Comparative Performance Analysis of Combined Structural Systems for A G+30 High-Rise Building Under Wind and Seismic Loads

Zohaib Mohd Khan[1], Waseem Malik[2]

[1]*P.G. Student, Department of Civil Engineering, Nawab Shah Alam Khan College of Engineering and Technology*

[2]*Assistant Professor, Department of Civil Engineering, Nawab Shah Alam Khan College of Engineering and Technology*

***Abstract*—The rapid growth of urban population and limited land availability in metropolitan cities have increased the demand for high-rise buildings. With increasing building height, lateral loads due to wind and earthquake become critical and significantly influence structural behaviour. This paper presents a comparative performance analysis of eight lateral load-resisting structural systems for a G+30 high-rise building located in Mumbai, Maharashtra, India. The building has a regular square plan of 30 m x 30 m and an approximate height of 101 m. Equivalent static analysis, response spectrum analysis, wind analysis and modal analysis are used to evaluate storey displacement, storey drift, base shear, natural time period and torsional irregularity. The results show that the conventional Moment Resisting Frame system gives the maximum displacement and drift, whereas the Core Wall with Diagrid Structural System gives the best overall performance with minimum displacement of 48 mm, minimum drift of 1.843 mm, lowest natural time period of 2.136 s and acceptable torsional behaviour.**

***Index Terms*—High-rise building, wind load, seismic load, lateral load-resisting system, storey displacement, storey drift, core wall, diagrid system.**

I. INTRODUCTION

Rapid urbanisation and limited land availability in metropolitan cities have increased the need for high-rise construction. In tall buildings, lateral loads produced by wind and earthquake often govern the design because they directly influence displacement, drift, base shear, stability and occupant comfort. A conventional moment resisting frame provides architectural flexibility, but its lateral stiffness may be insufficient for high-rise structures. Therefore, additional lateral load-resisting systems such as steel bracing, shear walls, core walls, outriggers and diagrids are commonly used to improve stiffness and control deformation [1]-[6]. The present study compares different combined structural systems for the same G+30 building configuration under identical gravity, wind and seismic loading conditions.

II. OBJECTIVES

The objectives of this study are: (i) to develop and analyse a G+30 high-rise building model under gravity, wind and seismic loads; (ii) to compare the behaviour of moment resisting frame, braced frame, shear wall, core wall, outrigger and diagrid-based structural systems under identical loading conditions; (iii) to evaluate major structural response parameters, including storey displacement, storey drift, base shear, mode 1 natural time period and torsional irregularity; (iv) to examine the influence of additional lateral load-resisting elements on structural stiffness, deformation control and serviceability performance; and (v) to recommend the most efficient combined structural system for the selected high-rise building.

III. METHODOLOGY

A regular G+30 high-rise building located in Mumbai is modelled with a square plan of 30 m x 30 m and an approximate height of 101 m. The same building geometry and loading conditions are used for all models to obtain a consistent comparison. Concrete

grades M30 and M40, reinforcement steel Fe550 and structural steel Fe345 are considered. The slab thickness is 200 mm, column sizes vary from 450 mm x 450 mm to 850 mm x 850 mm, beam sizes are 450 mm x 450 mm and 450 mm x 600 mm, core wall thicknesses are 500 mm and 600 mm, and shear wall thicknesses are 250 mm and 300 mm. The numerical modelling and analysis are carried out using ETABS.
Wind loading is considered for an urban/developed area in Mumbai with risk coefficient k1 = 1.0, terrain category 3, topography factor k3 = 1.0 and importance factor k4 = 1.0. For seismic loading, zone factor Z = 0.16, soil type II, importance factor I = 1.25, damping ratio 5% and response reduction factor R = 5 are used as modelling assumptions. Equivalent static analysis, response spectrum analysis, wind analysis and modal analysis are performed with reference to the relevant Indian Standard provisions [7]-[10].

The eight structural systems considered are as follows:
M1: Moment Resisting Frame Structural System.
M2: Moment Resisting Frame with Steel Bracing Structural System.
M3: Moment Resisting Frame with Shear Wall Structural System.
M4: Moment Resisting Frame with Core Wall and Bracing Structural System.
M5: Moment Resisting Frame with Shear Wall, Core Wall and Bracing Structural System.
M6: Core Wall with Shear Wall Structural System.
M7: Core Wall with Shear Wall and Outrigger Structural System.
M8: Core Wall with Diagrid Structural System.

The ETABS model views for M1 to M8 are presented in Fig. 1 and Fig. 2.

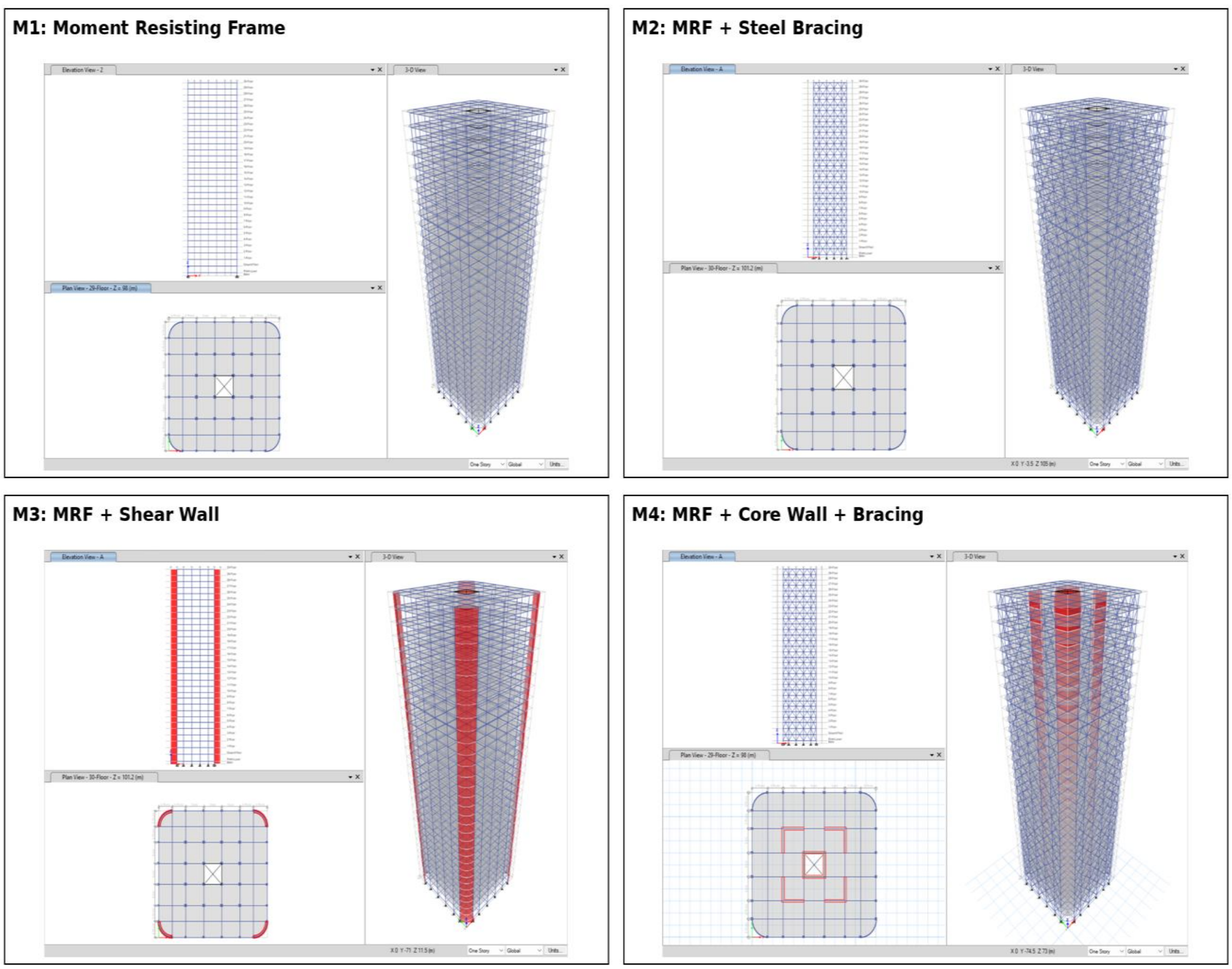

Fig. 1. ETABS model views of M1 to M4 structural systems.

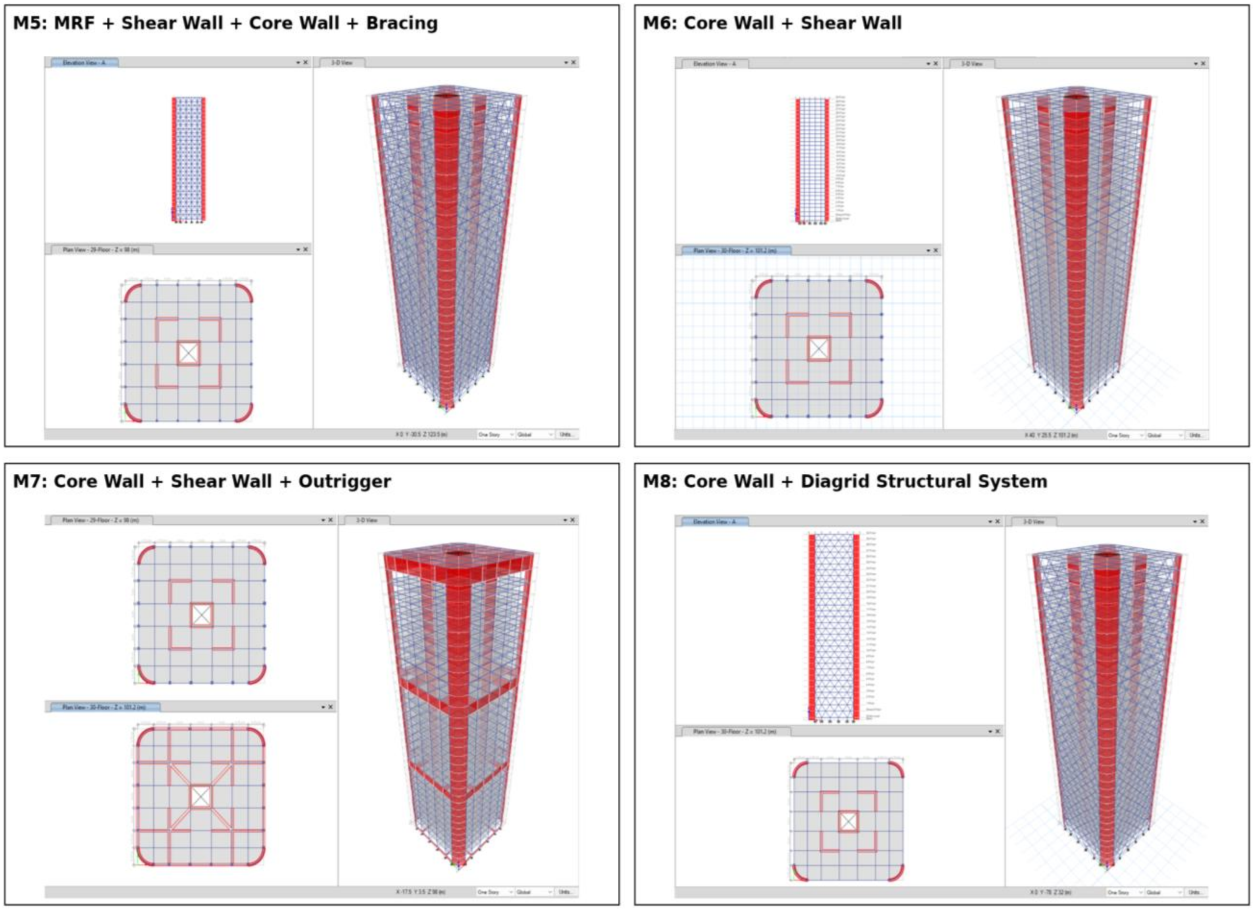

Fig. 2. ETABS model views of M5 to M8 structural systems.

TABLE I. STRUCTURAL MODELS USED IN THE STUDY

Model	Structural system
M1	Moment Resisting Frame
M2	MRF + Steel Bracing
M3	MRF + Shear Wall
M4	MRF + Core Wall + Bracing
M5	MRF + Shear Wall + Core Wall + Bracing
M6	Core Wall + Shear Wall
M7	Core Wall + Shear Wall + Outrigger
M8	Core Wall + Diagrid Structural System

Note: The values in Table II match the graph labels and the result discussion. The reference/limit values plotted in the graphs are displacement = 408 mm, storey drift = 12.8 mm, reference time period Ta = 2.39 s and torsional irregularity ratio = 1.5.

TABLE II. CONSOLIDATED RESULT VALUES USED IN TEXT AND FIGURES

Model	Displacement (mm)	Drift (mm)	Base shear (kN)	T1 (s)	Torsion ratio
M1	355	17.019	10809.23	8.743	1.080
M2	112	3.190	12243.28	4.676	1.052
M3	64	2.400	14647.48	3.172	1.138
M4	82	3.050	16130.20	3.349	1.976
M5	62	2.250	20182.95	3.032	1.040
M6	127	4.800	15954.19	4.975	1.042
M7	65	2.800	18936.05	3.306	1.114
M8	48	1.843	29004.28	2.136	1.071

IV. RESULTS AND DISCUSSION

The structural response of the eight models is compared using storey displacement, storey drift, base shear, natural time period and torsional irregularity. The graph values, table values and text discussion have been checked and made consistent so that the result interpretation remains uniform throughout the paper.

A. Storey Displacement

The Moment Resisting Frame system gives the maximum storey displacement of 355 mm. The Core Wall with Diagrid Structural System gives the minimum displacement of 48 mm. The displacement of M8 is reduced by 86.48% compared with M1 and remains below the allowable limit of 408 mm. Although all models satisfy the displacement limit, combined systems show much better lateral control than the bare frame.

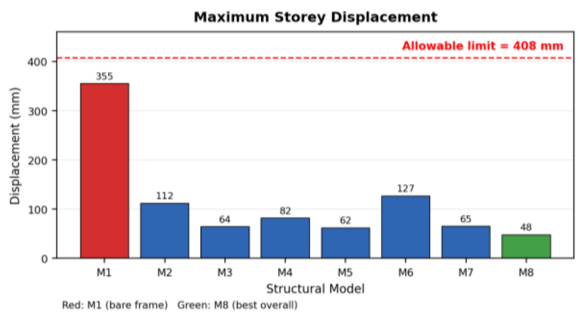

Fig. 3

B. Storey Drift

Storey drift is an important serviceability parameter for high-rise buildings. The Moment Resisting Frame system shows the maximum drift of 17.019 mm and exceeds the allowable drift limit of 12.8 mm. The Core Wall with Diagrid Structural System shows the minimum drift of 1.843 mm, while MRF with Shear Wall, Core Wall and Bracing shows a drift of 2.250 mm. Hence, combined systems are more effective in controlling inter-storey deformation.

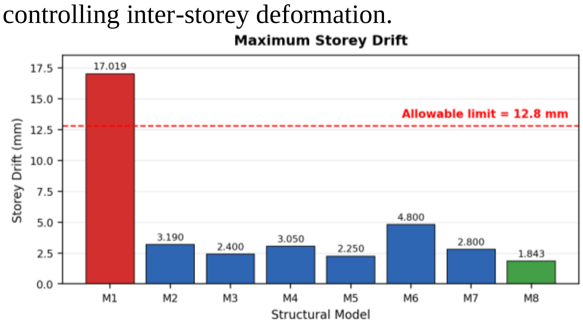

Fig. 4. Maximum storey drift of structural models.

C. Base Shear

Base shear generally increases with the stiffness of the structural system. The Moment Resisting Frame system develops the lowest base shear of 10809.23 kN, whereas the Core Wall with Diagrid Structural System develops the highest base shear of 29004.28 kN. The higher base shear in M8 is due to its higher lateral stiffness; however, it provides the best control over displacement and drift.

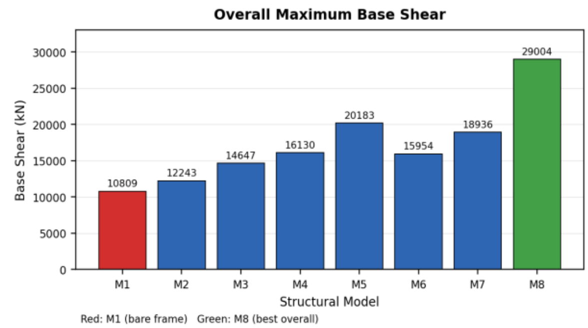

Fig. 5. Overall maximum base shear of structural models.

D. Natural Time Period

The natural time period indicates the flexibility of a structural system. A higher time period represents a more flexible system, while a lower time period indicates greater stiffness. The Moment Resisting Frame system has the highest mode 1 time period of 8.743 s. The Core Wall with Diagrid Structural System has the lowest time period of 2.136 s, confirming that it is the stiffest model among the systems considered.

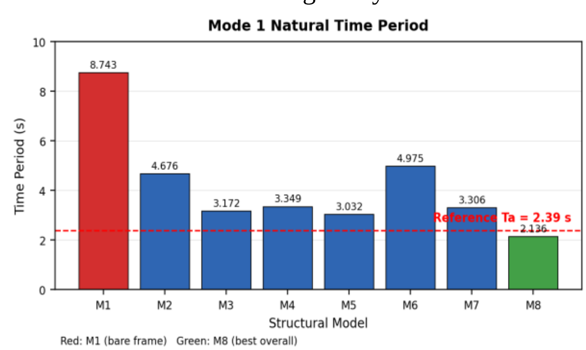

Fig. 6. Mode 1 natural time period of structural models.

E. Torsional Irregularity

Torsional irregularity is used to assess twisting behaviour caused by uneven stiffness distribution. Most structural systems show acceptable torsional behaviour. However, MRF with Core Wall and

Bracing shows the highest torsional irregularity ratio of 1.976, which is above the allowable limit of 1.5 and therefore requires careful stiffness arrangement. The Core Wall with Diagrid Structural System shows an acceptable torsional ratio of 1.071.

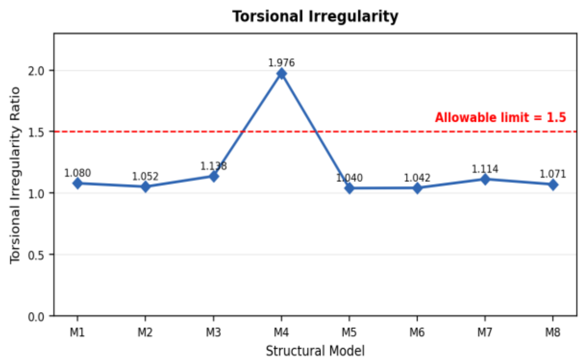

Fig. 7. Torsional irregularity ratio of structural models.

F. Overall Performance

Based on displacement, drift, base shear, natural time period and torsional behaviour, the Core Wall with Diagrid Structural System is the most efficient structural system for the selected G+30 building. The MRF with Shear Wall, Core Wall and Bracing system ranks second due to its good displacement, drift and time period performance. The Core Wall with Shear Wall and Outrigger system also performs well because the outrigger improves interaction between the central core and exterior columns. The conventional MRF is least efficient for displacement and drift, while M4 requires special attention because of poor torsional performance.

V. CONCLUSION

The comparative analysis shows that the selected structural system has a significant influence on the lateral performance of high-rise buildings under wind and seismic loads. The conventional Moment Resisting Frame system gives the highest storey displacement of 355 mm and the highest drift of 17.019 mm, indicating lower lateral stiffness. The Core Wall with Diagrid Structural System gives the minimum storey displacement of 48 mm, which corresponds to an 86.48% reduction compared with the Moment Resisting Frame system.

The Core Wall with Diagrid Structural System also gives the minimum storey drift of 1.843 mm and the lowest natural time period of 2.136 s, indicating excellent lateral stiffness. The base shear is lowest in the Moment Resisting Frame system at 10809.23 kN and highest in the Core Wall with Diagrid Structural System at 29004.28 kN due to the higher stiffness of the diagrid system. Most systems show acceptable torsional behaviour, but the MRF with Core Wall and Bracing system shows a torsional ratio of 1.976 and requires careful stiffness arrangement. Overall, the Core Wall with Diagrid Structural System is recommended as the most suitable system for improving lateral stiffness and reducing deformation in the selected G+30 high-rise building.

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