A Review on The Performance of Ring foundations resting on reinforced and unreinforced soil

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Abstract. This manuscript presents a literature review of research undertaken on the bearing capacity of the ring foundations noticed that it is affected severely bearing capacity and settlement of ring footings under by the ratio of radius of the ring and the optimum value was 0.4 beyond which the bearing capacity of ring footing decreased under static conditions, different values have been found under dynamic conditions. It is to be acknowledged that most experimental tests were carried out statically mostly with small scale physical model. In contrast, only a few were undertaken with a dynamic test. It was observed that the optimal size and orientation of the reinforcement layer represent the main factors to enhance the bearing capacity and minimize the settlement for the ring footing located on geogrid reinforced sandy soil. In particular, the embedment depth for reinforcement, the space between two-layers, and the size of geogrid equal to (0.3-0.32), 0.32, and (3.5-4.0) of the outer diameter of footing respectively. Furthermore, it was found that the evaluation of bearing capacity factor Nγ strongly affected by the ratio of the radius for both smoothly base and rough base of the ring footings particularly the factor Nγ, particularly for greater values of the ratio of radius, the value of Nγ is considerably higher for roughly surfaces than that for a smoothly base.

Keywords: ring footing, bearing capacity, soil reinforcement, geogrid, experimental model.

1. Introduction
The lowest portion of structures that transmits its weight to the fundamental soil is the foundation. Shallow foundations comprise many types. The suitable type is chosen according to the structure that the footing will carry. One of the types is the ring footing that used in structures that have circular or round planes also all loads transmit by the wall to the foundation and end to the soil. Oil tanks, tall transmission tower, and silos all these structures are supporting on ring foundation and exposure to horizontal load (wind load), as well as vertical load the combining between these loads, cause inclined load, place of horizontal loads at any point along with the elevation of structures cause eccentricity load, the bearing capacity of foundations varies with the shape of the footing, soil limitations, and loading states [1]. Various partnerships have been suggested to measure bearing capacity and settlement, for circle, and square foundation. The ring foundation, that appears to be more appropriate and cost-effective axisymmetric structures such as storage tanks, Most of the researchers used the finite element method to evaluate the bearing capacity of footings and to find the relation between load and settlement, The Finite Element
Method (FEM) is a numerical technique for finding an approximate solution to the partial differential equation (PDE) and their systems also an integral equation.

A few researchers have inquired about bearing capacity and settlement of ring footings and tried to find expression, numerically as well as experimentally. Egorov 1965 [2] assumed an equation for estimating the settling and the reaction stress of a rigid ring base subjected to vertical load, several researchers examined the bearing capacity of rings footings depending on the finite element method which represents close to beam on elastic foundation.

Fisher 1957 [3] Suggested a method for calculating ring foundation settling on a semi-infinite elastic media. Several relationships were proposed later to estimate the ultimate bearing capacity and settlement of ring foundations [2]. Bowles has proposed the bearing capacity and settlement of ring footings by finite elements. Ohri et al. 1997 [4] introduced a series of experimental experiments on models of ring foundations, they indicated that, with a ratio of radius = (0,38), the bearing capacity with dune sand would exceed its limit.

2. Reinforcement of Soil Under The Ring Footings

A few of researchers studied the impact of reinforcement by geogrid on the settlement and bearing capacity of ring foundations also investigated the impact of embedment depth and the number of layers under the footing Naderi and Hataf (2014) [5], Gazive and Lavasan (2008) [6], Abbas and Al-Dorry (2013) [7], El-Sawwaf and Nazir (2012) [8], Boushehrian and Hataf (2003) [9], Dhatrak and Mishra (2016) [10] showed that The bearing capacity of ring footings increased with an increased number of geogrid layers, some of these researchers like Abbas and Al-Dorry (2013) [7] and El-Sawwaf and Nazir (2012) [8] stated that the bearing capacity of ring footing increased with an increased the number of layers till the ratio of the radius of the ring foundation become more than 0.4 after this value the bearing capacity of ring footings decreased. These researches give a good indication of to use of geogrid to reinforce the soil under the ring footing and depending on these results as a guideline in designing the ring footing.

Also, Abbas and Al-Dorry (2013) [7] found that the number of layers increased when the embedment depth decreased, El-Sawwaf and Nazir (2012) [8] found that the best number of layer was 3 layers, and after that the rate of Bearing capacity enhancement seems to be steady. When eccentrically loading was applied to ring footing located on the compacted layer of sand. Also, these results coincide with that found by Dhatrak and Mishra (2016) [10] who found the maximum number of layers equal to 3.

Agrawal and Singh (2013) [11] showed that the bearing capacity of ring footings decreased when the depth of reinforcement supported at a depth of 1.5B and 2B respectively.

Lavasan and Shanz (2013) [12] found that the best value of bearing capacity and settlement given at the depth of the embedment for one layer and two-layer equal to 0.32D₀ and 0.3 D respectively, also stated that the critical values of the diameter of a geogrid layer are about 4D₀ and The critical value of vertical spacing between two layers of geogrid is approximately equal to 0.32D₀ for reinforced sand with 2 layers of geogrid but Abbas and Al-Dorry (2013) [7] found that the best depth ratio of the top layer geogrid was (0.5-0.53D₀). Laman and Yildiz (2007) [13] suggested that the optimum size equal to 3D, these differences in the opinions of the researcher may be due to the differences between geogrid material quality or differences in the types of loading or types of soil which the ring footings resting on it.

3. Effect of The Ring Radius Ratio on The Bearing Capacity of Ring Foundations

Several researchers made a set of experimentally tests and numerically work to find the best ring footing Radius ratio that gives the maximum bearing capacity of ring footing. [7], [14], [5], [16], [17], [8], [18], [12], [15], [13], [10], [19], and [20] all these researchers were reached to the same finding, they found that the optimum ratio of footing that gave the best bearing capacity was 0.4. and after this value, the bearing capacity of ring footing decreased for both concentric and eccentric loading.

Tang and Phoon 2018 [21], Zhu (1998) [22], and Rupani and Bhoi (2019) [23] Computed the bearing capacity of the ring foundation located on dense sand numerically and experimentally and
found that at 0.35 from the radius ratio of the ring given the optimum bearing capacity of ring footing and when the radius ratio increased the bearing capacity of ring foundations decreased linearly. Ahmad et al 2016[24] studied the settlement and the bearing capacity of the shallow ring and circular footings located on anisotropic soil found that The significant value of ri / ro is 0.6 which is similar to the value seen in previous studies. Ohri et al. (1997) [4], Boushehrian and Hataf (2003) [9]

From all these findings noticed that as the radius ratio of the ring decreased the surface area increased then the surface of friction between the footing and the soil increased that lead to increase the bearing capacity of the ring footing till the ratio of the radius reach to 0.4, for the ratio more than 0.4 the surface area of the ring footing begin decreased so that the bearing capacity of footing decreases linearly. A few researchers gave different values for the optimum radii ratio but very close to to the 0.4 that maybe because of the deference of condition of the studies

4. Bearing Capacity Factors Ny, Nq And Nc Of The Soil Under The Ring Footings

The bearing capacity factors Ny, Nq, and Nc for ring foundations have calculated by a very little researcher and using a different numerical method and with different conditions and made comparisons with the other previous studies, if possible. The bearing capacity factors, Ny, Nq, and Nc of the ring footings affected by dilating angles of the soil [25] Chavda and Dodagoudar (2019).

[[[1], [26], [27], [25], [28], [29], [30], [31]] have used numerical methods to evaluate the bearing capacity factor and found that the bearing capacity factors are different for a different ratio of the radius the ring footings and decreased with increased this ratio. Hosseininia (2016) [27] found that factor Ny was the most altered by the radius ratio of ring foundations. Chavda and Dodagoudar (2019) [25] noticed that with the rise in the friction angle of the soil, the values of the bearing capacity factor, Ny, Nq and Nc rise. It also found that the value of the factors Ny, Nq, and Nc increased with decreased radii ratio for both the smooth base of the ring and roughly base ring footings. And the value of the Ny of the rough base and smooth base of the ring footings reduces when rise in the ratio of radius ring between zero and 0.9 and after that Ny raises and attitudes to the value of Ny of the strip foundation at the ratio of radius = 1. besides Zhao and Wang 2008 [32], The Ny measured value from the FLAC is in good agreement with the previous findings. Choobbasti, et al 2010 [31] showed that when the ratio between internal and external radius becomes more than 0.6 the factor Ny increased.

Most of the researchers reached to the same finding that the factor of bearing capacity raised with decreased the ratio of the radius of the ring that means increased the surface area of the ring footing especially the Ny factor, that because the Ny depends on the friction between the footing surface and the soil so that this factor increased with decreased radii ratio and angle of internal friction especially when using rough ring footing surface.

[33], [34], [30], [35] have calculated the value of Nc numerically and found that the factor Nc decreased With increasing radii ratio. Sangseom and Julie 2016 [30] observed that for heterogeneous soil soft overlying stiff clay, a decrease in Nc value with H / D is seen for H / Do 0.25, which is especially important for low Ri / R0 value. However, Nc value has a growing preference for stiff overlying soft clay, as H / D increases: This is particularly pronounced for the limited Ri / R0 values. Bennmabrek et al 2017 [34] finding that The value of the ratio of the radius providing the highest value of Nc is discovered to be proportional to the value of q and sited between 0.25–0.50 range. [25] Chavda and Dodagoudar (2019) noticed that The optimum value of Nc at the ratio of radius equal to 0.25 for rough base footing.

[33], [36], [34],[37] investigated numerically about the factor of bearing capacity Ny and noticed that Ny decreased with increased values of the radii ratio of ring footings. ) Sargazi and Hosseininia 2017 [37] found that the value 0.25 gave the maximum value of Ny when applied eccentric load on the ring footing.

Keshavarz and Kumar 2017 [38] computed the bearing capacity of the ring footing by the method of stress characteristics (SCM) for smoothly base and roughly base of the ring foundations. he found that the values of the bearing capacity factors seem to be maximal for a rough footing relating to the convincing value of the ratio of the radius that usually lies between 0.1 and 0.5. In addition, the bearing capacity factors Nc and Nq decrease steadily for a smooth base of the footing with a rise in ri / ro value. The factor Ny for a smoothly base of footing indicates just a small difference with ri / ro shifts..
5. The Behavior of The Ring Footings Under The Action of Dynamic Loading

Ding et al 2017 [39] Studied the vibration characteristics of a rotating ring aided by an observational method, simulator of numerical simulation (FE) and experimental using the analog of the Timoshenko beam theory. he found that the FE modeling and the experimentation both verify that the proposed Timoshenko ring method shows natural frequencies with high precision for flexural vibration. In comparison, major variations occur between the Euler Bernoulli and Timoshenko ring models for a limited ring radius or a big ratio of thickness to ring radius.

John and Kause (1984) [40] noticed that the continuous torsional and rocking stiffness of the ring foundation does deviate greatly from the equivalent strength of the ring foundation for values of the internal radius to an external radius ratio of approximately 0.75. Static horizontal and vertical rigidity changes significantly for the value of the ratio bigger than almost zero to 60.

Veletsos, and Tang, 1986 [41] Analyzed the dynamic behavior of vertically enthusiastic ring footings with the mass funded on the homogeneous and uniform surface, linear half-space, the harmonic reaction of the foundations was analyzed across a wide range of parameters and observed that The harmonic and the transitory reactions can be computed with high precision over a variety of conditions by taking into account the foundation-soil system as a single-degree-of-freedom system.

Veletsos, and Tang, 1987[42] made an inclusive analysis of the Frequency rocking reaction of, rigid, ring footings borne on a homogeneous elastic half-space surface. The surveyed include the foundation’s rigidity and damping coefficients, spring dashpot demonstration of the supporting medium; and the natural stress at the foundations medium interface. The findings were compared in each case with those obtained with a solid disk of the same size, and it was found that the two sets of findings varied significantly.

6. Other Previous Studies On The Ring Footings Behaviors

Thomas and Philip 2017[17] investigated the bearing capacity of ring foundations resting on both unreinforced sand reinforced sand by geonet. and found that the bearing capacity depending on the depth and the number of layers of reinforcements. If the number of layers increases then the bearing capacity increased. As the depth increases, the bearing capacity decreases, besides, made a comparison between the numerically and experimentally work analyses and found that the experimental analyses gave values close to those in numerical analyses.

Shalaby  2017 [43] Introduced a strategy using trench sand and stone piles to stabilize the soft clay below the foundation of the pit. Also studied The influence of factors involved depth, sand trenches thickness. Findings showed that the mixture of sand trench stone piles reduces settling and improves footing capacity. The sand trench and stone pile measurements seemed the significant element in enhancing ring footing behavior on soft clay soils. The significant decrease in settlement largely depends on the sand trench proportions as well as the size of stone piles appropriate depth and replacement sand trench diameter is 1.5 times the foundation diameter, the bearing capacity remains almost constant despite the use of a sand trench with a thickness reaching two times the width of the ring foundation.

Tsouvalas and Metrikine 2019[44] developed a new high-order method for rotation ring vibration in plan The inner side of the ring is bound by an elastic foundation to an unyielding pole, while the outer part is traction free and allows A contrast with the theories of the lower order. It has been shown that including for thin rings on elastic foundations, high-order correction has to be regarded, besides those of the Timoshenko principle, for the reliable calculation of the critical speeds of rotating rings. In forecasting the complex behavior of either static or revolving rings the new high order method is preferable to the current ring model. The concept refers to all plane pressure and plane strain configurations without lack of generality Sudhakar and Sandeepl 2019[20] investigated experimentally about the cyclic and static performance of the models ring footings and circular footings located on sandy soil reinforced by using geocell. And it was observed that the bearing capacity of the ring foundation with an internal to an external diameter ratio of 0.4 is about the same as those of the stable and periodic circular foundation... for the ring and circle foundations, the average size of the geocell was 4 times the foundation diameter, Surface heaving and settling decreased with increases in geocell size. In the situation of the circular foundations the maximum depth to put the geocell calculated as 0.1
and equal to 0.25 times from the outer size for the ring foundations. The findings show that the foundation efficiency is higher for the soil reinforced by geocell due to cyclic loading than that of unreinforced soil Hataf and Fatolahzadeh 2019[14] investigated the bearing capacity of circular a ring foundations resting on sandy slope soil reinforced by geogrid, and found that the ring footings with Din/Dout<0.4, the tolerated load is almost equal for the unreinforced case and reinforced cases, additionally observed the bearing capacity for the circle and ring footings above slope considerably increases if the reinforcement layers are implemented correctly, also, made a comparison between the numerically and experimentally findings and found that experimental results gave values close to those in numerical results.

[5] Naderi and Hataf 2013 [5] investigated numerically and To determine intrusion impact on neighboring circular and ring bearing capacity Footings over reinforced and unreinforced sandy soil Experimentally test and numerically have shown that the bearing efficiency of two spaced circular foundations and ring foundations is higher when they are precisely parallel to each other. also reductions when increased the spacing of the foundation diameter ratio. And noticed that for the footing diameter ration more than 4, approximately the bearing capacity of nearby foundations was the same as that for single footing. And noticed that the bearing capacity of ring footings greater than that for the circular footings in the same conditions.

Ghazavi and Lavasan 2008 [6] studied The effect of reinforcement on failure mechanisms and soil movement for spreading and intervening ring foundations on cohesionless granular soil and that achieved by numerical and experimental work and found that when adding two ring footings completely close together, the system of two ring footings acting as a single semi-rectangular unit. soil Reinforcement causes a considerable decrease in the effect of interference on failure mechanism and displacement counters.

Vali, Ramin, et al 2019 [45] investigated the impact of loads location and the radius ratio (ri/ro) on the bearing capacity of ring footings in different cases including the smooth base of footing and rough base of footings resting on cohesive and frictional soil and used finite element limit analysis (FELA), therefore investigated about the region of failure under the footing in different cases, T1, T2, T3, and T4 represent the cases of load location as shown in figure Fig.1, the result shows that the perfect position of the load was T4 for the circular footing location on cohesive soil, and the factor Nc of bearing capacity decrease in the position cases T1, T2 and T3. Also reduction to 8.69%, 53.16%, and 8.74%, respectively when the ratio between inner to outer radius increase from 0.0 to 0.9, for determining Ny (the factor of bearing capacity of cohesive soil) they found that the location load T2 was the best location when calculating the bearing capacity of frictional soils. Also found that the depth of the failure region extends deeper in the case of the rough base of ring footings Fig.2

Azmoodeh and Arafat 2015 [46] studied numerically the effect of different type and depth of the granular soil on the bearing capacity of the ring footings, from the results found that the bearing capacity of ring footings increases when the soil particles becoming coarse that because the increasing the contact area and the friction between the footing and the soil.

[19] Sharma and Kumar 2017 presented a numerically study to understand the behaviors of ring footings resting on sand with two cases of density first case was loose sand, the second case was compacted "randomly distributed fiber-reinforced sand (RDFS) " eccentricity load, inclined load and both of eccentric-inclined loadings. From the result, they found that when the inclination and eccentricity of load increased the ultimate load of footing decrease in case of loose sand, while when the ring footing resting on (RDFS) the reduction in ultimate load was very little.

Naseri and Hosseininia 2015 [47] computed the settlement of ring footing that resting on elastic half space. The settlement estimation of the ring footing is attainable depending on displacement factors, that is achieved by using of the elasticity theory and The relation between ring foundation settling and internally and externally rings radius was examined they also suggested a mathematical expression for the impact of the geometry of the ring footings in term of the radius ratio.

Al-Khaddar and Al-Kubaisi 2017 [48] investigated numerically about the behaviors of ring footing located on two layers when applied inclined load. Furthermore, the effect of multi-layered soil has been simulated in the model. The results showed that both vertically and horizontally stresses are affected when the inclination angle of the load exceeded 45 degrees with a reduction of (40-80) %
when compared to those with an incline angle of zero degrees. Furthermore, the bending moment and shear forces within the footing were affected by the diameter ratio of inner diameter to the outer diameter and by the inclination angle of the load.

**Figure 1.** variation of loads location on the ring footings (Vali, Ramin, et al 2019) [45]
Figure 2. Mechanisms of failure for the rough and smooth footings for $\phi = 35^\circ$. (Vali, Ramin, et al 2019) [45]
7. **Light Points in Literature**

Throughout the reviewing of most studies on ring footing, several points have been noticed. Several studies have been performed experimentally on small scale physical models and others studied this issue numerically. Most of the studies are performed statically and little studies were done under dynamic loading. Also, scarce studies done on the impact of eccentric load on the behavior of ring footing. Little studies are available on studying the effect of soil reinforcement on the performance of ring footing. All the aforementioned studies are close to the finding that the radii ratio playing a
significant role in bearing capacity and settlement of ring footings. They found that the radii ratio of 0.4 is the optimum ratio beyond which the bearing capacity reduced clearly. Other important factors that focused on in the previous studies are the bearing capacity factors. Most of the published researchers refer to that Ny is an essential factor that affects on the bearing capacity of rough ring footings on sand soil especially when the radii ratio below 0.5, while for smooth footings marginal effects were observed with the changes in radii ratio. It is important to note that neither static nor dynamic or quasi-static studies have shown to spotlight on the effect of soil layering on the behavior of ring footings loaded concentric or eccentrically.

7. Conclusions

1- Most researchers who studied the bearing capacity of ring footings noticed that the bearing capacity of the ring footing affected severely by the maximum radius ratio of the ring and found that the best radius ratio of footings that given the highest bearing capacity was 0.4. and after this value, bearing capacity of ring footings decreased linearly. several researchers gave different values for the optimum radii ratio but very close to to the 0.4 that maybe because of the deference of condition of the studies

2- The density of soil influenced the bearing capacity of footing whereas when the ring footings resting on loose sand soil the ultimate bearing capacity of footings decreased when inclination and eccentricity of loads increased but this reduction became less when the ring footing resting on soils compacted randomly. Bearing capacity increased with an increased internal friction angle of the cohesiveness soil that the ring footings resting on it

3- Using geogrid to reinforce the soil leads to increase bearing capacity and decreased settlement therefore the percentage of improvement depends on the location and size of reinforcement as well as several layers of geogrid.

4- Optimum size and orientation of reinforcement layer represented the main factor to increase the bearing capacity and minimize the settlement for the ring footing resting on sandy soil reinforced with geogrid, finally, the researchers found that the embedment depth for one layer of reinforcement that gave the optimum value of bearing capacity and settlement was 0.32Do and for two-layer was 0.3 Do, the space between two-layer equal 0.32Do, and found the size of geogrid reinforced sand soil equal to 4Do and 3.5Do for one and two-layer respectively.

5- The factors of bearing capacity increases with decreased the ratio of radius of the footing that means increased the surface area of the ring footing especially the Nγ factor, that because the Nγ depends on the friction between the footing surface and the soil so that this factor increased with decreased ratio of the radius and angle of the friction especially when using rough ring footing surface.

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