Parametric Study on Behavior of Concrete Shell under Uniform Loading

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Abstract- **Concrete is strong in compression and weak in tension, makes it an elegant choice for a shell roof construction. Concrete shell roofs have been widely used in the construction field for reasons concerning aesthetic appearance or achieving an economical design of a building with large spans. A shell roof, because of its dominant in-plane forces has a distinct behavior compared to flat roof. Membrane forces (In-plane forces) can be characterized into meridional and circumferential (hoop) forces in a doubly-curved shell structure. The shell roof chosen for the current study is a truncated doubly-curved spherical shaped thin-shell with a positive Gaussian curvature.An advanced finite element package ANSYS has been employed for shell modelling and analysis. A suitable 8 node quadratic shell element has been used for finite element modelling of shell surface. Ten doubly-curved spherically shaped domes have been modelled and analyzed in ANSYSWorkbench. The behavior of shell roof changes as its rise changes. A parametric study is done varying the rise to span ratio of a flat roof to that of a hemispherical dome in static loading conditions.The theoretical validation is found to be in good agreement with ANSYS models. The study circumscribes the behavioral aspects of a spherical thin shell roof accounting various rise to span ratios.**

Keywords: Doubly-curved spherical shell roof; Membrane forces; Rise of shell; Quadratic Shell element

I. INTRODUCTION

Dome structures have made a footprint in the architecture of many civilizations from time immemorial. Its implementation has been viable for materials such as brick, stone, glass, concrete, metal, wood and lately with ferrocement. Its character of exhibiting membrane (in-plane) forces will be due to its initial curvature. A spherical shell roof defines its geometry by the rise and span it possesses. Lower the rise, larger will be the radius of curvature. Concrete being strong in compression, makes it a versatile material for shell roof construction. Membrane is used to make validation for the results from finite element analysis. This paper focuses on comparing the behavior of finite element model of shell roof and that of theoretical model in various rise to span ratios.

It can be difficult to obtain analytical solution for a complex structure due to its complexity of geometry. But when the whole structure is discretized into suitable sized finite elements, the solution can be obtainable. In order to circumvent huge computational efforts and complex theories,shell elements chosen were of belonging to a domain of 2 dimensional elements and thus theoretical validation has been pursued with an assumption of thin shell. Finite element package ANSYS^{TM} has been employed to model and analyze the structures. For a better accuracy of results, quadratic elements have been chosen for each and every shell structure. SHELL281 is quadratic element available in ANSYS Workbench element library. SHELL281 has been used to model shell roofs. The aim of the study is to observe the change of meridional stress and circumferential stress curves with change of rise to span ratio.10 shell structures are modeled in ANSYS Workbench varying only the rise of the dome from 0.0 m to 5m. A uniform shell thickness of 0.12m; shell roof span of 10 m; Material assigned and employed in each simulation is concrete with Young's modulus of 30 GPa and Poisson's ratio of 0.18.
Following are the shell elements available in ANSYS element library:

SHELL 41 is a 3-D element possessing membrane (in-plane) stiffness but no bending (out-of-plane) stiffness. This is quite a unique element vouching the classical membrane theory of shells. It is intended for shell structures where bending isn't of much significance. The element has a linear displacement polynomial and has strictly 3 degrees of freedom at each node i.e. translations in the nodal x, y, and z global coordinate directions.

It is of exigency that the four nodes defining the element should be contained in a plane which would be perfectly flat; if however, the element sustain the effects of a finite bending stiffness so that the element may have a leeway on a slightly curved or a warped shape. But a slightly curved or a warped shape can notify a warning message in the post-processing stage for which we might want to suggest triangular shaped elements to confront the particular problem. An assembly of SHELL41 elements depicting a flat plane should be perfectly flat; otherwise singularities may arise in the transverse direction to the plane.

SHELL181 can have a leeway of employing it for analyzing thin to moderately-thick shell structures. It consists of 4 nodes with 6 degrees of freedom at each node (translations in x, y, and z directions, and rotations about the x, y, and z-axes). Mathematically, the element is linear and is cut below to its quadratic version. The triangular form of the element (3 node element) is usually not preferred and henceforth this paper employs shell elements in its quadrilateral shape in fact the application suggests not to use the triangular shaped elements especially in the high stress gradients. The through thickness stresses are assumed to be zero in this particular element.

SHELL281 employs an advanced shell formulation that accurately incorporates the curvature effects which blatantly provides an upper hand in a curved shell simulations. The program has an intuition of choosing this particular element over conventional shell elements SHELL41 and SHELL181. In fact restricting the calculations to membrane effects might hamper the accuracy of the problem.

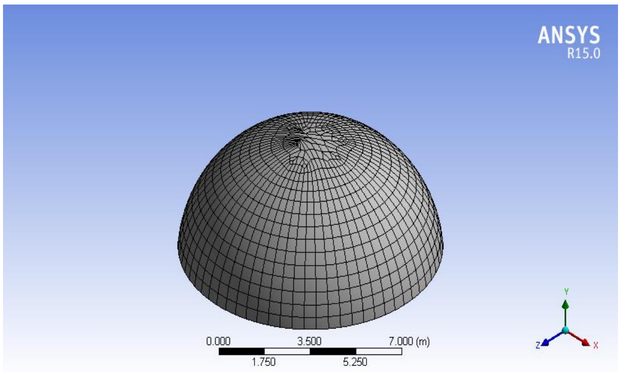


Figure (a)-Isometric view of the meshed model

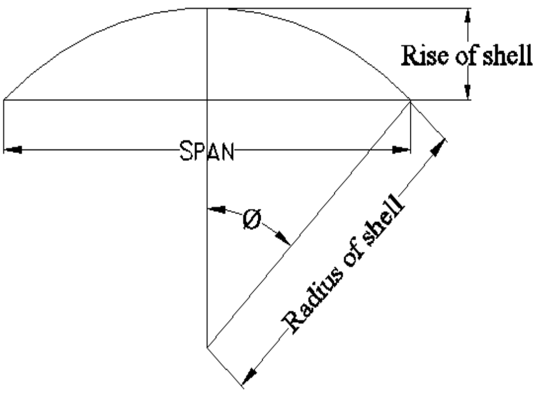
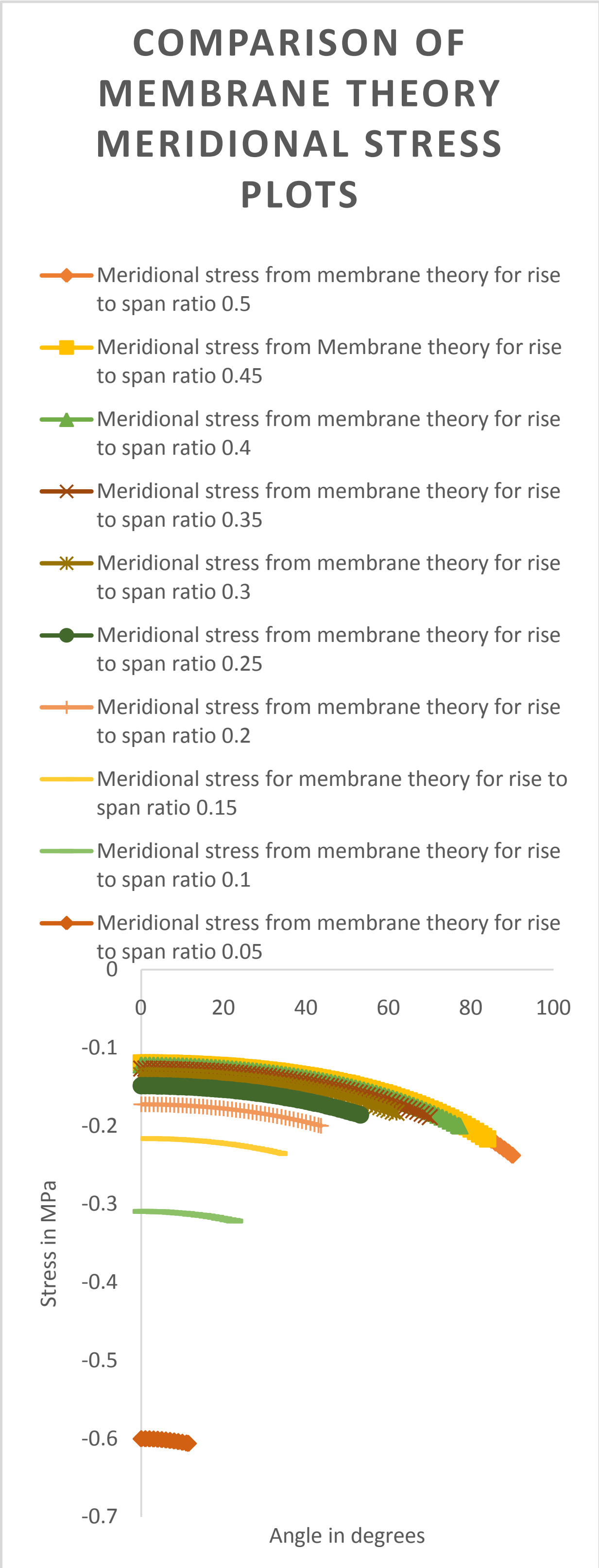
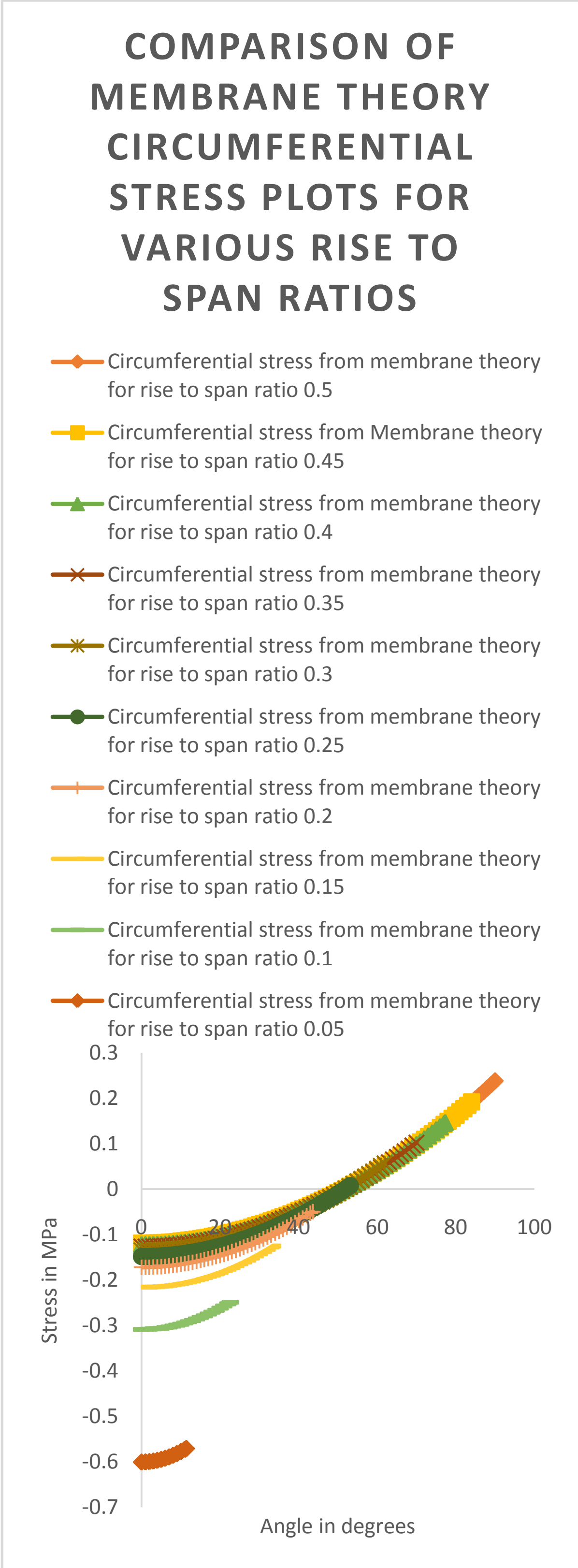


Figure (b) Elevation view of shell model

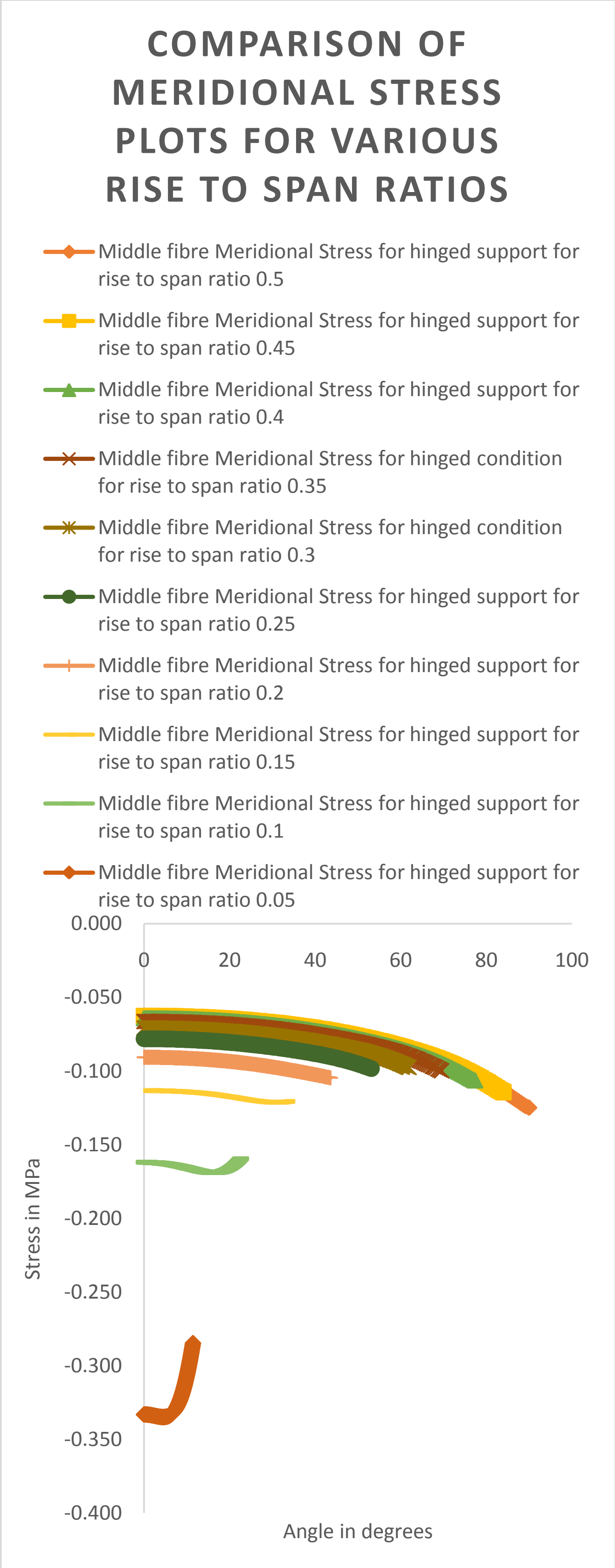
Self-weight of shell has been assigned along with a live load vertical pressure of 3kN/m^2.
A theoretical validation was established with ANSYS isolated hinged shell models.

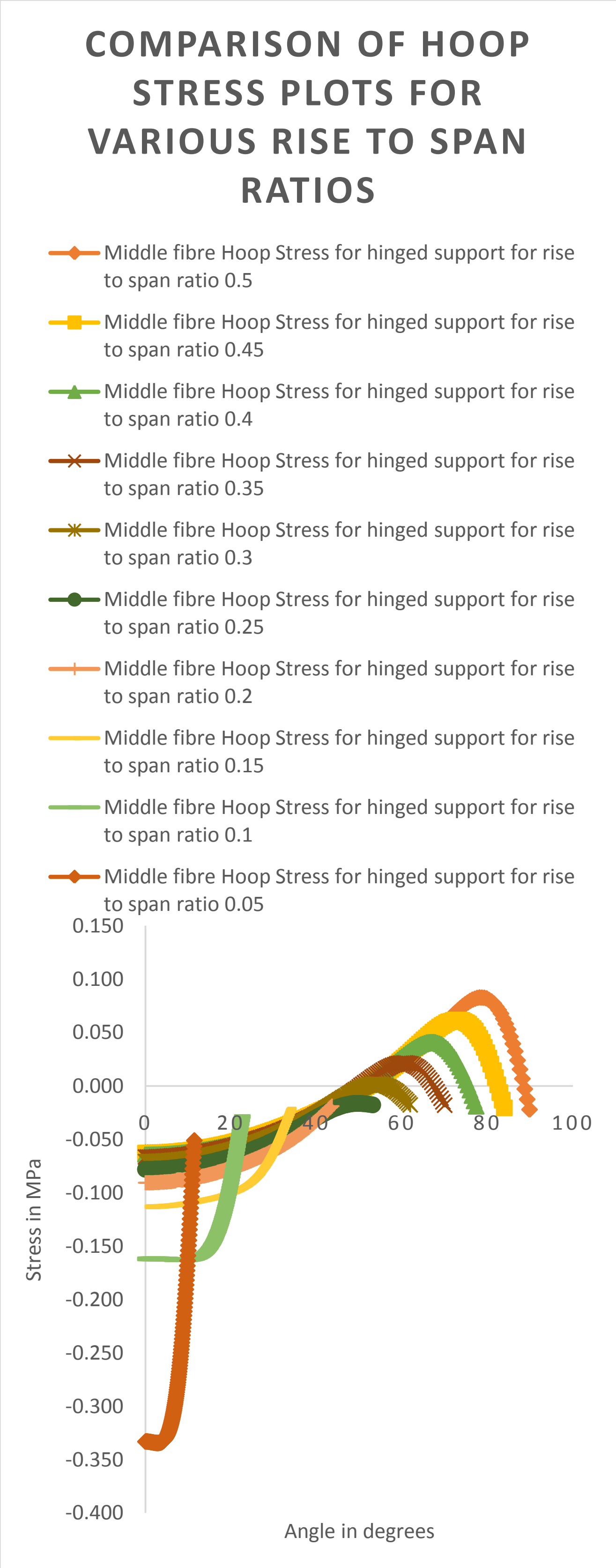
II. RESULTS AND DISCUSSIONS





Figures1 And 2-Comparison Graphs From Theoretical Results





Figures 3 and 4: Comparison graphs from ANSYS results

Figure 1 and 2 present comparison stress plots from membrane theory. The stress curves show congruency with each other but there is an exponential increase in the magnitude of membrane stresses as the shell makes a transition from non-shallow shell to shallow shell. The theory suggests that the hoop stresses would be extensional (tension) at the points greater than 51°50'.

Figure 3 and 4present comparison stress plots from ANSYS models. The stress pattern of curves of shells are similar when they belong to a domain of non-shallow shells. There is a peculiar shift in the pattern of stress curves as shell makes a transition from non-shallow to shallow shell. This pattern shift can be noted for each and every table. The non-shallow shells show a distinction in their behavior to that of shallow shells. Figures have been plotted considering the symmetry of shells. 0 degrees in the x-axis would be the apex of shell and the last plotted data of a curve would be its semi-circularangle ϕ.

CONCLUSIONS

1. A distinction in the behavioral aspects can be made between shallow and non-shallow shells from the plots constructed.
2. There is an exponential increase in the membrane stress in the mid-span in every stress plot comparison.
3. There is a significant change in membrane stresses as it makes a transition from non-shallow shell to shallow shell.
4. An appreciable change in the pattern of stress curves (span-to-rise ratio <0.25) can be observed in each comparison plot constructed.
5. Slope of stress curves increases as non-shallow shells make a transition to shallow shells.
6. Tendency of a shell to extend (extensional ability) increases as rise to span decreases.
7. A suitable rise to span ratio in the range of 0.13 to 0.16 shall be suggested for an optimum behavior of shell.

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