International Journal of Psychosocial Rehabilitation, Vol. 24, Issue 01, 2020
ISSN: 1475-7192

Influence of Structural System on Behavior of Reinforced Concrete High-rise Buildings Subjected to Lateral Loads

Manish A. Kewalramani* and Osama Ahmed Mohamed

Abstract--- *The construction of high-rise reinforced concrete buildings is high in demand worldwide inviting new challenges in terms of structural analysis and design. Lateral loads resulting from wind or earthquake in any high rise building are usually resisted by a system of coupled shear walls. However, in case of very tall buildings with reduced stiffness sufficient lateral stiffness needs to be provided by carefully examining feasible structural systems. The present work presents a comparative analysis aimed towards selection of optimal structural system by measuring structural efficiency in terms of parameters such as time-period, storey displacement, drift, lateral displacement, base shear and core moments. The results obtained are compared among various structural systems to determine a suitable structural system that can be used for high-rise concrete buildings. The study is based on incorporating different structural systems on the same building so as to have a comprehensive comparison based on identical conditions. The results are determined using a commercial structural analysis and design software – ETABS. The main emphasis is to study behavior of these structural building models subjected to wind load in both X and Y directions.*

Keywords--- *High-rise Buidings, Lateral Design Loads, Storey Displacement, Drift, Base Shear.*

I. INTRODUCTION

The research focuses on the effects that are subjected laterally such as wind forces, seismic forces, waves, and blast forces on high-rise buildings. Due to the current economic climate, some buildings have showed a high development in the height comparing to other buildings. Usually, high-rise buildings can have a similar deformation relevant to the deformation of a cantilever beam. Structural system is an important ingredient to success of high-rise buildings. Due to application of lateral loads for stability and safety it is essential that structure should be supported adequately with resisting elements. The current study discusses the major effects due to such lateral loads on high-rise buildings. The lateral loads are the loads that act horizontally on the building; it includes wind load, seismic loads such as earthquakes, waves, and burst loads. Wind loads affects all exposed surfaces of building simultaneously with increased intensity at higher level compared to lower level. The prime objective of any structure system (or form) is to safely transfer loads through inter-connected structural elements. Structural systems prevent failure caused due to the extreme stresses arising from design loads. In general various structrual systems implemented on high-rise concrete buildings include rigid frame, combination of braced frame, braced and shear-walled frame, shear-walled frame, outrigger, framed-tube, braced-tube and bundled-tube.

Dr. Manish A. Kewalramani, Assistant Professor, Civil Engineering at College of Engineering, Abu Dhabi University, Abu Dhabi United Arab Emirates.*

Dr. Osama Ahmed Mohamed, Professor, Structural Engineering and Mechanics and Associate Dean with College of Engineering, Abu Dhabi University, Abu Dhabi, United Arab Emirates.

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

II. Research Objectives

Present parametric comparison in terms of story drifts, story displacements, time-period, lateral displacements, and base shear of high rise buildings with different structural systems subjected to lateral design forces.

Identification of appropriate structural system for high rise buildings in order to reduced lateral deformations due to lateral forces without relating to the various materials used in tall buildings.

III. Methodology

In present study the influence of four different structural systems namely bracing, moment resisting frame, combination of bracing and shear walls, and outriggers on high rise building is studied. The building models are applied design loads in the direction of gravity (dead load, live load and superimposed dead load) and lateral forces (wind) in both X and Y directions. The parameters of study include time-period, total lateral displacements, story displacements, story drifts, and the base shear to identify the effects that each structural system entail to building models. Model description, design loads and guest factor considered for study is included herewith. Building models are created and analyzed using ETABS – a commercial structural software for building analysis and design. The analysis of all buildings is carried out using equivalent static method in Zone IV. ETABS being 3D object based modeling and visualization tool makes behavior of structural system in high-rise reinforced concrete building easy to interpret.

3.1. Load Assignment

All of building models systems are assigned three types of loadings (dead, superimposed dead, live and wind loads in both X and Y direction) in line with ASCE7-10.

3.2. Method of Analysis

For the purpose of fair comparison in critical parameters of study the building geometry, structural members, concrete grade etc. are kept constant for buildings with different structural systems. The study aims to identify the importance of each structural system in terms of lateral load parameters.

IV. Model Description

The plan view of high rise building model used in present study is shown in Fig. 1. Grid spacing in X and Y direction is included in Table 2.

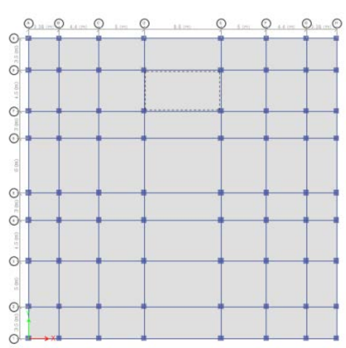

Fig. 1: Plan view of high-rise building model

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

Table 1 includes building storey data used for modelling high-rise buildings with different structural systems.

Table 1: Building Storey Data.

Number of Stories	40
Typical Story height	3.6 m
Base Story height	4 m

Table 2 includes geometric properties of buildings such as number of spans, each span length (in both X and Y directions) that are essential to define building geometry.

Table 2: Geometric Properties of Building Models.

Spans in X direction	7 spans
Spans in Y direction	8 spans
Number of Grid Lines in X direction	8 grid lines
Number of Grid Lines in Y direction	9 grid lines
Spacing in X direction	3.36m, 4.4m, 5m. 8.5m, 5m, 4.4m, and 3.36m
Spacing in Y direction	3.5m. 4.5m, 3m, 6m, 3m, 4.5m, 6m, and 4.5m

Table 3 below includes structural frame properties such as slab thickness, beam and column cross-section dimensions, and position of bracing etc.

Table 3: Strucural Frame Properties of Building Models

Structural Element	Grade of Concrete	Cross-Section Characteristics
Slab	40 MPa	Thickness – 200mm
Beams	40 MPa	B1-200×600 and B2-200×640 (mm)
Columns	40 MPa	600×600 mm
Bracing	along Elevations 1 and 9	200×600 mm^2
Moment Resisting Frame	along Elevations 1 and 9	–
Shear wall	50MPa	Thickness – 250mm

Table 4 and Table 5 below show the assigned design loads to various building models and wind load parameters respectively.

Table 4: Design load assigned to Building Models

Dead Load	Self-weight of structrual components
Live Load	3.5 kN/m^2
Superimposed dead load (SDL)	4 kN/m^2
Wind X	According to ASCE7-10
Wind Y	According to ASCE7-10

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

Table 5: Wind load parameters

Wind speed	100 mph (44.704 m/sec)
Exposure	B
Risk Category	IV
K_d	0.85 for building
K_{zt}	1 (flat terrain)
GC_{pi}	±0.18

4.1. Gust Factor

Gust factor (GF) is defined as the ratio between the peak winds gust of a specific duration to the mean wind speed for a period. To ensure the stability of the structure and looking at natural frequency of the structure the modified gust factor value was obtained as 0.975 and 1.023 for wind force in X and Y direction respectively.

4.2. Structural Systems

4.2.1 Bracing System

Bracings are the additional members that usually added diagonally to the edge frames in a building to reduce the deformation of the building due to lateral forces. There are several types of bracings, such as single diagonal bracing, cross-bracing, eccentric bracing, V bracing, and K bracing. All these types aims to resist the lateral loads by reducing the deflection or the drift of the building by decreasing the deformation of the building.

4.2.2 Rigid Frame System

Rigid frame systems (also known as moment frame systems) consists of beams and columns used in both reinforced concrete buildings and steel buildings as shown in Fig. 2. The whole idea of the rigid frame system came from high-rise steel buildings predominantly and later adopted for high-rise reinforced concrete buildings. The system includes rigid frame which is unbraced that is capable to resist the gravity and lateral loads by the resistance of the deformation of the members. Stiffness of the rigid frame system depends on the bending rigidity of the beams and columns that are subjected to both gravity and lateral loads.

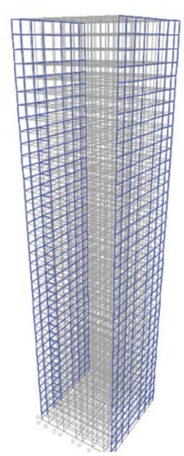

Fig. 2: Rigid Frame (MRF) System

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

4.2.3 Shear wall and Bracing System

Braced frame and shear-shear walled system, is the system that includes both bracings and shear walls in the structure to resist the deformation of the building laterally as shown in Fig. 3.

In concrete structures, bracings and shear walls are also made of concrete, shear walls are walls that are designed monolithically to resist the lateral deformation due to wind, earthquakes and other types of lateral loads. The system is used for buildings that are highly exposed to lateral loads such as wind, and earthquakes. This system is used to prevent the lateral deformation or the drift of the flexible buildings in particular. This type of building includes both shear walls, and bracings in the same building. Shear wall is placed in the middle of the plan to avoid torsion of the building.

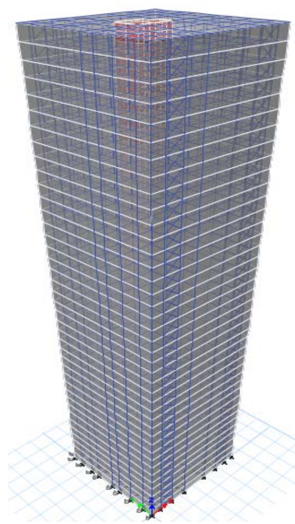

Fig. 3: Shear Wall and Bracing System

V. RESULTS AND DISCUSSION

5.1 Storey Base Shear

Storey base shear is the shear force is a force acting in the lateral direction on any structural member. It is important as lateral forces such as seismic forces in the building are greatest at the base of the building. Therefore, base shear results were obtained for few different base columns (A3 and F9) due two wind modals (one and two) in both X and Y directions as shown in Table 6.

Table 6: Base Shear for Columns A3 and F9.

Load Case		A3				F9			
		Bracing	Rigid F.	SW+Brac.	Outrig.	Bracing	Rigid F.	SW+Brac.	Outrig.
Wind 1	X	0.848	-12.473	0.439	-5.080	-6.060	18.543	-1.011	2.345
	Y	130.167	245.406	-5.312	130.216	105.835	-913.553	-6.501	119.414
Wind 2	X	146.605	232.736	-5.037	123.448	131.565	-866.611	-6.165	113.207
	Y	-0.894	13.153	-0.462	5.358	4.900	-19.554	1.066	-2.473

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

It can be observed that,

1. Wind modal 1 and wind modal 2 load cases are opposite in terms of directions.
2. The load cases wind modal 1 in the X direction and wind modal 2 in the Y direction act in the same direction and produce similar magnitude of base shear (but opposite direction).
3. The load cases wind modal 1 in the Y direction, and wind modal 2 in the X direction produce similar values of base shear with no difference in sign (same direction).
4. Large reduction of shear at the base when shear walls are used.
5. Rigid frame system produce the largest shear value at the base, where F9 changes it direction due to different building behavior than other cases.
6. In terms of outrigger system and rigid frame system, similar results were observed in terms of direction but rigid frame system produce larger base shear.

5.2 Storey Drift

The Story drift is defined as the point value at story x – the point value at the below or above for the same point (difference between the two stories) while the lateral displacement (or storey displacement) is the displacement that occur due to lateral loads on a specific storey. Storey drift comparison between the four structural systems due to wind modal 1 load case and modal case 2 in the X direction is shown in Table 7.

Table 7: Storey Drift (mm) at various levels.

Location	Bracings		Rigid Frame		SW+Brace		Outrigger	
	Mod1X	Mod2X	Mod1X	Mod2X	Mod1X	Mod2X	Mod1X	Mod2X
Story 10	0.0035	0.0036	0.2071	0.2184	0.0016	0.0017	0.0046	0.0049
Story 20	0.0031	0.0032	0.1484	0.1564	0.0017	0.0018	0.0025	0.0026
Story 30	0.0021	0.0023	0.0299	0.0316	0.0013	0.0014	0.0022	0.0023
Story 40	0.0014	0.0014	0.0096	0.0101	0.0010	0.0010	0.0010	0.0010

The story drift in case of rigid frame structural system produce the largest story drifts (with maximum value between stories 10 and 20) compared to other structural systems.

5.3 Lateral Displacement

Lateral displacement is the displacement or lateral movement that occur due to lateral forces such as seismic and/or wind loads. The lateral displacement is calculated from the base to the top of the building where it shows the total displacement of the building as shown in Fig. 4.

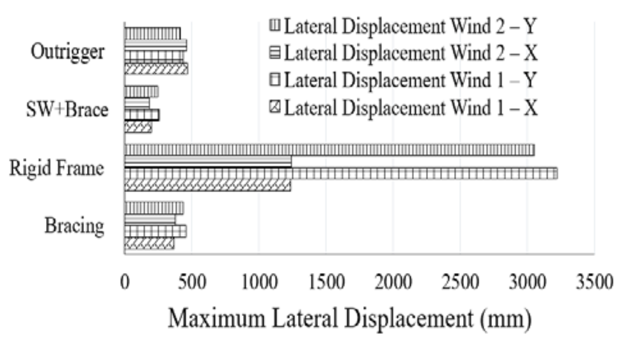

Fig. 4: Lateral displacement (mm) for Strucutral Systems

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

International Journal of Psychosocial Rehabilitation, Vol. 24, Issue 01, 2020
ISSN: 1475-7192

In cases of bracings system, rigid frame system and shear wall with bracings system, the displacement in Y direction is greater than the displacement in X direction. Rigid frame system in high-rise concrete buildings produce more than double the value of lateral displacement comparing it to the other cases. Minimum lateral displacement is produced by using shear wall and bracing system when comparing the data with other case studies, where shear wall has decreased the lateral displacement when adding it to bracing system.

5.4 Maximum Storey Displacement

Storey Displacement is the displacement of a specific story in any of the direction due to wind forces. Storey displacement at various locations for structural systems considered in present study are shown in Table 8. It was observed that rigid frame has the highest lateral displacement in both X and Y directions. Outrigger system has higher value of displacement in X direction than Y direction, which is vise-versa comparing to the other cases due to the effect of the belt that has been added in the middle story of the high-rise building. In general, displacements in Y direction is higher than displacements in X directions in all cases.

Table 8: Maximum Storey displacement (mm) due to wind modal 1 load case in the X direction.

Location	Wind force direction	Bracings	Rigid Frame	SW+Brace	Outrigger
Story 10	X	91.614	1162.720	40.233	188.730
	Y	181.086	627.498	58.164	180.318
Story 20	X	211.843	1815.912	102.681	328.129
	Y	318.293	1064.651	143.135	311.543
Story 30	X	304.537	639.139	156.236	413.575
	Y	410.588	1939.113	210.704	389.769
Story 40	X	364.675	1232.362	195.213	466.963
	Y	457.783	3219.553	255.398	436.188

5.4 Fundamental translational natural period of the building

It is a ratio that aims to describe the behavior of buildings under seismic load. Natural Period of a building is the time taken by it to undergo one complete cycle of oscillation. It is an inherent property of a building controlled by its mass m and stiffness k. The estimation of time-period is indication of building's behavior when subjected to seismic vibrations.

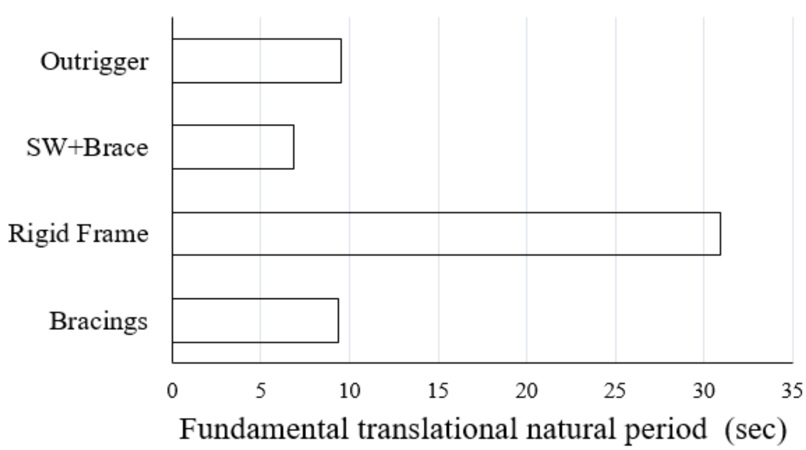

Fig. 5: Fundamental translational natural period (sec) for Structural systems

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019

The rigid frame system shows bigger fundamental period comparing it with the rest of the systems, where the values indicate that the moment resisting frame is not sufficient in terms of the resistance of the building in terms of seismic loads.

VI. CONCLUSION

The present study aims to identify appropriate structural system for a reinforced concrete high rise building among four different structural systems. A rigid frame system is not recommended to be used in high-rise concrete buildings as it produces large values of critical parameters related to overall lateral behavior. Outrigger system is considered suitable for buildings less than 40 stories. Bracing system and shear wall with bracing system fits the building characteristics where they minimized the lateral deformation due to wind loads in both X and Y directions compared to rigid frame and outrigger structrual system. Rigid frame system has the highest values for all parameters included in present study and thus it is an indication that rigid frames are not sufficient for high-rise concrete structures. It is also noteworthy that bracing system is preferred for buildings typically less than forty stories, as with increase in building height the efficiency of bracing system decreases. A similar observation applies to outrigger structural system. Practically in structural engineering in order to design complete bracing system for a reinforced concrete building several design criterion needs to be considered such as design constraints, materials, maximum deflection and frequency. Shear wall system is the most applicable system that can be used for high-rise buildings.

REFERENCES

[1] Badami, S. (2014). A study on behavior of structural systems for tall buildings subjected to lateral loads, *International Journal of Engg. Research and Tech. (IJERT),* ISSN: 2278-0181, vol. 3(7), 989-994.

[2] Patel H.J., Parikh K.B., Darji A. R. (2016). Parametric study on Braced tube structural system, *International Journal of Emerging Technologies and Innovative Research,* ISSN: 2349-5162, Vol.3, Issue 6, pp. 129-134, June-2016.

[3] ASCE7-10. Story dirft limitation – ASCE7-10.

[4] Habitat, C. O. (2012). Outrigger System. *Illinois, USA: Council on tall buildings and urban habitat.*

[5] History, T. J. (1968). Society for the History of Technology and The Johns Hopkins University Press are collaborating with JSTOR. *The First Reinforced-Concrete Skyscraper: The Ingalls Building in Cincinnati and its place in*.

DOI: 10.37200/IJPR/V24I1/PR200159
Received: 08 Nov 2019 | Revised: 10 Dec 2019 | Accepted: 26 Dec 2019