

# Study of Structural Behavior of High-Rise Buildings Affected by Wind Load

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## ABSTRACT

The purpose of research is to analysis reinforced concrete tall buildings affected by wind loads. A tower, ground floor plus 19 story, the structural system comprises of three systems which the first one is ordinary shear walls as lateral force resisting system the second one is the rigid frame system and the third one will be combine between shear and rigid frame; the research will compare the structural behavior of three systems individually according to the horizontal and vertical loads which are wind load, live and dead loads.

The three models will be analyzed using finite element based programs (ETABS), and (SAFE). ASCE Lateral forces resulting from wind (Directional procedure) will be manually calculated, and the results will be compared to (ETABS) for check, stability criteria and story shear resulting from wind will be compared between three systems according to:

- Maximum displacements and inter-story drifts of the three systems.
- P-delta effects.
- Comparison of Story Shear from Manual Calculation and ETABS Analysis.
- Shear and moments of elements.
- base shear and overturning moment.
- Foundation bearing capacity and Settlement.

**Keywords-** High-rise buildings, wind loads, structural behavior, rigid frame system, shear wall system, dual system, finite element analysis (FEA), ASCE, ETABS, SAFE.

## I. INTRODUCTION

In defining high-rise buildings, there is no general consensus on the height or number of stories above which buildings should be classified as tall buildings or Skyscrapers. There is different opinion in defining high-rise buildings:

By structural designers high-rise building is the buildings that require an unusual structural system and where wind loads are prominent in analysis and design.

By architectural designers as buildings requiring interdisciplinary work in particular with structural designers, and with experts in the fields of aerodynamics, mechanics and urban planning that affect design and use.

In addition, by civil engineers as buildings needing unusual and sophisticate construction techniques. Today it is almost impossible to imagine a major city without tall buildings. As the most important symbols of today’ s cities, tall buildings have become a source of faith in technology and national pride, and have changed the concept of the modern city along with its scale and appearance. Despite the fact that tall buildings have moved city life away from the human scale, in general it is accepted that these buildings are an inevitable feature of urban development.

The most important factors enabling the construction of tall buildings are developments and innovations in the following areas:

materials, construction techniques, operating (mechanical) systems, structural systems and analysis, but at the same time, the increase in the height of buildings makes them vulnerable to wind and earthquake induced lateral loads.

**II. METHODOLOGY**

A comprehensive analytical approach was adopted, combining manual code-based calculations with advanced finite element modeling.

**2.1 Building Prototype**

A 20-story residential tower (Ground + 19) with a 3-meter typical story height and a 24m x 20m rectangular plan was analyzed. The building was assumed to be located in a high-wind region (Basic Wind Speed,  $V = 62.5$  m/s) with Exposure Category B.

**2.2 Structural Systems Configurations**

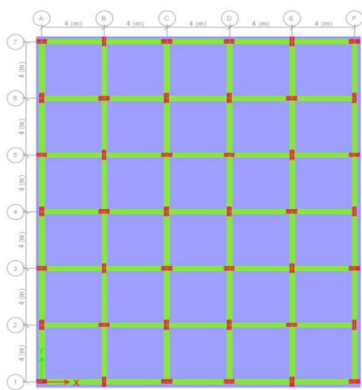
Three distinct 3D models were developed in ETABS v16.2:

Model RF (Rigid Frame): Comprising beams (700x350 mm) and columns (900x450 mm) with monolithic moment-resisting connections.

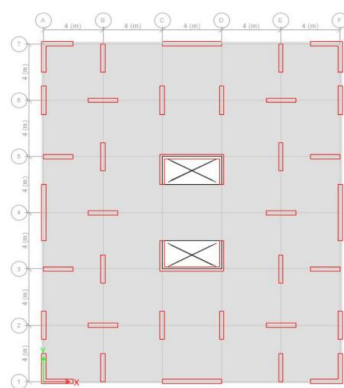
Model SW (Shear Wall): Utilizing a central core and strategically placed planar shear walls (300 mm thick) as the primary lateral system, with gravity columns.

Model DS (Dual System): A combination of the Rigid Frame and the Shear Wall system, designed to interact and resist lateral loads in tandem.

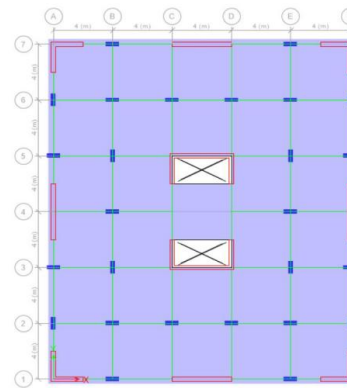
All models shared identical gravity loading: Dead Load (self-weight + 3.79 kN/m<sup>2</sup> partitions , + 2.0 kN/m<sup>2</sup> finishes) and Live Load (1.92 kN/m<sup>2</sup>). A mat foundation was modeled in SAFE 2016 for geotechnical assessment.



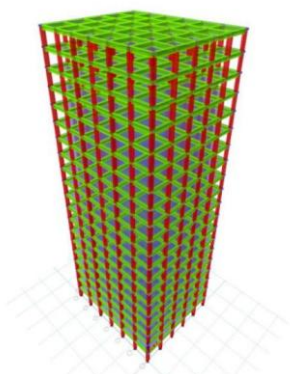
**Figure 1. Rigid Frame Plan Figure**



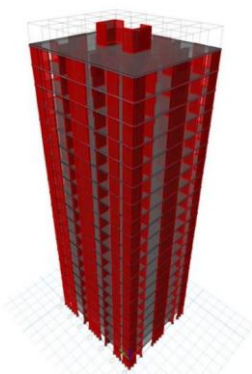
**2. Shear wall Plan Figure**



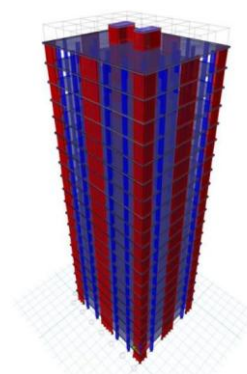
**3. Dual System Plan**



**Figure 4. Rigid Frame Model Figure**



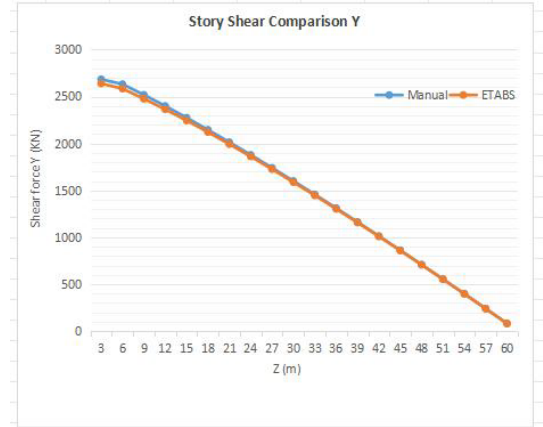
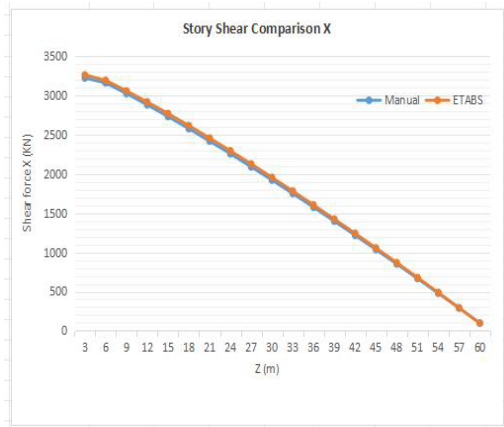
**5. Shear Wall Model Figure**



**6. Dual system Model**

**2.3 Wind Load Calculation and Application**

Wind pressures and story forces were calculated manually according to the Directional Procedure of ASCE 7-10 (Chapter 27). Key parameters included a Gust Effect Factor (G) of 0.85 for rigid structures, velocity pressure exposure coefficient (Kz), and external pressure coefficients (Cp). The resulting story-wise wind loads in two orthogonal directions (X and Y) were calculated and used to verify the ETABS auto-generated wind loads, showing excellent agreement (average difference < 3%).



**Figure 7. Story shear comparison for all systems wind X Figure 8. Story shear comparison for all systems wind Y**

**III. RESULTS AND DISCUSSION**

The results from the ETABS and SAFE analyses are summarized and compared below. Linear static analysis was performed in ETABS for the load combinations prescribed by ASCE 7-10. The analysis outputs extracted for comparison included:

- Maximum lateral displacement and inter-story drift.
- Story shear forces.
- Stability coefficients ( $\theta$ ) for P-Delta evaluation per ACI 318-14.
- Internal forces in critical members.

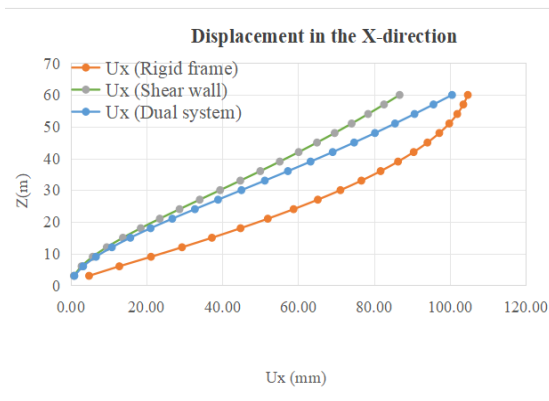
A subsequent analysis in SAFE evaluated the mat foundation's soil pressure, and settlement under combined loading.

**3.1 Global Lateral Displacement and Drift**

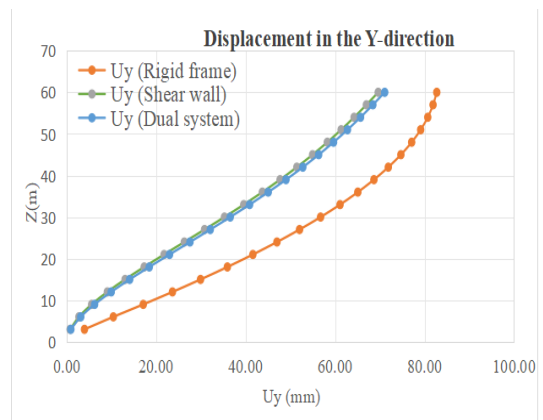
The allowable story drift is  $\frac{h_x}{500} = \frac{3000}{500} = 6$  mm.

It's evident from table (4.4) that for all stories the lateral drift obtained from the prescribed lateral force in both direction are less than the limiting value of 6 mm.

The allowable overall building drift for strength level Wind force is  $\frac{H}{500} = \frac{60000}{500} = 120$  mm, and the maximum building drift for Rigid frame is (104.73 mm), Shear wall (86.74 mm) and dual system (100.57 mm) which are within the limit.



**Figure 9. Displacement in X-direction**



**Figure 10. Displacement in Y-direction**

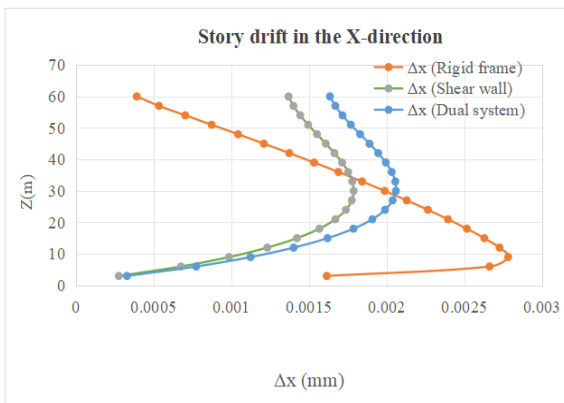


Figure 11. Story drift in the X-direction

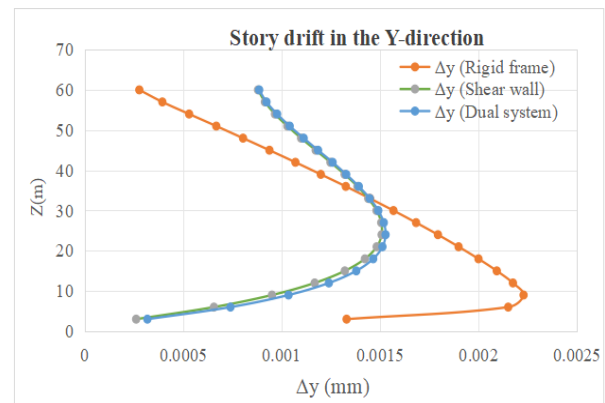


Figure 12. Story drift in the Y-direction

3.2 P-delta effects

The stability coefficient ( $\theta$ ) for P-Delta effects was calculated at each story. For all models and in both directions,  $\theta$  was  $\leq 0.15$ , with most values below 0.10 (Figure 13,14). According to ACI 318-14 ( $\theta \leq 0.10$  for wind), second-order P-Delta effects were deemed negligible and did not require explicit consideration in member design for this structure.

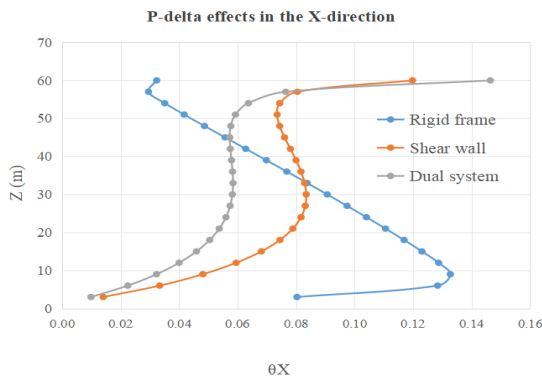


Figure 13.P-delta effects in the X-direction

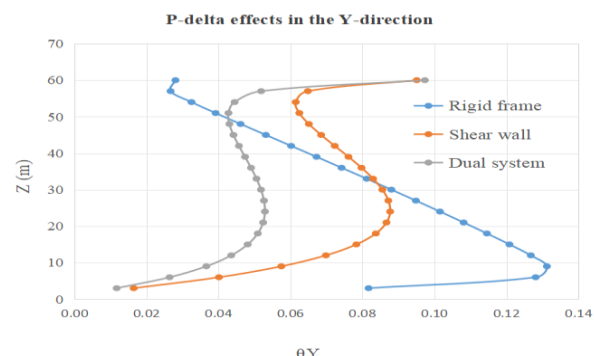


Figure 14.P-delta effects in the Y-direction

3.3 Internal forces

All pictures show the maximum values of the internal force for the three structural systems.

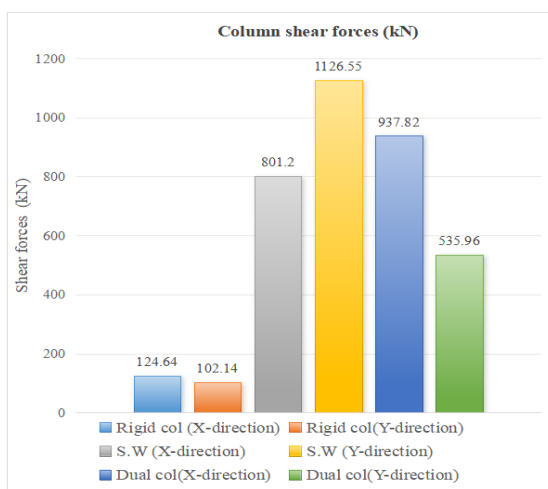


Figure 15 .Maximum column shear forces

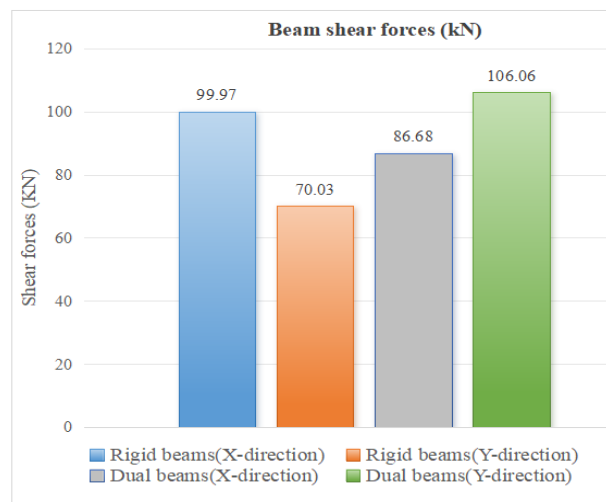


Figure 16. Maximum beam shear forces for rigid and dual systems

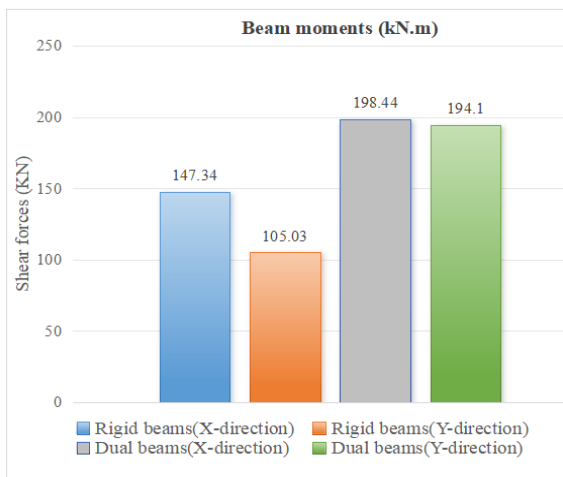


Figure 17. Maximum beam moments for rigid and dual systems

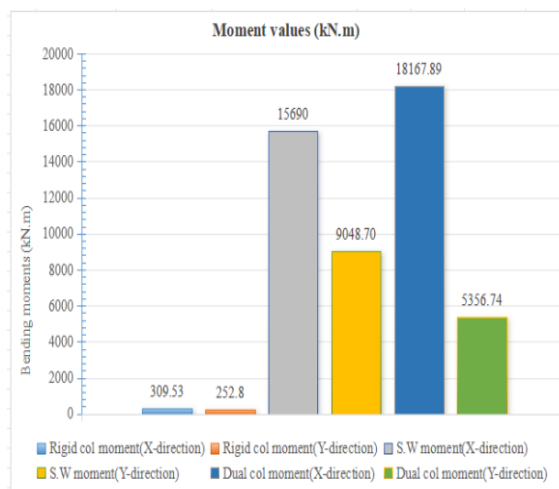


Figure 18. Maximum bending moments

3.4 Base shear and overturning moment for the three structural systems

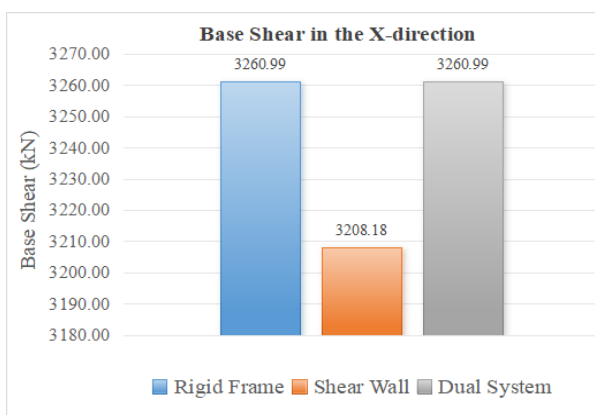


Figure 19. Base shear in the X-direction

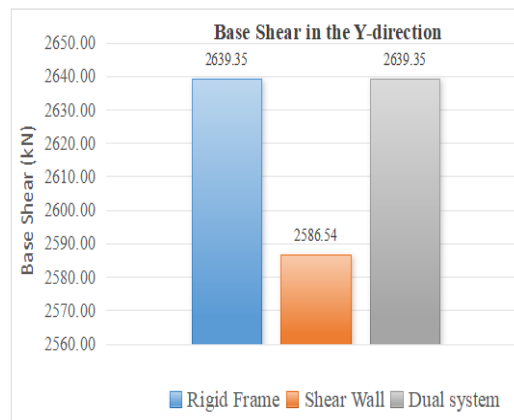


Figure 20. Base shear in the Y-direction

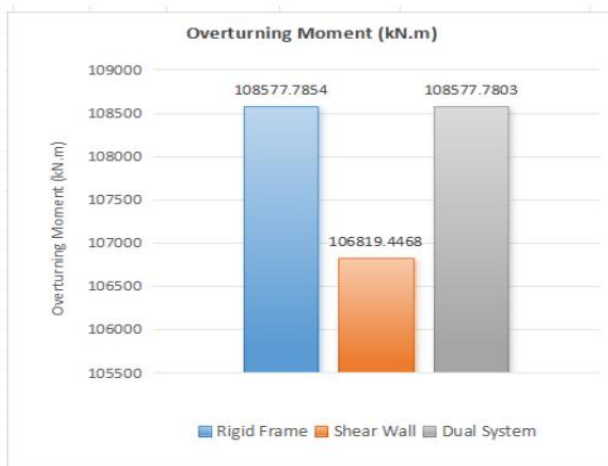


Figure 21. Maximum overturning moments

3.5 Foundation bearing capacity and settlement

Analysis of the common mat foundation in SAFE revealed critical findings:

Under service loads, the maximum soil pressure for the Rigid Frame model (353.85 kN/m<sup>2</sup>), and shear wall(358.16 kN/m<sup>2</sup>) did not exceed the assumed allowable bearing capacity (500 kN/m<sup>2</sup>).

The dual systems induced lower and more uniform soil pressures within the allowable limit.

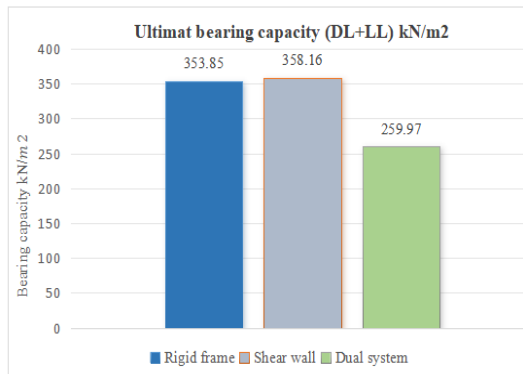


Figure 22. Ultimate bearing capacity (DL+LL)

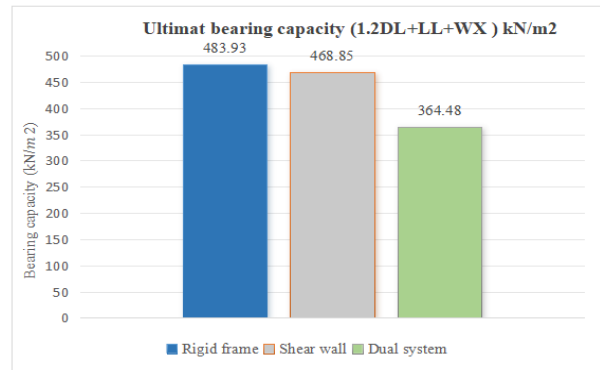


Figure 23. Ultimate bearing capacity (1.2DL+LL+WX)

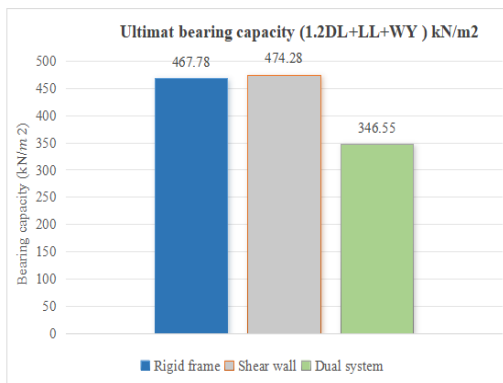


Figure 24. Ultimate bearing capacity (1.2DL+LL+WY)

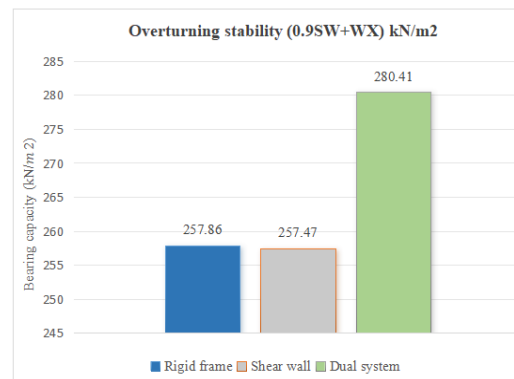


Figure 25. Overturning stability (0.9 SW+WX)

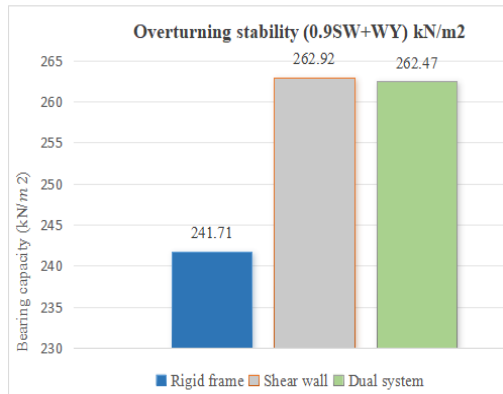


Figure 26. Overturning stability (0.9 SW+WY)

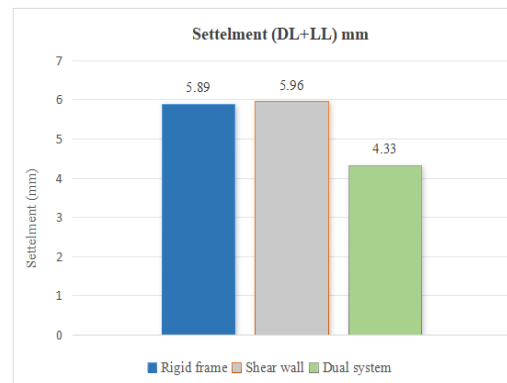


Figure 27. Settlement due to the combination (DL+LL)

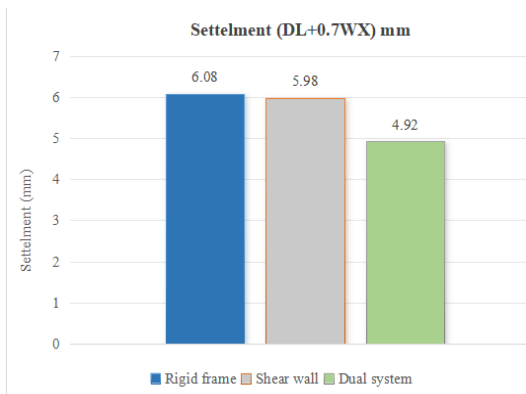


Figure 28. Settlement (DL+0.7WX)

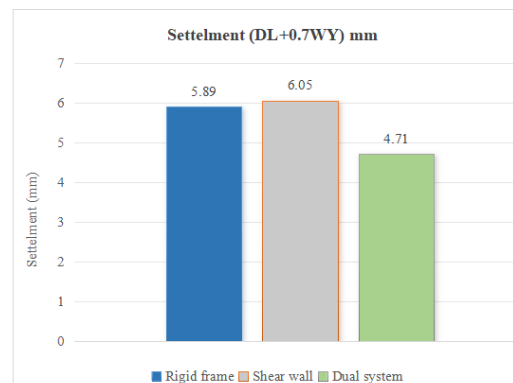


Figure 29. Settlement (DL+0.7WY)

#### IV. CONCLUSION

1. Shear wall system provided the highest reduction in lateral displacements with 17.2 % reduction from rigid frame and 4 % reduction with dual system.
2. Rigid frame experienced more shear-like deformations with maximum drift occurring in first few stories while shear wall system experienced more flexural behaviour with a more uniform distribution of drift. Dual system was able to provide up to 26 – 31 % less drift than rigid frame, thus providing optimum drift control because of the combination of both the frame and shear wall behaviours.
3. Only the dual system was able to satisfy the requirements of ACI 318-14 ( $\theta \leq 0.05$ ) for the P-Delta effect to be neglected. Rigid frame had exceeded this value by 160 % in first few stories while shear wall exceeded that value by 140 % in uppermost levels of the system. The dual system had 54 % lower P-Delta influences compared to the rigid frame.
4. The dual system redistributed loads well, where shear walls carry primary lateral loads (80 – 85 %), frames provide secondary resistance and drift control, and provide a great amount of stiffness without excessively increasing the total base shears.
5. The results of the ETABS analyses were in excellent agreement with the manual calculations (within 4 %), and thus proving the effectiveness of the analytical approach. 6. The foundation bearing demand was reduced by 25 % in X-direction due to rigid frame, 27 % in Y-direction due to shear wall, and 19 – 27 % in terms of settlement with other systems checked. This is directly related to improved load distribution and less eccentricity.
6. The Dual System is the Best Option for Supporting 20-Story Buildings in Areas with High Winds:
  - Optimal performance across all performance criteria.
  - The only system that meets the P-Delta criteria ( $\theta \leq 0.05$ ).
  - Reduces total foundation load by 25-26%.
  - Reduces total settlement in the two horizontal directions by 19-27%.
  - Provides a balanced distribution of drifts with peak drift located at mid-height (not at the critical portions of the structure).

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