

COMPARATIVE STUDY OF PERFORMANCE OF 60 STOREY STEEL BUILDINGS WITH EXO-SKELETON, FRAMED TUBE AND CONVENTIONAL STRUCTURAL SYSTEMS UNDER DYNAMIC LOADING

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Abstract - High rise steel buildings with Exoskeleton structural system, Framed tube structure system and Conventional structure system under dynamic loading for 60 storey are taken for the analysis. Earthquake zone III (Kolkata) & zone V (Darbhanga) and all soil conditions are considered to compare the results in terms of time period, storey displacement, storey drift and storey shear. For dynamic earthquake and dynamic wind analysis response spectrum method (IS 1893-2002) and gust factor method (IS 875-1987 part 3) are used respectively in ETABS V16 software. For steel design IS 800-2007 is considered.

Key Words: Exoskeleton system, Framed Tube system, Conventional system, Dynamic analysis, Gust Factor method, Response spectrum method, Time period, Storey displacement, Storey drift, Storey shear, ETABS.

1. INTRODUCTION

The nature of building perimeters has more structural significance in tall buildings than in any other building type due to their tallness, greater vulnerability to lateral forces occurs. Thus, it is quite desirable to concentrate on lateral load-resisting systems on the perimeter of tall buildings to increase their structural depth and resistance to lateral loads.

An "exoskeleton" is basically a Greek word, meaning "outer skeleton". It is the external skeleton that protects an animal's body as per zoology. In civil engineering, it is an external supporting structure that resist lateral loading.

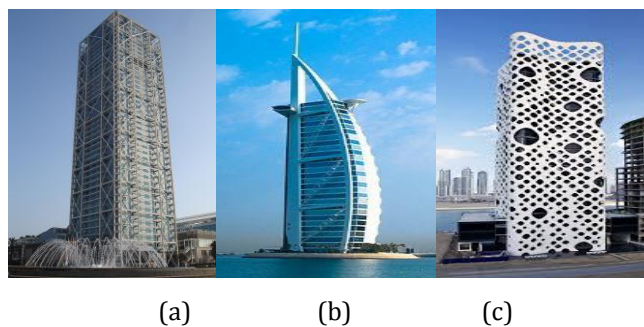


Fig -1: Exoskeleton structure (a) Hotel De Las Artes, Spain (b) Hotel Burj Al Arab, Dubai (c) O-14 Business Bay, Dubai

In Framed tube structure system columns are closely spaced at the perimeter and columns joined by

beams which resist lateral loads. This creates tube as continues perforated chimney. This type of structure is constructed up to 100 stories.



Fig -2: Framed Tube structure (a) Brunswick Building, Chicago (b) De Witt Chestnut Apartment, Chicago (c) World Trade Centre (1973-2001)

2. Research Significance

In high rise buildings it is necessary to analyze dynamic loads. As the height of the building increases, lateral loads like earthquake and wind loads acting on building become more venerable so it is necessary to analyze the lateral loads.

In this paper three systems are compared in terms of time period, displacement, drift, and shear. To analyze the lateral loading two locations Kolkata and Darbhanga are considered. The objective of this study is to find out which system is better to resist dynamic earthquake and dynamic wind load

3. Modelling and Analysis

3.1 Building Configuration

For the comparison of exoskeleton, framed tube and conventional structure systems a square plan of 36 x 36 m having typical storey height and bottom storey height of 3m is considered. The total structure height is 180 m. Fe 345 material having weight density 76.9729 kN/m³ is selected. Typical floor slab thickness is 120mm having M30 grade of concrete is considered. In Exoskeleton system, exoskeleton members are provided at 1m outside the plan in all direction. In all systems main beams, secondary beams and exoskeleton members named B1, B3 and E3 respectively are of ISMB 550 with top and bottom cover plate of 220 x 50 mm and inclined beams in plan named B2 is of ISMB 600 with top and bottom cover plate of 250 x 50 mm are considered.

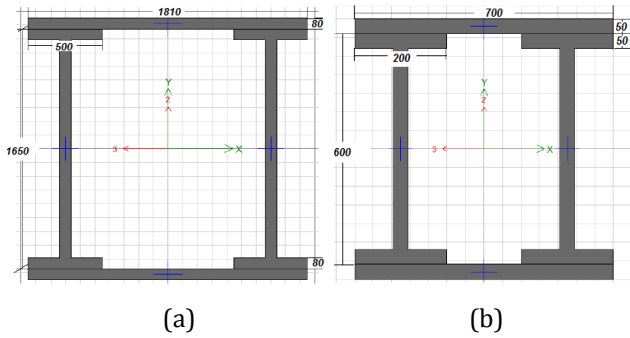


Fig-1: Column details (a) Interior column C1, (b) Exterior column C2

3.2 Model Preparation

Modelling is done using ETABS v16 software.

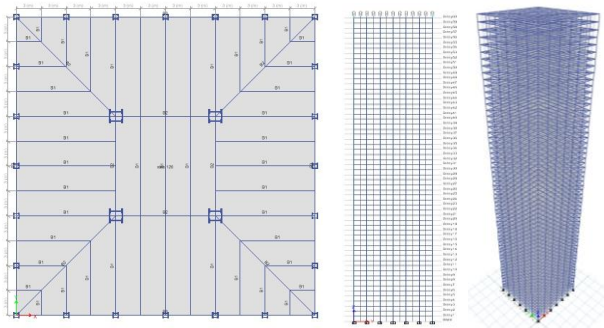


Fig-2: Plan, Elevation & 3D view of Conventional system

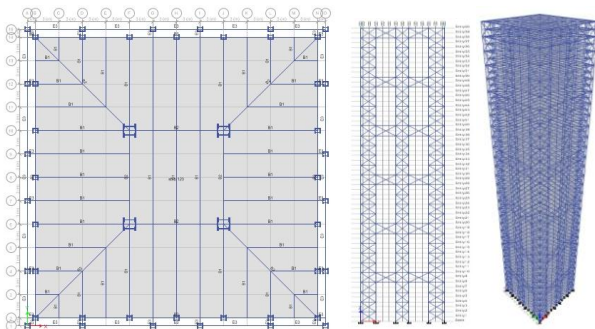


Fig-3: Plan, Elevation & 3D view of Exoskeleton system

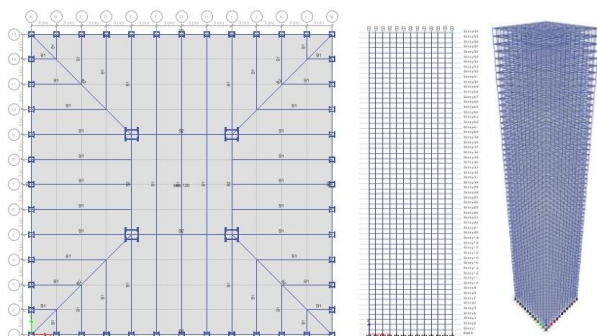


Fig-4: Plan, Elevation & 3D view of Framed tube System

3.3 Dynamic analysis methods and Loading Data

Dead Load = 1.5 kN/m²

Live Load = 2.5 kN/m²

Cladding Load = 0.108 kN/m²

3.3.1 Response spectrum method

A response spectrum method is straight forward graphical portrayal of unflinching state reaction for dislodging, speed or quickening of oscillators of fluctuating normal response that are forced into motion by the same base vibration. In this method response of multiple modes of a building is consider for the analysis. The response of a structure can be defined as a combination of modes that in a vibrating string correspond to the "harmonic". To perform response spectrum analysis, it is necessary to know the earthquake intensity at zone on which the building.

Table -1: Earthquake Loading data

Location	Kolkata	Darbhong
Zone	3	5
Zone Factor, Z	0.16	0.36
Importance Factor, I	1.2	1.2
Response reduction Factor, R	5	5
Soil Type	I,II & III	I,II & III

3.3. Gust Factor method

Gust factor method is rational and realistic and it is considered for the computation of dynamic wind loads in the case of very tall frames and structures. It becomes necessary to study the criticality of wind forces in the case of multi-storied frames particularly on more serve wind zones. Here, basic wind speed for Kolkata and Darbhong is 50m/s and 55 m/s respectively. For the dynamic wind analysis terrain category III and class C is consider.

3.3.2.1 Calculation of dynamic wind load

Criteria to satisfy for the requirement of dynamic analysis as per IS 875-1987 part 3

Case1: If height to least lateral dimension ratio > 5.

Table -2: Dynamic wind analysis check case-1

System	H (m)	D (m)	H/D	Dynamic analysis
Conv. & Fram.	180	36	5	= 5 Not Required
Exoskeleton	180	38	4.73	< 5 Not Required

Hence, Dynamic analysis is not required for 60 storey structure.

Case 2 : If natural frequency (f) < 1.0 Hz.

Table -3: Dynamic wind analysis check case-2

System	H (m)	D (m)	T=0.09 H/√D	f (Hz)	Dynamic Analysis
Conv. & Fram.	180	36	2.7	0.37	< 1 Required
Exoskeleton	180	38	2.63	0.38	< 1 Required

Hence, Dynamic analysis of all models is required to study.

Hence, From above two cases it is clear that dynamic analysis is required to study in these models.

As per IS-875-1987 (part-3), (Cl-8.3)

$$F_z = C_f \cdot A_e \cdot P_z \cdot G$$

Where, F_z = along wind load on structure at any height z corresponding to strip area A_e , C_f = force coefficient for the building = 1.4 (IS 875, part-3, Fig 6A), A_e = effective frontal area considered for the structure at height z, $A_e = 108 \text{ m}^2$ for Conventional and Framed tube system and $A_e = 114 \text{ m}^2$ for Exoskeleton system, P_z = design pressure at height z due to hourly wind obtained as $0.6V_z^2$ Where, V_z = design wind velocity in m/s at height z (m)

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3$$

Where, V_b = basic wind speed, k_1 = Risk coefficient factor = 1.08 (IS- 875, part-3, Table 1), k_2 = Hourly mean wind speed factor (IS-875, Part-3, Table-33), k_3 = topography factor = 1 (IS-875, Part-3, CL 5.3.3).

G = Gust Factor (IS-875, Part-3, CL 8.3)

$$G = 1 + g_f \cdot r \cdot \sqrt{\left[\frac{B(1 + \phi)^2 + \frac{SE}{\beta}}{\beta} \right]}$$

Where, g_f = peak factor, r = roughness factor, $g_f \cdot r$ = Value of $g_f \cdot r$ is obtain from IS-875 part 3 = 0.95, B = background factor and is obtained from IS-875 part-3 Fig-9, $\phi = 0$ for building height greater than 25 for category 3, S = Size reduction factor (IS-875, Fig-10), β = Damping coefficient = 0.0020 (IS-875, Table 34), To find out B

$$\lambda = (C_y \cdot b) / (C_z \cdot h) \quad (\text{IS-875, Fig 9, page-50})$$

Where,

C_y = lateral correlation constant = 10 (IS-875, page 52), C_z = longitudinal correlation constant = 12 (IS-875, page 52), b = breadth of the structure normal to the wind stream, h = height of the structure, $L(h)$ = a measure of turbulence length scale (IS-875, Fig-9)

Table -4: For value of λ and B

Height, h(m)	L(h)	$\lambda = (C_y \cdot b) / (C_z \cdot h)$		$\frac{(C_z \cdot h)}{L(h)}$	B
		Conv. & Fram.	Exoskeleton		
180	2000	0.17	0.18	1.08	0.60

Values of K_2 , S, E and G are interpolated and from that values Along wind dynamic loads are evaluated for each storey for Kolkata and Darbhanga location.

4. Result Analysis

Results obtained from ETABS software in terms of Fundamental time period, storey displacement, storey drift, storey shear are exported to excel to make a charts. Due to symmetry results in X and Y direction are approximately same.

4.1 Fundamental Time Period

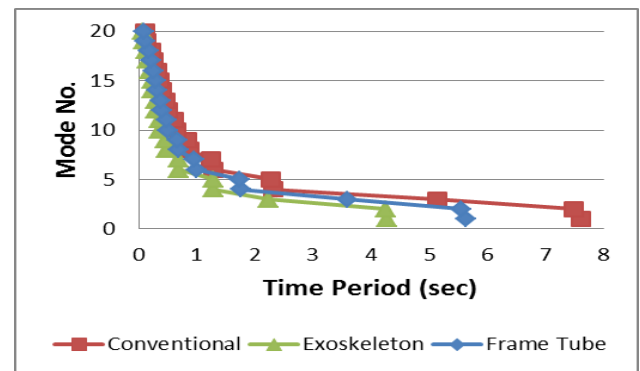


Chart -1: Fundamental Time Period

4.2 Storey Displacement

Permissible storey displacement for steel building is $H/300$. Here, Height of structure H is 180 m therefore maximum permissible limit is 600 mm. Hence, displacements of all models are within permissible limit.

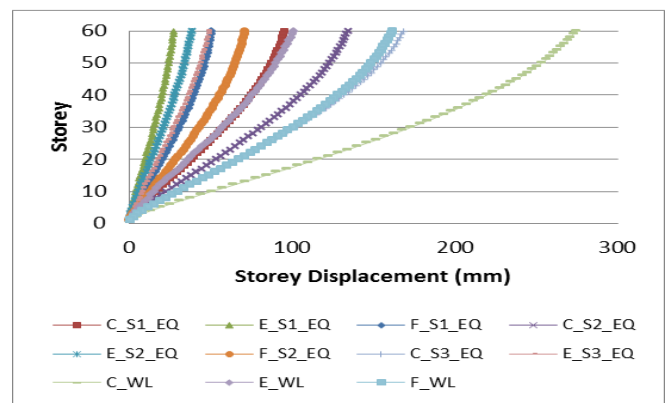


Chart -2: Storey Displacement for Kolkata (zone 3)

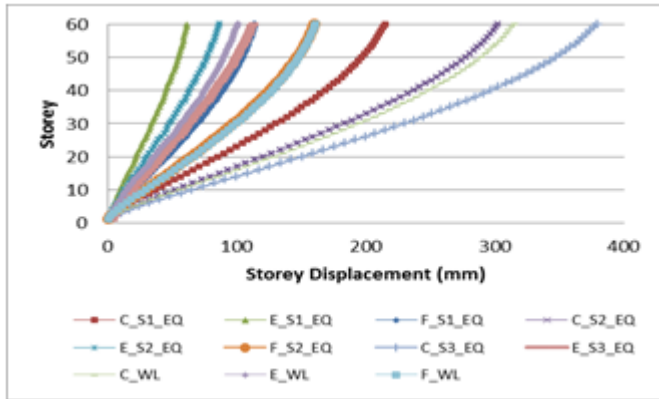


Chart -3: Storey Displacement for Darbhanga (zone 5)

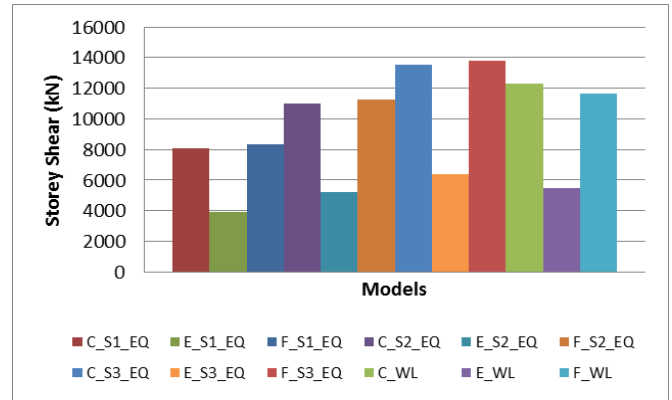


Chart -7: Maximum Storey Shear for Darbhanga (zone 5)

4.3 Storey Drift

Permissible limit for storey drift is 0.004 times the storey height. Hence all models are within permissible drift criteria.

Chart -4: Storey Drift for Kolkata (zone 3)

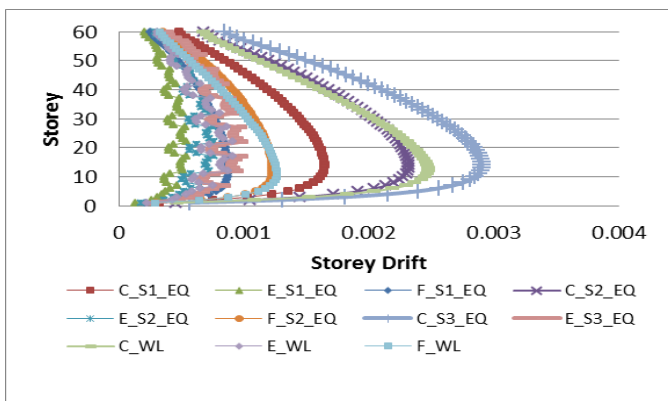


Chart -5: Storey Drift for Darbhanga (zone 5)

4.4 Storey Shear

Here Maximum storey shear of all systems for earthquake and wind load are represented in form of chart.

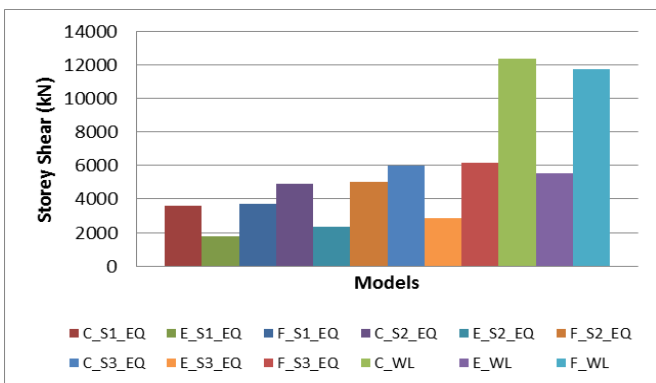


Chart -6: Maximum storey shear for Kolkata (zone 3)

3. CONCLUSIONS

For the analysis 36m x 36m square regular plan is considered and that is analyzed for dynamic loading using response spectrum method and gust factor method and get results in terms of time period, displacement, drift and shear using ETABS software.

From the results it is observed that,

- Exoskeleton system is stiffer than the frame tube and conventional system.
- For dynamic earthquake load maximum displacement is in conventional system and it is approximately decreases 47% in Framed tube system and decreases 71% in Exoskeleton system for all soil conditions at both locations.
- Displacement due to dynamic wind load at Kolkata is reduced to 41% in framed tube system and 63% in exoskeleton system than conventional system.
- Displacement due to dynamic wind load at Darbhanga is reduced to 48% in framed tube system and 67% in exoskeleton system than conventional system.
- Maximum storey drift of exoskeleton and frametube structure system decreases 67% and 47% respectively for the dynamic earthquake loading and decreases 63% and 49% respectively for dynamic wind loading than the conventional structure system at both direction.
- Maximum storey shear of exoskeleton and frame tube structure system decreases 51% and increases 3% respectively for the dynamic earthquake loading and decreases 55% and 5% respectively for dynamic wind loading than the conventional structure system in both direction at both locations.

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