

# Model Test on Bearing Capacity of Conical Shell Strip Footing on Reinforced Clay

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**ABSTRACT:** The bearing capacity of footings constructed on soft clay soil is considerably governed by soil settlement. 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 in the case of shells with the straight-line property and axisymmetric shells, this is achieved without much extra input of labour. The use of geogrid reinforcement in single or multiple layers increase the tensile strength of soil. In this paper a Conical shell strip footing is considered, which is suitable for water tanks and tower like structures. Numerical Analysis are conducted for determining bearing capacities of Conical shell and flat strip footing on unreinforced and reinforced clay using PLAXIS 2D Software. The studies indicated that, the bearing capacity of shell footing on reinforced clay is higher than those on unreinforced cases and the load settlement curves were significantly modified. The shell foundation over reinforced subgrade can be considered a good method to increase the Bearing Capacity and decrease the resulting settlement.

**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 in general economic alternatives to plain shallow foundations in situations involving heavy superstructural loads to be transmitted to weaker soils.[6]. 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. 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 – and used in instances which are few and far between. 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.

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.

Dr. Pusadkar Sunil Shaligram [2] studied on Triangular shell footing used as a strip footing resting on two-layered sand, reinforced with geotextiles. The upper layer of sand is weaker than followed layer. The geotextile layer at various levels below the footing shows increase in ultimate bearing capacity at upper layer and decrease in the settlement. It was also observed that the placement of geotextile below footing produce better load-settlement characteristics when geotextile was placed. It also suggests the use of precast concrete technology construction of shell foundations. The advantage of shell footing can be better used for placing the footing on weak soil reinforced with geotextiles.

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Murat Ornek, Ahmet Demir, Mustafa Laman And Abdulazim Yildiz [5] studied numerical predictions of the scale effect for circular footings supported by partially replaced, compacted, layers on natural clay deposits. The results of this parametric study showed that the stabilization had a considerable effect on the bearing capacity of the circular footings and for a given value of H/D the magnitude of the ultimate bearing capacity increases in a nonlinear manner with the footing diameter. The Bearing Capacity Ratio (BCR) was defined to evaluate the improved performance of the reinforced system. It was found, based on numerical and field-test results 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 [6] 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) in horizontal projection, with different embedment depth,  $a$  ( $a = 60, 75$  and  $112.50$  mm) and 20 mm thickness. The transverse footing length is 29 cm to satisfy the plain strain condition. A series of loading tests were carried out on model shell footing with and without single layer of reinforcement. The tests were done for shell foundation at different shell embedment depth and subgrade density. The results were compared with those for flat foundations without reinforcement. The model test results were verified using finite element analysis using program PLAXIS.

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. The axis of symmetry and the right vertical boundaries are laterally constrained. The right boundary was chosen at a distance approximately  $6B$  from the axis of symmetry while the hinged bottom boundary was established at a depth  $6B$  for vertical and lateral constrains. A significant enhancement in bearing capacity is achieved by increasing the ratio between the granular soil thickness and the footing diameter ' $H/B$ ' up to four for surface foundations ( $D/B = 0$ ) and up to six for deeper foundations ( $D/B = 1.0$ ). The failure mechanism is characterized by punch shear failure in the granular soil and Prandtl failure in the lower soft clay soil. It is concluded that the bearing capacity of foundations on soft clay can be improved by a layer of compacted sand or gravel.

## II. EXPERIMENTAL SETUP

### A. Testing Tank :

Fig. 1a 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 sufficiently rigid to maintain plane strain conditions by minimizing the out of plane displacement in all directions. The tank walls were braced from the outer surface using horizontal beam fitted at the mid depth of the tank. The loading system consists of a hand-operated hydraulic jack and pre-calibrated load ring to apply the load manually to the footing soil system and the settlement was measured by dial gauges fixed at footing surface.

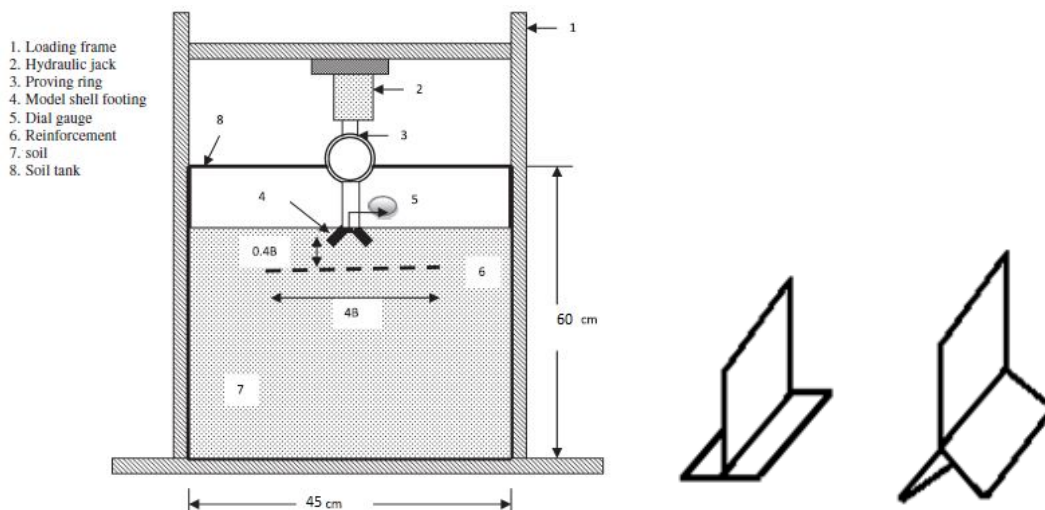


Fig 1: a) Experimental setup - testing tank, b) Strip Footing Models (10cm x 14cm x 20cm)

### B. 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. Sketches of the foundation models are illustrated in Fig. 1 b. The load is transferred to the footing through a loading arm which was fixed rigidly by welding at the mid of foundation models.

## III. TESTING MATERIALS

### A. 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 one or more clay minerals with traces of metal oxides and organic matter. Clays are plastic due to their water content and become hard, brittle and non-plastic upon drying or firing. 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. 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.

### B. Reinforcing Material :

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

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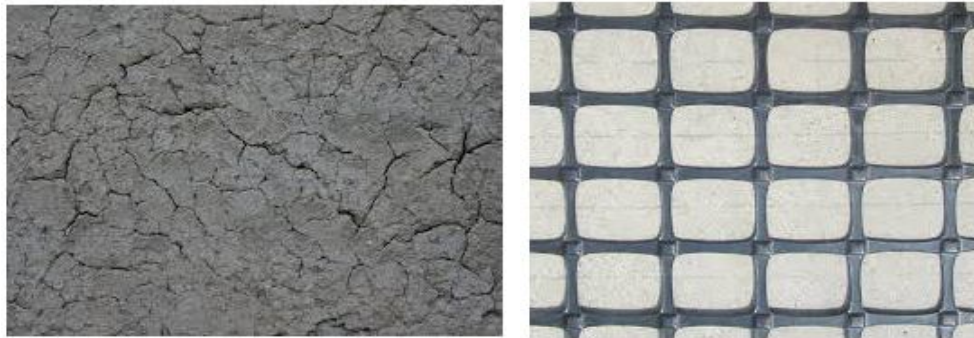


Fig 2: a) Soft Clay, b) High tenacity polyester

## IV. TESTING PROGRAMME

### A. 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)-1985]
- Standard Proctor Test [IS : 2720 (Part VII)- 1980]
- Triaxial Compression Test [IS : 2720 (Part XII) - 1984]

### B. Model Test :

Model testing represents a major tool available to the geotechnical engineer since it enables the study and analysis of design problems by using geotechnical materials. Here a model is tested and the results are then extrapolated to a prototype situation. Modelling has a major role to play in geotechnical engineering. Physical modeling is concerned with replicating an event comparable to what might exist in prototype. The model is often a reduced scale version of the prototype. The two events should obviously be similar and that similarity needs to be related by appropriate scaling laws. Modelling of foundation behaviour is the main focus of model test studies. A wide range of foundations have been used in practical situations including strip foundations, pile foundations and caissons. The main objective of model testing for foundation behaviour is to investigate the Load-settlement curves from which yield and ultimate bearing capacity of the foundation may 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 prearranged 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 as shown in fig 1a. A series of loading tests were done for the foundations on both unreinforced and reinforced clay subgrade using Geotextile that was placed at fixed distance equal to  $0.5B$  below the foundation tip with constant length equal to  $4B$ . In the testing program both plate sides of the shell foundations were embedded in the clay. The increase in the ultimate load of a shell footing as

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compared to its flat counterpart is recognized in the present study as the shell efficiency factor ( $\eta$ ). It is defined as given in Eq. (1), as the ratio between the differences in ultimate loads of shell footings over the ultimate load of flat footing.[6]

$$\eta = \frac{Q_{us} - Q_{uf}}{Q_{uf}} \quad (1)$$

where

$Q_{us}$  : ultimate load of shell footing;

$Q_{uf}$  : ultimate load of flat footing.

In order to examine the settlement characteristics of shell footings versus that of the conventional flat one, a non-dimensional settlement factor ( $F_d$ ) was introduced. The settlement factor was calculated at the ultimate load ( $Q_u$ ) to reflect the settlement characteristics of the footings throughout the loading process. The settlement factor is presented in Eq. (2). It should be noted that a lower value of settlement factor indicates better settlement characteristics. [6]

$$F_d = \frac{\delta_u \times \gamma \times A_h}{Q_u} \quad (2)$$

where

$\delta_u$ : settlement at ultimate load;

$\gamma$ : soil unit weight;

$A_h$ : area of footing in horizontal projection;

$Q_u$ : ultimate load.

## V. RESULTS AND DISCUSSIONS

### A. Properties of clay sample

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

### B. Model Test Results

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.

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

Fig 6 presents the load settlement curves for flat and shell footing with and without reinforcement. It can be 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.

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/cm <sup>3</sup> )	1.501
Cohesion, c (kN/m <sup>2</sup> )	10
Angle of internal friction	5

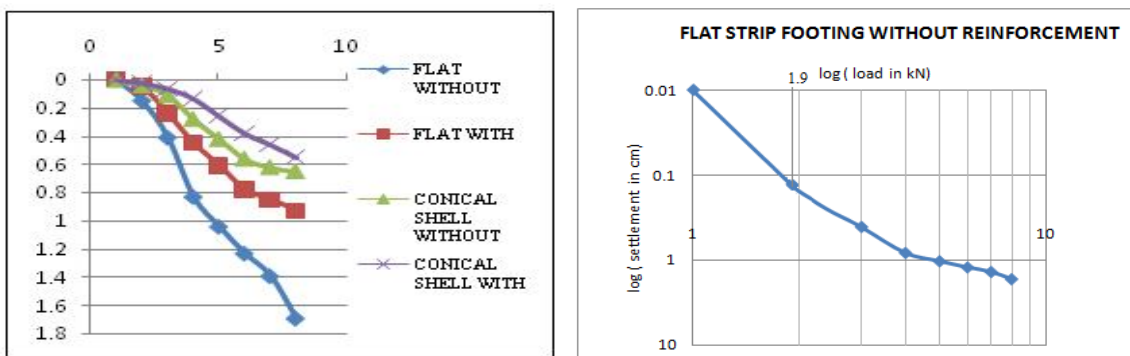


Fig 3: a) Load Settlement curve for the tests conducted, b) Load Settlement curve for Flat Strip footing without reinforcement.

It can be observed from fig. 3 b to fig. 5 that the shell footings have higher ultimate loads than flat one. Shell footing ensures better enclosibility of the shell inside the space of the footing by preventing the soil from flowing outward. Also, the soil wedge inside the shell footing is gradually compacted during the loading stages; thus, the sub grade soil is improved and the settlement is decreased. This can be very significant, particularly when the density of the soil is poor/low. The bearing capacity of shell footing was increased compared with flat footing on the same soil.

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

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

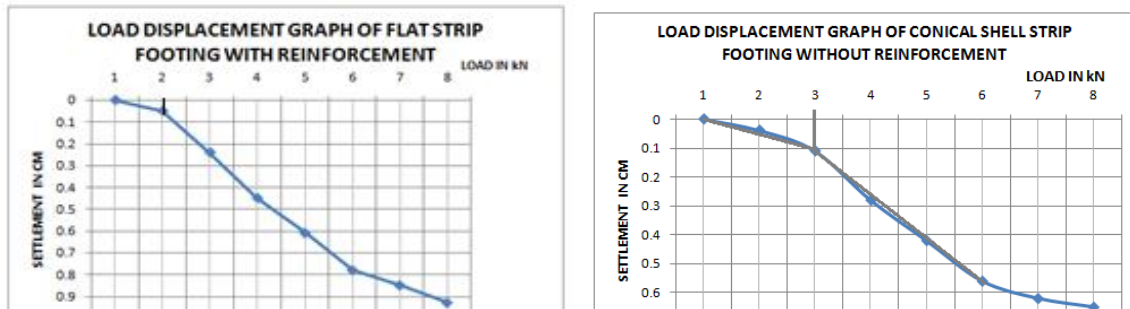


Fig 4: Load Settlement curve for a) Flat Strip footing with reinforcement, b) Conical shell Strip footing without reinforcement.

**Effect of shell configuration and reinforcement on settlement characteristics**

Table 2: Settlement Factor for the footings with and without reinforcement

Footing Type	$F_d \times 10^{-5}$
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 ( $F_d$ ). The comparison between shell and flat footings indicates that the shell footings possess a lower settlement factor which demonstrates better settlement characteristics for shell footings. The comparison between the shell footing without reinforcement and with reinforcement shows that the settlement factor decreases remarkably for the shell footing with reinforcement. But the reduction in settlement for reinforced shell footing is higher than that of unreinforced cases. This again confirmed the effectiveness of the reinforced layer in controlling the vertical settlement of the shell footing due to resulting combined effect.

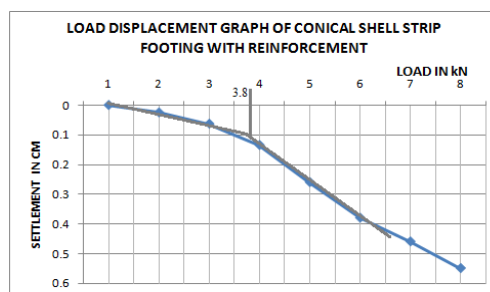


Fig 5: Load Settlement curve for Conical shell Strip footing with reinforcement.

**VI. CONCLUSION**

In the present paper, the geotechnical behavior of shell foundation with and without single layer of reinforcement was investigated experimentally and compared with flat footing. The following major conclusions are put in a

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quantitative form to the extent possible. Even though the values so given apply to the specific data used in the analysis, they can be considered indicative of the general trend of these results.

- Bearing Capacity of Flat Strip Footing in Reinforced soil was increased by about 147% than the bearing capacity of the same footing in plain soil.
- Bearing Capacity of Conical Shell Strip Footing in Reinforced soil was increased by about 29% than the bearing capacity of the same footing in plain soil.
- On comparing the bearing capacity of Conical Shell Strip Footing with Flat strip footing in plain soil, it was observed that the bearing capacity of Conical Shell Strip Footing was increased by about 270% than that of Flat Strip Footing.
- In Reinforced Soil, it was observed that the bearing capacity of Conical Shell Strip Footing was increased by about 94% than that of Flat Strip Footing.
- Shell Efficiency in unreinforced clay was observed to be 2.7 and that in reinforced clay was observed to be 0.9 when compared with flat strip footing.
- 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.

## VII. SCOPE FOR FUTURE WORK

- i. Model Tests can be conducted on clay considering different water levels and different embedment lengths of footings.
- ii. Model Tests can be conducted on clay with different shell strip footing angles.
- iii. Model tests can be compared with Finite Element software PLAXIS.

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