Experimental Investigation of the Bearing Pressure for Circular and Ring Footings on Sand

Hashim G. Rasheed Al-Sumaiday **Israa S. Hussain Al-Tikrity**
Civil Engineering Department, University of Tikrit

Abstract

This paper presents the results of laboratory model tests of bearing pressure of circular and ring footing on sand. The effects of the embedment depth, internal friction of sand and the ratio of the inner to the outer diameter of the ring footing have been studied, in order to understand the behavior of the sand under the ring footing comparing with the circular one. An optimum ratio of the inner to outer diameter of the ring footing have been indicated which was (0.4), at which the bearing capacity will be greater than the circular footing. Also, the results indicated that there was no interested effect of the embedment depth on that optimum ratio.

Keywords: Bearing capacity, Circular footing, Ring footing, Sand.

دراسة مختبرية لقابلية تحمل الأساس الدائري والحلقي على تربة رملية

الخلاصة

في هذا البحث تم دراسة قابلية تحمل الأساس الحلقي بالمقارنة مع الأساس الدائري على تربة رملية باستخدام نموذج مختبري لهذا الغرض. تم دراسة تأثير عمق دفن الأساس، زاوية الاحتكاك الداخلي للتربة الرملية ونسبة القطر الداخلي إلى القطر الخارجي للأساس الحلقي على قابلية التحمل، في محاولة لفهم سلوك التربة الرملية تحت الأساس الحلقي مقارنة مع الأساس الدائري. تم تحديد قيمة مثلى لنسبة القطر الداخلي الى القطر الخارجي للأساس الحلقي وقد وجد انها تساوي (0.4)، والذي تزداد عنده قابلية التحمل عن الأساس الدائري، كذلك تبين عدم وجود تأثير واضح لعمق دفن الأساس على تلك النسبة.

الكلمات الدالة:قابلية التحمل، الأساس الدائري، الأساس الحلقي، تربة رملية.

Notations

B: Foundation width (or diameter of circular foundation).
BCR: Bearing capacity ratio.
c: Soil cohesion.
D_f : Depth to base of footing from ground surface (m).
d_c, d_q, d_γ : Depth factors (functions of the soil friction angle, φ).
q : Effective over burden pressure.
q_{ult} : Ultimate bearing capacity .
Nc, N_q, N_γ : Bearing capacity factors (functions of the soil friction angle, φ).
R_{in}: Internal diameter of ring footing.
R_{ou}t: External diameter of ring footing.
S_c, S_q, S_γ : shape factors (functions of the soil friction angle, φ).
γ : Effective unit weight (kN/m^3)
φ : Soil internal friction angle.

Introduction

The bearing capacity and settlement of foundations proved to be a function of the shape of the footing, foundation soil parameters and conditions. Different correlations have been proposed to calculate the bearing capacity and settlement of strip, circular and square foundations. The ring foundation, which seems to be more suitable and economical for axi-symmetric structures such as silos, chimneys, and storage tanks, has not received as much attention. Fisher[1] was the first how studying the behavior of ring footing and its bearing capacity. Egorov [2], Ohri et al.[3] and more recently Hataf and Razavi[4] have also studied the behavior of ring footings and its properties.

This paper presents the results of laboratory model tests on the bearing capacity behavior of a ring footing resting on sand.

Bearing Capacity of circular footing

There are several methods for determining the bearing capacity of shallow foundation.

Terzaqi in 1943 was the first to present a theory for the evaluation of the ultimate bearing capacity of strip footing under general shear failure, and then it has been modified for other types of foundations such as square, circular and rectangular by introducing shape factors (eq. 1). Terzaghi equation has been quite popular with designers[5].

Meyerhof in 1963 presented a general bearing capacity equation which takes into account the shape and the inclination of load (eq. 2).

Hanson in 1970 extended the work of Meyerhof by including two additional factors to take care of base tilt and foundation on slopes.

$$q_{ult.} = cN_cS_c + q\,N_qS_q + 0.5\,\gamma BN_\gamma S_\gamma \ldots.(1)$$

$$q_{ult.} = cN_cS_cd_c + q\,N_qS_qd_q + 0.5\,\gamma BN_\gamma S_\gamma d_\gamma \quad . \quad . \quad \ldots\ldots(2)$$

Where:
q_{ult}=ultimate soil bearing pressure
c =cohesion of soil (kPa)
q = effective over burden pressure at the base level of the foundation = γ D_f (kPa)
γ =effective unit weight (kN/m^3)
D_f = depth to base of footing from ground surface (m).
B = width of foundation (or diameter of circular foundation) (m)
S_c, S_q, S_γ = shape factors (functions of the soil friction angle, φ)
d_c, d_q, d_γ = depth factors (functions of the soil friction angle, φ)

Nc, N_q, N_γ = bearing capacity factors (functions of the soil friction angle, φ).

The three above methods are widely used (Bowels[6]) and (Das[7]), thus, the comparison with obtained results in this research draws together with one of these methods.

Bearing Capacity of ring footing on sand

Fisher[1] proposed a method to predict the settlement of ring footings on a semi-infinite elastic media. Egorov[2] later proposed some relations to predict the bearing capacity under the ring footing and its settlement. Bowles[8] has also predicted the bearing capacity and settlement of ring footings using finite element method. Ohri et al.[3] performed a series of laboratory tests on model ring footings, they proposed that for a ratio of internal to external radius of the ring (n) equal to (0.38) the unit bearing capacity reaches its maximum for dune sand. Hataf and Razavi[4] suggested a range (0.2–0.4) of that ratio, which reached the bearing capacity to the maximum. They also proposed a semi empirical relation to predict the unit bearing capacity of ring footings on sand soil.

Zaho and Wang[8] utilizes a finite difference code FLAC to study bearing capacity factor Nc for ring footings in cohesionless, frictional and ponderable soil. The value of Nc is found to decrease with an increase in ri/ro.

Experimental study

The experimental program reported herein, that involves small scale load tests, was carried out using a test facility in the Structural Engineering Laboratory of the Civil Engineering at the Tikrit University. Details of the experimental program, and analysis of the test results of model studies of the load-bearing capacity of circular and ring footings resting on sand bed are presented below.

Materials

Clean, oven-dried beach sand at 55% and 80% relative density was used as a sand bed in the laboratory model tests. Table 1 summarizes the basic properties of the sand used in this study. The sand was classified as poorly graded sand (SP) as per the Unified Soil Classification System. The angle of internal friction of the sand was determined by direct-shear tests according to the ASTM D3080-03 under normal pressures of (50, 100 and 200 kPa) and the results were (35º) and (40º) for relative density 55% and 80% respectively.

The Model Footings

Loading tests were carried out on a circular and ring rigid footing fabricated from mild steel. The model footing was 30 mm thick and 100 mm in diameter. Three different footing embedment's depths of 0, 50 and 100 mm were investigated. The soil beds were prepared in a steel box with inside dimensions 900 mm × 900 mm and 500 mm in height. The sides and the bottom were made of 6 mm thickness plate; the purpose of higher thickness is to give rigidity against pressure.

The Loading Frame

The test box was placed over 1100×1100 mm strong steel base of 80mm thick. The base was connected to a stiff loading frame, which was locally manufactured.

As shown in Figure (1), the frame consists of two columns of steel channels 1520 mm height, which intern bolted to a loading platform. The platform was designed to slide along the columns and can be fixed at any desired height by means of slotting spindles and holes provided at different intervals along the two columns. The two steel columns were fixed by four short steel angle pieces connected to the lower plate in the frame.

The Loading System

The load was applied by means of mechanical arrangement technique that was employed for the test. It has been carefully selected a wheel to provide a speed of loading, which was nearly 0.133mm/sec. The proving ring was attached to a cylindrical steel toothed shaft device of 550mm long and 40 mm diameter, which was used to transfer the load to the footing and help to adjust the height of the ring to any required position before or after test. A spherical recess was made at the end of the proving ring to accommodate the ball connection with the footing. Dial gauge with accuracy of 0.02 mm and maximum travel of 50 mm was attached to the footing surface to measure the vertical displacement. This gauge was fixed in place on supports steel angles by means of threaded rods.

Model Preparation for Soil

The sand was prepared by a raining technique with a specially designed hopper system. The effective size (D10), uniformity coefficient (Cu), and coefficient of curvature (Cc) for the sand were (0.15), (2.60), and (1.07), respectively. The relative density was monitored by collecting samples in small cans of known volume placed at different locations in the test box and beneath it[9]. The difference in densities measured at various locations was found to be less than 1%. The raining technique adopted in this study provided two relative density of approximately 55% and 80%, with a unit weight of (15kN/m^3) and (16.8kN/m^3) respectively, that was conducted by controlling the height of sand raining for each case. A series of direct shear tests were performed, the estimated internal friction angle at the relative density of 55% was approximately (35°) and it was (40°) for the relative density 80%. The layer was then leveled with extra care to produce minimum disturbance of the surface. Then, the footing was placed at the center of the box. Then the dial gauge was fitted at a suitable position. The test started by applying the load, through a calibrated proving ring of 28 kN maximum capacity with recording settlement, this was continues until the soil failed. The failure criteria which adopted in this study was reaching the settlement till 10% of the footing diameter.

Results and Discussion

Ultimate bearing capacity for circular footings on sand

These tests were conducted for circular footings on sand. The ultimate load at D_f/B = 0, 0.5, 1 occurred at s (s is the settlement of foundation). Table(2) summarized the results of experimental ultimate bearing capacity for embedment ratio obtained from these tests for relative density 55% and 80%.

For a vertical loading condition, the ultimate bearing capacity(q_{ult}) of a shallow foundation for circular footing on sand can be predicted without a cohesion component. As a result, Meyerhof [10] bearing capacity equation can be used as follows:

$$q_{ult.} = \gamma D_f N_q S_q d_q + 0.5\,\gamma B N_\gamma S_\gamma d_\gamma \quad .....(3)$$

B = the footing width, (m)
γ = the unit weight of the soil (kN/m^3)
N_γ, N_q = bearing capacity factors (functions of the soil friction angle, φ)
S_q, S_γ = shape factors (functions of the soil friction angle, φ)
d_q, d_γ = depth factors (functions of the soil friction angle, φ)

Using the above relationship, the theoretical ultimate bearing capacities of circular footing for the present test conditions have been calculated and are summarized in Table(2) and plotted in Figure(2-a) and Figure(2-b) along with the experimental values. Generally, the experimental values are higher than those obtained using eq. (3), as like as it had been pointed out by several investigators in the past [10], this is not very unusual primarily due to the inherent difficulty in establishing the proper magnitude of φ for bearing capacity calculations.

Ultimate bearing capacity for ring footings on sand

These tests were conducted for ring footings on sand. The ultimate load at D_f/B= 0, 0.5, 1 occurred at s (s is the settlement of foundation) for R_{in}/R_{out} = 0.3, 0.4, 0.5 (where R_{in} is the internal diameter of the ring footing and R_{out} external diameter).The pressure versus settlement curves for circular and ring footing generated at each footing depth are shown in Figures(3-a), (3-b), (4-a), (4-b), (5-a), and (5-b). From these figures it can be noted that the bearing capacity increase with increasing (R_{in}/R_{out}) ratio comparing with the circular footing of the same radius and it reaches a maximum value at (R_{in}/R_{out} =0.4). This ratio could be considered as an optimum ratio, and after that ratio, the bearing capacity starts decreasing. This could be explained by creating additional shear failure surface to that one suggested by Terzaghi[11] and Hansen[12] as shown in Figure (6). This additional shear failure surface started from the internal edge of the ring footing and finished at the end of the wedge zone of the shear failure surface. However, that additional shear failure surface increasing friction area of active zone. This explanation can be suitable with the optimum ratio of ring footing(R_{in}/R_{out}=0.4). Also it can be noticed clearly that the bearing capacity decreased after that ratio, and that belongs to approach both of the external and internal shear failure surface. So, it returns to work as one shear failure surface. Also, when the ratio (R_{in}/R_{out}) extend to (0.5), the bearing capacity will reduced because of the high interaction between both of the external and internal shear failure surface in small zone as shown in Figure (7).

Effect of footing embedment depth on optimum (R_{in}/R_{out})

From Figure(8-a), and Figure(8-b), it can clearly noticed that changing in footing embedment depth had no effect on the optimum (R_{in}/R_{out}) that it suggested in the latest paragraph because at that maximum (BCR) occurred for all cases of (D_f/B) at ($R_{in}/R_{out}=0.4$) . Also, it is ratio) which is defined as in Eq.(4)[4] that used for describing the improvement in load bearing capacity due to the change in(R_{in}/R_{out}) ratio :-

$$BCR = q_{ult}(Ring)/q_{ult}\ (cir.) \quad \ldots\ldots\ldots(4)$$

Where q_{ult}(Ring) and q_{ult}(cir.) are the ultimate load-bearing capacity values for the ring and circular footings, respectively.

Effect of the angle of internal friction (φ) on optimum (R_{in}/R_{out})

Also from Fig. (8-a) and Fig.(8-b), it can clearly noticed that changing the angle of internal friction which related to the change in relative density had no effect on the optimum (R_{in}/R_{out}) because the maximum (BCR) occurred for angle of internal friction (35°, 40°).

Conclusions

The main points that can be drawn from this study are summarized as follows:

1-Bearing capacity of ring footing at specific range of ratio of inner to outer diameter is greater than that of circular footing with similar properties on sand.

2- The increasing of bearing capacity for the ring footing reaches maximum value at the ratio($R_{in}/R_{out} = 0.4$).

3- There are no clear effect of the embedment depth on the optimum ratio of the ring footing.

4- There are no clear effect of the internal friction angle on the optimum ratio of the ring footing.

important to say that we used the parameters (BCR) (bearing capacity

References

1. Fisher, K., (1957). Zur Berechnung der setzung Von undamenten in der form einer Kreisformigen Ringflache. Der Bauingenieur, Vol. 32, No. 5. Berlin, Germany, pp. 172–174 (in German).
2. Egorov, K.E. (1965). Calculation of bed for foundation withring footing. Proceedings of the Sixth International Conference on Soil Mechnical Foundation of Engineers, Vol. 2, Montreal, pp. 41–45.
3. Ohri, M.L., Purhit, D.G.M., Dubey, M.L., (1997). Behavior of ring footings on dune sand overlaying dense sand. Pres. International Conference of Civil Engineers, Tehran, Iran.
4. Hataf, N., Razavi, M.R., (2003). Behavior of ring footing on sand. Iranian Journal of Science and Technology, Transaction B, Vol. 27, pp. 47–56.
5. Murthy, V.N.S. (2006), “Geotechnical Engineering” Marcel Dekker, Inc, New York 1029p.
6. Bowles, J.E., (1977). Foundation Analysis and Design, second ed. McGraw-Hill, New York.
7. Das, B.M., (1999). Shallow Foundations: Bearing Capacity and Settlement. CRC Press.
8. Zaho, L., Wang, J. H. (2008), "Vertical bearing capacity for ring footings" Volume: 35 Issue: 2 Pages: 292-304.

9. Bowles, J.E., (1997), Foundation Analysis and Design, 5thEdition. McGraw-Hill, New York.
10. Meyerhof, G.G., (1963). Some recent research on bearing capacity of foundations. Canadian Geotechnical Journal 1 (1), 16–26.
11. Terzaghi, J. C., (1943), "Theoretical Soil Mechanics", John Wiely, New Yourk.
12. Hansen, W. E., Peck, R.B. and Thornburn (1970), "Foundation Engineering", John Wiley and Sons, New York, U.S.A. 33. Limited. 589p.
13. Sireesh, S., Sitharam, T. G. and Dash, S. K. (2008), “Bearing Capacity of Circular Footing on Geocell-Sand Matters Overlying Clay Bed with Void”, Geotextiles and Geomembranes, Vol.27, pp. 89-98.
14. Al-Azzawi, M., A., (2010), "Behavior of Rectangular Footing Subjected to Gypseous Soil Under Eccentricity-Inclined Load" MSC thesis, university of Tikrit.

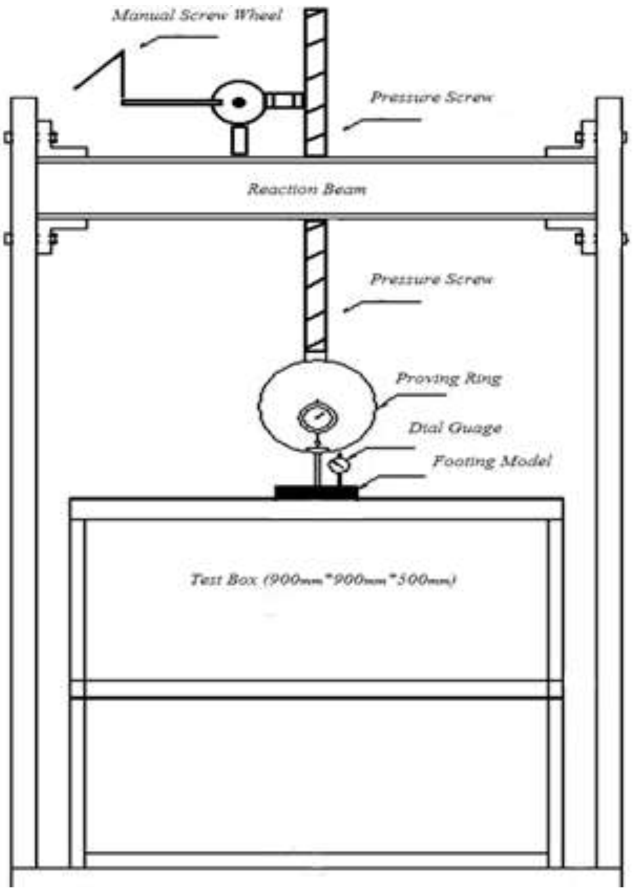

Fig. (1) Testing equipments for experimental set up

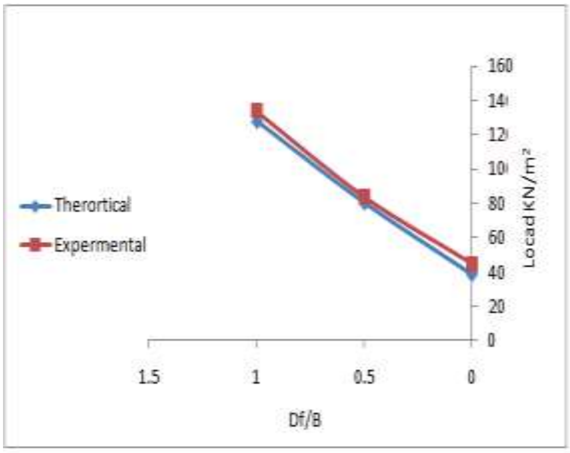

Fig. (2-a)Variation of q_{ult} with D_f/B for experimental and theoretical calculations for relative density 55%

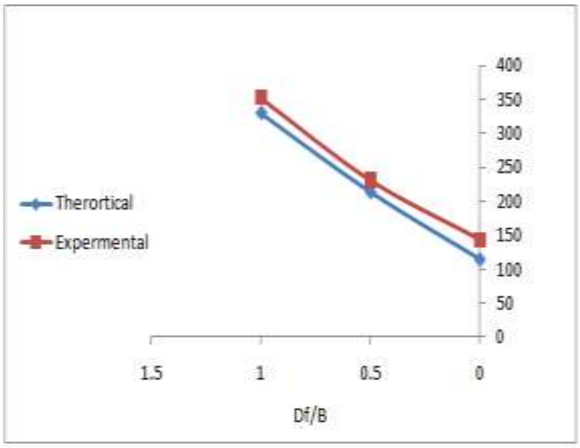

Fig.(2-b) Variation of q_{ult} with D_f/B for experimental and theoretical calculations for relative density 80%

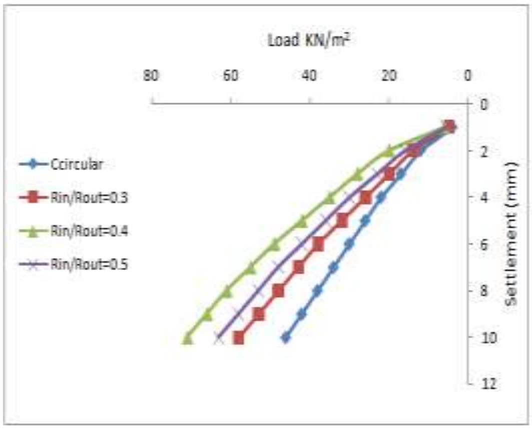

Fig. (3-a) Load-Settlement relationship of $D_f/B=0$ for relative density 55%

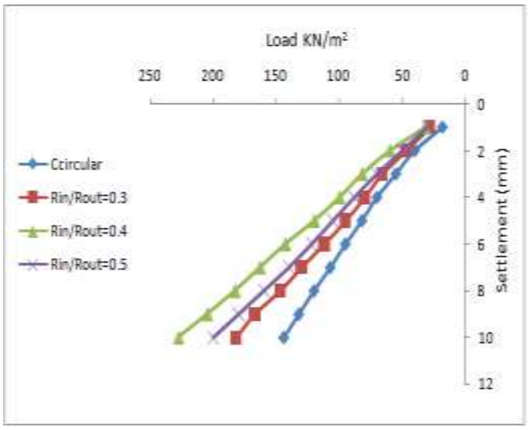

Fig. (3-b) Load-Settlement relationship of $D_f/B=0$ for relative density 80%

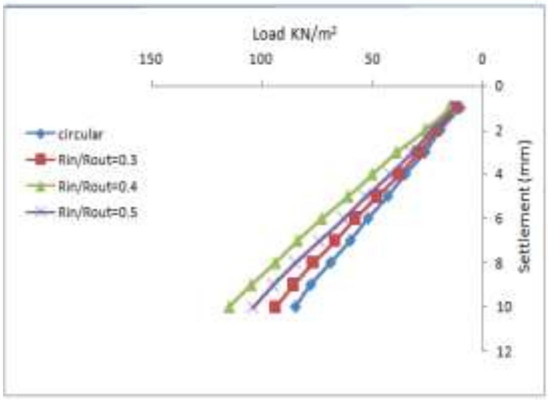

Fig. (4-a) Load-Settlement relationship of $D_f/B=0.5$ for relative density 55%

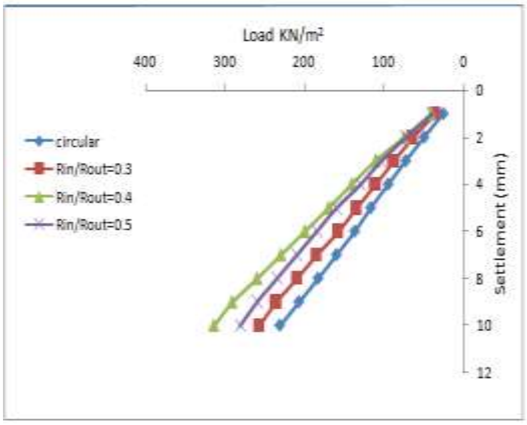

Fig. (4-b) Load-Settlement relationship of $D_f/B=0.5$ for relative density 80%

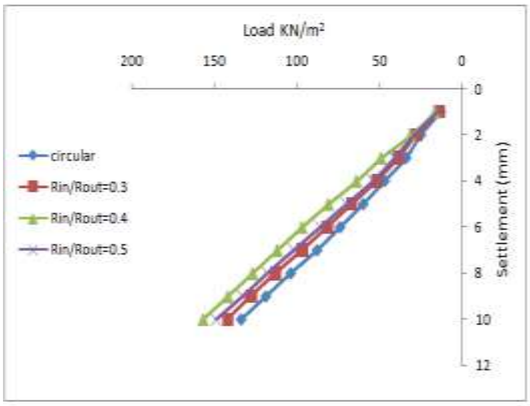

Fig. (5-a) Load-Settlement relationship of $D_f/B=1$ for relative density 55%

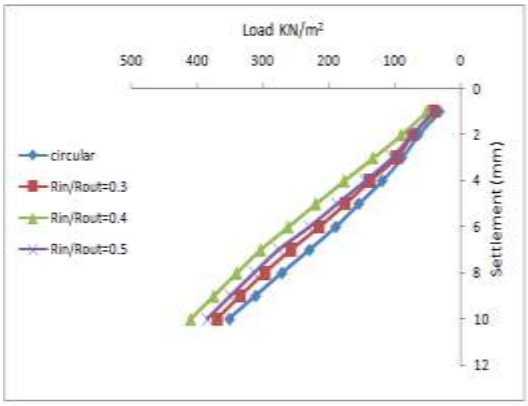

Fig. (5-b) Load-Settlement relationship of $D_f/B=1$ for relative density 80%

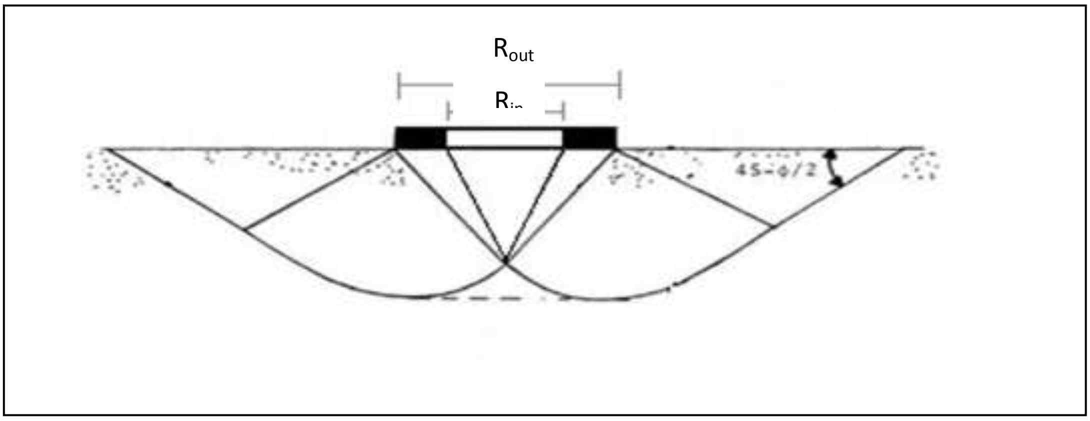

Fig. (6) Shear failure surface for ring footing at optimum (R_{in}/R_{out})

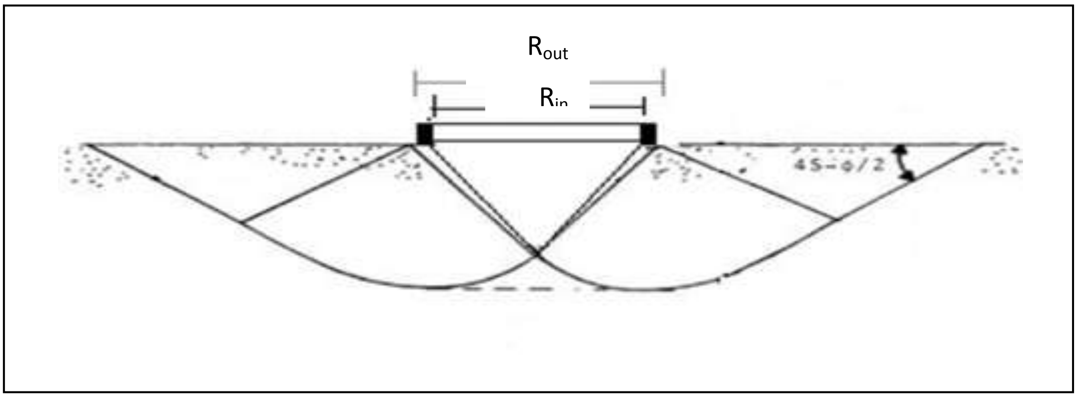

Fig. (7) Shear failure surface for ring footing at (R_{in}/R_{out}) > 0.4

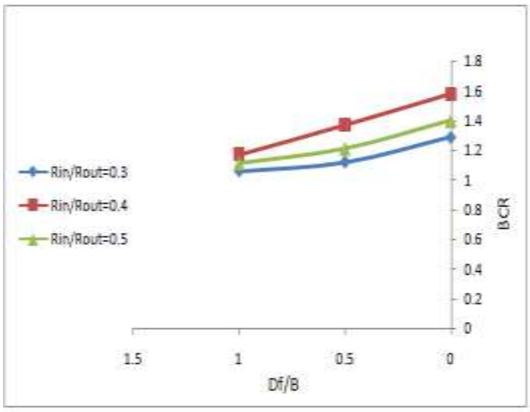

Fig. (8-a) Variation of (BCR) with (D_f/B) for relative density 55%

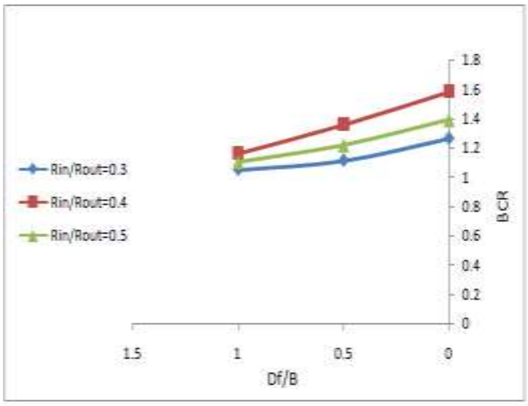

Fig. (8-b) Variation of (BCR) with (D_f/B) for relative density 80%

Table (1) Properties of sand.

Property		value
Specific gravity		2.63
Maximum dry unit weight (kN/m^3)		18.58
Minimum dry unit weight (kN/m^3)		12.14
Relative density during model test (%)	55.0	80.0
Effective grain size, D10 (mm)		0.15
D60 (mm)		0.39
D30 (mm)		0.25
Coefficient of uniformity, Cu		2.60
Coefficient of curvature, Cc		1.07
Internal friction angle (ϕ) (degree)	35.0	40.0
Cohesion, c (kPa)		0.00

Table(2) Experimental and theoretical ultimate bearing capacity of circular footing on sand at various footing depths

Footing embedment depth (cm)	Experimental ultimate bearing capacity (kpa)	Theoretical ultimate bearing capacity(kpa)	Relative density (%)
0	46	39	55
5	85	81	
10	133	128	
0	144	115	80
5	231	214	
10	352	330	