International Journal of Research Publication and Reviews, Vol 4, no 11, pp 3239-3253 November 2023

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Seismic Analysis of RCC Dome Structures with and without Parametric Openings

Muzaffar Khan[1], Rahul Sharma[2]

[1]Student [2] Professor at department of civil engineering at PITS Ujjain

ABSTRACT

This technical research paper investigates the seismic behaviour of Reinforced Concrete (RCC) domes, with a specific emphasis on the role of parametric openings. Four distinct models were developed in STAAD Pro: one representing a dome without openings and three featuring parametric openings strategically positioned at various heights.

Parametric openings were introduced to evaluate their impact on structural integrity and seismic response. The modelling process involved meticulous consideration of design parameters, material properties, and loading conditions. Seismic analysis, with a focus on simulations of seismic events in Zone 3 of India, was executed using the capabilities of STAAD Pro.

The paper presents and discusses the analysis results in its concluding section. Comparative assessments between domes without openings and those with parametric openings highlight structural variations and performance differences under seismic loading. The findings offer practical insights into the influence of openings on the seismic behavior of RCC domes, providing implications for structural design and contributing to the understanding of seismic vulnerability in Zone 3 regions.

Introduction

Historically, domes have adorned iconic structures, symbolizing architectural prowess and cultural identity. Modern engineering practices, coupled with computational advancements, now allow for a deeper understanding and manipulation of the form. The addition of parametric openings introduces a parametrically-driven approach, enabling architects and engineers to tailor the dome's behavior to specific functional and aesthetic requirements.

This study is prompted by a recognition of the potential impact that parametric openings can have on the structural behavior of RCC domes. While traditional domes exude a sense of solidity and continuity, the introduction of openings invites questions about stress distribution, load paths, and overall structural response. This thesis seeks to answer these questions through a systematic and comparative investigation.

Modelling and Analysis

Dome structures have been a symbol of architectural innovation and engineering prowess throughout history, showcasing a harmonious blend of aesthetic appeal and structural efficiency. In the realm of modern structural analysis and design, the use of advanced computational tools plays a pivotal role in exploring the behaviour of such intricate architectural elements. This chapter delves into the modelling and analysis of dome structures, specifically focusing on various configurations implemented within the STAAD Pro software.

The study revolves around four distinct dome models, each meticulously crafted to explore the structural response under different conditions. The models are characterized by the strategic placement of openings, influencing the distribution of loads and internal forces.

The aim is to gain insights into the performance of dome structures under diverse scenarios.

The following models have been developed and analysed in detail: 1.

Model 01: Dome with no opening 2.

Model 02: Dome with alternate openings in the top ring 3.

Model 03: Dome with alternate openings in the top and third ring 4.

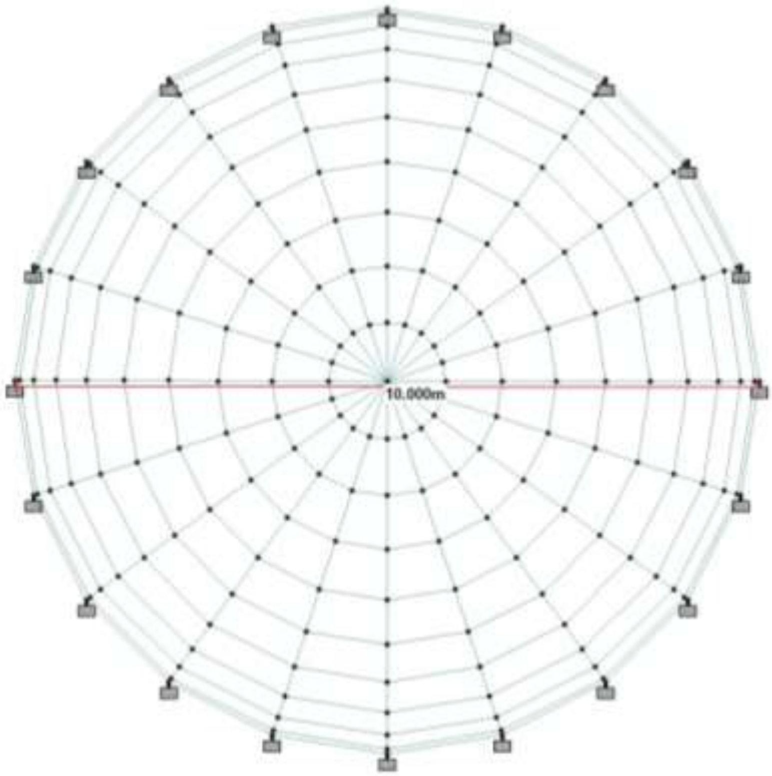
Model 04: Dome with alternating openings in the top, 3rd, and 5th rings Each model comprehensively describes the effects of different opening locations on the structural integrity and stability of the dome structure.

Using STAAD Pro as an analysis tool provides a robust platform for accurate simulation and evaluation, allowing detailed study of structural behavior under different loading conditions. To begin the investigation of the dome structure, the following chapter details the modeling process, the assumptions made, and the analytical methods used. The results of this study are expected to contribute not only to the understanding of dome structures, but also to the broader field of civil engineering, providing valuable insights for future design and optimization.

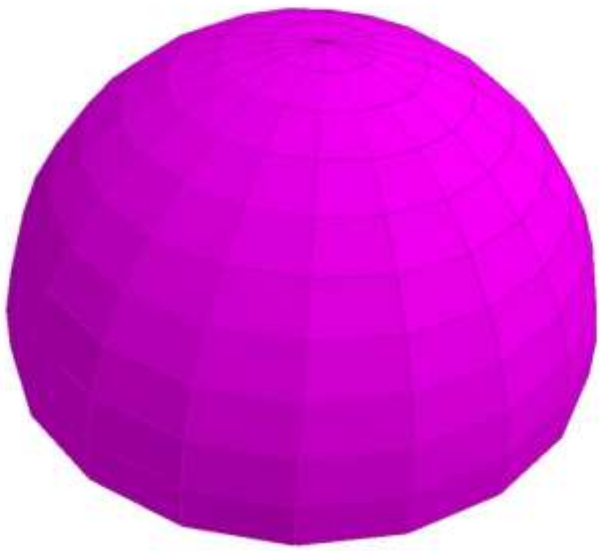
Models

Model	Particular
Model 01	Dome with no opening
Model 02	Dome with alternate opening in top part.
Model 03	Dome with alternate opening in top & third part.
Model 04	Dome with alternate opening in top, third & fifth part.

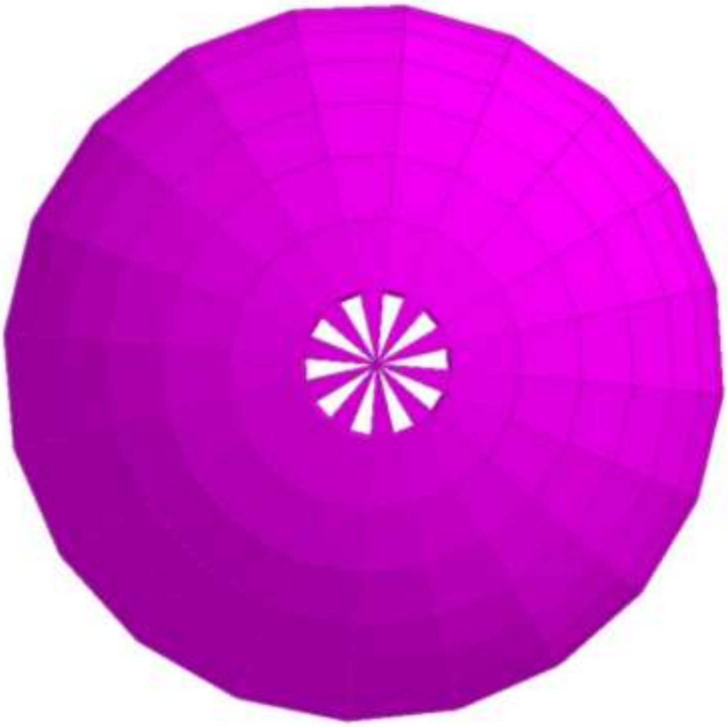
General plan –

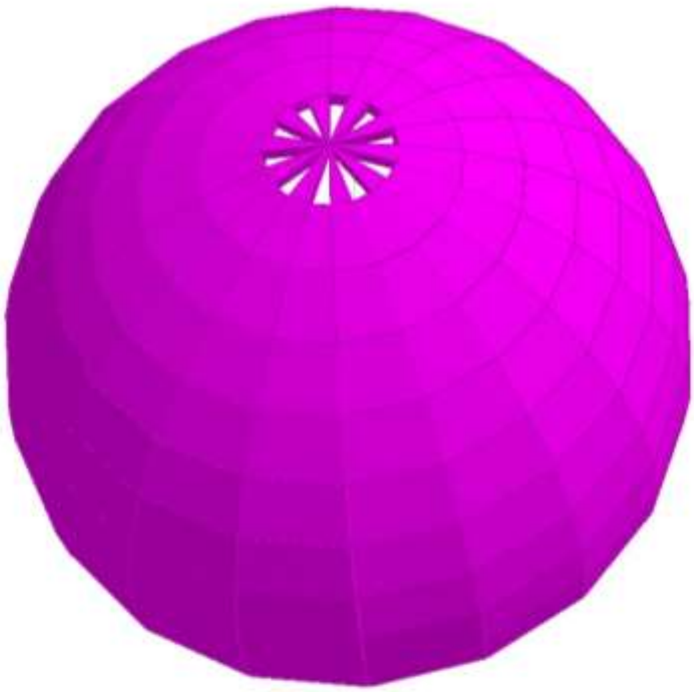


Model 01

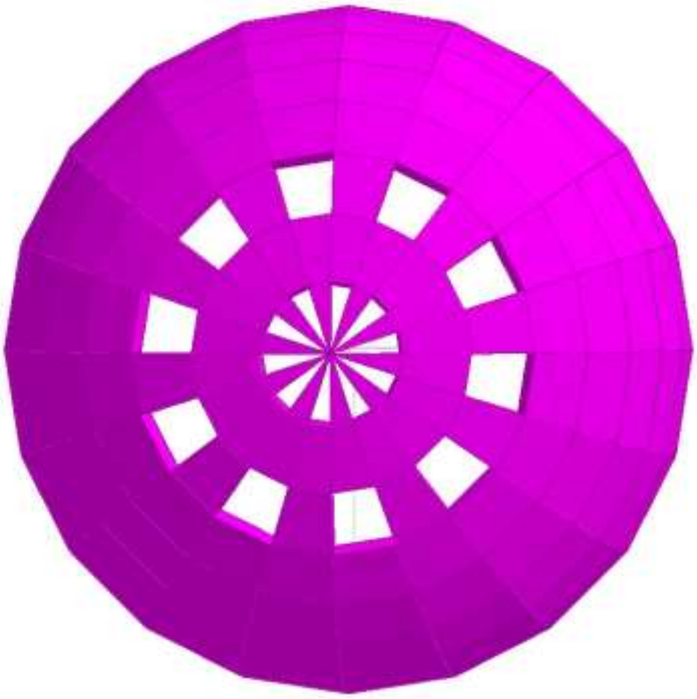


Model 02

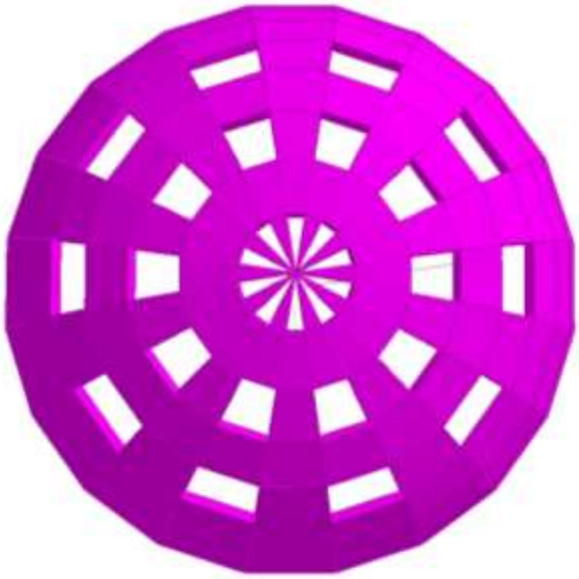




Model 03



Modal 04



Load Application and Calculation

The structural analysis begins with the application of loads as per the relevant design codes. The dome structure, constructed with concrete of grade M30 and reinforced with Fe 500, is subjected to a self-weight of the RCC material, a dead load of 1 kN/m², and a live load of 1 kN/m², The load are applied as plate load. Additionally, seismic loads are applied in accordance with the seismic zone classification for India, specifically defined as Zone III. The application of these loads follows the guidelines specified in IS 456: 2000, "Code of Practice for Plain and Reinforced Concrete."

Clause 23.2 of IS 456 outlines the determination of dead load, including the self-weight of the structure and any permanent loads. In this study, the density of concrete used for the dome, with a mix grade of M30, is considered in conjunction with the dimensions of the structural elements to calculate the self-weight and dead load.

Live load, as stipulated in Clause 4.1 of IS 456, is computed based on occupancy and usage considerations. For the purpose of this analysis, a uniform live load of 1 kN/m² is applied to simulate typical live load conditions on the dome structure.

The seismic loads are determined in accordance with IS 1893: 2016, "Criteria for Earthquake Resistant Design of Structures," considering the seismic zone factor for Zone III as per Clause 6.4.3.1. The combination of these loads is integral to comprehensively assessing the structural response under diverse conditions. Analysis is done in STAAD pro using equantent static method.

Analysis and Design Methodology

The structural analysis is carried out using STAAD Pro, a widely recognized and powerful structural analysis and design software. The dome structure, utilizing concrete of grade M30 and Fe 500 reinforcement, is modeled using plate elements, capturing the intricate geometry and behavior of the structure. The analysis is performed under various loading combinations as specified by IS 456, considering the simultaneous application of dead load, live load, and seismic load.

The design process, in accordance with IS 456, involves verifying critical sections and members based on the limit state design principles. The concrete of grade M30 and Fe 500 reinforcement, as used in the dome, conforms to the specifications outlined in Clause 5.3.2 of IS 456, ensuring the structural elements meet the prescribed safety and serviceability criteria. This approach aligns with the holistic evaluation of dome structures under real-world loading conditions, contributing valuable insights into the performance and safety of such architectural elements.

Results –

Plate Stresses

The following terminology had been used to measure and denote the plate stresses -

SQX (Membrane stress or in-plane stress along the X direction): SQX specifically represents the membrane stress (in-plane stress) along the stress component in the X direction.

SX (Bending stress along the X direction): SX represents the bending stress along the X direction. Specifically, SX indicates the stress component associated with bending along the X direction.

MX (resultant or total bending moment along the X direction): MX represents the resultant or total bending moment along the X direction. MX provides information about the overall bending behaviour of the plate in the X direction.

Model	SQX N/mm2	SQY N/mm2	MX kN-m/m	MY kN-m/m	MXY kN-m/m	SX N/mm2	SY N/mm2	SXY N/mm2
1	0	-0.001	-0.052	-0.052	0	-0.051	-0.057	0.002
2	0	0.002	-0.04	-0.08	-0.001	-0.015	-0.09	0.001
3	0	0	-0.028	0.048	0.002	-0.058	-0.04	0.006
4	0.001	-0.001	-0.062	-0.023	0.005	-0.01	-0.037	-0.011

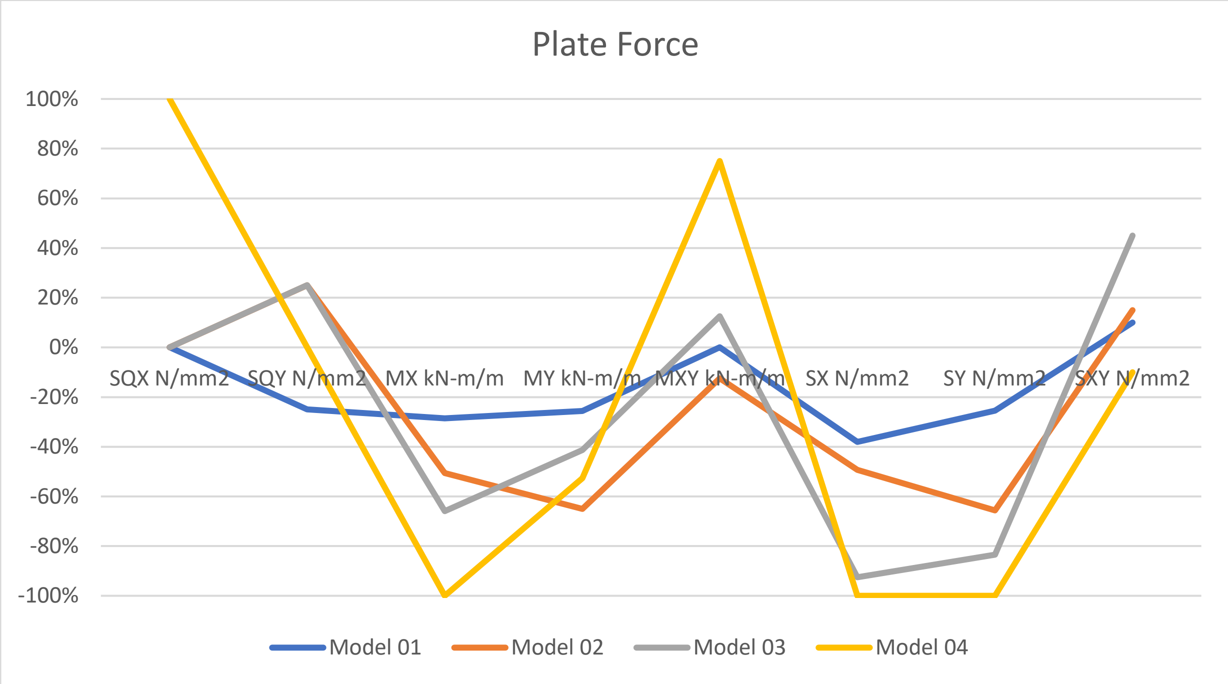
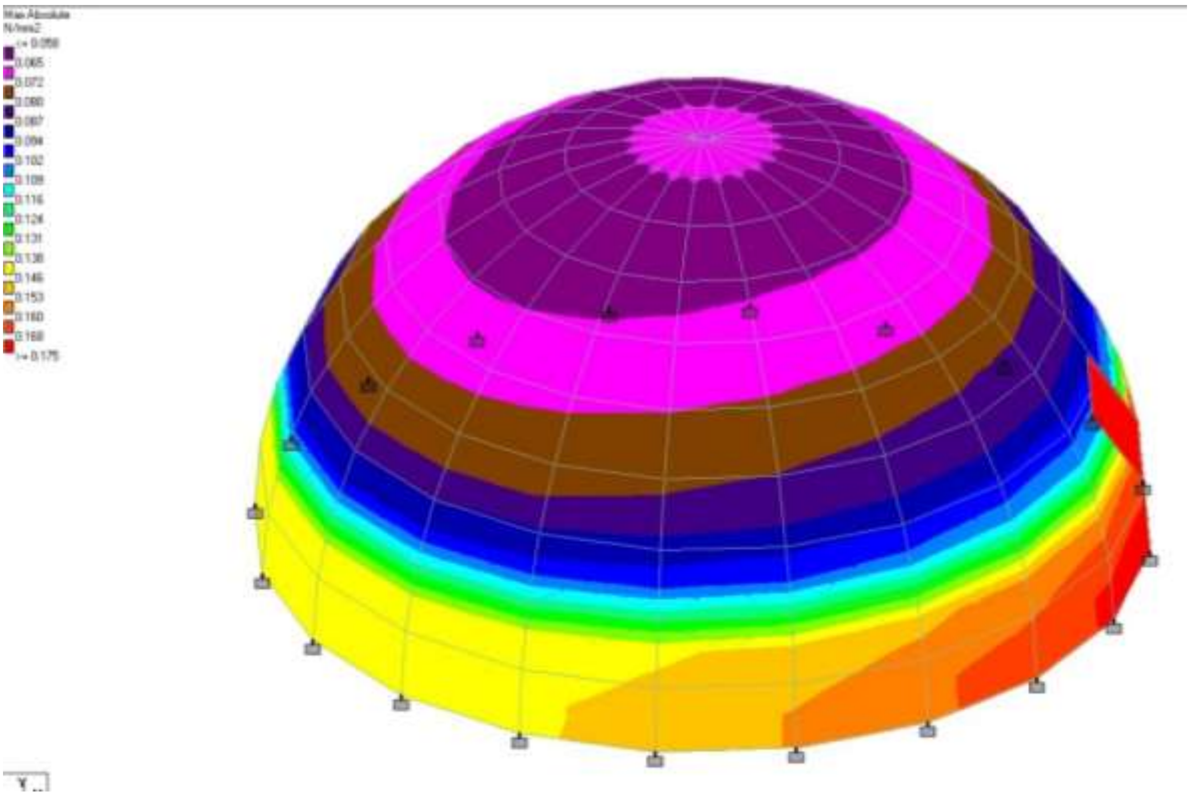
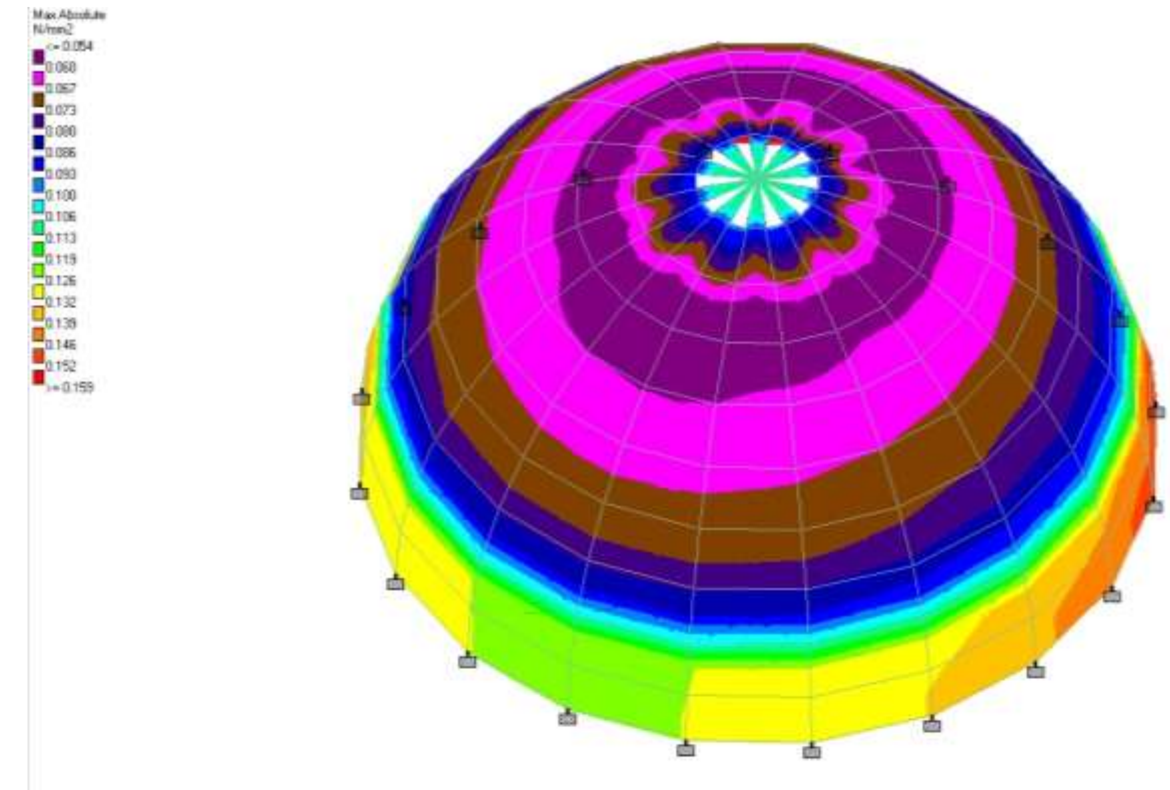
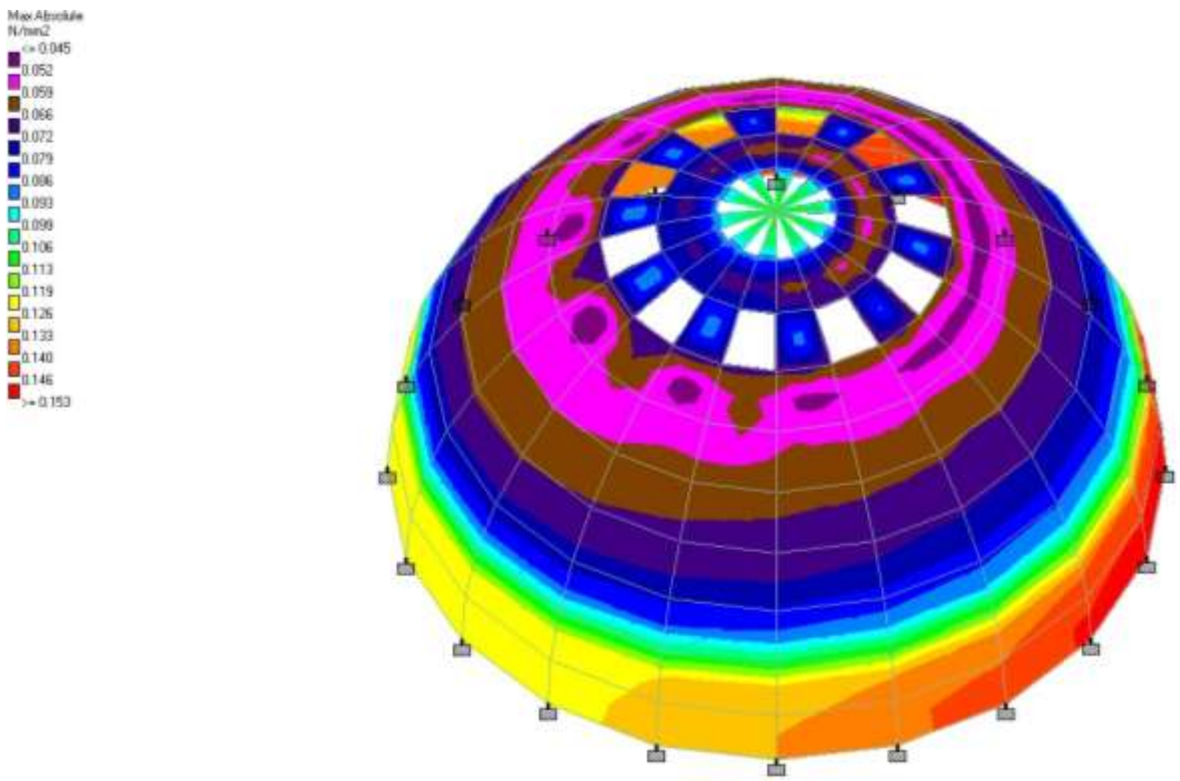
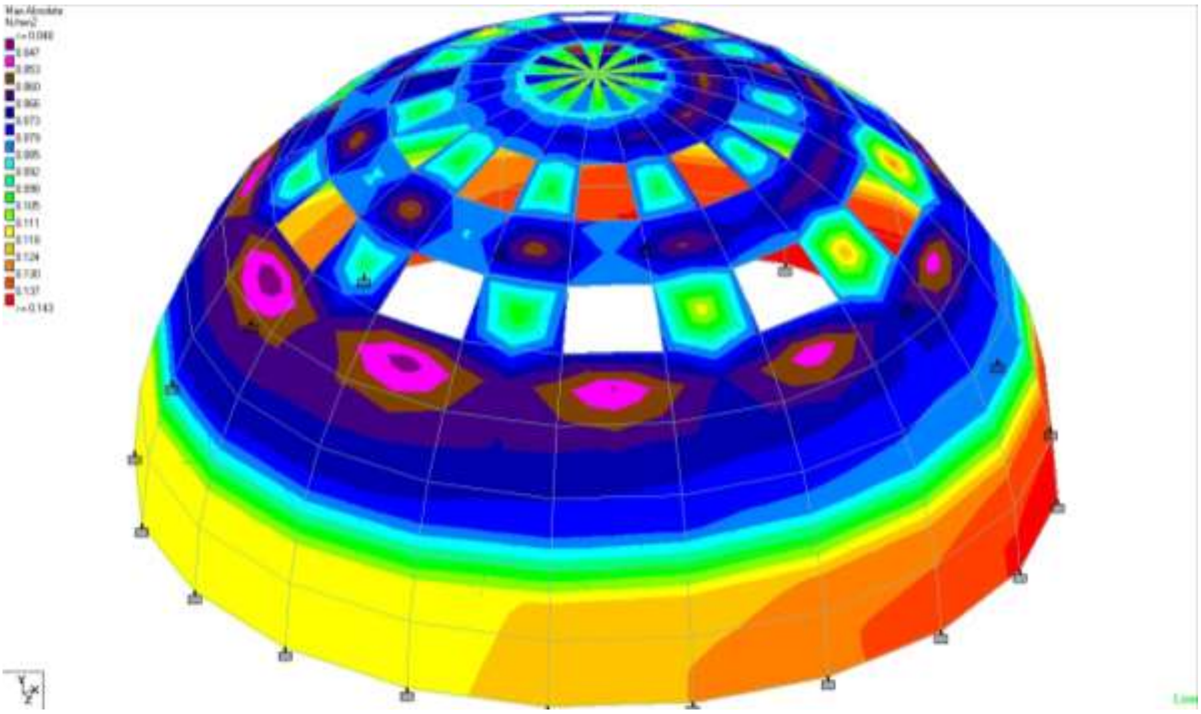


Plate Force
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
SQX N/mm2
SQY N/mm2
MX kN-m/m
MY kN-m/m
MXY kN-m/m
SX N/mm2
SY N/mm2
SXY N/mm2
Model 01
Model 02
Model 03
Model 04




Max Absolute
N/mm2
<= 0.054
0.060
0.067
0.073
0.080
0.086
0.093
0.100
0.106
0.113
0.119
0.126
0.132
0.139
0.146
0.152
>= 0.159


Max Absolute
N/mm2
<= 0.045
0.052
0.059
0.066
0.072
0.079
0.086
0.093
0.099
0.106
0.113
0.119
0.126
0.133
0.140
0.146
>= 0.153



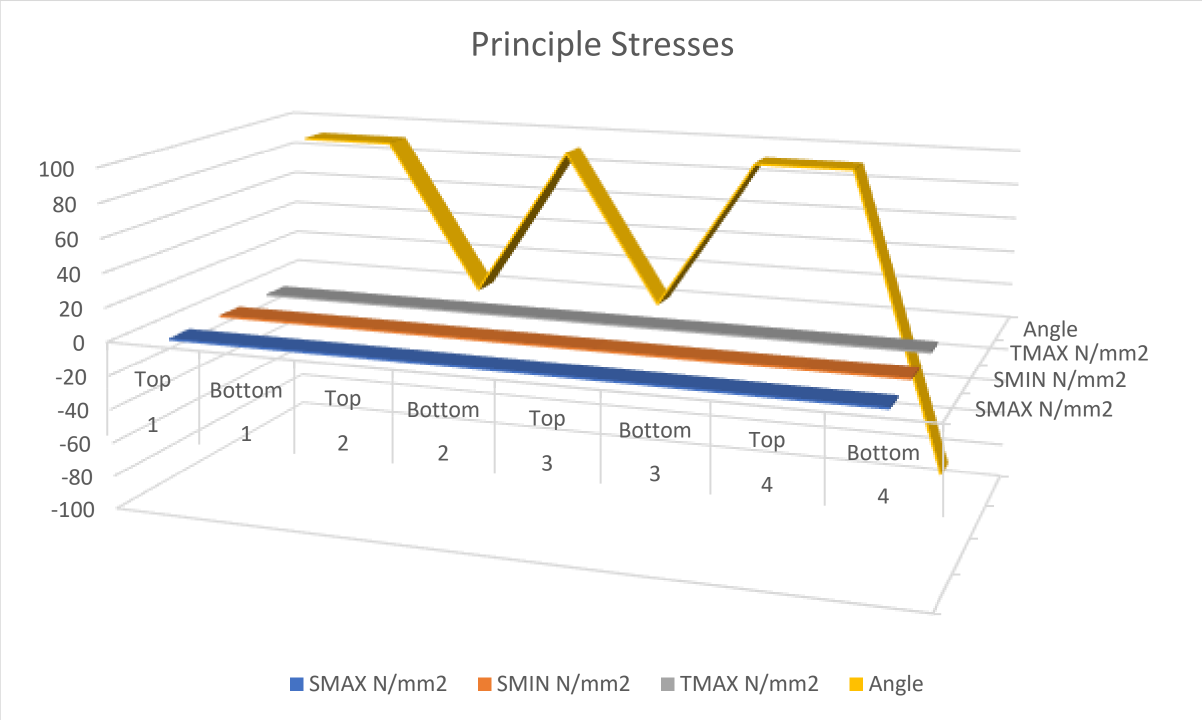
Comment:

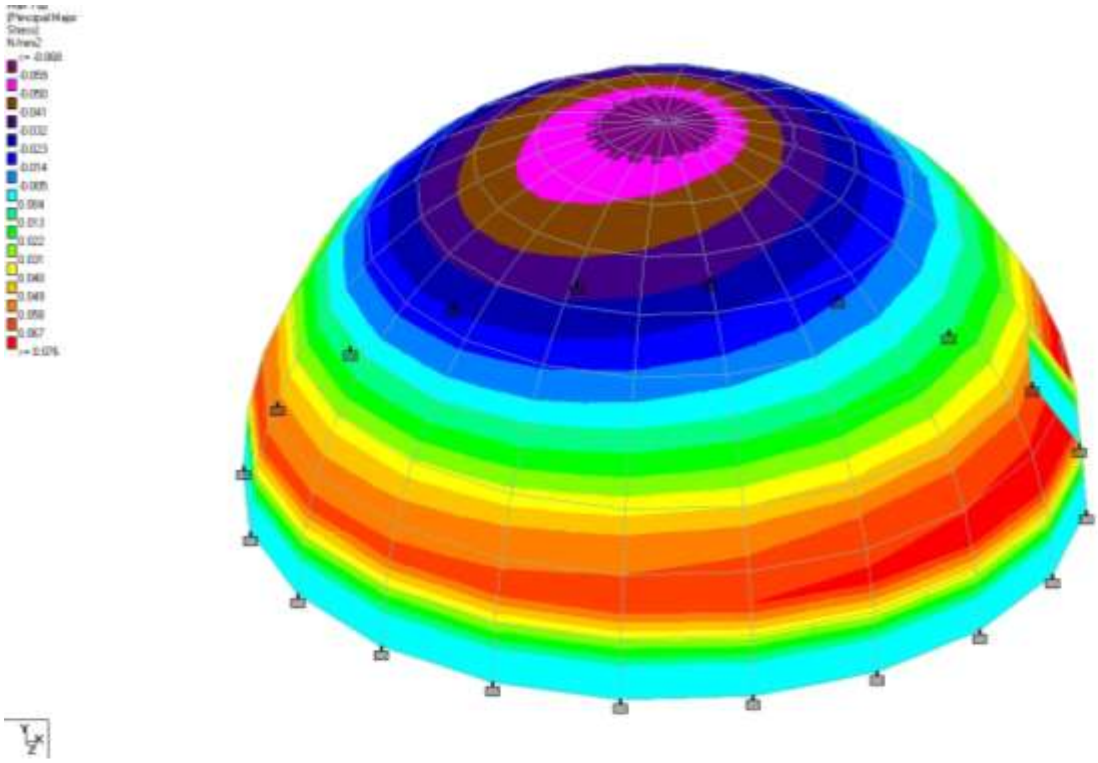
As it is clear from the above table and figures that, the value of absolute maximum stress in dome without opening is minimum at top but it increases with single opening at top, as the number of opening is increased at the next level the stress in dome tends to reduce at top as well as in the bottom area.

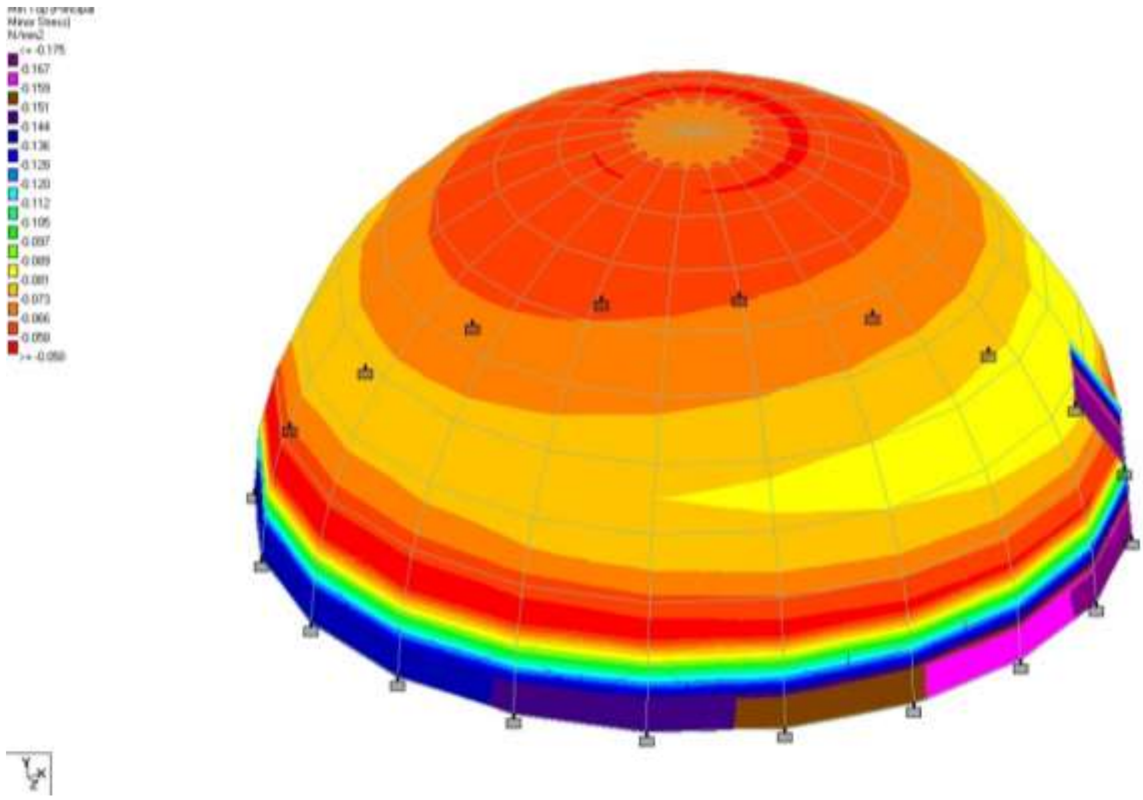
Principle Stress

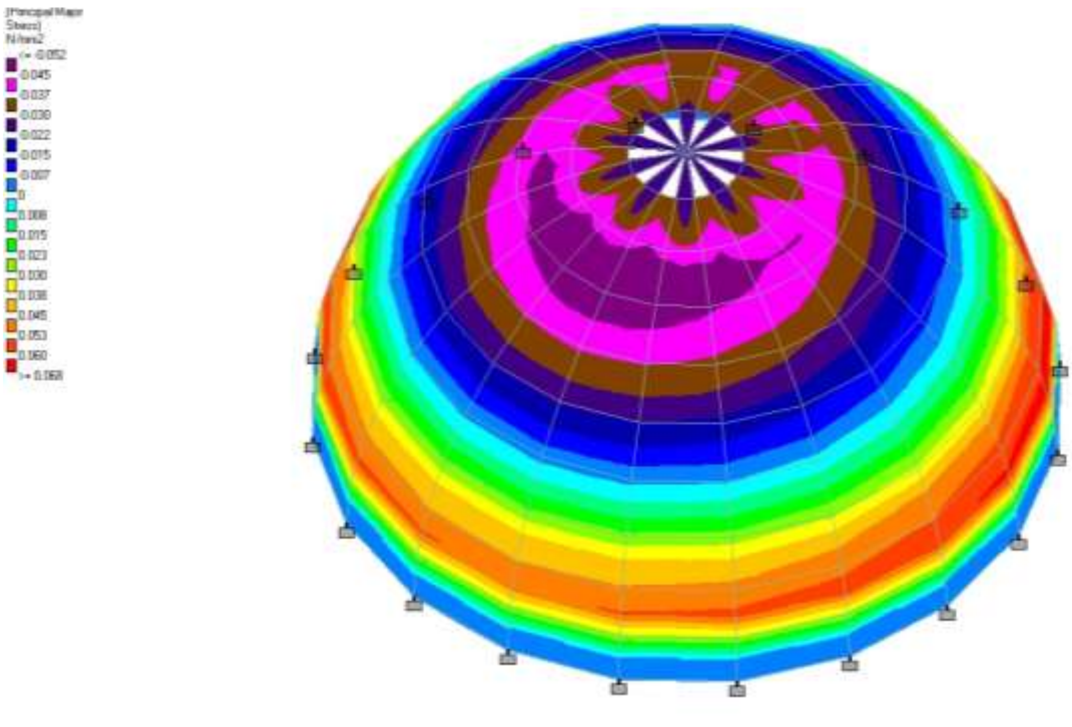
The below table indicates the results.

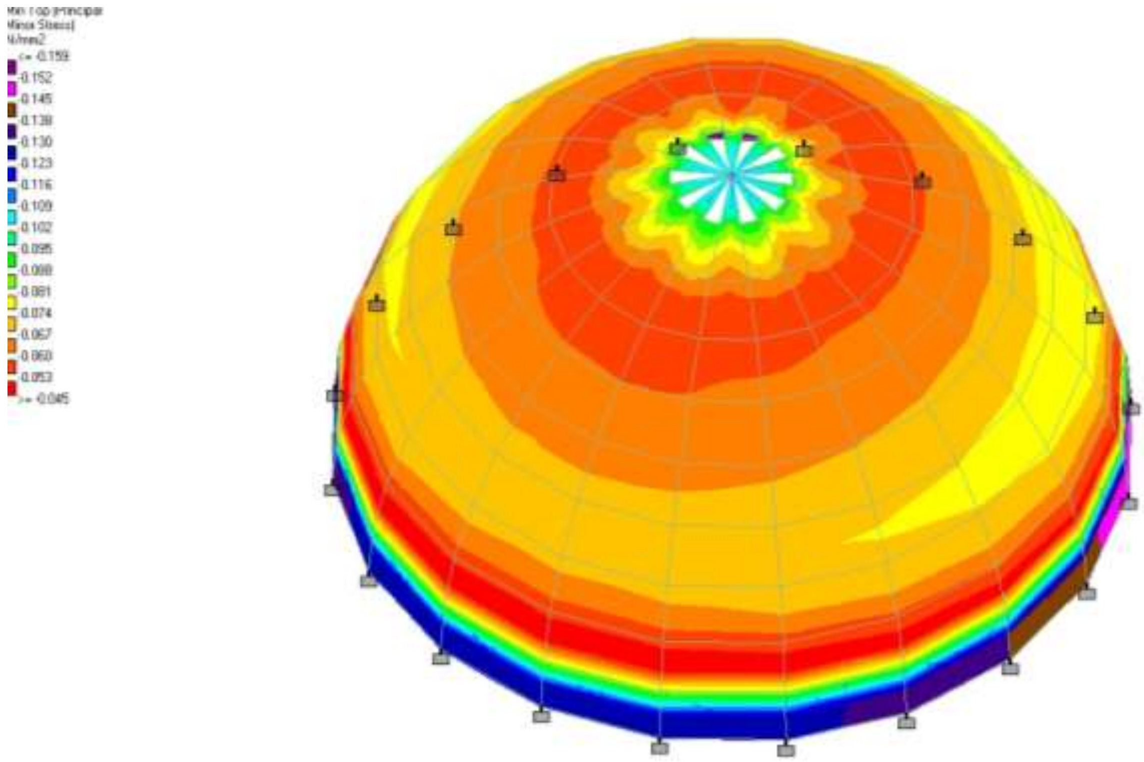
Model	Location	SMAX N/mm2	SMIN N/mm2	TMAX N/mm2	Angle
1	Top	-0.11	-0.12	0.005	90
1	Bottom	-0.072	-0.079	0.003	90
2	Top	0.113	-0.09	0.102	0
2	Bottom	0.09	-0.169	0.13	90
3	Top	0.108	-0.086	0.097	0
3	Bottom	0.083	-0.162	0.123	90
4	Top	-0.109	-0.202	0.047	90
4	Bottom	-0.068	-0.088	0.01	-90

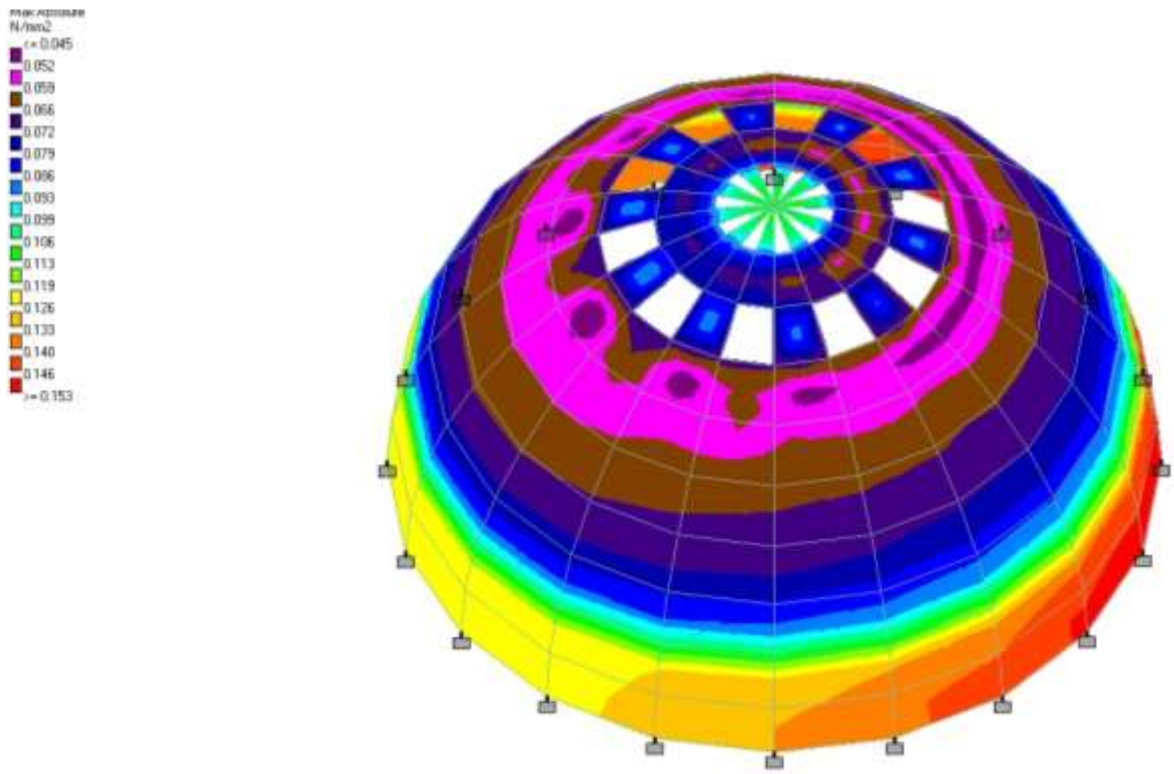

Principle Stresses
100
80
60
40
20
0
-20
-40
-60
-80
-100
Top 1
Bottom 1
Top 2
Bottom 2
Top 3
Bottom 3
Top 4
Bottom 4
Angle
TMAX N/mm2
SMIN N/mm2
SMAX N/mm2
SMAX N/mm2 SMIN N/mm2 TMAX N/mm2 Angle

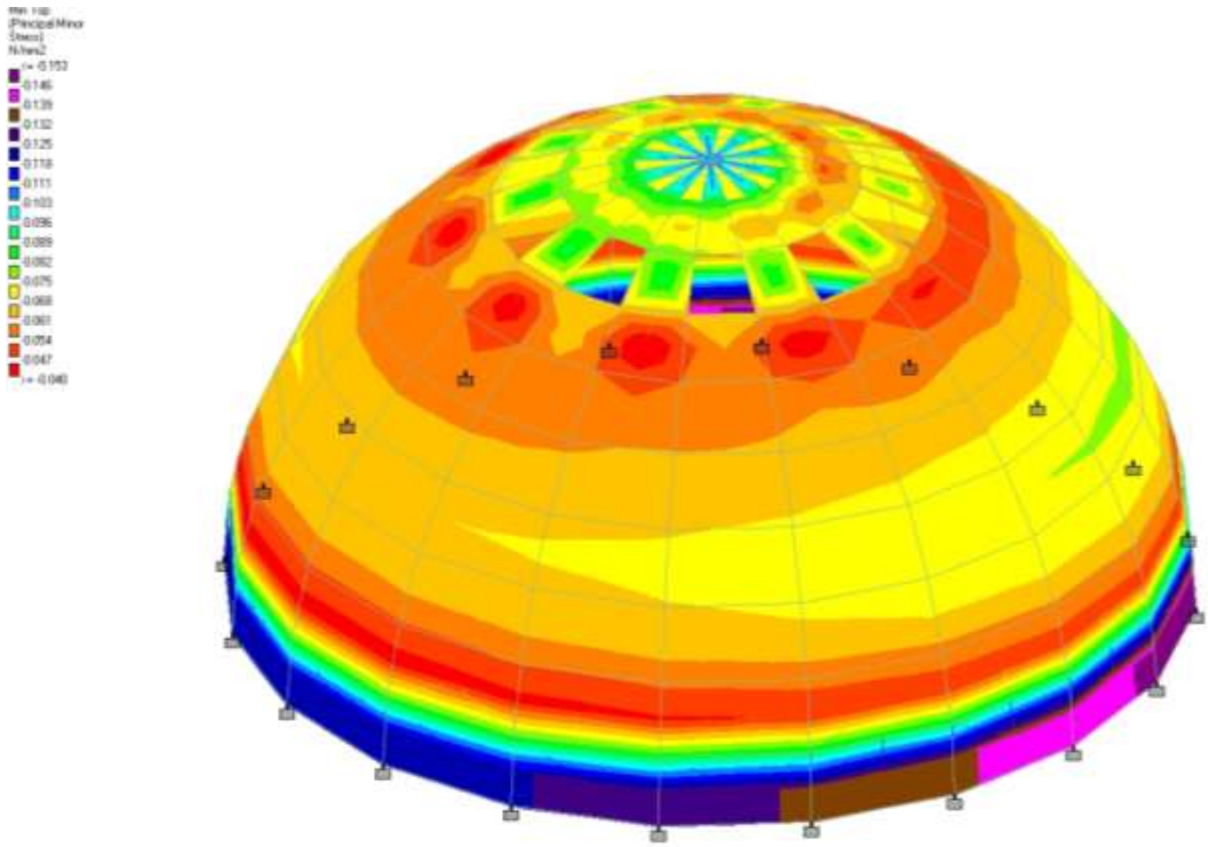


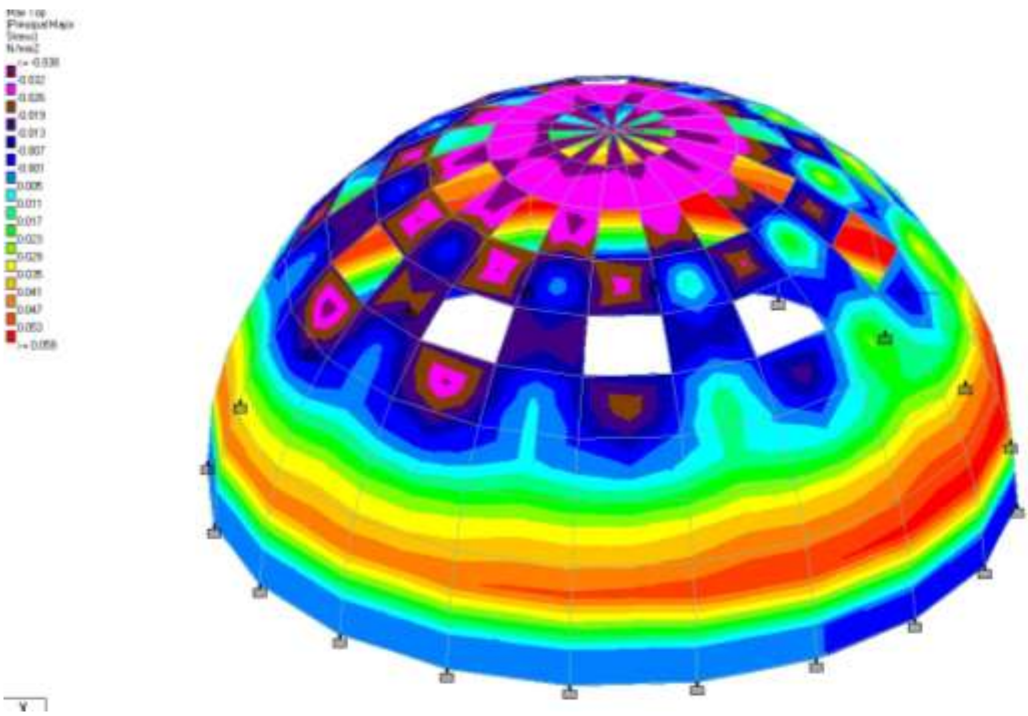

<= -0.175
-0.167
-0.159
-0.151
-0.144
-0.136
-0.128
-0.120
-0.112
-0.105
-0.097
-0.089
-0.081
-0.073
-0.066
-0.058
>= -0.050

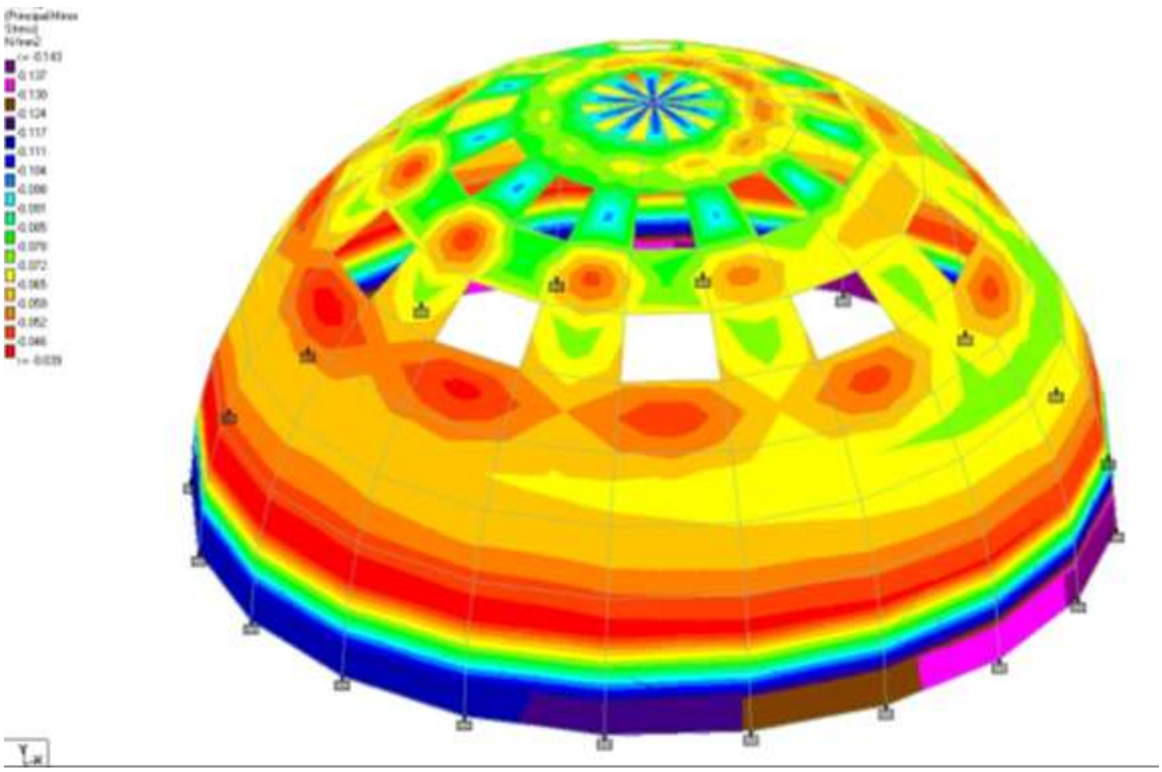

<= -0.052
-0.045
-0.037
-0.030
-0.022
-0.015
-0.007
0
0.008
0.015
0.023
0.030
0.038
0.045
0.053
0.060
>= 0.068


N/mm2
<= -0.159
-0.152
-0.145
-0.138
-0.130
-0.123
-0.116
-0.109
-0.102
-0.081
-0.074
-0.067
-0.060
-0.053
>= -0.045


N/mm2
<= 0.045
0.052
0.059
0.066
0.072
0.079
0.086
0.093
0.099
0.106
0.113
0.119
0.126
0.133
0.140
0.146
>= 0.153


-0.146
-0.139
-0.132
-0.125
-0.118
-0.111
-0.103
-0.096
-0.089
-0.082
-0.075
-0.068
-0.061
-0.054
-0.047


-0.032
-0.026
-0.019
-0.013
-0.007
-0.001
0.005
0.011
0.017
0.023
0.029
0.035
0.041
0.047
0.053



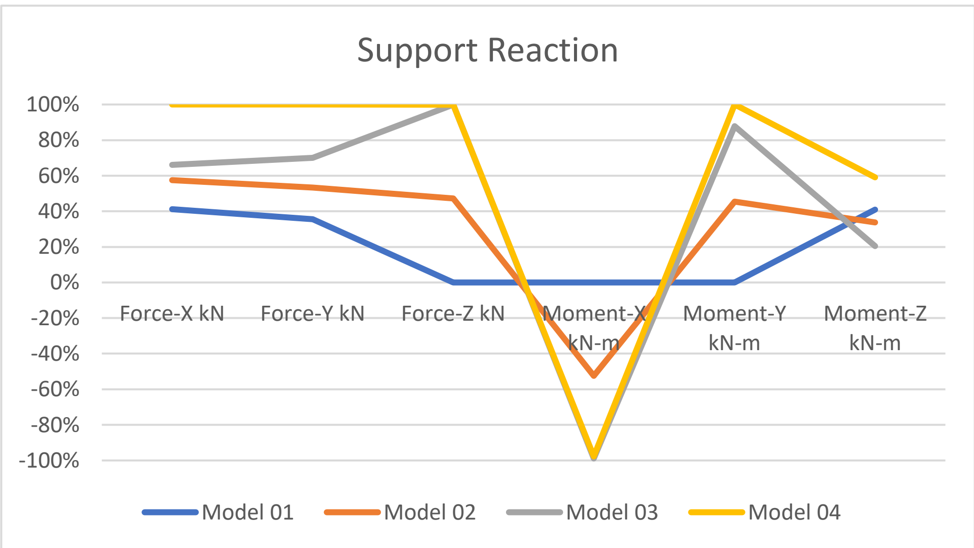
Comment:

As it is clear from the above table and figures that, the value of principle maximum stress in dome without opening is minimum at top but it increases with single opening at top, as the number of opening is increased at the next level the stress in dome tends to reduce at top as well as in the bottom area.

Support Reaction

The below table is for support reaction

Model	Force-X kN	Force-Y kN	Force-Z kN	Moment-X kN-m	Moment-Y kN-m	Moment-Z kN-m
1	7.088	54.934	0	0	0	0.523
2	2.812	27.301	3.483	-0.278	0.015	-0.093
3	1.476	25.814	3.874	-0.246	0.014	-0.168
4	5.841	46.247	-0.007	0.006	0.004	0.493



Comment:

Support reaction is minimum in model 03 i.e. 25.814 KN as compared to the other models.

Base Shear

Foundation shear force is the total lateral force that acts on the foundation (foundation) of a structure during an earthquake. This is the result of seismic forces acting on the structure due to ground movement. Foundation shear is an important parameter in seismic design because it represents the maximum force that a structure must withstand during an earthquake.

Model	Direction	Base Shear	
		Max	Min
1	X+	21.96	6.04
	X-	-21.96	-6.04
	Z+	21.96	6.04
	Z-	-21.96	-6.04

Model	Direction	Base Shear	
		Max	Min
2	X+	21.9	5.96
	X-	-21.9	-5.96
	Z+	21.9	5.96
	Z-	-21.9	-5.96

Model	Direction	Base Shear	
		Max	Min
3	X+	21.89	-5.82
	X-	-21.89	5.82
	Z+	21.89	-5.82
	Z-	-21.89	5.82

Model	Direction	Base Shear	
		Max	Min
4	X+	21.85	5.8
	X-	-21.85	-5.8
	Z+	21.85	5.8
	Z-	-21.85	-5.8

Comment:

It has been observed that there is very less amount change in the base shear in all the model.

CONCLUSION

The examination of principal maximum stress aligned with the findings on absolute maximum stress. The absence of openings led to minimal stress at the top, followed by an increase with a single opening, and subsequent reduction with additional openings at the next level. This consistent pattern further emphasizes the influence of the number and placement of openings on the structural response of dome structures. In terms of support reactions, it was noteworthy that Model 03 exhibited the minimum support reaction of 25.814 kN compared to the other models. This observation indicates the potential for optimization in terms of support conditions in dome structures, contributing to more efficient designs.

Surprisingly, the base shear across all models showed minimal variation. This finding suggests that the introduction of openings did not significantly impact the overall lateral forces experienced by the dome structures. This aspect is crucial for seismic design, emphasizing the robustness of dome structures in maintaining relatively stable lateral resistance under different configurations.

Reference –

19. C. Vipulanandan and R. A. Ismail (1999) - "Effect of Hurricane on Concrete and Steel Structures in Coastal Areas." Journal of Coastal Research, 15(4), 1009-1019.

20. D. Chao, Y. Guo, Y. Pi, S. Zhao (2014) - "Flexural-Torsional Buckling of Parabolic Steel Arches." Journal of Structural Stability and Dynamics, 16(3), 1550012.

21. Gambhir, M. L., and Neha Jamwal (2017) - "Sustainable Construction: Use of Rice Husk Ash in Concrete." Journal of Sustainable Cement-Based Materials, 6(3), 269-283.

22. K. P. Chong, H. K. C. Chan, and Y. F. Tuan (2009) - "BIM-Based Earthwork Quantity Takeoff: Case Study." Journal of Computing in Civil Engineering, 23(5), 261-269.

23. S. Mahesh and K. S. Babu Narayan (2015) - "Experimental Study on Partial Replacement of Cement with GGBS and Fine Aggregate with Copper Slag in Concrete." Journal of Construction and Building Materials, 94, 806-812.

24. John R. Crompton and R. Brent Swanson (1994) - "Benefits of Public Space: The Impacts of Perceived Cleanliness on Users' Enjoyment and Use of Urban Recreational Trail Corridors." Journal of Environmental Psychology, 14(3), 143-154.

25. T. Paul Teng and P. K. Wong (2005) - "The Use of Nonlinear Acoustic Techniques for Structural Health Monitoring of Concrete Structures." Journal of Nondestructive Evaluation, 24(4), 173-188.

26. M. L. Gambhir and Neha Jamwal (2017) - "Sustainable Construction: Use of Rice Husk Ash in Concrete." Journal of Sustainable Cement-Based Materials, 6(3), 269-283.

27. K. P. Chong, H. K. C. Chan, and Y. F. Tuan (2009) - "BIM-Based Earthwork Quantity Takeoff: Case Study." Journal of Computing in Civil Engineering, 23(5), 261-269.

28. S. Mahesh and K. S. Babu Narayan (2015) - "Experimental Study on Partial Replacement of Cement with GGBS and Fine Aggregate with Copper Slag in Concrete." Journal of Construction and Building Materials, 94, 806-812.

29. C. Vipulanandan and R. A. Ismail (1999) - "Effect of Hurricane on Concrete and Steel Structures in Coastal Areas." Journal of Coastal Research, 15(4), 1009-1019.

30. A. S. Balaji and M. K. Kannan (2018) - "Application of FRP Composites in Civil Engineering: A Comprehensive Review." Journal of Composite Materials, 52(22), 3061-3085.