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A COMPARATIVE STUDY OF LATERAL LOAD RESISTING SYSTEMS IN TALL STRUCTURES

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Abstract — *Early structures in the medieval period of twentieth century were assumed to carry only the gravity loads. However, today with the increase in urbanization along with the scantiness of land availability and high price rise, the need of the vertical development arises for fulfillment of various needs of human activities. Owing to these situations, advances have been in the development for the use of high-strength materials, lightweight material along with changes in structural design and establishment of slender buildings. These innovative methods require critical analysis with consideration of lateral loads such as wind and earthquake loads. Presently, numerous structural systems are available which can be utilized for analysis of the lateral resistance of tall buildings. In this way, proper examination is required for undertaking the consideration of proper type of structural system, which can be used to fulfill all our Structural & Architectural parameters along with effective utilization of the material & technology that can be useful for sustainability of the future. The present work, studies the response of the various structural system used in the buildings and its comparison. Four different structural systems were investigated, which includes Structural Wall + Moment Resisting Frame, Structural Wall System, Core Structural Wall system and Outrigger Structural System (Belt Truss System). 39 storey building having typical height 3.65m was considered. Moreover, Response Spectrum analysis and Static wind analysis were also performed and comparison of different structural parameters such as Base Shear, Storey Drift, and Storey Displacement were accomplished.*

Keywords- *Structural systems, Response spectrum, Tall Structures, Outrigger system, Structural wall system, Core-wall system, Rigid frame system*

I. INTRODUCTION

The resistance of tall buildings to wind as well as to earthquakes is the main determinant in the formulation of new structural systems that evolve by the continuous efforts of structural engineers to increase building height while keeping the deflection within acceptable limits and minimizing the amount of materials. Thanks to the sophisticated computer technology, modern materials and innovative structural concepts, structural systems have gone beyond the traditional frame construction.[1] Selection of structural system for tall buildings depends upon shape, horizontal and vertical aspect ratios, nature and magnitude of lateral loads, internal planning of the building, availability of material of construction, facade treatment and location [15]. The selected structural system should be strong enough to withstand anticipated loads without failure, stiff enough to keep lateral deflections and lateral load induced motions within limits with minimum cost [16].

1.1. The five major structural system used for the tall buildings are:

1. Rigid frame system
2. Rigid frame with shear wall system
3. Shear wall system
4. Structural core system
5. Outrigger system (Belt truss system)

1.1.1. Rigid frame system:

The word rigid means ability to resist the deformation. Rigid frame structures can be defined as the structures in which beams & columns are made monolithically and act collectively to resist the moments which are generating due to applied load. Rigid frame structures provide more stability. This type of frame structures resists the shear, moment and torsion more effectively than any other type of frame structures.[17]

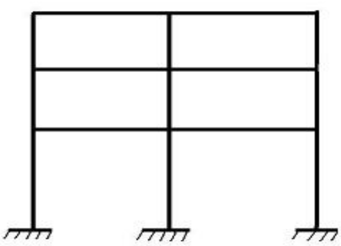

Figure 1: Rigid frame structure[17]

1.1.2. Rigid frame with shear wall system:
When shear walls are combined with rigid frame the walls which tend to deflect in flexural configuration, and the frames which tend to deflect in shear mode are constrained to adopt a common deflected shape by the horizontal rigidity of the girders and slabs. Consequences, the walls and frames interact horizontally, especially at the top to produce a stiffer and stronger structure.[7]

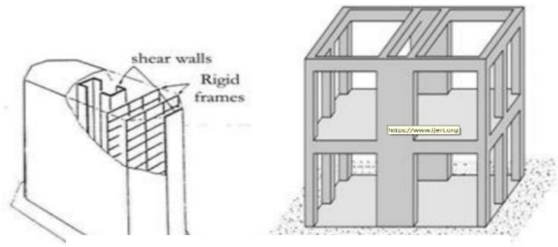

Figure 2: Rigid frame with Shear wall structure[7]

1.1.3. Shear wall system:
Very high plane stiffness and strength makes shear wall ideally suited for bracing tall buildings. In this system, walls are entirely responsible for the lateral load resistance of the building. They act as vertical cantilevers in the form of separate planar walls, and as nonplanar assemblies of connected walls around elevators, stair and service shafts. Because they are much stiffer horizontally hen rigid frames.[15]

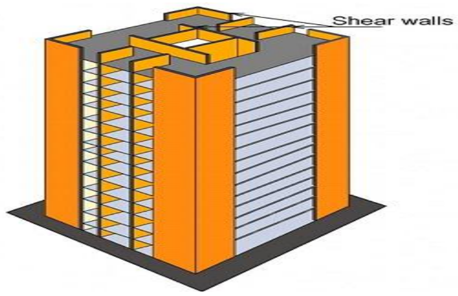

Figure 3: Shear wall structure[15]

1.1.4. Structural core system:
The central of arterial part of a multistory building that integrates functions and service needs for established occupants. Such areas are normally composed of toilet facilities, elevator banks, janitors' closet, utilities, mechanical facilities, smoke shafts and stair. Core is usually located at the Centre or side of building, the reinforced concrete wall, which is the major structural load bearing element and provides rigidity to resist deflection caused by strong wind.[9]

Figure 4: Structural core structure[9]

1.1.5. Outrigger system (Belt truss system):
The outrigger and belt truss system is one of the lateral loads resisting system in which the external columns are tied to the central core wall with very stiff outriggers and belt truss at one or more levels. The belt truss tied the peripheral column of building while the outriggers engage them with main or central shear wall. The aim of this method is to reduce obstructed space compared to the conventional method. The floor space is usually free of columns and is between the core and the external columns, thus increasing the functional efficiency of the building. Exterior columns restrained the core wall from free rotation through outrigger arms. Outrigger and belt trusses, connect planar vertical trusses and exterior frame columns. Outrigger system can lead to very efficient use of structural materials by mobilizing the axial strength and stiffness of exterior columns.[18]

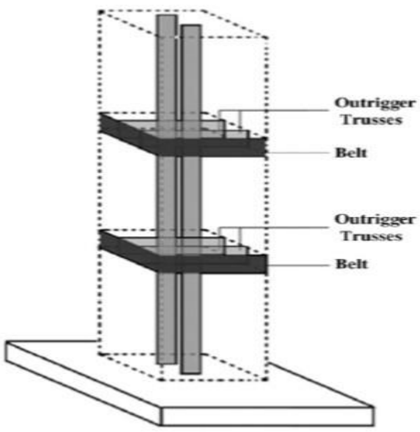

Figure 5: Outrigger system (Belt truss system)[18]

II. BUILDING CONFIGURATION

2.1. General details:
Basic structural details adopted in this present work are assumed based on practical application to option the realistic behaviour of the structure for which different building parameters mention below:

Building use:	Residential Purpose
Material:	Concrete

Typical storey height:	3.65 m
Height:	145.35m (39 Storey)
Structural Systems:	Structural Wall System, Moment Resisting Frame + Structural Wall System Core Structural Wall System, Outrigger Structural System-1(one outrigger structure provided at H/2), Outrigger Structural System-2(two outrigger structure provided at H/3 and 2H/3)
Location of Building:	Surat, Gujarat.
Grade of concrete:	M35 (As per IS 13920:2016 And IS 16700:2017)
Grade of steel:	Fe500D (As per IS 1786 And IS 13920:2016)
Masonry work:	Aerated Cement Concrete blocks (ACC) (Density:1000kg/m^3)

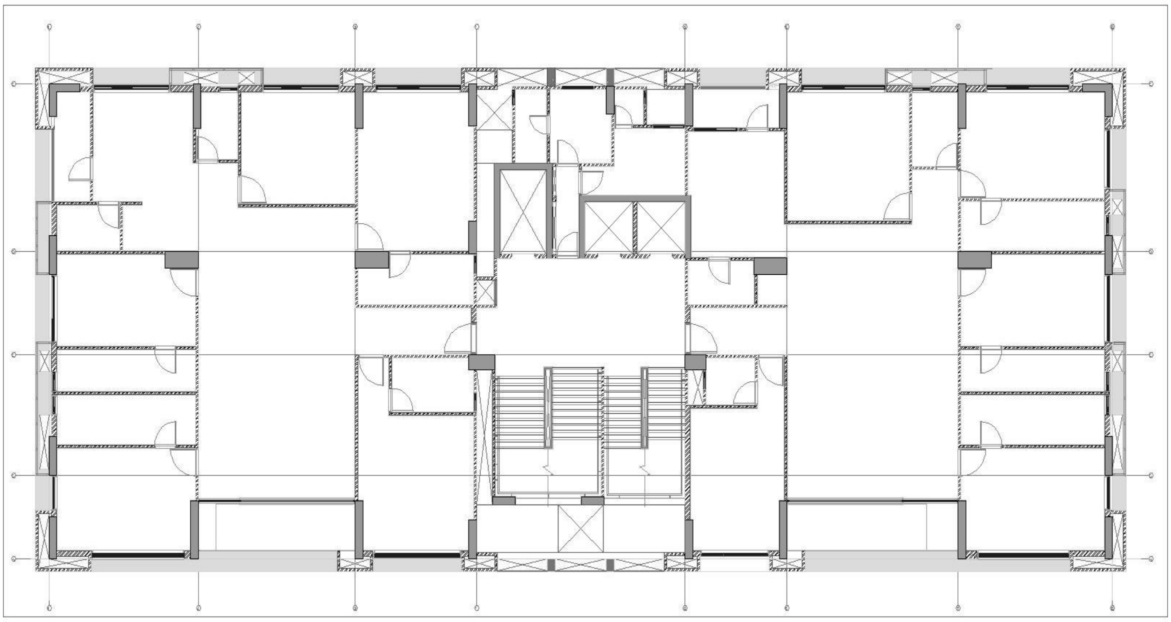

Figure 6: Adopted plan

2.2. Adopted member sizes:

2.2.1. Beams: (as per IS 16700:2017, IS 13920:2016, IS 456:2000)

Table 1: Sizes of Beams

Beam 150*400	Beam 300*600
Beam 230*300	Beam 300*900
Beam 230*400	Beam 375*600
Beam 230*600 G.B.	

2.2.2. Slabs: (as per IS 16700:2017, IS 13920:2016, IS 456:2000)

Table 2: Sizes of Slabs

Slab 200mm (two way)
Slab 125mm(one way)
Slab 125mm(two way)
Slab 150mm(one way)
Slab 150mm(two way)

2.2.3. Columns: (as per IS 16700:2017, IS 13920:2016, IS 456:2000)
As per the positions of the vertical elements the Grouping is done and are shown as per below:

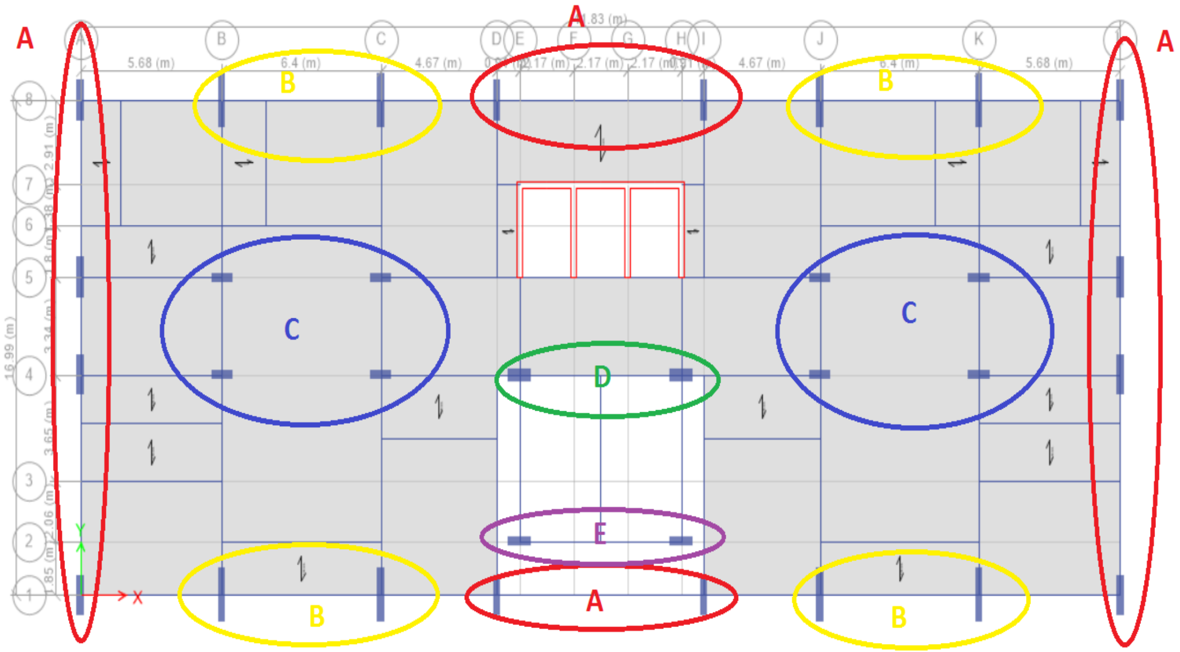

Figure 7: Grouping of vertical elements

Table 3: Sizes of vertical elements

39 Story (mm)												
Structural system	**Structural Wall A**		**Structural Wall B**		**Column C**		**Column D**		**Column E**		**Column F**	
Structural Wall + Moment Resisting Frame	Below 20 Story	Above 20 Story	Below 20 Story	Above 20 Story	Below 20 Story	Above 20 Story	Below 20 Story	Above 20 Story	Below 20 Story	Above 20 Story	Below 20 Story	Above 20 Story
	600 X 2400	500 X 2400	600 X 2400	500 X 2400	600 X 1000	500 X 1000	600 X 1000	500 X 1000	600 X 1000	500 X 1000	-	-
Structural Wall	**Structural Wall A**		**Structural Wall B**		**Structural Wall C**		**Structural Wall D**		**Structural Wall E**		**Structural Wall F**	
	600 X 2400	500 X 2400	600 X 2400	500 X 2400	600 X 1000	500 X 1000	600 X 1000	500 X 1000	600 X 1000	500 X 1000	-	-
Structural Core System	**Structural Wall A**		**Structural Wall B**		**Structural Wall C**		**Structural Core D**		**Structural Core E**		**Structural Core E**	
	600 X 2400	500 X 2400	600 X 2400	500 X 2400	600 X 1000	500 X 1000	300	300	-	-	-	-
	Structural Wall A		**Structural Wall B**		**Column C**		**Structural Core D**		**Outrigger E**		**Column F**	
Outrigger System 1	600 X 1800	500 X 1800	600 X 1800	500 X 1800	600 X 1000	500 X 1000	300	300	300	300	-	-
Outrigger System 2	600 X 1800	500 X 1800	600 X 1800	500 X 1800	600 X 1000	500 X 1000	300	300	300	300	-	-

2.2.4. Modifiers used in structural members:

As per the IS 1893:2016 and IS 16700:2017 the use of modifiers is mandatory which is given an applied in present analysis as follows:

For Structural Analysis, the moment of inertia shall be taken as:

70 percent of I_{gross} of Column and Walls

35 percent of I_{gross} of Beams

25 percent of I_{gross} of Slabs

2.2.5. Loading parameters:

Table 4: Loading parameters

Loads	Types	Value	Units
Live Load	Passage	3	kN/m^2
	Flat area	2	kN/m^2
	Terrace	1.5	kN/m^2
Dead Load	Slab:		
	Floor Finish	1.5	kN/m^2
	Sunk	1.5	kN/m^2
	Water Proofing	3	kN/m^2
	Partition	1	kN/m^2
	Beam:		
	Internal Wall	4.064	kN/m
	External Wall	8.125	kN/m
	Stair	26	kN/m
	Railing	4	kN/m
Location		Surat	
Wind Load		AS PER IS 875:2015 (PART-3)	
	Wind Speed	44	m/s
	Terrain Category	3	
	Importance Factor	1	
	Risk Coefficient	1	
	Topography Factor	1	
Earthquake Load		AS PER IS 1893:2016 (PART-1)	
	Type: SMRF (R)	5	
	Zone	III (0.16)	
	Importance Factor	1.2	
	Damping Factor	5	
	Site Soil Type	II	

2.2.6. Imposed load to be considered in calculation of seismic weight:

As per IS 1893:2016, cl.7.3.2 for calculation of design seismic force of buildings impose load should be considered as 25 percentages of impose load less then and equal to 3.

2.2.7. Method of Analysis:

In the present study, the analysis of the structure is made for lateral loads using equivalent static method (Linear Static Analysis), response spectrum analysis (Linear Dynamic Analysis) and static wind analysis are carried out using ETABS 2016 V16.2.0 Software.

III. RESULTS AND DISCUSSION

3.1. General:

In this present work response of the different structural system used in 39 storey (145.35m) buildings are observed and compared. Four different type of structural system is used in this work name as Structural Wall + Moment Resisting Frame, Structural Wall System, Core Structural Wall system and Outrigger Structural System (Belt Truss System) is used. 39 storey (145.35m) building had been investigated which typical storey height of 3.65m. equivalent static analysis, Response Spectrum analysis and Static wind analysis are performed. Different structural results are compared such as Base Shear, Storey Drift, and Storey Displacement. Along with the stability checks as per given in IS 456:2000.

3.2. Base Shear:

This results of Base Shear are taken from the ETABS 2016 V16.2.0 software following the codel provisions given in IS 1893:2016 (Part-1) for Earthquake Loads and IS 875:2015 (Part-3) for Wind Loading.

Table 5: Base Shear

Base Shear (kN)						
39 Storey						
Structural system	**EQ X**	**EQ Y**	**Response X**	**Response Y**	**Wind X**	**Wind Y**
Structural Wall + M.R.F.	5658.9732	3609.6038	5658.9732	3609.6038	4504.0475	11089.1295
Structural Wall	5591.984	3566.8744	5591.984	3566.8744	4504.0476	11089.1296
Structural Core System	5266.7248	3359.4062	5266.7248	3359.4062	4504.0476	11089.1298
Outrigger System 1	7145.1489	4540.8985	7145.1489	4540.8985	4504.0476	11089.1295
Outrigger System 2	7246.3388	4605.2069	7246.3388	4605.2069	4504.0476	11089.1295

Mainly two type of loading act on the building i.e. gravity load and lateral load due to earthquake or wind. The base shear of wind load is higher compared to earthquake load for 39 storey buildings considered in this study. Thus, wind load is governing for the design of structure.

3.3. Storey Displacement:

This results of Storey Displacement are taken from the ETABS 2016 V16.2.0 software following the codel provisions given in IS 1893:2016 (Part-1) for Earthquake Loads and IS 875:2015 (Part-3) for Wind Loading.

Max permissible lateral deflection

- For wind -- H/500 As per (cl. 20.5) IS 456:2000
- For earthquake -- Storey Drift <= h/250 (cl 7.11.1.1) IS 1893:2016 (part-1)

Both of this limits are also mentioned in (cl 5.4) IS 16700:2017

Where, H= Height of the building (m),

h=height of storey (m)

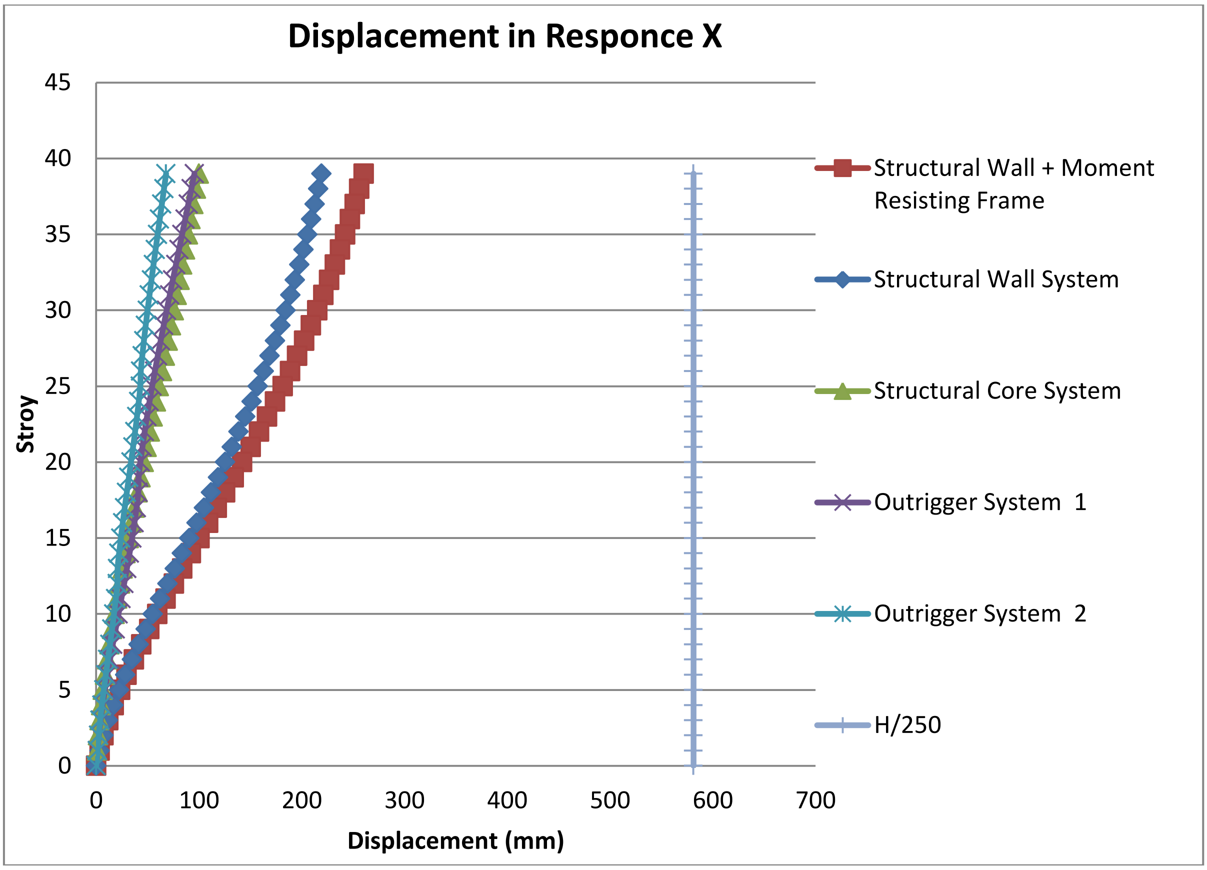

Figure 8: Displacement in response X direction

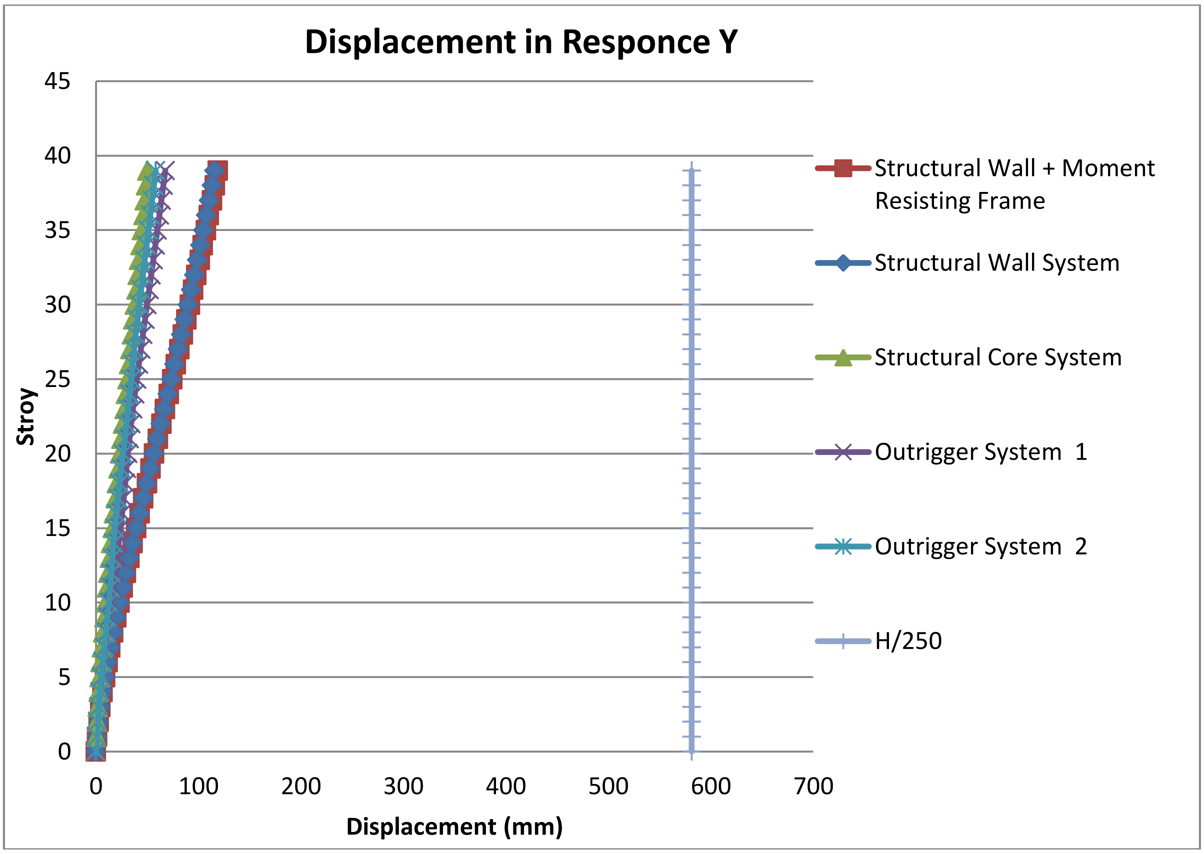

Figure 9: Displacement in response Y direction

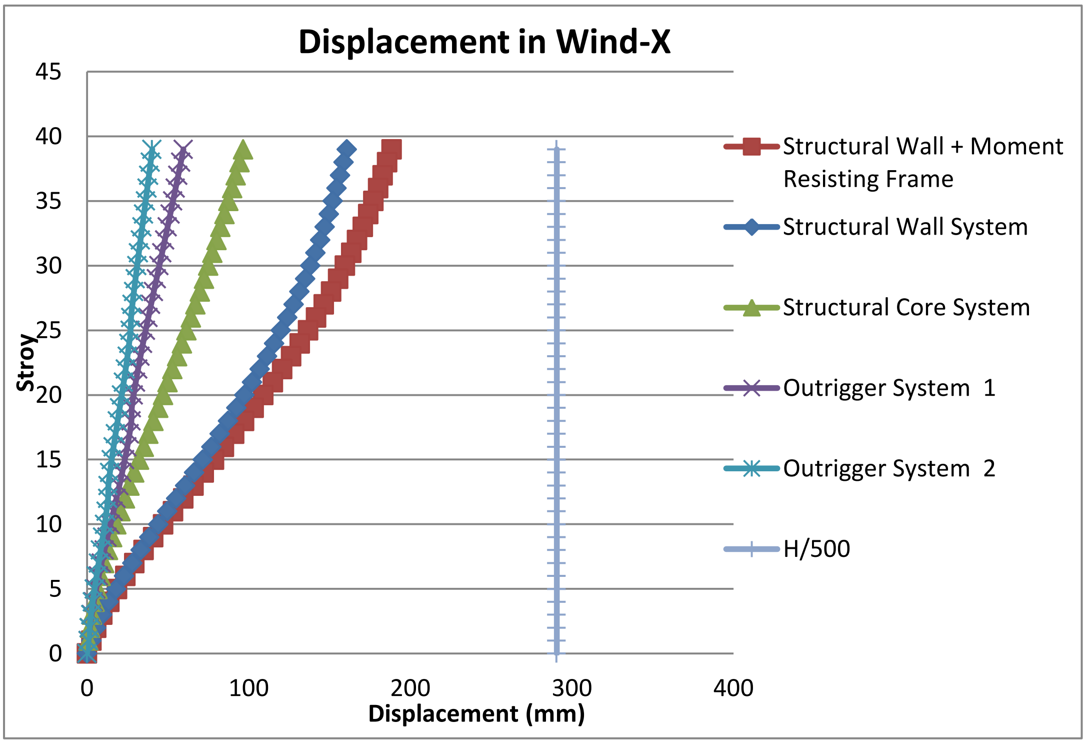

Figure 10: Displacement in wind X direction

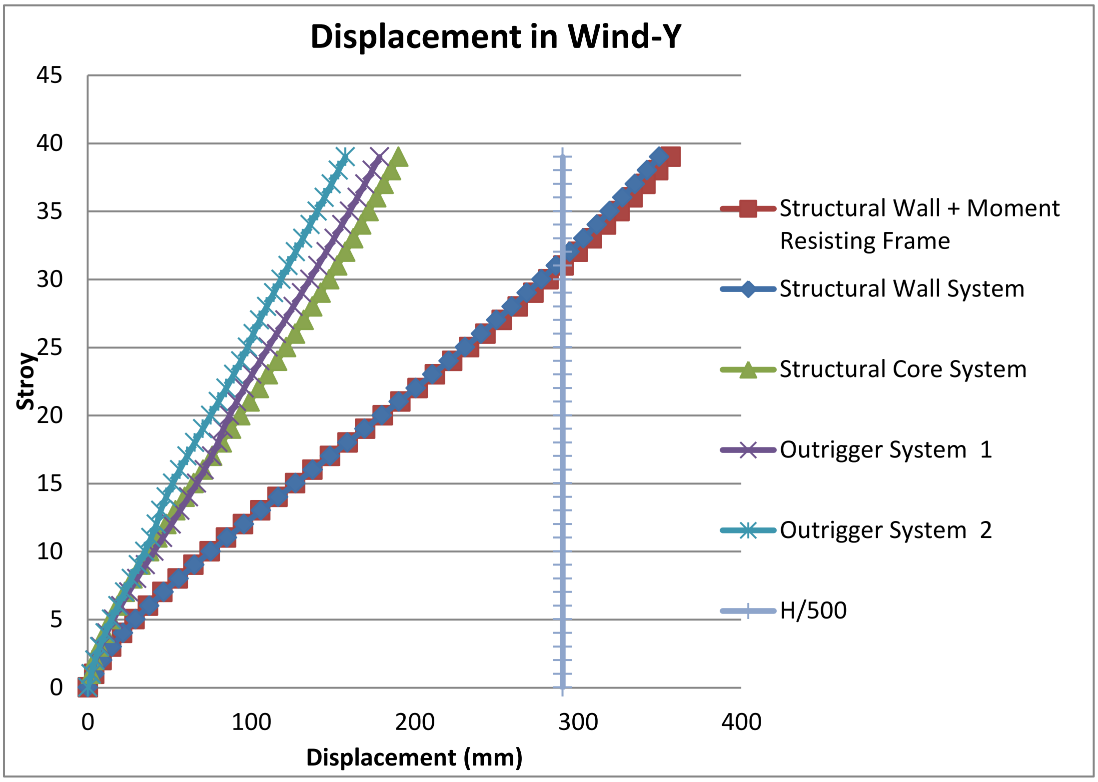

Figure 11: Displacement in wind Y direction

The displacement of 39 storey diagrid structure is shown in Fig. It is observed that displacement in x-direction and Y-direction due to static wind load is higher compared to earthquake load in all structural systems.

3.4. Storey Drift:

Table 6: Storey Drift

39 Storey							
	Response X	**Response Y**	**Wind X**	**Wind Y**	**h/250**	**h/500**	**Result**
Structural Wall + M.R.F.	8.534	3.742	6.319	10.804	14.6	7.3	NOT SATISFIED
Structural Wall	7.304	3.597	5.538	10.599	14.6	7.3	NOT SATISFIED
Structural Core System	3.148	1.592	2.976	5.713	14.6	7.3	SATISFIED
Outrigger System 1	1.781	1.779	1.873	5.339	14.6	7.3	SATISFIED
Outrigger System 2	1.438	1.719	1.284	4.842	14.6	7.3	SATISFIED

The inter-storey drift of 39 storey building is shown in table. It is observed that inter-storey drift limit (h/500) exceeds in structural wall + M.R.F. and structural wall system due to wind load.

IV. CONCLUSION

The Response of tall building under wind and earthquake loading is studied as per IS codes of practice. Seismic analysis with response spectrum method and wind load analysis are used for analysis of G+39 storey RCC building as per IS 1893(Part 1): 2016, IS 875 (Part 3): 2015, and IS 16700: 2017 codes respectively. The building with slenderness ratio of 8.55 for G+39 storey was studied, which is within limits of slenderness give in IS 16700: 2017.The building with aspect ratio 2.46, which is less than 5 limits specified by IS16700: 2017.Different structural systems like moment resisting frame + structural wall system, Structural wall system, Core structural wall system and outrigger structural system are studied.

- Observing the response of different structural system, the following conclusions are made,

1. For G+39 moment resisting frame + structural wall system and Structural wall system, exceeds the limit of displacement in wind Y-direction.
2. Outrigger system shows very less displacement and drift in G+39 storey. it can be used if there is larger irregularity, which creates larger displacement and drift.
3. For G+39, Structural core system gives best performance comparatively.
4. It is also been moving further higher, structural core system will also shows larger displacement and drift, where outrigger will be seen as performing better.

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