IMPACT OF DIAMETER AND HEIGHT VARIATIONS ON CHIMNEY STRUCTURAL PROPERTIES: A STAAD PRO ANALYSIS APPROACH

Devraj[1], Vinod Kumar Modi[2], RamanujJaldhari[3]
[1]M.Tech Scholar, Department of Civil Engineering, Kautilya Institute of Technology and Engineering, Jaipur, India, devrajsingh196@gmail.com
[2]Associate Professor, , Department of Civil Engineering, Kautilya Institute of Technology and Engineering, Jaipur, India,, vkmodiaen@gmail.com
[3]Assistant Professor, Aayojan School of Architecture, Jaipur, India, rd01586@gmail.com

Abstract: The devastating impact of earthquakes on infrastructure, particularly chimneys, underscores the limitations of static analysis in structural engineering. Chimneys play a pivotal role in industrial infrastructure, where their structural integrity is critical for withstanding various environmental forces. Chimneys are essential for the safe release of smoke and hot gases into the atmosphere from a variety of industrial processes. Chimneys, which are usually made to be vertical or almost vertical, use the stack effect to draw air to the combustion chamber and promote a smooth flow of gases. This study investigates the impact of height-to-diameter (h/D) ratios on the structural properties of chimneys using STAAD Pro software. The analysis focuses on shear stress, bending moments, membrane forces, displacements, and absolute pressures across four distinct chimney models. Methodologically, STAAD Pro is utilized for comprehensive structural analysis, offering insights into the behavior of chimneys subjected to lateral forces and wind loading. In conclusion, the study contributes valuable insights into optimizing chimney design parameters for enhanced structural resilience and safety. By understanding how h/D ratios influence chimney behavior, engineers can effectively mitigate structural vulnerabilities and optimize performance under varying environmental conditions.

Keywords: Chimney, STAAD Pro, Shear Stress, Bending Moment, Structural resilience

1. Introduction

Chimneys play a crucial role in safely venting hot gases and smoke from various industrial processes into the atmosphere. Typically designed to be vertical or nearly vertical, chimneys leverage the stack effect to facilitate the smooth flow of gases and enhance the combustion process by attracting air. In contemporary construction, reinforced concrete (RC) has become the material of choice for building chimneys, providing structural strength and durability. The seismic vulnerability of more seasoned fireplaces has turned into a squeezing concern, provoking an exhaustive reassessment of their primary honesty considering current construction standards. Most of stacks, remembering those for Turkey and worldwide, presently comply to rigid seismic guidelines to moderate expected harm during quakes. Since the windscreen is the chimney stack's outer shell, its protection is essential to the overall primary display. The current seismic regulations are an amalgam of advanced design guidelines and lessons learned from previous seismic events. The analysis highlights the necessity of evaluating newly constructed fireplaces, especially those that were constructed prior to the implementation of modern codes, to ensure their compliance with current security standards. Unlike previous plan standards that required precise seismic layouts, the current requirements emphasize robust foundational designs to increase the adaptability of contemporary chimney stacks. The analysis also delves into the interaction between stacks and wind stacks, which is a fundamental concept for constructions exposed to changing environmental conditions.This study contributes significant information to the field of primary designing by revealing insight into the seismic way of behaving of RC chimney stacks and their reaction to wind loads.

Wind's impact on RC chimneys is particularly significant because of their height and narrow profile. Tall designs suffer significant parallel powers from wind pressure, much as chimney stacks. These lateral wind loads have a fundamental impact on the primary behavior of RC chimneys. Because wind forces are a unique concept, a thorough inspection of their possessions is necessary to ensure the integrity and strength of the chimney stack structure. Another significant test of RC smokestacks' principal strength is seismic activity. Dynamic and normal loads from earthquakes can exert enormous pressure on a structure. Code managers typically recommend a semi-static methodology for assessment while handling seismic burdens.

Fig. 1 Insights of RC Chimney

In summary, Primary trustworthiness of RC chimney stacks is significantly impacted by wind, seismic, and temperature loads. This section gives a far-reaching investigation of the difficulties presented by these heaps, with a specific spotlight on the powerful idea of wind and seismic powers and the semi-static methodology suggested for seismic burden assessment. Understanding and relieving the effects of these heaps are fundamental for guaranteeing the well-being and unwavering quality of RC smokestacks in assorted natural circumstances.

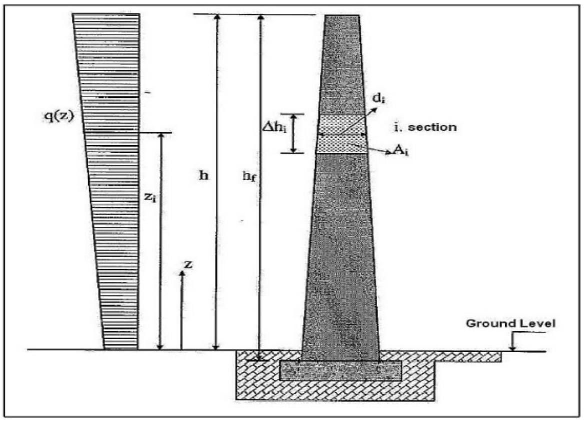


Fig. 2 Effect of load on RC Chimney

Dynamic Response and Resonance:

Reducing the dynamic response and resonance brought on by wind loads is one of the design issues in chimney construction. Reverberation occurs when the frequency of wind-induced vibrations coincides with the regular frequency of the chimney stack construction, causing intensified movements and anticipated subsurface damage. Engineers mitigate reverberation affects and ensure the primary reliability of stacks in windy situations by employing techniques such as vibration dampening, modular testing, and unique investigation.

Objectives of study

- To investigate the effect of wind load and earthquake load on the chimney computed in accordance with IS 875 (Part-III)-2015 and IS 1893-2016.
- To analysis the shear force and bending moment of chimney subjected to wind and earthquake loading for different H/d and D/d ratio chimney
- To analysis the displacement, absolute pressure and shell stressof chimney subjected to wind loading and earthquake loading for different H/d and D/d ratio chimney
- Comparative analysis on the effect of different H/d and D/d ratio of chimney on shear force, bending moment, displacement, absolute pressure and shell stress.

2. Literature Review

Datta et al. (2024) proposed a robust design optimization approach for concrete chimneys, which demonstrated its effectiveness in generating more robust designs under random loading conditions. This research contributes valuable insights to structural engineering and risk mitigation, particularly in the face of diverse and unpredictable loading scenarios. Kahkzand et al. (2024) suggested that combining windcatchers and radiative cooling techniques can improve ventilation rates and airflow in indoor spaces, reducing indoor temperatures by up to 3°C during peak hours, increasing air exchange rates by up to 8.3 and 7.8 air changes per hour, and enhancing overall ventilation without relying solely on mechanical systems. Longarini et al. (2024) reviewed seven significant built-up concrete chimney stacks to assess the feasibility of retrofitting them with Tuned Mass Dampers (TMDs). The study found that the slenderness ratio significantly enhances TMD parameters and mitigates seismic effects, while mathematicalcharacteristics minimally affect equivalent damping. Baldeh et al. (2024)

compared the effectiveness of fenestrated endovascular aneurysm repair (FEVAR) and chimney graft endovascular aneurysm repair (ChEVAR) for juxtarenal aortic aneurysms (JAAs), finding both methods had similar rates of postoperative mortality, acute kidney injury, and major adverse cardiac events. Bhatt et al. (2023) introduced a stress-strain model for cement and steel, deviating from the prescribed design codes. Gupta et al. (2023) researched the behavior and performance of built-up RCC chimneys at different heights using an enhanced lumped mass method and comparing single-degree-of-freedom and multidegreeoffreedom systems. Wang et al. (2022) highlighted the weakness of roundabout highly adaptable designs, such as chimneys, to vortex-induced vibration (VIV), necessitating a robust wind-resistant design.Li et al. (2020) focused on the wind-induced response of tall supported concrete stacks with varying shapes using CFD simulations and wind tunnel experiments. Wang et al. (2019) validated the accuracy of finite element analysis models in predicting chimney responses to wind-induced vibrations and identified critical factors influencing the dynamic behavior of constructed concrete chimneys. Zhang et al. (2018) conducted a comprehensive study on the wind load analysis of established concrete smokestacks using various analytical methods, providing valuable insights into the limitations and relevance of different analysis methods. The study by Turkeli et al. (2017) investigated the structural wind and earthquake analysis of reinforced concrete (RC) chimney stacks, which are increasingly vulnerable to wind storms and strong ground movements. The research found that the maximum elastic stress and shear stress increased by approximately 103.90% and 312.77% over or near the openings on the body of the RC chimneys, leading to brittle failure. Wadgave et al. (2016) highlighted the need for better understanding of the loads acting on these stacks and their structural behavior to create self-supporting designs. Jayalekshmi et al. (2015) investigated the significance of soil-structure interaction (SSI) in the study of tall reinforced concrete chimney stacks with piled raft foundations subjected to wind loads. Kaluram et al. (2015) emphasized the importance of specific geometric parameters, such as diameter-to-height ratio and the thickness of the concrete shell, in ensuring the structure's ability to physically resist lateral loads.

3.Methodology

This study analyzes wind loading behavior of reinforced concrete chimneys, focusing on height-to-diameter ratios. Structural analyses determine shear forces and bending moments, adhering to IS 875 guidelines.

This analysis helps design chimneys resistant to wind-induced stresses by assessing structural integrity and load distribution characteristics. It uses displacement and shell stress analyses to understand H/d ratio impact on deformation and stress distribution. The study aims to identify potential failure modes and improve plan boundaries. It uses computational strategies and limited component examination to understand wind stacking fireplace configuration.

Chimneys are vital structures in industries, facilitating the safe expulsion of gases and fumes generated during various processes. Their design and construction demand meticulous consideration of factors like height, diameter, material strength, and environmental conditions. In this analysis, we examine four chimney models – Model I, Model II, Model III, and Model IV – each with distinct specifications and characteristics.

The table presents four RCC chimney models for use in Jaipur, varying in height, diameter, flue count, material properties, and environmental factors. Each model follows Indian Standard codes for structural design and analysis, with varying top and bottom diameters and H/d ratios. All models incorporate a single flue and uniform thicknesses for cell walls, air gap, and firebrick lining, ensuring structural integrity, thermal insulation, and fire resistance.

The concrete grade used in all models is M-35, indicating a high-strength concrete mix suitable for structural applications. Similarly, Fe-500 steel grade is used for reinforcement, providing adequate strength and ductility. The modulus of elasticity for both steel and concrete is consistent across all models, facilitating uniform analysis and design considerations.

Standardization of the coefficient of thermal expansion guarantees uniform performance under temperature changes. In order to avoid structural deformations brought on by heat stresses, this value is crucial. STAAD Pro, a evaluating complicated structures like chimneys, is used for structural analysis and design. The IS codes adhered to guarantee performance and safety conformity with Indian standards.

In conclusion, every model reflects a distinct design strategy based on particular needs for diameter and height. All models meet strict commonly used program for modeling and

requirements and take environmental conditions, material strength, and structural stability into account, even if their size may differ. These RCC chimneys have been carefully designed and analyzed using the right software and standards to ensure that they can survive the rigors of their Jaipur operating environment.

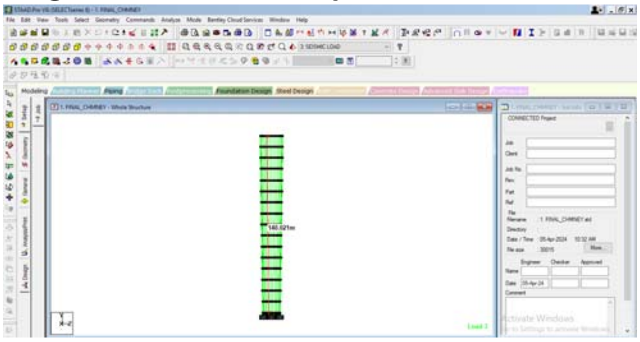
Table 1: General Parameter for RC Chimney Design

Parameter	Model-I	Model-II	Model-III	Model-IV
Height (H)	140 m	140 m	180 m	180 m
Top Diameter (D) (Inner)	10 m	8 m	11 m	9 m
Top Diameter (D_0) (Outer)	10.30 m	8.30 m	11.30 m	9.30 m
Bottom Diameter d (Inner)	14.00 m	11.00 m	13.00m	10.20 m
Bottom Diameter (do) (Outer)	14.30	11.30	13.30	10.50
H/d ratio	10 m	12.72 m	13.84 m	17.64 m
D/d ratio	0.714	0.727	0.85	0.88
No of Flues	1			
Thickness of Cell at Bottom	0.15m			
Thickness of Cell at Top	0.15m			
Thickness of air gap	0.08m			
Thickness of Fire brick Lining	0.15 m			
Bearing capacity of soil(kN/m^2)	160			
City	Jaipur			
Wind Zone	Zone-IV			
Wind Speed	47 m/s			
Concrete Grade	M-35			
Steel Grade	Fe-500			
Modulus of Elasticity of Steel	2.05 X 10□ MPa			
Modulus of Elasticity of Concrete (MPa)	0.26 X 10□			
Coefficient of thermal expansion (per □C)	11×10^{-6}			

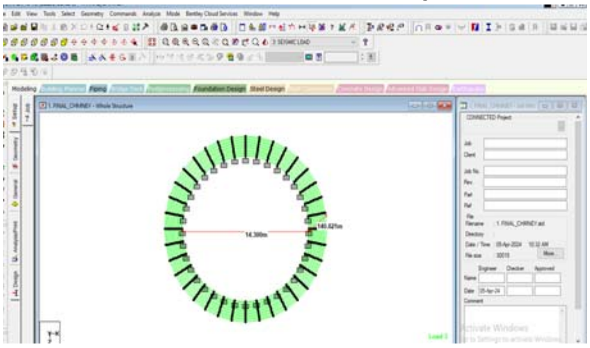
Detail of Four Models of Chimney

Model I

Height Detail of Chimney

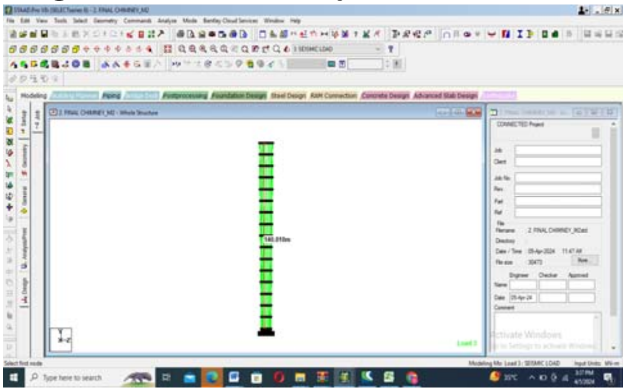


Diameter Detail of Chimney

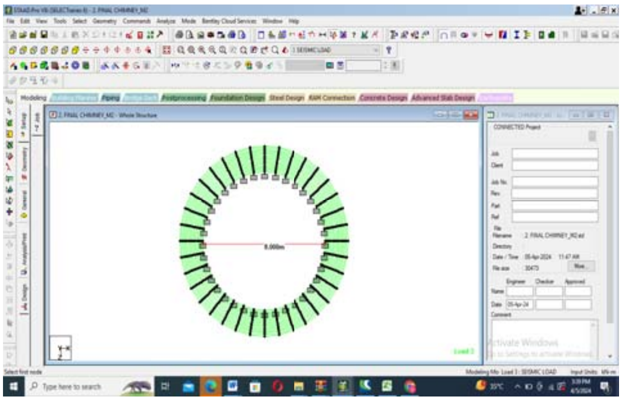


MODEL-II

Height Detail of Chimney

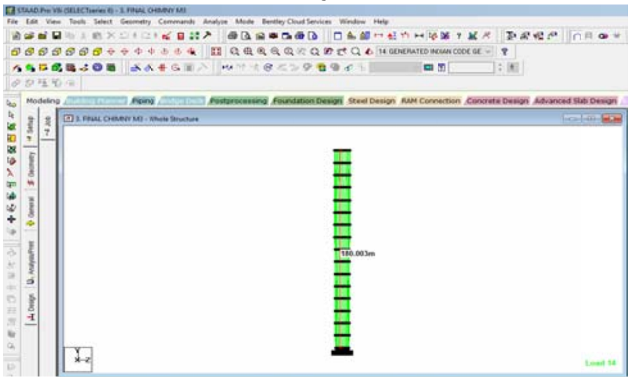


Diameter Detail

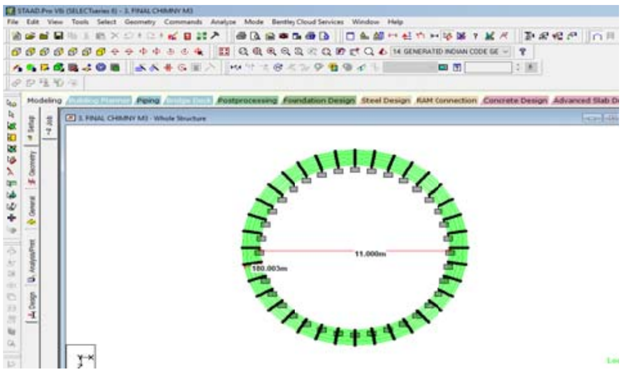


Model-III

Height Detail of Chimney

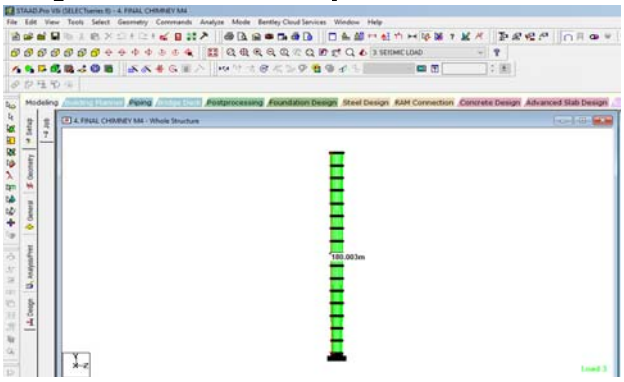


Diameter Detail

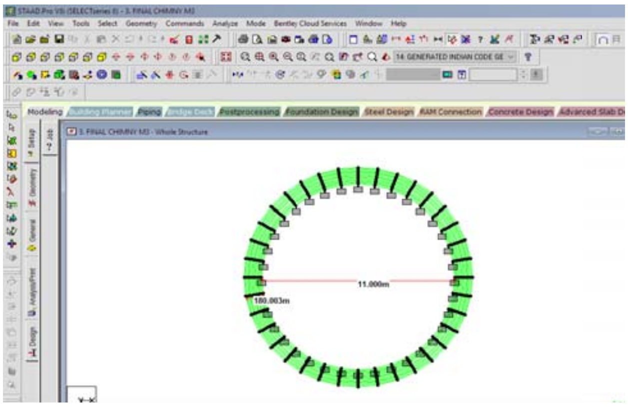


Model -IV

Height detail of Chimney



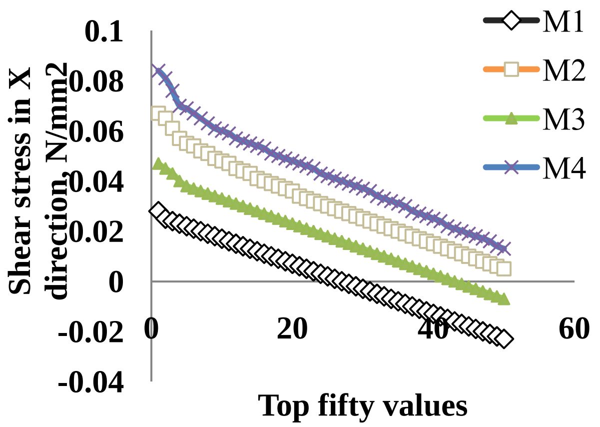
Diameter Detail



4. Result and Discussion

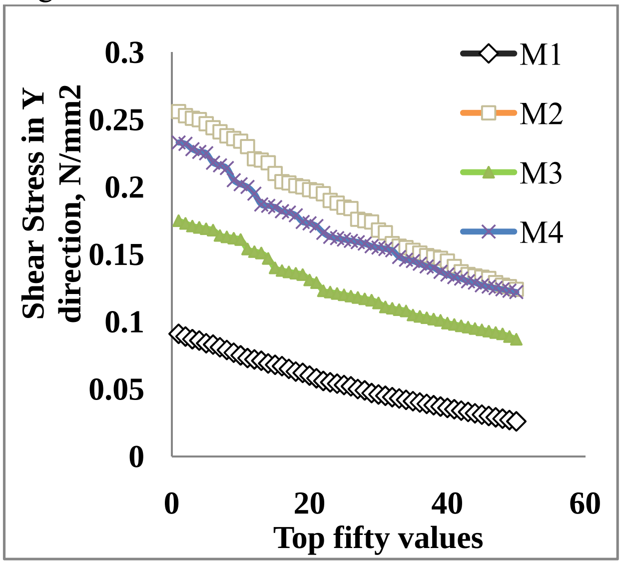
Comparison of Shear stress in X direction

The study reveals that variations in H/d and D/d ratios among four models result in unique structural characteristics and corresponding shear values. Higher H/d ratios cause increased shear, while D/d ratio changes cause varying shear behavior, highlighting the importance of considering these parameters.



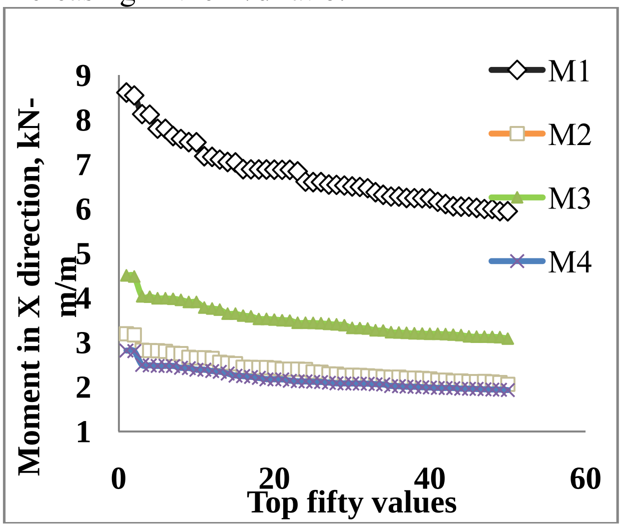
Comparison of Shear Stress in Y direction

The H/d ratio, the ratio of height to bottom diameter, significantly influences shear force. Models M1 and M2 exhibit this trend, with M2 experiencing greater shear forces due to its larger bottom diameter**.**



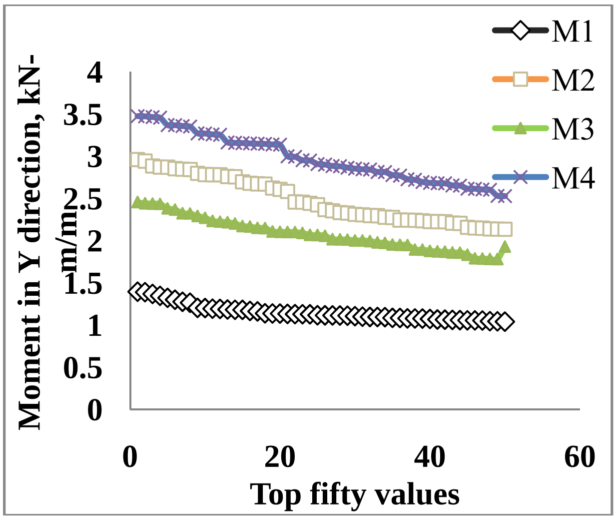
Comparison of Moment in the X direction

In analyzing the impact of H/d ratios on moment distribution, Hence, a very interesting result is observed in Model M1 and M2 where the height of the structure is 140 showing that by increasing the H/d ratio the moment in x direction decreases with the increment in D/d ratio. Further, In Models M3 and M4 where the height is 180 m shows the same trend that the moment in X direction decreases after increasing in the H/d ratio.



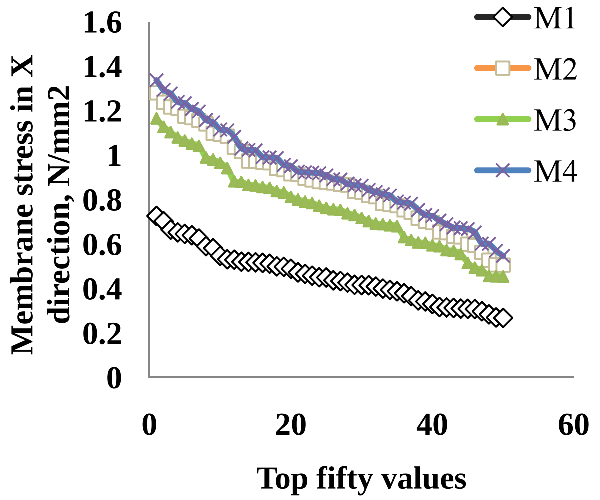
Comparison of Moment in the Y direction

The study reveals that the moment in the Y direction increases with an increase in the H/d ratio, particularly in Models M1 and M2, and higher in Models M3 and M4.



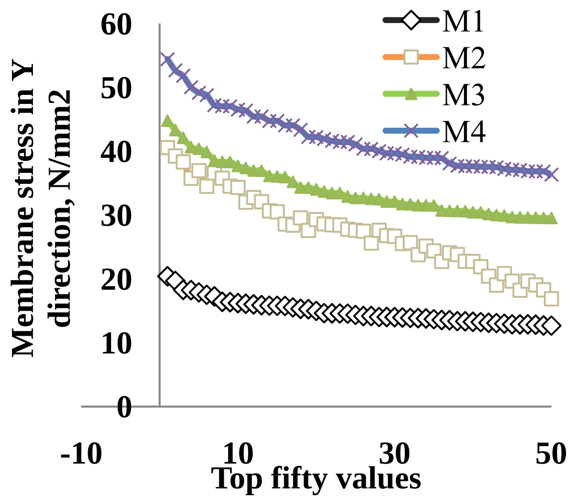
Comparison of Membrane Stress in X direction

The study reveals that H/d and D/d ratios significantly influence structural behavior. Higher H/d ratios result in uniform force distributions, while lower ratios indicate concentrated force distributions. Understanding these relationships is crucial for engineers to design structures for complex real-world applications.



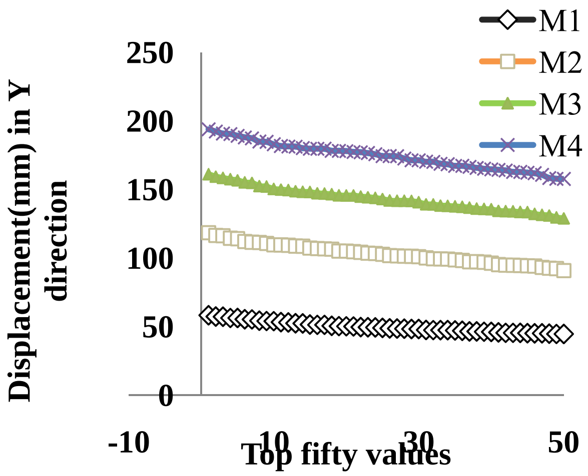
Comparison of Membrane Stress in Y direction

The H/d ratio significantly influences membrane force distribution among models. Models with higher H/d ratios, like M2 and M4, have higher membrane forces in the Y direction due to their increased height relative to diameter. Conversely, models with lower H/d ratios experience more concentrated loads, resulting in lower membrane forces.



Comparison of Displacement in Y direction

The dataset shows displacement values for four models, M1, M2, M3, and M4. Each model has varying degrees of displacement, influenced by their height-to-diameter and diameter-to-diameter ratios. The displacement increases with the H/d and D/d ratios.



Comparison of Minimum and Maximum Absolute Pressure

The data shows minimum and maximum absolute pressure values for four models, M1, M2, M3, and M4. The minimum values range from 0.108 to 0.053 N/mm2, while the maximum values range from 29.29 to 65.8 N/mm2, indicating a progressive increase in pressure magnitude from Model 1 to Model 4.

Table 2: Minimum and Maximum Absolute Pressure

Model	Min. Absolute Pressure (N/mm^2)	Max. Absolute Pressure (N/mm^2)
M1	0.108	29.29
M2	0.072	50.4
M3	0.078	56.1
M4	0.053	65.8

Comparison on Reaction in X and Ydirection

The data shows reactions in the X-direction for four models, M1, M2, M3, and M4, with varying reaction forces, ranging from 309.406 kN for Model 1 to 511.88 kN for Model 4 and in the Y direction shows varying reaction forces across four models, with Model 2 exhibiting the strongest force at 5466.803 kN, while Model 3 showed the strongest force at 8354.592 kN.

Table 3: Reaction in X & Y direction

Model	Reaction in X dir (kN)	Reaction in Y dir (kN)
M1	309.406	5746.167
M2	319.041	5466.803
M3	438.712	8354.592
M4	511.88	7945.433

5. Conclusions

As a result of increased lateral forces and wind loading, the research concludes that models with larger H/d ratios, such M2 and M4, display heightened shear forces, membrane forces, and moments in both the X and Y directions. Because of their higher structural compactness, these models also exhibit higher displacement and lower minimum absolute pressure values. Model M2 is the best design for structural applications because of its harmony between increased stability and mild displacement. It is appropriate for high-rise structures that need to be resilient and robust against outside pressures due to its effective force redistribution and reduced pressure values. The

Model M2 provides the best possible balance between structural integrity, stability, and height.

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