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Parametric Study Of Geodesic Dome Subjected To Wind Load For Different Geodesic Frequencies

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Abstract—Domes have been a prominent part of construction dating back from ancient times due to its uniqueness in providing maximum space with minimum surface area. Their popularity lost ground during the medieval period on account of tedious construction methods and skilled work requirements for large sized domes. The paper brings out the various advantages and key aspects of geodesic domes as the modern world looks out for energy efficient, eco-friendly and durable housing options. In this paper, comparison of geodesic dome is carried out for 60 meter diameter and class 1 division method. Class1 method1 is used for different frequencies like 5V, 10V, 15V, 20V, 25V. Model of dome is generated in CADRE GEO 7.0 software. Analysis and design is carried out by STAAD Pro V8i SS5. Optimization is performed using STAAD in-built 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 paper, the performance of anti-seism of a large-scale geodesic dome is studied with 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 oldest structural forms and it has been used in architecture from earliest times. Domes are of special interest to engineers and architects as they enclose a maximum amount of space with a minimum surface and have proved to be very economic in the consumption of construction materials. A dome is been proved as a most efficient self supporting structure for a large area due to its two curved direction.
Domes can be exceptionally suitable for covering sports stadium, assembly halls, exhibition centers, fish-farming aqua pods, swimming pools and industrial buildings, for getting large unobstructed areas with minimum interference from internal supports. Domes are given different names depending upon the way their surface is formed. Geodesic dome is a typical example of braced dome. Nowadays it is widely adopted for construction of exhibition hall all over the world. Geodesic domes constitute an important family of braced domes offering high degree of regularity and evenness in stress distribution. Data preparation and handling of graphics for geodesic forms are difficult and time consuming tasks and are the stages of analysis where mistakes are most commonly made. A geodesic dome is a hemispherical thin-shell structure (lattice-shell) based on a geodesic polyhedron. The triangular elements of the dome are structurally rigid and distribute the structural stress throughout the structure, making geodesic domes able to withstand very heavy loads for their size.

Architect and engineers have been excited about the possibilities of space structures for the past many years. They offer opportunities for variation in plan form and building profile, large uninterrupted spans, and excellent distribution of loads, optimum utilization of materials and prefabrication and mass production of easily transportable components. Hugh Kenner [1] studied and described all the mathematical information about division of geodesic features with explanations. M.P. Saka [2] studied for optimum geometry design for geodesic domes using harmony search algorithm. Eltayeb Elrayah Kralafalla [3] prepared computer aided processing of geodesic structural forms with detailed information about geometry division and results. Marek Kubik [4] studied and prepared excel sheet for design of pabal dome for Maharashtra where people were affected by 1993 killari earthquake to provide economic shelter to them.

Breakdown system provides some of the criteria for choosing the polyhedron. All system starts with triangular polyhedron face and subdivide it with a three way grid. Then push all vertices of the grid outward till they are a common distance from the center. By this way we will get division method. Most geodesic domes are based on icosahedrons.

Icosahedrons have 20 equilateral triangle faces that form very roughly a sphere. Due to geodesic geometry all the struts are of same length and all the triangles are of same size. All frequency domes can be traced back to this basic form, which can be classed as a 1v geodesic sphere. To increase the frequency general procedure is to subdivide a face into more triangles then project out the vertex of each triangle to an imaginary sphere encompassing the dome. Higher frequency domes just have more subdivisions. The Greek letter for Phase or frequency is Nu or Nv written N in Latin the lowercase (v) is used as the symbol for spatial frequency of a wave in physics and other fields, a measure of how often components of a structure repeat per unit of distance. Basically, the v in 3v stands for frequency.

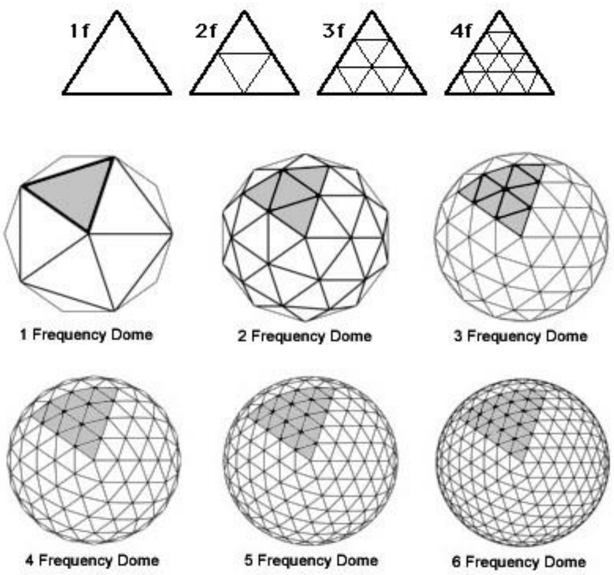

Fig. 1. Frequency of Geodesic dome

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. CADRE Geo is a design application for generating a wide variety of geodesic and spherical 3D (wire frame and surface models) for CAD or finite element analysis applications. Output are clean DXF files suitable for structural analysis applications. CADRE Geo also outputs detail design and construction information for domes such as hub and panel layouts, dimensions, dihedral angles, volume, surface area, etc. CADRE Geo can generate a complete set of hub or panel CAD drawings with a single command.

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.
- Aim of work 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 increases tonnage is increasing simultaneously for class1 method2 but member sizes reduces as frequency increases. For frequency 4 class1 method1 division is preferable where for frequency 8 class1 method2 division is preferable for obtaining optimum tonnage.

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Ashim Kanti Dey, Chinmoy Deka [6] stated For the same column and beam sizes it was observed that deformation in dome roof structure is 30% less than that in flat roof structure. For the same deformation, the sizes of columns were needed to be increased by 40% in the flat roof structure.A comparison was made between a flat roof structure and a dome roof structure on deformations imposed under lateral loading. STAAD Pro software was used to evaluate deformations, bending moments and shear forces under different combinations of loads.

A. Sujatha [7] concluded in her paper that byminimizing the defects, Geodesic domes give a better option as roof of larger span structures and are economical, as the materials required for manufacturing is less as compared to ordinary domes.Geodesic spheres are arrangements of polygons in great circles that approximate a true sphere. Of all structures built from linear elements, a Geodesic Dome has the highest ratio of enclosed volume to weight. This paper highlights the uses andapplications of geodesic domes along with their geometrical properties.

Astha Verma, Ashok K.Ahuja [8] paper describes the details of the experimental study carried out on the models of low-rise buildings with domical roofs. Wind pressure measurements are made on rigid models by placing them in an open circuit boundary layer wind tunnel. Conclusion in the study was wind pressure distribution on the surface of a domical roof is generally suction in nature. Maximum suction occurs near the peak of the dome which reduces both towards windward side and leeward side.

4. Methodology

In this dissertation work, an effort is made to study behavior 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 SS5is a comprehensive and integrated finite element analysis and design offering, including a state-of-the-art user interface, visualization capabilities, and international design codes. It is capable of analyzing any structure exposed to static loading, a dynamic response, wind, earthquake, and moving loads. STAAD-.Pro provides FEM analysis and design capabilities for any type of project including towers, culverts, plants, bridges, stadiums, and marine structures.

With an array of advanced analysis capabilities including linear static, response spectra, time history, cable, imperfection, pushover and non-linear analyses, STAAD-Pro provides your engineering team with a scalable solution that will meet the demands of your project every time. STAAD-Pro will eliminate the countless man-hours required to properly load your structure by automating the forces caused by wind, earthquakes, snow, or vehicles. In addition, no matter what material you are using or what country you are designing your structure for, STAAD Pro can easily accommodate your design and loading requirements, including U.S., European (including the Euro codes), Nordic, Indian, and Asian codes. Even special codes like AASHTO, ASCE 52, IBC, and the U.S. aluminum code can be catered.

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 for standard loads like dead load, live load, wind load and earthquake loads.
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^2but 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.

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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

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Vol 25, No. 2 (2024)
http://www.veterinaria.org
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In order to study time history analysis on the geodesic dome El-Centro seismic acceleration curve is used. The inputs of seismic acceleration are the basis for analysis of structural seismic analysis, different seismic exciting can yield different result, especially to the structure responses under seismic load.
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

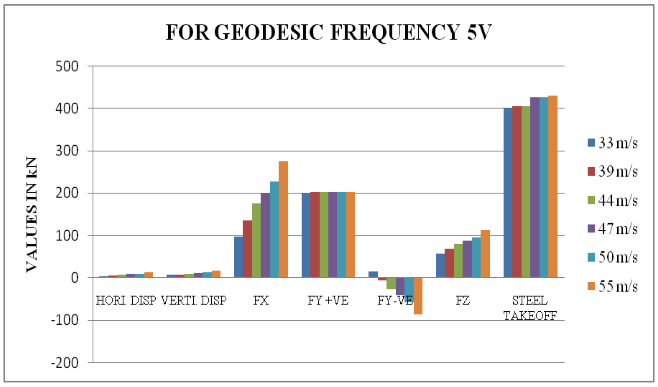

Figure. 2. Comparative statement of various parameters for geodesic frequency 5V

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 dead load, live 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

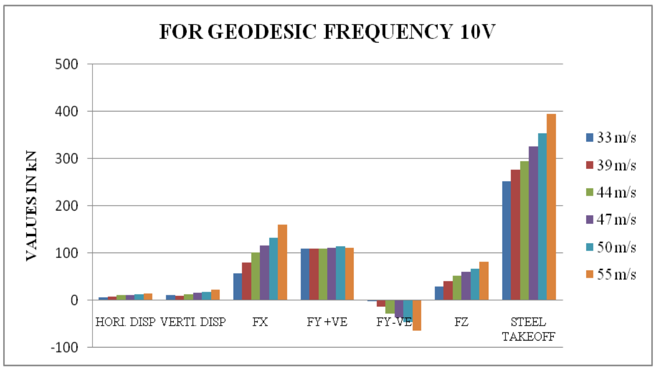

Figure. 3. Comparative statement of various parameters for geodesic frequency 10V

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 dead load, live 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.

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http://www.veterinaria.org
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5.1.3 For geodesic frequency 15V

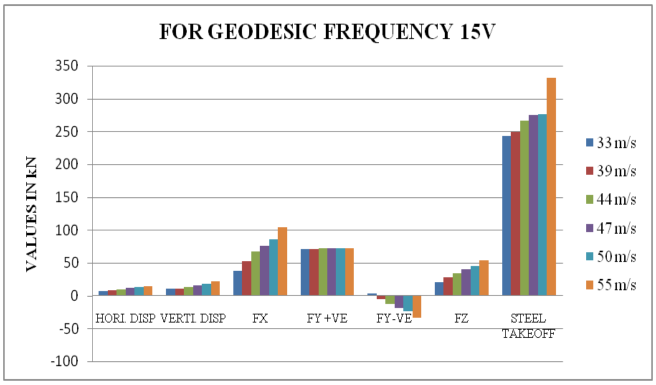

Figure. 5. Comparative statement of various parameters for geodesic frequency 15V

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 dead load, live 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

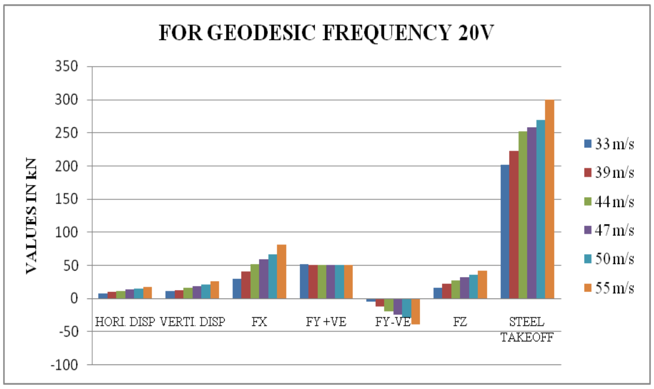

Figure. 4. Comparative statement of various parameters for geodesic frequency 20V

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

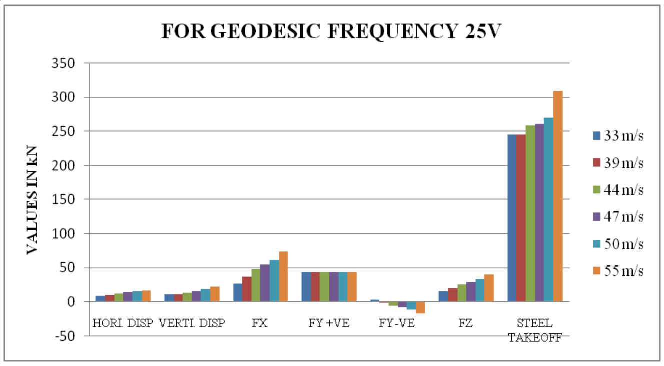

Figure. 6. Comparative statement of various parameters for geodesic frequency 25V

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

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Vol 25, No. 2 (2024)
http://www.veterinaria.org
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5.1.6 Horizontal displacement against wind speed

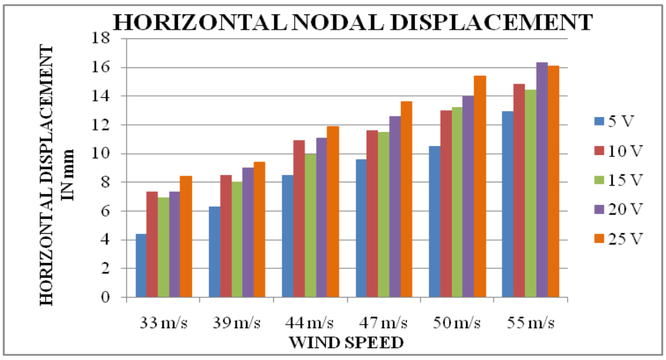

Figure. 7(a) Horizontal displacement v/s wind speed

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

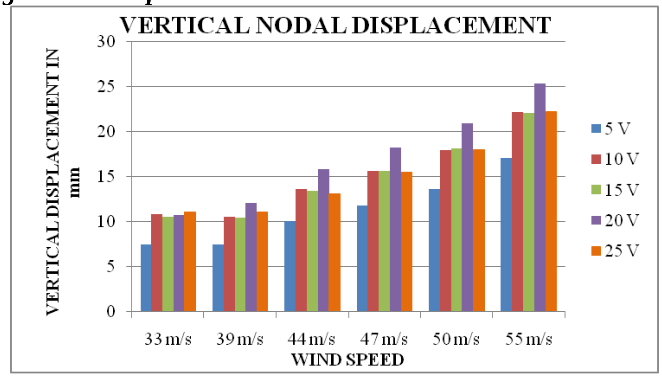

Figure. 7.(b) Vertical displacement v/s wind speed Maximum vertical displacement is observed for 20V.

5.1.8 Horizontal reaction against wind speed

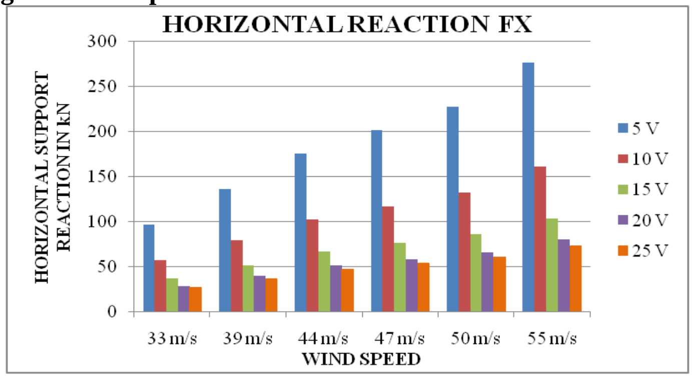

Figure. 7(c). Horizontal reaction v/s wind speed

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.

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http://www.veterinaria.org
Article Received: 3 September 2024 Revised: 4 October 2024 Accepted: 4 November 2024

5.1.9 Vertical downward reaction against wind speed

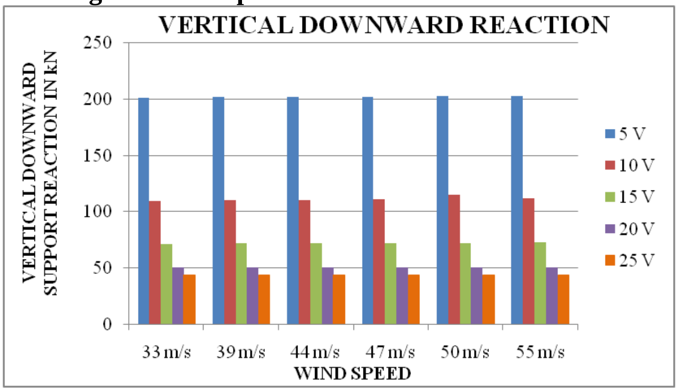

Figure.8 a) Vertical downward reaction v/s wind speed

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

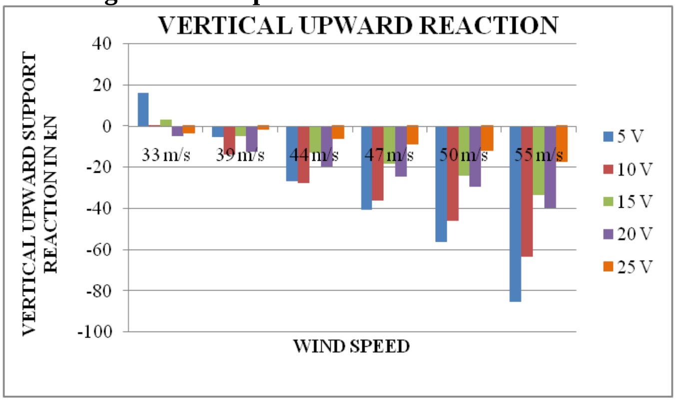

Figure. 8 b). Vertical upward reaction v/s wind speed

5.1.11 Steel takeoff against wind speed

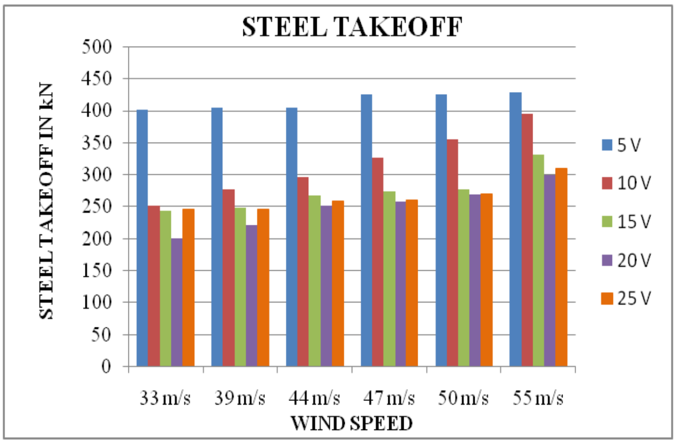

Figure. 9 Steel takeoff v/s wind speed

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.

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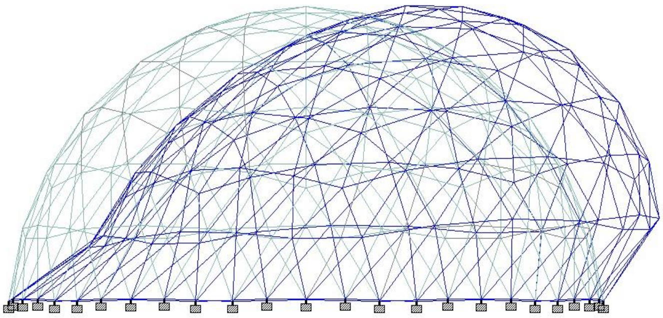


Fig. 10 a).Modal shape 1

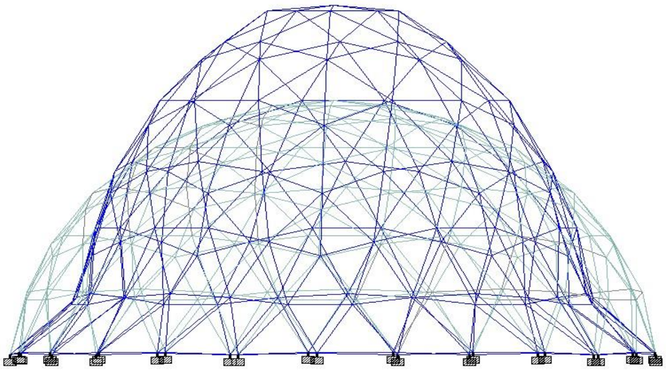
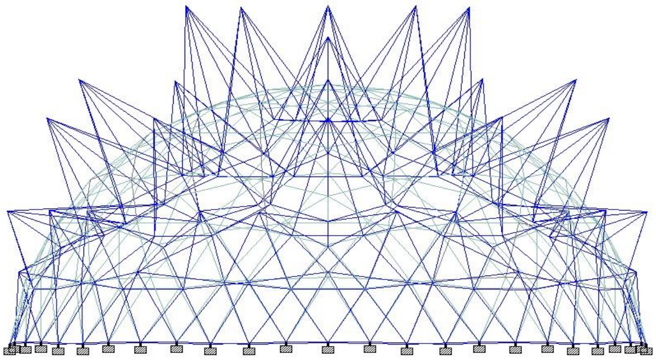


Fig. 10 b).Modal shape 2



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.
- Conclusion in the study was wind pressure distribution on the surface of a domical roof is generally suction in nature. Maximum suction occurs near the peak of the dome which reduces both towards windward side and leeward side.

REFERENCES

1. Hugh Kenner "Geodesic math and how to use it", University of California Press Berkeley, Los Angeles, London
2. M. P. Saka, “Optimum Geometry Design of Geodesic Dome Using Harmony Search algorithm”, Advances in structural engineering volume-10 No. 6 2007.
3. Eltayeb Elrayah Kralafalla, “Computer Added Processing Of Geodesic Structural Forms” A Thesis Submitted For The Degree Of Doctor Of Philosophy University Of Surrey Department Of Civil Engineering, August 1994
4. Marek Kubik,” Structural analysis of geodesic domes”, Durham university school of engineering, April 29,2009
5. Divyesh G. Mandali, Satyen D. Ramani "Comparative study for geodesic dome of class 1 subdivisions" JETIR (ISSN -2349-5162)
6. Ashim Kanti Dey, Chinmoy Deka "Effectiveness of Dome Structures in Reduction ofStresses under Transverse Loadings" Proc. of Int. Conf. on Advances in Civil Engineering 2012.
7. A. Sujatha "Geodesic dome and its applications" Indian Journal of Science and Technology Vol 7(3s), 5-6 March 2014
8. Astha Verma, Ashok K Ahuja "Wind Pressure Distribution on Domical Roofs" International Journal of Engineering and Applied Sciences (IJEAS)ISSN: 2394-3661, Volume-2, Issue-5, May 2015
9. IS800:2007. “General Construction in Steel- Code ofPractice” Bureau of Indian Standards.
10. IS875:1987. “Code of Practice for design load (otherthan earthquake) for Building and structures” Bureauof Indian Standards, (part-II) Imposed load.
11. IS875:1987. “Code of Practice for design load (otherthan earthquake) for Building and structures” Bureauof Indian Standards, (part-III) Wind load.
12. Vesmawala G. R., Dr. J. A. Desai, Dr. H. S. Patil, “Parametric study of lamella domes for optimum shape design”.(2003)
13. Shah, B J; Dr. H. S. Patil, “Discrete Optimization of Double layer grid supported on periphery using AI Technique”. ”.(2003)
14. H. Nooshin and P. Disney, “Elements of Formian” Space Structures Research Centre, Department of Civil Engineering, University of Surrey, Guildford, Surrey GU2 5XH, U.K. (2005)
15. L. J. Li, Z. H. Xie, Y. C. Guo, F. Liu, “Structural optimization and dynamic analysis for double-layer spherical reticulated shell structures”. Journal of Constructional Steel Research vol. no 62,(2006), page no. 943-949.
16. M. M. Alinia, S. Kashizadesh, “Effects of support positioning on thermal behavior of double –layer space truss domes.” Journal of Construction Steel Research vol. no. 63(2007) page no. 375-382.
17. Bhavikatti S. S., Itti S. V., Lakshmy T. K.,“Optimum design of single braced 3D-poly steel domes with central opening”.
18. El-Sheikh, A.I., and El-Bakry. H., “Experimental Study of Behavior of New Space Frame Truss System” Journal of Structural Engineering, ASCE Vol.22, No.8, pp845-853.(2007)
19. IS806:1986. “Code of Practice for use of Steel Tubes in General Building Construction” Bureau of Indian Standards.
20. M. P. Saka, “Optimum Geometry Design of Geodesic Dome Using Harmony Search algorithm”, Advances in structural engineering volume-10 No. 6 2007.