Structural Analysis and Comparative Study of Geodesic Dome and KIEWITT Dome by using ETABS Software

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Abstract: Dome is one of the most powerful representations of structure and architectural stream. Throughout history, domes have had a strong visual impact on the viewers. In the age of civilizations, the form of the dome was stuck to people's minds as an iconic sign for holy buildings, but in the present time structural engineers and architects have built dome to achieve new purposes using new building technologies. Instead of religious purposes, structural engineers and architects began using domes for achieving political, environmental, entertainment purposes like sports stadium, military shelters, exhibition halls etc. Types of domes, analysis and design of domes and implementation of these designs are tedious jobs to do unless studied in details. In this paper, we have analyzed the geodesic dome and kiewitt dome by using Extended Three-dimensional Analysis of Building System (ETABS) software and compared the results of maximum storey displacement, storey drifts, Stress and overturning moments. Structural performances under load combinations of bending moment, shear force and axial force are also being studied in this paper.

Keywords: Dome, Geodesic, Kiewitt, ETABS, Analysis, storey drift.

I. INTRODUCTION

1.1 Background of study-

According to evolution of building technology, especially in science of construction and materials, new functions appeared for domes. Dome is a structural element that has changed its shape, functions and materials from time to time representing the advancement of human being in technology. Domes have been constructed over the centuries from mud, stone, wood, brick, concrete, metal, glass, steel and plastic. In modern period, with the industrial revolution, domes are used all over the world in different styles. The size of it became wider than any other domes built previously. The fields of engineering and architecture have few common languages for domes. Engineering focused on structural behavior of dome and architecture focused on form and symbolism of dome. Advancement in mathematics, materials and production techniques resulted in new dome types. Geodesic dome is sphere like structure consisting network of triangles which provide a self-balancing structural framework that uses minimal materials. A geodesic structure uses a series of short, interconnected straight lines to approximate a spherical or rounded surface. They are based on a network of triangles which are very stable shapes. Kiewitt dome consist of a series of subdivided triangles along the circumferential direction, which have common vertex at the crown of dome. On the basis of the lattice forms of upper single layer reticulated shell, they can be called as rib-ring type, sunflower type and bird-nest type of suspen-dome. Kiewitt dome is commonly used in spatial structure. It has better progressive collapse resistance than other dome. There are many studies related to geodesic dome and kiewitt dome to determine which dome type is superior in terms of material efficiency, the minimized weight of each variant is compared for various subdivision frequencies.

1.2 Objective of the study-

In this paper, Structural analysis of two steel domes under same geometric parameters and different load combinations has been analyzed. The specific objectives of this project were defined as the following:

- To study how the geodesic dome and kiewitt dome reacts due to gravity load on ETABS-2017 software as per IS code.
- Compared the analysis result of geodesic dome and kiewitt dome to find out which is better structurally.
- Structural performance under load combination which includes dead load (IS code-875 Part-1), live load (IS code-875 Part-2) and seismic load (IS code-1893-2016) with scale factor (DL+LL+SL).

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- Comparative study is being done on the basis of maximum storey displacement, storey drifts, stress, overturning moments, bending moments, shear forces and axial forces.
- Conclude and comment on the outcome of the project based on the analysis results.

II. LITERATURE REVIEW

Willem Gythiel et al., (2020) compared the three commonly built different types of reticulated dome subjected to distributed loads. This paper aims to determine which type of reticulated dome is superior in terms of material efficiency by comparing the minimized weight of different dome types, taking into account stress and buckling constraints. The study includes hemispherical Schwedler, Kiewitt and Geodesic domes with a diameter of 16 m and a gravity load of 2 KN/m².

Xiaoyang Lu et al., (2012) discuss about parametric modeling of six typical reticulated domes which are Ribbed, Schwedler, Lamella, Kiewitt, Three way grid and Geodesic dome based on the structure features and a method for node generation for which macro program is designed by using ANSYS Parametric Design Language (APDL). This six typical reticulated dome modeling are realized under parameters such as span, high rise, grid number in circular and radial direction.

Zhi-hong zhang & Shi-lin Dong (2011) discuss about large-span hybrid spatial structures specially design for Gymnasium steel roof using structural system. According to the latticed forms of the upper single layer reticulated shell they can be called as Rib-ring type, Sunflower type, Kiewitt type and Bird-nest type of suspend domes. The paper utilized force density method for shape determination analysis. Dynamic relaxation method has been used in numerical analysis fields such as for load analysis of spatial or planar frames, linear elastic analysis of thin shells or load analysis of tensile structures. The pseudo mass or pseudo damping is used to change a static problem into dynamic problem. Therefore, it is called as Pseudo transient analysis method. The conclusion is load or action effects are thoroughly summarized for member section design.

Eyal Karni (2011) provides a comparison and reviews of space structures of structural performance in view of their self-weight per floor area in accordance with the obtained free span. A structural geometrical study of 240 modern structures was conducted leading to an analysis of 32 structures of various construction methods. In general, Space structures are designed to provide large free-span volumes for human activities such as sports, commerce, entertainment, culture, storage and military. Structural-geometrical classification of space structures includes rigid shells, cylindrical shells, dome shells, soft shells, pneumatic structure and prestressed tensile membrane structures, bar joint and cladding structures, Hypars and suspended cable structures.

III. METHODOLOGY

1.3 Software version and details-

I. AutoCAD 3D-2016

For the modeling of geodesic dome and kiewitt dome AutoCAD 3D-2016 has been used. AutoCAD is software for computer-aided design by Autodesk. AutoCAD 3D modeling is often used in architecture for designing 3D models, floor plans, buildings, etc.

II. ETABS-2017

For the analysis of the dome ETABS-2017 software, version 17.0.1 has been used. ETABS stands for Extended Three- dimensional Analysis of Building System. The dxf file from AutoCAD is imported in ETABS. ETABS is 3D modeling software for any kind of structural analysis and design. The advantages of ETABS are lots. Using this program you can perform both steel structure and RC structure design.

Layout-

Table 1- Geometric parameters of geodesic dome and kiewitt dome

Type	Span (m)	Rise (m)	Ratio (Rise/Span)	Figure number
Geodesic dome	50	25	1/2	Fig. 1
Kiewitt dome	50	10	1/5	Fig. 2

The layout for geodesic dome and kiewitt dome is carried out in the Autodesk AutoCAD 3D-2016 software as shown in figure below.

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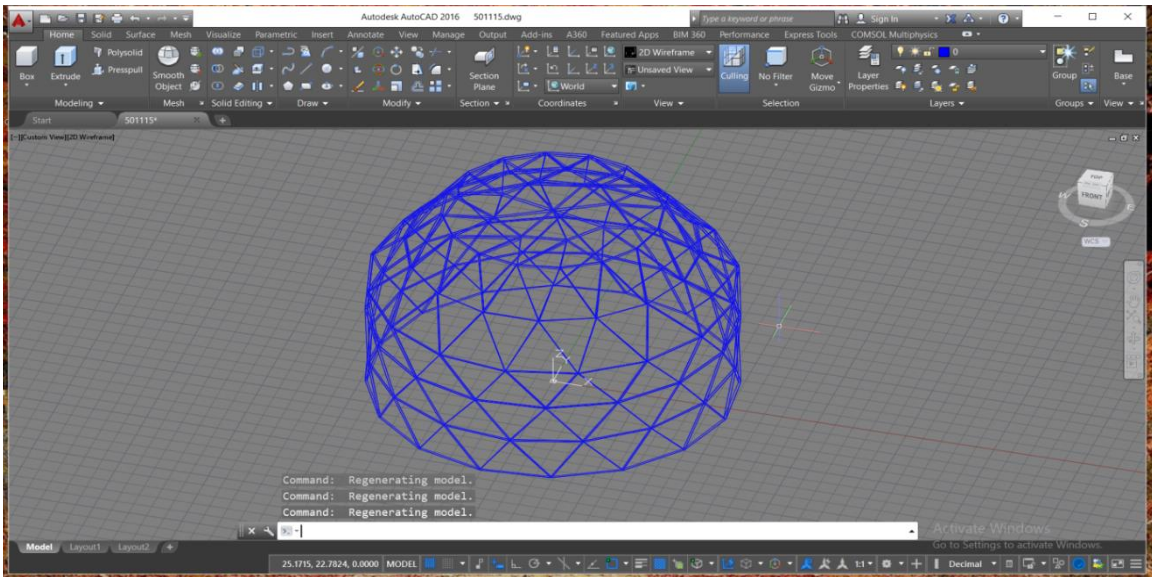

Fig. 1: Modeling of Geodesic dome

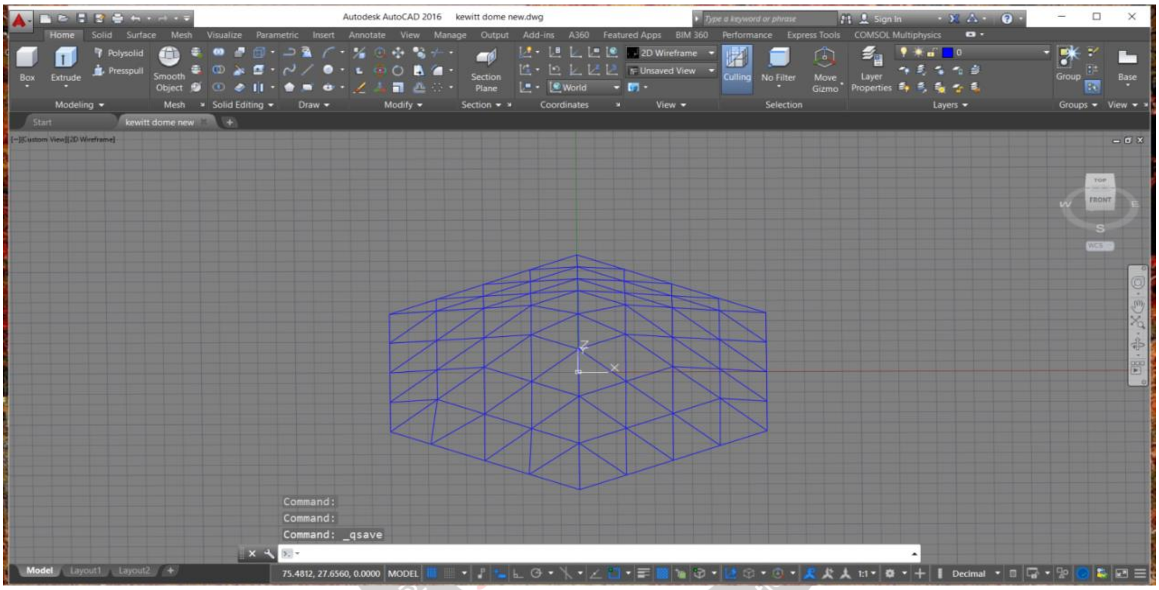

Fig. 2: Modeling of Kiewitt dome

1.4 Structural Modeling-

Geodesic dome and Kiewitt dome are exported from AutoCAD 3D in .dxf file format and then this file imported in ETABS-2017 then by providing material properties, load combinations and loadings for both domes then analysis has been done to check results. Fe345 Steel has been used for geodesic dome as well as kiewitt dome. As per Indian steel table, ISLC 100 has been used for frame sections.

1.5 Loadings-

For overall analysis considering the loads are dead load, live load and seismic load are generated by using ETABS-2017 software. Dead load is self-weight of the structure and these are permanent loads which are always present. IS 875-1987 (Part-1) has used for dead load of geodesic dome and kiewitt dome. We considered overall 4 KN/m² for both dome. Live load may vary over the time. It is weight of people and movable objects. We considered 1.50 KN/m² live load as per IS 875-1987 (Part-2). There are 4 seismic zones in India as per IS 1893-2016 (Part-1). The code gives recommendations for earthquake resistant design of structures. It is mandatory to follow these recommendations for design of structures.

The results after the analysis of geodesic dome and kiewitt dome are follows,

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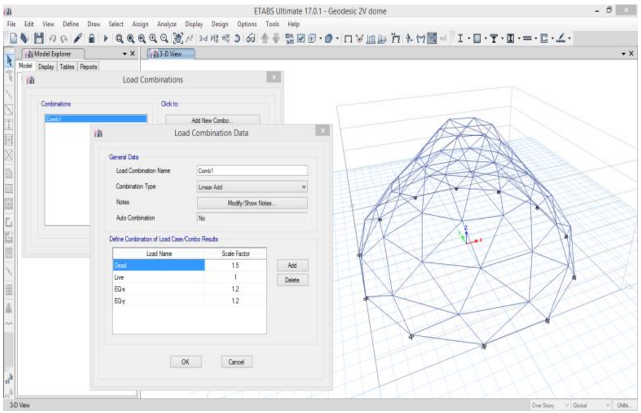

Fig. 3: Load combinations of Geodesic dome

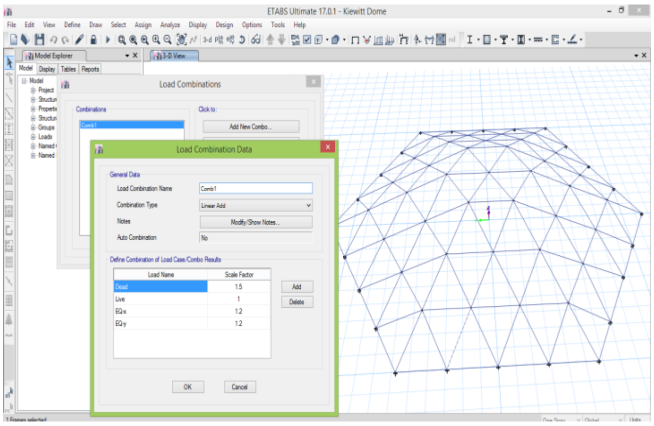

Fig. 4: Load combinations of Kiewitt dome

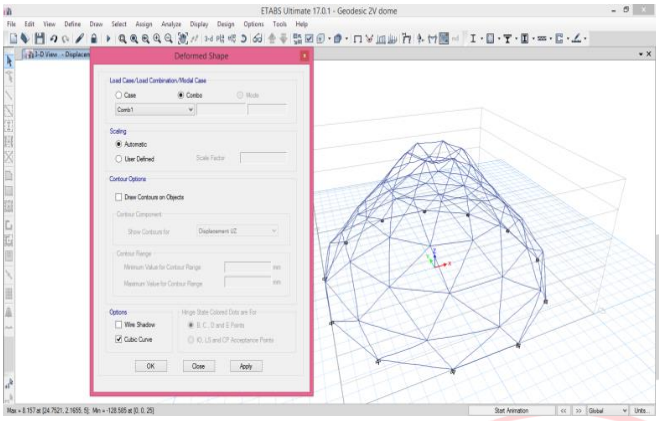

Fig. 5: Deformed shape of Geodesic dome

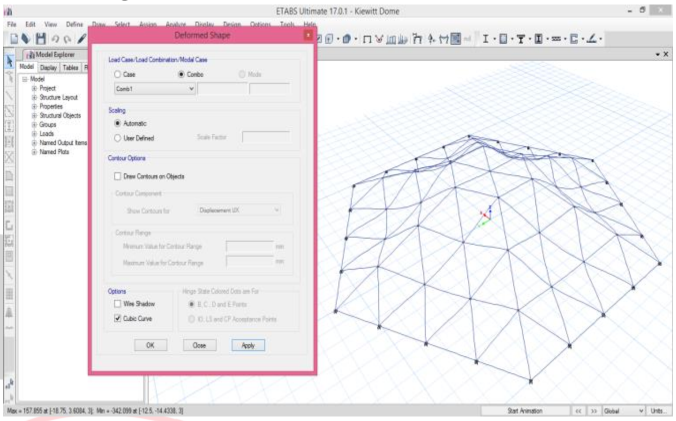

Fig. 6: Deformed shape of Kiewitt dome

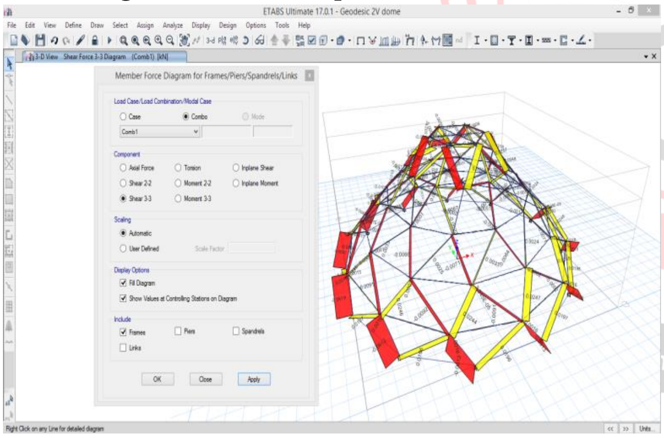

Fig. 7: Shear force of Geodesic dome

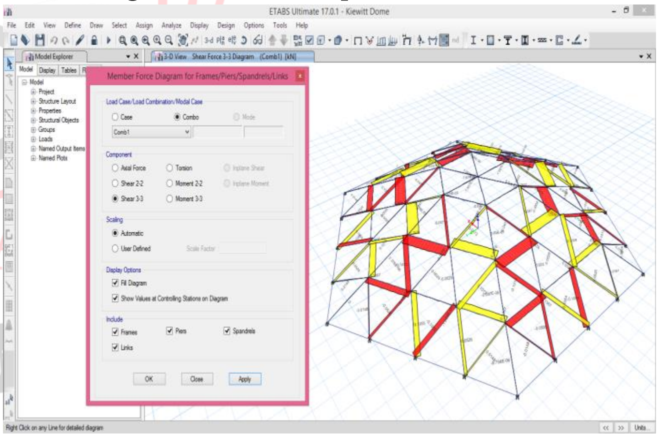

Fig. 8: Shear force of Kiewitt dome

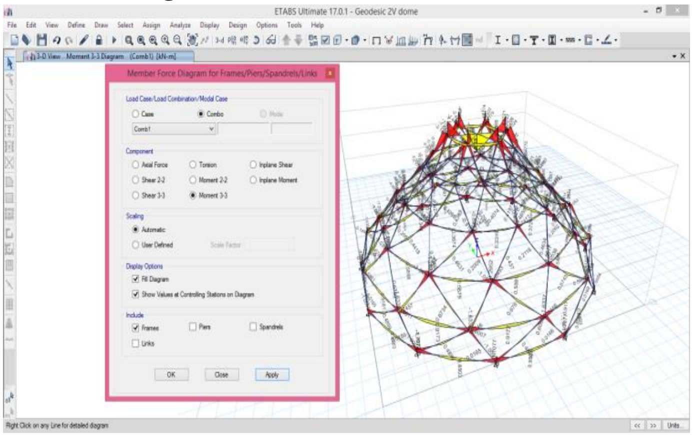

Fig. 9: Bending moment of Geodesic dome

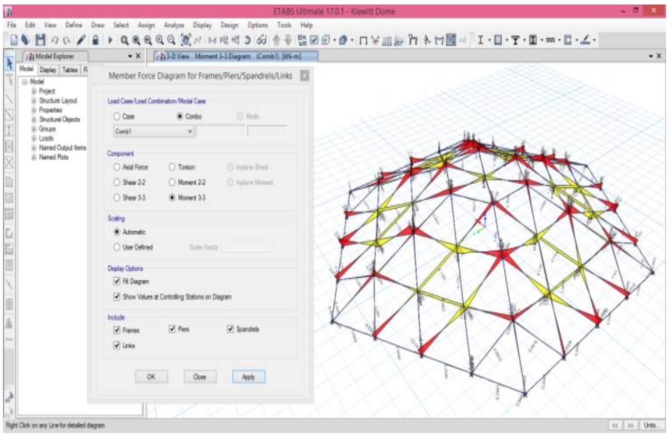

Fig. 10: Bending moment of Kiewitt dome

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IV. RESULTS AND COMPARISON

After the analysis on ETABS-2017, the results are obtained and from the above figures (Fig. 3 to Fig. 10), the following assumptions are made-

Table 2- Maximum and Allowable displacement, storey and stress

Type	Maximum displacement (mm)		Allowable displacement (mm)	Maximum storey drift (m)		Allowable storey drift (m)	Maximum stress (MPA)	Allowable stress (MPA)
	X	Y		X	Y			
Geodesic	8.163	12.43	76.9	0.00197	0.0030	0.1	284.81	300
Kiewitt	15.798	14.109	30.76	0.035	0.039	0.04	205.02	300

The maximum displacement, maximum storey drift and maximum stress of geodesic dome and kiewitt dome has listed in Table 2. From the above data following conclusions can be obtained,

1) The maximum displacement of geodesic dome appears at the story-1 in X direction and story-3 in Y direction. The maximum displacement of kiewitt dome appears at story-1 for X and Y direction. As per IS code 800-2007, the allowable displacement is 76.9 mm for geodesic dome and for kiewitt dome is 30.76 mm. Therefore, both domes satisfy the condition.
2) As per IS code 1893-2016, storey drift shall not exceed 0.004 times storey height. The maximum storey drift for geodesic dome is appears at storey-4 for X and Y direction and for kiewitt dome maximum storey drift appears at storey-1 in X and Y direction. The allowable storey drift for geodesic dome is 0.1 m and for kiewitt dome is 0.04 m. Therefore, as per results geodesic dome and kiewitt dome satisfies the condition of maximum storey drift.
3) The above table clearly shows that the maximum stress for geodesic dome is 284.81 MPA which is less than the allowable stress i.e. 300 MPA as shown in the table above.
   Similarly for the kiewitt dome the maximum stress value is 205.02 MPA which is less than the allowable stress i.e. 300 MPA. From the above we can conclude that the dimension and loads applied to the domes adopted are sufficient and within the permissible limits.
4) Graphical representation and comparison of maximum storey displacement, storey drift and overturning moments for geodesic dome and kiewitt dome as shown in fig. 11, fig. 12, fig. 13, fig. 14, fig. 15 and fig. 16.

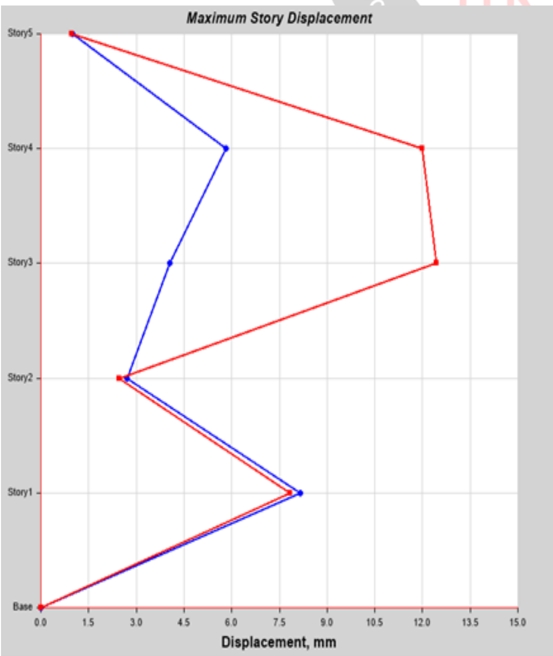

Fig. 11: Maximum storey displacement of Geodesic dome

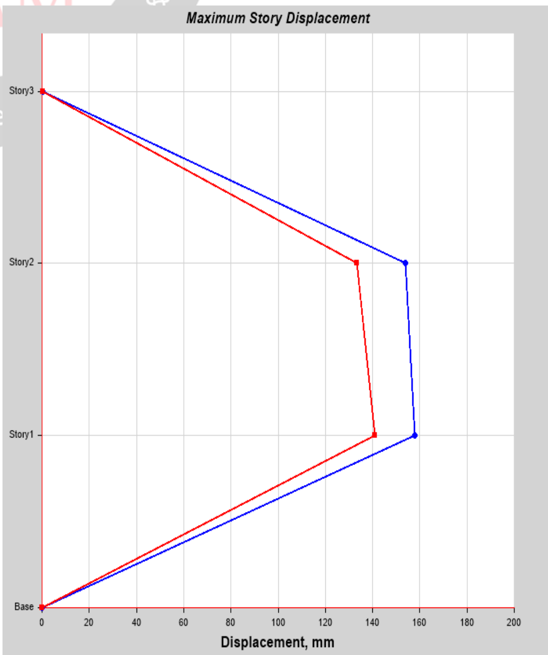

Fig. 12: Maximum storey displacement of Kiewitt dome

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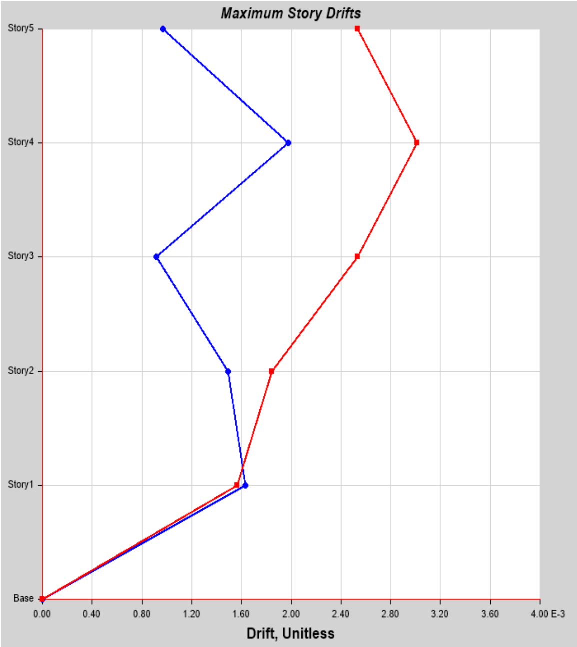

Fig. 13: Maximum storey drifts of Geodesic dome

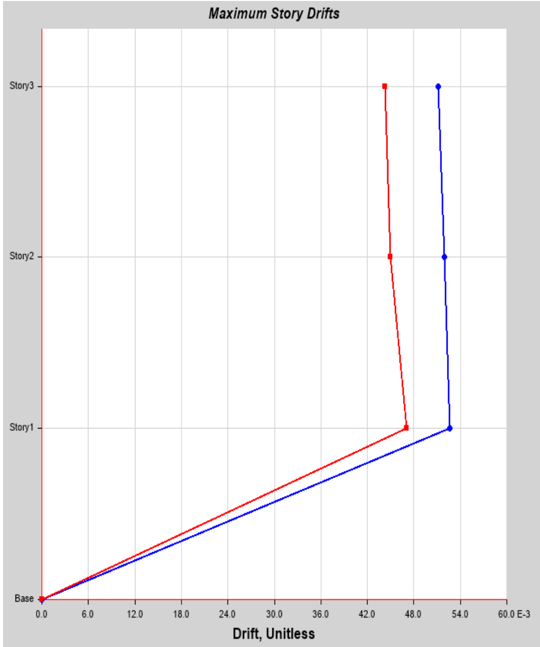

Fig. 14: Maximum storey drifts of Kiewitt dome

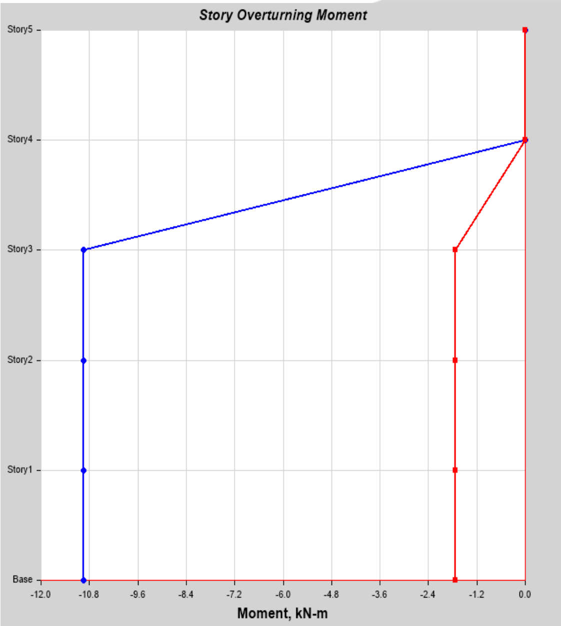

Fig. 15: Storey overturning moment of Geodesic dome

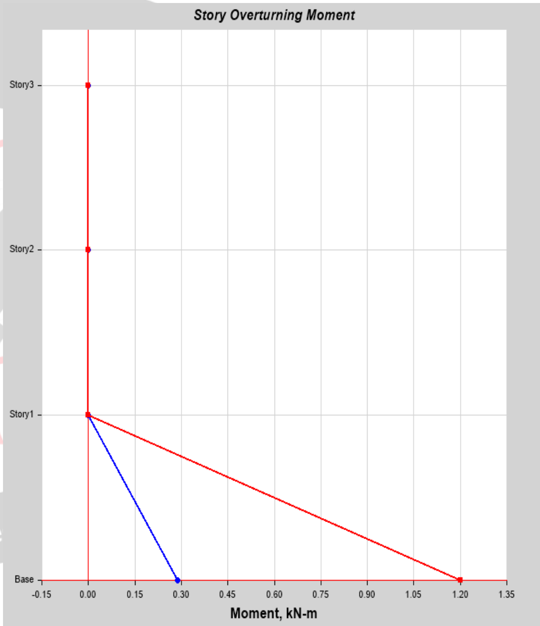

Fig. 16: Storey overturning moment of Kiewitt dome

V. CONCLUSION

This paper draws the following conclusions,

(1) As per IS code 1893-2016, storey drift shall not exceed 0.004 times storey height. The maximum storey drift for geodesic dome is appears at storey-4 for X and Y direction and for kiewitt dome maximum storey drift appears at storey-1 in X and Y direction. The allowable storey drift for geodesic dome is 0.1 m and for kiewitt dome is 0.04 m. Therefore, as per results geodesic dome and kiewitt dome satisfies the condition of maximum storey drift.

(2) As per IS code 800-2007, the maximum displacement for a frame shall not exceed 1/325 of the span. The allowable displacement is 76.9 mm for geodesic dome and for kiewitt dome is 30.76 mm. Displacement obtained for geodesic dome in X direction is 8.16 mm and in Y direction is 12.43 mm and for kiewitt dome in X direction is 15.79 mm and in Y direction is 14.10 mm. Both domes satisfy the condition. While the maximum displacement value for geodesic dome is far less than the allowable value. Therefore, Geodesic dome has better mechanical performance which can apply to large-span structures.

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(3) As per results, Geodesic dome is more stable and uniform stressed as compared to Kiewitt dome as per combination loading which includes dead load, live load and earthquake load.

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