Experimental Study on Conical Shell Footing

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Abstract: Footings are often situated for weak soil of significant depth underlain by comparatively strong soil strata. The shell footings are capable of supporting higher vertical loads, better load settlement characteristics and are economical in terms of material compared with the conventional footings. The development in analysis and design of shell type foundations have led to the understanding that there are more advantages of shell type foundations compared to their conventional flat counterparts. The ultimate load carrying capacity of conical shell footing on dry sand were determined in the present paper by conducting laboratory model tests. The conical shell footing withpeak angles of 900 and 126.880were designed and the models were casted with s reinforced concrete. And the specimens were tested using loading frame system. The results indicate that the ultimate load carrying capacity of the footing increases with decrease in peak angle. The results were compared with calculated theoretical value.

Keywords: Shell footing, conical shell footing, Ultimate load carrying capacity

1. INTRODUCTION

Shell foundation has been considered the best shallow foundation for transferring heavy load to weak soils, where a conventional shallow foundation undergoes excessive settlement.Concept of shell is not new in foundation design, considering construction of inverted brick arch foundationin this category. The use of inverted brick arches as foundation has been in practice in many parts of the world for a long time. Shells are essentially thin structures, thus structurally more efficient than flat structures. This is an advantage in situation involving heavy super structural loads to be transmitted to weaker soils. Shell footing is limited to a few geometries, such as conical, pyramidal, hyper and spherical footings. Shells are structures, which derive their strength from ‘form’, rather than ‘mass’, which enables them to put a minimum of material to maximum structural advantage. Shells hold properties for adoption in foundation as economic alternatives to the flat foundation in situations involving heavy column loads to be transmitted to weaker soils.

Esmaili and Hataf (2008), studied the ultimate load carrying capacities of conical and pyramidal shell foundations on unreinforced and reinforced sand by laboratory model tests and numerical analysis. To examine the effect of the shell thickness on the ultimate load capacity, three types of conical and pyramidal model shell foundations have been made and tested. Two types of flat foundations, i.e. circular and square foundations were also made and tested for comparison.A new term known as shell factor was introduced to represent the relation between the ultimate load carrying capacity of shell foundation with flat footing. The values of numerical analysis are close to those of laboratory test models. The ultimate load capacity of shell foundations is higher than that for counterpart flat foundations and that of shell foundation in reinforced sand is greater than that in unreinforced sand. Also the results show that, thickness of shell foundation increases its result come close to that of flat foundation.

Nissanka Fernando, et al (2011),investigated on the failure mechanism and bearing capacity of different types of shallow foundations in dry sand. The bearing capacity and settlement of conical and pyramidal shell foundation with their flat counterparts were determined in this paper by conducting laboratory model tests. The applied loads were noted for each 1 mm settlement upto 50 mm maximum settlement. Settlement factor and shell gain factor were introduced to compare the results with conical shell footing and pyramidal shell footing. And it was observed that both factors are higher for conical shell footing. But the pyramidal shell footing had less height of influence zone compared to conical one. The failure mechanism under shell foundation is same as that of the conventional flat foundations.

Adel Al-Azzawi (2013), studied on the behaviour of conical shell footing using finite element analysis. For this study two components of interacting system were modelled using finite element method.A 15 node iso-parametric triangular axis symmetric element with two degrees of freedom at each node was used for shell and soil. The soil- structure interactions were modelled by using interface elements. The parameters considered for the study were half vertical angle, footing embedment and edge beam. The results show that, as the semi vertical angle increases load carrying capacity decreases. Heeffect of adding edge beam at the bottom of the shell increases the load carrying capacity. And it also shows that the fully embedded shell footing has better load carrying capacity with the footing with no embedment depth.

2. METHODOLOGY

The ultimate load carrying capacity of conical shell footings were studied in the present paper.

To examine the effect of half shell angle, conical shell footing with two different angles were designed, casted and studied. The specimens were made of reinforced concrete. And testing were carried out to examine the parameters like half shell angle, settlement, stiffness, crack load, crack pattern, ductility behaviour and load-settlement curve.

3. MATERIAL USED

2.1. Cement

Chettinad 53 Grade Ordinary Portland Cement is used. Fineness of cement is 2% and specific gravity is 3.13.

2.2. Fine Aggregate

The sand used for this experimental work is locally available natural river sand with specific gravity 2.559. The sand layer is 20mm thick.

2.3. Coarse Aggregate

The grading of coarse aggregates of size 20mm and below is used as per specifications of IS 383-1970. The specific gravity of coarse aggregate is 2.79.

2.4. Water

The water should conform to IS 456-2000 standards. In this project, ordinary portable water available in the college campus was used to make the concrete.

2.5.Reinforcement

For this study Fe 500 HYSD bars with diameter 12 mm was used as main reinforcement and 8 mm bars was used as stirrups for columns.

4. PRELIMINARY INVESTIGATION

4.1. Properties of concrete

Concrete used for the specimens is of normal weight designed for M30 grade with a target mean strength of 38.25 N/mm^2 and a slump of 43 mm to provide required workability. The compaction factor obtained for the concrete is 0.785. Concrete compressive strength is determined from concrete cubes of 150 mm size according to IS 456 (2000) procedures.

Cement used in the concrete were Chettinad 53 grade Ordinary Portland Cement conforming to IS 12269:1987. Fine aggregate used in the mixes were natural river sand conforming IS 383:1970 with grading zone II. Coarse aggregate for this study was 20mm nominal size of aggregate as per the specifications of IS 383:1970. And the other material used for the mixes was ordinary portable water. The mix proportion used in the concrete mixture is 1: 1.82: 3.23: 0.5.

5. TEST SPECIMENS

5.1. Preparation of concrete cubes

To find out the strength of concrete the compressive strength of concrete cubes of size 150mm were casted and tested. After 24hours cubes were de-moulded and placed for curing for 3, 7 and 28days.

5.2. Preparation of conical shell footing

Reinforcedconcrete specimens with peak angles 90^0 and 126.88^0were used for testing. All models have same width, diameter and thickness. The empty space with in the footings was filled with sand for providing better contact area.And there results were compared to find out the ultimate load carrying capacity of conical shell footing.

The conical shell footing specimens were made of reinforced concrete with constant diameter (D= 700mm), thickness (t = 60mm) and different half shell angle (45^0 and 63.44^0). Total height of the footing was 600 mm. 12 mm bars were used as main reinforcement and 8 mm bars were used for stirrups. A rough base condition was maintained at the bottom of the specimen by using cement grout to maintain friction between specimen and soil. After 24 hours they were de-moulded and put in curing tank for 28 days curing. After that the specimens were tested in loading frame system to find out the ultimate load carrying capacity of the footing. The conical shell footings are shown in figure 1

Fig 1: Conical shell footing

6. DETAILS OF SPECIMEN

The conical shell footings were designed based on the design considerations given in IS:9546 – 1980.

First the shell parameters such as half shell angle (θ), distance from apex to column (s_1), distance from apex to end of shell (s_2) for different conical shell were obtained. And by using these values compression stresses and hoop tension were found out. Then by using the obtained stress values conical shell footing were designed for compressive force and hoop tension. From design the total height of the specimens and number and size of the reinforcements used were obtained as,total height of the footing was 600 mm. 12 mm bars were used as main reinforcement for footing and column and 8 mm bars were used for stirrups in column. The reinforcement details of conical shell footing are shown in figure 2.

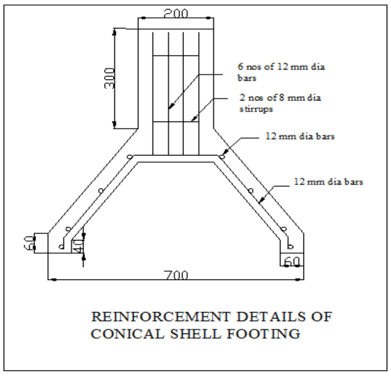

Fig 2: Reinforcement details of conical shell footing

7. LOAD CARRYING CAPACITY

The ultimate strength of conical shell footing (P_u) obtained from parametric study were compared with the strength obtained from the code. The equation for the ultimate strength that is the value of soil pressure at which the footing fails axially for uniform normal soil pressure under the assumptions of fixidity at the upper edge and a lower edge which is either free or provided with a ring beam and assuming constant spacing of hoop steel are given as

$$pnu = 6\left[\frac{N\cos\alpha(1-R)^2}{2r^2(R^2-3R+2)} + \frac{M\sin^2\alpha R}{r_2^2(Ro^3-3R+2)} + \frac{Nb\cos\alpha\sin\alpha(1-R)}{r_2^2(R^3-3R+2)}\right]$$

where,

N = ultimate capacity of shell per unit width in direct tension in the hoop direction

R_o = r_0, where $r_0/r_2$is the radius corresponding to the location of the plastic hinge

M = moment capacity of the plastic hinge per unit width(r_0 may be taken r_1 for all practical purposes)

N_b = ultimate capacity of the ring beam in direct tension

$$P_u = p_{nu} \text{ x } A_p$$

Table 1: Theoretical load carrying capacity of footing

Sl. No.	Half Shell Angle (θ)	Theoretical Load (kN)
1	45^0	623.32
2	63.44^0	554.40

8. EXPERIMENTAL TEST SETUP

The test base was made of a steel tray. The inside walls of the tank was polished to smooth to reduce the friction with the soil.

The loading frame system consist of hand operated hydraulic jack to apply load to the footing - soil system and the settlement was measured by using dial gauges fixed at footing surface.

The sand used for in this study is loose dry sand. A homogeneous bed of dry sand with thickness 20 mm was formed. The physical property of the sand was found out by testing the sand in the laboratory. Specific gravity of the sand was found as 2.559 and the bearing capacity of the sand was obtained as100 kN/m^2. A loose sand bed of 25 mm depth was prepared by placing the sand in zero fall height. In order to prepare the soil core under the shell model, the space under the shell was filled with sand. Experimental set-up for conical shell footing are sown in figure 3.

Fig 3 : Experimental Set-up

9. RESULT AND DISCUSSIONS

9.1 Compression test on concrete cubes

The compression test was conducted on concrete cubes of grade M30. Three cubes were tested for 7 and 28 days. The results obtained are shown in Table 2.

Fig 4: Testing of cubes

Table 2 : Compressive strength of concrete cubes

Days	Cube1	Cube2	Cube3	Avg. Compressive strength (N/mm^2)
3rd	20.92	20.05	20.05	20.34
7th	23.98	26.97	25.63	25.57
28th	35.63	36.82	36.59	36.48

9.2 Load – settlement behaviour

The load – settlement data were recorded and plotted for each specimen. Figure 5 & 6 shows load-settlement curve for conical shell footing with half shell angle 45^0. And figure7 & 8 shows load – settlement curve for conical shell footing with half shell angle 63.44^0.

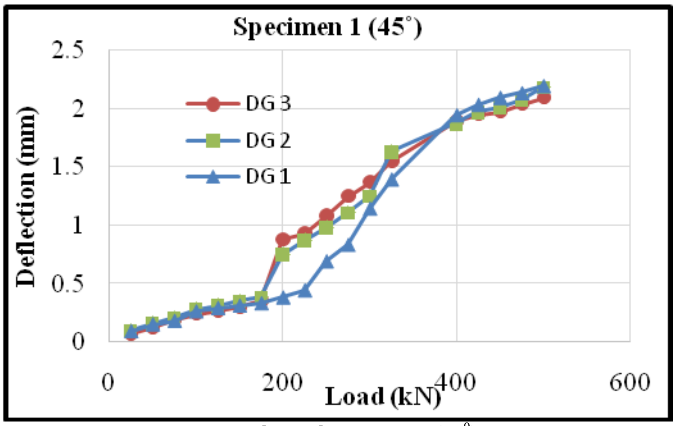

Fig 5: Load – settlement curve (45^0)

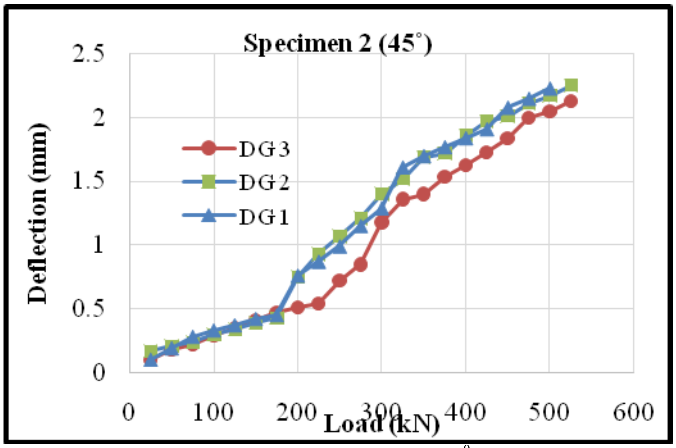

Fig 6: Load – settlement curve (45^0)

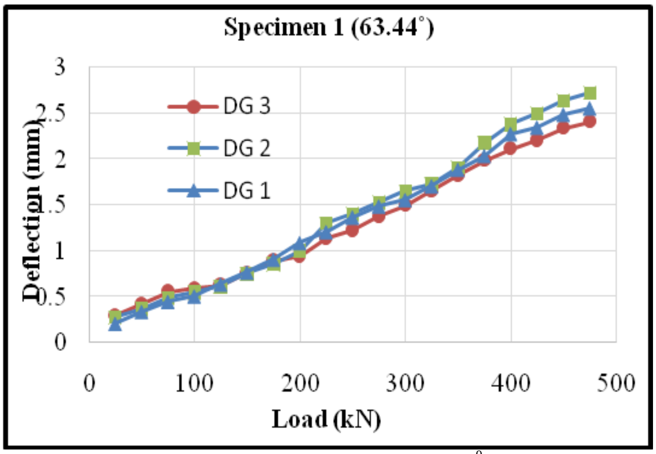

Fig 7: Load – settlement curve (63.44^0)

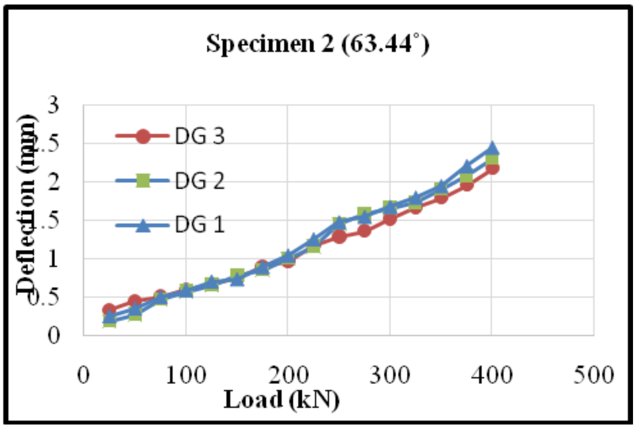

Fig 8: Load – settlement curve (63.44^0)

9.3 Comparison of theoretical and experimental load

Table 3 : Comparing theoretical and experimental load

Half shell angle	Theoretical load (kN)	Experimental load (kN)	Discrepancy (%)
45^0	623.32	512.5	21.62
63.44^0	554.40	437.5	26.72

The theoretical load calculated and the experimental load that taken by conical shell footing with half shell angle 45^0 and 63.44^0 is given. And we can see that footing with half shell angle 45^0 takes about 82% of theoretical load and that of footing with half shell angle 63.44^0 takes about 79% of the theoretical load. That means, conical shell footing with half shell angle 45^0 shows better load carrying capacity than the other.

9.4 Stiffness Character

$$\text{Stiffness} = \frac{\text{Load}}{\text{Deflection}}$$

Table 4: Stiffness of footings

Half Shell Angle	Specimen	Stiffness (N/mm)	
		Yield Value	Ultimate Value
45^0	1	223.88×10^3	232.23×10^3
	2	227.59×10^3	234.06×10^3
63.44^0	1	185.58×10^3	185.54×10^3
	2	180.28×10^3	177.62×10^3

The conical shell footing with half shell angle 45^0 shows better stiffness character.

9.5 Development ofcracks and crack pattern

The settlement of the footing was measured along the ring beam. The initial tension crack was occurred at the ring beam. With the increase in load these cracks were widened and extend upwards along the slope. And at the ultimate stage punching shear failure occurred at the column base. Figure 9 shows the crack formation and crack pattern in conical shell footing.

Fig 9: Crack pattern in Conical shell footing

9.6 Ductility Behavior

$$\text{Ductility}=\frac{\text{Ultimate Deformation}}{\text{Initial Yielding Deformation}}$$

Table 5: Ductility behaviour of footings

Half Shell Angle	Specimen	Ductility
45^0	1	1.071
	2	1.075
63.44^0	1	1.123
	2	1.128

The table 5 gives the ductility behaviour of conical shell footing with two different half shell angle. And it is clear from the figure that conical shell footing with half shell angle 63.44^0 shows better ductility behaviour than the other.

10. CONCLUSION

Based on the experimental study that were conducted on four specimens of conical shell footing with two different half shell angles the following conclusions can be drawn:

- The load carrying capacity of conical shell footing increases with decrease in half – shell angle.
- The load- settlement character of conical shell footing also getsimproved with decrease in half – shell angle.
- The conical shell footing takes nearly 80% of the theoretical load.
- The ductility and stiffness of conical shell footing increases with decrease in half – shell angle.

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