Experimental and Numerical Analysis on Bearing Capacity of Conical Shell Strip Footing on Reinforced Clay

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Abstract- **Shell foundations are in general economic alternatives to plain shallow foundations in situations involving heavy super structural loads to be transmitted to weaker soils. The use of shells in foundations, as in roofs, leads to considerable saving in materials and labour. The resulting economy is substantial in the developing countries of the world. In this paper we are considering the conical shell strip footing , which is suitable for water tanks and tower like structures. The ultimate load capacities of shell foundations on unreinforced and reinforced clay determined by laboratory model tests.**

Models of shell footing and flat footing constructed along with a suitable testing tank. The soil needed for the study collected from the Edathva region of Alappuzha district, Kerala. Laboratory tests conducted inorder to determine the engineering properties of soil. The model test results verified using finite element analysis using PLAXIS Software. It was found that the load carrying capacity of shell strip footing over reinforced sub grade is higher than both the shell strip footing without reinforcement and flat strip footing. So shell strip footing over reinforced sub grade possess lowest settlement and maximum Bearing Capacity.

Keywords- Axisymmetric Shells, Bearing Capacity, Conical Shell Strip Footing, Flat Strip Footing, Geogrid, Settlement, Soft Clay

I. INTRODUCTION

Construction of a structure on soft soils will always be a problem to civil engineers. Besides having low bearing capacity, soft soils are also high in compressibility that may result in large settlement, both total and differential settlement. Shell foundations are considered as the best shallow foundations for transferring heavy loads to weak soils, where a conventional shallow foundation undergoes excessive settlement. If in a highly compressive soil, conical shell strip footings are provided along with a suitable reinforcement, the settlement can again be reduced. The earth reinforcement using geogrid is a common method of ground improvement used nowadays. An added advantage is the scope they offer for precasting, low weight makes even large size shell footing amenable to precasting.

Shells are relatively newcomers in the realm of foundations starting out in the 1950s only. However, like in the superstructure, they have a forerunner in the form of brick arches inverted and used in foundations, in some parts of the world, including India, from very early times. Shell footing is limited to a few geometries, such as conical, pyramidal, hyper and spherical footings. The use of shells in foundations, as in roofs, leads to considerable saving in materials, and in the case of shells with the straight-line property and axisymmetric shells, this is achieved without much extra input of labour. The straight-line property of shell helps for easy shuttering. So no need of skilled labours for shuttering.

AbdulhaHz O. Al-Shenawy & Awad A. Al-Karni [1] studied calculation of the ultimate bearing capacity of shallow footing on a two layered system. The paper presents a detailed parametric study of the design parameters including the effect of angle of friction, the ratio of the thickness of sand layer to the footing width, the ratio of the depth of embedment to the footing width, and the ratio of the clay soil cohesion to the product of the clay unit weight by the footing width.

Murat Ornek, Ahmet Demir, Mustafa Laman And Abdulazim Yildiz [8] studied numerical predictions of the scale effect for circular footings supported by natural clay deposits. The results of this study showed that the stabilization had a considerable effect on the bearing capacity of the circular footings. The Bearing Capacity Ratio (BCR) was defined to evaluate the improved performance of the reinforced system. It was found that the bearing capacity ratio of the partially replaced, natural clay deposits increased with an increase in the footing diameter and there was no significant scale effect of the circular footing resting on natural clay deposits.

W.R. Azzam , A.M. Nasr [13] studied , the ultimate load capacities of shell foundations on unreinforced and reinforced sand by laboratory model tests. A test box, having inside dimensions of 90 x 30 cm in plane and 120 cm in depth, the wall thickness 6 mm is used. The strip shell footing models were made of steel plates with constant width B =150 mm The transverse footing length is 29 cm to satisfy the plain strain condition.

The experimental studies indicated that, the ultimate load capacity of shell footing on reinforced subgrade is higher than those on unreinforced cases. The existence of reinforced layer below the shell toe significantly modifies the bearing capacity failure. The wedge of rupture surface for the shell footing with reinforcement layer is deeper than those of flat and shell footing without reinforcement. The shell foundation over reinforced subgrade can be considered a good method to increase the effective depth of the foundation and decrease the resulting settlement. The numerical analysis helps in understanding the deformation behavior of the studied systems and identifies the failure surface of reinforced shell footing.

Kamal Mohamed Hafez Ismail Ibrahim [4] studied that the bearing capacity of footings constructed on soft clay soil is considerably governed by soil settlement. In this study a numerical finite element analysis using Plaxis program is used to solve the problem. Axisymmetric model was chosen to represent the problem where half the footing and the soil are analyzed. The Mohr-Column theory was used to simulate different soil behaviors. A drained condition was chosen for granular soil while an un-drained loading was chosen to represent the saturated soft soil. It is concluded that the bearing capacity of foundations on soft clay can be improved by a layer of compacted sand or gravel.

The structural performance of the shell foundation with respect to membrane stresses, bending moment, shear, deflection and ultimate strength of the shell itself was investigated in a wide range. However, the geotechnical behavior of shell foundation to determine the soil response with respect to settlement, bearing capacity, contact pressure distribution and deformation within the soil mass has taken little attention.

In this paper a new approach is adopted to study the geotechnical behavior of strip shell foundation resting on single layer of reinforcement to validate the reinforcement effect in the conjunction of adopting shell foundation. Here we are considering the conical shell strip footing, which is suitable for water tanks and tower like structures. The present study focuses on experimental and numerical analysis of Flat and Conical shell strip footings on reinforced and unreinforced clay to confirm the model test results and to compare the bearing capacities and efficiencies of the systems.

II. EXPERIMENTAL SETUP

i. Testing Tank

Fig. 1 shows a schematic view of the experimental model iron apparatus used in this research. Dimension Analysis was done to determine the size of test box and model footings. The test box, having inside dimensions of 45 x 15 cm in plane and 60 cm in depth, the walls thickness of the tank is 6 mm. The tank box was built in this test using iron, sufficiently rigid, to maintain plane strain conditions by reducing the out of plain displacement in all the directions. The tank walls were braced from the outer surface using beam fitted at the mid depth of the tank.

The load testing system consists of a hand-operated hydraulic jack and proving ring to apply the load manually to the model footing system and the settlement was measured by dial gauges fixed directly at footing surface.

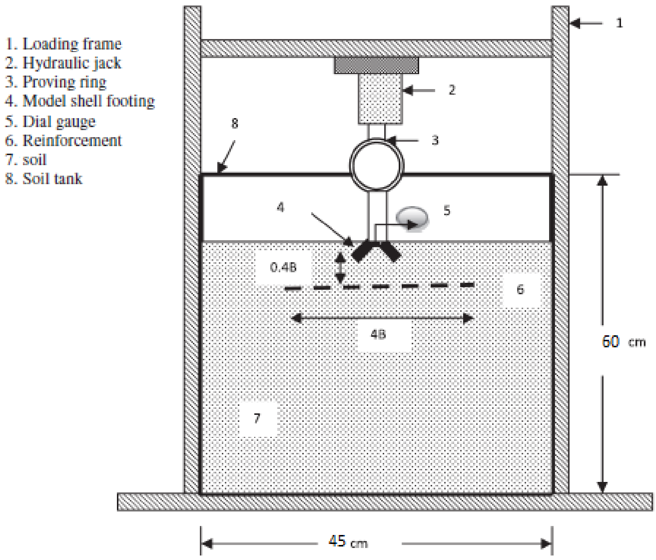

Fig 1: Experimental setup - testing tank

ii. Foundation Models

The strip shell footing models were made of iron plates with constant width B =80 mm in horizontal projection, with depth 200 mm. The transverse footing length is 14 cm to satisfy the plain strain condition. Fig. 2 shows the sketches of the foundation models. The load was transferred to the footing through a loading arm which was fixed rigidly by welding at the mid height of foundation models.

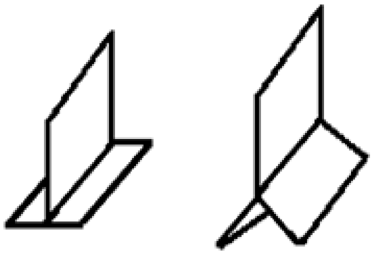

Fig 2: Strip Footing Models (10cm x 14cm x 20cm)

III. TESTING MATERIALS

i. Soil

The soil used in this study is highly compressive clay collected from Edathva region of Alappuzha District, Kerala. Clay is a fine-grained natural rock or soil material that combines different clay minerals with traces of some metal oxides and organic matter. Clays are plastic due to their water content and become really hard, brittle and non-plastic when dried or fired. Depending on the content of the soil, clay can appear in various colours, from white to dull gray or brown to a deep orange red.

Fig 3: Soft Clay

About 150 kg of disturbed soil sample and 10 kg of undisturbed soil sample was collected from a depth of 1.5 m below ground level. It was then wrapped and labelled properly and stored in the laboratory. Index and engineering properties of the soil were determined as per IS Specifications.

ii. Reinforcing Material

The Reinforcing material used in this study is High tenacity polyester (PET) with tensile strength 40kN/m. They were made from high strength polyester yarns which are coated with PVC materials for their protection , which are used in soil stabilization and reinforcement. They are possessing high elastic modulus offering low strain and strong resistance to damage due to mechanical, chemical and biological degradation. Applications include Reinforcement of steep slopes and Retaining walls, Sub-grade and Sub-base Reinforcement, Roads, Embankments, etc. The width of the strap is 0.25m.

Fig 4: High tenacity polyester

IV. EXPERIMENTAL TESTING PROGRAM

i. Soil Test

The collected clay sample was tested according to Indian Standards. The engineering properties and strength tests were conducted.
Major Laboratory tests conducted on Clay includes

- Grain Size Distribution [IS : 2720 (Part 4) - 1985]
- Atterberg Limits [IS : 2720 (Part V)-l985]
- Standard Proctor Test [IS : 2720 (Part VII)- 1980]
- Triaxial Compression Test [IS : 2720 (Part XII) - 1984]

ii. Dimension Analysis

Dimension analysis is the method for deducing elements of the form of a theoretical relationship from consideration of the variables and parameters that make up that relationship. The theory of dimension analysis is based on Buckingham’s theorem:

“ If an equation is dimensionally homogeneous, it can be reduced to a relationship amoung a complete set of dimensionless products.”

Consider a footing of 1m width which is placed at 1m below the ground level. According to David Muir Wood [2], the size of the models can be chosen in such a way that its scale can be 1 : 100, 1 : 10, etc. For this paper 1 : 10 scale is chosen. So footings are of size 100mm X 140 mm X 200 mm height. Strip is considered to be having a length of 140 mm inorder to satisfy plain strain condition.

$$n_L = \frac{length\ of\ model}{length\ of\ prototype} = \frac{100\ mm}{1000\ mm} = 0.1 \quad (1)$$

According to W. R. Assam, for neglecting the effect of the boundary conditions, the height of the tank was taken 6 times the footing width and length of the tank was taken greater than 4 times the footing width. So testing tank is of size 450mm X 150 mm X 600 mm height.

iii. *Model Testing*

Model testing is one of the major tool of a geotechnical engineer since it enables the study and analysis of design problems using geotechnical materials. Here a model is tested and the results are then extrapolated to a prototype situation. Modelling of foundation behaviour is the main focus of model test studies. A wide range of foundations are used in practical situations including strip foundations, pile foundations and caissons. The main objective of model testing is to investigate the Load-settlement curves from which ultimate bearing capacity of the foundation can be determined.

In the present study Clay was filled in the testing tank at optimum moisture content and maximum dry density in five layers. A total number of 4 tests were conducted on foundation models. They are

- Flat strip footing on plain clay.
- Flat strip footing on reinforced clay.
- Conical Shell strip footing on plain clay.
- Conical Shell strip footing on reinforced clay.

The embedment length of both the footings was 100 mm. Fifth layer is filled after placing the model footing in position. Then proving ring and displacement dial gauge were placed in position. A series of loading tests were conducted for the foundations on both unreinforced and reinforced clay subgrade using Geotextile that was placed at distance equal to 0.5B below the foundation with a constant length equal to 4B. At the time of testing both plate sides of the shell foundations were embedded in the clay.

The increase in the ultimate load of a shell footing as compared to flat strip footing is recognized in the present study as the shell efficiency factor (g). It is defined as given in Eq. (2), as the ratio between the differences in ultimate loads of shell footings over the ultimate load of flat footing.[13]

$$\eta = \frac{Qus - Quf}{Quf} \qquad (2)$$

where

Qus : ultimate load of shell footing;
Quf : ultimate load of flat footing.

In order to examine the settlement characteristics of conical shell footings versus that of the conventional flat one, a non-dimensional settlement factor (F_d) was introduced. The settlement factor is always calculated at the ultimate load (Qu) to reflect the settlement characteristics of the footings throughout the loading. The settlement factor is presented in Eq. (3). It is seen that a lower value of settlement factor indicates better settlement characteristics. [13]

$$F_d = \frac{\delta u \times \gamma \times Ah}{Qu} \qquad (3)$$

Where

δu: settlement at ultimate load;
γ: soil unit weight;
Ah: area of footing in horizontal projection;
Qu: ultimate load.

V. NUMERICAL ANALYSIS

PLAXIS 2D is a two dimensional finite element program, developed for analysis of deformation, stability and also the groundwater flow in geotechnical engineering. Plaxis generates full fixity at the base of the geometry taken and smooth conditions at all the vertical sides. To eliminate boundary effects due to loading, the horizontal and vertical dimensions were taken as model test.

The soil medium was modeled using 15-node triangular elements. Because of the symmetry of footing, only one half of the foundation system is considered. Typical graded finite-element mesh composed of the soil and foundation, together with the boundary conditions and the geometry of the system for the four cases of testing is shown in Fig.5

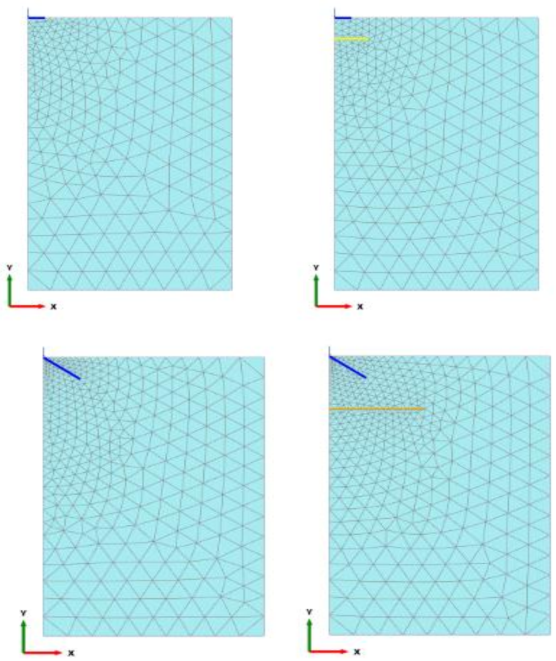

Fig.5 Connectivity plot

VI. EXPERIMENTAL ANALYSIS RESULTS

i. Properties of clay sample

Index and engineering properties of sample clay were determined in the laboratory as per Indian Standards and the results are here tabulated in Table 1.

TABLE 1: PROPERTIES OF SAMPLE CLAY

Properties of Soil	**Values**
Natural Moisture Content (%)	78
Specific Gravity	2.58
Liquid Limit (%)	86
Plastic Limit (%)	43.58
Plasticity Index (%)	42.42
Shrinkage Limit (%)	21.6
Coarse grained particle (%)	35.4
Fine grained particle (%)	64.6
Classification (ISC System)	CH
Optimum Moisture Content (%)	39.5
Maximum Dry Density (g/cm3)	1.501
Cohesion, c (kN/m^2)	10
Angle of internal friction	5

ii. Model Test

To compare the conical shell strip footing with flat strip footing in soft clayey soil and to determine the effect of reinforcement on the bearing capacity of flat strip footing and conical shell strip footings, model tests were conducted. The load–settlement curves were plotted for all tests and bearing capacity was calculated.

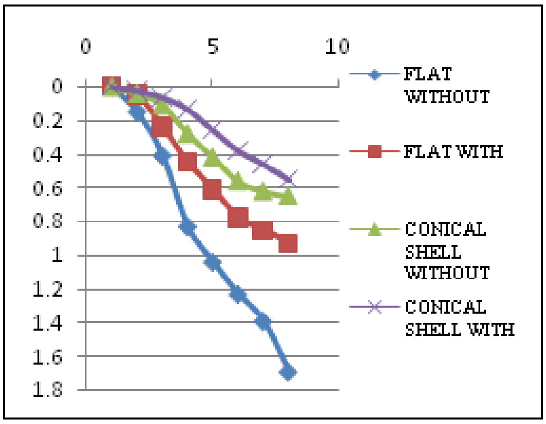

Fig 6: Load Settlement curve for the Model tests conducted

The load settlement curves of strip footings with and without reinforcement:

Fig 6 presents the load settlement curves for flat and conical shell footing with and without reinforcement. It is seen that the ultimate load increases due to both shell and reinforcement effects. The existence of shell footing can improve and increase the ultimate load compared with flat footing. The bearing capacity of shell footing on clay was increased compared with flat footing on the same soil.

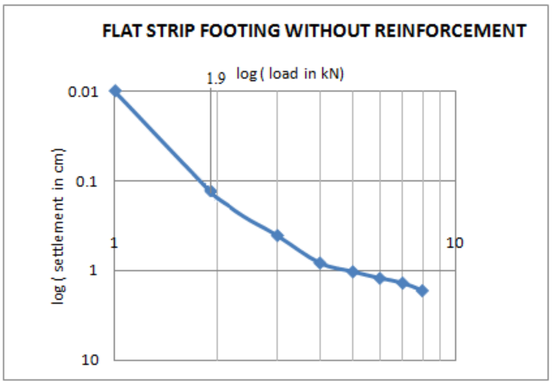

Fig 7: Load Settlement curve for Flat Strip footing without reinforcement.

It can be observed from fig. 7 to fig. 10 that the shell footings have higher ultimate loads than flat one. Shell footing ensures better enclosibility of the shell which is inside the space of the footing by preventing the soil from flowing outward. Also, the soil wedge developed inside the shell footing was gradually compacted during the loading stages; thus, the sub grade soil was improved and the settlement was decreased. This is very significant, particularly when the density of the soil is very low. The bearing capacity of conical shell footing was increased compared with flat footing on the same soil.

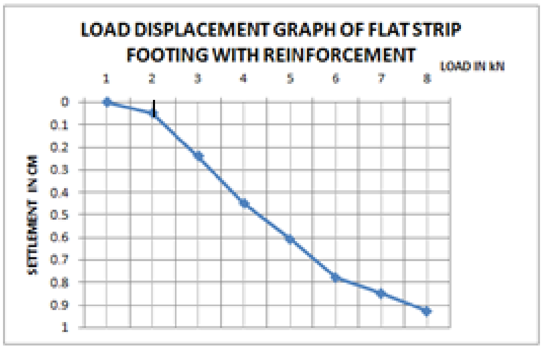

Fig 8: Load Settlement curve for Flat Strip footing with reinforcement.

The load carrying capacity of shell footing over reinforced sub grade is very much higher than the conical shell footing without reinforcement; this indicates that the reinforcement has a significant effect in increasing the strip footing load capacity. Reinforcement controls and decreases the vertical deformation and densification was induced. It can be seen that a combined effect was induced which is the shell effect and other is the reinforcement effect. Hence, both the soil inside the shell wedge and the soil along the reinforced layer became one unit and effectively interlocked. As a result, the footing load capacity increased and the settlement decreased.

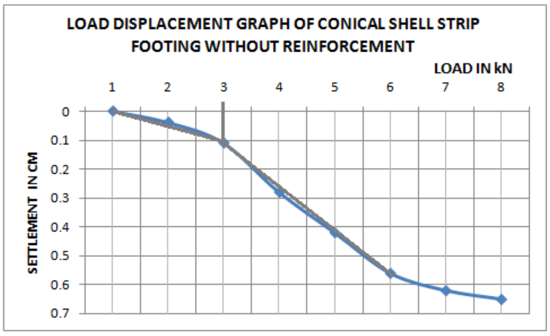

Fig 9: Load Settlement curve for Conical shell Strip footing without reinforcement.

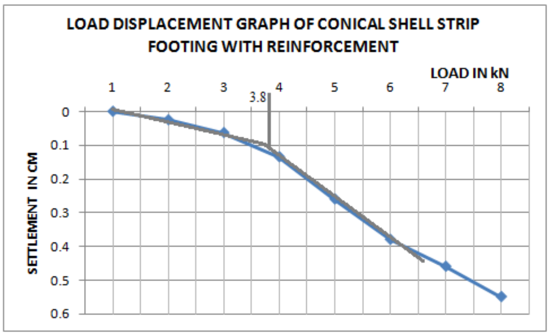

Fig 10: Load Settlement curve for Conical shell Strip footing with reinforcement.

The present reinforced layer below the shell reduces the pressure induced within the soil sub grade and increases the ultimate load capacity. The combined effect of such reinforcement reduces substantially the distortion rate in the sheared zone and limit the induced tensile strains which were produced at failure.

Effect of shell configuration and reinforcement on settlement characteristics

TABLE 2: SETTLEMENT FACTOR FOR THE FOOTINGS WITH AND WITHOUT REINFORCEMENT

Footing Type	$Fd \times 10^{-5}$
Flat without reinforcement	9.08
Flat with reinforcement	3.67
Conical without reinforcement	3.48
Conical with reinforcement	2.74

The effect of shell foundation as well as the existence of the reinforced layer on the resulting settlement at failure was studied by calculating settlement factor (Fd). The comparison between shell and flat footings indicates that the shell footings posses a lower settlement factor which demonstrates better settlement characteristics for conical shell footings.

The comparison between the shell footing without reinforcement and with reinforcement shows that the settlement factor decreases considerably for the conical shell footing with reinforcement. But the reduction in this settlement for reinforced conical shell footing is higher than that of unreinforced cases. This again confirmed the effectiveness of the PET reinforced layer in controlling the vertical settlement of the shell footing.

VII. NUMERICAL INVESTIGATION RESULTS

The modeling of both the flat strip footing and shell strip footing with and without reinforcement is done using Finite Element Software – Plaxis 2D. The calculation is done and Load Settlement Curves are plotted. The Table 8.1 shows the load and corresponding settlement values for each test.

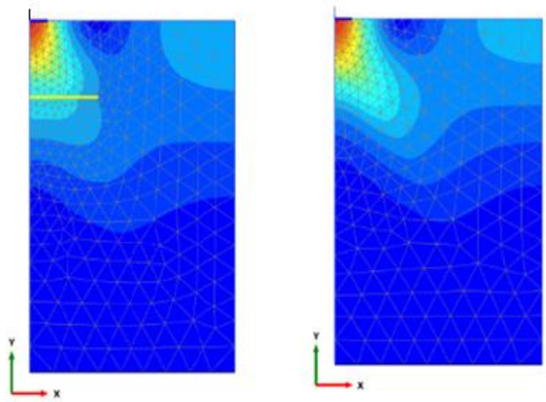

Fig. 11 Deformed plot for flat footing with and without reinforcement

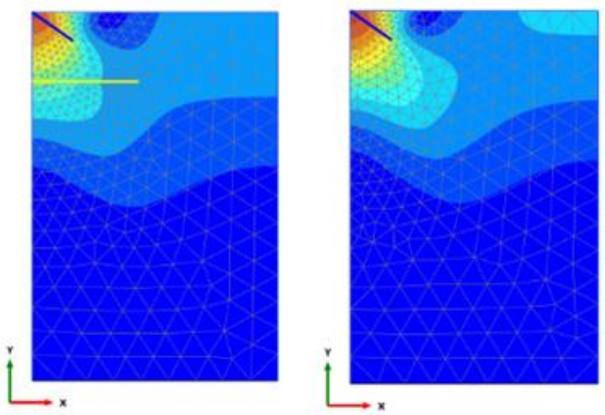

Fig. 12 Deformed plot for conical shell footing with and without reinforcement

The load settlement curves of strip footings with and without reinforcement:

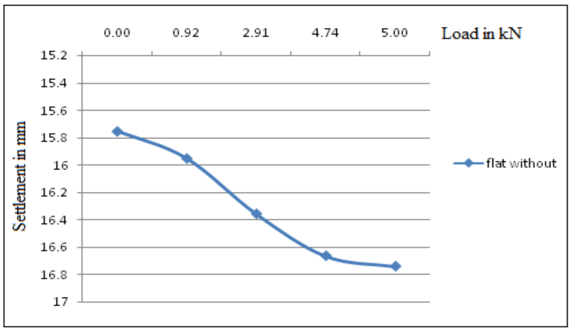

Fig 13 Load settlement Curve for flat footing without reinforcement

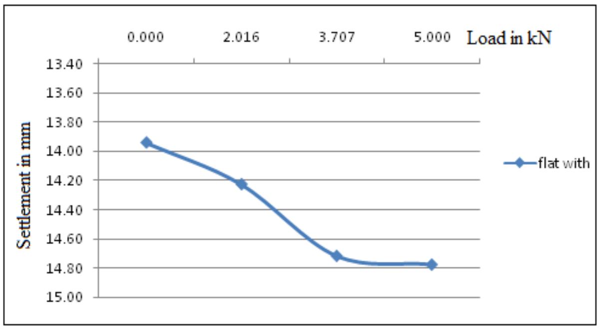

Fig 14 Load settlement Curve for flat footing with reinforcement

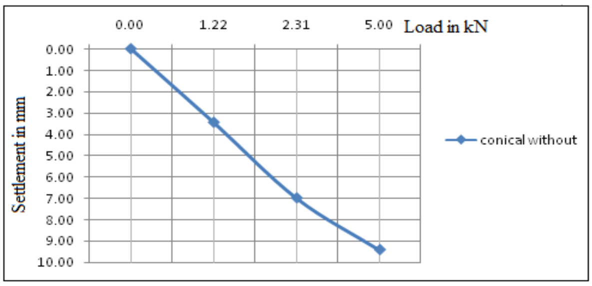

Fig 15 Load settlement Curve for Conical footing without reinforcement

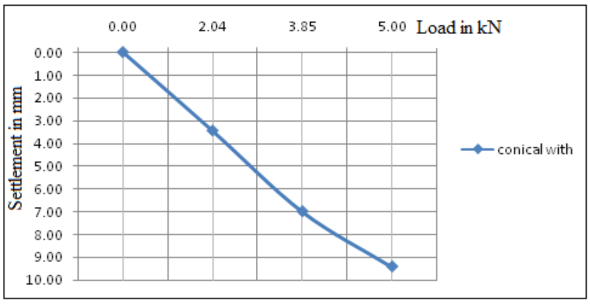

Fig 16 Load settlement Curve for Conical footing without reinforcement

Effect of conical shell configuration and reinforcement on settlement characteristics

- The shell footings have higher ultimate loads than flat one.
- The load carrying capacity of shell footing over reinforced sub grade is higher than the shell footing without reinforcement.
- The present reinforcement layer below the toe of the shell reduces the pressure induced within the sub grade and increases the ultimate load capacity.

TABLE 3: SETTLEMENT FACTORS

Footing Type	$F_d \times 10^{-5}$
Flat Without Reinforcement	12.7
Flat With Reinforcement	5.19
Conical Without Reinforcement	3.21
Conical With Reinforcement	1.93

- The comparison between shell and flat footings indicates that the shell footings possess a lower settlement factor leading to better settlement characteristics for shell footings.
- The comparison between the conical shell strip footing without reinforcement and with reinforcement shows that the settlement factor decreases considerably for the shell footing with reinforcement.

VIII. COMPARISON OF RESULTS

The Bearing Capacity Values are calculated both Experimentally and Numerically. The values obtained are shown in Table 4 . For better understanding of variation in bearing capacity for the different cases of footing, the results are compared as shown in Table 5. The values of settlement factors and the shell efficiencies , calculated both experimentally and numerically, are also compared for exact validation of the results.

TABLE 4 BEARING CAPACITY RESULTS

BEARING CAPACITY RESULTS		
Footing Type	Experimental	Numerical
Flat without Reinforcement	81 kN/sqm	92 kN/sqm
Flat with Reinforcement	200 kN/sqm	201.6 kN/sqm
Conical Shell without Reinforcement	300 kN/sqm	231 kN/sqm
Conical Shell with Reinforcement	380 kN/sqm	385 kN/sqm

TABLE 5 PERCENTAGE VARIATION IN BEARING CAPACITY VALUES

Comparison of Bearing Capacity			
		percentage variation	
Comparing	Compared with	experimental	numerical
Flat with Reinforcement	Flat without Reinforcement	147%	119%
Conical with Reinforcement	Conical Shell without Reinforcement	29%	67%
Conical Shell without Reinforcement	Flat without Reinforcement	270%	151%
Conical Shell with Reinforcement	Flat with Reinforcement	94%	91%

TABLE 6 SHELL EFFICIENCY

SHELL EFFICIENCY		
	EXPERIMENTAL	NUMERICAL
Unreinforced	2.7	1.5
Reinforced	0.96	0.91

IX. CONCLUSION

In the present paper, the geotechnical behavior of conical shell strip footing and flat strip footing, with and without single layer of reinforcement was investigated experimentally and numerically.

The following are the major conclusions put in a quantitative form. Even though the typical values so given apply only to the specific data used in the analysis, they can also be considered indicative of the general trend of results.

- When comparing the bearing capacity value, the conical shell strip footing with reinforcement possess highest value.
- When comparing the settlement factors, the reduction in settlement for reinforced shell footing is higher than that of unreinforced cases.
- The load carrying capacity of shell strip footing over reinforced sub grade is higher than both the shell strip footing without reinforcement and flat strip footing. So shell strip footing over reinforced sub grade possess highest bearing capacity and lowest settlement

X. SCOPE FOR FUTURE WORK

- Model Tests can be conducted on clay considering different water levels and different embedment lengths of footings.
- Model Tests can be conducted on clay with different shell strip footing angles.

XI. REFERENCES

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