skirted footings
To determine the effect of the length of skirt footings (L) on soil deformation, an un-skirted footings test was performed. Equation tests performed on un-skirted footings with skirt footings are using the same diameter (D) and the same test stages. The only difference lies in the work area of un-skirted footings that do not use the skirt wall under the circular footing.

Table 3. Un-skirted footings test result.

| D (m) | U 5 days (mm) | U 365 days (mm) | SF    |
|-------|---------------|-----------------|-------|
| 1     | 190           | 200             | 2.886 |
| 2     | 203           | 213             | 2.835 |
Figure 14 and figure 15 show the difference deformation at consolidation 365 days and consolidation 5 days, it means the skirt wall under circular footings has a major effect in reducing the deformations. There are big gaps between these two shallow foundations. When the diameter is 1 meter, the difference quite small. The biggest difference at deformation measure from both type of footings lies in diameter (D) 2 meters where the deformation decrease almost 100 mm for both of consolidation.

Figure 16 and figure 17 show the effective stress at both types of footings. The effective stress indicates the deformations of soil, at un-skirted footings the effective stress value far less than at skirts footings. Stress that occurs in the soil directly leads to the embankment without being blocked by the foundation. It means the capability of un-skirted footings to reduce the deformations value not as good as skirt footings (soil deformations tends bigger in un-skirted footings).

![Figure 14](image1.png)  ![Figure 15](image2.png)

**Figure 14.** Skirted vs un-skirted footings 365 days.  **Figure 15.** Skirted vs un-skirted footings 5 days.

![Figure 16](image3.png)  ![Figure 17](image4.png)

**Figure 16.** Effective stress at skirt footings.  **Figure 17.** Effective stress at un-skirted footings.
3.3 Mini pile
The method of soil improvement of peat soils for road embankment construction was issued by the Public Works Department with the number Pd T-11-2005-B, stabilization using cement and wooden pile. To compare the results of the skirt footings method with wooden piling and cement methods from the Public Works Department, wooden piling was replaced with the mini pile to adjust to current field conditions, and the cement was not used as a stabilizing material but was replaced by the consolidation ratio (OCR) of the original soil increased. The length of the mini pile used in the study matches the length of the skirt footings (L) to see the effect of the diameter of the skirt footings (D) on the possible soil deformation. The distance between the mini piles also follows the distance rules on the skirt footings, which are 1 meter. Mini pile calculation steps are the same as skirt footings calculation steps, the difference lies in the mini pile that does not have circular footings.

![Figure 18. Fieldwork mini pile.](image)

| L (m) | U 5 days (mm) | U 365 days (mm) |
|-------|---------------|-----------------|
| 1     | 20            | 21              |
| 2     | 13            | 16              |
| 3     | 19            | 30              |
| 4     | 27            | 58              |

There is a striking difference in deformation between the two types of shallow foundations. Figure 19 and figure 20 show the deformation that occurs in the mini pile is relatively small when compared with skirt footings with an average deformation stands at 27 mm for mini pile and 107 mm for the skirt footings, but the concern is the pattern of soil subsidence occurred. From figure 21 and figure 22, shows the vertical deformation results of research using a mini pile as a shallow foundation and skirt footings, soil deformation that occurs in the mini pile are very small but it can be seen that the deformation pattern decreases unevenly on the soil (differential settlement). The vertical deformation pattern of the mini pile appears to be spread deep into all layers, on the other hand, the vertical deformation pattern of skirt footings centered on stabilizing soil. This shows the function of circular footings (D) in holding deformation fixed in one area (stabilization soil).
4th International Conference on Civil Engineering Research (ICCER 2020)
IOP Publishing
IOP Conf. Series: Materials Science and Engineering 930 (2020) 012039
doi:10.1088/1757-899X/930/1/012039

4. Conclusion

The main purpose of this research is to investigate the effect of skirt footings on differential settlement and stability which the results show the embankment stability value goes up with the help of skirt footings. The function of the skirt wall under the footings is to hold the load from the embankment and distribute evenly to the soil around the skirt. The function of circular footings is to help the settlement of the soil evenly and to place the load area around the stabilization soil.

From the tests conducted, skirt footings are better at holding loads than un-skirted footings, this can be seen from the effective stress received by the pile is bigger when the skirt footings are used than the pile using un-skirted footings. Skirt footings are also better at resisting the effects of uneven decrease (differential settlement), this is evident from the vertical deformation pattern on the skirt footings concentrating the load on an area of land that has been stabilized while on the mini pile the distribution pattern is not centered on an area of land.

Figure 19. Skirt footings vs mini pile 365 days.

Figure 20. Skirt footings vs mini pile 5 days.

Figure 21. Vertical deformations at the mini pile.

Figure 22. Vertical deformations at skirt footings.
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