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A Review on Parametric Study of Ribbed and Schwedler Domes with Openings

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Abstract
A curve rotated about a central axis to form a surface typically used as roof creates a dome. The dome may be different geometric parameters with an infinite number of shapes. They are capable of having extraordinarily less thickness over large span areas due to their structural behavior. In this paper the behavior of rigidly jointed ribbed dome and schwedler dome with openings are considered. The proposed domes are modelled and analysed by using ANSYS. Stress variation, deformation profile are studied for different rise to span ratios. Parametric study is the key to determine optimum configuration. This provides direction for practical application for deciding domes with openings during construction.

Keywords: *Domes, ribbed dome, schwedler dome, openings, ANSYS, stress variation, deformation profile, rise to span ratio, parametric study, optimum configuration.*

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I. INTRODUCTION

Domes are curved structures capable of exhibiting extremely less thickness without being supported by any column. They have neither any angles nor corners and are unencumbered by columns or restrictions as a result of which it is considered to be structurally efficient and cost-effective due to its optimum utilization of resources. Infact, domes are widely incorporated in large span structures due to the structural characteristics it possesses and are often considered as light-weight structures. There is typically a minimum of 30% reduction in surface area in a dome than other comparable structural shapes and are advantageous due to their strength, stiffness, stability and rapid construction.

Steel structures are gaining wide popularity due to its numerous advantages in terms of durability, strength and architectural aspects and are often adopted in long span structures. Long-span dome structures are structural elements that create unobstructed, column-free spaces greater than 30 metres for a variety of functions such as public assembly venues, sports stadium, mosques, shopping malls and the like due to its efficient utilization of materials. Domes are capable of withstanding large load and self-weight without portraying much deflection and displacement. The internal meridional forces developed in dome structures are transferred to the support structure at its pedestal. Compressive forces are developed in a dome structure; loaded axisymmetrically with its self-weight, the magnitude of which increases from the crown to the base.

The difference between a dome structure and a rectangular structure lies in the variation in structural properties it exhibits to withstand the external pressure or load. Exposure to external load causes a rectangle to undergo sidesway, which further causes the angle between each member to change and the shape of the rectangle would change accordingly. On the other hand, a triangular shape would however retain its shape and inner angles, due to the triangle shape being self-braced and stabilized. A rectangle would require some forms of bracing elements or rigid connections in its geometry to lock itself in place.

A dome may include different geometrical configuration with an infinite number of shapes such as Geodesic dome, Ribbed dome, Schwedler dome and the like, commonly referred to as reticulated dome structures (domes composed of bars). The geometrical aspect of a ribbed dome incorporates the formation of trapeziums using horizontal rings at the point of intersection. Schwedler domes are formed by further subdividing a ribbed dome into triangles using diagonal members. Further, a Kiewitt dome structure consists of a series of subdivided triangles along the circumferential direction, which have a common vertex at the crown of the dome.

Openings are provided in domes for ensuring lighting and ventilation. Currently, researches on the influence of openings on the structural response of shell structures with respect to varying geometrical parameters are sparse and quite uncertain.

1.1 Domes

A dome is an architectural element similar to the hollow upper half of a sphere. They have neither angles, nor corners and are less supported by the columns or restrictions as a result of which it is considered to be structurally efficient and cost effective due to its optimum utilisation of resources. Domes are widely incorporated in large span structures due to the structural characteristics it posess and are often considered as light weight structures. There is typically a minimum of 30% reduction in surface area in a dome than other comparable structural shapes and are advantageous due to their strength, stiffness, stability and rapid construction.

1.2 Ribbed Dome

Ribbed dome is a dome with ribs that rotate around its vertical axis. Rib is a three dimensional which projects from the dome's interior surface. It can be in the form of hemispherical and polyhedral dome.
The dome has vertical compression along their meridians but horizontally experience compression only in a portion above the top. Below this point the hemispherical dome experiences tension horizontally.

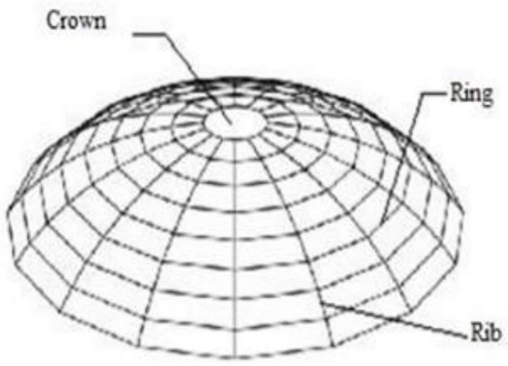

Figure 1: Ribbed Dome

1.3 Schwedler Dome

A schwedler dome consists of meridional ribs connected together to a number of horizontal polygonal rings and a diagonal member subdivide each trapezium formed by intersecting meridional ribs with horizontal rings into two triangles. It stiffens the resulting structure and it will be able to resist unsymmetrical loads.

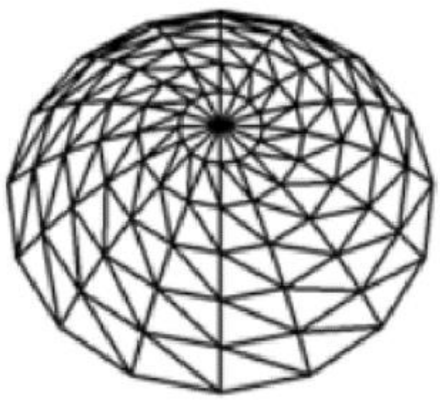

Figure 2: Schwedler dome

II. PARAMETRIC STUDY OF RIBBED AND SCHWEDLER DOME WITH OPENINGS

2.1 Gaussian Curvature

Gaussian curvature are used for classifying shell structure. Gaussian curvature for a three dimensional surfaces found by product of maximum and minimum principal curvatures. The Gaussian curvature can be classified as synclastic, anticlastic and monoclastic. Synclastic surface, both maximum and minimum principal curvatures have the same sign which results in positive Gaussian curvature. To carry loads, they mostly exhibit inplane meridional as well as circumferential stresses. The typical examples of a Synclastic surface are spheres and elliptical paraboloids. In Anticlastic surface, both maximum and minimum principal curvatures have different signs which results in negative Gaussian curvature. Due to the opposite sign of principal curvature, it acts as a combination of compressive and tensile arch behavior under vertical loads. The examples of Anticlastic surfaces are hypars. In Monoclastic surfaces, any one of principal curvatures is zero. The typical examples of Monoclastic surfaces are cylindrical shells. Dome with unconventional geometries has potential applications [2].

2.2 Modelling and Geometric Parameters

The spans (D) of the ribbed dome and schwedler dome are considered 20 m and 30 m, while the thickness of the dome is considered to be 10 cm. Three numbers of rings are selected and equally spaced. From Eq. 1, total angle subtended (Ø) by the dome is found out and this angle depends on the rise (H)-to-span ratio [3]. The geometry of dome can be clearly defined by using Fig.3.

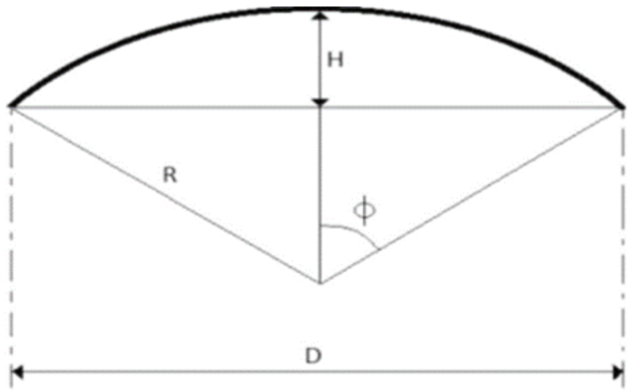

Figure 3: Total Angle Subtended by Dome

The stresses in dome are maximum at the crown and minimum at the bottom of dome as mentioned by [1]. The stresses acting at the bottom of a dome structure are called hoop stresses and are less compared to the stresses at the top. On observation of such a profile in stress variation, it has been recommended by [1] to provide openings at the bottom of the dome. Thus, considering this aspect for the rerch work, more openings can be provided at the bottom than the openings at the top. Surface area of a dome can be calculated using the formula = $2\times \pi r \times h$ square units where h is the dome height and r is the radius of dome. Formula for defining the area of opening as mentioned by [1] may be determined by deducting the area of dome after opening from the total area of dome.

Area of opening provided = Total area of dome – Area of dome after opening

$$\text{i.e.; } A_o = \frac{[(2\times\pi r\times h)-(2\times\pi r_1\times h_1)]}{2} \qquad (2.1)$$

where r_1 = radius of dome at second ring
h_1 = height of dome at second ring
r = radius of dome at bottom ring
h= height of dome from bottom ring

The procedure for the analysis of the dome configuration as follows:

1. Calculation of angle subtended by the dome using equation with respect to different rise-to-span ratio (H/D) based on which the radius of the spherical dome may be defined.
2. Generation of key points in ANSYS to model an arc of specified radius. The arc may further be divided into the required number of ribs of the dome.
3. The modelling of the dome structure should then be formulated using suitable commands about the axis and reference plane.
4. Assigning the shell element, material properties [Moment of inertia (I), area of the section (A), modulus of elasticity (E), yield stress and Poisson's ratio], and section sizes for the modelled dome structure.
5. Mesh generation of suitable size and assigning fixed supports at the bottom of the dome with rigidly connected joint members.
6. Applying load conditions and analysis of various structural parameters.

2.3 Material Properties and Loading Conditions

The moment of inertia (I) and area (A) of the section are constant for all members with different load conditions. The modulus of elasticity (E) of the member is taken as 210 kN/mm^2 , yield stress (fy) as 250 MPa and Poisson's ratio is 0.3. The joints are considered to be rigidly connected and all the supports as fixed supports. The members are exposed to both axial stresses and bending moments. By varying rise-to-span ratio, i.e., 0.10–

0.50 with an increment of 0.05 is considered for analysis. To know the behaviour of the dome, a vertical load of 500 kN is considered in the downward direction. The concentrated load is applied at the apex of the dome for calculating buckling load by varying rise-to-span ratio. For effective rise-to-span ratio, various parameters were calculated such as maximum axial stresses in rib and ring members, the maximum moment in the members and maximum deflection of dome structure by using ANSYS software.

III. CONCLUSIONS

- The heavy stress is observed near the surface. For better performance, against lateral loading, height of dome should be the minimum. Stresses are distributed more evenly for H/D ratio of 0.25. Therefore H/D ratio should be maintained above 0.25.
- Since rigid joints are provided chances of local instabilities are less. There is not much deflection for the dome structure.
- If axial stress and moments are deciding factors for the dome, then schwedler dome are preferred, since a considerable decrease in stresses and moments.
- Schwedler dome offers more even distribution of the dead load and reduces the unbraced length of the ribs.
- Providing an opening, the structure becomes more economical and buckling load on the dome was also reduced. Because of openings, there was failure observed in the vicinity of openings. It is recommended that strengthening should be done near openings.
- Due to the addition of a diagonal element, the stiffness of schwedler dome is increased. The cost of schwedler dome is also increased, but the reduction in stresses is observed.

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