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Parametric Study of Geodesic Dome Subjected to Wind Load For Different Geodesic Frequencies

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Abstract—Domes are very popular as per the architectural intent and structural intent due to their aesthetic appearance and higher load carrying capacity. During the medieval era the construction of domes lost the demand due to difficulties in construction and lack of availability of skilled labours. In this research we had studied about the advantages and major aspect of constructing the geodesic structure in the modern architecture. In this paper, comparative study of geodesic structure is worked out for 60 meter diameter and class 1 type division method. Class1 method1 is used for different frequencies like 5V, 10V, 15V, 20V, 25V. Modelling of structure is carried out on CADRE GEO 7.0 software. For the purpose of Analysis and design STAAD Pro V8i SS5 had been used. |Also Optimization of the structure is been worked out using STAAD optimization tool. In order to study the behavior of geodesic dome ratio of height to diameter of dome kept same as 0.5. This paper takes a look into the combination of impact of wind load for different zones with different geodesic frequencies. In this article, a large-scale geodesic dome performance is studied with non-linear dynamic analysis method also known as time history method.

Keywords—Geodesic dome, Geodesic frequency, STAAD Pro V8i SS5, CADRE GEO 7.0, Buckminister Fuller, Platonic geometry, Wind load, Steel dome, Braced structure.

1. Introduction

A dome is one of the ancient technique in both architecture and structural forms and it has been widely practice in ancient as well as modern architecture . Domes are are structurally benefits as they have higher load carrying capacity as compare to beam and also due to pleasant appearance. Also the construction of domes causes economy because the requirement of deep beams can be fulfilled by those structure. A dome transfer its load similar to that of beam along with the tangential forces and is been proved as one of the stable self supporting structure.

Domes are widely used in constructions of protecting pitch of the stadium, to achieve higher floor to floor height in assembly halls and exhibition centers, to maintain the sufficient oxygen circulation in Bio-floc farming, also as cover to swimming pools and industrial buildings to have higher work space without any obstruction of supports. Domes are classified as per surface is formed. One of the example for the braced dome is geodesic dome. In modern architecture its been widely used as roof for the experience centers and exhibition Centre along with auditoriums etc. Geodesic domes have been proved to distribute the stresses evenly in the family of braced domes. The analysis of such structure is tedious task and the chances of human error increases. A hemispherical thin-shell structure (lattice-shell) based on a geodesic polyhedron is also known as geodesic dome. The elements formed for the distribution of stresses in structure is effecitively done by formation of triangular elements allowing them to resist higher magnitude of load.

The use of geodesic domes offer higher advantages in the structure which poses obstruction free space either for the community function or for the work environment in industries. Hugh Kenner [1]is the researcher who had studied and proposed all the mathematical equations about discretization of geodesic features and had explanations in detail. M.P. Saka [2] the harmony search optimization tool had been used by author for the optimization of geodesic structure geometry. Eltayeb Elrayah Kralafalla [3] prepared CAD processing of geodesic structural model with higher accuracy about geometry division and results. Marek Kubik [4] the case study to provide economic shelter design and excel sheet for manual design calculation of pabal dome for Maharashtra in which large population was affected by 1993 killari earthquake

Polyhedron system criteriais suggested by the Breakdown systemn. Initially all the system strats with triangular polyhedron face and further it is divided into a three way grid. Then all vertices are moved outward till we achieve same distance from the center. Mostly all such are based on icosahedrons. A very rough sphere is obtained by having 20 equilateral. In the geodesic structure all the length of element and triangles have same size. All frequency domes can be classified as a 1v geodesic sphere. If one wants to increase the frequency it will be obtained by subdividing a face into higher numbers of triangular elements then projection of each of the vertex of every triangle to an imaginary sphere encompassing the dome. Higher is the subdivision higher is the degree of freedom. “The Greek letter for Phase or frequency is Nu or Nv written N in Latin the lowercase (ν) is used as the symbol for spatial frequency of a wave in physics and other fields”, The v is used as denomination of frequency.

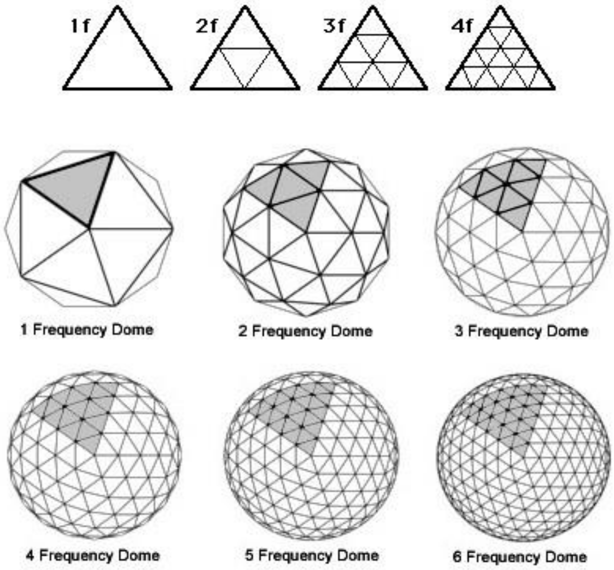


Fig. 1. Frequency of Geodesic dome

Class1- denotes subdivision of Icosahedrons. Icosahedrons have 20 triangular faces. This is the most common subdivision used these days. Almost all geodesic calculations are based on Class 1.

Class2- denotes subdivisionof Octahedron. Octahedron has 8 triangular faces. These are used in early days of geodesic.

Class3- denotes subdivision of Tetrahedron. Tetrahedron has 4 triangular faces. These are rarely used in geodesic design.

Geometry generation is done with the help of CADRE GEO 7.0. The computer programme known as CADRE Geo is been used for modelling the structure and for performing finite element analysis. The various design ouput required for the construction of geodesic structure can be obtain as the output file. The same programme can be used for the generation of CAD drawings.

2. Scope of Study

To achieve mentioned objectives decided scope of work shall be as follows,

- To study Geodesic dome properties height to depth ratio (H/D) kept constant as 0.5 for 60m diameter. Class 1 is also kept constant.
- In this scope various models are analyzed for different Geodesic frequencies like 5V, 10V, 15V, 20V, 25V.
- One of the objective is to find out the most economical Geodesic frequency due to the effect of wind load for different zones. For every frequency, model is analyzed for 33m/s, 39m/s, 44m/s, 47m/s, 50m/s and 55m/s.
- Square hollow sections having YST 240 are used for analysis purpose.
- Scope of study includes determination of support reaction variation with respect to frequencies and wind load
- Steel takeoff variation also plays important role while analyzing Geodesic domes.
- Comparative statement of horizontal, vertical displacement and support reactions is essential to achieve the goal.

3 Literature Review

Divyesh G. Mandali, Satyen D. Ramani [5] analyzed various domes for frequency 4, 6, 8, 10 and 12 of Class1 method and Class 1 method 2. They concluded that As frequency is directly proportional to the tonnage when studied for class1 method 2 but it was also concluded that the increase in frequency reduces the member sizes. The study shows that for class1 method1 division is suitable for frequency 4 where for class1 method2 it was observed at frequency 8

Ashim Kanti Dey, Chinmoy Deka [6] stated that the deformation is 30% less when the same cross section is been used for column and beam in dome roof structure. The similar deformation was oberved , when 40% increase were made in sizes of columns in the flat roof structure.A comparative study regarding a flat roof structure and a dome roof structure on deformations imposed under lateral loading. The various demands were obtained from the analysis performed in STAAD Pro.

A. Sujatha [7] concluded in her paperthe geodesic dome structure gives the economical design by reducing the defect, also they are economical due to less consumption of material during construction.True spheres can be obtained by arrangement of polygons in great circle. The highest ratio for the enclosed volume to weight Compairing all structures constructed from linear elements, was a Geodesic Dome . Alo the application and geometry of the geodesic dome were discussed in this paper

The authors of [8] paper represent details of the experimental study of domical roof low rise building. Wind analysis was performed for the measurement of wind pressure by placing them in wind tunnel. They Concluded that the suction was developed in the domical roof, in which the maximum was at the ridge and minimum near the supports.

4. Methodology

The study comprises of the behaviour of different Geodesic frequencies due to application of different wind loads.

On the basis of literature review and studies, I understood that several researchers have worked by using different methods to find the forces on Geodesic domes. Domes are analyzed in STAAD V8i SS5.

4.1 Model Generation

- **CADRE GEO** interface asks about diameter of dome, height of dome, frequency, class and method.
- After putting desired values in the interface CADRE GEO generates 3D DXF file which can be easily imported in STAAD Pro V8i SS5.

A. SOFTWARE OF ANALYSIS

STAAD Pro V8i is is a widely accepted software for the performing of analysis and design of the structure. Due to it user friendly interface it been widely used in the modelling of steel structure and the roof trusses and domes. The progamme has the ability to perform all type of linear nad non-linear analysis. STAAD Pro is been actively used by the professional for analysing the culverts, industrial roof, buildings, towers etc.

Withan increasing competition in the market the progamme has been updated such that all the structure can be analyzed for linear static analysis, Response spectrum analysis, Push over analysis and time history analysis. STAAD-Proallows the user to analyze the structure within the short span of time which cloud takes days for the same. Also the chances of human error is also minimizes due to the automation.The progamme is capable of handling the analysis regardless of material and the Standard country codes as well as international country codes, Including Chinese, American and European codes.

4.2 Modelling

To study the behavior of geodesic dome structure, different cases have been defined and their comparative graphs for these cases have been plotted. A typical steel structure will be analyzed and designed self weight i.e. dead load, the moving load i.e live load and the lateral load like earthquake and wind load.

Dead load includes self weight of the structure and metal sheeting as per IS 875 Part I.

Live load for non accessible roof live load is 0.75kN/m^{2}but reduction in the live load shall be done as per IS 875 Part II clause 4.1,

Figure below gives the idea about change in wind pressure due to change in height and position of periphery. Combination of both gives desired wind pressure. Table describes about internal and external wind pressure coefficient calculation for 33 m/s.Similarly, wind calculation are carried out for 39 m/s, 44 m/s, 47 m/s, 50 m/s and 55m/s.

DESIGN WIND SPEED 33 M/S

WIND CALCULATION UTPO 10M

RISK COEFFICIENT (K1)	TERRAIN COEFFICIENT (K2)	TOPOGRAPHY FACTOR (K3)	DESIGN WIND SPEED (Vb)	DESIGN WIND VELOCITY (Vz)	WIND PRESSURE (Pz)
1	0.99	1	33	32.67	0.64

WIND CALCULATION FROM 10M TO 15M

RISK COEFFICIENT (K1)	TERRAIN COEFFICIENT (K2)	TOPOGRAPHY FACTOR (K3)	DESIGN WIND SPEED (Vb)	DESIGN WIND VELOCITY (Vz)	WIND PRESSURE (Pz)
1	1.03	1	33	33.99	0.69

WIND CALCULATION FROM 15M TO 20M

RISK COEFFICIENT (K1)	TERRAIN COEFFICIENT (K2)	TOPOGRAPHY FACTOR (K3)	DESIGN WIND SPEED (Vb)	DESIGN WIND VELOCITY (Vz)	WIND PRESSURE (Pz)
1	1.06	1	33	34.98	0.73

WIND CALCULATION FROM 20M TO 30M

RISK COEFFICIENT (K1)	TERRAIN COEFFICIENT (K2)	TOPOGRAPHY FACTOR (K3)	DESIGN WIND SPEED (Vb)	DESIGN WIND VELOCITY (Vz)	WIND PRESSURE (Pz)
1	1.09	1	33	35.97	0.78

TABLE I. WIND CALCULATION FOR DIFFERENT HEIGHTS

FOR WIND SPEED 33 m/s PRESSURE

ANGLE	HEIGHT OF PROJECTED AREA IN M		EXTERNAL PRESSURE COEFFICIENT	INTERNAL PRESSURE COEFFICIENT	WIND PRESSURE (Pz)	F=(Cpe - Cpi) Pz
0-15	0	10	0.95	0.2	0.64	0.74
15-30	10	15	0.7	0.2	0.69	0.62
30-45	15	20	0.2	0.2	0.73	0.29
45-60	20	30	-0.4	0.2	0.78	-0.16
60-75	20	30	-0.9	0.2	0.78	-0.55
75-90	20	30	-1.15	0.2	0.78	-0.74
90-105	20	30	-1.1	0.2	0.78	-0.70
105-120	20	30	-0.8	0.2	0.78	-0.47
120-135	20	30	-0.4	0.2	0.78	-0.16
135-150	20	15	-0.05	0.2	0.73	0.11
150-165	15	10	0.2	0.2	0.69	0.28
165-180	10	0	0.35	0.2	0.64	0.35

TABLE II-A)WIND CALCULATION FOR 33M/S PRESSURE

FOR WIND SPEED 33 m/s SUCTION

ANGLE	HEIGHT OF PROJECTED AREA IN M		EXTERNAL PRESSURE COEFFICIENT	INTERNAL PRESSURE COEFFICIENT	WIND PRESSURE (Pz)	F=(Cpe - Cpi) Pz
0-15	0	10	0.95	-0.2	0.64	0.48
15-30	10	15	0.7	-0.2	0.69	0.35
30-45	15	20	0.2	-0.2	0.73	0.00
45-60	20	30	-0.4	-0.2	0.78	-0.47
60-75	20	30	-0.9	-0.2	0.78	-0.86
75-90	20	30	-1.15	-0.2	0.78	-1.05
90-105	20	30	-1.1	-0.2	0.78	-1.01
105-120	20	30	-0.8	-0.2	0.78	-0.78
120-135	20	30	-0.4	-0.2	0.78	-0.47
135-150	20	15	-0.05	-0.2	0.73	-0.18
150-165	15	10	0.2	-0.2	0.69	0.00
165-180	10	0	0.35	-0.2	0.64	0.10

TABLE-II B)WIND CALCULATION FOR 33M/S SUCTION

In order to study time history analysis on the geodesic dome El-Centro seismic data is been is used. The inputs of seismic data as per recorded by the nearest seismographic station is been given a input in programme for the analysis. The care should be taken of the whether the data provided matches with the working units in the model if not then the necessary scale factor is to be applied.

STAAD PRO has its own tool by which we can create time history definition. Damping ratio 0.05 is used. Below attached table gives the defining parameters.

5. Results and Discussions

After the analysis in STAAD Pro V8i SS5 horizontal, vertical nodal displacement, horizontal, vertical support reaction and steel takeoff results are collected in excel sheets. Based on these results comparison made is graphically represented below with its discussion. Also, modal shapes of time history analysis is shown by figures attached.

5.1 Comparison of results for different geodesic frequencies

5.1.1 For geodesic frequency 5V

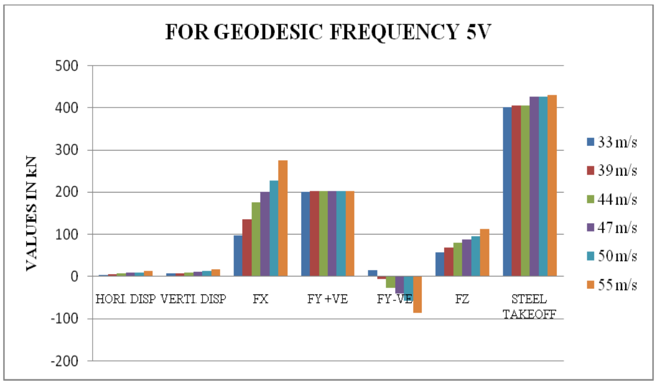


Figure. 2. Comparative statement of various parameters for geodesic frequency 5V

Figure. 10 show variation of different parameters due to wind pressure. Horizontal support reaction FX for wind speed 33 m/s is 2.85 times less as compared to FX for 55 m/s. Maximum vertical downward reaction shall remain same for wind speeds as downward reaction is due to self weight, imposed load and collateral load. Length of each member is around 7.85m, member is designed for its own length and slenderness ratio. Thus only 6.5% tonnage increase is observed by comparing with lowest wind speed and highest wind speed. Maximum uplift and maximum tonnage is observed among all the frequencies.

5.1.2 For geodesic frequency 10V

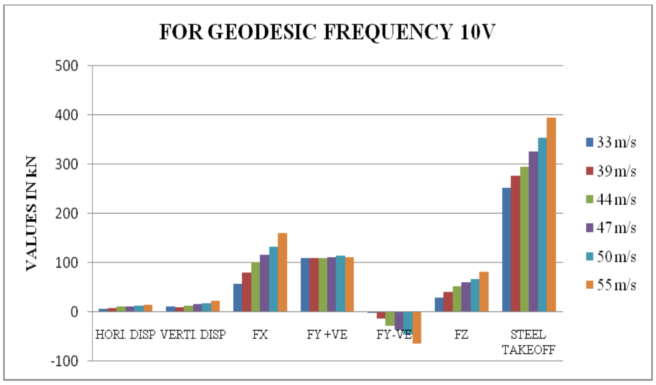


Figure. 3. Comparative statement of various parameters for geodesic frequency 10V

Figure. 11 also indicates the horizontal support reaction FX for wind speed 33 m/s is almost2.80 times less as compared to FX for 55 m/s. Maximum vertical downward reaction shall remain same for wind speeds as downward reaction is due to self weight, imposed load and collateral load. Length of each member is around 4m, member is designed for tension and compression forces. Thus, there is significant change in the steel takeoff. Tonnage increment is 1.55 times by comparing 33 m/s and 55 m/s. around 8% decrease in the tonnage by comparing with maximum tonnage of 5V frequency.

5.1.3 For geodesic frequency 15V

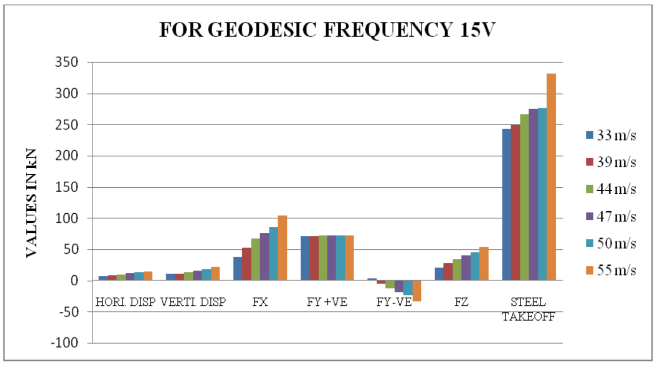


Figure. 5. Comparative statement of various parameters for geodesic frequency 15V

Figure. shows similar trend as compared to other two frequencies for horizontal support reaction FX. Maximum vertical downward reaction shall remain same for wind speeds as downward reaction is mainly due to self weight, imposed load and collateral load. Maximum length of member is around 2.65m. Thus, there is significant change in the steel takeoff. Around 20% decrease in the tonnage by comparing with maximum tonnage of10V frequency.

5.1.4 For geodesic frequency 20V

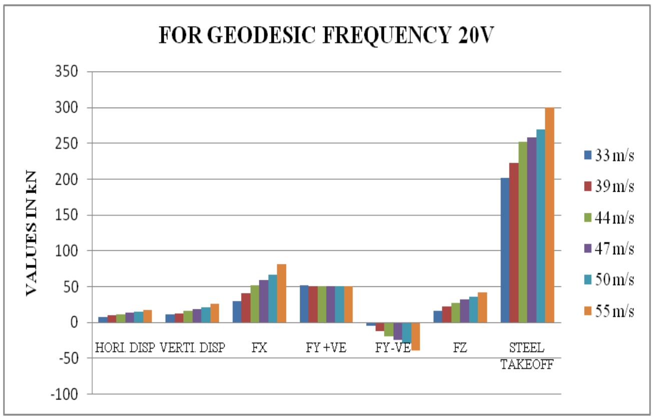


Figure. 4. Comparative statement of various parameters for geodesic frequency 20V

Figure. 13 shows similar trend as compared to other two frequencies for horizontal support reaction FX. Maximum length of member is around 2m. It is observed that tonnage value decreases from 5V to 15V and lowest tonnage value is observed for 20V.

5.1.5 For geodesic frequency 25V

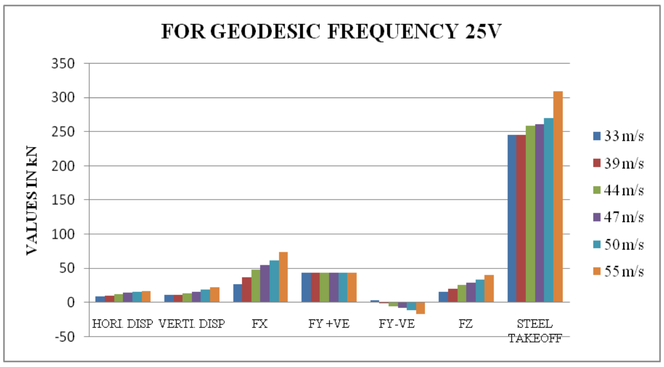


Figure. 6. Comparative statement of various parameters for geodesic frequency 25V

Figure. shows significant rise in the steel take off as compared to 20V frequency.

5.1.6 Horizontal displacement against wind speed

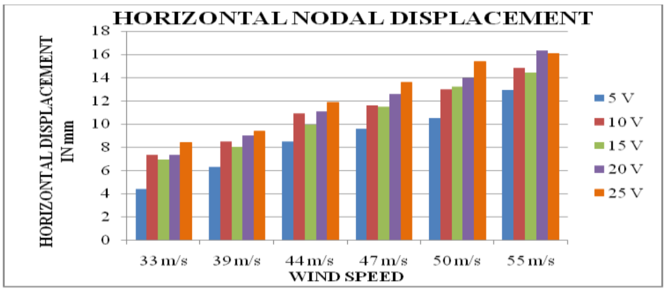


Figure. 7.Horizontal displacement v/s wind speed

There is sudden rise in the horizontal nodal displacement from 5V to 10V. Graph 6 shows lowest horizontal displacement as compared to other frequencies.

5.1.7 Vertical displacement against wind speed

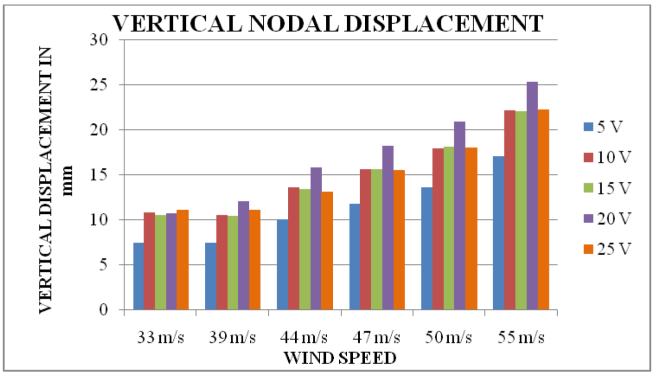


Figure. 7.a) Vertical displacement v/s wind speed

Maximum vertical displacement is observed for 20V.

5.1.8 Horizontal reaction against wind speed

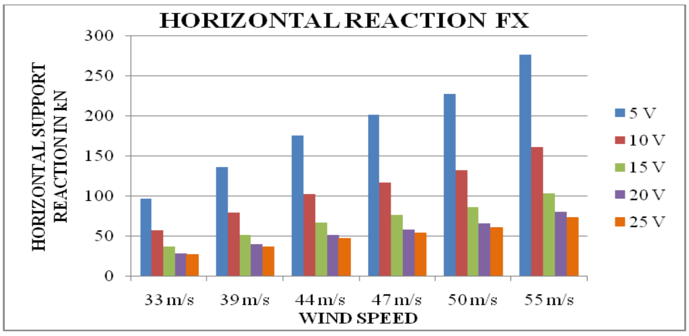


Figure. 7b). Horizontal reaction v/s wind speed

As earlier mentioned, horizontal FX reaction is 2.7-2.85 times less when we compare it for 5V and 25V. Same pattern is observed for all wind speeds.

5.1.9 Vertical downward reaction against wind speed

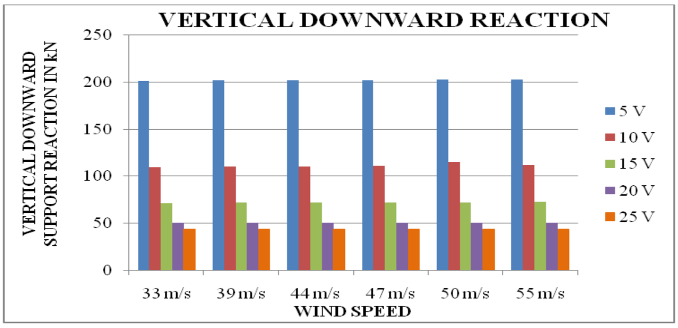


Figure.8 a) Vertical downward reaction v/s wind speed

Figure. show sudden decrease in vertical downward reaction from 5V to 10V and then gradual decrease from 10V to 25V.

5.1.10 Vertical downward reaction against wind speed

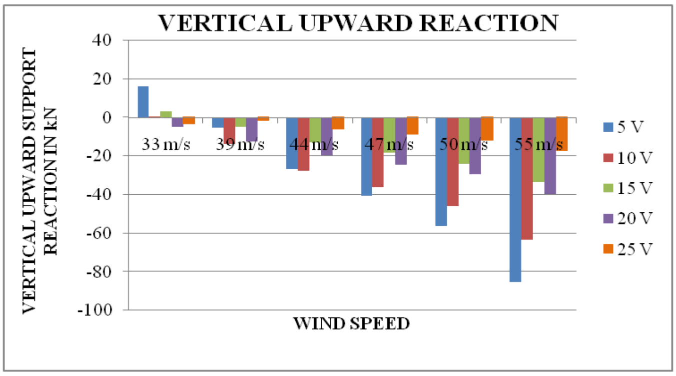


Figure. 8 b). Vertical upward reaction v/s wind speed

5.1.11 Steel takeoff against wind speed

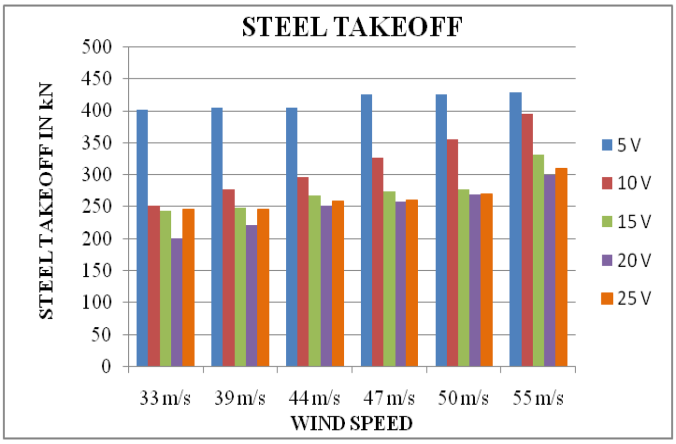


Figure. 9 Steel takeoff v/s wind speed

Figure. significant decreases in the tonnage value from 5V to 20V and increase in the tonnage from 20V to 25V. Among all wind speeds and frequencies, 20V frequency shows lowest value of tonnage.

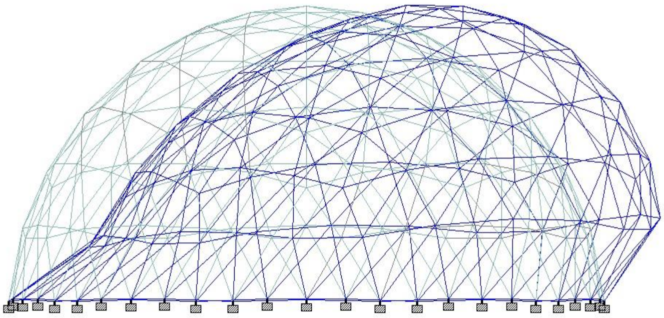


Fig. 10 a).Modal shape 1

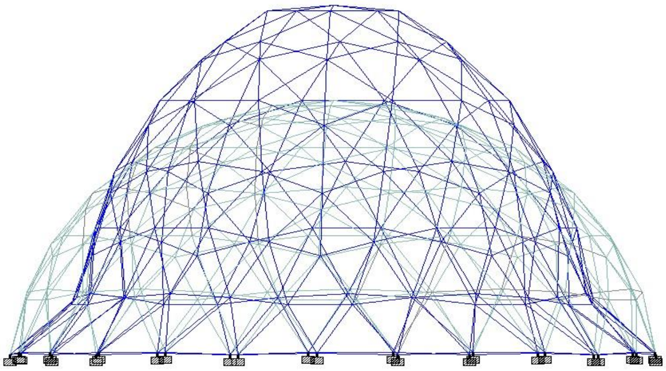
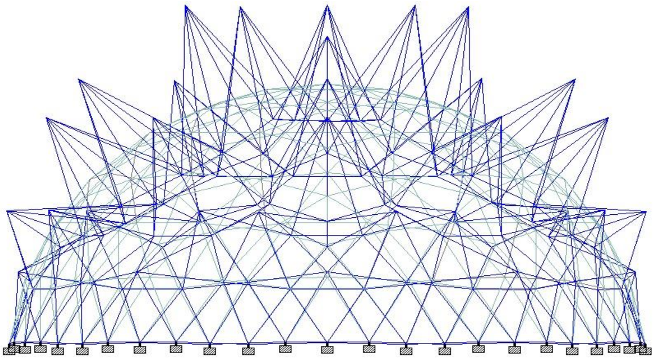


Fig. 10 b).Modal shape 2



10 c).Modal shape 3

6. Summary And Conclusion

When geodesic domes with different frequencies having H/D ratio 0.5 are analysed for different wind speeds according to code provisions, the results obtained highlights the importance of frequency of geodesic dome structure. Following broad considerations can be made in this respect:

- This study shows there is no significant change in vertical downward reaction for each frequency and for different wind speeds.
- Horizontal nodal displacement depends upon geodesic frequency and wind speed. Incremental variation is found in the displacement with respect to wind speed and increase in frequency.
- We can also conclude that for geodesic dome having diameter 60m and H/D ratio 0.5 most economical frequency is 20V. With reference to graph 11, it indicates that for different wind speeds steel takeoff decreases from 5V to 20V and after 20V steel takeoff will also increase.
- As frequency increases length of member increases. Length of the member plays vital role in the tonnage calculation. For 5V frequency design will govern for slenderness ratio.
- It was concluded that the wind analysis results in developing the suction pressure for the domical roof, which was observed maximum at the ridge level and minimum near the supports

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