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Dynamic Response Of Braced Domes Under Earthquake Load

Dr. Ihab S. Saleh, Tahseen A. Muhsen

Abstract- Ribbed dome is the oldest type of braced dome that had been constructed. A ribbed dome contains many of indistinguishable meridional bars, interconnected by compression ring. The joint connection of ribbed dome should be rigidly enough to keep the dome stable. Several types of domes that have been proposed to improve the resisting act from a ribbed dome to another type of dome. Finite element models of dome were prepared and analyzed by using SAP2000 V14 software.

Two types of analysis had been carried out, the first was a free vibration analysis which is used to obtain the natural frequency and mode shapes of dome, and the second was a forced vibration analysis which is achieved in time domain where the load inputs are ground acceleration and the output are displacements. EL-Centro earthquake data were used in this study because this seismic contains a large demined of frequencies and it is considered the strongest seismic which occurred at the world, this earthquake was happened in 1940 and caused many damages at that time.

Index Terms— Ribbed Domes, , Steel dome, Steel bracing, Finite Element Analysis, Earthquake load, Free and Forced vibration analyses

1 Introduction

Ribbed dome under EL-Centro earthquake load will be studied to found out dynamic response of the dome because it is contained a large domain of frequencies and its data is certain and reliant. Earthquake load through time-history analysis used to evaluate the dynamic responses of braced domes[1]. Three types of variables were considered in this study. In plane angle between ribs (15) degree, spacing between rings were (1.5 and 3) m and bracing distribution (one way successive and non-successively – two way successively and non-successively). Small opening was installed at the top area of the dome to connect the ribs by ring. The analyzed dome is similar to Mohammad Baqer AL-Sadir dome which is constructed in 2012 at AL-Najaf Al-Ashraf, mid of Iraq. The diameter (D) of this dome is 23.6 m at bottom and its height (H) is 18 m. Materials are used to represent the sections of dome are standard steel sections (I - section for ribs, C -section for rings and Angle – section for bracing). All steel sections which is used in this models are in accordance with Euro – Code because it is using in construction of the actual dome. Fig(1) and Fig(2) explain the model of dome_and Table (1) represent The details of analyzed models

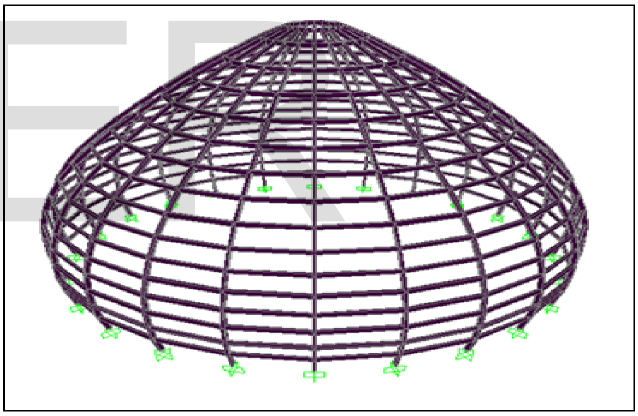

Fig 1. Geometry of dome

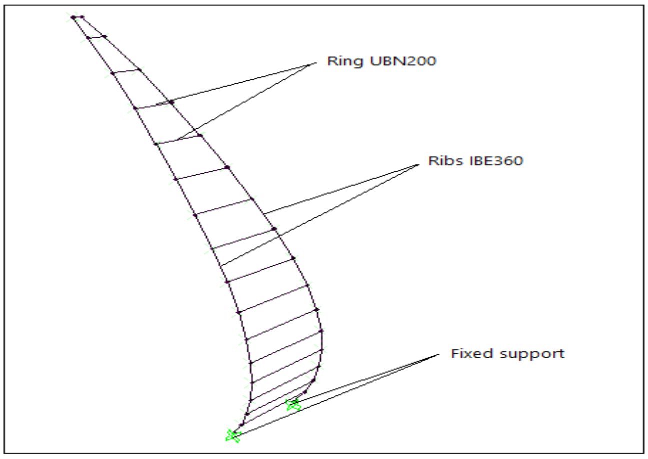

Fig 2. Ribs and rings details

- *Dr. Ihab S. Saleh is an lecturer of civil engineering at Basrah University, Basrah, Iraq.*
- *Tahseen A. Muhsen is currently pursuing masters degree in civil engineering in Basrah University, Basrah, Iraq, PH-009647711644925. E-mail: tahssein.alali@yahoo.com*

2 Material Properties Of Dome

The material of ribs and rings and bracing is steel, the properties of this material are shown in Table(1). The steel sections have a modulus of elasticity $E=2*10^5$ MPa and yield strength fy= 275 MPa and the thickness of coverage plate is 5 mm.

3 Free Vibration Analyses

Free vibration of any structure is very important to predict the natural frequencies and mode shapes of this structure. Different methods for calculating earthquake effects on buildings depend on its natural frequencies and mode shapes, a mechanical system is excited by an initial situation, such as a displacement, velocity or acceleration then it permits to free shake without additional forces effect, and it will fluctuate with its natural frequencies and finally decrease to zero because of damping effects[2].

4 Forced Vibration Analyses

Forced vibration is the result of non-stop external incentive, in contrast to natural vibration which, once started. It is an observed detail of engineering those assemblies of components and constructions with generous safety issues against dynamic loads will occasionally fail catastrophically when exposed to even quite mild forced vibration[15]. A forced vibration occur by external forces which affected on the system, and express on the system motion which occurs in response to a remaining excitation whose amount varies non-uniformly with time[3] .

5 Loading Details

In analyses and design of any structures, the loads on building are very important consideration. The structures are designed and constructed to resist all actions safety during their service life depending on codes requirements. The dead loads are constant during the time relatively, including the structure weight. Imposed or live loads are all the forces that are variable with time as temporary within cycle of normal operation, occasionally also mentioned to as probabilistic loads as live loads, and it not including environmental or construction loads. The dynamic load is any load which is variable with a time[4]. The used data in this study is El-centro earthquake data. The maximum acceleration of this earthquake was (0.349g)[5]. The relationship between the time and ground acceleration as shown in Fig (3).

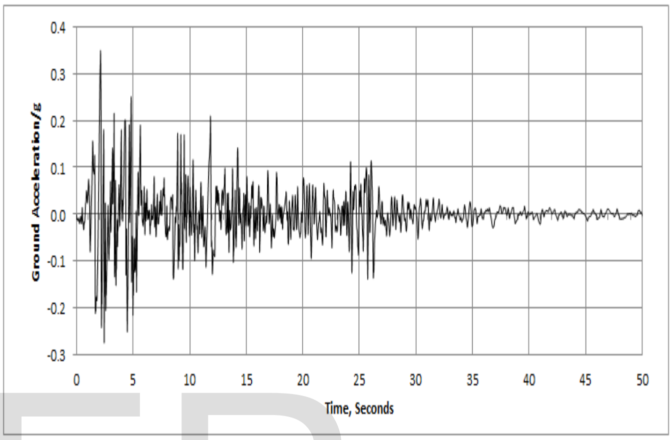

Fig.3 Recorded data of of El-Centro earthquake, NS component.

6 Finite Element Formulation

In this study SAP2000 is used to formulate and analyze the full system with one type of elements is used. The used element is BEAM and it is modeled as a straight line which is connected by double points at the ends. The element contains six degrees of freedom at any point, and it is divided to two types which are rotations round the pointed x, y and z axes and translations in the nodal x, y and z directions, the ribs and rings and bracing in the structure had been modeled and analyzed by using these elements[6].

7 Results

A steel dome with plane angle=15 degree is studied, two type of spacing between ring (1.5 and 3)m, four type of bracing which is used one way bracing successively and non-successively and two way bracing successively and non-successively.

7.1 Frequency

The vertical distance between the ring had been changed from 1.5m to 3m to study this effect on displacement and to obtain the time of maximum displacement after increase of vertical distance. Fig (4) and Fig (5) and Table (2) and Table(3) explain effect of spacing and bracing for seven mode shape for seven mode shape of models.

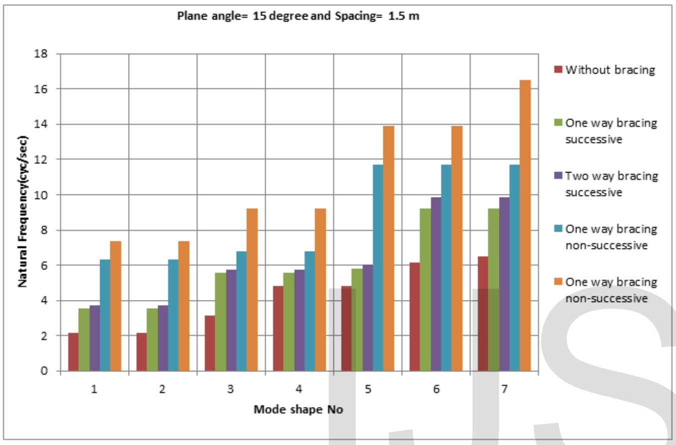

Fig.4 Relation between natural frequency and model number for θ=15 degree and spacing= 1.5m

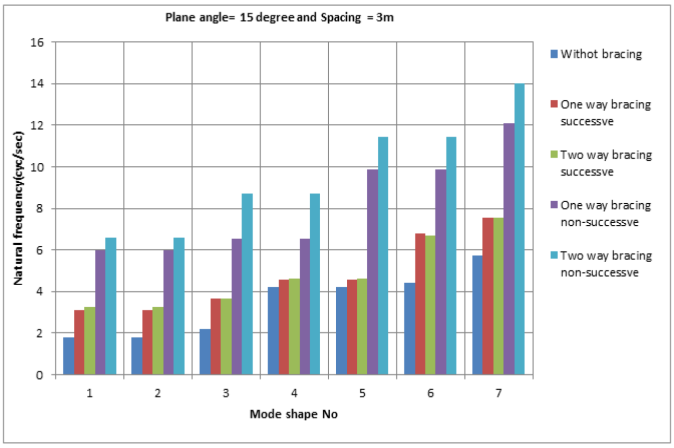

Fig.5 Relation between natural frequency and model number for θ=15 degree and spacing= 3m

The results showed that the increase of the spacing between the rings from 1.5m to 3m cause to decreasing of frequency approximately 10.82%.

Also showed that the natural frequency for any model is increased when the bracing is increased, and for one or two way bracing successively cases, the increase of natural frequencies is similar. The orientation of bracing effect on natural frequencies.

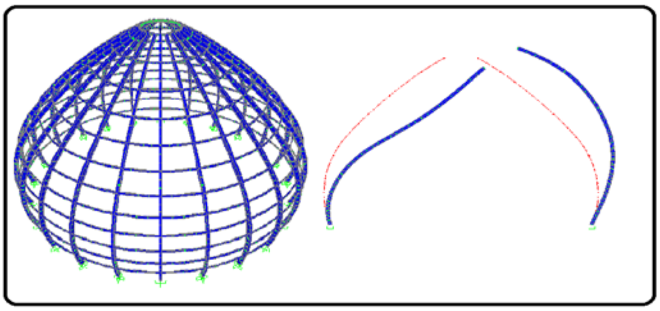

Fig.6 First Model shape (frequency=2.158 cyc/sec) for without bracing & S=1.5m

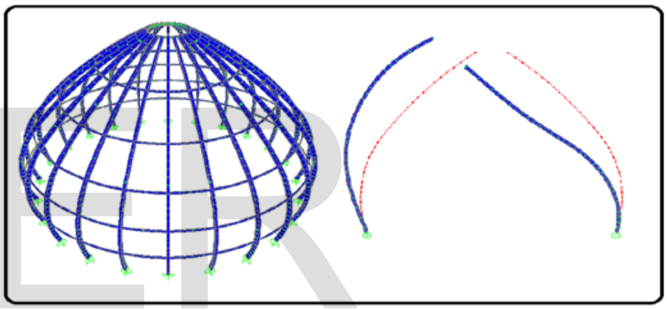

Fig.7 First Model shape (frequency=1.782 cyc/sec) for without bracing & S=3m

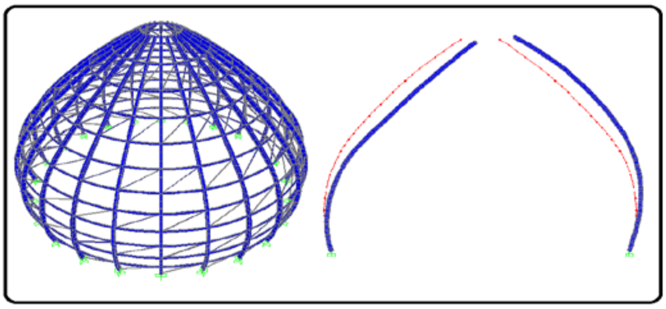

Fig.8 First Model shape (frequency=3.568 cyc/sec) for one way bracing successively & S=1.5m

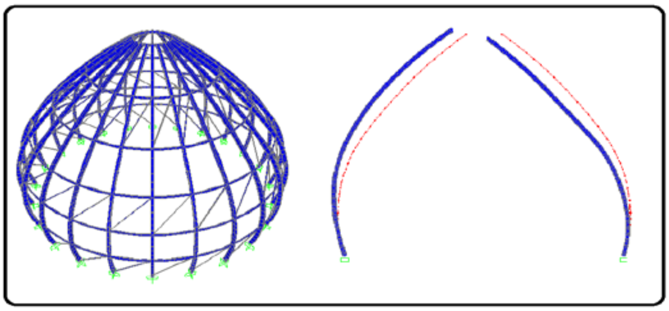

Fig.9 First Model shape (frequency=3.110 cyc/sec) for one way bracing successively & S=3m

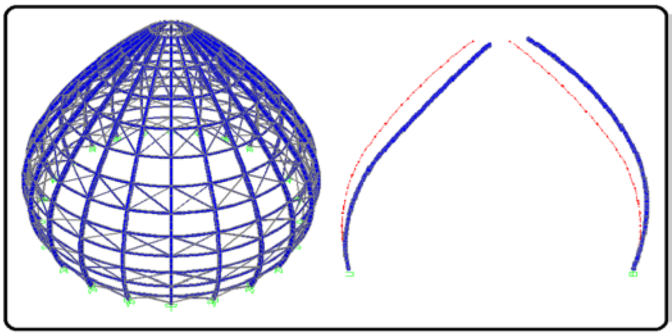

Fig.10 First Model shape (frequency=3.740 cyc/sec) for two way bracing successively & S=1.5m

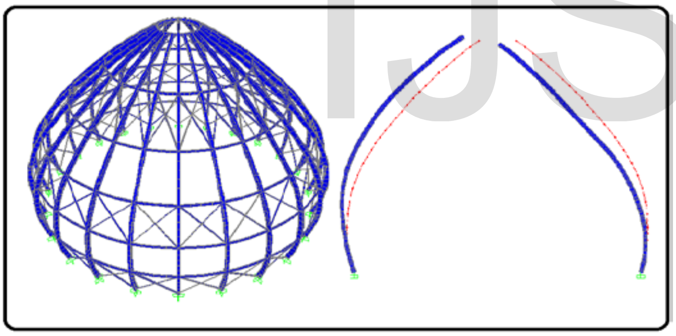

Fig.11 First Model shape (frequency=3.252 cyc/sec) for two way bracing successively & S=3m

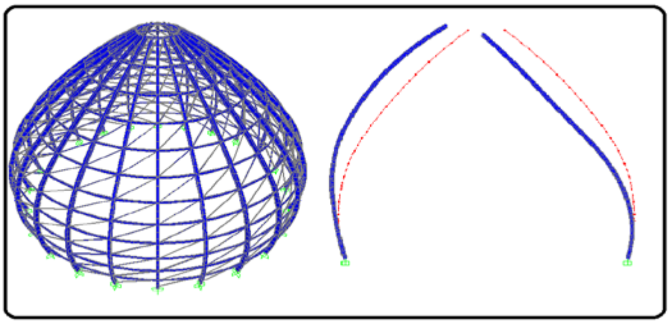

Fig.12 First Model shape (frequency=6.315 cyc/sec) for one way bracing non-successively & S=1.5m

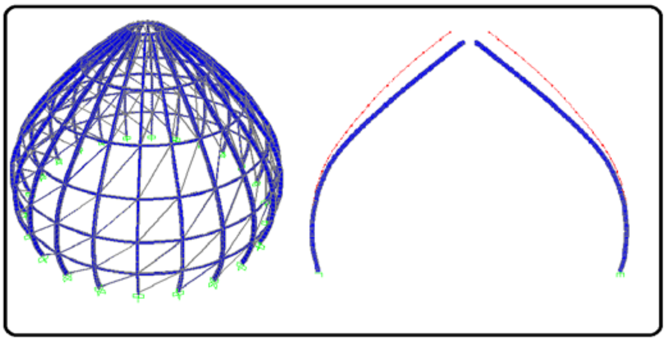

Fig.13 First Model shape (frequency=5.962 cyc/sec) for one way bracing non-successively & S=3m

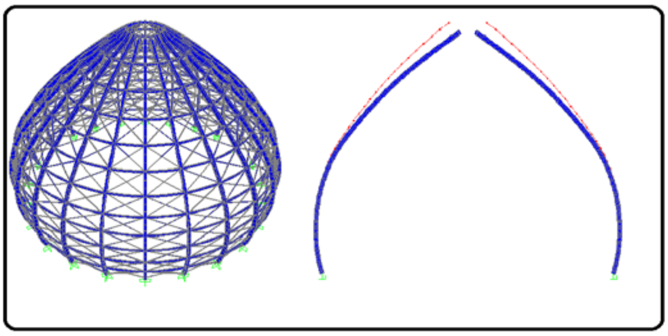

Fig.14 First Model shape (frequency=7.356 cyc/sec) for two way bracing non-successively & S=1.5m

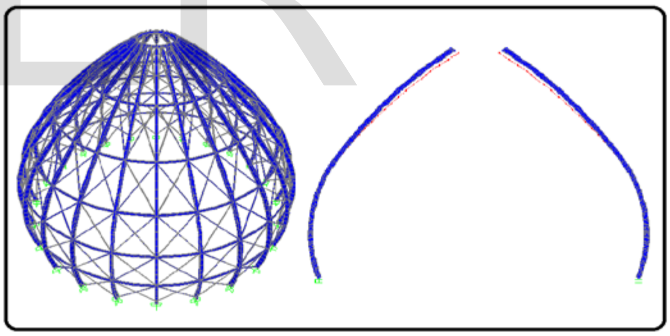

Fig.15 First Model shape (frequency=6.596 cyc/sec) for two way bracing non-successively & S=3m

7.2 Displacement

A dome building ,without bracing is considered as fundamental example . Four types of bracing are used. One way non-successive and one way successive and two way non-successive and two way successive are considered to be conducted the force analysis. The vertical distance between the ring had been changed from 1.5m to 3m to study this effect on displacement and to obtain the time of maximum displacement after increase of vertical distance.

Fig(15) and Fig(16) and Table((4) and Table (5) explain effect of bracing and spacing between rings on maximum displacement of a domes.

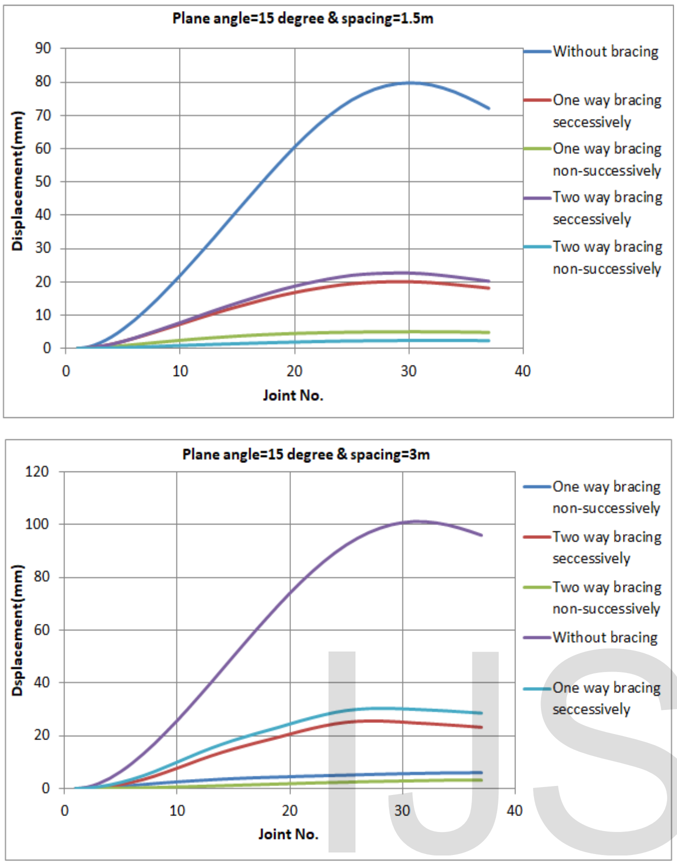

Fig.16 Variation in displacements for one ribs from a dome when change in type of bracing

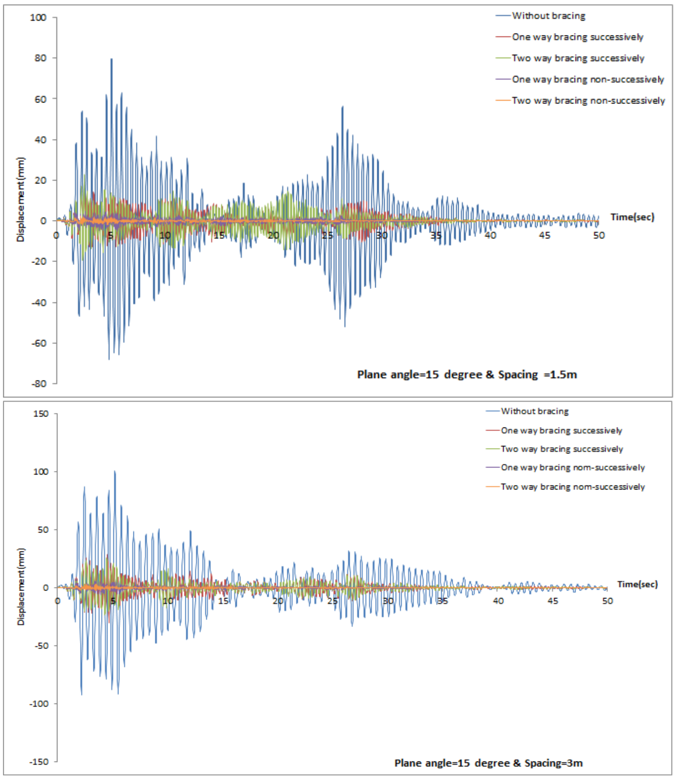

Fig.17 Variation in max. displacement of the dome when change type of bracing during the earthquake period.

The max displacement of dome increased when the vertical distance between the ring beams is increased approximately 26.78% (S=3m higher than S=1.5m) and the time of max. displacement for S=1.5m will be in 5.08 sec and for S=3m the time will be in 5.24 sec.

The results showed that the model with one way bracing successive have max displacement less than the model without bracing approximately 65.26% , and the model with two way bracing successive have max displacement less than the model without bracing approximately 73.95%, and the model with one way bracing non-successive have max displacement less than the dome without bracing approximately 86.36%. Also the model with two way bracing non-successive have max displacement less than the dome without bracing approximately 96.81%.

The results showed that the time of obtained maximum displacements are in the first five seconds from applied of seismic loads on the system unless the dome without

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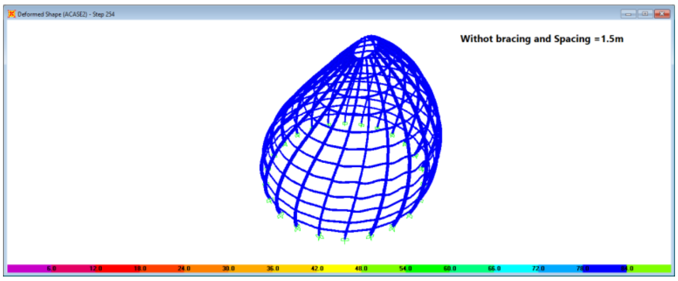
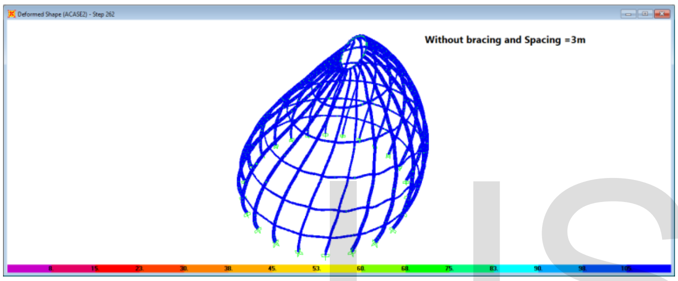
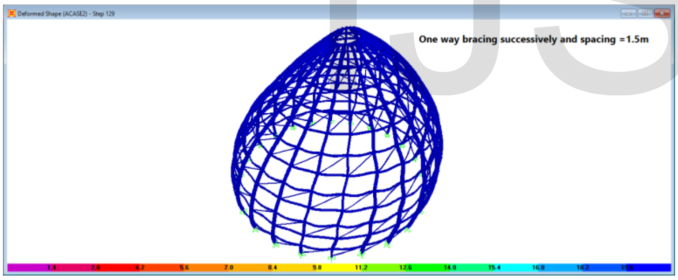
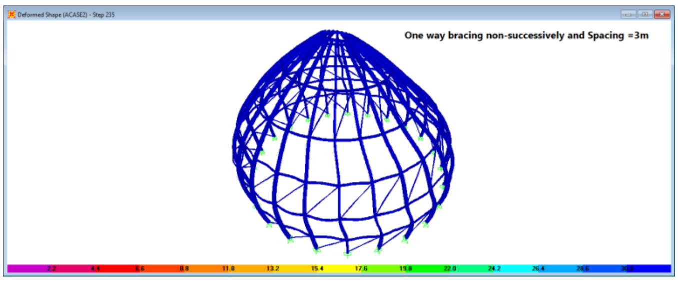
bracing and S=3m and plane angle 30 degree which occur in 12.60 second.

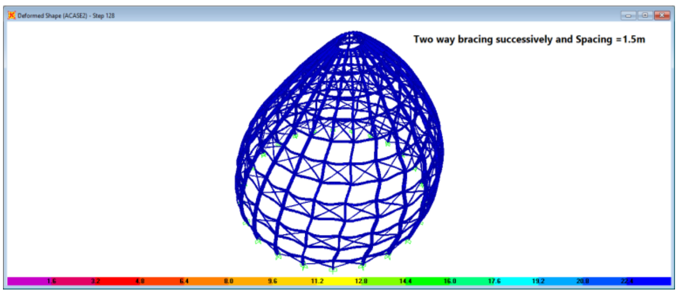
The results showed that the maximum displacements occur at nodes (27 to 35) from the ribs, it means in the top quarter of the dome, so it requests to increase the bracing in this part of the dome.

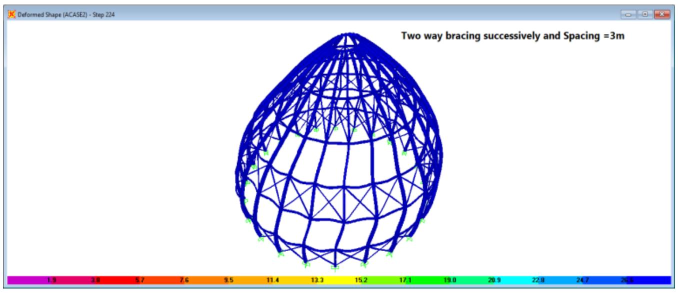


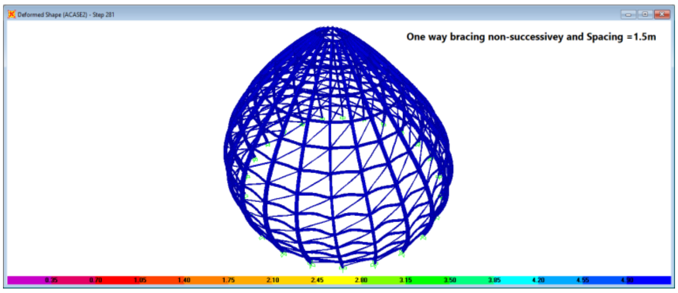


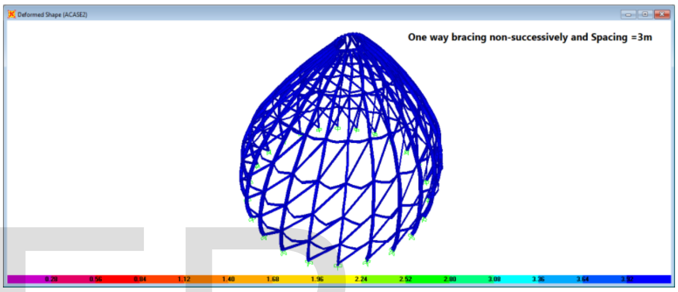


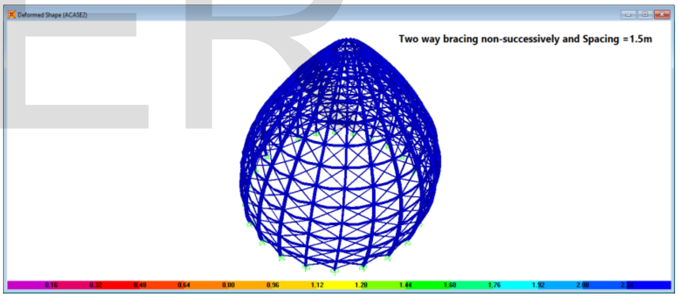












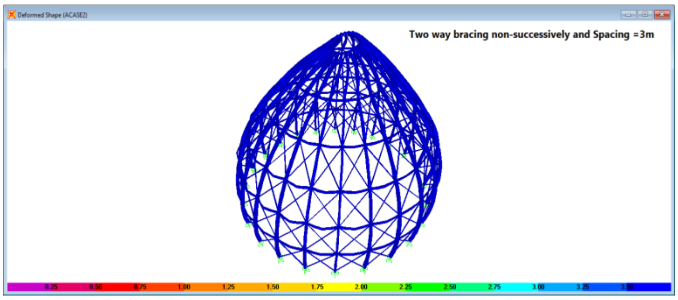


Fig.18 Deformed shape of domes

8 Conclusion

The main concluding remarks that have been achieved from the finite element analysis may be summarized as follows:

1- Differences between natural frequencies of dome models with one way successive bracing and two way successive bracing are very small, therefore, it is preferable to use one way successive bracing to reduce the weight and cost of the structure.
2- Increasing the spacing between rings form 1.5m to 3m lead to large change in frequencies.
3- Increasing the bracing lead to decrease displacement and natural frequencies of the models.
4- The orientation of bracing effects on the nodal displacement and natural frequency for any mode shape of domes.

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Table (1) Properties of material

Name	*Description*	*Unit*	*Value*
E	Modulus of elasticity	N/mm^2	$2*10^5$
G	Shear Modulus	N/mm^2	$77*10^3$
fy	Minimum yield stress	N/mm^2	275
fu	Minimum tensile stress	N/mm^2	410
νs	Poisson's ratio	-	0.3
ϱs	Density	KN/m^3	78

Table (2) Natural frequency(cyc/sec) of dome with spacing =1.5m

No.	*Without bracing*	*One way bracing successively*	*Two way bracing successively*	*One way bracing non-successively*	*Two way bracing non-successively*
1	1.7823	3.1102	3.252	5.9624	6.596
2	1.7823	3.1102	3.252	5.9624	6.596
3	2.179	3.6608	3.6375	6.5141	8.7186
4	4.2213	4.5862	4.5948	6.5141	8.7186
5	4.2213	4.5862	4.5948	9.8892	11.454
6	4.4215	6.7896	6.6935	9.8892	11.454
7	5.7319	7.5508	7.5621	12.076	13.99

Table (3) Natural frequency(cyc/sec) of dome with spacing =3m

No.	*Without bracing*	*One way bracing successively*	*Two way bracing successively*	*One way bracing non-successively*	*Two way bracing non-successively*
1	1.7823	3.1102	3.252	5.9624	6.596
2	1.7823	3.1102	3.252	5.9624	6.596
3	2.179	3.6608	3.6375	6.5141	8.7186
4	4.2213	4.5862	4.5948	6.5141	8.7186

5	4.2213	4.5862	4.5948	9.8892	11.454
6	4.4215	6.7896	6.6935	9.8892	11.454
7	5.7319	7.5508	7.5621	12.076	13.99

Table (4) Displacements (mm) of dome with spacing =1.5m

	Displacement(mm)				
Joint No.	*Without bracing*	*One way bracing successively*	*One way bracing non-successively*	*Two way bracing successively*	*Two way bracing non-successively*
1	0.00	0.00	0.00	0.00	0.00
2	0.48	0.18	0.09	0.16	0.02
3	1.72	0.64	0.29	0.60	0.07
4	3.53	1.30	0.55	1.26	0.15
5	5.84	2.14	0.85	2.14	0.25
6	8.54	3.09	1.18	3.15	0.36
7	11.58	4.12	1.51	4.27	0.49
8	14.85	5.17	1.83	5.41	0.61
9	18.37	6.25	2.15	6.59	0.74
10	21.98	7.32	2.45	7.78	0.87
11	25.72	8.41	2.74	8.99	0.99
12	29.58	9.50	3.01	10.22	1.11
13	33.48	10.55	3.26	11.41	1.23
14	37.48	11.57	3.49	12.56	1.34
15	41.46	12.54	3.71	13.67	1.44
16	45.40	13.47	3.90	14.74	1.55
17	49.33	14.39	4.08	15.82	1.64
18	53.17	15.27	4.24	16.85	1.74
19	56.91	16.08	4.38	17.83	1.83
20	60.50	16.80	4.50	18.71	1.92
21	63.89	17.46	4.60	19.50	2.00
22	67.01	18.04	4.69	20.21	2.07
23	69.87	18.59	4.77	20.89	2.14
24	72.42	19.06	4.84	21.48	2.20
25	74.62	19.45	4.89	21.96	2.25
26	76.42	19.72	4.93	22.29	2.29
27	77.85	19.90	4.97	22.50	2.32
28	78.89	20.00	4.99	22.61	2.35
29	79.53	20.06	5.01	22.67	2.37
30	79.77	20.04	5.01	22.65	2.39

31	79.63	19.94	5.01	22.51	2.40
32	79.11	19.75	5.00	22.26	2.41
33	78.23	19.48	4.98	21.91	2.41
34	77.04	19.17	4.95	21.51	2.40
35	75.56	18.83	4.91	21.09	2.38
36	73.90	18.48	4.87	20.65	2.36
37	72.09	18.12	4.82	20.20	2.32

Table (5) Displacements (mm) of dome with spacing =3m

Displacement(mm)					
Joint No.	*Without bracing*	*One way bracing successively*	*One way bracing non-successively*	*Two way bracing successively*	*Two way bracing non-successively*
1	0.00	0.00	0.00	0.00	0.00
2	0.49	0.17	0.08	0.10	0.01
3	1.81	0.64	0.28	0.39	0.03
4	3.79	1.35	0.54	0.85	0.07
5	6.41	2.30	0.85	1.51	0.13
6	9.52	3.47	1.18	2.36	0.20
7	13.10	4.84	1.53	3.41	0.28
8	17.01	6.44	1.87	4.69	0.37
9	21.27	8.18	2.20	6.15	0.47
10	25.70	9.97	2.51	7.68	0.58
11	30.35	11.78	2.79	9.26	0.69
12	35.17	13.57	3.05	10.84	0.81
13	40.07	15.27	3.29	12.35	0.94
14	45.10	16.81	3.52	13.71	1.06
15	50.11	18.23	3.73	14.97	1.19
16	55.07	19.54	3.91	16.14	1.31
17	60.00	20.79	4.07	17.27	1.44
18	64.81	21.99	4.21	18.37	1.57
19	69.48	23.19	4.34	19.47	1.70
20	73.99	24.44	4.48	20.61	1.83
21	78.26	25.68	4.61	21.73	1.96
22	82.24	26.84	4.73	22.78	2.08
23	85.92	27.91	4.84	23.71	2.19
24	89.29	28.82	4.95	24.50	2.30
25	92.27	29.55	5.06	25.10	2.40
26	94.80	30.01	5.17	25.44	2.50

27	96.94	30.28	5.29	25.58	2.60
28	98.65	30.37	5.40	25.56	2.69
29	99.92	30.33	5.50	25.40	2.77
30	100.75	30.18	5.60	25.15	2.84
31	101.14	29.99	5.68	24.87	2.91
32	101.08	29.80	5.76	24.62	3.00
33	100.62	29.59	5.84	24.37	3.08
34	99.82	29.37	5.90	24.11	3.14
35	98.72	29.12	5.94	23.82	3.16
36	97.41	28.84	5.96	23.51	3.16
37	95.94	28.55	5.97	23.18	3.13