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BEHAVIOUR OF SHELL FOUNDATIONS UNDER SUBSIDENCE OF CORE SOIL

TENUE DES FONDATIONS EN VOILE SOUS AFFAISEMENT DU SOL NOYAU

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SYNOPSIS: Shell foundations are generally found to be ecpnomic under conditions of heavy loads and weak soils. Since shells are considered to be vulnerable to load concentrations, partial loading brought about by a possible subsidence of the core soil under the shell foundation has been a matter of serious concern affecting the widespread use of these foundations. This problem has been addressed in respect of shell foundations in single cone, double cone and the hyperbolic paraboloid, analysing the systems by the finite element method, in which the soil is modelled by Winkler springs, for varying degrees of contact with the shell. The results have shown that the shell systems are perfectly stable upto the limiting values of contact that are possible in the field, thereby removing the fear existing in the minds of designers in this regard.

INTRODUCTION

Shell foundations have been established to be economic alternatives to plain shallow foundations in situations involving heavy superstructural loads to be transmitted to weaker soils (Kurian 1982). The use of shells in foundations, as in roofs, leads to considerable saving in materials, and in the case of axisymmetric shells and shells with the straight line property, this is achieved without much extra input of labour. The resulting economy is substantial in the developing countries of the world, where materials of construction are scarce and expensive, but labour, cheap and abundant. It is imperative that the construction industry in these countries should increasingly gravitate towards this technique in the interest of conservation of the scarce materials of construction, if not economy.

SHELLS IN FOUNDATIONS

The frustum of a cone in the upright position represents the simplest form in which a shell can be put to use in foundations (Fig. 1). While smaller conical shells can be used as footings for columns, shells of substantially larger dimensions can serve as rafts for tower-shaped structures such as chimneys, telecommunication towers, etc. The frusta of an upright cone on the outer side and an inverted cone on the inner side, joined in the form of a 'folded shell' can effectively replace plain annular rafts for supporting cylindrical structures, such as water tanks, or overhead structures supported on a circular row of columns (Fig. 2). Among the shells which have come into vogue in foundations, the hyperbolic paraboloid is perhaps the foremost, thanks to its simple geometrical features - derived from the straight line property - coupled with high structural efficiency. Four quadrants in this shell joined by a system of edge and ridge beams, the latter terminating at the column base, can efficiently serve as footings for columns (Fig 3). An added advantage in the present case is that the plan of the footing can be rectangular and further, individual units can be combined to serve as combined footings or rafts.

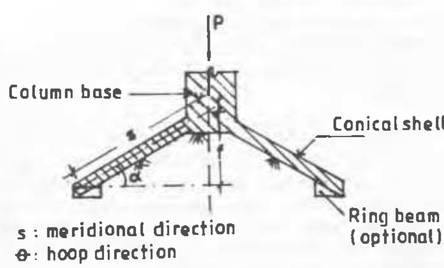


Fig. 1. Conical shell foundation

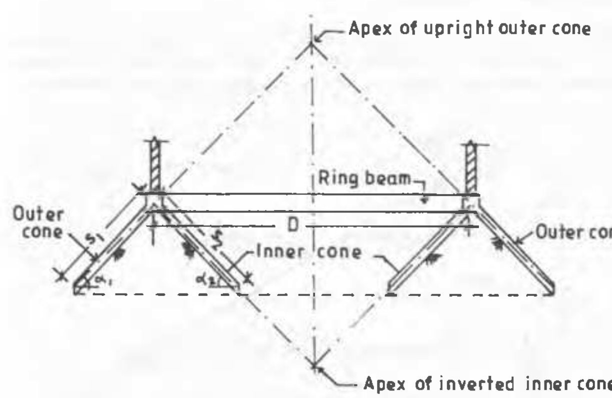


Fig. 2. Double cone folded shell foundation

PROBLEM OF CORE SUBSIDENCE

Depending upon their size, shell foundations can be cast in-situ or precast. In either method, it is important to ensure that there is perfect contact between the foundation and the soil at all points of contact, since partial

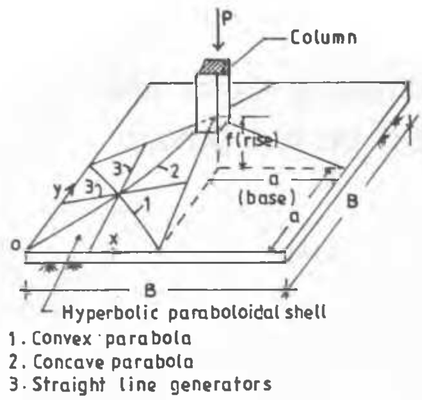


Fig. 3. Hyperbolic paraboloidal individual shell footing

contact will result in concentration of loads on the shell (soil reaction in this case) which can lead to premature collapse, as shell as a structural form is feared to be vulnerable to load concentration. The core soil, which is the soil filling the hollow space under the shell foundation, is profiled before casting the shell. If this core soil settles, starting with the top, it results in partial contact of the shell with the soil. Also, if a precast shell footing is placed on a prepared soil core, it may not be possible to ensure proper contact at all points. Since decreasing contact results in increase in concentration of loading on the shell from the soil, engineers are normally found to be much concerned about their safety and stability under conditions of partial contact.

The above fact prompted the present studies which present the analysis of shell foundations under partial soil contacts. In a situation such as the present one, where closed-form solutions are complex and formidable, a numerical method such as the finite element method has come in handy for providing an effective answer to the vexed question of the behaviour of shell foundations under conditions of core subsidence.

FINITE ELEMENT ANALYSIS

In the finite element analysis the soil under the centrally loaded shell foundation has been modelled by Winkler springs, and the system analysed for various degrees of

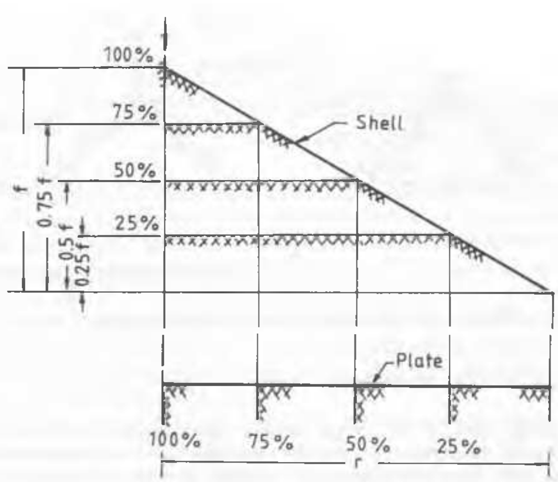


Fig. 4. Partial soil contacts considered in the analysis

contact between the shell and the soil. The contact parameter chosen for the studies is the ratio of the height over which the soil is present, to the full rise of the shell (Fig. 4). The cases analysed consist of 100%, 75% , 50% and 25% soil contact, 100% corresponding to the full contact (Vivekanandan 1988, Ram 1990). In order to model partial contacts the springs have been progressively removed, which is achieved by assigning them negligible stiffness (Kurian 1992).

The behaviour of the shells under partial soil contacts has been studied in terms of the variations in the verti-

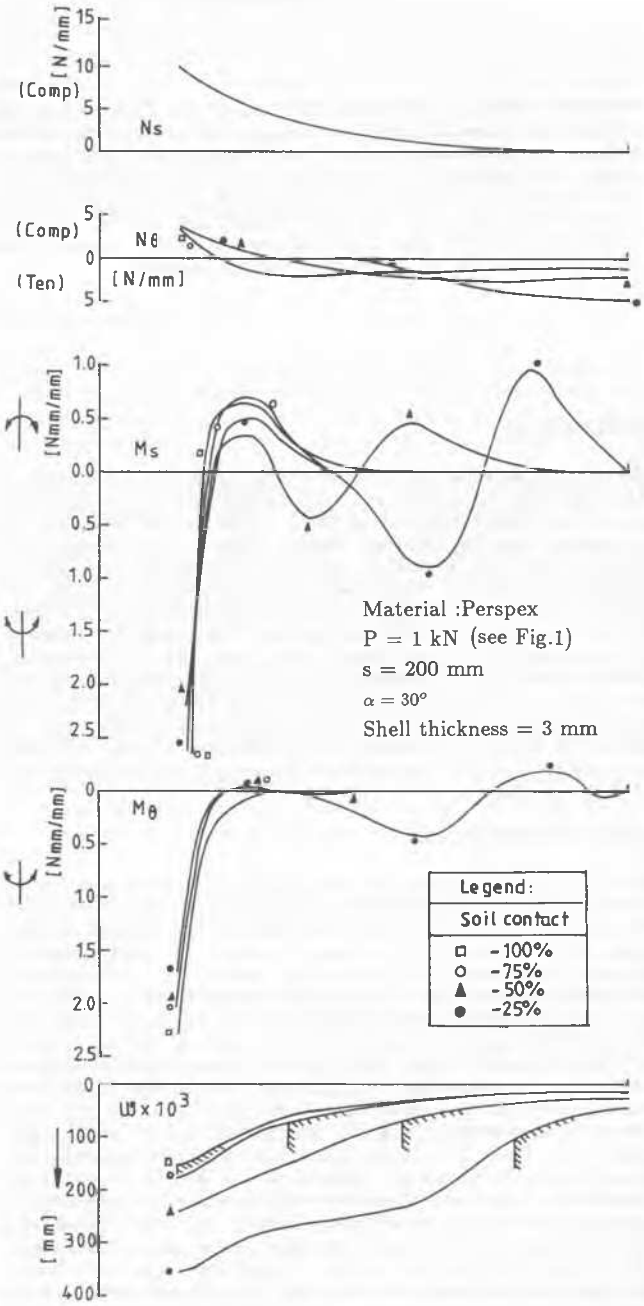


Fig. 5. Conical shell foundation: System response vs. degrees of soil contact

cal deformations (w) and the membrane (N,S) and bending (M) stress resultants in the shell and the edge beams. The size of the shell models and other relevant data used for the analysis are given together with the results.

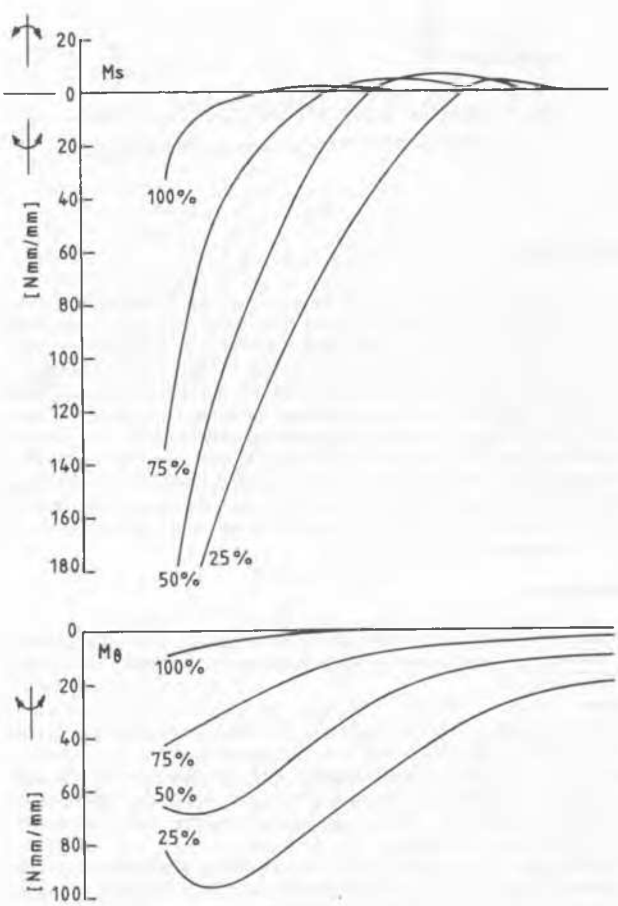
The results mentioned above in respect of the three shell foundations chosen for analysis, are presented and discussed in the following sections.

Conical Shell Foundation

The results pertaining to the conical shell foundation are presented in Fig.5 for various soil contacts. This is followed by the results of a flat circular plate of the same thickness analysed under identical conditions (Fig.6).

It is seen that the stress resultants and displacements increase in the shell with decreasing soil contact. The meridional compression is hardly influenced by the degree of contact unlike the hoop tension. As regards moments, the same in both directions get redistributed progressively from the region of no contact to the region where the contact is intact, without affecting the absolute maximum values.

In the case of the flat plate, even at 100% contact, the edges lose contact with the soil and lift up which required iterative analysis to be performed to arrive at a no-tension state between the shell and the soil. In sharp contrast to the performance of the shell under partial contact, the deformations and moments in the circular plate shoot up phenomenally with decrease in contact.



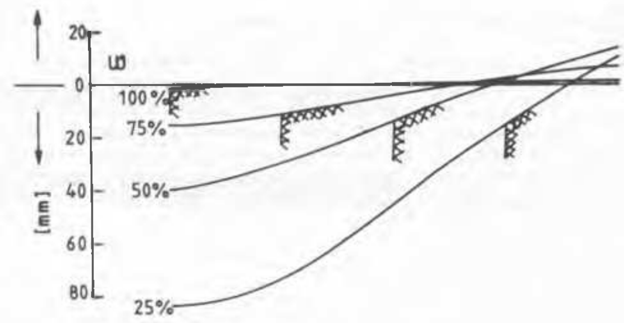
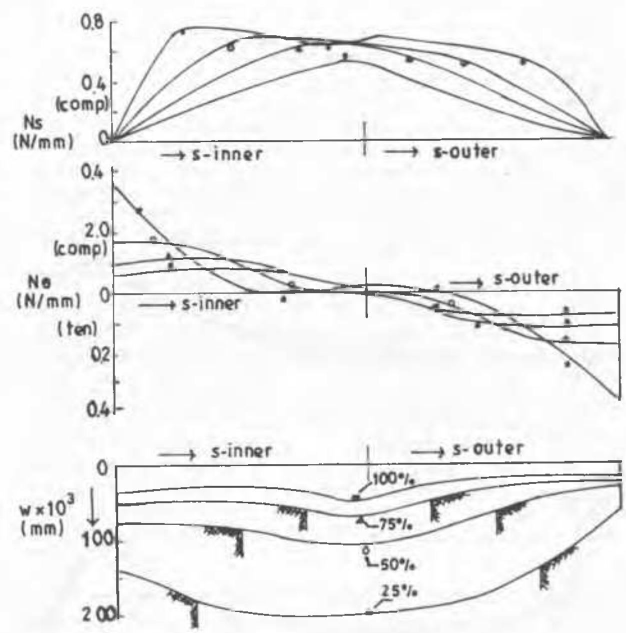


Fig. 6. Flat plate: Results under partial contacts

Double Cone Folded Shell Foundation

The results pertaining to this case are presented in Fig.7. Corresponding results show a similar trend as in the earlier case, except that the meridional compression increases and spreads over the entire shell.

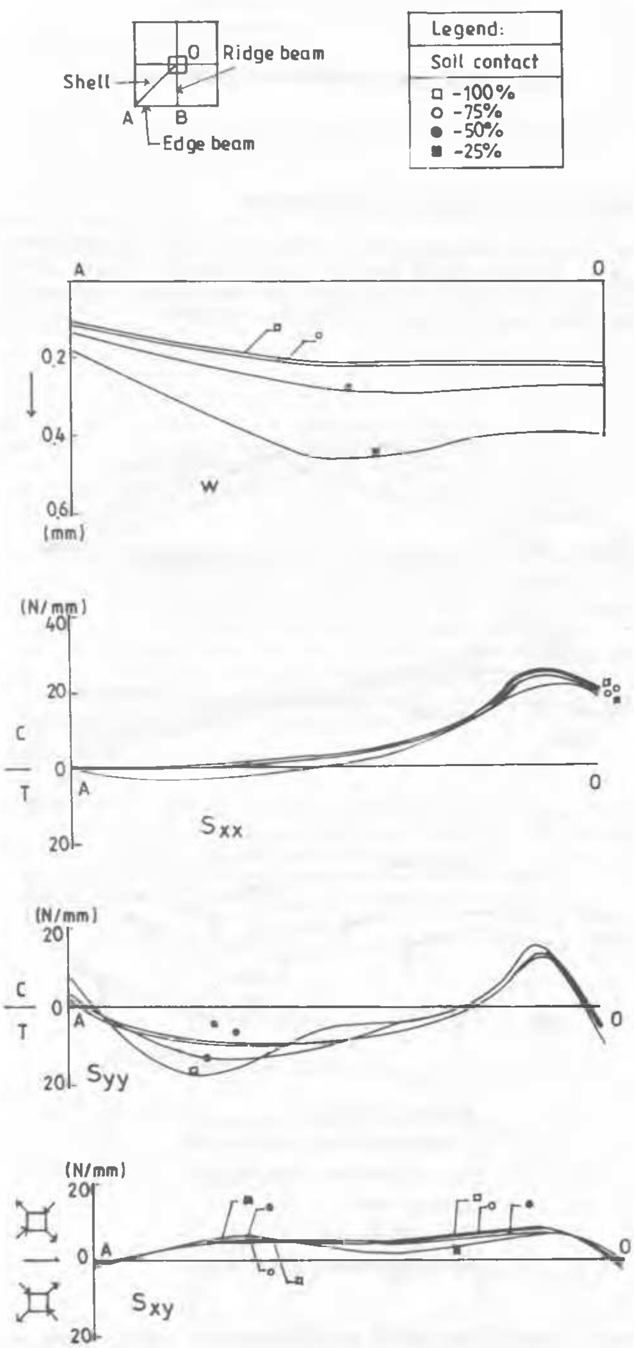


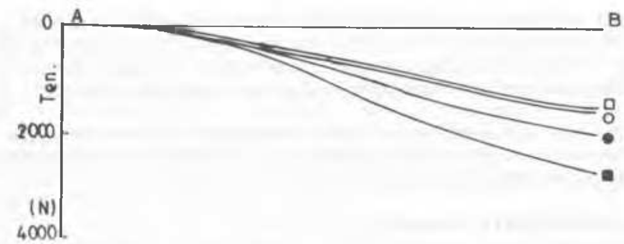
Material :Perspex
P (resultant ring load)= 1 kN
$s_1 = s_2 = 90$ mm (see Fig.2)
$\alpha_1 = \alpha_2 = 45°$
D = 348.50 mm
Shell thickness = 2.44 mm

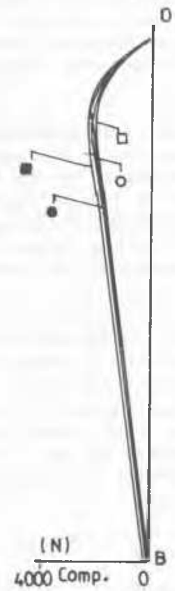
Fig. 7. Double cone folded shell foundations: System response vs. degrees of soil contact

Hyperbolic Paraboloidal Shell Foundation

The results pertaining to this case are only presented in respect of the shell diagonal and the edge and the ridge beams (Fig.8). Examination of the results reveals that the displacements and stress resultants increase with decreasing contact, with the profile in all cases remaining nearly the same. Between the beams, the axial force in the ridge beam is seen to be least affected.







Material :Aluminium alloy
P = 10 kN (see Fig.3)
B = 685.80 mm
f = 152.40 mm
Shell thickness = 6.35 mm
Edge and ridge beams
= 25.40 x 19.05 mm

Fig. 8. Hyperbolic paraboloidal shell foundation: System response vs. degrees of soil contact

CONCLUSIONS

It is commonly observed in respect of all the shells that the difference between the results pertaining to full and 75% contacts is very marginal. Partial contact, if any, need not be expected to exceed the condition represented by 75% contact considered in the analysis. The fact that the shell system is far more stable than its plain counterpart is indeed a great redeeming feature in respect of the behaviour of the shell. This is contrary to the fears expressed by designers in this regard, and as such these results must go a long way in popularising the use of shell foundations wherever conditions are favourable for their economic adoption.

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