Finite Element Analysis of Diamatic, Schwedler and Diamatic-Schwedler Hybrid Domes

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Abstract — *Domes are structure which encloses maximum space with minimum surface area and they are economical too. To improve the application function and structural characteristics of single reticulated dome, a hybrid type of dome is proposed. Here a combination of schwedler dome and Diamatic dome with different configuration are used. Eight domes where modelled, including schwedler dome, Diamatic domes and its hybrid domes using ANSYS 16.2 parametric design language (APDL).*

Eigen value buckling analysis and static analysis is carried out for obtain the structural performance of different dome with same span and height. First hybrid shows good structural performance compare to lattice dome. Hybrid domes are very economical and they show good structural features.

Keywords—*Diamatic Dome, Schwedler Dome, Hybrid Dome, Buckling Load, Static Analysis, ANSYS 16.2 APDL*

I. Introduction

Dome is structural system that can withstand a larger span with minimum interference between supports at the end of this structure. Geometry of a dome support itself without needing internal columns or interior load bearing walls. Structural systems, which enable the designers to cover large spans, have always been popular during the history. Beginning with the worship places in the early times, sports stadia, assembly halls, exhibition centres, swimming pools, shopping centres and industrial buildings have been the typical examples of structures with large unobstructed areas nowadays.

"Lattice space structures" that consist of discrete, normally elongated elements. Example for Lattice space structures are barrel vaults, domes, arches, etc. But apparently the dome providing an easy and economic method of roofing large areas and impressive beauty is the most fascinating one for the designers since the earliest times. Braced domes are generally made up of steel, but sometimes aluminium and glass- fibre reinforced plastics can be used. Different type of Braced domes are Ribbed domes, Schwedler domes, Lamella domes, Diamatic dome, Two and three-way grid domes and Geodesic domes. The behaviour of a braced dome is depends on the configuration of the members.

Lots of studies are carried out for found the behaviour of different domes. S.Yavuz[12] studied about optimum design of pin-jointed 3-D dome structures using global optimization techniques. He modelled pin-connected type steel dome with 354 members and 127 joints, it is a combination of schwedler and diamatic dome. Lu Xiaoyang[13] divide the dome into two parts: upper layer and lower layer, and construct them with two different typical single reticulated domes respectively to improve the application functions and structure characteristics of single reticulated dome. It laid a good foundation for structural analysis and optimization design.

A Schwedler dome consists of meridional ribs connected together to a number of horizontal polygonal rings and a diagonal member sub divide each trapezium formed by intersecting meridional ribs with horizontal rings into two triangles.it stiffen the resulting structure and it will be able to resist unsymmetrical loads. Diamatic Dome is a dome that can be describe as pie-shaped sector repeated radially around the crown of a dome. The present study was focused on the analysis of hybrid dome constructed using the diamatic dome and schwedler dome.

II. Objectives

The objective in analysis the hybrid dome structures by using the ANSYS software are:

1. To study structural behavior of Schwedler Dome and Diamatic dome for same span and height using ANSYS.
2. To study the structural behavior of Schwedler-Diamatic hybrid dome and to compare it with the single reticulated lattice domes.
3. To do the buckling analysis of Schwedler Dome, Diamatic dome and Schwedler-Diamatic hybrid domes using Finite Element analysis by ANSYS 16.2 software
4. To determine the best configuration in the hybrid domes

III. Structural And Geometric Parameters Of The Dome

Domes are having same span and height ratio. Total number of rings in the dome is taken as 8 and the number of members gets varied based on the configuration selected. Geometric and structural parameters used for the design are given below.

A. Geometric Parameters

The main geometric parameters of hybrid reticulated dome include: span *S*, rise high *F*, number of circle hoop symmetry areas kn, radial node cycles nx and the upper structure laps ns.

$$R = \frac{S^2}{8F} + \frac{F}{2}$$

$$Dpha = \begin{cases} \frac{s}{2nx}\sqrt{R^2 - \frac{S^2}{2}}, & \frac{F}{S} \neq \frac{1}{2} \\ \frac{90}{nx}, & \frac{F}{S} = \frac{1}{2} \end{cases}$$

Curvature radius of sphere R is obtained as 20m and the global angle (Dpha) obtained as 11.25^0 from the above equations [13]. Typical geometric scheme of the dome is given in figure 1.

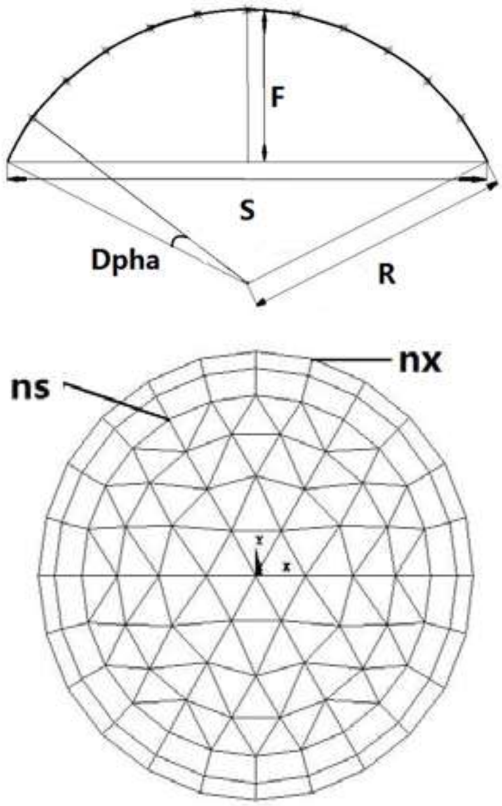

Fig 1: Diagram of hybrid reticulated dome

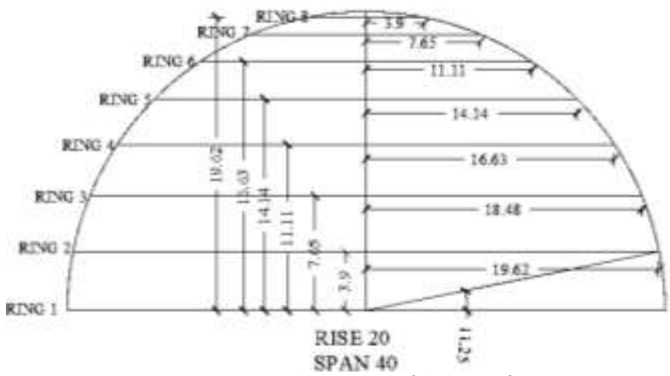

Fig 2: Geometric dimensions of the dome for modelling

Table I shows the geometric properties of domes modelled, including number of layers of schwedler and diamatic domes in different hybrid models.

Table I: Geometric Properties of Domes

Dome Type	S (m)	F (m)	Dpha (degree)	No of Schwedler Layer	No of Diamatic Layer
SC	40	20	11.25	7	0
DI	40	20	11.25	0	7
(H1)	40	20	11.25	6	1
(H2)	40	20	11.25	5	2
(H3)	40	20	11.25	4	3
(H4)	40	20	11.25	3	4
(H5)	40	20	11.25	2	5
(H6)	40	20	11.25	1	6

B. Structural Parameters

1) Member Properties:

Conventional rolled steel section having radius, R=2.5 cm is used for modelling. The area (A) of the section of the members is kept constant for ribs and rings. Table II shows the member properties of the dome and the total weight of the structure. Modulus of elasticity of steel is taken as 200000N/mm^2, poisons ratio as 0.3 and density of steel is taken as 7850Kg/m^3.

Table II: Member Properties of the dome

Dome Type	No of joint	R (mm)	A (mm^2)	no of member	W (Kg)
SC	193	25	1962.5	552	36753
DI	217	25	1962.5	600	36539
(H1)	91	25	1962.5	258	27411
(H2)	127	25	1962.5	360	29999
(H3)	157	25	1962.5	444	32364
(H4)	181	25	1962.5	510	34274
(H5)	199	25	1962.5	558	35634
(H6)	211	25	1962.5	588	36399

Maximum weight is for schwedler dome. It contains 552 elements. Diamatic shows little lesser value compares to schwedler where as it contain 600 elements.

2) Support Conditions:

All supports are given as fixed. It is assumed that the dome is rest on the ground.

3) Loads on the Structure:

For the study of general behaviour of dome roof cover over the dome is neglected.

Dead load: The dead load on the roof is the sum of weight of elements. Dead load is taken by the software itself by adding gravity load in positive Z direction. A positive acceleration in the Z direction stimulates gravity in the negative Z direction.

Live load: Roof live load can be taken as 900 N/m² (IS: 875 (Part 2) - 1987) to take into account the weight of the men climbing on the roof. But this load is compensated by snow load since roof live load and snow load cannot be acted at the same time.

Snow Load: Snow load is taken as per IS: 875 (Part 4) – 1987. Shape coefficient is taken by assuming the roof is simple curved roof.

IV. MODELLING

Finite Element Analysis (FEA) is a computer simulation technique used in engineering analysis by using the numerical technique of finite element method (FEM). Engineering software ANSYS R16.2 is used for the analysis.

BEAM188 is used for model the eight domes. The element is a linear, quadratic, or cubic two-node beam element in 3-D. BEAM188 has six degrees of freedom at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. Figure 3, 4, 5, 6, 7, 8, 9 and 10 shows the models generated in ANSYS software.

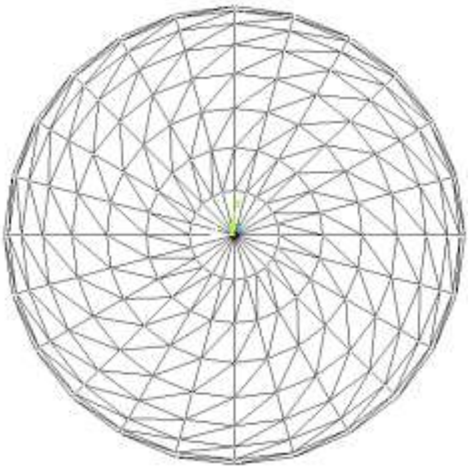

Fig 3: Schwedler dome

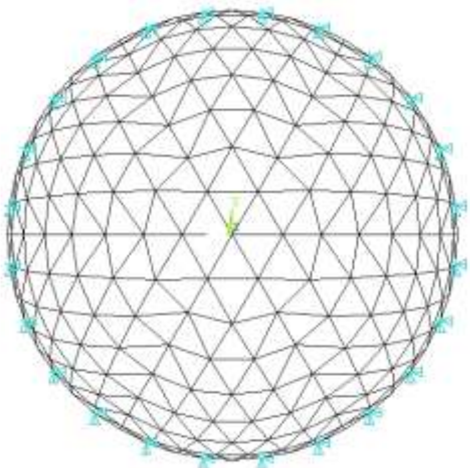

Fig 4: Diamatic Dome

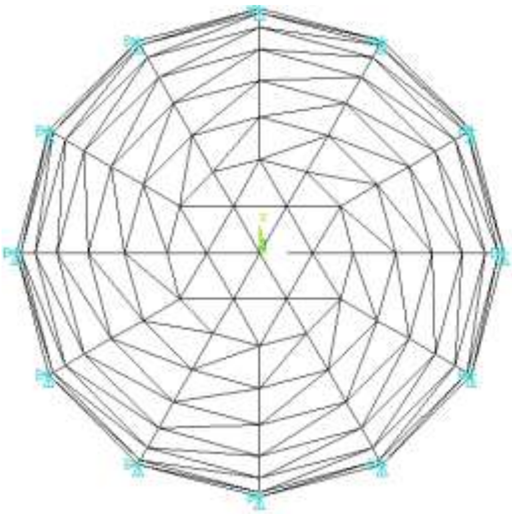

Fig 5: H1 Dome

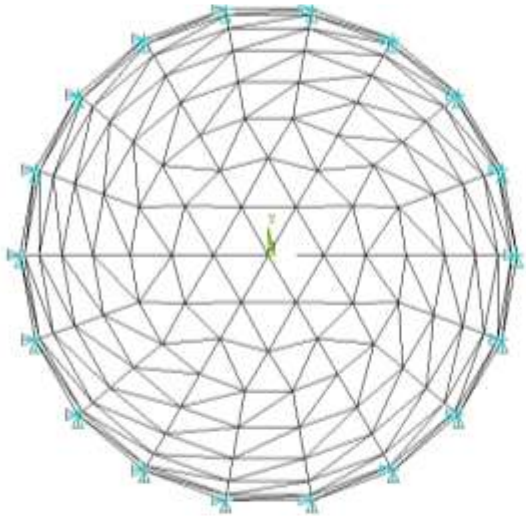

Fig 6: H2 Dome

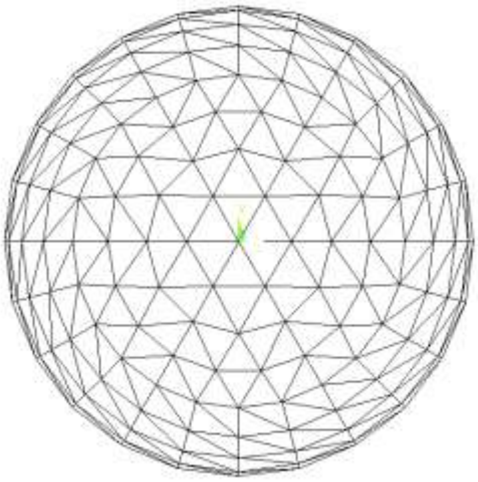

Fig 7: H3 dome

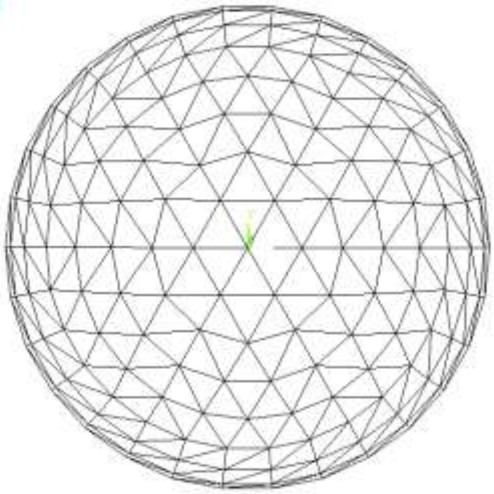

Fig 8: H4 Dome

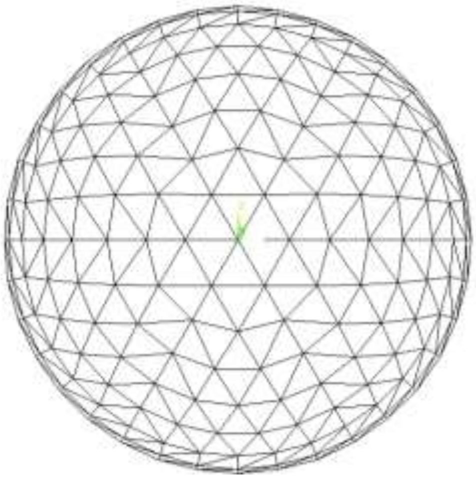

Fig 9: Dome H5

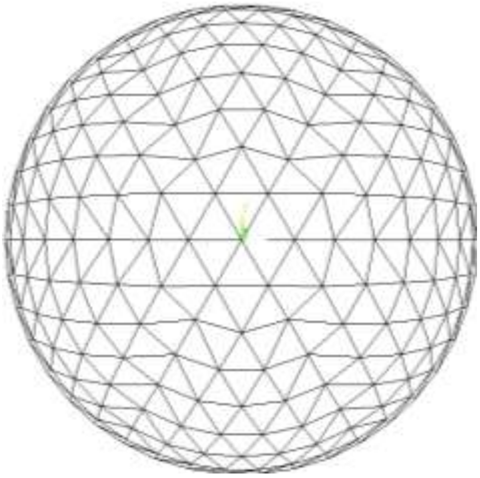

Fig 10: Dome H6

V. BUCKLING ANALYSIS

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.

There are two primary means to perform a buckling analysis, Eigenvalue analysis and Nonlinear buckling analysis. Here Eigen value buckling analysis is carried out. Eigenvalue buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigenvalues for the given system loading and constraints.

A. Results

The Eigenvalue solver uses a unit force to determine the necessary buckling load. Applying a load other than 1 will scale the answer by a factor of the load. After the analysis results are tabulated and the deflected diagrams are plotted. Table III shows the buckling load and deflection obtained from analysis.

Table III: Buckling load and Deflection

Dome Type	Buckling Load (N)	Deflection (mm)
SC	64800	100
DI	29736.9	100
(H1)	29731.9	45.5
(H2)	29736.7	45.3
(H3)	29737	45.2
(H4)	29736.9	45.2
(H5)	29736.9	45.1
(H6)	29736.9	45.1

In the case of diamatic dome buckling load obtained as 29736.9 N and schwedler gives a value of 64800N. So the schwedler domes are better as compare with the diamatic dome. Hybrids show an equal performance with diamatic dome and it having lower deflection value compare to the lattice dome. Figure 11 shows the variation of buckling load in domes.

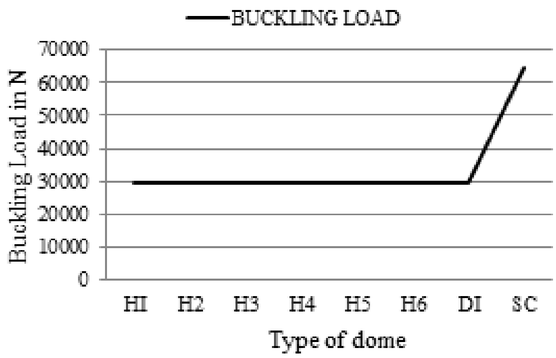

Fig 11: Graph shows the in buckling load in Various Domes

VI. STATIC ANALYSIS

Loads are calculated using the IS codes. Weight of roof covering and uniform snow load (IS 875 Part 3: 1987) is considered along with dead load for the static analysis. Results are discussed below.

A. Deflection

To check the stability of domes, deflection is a critical factor. A node experiences a much larger displacement than the neighbouring nodes when the combined axial forces in all of the members attached to a joint cannot balance the external load. Which lead to joint instability. Maximum deflections, Axial Forces and Moments obtained are given in table IV.

Table IV: Maximum Values of Deflection, Axial Force and Moment under Static Analysis for 40m Spanned Domes.

DOME	D max (mm)	F max (kN)	M max (kNm)
DI	9	102.01	89.94
H1	33	361.76	149.05
H2	20	238.43	107.86
H3	15	176.62	103.53
H4	12	139.43	99.8
H5	10	114.72	96.55
H6	9	97.61	96.31
SC	28	284.01	196.04

Displacement in Z direction is larger in every dome and Maximum deflections are found in bottoms rings.

From the graph (Fig 12) maximum deflection is for the first type of hybrid H1 and schwedler also shows high deflection as compare to other models. Minimum deflection is for Diamatic dome. As the number of diamatic dome increases deflection deceases.

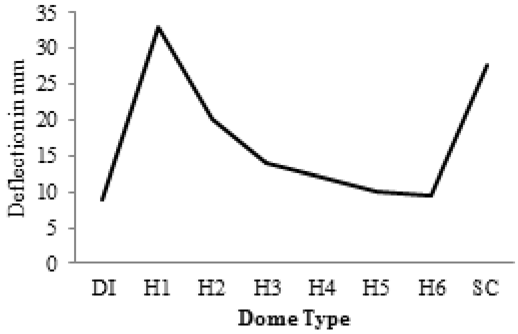

Fig 12: Maximum Deflection, Graphical Representation

B. Axial Force

Domes resist the load by arch action. Load on domes are mainly transferred to the support through meridian compressive stress and hoop tension in the members. Normally ribs are taking the compressive force and rings are taking the tensile force in the dome. Fig 13 shows the variation of maximum axial force for different domes.

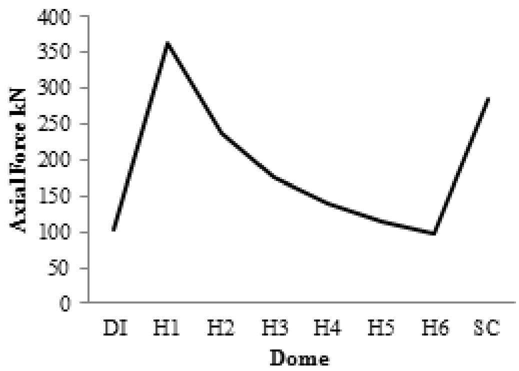

Fig 13: Graphical representation of Maximum Axial Force for Different Domes

Lattice domes like schwedler and diamatic shows maximum force along X direction, Schwedler shows a maximum value on the top ring while the diamatic shows on the bottom ring. Hybrid domes having a maximum axial force in Z direction, along the ribs. Among the six models H1 bear the maximum force.

C. Moment on Member

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.

Fig 14 shows the graphical representation of moment on the member for different domes. Maximum Moment is obtained for schwedler dome and having a value of 196.04kNm and occur at the crown portion. In Hybrid domes, H1 shows best performance and having a maximum value of 149.046kNm.

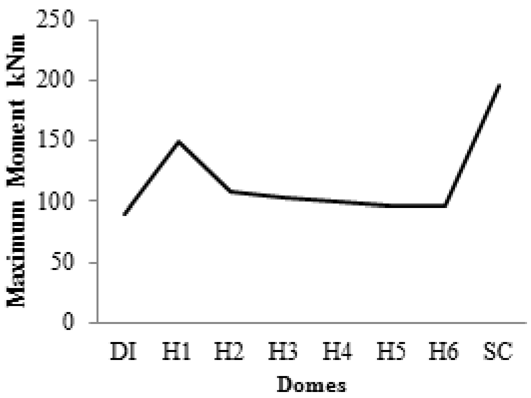

Fig 14: Graphical representation of Maximum Moment for Different Domes

Under static analysis, schwedler dome performed best as compare to diamatic dome. It is due to the high stiffness of the member because of its geometry. Out of hybrid domes H1 shows the good result, it's having maximum moment, maximum axial force. H1 having the lower number of member and lower weight. So it shows a good structural performance compare other hybrids.

VII. CONCLUSIONS

Six types of hybrid domes along with schwedler lattice dome and Diamatic lattice domes were modelled using Finite Element software ANSYS16.2. Different analyses like Eigen value buckling analysis, Static analysis are carried out. Load are calculated as per various IS cods. Also the total length of the elements and the weight of various domes are found out. Different results obtained are listed below.

- Buckling load on the member is higher for schwedler dome compared to the diamatic dome. Hybrid domes shows a lower deflection and higher load carrying capacity.
- The deflection of hybrid dome decreases with increase in the number of layers of diamatic dome.
- If axial force on members is considered as the deciding factor for selection of dome we can propose H1 domes.
- Maximum moment obtained for schwedler dome. As the number of schwedler layer in hybrid dome increases the moment value also increases.
- Considering the hybrid domes, H1 configuration shows best performance.

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REFERENCES

[1] A B Mohamad, *''Finite Element Analysis Of A Geodesic Dome Structure By Using STAAD.Pro Software''* Civil Engineering and Earth Resources University Malaysia Pahang 2015

[2] A Karim, *"Propagation Of Local Instabilities In Braced Domes' 'University* Of Surrey Department Of Civil Engineering Space Structures Research Centre January 1997

[3] C Anuj, *"Analysis and Design of Steel Dome Using Software"* IJRET: International Journal of Research in Engineering and Technology Vol:3 Issue: 03 | Mar-2014

[4] C Peter C, *"Finite Element Analysis of Ribbed Dome"* International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Trends and Recent Advances in Civil Engineering (TRACE- 24th-25th January 2014)

[5] E B James and B Fred, "*Experimental Study of a Schwedler Rigid Framed Dome",* Proceedings of the National Engineering Conference, American Institute of Steel Construction (1957)

[6] E I Ahmed *"Configurations of Braced Domes''* International Journal of Space Structures Vol. 26 No. 3 2011

[7] E Merilmol *"Finite Element Analysis and Parametric Study of Schwedler Dome Using ABAQUS Software"* International Journal of Engineering Trends and Technology (IJETT) – Volume 28 Number 7 - October 2015 ISSN: 2231-5381Page 333

[8] Greco et al. *"Nonlinear positional formulation for space truss analysis",* Finite Elements in Analysis and Design 42 (2006)

[9] K Deepti,*"Parametric Study and Optimization of Steel Dome"* International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 7, July - 2014

[10] K E Farsana *"Geometric Nonlinear Finite Element Analysis Of Schwedler Dome"* International Journal Of Advanced Research in Engineering & Management (IJAREM)2015

[11] M. Hosseini, S. Hajnasrollah and M. Herischian, *"A Comparative Study on the Seismic Behavior of Ribbed, Schwedler, and Diamatic Space Domes by Using Dynamic Analyses",* 15WCEE, Lisboan (2012)

[12] S.Yavuz,"*Optimum Design Of Pin-Jointed 3-D Dome Structures Using Global Optimization Techniques"*

[13] Xiaoyang Lu etal.*"Parametric Modeling of Hybrid type single Reticulated Dome"*2nd International Conference on Electronic & Mechanical Engineering and Information Technology (EMEIT-2012)

[14] Z Cao, F Fan *''The Stability Behaviors of Single-Layer Shells Based on The Whole-Course Response Analysis''*, 11th World Congress on Computational Mechanics (WCCM XI) 5th European Conference on Computational Mechanics (ECCM V) 6th European Conference on Computational Fluid Dynamics (ECFD VI) July 20 - 25, 2014

[15] IS: 875(Part-IV)-1987, "*Indian Standard Code of Practice for Design Loads (other than earthquake) for Building and Structures", Bureau of Indian Standard*. New Delhi, 1997.

[16] IS: 875(Part-IV)-1987, *"Code Of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures"* New Delhi, 1989.