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Ring Footing Bearing Capacity Constructed on Medium Dense Sandy Soil Treated by Kerosene

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ABSTRACT

This research discusses the behavior of footings with inner diameter to outer diameter ratios of (D_{inner}/D_{outer}= 0, 0.2, 0.3, and 0.4) constructed on sandy soil taken from Tikrit. The sandy soil with a relative density of 50% was treated with kerosene according to footing depths with footing diameter to outer diameter ratios of ($D_{footing}/D_{outer}$= $0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$) for time durations (2, 5.3, and 10.28) minutes. The times were determined according to a preliminary test to determine the penetration depth of kerosene in soil per minute. The tests were conducted on dry sandy soil ($D_{footing}/D_{outer}$= 0) as a reference for comparison with the kerosene-treated sandy soil ($D_{footing}/D_{outer}$= $0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$). Sixteen tests were conducted using a steel test setup of dimensions 900×900×600 mm. The results showed that the bearing capacity of the ring footings was better than that of the circular footings. In the sandy soil kerosene-treated conditions, there were better results compared to the dry sandy soils. For both dry and kerosene-treated soil conditions, the footing with (D_{inner}/D_{outer}= 0.4) achieved the ultimate bearing capacity. Due to the influence of kerosene on increasing the cohesion of the soil particles, the best depth for all the footings was ($D_{footing}/D_{outer}$= $1D_{outer}$).

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1. INTRODUCTION

The bearing capacity of unsaturated kerosene-polluted sandy soil was investigated by [1]. The kerosene content in the test samples varies from zero to 6%, based on their test results, they concluded that kerosene pollution significantly reduced the bearing capacity of the sandy soil. In research [2], ring footings are considered more economical for providing support for axis-symmetric structures such as bridge piers, water tower structures, transmission towers, silos and chimneys, the maximum bearing capacity of the ring footing is reached when the ratio of the inner diameter to the outer diameter is equal to 0.4, this may be due to the fact that the increase in the ring size of the foundation decreases with the ring width. In research [3], using the finite element technique with the (ELPLA) program and two variables, the ratio of the inner diameter to the exterior diameter and the friction angle, the study concluded that the best bearing capacity occurs when the ratio of the diameters is (D_{inner}/D_{outer}= 0.2-0.4) and the ideal friction angle is 30-35 degrees. [4] The researchers studied how to implement circular and ring footings on reinforced sand, with multiple layers of geogrid, and using different depths and distances between the layers on which the foundations are built, the results of the study showed that the number of reinforcement layers (N) decreases with increasing depth of the foundation ($D_{footing}/D_{outer}$) and that the optimum value of reinforcement layers for depth ($D_{footing}/D_{outer}$= 0) is (N=4) and for depth ($D_{footing}/D_{outer}$ = $0.5D_{outer}$ and $1D_{outer}$) is (N=3) and that the highest bearing capacity was achieved at a diameter ratio (D_{inner}/D_{outer}) of (0.4), and as the diameter ratio increases beyond (D_{inner}/D_{outer}= 0.4), the bearing capacity begins to slowly decrease. Moreover, research [5] used circular and ring footings based on sandy soil with ratios of diameter (D_{inner}/D_{outer}) of (0.3, 0.4, and 0.5) and depth to diameter ratios ($D_{footing}/D_{outer}$) of (0, $0.5D_{outer}$, and $1D_{outer}$), the results of the research showed that the bearing capacity of the circular footing and ring footings reaches its maximum limit when the radius ratio is (D_{inner}/D_{outer}) of (0.4), they also found no impact of the footing depth or the internal friction angle on the perfect ratio of the circular footings. Research [6] studied the theoretical method to calculate the value of bearing capacity by using the ABAQUS computer program to compare with the laboratory tests, the soil was sand with relative densities of 30, 50, and 70%, the circular footing had diameters of 75 and 100 mm, a box with dimensions of 620 x 620 x 500 mm was used to conduct the laboratory experiments, also, the results showed good agreement between the results of the theoretical method and the laboratory results, as it showed that with increasing sand density, the value of the bearing capacity rises, bearing capacity decreases with a decreasing diameter of the circular footing, the bearing capacity decreases. Research [7] investigated the behavior of the ring footing on multi-layered soil using the program Plaxis 2D and concluded that the bearing capacity increases with the increase in the ratio of the inner diameter to the outer diameter of the ring footings until it reaches 0.4, the bearing capacity is affected by the depth of the layers. If there is a weaker layer under the stronger layer, the bearing capacity decreases with the increase in the ratio of the diameter of the ring footings. Moreover, [8] the researchers conducted an experimental study on the settlement and bearing capacity changes of ring footings with different internal diameters and contact surface areas, the results showed comparison with the results obtained by applying the Terzaghi equation for bearing capacity, the experimental results showed that the bearing capacity was highest at a diameter ratio of 0.375, and then the bearing capacity decreased sharply at the diameter ratios of 0.555 and 0.8, this means that the load-bearing performance and stability of foundations decreased significantly with the increase of the ring base diameter ratio, the researchers concluded that the ring base diameter ratio should be around 0.375 to ensure good bearing capacity and stability. Research [9] studied the influence of kerosene on two forms of poorly graded sandy soil (S1 and S2), a direct shear test was performed on the behavior of both (S1 and S2) before and after mixing, the tests were conducted on S1 with 3% kerosene and S2 with 6% kerosene. [10] Ring footings are used in tanks, high-rise transportation towers, and silos because they are subjected to horizontal loading (wind load), many studies have been conducted regarding the bearing capacity and settlement of ring footings, generally, researchers in this field have used the finite element technique to evaluate the bearing capacity of various ring footings and have examined the behavior of ring footings experimentally under different conditions and parameters, including varying diameter ratios, soil type, and loading, they often use geogrids to determine the effect of soil reinforcement on the bearing capacity and settlement of ring footings. Moreover, [11] the researchers investigated the behavior of square footings resting on gypseous soil contaminated with kerosene percentages (5%, 10%, 15%, and 20%) and soil thicknesses ($D_{footing}/D_{outer}= 0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$), the results of this study showed that dry gypseous soils polluted with kerosene did not show an improvement in the bearing capacity and stability, while wet gypseous soil contaminated with kerosene may show a significant improvement in its bearing capacity and stability. In research [12], they studied the bearing capacity of a circular footing built on low gypseous content of soil, the experiments were conducted before and after the improvement using two different methods, the first method was using compressed cement dust (Casel), and the second method was using biaxial geogrids to reinforce the gypseous soil, they concluded from this study that the confined soil in the first method has a bearing capacity ratio BCR when the depth is equal to twice the radius (D= 2R) greater than the BCR values that were concluded from the second method when the soil was reinforced with a single layer, however, when the soil was reinforced with two or three layers, it led to a greater improvement than using cement dust. [13] studied the bearing capacity of ring footings on sandy soils and concluded that the bearing capacity rises with rising depth and the ratio (D_{inner}/D_{outer}) of ring footings, they also concluded that the ring footing showed the highest bearing capacity at a diameter ratio ($D_{inner}/D_{outer}= 0.4$). Moreover, [14] studied the behavior of ring footings resting on low gypseous and high gypseous soils, and the results were compared with the circular footing, it was found that the value of the bearing capacity of ring footings built on high and low gypseous soils at depths ($D_{footing}/D_{outer}= 0.5D_{outer}$ and $1D_{outer}$) affected by different ratios contrasts to depth ($D_{footing}/D_{outer}= 0.0$), and the good ratio for ring foundations was ($D_{inner}/D_{outer}= 0.4$). In research [15] the researchers studied the several laboratory tests of the loads applied to circular and ring foundations resting on sandy soil of different densities (loose, medium, and dense) and footings reinforced with geogrid, they concluded that the best value of bearing capacity and minimum settlement was for ring foundations with an internal diameter to external diameter ratio of 0.45 for dense sand and 0.4 for medium-density sand and loose sand. The object of this research is to provides a deeper understanding of the behavior of ring footings constructed on sandy soil treated with kerosene. This research studies varying parameters, including the depth of the footing, the ratio of the inner diameter to the outer diameter of the footings, and the timing of adding kerosene at specific depths that were determined through a test to find the depth of kerosene in the sandy soil every minute. Then, tests were conducted to find the bearing capacity and settlement of the sandy soil to which kerosene was added at (2, 5.3, and 10.28 minutes) for depths of footing ($D_{footing}/D_{outer}= 0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$), respectively. The results were then compared with those of dry soil at the depth of the footing ($D_{footing}/D_{outer}= 0.0$). This study provides a more detailed insight into the behavior of ring footings resting on sandy soil treated by kerosene, which is associated with specific kerosene application times and depths.

2. Material and Methods

2.1. Soil sampling

Local river sand was taken from the banks of Tikrit city, Salah al-Din Governorate, in Iraq (34° 43′ 32.7" N; 43° 39 43.2" E). After that, some engineering tests, such as the sieve analysis test, direct shear test and specific gravity test, were conducted to determine the sandy soil properties. Table 1 shows the properties of the used soil.

Table 1. Properties of sandy soil used in the tests.

Properties	Specification	Value
Specific gravity, (G_S)	ASTM D-854	2.65
Coefficient of uniformity, Cu	ASTM D-421	3.06
Coefficient of curvature, Cc	ASTM D-421	0.005
Unified soil classification system	ASTM D-2487	Sp
Maximum dry unit weight, γ_{dmax}(kN/m^3)	ASTM D-1557	16.69
Minimum dry unit weight, γ_{dmin}(kN/m^3)	ASTM D-4254	12.44
γ(kN/m^3) for sandy soil	ASTM D-4254	14.25
c (kN/m^2) for sandy soil	ASTM D-3080	0
ϕ (degree) for sandy soil	ASTM D-3080	31

2.2. The Used Kerosene

Density of kerosene 0.78 g/cm³ (equivalent 7.6 kN/m³), was used in the laboratory experiments. A total of 300 liters of kerosene was used in experiments of this study**.**

2.3. The Used Setup

The setup includes two perpendicular supports for the applied load and a horizontal support to hold the loading arm. The loading arm rotates to apply the load, while the arm rotates to distribute it. Also, contains one dial gauge for measures pressure and two dial gauges for measure settlement. A proving ring is located between the load-bearing arm and the footing model, where it works to pass the applied load from the loading arm to the footing model. The internal dimensions of the setup are 900 x 900 x 600 mm, and the soil to be tested is placed inside. Figure 1 shows the setup.

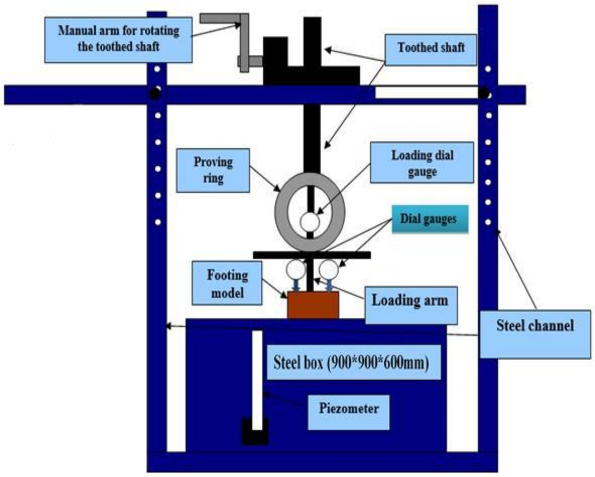

Figure 1. The setup model used in the testing.

2.4. Footing models

In this study, a circular footing with a diameter of 150 mm and a thickness of 15 mm was used, and the ring footings, proposed in this study with inner diameter to outer diameter ratios (D_{inner}/D_{outer}) of (0.2, 0.3, and 0.4). These ratios are most common in use. All footings were made of solid steel. Figure 2 shows the models of the circular and ring footings.

Figure 2. The footing models Proposed for use in this research.

2.5 Experimental setup

The soil volume to be tested (900 x 900 x 600 mm) for depth 500 mm according to the dimensions of the setup used, was split into 5 layers (100 mm), every layer measuring 900 x 900 x 100 mm. The tests are performed as follows:

1. The density was calculated and multiplied by the volume value, to obtain the weight of each layer.
2. Signs were put into the setup for every 100 mm thickness. Soils were then weighed for every layer and put in the test setup according to the marks inside the setup, and containers were placed for every layer.
3. The process of manually compacting the soil, using a hand gavel weighing (1 kg), was used to the extent indicated in the setup. Figure 3 shows the method of manually compacting the sandy soil.
4. Containers of the predetermined size were placed in the sandy soil. As shown in Figure 4, the container was removed after the compaction process and used to take samples of the sandy soil. After compaction, the samples were weighed to calculate the relative density and compare it with the relative density of the soil before compaction.

Figure 3. The method of compaction sandy soil

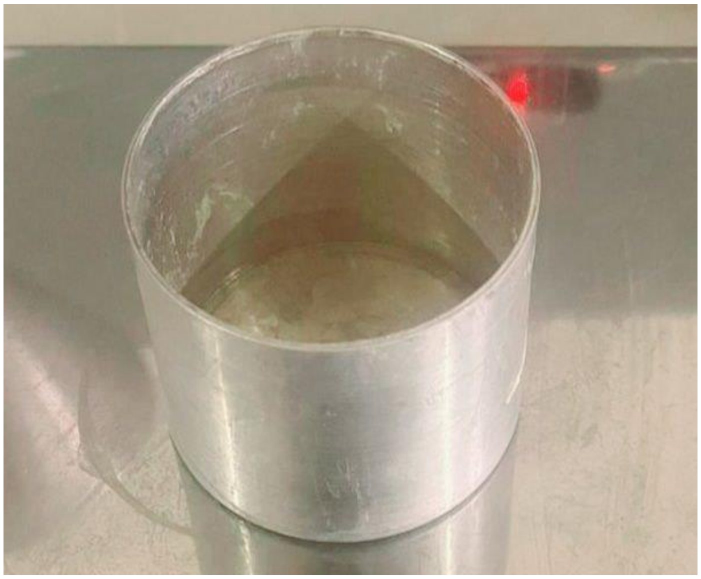

Figure 4. The used container.

5. If the relative density value of the container was less than the required relative density, the number of blows should be increased. If the value was higher, meaning it exceeds the required density, the number of blows should be decreased. The permissible deviation is 1%.
6. The kerosene addition process using a mesh of equal dimensions containing an equal number of droppers, as shown in Figure 5. The tests were conducted by adding kerosene to the soil and recording the depth every minute by conducting an experiment to find the depth of kerosene in sandy soil for every minute. Specific time values for the depths used in this study ($D_{footing}/D_{outer}$ = $0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$) were extracted from the penetration curve and were (2, 5.3, and 10.28 minutes), respectively. These times were adopted for conducting soil treatment tests.

Figure 5. The mesh used to add kerosene.

7. Circular or ring footings were placed on the soil surface in the center. A pressure gauge connected to the setup was placed to read the pressure value, and a settlement gauges were placed on each side of the footing to read the settlement value when the load was transferred. The average of the two readings was taken to determine the settlement value of the foundation. Before conducting the experiment, and to determine the stability of the footing, the bubble level program was downloaded to a phone, and it was placed horizontally on the footing surface, as

shown in Figure 6. The load was then applied, the pressure value was read from the pressure gauge connected to the setup, and the settlement was read from both gauges installed on the sides.

Figure 6. The mechanism used for applying load and measuring load and settlement.

3. RESULTS AND DISCUSSION

The initial test was to determine the penetration time of kerosene into the soil. The penetration depth was recorded every minuteand. Reaching a maximum depth of 23 cm and a maximum time of 11 minutes. Figure 7 illustrates the resulting relationship between depth and time. The measured times were 2 minutes for depth $0.5D_{outer}$, 5.3 minutes for depth $1D_{outer}$, and 10.280 minutes for depth $1.5D_{outer}$. The decrease in kerosene penetration rate with increasing depth is attributed to two main factors:

*Soil properties, the bulk density of soil increases at greater depths due to particle compaction and changes in grain gradation, leading to a decrease in the void ratio and consequently a decrease in permeability.
*Viscosity, the more stable temperature at depth contributes to an increase in the viscosity of kerosene, which hinders the penetration process.

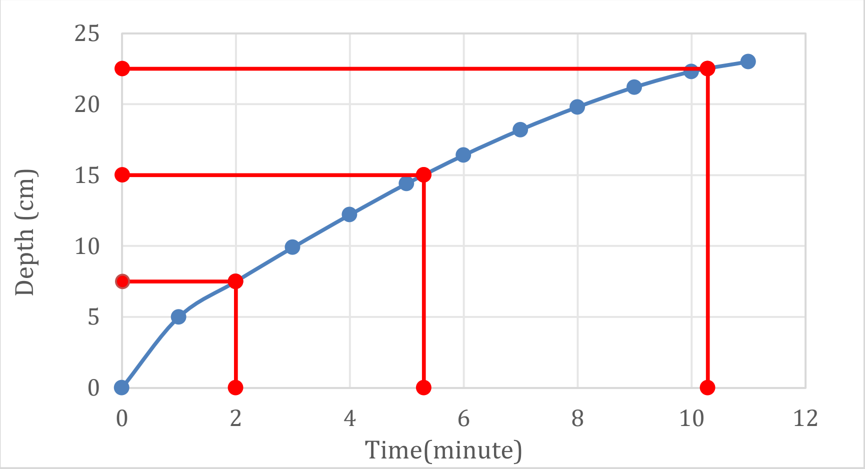

Figure 7. Depth of treated sand with kerosene versus time.

As we also conducted 16 tests (drying tests and kerosene addition tests depending on the time allocated to each depth). Where it was conducted for each of the ring footings, four tests were conducted based on the depth of the footing ($0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$) and according to the specific time periods of each depth (2, 5.3 and 10.28 minutes). The area of the footings was calculated using (1), and the bearing capacity q_u value was calculated using (2).

$$\text{Area}= \frac{\pi}{4}\left(D_o^2 - D_i^2\right) \tag{1}$$

$$q_{u}= \frac{Load}{Area} \tag{2}$$

Figure 8 shows the relationship between pressure and ratio settlement divided by the outer diameter of the footing. Results of dry state tests are in good agreement with the tests of previous studies in terms of the best ring foundation and the best bearing capacity values. Table 2 a comparison was made between the experimental value of the bearing capacity in this current research and previous research, for sandy soil with an average density of 50%, for the circular and ring footings (D_{inner}/D_{outer}= 0, 0.2, 0.3, and 0.4), and for the specified depth ($D_{footing}/D_{outer}$ = 0).

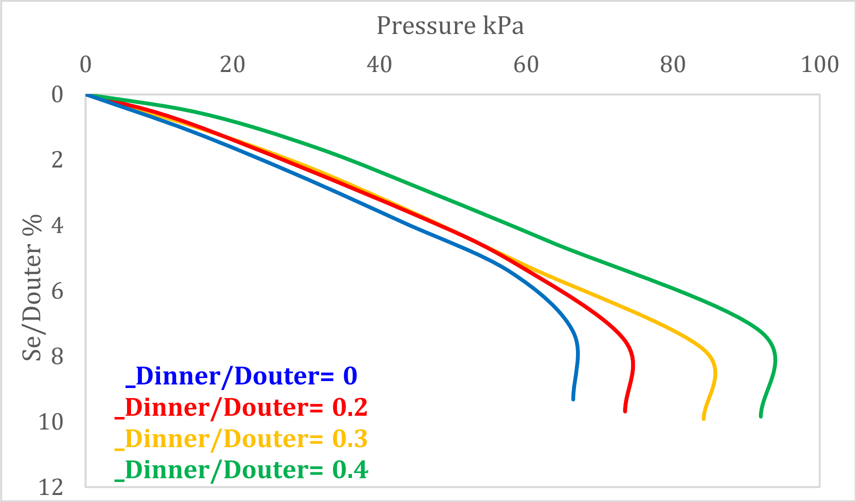

Figure 8. Pressure versus S_e/D_{outer} % for depth of footing ($D_{footing}/D_{outer}$= 0) and different diameter ratios.

Table 2. Comparison of the experimental value of the bearing capacity of the present research with beforehand research for dry sandy soil when ($D_{footing}/D_{outer}$= 0.0).

Ratio of depth of footing $D_{footing}/D_{outer}$= 0.0	**Bearing capacity kPa**							
	Current research				**Beforehand research [13].**			
	D_i/D_o=0	D_i/D_o=0.2	D_i/Do=0.3	D_i/D_o=0.4	D_i/D_o=0	D_i/D_o=0.2	D_i/D_o=0.3	D_i/D_o=0.4
	66.42	73.48	84.19	91.97	72.15	85.24	80.19	85.63

Figures (9-11) show the results of treated soil for the ratio of depth of footings ($D_{footing}/D_{outer}$= 0, $0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$) with different ratios of inner diameter divided by outer diameter (D_{inner}/D_{outer}= 0, 0.2, 0.3, and 0.4). Found that it is improved in bearing capacity at a ratio of depth of footing ($D_{footing}/D_{outer}$= $0.5D_{outer}$) by 30.42%, 54.89%, 67.50%, and 90.99%, respectively, as shown in Figure 9. Also, the values of the bearing capacity for a ratio of depth of footing ($D_{footing}/D_{outer}$= $1D_{outer}$) improved by 52.16%, 63.74%, 81.09%, and 110.58%, respectively, as shown in Figure 10, and the bearing capacity for a ratio of depth of footing ($D_{footing}/D_{outer}$= $1.5D_{outer}$) was improved by 8.68%, 32.76%, 58.44%, and 76.67%, respectively, as shown in Figure 11. All these improvements are compared to the bearing capacity for the soil with the ratio of depth of footing ($D_{footing}/D_{outer}$= 0.0) and the ratio of inner diameter divided by outer diameter (D_{inner}/D_{outer}= 0).

These figures show the relationship between bearing capacity and settlement in each case and that all kerosene addition times were used at specific depths. Showed an improvement in the value of bearing capacity of the sandy soil treated with kerosene and an improvement in reduced settlement compared to the dry sandy soil. This is due to the fact that kerosene increased the cohesive strength of the treated soil. Due to the fact that the sandy soil used is poorly graded and of almost uniform size and there are no small particles to fill the voids. This causes a high ratio of voids, since kerosene is a liquid substance, it fills the pore spaces and forms a thin layer on the surface of the sand grains. This increases the frictional forces between the sand grains. Since sand clearly depends on friction between its grains for the purpose of cohesion, kerosene leads to cohesion between the sand grains, which leads to an increase in the bearing capacity. Table 3 shows the pressure for sandy soil dry and treated with kerosene.

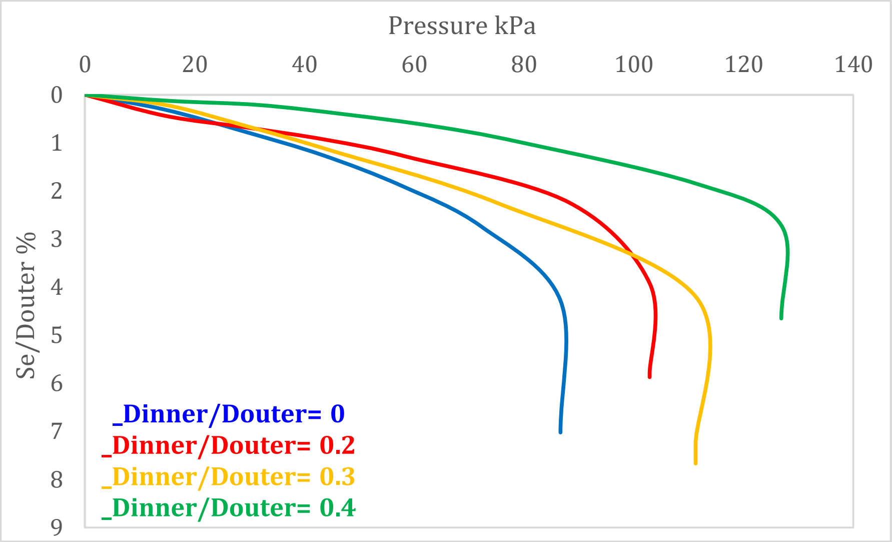

Figure 9. Pressure versus S_e/D_{outer} % for depth of footing ($D_{footing}/D_{outer}$= $0.5D_{outer}$) and different diameter ratios.

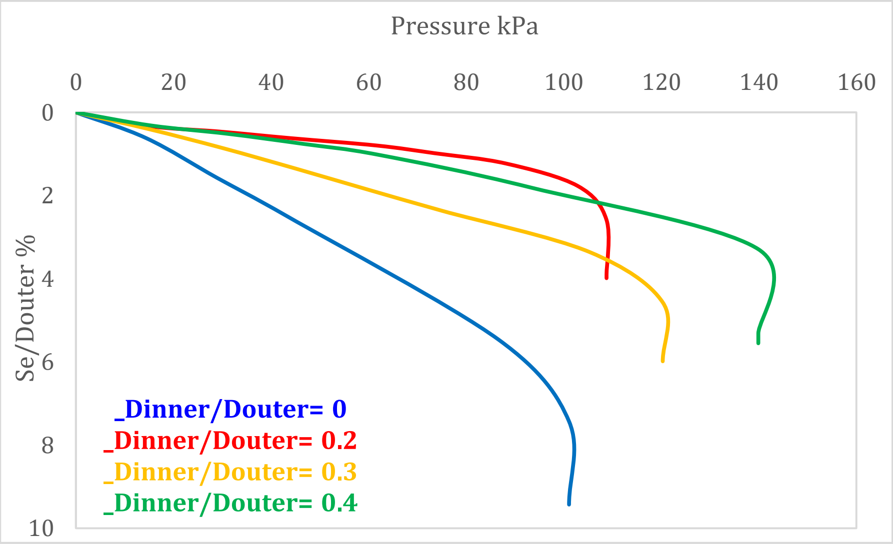

Figure 10. Pressure versus S_e/D_{outer} % for depth of footing ($D_{footing}/D_{outer}$= $1D_{outer}$) and different diameter ratios.

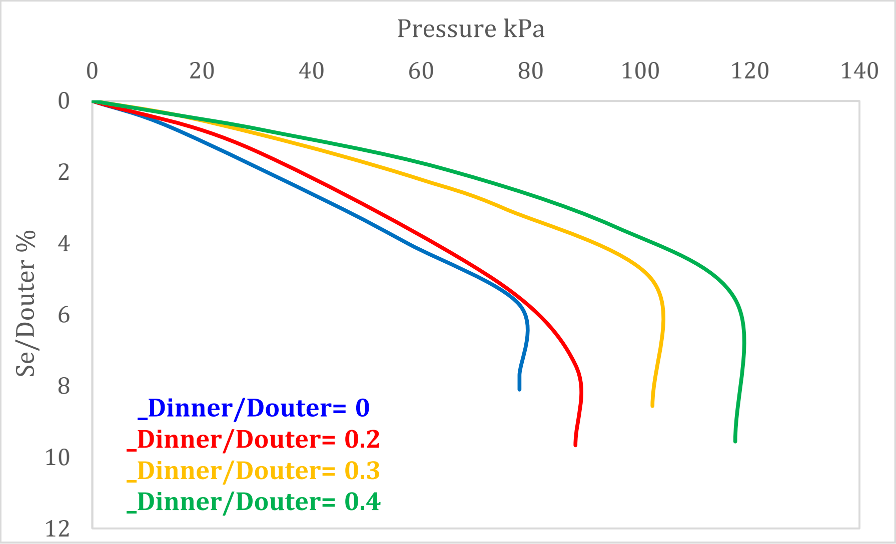

Figure 11. Pressure versus S_e/D_{outer} % for depth of footing ($D_{footing}/D_{outer}$= $1.5D_{outer}$) and different diameter ratios.

3.1 The effect of depth of kerosene on the bearing capacity.

Figure 12. Shows the value the value of the bearing capacity of circular footing and ring footings for a ratio of diameter (D_{inner}/D_{outer}=0, 0.2, 0.3, and 0.4) resting on dry sandy soil with a ratio of depth of footing ($D_{footing}/D_{outer}$=0). In contrast, Figures 13 to 15 show the value of the bearing capacity of the same footings resting on sandy soil treated by kerosene for footing depth ratios ($D_{footing}/D_{outer}$= $0.5D_{outer}$, $1D_{outer}$, and $1.5D_{outer}$). Through pilot tests, it was found that the value of the bearing capacity gradually rises until it attains the value when it is the ratio of diameter (D_{inner}/D_{outer}=0.4), which is the best diameter ratio, as these results are consistent with the research [4, 5, and 13].

This improvement is attributed to the stress distribution mechanism in the ring footing, where most of the footing load is concentrated at the outer effective edge (the region that contributes significantly to shear resistance), reducing stress concentration in the center of the footing. This distribution results in more balanced and distributed stresses in the soil, enhancing the overall shear resistance of the soil.

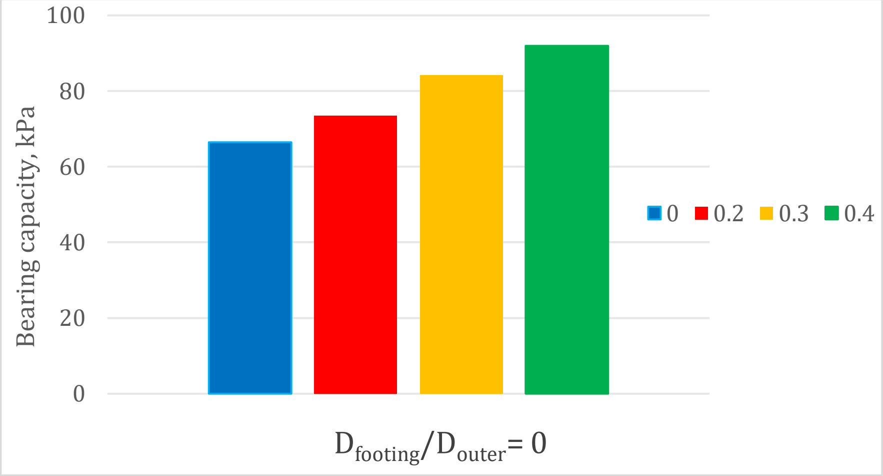

Figure 12. Bearing capacity versus ratio of footing depth ($D_{footing}/D_{outer}$= 0) for different diameter ratios.

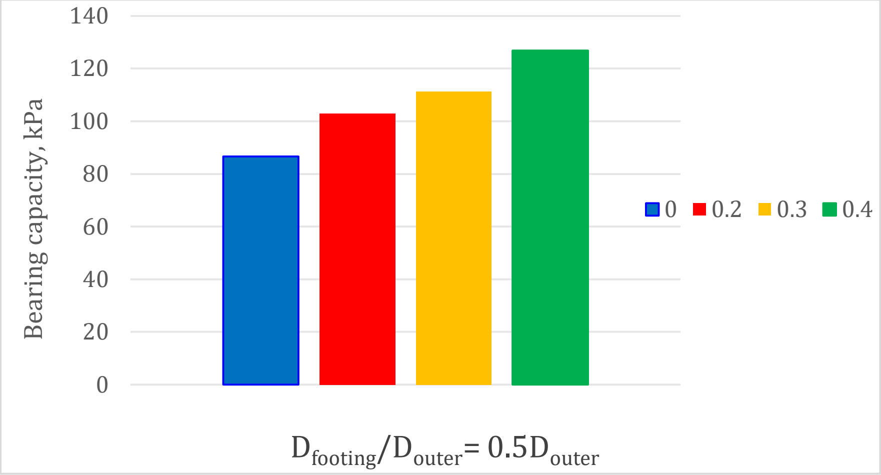

Figure 13. Bearing capacity versus ratio of footing depth ($D_{footing}/D_{outer}$= 0.5D_{outer}) for different diameter ratios.

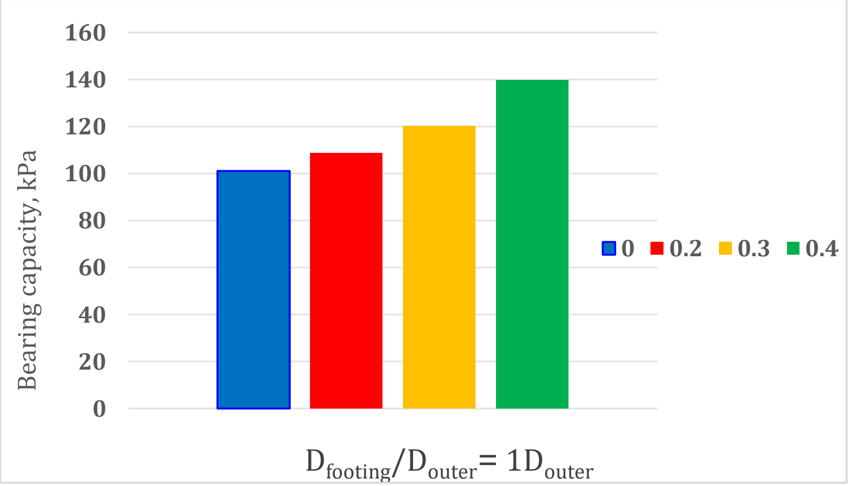

Figure 14. Bearing capacity versus ratio of footing depth ($D_{footing}/D_{outer}$= 1D_{outer}) for different diameter ratios.

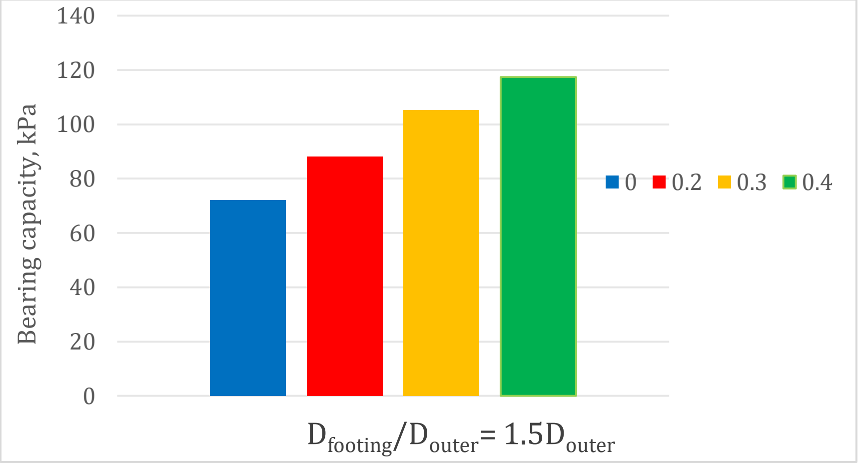

Figure 15. Bearing capacity versus ratio of footing depth ($D_{footing}/D_{outer}$= 1.5D_{outer}) for different diameter ratios.

5. CONCLUSION

1- The bearing capacity of sandy soil treated with kerosene increases with the increase in the depth ratio of the ring footings compared to the circular footing ($D_{in.}/D_{out}$.= 0) and at all the depth ratios ($D_{f.}/D_{out.}$= 0, 0.5, 1, and 1.5).

2- The bearing capacity increases with the increase in the ratio of the inner diameter to the outer diameter of the ring footings, with the maximum bearing capacity being at the diameter ratio ($D_{in.}/D_{out.}$= 0.4). By balancing the load concentration on the effective outer ring and reducing stress from the center, this distribution ensures that the apparent cohesion enhanced by kerosene bears the greater part of the load, increasing the efficiency of the footing in contaminated soils.

5- The good ratio of diameter was determined (D_{inner}/D_{outer}) of (0.4) for the ring footings at all the depths.

6- The good ratio of depth was determined ($D_{footing}/D_{outer}$) of ($1D_{outer}$) for all the ring footings.

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