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Study of Torsional and Stiffness Properties of the RC Buildings with Shear wall and Steel Bracing with Lateral Loadings

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Abstract:
The equivalent static analysis and response spectrum analysis were performed for sixteen different models with different positioning of lateral load resisting systems in building. For the development of seismic response curve of the represented model is presented in tabular form and graphically shown in figure. Seismic response curve has been generated according to the response spectra curve of IS 1893:2016. The following parameters are compared between Equivalent Static Method and Response Spectrum Method with different positions of shear wall, braces and combined system in each model.

Keywords: Shear wall, bracing, equivalent static method , response spectrum method

1. Introduction

As the Indian subcontinent lies in the boundary of the Eurasian and Indian plates the probability of earthquakes affecting the performance of any structure is very high. Structures are susceptible to collapse during moderate to strong ground motion which trigger hugelosses to the human society in terms of lives and economy. The seismic design of building structures is typically conducted to satisfy the life safety using modern design codes. The design codes have been finalized conducting a number of studies including the seismic hazard analysis. RC Moment-Resisting Frames are the modeling system that are used all over the world, these systems are mainly used because of their ductility, speed and the simplicity in construction. Usually these type of buildings are designed as per procedures that are clearly based on seismic design codes. Beams and columns are assembled in a rectilinear way forming a Moment resisting frame, and beams are tightly connected to the columns. Rigid frame action mostly provides the resistance to the lateral forces that is because of the development of bending and shear force in the frame members and joints Depending upon the structure of the joint the Moment frame can't dislocate sideways without bending the beams or columns under the rigid beams-column joints. Properly built and complex buildings with shear walls have shown very good performance for many earthquakes in the past. In high seismic regions shear walls need special detailing. Also steel bracings in Rc buildings are used to resist the lateral loading now days. To make strong and ductile RC buildings normally shear walls and steel bracings are used [1].

The continuity of the frame also increases resistance to gravity loading by reducing the positive moments in the girders. The advantages of a rigid frame are the simplicity and convenience of its rectangular form.

Rigid frames are considered economical for buildings of up to about 25 stories, above which their drift resistance is costly to control [2].
This makes the bracing system highly efficient in resisting the lateral loads. Also, another reason for the braced frame system to be efficient is, it makes the structure laterally stiff. With least addition of the material to the frame and it forms economical structure for any heights[3]. To resist the torsional effect on the structures steel bracing also introduced in the structure which help to resist the lateral loadings as well as torsional effect [4].
It observed that the shear wall at periphery (model-2) shows less time period than other model. It observed that as the lump mass of building is increased the time period is decrease[5].

Shaligram and Parikh (2018), From the literature review, it has been concluded that steel bracings can be used as lateral load resisting system of multistory building of 10 to 20 stories whereas Shear wall can be used for 20 to 35 storey building as lateral load resisting system. But shear wall has more structural weight compared to steel bracings which might be uneconomical for 10 to 15 stories. [6].

Dharanya A, Gayathri S and Deepika M (2017) The main parameters compared are lateral displacement, base shear, storey drift, axial force, shear force and time period. The natural time period of the structure has highly reduced after placing shear wall than the bracings, which will improve the stability against earthquake and make the structure more stable. The structure has a minimum lateral displacement with shear wall and bracings compared with bare frame. Structure with shear wall system has a least lateral displacement. Also different types of bracings such as V shape, inverted V shape and Y shape can be replaced and analyzed [7].

Islam, Kumawat, Bilonia, Ahmad and Kumar(2018), By placing shear walls and bracing in periphery of buildings total 18 models were analyzed. In conclusion, the amount of concrete used in case of shear wall structure was more than that of bracing and RC-frame & deflection and bending moment in case of shear wall are very less as compare to RC-frame and bracing so structurally shear wall structure is more suitable[8].

Baral and Ghimire (2021) Storey drift is minimum at centrally located shear wall building. It is clear that by providing shear walls in interior core, we can decrease the storey drift by 42.1% than the structures without shear walls. It is observed that placing shear walls away from the center of gravity resulted in increase in most of member forces and overturning moment. Overturning moment is increased by 10% when shear wall is placed away from center of gravity[9].

Somasekharaiah1, Y B and Basha (2016), Totally five models of 20 storey each are considered for Modal analysis, Equivalent static analysis. Response spectrum analysis and the analysis work are carried out by using ETABS 2015 software. On comparing the results obtained, shear wall shows the good resistance for earthquake load compared to the other systems which is consider for the analysis[10].

Tejaswini M L, Kishor K N and Harsha D H (2018) The performance of building was evaluated on the basis of following parameters –Storey displacement, Storey drift, Base shear. In this work, the shear walls and bracings are provided at different locations with the overall analysis to be carried out using

Etabs9.7 software.. It is found that providing shear wall at corners gives more strength when compared to bare frame and bracing type models[11].

Poudel and Suwal (2020), In their research, the results shows that steel bracing can be effectively used as a retrofitting measure in order to increase the structural stiffness and decrease inter-storey drift as well as storey displacement of RC frame structure. Among different types of steel bracings X- type and Inverted V bracing showed significant decrease in storey displacement as well as storey drift of the buildings[12].

Baikerikar and Kanagali (2014) The study has been carried out for the Zone V and soft soil as specified in IS 1893-2002. Three cases are taken for study Case 1: Bare Frame, Case 2: Bracings in Middle & Case 3: Bracings at Corners. In conclusion Minimum drift is given by Case 2, overall Case 2 performs better than Case 3 because of the continuity of braces being maintained by Case 2[13].

Patel et al. (2019), In this paper, bracing system and Combined system models are equipped and analyzed with four types of bracing X bracing, V bracing, inverted V bracing and K bracing. These bracings are equipped with box section (200x200x12) [14].

Rana and Mehta (2018), In their study, different types of models are considered and seismic parameter are observed. This study also incorporates how the shear force, bending moment for beam and axial Force for column vary with change in the position of RC shear wall [15].

Yizhen Yang and Hong Gan (2013), In this paper through the analysis of the different Angle fully reflects the location of shear wall structure seismic performance of the difference of influence and through the analysis the conclusion, uniform in the frame shear structure, decentralized shear wall surrounding symmetrical arrangement ways to improve the seismic performance of the structure[16].

Harne V (2014), A study has been carried out to determine the strength of RC shear wall of a multistoried building by changing shear wall location. Three different cases of shear wall position for a 6 storey building have been analyzed. Incorporation of shear wall has become inevitable in multi-storey building to resist lateral forces[17].

Mishra, Kushwaha and Kumar (2015), In their study, the lateral displacement in X- direction and Z-direction is restricted more by the intermediately configured shear wall making building structure safe to shear failure. The Proportionate material requirement for the restriction of applied load safely; in the construction of building also shows the Intermediate configuration will be more economical than other with exception of steel in core and concrete in periphery position; but this could not retard structural buckling considerably[18].

Singh and Tanwar (2021), In this study, Various parameters such as base shear, fundamental natural time period of vibrations are evaluated on the basis of both methods of analysis and the best arrangement of shear wall is suggested. In both equivalent static analysis and response spectrum analysis method, it has been observed that model having box shaped shear walls at the centroid of the building, M-5 shows the least value of maximum lateral displacement X-direction and Y-direction both[19].

Shukla and K. (2022), The study It has been found that shear walls situated at the centre in the form of a core perform effectively against lateral loads. Displacement at the top of such a building is approximately 2.5 times less than the top story displacement of a building without a shear wall. Shear walls located at corners are the least effective[20].

Williams and Tripathi (2016), in this study the location of shear wall do not have significant effect on the nonlinear behavior except that the position of hinges vary. The study of effect of shear wall location in eccentrically loaded structures, especially its nonlinear behaviour gives a more precise idea on provision of shear wall[21].

Ahiwale, Kontoni and Darekar (2023), This research the XBF is preferred to improve the overall seismic performance of the structure over other braced frames. In addition, the bracing elements were found to be quite successful in reducing drifts, as seen by the reduction of inter-storey drifts compared to unbraced frames. Steel braces also contributed to reducing the global damage index (GDI) significantly [22].

Rahman, Teguh, and Saleh (2021), the results show that the slightest interstory drift occurs in Model 2, namely 0.041 mm. The decrease in deviation value that arises in Model 2 is 12.6 mm, with 34.35%. In Model 1, the story drift exceeds the allowable limit, so that with such a model, it is not feasible. Therefore, it is necessary to add shear walls or a bracing system[23].

Islam, Chakraborty, and Kim (2022), In this study, the outcomes exposed that a significant increase in the seismic responses occurs due to the nonlinearity in the building systems. It was also found that building with shear wall exhibits maximum resistance and minimum nonlinearity when subjected to dynamic loadings[24].

Birendra K. Bohora (2021), In his study, the linear dynamic analysis is the response spectrum analysis (RSA) carried out to study dynamic behaviors in means of top story displacement, story drift, fundamental time period, story stiffness, and story shear. The results are analyzed and made some decisions based on seismic performance. It is also observed that it is better to use the X bracing system for lateral load resisting elements [25] [26].

2. METHODOLOGY: ANALYSIS & METHODS

In this study, 13 storey (G+12) buildings with regular in plan buildings with 3m story height each. This building consists of five spans of 4 meter in X direction and in Y direction as shown in figure. The square plan of all buildings measures 20 m x 20 m. Building with shear wall, bracing and combined system are modeled with five different positions named as Type- I, Type- II, Type- III, Type- IV and Type- V.

Members of the structure like beam, column and braces were modeled as frame element with prismatic section with specific defined material properties of concrete, steel (rebar's) and structural steel. The foundation level was assumed fixed and meshing of the shell element i.e. slab and shear wall was done. Concrete grade of M 25 and steel (rebar's) of grade Fe 500 as material for beam, slab, shear wall, M 30 for column and structural steel of Fy 250 for X-braces were assigned. Slab and shear wall were modeled as shell element with slab having rigid diaphragm in each story level. Each model was designed as per IS 1893 load combinations for linear static and response spectrum method with soil type ii and seismic zone IV. The size of columns is 625 mm x625mm and size of beam is 600x400 in each models are considered. In the models the thickness of shear wall is 400mm. and other parameter and configurations are as shown in figure 1 and table 1.

2.1 Bared Frame:

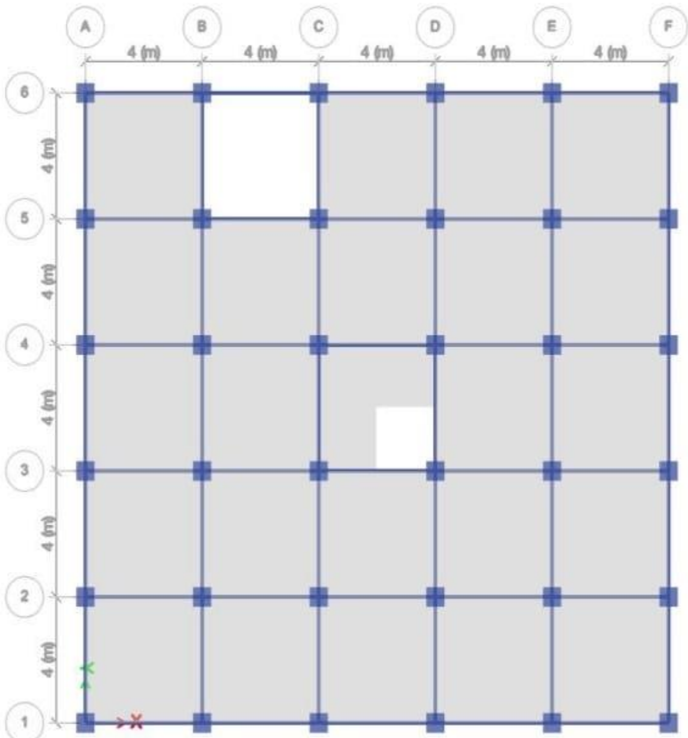
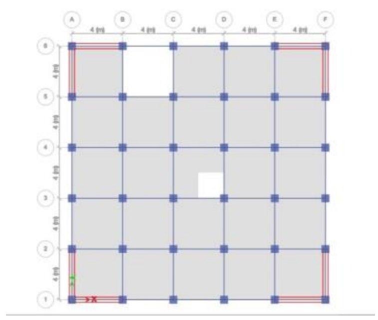
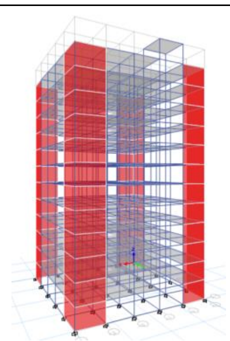


Figure 1. Plan of Bare Frame Model

Table 1 Different Locations of Shear Wall System

Shear Wall System		
Type/Location	Plan	3 D
Type- I System (Outer Corner)		

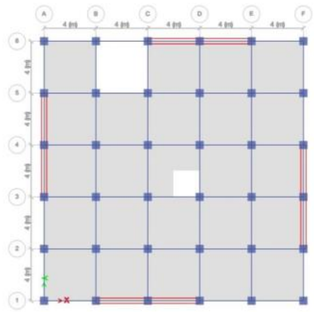
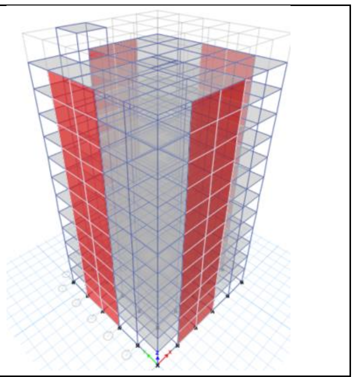
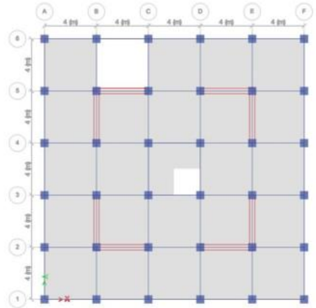
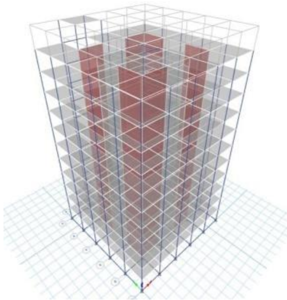
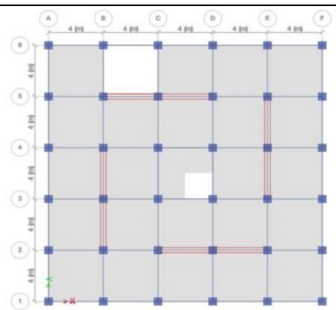
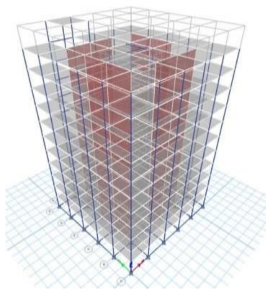
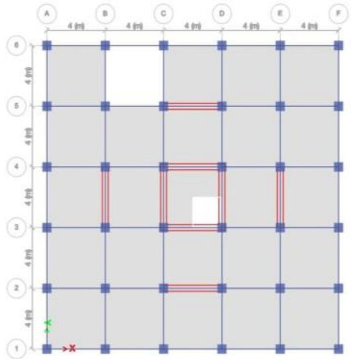
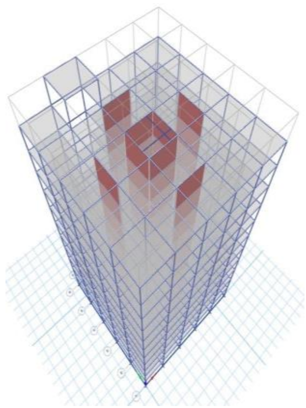
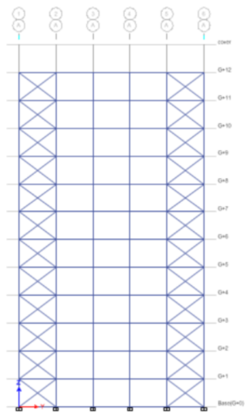
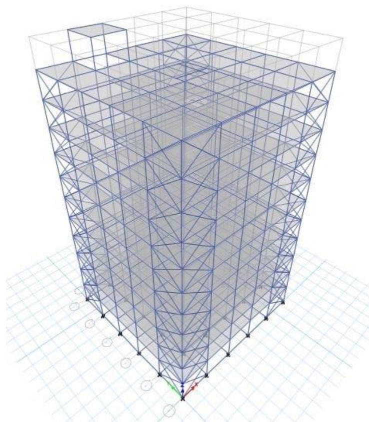
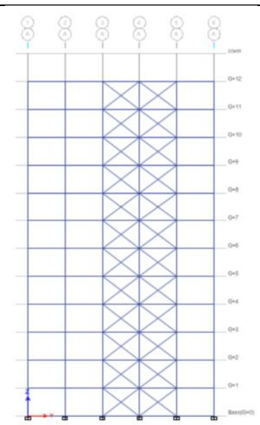
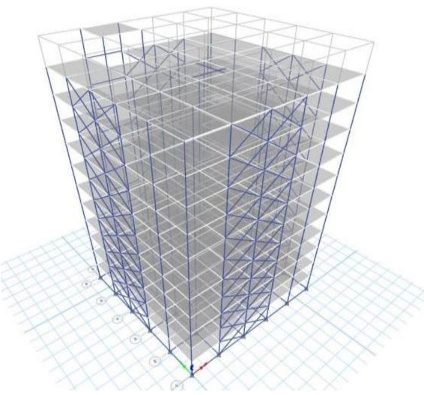
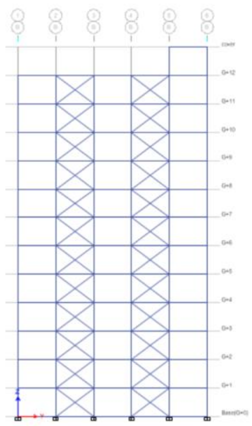
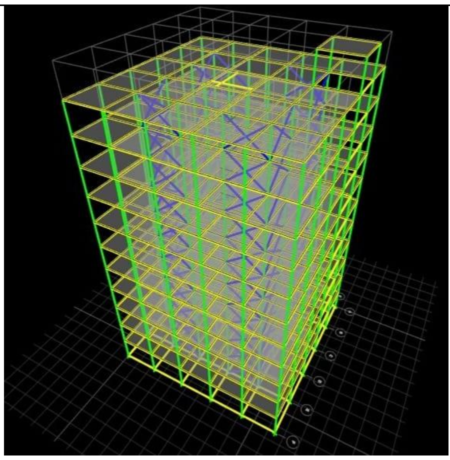
Type- II System (Center of Outer Sides)		
Type- III System (Middle Corner)		
Type- IV System (Center of Middle Sides)		
Type- V System (Inner Core and Middle Sides)		

Table 2. Different Locations of Bracing System

Steel Bracing System		
Type/Location	Elevation	3 D
Type- I System (Outer Corner)		
Type- II System (Center of Outer Sides)		
Type- III System (Middle Corner)		

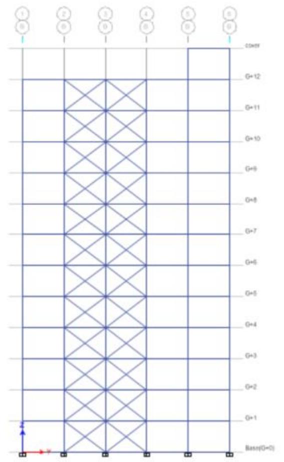
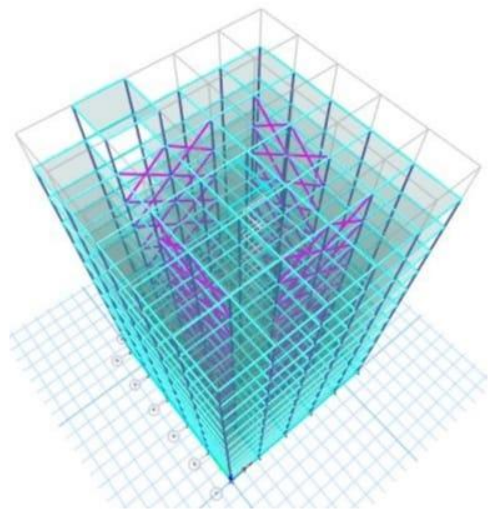
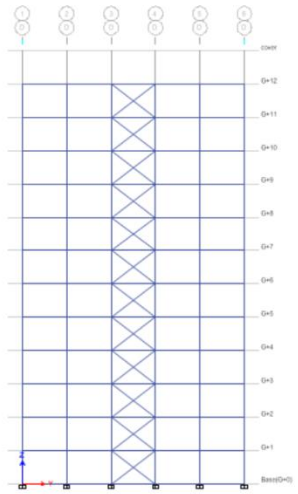
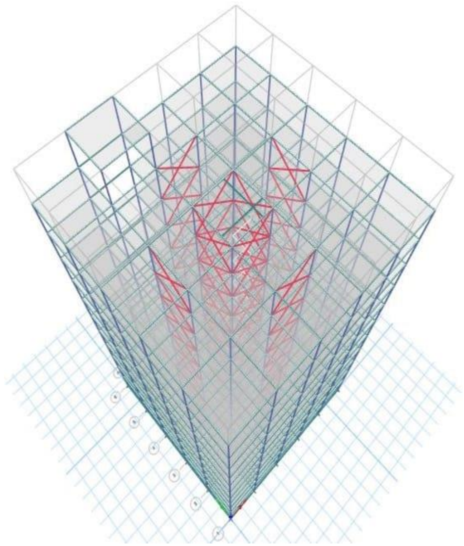
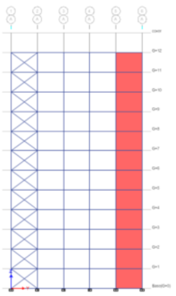
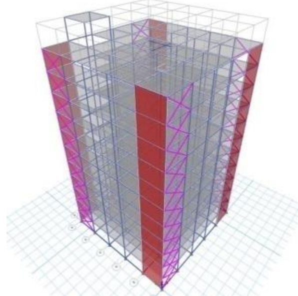
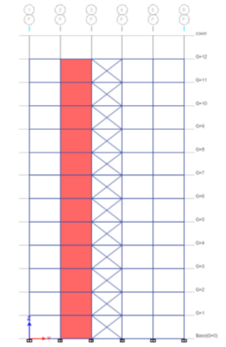
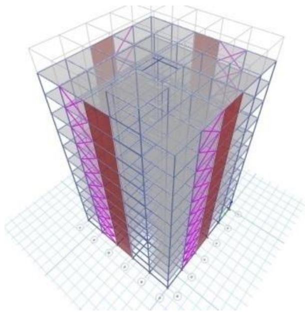
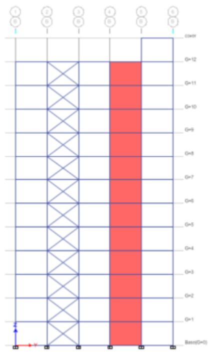
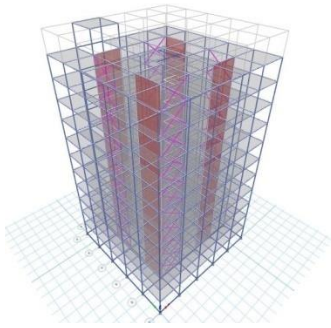
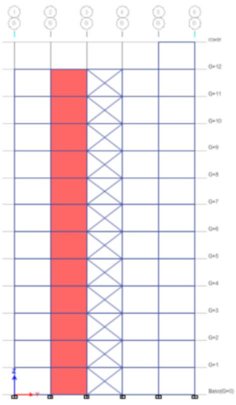
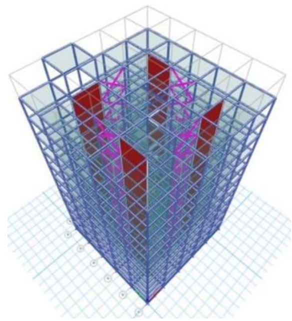
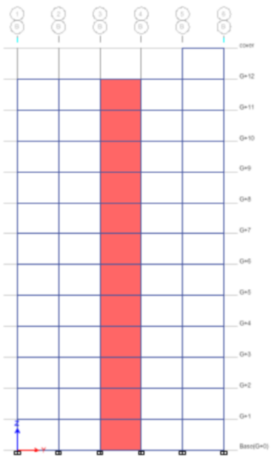
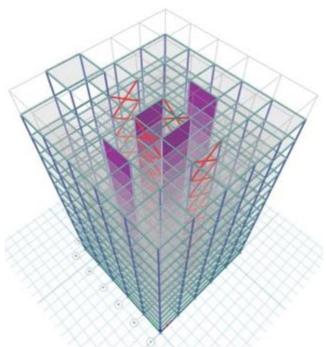
Type- IV System (Center of Middle Sides)		
Type- V System (Inner Core and Middle Sides)		

Table 3. Different Locations of Combined System

Combined (Shear Wall + Steel Bracing) System		
Type/Location	Elevation	3 D
Type- I System (Outer Corner)		

Type- II System (Center of Outer Sides)		
Type- III System (Middle Corner)		
Type- IV System (Center of Middle Sides)		
Type- V System (Inner Core and Middle Sides)		

3: RESULTS AND DISCUSSION

The equivalent static analysis and response spectrum analysis were performed for sixteen different models with different positioning of lateral load resisting systems in building. For the development of seismic response curve of the represented model is presented in tabular form and graphically shown in figure. Seismic response curve has been generated according to the response spectra curve of IS 1893:2016. The following parameters are compared between Equivalent Static Method and Response Spectrum Method with different positions of shear wall, braces and combined system in each model.

i. Storey Stiffness: The lateral stiffness Ks of a story is generally defined as the ratio of story shear to story drift. For frames subjected to regular lateral, load distributions, variations in the lateral stiffness of a given story for the several load cases are small enough to be neglected.

ii. Diaphragm Maximum to Average Drift Ratio for Torsion: Higher the value of diaphragm maximum drift to average drift ratio, the building is more vulnerable to torsion. As per IS 1893 :2016, the torsional effect is negligible up to the maximum to average drift ratio less than or equals to 1.2.

3.1 Parameters Discussed in Shear Wall System Using ESM and RSM

Storey Stiffness

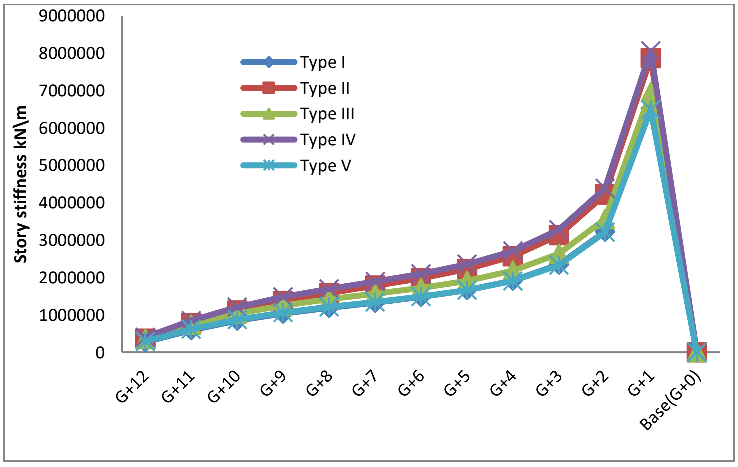


Figure 2 Storey Stiffness Along X- Direction in Shear Wall System (EQx ULS) by ESM

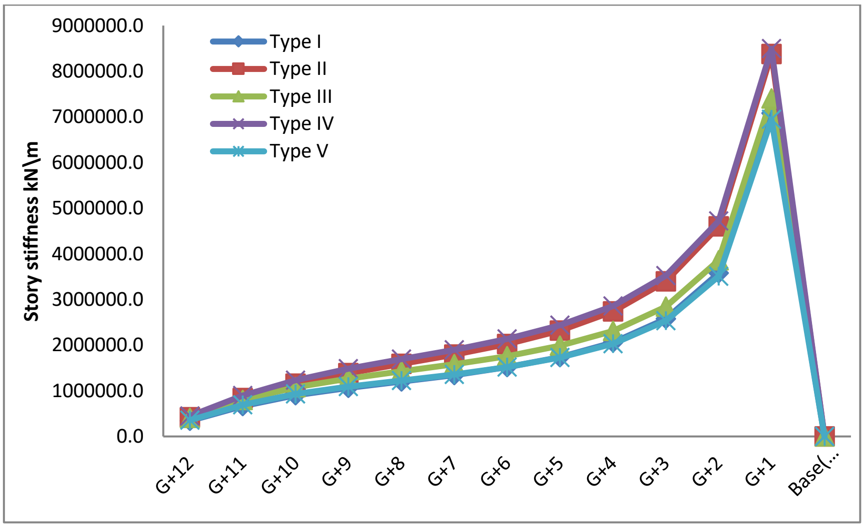


Figure 3. Storey Stiffness Along X- Direction in Shear Wall System (RSx) by RSM

Values of storey stiffness in bracing system along X-direction by the action of seismic force for all locations of shear walls using ESM and RSM are tabulated and plotted in figure. By analyzing these values, it can be concluded that type- II model of shear wall system has higher value of storey stiffness than that of other types (positions) by RSM but the same result is for type- IV model by using ESM. The decreasing order of storey stiffness by ESM are type- IV, type- II, type- III, type- I and type- V respectively and that by RSM are type- II, type- IV, type- III, type- I and type- V respectively. Type- II and type- IV curves in both methods of analysis and type- I and type- V curves in ESM nearly coincide with each others. In RSM, type- I and type- III curves nearly coincide at their peaks with each other. It can be concluded that the type (location of shear wall) with higher stiffness shows lesser deflection and vice versa.

Diaphragm Maximum to Average Drift Ratio

Table 4 X- Direction Diaphragm Maximum to Average Drift Ratio in Shear Wall System

Direction Diaphragm Maximum to Average Drift Ratio in Shear Wall System along X direction											
Storey	Elevation(m)	Type I		Type II		Type III		Type IV		Type V	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.018	1.011	1.003	1.011	1.015	1.007	1.015	1.008	1.007	1.002
G+11	33	1.044	1.018	1.03	1.025	1.075	1.045	1.087	1.048	1.058	1.035
G+10	30	1.043	1.018	1.03	1.024	1.076	1.044	1.089	1.047	1.065	1.037
G+9	27	1.042	1.017	1.03	1.023	1.076	1.043	1.09	1.047	1.072	1.04
G+8	24	1.042	1.016	1.031	1.023	1.077	1.042	1.092	1.046	1.079	1.044
G+7	21	1.041	1.016	1.031	1.022	1.077	1.041	1.093	1.046	1.084	1.048
G+6	18	1.04	1.015	1.031	1.022	1.077	1.04	1.094	1.046	1.09	1.051
G+5	15	1.039	1.015	1.031	1.021	1.077	1.04	1.095	1.046	1.096	1.054
G+4	12	1.039	1.014	1.032	1.02	1.078	1.04	1.097	1.046	1.102	1.057
G+3	9	1.038	1.014	1.032	1.02	1.079	1.04	1.098	1.046	1.11	1.059
G+2	6	1.038	1.013	1.032	1.019	1.081	1.041	1.1	1.046	1.122	1.061
G+1	3	1.039	1.013	1.034	1.018	1.089	1.044	1.103	1.045	1.136	1.062

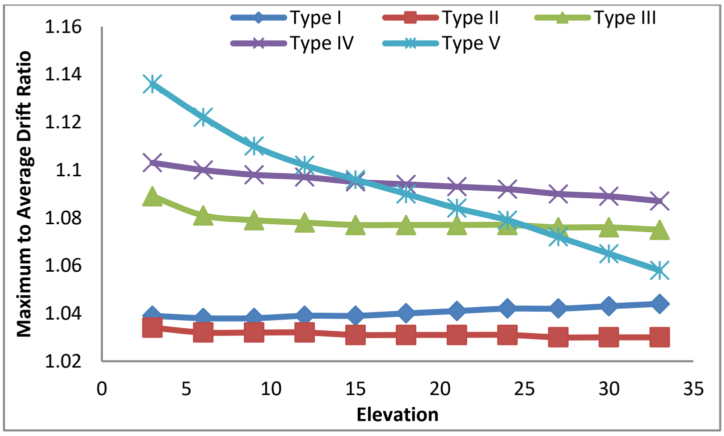


Figure 4. X- Direction Diaphragm Max to Avg Drift Ratio in Shear Wall System (EQx by ESM

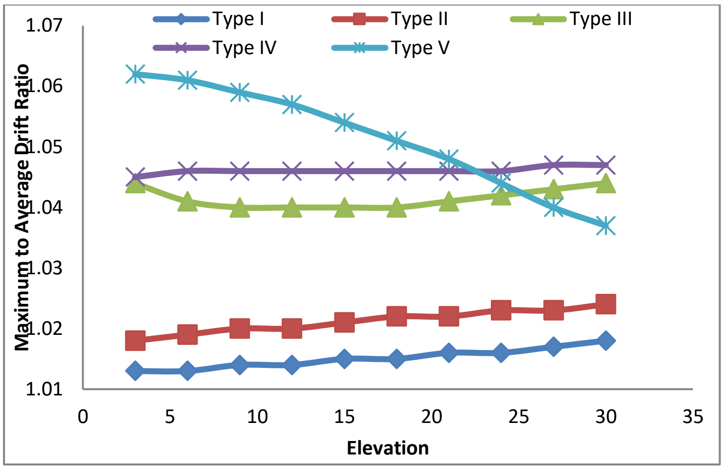


Figure 5. X- Direction Diaphragm Max to Avg Drift Ratio in Shear Wall System (RSx) by RSM

Diaphragm maximum to average drift ratio in all types (locations) of shear wall system along X-direction by the effect of seismic force is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all types, the ratio by ESM is greater than that by RSM. In overall, type- I position has lesser value of diaphragm maximum to average drift ratio than that of other positions. The decreasing order of maximum value of the ratio in all types are as type- V, type- IV, type- III, type- II and type- I respectively. It can be concluded that the location of the shear wall with smaller value of diaphragm maximum to average drift ratio contributes less torsional susceptibility.

3.2 Parameters Discussed in Bracing System Using ESM and RSM

Storey Stiffness

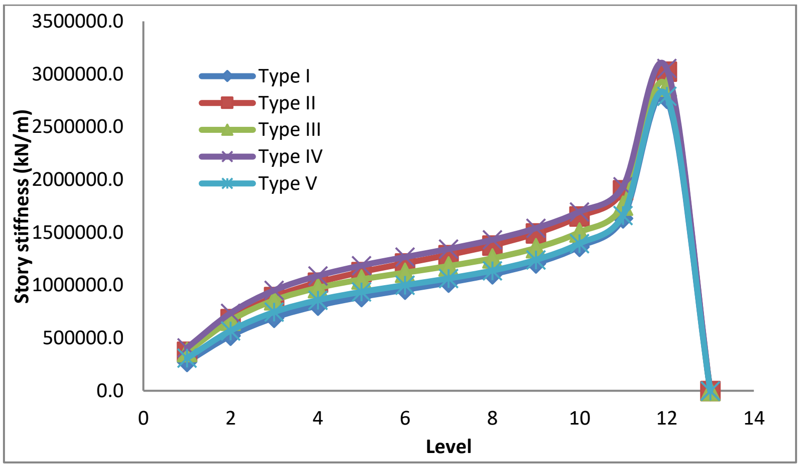


Figure 6. Storey Stiffness Along X- Direction in Bracing System (EQx) by ESM

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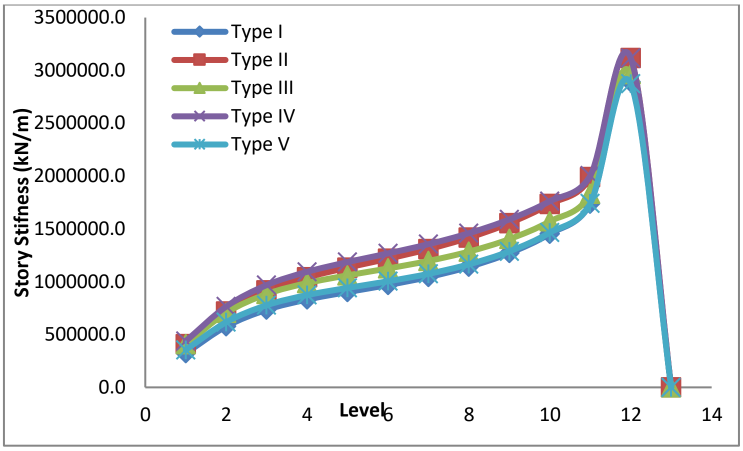

Figure 7. Storey Stiffness Along X- Direction in Bracing System (RSx) by RSM

Values of storey stiffness in bracing system along X-direction by the action of seismic force for all locations of steel braces using ESM and RSM are tabulated and plotted in figure. By analyzing these values, it can be concluded that type- II model of bracing system has higher value of storey stiffness than that of other types (positions) by RSM but the same result is for type- IV model by using ESM. The decreasing order of storey stiffness by ESM are type- IV, type- II, type- III, type- I and type- V respectively and that by RSM are type- II, type- IV, type- III, type- I and type- V respectively. Type- II and type- IV curves in both methods of analysis and type- I and type- V curves in ESM nearly coincide with each others. In RSM, type- I and type- III curves nearly coincide at their peaks with each other. It can be concluded that the type (location of bracing) with higher stiffness shows lesser deflection and vice versa.

Diaphragm Maximum to Average Drift Ratio

Table 5 X- Direction Maximum to Average Drift Ratio in Bracing System

Direction Diaphragm Maximum to Average Drift Ratio in Bracing System along X direction											
Storey	Elevation(m)	Type I		Type II		Type III		Type IV		Type V	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.017	1.01	1.017	1.009	1.014	1.009	1.015	1.009	1.011	1.001
G+11	33	1.052	1.025	1.055	1.028	1.074	1.052	1.082	1.047	1.079	1.014
G+10	30	1.05	1.023	1.054	1.025	1.076	1.05	1.085	1.045	1.086	1.01
G+9	27	1.049	1.021	1.053	1.024	1.078	1.048	1.087	1.043	1.092	1.009
G+8	24	1.048	1.02	1.052	1.023	1.078	1.047	1.088	1.042	1.096	1.008
G+7	21	1.047	1.019	1.052	1.022	1.079	1.046	1.089	1.041	1.099	1.008
G+6	18	1.047	1.019	1.051	1.022	1.08	1.045	1.09	1.041	1.102	1.009
G+5	15	1.046	1.018	1.051	1.021	1.081	1.045	1.092	1.04	1.105	1.008
G+4	12	1.045	1.018	1.05	1.02	1.082	1.045	1.093	1.04	1.109	1.008
G+3	9	1.045	1.017	1.05	1.019	1.084	1.046	1.095	1.041	1.115	1.008
G+2	6	1.045	1.017	1.049	1.019	1.087	1.048	1.096	1.041	1.12	1.682
G+1	3	1.049	1.017	1.052	1.019	1.09	1.049	1.095	1.039	1.119	1.011

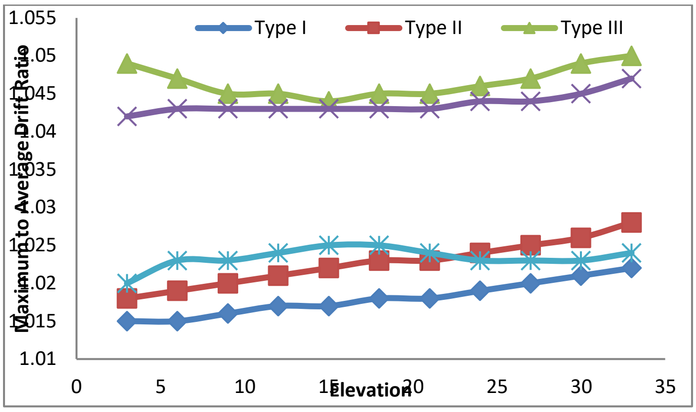

Figure 8. X- Direction Diaphragm Max to Avg Drift Ratio in Bracing System (Eqx) by ESM

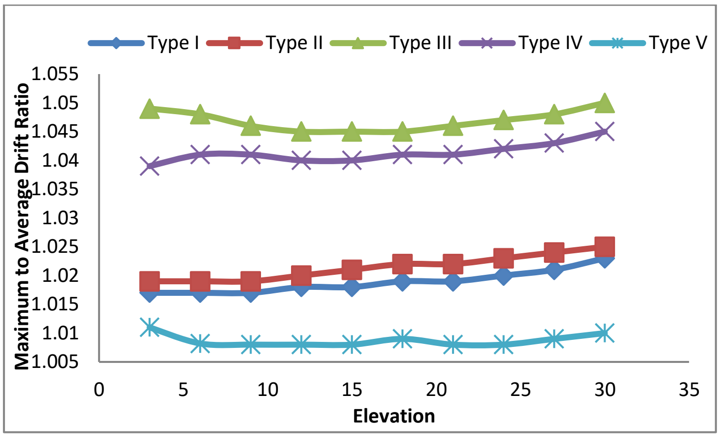

Figure 9. X- Direction Diaphragm Max to Avg Drift Ratio in Bracing System (RSx) by RSM

Diaphragm maximum to average drift ratio in all types (locations) of bracing system along X- direction by the effect of seismic force is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all types, the ratio by ESM is greater than that by RSM. It is seen that type- I position has lesser value of diaphragm maximum to average drift ratio than that of other positions. The decreasing order of maximum value of the ratio in all types are as type- V, type- IV, type- III, type- II and type- I respectively. It can be concluded that the location of the steel braces with smaller value of diaphragm maximum to average drift ratio contributes less torsional susceptibility. Type- II position of bracing has better performance against torsion than that of all other types except of type- I.

3.3 Parameters Discussed in Combined System Using ESM and RSM

Storey Stiffness

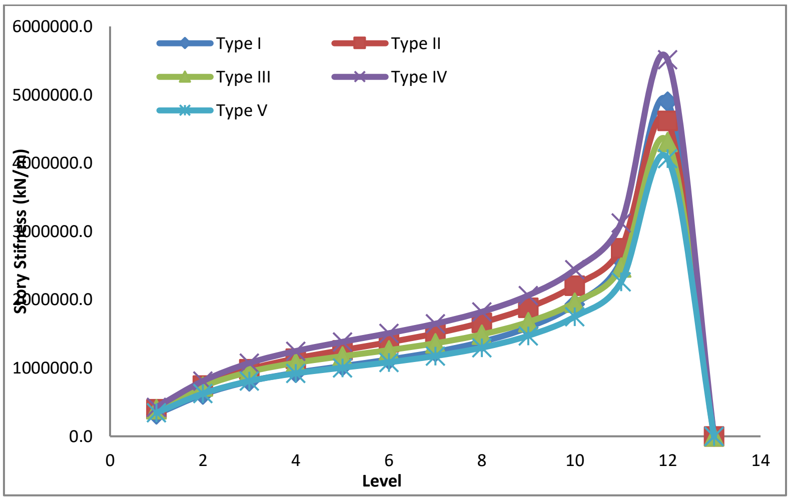

Figure 10. Storey Stiffness Along X- Direction in Combined System (EQx) by ESM

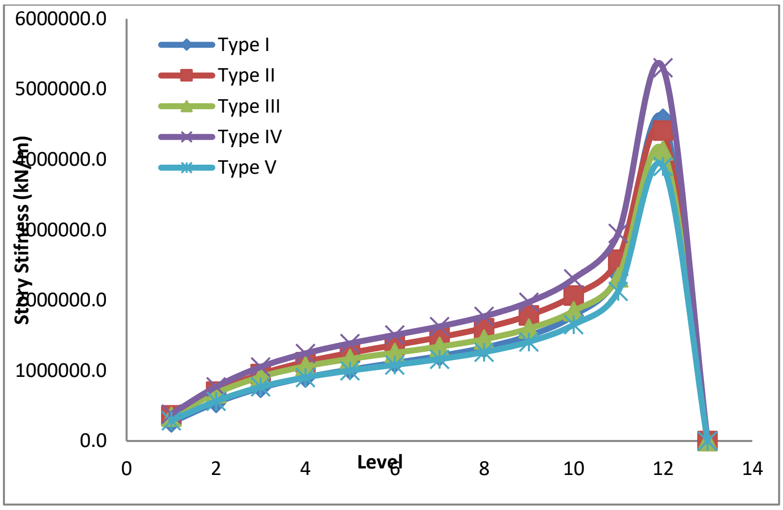

Figure 11. Storey Stiffness Along X- Direction in Combined System (RSx) by RSM

Values of storey stiffness in combined system along X-direction by the action of seismic force for all locations of combined system using ESM and RSM are tabulated and plotted in figure. By analyzing these values, it can be concluded that type- II model of combined system has higher value of storey stiffness than that of other types (positions) by RSM but the same result is for type- IV model by using ESM. The decreasing order of storey stiffness by ESM are type- IV, type- II, type- III, type- I and type- V respectively and that by RSM are type- II, type- IV, type- III, type- I and type- V respectively. Type- II and type- IV curves in both methods of analysis and type- I and type- V curves in ESM nearly coincide with each others. In RSM, type- I and type- III curves nearly coincide at their peaks with each other. It can be concluded that the type (location of combined system) with higher stiffness shows lesser deflection and vice versa.

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. Diaphragm Maximum to Average Drift Ratio

Table 6 X- Direction Diaphragm Maximum to Average Drift Ratio in Combined System

Direction Diaphragm Maximum to Average Drift Ratio in Shear Wall System along X direction											
Storey	Elevation(m)	Type I		Type II		Type III		Type IV		Type V	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.013	1.006	1.017	1.008	1.015	1.009	1.014	1.007	1.01	1.002
G+11	33	1.049	1.022	1.062	1.028	1.075	1.05	1.084	1.047	1.075	1.024
G+10	30	1.048	1.021	1.06	1.026	1.077	1.049	1.087	1.045	1.083	1.023
G+9	27	1.047	1.02	1.059	1.025	1.078	1.047	1.089	1.044	1.088	1.023
G+8	24	1.046	1.019	1.058	1.024	1.078	1.046	1.09	1.044	1.093	1.023
G+7	21	1.045	1.018	1.057	1.023	1.079	1.045	1.092	1.043	1.097	1.024
G+6	18	1.044	1.018	1.056	1.023	1.079	1.045	1.093	1.043	1.101	1.025
G+5	15	1.043	1.017	1.055	1.022	1.08	1.044	1.094	1.043	1.105	1.025
G+4	12	1.043	1.017	1.054	1.021	1.081	1.045	1.096	1.043	1.109	1.024
G+3	9	1.042	1.016	1.053	1.02	1.083	1.045	1.097	1.043	1.115	1.023
G+2	6	1.042	1.015	1.052	1.019	1.086	1.047	1.099	1.043	1.123	1.023
G+1	3	1.043	1.015	1.052	1.018	1.091	1.049	1.101	1.042	1.129	1.02

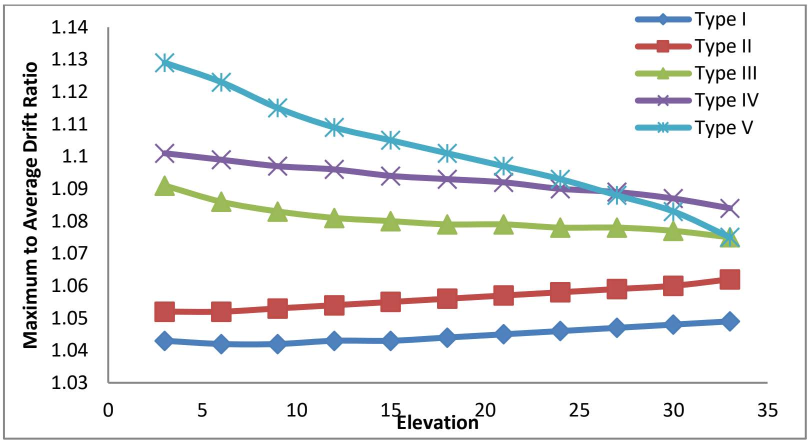

Figure 12. X- Direction Diaphragm Max to Avg Drift Ratio in Combined System (EQx) by ESM

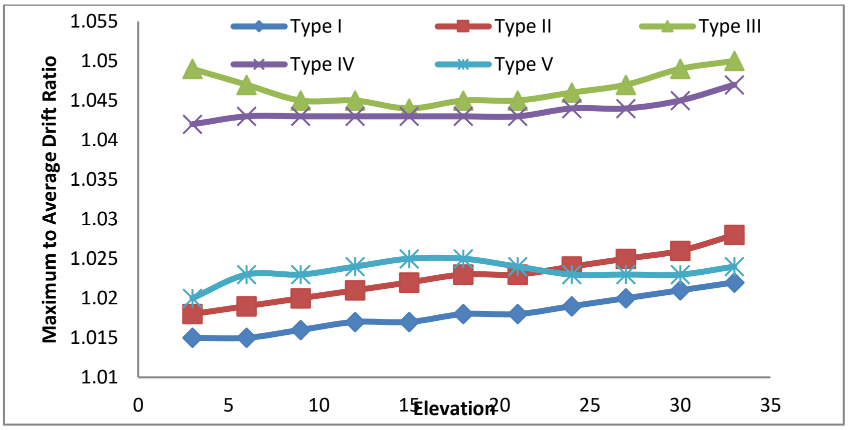

Figure 13. X- Direction Diaphragm Max to Avg Drift Ratio in Combined System (RSx) by RSM

X- direction diaphragm maximum to average drift ratio in all types (locations) of combined system by the effect of seismic force is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all types, the ratio by ESM is greater than that by RSM. It is seen that type- I position has lesser value of diaphragm maximum to average drift ratio than that of other positions. The decreasing order of maximum value of the ratio in all types are as type- V, type- IV, type- III, type- II and type- I respectively. It can be concluded that the location of combined system (shear walls + steel braces) with smaller value of diaphragm maximum to average drift ratio contributes less torsional susceptibility. Type- II position of the combined system has better performance against torsion than that of all other types except of type- I.

3.4 Parameters Discussed in Type- I of All Systems Using ESM and RSM

Storey Stiffness

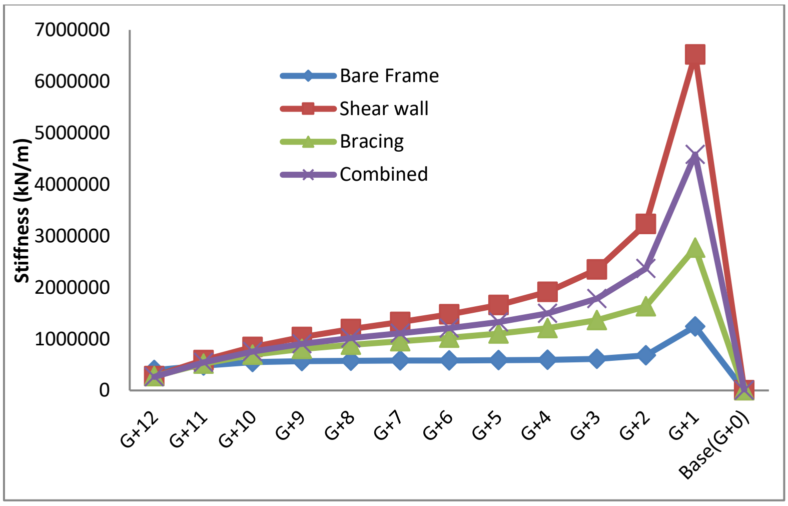

Figure 14. Storey Stiffness Along X- Direction in Type- I System (EQx) by ESM

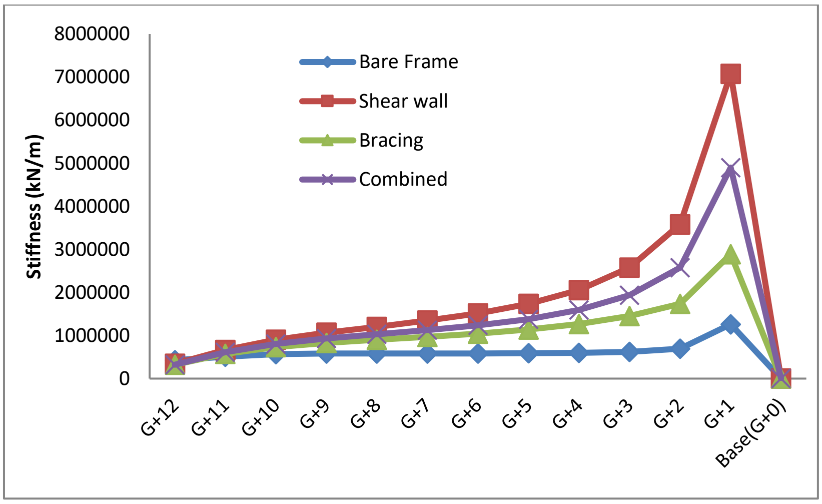

Figure 15. Storey Stiffness Along X- Direction in Type- I System (RSx) by RSM

Storey stiffness by seismic forces along X-direction for all Type- I position systems (models) are plotted and tabulated using ESM and RSM. By analyzing these values, it can be concluded that all the systems of Equivalent Static Method in X-direction have larger maximum value of storey stiffness at G+1 storey than that of Response Spectrum Method. Also it can be seen that model with shear wall system has higher stiffness than other system models. Shear wall, combined, bracing and bare frame system respectively have decreasing order of storey stiffness values. This storey stiffness can play a major role for lateral stability of the structure. Having higher stiffness, it shows lesser deflection & drift and vice versa.

Diaphragm Maximum to Average Drift Ratio

Table 7 X- Direction Diaphragm Maximum to Average Drift Ratio in Type- I System

X -Direction Diaphragm Maximum to Average Drift Ratio in Type I System									
Storey	Elevation(m)	Bare Frame		Shear wall		Bracing		Combined	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.018	1.017	1.018	1.011	1.017	1.01	1.013	1.006
G+11	33	1.088	1.078	1.044	1.018	1.052	1.025	1.049	1.022
G+10	30	1.089	1.067	1.043	1.018	1.05	1.023	1.048	1.021
G+9	27	1.089	1.06	1.042	1.017	1.049	1.021	1.047	1.02
G+8	24	1.088	1.057	1.042	1.016	1.048	1.02	1.046	1.019
G+7	21	1.088	1.055	1.041	1.016	1.047	1.019	1.045	1.018
G+6	18	1.088	1.053	1.04	1.015	1.047	1.019	1.044	1.018
G+5	15	1.088	1.053	1.039	1.015	1.046	1.018	1.043	1.017
G+4	12	1.088	1.053	1.039	1.014	1.045	1.018	1.043	1.017
G+3	9	1.089	1.052	1.038	1.014	1.045	1.017	1.042	1.016
G+2	6	1.089	1.052	1.038	1.013	1.045	1.017	1.042	1.015
G+1	3	1.089	1.052	1.039	1.013	1.049	1.017	1.043	1.015

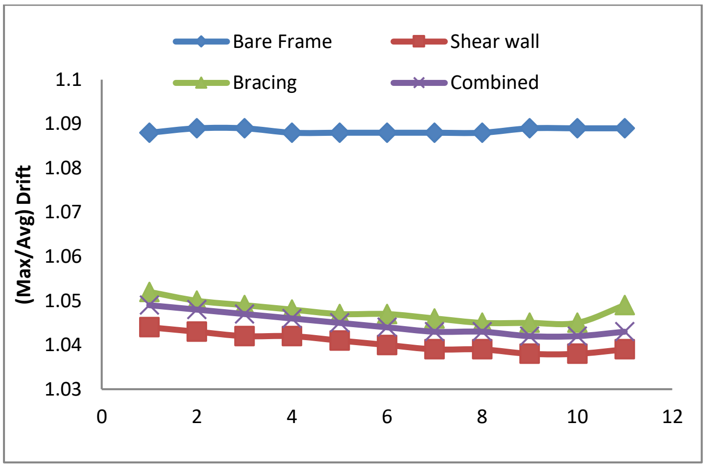

Figure 16. X- Direction Diaphragm Max to Avg Drift Ratio in Type- I System (EQx) by ESM

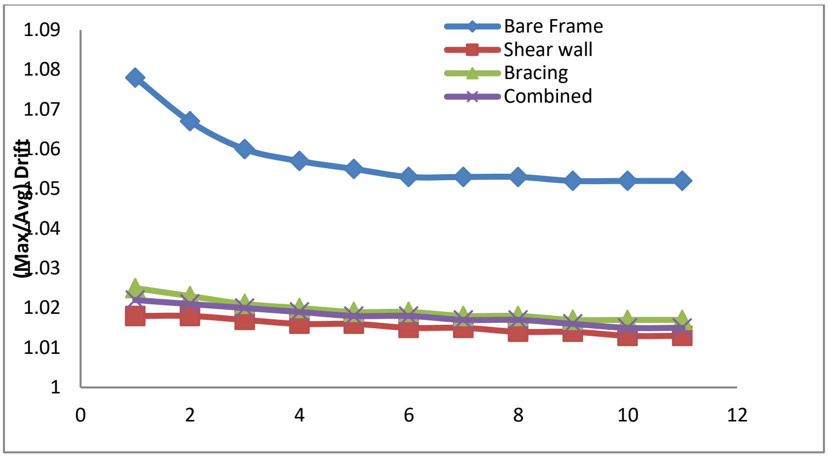

Figure 17. X- Direction Diaphragm Max to Avg Drift Ratio in Type- I System (RSx) by RSM

Diaphragm maximum to average drift ratio along X- direction in Type- I position of all the system due to seismic force effect is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all system, the ratio by ESM is greater than that by RSM. It is observed that shear wall system has lesser value of diaphragm maximum to average drift ratio than that of other systems by both RSM and ESM. Bare frame, bracing, combined and shear wall have decreasing order of the ratio. So, it can be concluded that shear wall system contributes less torsional susceptibility than other systems.

3.5 Parameters Discussed in Type- II of All system Using ESM and RSM

Storey Stiffness

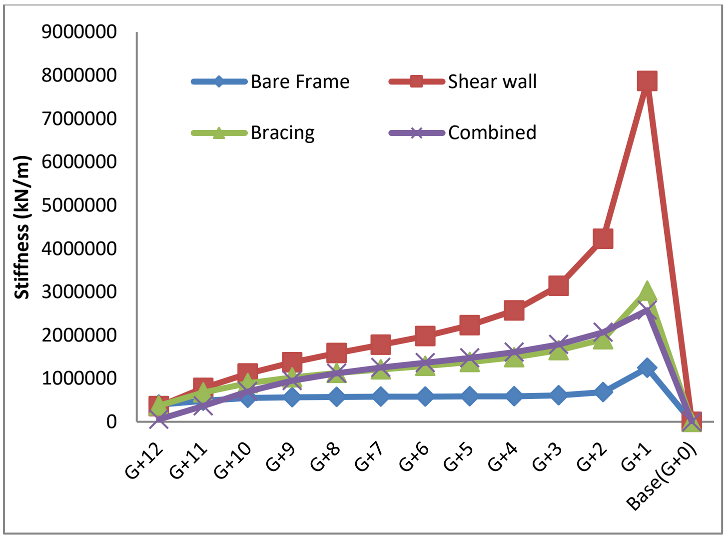

Figure 18. Storey Stiffness Along X- Direction in Type- II System (EQx) by ESM

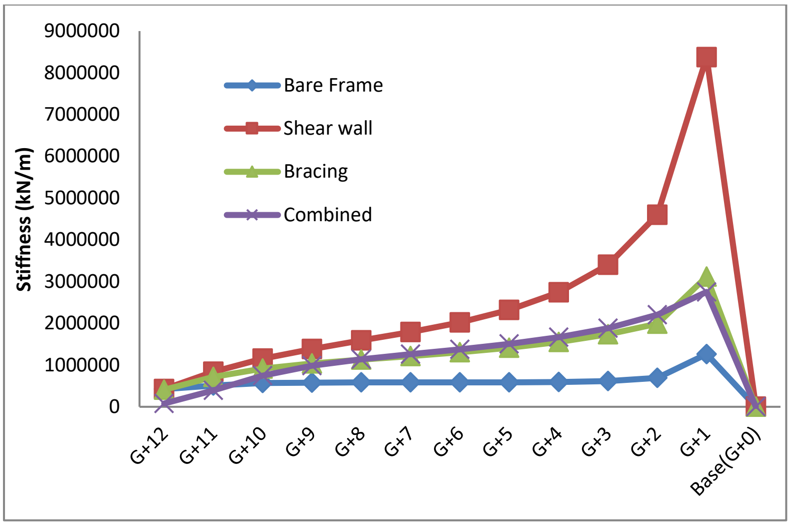

Figure 19 Storey Stiffness Along X- Direction in Type- II System (RSx by RSM

Storey stiffness by seismic forces along X-direction for all type- II position systems (models) are plotted and tabulated using ESM and RSM. By analyzing these values, it can be concluded that all the systems of Equivalent Static Method in X-direction have larger maximum value of storey stiffness at G+1 storey than that of Response Spectrum Method. Also it can be seen that model with shear wall system has higher stiffness than other system models. Shear wall, combined, bracing and bare frame system respectively have decreasing order of storey stiffness values. This storey stiffness can play a major role for lateral stability of the structure.

Diaphragm Maximum to Average Drift Ratio

Table 8 X- Direction Diaphragm Maximum to Average Drift Ratio in Type- II System

X -Direction Diaphragm Maximum to Average Drift Ratio in Type II System									
Storey	Elevation(m)	Bare Frame		Shear wall		Bracing		Combined	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.018	1.017	1.003	1.011	1.017	1.009	1.017	1.008
G+11	33	1.088	1.078	1.03	1.025	1.055	1.028	1.062	1.028
G+10	30	1.089	1.067	1.03	1.024	1.054	1.025	1.06	1.026
G+9	27	1.089	1.06	1.03	1.023	1.053	1.024	1.059	1.025
G+8	24	1.088	1.057	1.031	1.023	1.052	1.023	1.058	1.024
G+7	21	1.088	1.055	1.031	1.022	1.052	1.022	1.057	1.023
G+6	18	1.088	1.053	1.031	1.022	1.051	1.022	1.056	1.023
G+5	15	1.088	1.053	1.031	1.021	1.051	1.021	1.055	1.022
G+4	12	1.088	1.053	1.032	1.02	1.05	1.02	1.054	1.021
G+3	9	1.089	1.052	1.032	1.02	1.05	1.019	1.053	1.02
G+2	6	1.089	1.052	1.032	1.019	1.049	1.019	1.052	1.019
G+1	3	1.089	1.052	1.034	1.018	1.052	1.019	1.052	1.018

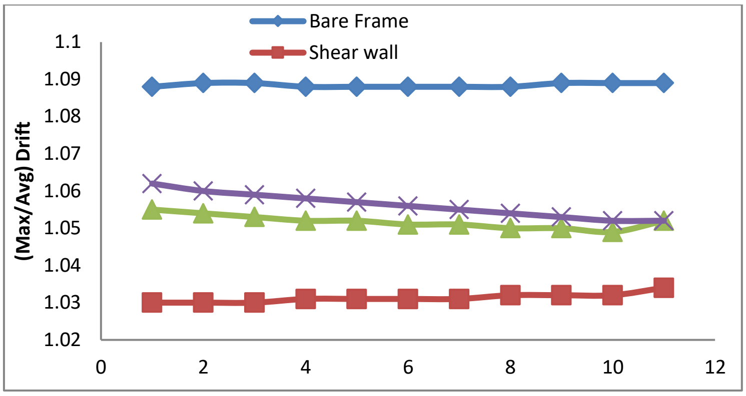

Figure 20. X- Direction Diaphragm Max to Avg Drift Ratio in Type- II System (EQx) by ESM

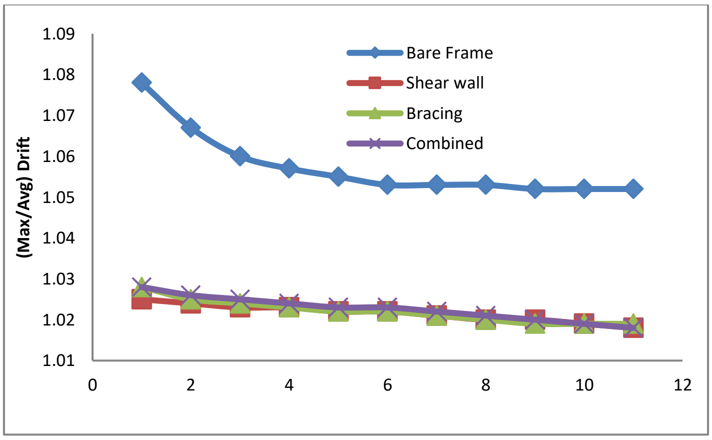

Figure 21. X- Direction Diaphragm Max to Avg Drift Ratio in Type- II System (RSx) by RSM

Diaphragm maximum to average drift ratio along X- direction in Type- II position of all the system due to seismic force effect is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all system, the ratio by ESM is greater than that by RSM. It is observed that shear wall system has lesser value of diaphragm maximum to average drift ratio than that of other systems by both RSM and ESM. Bare frame, bracing, combined and shear wall have decreasing order of the ratio. So, it can be concluded that shear wall system contributes less torsional susceptibility than other systems.

3.6 Parameters Discussed in Type- III of All System Using ESM and RSM

Storey Stiffness

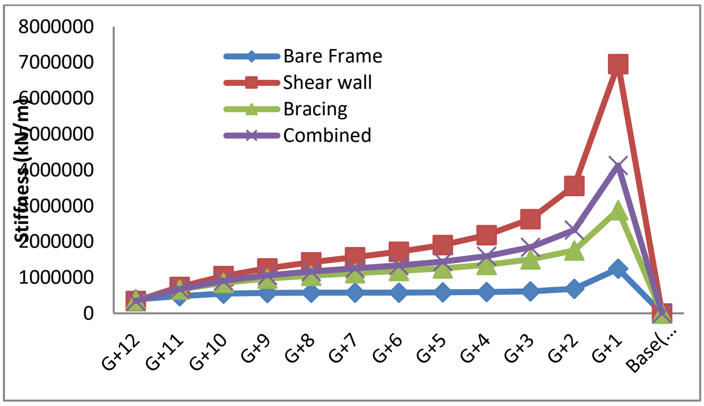

Figure 22. Storey Stiffness Along X- Direction in Type- III System (EQx by ESM

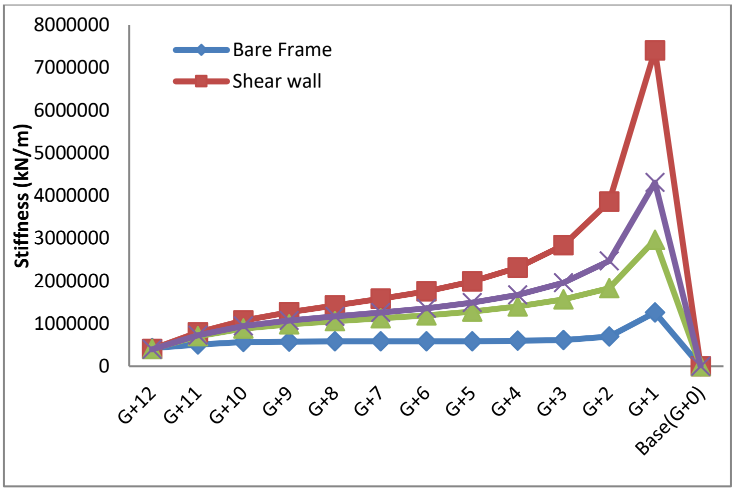

Figure 23. Storey Stiffness Along X- Direction in Type- III System (RSx) by RSM

Values of storey stiffness by seismic forces along X-direction for all type- III position systems (models) are plotted and tabulated using ESM and RSM. By analyzing these values, it can be concluded that all the systems of Equivalent Static Method in X-direction have larger maximum value of storey stiffness at G+1 storey than that of Response Spectrum Method. Also it can be seen that model with shear wall system has higher stiffness than other system models. Shear wall, combined, bracing and bare frame system respectively have decreasing order of storey stiffness values.

Diaphragm Maximum to Average Drift Ratio

Table 9. X- Direction Diaphragm Maximum to Average Drift Ratio in Type- III System

X -Direction Diaphragm Maximum to Average Drift Ratio in Type III System									
Storey	Elevation(m)	Bare Frame		Shear wall		Bracing		Combined	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.018	1.017	1.015	1.007	1.014	1.009	1.015	1.009
G+11	33	1.088	1.078	1.075	1.045	1.074	1.052	1.075	1.05
G+10	30	1.089	1.067	1.076	1.044	1.076	1.05	1.077	1.049
G+9	27	1.089	1.06	1.076	1.043	1.078	1.048	1.078	1.047
G+8	24	1.088	1.057	1.077	1.042	1.078	1.047	1.078	1.046
G+7	21	1.088	1.055	1.077	1.041	1.079	1.046	1.079	1.045
G+6	18	1.088	1.053	1.077	1.04	1.08	1.045	1.079	1.045
G+5	15	1.088	1.053	1.077	1.04	1.081	1.045	1.08	1.044
G+4	12	1.088	1.053	1.078	1.04	1.082	1.045	1.081	1.045
G+3	9	1.089	1.052	1.079	1.04	1.084	1.046	1.083	1.045
G+2	6	1.089	1.052	1.081	1.041	1.087	1.048	1.086	1.047
G+1	3	1.089	1.052	1.089	1.044	1.09	1.049	1.091	1.049

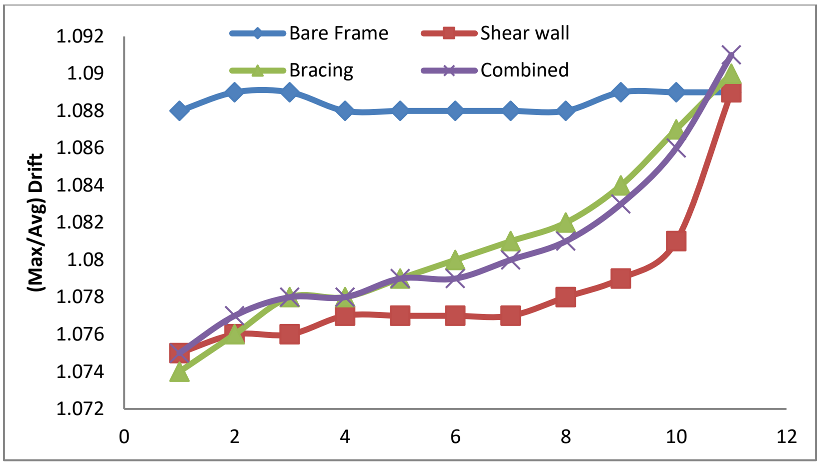

Figure 24. X- Direction Diaphragm Max to Avg Drift Ratio in Type- III System (EQx) by ESM

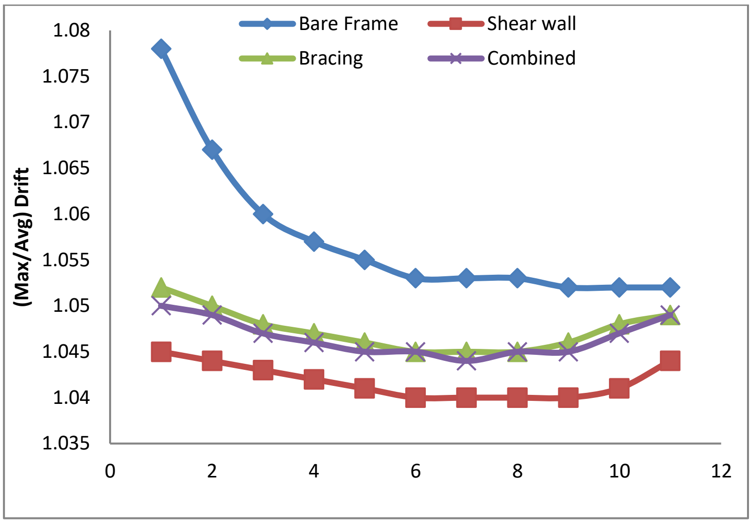

Figure 25. X- Direction Diaphragm Max to Avg Drift Ratio in Type- III System (RSx) by RSM

X- direction diaphragm maximum to average drift ratio in Type- III position of all the system by the effect of seismic force is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all system, the ratio by ESM is greater than that by RSM. In overall, shear wall system has lesser value of diaphragm maximum to average drift ratio than that of other systems. It can be concluded that shear wall system contributes less torsional susceptibility than other systems.

3.7 Parameters Discussed in Type- IV of All system Using ESM and RSM

Storey Stiffness

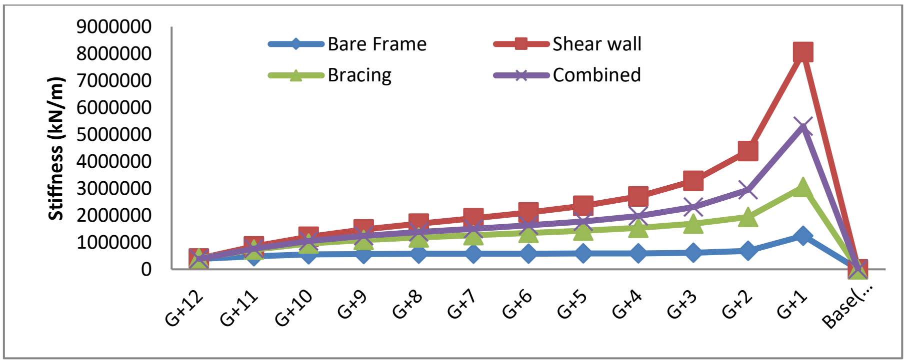

Figure 26 Storey Stiffness Along X- Direction in Type- IV System (EQx) by ESM

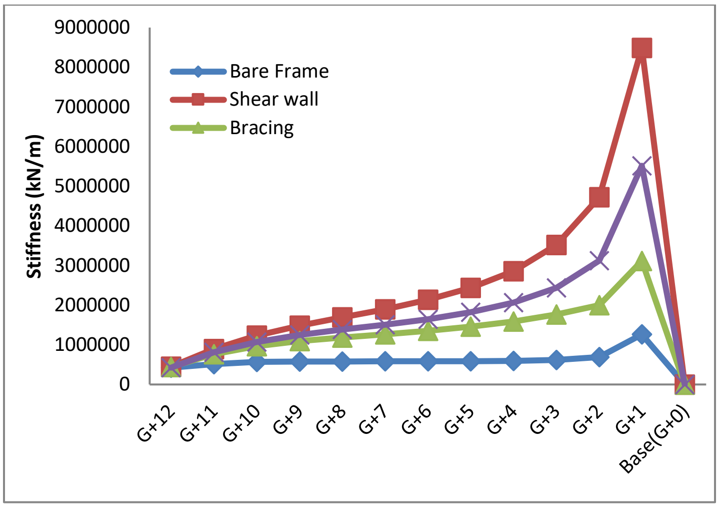

Figure 27. Storey Stiffness Along X- Direction in Type- IV System (RSx) by RSM

Values of storey stiffness by seismic forces along X-direction for all Type- IV position systems (models) are plotted and tabulated using ESM and RSM. By analyzing these values, it can be concluded that all the systems of Equivalent Static Method in X-direction have larger maximum value of storey stiffness at G+1 storey than that of Response Spectrum Method. Also it can be seen that model with shear wall system has higher stiffness than other system models. Shear wall, combined, bracing and bare frame system respectively have decreasing order of storey stiffness values. In summary, shear wall system has higher values of storey stiffness at all stories than that of other systems.

Diaphragm Maximum to Average Drift Ratio

Table 10 X- Direction Diaphragm Maximum to Average Drift Ratio in Type- IV System

X -Direction Diaphragm Maximum to Average Drift Ratio in Type IV System									
Storey	Elevation(m)	Bare Frame		Shear wall		Bracing		Combined	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.018	1.017	1.015	1.008	1.015	1.009	1.014	1.007
G+11	33	1.088	1.078	1.087	1.048	1.082	1.047	1.084	1.047
G+10	30	1.089	1.067	1.089	1.047	1.085	1.045	1.087	1.045
G+9	27	1.089	1.06	1.09	1.047	1.087	1.043	1.089	1.044
G+8	24	1.088	1.057	1.092	1.046	1.088	1.042	1.09	1.044
G+7	21	1.088	1.055	1.093	1.046	1.089	1.041	1.092	1.043
G+6	18	1.088	1.053	1.094	1.046	1.09	1.041	1.093	1.043
G+5	15	1.088	1.053	1.095	1.046	1.092	1.04	1.094	1.043
G+4	12	1.088	1.053	1.097	1.046	1.093	1.04	1.096	1.043
G+3	9	1.089	1.052	1.098	1.046	1.095	1.041	1.097	1.043
G+2	6	1.089	1.052	1.1	1.046	1.096	1.041	1.099	1.043
G+1	3	1.089	1.052	1.103	1.045	1.095	1.039	1.101	1.042

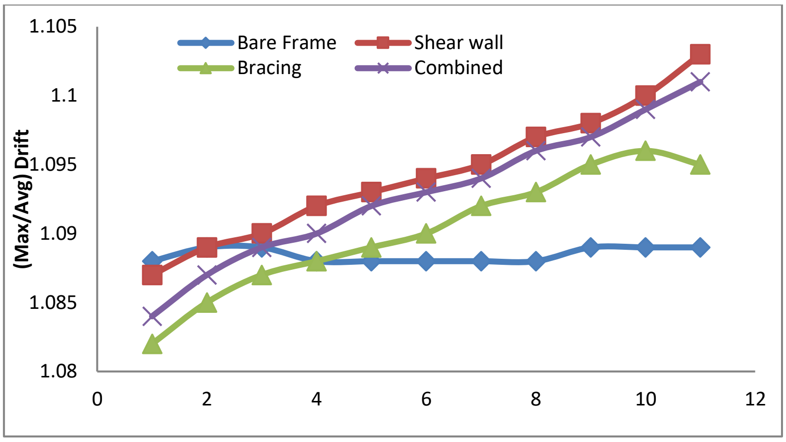

Figure 28. X- Direction Diaphragm Max to Avg Drift Ratio in Type- IV System (EQx by ESM

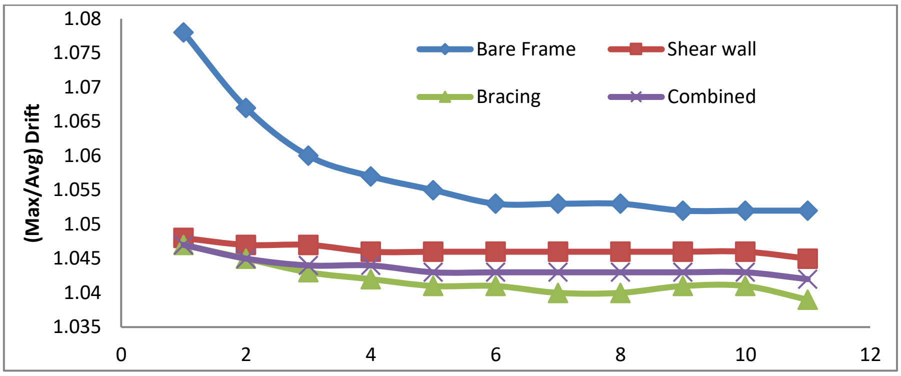

Figure 29. X- Direction Diaphragm Max to Avg Drift Ratio in Type- IV System (RSx by RSM

Diaphragm maximum to average drift ratio in Type- IV position of all the system along X- direction by the effect of seismic force is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all systems, the ratio by ESM is greater than that by RSM. In overall, bare frame system has lesser value of diaphragm maximum to average drift ratio than that of other systems using ESM but that for shear wall system using RSM. The decreasing order of the ratio in these three systems by both methods are bracing, combined and shear wall system. It can be concluded that among these three systems rather than bare frame, shear wall system contributes less torsional susceptibility.

3.8 Parameters Discussed in Type- V of All system Using ESM and RSM

Storey Stiffness

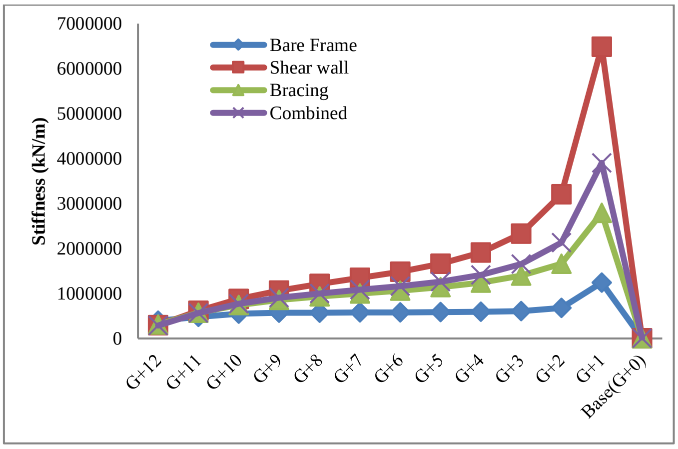

Figure 30. Storey Stiffness Along X- Direction in Type- V System (EQx) by ESM

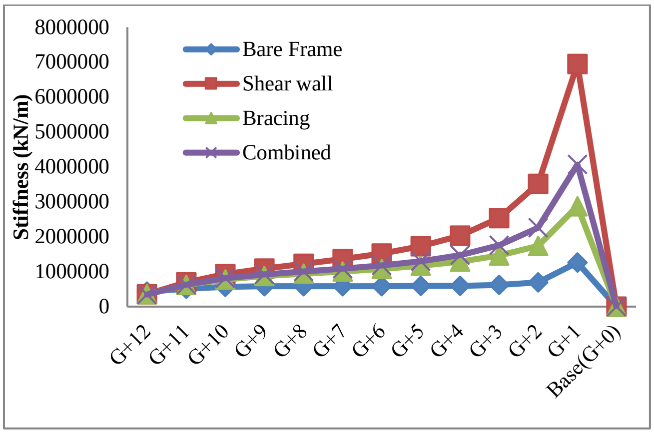

Figure 31. Storey Stiffness Along X- Direction in Type- V System (RSx) by RSM

The storey stiffness values by seismic forces along X-direction for all Type- V position systems (models) are plotted and tabulated using ESM and RSM. By analyzing these values, it can be concluded that all the systems of Equivalent Static Method in X-direction have larger maximum value of storey stiffness at G+1 storey than that of Response Spectrum Method. Also it can be seen that model with shear wall system has higher stiffness than other system models. Shear wall, combined, bracing and bare frame system respectively have decreasing order of storey stiffness values. In summary, shear wall system has higher values of storey stiffness at all stories than that of other systems.

Diaphragm Maximum to Average Drift Ratio

Table 11 X- Direction Diaphragm Maximum to Average Drift Ratio in Type- V System

X -Direction Diaphragm Maximum to Average Drift Ratio in Type V System									
Storey	Elevation(m)	Bare Frame		Shear wall		Bracing		Combined	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+12	36	1.018	1.017	1.007	1.002	1.011	1.001	1.01	1.002
G+11	33	1.088	1.078	1.058	1.035	1.079	1.014	1.075	1.024
G+10	30	1.089	1.067	1.065	1.037	1.086	1.01	1.083	1.023
G+9	27	1.089	1.06	1.072	1.04	1.092	1.009	1.088	1.023
G+8	24	1.088	1.057	1.079	1.044	1.096	1.008	1.093	1.023
G+7	21	1.088	1.055	1.084	1.048	1.099	1.008	1.097	1.024
G+6	18	1.088	1.053	1.09	1.051	1.102	1.009	1.101	1.025
G+5	15	1.088	1.053	1.096	1.054	1.105	1.008	1.105	1.025
G+4	12	1.088	1.053	1.102	1.057	1.109	1.008	1.109	1.024
G+3	9	1.089	1.052	1.11	1.059	1.115	1.008	1.115	1.023
G+2	6	1.089	1.052	1.122	1.061	1.12	1.682	1.123	1.023
G+1	3	1.089	1.052	1.136	1.062	1.119	1.011	1.129	1.02

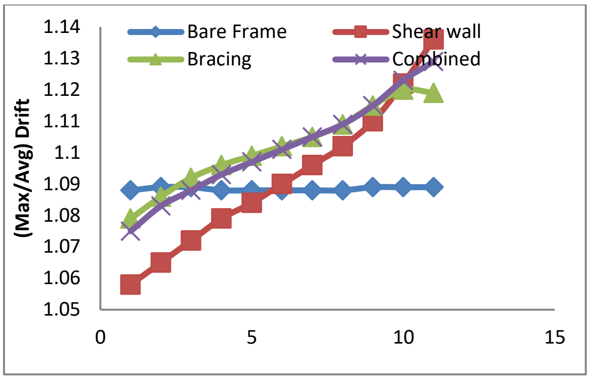

Figure 32. X- Direction Diaphragm Max to Avg Drift Ratio in Type- V System (EQx) by ESM

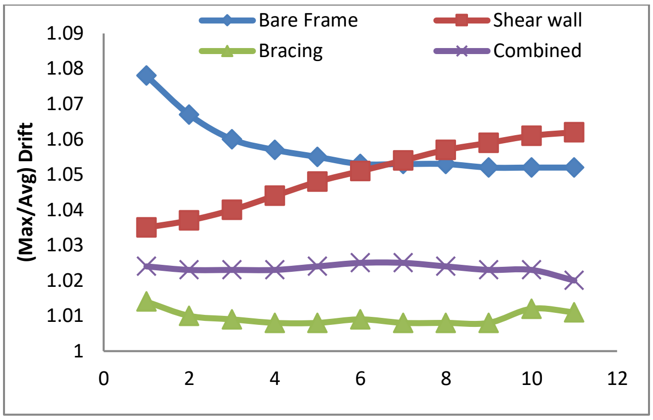

Figure 33. X- Direction Diaphragm Max to Avg Drift Ratio in Type- V System (RSx) by RSM

Diaphragm maximum to average drift ratio in Type- V position of all the system along X- direction by the effect of seismic force is presented in tabular form and graphically using ESM and RSM as shown in figure above. It is observed that for all systems, the ratio by ESM is greater than that by RSM. The decreasing order of the ratio in three systems except bare frame by both methods are bracing, combined and shear wall system. It can be concluded that among these three systems rather than bare frame, shear wall system contributes less torsional susceptibility. From above graphs, among all the system, bare frame system has better response for torsional effect up to G+5 storey, after G+5 shear wall is better than all others.

Discussion

Equivalent Static Method (ESM) and Response Spectrum Method (RSM) with different position/locations (type- I, type- II, type- III, type- IV and type- V) of shear wall, steel bracing and combination of shear walls and braces (combined) systems are compared in terms of maximum storey displacement, maximum storey drift, storey shear, overturning moment, storey stiffness and diaphragm maximum to average drift ratio.

Following observations were noticed:

i. In all types/locations of any system there is no considerable difference in the distance between center of mass and center of rigidity.

ii. It is seen that in continuous lateral load resisting system location without corners (i.e. type- II and type- IV) has greater stiffness than that in continuous lateral load resisting system with corners.

iii. The stiffness of continuous systems (type-I, type-II, type-III, and type-IV) is higher than that of discontinuous systems (type-V), according to observations.
iv. Outer sides (periphery) central location (Type- II position) of each system has better performance in terms of all considered parameters than other three type of location.
v. Hence, it can be observed that Type-II position of shear wall system is structurally more efficient than other location and systems to overcome the earthquake effect.

Shear wall system has higher base shear capacity than bracing and combined systems due to its higher in-plan stiffness. As per Response Spectrum Method (RSM), for type- II position of shear wall, bracing and combined system with respect to bare frame system, percentage increase in maximum value of storey stiffness are 563 %, 147% and 266% respectively and percentage decrease in maximum value of diaphragm maximum to average drift ratio are 3.1%, 3.1% and 3.2% respectively.

4: CONCLUSIONS AND SUMMARY

After Equivalent Static Analysis and Response Spectrum Analysis of eleven storied buildings of sixteen different models using earthquake loading according to NBC 105:2020 by locating shear wall, steel bracing and combined system (shear walls + braces) at five different positions (type-I, type- II, type- III, type- IV and type- V), the following conclusions can be drawn:

1. Based on the analysis, it can be observed that placing the shear wall at the central location of the outer sides (Type-II) results in a better response with lower displacement and higher stiffness compared to other systems and locations. It is evident that by incorporating shear walls in the Type-II position, the displacement of the top storey can be reduced by 29.45% and maximum storey stiffness can be increased by 563% compared to a bare frame model.
2. The performance improvement rates are as follows: shear wall system > combined system > bracing system > bare frame system.
3. In a continuous lateral load resisting system (type- II and type- IV) without corners, the lateral load is uniformly distributed throughout the wall, resulting in an even distribution of stress. In contrast, the system with corners (type- I and type- III) can create stress concentration points where the wall is more likely to fail under lateral load. The continuous lateral load resisting systems without corners has greater stiffness than continuous system with corners due to its uniform distribution of load, symmetric design, and predictable structural behavior which leads to less deformation and better performance.
4. The continuous systems (type- I, type- II, type- III, type- IV) has greater stiffness than a discontinuous system (type- V) due to its uniform distribution of load, greater wall length, and fewer stress concentration points.
5. The order of increasing seismic performance for all considered systems, based on location, is as follows: type-II, type-IV, type-III, type-I, and type-V.

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