Dynamic Analysis of Reticulated Roof Shell Structures

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Abstract**-** Large span roof shell structures have an inherent tendency to be unstable under dynamic loads. However the dynamic behavior of these is not well documented. An in depth analysis is required to understand its bending, vibration, axial, buckling etc. However, the present investigation focused on free vibration behavior. In this research study, models of spherical single layer reticulated roof shell structures were established in Finite Element software CSi SAP2000. Based on free vibration frequency the dynamic behavior of these structures was investigated in this research paper. Parametric analysis was conducted and the influence of these parameters on the structure was observed in terms of free vibration frequency. Several parameters were considered for the analysis such as, different span diameters, different roof loading and rise to span ratios. Based on the analysis, the optimum rise to span ratio was found out.

Index Terms**-** Free vibration analysis, Parametric analysis, Reticulated shell structure, Simulation Model

I. INTRODUCTION

In recent years single later reticulated shell structures are being favored to cover large column free areas such as roofs of large auditorium halls, stadiums, etc. These structures need to be lightweight without sacrificing strength. Reticulated structures provide a very high strength to weight ratio and become the obvious choice. Reticulated shells are amongst the most effective structures available, particularly as roof assemblies. However, the difficulty of their fabrication, design, analysis and some other reasons such as air-conditioning limit their use.

With recent developments in the economic and social sectors, the size of construction projects is continuously growing, and this has led to a wide use of large span roof structures in actual engineering. Due to the fact that reticulated structures are of elegant, unique style, and their low weight and high strength, they have been frequently used in large-span roofs. These structures are mainly employed in public buildings like stadiums, airports, music theatres, exhibition halls, railway stations, wedding halls and auditorium halls. Due to their use in public facilities continuously increasing, the dynamic behavior of a reticulated shell under earthquake loading is hugely significant because it affects the security of a building and also has a enormous influence on the social and economic progress and the safety of general public. Consequently, this has led to an increase in the effort put in by researchers around the world to study the issues, like the dynamic behavior and collapse mechanism of these light weight structures exposed to earthquake loading. Existing studies mostly focus on the response of reticulated structures under static loading.

These latticed reticulated structures exhibit different behavior from the conventional structures such as steel framed and reinforced concrete framed structures in that they have closely spaced basic frequencies and substantial higher modal effects. There are no particular codes of design for long span spatial structures under dynamic loading. Free vibration analysis to understand these structures' dynamic behavior such as its variation with numerous common parameters is the first step in creating a code of design for long span shell structures. This will also help in finding and identifying the most significant modes of vibration for modal combinations.

II. EXAMINATION OF THE VARIATION OF NATURAL FREQUENCY BY PARAMETRIC ANALYSIS

a) Setup of model:

In this research paper, the widely used Keiwitt single-layer spherical reticulated shell as presented in figure 1 is used as a model in numerical analysis.

- Different ratios of rise to span and span diameters considered:

Six ratios of rise to span and three spans were considered while bearing in mind the actual engineering practices for the numerical analysis of reticulated shells as presented in Table 1. The pattern divisions of the shell members were considered such that the length of members of shells should be same (from 3 to 5 m) for shells with varying spans and ratios of rise to span so as to assess analyze the complete behavior of a spherical single layer reticulated shells. Consequently, for shells of spans of 30m, 40m and 50m, the numbers of circular rings were taken as 5, 6 and 7, respectively.

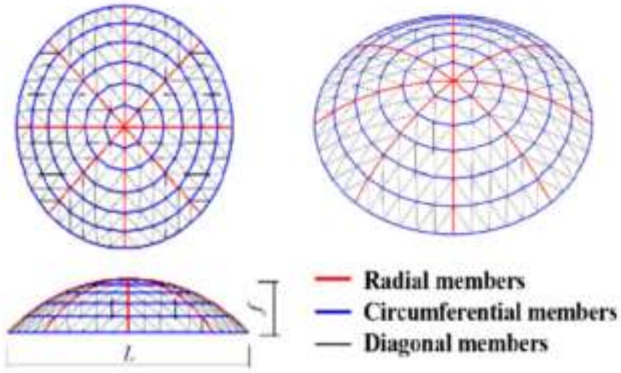

Figure 1: Keiwitt single layer reticulated structure

- Roof loading considered:

While considering the practical engineering solutions, roof loadings for parametric analysis of: a) 0.6 kN/m2 , b) 1.2 kN/m2, and c) 1.8 kN/m2 were used in establishing finite element models in the investigation. The load was uniformly distributed over the shell on joints.

- Sections of members:

Each shell model comprises of two different cross-sections, as can be understood from Figure 1, where red and blue coloured lines designate the larger section of ISNB110M and the finer lines designate smaller section of ISNB90M.

Dimensions of member sections are as follows:
1] ISNB110M: Radial and Circumferential members
Outer Diameter =127mm.
Thickness =4.8mm.
2] ISNB100M: Diagonal members
Outer Diameter =114.3mm.
Thickness =4.5mm.

- Material used was Fe250.

Table 1: Summary of parameters

Parameter	Details of parameter
Span (m)	30, 40 ,50
Roof load (kN/m^2)	0.6, 1.2, 1.8
Rise-span ratio f/L	1/3, 1/4, 1/5, 1/6, 1/7, 1/8
Material	Fe250
Support conditions	Hinged on peripheral nodes

b) Mode shapes

From the analysis it was observed that the first mode of reticulated shells with hinged support is horizontally vibrating un-symmetric mode shape, as can be seen in Figure 2. Third mode is symmetric vertically vibrating mode shape as shown in Figure 3.

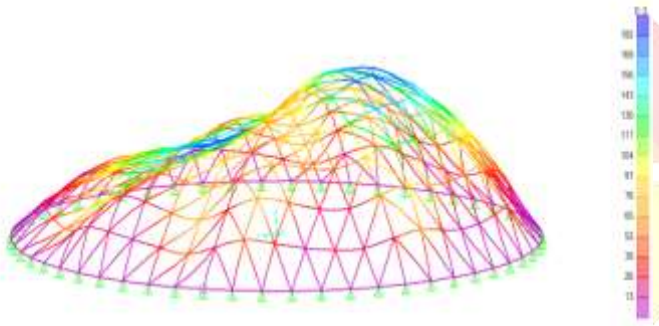

Figure 2: 1st mode shape of spherical reticulated shells

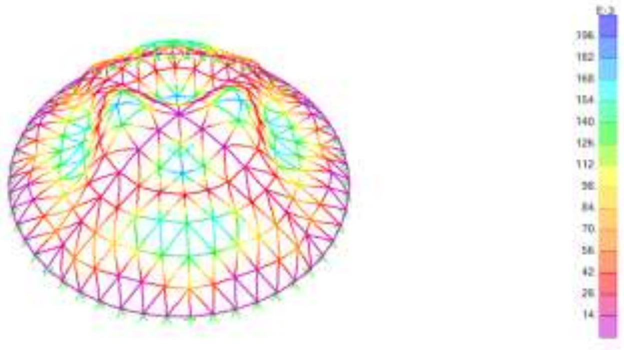

Figure 3: 3rd mode shape of spherical reticulated shells

c) Investigation of natural frequencies

There is an evident skip which is found in the most important section of the basic frequencies, as showed in Figure 4. To study the cause of the skip, the mode shapes of vibration near the critical section, which are the 1st, 2nd, 3rd modes have to be observed. From the mode shape, the first and second order vibrations are the unsymmetric horizontal vibrations of the entire structure while the third-order vibrational mode is the symmetrical vertical vibration of the complete structure. Therefore, it can be determined that this abrupt change in mode of vibration has caused the skip in natural frequencies. From the analysis four stages of natural frequencies of vibrations of the reticulated shells were also observed:

a)The first and second mode order; b)Third–168th mode order; c) 169th–174th mode order; d) 175th–400th mode order.

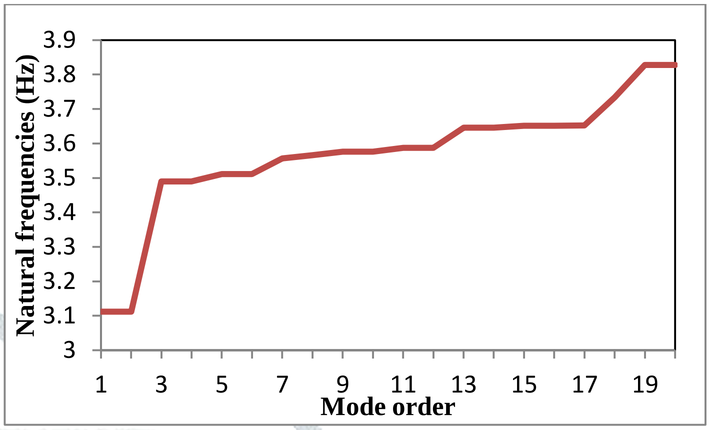

Figure 4: Variation of natural frequencies

III. RESULTS OF THE PARAMETRIC ANALYSIS

Figures 5, 6 and 7 present the graphs showing the variations in natural modal frequency of the hinge supported reticulated roof shells due to various parameters like spans(L), rise to span ratio(f/L) and different roof loading. The natural modal frequencies of these shells were found to increase with increasing rise-span ratio, while they decrease with increase in span and the roof load applied on the structure.

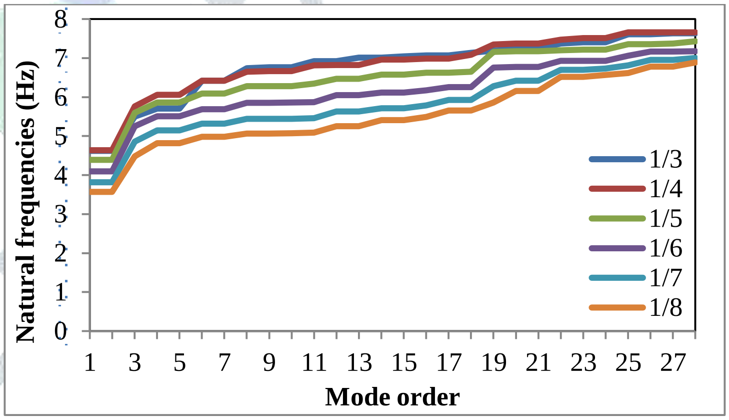

Figure 5: Variation of natural frequency with ratio of rise to span (f/L)

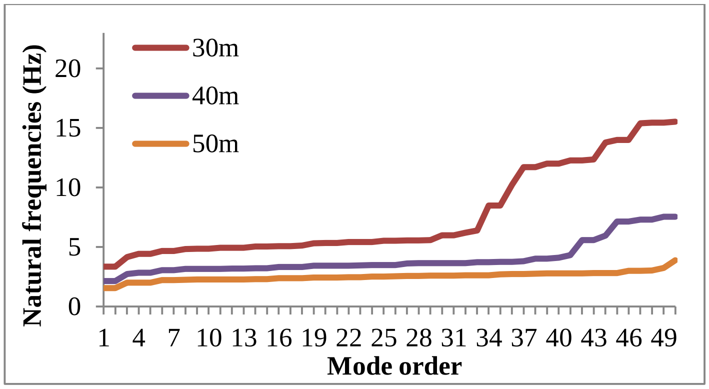

Figure 6: Variation of natural frequency with span

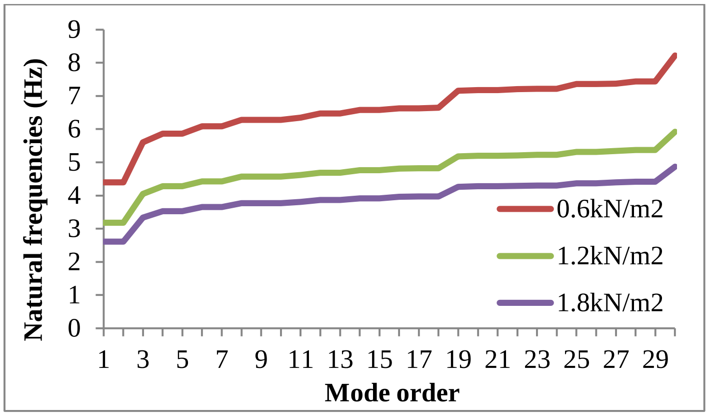

Figure 7: Variation of natural frequency with roof loading

It was also observed while designing the single layer reticulated structures for different rise to span ratios, the utilization ratios for the same cross sections of members decreased with the decrease in f/L ratio from 1/3 to 1/5. Then the utilization ratio of members increased with further decrease in f/L ratio from 1/5 to 1/8. Also the number of members having a higher utilization ratio decreased from an f/L of 1/3 to 1/5, while it increased from 1/5 to 1/8, in the same manner. Thus indicating that single layer reticulated shells reached an optimum level of design at a rise to span ratio of 1/5. This is further supported by another observation that the reactions at supports also reached an optimum at f/L of 1/5 as observed from figures 8 and 9.

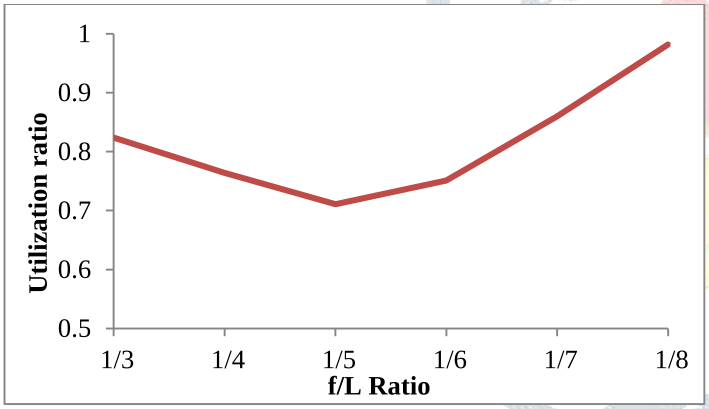

Figure 8: Variation of utilization ratio of critical members with f/L ratio

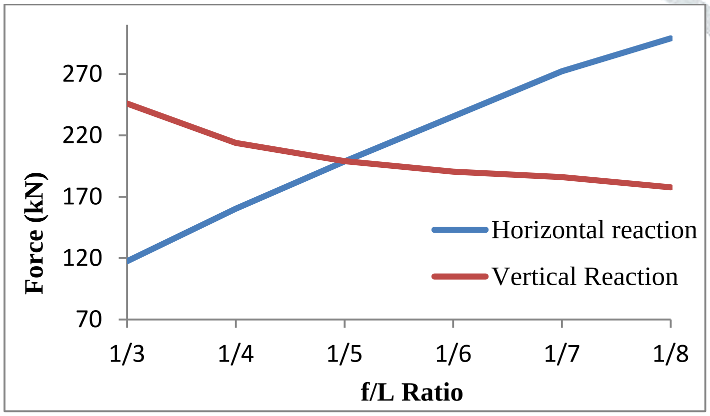

Figure 9: Variation of reactions with f/L ratio

As seen from figure 9, it was observed that horizontal reactions increased with decreasing rise-span ratio and the vertical reactions increased with decreasing rise-span ratio from 1/3 to 1/8. This led to an optimum at an f/L of 1/5.

IV. CONCLUSION AND FURURE SCOPE

The finite element models of reticulated shells with hinged supports were established in CSi SAP2000. The natural vibration frequencies of these shell models were explored thoroughly. The occurrences given below were observed:

- The natural vibration frequencies of spherical reticulated shells increase with increase in f/L ratio and decrease with an increase in span and roof loading on the shell. This phenomenon can be attributed to the structure being heavier for larger spans and roof loads.
- Four stages of natural frequencies were observed.
- With lower rise-span ratios even though the load on structure reduced, the height of the structure also decreased thus causing a decrease of the base frequency of the structure.
- Vertical support reaction decreased with decrease in the rise to span ratio and the horizontal reaction (radially inward) increased. The reactions reached an optimum value for a f/L ratio of 1/5.
- The rise to span ratio of 1/5(0.2) was observed to be optimum in terms of reactions of supports and the utilisation of member sections. Thus with the use of a rise to span ratio of 1/5, smaller sections can be employed compared to the member sections used in shells of other f/L ratios.

Additional studies are still needed to be carried out to explore the dynamic behavior of various types of reticulated shells, like, elliptical reticulated shell, cylindrical reticulated shell parabolic latticed shells etc. The effect of substructure on the variation of natural frequencies should also be explored also the effect of the unsymmetrical loading should be studied. Likewise impact of initial geometric inadequacies on the natural modal frequencies of roof shells remains to be studied.

V. REFERENCES

1. Huihuan Maa, Zhiwei Shanb, Feng Fan, “Dynamic behaviour and seismic design method of a single-layer reticulated shell with semi-rigid joints”, Thin-Walled Structures 119 (2017) 544–557.
2. Bo Chen, Ke Wang, Jianqiu Chao, Qingshan Yang, “Equivalent Static Wind Loads on Single-Layer Cylindrical Steel Shells” Journal of Structural. Eng., (2018), 144(7): 04018077.
3. P.Srinivasa Rao, Alapati Prasada Rao, “Behavior of cylindrical shells subjected to support settlements” Journal of Structural. Eng. (1988).114:931-941.
4. F.Resinger, R.Greiner’ “Buckling of wind loaded cylindrical shells -application to unstiffened and ring-stiffened tank” Proceedings of a state-of-the-Art Colloqium @Springer J Berlin Heidelberg New York (1982).
5. Jie Zhonga,, Junping Zhanga, Xudong Zhib,c, Feng Fa, “Identification of dominant modes of single-layer reticulated shells under seismic excitations” Thin-Walled Structures 127 (2018) 676–687.
6. Xiaotong Ma1, Xiuli Wang, Chao Bao Hua Lu, Wenwei Yang, “Dynamic Response Analysis and Model Test Research on K6 Single-Layer Spherical Reticulated Shells Subjected to Impact Load” International Journal of Steel Structures, Springer (2018).

7. Tijo K Robinson, A.S. Nisha,"Dynamic characteristics of large reinforced concrete ellipsoidal domes" International Journal of Scientific & Engineering Research, Volume 7, Issue 10,(2016).
8. Wenfeng Dua, Qi Liua, Zhiyong Zhoua, Nasim Uddin, "Experimental investigation of innovative composite folded thin cylindrical concrete shell structures" Thin-Walled Structures 137 (2019) 224–230.
9. Peng Huang, Xuan-yi Zhou, Ming Gu, "Experimental study of wind loads on cylindrical reticulated shells" Appl. Math. Mech. -Engl. Ed., 34(3), 281–296 (2013).