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Buckling Analysis and Parametric Study of Hemispherical and Pointed Domes with Lamella and Diamatic Configuration

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Abstract— *There are different types of domes and different types of failures for the domes. For understanding the behaviour of these dome structures, this thesis was focused on hemispherical and pointed domes with lamella and diamatic configuration. The proposed dome were modelled and analyzed using software ANSYS 16.1 for different rise to span ratios and the results were studied for axial force, maximum moments in the members and deflection of dome and the most effective rise to span ratio for the given span of each type was found.*

Failure of dome structure is mainly due to buckling of members. Hence a buckling analysis was carried out to find the buckling load of these domes. The behavior of both domes was compared based on the analyzed results and the most efficient shape and configuration among the above was found.

Keywords— *Ansys, Buckling analysis, Diamatic dome, Hemispherical dome, Lamella dome, Pointed dome.*

I. INTRODUCTION

Dome structures are the most preferred type of large spanned structures. Domes have been of special interest in the sense that they enclose a maximum amount of space with minimum obstructions and impressive beauty. Domes have been constructed from a wide variety of building materials over the centuries, from mud to stone, wood, brick, concrete, metal, glass and plastic. Braced steel dome structures have been widely used all over the world during last three decades.

A dome is an element of architecture that resembles the hollow upper half of a sphere. Dome structures made of various materials have a long architectural lineage extending into prehistory. A dome can be thought of as an arch which has been rotated around its central vertical axis. Thus domes, like arches, have a great deal of structural strength when properly built and can span large open spaces without interior supports. They were quick to realize the potential and advantages of relatively high strength and comparatively light weight. This feature provides economy in terms of consumption of constructional materials.

A dome is a structural system that consist of one or more layers of element that are arched in all direction and rotated around it central vertical axis. The surface of a dome may be a part of a single surface such as a sphere or a paraboloid, and it may consist of a patchwork or different surfaces.

A. Braced Domes

Braced domes were mainly classified into ten principal types, that are Ribbed domes, Schwedler domes, Lamella domes, Network domes, Plate-type domes, Diamatic domes, Stiffly Jointed Framed domes, Kiewitt domes, Two-way and Three-way Grid domes and Geodesic domes. However, this study would narrow down the analysis to two type of domes which are Lamella domes and Diamatic domes.

The lamella dome is made up of many similar units and the arrangement pattern is in a diamond. Each lamella unit has a length which is twice the length of the side of a diamond. The lamella domes are renowned due to their exceptionally good behavior under excessive wind loadings, as well as in fire and seismic disturbances.

Diamatic Dome is a dome that can be described as pie-shaped sector repeated radially around the crown of a dome. In diamatic dome, the apex of each sector has a width of zero and at its base, a sector is 360 degrees divided by the number of sectors that exist.

B. Different Shaped Domes

Domes are of different shapes such as pointed, hemisherical, catenary, faceted etc**.** Hemispherical and Pointed shapes are selected for the present study. The hemispherical dome is half of a sphere. A pointed dome is also known as an onion dome and it is greater than hemispherical dome with a pointed top in an ogee profile.

II. OBJECTIVES

- To analyze the behavior of pointed and hemispherical domes under both lamella and diamatic configuration.
- To find the axial force, deflection and buckling load for hemispherical and pointed domes with lamella and diamatic configuration for each rise to span ratio.
- To find out which shape is more efficient.
- To obtain a suitable rise to span ratio for hemispherical and pointed domes with lamella and diamatic configuration.

III. GEOMETRICAL PARAMETERS OF DOME

Hemispherical and pointed dome with lamella and diamatic configuration are selected for the analysis. The joints are considered to be rigid. The spans (D) of the domes considered for analysis is 40m. Total number of rings in the diamatic dome is selected as 4 and it is equally spaced, that is the members in meridian line have same length.

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Different rise to span considered for analysis is in between the values 0.10 to 0.50 with an increment of 0.05. Height of dome for different rise to span ratio is shown in table I.

TABLE I. Height of the dome.

H/D ratio	Height of the dome (m)
0.1	4
0.15	6
0.2	8
0.25	10
0.3	12
0.35	14
0.4	16
0.45	18
0.5	20

IV. STRUCTURAL PARAMETERS OF DOME

The joints of dome structures are considered to be rigid. Rectangular steel tubes are used for the dome structure. The area (A) and moment of inertia (I) of the section of the members are kept constant for stiffeners and rings of the dome. The modulus of elasticity of steel is taken as 2.1 x 10^5 N/mm^2. Member properties of lamella and diamatic domes for the given span are given in table II and table III.

TABLE II. Member properties of lamella domes.

Span (m)		Size of member (mm)	Thickness (mm)	Area of section (mm^2)	Moment of inertia (mm^4 ×10^4)
40	stiffeners	200×200	25	17500	9110
	rings	150×150	25	12500	3390

TABLE III. Member properties of diamatic domes

Span (m)		Size of member (mm)	Thickness (mm)	Area of section (mm^2)	Moment of inertia (mm^4 ×10^4)
40	stiffeners	200×200	25	17500	9110
	rings	150×150	25	12500	3390
	ribs	200×200	25	17500	9110

V. MODELLING

Four types of domes namely hemispherical lamella, hemispherical diamatic, pointed lamella, pointed diamaticThe surface material is also provided in the model. 9 models were created for each type by varying the rise to span ratio there by a total of 36 models were modeled in Autocad and imported to ANSYS 16.1 software where the analysis of all models were performed.

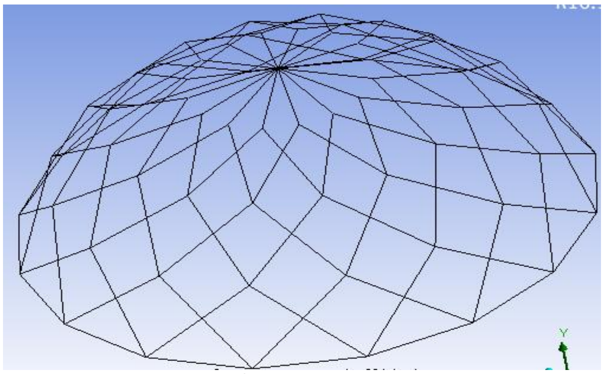

Fig. 1. Model of hemispherical lamella dome.

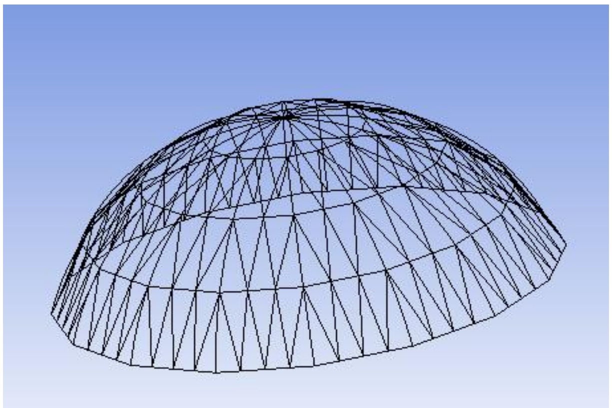

Fig. 2. Model of hemispherical diamatic dome.

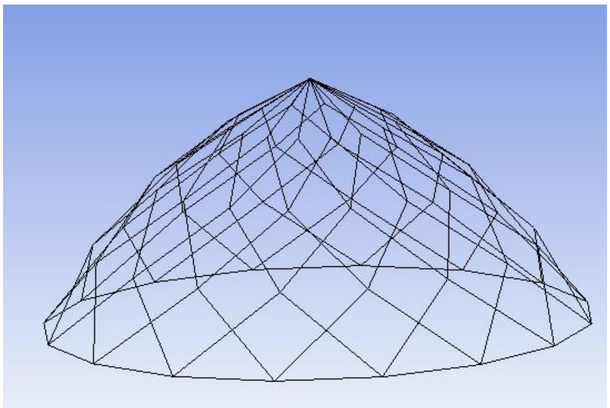

Fig. 3. Model of pointed lamella dome.

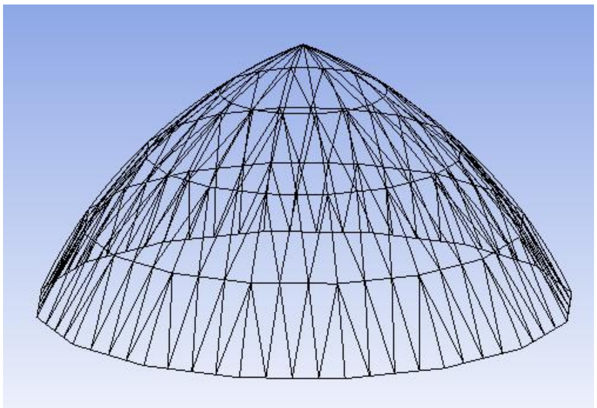

Fig. 4. Model of pointed diamatic dome.

All the domes were analysed for a vertical load of 1000 N/mm^2 and a horizontal load of 1500 N/mm^2. The load value is taken from the reference journal. Fixed supports were provided for all the models.

VI. RESULTS AND DISCUSSION

The influence of rise to span ratio, shape and configuration of the domes on their structural behaviour has been studied in terms of axial force, deflection and buckling load.

Linear static analysis was conducted for obtaining the deflection, axial force. Eigen value buckling analysis was conducted for obtaining the maximum buckling load.

A. Axial Force Results

The maximum axial force experienced on each type tabulated for each H/D ratio are shown in the table IV, V, VI and VII.

TABLE IV. Maximum axial force on hemispherical lamella dome for different H/D ratio.

H/D ratio	Axial force (kN)	
	Tension	Compression
0.1	18.55	66.26
0.15	23.42	56.75
0.2	28.1	54.53
0.25	41.21	52.74
0.3	46.93	79.70
0.35	66.83	79.86
0.4	71.00	78.43
0.45	87.61	87.68
0.5	90.61	90.86

Axial force shows a sudden increase beyond an H/D ratio of 0.3. If axial forces on members are considered as deciding factor for selection of rise to span ratio for the hemispherical lamella dome structure, we can propose a rise to span ratio below 0.3.

TABLE V. Maximum Axial force on hemispherical diamatic dome for different H/D ratio.

H/D ratio	Axial force (kN)	
	Tension	Compression
0.1	11.6	77.31
0.15	27.32	69.912
0.2	29.98	62.86
0.25	36.70	67.81
0.3	33.99	62.25
0.35	81.72	105
0.4	85.14	127
0.45	100	130
0.5	115	160

It is seen that as the H/D ratio increases the stiffeners at the upper bottom-middle range shows maximum tension. But for lesser H/D ratio, it is concentrated on stiffeners at bottom. If axial forces on members are considered as deciding factor for selection of rise to span ratio for the hemispherical diamatic dome structure we can propose a rise to span ratio below 0.35.

TABLE VI. Maximum axial force on pointed lamella dome for different H/D ratio.

H/D ratio	Axial force (kN)	
	Tension	Compression
0.1	19.75	75.91
0.15	25.12	74.97
0.2	34.28	83.77
0.25	34.36	72.55
0.3	37.16	71.22
0.35	40.76	85.99
0.4	43.87	89.6
0.45	62.66	118.7
0.5	66.5	113.87

Axial compressive force shows a sudden increase at H/D ratios 0.2 and 0.45. After an H/D ratio of 0.3, the axial compressive force keeps on increasing. Hence for the pointed lamella dome structure, we can propose a rise to span ratio below 0.3, if axial forces on members are considered as deciding factor for the selection of rise to span ratio.

TABLE VII. Maximum axial force on pointed diamatic dome for different H/D ratio.

H/D ratio	Axial force (kN)	
	Tension	Compression
0.1	14.21	70.88
0.15	14.45	68.41
0.2	13.83	63.32
0.25	18.56	59.83
0.3	22.89	51.5
0.35	23.86	57.54
0.4	26.45	46.5
0.45	54.78	69.76
0.5	57.84	62.25

Axial tensile force shows a gradual increase with increase in H/D ratio upto 0.4 and a sudden increase is observed at an H/D ratio of 0.45. Axial compressive force shows a sudden increase at an H/D ratio of 0.4. Hence an H/D ratio of 0.4 and below is recommended for the pointed diamatic dome structure, if axial forces on members are considered as deciding factor for the selection of rise to span ratio.

B. Maximum Deflection

Deflection of members is also one of the critical factors which need to be checked for the stability of domes. Deflection values obtained for each type is tabulated in TABLE VIII.

TABLE VIII. Maximum deflection on each domes for different H/D ratio.

H/D ratio	Maximum Deflection (mm)			
	Hemispherical lamella	Hemispherical diamatic	Pointed lamella	Pointed diamatic
0.1	1.9	2.002	2.14	2.51
0.15	1.22	1.24	1.73	1.97
0.2	0.95	1.10	1.30	1.31
0.25	0.91	0.99	1.06	1.14
0.3	0.87	0.91	0.95	1.26
0.35	1.1	1.18	1.03	1.11
0.4	1.26	1.35	1.05	1.18
0.45	1.5	1.43	1.17	1.27
0.5	1.7	1.71	1.14	1.48

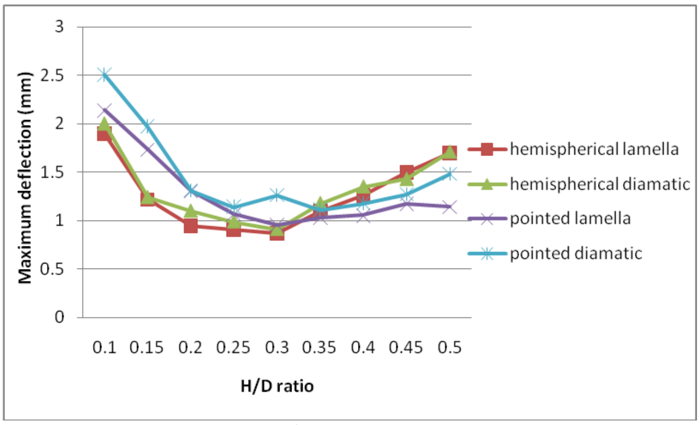

Fig. 5. Maximum deflection versus H/D ratio graph.

The deflection values are minimum for hemispherical lamella dome when compared to the other three types. In the first three types, the least value of deflection is obtained for a rise to span ratio of 0.3, and for pointed diamatic dome, the least deflection is occurring at an H/D ratio of 0.35.

C. Buckling load

Buckling is characterized by a sudden sideways failure of a structural member subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding.

Eigen value buckling analysis was carried out to find the critical buckling load. The values obtained for buckling load for each type are shown in table IX.

TABLE IX. Maximum buckling load on each domes for different H/D ratio.

H/D ratio	**Buckling load (kN)**			
	Hemispherical lamella	**Hemispherical diamatic**	**Pointed lamella**	**Pointed diamatic**
0.10	517190	496715	414148	195466
0.15	1059095	1065533	503003	230217
0.20	1593303	1175523	719594	315765
0.25	1834733	1752692	1158540	561750
0.30	2642382	1906105	1308068	694247
0.35	1463499	1735620	1402162	810845
0.40	3442015	1776579	1398250	710908
0.45	1471051	1436315	1385289	420447
0.50	2754863	1308280	1296257	376825

In case of hemispherical lamella dome, maximum buckling load is obtained for an H/D ratio 0.4, whereas in case of hemispherical diamatic, pointed lamella and pointed diamatic, maximum buckling load is obtained at an H/D ratio of 0.3,0.35 and 0.35 respectively.

VII. CONCLUSIONS

From the values obtained for axial force, maximum deflection and buckling load, the performance of each type is compared. Hemispherical shape and lamella configuration shows good performance. By adopting lamella configuration, we can reduce the section for rib and ring members of the dome.

1. From the results obtained for axial force, maximum moment, deflection and buckling load, best rise to span ratio for hemispherical lamella dome is in between 0.25 to 0.3.
2. Best rise to span ratio for hemispherical diamatic dome is obtained as 0.3.
3. Rise to span ratio of 0.3 is the best choice for pointed lamella dome.
4. Best rise to span ratio for pointed diamatic dome is 0.3.
5. Of the four type of domes considered, the best rise to span ratio is within the range 0.25 to 0.35.
6. Domes with lamella configuration shows better performance than diamatic domes.
7. Hemispherical shape is the best shape when compared to domes with pointed shape.

VIII. ACKNOWLEDGMENT

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