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SEISMIC RESPONSE OF MULTI-STOREY BUILDINGS: EFFECT OF SHEAR WALL PLACEMENT ON STRUCTURAL PERFORMANCE

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ABSTRACT

Shear walls are a type of structural system that provides lateral resistance to a building or structure. They resist in-plane loads that are applied along its height. The applied load is generally transferred to the wall by a diaphragm or collector or drag member. The performance of the framed buildings depends on the structural system adopted for the structure, the term structural system or structural frame refers to load-resisting sub-system of a structure. The structural system transfers loads through interconnected structural components or members. These structural systems need to be chosen based on its height and loads and need to be carried out, etc. This application is completely independent of shear wall and different shear wall location in structural system.

In depth review of these papers along with extraction of strength, weakness and gaps are discussed. Problem statement and the objectives are framed to analyze the efficiency of shear wall location to resist lateral displacement and deflections. The seismic analysis of multi storey building with influence of different shear wall locations is analyzed as per Response Spectrum Analysis method by using STAAD PRO. V8i software. For the investigation purpose G+10 multi storey regular structure situated in Seismic zone V is designed using as per IS 1893:2002. Five different model are designed with shear wall at various locations. Performance of these 5 models with shear wall at different locations are analyzed in terms of various strength and stiffness parameters against the bare frame reference model. Various strength and stiffness parameters analyzed are Lateral displacement, torsion, bending moment and axial force. Model with shear walls in all four corners is found to be the most efficient shear wall location in structure.

Keywords: Shear Wall, IS 1893:2002, STAAD PRO And Lateral Displacement.

I. INTRODUCTION

Tall buildings are the most complex built structures since there are many conflicting requirements and complex building systems to integrate. Today's tall buildings are becoming more and more slender, leading to the possibility of more sway in comparison with earlier high-rise buildi6\[[\ngs. Thus the impact of wind and seismic forces acting on them becomes an important aspect of the design. Improving the structural systems of tall buildings can control their dynamic response. With more appropriate structural forms such as shear walls and tube structures, and improved material properties, the maximum height of concrete buildings has soared in recent decades. Therefore; the time dependency of concrete has become another important factor that should be considered in analyses to have a more reasonable and economical design. In many structures the lateral resistance in one horizontal direction is provided by several members. In medium to high-rise buildings, Reinforced Concrete (RC) walls systems are commonly used to resist forces induced by earthquake. However, these structural systems are required to withstand earthquakes without collapsing and without incurring major damage. In order to achieve satisfactory earthquake response of RC shear walls structures, three methods can be identified as being practical and efficient. These are structural isolation, energy absorption at plastic hinges and use of mechanical devices to provide structural control. The use of those methods is very efficient but expensive and difficult to carry out. From a technological point of view, the strengthening of RC shear walls structures has been accomplished by adopting standard materials, mainly cement, concrete and steel. However, new reinforcement approaches are rising they are based on the idea that the strengthening should be light and removable and, should not change the structural scheme of the construction. Composite materials appear to be good candidates to substitute standard materials. Since they are light, simple to install and are also removable. Moreover, composite materials are characterized by high strength, good durability and lower installation and maintenance cost. Thus, one promising technique to improve the overall strength of RC shear walls structures and to reduce their seismic vulnerability is to retrofit the RC shear walls structures using Fibers Reinforced Plastic (FRP). Medium-rise and high-rise concrete core-wall buildings have been used intensively due to its lower costs and faster construction compared with other medium-rise and high-rise buildings using other lateral-force-resisting system.

1.1.2 Lateral Loads

Most lateral loads are live loads whose main component is a horizontal force acting on the structure. Typical lateral loads would be a wind load against a facade, an earthquake, the earth pressure against a beach front retaining wall or the earth pressure against a basement wall. Most lateral loads vary in intensity depending on the building's geographic location, structural materials, height and shape. The dynamic effects of wind and earthquake loads are usually analyzed as an equivalent static load in most small and moderate-sized buildings.

- **Wind Loads**

The most common lateral load is a wind load. Wind against a building builds up a positive pressure on the windward side and a negative pressure (or suction) on the leeward side. Depending upon the shape of the structure it may also cause a negative pressure on the side walls or even the roof. The pressure on the walls and roof is not uniform, but varies across the surface. Winds can apply loads to structures from unexpected directions. Thus, a designer must be well aware of the dangers implied by this lateral load. The magnitude of the pressure that acts upon the surfaces is proportional to the square of the wind speed. Wind loads vary around the world. Meteorological data collected by national weather services are one of the most reliable sources of wind data. Factors that affect the wind load include the geographic location, elevation, degree of exposure, relationship to nearby structures, building height and size, direction of prevailing winds, velocity of prevailing winds and positive or negative pressures due to architectural design features (atriums, entrances, or other openings). All of these factors are taken into account when the lateral loads on the facades are calculated. It is often necessary to examine more than one wind load case.

- **Earthquake Loads**

Earthquake loads are another lateral live loads. They are very complex, uncertain, and potentially more damaging than wind loads. It is quite fortunate that they do not occur frequently. The earthquake creates ground movements that can be categorized as a "shake," "rattle," and a "roll." Every structure in an earthquake zone must be able to withstand all three of these loadings of different intensities. Although the ground under a structure may shift in any direction, only the horizontal components of this movement are usually considered critical in a structural analysis. It is assumed that a load-bearing structure which supports properly calculated design loads for vertical dead and live loads are adequate for the vertical component of the earthquake. The "static equivalent load" method is used to design most small and moderate-sized buildings. The lateral load resisting systems for earthquake loads are similar to those for wind loads. Both are designed as if they are horizontally applied to the structural system. The wind load is considered to be more of a constant force while the earthquake load is almost instantaneous. The wind load is an external force, the magnitude of which depends upon the height of the building, the velocity of the wind and the amount of surface area that the wind "attacks." The magnitude earthquake load depends on the mass of the structure, the stiffness of the structural system and the acceleration of the surface of the earth. It can be seen that the application of these two types of loads is very different.

1.1.3 Types of Lateral Load Resisting Systems

Different types of lateral load resisting system which can be employed to improve the lateral stiffness & strength of the structure such as;

- Shear wall structures
- Braced frame systems
- Rigid frames
- In-filled frame structures
- Flat slab structures
- Tube structures

- Suspended structures
- **Shear Wall Structures**

Shear walls are specially designed structural walls incorporated in building to resist lateral forces that are produced in the plane of the wall due to wind, earthquake and other forces. These walls behave more like flexural members. They are usually provided in tall buildings and have been found to be of immense use to avoid total collapse of building under seismic forces. These include the vertical walls of concrete or masonry. Sometimes these are also used in combination with the rigid frames. These walls are considered effective in resisting the horizontal shear acting along their length due to the lateral loading of wind or earthquake as a result of large in-plane stiffness.

- **Braced Frame Systems**

Bracing is generally viewed as an exclusive steel system but nowadays steel bracings are also used in reinforced concrete frames, it is an efficient and economical way for improving the lateral stiffness and resistance of rigid frame system. The bracing will almost eliminate the bending of columns and beams by resisting lateral loads primarily through axial stress, thus allowing for slenderer elements. These structures with braced frames increase the lateral strength and also the stiffness of the structural system and hence reduce the drift.

- **Rigid Frames**

In these structures, the lateral stability is provided by the moment resisting connections of the beams and columns. These forms are only used up to 25 stories as for the higher buildings, the demand of the lateral forces increases and can result in larger size of beams and columns. Such forms are normally preferred for the concrete buildings.

- **Infilled Frame Structures**

In these structures space between the columns and beams is filled with the brick masonry or block masonry. Such forms are used for tall buildings up to 30 stories.

- **Flat Slab Structures**

In such systems, a slab of uniform thickness is used to connect all the columns and there are no beams spanning between columns. Slabs are considered as rigid diaphragms in such forms that transfer the lateral load to the columns. These types of structures are used only for the tall buildings up to 25 stories.

- **Tube Structures**

In these structures, lateral resistance is provided by the moment resisting frame (tube) present at the periphery of the building. Tube consists of closely spaced columns that are joined with deep beams. The gravity loading is shared by both inner columns and tube whereas lateral load is resisted by the exterior tube. The structures can be constructed for tall buildings ranging from 40 to more than 100 stories.

- **Suspended Structures**

The suspended structures, consist of a central core with the cantilevers at roof level to which the vertical hangers of steel cable are attached. The roof slabs are suspended from the hangers. These are used for relatively less high buildings.

II. LITERATURE REVIEW

A literature review is necessary to know about the research area and the problems in that area those have been solved and need to be solved. A proper literature review provides solid background for a noble research work. To start a research work, the first step is to find the problem of research and to choose specific objectives of need. There has been many procedures and processes defined by the researchers to undergo through and arrive at certain conclusion of research objectives. In order to choose specific objectives of research one need to follow a typical process to arrive at the conclusion of uniqueness, novelty and significance of the problem in a specific area / sub area. One has to start with a broader domain of some area / sub area and while doing study of literature narrow down the domain to specific point of issue to decide upon. Literature survey includes the study of various sources of literature in the area of research. It includes finding the related material from magazines, books, research articles, scientific research papers published in various conferences, journals & transactions. Study and understanding the literature other than scientific research papers is bit easy as it elaborates the concepts in simple and explanatory techniques. At the same time these contents cannot be considered as base to arrive at the conclusion of framing research objectives as it is not supported through proper review by various researchers working in the area. Review of a scientific research paper is a tedious job. It needs the prior knowledge of the area of research. The scientific research papers are highly structured, compact and precise in explanation. One may take few days to few weeks to understand a research paper published in standard peer reviewed journals. The researchers need to adopt certain path for doing literature review of such literature. One of the typical processes was followed by us to make a literature review and frame the objectives of research.

Comparative Analysis of Research Works Reviewed on

S. NO .	No. of story	Seismic Zone	Shear wall location	Hardware/ software used	Approach/ Methodology	Output Parameters	Results
1	10 storey.	V	Outer (X & Y direction)	SAP 2000	Nonlinear time history analysis	Shear deformation Seismic damage	Lateral Displacement ↓ 7.8% Shear Deformation ↓ 86%
2	12 storey.	IV	Outer(X direction)	ETABS Software.	Response spectrum method	Base shear Axial force Lateral displacement	Axial forces ↓ 12% Lateral Displacement ↓ 26% Base Shear ↓ 26.5%
3	4 Storey. 6 storey. 8 storey. 10 storey.	II	Corner shear wall	ETABS Software	Dynamic analysis Mathematical analysis	Base shear Mass stiffness distribution Soil condition	Mass Stiffness Ratio ↑ 20% Base Shear ↓ 40%
4	15 Storey.	IV	Core type Outer (X direction)	SAP 2000 STAAD PRO	Elastic and elsto-plastic analysis	Shear force Storey drift Bending moment	Shear Force ↓ 36% Storey Drift ↓ 56.7% Bending Moment ↓ 19%
5	6 Storey.	II	Outer (X and Z direction)	STAAD PRO.	Equivalent static method	Inter storey drift Displacement Storey shear	Storey Shear ↓ 15% Lateral Displacement ↓ 76% Inter Storey Drift ↓ 34%
Z6	7 Storey.	III IV V	Corner type	STAAD PRO.	Response spectrum method	Lateral displacement Storey drift Reinforcement distribution	Reinforcement Distribution ↓ 2.76% Lateral Displacement ↓ 30% Storey Drift ↓ 11%
7	41 Storey.	III	NA	STAAD PRO	Response spectrum method	Base shear Roof displacement Acceleration	Base Shear ↑ 38.8% Acceleration ↑ 0.05% Roof Displacement ↑ 49%
8	21 Storey.	IV	Corner type	SAP 2000	Linear time history analysis	Displacement Period variation	Lateral displacement ↓ 76.71% Period Variation ↓ 0.8%
9	• 15	II	Outer (+X and –X) Central core	STAAD PRO	Dynamic linear Response spectrum method	Axial forces Lateral stiffness Lateral Displacement	Lateral displacement ↓ 49.9% Axial Force ↓ 51% Lateral Stiffness ↑ 47%

Gaps in the Published Research:

There are various studies on different shear wall locations. Experimental and analytical approach is used to get the picture of actual behavior of structure. Investigation has been performed for many years with different models. Modeling with STADD Pro. Also helps to get to know about behavior of shear wall dynamic analysis. On the same hand little work is done on optimization location of shear wall and control of structure from tilting in order to reduce lateral displacement in frame structure. These studies focused on actual behavior of RC structure with different shear wall locations. On the basis of literature review gaps in published research works are-

- Results of the analyzed structures were only obtained along X direction, whereas the deflection along Z direction were neglected.
- Most of the authors installed shear wall at the intermediate core of the structure, only very few authors analyzed the efficiency of the structure with shear wall at all the corners.

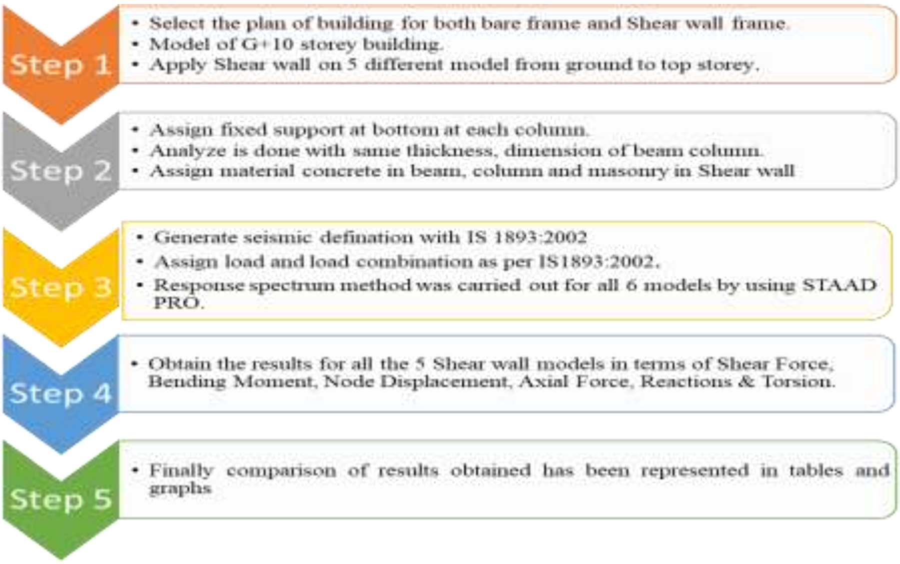
- Limited research was done on the effective thickness of the shear wall system, which plays a significant role in stability of the structure.
- The structural weight of the building increased significantly after the application of shear wall system.

III. RESULTS AND DISCUSSION

Shear walls are vertical elements of the horizontal force resisting system. Shear walls are constructed to counter the effects of lateral load acting on a structure. In residential construction, shear walls are straight external walls that typically form a box which provides all of the lateral support for the building. It consists of reinforced concrete walls and reinforced concrete slabs. Wall thickness varies from 140 mm to 500 mm, depending on the number of stories, building age, and thermal insulation requirements. In general, these walls are continuous throughout the building height; however, some walls are discontinued at the street front or basement level to allow for commercial or parking spaces. Usually, the wall layout is symmetrical with respect to at least one axis of symmetry in the plan.

Details of Methodology Selected

For the investigation purpose an irregular (G+10) reinforced concrete structure was modelled & analyzed in STAAD Pro. The structure consisted of 6 bays of 4.2m along x direction & 4 bays of 4.2m along Z direction. The height of ground floor is 3.5 and after ground level height of each storey is 3m. The analysis of 6 different models were completed in 5 steps.



Step 1
- Select the plan of building for both bare frame and Shear wall frame.
- Model of G+10 storey building.
- Apply Shear wall on 5 different model from ground to top storey.

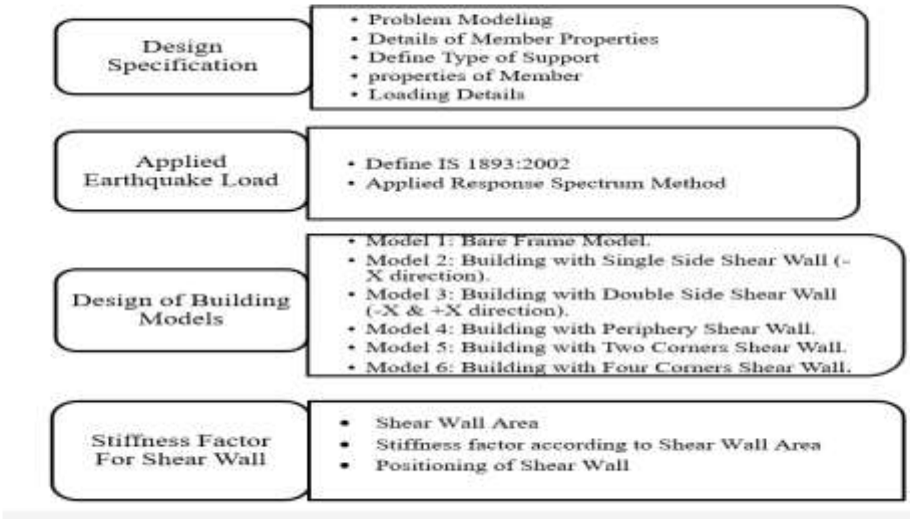
Step 2
- Assign fixed support at bottom at each column.
- Analyze is done with same thickness, dimension of beam column.
- Assign material concrete in beam, column and masonry in Shear wall

Step 3
- Generate seismic defination with IS 1893:2002
- Assign load and load combination as per IS1893:2002.
- Response spectrum method was carried out for all 6 models by using STAAD PRO.

Step 4
- Obtain the results for all the 5 Shear wall models in terms of Shear Force, Bending Moment, Node Displacement, Axial Force, Reactions & Torsion.

Step 5
- Finally comparison of results obtained has been represented in tables and graphs

Design Specification



Design Specification
- Problem Modeling
- Details of Member Properties
- Define Type of Support
- properties of Member
- Loading Details

Applied Earthquake Load
- Define IS 1893:2002
- Applied Response Spectrum Method

Design of Building Models
- Model 1: Bare Frame Model.
- Model 2: Building with Single Side Shear Wall (-X direction).
- Model 3: Building with Double Side Shear Wall (-X & +X direction).
- Model 4: Building with Periphery Shear Wall.
- Model 5: Building with Two Corners Shear Wall.
- Model 6: Building with Four Corners Shear Wall.

Stiffness Factor For Shear Wall
- Shear Wall Area
- Stiffness factor according to Shear Wall Area
- Positioning of Shear Wall

Figure: Design Work Process Flow

Experimental Details

Six models were designed and analyzed in Software package STAAD PRO.

- Bare Frame Structure for G+10 storey.
- 5 Shear wall frame Structure for G+10 storey

The performance has been compared on the basis of

- Shear force in X, Y and Z direction.
- Bending moment in X, Y and Z direction.
- Node displacement in X, Y and Z direction.
- Support Reaction in X, Y and Z direction.
- Maximum Axial force.
- Maximum Torsion.
- Weight of the structure with different Shear wall frame systems.

Result

The Seismic load analysis of the frame model has been done using software STAAD Pro. And the results are shown below. The parameters analyzed are Shear force, Bending moment, Node displacement, Reactions, Axial forces & Torsion. Results were obtained as per Equivalent static analysis method by using STAAD Pro. V8i software.

Model 1: Bare Frame

Shear Force and Bending Moment

Table 1 displays the maximum Shear Force & Bending Moment values obtained along X, Y & Z direction for model 1: Bare frame

Table 1: Shear force & bending moment details of Model 1 Bare frame

	Beam	L\C	Node	Fx	Fy	Fz	Mx	My	Mz
Max Fx	33	7 1.5(DL+LL+EL)	30	6781.469	510.113	0.078	-0.524	-1.101	15745.86
Min Fx	6	6 1.5(DL+EL)	73	-4781.7	675.892	0.718	-1.331	11.477	414.704
Max Fy	29	6 1.5(DL+EL)	26	728.346	723.381	0.032	-0.349	-0.449	17471.95
Min Fy	396	7 1.5(DL+LL+EL)	178	-16.206	-735.614	-0.294	0	-4.158	10250.05
Max Fz	2002	9 1.5(DL+LL+EL)	722	-32.929	-0.413	19.872	4.912	-1699.66	-3.03
Min Fz	30	8 1.5(DL+EL)	27	965.011	-0.023	-722.635	0.352	21348.11	-0.304
Max Mx	1566	7 1.5(DL+LL+EL)	559	-166.398	169.179	-0.884	7.472	11.713	706.718
Min Mx	1512	7 1.5(DL+LL+EL)	523	-166.398	169.179	0.884	-7.472	-11.713	706.718
Max My	30	8 1.5(DL+EL)	27	965.011	-0.023	-722.635	0.352	21348.11	-0.304
Min My	931	9 1.5(DL+LL+EL)	333	256.929	-0.032	-285.189	0.482	-6337.25	0.739
Max Mz	30	6 1.5(DL+EL)	27	973.95	721.617	0.032	-0.361	-0.43	17486.23
Min Mz	396	6 1.5(DL+EL)	177	-15.985	-708.826	-0.294	0	4.158	-10109.9

Node Displacement

Table 2 displays the maximum N.D displacement values obtained along X, Y & Z direction for model 1: Bare frame.

Table 2: Node displacement details of Model 1 Bare frame

	Nodes	L\C	X	Y	Z	Rst	rX	rY	rZ
Max X	751	7 1.5(DL+LL+EL)	32.677	0.251	0.001	32.678	0	0	-0.008
Min X	732	9 1.5(DL+LL+EL)	-0.002	0.259	29.719	29.72	0.009	0	0
Max Y	727	6 1.5(DL+EL)	32.616	0.274	0.002	32.617	0	0	-0.008
Min Y	756	7 1.5(DL+LL+EL)	32.676	-0.412	0	32.678	0	0	-0.008
Max Z	729	9 1.5(DL+LL+EL)	0.001	0.246	29.78	29.781	0.01	0	0
Min Z	787	7 1.5(DL+LL+EL)	32.616	0.264	-0.002	32.617	0	0	-0.008
Max rX	291	9 1.5(DL+LL+EL)	0	0.182	11.707	11.708	0.03	0	0
Min rX	790	7 1.5(DL+LL+EL)	32.608	-0.082	-0.001	32.609	0	0	-0.007
Max rY	739	7 1.5(DL+LL+EL)	32.655	0.252	0.001	32.656	0	0	-0.008
Min rY	775	7 1.5(DL+LL+EL)	32.655	0.252	-0.001	32.656	0	0	-0.008
Max rZ	768	9 1.5(DL+LL+EL)	-0.001	-0.083	29.71	29.71	0.008	0	0
Min rZ	241	7 1.5(DL+LL+EL)	9.644	0.162	0	9.645	0	0	-0.032
Max Rst	756	6 1.5(DL+EL)	32.676	-0.393	0	32.679	0	0	-0.008

Reactions

Table 3 displays the maximum Reaction values obtained along X, Y & Z direction for model 1: Bare frame

Table 3: Reaction details of Model 1 Bare frame

	Node	L\C	Fx	Fy	Fz	Mx	My	Mz
Max Fx	37	9 1.5(DL+LL+EL)	1.999	1207.233	-720.472	-21316.4	0.695	-21.745
Min Fx	26	6 1.5(DL+EL)	-723.381	728.346	0.032	0.449	-0.349	17471.95
Max Fy	30	7 1.5(DL+LL+EL)	-510.113	6781.469	0.078	1.101	-0.524	15745.86
Min Fy	1	6 1.5(DL+EL)	-675.892	-4753.07	0.718	7.65	-1.331	16489.28
Max Fz	4	7 1.5(DL+LL+EL)	-719.992	1200.76	2.226	24.392	-0.708	17464.93
Min Fz	27	8 1.5(DL+EL)	0.023	965.011	-722.635	-21348.1	0.352	-0.304
Max Mx	4	7 1.5(DL+LL+EL)	-719.992	1200.76	2.226	24.392	-0.708	17464.93
Min Mx	27	8 1.5(DL+EL)	0.023	965.011	-722.635	-21348.1	0.352	-0.304
Max My	54	7 1.5(DL+LL+EL)	-510.074	6761.491	-0.337	-4.357	1.444	15743.06
Min My	18	7 1.5(DL+LL+EL)	-510.074	6761.491	0.337	4.357	-1.444	15743.06
Max Mz	27	6 1.5(DL+EL)	-721.617	973.95	0.032	0.43	-0.361	17486.23
Min Mz	37	9 1.5(DL+LL+EL)	1.999	1207.233	-720.472	-21316.4	0.695	-21.745

Axial Force & Torsion

Table 4 displays the maximum Axial force and Torsion values obtained for model 1: Bare frame.

Table 4: Axial force & Torsion details of Model 1 Bare frame

			Shear Force		Torsion	Bending	
		Axial Force	Fx	Fy		Mx	My
Rect 11.81x17.72	Max +ve	207.254	678.349	10.806	3.257	157.46	10261.08
	Max -ve	-169.326	-735.614	-10.806	-3.257	-157.883	-10109.9
Rect 17.72x23.62	Max +ve	6781.469	723.381	19.872	7.472	21348.11	17486.23
	Max -ve	-4781.695	-12.807	-722.635	-7.472	-6337.25	-7203.81

Model 2: Single Side Shear Wall (-X direction)

- **Shear Force & Bending Moment**

Table 5 displays the maximum S.F & B.M values obtained along X, Y & Z direction for model 2: Single side shear wall (-X direction)

Table 5: Shear force & bending moment details of Model 2 single side shear wall (-X direction)

Max Fx	9	7 1.5(DL+LL+EL)	4	6695.495	217.718	0.252	-1.182	-11.299	468.487
Min Fx	8	6 1.5(DL+EL)	75	-3663.496	238.545	1.248	-1.514	12.299	-209.229
Max Fy	99	6 1.5(DL+EL)	75	-2246.014	272.311	-0.029	10.997	12.907	-102.394
Min Fy	656	9 1.5(DL+LL+EL)	262	-0.021	-146.328	-0.266	0	-0.423	215.238
Max Fz	1455	7 1.5(DL+LL+EL)	513	3.002	53.83	30.66	0.196	-51.546	67.195
Min Fz	41	9 1.5(DL+LL+EL)	39	1497.512	-0.076	-134.161	0.04	447.7	-0.119
Max Mx	114	7 1.5(DL+LL+EL)	90	1005.406	94.955	15.458	12.954	9.898	-37.589
Min Mx	299	7 1.5(DL+LL+EL)	96	818.461	36.318	24.169	-20.94	-39.21	54.119
Max My	41	9 1.5(DL+LL+EL)	39	1497.512	-0.076	-134.161	0.04	447.7	-0.119
Min My	933	9 1.5(DL+LL+EL)	334	252.65	0.03	-52.896	-0.016	-132.661	-0.08
Max Mz	8	6 1.5(DL+EL)	3	-3634.869	238.545	1.248	-1.514	7.746	468.683
Min Mz	100	7 1.5(DL+LL+EL)	10	4052.535	259.934	1.257	11.499	-7.85	-247.15

Node Displacement

Table 6 displays the maximum Node Displacement values obtained along X, Y & Z direction for model 2: Single side shear wall (-X direction)

Table 6: Node displacement details of Model 2: Single side shear wall (-X direction)

	Node	L\C	X	Y	Z	Rst	rX	rY	rZ
Max X	787	7 1.5(DL+LL+EL)	145.924	-0.421	21.537	147.505	0	0.003	-0.001
Min X	75	5 1.5(DL+LL)	-0.053	-0.565	-0.013	0.568	0	0	0
Max Y	297	6 1.5(DL+EL)	48.064	3.513	2.562	48.26	0	0.002	-0.003
Min Y	442	7 1.5(DL+LL+EL)	67.988	-6.96	-3.836	68.45	0	0.002	-0.003
Max Z	730	9 1.5(DL+LL+EL)	0.002	-0.922	140.103	140.106	0.002	0	0
Min Z	792	6 1.5(DL+EL)	145.899	-2.706	-22.076	147.584	0	0.003	-0.001
Max rX	292	9 1.5(DL+LL+EL)	0.009	-0.61	55.107	55.111	0.005	0	0

Min rX	222	6 1.5(DL+EL)	27.707	-1.594	-7.455	28.736	-0.001	0.001	-0.003
Max rY	595	7 1.5(DL+LL+EL)	97.643	-0.739	20.846	99.846	0	0.003	-0.003
Min rY	24	7 1.5(DL+LL+EL)	10.08	-1.068	-1.897	10.312	-0.001	0	-0.004
Max rZ	756	9 1.5(DL+LL+EL)	-0.026	-2.044	139.557	139.572	0.002	0	0
Min rZ	277	7 1.5(DL+LL+EL)	42.957	-0.146	7.288	43.571	0.001	0.001	-0.006
Max Rst	792	6 1.5(DL+EL)	145.899	-2.706	-22.076	147.584	0	0.003	-0.001

Reactions

Table 7 shows the maximum Reaction values obtained along X, Y & Z direction for model 2: Single side shear wall (-X direction).

Table 7: Reaction details of Model 2 Single side shear wall (-X direction)

	Node	L\C	Fx	Fy	Fz	Mx	My	Mz
Max Fx	3	5 1.5(DL+LL)	2.564	1114.26	1.132	1.583	-0.114	-3.668
Min Fx	3	6 1.5(DL+EL)	-238.545	-3634.869	1.248	-7.746	-1.514	468.683
Max Fy	4	7 1.5(DL+LL+EL)	-217.718	6695.495	0.252	11.299	-1.182	468.487
Min Fy	3	6 1.5(DL+EL)	-238.545	-3634.869	1.248	-7.746	-1.514	468.683
Max Fz	54	6 1.5(DL+EL)	-95.265	1824.398	24.011	83.324	-9.241	296.97
Min Fz	39	9 1.5(DL+LL+EL)	0.076	1497.512	-134.161	-447.7	0.04	-0.119
Max Mx	54	6 1.5(DL+EL)	-95.265	1824.398	24.011	83.324	-9.241	296.97
Min Mx	39	9 1.5(DL+LL+EL)	0.076	1497.512	-134.161	-447.7	0.04	-0.119
Max My	18	7 1.5(DL+LL+EL)	-102.112	1933.77	22.378	80.202	0.738	280.508
Min My	61	7 1.5(DL+LL+EL)	-106.101	151.897	-22.09	-79.68	-9.784	320.909
Max Mz	3	6 1.5(DL+EL)	-238.545	-3634.869	1.248	-7.746	-1.514	468.683
Min Mz	3	5 1.5(DL+LL)	2.564	1114.26	1.132	1.583	-0.114	-3.668

Axial Force & Torsion

Table 8 displays the maximum A.F & Torsion values in obtained for model 2: Single side shear wall (-X direction).

Table 8: Axial force & Torsion details of Model 2 Single side shear wall (-X direction)

		Axial	Shear		Torsion	Bending	
Section		Max Fx	Max Fy	Max Fz	Max Mx	Max My	Max Mz
Rect 0.30x0.45	Max +ve	121.683	83.027	18.191	4.651	47.462	227.161
	Max -ve	-113.81	-152.326	-28.283	-4.373	-43.064	-212.648
Rect 0.45x0.60	Max +ve	5353.113	134.213	5.588	17.486	446.756	366.996
	Max -ve	-3420.078	-31.763	-135.831	-5.806	-129.882	-152.015

Model 3: Double Side Shear Wall (-X and +X direction)

- **Shear Force & Bending Moment**

Table 9 shows the maximum Shear force & bending moment values obtained along X, Y & Z direction for model 3: Double side shear wall (-X and +X direction)

Table 9: Shear force & bending moment details of Model 3: Double side shear wall (-X and +X direction)

	Beam	L\C	Node	Fx	Fy	Fz	Mx	My	Mz
Max Fx	9	7 1.5(DL+LL+EL)	4	5575.274	31.403	-2.064	-1.348	2.758	113.739
Min Fx	8	6 1.5(DL+EL)	75	-3640.564	39.416	4.945	-1.403	8.464	9.941
Max Fy	2099	9 1.5(DL+LL+EL)	211	1.455	141.264	0.166	-0.063	-0.331	214.085
Min Fy	666	9 1.5(DL+LL+EL)	285	-2.947	-152.217	0.29	-0.092	0.518	226.329
Max Fz	1455	7 1.5(DL+LL+EL)	513	4.642	57.378	29.017	-0.642	-48.412	72.899
Min Fz	41	9 1.5(DL+LL+EL)	39	1494.361	-0.072	-139.977	0.088	463.885	-0.11
Max Mx	1923	7 1.5(DL+LL+EL)	672	67.156	14.458	0.237	7.946	-0.033	5.865
Min Mx	1977	7 1.5(DL+LL+EL)	708	67.156	14.458	-0.237	-7.946	0.033	5.865
Max My	41	9 1.5(DL+LL+EL)	39	1494.361	-0.072	-139.977	0.088	463.885	-0.11
Min My	949	9 1.5(DL+LL+EL)	345	251.244	0.052	-54.871	0.056	-137.585	-0.132
Max Mz	666	9 1.5(DL+LL+EL)	285	-2.947	-152.217	0.29	-0.092	0.518	226.329
Min Mz	656	8 1.5(DL+EL)	250	-0.936	-123.789	-0.357	0.001	0.575	-206.207

Node Displacement

Table 10 shows the maximum Node Displacement values obtained along X, Y & Z direction for model 3: Double side shear wall (-X and +x direction).

Table 10: Node displacement details of Model 2: Double side shear wall (-X and +X direction)

	Node	L\C	X	Y	Z	Rst	rX	rY	rZ
Max X	730	7 1.5(DL+LL+EL)	91.626	-6.201	-0.042	91.836	0	0	-0.002
Min X	732	9 1.5(DL+LL+EL)	-0.028	-0.125	143.833	143.833	0.002	0	0
Max Y	369	6 1.5(DL+EL)	46.855	3.655	0.009	46.997	0	0	-0.003
Min Y	514	7 1.5(DL+LL+EL)	65.824	-6.376	-0.014	66.132	0	0	-0.003
Max Z	730	9 1.5(DL+LL+EL)	-0.005	-0.745	144.499	144.5	0.002	0	0
Min Z	789	7 1.5(DL+LL+EL)	91.622	2.756	-0.105	91.663	0	0	-0.002
Max rX	292	9 1.5(DL+LL+EL)	0.005	-0.435	56.823	56.825	0.006	0	0
Min rX	789	7 1.5(DL+LL+EL)	91.622	2.756	-0.105	91.663	0	0	-0.002
Max rY	523	7 1.5(DL+LL+EL)	68.372	-0.866	0.061	68.378	0	0	-0.003
Min rY	559	7 1.5(DL+LL+EL)	68.372	-0.866	-0.061	68.378	0	0	-0.003
Max rZ	756	9 1.5(DL+LL+EL)	-0.025	-2.044	143.78	143.795	0.002	0	0

Reactions

Table 11 shows the maximum Reactions values obtained along X, Y & Z direction for model 3: Double side shear wall (-X and +X direction).

Table 11: Reaction details of Model 3: Double side shear wall (-X and +X direction)

	Node	L\C	Fx	Fy	Fz	Mx	My	Mz
Max Fx	63	9 1.5(DL+LL+EL)	629.953	2887.785	-116.868	-488.952	6.691	17.764
Min Fx	4	7 1.5(DL+LL+EL)	-1189.294	8670.659	-2.881	-2.938	-1.42	73.095
Max Fy	4	7 1.5(DL+LL+EL)	-1189.294	8670.659	-2.881	-2.938	-1.42	73.095
Min Fy	3	6 1.5(DL+EL)	-476.214	-5389.114	5.872	6.687	-1.534	97.264
Max Fz	3	7 1.5(DL+LL+EL)	-412.485	-5094.623	7.5	8.624	-1.581	99.097
Min Fz	39	9 1.5(DL+LL+EL)	0.072	1494.361	-139.977	-463.885	0.088	-0.11
Max Mx	3	7 1.5(DL+LL+EL)	-412.485	-5094.623	7.5	8.624	-1.581	99.097
Min Mx	64	9 1.5(DL+LL+EL)	-629.972	2887.886	-117.025	-489.086	-6.702	-17.762
Max My	63	9 1.5(DL+LL+EL)	629.953	2887.785	-116.868	-488.952	6.691	17.764
Min My	64	9 1.5(DL+LL+EL)	-629.972	2887.886	-117.025	-489.086	-6.702	-17.762
Max Mz	28	7 1.5(DL+LL+EL)	-53.942	1506.037	-0.277	-0.416	-0.758	151.364
Min Mz	64	9 1.5(DL+LL+EL)	-629.972	2887.886	-117.025	-489.086	-6.702	-17.762

Axial Force & Torsion

Table 12 shows the maximum Axial force & Torsion values obtained for model 3: Double side shear wall (-X and +X direction).

Table 12: Axial force & Torsion details of Model 3: Double side shear wall (-X and +X direction)

		Axial	**Shear**		**Torsion**	**Bending**	
Section		**Max Fx** kN	**Max Fy** kN	**Max Fz** kN	**Max Mx** kNm	**Max My** kNm	**Max Mz** kNm
Rect 0.30x0.45	Max +ve	123.707	83.059	27.337	4.866	45.576	240.224
	Max -ve	-116.019	-160.007	-27.337	-4.866	-41.908	-218.98
Rect 0.45x0.60	Max +ve	5351.596	138.671	5.177	6.662	207.462	378.092
	Max -ve	-3418.615	-17.89	-72.537	-6.662	-123.602	-157.802

4 Models 4: Periphery Shear Wall

- **Shear Force & Bending Moment**

Table 13 shows the maximum Shear force & bending moment values obtained along X, Y & Z direction for model 4: Periphery shear wall

Table 13: Shear force & bending moment details of Model 4: Periphery shear wall

	Beam	L\C	Node	Fx	Fy	Fz	Mx	My	Mz
Max Fx	64	7 1.5(DL+LL+EL)	64	5837.309	33	2.321	1.448	-3.1	120.307
Min Fx	63	6 1.5(DL+EL)	135	-3902.716	42.046	-5.175	1.498	-8.862	10.472
Max Fy	2097	9 1.5(DL+LL+EL)	427	-23.777	86.924	14.75	-0.033	-25.961	126.847
Min Fy	1037	7 1.5(DL+LL+EL)	429	57.919	-125.067	11.927	0.397	18.652	188.154
Max Fz	1455	7 1.5(DL+LL+EL)	513	5.142	59.217	32.009	-0.667	-53.594	75.846
Min Fz	908	8 1.5(DL+EL)	312	156.978	2.546	-76.638	-0.854	113.926	3.687
Max Mx	1923	7 1.5(DL+LL+EL)	672	65.916	15.149	-2.235	8.434	2.955	6.009
Min Mx	1977	7 1.5(DL+LL+EL)	708	65.915	15.149	2.242	-8.44	-2.964	6.008
Max My	53	9 1.5(DL+LL+EL)	52	1480.477	-0.02	-65.168	-0.651	221.944	-0.027
Min My	1923	8 1.5(DL+EL)	744	-4.178	3.368	-71.664	4.669	-130.477	-6.069
Max Mz	1037	7 1.5(DL+LL+EL)	429	57.919	-125.067	11.927	0.397	18.652	188.154
Min Mz	1039	6 1.5(DL+EL)	430	-58.155	-101.932	11.892	0.379	-18.569	-172.678

Maximum Shear Force & Bending Moment Value Along X, Y & Z Direction

Table 14 shows the comparison of Maximum Shear Force & Bending Moment values of all the analyzed models, while efficiency in percentage of different models to resist Shear Force & Bending Moment against Bare Frame is displayed in table 14.

Table 14: Comparison of Maximum S.F & B.M values

Models	Fx	Fy	Fz	Mx	My	Mz
Model 1	6781.469	723.381	19.872	7.472	21348.11	17486.23
Model 2	6695.495	272.311	30.66	12.954	447.7	468.683
Model 3	5575.274	141.264	29.017	7.946	463.885	226.329
Model 4	5837.309	86.924	32.009	8.434	221.995	188.154
Model 5	6197.376	108.96	34.238	9.37	194.247	298.512
Model 6	4958.820	66.968	31.31	8.456	142.559	151.026

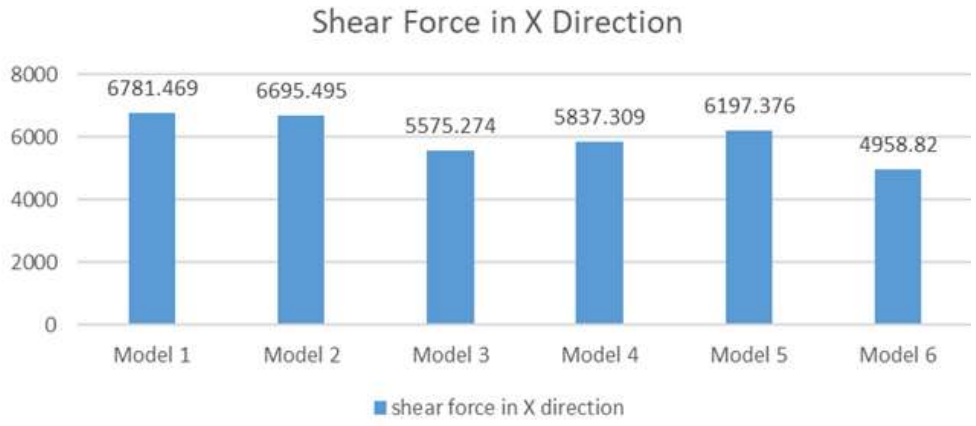
Table 15: Efficiency in % to resist Shear Force & Bending Moment

	Fx	Fy	Fz	Mx	My	Mz	
Model 2	1.26%	6.23%	53.99%	73.37%	97.90%	97.31%	
Model 3	17.79%	80.48%	46.02%	6.35%	97.83%	98.71%	
Model 4	13.92%	8.80%	6.11%	12.88%	98.97%	98.93%	
Model 5	8.62%	84.94%	72.29%	25.41%	99.09%	98.29%	
Model 6	73.13%	90.75%	57.55%	13.17%	99.33%	99.14%	

Table 15 shows the maximum Shear Force along X & Y Direction which need to be controlled by using additional load resisting system. In table 15 the column of Fz and Mx in the red blocks are marginal (As shown in table 14) Shear force along Z direction increases due to the self-weight of the RC shear wall system which are minimal. Also, the reinforcement detailing of the particular Beams remains unaffected along Z direction.

- **Maximum Shear Force in X Direction**

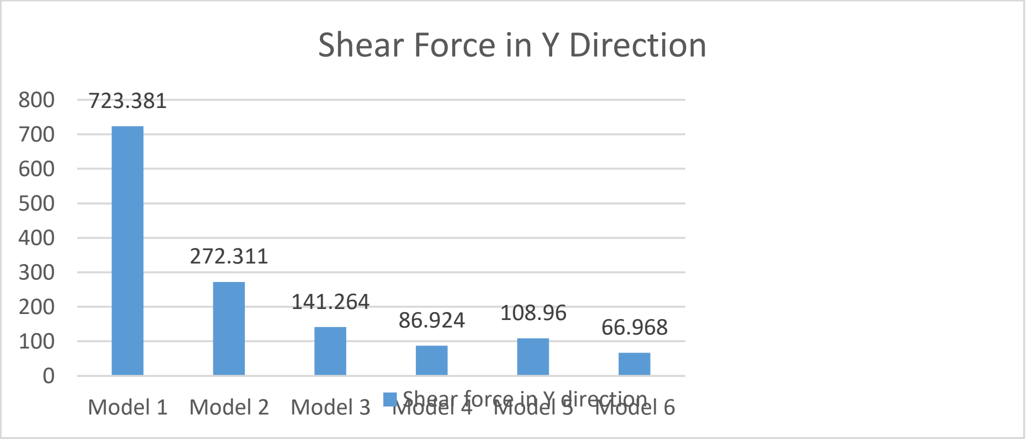
Graph 1 shows the variation in Maximum Shear Force along X direction for different models as shown by Table 14



Graph 1: Comparison of Maximum Shear Force in X direction

- **Maximum Shear Force in Y Direction**

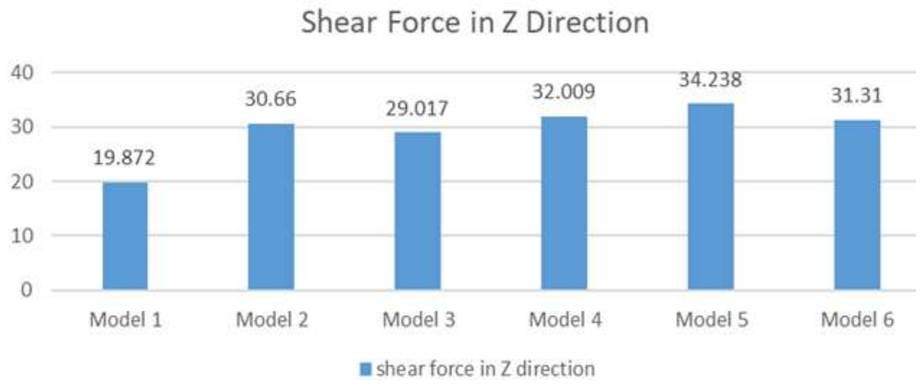
Graph 2 shows the variation in Maximum Shear force along Y direction for different models as shown by Table 14



Graph 2: Comparison of Maximum Shear Force in Y direction

- **Maximum Shear Force in Z Direction**

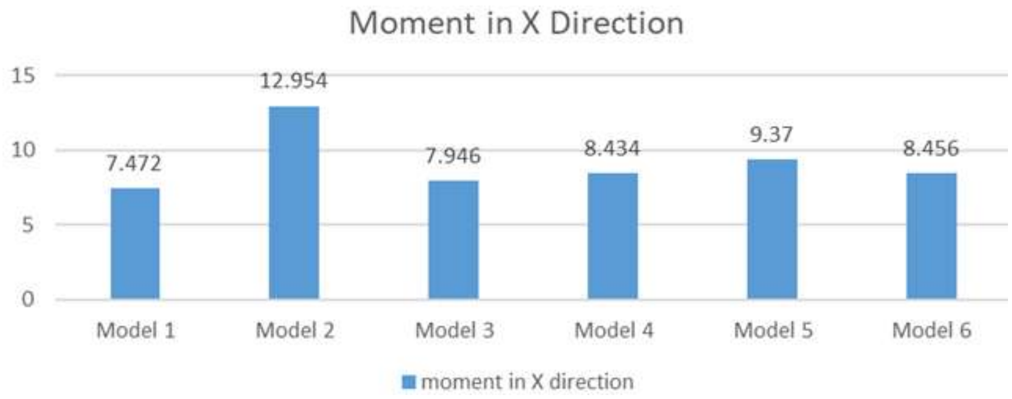
Graph 3 shows the variation in Maximum Shear force along Z direction for different models as shown by Table 14



Graph 3: Comparison of Maximum Shear Force in Z Direction

- **Maximum Bending Moment in X Direction**

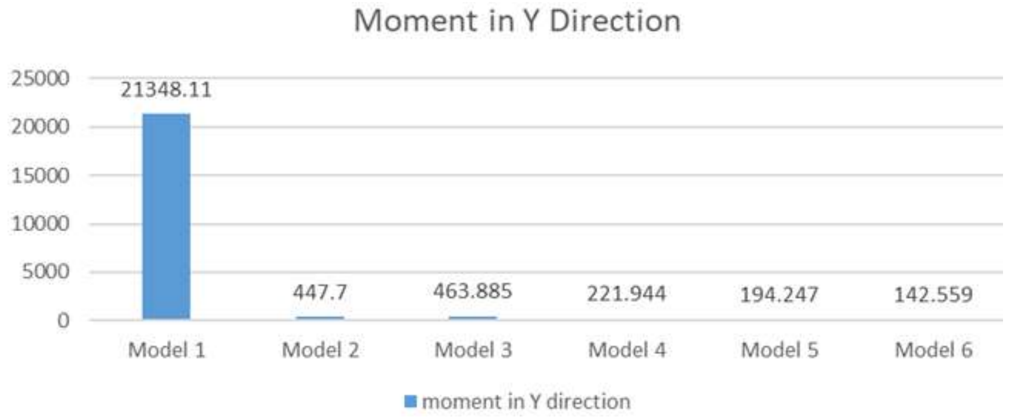
Graph 4 shows the variation in Maximum Bending Moment along X direction for different models as shown by Table 15



Graph 4: Comparison of Maximum Bending Moment in X Direction

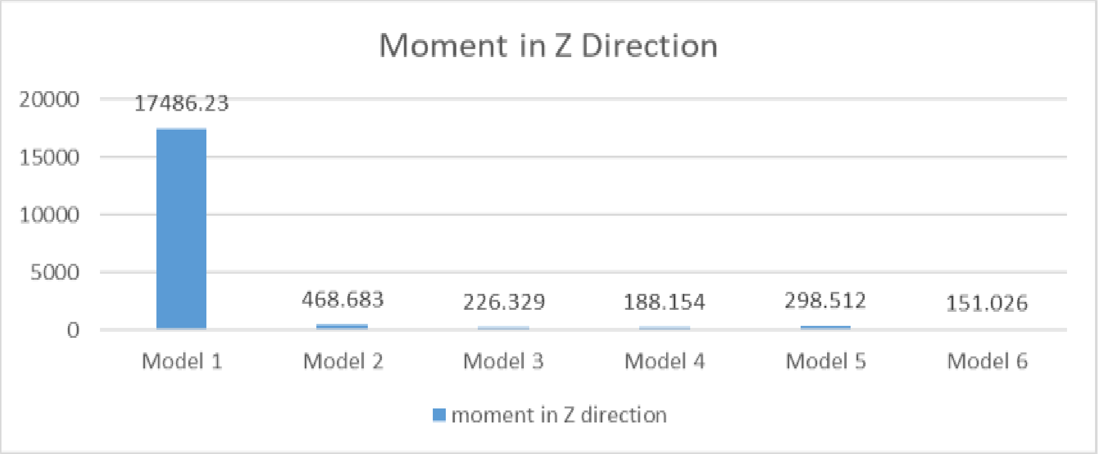
- **Maximum Bending Moment in Y Direction**

Graph 5 shows the variation in Maximum Bending Moment along Y direction for different models as shown by Table 15



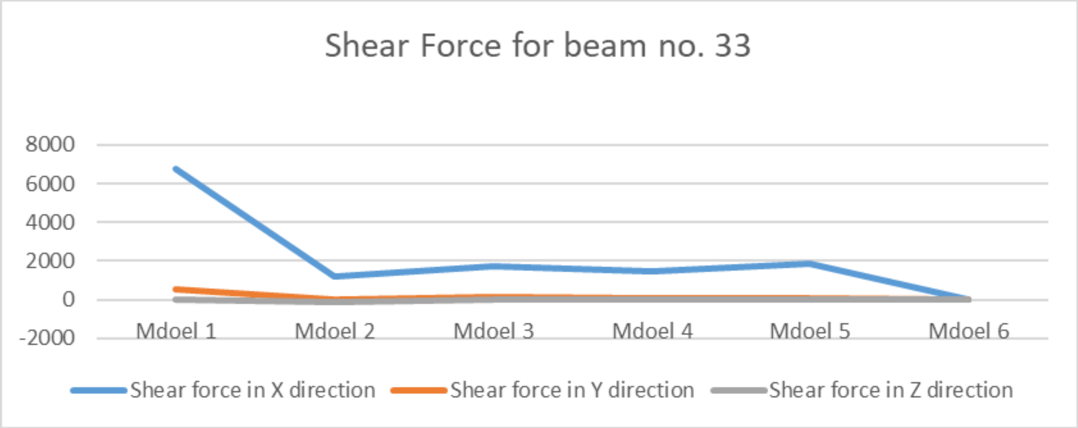
Graph 5: Comparison of Maximum Bending Moment in Y Direction

- **Maximum Bending Moment in Z Direction**
- Graph 6 shows the variation in Maximum Bending Moment along Z direction for different models as shown by Table 15



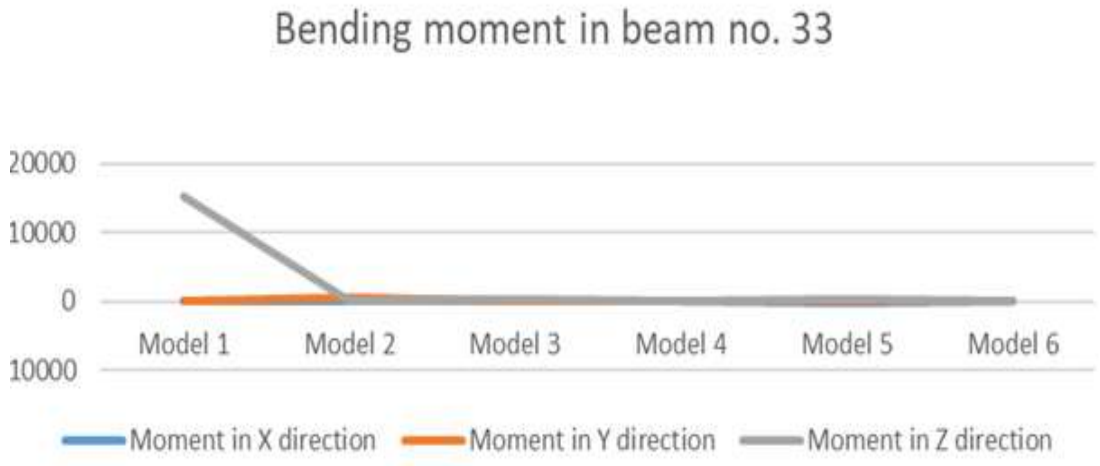
Graph 6: Comparison of Maximum Bending Moment in Z Direction

- **Maximum Shear Force of Beam 33 X, Y and Z direction**



Graph 7: Comparison of Maximum Shear Force for Beam 33 in X, Y and Z direction

- **Maximum Bending Moment on Beam 33 X, Y and Z Direction**



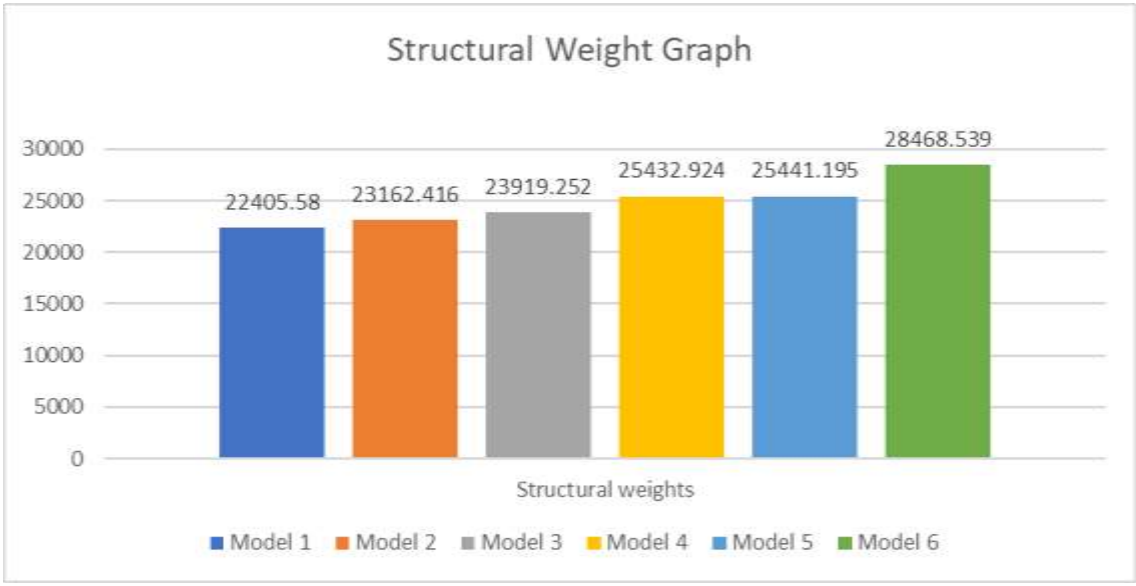
Graph 8: Comparison of Maximum Bending Moment for Beam 33 in X, Y and Z direction

Structural Weight

Table 16: Structural weights of models

Models	Weight (KN)
Model 1	22405.195
Model 2	23162.416
Model 3	23919.252
Model 4	25432.924
Model 5	25441.195
Model 6	28468.539

With the presentation of external load resisting system, the structural weight of all the models increased. The increase in structural weight of different models were obtained by software STAAD Pro V8i in Post processing mode. The structural weight not only increases the Dead Load on the structure but also affects the cost of the application of system. The weight of all the models are obtained in K.N



Graph 9: Comparison of Structural Weight

IV. CONCLUSION

Following conclusions were drawn after analyzing 5 Shear wall models with Bare frame model.

- Shear wall at four corners controlled the maximum Shear Force 73.13% along X direction.
- Shear wall at four corners controlled the maximum Shear Force 90.75% along Y direction.
- Shear wall at four corners controlled the maximum Bending Moment 99.33% along Y direction.
- Shear wall at four corners controlled the maximum Bending Moment 99.14% along Z direction.
- Shear wall at four corners controlled the maximum Displacement 75.08% along X direction.
- Shear wall at double corners controlled the maximum Displacement 28.77% along Y direction.
- Shear wall at four corners controlled the maximum Displacement 76.46% along Z direction.
- Shear wall at four corners provided maximum Support Reaction 199.31% along X direction.
- Shear wall at four corners provided maximum Support Reaction 43.27% along Y direction.
- Shear wall at double corners controlled Axial Force 50.49%.
- Shear wall at periphery-controlled Torsion 59.09%.

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