# GEOTECHNICAL BEHAVIOUR OF STRIP CURVED SHELL FOUNDATION MODEL

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**Abstract**

**The geotechnical behaviour of curved shell strip foundation model was numerically analyzed using a finite element program OptumG2 (V1.12). The footings were analyzed in dry sand in three states, loose, medium, and dense. The results obtained were compared with those of a flat strip footing having the same width of 0.16 m as that of the curved shell measured horizontally. The thickness of shell was kept as 0.02 m and that of the flat strip was kept as 0.04 m. The stress distributions and vertical displacements were obtained and ultimate loads were determined. The results were interpreted using a shell efficiency factor and shell settlement factor. The curved shell strip foundation exhibited more than 30 percent greater ultimate loads and over 50 percent lesser settlements as compared to that of flat strip footing.**

**Index Terms—shell foundations, OptumG2, surface strip footings, numerical modeling.**

## I. INTRODUCTION

The first use of shells in foundation was done by a Mexican architect Felix Candela in Mexican soil [1]. Shells derive their strength from its form or geometry rather than from its mass [5]. They have shown excellent performance when used as roof structures in the past and have been in use till today. The use of shells has shown to give huge savings in material costs owing to their reduced thickness [5]. Past researches on shell foundations have shown improved performance with regards to load capacity and settlement characteristics. Shell foundations of various shapes were used for studying their geotechnical behaviour, experimentally and numerically such as triangular [1] and [2], hypar or hyperbolic paraboloid [3] and [4], pyramidal [1], [2] and [6].

## II. FINITE ELEMENT MODEL

In the present study a strip curved shell footing model was analyzed using a finite element software *OptumG2 V 1.12*. The width of the footing model measured horizontally was kept at 0.16 m. As strip footings have infinite length as compared to their other two dimensions the models were analyzed as plane strain models. To compare the results a flat strip footing of same width was also analyzed. The footings were analyzed on dry sand in three states, loose, medium, and dense. The extent of the sand medium was taken as 2.4m x 0.64m. The sand with different densities was arrived at by varying the unit weights adopted from [1]. The various features from the program were used to fix the boundary conditions and type of analysis. Standard fixities were taken as the boundary conditions which provide a partial fixity allowing vertical motion at the sides and a total fixity at the bottom of the sand medium. The sketch of the footing models are given in Fig. 1

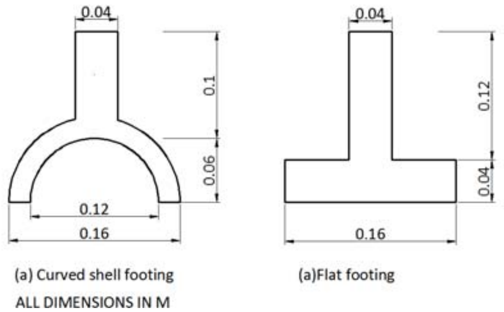


Fig. 1 Sketch of the footing models used in analysis

## III. NUMERICAL MODELING

The footings were analyzed using the multiplier elasto-plastic analysis from the program which is a combination of the limit analysis and elasto-plastic analysis. The loads applied are incremented till failure. Six-noded Gaussian triangular elements were used to discretize the footing and the sand medium. Mesh refinement was adopted at locations subjected to stress concentrations. A discretized model of the footing and sand medium is shown in Fig. 2. The footing was modeled as a concrete footing having unit weight of 25 kN/m$^3$.The footing was made rigid so as to ensure failure of soil before footing failure. The sand model is also discretized using six-noded Gaussian elements from the program. The properties of the sand in three states are given in Table I

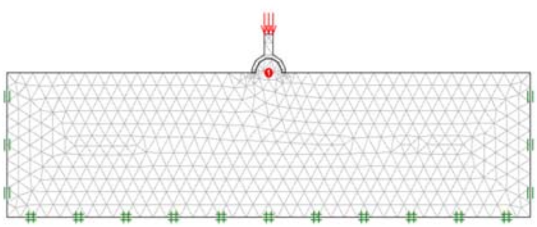

Fig. 2 Discretized model of the footing

Table I Properties of Sand in varying states of densities

| Property | Loose sand | Medium sand | Dense sand |
|---|---|---|---|
| Density $\rho$ (kN/m$^3$) | 16.4 | 17.6 | 18.4 |
| Angle of friction, $\phi$ | 33 | 37 | 40 |
| Elastic modulus , $E$ (MPa ) | 20 | 35 | 50 |
| Poisson's ratio, $\mu$ | 0.3 | 0.25 | 0.2 |

## IV. NUMERICAL ANALYSIS

### *A. Analysis in loose sand*

The footings both curved shell and flat footing were analyzed in loose sand. The properties of sand in loose state are given in Table I. The stress distributions and the vertical displacements as obtained from the finite element program OptumG2 are given in Fig. 3 and Fig. 4 respectively.

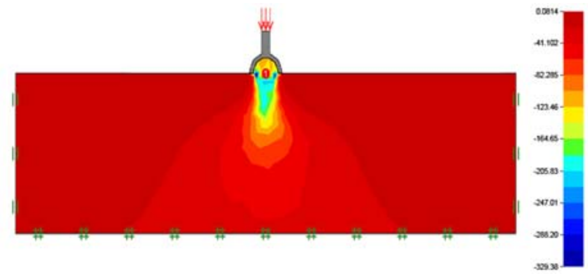

Fig. 3 Stress distribution in kN/m$^2$ under curved shell footing in loose sand

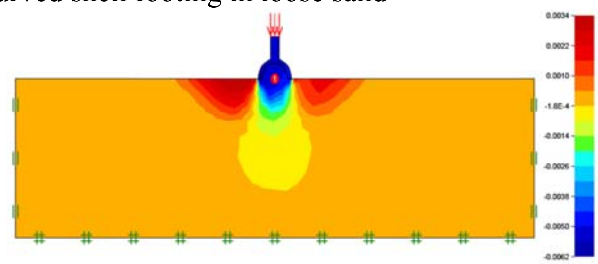

Fig. 4 Vertical displacement in m under strip curved shell footing in loose sand

The stress displacement curves for strip curved shell footing and strip flat footing in loose sand is given in Fig. 5. The stress displacement diagram shows that the stresses under curved shell footing are much more than that under the flat strip footing.

Owing to the increased area of contact between the footing and the core soil, there is increased frictional resistance making the core soil act integrally with the footing. Due to this cupping effect the vertical displacement are also found to be lesser in case of the curved shell footing.

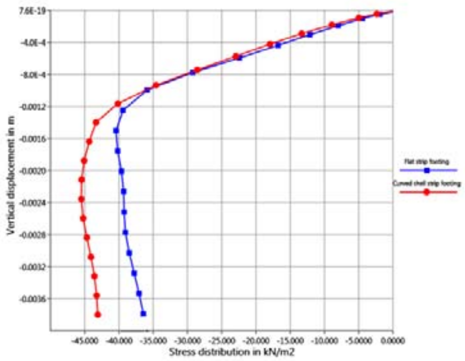


Fig. 5 stress displacement curve for strip footings in loose sand

If we take the plane passing through the base of the curved shell footing to be the same plane passing through the base of the flat footing we can conclude that the frictional resistance between the core sand and the foundation sand will be more than the frictional resistance between footing and sand.

*B. Analysis in medium sand*

The footings both curved shell and flat footing were next analyzed in medium sand. The properties of sand in medium state are given in Table I. The stress distributions and the vertical displacements as obtained from the finite element program *OptumG2* are given in Fig. 6 and 7 respectively

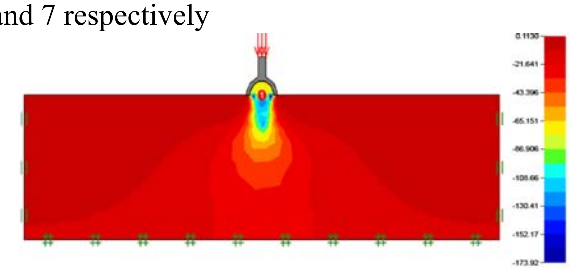

Fig. 6 Stress distribution in kN/m$^2$ under curved shell strip footing in medium sand

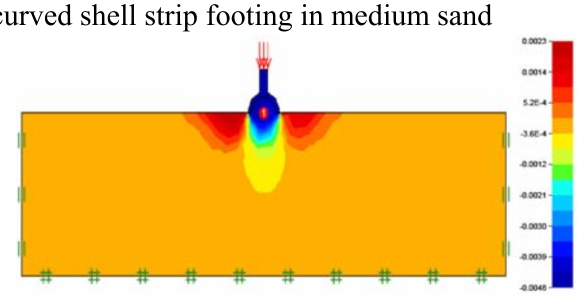

Fig. 7 Vertical displacement in m under curved shell strip footing in medium sand

The stress versus vertical displacement curve for the curved shell strip footing and flat strip footing in medium sand is given in Fig. 8.

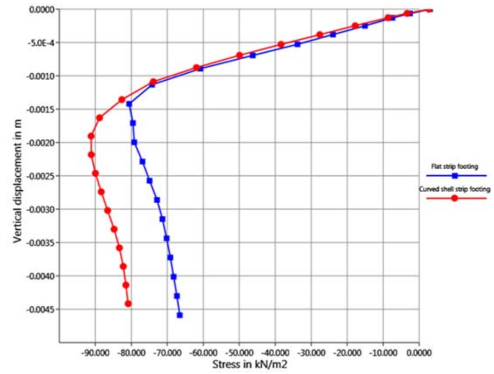


Fig. 8 Stress displacement curve for strip footings in medium sand

The stress displacement graph of the strip footings in medium sand also shows a similar behaviour of the curved shells trip footing showing higher stress distribution as compared to the flat strip footing. The vertical displacements were also found to be lesser in case of the curved shell strip footing. Due to increased density of the sand the strength of natural foundation has increased as compared to the previous case

*C. Analysis in dense sand*

The footings were then analyzed in dense sand whose properties are given in Table I. The Fig. 9 and 10 shows the stress distribution and displacements respectively under the curved shell strip footing.

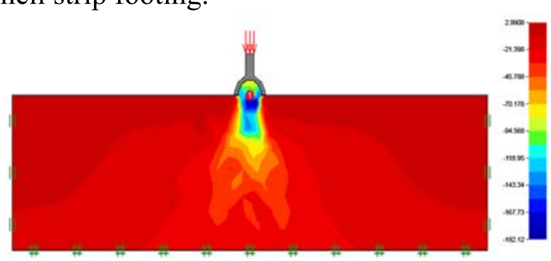

Fig. 9 Stress distribution in kN/m$^2$ under curved shell strip footing in medium sand

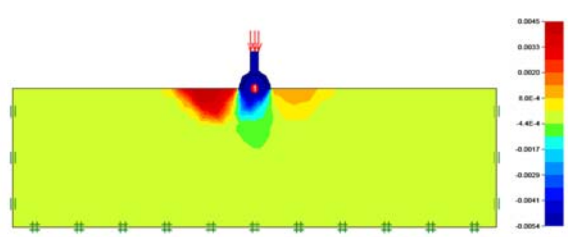

Fig. 10 Vertical displacement in m under curved shell strip footing in medium sand

The stress displacement curves are given in Fig. 11. The behaviour of curved shell strip footing showed a similar trend even in dense sand with the curved shell strip footing showing higher load capacity as compared to that of flat strip footing. The vertical displacements were also lesser in case of the shell strip footing

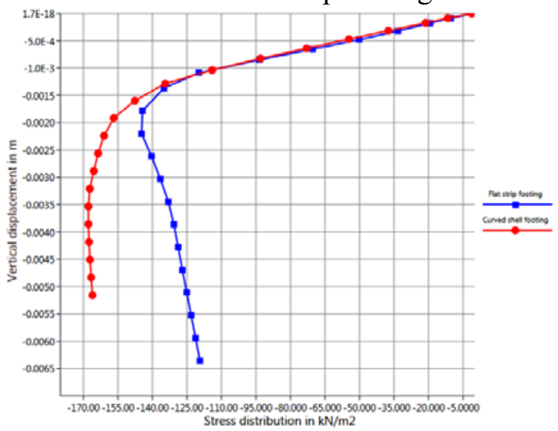


Fig. 11 Stress displacement curve for footings in dense sand

## V. RESULTS

The results from the study are interpreted in terms of two factors; shell efficiency factor and settlement factor as adopted from [1]

The shell efficiency factor [1] denoted by $\eta$ is given by

$$\eta = \frac{Qus - Quf}{Quf} \qquad (1)$$

Where $Q_{us}$ is ultimate load of curved shell strip footing and $Q_{uf}$ is ultimate load of flat strip footing.

The shell efficiency factor ($\eta$) computed using (1) with varying angle of friction ($\phi$) is given in Table II

Table II Shell efficiency factor for the varying sand states

| Shell efficiency factor ($\eta$) | Curved shell strip footing |
|---|---|
| Loose (ϕ = 33) | 0.28 |
| Medium (ϕ = 37) | 0.32 |
| Dense (ϕ = 40) | 0.36 |

The higher the shell efficiency factor the better is its behaviour as compared to the flat strip footing. In this case the shell efficiency factor increases with increase in the angle of friction indicating that the effect of the curved shell shape improves with the increase in the density of sand

The second factor is the shell settlement factor $F_\delta$ given by

$$F_\delta = \frac{\delta_h \cdot \gamma \cdot A_h}{Qu} \qquad (2)$$

Where $\delta_h$ is the settlement at ultimate load

$\gamma$ is the unit weight of sand

$A_h$ area of footing in horizontal projection

$Q_u$ is the ultimate load

The variation of settlement factor ($F_\delta$) with varying density of sand computed using (2) is given in Table III

Table III Settlement factor for varying densities

| | Settlement factor $F_\delta$ | | |
|---|---|---|---|
| Sand state | Loose (φ= $33^0$) | Medium (φ= $37^0$) | Dense (φ= $40^0$) |
| Flat strip | 0.0032 | 0.0019 | 0.0016 |
| Curved shell strip | 0.0015 | 0.0009 | 0.0006 |

The lesser the settlement factor the better is the settlement characteristics. The Fig.ures in the above table clearly show that the curved shell strip footings exhibit better settlement characteristics as compared to flat strip footings.

## VI. CONCLUSION

The above study is done on a conceptual model and its practical implications are yet to be studied experimentally. Though the geotechnical behaviour of the curved shell strip foundation is found to show better performance as compared to the conventional flat strip footing the problems facing its construction still poses uncertainties due to its curved shape. One way to overcome this difficulty would be using precast members. However it is a topic for research still in its infancy and needs to be backed by repeated tests and better understanding of its practical behaviour.

## REFERENCES

[1] M. Abdel-Rahman, “Geotechnical behavior of shell foundations,” Ph. D Thesis, Department of Civil Engineering, Concordia University, Montreal, Canada, March 1996.

[2] A. M. Hanna, M. Abdel-Rahman, “Experimental investigation on shell foundations on dry sand,” Canadian Geotechnical Journal, vol. 38, pp. 828-846, July 1998.
[3] B. B. K. Huat, T. A. Mohammed, “Finite Element Study Using FE Code (PLAXIS) on the Geotechnical Behaviour of Shell Footings,” Journal of Computer Science, vol. 2, no. 1, pp. 104-108, 2006.
[4] N. P. Kurian, D. V. M. Jayakrishna, “Analytical studies on the Geotechnical Performance of Shell Foundations,” published, NRC Research press web site at http:// cgi.nrc.ca , May 2005.
[5] N. P. Kurian, “Modern Foundations: Introduction to Advanced Techniques,” ISBN 10: 0070964696, Tata McGraw-Hill Publishing Company Limited, 459 pp, 1982.
[6] R. Rinaldi, “Inverted Shell Foundation Performance In Soil,” A Thesis in the Department of Building, Civil & Environmental Engineering, Concordia University, Montreal, Quebec, Canada, April 2012.