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Comparative Study on the Wind Resistance of RC Frames with Staircase, Core and Infill Walls

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Abstract: Tall buildings are highly vulnerable to significant lateral displacements resulting from wind and other horizontal forces. To counteract these effects, incorporating efficient lateral load-resisting systems is vital. Commonly employed systems include moment-resisting frames, shear core walls, and dual systems that integrate both to enhance overall structural stability. This research offers a comparative evaluation of different lateral load-resisting configurations using STAAD. Pro V8i. Ten detailed three-dimensional reinforced concrete (RC) models of G+30 storey buildings were developed. These models incorporate varied combinations of staircases, core walls, and masonry infill walls. The study examined a bare frame, a frame with both external (200 mm) and internal (100 mm) infill walls, and additional models featuring only external infill walls of varying thicknesses (200 mm, 150 mm, and 100 mm). Top-storey lateral displacements under wind loading were analyzed for each configuration. The findings reveal that incorporating non-structural elements such as staircases, core walls, and infill masonry significantly boosts the lateral stiffness of the structure. This highlights the necessity of accurate modeling of these components to ensure dependable structural behavior and improved wind resistance in tall buildings.

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I. INTRODUCTION

As the height of a building increases, its exposure to lateral forces—particularly those caused by wind and seismic activity—becomes more significant. In tall structures, these forces must be explicitly addressed during the design process, as they play a crucial role in determining the structural performance and overall stability of the building. When lateral loads dominate the design considerations, the building is typically classified as a high-rise. These structures are prone to notable lateral displacements and inter-storey drifts, which can compromise both structural integrity and occupant comfort. As a result, incorporating effective systems to resist lateral loads is essential for ensuring both safety and serviceability.

To counteract these lateral forces, various structural systems are utilized, including moment-resisting frames, shear core walls, and dual systems that combine the two. Each system provides unique benefits in terms of stiffness, load-carrying capacity, and energy dissipation. Key parameters used to evaluate the performance of these systems include peak inter-storey drift and overall lateral displacement, both of which indicate the structure's ability to remain stable and functional during lateral loading conditions.

For Structural Engineers, choosing the right lateral load-resisting system is critical to controlling deformations within the permissible limits established by relevant codes and standards. Among the most effective solutions are shear-resisting components such as core walls, stairwells, and infill masonry walls. These elements significantly enhance the stiffness and strength of tall buildings and are an integral part of contemporary design strategies aimed at achieving optimal lateral performance.

II. LITERATURE RIEVIEW

Staircases, often designed primarily for vertical circulation, been shown to significantly influence the lateral stiffness and seismic behavior of reinforced concrete (RC) frame structures. Numerous studies have identified their structural contributions and the associated challenges under dynamic loading conditions.

Lavado et al. (2004) emphasized the critical role of staircases during seismic events in RC frame buildings. Their comparative analysis of buildings with and without stair slabs revealed the formation of localized stiffness around stairwells. This "shear wall-like" behavior amplifies axial forces in adjacent columns and beams, thereby affecting the overall strength and ductility demands, often

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overlooked in simplified models.

Cosenza et al. (2008) investigated the performance of existing moment-resisting RC frames and highlighted that staircases not only increase the overall stiffness of the structure but also reduce the fundamental time period. However, this stiffness can inadvertently attract higher seismic forces, potentially leading to brittle failure in short columns subjected to shear.

Wang et al. (2009) studied the seismic dynamics of buildings integrated with stairwells. Their findings indicated a significant rise in lateral stiffness and notable changes in internal force distribution and nodal responses during ground motion excitations.

Ke et al. (2009) identified staircase-associated elements such as corner columns, beams, and slabs as the most vulnerable under seismic loading, frequently yielding before the rest of the structure. This suggests that staircases often act as the first line of failure in RC frames.

Cuiqiang et al. (2010) examined the contribution of stair stiffness at nodal points and observed that decoupling the stair stiffness can alter the mode shapes and fundamental vibration direction of the building, underlining the influence of staircase geometry and orientation.

Cheng et al. (2011) analyzed staircase configurations in masonry stairwells and RC frames and found that the step slabs act akin to K-type braces, reducing floor-level shear deformation. However, their inclusion also increased internal force demands on stair components.

Zhu et al. (2011) conducted a performance-based assessment comparing models with and without staircases. They detailed the dual nature of staircases as both structural contributors and potential seismic hazards, offering practical guidelines for design and retrofitting.

Zhang et al. (2011) further reinforced that staircases function as K-type braces in multistory frames. While they enhance lateral stiffness and reduce deformations, this effect is frequently ignored in conventional structural design. The authors recommended design adaptations and retrofitting measures to account for these forces in new and existing structures.

Asteris et al. (2012) studied infill walls but proposed a similar concept for any structural appendage (like staircases), emphasizing how non-structural elements alter global dynamic properties such as mode shapes and stiffness centers

Danish et al. (2013) also noted the contribution of non-structural elements like infill walls to overall building stiffness. Their findings serve as a benchmark when comparing the stiffness contributions of staircase slabs, emphasizing their role in modifying time periods and inter-storey drifts.

Mark and Sreevalli (2021) conducted a nonlinear analysis of RC frames with and without infill using ABAQUS software. Their study showed that masonry infill walls increase both lateral strength and stiffness but could become vulnerable under excessive drift, especially during cyclic wind loading. Frames with fully infilled bays demonstrated higher energy dissipation compared to those with openings.

III. METHODOLOGY

➤ *Model Parameters*

Table 1 Model Parameters

Parameter	**Value**
Building Type	RC Frame
Plan Dimensions	70.0m × 20.0m
No. of Storeys	G + 30
Storey Height	3.0m
Slab Thickness	150 mm

➤ *Material Properties*

The structural components were modeled using M30 grade concrete and Fe500 steel. The stress-strain behavior follows IS 456:2000. Below are the material properties:

Table 2 Material Properties

Property	**Value**
Characteristic Strength of Concrete (F_{ck})	30 MPa
Yield Strength of Steel (F_y)	500 MPa
Modulus of Elasticity of Steel (E_s)	210,000 MPa
Ultimate Strain in Bending (ε_u)	0.0035

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➢ *Structural Modelling and Configuration*

In this study, ten different configurations of reinforced concrete (RC) frames have been analyzed to evaluate the influence of staircases, core walls, and infill wall arrangements on the lateral behavior of high-rise buildings. The structural models include a bare frame, as well as frames incorporating various combinations of internal and external masonry infill walls. Specifically, the configurations consist of:

- A bare frame (without infill or staircase),
- A frame with both external and internal infill walls (200 mm and 100 mm thick, respectively),
- Frames with only external infill walls of varying thicknesses (200 mm, 150 mm, and 100 mm),
- Additional variations of these configurations with or without the inclusion of staircase and core wall elements.

All models represent a 30-storey (G+30) RC structure, with a total plan dimension of 70.0 m × 20.0 m. Each storey has a uniform floor-to-floor height of 3.0 meters. The base of every structure is assumed to be fixed at ground level, ensuring full restraint against movement and rotation.

The floor system is modeled using a solid reinforced concrete slab of 150 mm thickness, spanning between beams. All structural components—beams, columns, slabs, and walls are considered to be made of homogeneous, isotropic material, with identical elastic modulus values in both tension and compression.

The standard dimensions and cross-sections of various structural members used across all models are summarized below:

➢ *Structural Member Details*

Table 3 Structural Member Details

Member Type	**Dimensions (mm)**
Plinth Beams	300 × 400
Floor & Roof Beams	300 × 500
Columns	300 × 1200
External Infill Walls	100, 150, and 200
Internal Infill Walls	100
RCC Slabs	150

- *Loads Considered*

The structural analysis was carried out by applying the following loads according to the relevant Indian Standards:

- *Dead-Load*

Applied as per the guidelines specified in **IS 875: Part I – 1987**. This includes the self-weight of structural elements such as slabs, beams, columns, walls, and finishes.

- *Live-Load*

Imposed loads were considered based on the recommendations in **IS 875: Part II – 1987**, representing occupancy-related loads such as furniture, occupants, and movable equipment.

- *Wind*

Wind effects were evaluated in accordance with **IS 875: Part III – 2015**, considering factors such as basic wind speed, terrain category, building height, and exposure conditions.

IV. RESULTS AND DISCUSSION

➢ *General Observations*

The models analyzed consist of ten structural configurations with and without staircases, core walls, and varying infill wall thicknesses. The focus was on evaluating the lateral displacements caused by wind loads. All structures were 30 stories tall (G+30), with a total height of 93 meters and plan dimensions of 70.0 m x 20.0 m. The wind load was modeled using a basic wind speed of 39 m/s as per IS 875 Part III.

➢ *Model Classification*

The different models were categorized as follows:

- RF1 / RFSC1 – Bare frame (with/without staircase and core wall)
- RF2 / RFSC2 – Frame with external infill (200 mm) and internal infill (100 mm)
- RF3 / RFSC3 – Frame with only external infill (200 mm)
- RF4 / RFSC4 – Frame with only external infill (150 mm)
- RF5 / RFSC5 – Frame with only external infill (100 mm)

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➢ *Lateral Displacement vs. Height for Different Structural Configurations*

- *Case 1: Bare Frame*

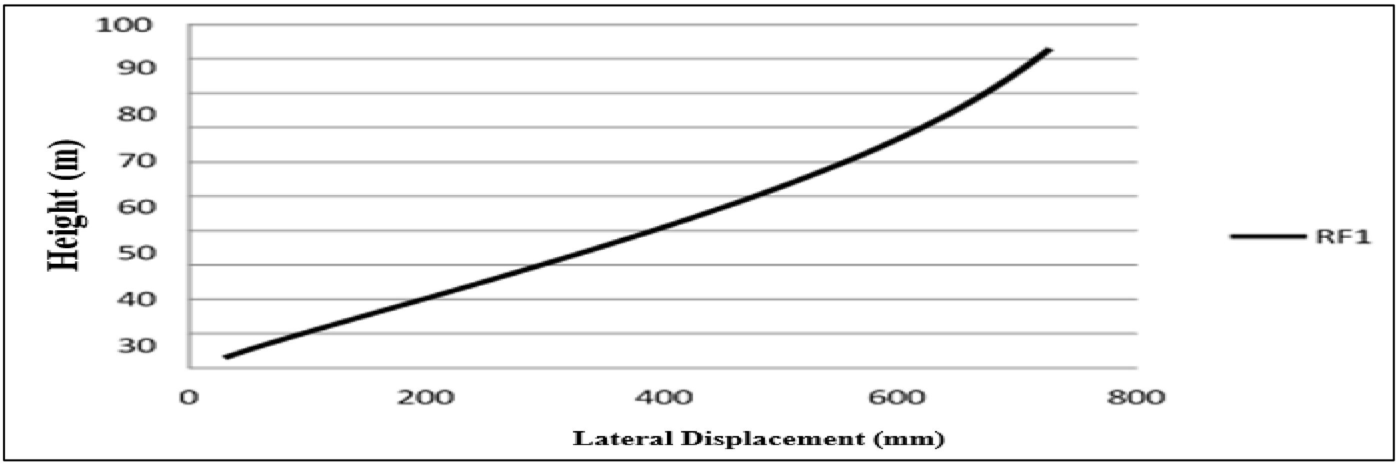

Fig 1 RF1

- *Case 2: Frame with 200 mm External Infill and 100 mm Internal Infill Walls*

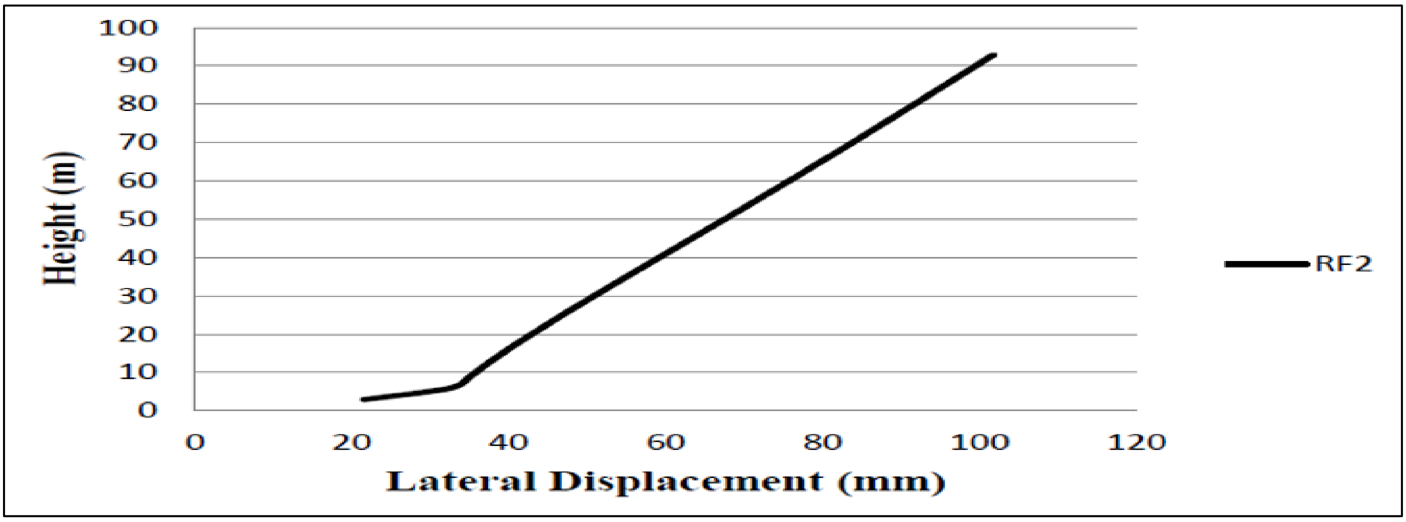

Fig 2 RF2

- *Case 3: Frame with Only External Infill Walls of 200 mm Thickness.*

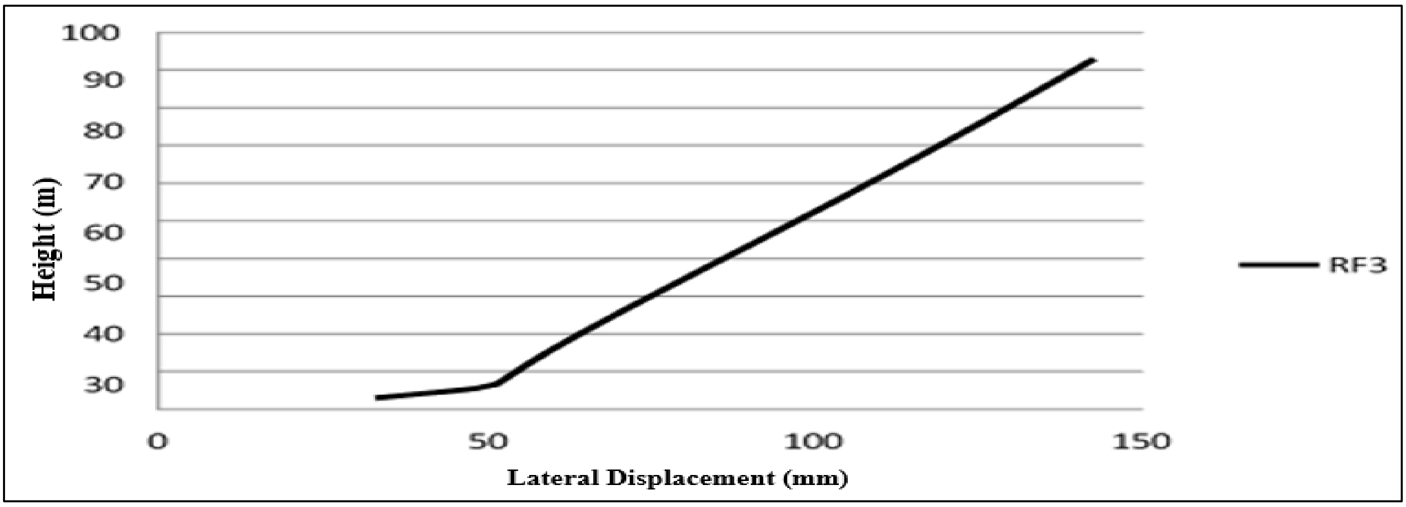

Fig 3 RF3

- *Case 4: Frame with Only External Infill Walls of 150 mm Thickness*

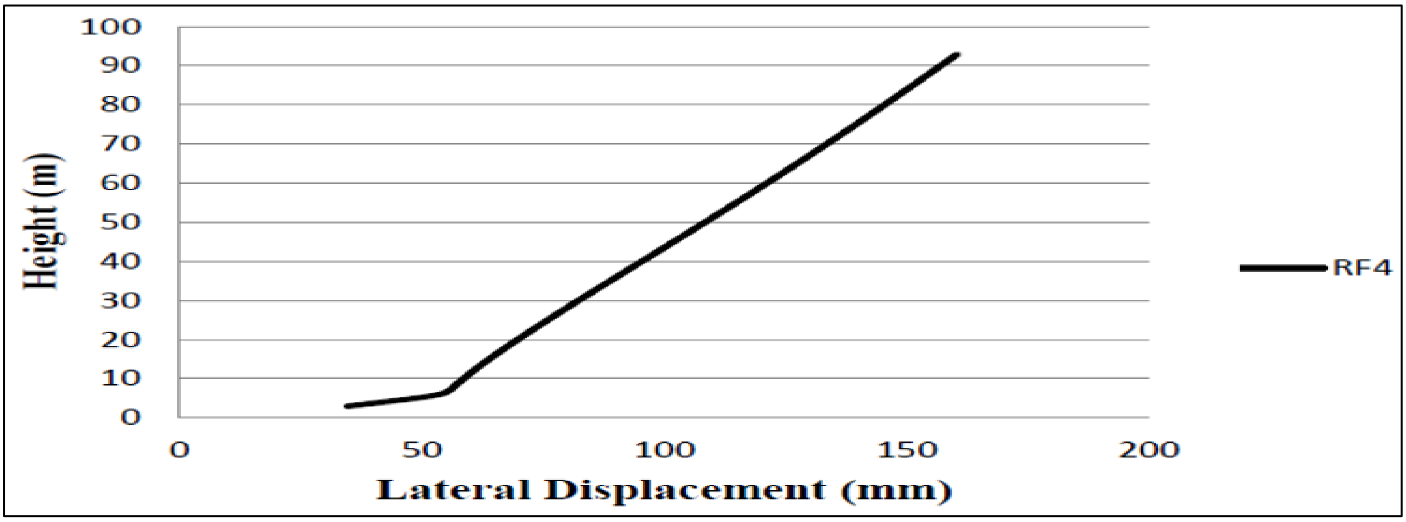

Fig 4 RF4

- *Case 5: Frame with Only External Infill Walls of 100 mm Thickness*

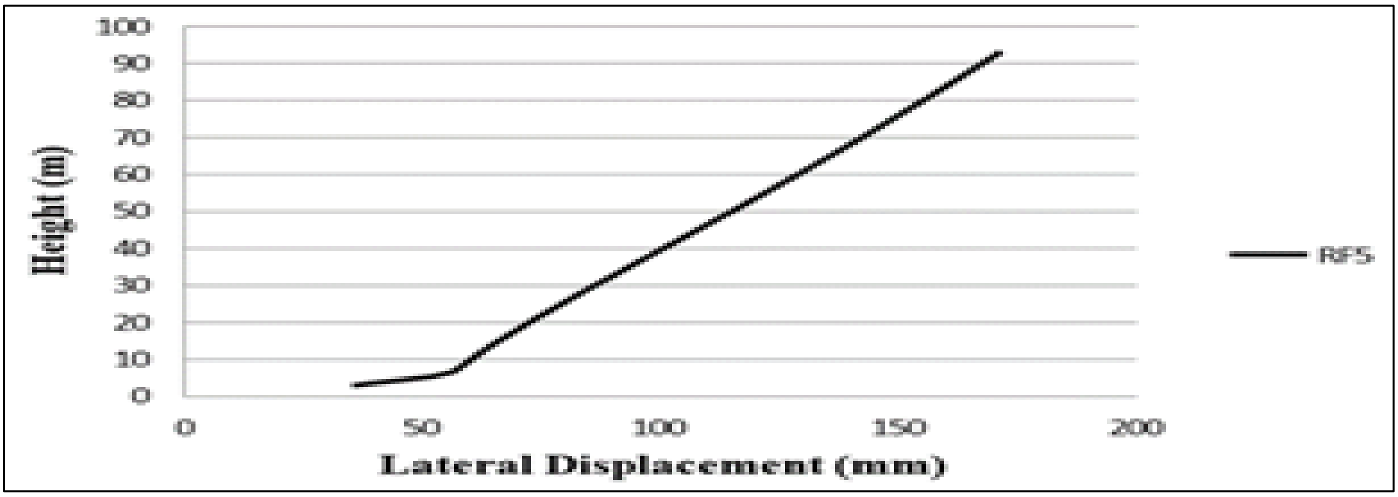

Fig 5 RF5

- *Case 6: Frame with Staircase &Core walls*

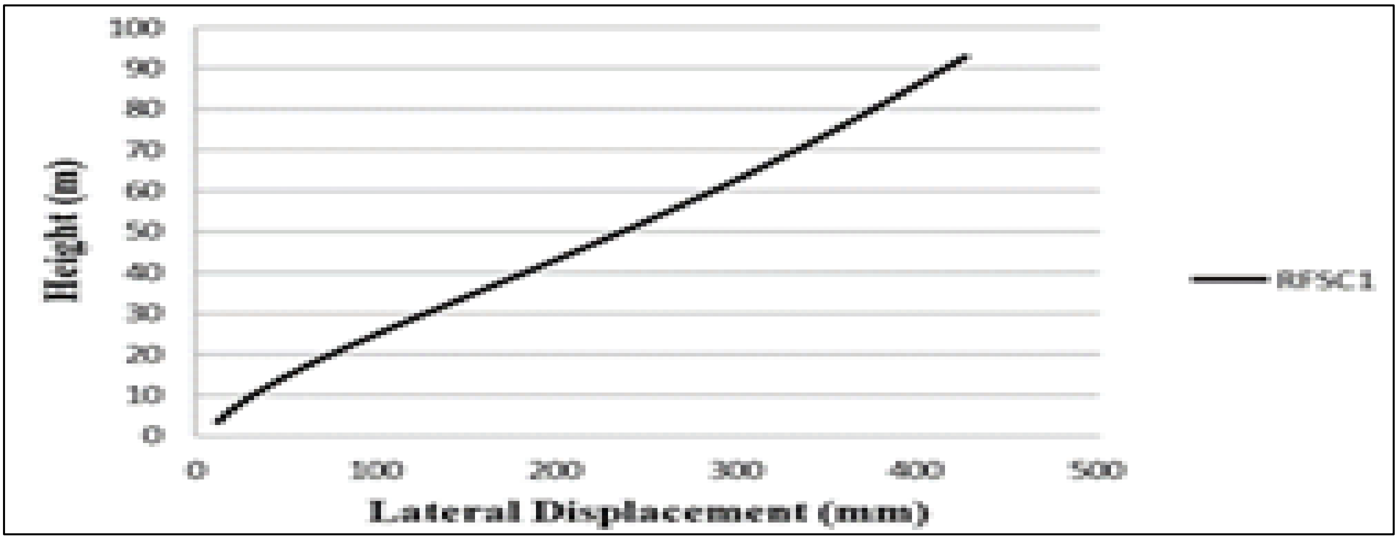

Fig 6 RFSC1

- *Case 7: Frame with Staircase, Core Wall, 200 mm External Infill, and 100 mm Internal Infill Walls*

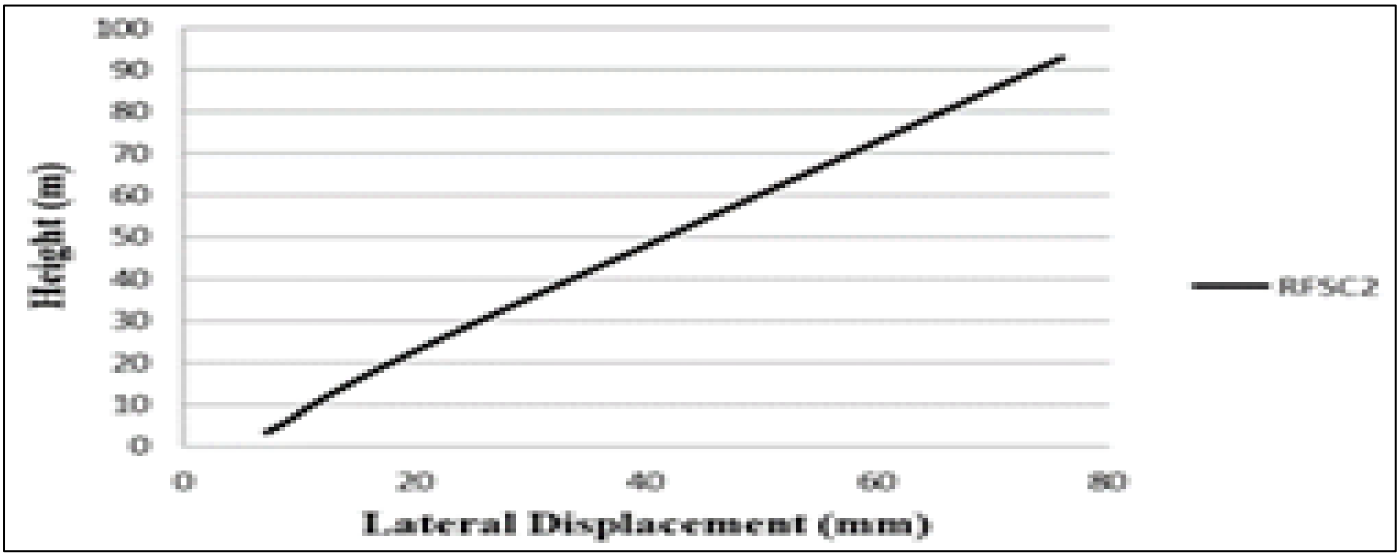

Fig 7 RFSC2

- *Case 8: Frame with Staircase, Core Wall, and 200mm External Infill wall*

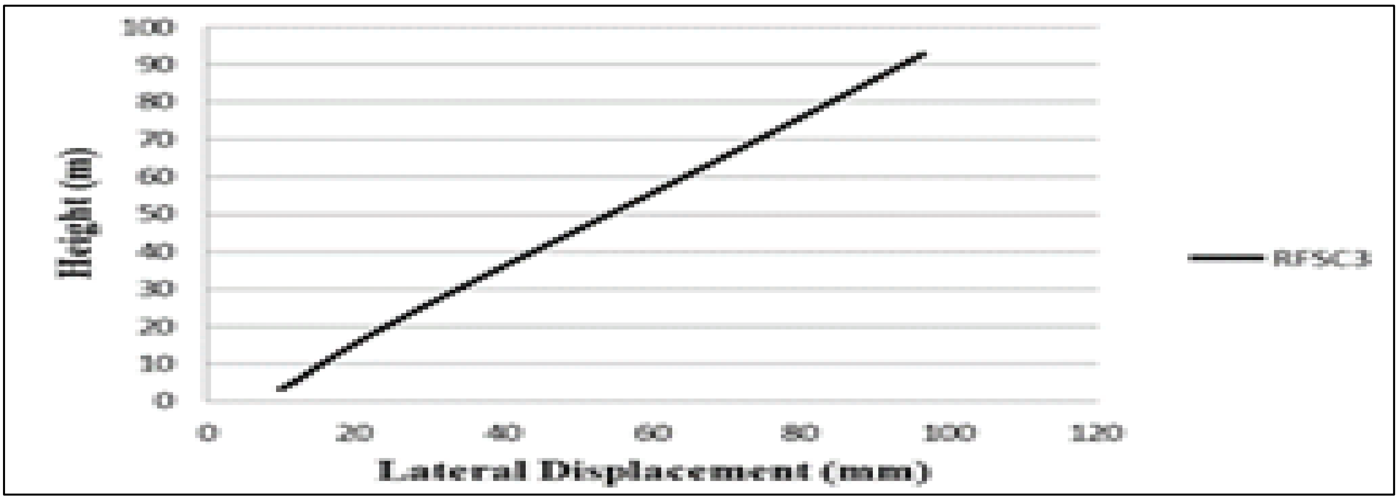

Fig 8 RFSC3

- *Case 9 Frame with Staircase, Core Wall, and 150mm External Infill wall*

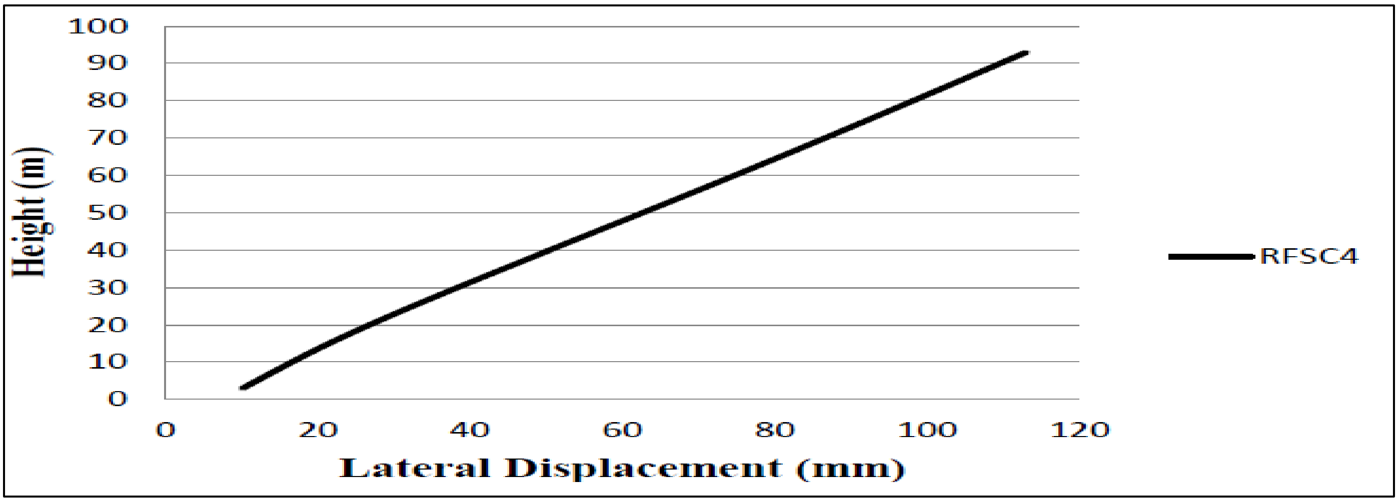

Fig 9 RFSC4

- *Case 10: Frame with Staircase, Core Wall and 100mm External Infill wall*

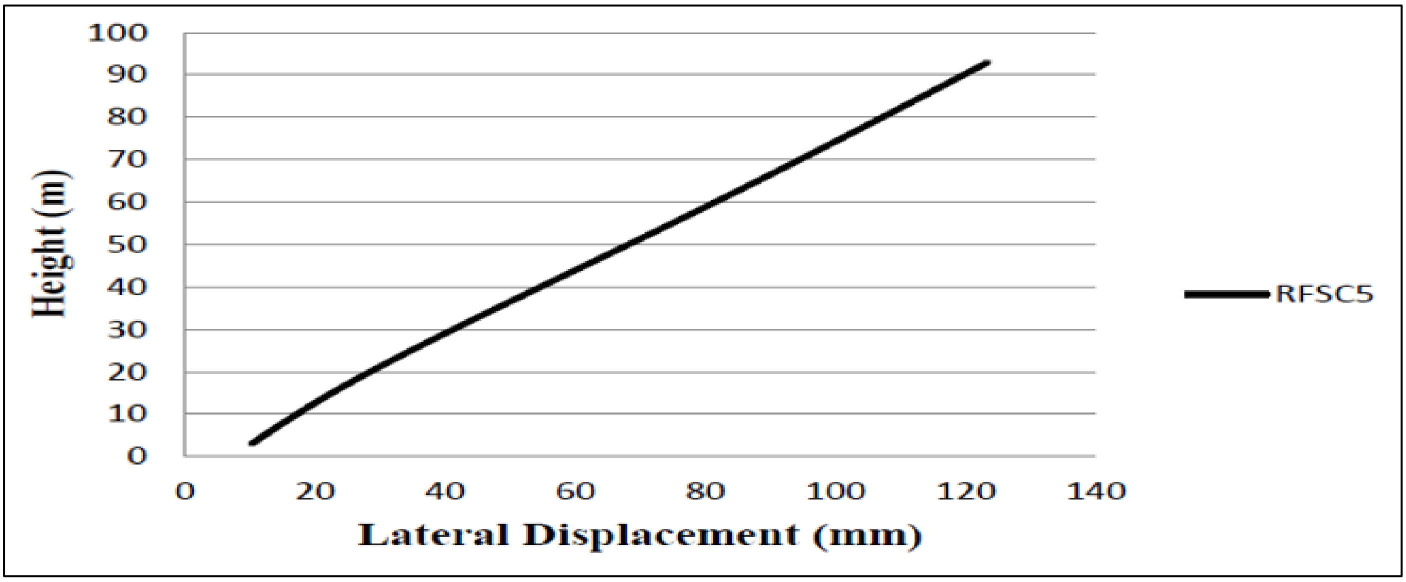

Fig 10 RFSC5

- *Comparison -1*

Table 4 Comparison between Bare Frame (RF1) and Frame with External infill 200mm & Internal infill 100mm (RF2)

Type of Structure	Max. Lateral Displacement (mm)	Permissible Lateral Displacement (mm)	Percentage of Variation in Lateral Displacement ((RF1-RF2)/RF1))X100
Bare Frame (RF1)	737.82	186	85.73
Frame with external infill 200mm and internal infill 100mm (RF2)	105.23	186	

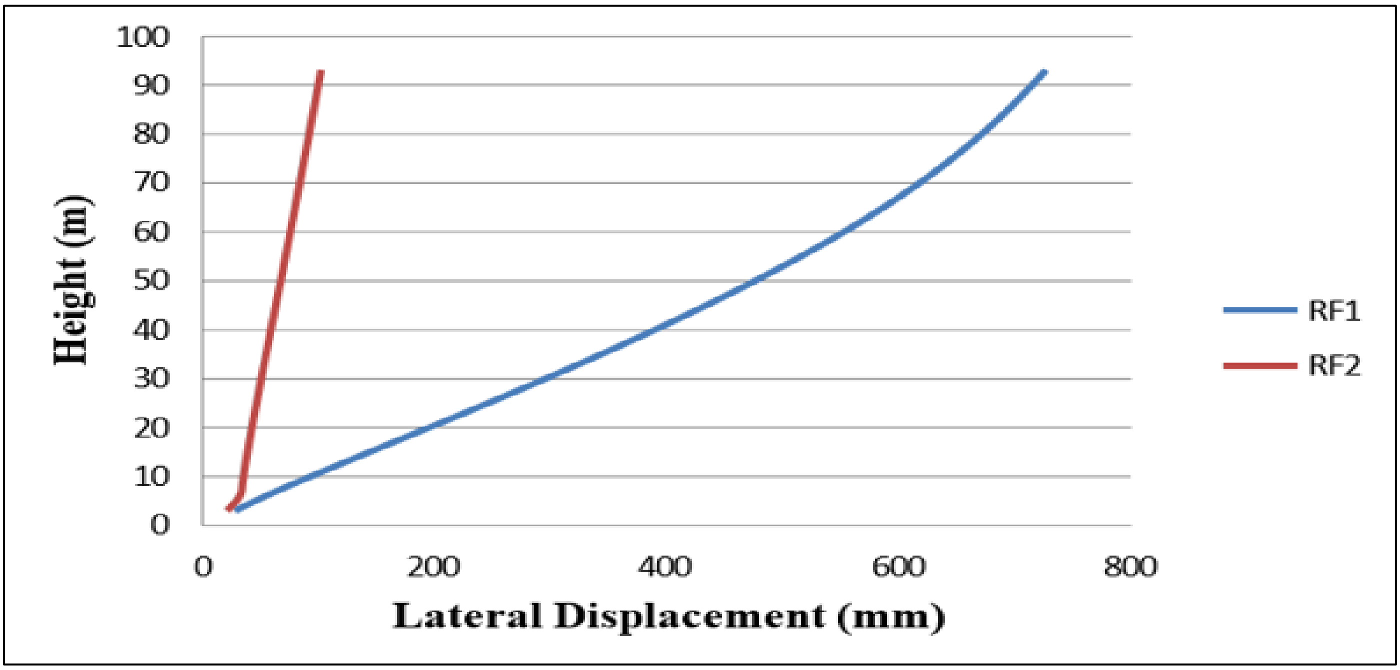

Fig 11 Comparison of Lateral displacement Vs Height for Bare frame (RF1) and Frame with External infill 200mm & Internal infill 100mm (RF2)

➢ *Comparison-11*

Table 5 Comparison between Bare Frame (RF1) and Frame with Staircase & Core wall (RFSC1)

Type of Structure	**Max. Lateral Displacement (mm)**	**Permissible Lateral Displacement (mm)**	**Percentage of Variation in Lateral Displacement** ((RF1-RFSC1)/RF1))X100
Bare Frame (RF1)	737.82	186	41.49
Frame with staircase and core wall (RFSC1)	431.65	186	

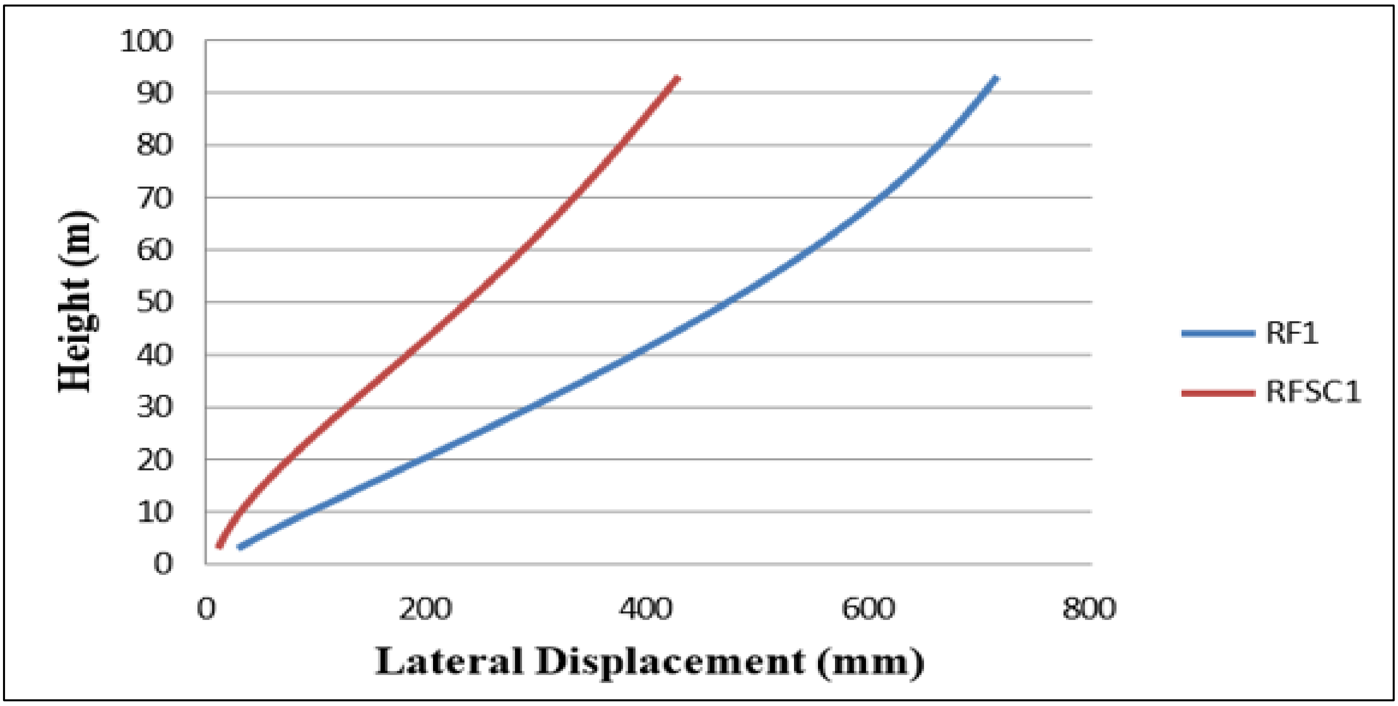

Fig 12 Comparison of Lateral displacement Vs Height for Bare Frame (RF1) and Frame with Staircase & Core wall (RFSC1)

➢ *Comparison-111*

Table 6 Comparison between Bare Frame (RF1) and Frame with Staircase, Core wall & External infill 200mm (RFSC3)

Type of Structure	**Max. Lateral Displacement (mm)**	**Permissible Lateral Displacement (mm)**	**Percentage of Variation in Lateral Displacement** ((RF1-RFSC3)/RF1))X100
Bare Frame (RF1)	737.82	186	86.62
Frame with staircase, core wall and only external infill 200mm (RFSC3)	98.75	186	

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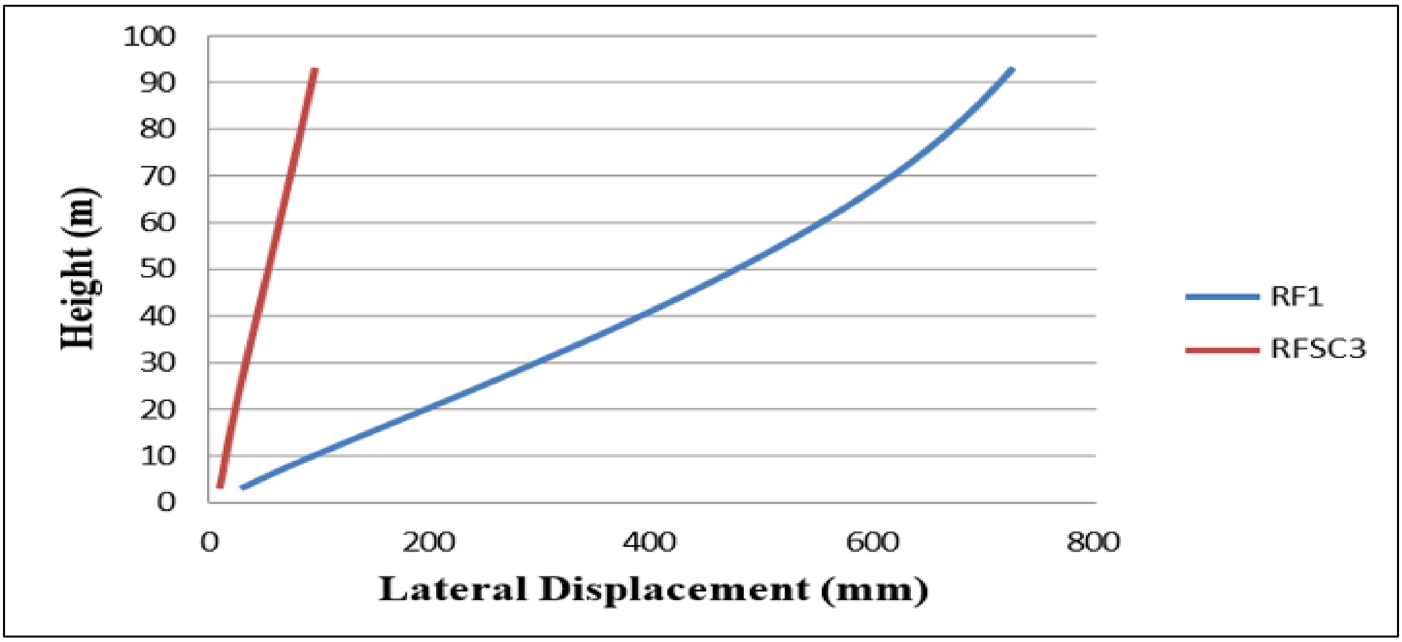

Fig 13 Comparison of Lateral displacement Vs Height for Bare frame (RF1) and Frame with Staircase & Core Wall External infill of 200mm thick (RFSC3)

V. CONCLUSION

The lateral displacement of R.C framed structure with and without considering Staircase, Core wall & Infill walls was investigated using the linear static analysis. Following were the major conclusions drawn from the study.

- Among all the configurations analyzed, the **bare frame model (RF1)** exhibited the **highest lateral displacement**, confirming the importance of additional lateral load-resisting elements.
- For most models, the **story-wise lateral displacements** remained within the acceptable limits specified by relevant design codes, with the exception of the **bare frame (RF1)** and the **frame with only staircase and core wall (RFSC1)**. Despite this, RFSC1 showed notable improvement when compared to the bare frame, highlighting the beneficial effect of including shear components.
- The **maximum improvement in lateral stiffness** was observed in the configuration that included a **staircase, core wall, and 200 mm thick external infill walls (RFSC3)**, where the **top-storey displacement was reduced by approximately 85.73%** compared to the bare frame.
- Overall, the results clearly demonstrate that **integrating the stiffness contribution** of architectural and structural elements like **staircases, core walls, and infill walls** can lead to significant reductions in lateral displacements. Accurate representation of these components in structural models is therefore crucial in the design of wind-resistant high-rise buildings.
- The analysis showed that **increasing the thickness of external infill walls** results in a noticeable improvement in lateral stiffness. Thicker infill walls (e.g., 200 mm) provided better resistance to wind-induced displacements than thinner ones (e.g.,100 mm), highlighting their structural significance.
- The combination of **staircase, core wall, and infill walls** was more effective in reducing lateral displacement than any individual component alone. This underscores the **synergistic contribution** of multiple lateral load-resisting systems working together.
- Staircases and core walls act as **integral bracing systems** even though they are often overlooked in typical frame analyses. Their inclusion can drastically enhance the overall lateral stability of tall buildings, particularly under wind loading.
- The study emphasizes the need for structural designers to **explicitly model non-structural elements** such as staircases and infill walls when evaluating wind performance, especially in high-rise construction where lateral stiffness is critical.
- Incorporating masonry infill walls, which are already required for functional and architectural purposes, can serve dual roles by also enhancing structural performance—making them a **cost-effective** addition to the wind resistance system.

SCOPE OF FURTHER STUDY

➢ *Nonlinear Behavior Assessment:*

A more in-depth understanding can be gained by conducting **nonlinear static (pushover) or dynamic (time history)** analyses to evaluate the performance of frames under extreme or progressive loading conditions.

➢ *Material Variations and Advanced Composites:*

Future studies can explore the use of **high-performance materials**, such as fiber-reinforced concrete or steel-concrete composite frames, to assess their impact on wind resistance and lateral stiffness.

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➢ *Influence of Building Geometry:*

Varying the **plan shape or elevation profile** of the building (e.g., L-shaped, T-shaped, or stepped structures) can offer additional insights into how geometry influences structural behavior under lateral loads.

➢ *Realistic Modeling of Staircase and Core Systems:*

More **detailed modeling techniques**, including stair stringers, landing slabs, and openings in core walls, can be incorporated to improve the accuracy of simulation results.

➢ *Cost-Benefit and Optimization Analysis:*

An economic analysis could be performed to **balance performance and cost**, identifying the most efficient combination of elements for wind resistance without overdesign.

➢ *Parametric Studies and Design Guidelines:*

A comprehensive **parametric study** involving multiple building heights, aspect ratios, and infill configurations can help establish more generalized **design recommendations** or simplified modeling rules for practicing engineers.

➢ *Seismic Load Analysis:*

While this study focused solely on wind-induced lateral displacements, future work can investigate the performance of these structural configurations under **seismic loads**, using both linear and nonlinear dynamic analyses

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