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Cyclic Settlement of Footings of Different Shapes Resting on Clayey Soil

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K E Y W O R D S

Foundation, shape, clay, cyclic load, settlement..

A B S T R A C T

An experimental investigation is carried out to investigate the impact of the footing shape, when rested on clayey soil under cyclic loading condition. The model footings used in this study are circular, square and the area of footings is fixed. Cyclic load test is carried out on the cohesive soil with three undrained shear strengths (20 kPa, 40 kPa and 70 kPa). Two depths of foundation embedment (at surface and 5 cm) to know the effect of the depths of the foundations on the change of settlement and total vertical stress and two rates of loading (3 mm/sec and 6 mm/sec) are used. It has been observed that the bearing capacity varies in increasing order as Solid, Circular and Square. It is found that the cyclic settlement in the square foundation is less than the circular foundation. The results reveal that the shape of the footing has a significant effect on its bearing capacity and the settlement characteristics. The vertical stress reaches a constant value which is greater below circular footing and it is about (70.9 - 92.7) % greater than below square footing.

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1. Introduction

Design and construction of a proper foundation is a prerequisite step before establishment of any superstructure as it connects the building structure with the ground. Footings serve to distribute the building load to the soil. Foundations are designed in consideration with the soil strength and their various properties. Footings design is specific for each respective building site, depending upon the structural plan and the orientation of the columns in superstructure. It can be designed and oriented in various shapes e.g. circular, square, rectangle etc. Different types of footing having their own merits and de-merits. For example, in case of square and rectangular footing, both are special in ease of constructability, reinforcement placement and placing of concrete. Furthermore, circular type footings are specially used in structures that are circular in plan and the load transfers takes place from external walls to the footings before it gets transferred into the ground. For the calculating the bearing capacity of the footings and analysis of the behavior of soil, load tests are carried out in the field. One such test is PLT (plate load test) which is used to determine the bearing capacity and settlement of the foundation under the load for clayey and sandy soils. But these are costly and also time consuming. Therefore these tests are performed on typical models with surface properties and different sizes for diverse loading states in a laboratory. Based on the values of the engineering properties of soil, the foundation can be designed accordingly. There are numerous methods for increasing the ultimate bearing capacity of the footing and decreasing the soil settlement reduction of the footing. However, large numbers of observations have been adopted for development of the footing behavior. The behavior of rectangular and square foundations on clayey soils were also studied by some researchers like Pathak et al., [1], from the series of laboratory tests they concluded that for the same width of footing the ultimate bearing capacity of footings decreases with increases in Length to Breadth ratio (L/B) of the footing. The bearing capacity value of square footing was found to be more than that of rectangular and circular footings stated that they have same area as that of the square footing. Also as the size of the footing increases the bearing capacity increases, keeping L/B ratio same. Meyerhof [2] gave the corrections in the form of different N values, based on depth and shape of the footing (in addition to the strength ratio of the layers). Factors are immediately concerning of the distance between neighboring foundations. Most previous studies have concentrated on the maximum bearing capacity of interfere strip foundations on un-reinforced soils ([3]; [4]). They incorporated the stress characteristics method to obtain the bearing capacity factor Nc for ring footings (both rigid and smooth). Krishna et al., [5] also studied the performance of square footings reposing on laterally confined sands. Pavan and Aruna [6] studied load-settlement characteristics of square footings reposing on sands whether there is a confinement or not. After conducting a number of experiments, from the load-settlement characteristics they stated that the load carrying capacity of the footing resting on the Confined cells that is located at deepness that equals to footing’s width comparable to the loading that was conducted by footings in the uncovered case. Going through the literature and the works of the previous researchers it was necessary to investigate the shape’s influence of the footings on its bearing capacity. Fattah et al. [7] conducted a study to investigate the experimental behavior of dry sandy soil under foundations subjected to cyclic load. It was concluded that the more the depth of footing (D_f increasing), the soil settlement decreases. The objective of the present work is an investigation of the effect of footing shape on the cyclic behavior of footings on clayey soil. Model tests are carried out instead of small scale laboratory tests.

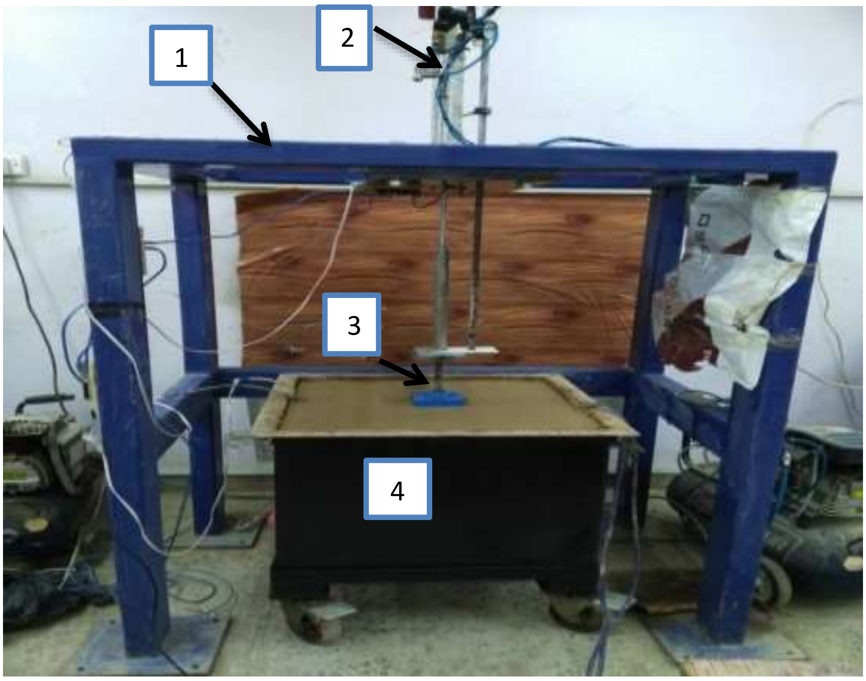
2. Experimental Work

I. Soil index characteristics

Brown clay soil from a site south of Baghdad city near Al-Rashid camp. Typical testing was performed to decide the soil's physical properties. Table 1 shows the information of that. According to the Unified Soil's Classifying System U.S.C.S, the soil was categorized to be (CL).

II. Loading setup and manufacturing design

To consider the impact of various parameters on the periodic transport of loads due to traffic in sandy soils, it is important to mimic the cases as soon as potential to those happening within the area. To achieve this goal, a special testing device and other accessories are designed and manufactured. The manufactured loading machine has the ability to apply diverse periodic loads from 134 N to 422 N as utilizing (cylinder 1) and starting from 328 N to 1031 N as utilizing (cylinder 2). Figureure 1 shows the overview of the manufactured device. The produced load machine contains components as explained below: Steel load framing, 2. Axial load system, 3. Model footings, in addition to 4. Steeling box (test container).



Figurer 1: Overall outlook of the produced device: 1. Steel load framing, 2. Axial load system, 3. Model footings, 4. Steeling box (test container)

Table 1: Physical characteristics of the Clayey Soils

Test	Value	Specification
Liquid limit (LL), %	43	ASTM D 4318-(2010)[8]
Plastic limit (PL), %	19	ASTM D 4318-(2010)[8]
Plasticity index, %	24	ASTM D 4318-(2010)[8]
Specific gravity (Gs)	2.67	ASTM D 854-(2010)[9]
Gravel %, > 4.75 mm	0	ASTM D 422-(2010)[10]
Sand %, 0.075-4.75 mm	3	ASTM D 422-(2010)[10]
Silt %, 0.005-0.075 mm	35	ASTM D 422-(2010)[10]
Clay %, < 0.005 mm	62	ASTM D 422-(2010)[10]
Activity	0.39	ASTM D 422-(2010)

III. Model footings and steeling box

Two steeling foundations of 20 mm thickness had been utilized having dissimilar lengths to circular footings that have diameter 113 mm as well as square footings with (100 mm×100 mm) lengths. A soil box had been utilized having interior lengths (600*600) mm as well as 500 mm deepness manufactured to be single piece; the box was produced with (6 mm) thick steel plate. A201TEKSCAN's ultra-slim flexible pressure sensors and 1,500 kPa flexiforce sensors calculate the stress straight below the footings. These sensors feature a width of 14 mm, a thickness of 0.203 mm, and a sensor area of 9.53 mm in diameter.

IV. Preparation of the test model

The test was done at different liquidity indices conformable to Cu= 20 kPa, 40 kPa and 70 kPa. A quantity of 250 kg of air-dried and pulverized clay sample was mixed with the required quantity of water. The mixing procedure was conducted by using a large mixer produced for this purpose; each 25 kg of dry soil was mixed separately till completing the whole quantity. After thorough mixing, the wet soil was kept inside tightened polythene bags for a period of 48 hours

Figurer 2: Preparation of Clayey Soil by Grinding

This period was enough to get uniform water content. After that, the soil was placed in a steel container (500*600*600) mm in 10 layers, each layer was pressed gently via using a wooden tamper, then the leveled layer was tamped gently with a manufactured metal hammer of 9.87 kg and dimension of (75*75) mm. Care was taken to avoid the entrapped air by tapping the clay layers gently with a wooden plank.

Figurer 3: Placing the Clay in the Box and Compaction Gently by Wooden Tamper to Avoid the Entrapped Air

This process continues for the 10 layers till reaching a thickness of 500 mm of soil in the steel container. After completing the last layer, the top surface was leveled to get as near as possible a flat surface, which is then covered with polythene sheet to prevent any loss of moisture.

Figurer 4: Surface Adjustment of the Model and Carrying the Model into the Load Setup.

A wooden board of similar area to that of the surface area of bed soil is placed, and then a setting pressure of 5 kPa was applied. The bed was left for a period of 48 hours to regain part of its strength. After preparing the model for test, it was carried and centered in the load setup and then the load spreader beam was lowered carefully until it touched the footing. After that, the load was adjusted by the pressure gage as required and then the test was started.
Vertical settlements were measured by linear variable displacement transformer (LVDT) which was used to measure the movement under the shaft. Stress transmitted developing from the applied load was recorded by two pressure cells installed on the clay surface at different depths (100 and 200) mm in the clay layer, they were placed at specific locations to measure the stresses transmitted to the clay layer.

Figurer 5: Installing Pressure Cells and Piezometer and Checking the Distance from the Surface to the Sensors Equal to 2B= 20 cm

The layout of the pressure cells distribution was varied since the footings were laid at different depths; (at surface, depth 50 and 100) mm. Figureures (2) to (7) show the sequence of model preparation process.

Figurer 6: Installing Pressure Cells and Piezometer and Checking the Distance from Surface to Sensors Equal to B= 10 cm

Figurer 7: Footing at Surface and at Depth 5 cm

3. Model Test Results under Cyclic Load

A set of 43 model testing was conducted for clayey soil to be referred to beneath cyclic loading on models resting on clay prepared at three different undrained shear strengths; 20 kPa, 40 kPa, and 70 kPa, these strengths correspond to soft, medium and stiff clay, in turn. In all model testing, the failing was described to be the loading that causes a settling corresponds to 10% to the footing's width based upon the failing standard stated according to Terzaghi, [11]. For the purpose of selecting the value of the applied loading upon the footing's model, the theoretic final bearing capability of the footings had been measured consistent with variables; undrained shear strength, depth, width as well as foundation's shape. The measurements had been done depending upon Hansan equality:

Figurer 7: Footing at Surface and at Depth 5 cm.

3. Model Test Results under Cyclic Load

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Table 2: Summary of the Calculated Theoretical Static Bearing Capacity Values

Load applied (N)	Qall (N), (Theoretical)	$q_{ult.}$ (kPa), (Theoretical)	D_f (mm)	Undrained shear strength (cu), kPa	State of soil	Type of foundation
Square	Soft	20	0	123.36	493.44	246.72
			50	144.703	578.812	246.72
	Medium	40	0	246.72	986.88	493.44
			50	288.623	1154.492	493.44
	Stiff	70`	0	431.76	1727.04	863.52
			50	504.503	2018.012	863.52
Circular	Soft	20	0	123.36	494.85	246.72
			50	142.337	570.984	246.72
			100	161.315	647.116	246.72
	medium	40	0	246.72	989.72	493.44
			50	283.892	1138.834	493.44
			100	321.065	1287.951	493.44
	Stiff	70	0	431.76	1732	863.52
			50	496.224	1990.602	863.52
			100	560.688	2249.203	863.52

$$q_{ult} = c\ Nc\ Sc\ dc + q\ Nq\ Sq\ dq + 0.5\ \square\ B\ N\gamma\ S\gamma\ d\gamma \quad (1)$$

AS:

q_{ult} = ultimate bearing capability,
c = soil's cohesion,
q = surcharge (γD_f),
D_f = footing's depth,
Nc, Nq and Nγ = bearing capability factors,
B = foundation's width,
γ = soil's unit weight,
Sc, Sq, Sγ = shape factors, and
dc, dq, dγ = depth factors,

Table 2 displays the outcomes of qult, qall and undrained shear strength calculated through the straight shear tool along with the loading used in experimental. It should be noted that, the safety factor equals 2.5.

I. Impact of shape of foundations on settlement

Figureures 8 to 12 present the effect of foundation shape on the settlement. From the Figureures, it can be observed that the settlement in square footings can be smaller than settlement in circular footing and this agrees with prior researches; the settlement for a square footing is smaller than the one of a circular settlement at all times of cyclic loading. Not just the settlement of the square footings can be smaller yet in addition the bearing capacity of the square footings is higher than the one of circular footings.

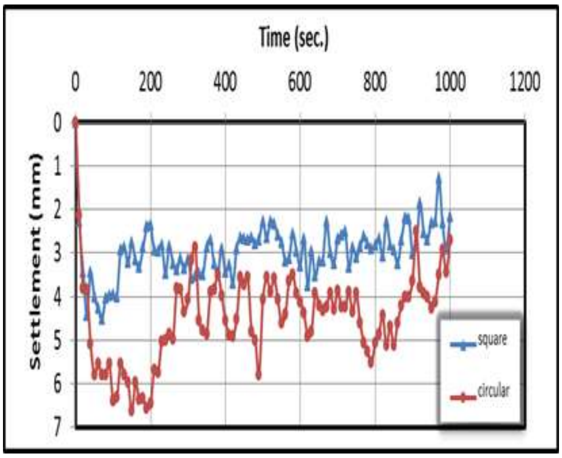
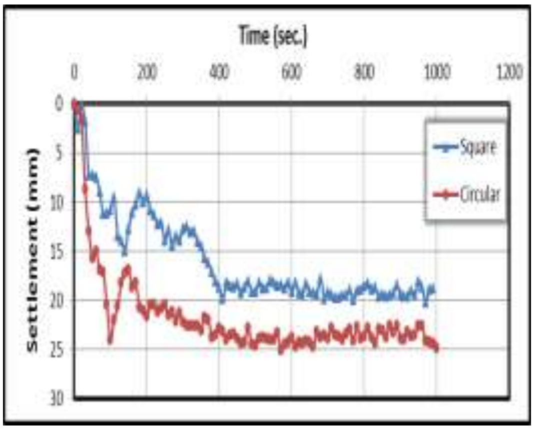
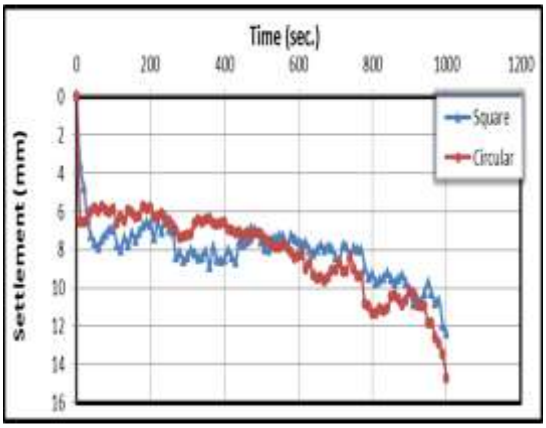


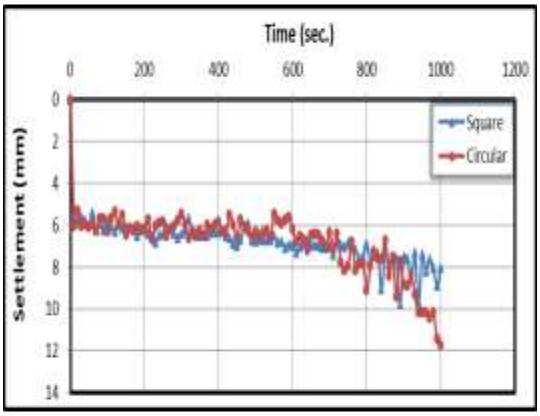
Figure 8: Settlement Change with Time when the D_f = 0, cu = 20 kPa and Velocity = 6 mm/sec



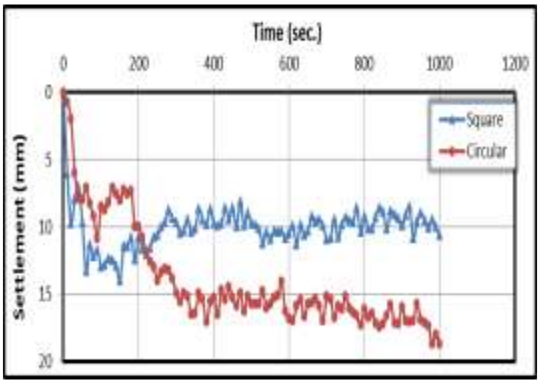
Figurer 9: Settlement Change with Time when the D_f = 0, cu = 70 kPa and Velocity = 6 mm/sec.



Figurer 10: Settlement Change with Time when the D_f = 0, cu = 40 kPa and Velocity = 6 mm/sec.



Figurer 11: Settlement Change with Time when the D_f = 5 cm, cu = 40 kPa and Velocity = 6 mm/sec.

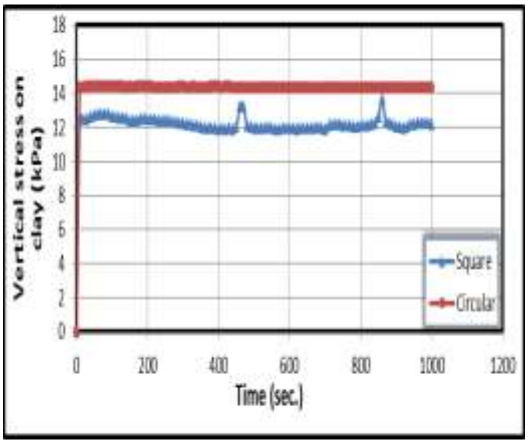


Figurer 12: Settlement Change with Time when the D_f = 5 cm, cu = 70 kPa and Velocity = 6 mm/sec.

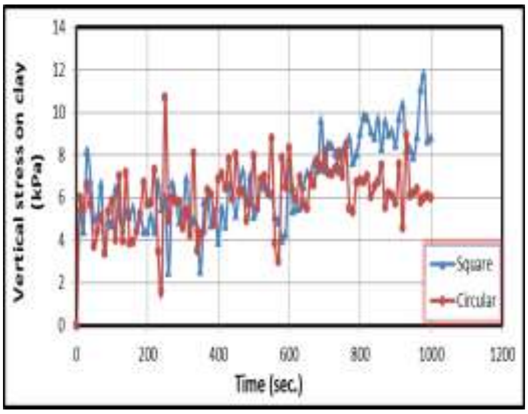
The cyclic settlement in circular footing is higher than settlement in square footing by about (49.4-68.2) %.

II. Effect of foundation shape on the transmitted vertical stress

As shown in Figureures 13 to 23, all the values of the average vertical stress below circular footing are higher than those below square footing in all soft, medium and stiff clays and at all depths (footing at surface or at depth 5 cm). This is because the settlement of circular footings is higher than square footings, so the applied loading closes somewhat of a place sensor. Vertical stress reaches a constant value which is greater in circular footing by about (70.9 - 92.7) % than square footing.



Figurer 13: Vertical Stress Change with Time when cu = 20 kPa, D_f = 0 cm, Velocity = 6 mm/sec at Depth 10 cm



Figurer 14: Vertical Stress Change with Time when cu = 20 kPa, D_f = 0 cm, Velocity = 6 mm/sec at Depth 20 cm.

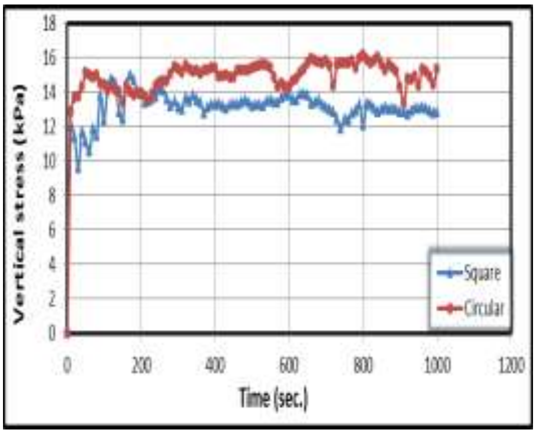


Figure 15: Vertical Stress Change with Time when cu = 20 kPa, D_f = 5 cm, Velocity = 3 mm/sec at Depth 10 cm

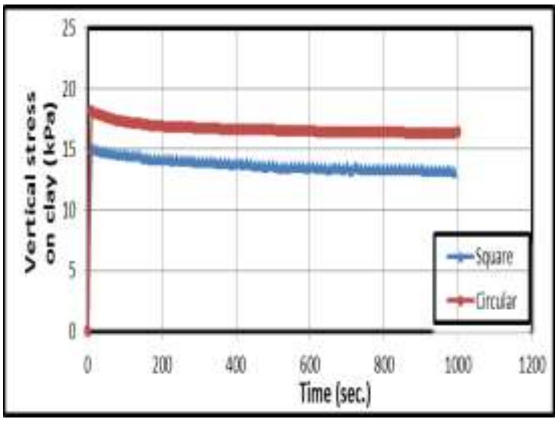


Figure 16: Vertical Stress Change with Time when cu = 40 kPa, D_f = 0 cm, Velocity = 6 mm/sec at Depth 10 cm.

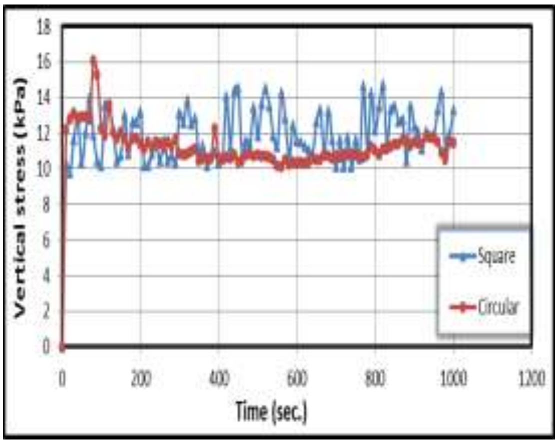


Figure 17: Vertical Stress Change with Time when cu = 40 kPa, D_f = 0 cm, Velocity = 6 mm/sec at Depth 20 cm

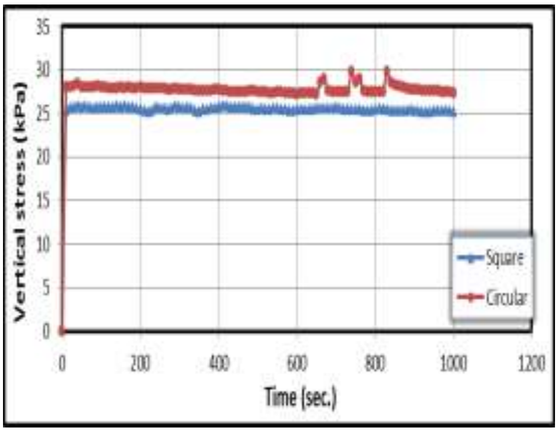


Figure 18: Vertical Stress Change with Time when cu = 40 kPa, D_f = 5 cm, Velocity = 6 mm/sec at Depth 10 cm

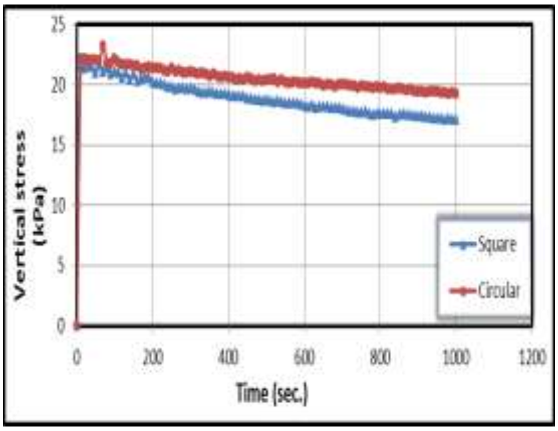


Figure 19: Vertical Stress Change with Time when cu = 40 kPa, D_f = 5 cm, Velocity = 6 mm/sec at Depth 20 cm

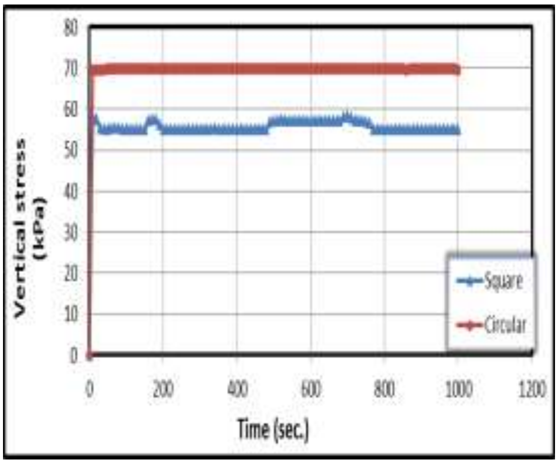


Figure 20: Vertical Stress Change with Time when cu = 70 kPa, D_f = 0 cm, Velocity = 6 mm/sec at Depth 10 cm

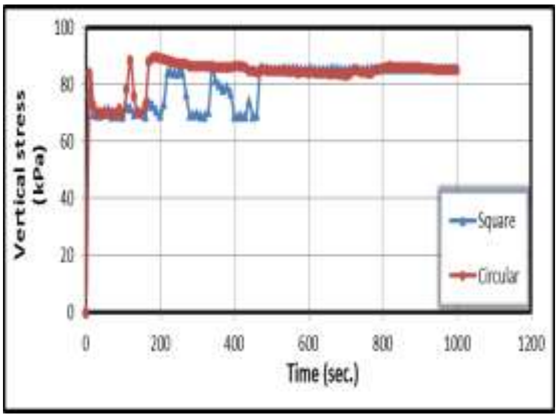


Figure 22: Vertical Stress Change with Time when cu = 70 kPa, D_f = 5 cm, Velocity = 6 mm/sec at Depth 10 cm

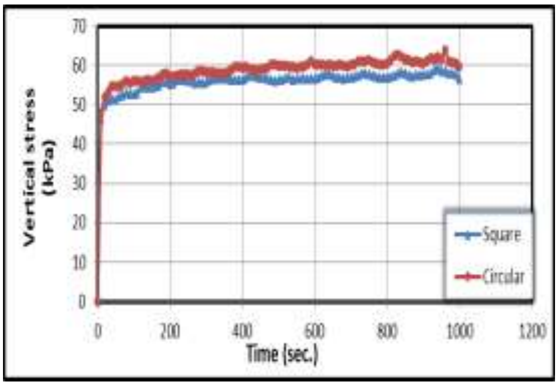


Figure 23: Vertical Stress Change with Time when cu = 70 kPa, D_f = cm, Velocity = 6 mm/sec at Depth 20 cm

Table 3: Values of the Cyclic Load Settlement

Df (cm)	Cu = 20 kPa	Cu = 40 kPa	Cu = 70 kPa
Velocity (6 mm/sec)			
	Square footing		
	Cyclic load settlement (mm)		
At surface	4.53	12.37	20.18
5 cm	-	9.82	14.01
	Circular footing		
	Cyclic load settlement (mm)		
At surface	6.64	14.74	25.12
5 cm	-	12.0	18.71

Table 4: Values of the Maximum Vertical Stress in the Clay

Df (cm)	Cu = 20 kPa	Cu = 40 kPa	Cu = 70 kPa
	Velocity = (3 mm/sec.)		
	Square footing		
	Max. vertical stress (kPa) at depth 10 cm.		
5 cm	14.97	-	-
	Circular footing		
	Max. vertical stress (kPa) at depth 10 cm.		
5 cm	16.15	-	-
	Velocity = (6 mm/sec.)		
	Square footing		
	Max. vertical stress (kPa) at depth 10 cm.		
At surface	13.65	15.07	58.17
5 cm	-	25.88	85.75
	Square footing		
	Max. vertical stress (kPa) at depth 20 cm.		
At surface	-	14.71	38.99
5 cm	-	21.66	59.31
	Circular footing		
	Max. Vertical stress (kPa) at depth 10 cm.		
At surface	14.42	18.11	69.74
5 cm	-	29.74	89.42
	Circular footing		
	Max. vertical stress (kPa) at depth 20 cm.		
At surface	-	16.07	39.77
5 cm	-	23.26	63.58

The result obtained from the model test performed by Patel and Bhoi [12] on the different footings to examine the influence of footing‘s shape on the bearing pressure and settlement showed that the ultimate bearing capacity of the footing increases in order circular, square and rectangle, relative density being 80% . Similar trend is observed for 60% relative density. It was observed that the bearing pressure increases with increase in area of the footing. In case of rectangle footing designed as L=1.5B and 2B of the square footing, result obtained is fascinating; the bearing pressure increases and reaches maximum for the footing having L=1.5B, after that it decreases for L=2B. Bearing pressure for the square footing having width 15 cm is higher than that of circular footing having diameter of 15 cm. This is due to more confining effect in case of square footing than circular footing because for the given lateral dimension, the area of square is higher than that of the solid circle. It is noticed that low frequencies lead to the lowest cyclic strength and more degradation effects than higher frequencies. Tables 3 and 4 summarize the value of the maximum cyclic settlement and maximum total vertical pressure

4. Conclusions

1. The cyclic settlement of square footing on clayey soil is smaller than the settlement of circular footing at all times of cyclic loading.
2. Not just the settling of the square footings can be smaller yet in addition, the bearing capability of the square footings is higher than the one of circular footings.
3. The average vertical stress below circular footings is higher than that below square footings in all soft, medium and stiff clays and at all depths (footing at surface or at depth 5 cm).
4. The vertical stress reaches a constant value which is greater below circular footing and it is about (70.9 - 92.7) % greater than below square footing.

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