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Seismic Evaluation of a Multi-Strorey Building with RC Moment Resistance Frame and Shear Wall

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Abstract: ***In the era of rapid urbanization multi-storey buildings are the only solutions for overcoming the problems scarcity of availability of land and its increasing cost. However, it should be should be designed to withstand the lateral loads exerted by wind and earthquake within the limits prescribed by the prevailing Standards of the region. For tall building, Earthquake forces, static and dynamic in nature, may behave non-linearly. The nonlinearity is generally observed in geometry and materials of the building. Seismic resistance of buildings is a need-based concept aimed at improving the enforcement of any building under future earthquakes. Thus, the present study is based on seismic analysis which incorporates geometric nonlinearity in the analysis. In the present study the seismic analysis of multistory (G+6) hypothetical building with moment resisting (MR) frame and Structural wall (Shear wall) was analyzed. The seismic information considered for the present work was zone IV (hazard factor 0.24) as per IS code 1893:2002 in the Bhiwani region. The building seismic performance was evaluated using various parameters such as fundamental period, base shear, seismic drift, stability coefficient, P-delta analysis, inter-story drift, displacement. The evaluation of seismic performance of the building indicates that both the moment resisting (MR) frame and shear wall have improved the seismic performance of the building but MR frame appeared to have better alternative than shear wall for resisting the seismic force.***

Keywords: Seismic Analysis, Moment resisting frame, Shear wall, Lateral Displacement, Story Drift, P-delta effect

1. Introduction

Earthquake is a natural disaster which continually affects structure and lives across the Globe. The main reason behind this is the ignorance, lack of awareness on the risk due to earthquakes and also the limited knowledge on the behavior of the structures during earthquake leading to its failure [1], [2]. Increasing urbanization, population density accompanied by the inaccessibility to sufficient land, tall buildings are the preferred structure in big cities. In the event of earthquake due to above mentioned reasons make the city dweller even increasingly more vulnerable [3].

Over the decades many of the researchers come on the conclusion that the earthquake does not kill the peoples but the buildings do. Now a day the engineers believe that it can be possible to build the earthquake-resistant buildings which are not only economical but also prevent the collapse of the buildings and so as the life of its residents [4].The simplest philosophy in the design of earthquake resistant building is strong column-weak beam (SCWB). It implies that the columns of the structure must be stronger than the beams. It avoids progressive collapse of a structure due to cascade effect created in the event of column failure at the lower levels. In this philosophy, beams to behave relatively ductile compared to columns which helps the structure to dissipate seismic energy better, without total collapse. [5], [6].

The researchers have developed several modern techniques for improving the earthquake resistance of the building beyond the SCWB philosophy by providing necessary lateral structures like brace frame, shear wall, moment frame, etc [7], [8]. The moment resistant (MR) frame gives stability to the structures by providing the rigid connection to the structure which resists the deformation and also resists the movement of the elements relative to each other. Braced frames resist loads through a series of trusses made of steel members. Shear walls also provide resistance to lateral forces by cantilever action through shear and bending. The slab connected to the shear wall must function as a horizontal diaphragm [9], [10].

However, each of these lateral structural elements has its own advantaged and disadvantages. Besides, the optimal design of these lateral elements in terms of strength, economy and aesthetic would be a matter of challenge for the engineers [11]. Keeping in view the above facts, the present communication aimed at comparative appraisal of seismic performances of a multistory building with MR frame and shear wall as lateral resisting structure.

2. Objectives

The present work has been carried with prime objective of a comparative assessment seismic performance of a RCC building with MR frame and Shear wall as lateral structure. However, the following are the specific objectives of present study:

- To study the behavior of the RC frame building under seismic and wind force.
- To study the seismic drift and stability coefficient for RC buildings with MR frame and Shear wall.
- To study the inter-story drift and displacement for RC building buildings with MR frame and Shear wall under serviceability and ultimate limit state methods.
- To study the performance for RC buildings with MR frame and Shear wall during earthquake.

3. Methodology

3.1 Building Description

The studied building is hypothetical six story (G+6) RCC residential building. The complete detail of the building is presented in Table 4.1

Table 1: Building Description

Building Importance category	Normal structures	
Number of stories	7	
Total height	24 m	
Floor plan	(-10, -10), (10, -10), (10, 10), (-10, 10)	
Floor plan properties	Area:400 m^2; Perimeter length: 80 m; Centroid: (0, 0) m; Bound lengths: (20, 20) m	
Inter-story height	3.0 m	
Floor	Weight type: Medium, Dead load: 2.90 kPa, Live load: domestic (2.00 kPa)	
Interior wall	Weight type: Light, Dead load: 0.30 kPa (over floor area)	
External wall	Weight type: Medium, Dead load: 1.26 kPa (over wall area)	
Roof	Weight type: heavy, Height: 3 m, Dead load: 4.80 kPa (over floor area), Live load: 0.25 kPa (over floor area)	
Structure in X & Y direction	Locations: (0, -9.876), (0, 9.876)	
Soil information	Parameter	Soil C (Medium)
	Description	Less than 20m soft clay or less than 60m hard clay, or less than 60m medium sand over bedrock, or less than 100m gravels., Presumptive values
	Density	1850 kg/m^3
	Poisson's ratio	0.3
	Modulus of Elasticity E_s	400 MPa (includes improvement factor: 2.00)
	Allowable bearing pressure(q_a)	250 kPa (includes improvement factor: 1.00)
Parameter	**MR frame**	**Shear Wall**
Polar moment of inertia, J	3.292e+09 Nm	J=1.242 e+09 Nm
Rigidity (X & Y)	8.47e+06 N/m	3.18e+06 N/m
torsion factor (X & Y dir)	1.101	1.101

3.2. Building Model

The building floor layout plans are symmetrical for both the building frame as the centroid and centre of mass of the buildings coincide to each other. Thus the characteristics of the buildings are same in both X-direction and Y-direction. The 3D views of buildings with moment resistance frame and for building with shear wall are presented in Figures 1-2.

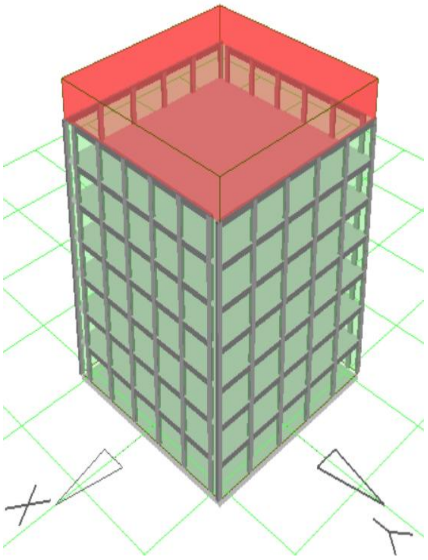

Figure 1: Building with Moment resistance frame

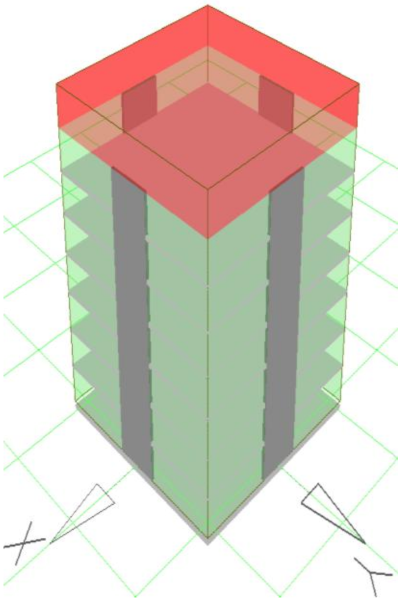

Figure 2: Building with Shear Wall

3.3 Wind and terrain information

The region which are considered for the present work is zone 4, the wind velocity present here is 47 m/s with terrain category 2 as per IS code 875:1987. The gust speed (VR) 3 second depends on the design of building, wind region, the limit state under consideration and building importance. For Ultimate Limit State the VR value is considered 45m/s and Serviceability Limit State the value of VR are considered as 37 m/s respectively. Shielding multiplier (M_s), Wind direction multiplier (M_d), Lee effect multiplier (M_l), Hill shape multiplier (M_h) , Topographic multiplier (M_t) Site elevation multiplier (M_e), all are considered to be unity. The aerodynamic shape factors and wind pressure coefficient used in the study are presented in Table 2.

Table 2: Wind Pressure Coefficients

Coefficient	X and Y Direction
d/b ratio	1.00
d/h ratio	0.83
Combination factor coeff., k_c	0.90
Dynamic response factor, C_{dyn}	1.00
Windward pressure coeff., $C_{p,e}$	0.80
Leeward pressure coeff., $C_{p,e}$	-0.50
Drag on side walls, C_f	0
Aerodynamic Shape factor (C_{fig}) Windward wall	0.72
Aerodynamic Shape factor (C_{fig}) Leeward wall	-0.45
Drag on side walls	0

3.4. Component load for the building using ULS and SLS

To calculate the component loads for the hypothetical building with different braced frame using the method ULS and SLS Table 3 and Table 4 respectively.

Table 3: Component Loads for the building using ULS

Level	Fx (kN)	Vx (kN)	Mx (kNm)	Fy (kN)	Vy (kN)	My (kNm)
7	92.4	92.4	0.0	92.4	92.4	0.0
6	59.2	151.6	277.3	59.2	151.6	277.3
5	57.4	209.0	732.1	57.4	209.0	732.1
4	55.0	264.0	1359	55.0	264.0	1359.0
3	52.2	316.2	2151	52.2	316.2	2151.1
2	48.3	364.5	3099	48.3	364.5	3099.7
1	41.8	406.3	4193	41.8	406.3	4193.1
0	20.9	472.2	5411	20.9	472.2	5411.9
Total	427			427.2		

Table 4: Component Loads for the building using SLS

Level	Fx (kN)	Vx (kN)	Mx (kNm)	Fy (kN)	Vy (kN)	My (kNm)
7	62.5	62.5	0.0	62.5	62.5	0.0
6	40.0	102.5	187.4	40.0	102.5	187.4
5	38.8	141.3	494.9	38.8	141.3	494.9
4	37.2	178.5	918.8	37.2	178.5	918.8
3	35.3	213.8	1454.3	35.3	213.8	1454.3
2	32.6	246.4	2095.5	32.6	246.4	2095.5
1	28.3	274.7	2834.7	28.3	274.7	2834.7
0	14.1	288.8	3658.7	14.1	288.8	3658.7
Total	288.8			288.8		

3.5 Seismic information

The seismic information considered for the present work is zone IV (Hazard factor – 0.24) and soil type is medium soil (C) as per IS code 1893:2002. For Ultimate Limit State or ULS (500 years of Recurrence interval) and Serviceability Limit State or SLS (25 years of Recurrence interval), the value of Return Period factor are considered as 1.0 and 0.25 respectively.

4. Result and Discussion

4.1. Seismic response parameter

The seismic response parameter for the MR Frame and the structural wall structure are analyzed by the ULS and SLS method. For this analysis, the IS Code 1893(part-1):2002 is used the seismic parameters for ULS method are shown in Table 5. The fundamental period for the MR frame and structural wall are different. The base shears without p-delta and with p-delta are seen to be more or highest for the MR Frame and thus the less for the structural wall structure. The base moment with p-delta is maximum into the MR Frame thus the less into the structural wall structures. The torsion for the MR Frame and the structural wall are observed to be same, increase in the base shear shows that increment in the stiffness in the structure. The values of base shear are equal in both the direction that is in X-direction and in Y-direction due to the same stiffeners used into the building. The value of the ductility factor is more into the structural wall as compare to MR frame so the demand for elastic behavior is more in the shear wall.

Table 5: Seismic Response using Ultimate Limit State method

Seismic Response	*MR frame*	*Shear wall*
Fundamental Period (T) (s)	1.85	1.51
Ductility Factor, μd	4.00	5.00
Return Period Factor, R	1.0	1.0
Structural Performance Factor, Sp	0.70	0.70
Spectral shape Factor, Ch(T)	0.715	0.872
Inelastic Spectrum Scaling factor, kμ	4.000	5.000
Elastic Site Coefficient, C(T)=Ch Z R N(T,D)	0.179	0.218
Seismic coefficient, Cd(T)=C(T) Sp / kμ	0.0325	0.0325
Base shear (kN)	509.7	492.1
Base shear incl. P-Δ (kN)	980.1	946.4
Base moment incl. P-Δ (kNm)	15474.9	14976.5
Torsion factor (applied to component)	1.10	1.10
Component base shear incl. torsion (kN)	539.7	521.0

Table 6: Seismic Response using Serviceability Limit State method

Seismic Response	MR frame	Shear wall
Fundamental Period (T) (s)	1.36	0.86
Ductility Factor, μd	1.00	1.00
Return Period Factor, R	0.25	0.25
Structural Performance Factor, Sp	0.70	0.70
Spectral shape Factor, Ch(T)	0.942	1.328
Inelastic Spectrum Scaling factor, kμ	1.000	1.0000
Elastic Site Coefficient, C(T)=Ch Z R N(T,D)	0.059	0.083
Seismic coefficient, Cd(T)=C(T) Sp / kμ	0.0412	0.0581
Base shear (kN)	646.2	879.5
Base moment incl. P-Δ (kNm)	10203.3	13918.6
Torsion factor (applied to component)	1.10	1.10
Component base shear incl. torsion (kN)	355.8	484.3

The seismic response parameter for the SLS is shown in Table 6.The ductility factor is the same for both MR Frame and Structural wall structures. The value of structural performance is 0.70 in both structures. The value of the return factor is 0.25 which is also same for the structure. The Value of the base shear is more in the shear wall structure as compared to the MR Frame structure. The value of the base shear and the value of the base moment is more in the ULS method in both the case because in ULS method the building is designed for the extreme load with the large time period.

4.2. Seismic drift

Table 7 shows that drift determined by using ULS method for both the MR Frame and structural wall structure in both the direction that is X-direction and Y -direction. The value of shear, foundation and flexural is increase with the increase in story height. The value of total drift is higher in the shear wall structure as compare to MR Frame structure.

Table 7: Seismic drift (in mm) for MR Frame using ULS methods

Level	Shear	Flexural	Foundation	Total
7	367.8	4.1	0.6	372.5
6	343.5	3.3	0.5	347.3
5	304.1	2.5	0.4	307.0
4	253.3	1.7	0.3	255.4
3	193.3	1.0	0.3	194.6
2	126.4	0.5	0.2	127.1
1	54.9	0.1	0.1	55.1
0	0.0	0.0	0.0	0.0

Table 8: Seismic drift (in mm) for Shear wall structure using ULS method

Level	Shear	Flexural	Foundation	Total
7	3.1	357.6	18.3	379.1
6	2.9	285.4	15.7	304.1
5	2.6	215.1	13.1	230.8
4	2.2	149.0	10.5	161.7
3	1.7	90.5	7.9	100.0
2	1.2	43.3	5.2	49.7
1	0.6	11.6	2.6	14.8
0	0.0	0.0	0.0	0.0

Table 8 shows that drift determined by using the SLS method for both the MR Frame and structural wall structure in both the direction that is X-direction and Y -direction. The value of shear, foundation and flexural is increase with the increase in story height. The sum of shear, foundation and flexural is produced the total drift in both the direction of the structure. The value of total drift is higher in the MR Frame structure as compare to the shear wall structure.

4.3. Stability coefficient

The results for story-wise stability coefficient (θ) are presented in Table 9. The stability coefficient not only gives a method for calculating the P-Delta effect but also provide the basis for the design of P-Delta effects.

Table 9: Story wise stability coefficients for different structures

Level	MR Frame	Shear Wall
7	0.060	0.180
6	0.113	0.206
5	0.162	0.218
4	0.212	0.216
3	0.261	0.195
2	0.310	0.151
1	0.267	0.072

4.4. Inter-story drift

Inter story drift is one such parameter to measure the lateral displacement of the building. During a seismic event, buildings swing laterally and such lateral displacement is manageable to a limited extent. If the lateral displacement exceeds the limit (inter-story drift under design earthquake forces be restricted to 0.4% of story height), it may cause non-structural damage, structural damage to the building. Table 10 displays the inter-story drift of the building for both the case. It is observed that the inter-story drift increases from the ground to the top of the building.

Table 10: Inter-story Drift (mm) of the building under MR frame and Shear wall

Level	MR frame	Shear wall
7	11.9	35.5
6	19.0	34.7
5	24.4	32.7
4	28.7	29.2
3	31.9	23.9
2	34.0	16.5
1	26.0	7.1

The value of inter-story drift is observed to be lower for MR frame indicate its superiority in providing resistance to the building over the shear wall. The observations indicate that building with MR frame is most ductile (flexible) system among the two.

4.5. Displacement

The displacement of the story is the absolute displacement value caused due to the effect of wind and earthquake forces or we can say due to the lateral forces, the total displacement of the story must be controlled to reduce the p-delta effect and to provide the stability of the structure. The displacements of the structure which will occur due to the wind and earthquake forces are shown in Figure 3. The value of the displacement in both the direction that is for X-direction and Y-direction are the same because of the symmetrical nature of the building.

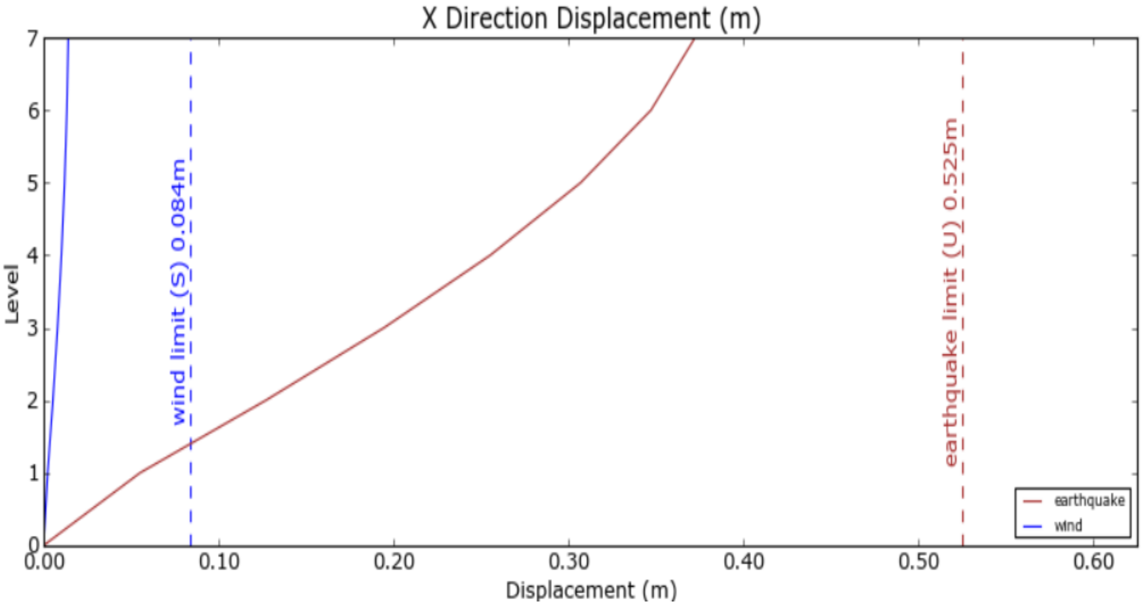

Figure 3: Story wise displacement of the building with moment resistance frame

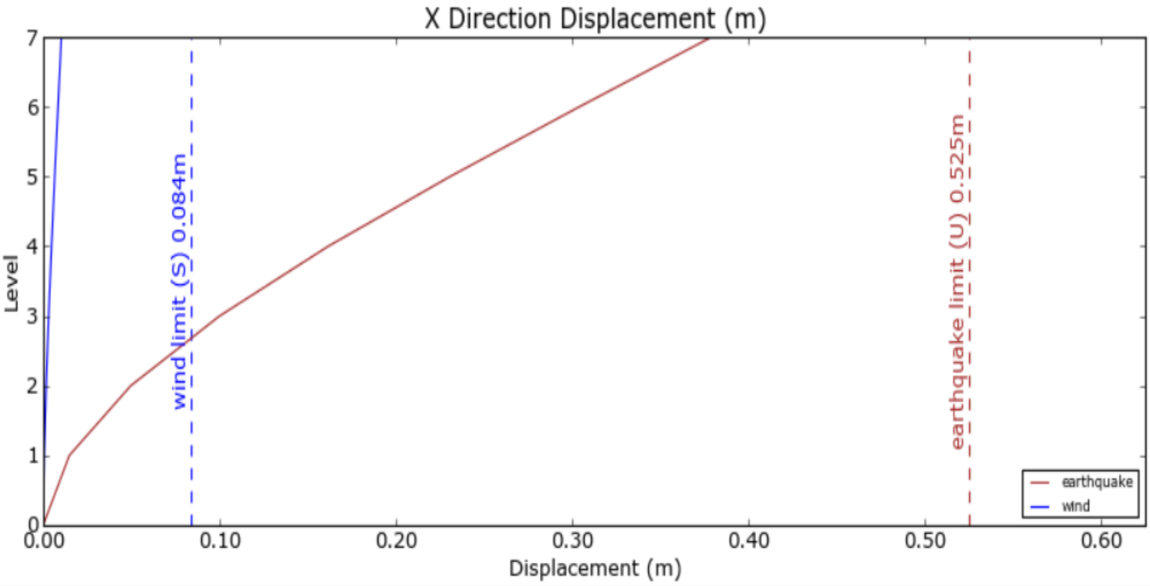

Figure 4: Story wise displacement of the building with Shear wall

Both the figures for X-direction and Y-direction indicates that the limiting value for the wind displacement is 0.084m but from the figure we will observe that the value is 0.035 and the limiting value for the earthquake is 0.525 but from the figure we observe that the value is about 0.035 m so our structure is safe for both the cases.

4.6. Inter-story drift ratio

The term inter-story drift ratio may be defined as the difference in the displacement of the two consecutive stories divided by the height of the story. The value of the drift must be according to the limiting value otherwise the non-structural members like a wall, partition wall and glazing may suffer crack. The inter-story drift caused because of the lateral force like wind and earthquake forces are shown in Figure 5. As the structure is symmetric, the value of drift ratio in both X-direction and Y-direction are the same hence the figure only for the X-direction is presented.

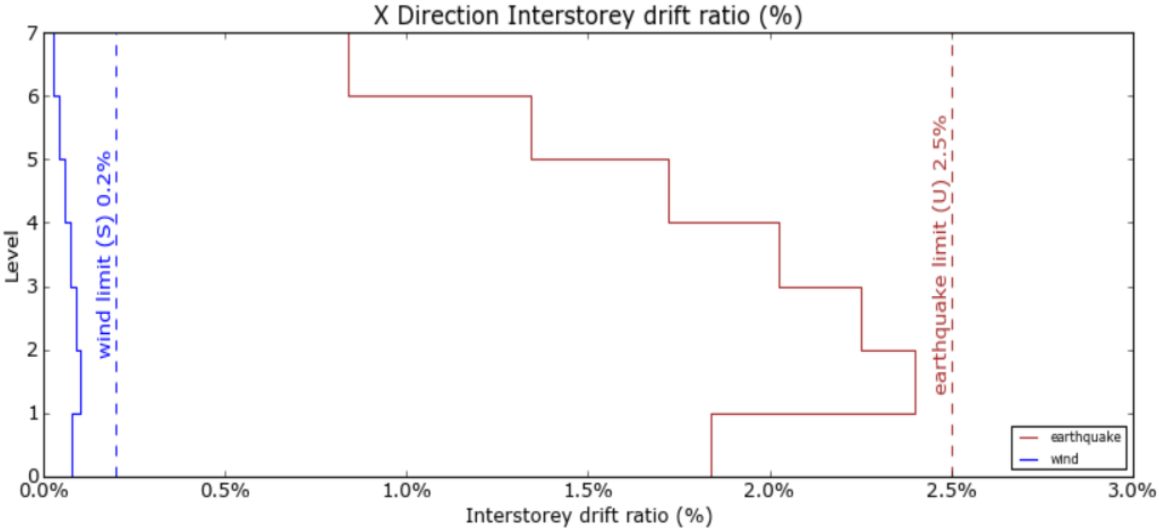

Figure 5: Inter story drift ratio of the building with moment resistance frame

Figure 5 shows that inter story drift ratio of building, in this figure the drift ratio for the level -1 is more but after that, the drift ratio will decreases. The limiting value for an earthquake is 2.5% but at the level-7 the value is 0.7% so the building is safe for an earthquake. Similarly, the limiting value of the drift ratio for the wind is 0.2% and on the level-1 value of the drift ratio is more but at the level-7 this value is decreased. Thus, the building design is within the safe limit for lateral load exerted by wind and earthquake as well.

As per the IS code 1893:2002, the story drift in any story due to the minimum specified design lateral force with a partial load factor of 1.0 shall not exceed 0.004 times or 0.4% of the story height i.e.14mm for the present study. The inter story drift for level 1 and level 2 are observed to be 0.65% and 0.55% respectively. For the rest of the level, the values of inter story drifts are found to be well within the prescribed limit.

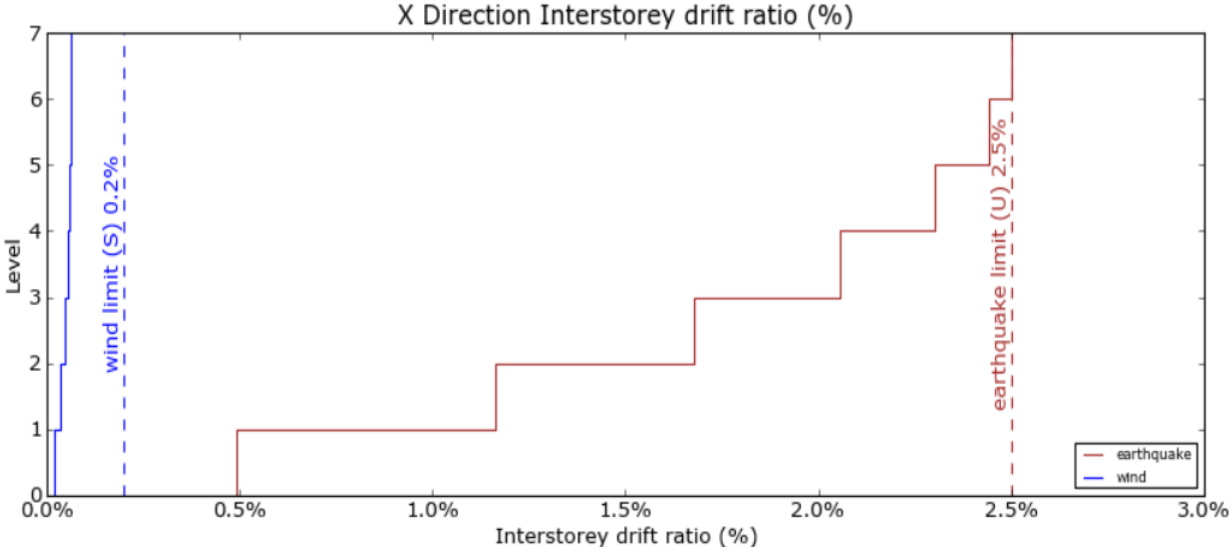

Figure 6: Inter story drift ratio of the building with Shear wall

Figure 6 shows that inter story drift ratio of building, in this figure the drift ratio for the level -1 is more but after that, the drift ratio will decreases. The limiting value for an earthquake is 2.5% but at the level-7 the value is 0.7% so the building is safe for an earthquake. Similarly, the limiting value of the drift ratio for the wind is 0.2% and on the level-1 value of the drift ratio is more but at the level-7 this value is decreased. Thus, the building design is within the safe limit for lateral load exerted by wind and earthquake as well.

4.7. Performance Analysis

The section present here is the final report on the performance of the designed building with the different conditions i.e. with moment resistance frame structure and for the shear wall. The building is symmetric so that the figure is present here is only in X-direction. The results which are discussed here are both for serviceability limit state (S) and the ultimate limit state (U) for both the earthquake and serviceability limit state (S) for wind force.

The results presented here are in terms of maximum allowable percentage value of shear, moment and drift. It means that the value which is less than 100% or equal to 100% is safe in design but if the value is greater than the design is considered to be over design and the building is considered to be unsafe.

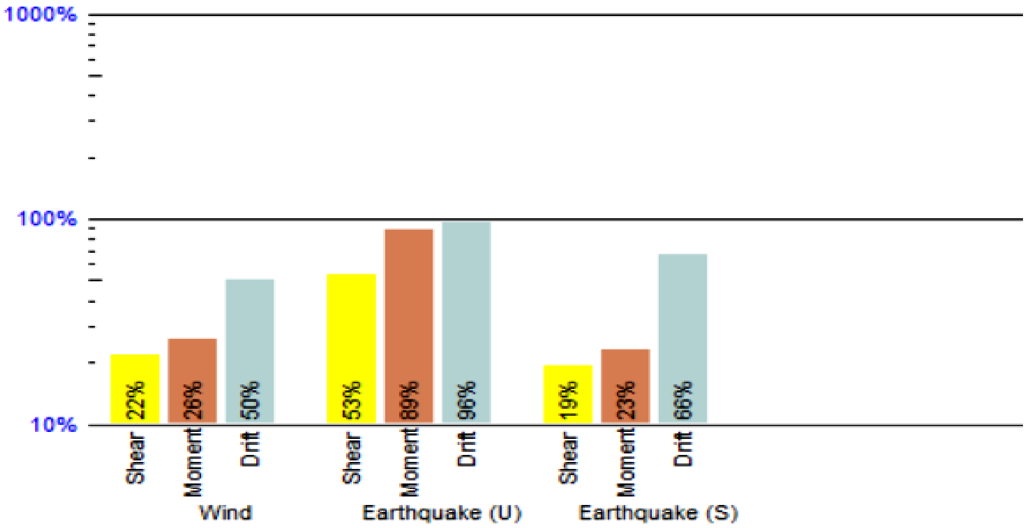

Figure 7: Seismic performance of building with MR frame

Figure 7 shows that the result for wind the value of the drift is about 50% and for the shear and moment is 22% and 26% respectively. The value of earthquake for ultimate limit state method is 96% for the drift which is the maximum as compared to moment and shear, also the value of moment and shear is 53% and 89% respectively and because the values are near to 100% the design is considered to be safe design so the design is safe for the earthquake in ultimate state method. The value of earthquake for serviceability limit state method is 66% for the drift which is the maximum as compared to moment and shear, also the value of moment and shear is 19% and 23% respectively and because the values are less than 100% the design is considered to be safe design so the design is safe for the earthquake in serviceability limit state method.

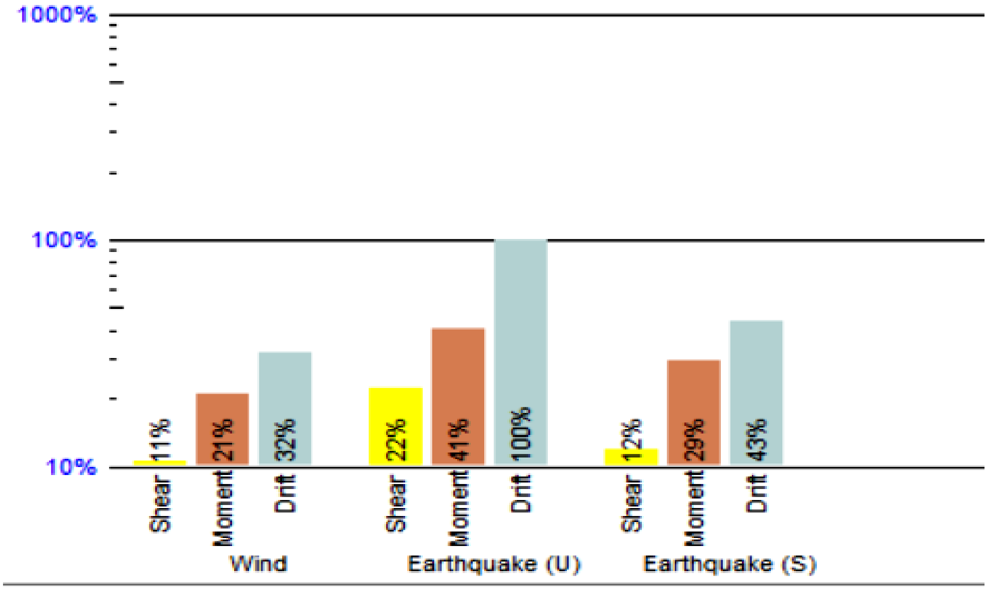

Figure 8: Seismic performance of building with Shear wall

Figure 8 shows that the result for wind the value of the drift is about 50% and for the shear and moment is 22% and 26% respectively. The value of earthquake for ultimate limit state method is 96% for the drift which is the maximum as compared to moment and shear, also the value of moment and shear is 53% and 89% respectively and because the values are near to 100% the design is considered to be safe design so the design is safe for the earthquake in ultimate state method. The value of earthquake for serviceability limit state method is 66% for the drift which is the maximum as compared to moment and shear, also the value of moment and shear is 19% and 23% respectively and because the values are less than 100% the design is considered to be safe design so the design is safe for the earthquake in serviceability limit state method.

5. Conclusion

(G+6) bare RCC building with MR frames and Structural wall was analyzed for it seismic performance under ultimate and serviceability limit state methods using RESIST software. The major conclusion derived out of this study is that MR frame performed better than the shear wall in making the building earthquake resistant by providing additional stiffness. However, the following are some of the specific conclusions drawn from the results of the present study:

- The MR frame has experienced larger lateral weights as compared to building with shear wall.
- The values of fundamental periods, base moment, base shears with p-delta and without p-delta are observed to be large in case of MR frame building compared to building with shear wall.
- The seismic drift determined using both ULS and SLS methods are found to have increased from ground to top story and also observed in the order of MR frame Structural wall.
- The value of stability coefficients (θ) were found in the order of MR frame > Structural wall.
- Moreover, for a given story inter story, drifts increases with increase with θ.
- The P-delta value is greatest for building with Shear wall and minimum in case of building with MR frame.
- Displacements concerning seismic load with P-delta effects were higher in comparison to displacement w.r.t earthquake load without P-delta effects indicating that-delta effects have more effect in designing of a structure rather than linear order effects.
- Inter story drift ratio is very large (exceeding the limit) in lower two stories and decreases with increase in level reaching to a minimum for the top story.
- The values of inter story drift are found to be higher for building with the Shear wall. The value of inter story drift is observed to be lower for MR frame in this study.

Displacements were greatly reduced by the use of MR frame as compared to the Shear wall. Displacement values were within the permissible limit as per IS code 1893:2002. For control of lateral displacement under seismic load, the MR frame is most efficient in the present study by increasing the stiffness of building.

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