COMPARATIVE SEISMIC ANALYSIS OF K8 KIWIETT RETICULATED DOME STRUCTURE, K8-Ribbed HYBRID AND DOME STRUCTURE WITH OPENING

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Abstract - *Reticulated dome structures are the preferred choice for large spanned structures. The analysis and design of these dome structures differ significantly from low-rise dome structures due to lateral forces caused by wind and earthquakes. The dome structure system features rigid connections between members and fixed hinge bearings. This study focuses on the seismic behavior of dome structure patterns, specifically Kiewitt-8, Kiewitt-Ribbed Hybrid(K8), and Dome with opening, to identify structural efficiency. These domes resist both gravity and lateral loads through axial action of the members. The span length of 60m with various h/s ration 0.20, 0.25,0.30, 0.35 are considered for the study and design purposes. Earthquake parameters are based on IS 1893-2016. The analysis of dome structure systems will be carried out using the Sap2000 analysis and design software. This research examines a set of structures using reticulated Kiewitt dome structures with three different patterns for varying rise-to-span ratios. The seismic behavior of these different reticulated Kiewitt dome models is compared based on vertical rare earthquake loads in terms of Response, time period, base reaction, P-delta effect, plastic hinge patterns, and failure mechanisms of the dome structure.*

Key Words: **Reticulated dome, Kiewitt dome structure, rise to span ratio, p-delta analysis, plastic hinge.**

1.INTRODUCTION

Spatial structures have been widely utilized in the construction of various large span structures over the last few decades, including aircraft hangars, exhibition halls, stadia, airport terminals, gymnasia, bridge systems, railway platform shelters, shopping malls, and atriums. These structures are known for their aesthetic appeal and engineering efficiency, enabling them to cover extensive spans. The installation of a reticulated dome's main structure can be completed rapidly in just a few hours, as opposed to the months or years required for heavier structures. There is no evidence to suggest that well-designed domes have experienced any issues or damage from wind or typhoons. A reticulated dome is a type of spatial structure that resembles a section of a sphere, constructed from a grid of triangles that form a spherical surface. The more triangles used, the closer the dome resembles a perfect sphere. The pattern of a Kiewitt dome consists of subdivided triangles along the circumferential direction, all meeting at a common vertex at the dome's crown. Here's the pattern involves K8 Kiewitt, K8 Kiewitt-Ribbed Hybrid and K8 Kiewit dome with opening.

The nonlinear dynamic response history analyses were conducted on a reticulated dome at various seismic record magnitudes to calculate collapse loads. Ming Zhang (2019) compared different types of reticulated domes in terms of material efficiency by analyzing weight, stress, and buckling constraints. Parvathy K.T (2020) determined the maximum lateral force under seismic loading through analysis, while F. Fan (2018) conducted finite element analysis to study plasticity spread and node displacement under seismic loading. Feng Fan (2014) conducted parametric analyses on a single-layer reticulated dome under seismic load, showing an increase in limit load with decreasing rise-span ratio, roof mass, and initial defects. FAN Feng (2008) discussed the Hamilton variation principle and central difference method for solving non-linear dynamic problems. Different failure modes were identified for a single-layer Kiewit reticulated dome under impact loads based on vertical displacement, stress, and plastic deformation.

1.1 BUILDING CONFIGURATION

The structural patterns of the reticulated dome modal Kiewitt are K8 Kiewitt, K8 Kiewitt-Ribbed Hybrid and K8 Kiewit dome with opening. being considered for analysis. A total of 16 models are being analyzed and designed with rise to span ratios of 0.20, 0.25, 0.30, 0.35, and spans of 60m. The first step involves analyzing and designing all structures, followed by comparing the results for different dome patterns and h/s ratio. The typical plan and elevation can be seen in figure given. Dead load, live load, and earthquake load cases are taken into account for the analysis and design. The modelling, analysis, and design of all reticulated dome models are being conducted using SAP2000 software. For linear static analysis and design, beam elements and braces are modeled using truss elements. The support conditions are assumed to be hinged supports, and all structural members are designed according to IS 800:2007.

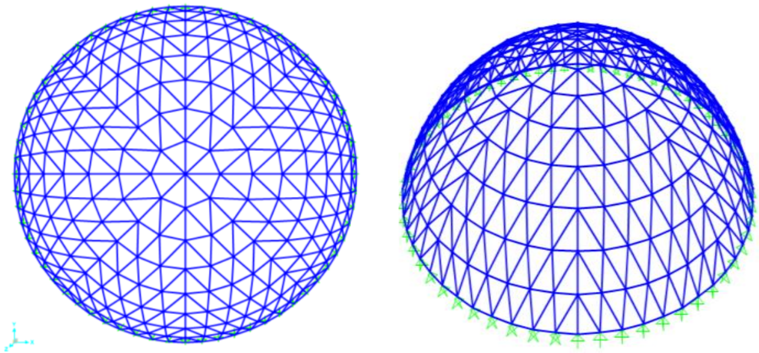

Figure 1 1. Reticulated dome's standard floor plan and elevation are as above

Table 1 - Dome Parameters

Dome Span	60m
Rise to Span ratio	0.20, 0.25, 0.30, 0.35
Dome's Pattern	K8 Kiewitt, K8 Kiewitt-Ribbed Hybrid, Dome with opening
Young's modulus	210 GPa
Material Grade	Fe345
Section Properties	Hollow steel tubes i) 0.095 x 3.500E-03 ii) 0.102 x 3.000E-03

Table 2 – Loading Conditions

Dead load	0.5 kN/m2
Live Load	1.5 kN
Zone Factor(Z)	0.24
Importance Factor(I)	1
Response reduction factor(R)	5
Soil Type	II – Medium

Table 3 – Dome Models

Dead load & Live load	0.5 kN/m2 & 1.5 kN/m2
Zone Factor(Z)	0.24
Importance Factor(I)	1
Response reduction factor(R)	5
Soil Type	II – Medium

1.2 MODAL ANALYSIS

The seismic analysis of a reticulated dome structure begins with the first modal analysis, which is conducted in the form of the Fundamental Natural Time-Period. The time taken for each complete cycle of oscillation is known as the Fundamental Natural Period of the system. This time period is an inherent characteristic of the system, allowing it to vibrate freely without any external force, and is dependent on the mass and stiffness of the structure. The natural time period is inversely proportional to the frequency of the structure, indicating that a structure with a higher natural time period is less rigid compared to one with a lower natural time period. The relationship between frequency and time period is expressed by the following equation.

$T=2\pi/\omega$

The seismic behavior of the reticulated various mentioned patterns of K8 dome structure is influenced by the rise to span ratio increase, which results in a corresponding increase in the time period. Conversely, as the rise to span ratio decreases, the time period decreases in value. The stiffness of the dome structure is affected by the time period reduction in the reticulated K8 Kiewit-Ribbed Hybrid dome. When comparing the modal time period of a rise to span ratio of 0.2 to 0.25, there is a decrease of 10.83%. Similarly, comparing a ratio of 0.25 to 0.30 results in a decrease of 3.91%, and comparing a ratio of 0.20 to 0.40 shows a decrease of 29.42% in the dome's modal time period.

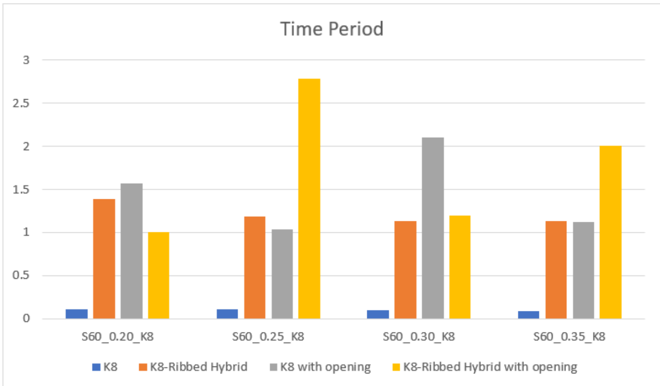

Chart 1 Time period comparison for different pattern of above-mentioned reticulated dome structure.

In analyzing the reticulated K8 dome structures with various different pattern reticulated dome structure which varying rise and rise to span ratios, it was observed that as the dome rise increases, the time period value also decreases. Conversely, a reduction in the rise to span ratio leads to an increase in the time period value. The stiffness of the K8 dome structures is directly correlated to the time period. For instance, when comparing the modal time period of a 10m rise dome to an 20m span dome, there was a 21.36% increase in the time period value. Similarly, comparing the

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 04 | Apr 2024 www.irjet.net p-ISSN: 2395-0072

modal time period of a 0.20 h/s dome to a 0.35 h/s dome resulted in a 29.13% increase in the time period value.

2. P-DELTA ANALYSIS OF RETICULATED DOME STRUCTURE

P-Delta analysis is an analytical method used to assess the impact of deformation on structures when subjected to lateral loads such as wind or earthquakes. This technique takes into account the second-order effects that arise from the deformation, considering both axial and transverse loads applied to beam or wall elements. P-Delta analysis becomes necessary when a structure experiences significant vertical and lateral forces simultaneously, resulting in both first and second-order lateral displacement. This analysis addresses the nonlinear geometric effect caused by the interaction of large direct stress with transverse bending and shear behavior.

Table 4 - Dome model for Various pattern dome for P-delta effect

Model Name	DL	LL	P-Delta
D_S60_R0.20_K8	1.4	0.7	1.9094
D_S60_R0.25_K8	1.4	0.7	2.5659
D_S60_R0.30_K8	1.4	0.7	7.36
D_S60_R0.35_K8	1.4	0.7	3.2221
H_S60_R0.20_K8	1.4	0.7	6.1021
H_S60_R0.25K8	1.4	0.7	3.2606
H_S60_R0.30_K8	1.4	0.7	11.5741
H_S60_R0.35_K8	1.4	0.7	7.048
O_S60_R0.20_K8	1.4	0.7	7.3696
O_S60_R0.25_K8	1.4	0.7	3.8221
O_S60_R0.30_K8	1.4	0.7	1.6094
O_S60_R0.35_K8	1.4	0.7	10.574

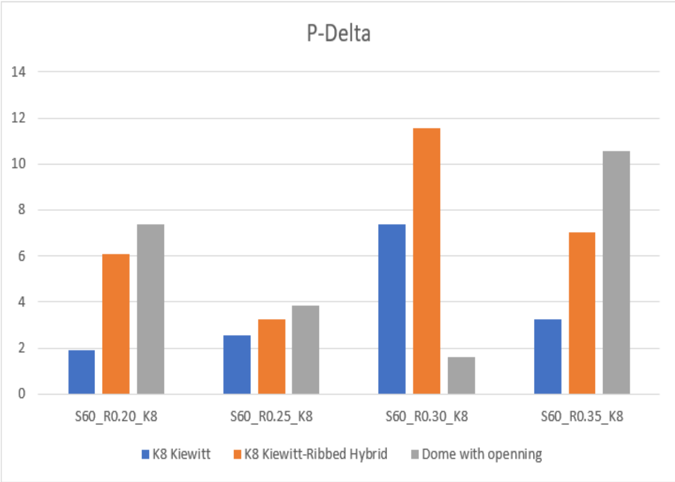

Chart 2 P-Delta Comparison Graph

Indian Standard (IS) codes offer recommendations for structural analysis and design. When it comes to P-Delta effects, IS codes usually suggest load combinations that include dead load (DL) and live load (LL). Some common combinations are:

1.2 DL + 0.5 LL: Considered conservative for overall sway effects.

1.0 DL + 0.7 LL: Provides accurate results for capturing P-Delta effect caused by sway.

1.0 DL + 0.5 LL: Considered conservative in the absence of lateral load.

Scale factor: DL- 1.4 LL - 0.7

- D_S60_R0.30_K8 K8 Kiewitt-Ribbed Hybrid dome has higher P-delta value than H_S60_R0.30_K8 and O_S60_R0.30_K8.
- D_S60_R0.30_K8 K8 Kiewitt dome has higher P-delta value than H_S60_R0.30_K8 and O_S60_R0.30_K8.
- D_S60_R0.35_K8 K8 Dome with opening has higher P-delta value than H_S60_R0.20_K8 and O_S60_R0.25_K8.
- Differences around 0.50-0.52% between these various pattern values of P-Delta analysis.

2.2 Plastic Hinge

The K8 modal of the reticulated dome structure is characterized by a D_S60_R0.20_K8 dome structure, with the plastic hinge deformation occurring at the center marked by the "•". Although the forty-eight members near the support experience plastic deformation at the top, they are all in the B-IO stage. There is no requirement for repair, and the structure can be used without interruption.

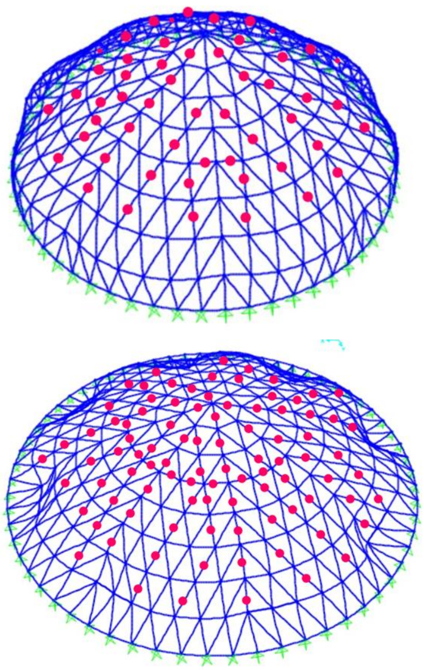

Fig 2.1 D_S60_R0.20_K8 and D_S60_R0.25

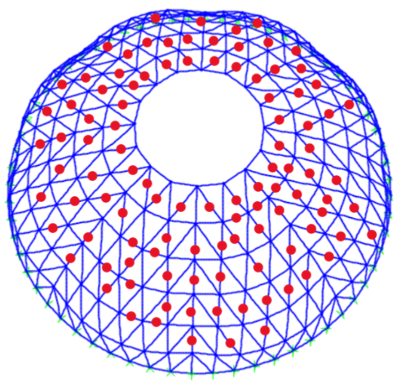

Fig 2.2 O_S60_R0.20_K8

The K8 dome structure is a model of the reticulated dome structure with 8 members, featuring a plastic hinge at the center of plastic deformation. The top of the plastic deformation stage near the support consists of sixty-four members.

2.3 COMPARISON OF DIFFERENT PATTERNS RETICULATED DOME STRUCTURE

Table 5 – Displacement & Base shear at ultimate points

Displacement & Base Shear at ultimate point		
Model Name	**Base Shear (Kn)**	**Displacement(mm)**
D_S60_0.20_K8	132404.31	138.977
D_S60_0.25_K8	207814.38	440.631
D_S60_0.30_K8	313020.63	640.75
D_S60_0.35_K8	312004.38	288.977
H_S60_0.20_K8	169804.31	238.977
H_S60_0.25_K8	307814.38	850.631
H_S60_0.30_K8	253020.63	560.75
H_S60_0.35_K8	139004.38	188.977
O_S60_0.20_K8	369804.31	298.977
O_S60_0.25_K8	607814.38	740.631
O_S60_0.30_K8	353020.63	390.75
O_S60_0.35_K8	239004.38	169.977

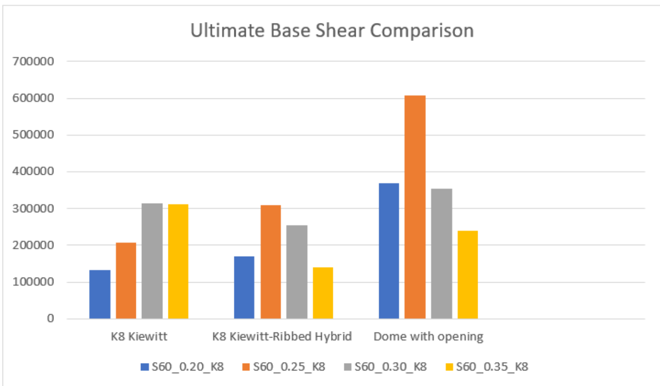

Chart 3- Comparison of ultimate Base Shear for various configurations of reticulated dome structures.

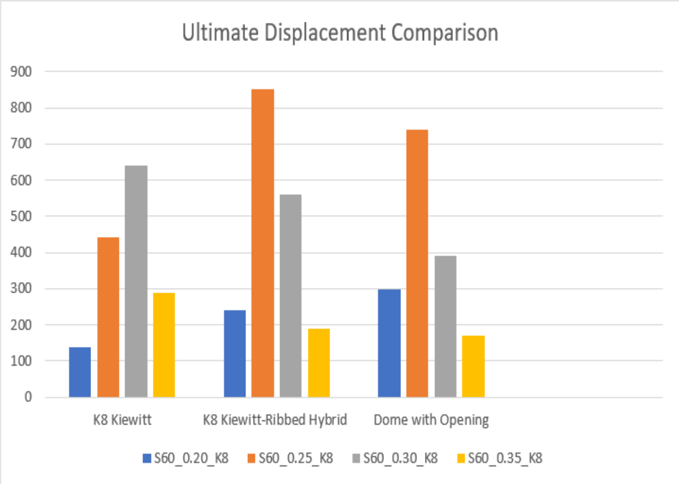

Chart 4 – Comparison of ultimate Displacement for various configurations of reticulated dome structures.

3. CONCLUSIONS

- The reticulated dome models demonstrate that among various geometric factors taken into account, only the "rise-to-span ratio" and the "relative stiffness of the supports" have a significant impact.
- The reticulated dome of the displacement of less than 1/400 of rise of the structure is safe (IS 1893 part 4).
- In accordance with IS 1893 (part 4), a tall structure with a plan dimension greater than its height must be engineered to accommodate a vertical displacement of 1/400 of its height. Various designs of reticulated dome models with rise to span ratios of 0.20 and 0.30 only meet the necessary codal criteria.
- The seismic behavior of the reticulated various mentioned patterns of K8 dome structure is influenced by the rise to span ratio increase, which results in a corresponding increase in the time period. Conversely, as the rise to span ratio decreases, the time period decreases in value.
- The stiffness of the dome structure is affected by the time period reduction in the reticulated K8 Kiewit-Ribbed Hybrid dome.
- When comparing the modal time period of a rise to span ratio of 0.2 to 0.25, there is a decrease of 10.83%. Similarly, comparing a ratio of 0.25 to 0.30 results in a decrease of 3.91%, and comparing a ratio of 0.20 to 0.40 shows a decrease of 29.42% in the dome's modal time period.
- An increase in the rise to span ratio results in an increase in both EQ and gravity load. The EQ and gravity load values for the reticulated K8 dome are 66.784 KN
- Differences around 0.50-0.52% between these various pattern values of P-Delta analysis.
- The rise in various reticulated dome structures increases the stiffness of the dome.
- The rise to span ratio of the reticulated dome structure increases as the time period and displacement increase.
- The response modification factor and ductility factor have an impact on the reticulated dome structure.

ACKNOWLEDGEMENT

I express my sincere thanks to Prof. Dipak Jivani for their utmost guidance and motivation on both research as well as on my career.

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