Bearing capacity of circular skirted footing on clay soil

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Abstract. Footing foundation has been worldwide used in resisting light to medium load of structures. Footing’s design has to consider the bearing capacity and the settlement of soil below. This research focuses on the investigation of the effect of skirt on circular footing to improve the footing performance in resisting vertical load on clay soil. There are nine samples of circular footing tested in vertical load system in laboratory in the diameter of 75 mm, 100 mm and 150 mm with length of skirt 100 mm and 150 mm on clay by keeping the similar water content and compaction method. The results show that the skirt effectively reduces the foundation settlement on clay which is observed on similar load 1 kN. The observations on L/D ratio on similar diameter also show that the higher L/D ratio the smaller settlement. On the observations of settlement 3 mm with similar diameter show that the longer the skirt the higher load retained by footing.

1. Introduction
Foundation is the part of structure which serves exclusively to transmit load from structure on to the sub-soil. One of the causes of the building collapse is the instability of the foundation, either the foundation design or the instability of soil. As known, clay is classified as one of the problematic soils due to its low shear strength and excessive settlement. Therefore, it is necessary to improve and to investigate either on the soil or the foundation design. In order to solve these problems, a vertical plates or skirts made out of steel are attached to the footing or called skirt foundation. Wakil [1] studied the skirt circular footing to improve the bearing capacity on sandy soil. The research was performing eighteen laboratory experiments on circular footing of different diameter and skirt length. Ashraf and Wasim [2] reported that the improvement of bearing capacity is remarkable; using both partially replaced sand pile with and without confinement by skirts. Golmoghani and Rowshanzamir [3] evaluated bearing capacity of skirted footing on sand. The test results were found that using structural skirts may improve the footing bearing capacity up to 3.68 times greater than the average value of calculated ultimate bearing capacity of foundations with the same depth of skirt. Satria [4] reported that the additional of skirt on the circular footing is very effective to improve the ultimate bearing capacity on the sand soil. With the same diameter of circular footing, as the length of skirt increases, the ultimate bearing capacity increases. There are also other researches related to bearing capacity of skirted foundation in sand [5-7].
2. Method of test

To study the behavior of the effect of skirted footing on clay, six laboratory tests of skirted footing and three others without skirts were conducted on small-scale model of circular footing machined from steel plates having diameter (D) equal to 75 mm, 100 mm, 150 mm and of thickness 20 mm. The thin circumferential skirts are welded firmly and accurately around the periphery of footing, of thickness in 10 mm. Their lengths were 100 mm and 150 mm, measured after welding to footing. The skirt length (L) to the footing diameter ratio (L/D) are 1.33 (100/75), 1.00 (100/100), 0.67 (100/150), 2.00 (150/75), 1.50 (150/100), 1.00 (150/150) and three unskirted footing L/D are 0.00. The model footings have smooth face and notch at the center of top face for mounting piston to transfer the load when testing. There are two open hole drilled at the top face of footing to observe the top surface of the soil. The illustration of skirt circular footing is shown in figure 1.

![Figure 1. Skirt circular footing.](image)

Where,

- \( D \) = diameter of skirt circular footing
- \( L \) = length of skirt
- \( T_f \) = thickness of footing

The soil used in this research is clay coming from District Sukoharjo, Central of Java, Indonesia. The soil was kept in same condition of water content and compaction method in each laboratory test. The bin was made of cylinder steel, having height 500 mm and diameter 600 mm. The vertical loadings are measured by frame load testing machine with hydraulic loading machine, it has maximum load of 250 kN. Two dial gauges installed to measure the vertical displacement. Both were placed on the top face of footing. The compaction was used the hammer with 5.5 lbs (2.5 kg) weight and 12 inch (305 mm) free fall height. The set-up of loading test is shown in figure 2.

First stage is preparing and setting up the equipment and clay that comes from same location. The soil is dried on the temperature (27-30°C) and passed no. 4 sieve. Second stage is investigating the air-dried water content. Third stage is conducting the laboratory test. The value of water content for this research must be kept in same condition for all nine models laboratory test. Adding the water into the soil and mix to produce homogenous water content in all area. Then, compact the 10 layers of soil and giving 100 blows for each layer. Set the soil bin on the hydraulic loading machine and place the skirt footing with L/D = 1.33 right on center of the bin, push it until all the skirt is already inside the soil. Observe the top surface of the clay inside the skirt via two open holes on the footing. Set the two dial gauges on the left and the right position to observe the vertical displacement. Then running the hydraulic loading machine, observe and record all of the magnitude that occurred on each dial. The settlement value is shown on the two dial gauges and the load value is shown on the digital device of the hydraulic loading machine. The last is stopping the loading when the load decrease as the indication that the foundation failure. The subsequent experiment, conduct the same test as sequence before but it just replaces the footing with value L/D = 0.0 (unskirted circular footing), 1.33, 1.00, 0.67, 2.00, 1.50, 1.00.
3. Result and discussion

The research is conducted in similar water content and compaction method. The water content was investigated around 15%. This value kept for all testing model as reference. The result of the investigation shows load settlement curves for all model footing. The general result is presented in figure 3 - figure 5. The horizontal and vertical axes show the load and settlement value respectively.

![Set up of loading test](image)

**Figure 2.** Set up of loading test.

![Load-settlement for footing diameter 75 mm](image)

**Figure 3.** Load-settlement for footing diameter 75 mm.
It can be seen from figure 3 – figure 5 that the load-settlement relationship for all curves are fairly linear for small-load range, and then the relationship is nonlinear for large-load ranges and does not exhibit any peak value.

### 3.1 Settlement in similar load as reference

In order to investigate the magnitude of settlement due to the influence of the additional skirt to circular footing, it has to observed on the similar value of load (P, kN). It is taken 1 kN. The settlement on similar load (1 kN) is shown on table 1. The magnitude of settlement which is caused by the different skirt length indicated that the longer skirt the smaller settlement. It is shown on diameter (D) 150 mm with the length (L) 0.00 mm= 1.72 mm of settlement, (L) 100 mm= 0.90, (L) 150 mm= 0.52 mm. Table 1 also shows the different condition on L/D ratio, which is observed from the similar diameter and different skirt length. The higher L/D ratio the smaller settlement.

Figure 6 shows the smallest settlement of skirt circular footing is the footing that attached by the longest skirt 150 mm to the widest diameter 150 mm. The skirt gives resistant due to the sleeve friction
between clay and shaft (i.e. skirt) of footing. This resistant contributes on minimizing the settlement due to vertical loading. As the skirt gets longer, the area of shaft also larger and as consequent, the resistant raises to produce a smaller settlement.

Table 1. Settlement magnitude on load 1 kN.

| Footing diameter D (mm) | Skirt length, L (mm) | L/D | Settlement (S) (mm) |
|------------------------|----------------------|-----|--------------------|
| 75                     | 0                    | 0.00| 12.63              |
| 75                     | 100                  | 1.33| 7.35               |
| 75                     | 150                  | 2.00| 1.59               |
| 100                    | 0                    | 0.00| 8.90               |
| 100                    | 100                  | 1.00| 2.59               |
| 100                    | 150                  | 1.50| 1.70               |
| 150                    | 0                    | 0.00| 1.72               |
| 150                    | 100                  | 0.67| 0.90               |
| 150                    | 150                  | 1.00| 0.52               |

Figure 6. L/D Ratio-settlement relationship, different D.

3.2 Load in similar settlement as reference
Based on the test and investigation of six models of skirt footing and three models of unskirted footing to study the load magnitude due to the influence of the variant skirt length to the different diameter, it could be observed in the similar settlement in 3 mm and the results can be seen on table 2. Figure 7 shows the longer skirt the higher load in similar diameter. It also happens on L/D ratio which is observed in similar diameter with different skirt length. It obviously can be analyzed that the longer skirt the larger area of resistant due to sleeve friction between cohesive soil and the shaft and end up with the magnitude of load gets higher. As shown in figure 7, the higher L/D ratio the higher load in similar settlement 3 mm with different diameter.
Table 2. Load magnitude in similar settlement on 3 mm.

| Footing diameter D (mm) | Skirt length, L (mm) | L/D  | Area     | Load (P) (kN) |
|-------------------------|----------------------|------|----------|--------------|
| 75                      | 0                    | 0.00 | 4419.64  | 0.54         |
| 75                      | 100                  | 1.33 | 4419.64  | 0.80         |
| 75                      | 150                  | 2.00 | 4419.64  | 1.13         |
| 100                     | 0                    | 0.00 | 7857.14  | 0.74         |
| 100                     | 100                  | 1.00 | 7857.14  | 1.05         |
| 100                     | 150                  | 1.50 | 7857.14  | 1.42         |
| 150                     | 0                    | 0.00 | 17678.57 | 1.47         |
| 150                     | 100                  | 0.67 | 17678.57 | 1.99         |
| 150                     | 150                  | 1.00 | 17678.57 | 2.10         |

Figure 7. L/D ratio-load relationship in similar settlement 3 mm, different D.

4. Conclusion
From the accomplished laboratory tests, we derived some conclusions. The additional skirt on circular footing is effective to reduce the settlement on clay as can be seen when it is observed on the similar load on 1 kN load on the same diameter of circular footing, the longer skirt the smaller settlement. The magnitude of settlement for the influence of skirt length to the footing diameter, L/D ratio observed on the similar diameter of footing different length of skirt. It shown that the higher L/D ratio the smallest settlement. The magnitude of loading of the skirted and unskirted circular footing observed on similar settlement in 3 mm, it is explained that at the diameter of footing, the longer skirt the higher load.

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