Parametric Analysis of Single layer Ribbed dome with Diagonal membres

Anu J S[1], Preethi M [2]

[1]PG Student, Department of Civil Engineering,FISAT, Angamaly, India
[2]Assistant Professor, Department of Civil Engineering,FISAT, Angamaly, India

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Abstract - In the recent years, there have been an increasing number of structures using steel domes as one of the most efficient shapes in the world. Beginning with the worship places in the early times, sports stadium, assembly halls, exhibition centers, swimming pools, shopping malls and industrial building have been the typical example of structures with unobstructed areas nowadays. There are different types of domes and different types of failures for domes. This study is focused on the ribbed domes. The ribbed dome is one of the types of dome which will not be structurally stable unless it is designed as a rigidly-jointed system since it does not have diagonal elements. The various parameters taken into account for the study are, height to span ratio, member cross-section and material. The proposed dome is modeled and analysis is done using the software ETABS 15 for different load cases and the results are compared. Failure of the dome is generally due to the displacement and buckling of the structure. Maximum displacements occur at the intermediate part of the structure, hence the behaviour of the dome with diagonal members at the intermediate part are studied. Linear static analysis, nonlinear time history analysis and buckling analysis are conducted for all parameters and result are compared. Axial force, maximum displacement, base shear, buckling load for all the cases are compared.

Key Words: Single layer ribbed dome, Height to span ratio, member cross-section, Material

1.INTRODUCTION

Domes are space structures which cover large circular area like auditoriums, circular tanks, exhibition halls, temporary tents, etc. They are constructed of masonry (small spans), steel frames or reinforced concrete. Steel is an excellent material for this purpose, as it can take up the required shape easily. The domes are generally not used in small structures because the formwork and shuttering is very costly, however, for large spans and for the repeatative works and they are economical. Skeletal dome structures can be classified into several categories depending on the orientation and position of the principal members. The most popular types of domes are ribbed domes, Schwedler domes, three-way grid domes and parallel lamella domes, from which ribbed domes were considered for the study. Ribbed domes are formed from a number of identical rib members, which follow the meridian line of the dome and span from the foundations up to the top of the structure. Ribbed dome consists of a number of intersecting "ribs" and "rings". A "rib" is a group of elements that lie along a meridian line and a "ring" is a group of elements that constitute a horizontal polygon. Ribs can be radial trussed or solid. It is generally interconnected at the crown and a tension ring at the foundation which stiffens the ribs. A ribbed dome will not be structurally stable unless it is designed as rigidly-jointed system, since it does not have diagonal elements.

2.LITERATURE REVIEW

Aitziber Lopez [1] studied about the analysis of tubular single layer structures involves geometric nonlinear methods that can consider large displacement of nodes. They introduced a formula for single layer spherical domes which can be applied to domes with semi rigid joints. Effects of semi rigidness of joints in domes, as well as the influence of assumed initial geometric imperfections on the reduction of collapse loads, were investigated by Shiro Kato [9]. It is concluded, for domes designed in practice, inelastic behaviour in conjunction with the influence of joint semi rigidness is more important than imperfection sensitivity. Ronaldo c [11] studied that the strength capacity of reticulated spherical dome is generally associated with inelastic buckling of its slender members and more often of the partially restrained connections between members.

3.GEOMETRIC PARAMETERS OF RIBBED DOME

The ribbed dome consist of two members, rib and ring having same section properties. Figure 1 shows the parameters which depend on the behaviour of dome such as height (H), span (D), length (L), area (A), thickness of dome (t) moment of inertia (I) and number of rings (a).

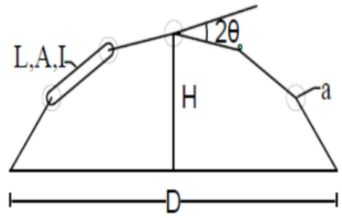

Figure 1: Parameters of ribbed dome

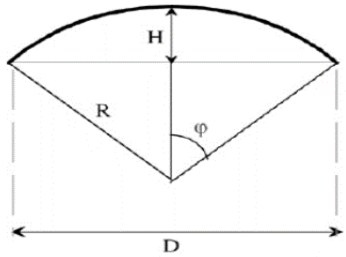

Figure 2: Scheme of derivation of Eq1

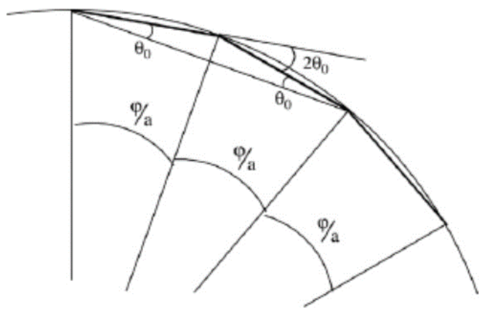

Figure 3: Meridian section of a ribbed dome

The total angle (2 φ) subtended by the dome can be derived from Figure 2. This angle depends on the height to span ratio (H/D) of the dome.

$$\tan\varphi = \frac{4D/H}{\left(\frac{D}{H}\right)^2 - 4} \quad (1)$$

where D is diameter and H is height of dome. The total angle is divided equally to determine the position of the rings. The angle between members located along the meridian lines or angle between ribs is thus $2\theta_0$ and was obtained from Figure 3, where

$$\theta_0 = \frac{\varphi}{2a} \quad (2)$$

$$\text{Number of ribs} = \frac{\text{Total angle of dome}}{2\theta_0} \quad (3)$$

Angle between the ribs and number of ribs were calculated from equations (2) and (3) respectively. Here the total angle of dome is 360°. From the studies conducted by A. Kaveha (1998) who have developed an optimum topology design algorithm method based on the hybrid Big Bang Big Crunch optimization (HBB_BC) for the Schwedler and ribbed domes and Aitziber Lopez (2001) who have developed direct evaluation of the buckling loads of semi-rigidly jointed single-layer latticed domes under symmetric loading. It was observed that, there was no change in the performance of the dome while increasing the number of rings. From the journal it was found that rings of dome when limited to three, revealed better performance against different loading conditions.

4.STRUCTURAL MODEL PARAMETER OF RIBBED DOMES

The joints of dome structures were considered as rigidly connected and the members were exposed to both axial forces and bending moments. Hollow rectangular Steel tube sections were used for the construction of dome. For analysis, 20 m span dome with stem wall was considered with height to span ratio (H/D) ranging from 0.10 to 0.60 with an increment of 0.05. Stem wall is a vertical wall equal in diameter to the base of the dome extending from the base of dome to the ground. For hemispheres, where the height is equal to half the diameter of corresponding dome. Here stem wall with height 10m is considered for the study. Table 1 shows the member properties of 20 m span dome. Parameters were consider for analysis are member cross-section and different types of steel material, and this paper also deals with how to improve structural stability of ribbed dome. A ribbed dome will not be structurally stable unless it is designed as rigidly-jointed system, since it does not have diagonal elements. From the literature reviews domes with diagonal member were more structurally stable. Hence diagonal members were provided on ribbed domes and their behaviour under various load conditions were studied. Various parameters used for the analysis and properties of materials are shown in Table 2. The area (A) and moment of inertia (I) of the section of the members were kept constant for ribs and rings of the dome. The 3 D model of the dome structure with and without diagonal member modeled using ETABS software as shown in Figure 4.

Table 1: Member properties of dome

Span (m)		Size of member (mm)	Thickness (mm)	Area of section (mm^2)	Moment of inertia (mm^4)x10^4
20	Rib	110 x110	25	8500	1110
	Ring	90 x 90	20	5600	495
	Stem wall	300 x300	25	14375	5684
	Diagonal member	90 x 90	20	5600	495

Table 2: Parameters of dome

Parameters	Specification	
Span ratio	0.10 to 0.50	
Member cross-section	Identical	Rib 110 x110
		Ring 110 x 110
	Non-identical	Rib 110 x110
		Ring 90 x 90
Materials	Fe250, SS 304, Q235	

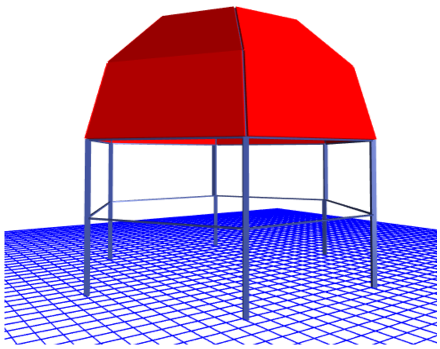

Figure 4(a): Ribbed dome with 0.50 H/D ratio without diagonal member

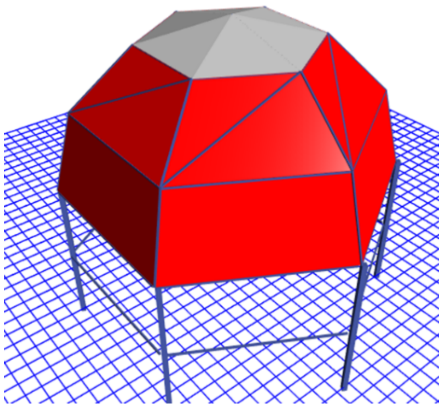

Figure 4(b): Ribbed dome with 0.50 H/D ratio with diagonal member

For the study of general behaviour of dome, loading conditions was considered at the apex of the dome and other nodes of dome except the supports. According to practical use vertical load of 150N on apex and 10N on other nodes were applied. Linear static analysis, buckling analysis, Non-linear time history analysis are considered for analysis. Maximum axial forces in rib and ring members, maximum moment in the member, base shear, maximum deflection, and maximum buckling load of dome structure are the criteria's chooses for finding out the most effective height to span ratio, member cross-section and material for the ribbed domes.

5.LINEAR STATIC ANALYSIS

5.1 Wind analysis

Dome were analyzed under the application of wind loads. Wind forces were calculated by using IS 875: 1987 (part 3). Wind speed for the region was assumed as 39 m/s. Dome was considered to be terrain category II. Risk coefficient (k3 factor) and topography (k1 factor) adopted as 1. Axial force, Maximum bending moment and maximum displacement were obtained and analyzed under both cases.

5.1.1Axial Force on members without diagonal 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. While the load acting on ribs and ring undergo the compressive force and tensile force in the dome respectively. Figure 5 and 6 represents compression and tension force of domes for various parameters under the linear static analysis of dome with and without diagonal member respectively.

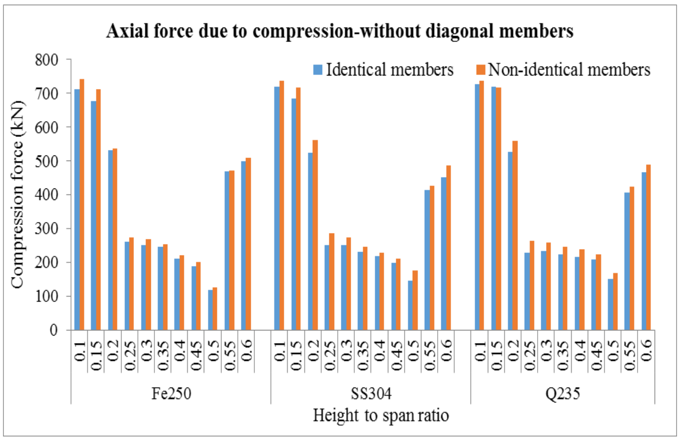

Figure 5(a): Axial force due to Compression for different height to span ratio in ribbed domes without diagonal using different material for identical and non- identical members

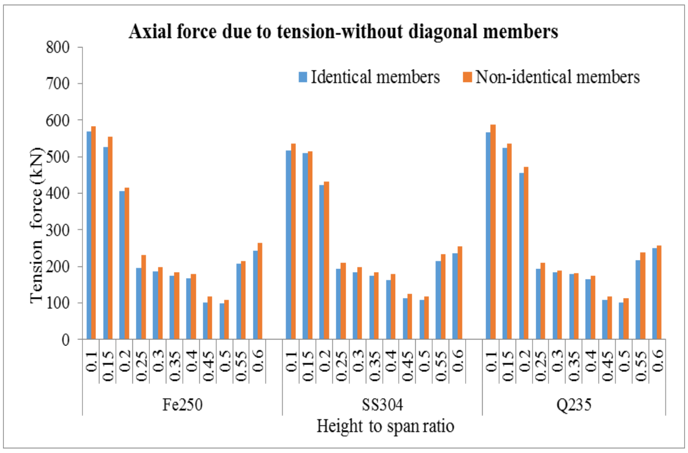

Figure 5(b): Axial force due to Tension for different height to span ratio in ribbed domes without diagonal using different material for identical and non- identical members

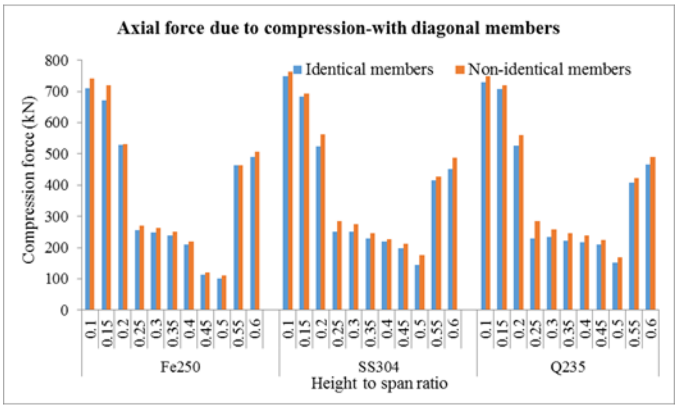

Figure 6(a): Axial force due to Compression for different height to span ratio in ribbed domes with diagonal using different material for identical and non- identical members

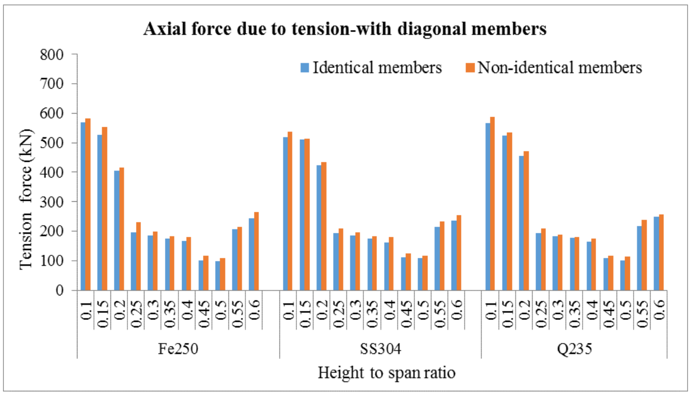

Figure 6(b): Axial force due to Tension for different height to span ratio in ribbed domes with diagonal using different material for identical and non- identical members

Domes with and without diagonal members showed similar performance for all the parameters studied. The domes with diagonal members showed lower compressive and tensile force compared to the domes without diagonal members. From linear static analysis, compression force predominated tensile force. Maximum axial force were observed at the apex of dome under linear static analysis. The axial force decreased with increases in height to span ratio and showed a minimum value in between the height to span ratios 0.25 to 0.50. Dome with non-identical section showed higher compressive force when compared to the identical sections. Hence identical member with height to span ratio 0.25 to 0.35 is more suitable for practical use.

5.1.2 Maximum moment in the members of domes

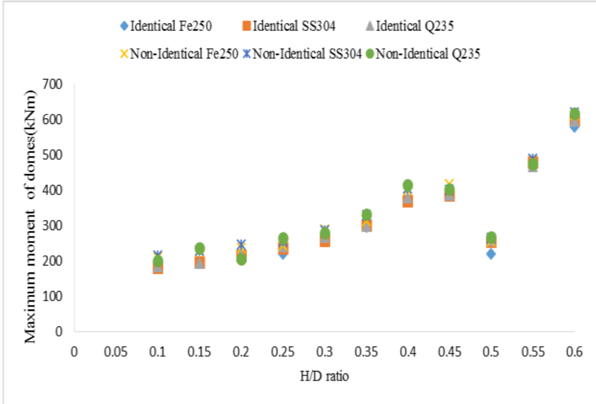

Figure 7(a): Maximum moment of domes due to change in material without diagonal member

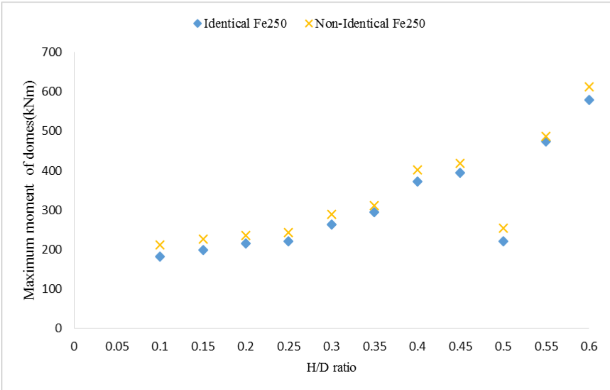

Figure 7(b): Maximum moment of domes due to change in member cross-section without diagonal member

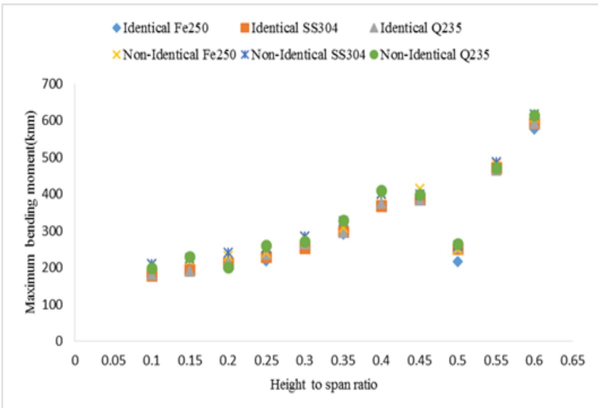

Figure 8(a): Maximum moment of domes due to change in material with diagonal member

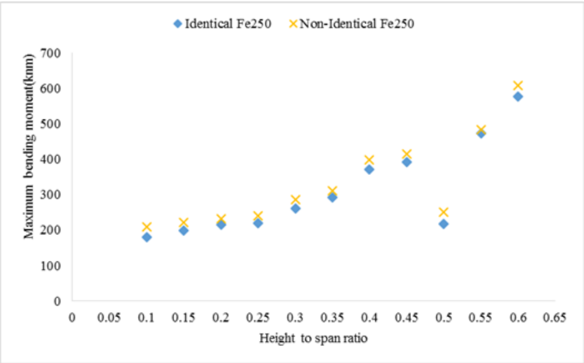

Figure 8(b): Maximum moment of domes due to change in member cross-section with diagonal member

From linear static analysis, the maximum moment of the dome structure, moment increased with the increase in height to span ratio. Due to the semi spherical shape of domes, a sudden reaction in bending moment was observed for the domes with height to span ratio 0.50.

5.1.3 Displacement of Ribbed dome without diagonal member

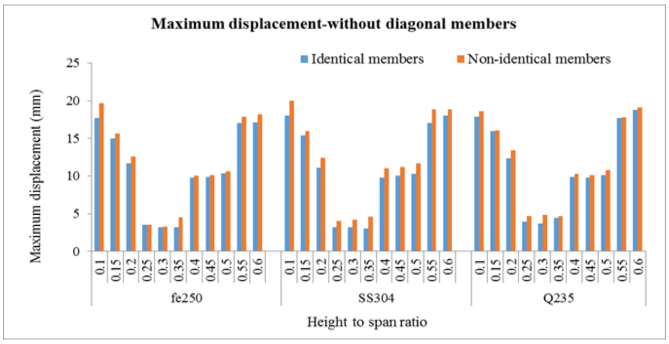

Figure 9(a): Maximum displacement for different height to span ratio in ribbed domes without diagonal using different material for identical and non- identical members

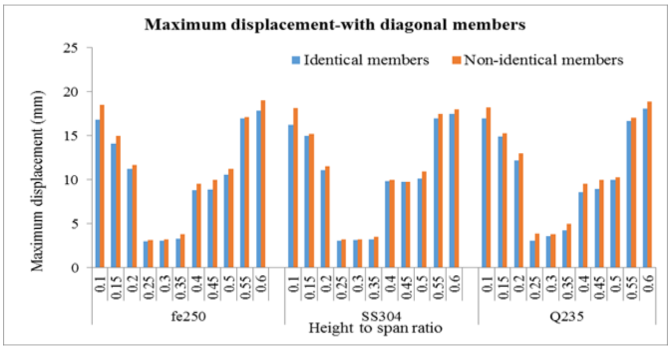

Figure 9(b): Maximum displacement for different height to span ratio in ribbed domes with diagonal using different material for identical and non- identical members

Maximum displacement was observed at the centre ring of the dome and a minimum displacement was observed between a height to span ratio of 0.25 to 0.50. Hence H/D ratio ranges 0.25 to 0.50 are recommended for construction. For all the parameters considered, change in material showed no significant effect on all models.

5.2 Seismic Analysis

The equivalent static seismic loads were calculated as per IS 1893: 2002 guidelines. Dome structures was assumed to be in seismic zone III and the soil type was taken as medium. Importance factor of 1.5 and response reduction factor 5 were adopted.

5.2.1 Base shear of domes

The seismic analysis results, storey shear values for dome without diagonal member and with diagonal members were obtained. Figure 10 represents the effect of base shear of for identical and non-identical members under change in material of dome with and without diagonal members.

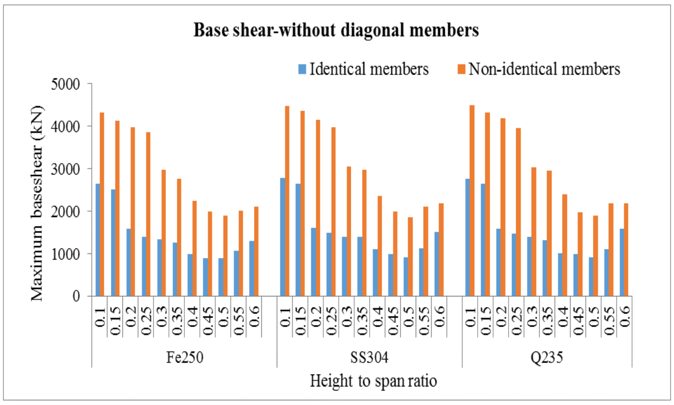

Figure 10(a): Base shear for different height to span ratio in ribbed domes without diagonal using different material for identical and non- identical members

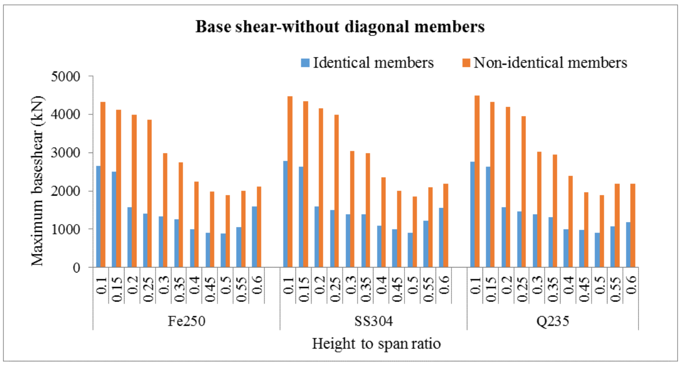

Figure 10(b): Base shear for different height to span ratio in ribbed domes with diagonal using different material for identical and non- identical members

Under seismic loads, domes with and without diagonal members showed similar performance for all the parameters considered. Domes with diagonal member showed lower base shear compared to domes without diagonal members. As the height to span ratio increases, the base shear reduced considerably and the domes with identical member cross-section showed lower base shear when compared to the non-identical members. The change in material showed no significant effect under linear seismic analysis.

6.TIME HISTORY ANALYSIS

Northridge California vibration time history data was used to stimulate the structure. The 1994 Northridge California occurred on Janauary 17th in the Fernando Valley shook the entire Los Angeles metropolitan area. It had a moment magnitude of 6.8 and a maximum perceived intensity of X (intense) on the Mercalli intensity scale. It was the first major earthquake to be recorded by a strong motion seismograph located next to a fault rupture.

Time history analysis is carried out in ribbed domes with and without diagonal members and the responses studied are lateral displacement and base shear. Fe 250 material is used for both.

5.1 Base shear of domes

During time history analysis highest base shear values obtained between 10 to 10.5 sec as shown Table 3. A typical example of base shear of with and without diagonal member of 0.50 height to span ratio of Fe250 material as shown in figure 11.

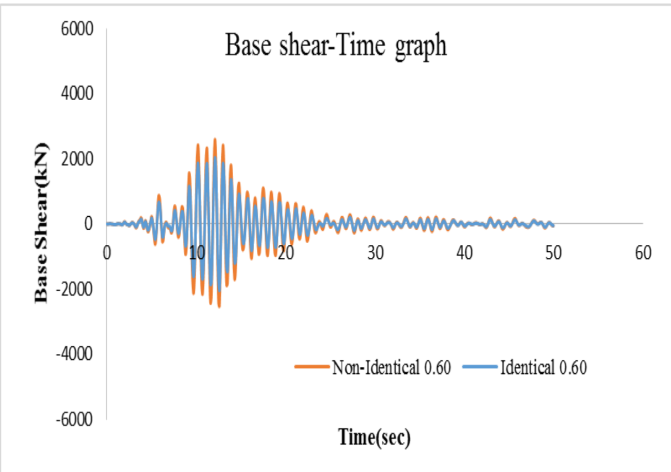

Figure 11(a): Base shear of H/D ratio 0.50 without diagonal member

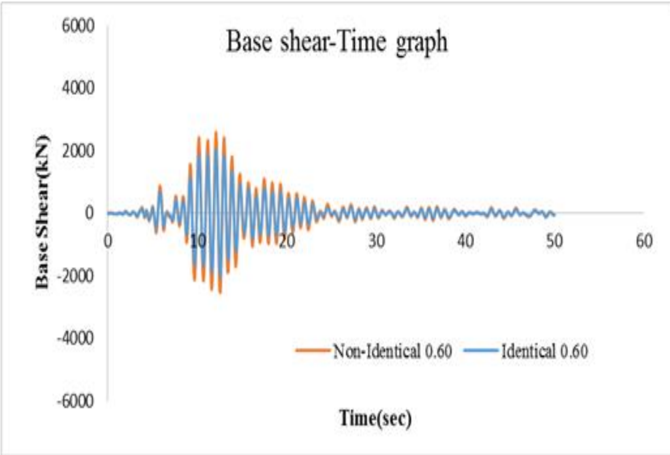

Figure 11(a): Base shear of H/D ratio 0.50 with diagonal member

Table 3: Base shear of domes with and without diagonal member

H/D ratio	Maximum base shear(kN)				Percentage of differenc $1-\frac{b}{a}$x100%	
	Without diagonal member (a)		With diagonal member(b)			
	Identical	Non-Identical	Identical	Non-Identical	Identical	Non-Identical
0.10	3808	4976	3789	4868	0.50	2.17
0.15	3587	4639	3545	4587	1.17	1.4
0.20	3048	4204	3011	4198	1.2	1.42
0.25	3005	3956	2986	3824	0.63	3.33
0.30	2970	3894	2921	3785	1.64	2.79
0.35	2272	3694	2218	3512	2.37	4.9
0.40	2361	3129	2316	3045	1.97	2.68
0.45	2262	3098	2254	3005	0.35	2.00
0.50	2160	3072	2153	2985	0.32	2.8
0.55	2002	2395	2000	2265	0.099	2.42
0.60	1873	2597	1868	2478	2.6	2.58

5.2 Displacement of domes

Table 4 shows maximum displacement of dome with and without diagonal members. A typical example of the lateral displacement of the 0.50 height to span ratio dome with different member cross-section shown in figure 9.4.

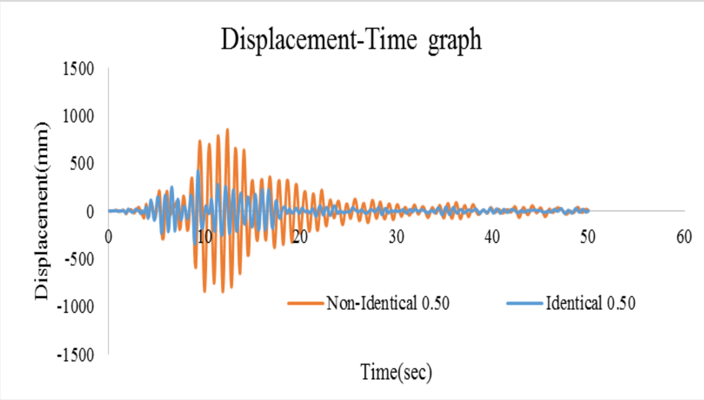

Figure 12(a): Base shear of H/D ratio 0.50 without diagonal member

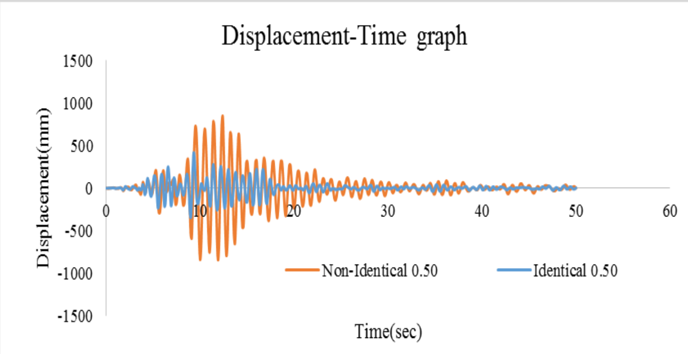

Figure 12(b): Base shear of H/D ratio 0.50 without diagonal member

Table 4: Maximum displacement of domes with and without diagonal member

H/D ratio	Maximum lateral displacement				Percentage of difference $1-\frac{b}{a}x100\%$	
	Without diagonal member		With diagonal member			
	Identical	Non-Identical	Identical	Non-Identical	Identical	Non-identical
0.10	858	1140	824	1127	3.08	1.1
0.15	818	1092	807	1081	1.3	1
0.20	806	1010	795	999	1.3	1.08
0.25	740	999.3	727	991	1.7	0.80
0.30	627	987	612	982	2.39	0.50
0.35	606	960.3	599	956	1.11	0.416
0.40	598	844	592	840	0.61	0.47
0.45	491	767.5	488	764	0.61	0.39
0.50	402	731	397	728	1.24	0.410
0.55	395	720	389	717	1.5	0.417
0.60	325	619	319	612	1.8	1.13

Ribbed dome with and without diagonal member showed similar behaviour for all parameters considered. Lower base shear with a negligible change of 2% was observed for the domes with diagonal members when compared with domes without diagonal members. Among the two types of designed domes, ribbed dome with diagonal members are less vulnerable to seismic loads. A gradual decrease in base shear and lateral displacement of dome was observed for all models with an increase in height to span ratio. From the results obtained, domes with non-identical members are more susceptible to base shear and lateral displacement. Domes with higher height to span ratio (H/D ratio) are less vulnerable to seismic excitations.

7.CONCLUSION

The parametric analysis of single layer ribbed dome with diagonal member was accomplished by analytical methods. Linear static analysis and non- linear time history analysis were conducted using ETABS 15. Various parameters; such as height to span ratio, member cross-section, materials were considered, in order to study the effect on Ribbed dome and ribbed dome with diagonal members.

The conclusions inferred from the overall study are as follows:

i. Linear Static analysis were performed and it was observed that domes with and without diagonal members have no considerable change as the percentage of variation was observed to be very low. The axial force, maximum bending moment, maximum displacement and storey shear for all the models were compared and the values were much higher for ribbed dome with non-identical members under seismic load and wind load. From the linear static analysis, it can be concluded that H/D ratio ranging from 0.25 to 0.50 can be recommended for construction.

ii. Non-linear Time history analysis were performed considering the 1994 Northridge earthquake. Fe250 material was used for both ribbed dome with and without diagonal member and it was observed that the ribbed dome with identical members have less lateral displacement and base shear with an increase in H/D ratio. From the time history analysis, higher height to span ratio can be recommended for construction.

Ribbed dome with diagonal members performed well against different analysis, but their percentage variation ranges 0-2%. Hence providing diagonal members will make the ribbed dome uneconomical. From the studies it was concluded that, higher height to span ratio showed better performance. From linear static height to span ratio ranging from 0.25 to 0.50 showed better performance. For all parameter considered change in material showed no significant effect on all the analysis.

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