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ANALYTICAL STUDY ON FUNICULAR SHELLS WITH VARYING RISES

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ABSTRACT

The construction of buildings has started by using concrete many years ago and from then there hasn't been much improvement in terms of structural design of buildings. In this project, a new way of designing the structure of building by using funicular shells as roof is explored. Funicular shells are the structural systems, which has a special nature and the load is carried on the curvature of shell. Funicular shells which consists of zero percentage steel reinforcement are used for both flooring and roofing systems. The study aims to investigate funicular shells of varying spans of 1 m to 2 m with varying rises of L/10 to L/20 are analyzed. The results suggest that the L/D ratio plays an important role in the deflection, tensile stress, compressive stress and strain values. The accession in rise of the shell is more advantageous in reducing the deformation values. Conclusions are drawn based on the results produced from the software.

Keywords - Funicular shells, shell curvature, zero percentage steel reinforcement, L/D ratio.

I. INTRODUCTION

As the cost of materials used for the construction (like cement, steel, aggregates, etc.,) are increasing day by day, the total cost of construction is also increasing [Lakshmikandhan, et al., 2014]. Considering the fact, latest ways of designing with reduced material usage are worked on, so that the cost of constructing buildings could be reduced. This finally helps in building the economy of the country as the investments involved in the construction is very huge.

The new methods involved are usage of funicular shells as roofing structure instead of reinforced cement concrete slabs. As the funicular shells are made of only concrete of up to 20 to 25 mm thick without any steel reinforcement, lot of cost involved in construction can be reduced against the normal steel reinforced cement concrete slabs which are 150 to 200 mm thick and also requires steel, which is the costly material among the construction materials [Bhattacharya and Ramaswamy, 1978].

By the above-mentioned type of new structural design it is possible to reduce the construction cost, to improve the stability of the building and also to speed up the construction process as the funicular shells are precast ones which are directly placed over the grid beams [Abolhassan Vafai, et al., 1975]. Due to the usage of funicular shells the self-weight of the building drastically reduces so that dimensions of the structural members is reduced and the further reduces and accidents will be controlled as the members used are light weight members [Deepa shri and Thenmozhi, 2014].

The project visualize on increasing the performance of the structure and a concept of replacing the traditional structural elements with the modified or totally new elements so that the cost of the building can be reduced and also the dead load of the structure is reduced.

In this work, funicular shells of three dimensions are designed which are 1 m, 1.5 m and 2 m. The central rises given to these funicular shells are varied from L/10 to L/20 as per IS recommendations. Each dimension consists of three rises and therefore a total of nine funicular models are designed. The thickness of shell is adopted as 20 mm and the grade of the concrete is taken as M20 as per clause 4.2.1 of IS 6332:1984.

II. ANALYTICAL INVESTIGATION

A funicular shell is used instead of regular slab. Analysis and design of the shell is made accordingly.

A. DESIGN OF FUNICULAR SHELL

In this work, a funicular shell is designed following the guidelines of IS 6332:1984. From clause 5.1.2 of IS 6332:1984, the equation to find the third co-ordinate of funicular shell is given below

$$Z = \frac{Z_{max}(a^2-x^2)(b^2-y^2)}{(a^2b^2)} \qquad (I)$$

where

Z is the altitude at point x, y

Z_{max} is the maximum central rise of the shell

a is half the length of the shell and

b is half the width of the shell.

Funicular shell of various dimensions 1000 ×1000 mm, 1500×1500 mm, 2000×2000 mm are designed from the above equation (I). So, in the above equation the values a, b (half the dimension of the shell) and Z_{max} are substituted. Here central rise varies from L/10 to L/20 as per the IS recommendations which is Z_{max}. By substituting the above values in the equation, a simplified equation is obtained which gives the rise (Z coordinate) for different X and Y coordinates. Here central part of the shell is taken as the origin.

The simplified equation for 1000×1000 mm dimension and 100 mm (L/10) rise is given below

$$Z = 0.1 - 0.4(x^2) - 0.4(y^2) + 1.6(x^2y^2) \quad \text{(II)}$$

Replacing the X and Y coordinates in above equation (II), Z coordinate at different points can be obtained. As the funicular shell is a symmetrical one, the Z coordinate will be the same in all the four directions of the axes. The rise (Z coordinate) for different points along the positive X axis which gives the geometrical representation of the funicular shell are shown in Table 1.

Table 1 Co-ordinates of the funicular shell

X coordinate (m)	Y coordinate (m)	Z coordinate (m)
0	0.1	0.096
0	0.2	0.084
0	0.3	0.064
0	0.4	0.036
0	0.5	0
0.1	0.1	0.09216
0.2	0.2	0.07056
0.3	0.3	0.04096
0.4	0.4	0.01296
0.5	0.5	0

Funicular shell is modelled in ANSYS software using the coordinates found earlier. The key points are created using the coordinate values and are joined by lines, and also the lines are filled by areas which makes it easier for the meshing work. Meshing is the core of finite element analysis and only if meshing is done, the models can be analyzed. The research investigation is carried out for three shells of dimensions 1000×1000 mm, 1500×1500 mm, 2000×2000 mm. The shells each having three different rise ratios of L/10, L/15, L/20 are modeled. The plan and cross-sectional view of the funicular shell is shown in Fig. 1. The side view of the funicular shell of dimension 1000 mm × 1000 mm of central rise 100 mm is shown in Fig. 2.

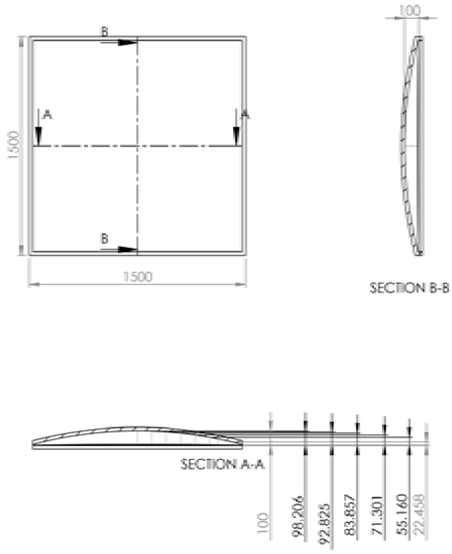

Fig. 1: Plan and cross-sectional views of Funicular shell

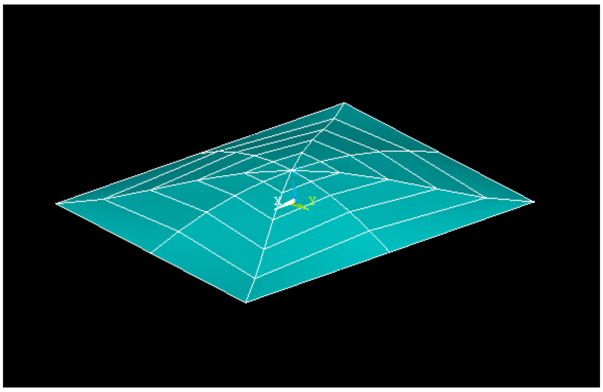

Fig. 2: Side view of the funicular shell

B. **ANALYSIS OF FUNICULAR SHELL**

After modeling is done, the shell must be analyzed. The model is considered as a shell in the Civil FEM software. The grade of the concrete is adopted as M20 grade and the thickness of the shell is considered as 20 mm. The shell is tested under static structural condition. The nodes at the edges are considered as the fixed support and then a pressure of 5 kN/m^2 is applied at the top of the shell for around 200 mm. The shell is then analyzed and the results are taken. The properties of the concrete are given to the shell are furnished in the Table 2.

Table 2: Properties of Funicular Shell

Property	Value
Density	2447.5 kg/m^3
Modulus of elasticity	2.5×10^{10} N/m^2
Poison's ratio	0.18

III. RESULTS AND DISCUSSION

The maximum principal stress and the minimum principal stress are considered as the tensile stress and the compressive stress respectively. The change in length of the shell due to tensile stress and compressive stress are called tensile strain and compressive strain respectively. Usually, the tensile strain has an increase in length and the compressive strain has a decrease in length. The results of the displacement, tensile stress, compressive stress, tensile strain and compressive strain are taken from the software. It is noted that there is a decrease in the tensile stress and a increase in the compressive stress when the shell rise is increased. Also, there is a constant decrease in the displacement when the shell rise is increased. The tensile and compressive stress contours are shown in Fig. 3 and Fig. 4 respectively. Correspondingly, the tensile and compressive strain contours are shown in Fig. 5 and Fig. 6 respectively. Also, the displacement contour is shown in Fig. 7. The results are shown for dimension 1000×1000 mm with central rise 100 mm only.

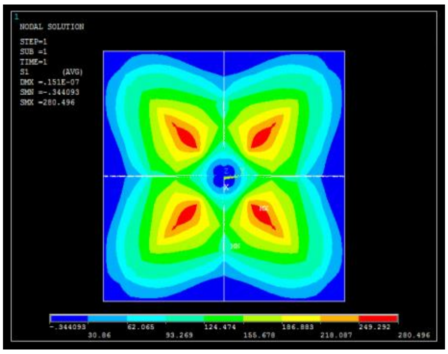

Fig. 3: Tensile stress contour

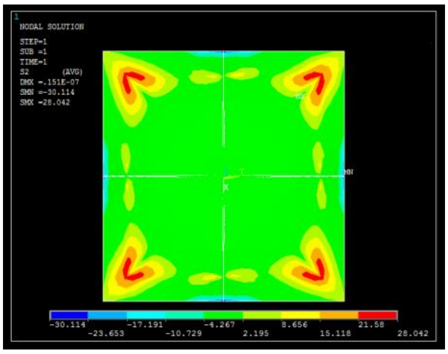

Fig. 4: Compressive stress contour

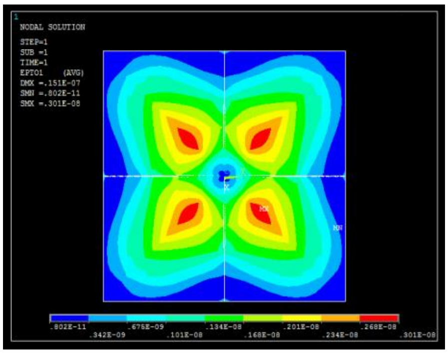

Fig. 5. Tensile strain contour

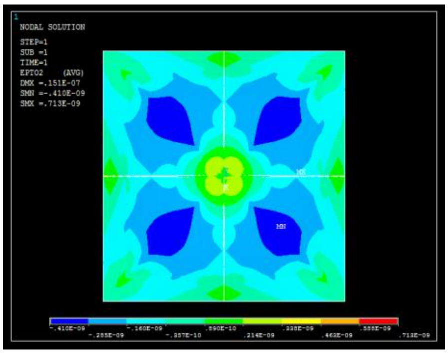

Fig. 6: Compressive strain contour

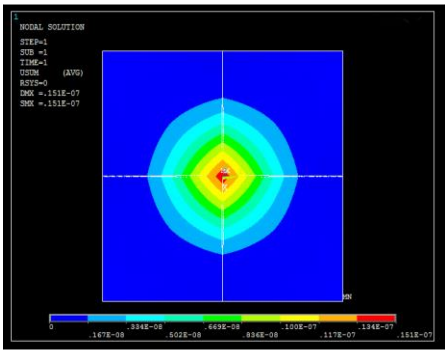

Fig. 7: Displacement contour

The results are compared for different span to rise ratio and graphs are plotted for tensile stress versus span to rise ratio, compressive stress versus span to rise ratio, tensile strain versus span to rise ratio, compressive strain versus span to rise ratio and displacement versus span to rise ratio and are shown in Fig. 8, Fig. 9, Fig. 10, Fig. 11 and Fig. 12 respectively.

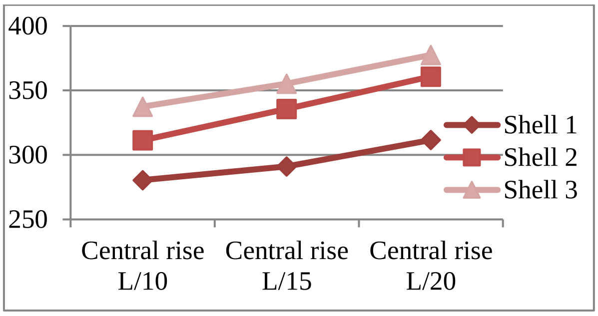

Fig. 8: Tensile stress versus span to rise ratio

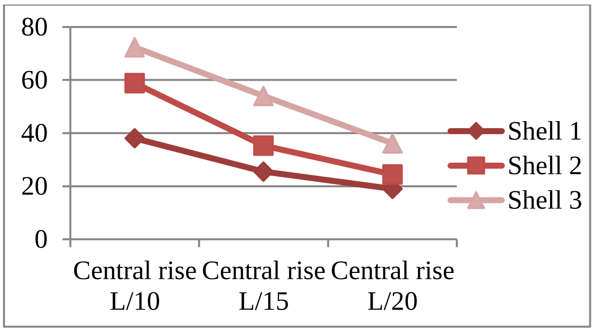

Fig. 9. Compressive stress versus span to rise ratio

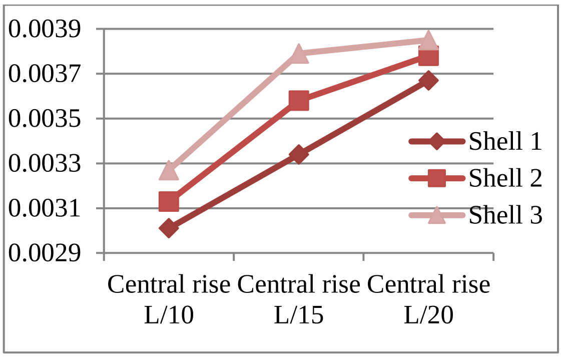

Fig. 10: Tensile strain versus span to rise ratio

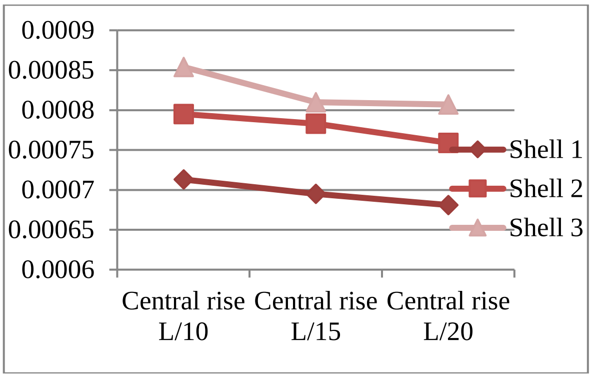

Fig. 11:. Compressive strain versus span to rise ratio

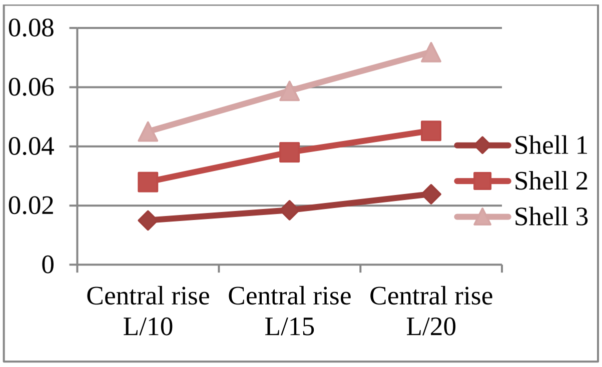

Fig. 12: Displacement versus span to rise ratio

The plotted graphs show that there is a constant decrease in the tensile stress, tensile strain and displacement and a constant increase in the compressive stress and compressive strain when the central rise gets increased.

IV. CONCLUSIONS

To reduce the materials usage in the construction of building a new type of building design is adopted in this work and accordingly different ideas are adopted from the various references to achieve slender and economical sections which in turn reduce the dead weight of the building.

Funicular shell is modeled in ANSYS. For less concrete quantity compared to normal slab, funicular shell showed good load carrying capacity with negligible deflection.

Usage of steel is completely avoided as the shell is totally a compressive member. It can be inferred that funicular shell as roof is completely economical and can be used readily.

The analytical study has been carried out for the funicular shells with different spans and different rises. The results prove that the tensile stress, tensile strain and displacement values goes on increasing and the compressive stress and compressive strain values goes on decreasing when the central rise lowers. Therefore, comparatively, it is concluded that when the span to rise ratio decreases (i.e) the funicular shell with increased central rise is more effective.

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