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Seismic Performance of Reinforced Concrete Buildings with Different Lateral Load

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Abstract - Shear wall, steel bracing and combined system are the most commonly used lateral-load resisting technique for high-rise buildings. Shear walls have very high in-plane strength and stiffness, which can be used simultaneously for resisting large horizontal and gravity loads. The aim of this study is to examine how well reinforced concrete buildings withstand seismic activity using various systems for resisting lateral loads. In this study, a reinforced concrete building with 12 floors (G+12) and 5 X 5 bays is selected, and various lateral load resisting frame systems are applied in different positions. These are shear wall, bracings, shear wall-bracings combinations (Combined) at five different locations/patterns i.e., at outer corners (Type- I), center of outer sides (Type- II), middle corners (Type- III), center of middle sides (Type- IV), and inner core and middle sides (Type- V) respectively. A total of sixteen models are created for this study, with one being a bare frame and the other fifteen consisting of three types of lateral load resisting systems arranged in five different configurations each. With the assistance of ETABS all models are analyzed by Equivalent Static Analysis and Response Spectrum Analysis. The performance of building is evaluated on the basis of following parameters- maximum storey displacement, maximum storey drift and storey shear. At last the results are compared for different models. Among the three systems, the shear wall system exhibits the least displacement and the highest stiffness. Response of combined system is better than that of bracing system. Overall, the Type II shear wall model is more earthquake-resistant and structurally efficient than the other fifteen models.

Key Words**:** Equivalent Static Analysis, Response Spectrum Analysis, Maximum storey displacement, Maximum storey drift, Storey shear

1.INTRODUCTION

Earthquake is one of the most destructive natural disaster in the world which not only cause damage to the buildings but also loss of many lives. Many past events prove that whole region of Nepal is prone to earthquake and it lies in the seismically active zone. It causes unique engineering design problem in most of civil engineering structures and there is zero probability of the structure that will never be affected by a major earthquake.

Lying in one of the most seismically active regions of the world, India has a long history of earthquakes. The first documented earthquake event in the country dates back to 29 June 1947, near the India china location. The quake, measuring 7.3 on the Richter scale, took the life of the. India has witnessed at least one major earthquake per century[1]. Reinforced concrete building can adequately resist both horizontal and vertical load. Whenever there is requirement for a multistory building to resist higher value of seismic force, lateral load resisting system such as shear wall should be introducing in a building. Shear wall can be provided both along the lengthwise and widthwise of the building. Properly designed building with best positioning of shear wall has shown good performance in past earthquake. Nowadays most of the buildings are constructed with increased stories and height (multistoried). In other hand, India lies in highly vulnerable earthquakes zones where next major earthquake becomes nearer by each passing days. So, there has been more than ever to find and adopt the efficient structural system to safe guard the building from the intense ground shaking during the earthquake. And the introduction of shear walls in concrete frame building makes the structure more efficient to resist the lateral loads. Hence the study of shear wall with concrete frame structure is more desirable.

In other part people are attracting to construct multistoried buildings to maximize space for their commercial purpose and residential growth. Lateral forces like earthquake and wind forces are influenced by the shapes of buildings. Tall buildings attract the more seismic forces since they are more flexible. They absorb earthquake vibration along their height. So it is necessary to analyze these multi-storied buildings to check acceptability behavior (performance of buildings) against earthquake. For the improvement of performance of buildings towards earthquake loads different types of lateral load resisting frame system can be employed. Following are the lateral load resisting system which can be used in high-rise building: Shear wall system, Braced system, Outrigger system, Rigid frame system, Frame tube system, Bundle tube system, Trussed tube system, Diagrid system etc [2].

This research is mainly concerned with the following system: Shear wall, Bracings, Shear wall-bracings combination and Embedded bracing in shear wall.

1.1 Rigid Frame Structure

A rigid frame is the load-resisting framework constructed with straight or curved members connected by essentially rigid connections which resist movements induced at the joints of members. Rigid frame also called as moment-resisting frames. Its members can take bending moment, shear, and axial loads. A rigid-frame high-rise structure typically comprises of parallel or orthogonally arranged bents consisting of columns and girders with moment-resistant joints. 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].

1.2 Shear Wall System

In structural engineering, a shear wall is a vertical element of a lateral force-resisting system that is designed to resist in-plane lateral forces, typically wind and seismic forces. The shear wall serve both architecturally as partitions and structurally to carry gravity and lateral loads. Shear wall generally starts at foundation level and are continued throughout the building height. It has very effective stiffness as well as strength which make them ideal for high rise buildings. In a shear wall structure, such walls are entirely responsible for the lateral load resistance of the building. They act as vertical cantilevers in the form of separate planar walls and as non-planar assemblies of connected walls around elevator, stair and service shafts. Because they are much stiffer horizontally than rigid frames, shear wall structures can be economical up to about 35 stories. In low to medium-rise structures shear walls are combined with frames, it is reasonable to assume that shear walls attract all the lateral loading so that the frame may be designed for only gravity loading. Shear wall structures have been shown to perform well in an earthquake for which ductility becomes an important consideration in their design [2].

1.3 Bracing System

Bracing system Braced frame system in the structure consists of truss members as bracing elements. These bracings are commonly used in structures, subjected to lateral loads. They resist lateral forces mainly with the brace members in compression or tension. 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].

Steel bracing systems can be used effectively for seismic retrofitting of existing RC buildings as well as for seismic design of new buildings. In braced frames, the lateral resistance of the structure is provided by diagonal members that together with the beams form the web of the vertical truss with the columns acting as chords. Because the horizontal shear on the building is resisted by the horizontal components of the axial tensile and compressive actions in the web members bracing systems are highly efficient in resisting lateral loads. Bracing is generally regarded as an exclusive steel system but nowadays steel bracings are also used in reinforced concrete frames. The efficiency of bracing in being able to produce a laterally very stiff structure for a minimum of additional material makes it an economical structural form for any height of building, up to the very tallest. Generally, braces are of two types, concentric and eccentric. Concentric braces connect at the beam-column intersection, whereas eccentric braces connect to the beam at some distance away from the beam-column intersection. Also, bracings are categorized as vertical bracings and horizontal bracings system depending upon the path of transferring load. Vertical bracing is placed in the form of diagonals between column lines in vertical planes to transfer horizontal forces to ground level, whereas the horizontal bracing system is provided in horizontal planes at each floor level, to transfer horizontal forces to the vertical bracings[2].

Braces can be grouped into various categories [3], (a)Based on the material used in braces such as RCC brace (These are the braces which are made up of reinforced cement concrete. The Cross section of concrete brace is similar to RCC beam or column section.) And Steel brace: in Steel braces different types of steel sections can be used such as channel sections, angle sections, I sections etc or tubular section. These braces usually resist large tension force and fail in buckling. The main advantage of steel braces is it can be replaced after the damage hence making it economical.

1.4 Problem Statement

Numerous research studies aim to determine the most favorable location for installing shear walls and bracing systems in reinforced concrete (RC) buildings to improve their seismic performance. Many such studies compare the effectiveness of shear wall and bracing systems when placed in different positions. Although research shows that shear walls are the best system for lateral load resistance in RC buildings, the exclusive use of shear walls can become costly for multi-story buildings. Unfortunately, researchers have not focused on comparing the performance of combined shear wall and bracing systems when placed in various positions within a building. However, a combined system of shear walls and bracing may offer better structural efficiency for RC buildings. In this study, the performance of different lateral load resisting frame systems, including shear walls, bracing systems, and combined shear wall-bracing systems, is compared across various positions in the building, including outer corners (Type-I), the center of outer sides (type-II), middle corners (type-III), the center of middle sides (type-IV), and the inner core and middle sides (Type-V), with respect to different parameters.

2. LITERATURE REVIEW

Literature related to lateral load resisting system (mainly shear wall, bracings and their combination) and their comparative study/analysis related articles are collected and many documents concerning analytical and research paper were thoroughly studied. Different materials on the related topic are reviewed for conceptualization towards theory and its application in ETABS software.

Mehta and Dhameliya (2017) studied the (G+17) storey building was analyze with different shear-wall configuration. The modeling is done to examine the effect of different cases on seismic parameters like base shear, lateral displacements, lateral drifts and model time period for the Zone-V in medium soil as specified in IS:1893-2002. It observed that shear wall at center (Model-4) shows maximum reduction in displacement and drift up to 62% compare to bare frame. It observed that the shear walls 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), In their review paper, different lateral load resisting systems are compared in terms of various parameters such as storey displacement, storey drift, Modal time period, storey forces for seismic load using response spectrum method and top storey displacement, axial forces, material consumption and time period using Gust factor approach as per IS 875 (Part-3)-1987 using ETABS-2015 software. So, it is the most suitable lateral load resisting system in high rise building for seismic load and wind load [6].

Dharanya A, Gayathri S and Deepika M (2017) studied a G+4 storey residential RC building with soft storey has to be analyzed with cross bracings and shear wall. This analysis was made as per IS 1893:2002 codal provision by using ETABS software. The cross bracings such as X bracing are to be provided at the outer periphery of the column and the shear walls are provided at the corners of the buildings. The building models are analyzed by equivalent stiffness method using ETABS software. The main parameters compared are lateral displacement, base shear, storey drift, axial force, shear force and time period. 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), In this paper a comparison cost and deflection of ordinary building with shear wall and bracing in RCC framed structure with different locations were studied and results were presented using Stead pro v8i Software. 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) in their study, G+7 storied building with Shear wall in six different positions has been considered i.e. one model is bare frame in each location of Shear and rest of others with Shear walls in different positions. Models are studied in all positions for comparing storey displacement, storey drift, storey Shear, storey overturning moment and storey stiffness with different positioning of Shear wall. 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), the main aim of this study is to analyze the behavior of commonly used lateral force resisting systems. 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) studied G+9 storey building, along with shear wall and bracings were being considered for the analysis. 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 seismic performance of reinforced concrete RC frame retrofitted with different types of steel bracing has been studied using dynamic response spectrum method. Three models which represents moment resisting RC frame of 7, 12 and 18 stories as low, mid-rise and high-rise buildings respectively were selected as a case study and are designed for gravity loads and seismic forces according to Indian standard code with the help of Finite Element Software SAP2000. 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), The models are assumed to be located in seismic zone V and the response spectrum method is used in the analysis. The results of different type of building models are obtained as: Combined system is an effective system than shear wall and bracing systems in terms of lateral displacement for tall buildings having more than 20 stories[14].

Rana and Mehta (2018), In theirstudy, four different Model of RCC building are used, one with no shear wall and other four models with different position of shear wall. Results will be obtained from analysis and plotted to compare and to have knowledge of behavior of RCC framed structures with shear walls using Response Spectrum Analysis which is subjected to earthquake load in zone V [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 building under analysis consist of 11 floors and has 5 bays along both directions with a span of 4m each, floor to floor height is 3m, ground floor to first floor height is 2.80m. 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, seven models are considered to have suitable various shear walls arrangements. 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 focused only on symmetrical building shapes, and lateral loads were calculated using the equivalent static method. The high-rise building includes both framed systems and shear walls. The shear walls are distributed in such a way that the floor plan length of walls is the same in all the buildings, so results are affected by the arrangement and location of walls only. It has been found that shear walls situated at the center 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), Objectives of the study is to discuss the effect of shear wall and its location on the linear and nonlinear behavior of irregular buildings with different eccentricities. The study of effect of shear wall location in eccentrically loaded structures, especially its nonlinear behavior gives a more precise idea on provision of shear wall [21].
Ahiwale, Kontoni and Darekar (2023), This research compares the seismic behavior of RC structures with several types of bracing systems. Inverted V-braced frames (IVBF), V-braced frames (VBF), X-braced frames (XBF), diagonally braced frames (DBF), three-member gate braced frames (TMGBF), modified inverted V-braced frames (MIVBF), K-braced frames (KBF), and Z-braced frames (ZBF) are the types of braces under investigation. The SAP2000 software is used to model and evaluate ten-storey RC-frame structures with first-storey heights of 3.5, 4, and 4.5 m. Pushover and nonlinear time-history analyses were carried out. Steel braces also contributed to reducing the global damage index (GDI) significantly[22].

Rahman, Teguh, and Saleh (2021), This study compares the results of the structural analysis to three structural models. The 10- story of the structural response used in the research includes the story drift, base shear, displacement, and structural behavior due to the earthquake force. Therefore, it is necessary to add shear walls or a bracing system[23].Islam, Chakraborty, and Kim (2022), 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 hillside building 3D model having different types of structural elements is introduced and analyzed with a seismic effect. 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].

Mohammadi, Kumar, and Rishi (2023), They aimed to find out the optimum positioning of the shear wall in a multi-story building on the sloped ground. In addition, the plan irregularity plays an important role while considering the building models for seismic analysis. In addition, a combination of shear walls and bracings may be a good choice for the earthquake resistance design of the structure[26].

Biradar and Mangalgi (2014), In their study, 7 models with different bracing systems have been modeled and analyzed for linear static (ESA), linear dynamic(RSA), nonlinearstatic (Pushover Analysis) and nonlinear dynamic analysis (Time history Analysis) by ETABS software. Results such as fundamental time period,seismic base shear, storey displacement and storey drift have been evaluated and compared with bare frame model. Model 2 (X bracing system) is showing better seismic performance out of all the models[27].
The majority of researchers concentrate exclusively on a single system of lateral load resisting structures, typically either shear walls or bracing, when analyzing the response of reinforced concrete buildings [28]-[30]. They do not show much interest in exploring the potential benefits of a combined system that utilizes both shear walls and bracing for a more efficient seismic response. While the use of shear walls alone can improve parameters such as drift, displacement, and torsion, it can also drive up construction costs. Conversely, a bracing system alone may not offer the same level of structural performance as a shear wall system, but it may be more cost-effective. Therefore, in terms of balancing cost-effectiveness and structural efficiency, it is recommended that the combined system be examined in research. This study compares the performance of three systems, taking into account various parameters and different locations of the lateral load resisting elements.

3. METHODOLOGY: ANALYSIS & METHODS

3.1 Details of model

For this study, a G+12 storey building with 3 meters' height for each story, regular in plan is modeled. This building consists of five spans of 4 meter in X direction and in Y direction as shown in figure 1. 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.

3.2 Modelling of structure

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. Other important details are as shown in table 1.

Table 1. Different Properties and Parameters

Parameters	Data	Units
Grade of concrete, fck (Column)	M30	MPa
Grade of concrete, fck (others)	M25	MPa
Grade of Steel (rebar's)	Fe 500	MPa
Grade of Structural Steel (braces)	Fy 250	MPa
Specific Weight of RCC	25	kN/m^3
Poisson's Ratio of Concrete	0.2	
Modulus of Elasticity Concrete	22360.68	MPa
Floor Height	3	m
Impose Load (Normal)	4	kN/m^2
Impose Load (Storage)	5	kN/m^2
Roof Live Load (accessible)	1.5	kN/m^2
Roof Live Load (inaccessible)	1.5	kN/m^2
Floor Finish Load	1.5	kN/m^2
Lift Load	15	kN/m^2
Water tank load	1.5	kN/m^2
Shear wall thickness	400	mm
Slab thickness	125 for every slab except for the top slab (250) that supports the elevator	mm
Size of Column	625x625	mm x mm
Size of Beam	600x400	mm x mm

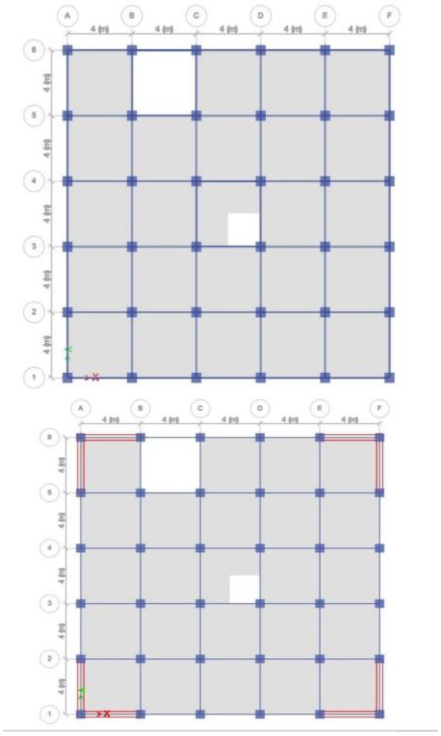

Figure 1. Plan view of the given models

4: 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.

4. 1 Parameters Discussed in Shear Wall System Using ESM and RSM

a. Maximum Storey Displacement

Maximum storey displacement due to seismic force along X-direction for all types (location) of shear wall system as per ESM and RSM are tabulated and shown graphically above. It is seen that Type- II location has lesser value of maximum storey displacement than that of others. The Type- II and Type- IV location has almost same values. The decreasing order of displacements are in type- V, type- I, type- III, type- IV and type- II position respectively. The top storey displacement by RSM is lesser than that by ESM in all types except in type- I as shown in figure 2 and 3.

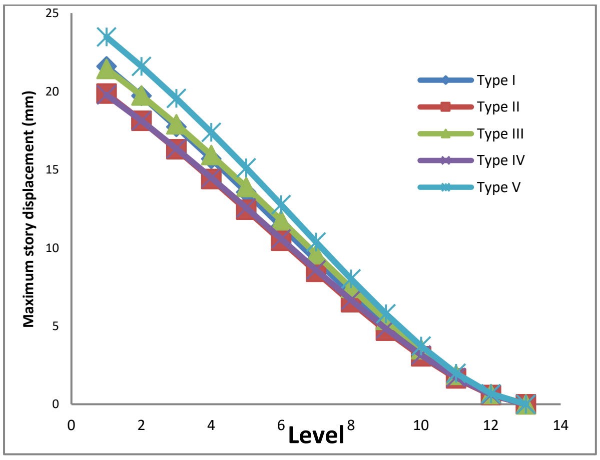

Figure 2. Maximum Storey Displacement along X- Direction in Shear Wall (EQx) by ESM

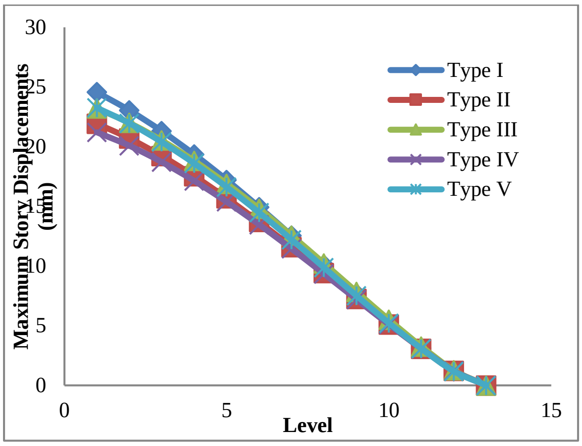

Figure 3. Maximum Storey Displacement Along X- Direction in Shear Wall System (RSx) by RSM

b. Maximum Storey Drift

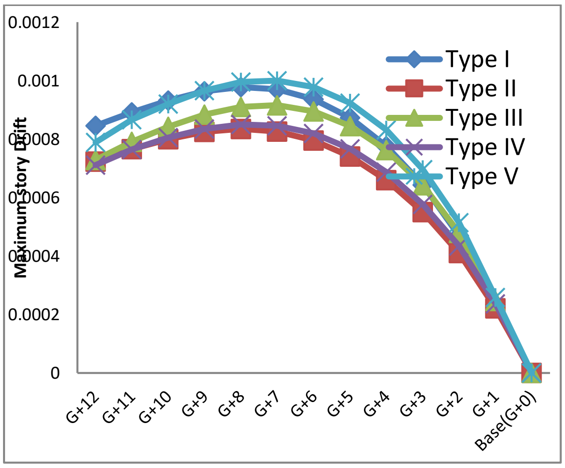

Figure 4 Maximum Storey Drift Along X- Direction in Shear Wall System (EQx) by ESM

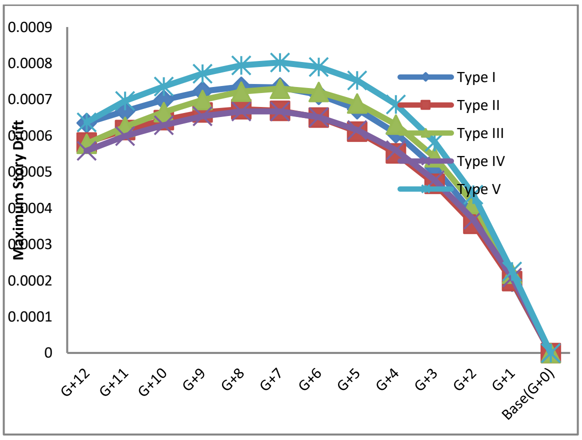

Figure 5 Maximum Storey Drift Along X- Direction in Shear Wall System (RSx) by RSM

Maximum storey drift due to earthquake force along X-direction in shear wall system of all types (locations) using ESM and RSM are presented in tabular and graphical form as shown in figure above. From both method of analysis type- II system (location) has better response in term of maximum storey drift than that in rest other types (locations). It is observed that all storey drift of the shear wall system of all locations by RSM is greater than that by ESM. All types have maximum storey drift value at G+6 storey. Type- V, type- I, type- III, type- IV and type- II respectively have decreasing order of maximum storey drift values (shown in figure 4 and 5).

5.2 Parameters Discussed in Bracing System Using ESM and RSM

a. Maximum Storey Displacement

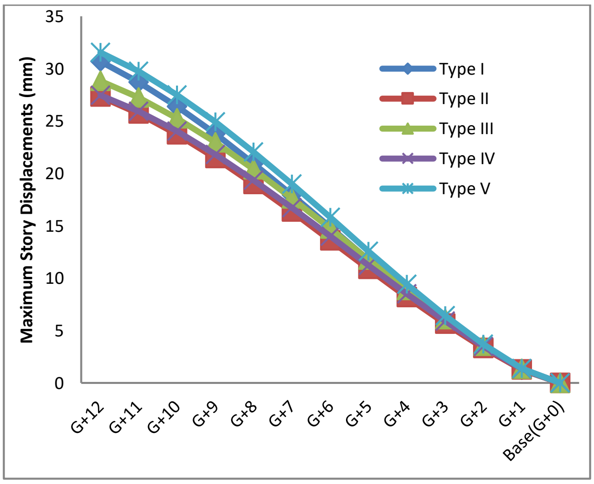

Figure 6 Maximum Storey Displacement Along X- Direction in bracing System (EQx by ESM

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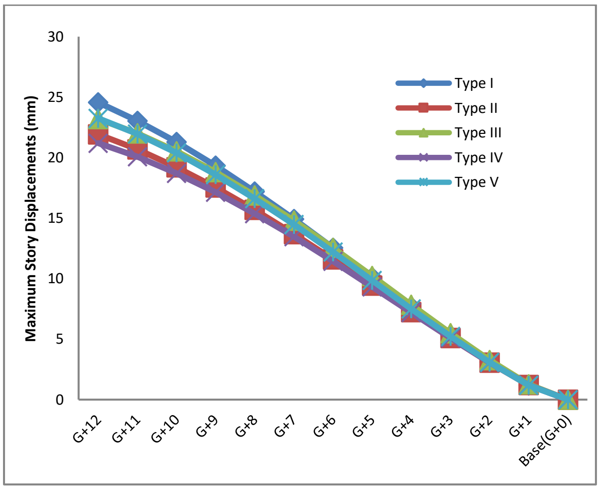

Figure 7 Maximum Storey Displacement Along X- Direction in bracing System (RSx) by RSM

Maximum storey displacement due to seismic force along X-direction for all types (location) of bracing system as per ESM and RSM are shown graphically above (figure 6 and 7). It is seen that Type- II location has lesser value of maximum storey displacement than that of others. The Type- II and Type- IV location has almost same values. The decreasing order of displacements are in type- V, type- I, type- III, type- IV and type- II position respectively. The top storey displacement by RSM is greater than that by ESM in all types except in type- I and type- II position of bracing.

b. Maximum Storey Drift

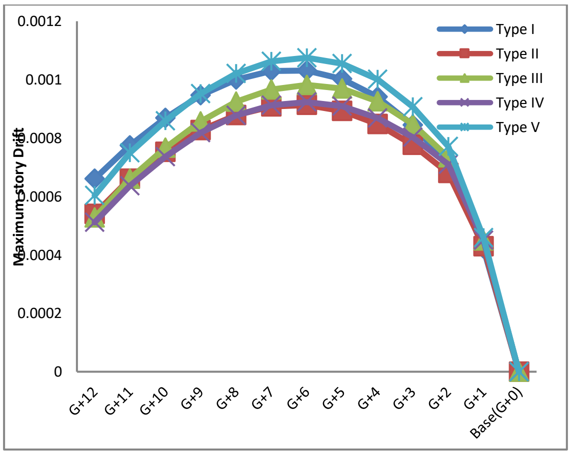

Figure 8 Maximum Storey Drift Along X- Direction in Bracing System (EQx) by ESM

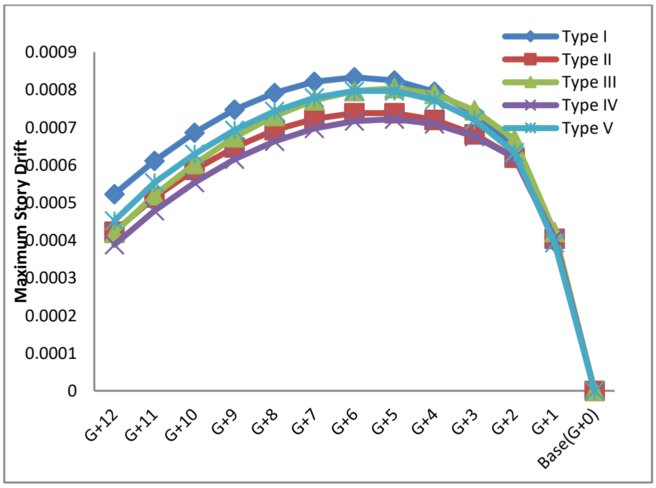

Figure 9 Maximum Storey Drift Along X- Direction in Bracing System (RSx) by RSM

Maximum storey drift due to earthquake force along X-direction in bracing system of all types (locations) using ESM and RSM are presented in and graphical form as shown in figure 8 and 9 above. From both method of analysis type- II system (location) has better response in term of maximum storey drift than that in rest other types (locations). It is observed that all storey drift of the bracing system of all locations by RSM is greater than that by ESM. All types have maximum storey drift value at G+6 storey. Type- V, type- I, type- III, type- IV and type- II respectively have decreasing order of maximum storey drift values except at G+11 and G+10 storey.

4.3 Parameters Discussed in Combined System Using ESM and RSM

a. Maximum Storey Displacement

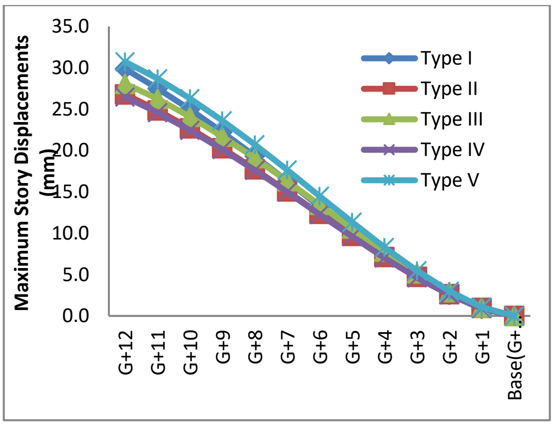

Figure 10 Maximum Storey Displacement Along X- Direction in Combined System (EQx by ESM

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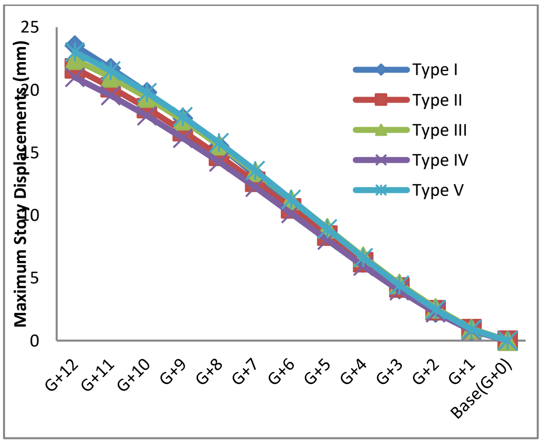

Figure 11 Maximum Storey Displacement Along X- Direction in Combined System (RSx by RSM

Due to the action of seismic force, maximum storey displacement along X- direction for all types (location) of combined system using ESM and RSM are shown (shown in figure 10 and 11) graphically above. It is seen that Type- II location has lesser value of maximum storey displacement than that of others. The Type- II and Type- IV location has almost same values. The decreasing order of displacements are in type- V, type- I, type- III, type- IV and type- II position respectively. The top storey displacement by RSM is greater than that by ESM in all types except in type- I and type- II position of combined system.

b. Maximum Storey Drift

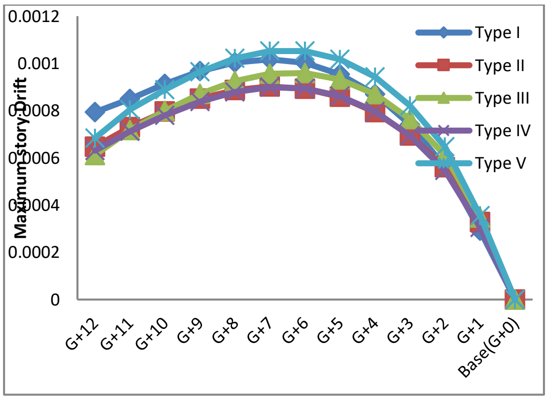

Figure 12 Maximum Storey Drift Along X- Direction in Combined System (EQx) by ESM

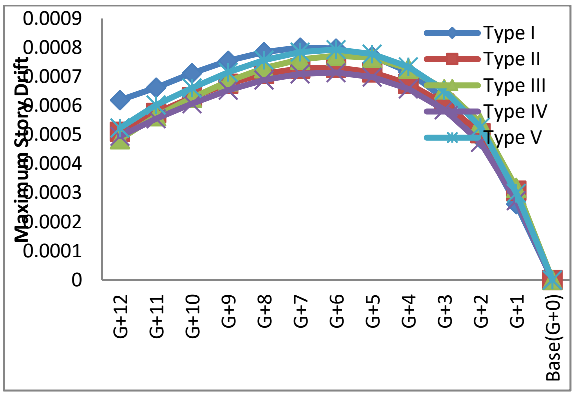

Figure 13 Maximum Storey Drift Along X- Direction in Combined System (RSx) by RSM

Maximum storey drift due to earthquake force along X-direction in combined system of all types (locations) using ESM and RSM are presented in graphical form as shown in figure 12 and 13 above. From both method of analysis type- II system (location) has better response in term of maximum storey drift than that in rest other types (locations). It is observed that all storey drift of the combined system of all locations by RSM is greater than that by ESM. All types have maximum storey drift value at G+6 and G+7 storey. Type- V, type- I, type- III, type- IV and type- II respectively have decreasing order of maximum storey drift values except at G+11 and G+10 storey.

4. 4 Parameters Discussed in Type- I of All Systems Using ESM and RSM

a. Maximum Storey Displacement

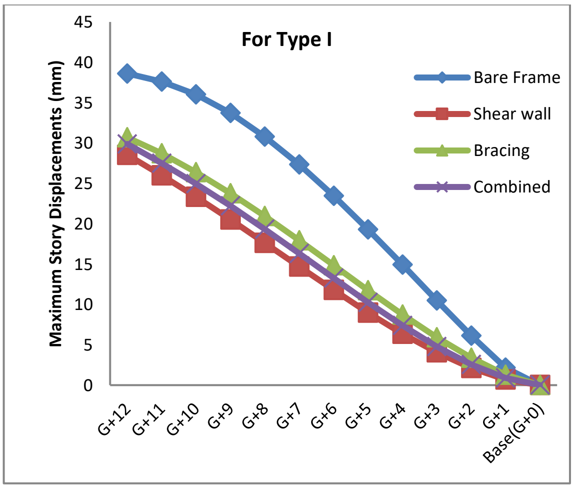

Figure 14 Maximum Storey Displacement Along X- Direction in Type- I System (EQx) by ESM

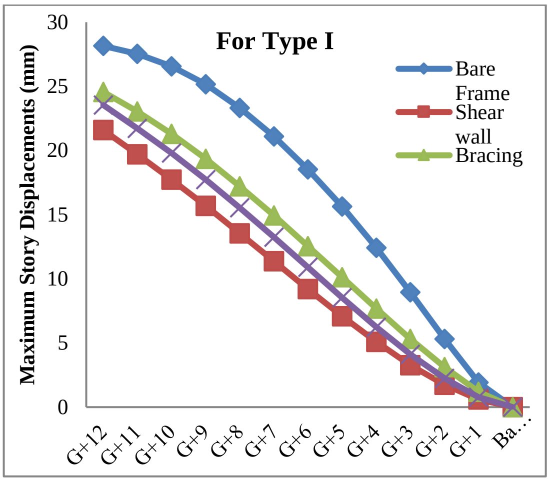

Figure 15 Maximum Storey Displacement Along X- Direction in Type- I System (RSx) by RSM

By ESM and RSM, values of maximum storey displacement due to seismic forces in X-direction for all Type-I four models of building that is bare frame, shear wall, bracing and combined (shear wall + bracing) system are plotted as shown in figure 14 and 15 above. By analyzing these values, it can be concluded that shear wall model has lesser values of displacement as compared to others. All the type I model has increasing order of value of displacement as: Bared frame > bracing > braced shear wall (combined) > shear wall system. The top storey displacement by RSM is greater than that by ESM in all systems.

b. Maximum Storey Drift

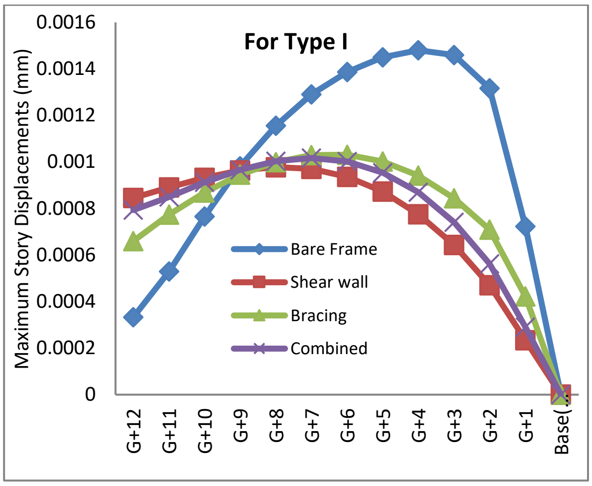

Figure 16 Maximum Storey Drift Along X- Direction in Type-I System (EQx ULS) by ESM

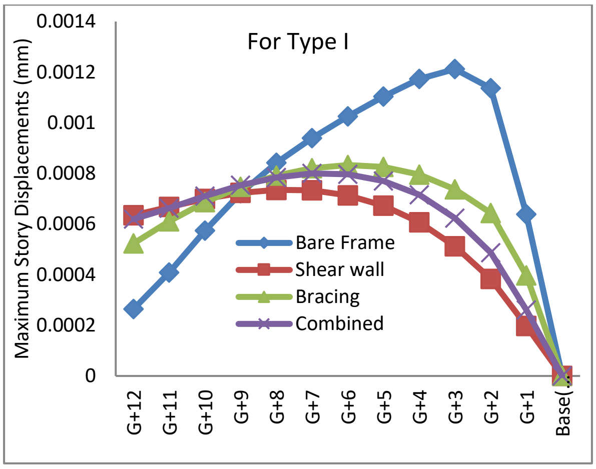

Figure 17 Maximum Storey Drift Along X- Direction in Type-I System (RSx) by RSM

Maximum storey drift due to earthquake force along X-direction in Type- I position of all system using ESM and RSM are presented in graphical form as shown in figure 16 and 17 above. From both method of analysis shear wall system has better response in term of maximum storey drift than rest others. Bare frame system has rapid variation in storey wise drift values. It is observed that all storey drift of all the system by RSM is greater than that by ESM. Bare frame system has maximum storey drift at G+3 storey and that at G+7 storey for rest other systems. Bare frame, bracing, combined and shear wall system respectively have decreasing order of maximum storey drift values.

c. Storey Shear

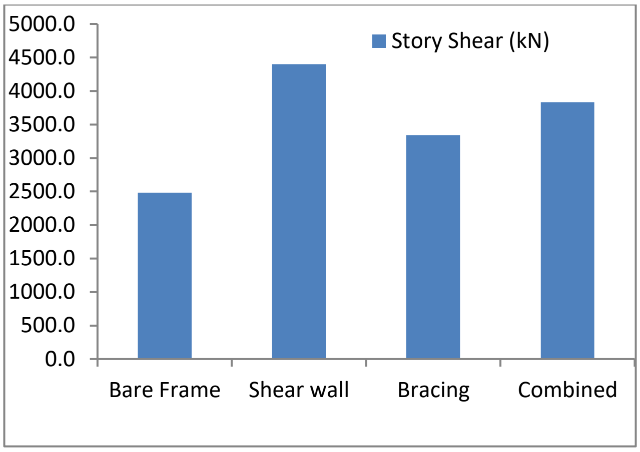

Figure 18 Storey Shear Along X- Direction in Type- I System (EQx) by ESM

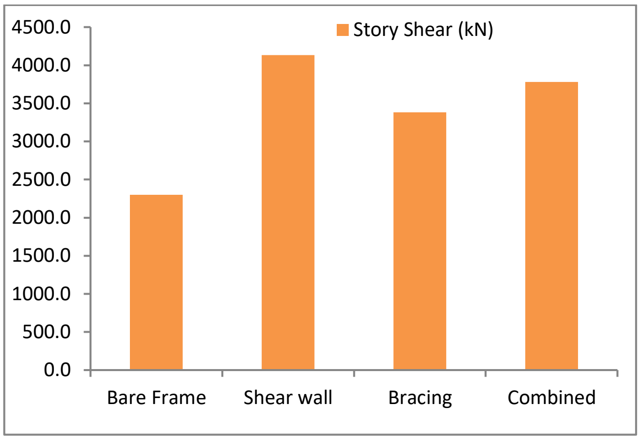

Figure 19 Storey Shear Along X- Direction in Type- I System (RSx) by RSM

By ESM and RSM, storey shear due to earthquake load (EQx) and (RSx) along X- direction in Type- I position of all the system are and shown in figure 18 and 19 graphically above. It is observed that at top storey, storey shear by RSM is greater than that by ESM but the base shear is equal from both methods. Base shear of shear wall system is greater than other systems. The decreasing order of base shear value is as from shear wall, combined, bracing and bare frame system. Also, it is concluded that if the storey height increases, storey shear decreases and vice versa.

4. 5 Parameters Discussed in Type- II of All system Using ESM and RSM

a. Maximum Storey Displacement

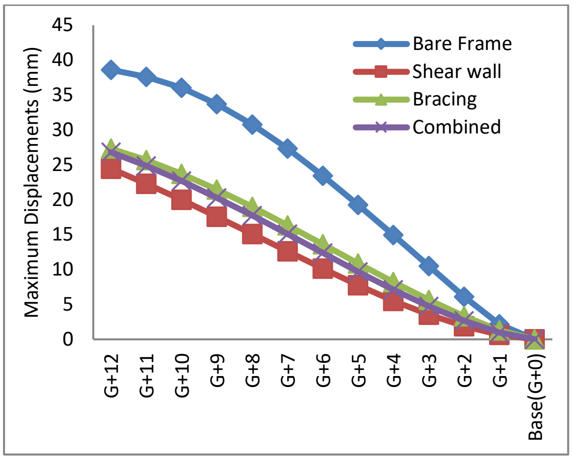

Figure 20 Maximum Storey Displacement Along X- Direction in Type- II System (EQx by ESM

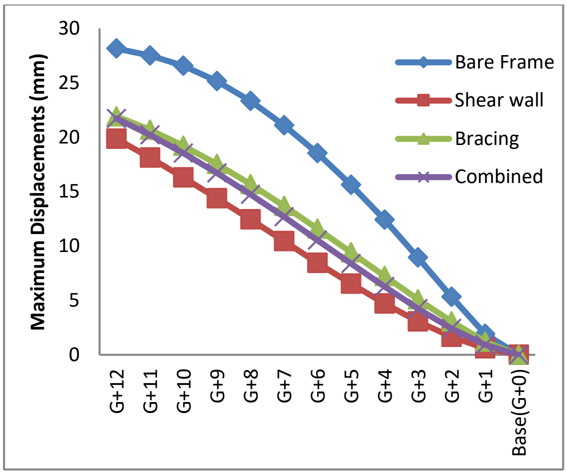

Figure 21 Maximum Storey Displacement Along X- Direction in Type- II System (RSx) by RSM

Maximum storey displacement due to seismic force along X-direction for all lateral load resisting system in Type- II position as per ESM and RSM are shown graphically above (shown in figure 20 and 21). It is seen that shear wall system is better than other system. The decreasing order of response are shear wall, combined, bracing and bare frame system. The top storey displacement by ESM is greater than that by RSM in all system except in shear wall system.

b. Maximum Storey Drift

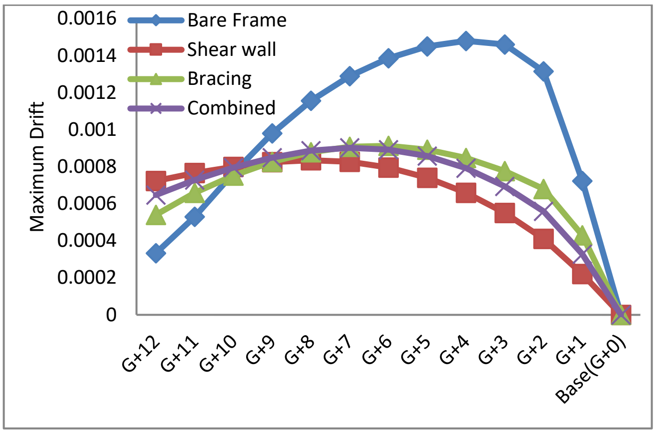

Figure 22 Maximum Storey Drift Along X- Direction in Type- II System (EQx) by ESM

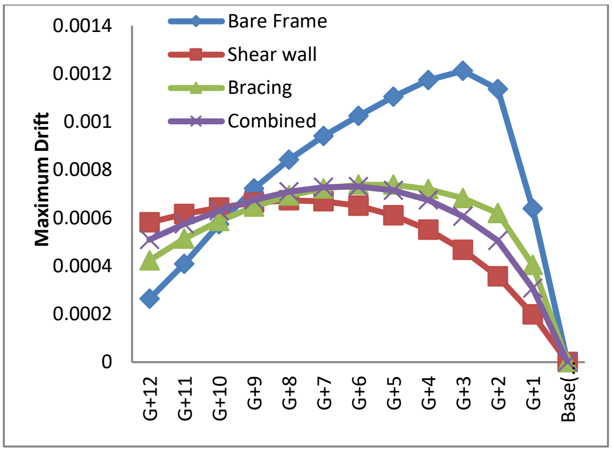

Figure 23 Maximum Storey Drift Along X- Direction in Type- II System (RSx) by RSM

Using ESM and RSM, maximum storey drift due to earthquake force along X- direction in Type- II position of all system are presented in graphical form as shown in above figure 22 and 23. From both method of analysis shear wall system has better response in term of maximum storey drift than rest others. Bare frame system has rapid variation in storey wise drift values. It is observed that all storey drift of all the system by RSM is greater than that by ESM. Bare frame system has maximum storey drift at G+3 storey and that at G+7 storey for rest other systems.

c. Storey Shear

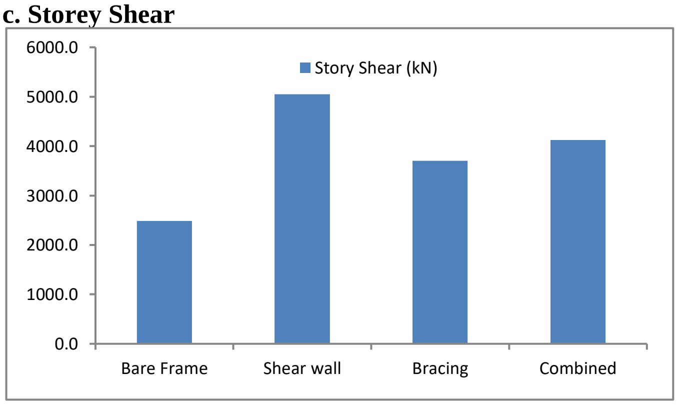

Figure 24 Storey Shear Along X- Direction in Type- II System (EQx) by ESM

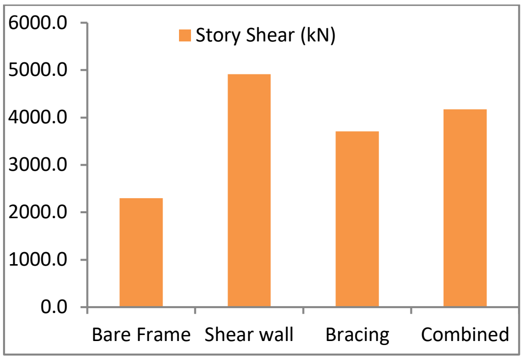

Figure 25 Storey Shear Along X- Direction in Type- II System (RSx) by RSM

By using ESM and RSM, storey shear due to earthquake load (EQx) and (RSx) along X- direction in type- II position of all the system are shown graphically above figure 24 and 25. It is observed that at top storey, storey shear by RSM is greater than that by ESM but the base shear is equal from both methods. Base shear of shear wall system is greater than other systems. The decreasing order of base shear value is as from shear wall, combined, bracing and bare frame system. Also, it is concluded that if the storey height increases, storey shear decreases and vice versa.

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

a. Maximum Storey Displacement

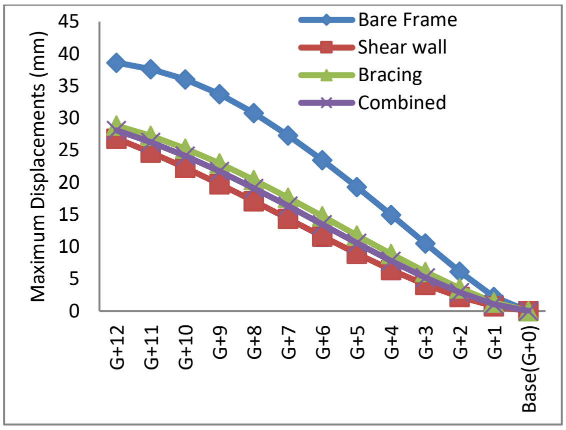

Figure 26 Maximum Storey Displacement Along X- Direction in Type- III System (EQx by ESM

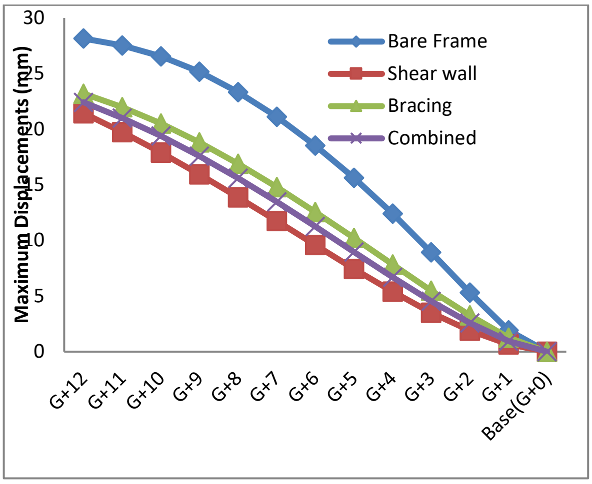

Figure 27. Maximum Storey Displacement Along X- Direction in Type- III System (RSx) by RSM

Maximum storey displacement along X- direction for all lateral load resisting system in Type- III position as per ESM and RSM are tabulated and shown graphically above figure 26 and 27. It is seen that shear wall system is better than other system. The decreasing order of response are shear wall, combined, bracing and bare frame system. The top storey displacement by RSM is greater than that by ESM in all system except bare frame.

b. Maximum Storey Drift

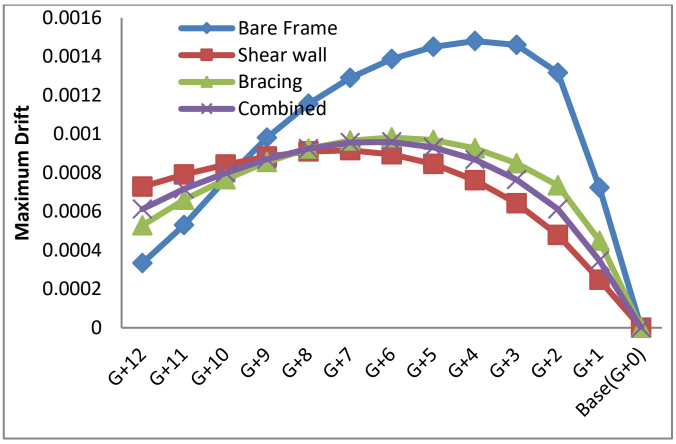

Figure 28 Maximum Storey Drift Along X- Direction in Type- III System (EQx ULS) by ESM

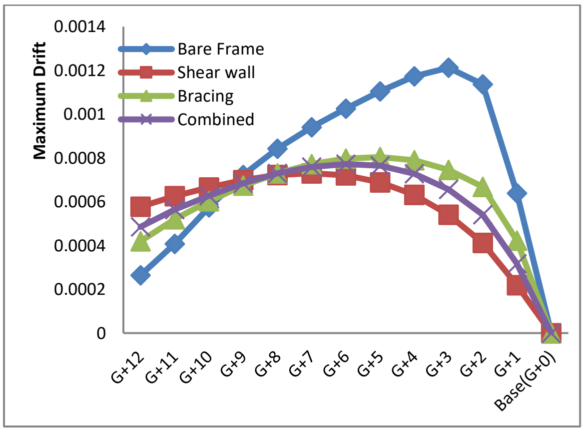

Figure 29 Maximum Storey Drift Along X- Direction in Type- III System (RSx) by RSM

Using ESM and RSM, maximum storey drift due to earthquake force along X- direction in Type- III position of all system are presented in graphical 28 and 29 form as shown in above. From both method of analysis shear wall system has better response than rest others. Bare frame system has rapid variation in storey wise drift values. It is observed that all storey drift of all the system by RSM is greater than that by ESM. Bare frame system has maximum storey drift at G+3 storey and that at G+6 storey for rest other systems.

c. Storey Shear

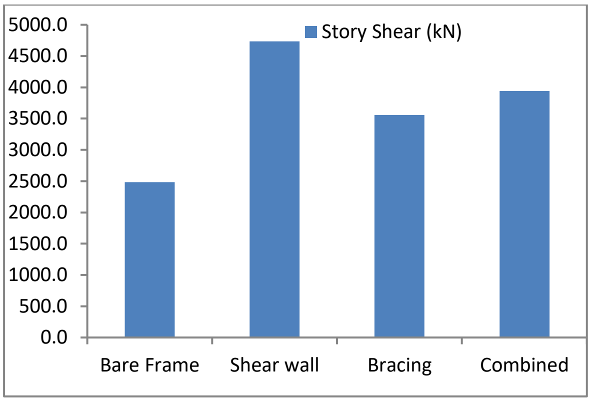

Figure 30. Storey Shear Along X- Direction in Type- III System (EQx) by ESM

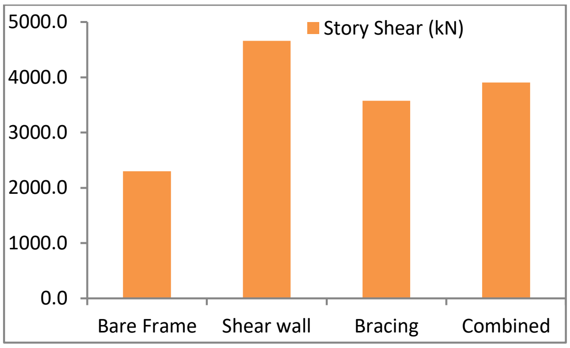

Figure 31 Storey Shear Along X- Direction in Type- III System (RSx) by RSM

Storey Shear due to earthquake load (EQx) and (RSx) along X- direction in type- III position of all the system by using ESM and RSM are shown in figure 30 and 31 graphically above. It is observed that at top storey, storey shear by RSM is greater than that by ESM but the base shear is equal from both methods. Base shear of shear wall system is greater than other systems. The decreasing order of base shear value is as from shear wall, combined, bracing and bare frame system. Also, it is concluded that if the storey height increases, storey shear decreases and vice versa.

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

a. Maximum Storey Displacement

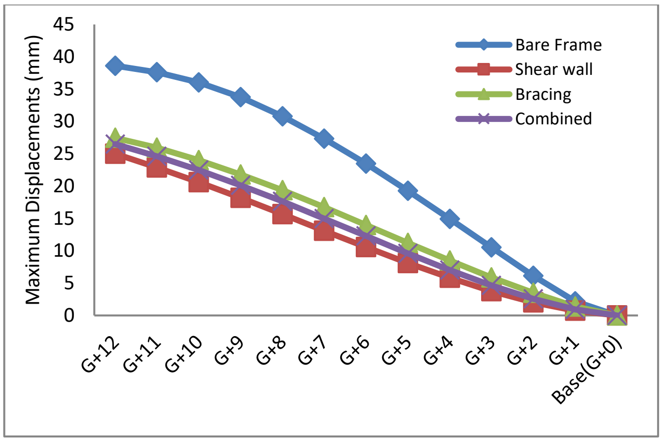

Figure 32 Maximum Storey Displacement Along X- Direction in Type- IV System (EQx) by ESM

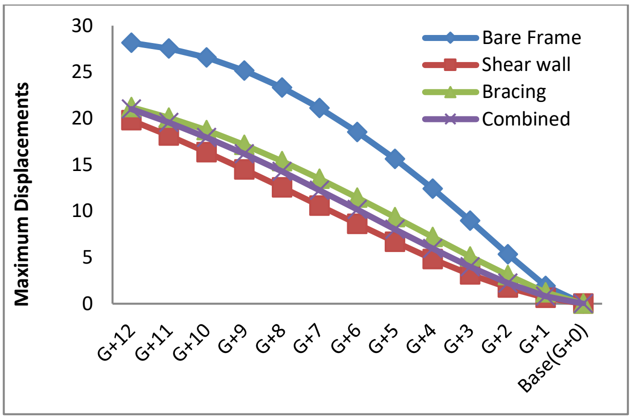

Figure 33 Maximum Storey Displacement Along X- Direction in Type- IV System (RSx) by RSM

Maximum storey displacement by the action of seismic forces (EQx and RSx) along X- direction for all lateral load resisting system in Type- IV position as per ESM and RSM are shown graphically above (figure 32 and 33). It is seen that shear wall system has better response (least maximum storey displacement) than that of other systems. The decreasing order of storey displacement values are shear wall, combined, bracing and bare frame system respectively. The top storey displacement by RSM is greater than that by ESM in all system except in bare frame.

b. Maximum Storey Drift

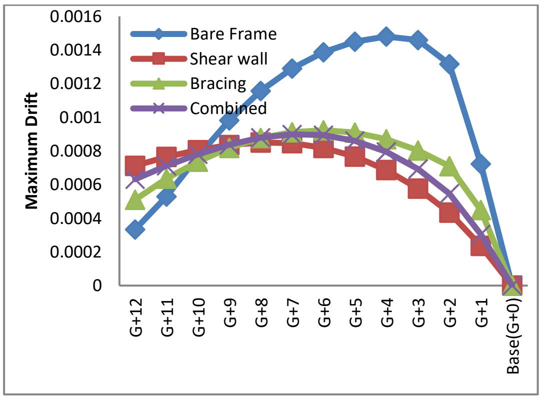

Figure 1 Maximum Storey Drift Along X- Direction in Type-IV System (EQx) by ESM

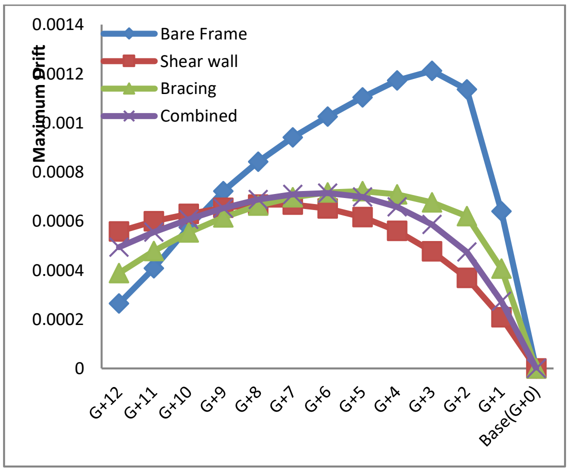

Figure 35 Maximum Storey Drift Along X- Direction in Type-IV System (RSx) by RSM

Using ESM and RSM, maximum storey drift due to earthquake force along X- direction in Type- IV position of all systems are presented in tabular and graphical form as shown in figure 34 and 35 above. From both method of analysis shear wall system has better response in term of maximum storey drift i.e. lesser values of storey drift than that of rest others. Bare frame system has rapid variation in storey wise drift values where as in other three systems there is smooth and continuous variation in same pattern. It is observed that all storey drift of all the system by RSM is greater than that by ESM. Bare frame system has maximum storey drift at G+3 storey and that at G+6 storey for rest other systems.

c. Storey Shear

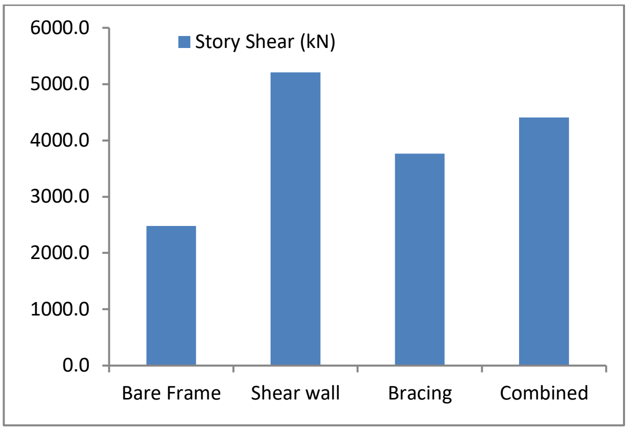

Figure 36 Storey Shear Along X- Direction in Type- IV System (EQx) by ESM

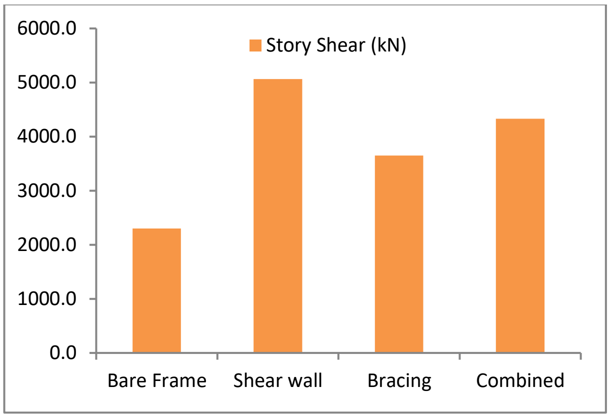

Figure 37 Storey Shear Along X- Direction in Type- IV System (RSx) by RSM

Storey shear due to earthquake load (EQx) and (RSx) along X- direction in Type- IV position of all the system by using ESM and RSM are shown figure 36 and 37 graphically above. It is observed that at top storey, storey shear by RSM is greater than that by ESM but the base shear is equal from both methods. Base shear of shear wall system is greater than other systems. The decreasing order of base shear value is in shear wall, combined, bracing and bare frame system respectively. Also, it is concluded that if the storey height increases, storey shear decreases and vice versa.

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

a. Maximum Storey Displacement

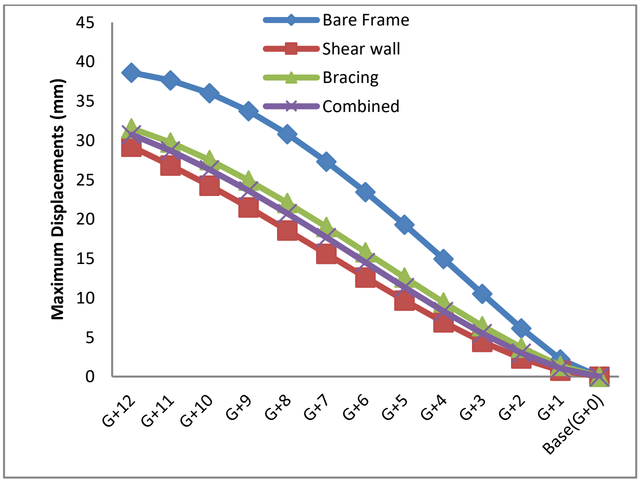

Figure 38 Maximum Storey Displacement Along X- Direction in Type- V System (EQx by ESM

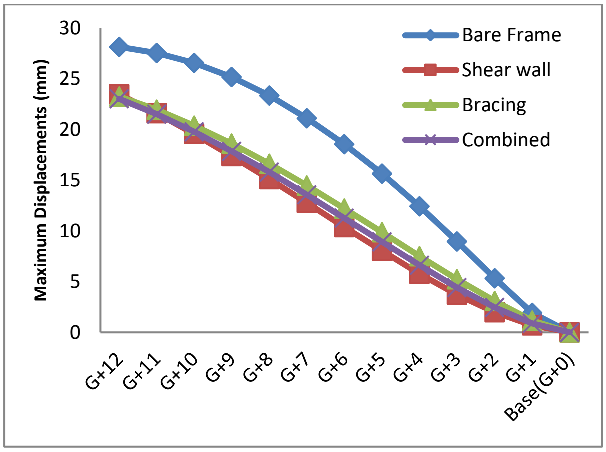

Figure 2 Maximum Storey Displacement Along X- Direction in Type- V System (RSx) by RSM

Maximum storey displacement by the action of seismic forces (EQx and RSx) along X- direction for all lateral load resisting system in Type- V position as per ESM and RSM are tabulated and shown figure 38 and 39 graphically above. In ESM, shear wall system has better response (least maximum storey displacement) than that of other systems. In RSM, except at top storey all the stories of shear wall system has lesser value of maximum storey displacement than that of other systems. The top storey displacement by RSM is greater than that by ESM in all system except in bare frame. It can be concluded that, in overall, the decreasing order of storey displacement values are shear wall, combined, bracing and bare frame system respectively.

b. Maximum Storey Drift

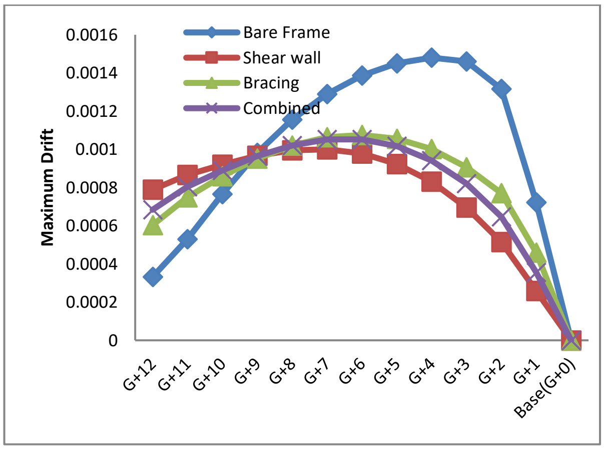

Figure 40 Maximum Storey Drift Along X- Direction in Type- V System (EQx) by ESM

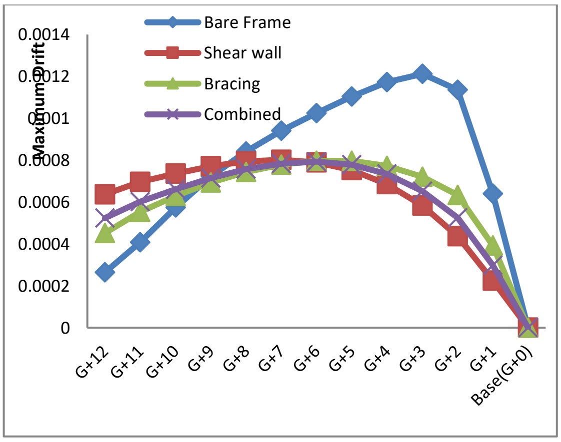

Figure 41 Maximum Storey Drift Along X- Direction in Type- V System (RSx) by RSM

Using ESM and RSM, maximum storey drift due to earthquake force along X- direction in Type- V position of all systems are presented in graphical form as shown in figure 40 and 41 above. From both method of analysis shear wall system has better response in term of maximum storey drift i.e. lesser values of storey drift than that of rest others. Bare frame system has rapid variation in storey wise drift values where as in other three systems there is smooth and continuous variation in same pattern. It is observed that all storey drift of all the system by RSM is greater than that by ESM. Bare frame system has maximum storey drift at G+3 storey and that at G+6 storey for rest other systems.

c. Storey Shear

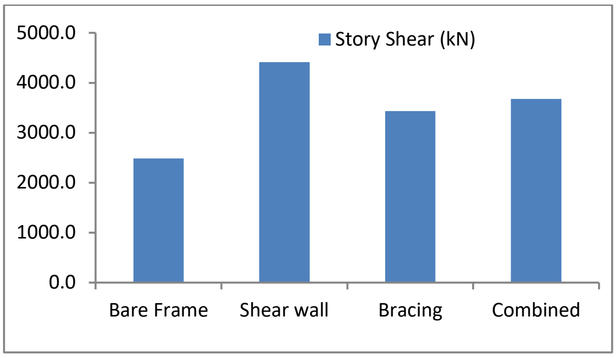

Figure 42 Storey Shear Along X- Direction in Type- V System (EQx) by ESM

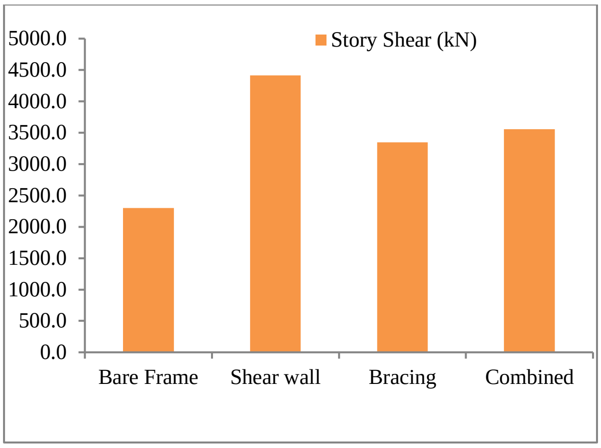

Figure 43 Storey Shear Along X- Direction in Type- V System (RSx) by RSM

Storey shear due to earthquake load (EQx ULS) and (RSx ULS) along X- direction in Type- V position of all the system by using ESM and RSM are shown figure 42 and 43 graphically above. It is observed that at top storey, storey shear by RSM is greater than that by ESM but the base shear is equal from both methods. Base shear of shear wall system is greater than other systems. The decreasing order of base shear value is in shear wall, combined, bracing and bare frame system respectively. Also, it is concluded that if the storey height increases, storey shear decreases and vice versa.

6. 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:

i. 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.

ii. In each position (type- I, type- II, type- III, type- IV and type- V) of the building, the seismic performance of a building with a shear wall system is superior to the other two systems. The performance improvement rates are as follows: shear wall system > combined system > bracing system > bare frame system.

iii. 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.

iv. 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.

v. 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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