Behaviours of Ring and Circular Footings Subjected to Eccentric Loading: a comparative Study

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Abstract. This study experimentally examined the behaviours of ring and circular footings resting on loose sand overlying dense sand based on the application of eccentric loads with eccentricity values of 0, 4, 8, and 16 mm. Many researchers have examined the effects of concentrated loads on ring footings numerically; however, few studies have taken into account the effect of eccentric loads on ring footings on loose and dense sand, and even fewer have done so experimentally. This paper thus presents the experimental work done to understand and make comparisons between circular and ring footings under such circumstances. The results of the tests indicate that there is a significant increase in the bearing capacity and a decrease in the settlement of ring footings in comparison with circular footings under the same conditions. Further, ring footings offer approximately the same behaviours as circular footings with respect to eccentric loads. These results indicate that the use of ring footings rather than circular footing can provide improved structural performance at low cost.

Keywords: Bearing capacity, Circular footing, Eccentric load, Ring footing

1. Introduction

A ring footing is one of the types of shallow foundation designed to avoid large settlement and to help provide stability for structures against overturning and sliding ([28] Becker and Lo, 1979; [29] Ostroumov and Khanin, 2007), Oil tanks, tall transmission towers, and silos all utilise ring foundations due to being exposed to horizontal load (wind load). Several different relationships have been suggested in terms of bearing capacity and settlement for ring foundations, and most researchers in this field have used the finite element method to evaluate the bearing capacity of various ring footings to find the relationship between load and settlement under various conditions and parameters, varying radius ratio, type of soil, and type of loading, as well as determining the influence of reinforced soil on the bearing capacity and settlement of ring footings by using geogrid. Other researchers have examined the behaviours of ring footings experimentally [6] (Haroon and Misra 1980; [7] Al-Sanad et al. 1993; [8] Ismael 1996; [9] Ohri et al. 1997; [10] Hatay and Razavi 2003; [7] Al-Sanad et al. 1993; and [8] Ismael (1996)). [11] Sharma and Kumar (2017) presented a numerical study of the behaviour of ring footings located on sand; they found that when the inclination and eccentricity of load increased, the ultimate load of footing decreased in the case of loose sand. [12] Al-Khaddar and Al-Kubaisi (2017) numerically investigated the behaviours of ring footings under the effect of inclined loads, with results that showed that both vertical and horizontal stresses were affected when the inclination angle of the load exceeded 45 degrees, offering a reduction of 40 to 80% as compared...
to those measured at an incline angle of zero degrees. However, less research has highlighted the behaviour of ring footings under the influence of eccentric loads, although [24] El Sawwaf and Nazir (2012) examined the performance of ring footings under the effect of eccentric loads when the foundations were located on a compacted replaced layer of sandy soil overlying loose sand, and [21] Omid and Hosseiniinia (2017) numerically investigated the bearing capacity of rough ring foundations resting on sandy soil subjected to eccentric loads.

Various researcher have examined the optimum radius ratio of the ring footing, including [25] Abbas and Al-Dorry (2013) [15] Al-Sumaiday and Al-Tikrity (2013), [27] Erfan and Hataf (2014), [17] Mehrjardi (2008), [18] Shankar and Kumar (2018), [24] El-Sawwaf and Nazir in (2012), [19] Thomas and Philip (2017), [13] Lavasan and Schanz (2013), [16] Hataf and Fatolahzadeh (2019), [14] Laman and Yildiz (2007), [22] Dhatrak and Mishra (2016), [11] Sharma and Kumar (2017), and [20] Sudhakar and Sandeep (2019). All these researchers were in agreement that the optimum ratio of footing, that is, the one that gave the best bearing capacity, was 0.4; after this value, the bearing capacity of ring footing decreases for both concentric and eccentric loadings. A few researchers have also studied the behaviour of ring footings resting on reinforced soil, such as [27] Erfan and Hataf (2014), [26] Gazive and Lavasan (2008), [25] Abbas and Al-Dorry (2013), [24] El-Sawwaf and Nazir (2012), [23] Boushehrian and Hataf (2003), and [22] Dhatrak and Mishra (2016), showing that the bearing capacity of ring footings increases with an increased number of geogrid layers. Researchers such as [25] Abbas and Al-Dorry (2013) and [24] El-Sawwaf and Nazir (2012) also stated that the bearing capacity of ring footing increased with an increase in the number of layers, at least until the ratio of the radius of the ring foundation becomes greater than 0.4, causing the bearing capacity of the ring footing to decrease as noted above.

In this paper, eccentric loads were adopted to help develop an understanding of the response of circular and ring footing models resting on sandy soil with various relative densities and different values of load eccentricity. The adopted values of eccentricity were e = 0, 4, 8, and 16 mm. A comparison was also made between the responses of the ring and circular footings in each case.

2. Experimental work

2.1 Materials and model footings

The soil sample, from a ditch in the Karbala governorate in the middle of Iraq, was classified as poorly graded sand according to USCS. The grain distribution size of the sample was determined according to ASTM D-421, as shown in figure 1. The soil was dried in natural air and passed through sieve no. 10.

The physical and mechanical properties of the soil are shown in Table 1. Two models of steel footing were used in the experiment, a ring footing with an external diameter of 100 mm and an internal diameter 40 mm and circular footing with a diameter of 100 mm, as shown in Figure 2.
Table 1. Soil properties

| Property                      | Value | Specification     |
|-------------------------------|-------|-------------------|
| Coefficient of uniformity ($C_u$) | 2.93  |                   |
| Coefficient of curvature ($C_c$) | 0.92  | ASTM D 2487       |
| Specific gravity ($G_s$)      | 2.649 | ASTM D 854        |
| Angle of internal friction ($\theta$) Dr=30% | 28°   | ASTM D 3080       |
| Angle of internal friction ($\theta$) Dr=90% | 41°   | ASTM D 3080       |
| Maximum dry unit weight ($\gamma_{dmax}$) | 17.45 kN/m$^3$ | ASTM D 2049-69 |
| Minimum dry unit weight ($\gamma_{dmin}$) | 14.19 kN/m$^3$ | ASTM D 4254-00 |

Figure 1. Particle size distribution

Figure 2. Photo illustrating the ring footing, external diameter 100 mm and internal diameter 40 mm, and circular footing, diameter 100 mm
2.2 Apparatus

Experimental work was conducted using the physical model to help understand the performance of the ring and circular footings resting on unreinforced sandy soil, as shown in Figure 2. The apparatus consisted of a glass box with internal dimensions of 0.6 x 0.6 x 0.6 m, with 10 mm thick glass. The loading system consisted of a steel arch frame and a manual mechanical jack of 1 ton used to apply eccentric loads in addition to the concentrated load. The jack was connected to a load cell, SC516C-1 ton, to measure the applied load on the footing. Two LVDTs of 50 mm capacity were placed at the right and left of the jack to measure the settlement of the footing.

2.3 Sand preparation and testing programme

Two layers of sand were used in the study. At the top, loose sand with a relative density of 30% was placed to 20 cm depth, and dense sand with a relative density of 90% was used at the bottom of the container at 40 cm depth; these were selected as the surface layer of the soil in the field is often loose and usually about 2 m deep, while the deeper layers have denser soil. The dense layer was prepared by tamping using a 13 Kg weight steel tamper. It was tamped in thin layers of 2.5 cm each, with 25 blows dropped from a height of 200 to 300 mm to achieve uniform compaction. The loose top layer was prepared by pouring the sand from a 2.5 cm height and levelling the surface to the required relative density of 30% and thickness of 20 cm, as shown in Figure 3. After that, the footing to be tested was placed at the centre of the soil surface and loaded by means of the mechanical jack according to the specified condition (concentric or eccentric loading). The settlement readings were then recorded by the LVDTs after each load increment and the relationship between the load and settlement was plotted. Eight model tests were carried out, with both ring and circular footings examined with eccentricities of 0, 4, 8, and 16 mm; these values were chosen based on previous studies in which the critical value was found to be 16 mm. This value was thus divided into three cases to help develop understanding of the behaviour of the footings.

3. Results and discussion

The results shown in Figures 5 to 10 show that the loading with zero eccentricity caused almost uniform settlement, while loading with eccentricity caused differential settlement. Figure 4 shows the circular footing under the effect of loading conditions e=4 mm and e=0, highlighting the fact that a significant differential settlement can be observed under the loading with e=4 mm, while uniform settlement is seen in concentric loading.

![Figure 3. The test container with loose and dense sand](image)
Figures 5 and 6 show the behaviours of the circular and ring footings, respectively, under the effects of eccentric loads. From Figure 5, it is clear that the bearing capacity decreases when the eccentricity of the loads increases, with the differential settlement increasing linearly with increases in the eccentricity. Similar results were found by [4] Al-Mosawe et al 2009, [5] Al-Mosawe et al 2011, [2] Al-Busoda and Salman 2013, [1] Albusoda and Hussien 2013, and [3] Albusoda et al 2018. The failure was local shear failure, as under the effect of loading, the soil compacted and settlement occurred; the deformation in the soil was thus not clear.

Friction between the base of the footing and the soil decreased when the eccentricity increased. The bearing capacity of the ring footing was also higher than that of the circular footing under similar conditions, potentially due to the re-arrangement in the soil particles under the ring footing being easier than that of those under the circular one.

Comparing the ring and circular footing, the stability of the ring footing was greater than that in the circular footing, especially at an eccentricity of 16 mm; this should encourage the use of ring footings rather than circular footings to facilitate cost-savings.
Figure 5. Load settlement curves for circular footing subjected to eccentric loading.

Figure 6. Load settlement curves for ring footing subjected to eccentric loading.

Figure 7 shows the difference in bearing capacity and settlement between the ring and circular footings with no eccentric load; the bearing capacity for the ring footing is still higher than that for the circular footing.
Figure 7: Comparison of load settlement curves for circular and ring footings (e= 0)

In general, figures 8, 9, and 10 show similar comparative behaviours for the ring and circular footings at e= 4, 8, and 16 mm: the bearing capacity for the ring footing is slightly higher than that for the circular footing, the stability of the ring footing is higher than that in the circular footing, and the type of failure is local shear failure.

Figure 8 Comparison of load settlement curves for circular and ring footings (e= 4mm)
Figure 9 Comparison of load settlement curves for circular and ring footings (e= 8mm)

Figure 10 Comparison of load settlement curves for circular and ring footings (e= 16mm)

Figure 11 illustrates that the ultimate bearing capacity for the ring footing is greater than that for the circular footing as the friction under the base of the ring footing higher than that in the circular footing; the soil in the hole of the ring footing also facilitates an increase in the bearing capacity of the ring footing.
4. Conclusions

In this study, the bearing capacity and settlement for ring and circular footing models resting on loose sand overlying a dense sand layer were studied under different eccentric loads. By comparing the results for the two footing models, the following conclusions were obtained:

1. In general, the results indicate that differential settlement increases with increased eccentricity as the bearing pressure under the footing changes.
2. A ring footing subjected to eccentric loading shows a higher bearing capacity than a circular footing subjected to the same loading conditions.
3. The behaviour of ring footings is close to the behaviour of circular footings in terms of the type of failure that occurs in both footings; ring footings are thus to be preferred in the design of structures as they require less materials and lower the cost of construction.
4. According to the results obtained, it is also recommended that designers use a ring footing rather than a circular footing as it provides more stability, higher bearing capacity, and less settlement in comparison with the equivalent circular footing.

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