

# Analysis of Single Layer Reticulated Roof Shell Structure

Sisna Siraj<sup>1</sup> Hari Priya. S<sup>2</sup>

<sup>1</sup>M.Tech Student <sup>2</sup>Assistant Professor

<sup>1,2</sup>Department of Civil Engineering

<sup>1,2</sup>Rajadhani Institute of Engineering and Technology, Nagaroor, Kerala, India

**Abstract**— Single-layer reticulated structures are extensively used because of their potential to cover wide areas with different form shapes, mild weight and without intermediate support. Large span roof shell structures have a structural tendency to be unsteady during the effect of static loading as well as under dynamic loading. To understand the behaviour of shell structure analysis, need to be carried out. However, the analysis was required to be done for understanding its bending, vibration, axial, buckling etc. In this thesis paper, models of spherical single layer reticulated shell structures were established in Finite Element software FEAST<sup>SMT</sup>. Based on static analysis maximum response of the vertical displacement of the structure is investigated as well as under free vibration frequency, dynamic behaviour of the structure was also investigated in this research paper. Parametric analysis was conducted and the influence of these parameters on the structure were observed in terms of free vibration frequency. Several parameters were considered for the analysis such as, different span diameters and rise to span ratios. Based on the analysis, the optimum rise to span ratio was found out.

**Keywords:** Free vibration analysis, Parametric analysis, Reticulated shell structure, Simulation Model, Vertical deflection, FEAST<sup>SMT</sup>

## I. INTRODUCTION

Over the last few decades, spatial structures were widely used in the construction of many large structures such as aircraft hangars, exhibition halls, stadiums, airport terminals, gymnasiums, bridge systems, platform canopies, shopping malls and atriums. Spatial structures represent the ultimate in structural system aesthetics and engineering efficiency, with the ability to span very large spans behind its elegance and simplicity. The main construction of the mesh dome is lightweight, very quick to install in just a few hours, not months or years.

Due to their ability to cover large areas with a variety of shapes, as well as their light weight and lack of intermediate support, single-layer reticulated structures have become popular in recent years. Single-layer structures are appealing because they are both light and beautiful. This has led to an increase in the effort put in by researchers around the world to study the issues, like the dynamic behaviour and collapse mechanism of these lightweight structure. Existing studies mostly focus on the response of reticulated structures under static loading. There is no evidence of problems with these structures, and there is no damage to the dome from winds or typhoons. These are well designed.

A mesh dome is a space-like structure that looks like a part of a sphere. This device consists of a triangular grid that ultimately forms a spherical surface. The greater the number of triangles, the closer to the shape of a spherical dome. The design of the Kiewit dome consists of a series of subdivided triangles along the circumferential direction, sharing a

common vertex with the dome crown. (I) Reticulated dome structure, K6 (II), Reticulated dome structure K8, (III) Reticulated dome structure K10. Single layer reticulated shell structures are analysed using the finite element program FEAST<sup>SMT</sup>. The purpose of this thesis is to study the effect of boundary condition on the stress distribution in shell structures based on certain parameters like rise span ratio, and different diameters are to provide a summary of analysis methods. In order to accomplish this objective, this paper will 1) discuss the general properties of shell structures, 2) introduce methods of analysis, 3) analysis done to determine the relationship between certain variables like vertical deflection under the static loading and frequency mode order under free vibration analysis. A static structural analysis calculates the effect of steady (or static) loading conditions on a structure, while ignoring inertia and damping effects. Static elastic- plastic analysis is done to find its varying deflection under varying rise span ratios. Free vibration analysis to understand these structures dynamic behaviour such as its variation with numerous common parameters will help in finding and identifying the most significant modes of vibration for model combinations.

## II. METHODOLOGY

- 1) The coordinate values are obtained from CAD system by creating segment of a model using specified geometric values.
- 2) Creating a model in FEAST by using the coordinated values obtained from the CAD system.
- 3) Analysis of shell structure in FEAST
- 4) Data Comparison
- 5) Result and Discussion

## III. MODEL DESCRIPTION

In this paper, the members of K6 pattern single-layer reticulated domes are hollow steel tubes. The material of rods is Q235 steel and span of K6 pattern single-layer reticulated domes are 30meter,40 meter and 50 meters. The section size of slant rods is  $\phi 114\text{mm}$  and the section size of other rods is  $\phi 127\text{mm}$ . The rise-span ratio changes in range from 1/3 to 1/7. It is assumed that the connection between the members is rigid, and the bearing is fixed support. The elastic modulus of the material is 210GPa, and the Poisson's ratio is 0.3. The density of steel is 7850Kg/m<sup>3</sup>. The segmentation frequency of K6 pattern single-layer reticulated domes is six. The analysis model of structure is shown in "Fig.1". In this paper, the structural dynamic free vibration analysis and static elastic-plastic analysis were carried out by using FEAST<sup>SMT</sup> finite element analysis software.

Parameter	Details of parameter
Span (m)	30, 40, 50
Rise-span ratio f/L	1/3, 1/4, 1/5, 1/6, 1/7
Material	Fe250

Support conditions	Bottom nodes arrested
--------------------	-----------------------

Table 1: Summary of Parameters

Five ratios of rise to span and three spans were considered. 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 analyse the complete behaviour of a spherical single layer reticulated shells. Consequently, for shells of spans of 30m, 40m and 50mm.

#### IV. MODELS CONSIDERED FOR ANALYSIS

Following 5 models are analysed by static elastic-plastic analysis and free vibration analysis for shell span of 30m for various rise span ratios using FEASTSMT software.

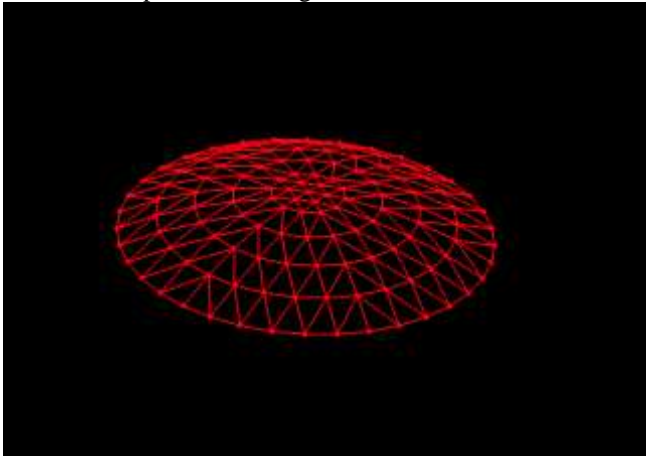


Fig. 2: Model of a single-layer reticulated shell of rise span ratio1 /7

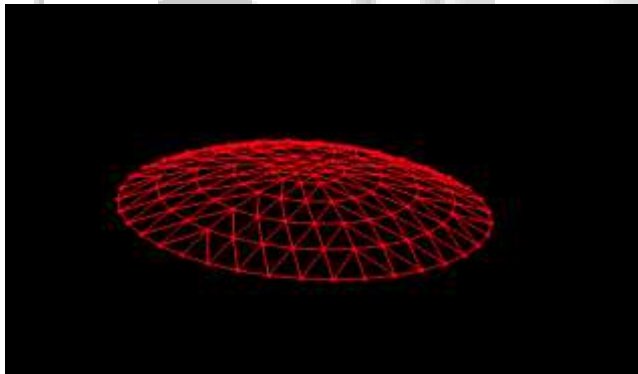


Fig. 3: Model of a single-layer reticulated shell of rise span ratio1 /6

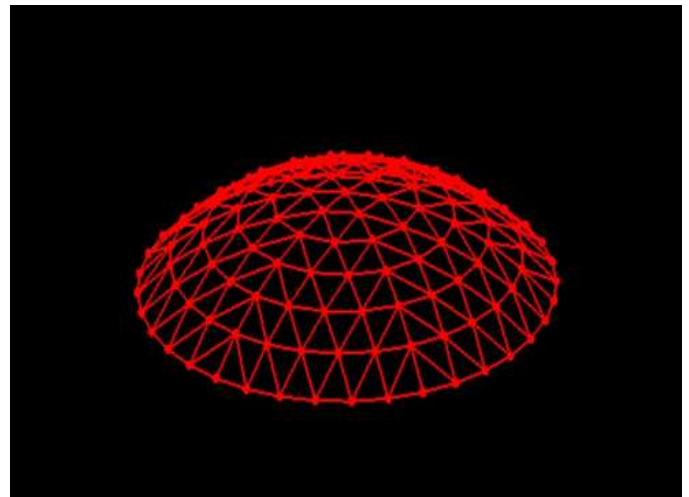


Fig. 4: Model of a single-layer reticulated shell of rise span ratio1 /5

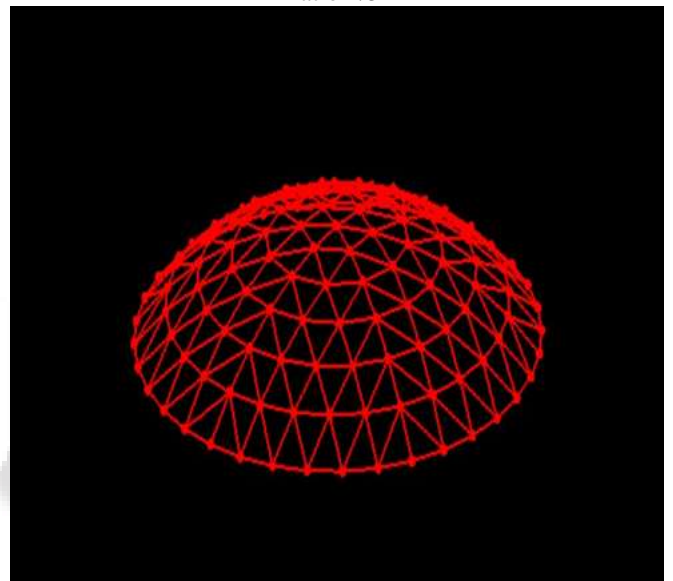


Fig. 5: Model of a single-layer reticulated shell of rise span ratio1 /4.

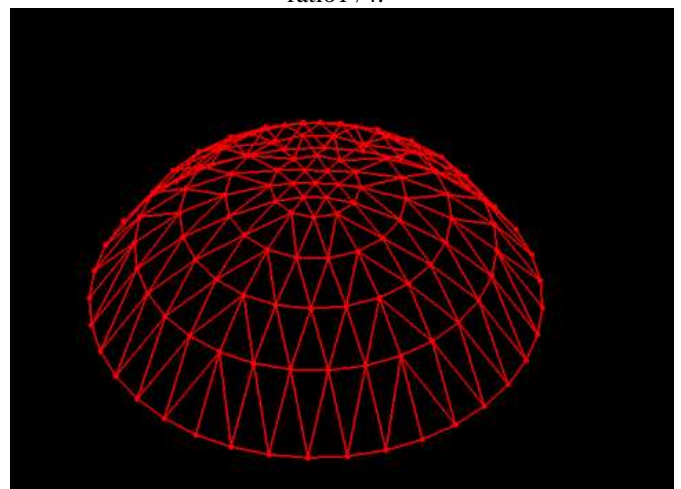


Fig. 6: Model of a single-layer reticulated shell of rise span ratio1 /3.

## V. RESULTS OF THE PARAMETRIC ANALYSIS

The results obtained from the FEASTSMT analysis of reticulated shell structure for static analysis and free vibration analysis results are tabulated and discussed for the parameters of shell diameter and its corresponding rise span ratio.

### A. Static analysis of single layer reticulated shell structure for varying rise span ratios

A static structural analysis calculates the effect of steady (or static) loading conditions on a structure, while ignoring inertia and damping effects. Static elastic-plastic analysis is done to find its varying deflection under varying rise span ratios. From this analysis results it can be concluded that the static analysis method indicate that the vertical displacement response decreases with the increase of the rise-span ratio in condition of the same member section as shown in "Fig.7".

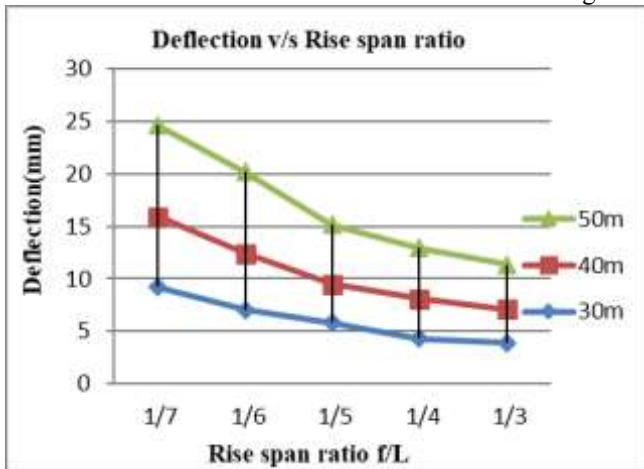


Fig. 7: Variation of deflection with ratio of rise to span (f/L) at different span.

### B. Free Vibration analysis is carried out for a single-layer reticulated shell

Based on free vibration frequency the dynamic behaviour 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 and rise to span ratios. Free vibration analysis also gives different mode shapes at different modes corresponding to its varying natural frequency (Hz) value. Graph can be plotted between mode order and natural frequency. Free vibration analysis to understand these structures dynamic behaviour such as its variation with numerous common parameters will also help in finding and identifying the most significant modes of vibration for model combinations. The natural model frequencies of these shells were found to increase with increasing rise-span ratio. "Fig.8 and 9" present the graphs showing the variations in natural model frequency of the fixed supported reticulated roof shells due to various parameters like spans(L) and rise to span ratio(f/L) up to mode 1 to 20. The natural model frequencies of these shells were found to increase with increasing rise-span ratio, while they decrease with increase in span.

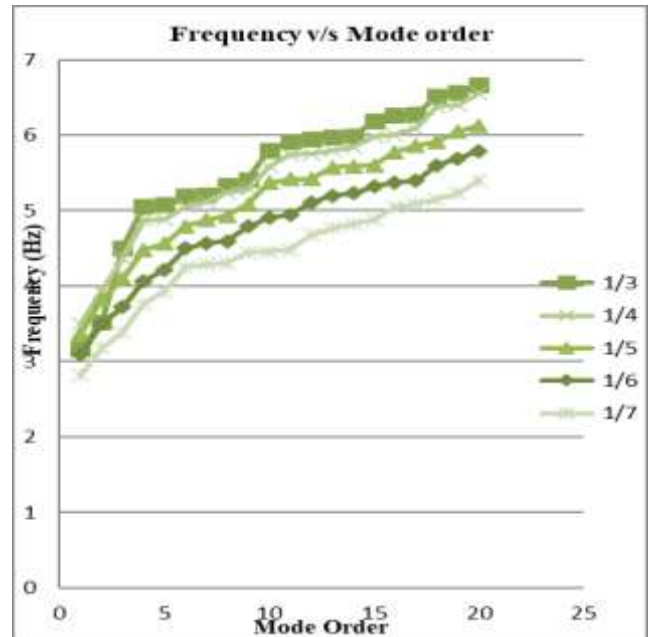


Fig. 8: Variation of natural frequency with ratio of rise to span (f/L) at 40m span

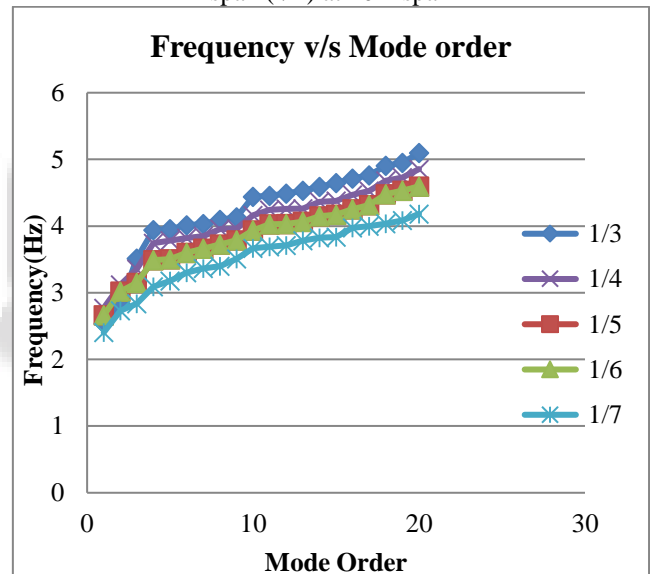


Fig. 9: Variation of natural frequency with ratio of rise to span (f/L) at 50m span

### C. Mode shapes:

From the free vibration analysis, it was observed that the first mode of reticulated shells with fixed support is horizontally vibrating un-symmetric mode shape, as can be seen in "Fig.10". Third mode is symmetric vertically vibrating mode shape as shown in "Fig.11".

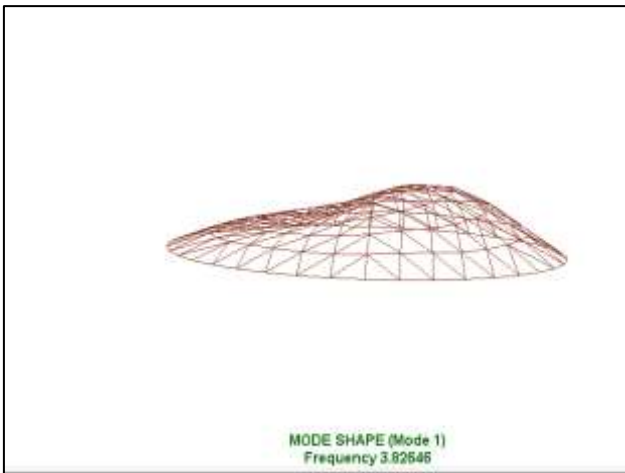


Fig. 10: 1st mode shape of spherical reticulated shells

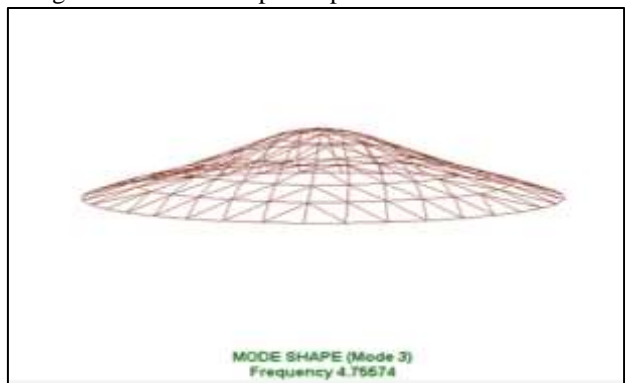


Fig. 11: 3rd mode shape of spherical reticulated shells

While designing single-layer mesh structures with different rise-to-span ratios, it was also observed that as the  $f/L$  ratio decreased from  $1/3$  to  $1/5$ , the utilization of the same cross section of the element decreased. Then, as the  $f/L$  ratio further decreased from  $1/5$  to  $1/7$ , the element usage increased. In addition, the number of members with high utilization rate decreased from  $1/3$  to  $1/5$  in  $f/L$ , and also increased from  $1/5$  to  $1/7$ . This shows that the single layer mesh shell achieved the optimum design level with a  $1/5$  rise-to-span ratio. This is further supported by another observation that the reaction on the support also reached optimal at  $1/5 f/L$ , as shown in “Fig.12”.

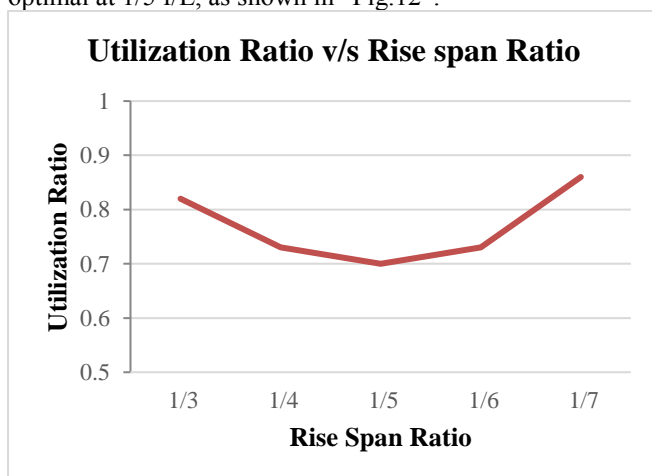


Fig. 12: Variation of utilization ratio of critical members with  $f/L$  ratio

## VI. CONCLUSIONS AND FUTURE SCOPE

The finite element models of reticulated shells with fixed supports were established in FEAST<sup>SMT</sup>. The natural vibration frequencies of these shell models were explored thoroughly. The occurrences given below were observed:

From these analysis results, it can be concluded that the static analysis method shows that the vertical displacement response decreases as the rising span ratio increases under the same beam cross-section conditions.

The natural frequency of a spherical mesh shell increases with increasing  $f/L$  ratio and decreases with increasing shell span. This phenomenon can be due to the heavier structure over longer spans.

Lower rise-span ratios reduce the effect of load on the structure, but also reduce the height of the structure and lower the fundamental frequency of the structure.

The rise to span ratio of  $1/5(0.2)$  was observed to be optimum in terms of reactions of supports and the utilization of member sections. Therefore, the use of a rise to span ratio of  $1/5$ , smaller sections can be designed as optimum.

Additional research is required to investigate the dynamic behaviour of different types of mesh shells, including Examples: elliptical mesh shells, cylindrical mesh shells, parabolic grid shells, etc. The effect of the substructure on natural frequency fluctuations should also be investigated. The effects of unbalanced loads should also be investigated.

## REFERENCES

- [1] Liang Zheng, “Finite Element Analysis of a Single-Layer Reticulated Dome under Impact Loading,” *Advanced Materials Research*, Volume 163-167, pp. 327-331, (2011)
- [2] Liang Zheng, “Finite Element Analysis of a Single-Layer Reticulated Dome and the suspendome under Impact Loading,” *Advanced Materials Research*, Volume 594-597, pp. 844-848, (2012)
- [3] Jinfeng CAO “Overall Stability Analysis of Dome Steel Structure on Dome Roof in Large Tanks Based on FEM (2012),” *Advanced Materials Research*, Volume 446-449, pp.121-125, (2012)
- [4] Xiaotong Ma, “Dynamic Response Analysis and Model Test Research on K6 Single-Layer Spherical Reticulated Shells Subjected to Impact Load,” *International Journal of Steel Structures*, ISSN 1598-2351, (2019)
- [5] ChiragD.Magar, “Dynamic Analysis of Reticulated Roof Shell Structures,” *Journal of Emerging Technologies and Innovative Research*, Volume 7, Issue 9, (2020)
- [6] L.J.Li., “Structural optimization and dynamic analysis for double-layer spherical reticulated shell structures,” *Journal of Constructional Steel Research*, pp. 943–949, (2006)
- [7] Xiuli Wang, “Overall Dynamic Analysis of K-reticulated Shell Structure with BRB in Severe Earthquakes,” *Advanced Materials Research*, Volume,535-537,pp.2017-2020, (2012)
- [8] M. Zeinoddini, “The Stability Study of an Innovative Steel Dome,” *International Journal of Space Structures*, (2004)
- [9] Li Hong-mei, “Dynamic Collapse Analysis of Reticulated Shell Structures with Substructures,”

*International Conference on Structural, Mechanical and Materials Engineering*, (2015)

- [10] Sheng-Fu GAO, "Seismic response analysis of K8 pattern single-layer reticulated domes under vertical rare earthquake," *Procedia Engineering*, Volume 210, pp. 417–424, (2017)
- [11] Zhi-Wei Yu, "Effect of substructures upon failure behavior of steel reticulated domes subjected to the severe earthquake," *Thin-Walled Structures*, Volume 49, pp. 1160–1170, (2011)
- [12] Huijuan Liu, "A Spiral Single-Layer Reticulated Shell Structure: Imperfection and Damage Tolerance Analysis and Stability Capacity Formulation for Conceptual Design," Volume 11, pp. 280, (2021)
- [13] Haitao Zhou, "Simulation Method on Progressive Collapse of Shell Model under Severe Earthquake," *Advanced Materials Research*, Volume 163-167, pp. 544-549, (2011)
- [14] Li Lin, "Dynamic Response of a Single-Layer Reticulated Dome during Aircraft Impact Based on S-J Modeling Method," *Shock and Vibration*, Article ID 9056810, 12 pages, (2019)
- [15] Chang Wu, "Dynamic Response of Reticulated Domes under the Impact," *Applied Mechanics and Materials*, Volume 638-640, pp. 58-61, (2014)
- [16] Jun Xu, "Probabilistic seismic analysis of single-layer reticulated shell structures controlled by viscoelastic dampers with an effective placement," *Engineering Structures*, Volume 222, (2020)
- [17] Yang Yang, "Seismic Performance of Double Layer Spherical Reticulated Shell with Replaceable Bar-Type Dampers," *International Journal of Space Structures*, Volume 26, pp.1, (2011)