Finite Element Analysis and Parametric Study of Schwedler Dome Using ABAQUS Software

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Abstract— *There are different types of domes and different types of failures for the domes. This project will be focused on the schwedler domes. For understanding the behaviour of schwedler dome structure, in this project schwedler spherical dome with rigid joints are considered. Three different spans of domes are considered for analysis. The proposed dome will be modelled and analysis to be done by using software's ABAQUS and Staad.Pro for different rise to span ratios for different load cases and results are compared. Failure of dome structure is due to buckling of members. In the present study buckling load of schwedler spherical dome is calculated.*

Keywords — *Schwedler dome, Abaqus 6.1, Buckling load*

I. INTRODUCTION

Domes are one of the oldest and well-established structural forms and have been used in architecture since the earliest times. They are of special interest to engineers as they enclose a maximum amount of space with a minimum surface and have proved to be very economical in terms of consumption of constructional materials.

A Schwedler dome also consists of meridional ribs connected together to a number of horizontal polygonal rings to stiffen the resulting structure so that it will be able to take unsymmetrical loads. Each trapezium formed by intersecting meridional ribs with horizontal rings is sub- divided into two triangles by a diagonal member. Sometimes the trapezium may also be subdivided by two cross-diagonal members. This type of dome was introduced by a German engineer J.W. Schwedler in 1863. The great popularity of Schwedler domes is due to the fact that, on the assumption of pin connected joints, the structure can be analysed as statically determinate. In practice, in addition to axial forces, all the members are also under the action of bending and torsional moments. Many attempts have been made in the past to simplify their analysis, but precise methods of analysis using computers have finally been applied to find the actual stress distribution.

Present study is focused on the schwedler dome analysis .A. Kaveh[9] studied about optimal design of Schwedler and ribbed domes via hybrid Big Bang Big Crunch algorithm (Journal of Constructional Steel Research), Anastasios Argyriou [7] studied about second order plastic analysis and design of a steel Schwedler dome by means of special software, Xiang Bing Min [8] studied about ultimate Bearing Capacity Analysis of Schwedler Suspendome, M. Hosseini, S.[5] Studied about a comparative study on the Seismic Behaviour of Ribbed, Schwedler, and Diamatic Space Domes by Using Dynamic Analysis, Peter Chacko [3]Studied about finite Element Analysis of Ribbed Dome

In this project schwedler dome with rigid joints are considered. The spans (D) of the dome considered for analysis are 20m, 30m and 40m. And their height-to-span ratio of varies from 0.1 to 0.5. However, due to the large number of nodes and elements of shell structures, the variation of span, rise high, meshing size, type and other parameters can influence the internal force redistribution of shell structures

II. SCOPE AND OBJECTIVES OF THE PROJECT

A. *Scope of the project*

Large open areas without intermediate supports have always been a challenging task for structural engineers. Dome structures are the most preferred type of large spanned structures. For this reason it is important that we have a general understanding about the behaviour of dome structure for different loading conditions. From the literature studies we can see that the failure of dome is generally due to buckling of the structure. So it is important that we know the buckling load of a dome structure.

B. *Objectives of the project*

The behaviour of dome with different loads will be analysed for different rise to span ratios. The results will be studied for axial force, maximum moments in the members and deflection of dome to find out most effective rise to span ratio for the given span. Buckling load of schwedler spherical dome is calculated, from which a proper rise to span ratio for the schwedler dome structure is chosen.

III. GEOMETRICAL AND STRUCTURAL PARAMETERS OF THE DOME

A. *Geometrical parameters*

In this paper schwedler spherical dome with rigid joints are considered. Total number of rings in the dome is selected as 3 and it is equally spaced, that is the members in meridian line have same length.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.1 for three different spans.

TABLE 1: HEIGHT OF DOMES

H/D Ratio	Span of domes		
	20m	30m	40m
	Height of Domes (m)		
0.10	2.0	3.0	4.0
0.15	3.0	4.5	6.0
0.20	4.0	6.0	8.0
0.25	5.0	7.5	10.0
0.30	6.0	9.0	12.0
0.35	7.0	10.5	14.0
0.40	8.0	12.0	16.0
0.45	9.0	13.5	18.0
0.50	10.0	15.0	20.0

B. *Structural parameters*

1) *Member Properties*

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 ribs and rings of the dome with different loads acting on the dome. The modulus of elasticity of steel is taken as 2.1 X 10^5 N/mm^2. Thickness of the steel plate is 80 mm. Member properties of domes for different spans are given in Table.2

TABLE 2: MEMBER PROPERTIES OF DOMES

Span		Size of Member (mm)	Thickness (mm)	Area of Section (mm^2)	Moment of Inertia (mm^4)x 10^4
40m	Rib	200 X 200	25	17500	9115
	Ring	150 X 150	25	12500	3385
	Diagonal Member	100 X 100	20	6400	725
30m	Rib	160 X 160	25	13500	4241
	Ring	120 X 120	25	9500	1527
	Diagonal Member	80 X 80	20	4800	320
20m	Rib	110 X 110	25	8500	1112
	Ring	90 X 90	20	5600	495
	Diagonal Member	60 X 60	18	3024	105

2) *Supports*

All the supports are provided as fixed supports.

3) *Loads*

For the study of general behaviour of dome with several loading conditions are considered.

3.1) Self-weight: The self-weight of the structure can be generated by Staad.Pro itself with the self-weight command in the load case column.

3.2) Dead load: Dead load can also be specifying the plate thickness and the load on the floor per square metre. Calculation of the load per square metre was done considering weight of rib, ring and diagonal member

3.3) Live Load: The imposed load is 0.75 kN/m^2 as specified in IS 875: Part II. This load acts on the plan area of the dome. It is necessary to consider cases where the load covers part only of the roof.

3.4) Wind load: The wind load values were generated by the software itself in accordance with IS 875 part III. Under the define load command section, in the wind load category, the definition of wind load was supplied. The wind intensities at various heights were calculated manually and feed to the software. Based on those values it generates the wind load at different floors. The design wind speed and wind pressure (Pz =527.117N/m^2) based on the height of structure.

3.5) Load Combinations: IS 456:2000 and IS 1893(Part-1):2002 stipulates the combination of the loads to be considered in the design of the structures. The different combinations used were:

1. 1.5 (dl + ll)
2. dl + 1.5 wind+x
3. dl +1.5 wind-x
4. dl + ll + 1.2 wind+x
5. dl + ll + 1.2 wind-x

IV. MODELLING

Abaqus and Staad offer a wide range of capabilities for simulation of linear and nonlinear applications. Problems with multiple components are modelled by associating the geometry defining each component with the appropriate material models and specifying component interactions.

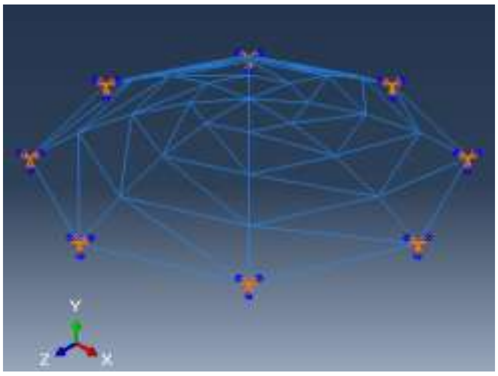

Fig. 1 Isometric View of Schwedler Dome modelling in ABAQUS

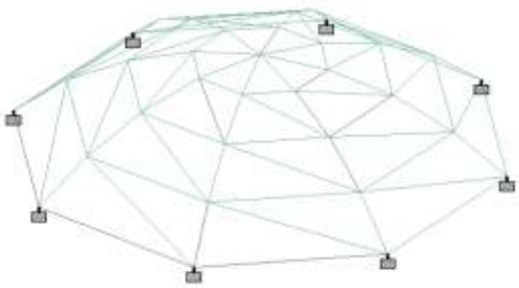

Fig. 2 Isometric View of Schwedler Dome modelling in STAAD PRO

VI. RESULTS AND DISCUSSIONS

A. *Axial Force on Members*

Load on domes are mainly transferred to the support through meridian compressive stress and hoop tension in the members that is the arch action of the dome structure. Normally ribs are taking the compressive force and rings are taking the tensile force in the dome when loads are acting.

TABLE 3: MAXIMUM AXIAL FORCE ON 20m SPANNED DOME FOR DIFFERENT LOAD CASES [ABAQUS] (kN)

H/D ratio	1.5(DL+LL)	DL+ 1.5WL+X	DL+ 1.5WL-X	DL+LL+ 1.2WL+X	DL+LL+ 1.2WL-X
0.1	14.62	7.307	6.954	8.768	8.038
0.15	13.23	6.724	6.582	8.222	7.954
0.2	11.93	5.944	5.495	7.948	7.115
0.25	14.23	7.715	7.512	10.58	9.699
0.3	16.53	8.883	8.428	11.5	10.54
0.35	18.55	9.976	9.987	12.58	11.54
0.4	20.054	11.64	11.954	13.96	12.8
0.45	21.763	13.15	12.996	15.78	13.95
0.5	23.485	14.88	14.967	17.86	15.98

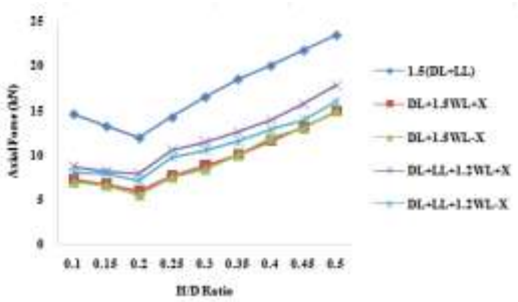

Fig .3 Axial Force V_s H/D Ratio for 20m Spanned Dome

TABLE 4: MAXIMUM AXIAL FORCE ON 20m SPANNED DOME FOR DIFFERENT LOAD CASES [STAAD] (kN)

H/D ratio	1.5(DL+LL)	DL+ 1.5WL+X	DL+ 1.5WL-X	DL+LL+ 1.2WL+X	DL+LL+ 1.2WL-X
0.1	19.43	7.316	6.22	13.14	12.264
0.15	16.89	6.786	5.054	11.59	10.204
0.2	14.81	6.094	4.134	9.828	8.784
0.25	17.409	7.823	4.636	12.37	9.82
0.3	18.73	8.805	4.806	13.547	10.348
0.35	20.42	9.993	5.114	15.027	11.124
0.4	22.372	11.354	5.523	16.74	12.076
0.45	24.539	12.881	6.01	18.658	13.161
0.5	26.89	14.565	6.554	20.761	14.352

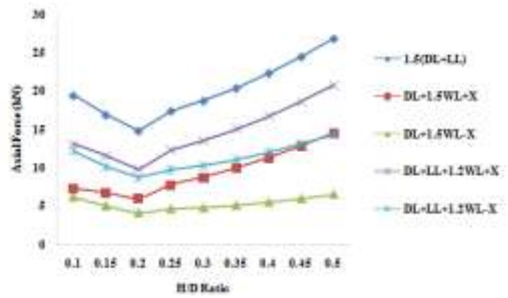

Fig .4 Axial Force V_s H/D Ratio for 20m Spanned Dome

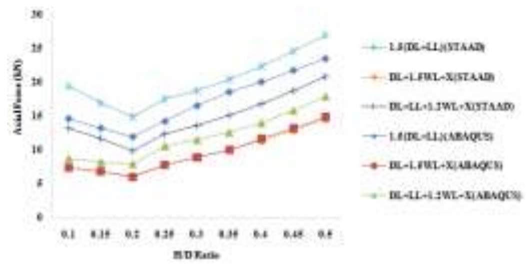

Fig.5 Comparison of Axial Force for Dome

Compare the result of axial forces obtained in both the software's show similar type variation at different H/D ratios. Axial force values on the rib member of the dome get a slightly lower value than one obtained in ABAQUS, due to the reason that, in ABAQUS software, meshing of elements can be performed to get more accurate result.

B. Maximum Moment on Members

Due to the rigidity of the joints there will be moments in the dome members. It is not at all feasible to have a large concentration of moment in a member, which will affect the stability of structure.

TABLE 5: MAXIMUM MOMENT ON 30m SPANNED DOME FOR DIFFERENT LOAD CASES [ABAQUS] (kNm)

H/D ratio	1.5(DL+LL)	DL+ 1.5WL+X	DL+ 1.5WL-X	DL+LL+ 1.2WL+X	DL+LL+ 1.2WL-X
0.1	5.628	3.02	3.025	3.021	3.018
0.15	5.593	3.005	3.021	3.031	3.025
0.2	5.746	3.162	3.161	3.163	3.162
0.25	5.831	3.241	3.305	3.248	3.291
0.3	6.216	3.542	3.539	3.551	3.549
0.35	6.702	3.826	3.83	3.896	3.891
0.4	7.321	4.284	4.291	4.321	4.336
0.45	8.224	4.645	4.647	4.648	4.646
0.5	9.268	5.26	5.242	5.241	5.246

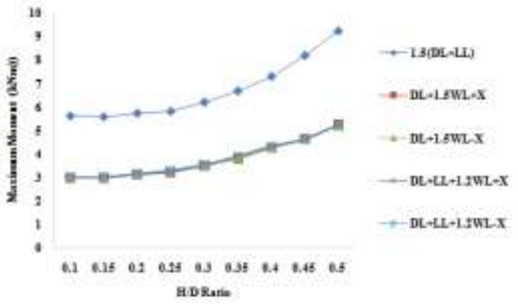

Fig .5: Maximum moment V_s H / D Ratio for 30m Spanned Dome

TABLE 6: MAXIMUM MOMENT ON 30m SPANNED DOME FOR DIFFERENT LOAD CASES [STAAD] (kNm)

H/D ratio	1.5(DL+LL)	DL+ 1.5WL+X	DL+ 1.5WL-X	DL+LL+ 1.2WL+X	DL+LL+ 1.2WL-X
0.1	7.611	5.047	5.075	5.063	5.086
0.15	7.556	5.004	5.047	5.021	5.055
0.2	7.623	5.045	5.099	5.061	5.104
0.25	7.782	5.166	5.231	5.162	5.214
0.3	8.135	5.463	5.437	5.453	5.438
0.35	8.648	5.804	5.729	5.795	5.735
0.4	9.188	6.159	6.091	6.152	6.097
0.45	9.753	6.53	6.469	6.526	6.477
0.5	10.361	6.928	6.879	6.926	6.887

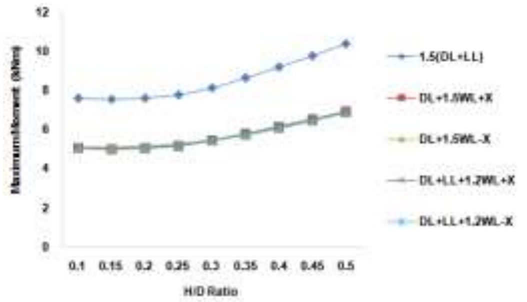

Fig .6: Maximum moment V_s H / D Ratio for 30m Spanned Dome

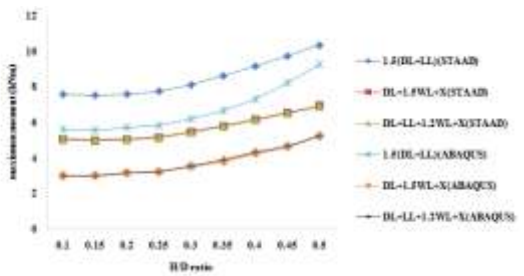

Fig.7 Comparison of Maximum Moment of Dome

Moment in a dome is found to be maximum at third ring member from the apex of the dome. For the entire load cases, values of moment obtained by STAAD is found to be higher than the values obtained by ABAQUS software by 15% to 20% as meshing of elements can be performed using ABAQUS software.

C. Maximum Deflection of Dome

Deflection of members is the critical factors which need to be checked for the stability of domes. If a joint of a dome shows considerable deflection with respect to other joints in the dome it may lead to joint instability of the dome structure.

TABLE 7: MAXIMUM DEFLECTION ON 40m SPANNED DOME FOR DIFFERENT LOAD CASES [ABAQUS] (mm)

H/D ratio	1.5(DL+LL)	DL+ 1.5WL+X	DL+ 1.5WL-X	DL+LL+ 1.2WL+X	DL+LL+ 1.2WL-X
0.1	2.235	1.364	1.362	1.679	1.68
0.15	1.597	0.728	0.728	0.954	0.954
0.2	1.162	0.518	0.517	0.668	0.668
0.25	0.856	0.374	0.374	0.553	0.554
0.3	0.782	0.324	0.324	0.513	0.514
0.35	0.756	0.319	0.318	0.511	0.509
0.4	0.805	0.321	0.321	0.532	0.533
0.45	0.859	0.367	0.367	0.553	0.553
0.5	0.942	0.385	0.385	0.601	0.602

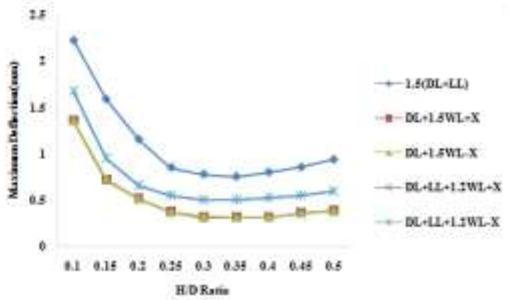

Fig .8 Maximum Deflection V_s H / D Ratio of 40m Spanned Dome

TABLE 8: MAXIMUM DEFLECTION ON 40m SPANNED DOME FOR DIFFERENT LOAD CASES [STAAD] (mm)

H/D ratio	1.5(DL+LL)	DL+ 1.5WL+X	DL+ 1.5WL-X	DL+LL+ 1.2WL+X	DL+LL+ 1.2WL-X
0.1	2.689	1.271	1.272	1.781	1.781
0.15	1.472	0.687	0.687	0.969	0.969
0.2	1.051	0.479	0.479	0.687	0.687
0.25	0.877	0.388	0.388	0.569	0.569
0.3	0.809	0.348	0.348	0.523	0.523
0.35	0.798	0.335	0.335	0.515	0.515
0.4	0.824	0.341	0.341	0.532	0.532
0.45	0.878	0.361	0.361	0.568	0.568
0.5	0.955	0.394	0.394	0.621	0.621

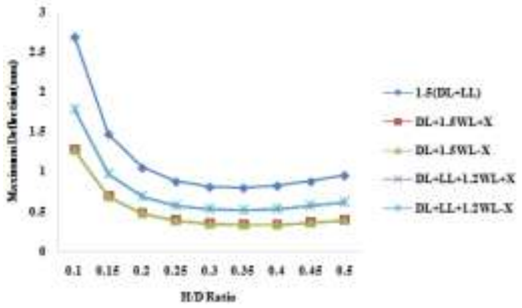

Fig .9 Maximum Deflection V_s H / D Ratio of 40m Spanned Dome

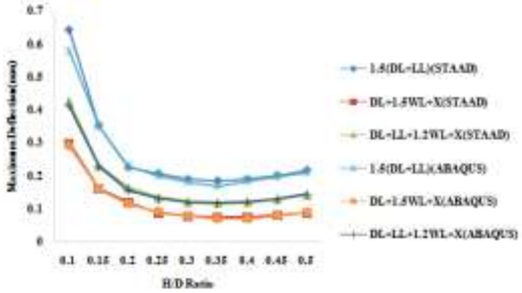

Fig.10 Comparison of Maximum Deflection of Dome

Schwedler dome shows good performance against the lateral loads. Deflection due to horizontal loads is slightly lower than the deflection obtained using ABAQUS software as compared to STAAD software. Variation in deflection is same in both the case.

D. Buckling Load Calculation

Failure of dome is generally due to buckling of the structure. It is a sudden failure occurs to the structure when in reaches a critical load, which is the maximum load which a member can support before it becomes unstable. Buckling load for different spanned dome with different H/D ratio is considered for the analysis.

The buckling of single-layer structures can appear in several ways. In particular, a single-layer dome can exhibit:

(i) ***Member buckling***, where the buckling of one member in a single-layer dome can imply the collapse of the structure. Member buckling can be avoided by ensuring an adequate bending stiffness of the members.

(ii) ***Node instability***, will occurs when the combined axial forces in all of the members attached to a joint cannot balance the external load. When this happens the node experiences a much larger displacement than the neighbouring nodes. The dynamic loads involved when the node leaps from one position to a more distant position are very harmful for the whole structure.

(iii) ***Line instability***, which appears when all the nodes and members in a ring are involved in the loss of stability

(iv) ***General instability***, where the loss of stability simultaneously appears at several nodes.

TABLE 9: BUCKLING LOAD OF 20M SPANNED DOME

H/D Ratio	Buckling Load, P [N]	% Buckling Load P/P_u x 100
0.10	10976	14.35
0.15	14559	19.1
0.20	24535	32.1
0.25	46614	60.9
0.30	54944	71.8
0.35	59164	77.3
0.40	64291	84.1
0.45	70109	91.6
0.50	*Pu* = 76497	100

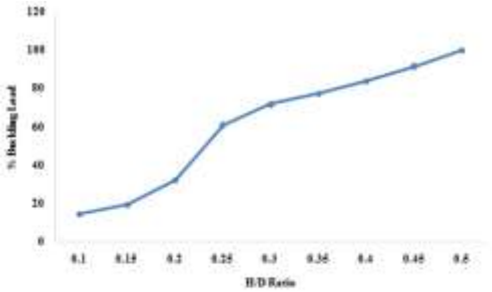

Fig.11 Percentage Buckling load V_s H/D Ratio for 20m Span Dome

VII. CONCLUSIONS

Schwedler dome shows good performance against the horizontal loads. Due to its structural symmetry and shape provide dome good performance against horizontal loading. Providing diagonal elements to the dome structures seems to be a good practice. Provision of diagonal members to the dome structure can reduce the section for rib and ring members of the dome from the parametric studies, following conclusions are arrived at.

1. If axial forces on members are considered as deciding factor for the selection of rise to span ratio for the schwedler dome structure, a rise to span ratio below 0.25 can be proposed.
2. Moment in a dome is found to be maximum at third ring member from the apex of the dome. If moment on members is considered as deciding factor for the selection of rise to span ratio for the schwedler dome structure, a rise to span ratio (H/D) in between 0.15 to 0.40 can be proposed.
3. If deflection of dome is considered as a deciding factor for the selection of rise to span ratio for the schwedler dome structure, a rise to span ratio in between 0.25 to 0.45 can be proposed.
4. If buckling load on members is considered as a deciding factor for selection of rise to span ratio for the schwedler dome structure, a rise to span ratio above 0.35 can be proposed.
5. From all the above results obtained on an average it is better to choose rise to span ratio in between 0.25 to 0.35 for schwedler dome.

6. The results obtained by the analysis using STAAD is found to be 15% to 20% higher than that of the values obtained using ABAQUS software due to the reason that, in ABAQUS software, meshing of elements can be performed to get more accurate result.

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