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SEISMIC PERFORMANCE OF REINFORCED CONCRETE BUILDINGS WITH DIFFERENT LATERAL LOAD RESISTING SYSTEMS

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ABSTRACT

The objective of this research 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 11 floors (G+11) 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. Earthquake load is calculated as per NBC 105:2020, the various parameters like response reduction factor, ductility factor, over strength factors, building importance factor, zone factor are taken and are applied to a building located in Birendranagar, Surkhet. The ETABS-2018 software was used to create models of the buildings.

The performance of building is evaluated on the basis of following parameters- maximum storey displacement, maximum storey drift, storey shear, storey stiffness, overturning moment and diaphragm maximum to average drift ratio (for torsion). 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.

KEYWORDS: *Equivalent Static Analysis, Response Spectrum Analysis, Maximum storey displacement, Maximum storey drift, Storey shear, Storey stiffness, Overturning moment, Torsion.*

INTRODUCTION

A. Background

Nepal, situated in one of the most seismically active regions of the world, has a lengthy record of earthquakes. The initial recorded earthquake in Nepal occurred on June 7, 1255, while Abahya Malla was the reigning king of the Malla Dynasty in Nepal. This earthquake, which registered 7.8 on the Richter scale, claimed the life of the king and 2200 individuals, about one-third of Kathmandu's population at the time. Throughout history, Nepal has experienced a significant earthquake at least once every century[1]. Nowadays most of the buildings are constructed with increased stories and height (multistoried). In other hand, Nepal lies in highly vulnerable earthquakes zones where next major earthquake becomes nearer by each passing days. After Gorkha earthquake people are more concern on earthquake resistance buildings. They are in search of efficient structural system. 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 imperative 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. The following are various lateral load resisting systems that can be employed in high-rise constructions: Shear wall system, Braced system, Outrigger system, Rigid frame system, Frame tube system, Bundle tube system, Trussed tube system, Diagrid system etc [2].

The Bracing system is capable of withstanding lateral forces predominantly through the compression or tension of its brace members, which renders the system highly effective in countering the lateral loads. In addition, the braced frame system's efficiency can be attributed to its ability to provide lateral stiffness to the structure. With least addition of the material to the frame and it forms economical structure for any heights [3].

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

There are various methods available for the evaluation of seismic performance of any structures. According to NBC 105: 2020 they are categories as [4]:s

1) Equivalent Static Method/Analysis (ESA)
2) Linear Dynamic Analysis Method
    I. Modal Response Spectrum Method (RSM)
    II. Elastic Time History Analysis (ETHA)
3) Non-linear Methods
    I. Non-linear Static Analysis

II. Non-linear Time History Analysis

For this study, ESM and RSM methods are adopted due to its simplicity and being the modeled structure regular.

B. 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 efficiency of the 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.

A. Objectives

The main aim of this study is:

1) To investigate the seismic performance of RC buildings with different lateral load resisting system.

Other generalized objectives are as followings:

1) To compare the results of analysis using Equivalent static Method & Response Spectrum Method.

2) To compare the performance of structure for different lateral load resisting system with respect to different parameters: Storey displacement, Storey drift, Base shear, Stiffness, Storey overturning moment and Torsion in different position of building.

3) To find out the efficient system and its position in RC building.

LITERATURE REVIEW

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.

Model considered for analysis:

Model – 1: Bare frame

Model – 2: Shear wall along periphery

Model – 3: Shear wall at core and periphery

Model – 4: Shear wall at core

By comparing the storey drift values, it is apparent that the most significant reduction in drift values is achieved when the shear walls are placed at the center (core) of the structure. Specifically, the results indicate that incorporating a shear wall in the center (Model-4) leads to a maximum decrease in displacement and drift, with a reduction of up to 62% in comparison to a bare frame. 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), In their review article, various lateral load resisting systems are compared based on 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 in accordance with IS 875 (Part-3)-1987 using ETABS-2015 software. The study's primary objective is to determine the most efficient and cost-effective system. Based on the literature review, steel bracings can be employed as a lateral load resisting system for multistory buildings with 10 to 20 stories, while Shear walls can be used for buildings with 20 to 35 stories. However, Shear walls are heavier in structure than steel bracings, which may be uneconomical for buildings with 10 to 15 stories. The Diagrid system is the most efficient and cost-effective for high-rise buildings with more than 35 stories, providing flexibility in building space planning and elevation. Therefore, the Diagrid system is the most suitable lateral load resisting system for high-rise buildings under seismic load and wind load.[6].

Dharanya A, Gayathri S and Deepika M (2017) analyzed a residential RC building with a soft storey that had four stories above ground level. They compared the performance of the building with cross bracing and shear wall lateral load resisting systems as per the IS 1893:2002 codal provision using ETABS software. The X-bracing was placed at the outer periphery of the column, while the shear walls were located at the building corners. The equivalent stiffness method was used to analyze the building models with ETABS software. The lateral displacement, base shear, storey drift, axial force, shear force, and time period were the main parameters analyzed. The natural time period of the structure was significantly reduced after placing the shear wall compared to the bracing system, which improved the structure's stability against earthquakes and made it more stable. The building had the least lateral displacement with the shear wall and bracing systems compared to the bare frame. Based on the analysis, it was concluded that the shear wall was more effective in improving the lateral stability of the structure than the bracing system. Future scope of this work is that it can be analyzed by using different locations of shear wall. 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), using of staad.pro v8i software 5 storey, 10 storey and 20 storey building frame with each storey in two zones (zone3 and zone5) were taken. This paper analyzed the cost and deflection of a reinforced concrete (RCC) framed structure with shear walls and bracing at different locations, in comparison to an ordinary building and results were presented using Staad pro v8i Software. 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 & the deflection and bending moment are significantly lower in the case of a shear wall compared to a RC-frame and bracing, making a shear wall structure more appropriate structurally [8].

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].

RESEARCH DESIGN

A. Details of Model

For this study, a G+11 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. The square plan of all buildings measures 20 m x 20 m. Building with shear wall, bracing and combined system are modeled with four different positions named as Type- I, Type- II, Type- III, Type- IV and Type- V.

B. Modeling 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 (rebars) 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 (rebars) 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 NBC 105:2020 load combinations for linear static and response spectrum method with soil type B and seismic zone region in Birendranagar, Surkhet.

B. Properties of Members

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 (rebars)	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
Type of Steel Bracing	X- Bracing (I section)	

D. Figure of Models

Bared Frame:

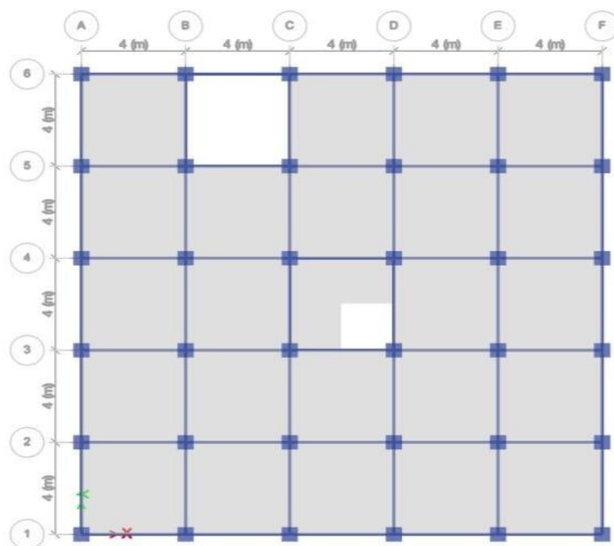


Figure 1 Plan of Bare Frame Model

Shear Wall System:

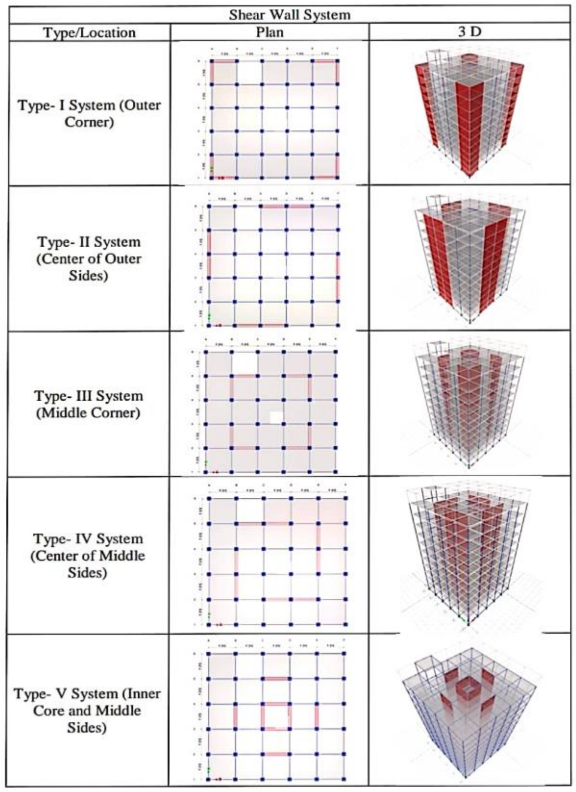


Figure 2 Different Locations of Shear Wall System

Bracing System:

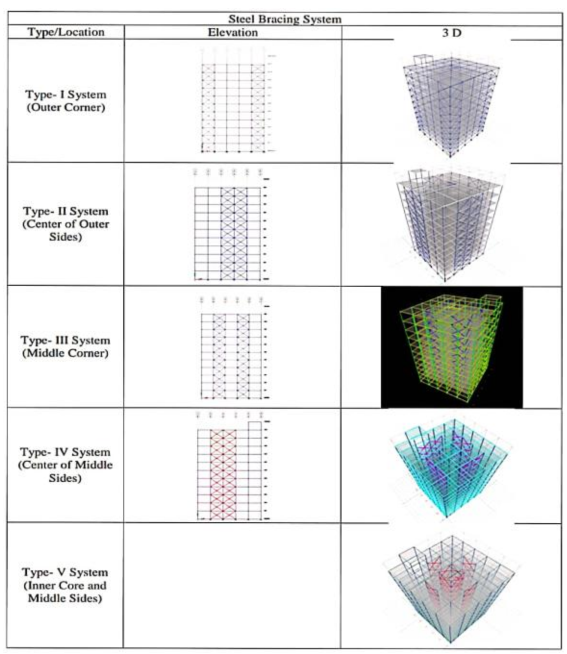


Figure 3 Different Locations of Bracing System

Combined (Shear Wall + Bracing) System:

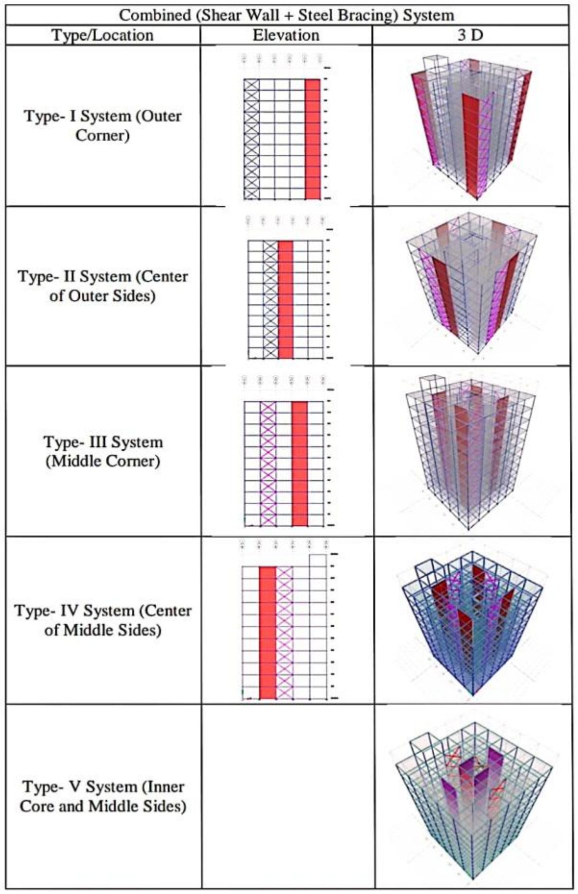


Figure 4 Different Locations of Combined System

METHODOLOGY

A. Modeling of the Building

To accomplish the above objectives of this thesis work, following procedure were adopted:

1. Regular Bare framed model for G +11 storeys is selected and each of four cases with different position of Shear Wall, Bracing and Combined System (Shear Wall + Bracing) are developed.
2. Preliminary sizing was done to fix the size of column, beam, shear wall and diagonal (X) steel braces of different models. The initial size of member's dimension was changed as per requirement.
3. Modeling and Analysis is done using ETABS 2018. The design check determines the size of frame members i.e. beam and column. Analysis is done by linear static analysis i.e. Equivalent Static Method and linear dynamic analysis i.e. Response Spectrum Method.
4. Seismic zone considered is Birendranagar, Surkhet with soil type B.
5. Parameters considered in this project are Storey displacement, Storey drift, Base shear, Stiffness, Storey overturning moment and Torsion (Maximum to Average drift ratio).

6. After analysis fundamental parameters were studied individually. Comparison between the different systems with different position with respect to different parameters are studied for all cases.
7. Based on the result obtained from analysis and design, the conclusion and recommendation are made.
8. Design as per NBC 105:2020 for earthquake, IS 456:2002 for RCC and IS 800:2007 for steel is done for respective cases.

G+11 Storey building with each floor height of 3m is selected in this research work because in our country Nepal, here has been a considerable increase in the construction of tall buildings both in case of residential and commercial too. The modern trend is towards more tall and slender structures. So, this G+11 storey building is a representative building for all tall buildings. If a result satisfies for the high rise structure, then it obviously satisfies for low rise structure.

There are two methods here we used for analyzing our research model: Equivalent Static Method (ESM) and Response Spectrum Method (RSM). The methodological flow chart is given as:

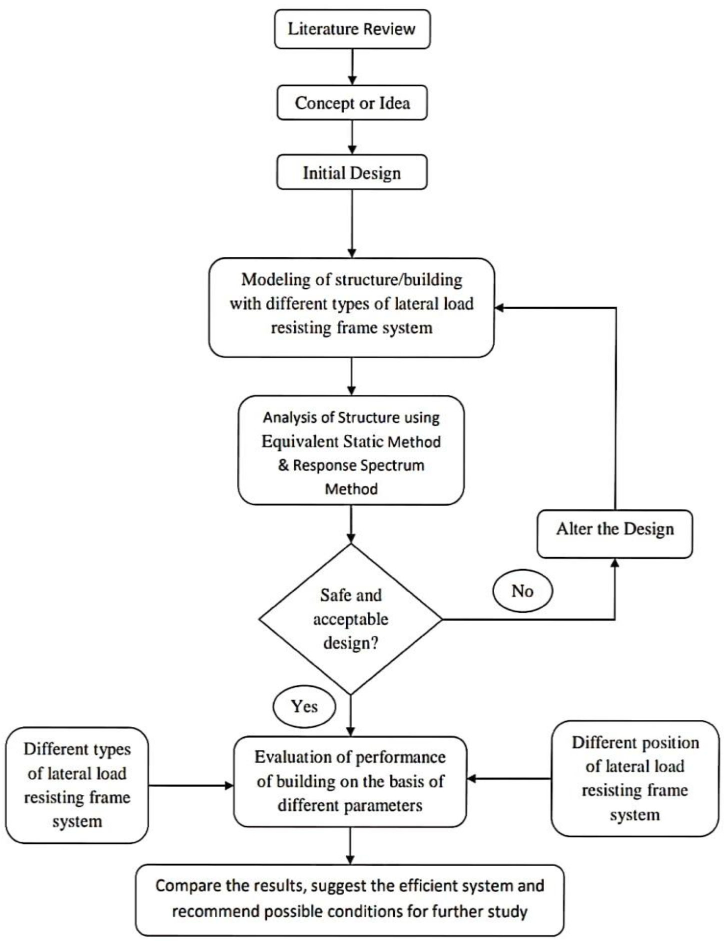


Figure 5 Methodological Framework

RESULTS AND DISCUSSION

A. Results

Parameters Discussed in Shear Wall System Using ESM and RSM:

a. Maximum Storey Displacement

TABLE 2 MAXIMUM STOREY DISPLACEMENT ALONG X- DIRECTION IN SHEAR WALL SYSTEM (ULS)

Maximum Storey Displacement Along X- Direction in Shear Wall System (ULS)											
Storey	Elevation (m)	Type I (mm)		Type II (mm)		Type III (mm)		Type IV (mm)		Type V (mm)	
		ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM	ESM	RSM
G+11	33	75.494	74.991	57.175	57.393	69.229	70.406	58.307	59.747	81.379	82.897
G+10	30	68.432	67.888	51.86	51.996	63.244	64.245	53.08	54.331	74.374	75.757
G+9	27	60.832	60.268	46.102	46.168	56.672	57.508	47.376	48.439	66.68	67.923
G+8	24	52.874	52.315	40.081	40.088	49.66	50.343	41.357	42.239	58.463	59.562
G+7	21	44.636	44.111	33.861	33.827	42.273	42.821	35.087	35.8	49.785	50.741
G+6	18	36.28	35.821	27.57	27.514	34.659	35.092	28.695	29.255	40.819	41.634
G+5	15	28.029	27.658	21.372	21.311	27.028	27.363	22.349	22.774	31.809	32.484
G+4	12	20.159	19.89	15.468	15.417	19.642	19.893	16.26	16.566	23.075	23.607
G+3	9	12.997	12.829	10.091	10.056	12.82	12.997	10.671	10.875	15.005	15.389
G+2	6	6.926	6.846	5.506	5.491	6.943	7.052	5.866	5.984	8.065	8.301
G+1	3	2.374	2.354	1.983	1.982	2.435	2.482	2.133	2.18	2.781	2.876
Base(G+0)	0	0	0	0	0	0	0	0	0	0	0

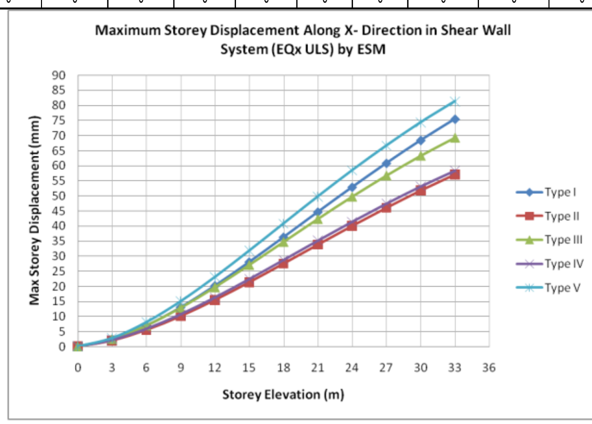


FIGURE 6 MAXIMUM STOREY DISPLACEMENT ALONG X- DIRECTION IN SHEAR WALL SYSTEM (EQX ULS) BY ESM

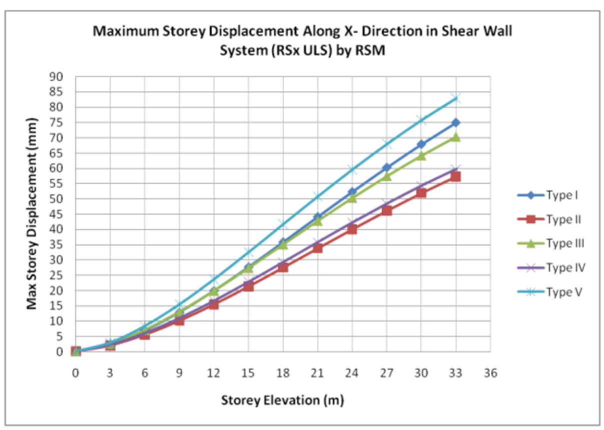


FIGURE 7 MAXIMUM STOREY DISPLACEMENT ALONG X- DIRECTION IN SHEAR WALL SYSTEM (RSX ULS) BY RSM

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 greater than that by ESM in all types except in type- I.

b. Maximum Storey Drift

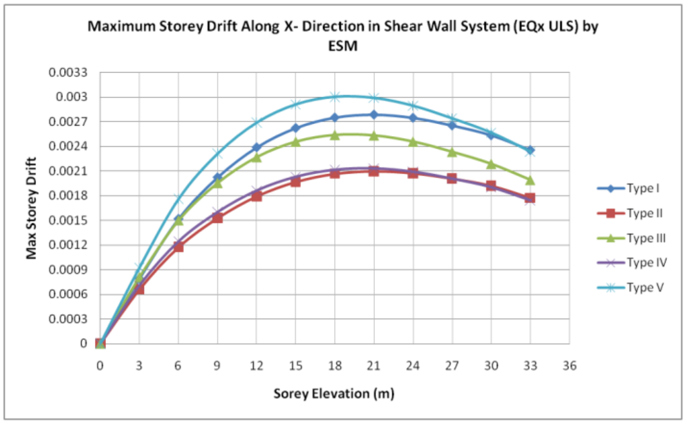


Figure 8 Maximum Storey Drift Along X- Direction in Shear Wall System (EQx ULS) by ESM

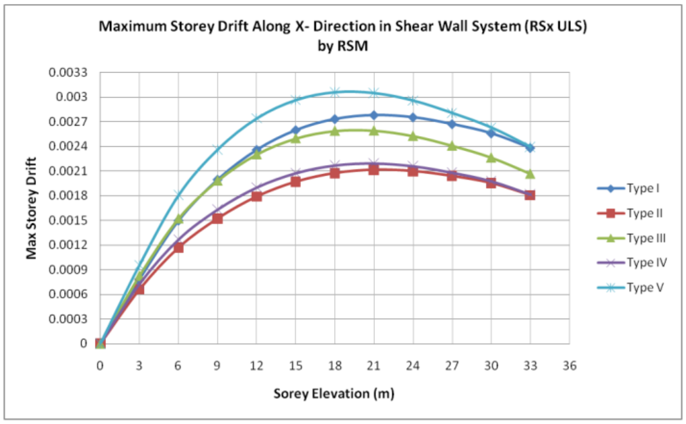


Figure 9 Maximum Storey Drift Along X- Direction in Shear Wall System (RSx ULS) by RSM

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 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.

c. Storey Stiffnes

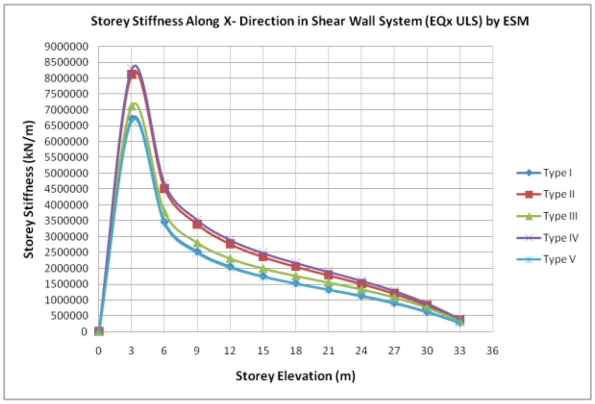


Figure 10 Storey Stiffness Along X- Direction in Shear Wall System (EQx ULS) by ESM

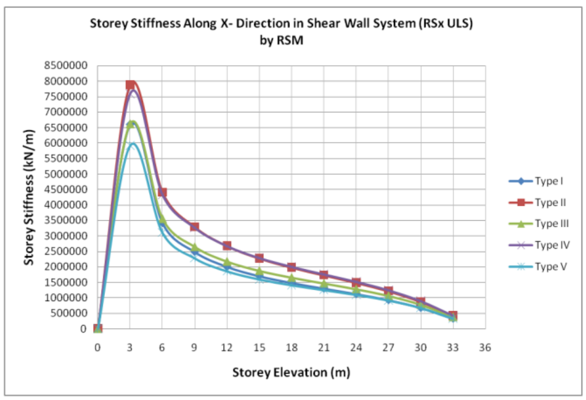


Figure 11 Storey Stiffness Along X- Direction in Shear Wall System (RSx ULS) by RSM

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 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.

d. Diaphragm Maximum to Average Drift Ratio

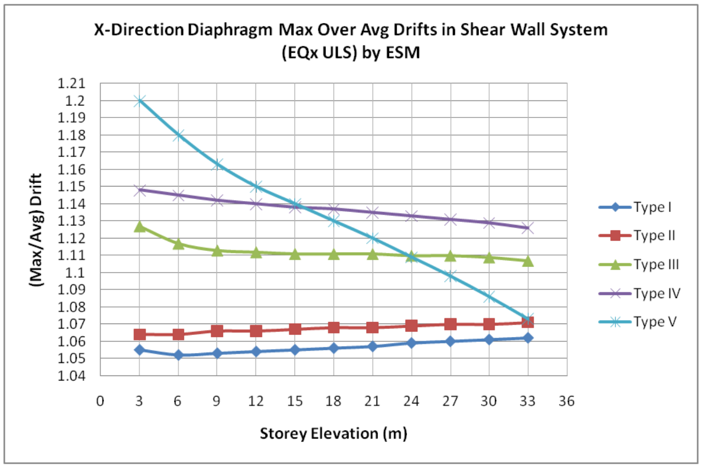


Figure 12 X- Direction Diaphragm Max to Avg Drift Ratio in Shear Wall System (EQx ULS) by ESM

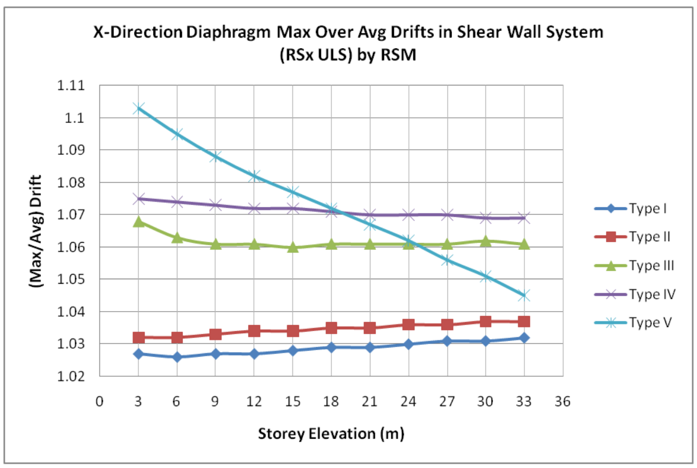


Figure 13 X- Direction Diaphragm Max to Avg Drift Ratio in Shear Wall System (RSx ULS) by RSM

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 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.

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

a. Maximum Storey Displacement

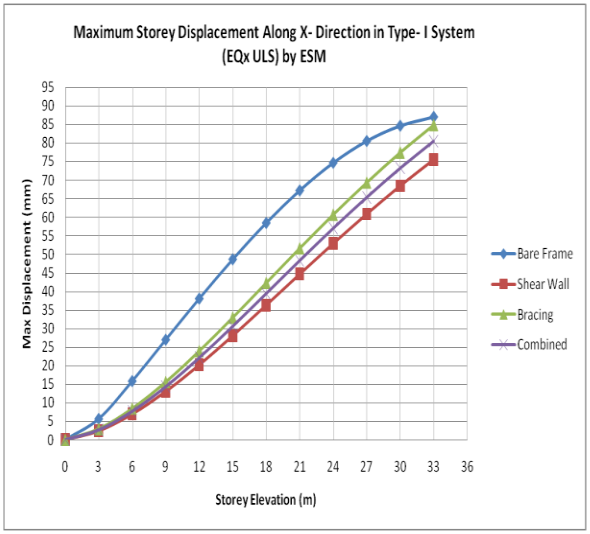


Figure 14 Maximum Storey Displacement Along X- Direction in Type- I System (EQx ULS) by ESM

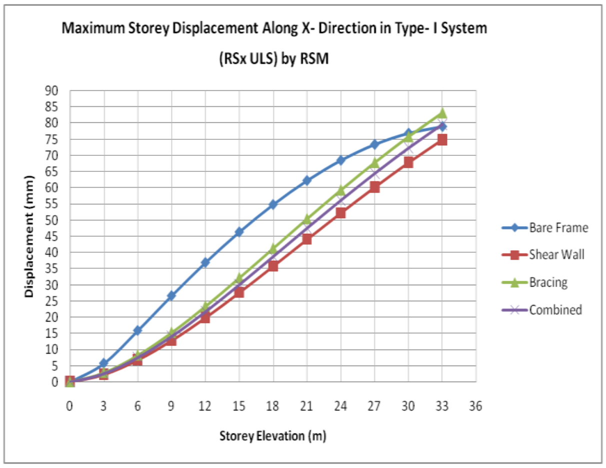


Figure 15 Maximum Storey Displacement Along X- Direction in Type- I System (RSx ULS) by RSM

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 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

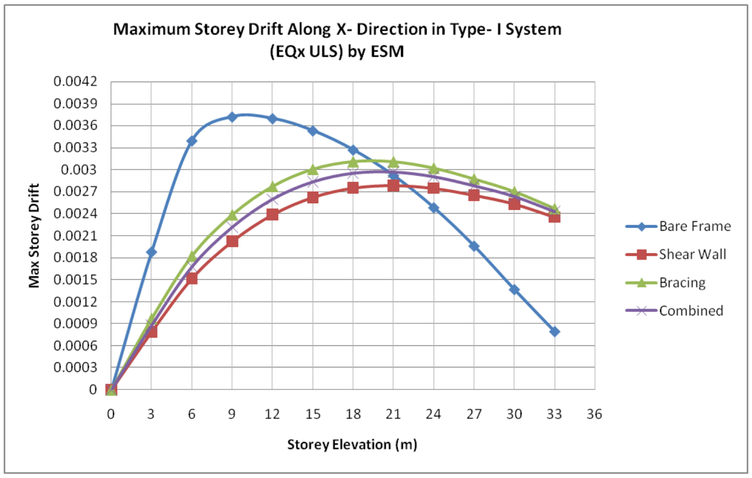


Figure 16 Maximum Storey Drift Along X- Direction in Type- I System (EQx ULS) by ESM

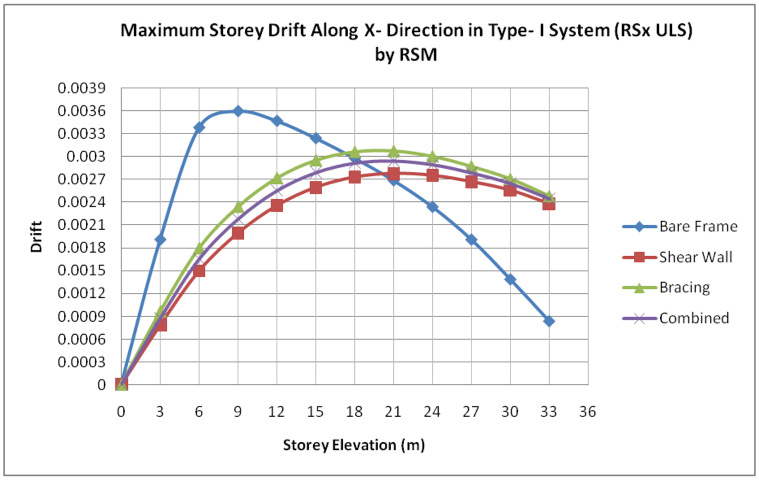


Figure 17 Maximum Storey Drift Along X- Direction in Type- I System (RSx ULS) by RSM

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 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

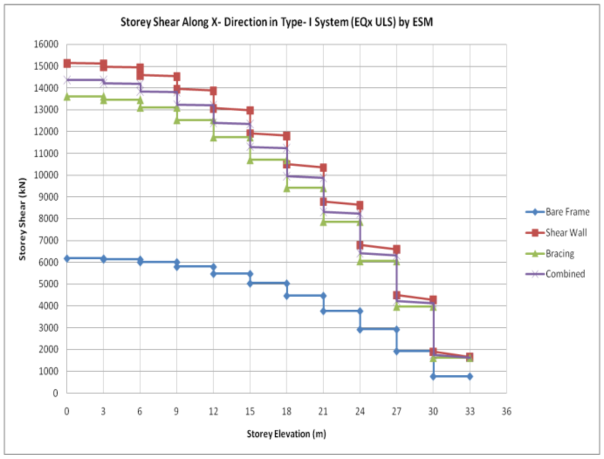


Figure 18 Storey Shear Along X- Direction in Type- I System (EQx ULS) by ESM

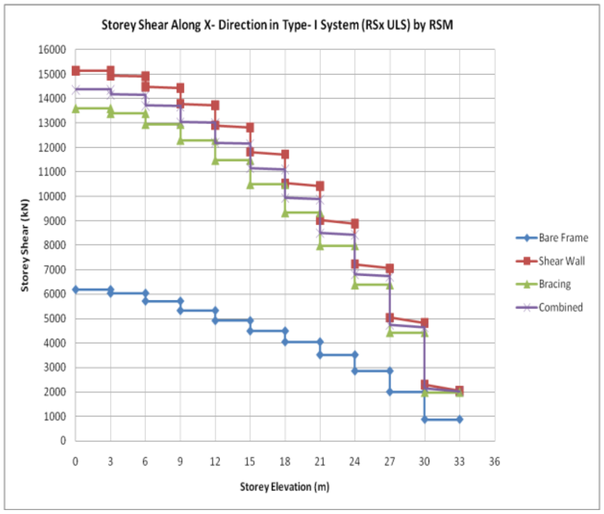


Figure 19 Storey Shear Along X- Direction in Type- I System (RSx ULS) by RSM

By ESM and RSM, storey shear due to earthquake load (EQx ULS) and (RSx ULS) along X-direction in Type- I position of all the system are shown 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.

d. Overturning Moment

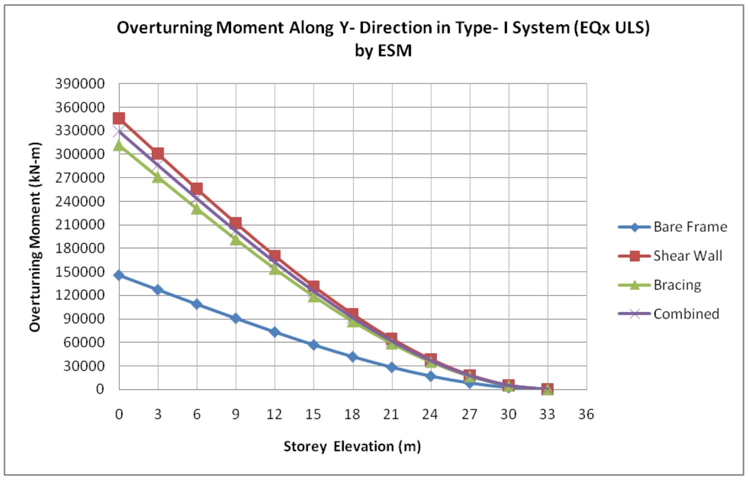


Figure 20 Overturning Moment Along Y- Direction in Type- I System (EQx ULS) by ESM

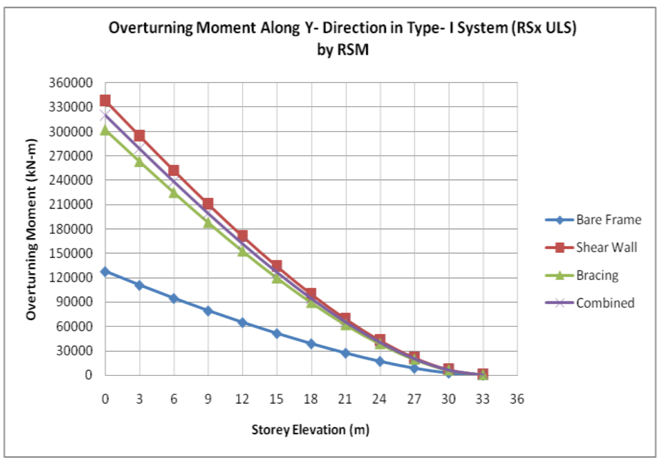


Figure 21 Overturning Moment Along Y- Direction in Type- I System (RSx ULS) by RSM

Absolute values of overturning moment in Y- direction using ESM and RSM by seismic forces (EQx ULS and RSx ULS) for all Type- I position systems (models) are plotted as shown in figure above. The maximum values of overturning moment at base (G+0) due to seismic force in X- direction are seen in ESM than that of RSM. In both methods the decreasing order of values of overturning moment are in the systems shear wall, combined, bracing and bare frame respectively. Also, it is concluded that if the storey height increases, overturning moment decreases and vice versa.

e. Storey Stiffness

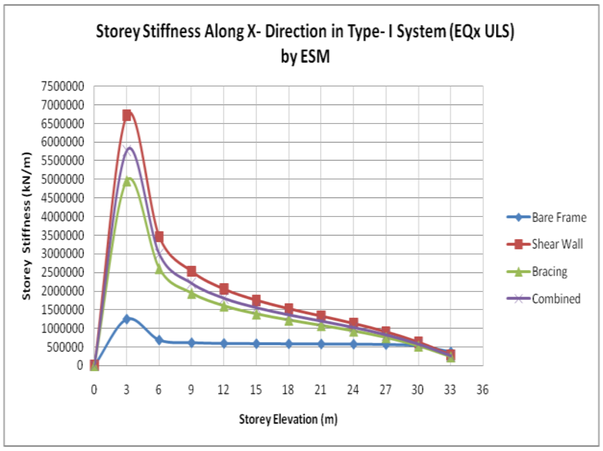


Figure 22 Storey Stiffness Along X- Direction in Type- I System (EQx ULS) by ESM

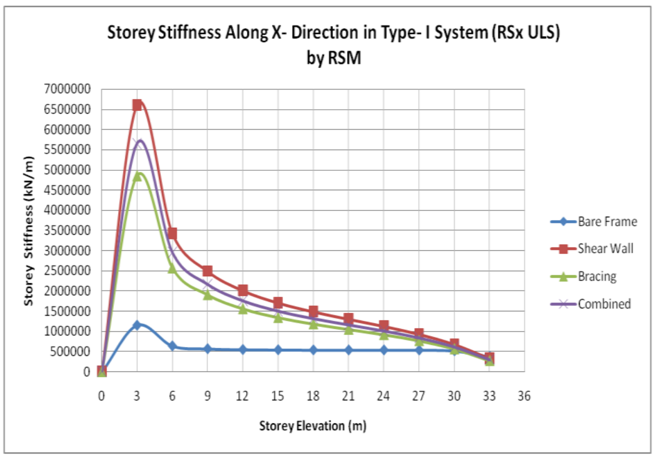


Figure 23 Storey Stiffness Along X- Direction in Type- I System (RSx ULS) by RSM

Storey stiffness by seismic forces along X-direction for all Type- I position systems (models) are plotted 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.

f. Diaphragm Maximum to Average Drift Ratio

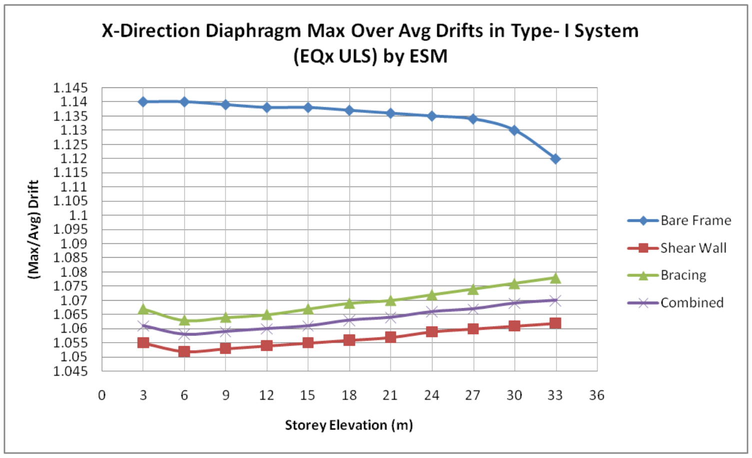


Figure 24 X- Direction Diaphragm Max to Avg Drift Ratio in Type- I System (EQx ULS) by ESM

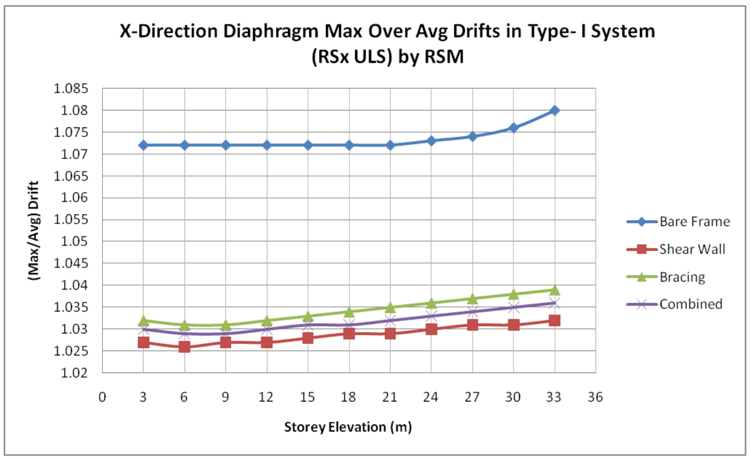
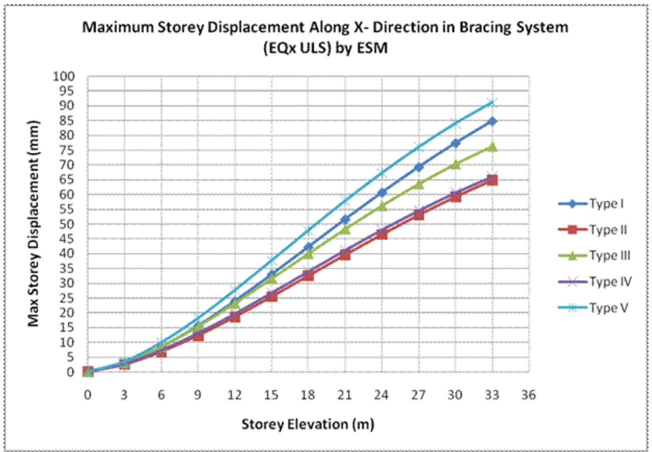
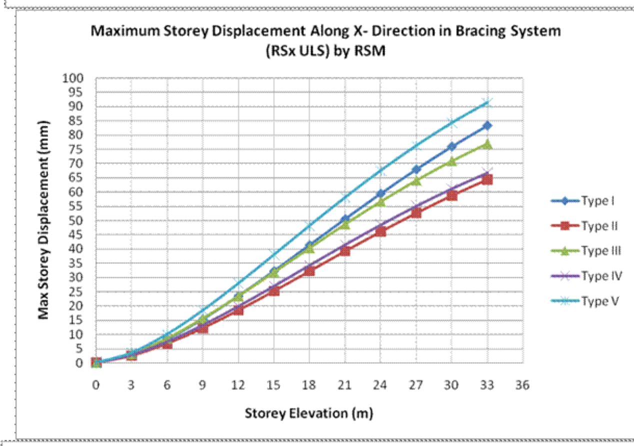


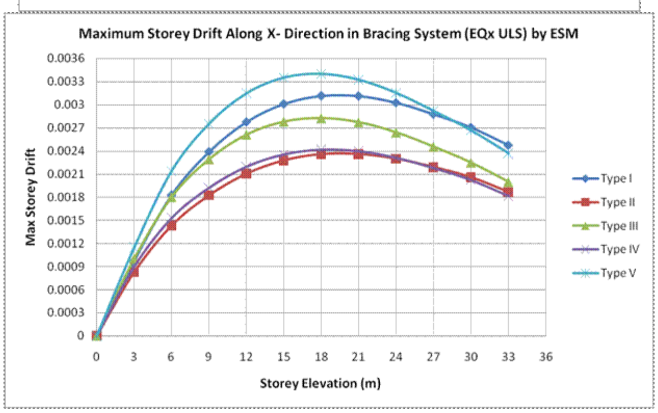
Figure 25 X- Direction Diaphragm Max to Avg Drift Ratio in Type- I System (RSx ULS) by RSM

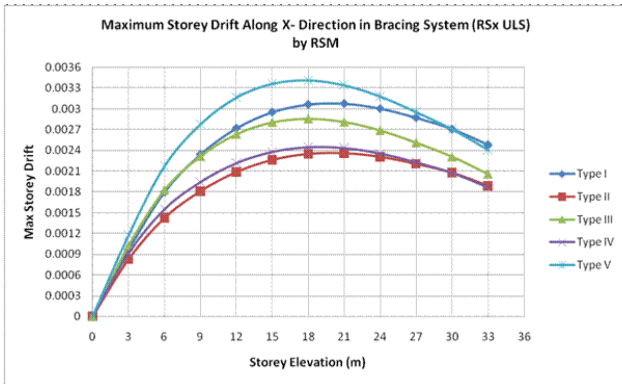
Diaphragm maximum to average drift ratio along X- direction in Type- I position of all the system due to seismic force effect is presented graphically using ESM and RSM as shown in figure above. It is observed that for all system, the ratio by ESM is greater than that by RSM. It is observed that shear 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.

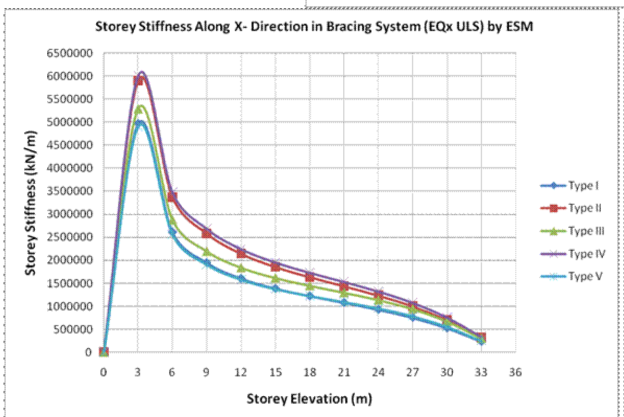
Other Graphs from Observations:

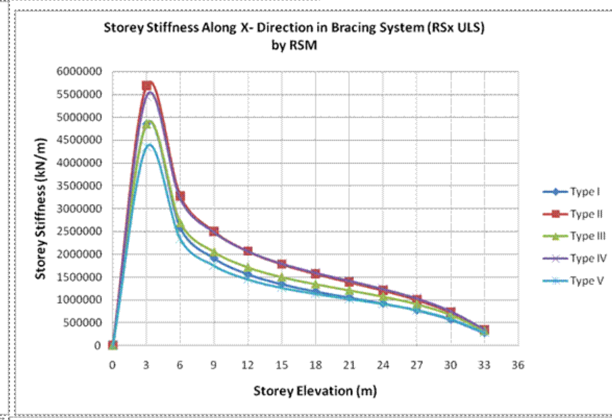


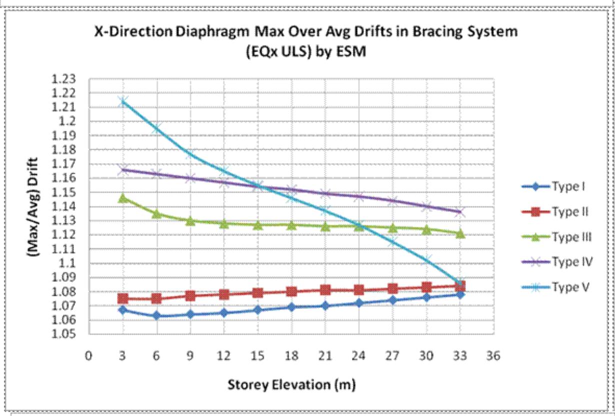


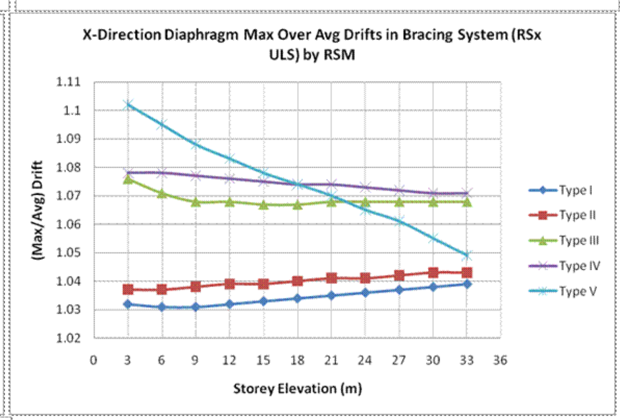


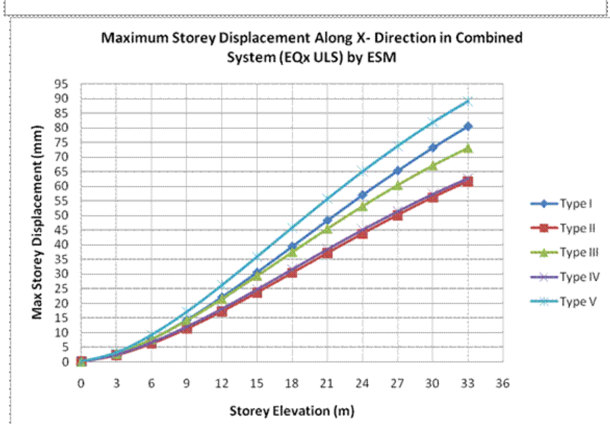

Maximum Storey Drift Along X- Direction in Bracing System (RSx ULS) by RSM
Max Storey Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

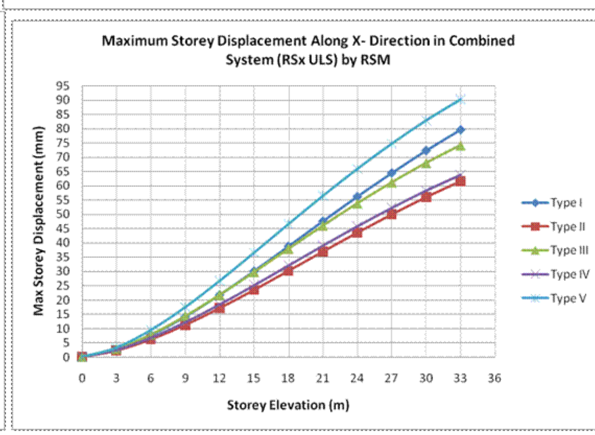

Storey Stiffness Along X- Direction in Bracing System (EQx ULS) by ESM
Storey Stiffness (kN/m)
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

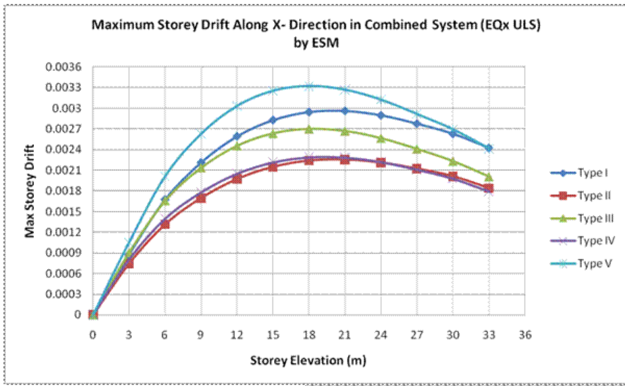

Storey Stiffness Along X- Direction in Bracing System (RSx ULS) by RSM
Storey Stiffness (kN/m)
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

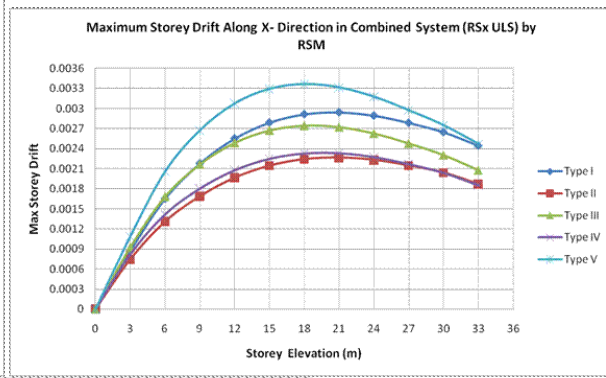

X-Direction Diaphragm Max Over Avg Drifts in Bracing System (EQx ULS) by ESM
(Max/Avg) Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

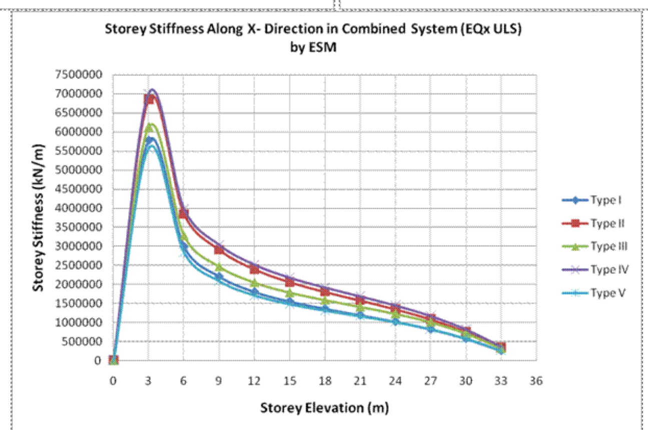

X-Direction Diaphragm Max Over Avg Drifts in Bracing System (RSx ULS) by RSM
(Max/Avg) Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

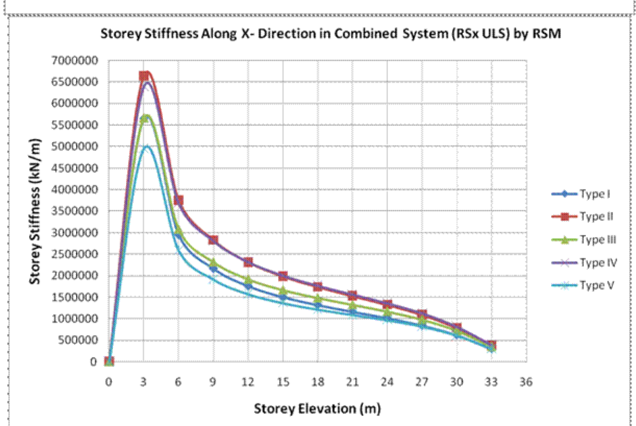

Maximum Storey Displacement Along X- Direction in Combined System (EQx ULS) by ESM
Max Storey Displacement (mm)
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

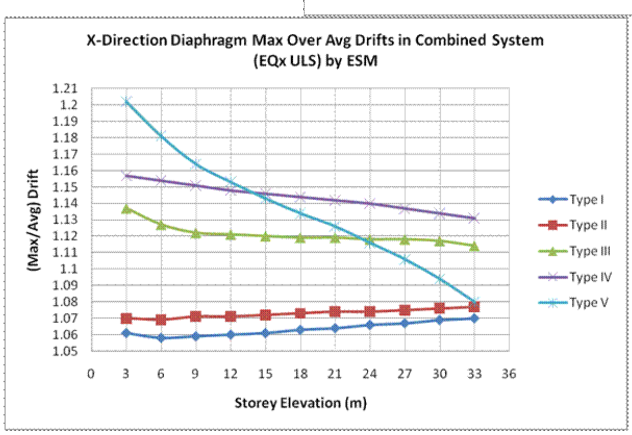

Maximum Storey Displacement Along X- Direction in Combined System (RSx ULS) by RSM
Max Storey Displacement (mm)
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

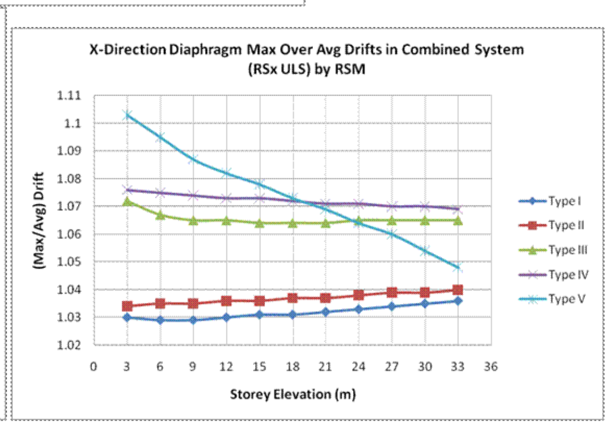

Maximum Storey Drift Along X- Direction in Combined System (EQx ULS) by ESM
Max Storey Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V


Maximum Storey Drift Along X- Direction in Combined System (RSx ULS) by RSM
Max Storey Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

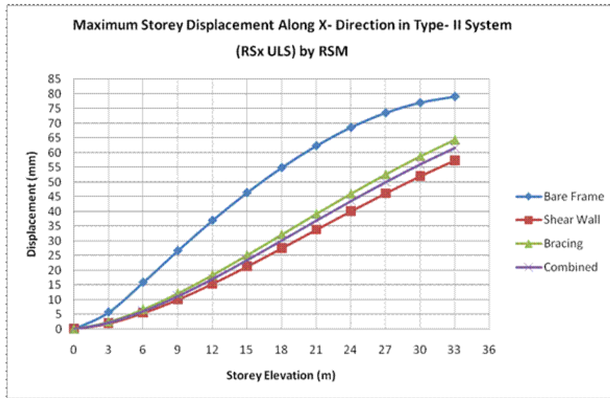

Storey Stiffness Along X- Direction in Combined System (EQx ULS) by ESM
Storey Stiffness (kN/m)
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

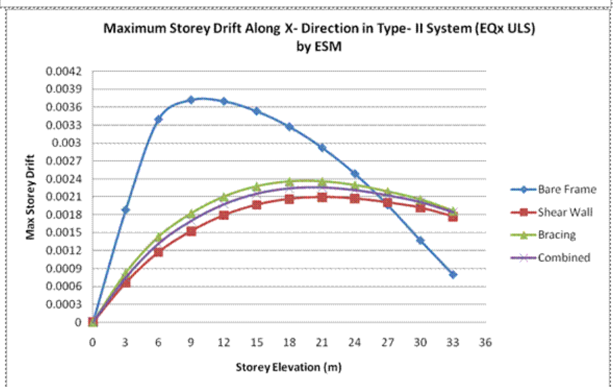

Storey Stiffness Along X- Direction in Combined System (RSx ULS) by RSM
Storey Stiffness (kN/m)
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

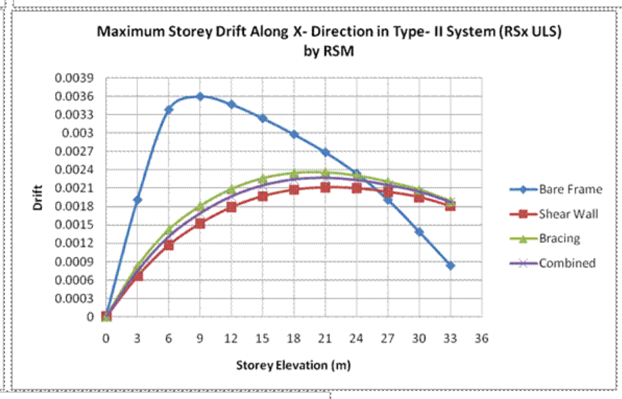

X-Direction Diaphragm Max Over Avg Drifts in Combined System (EQx ULS) by ESM
(Max/Avg) Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

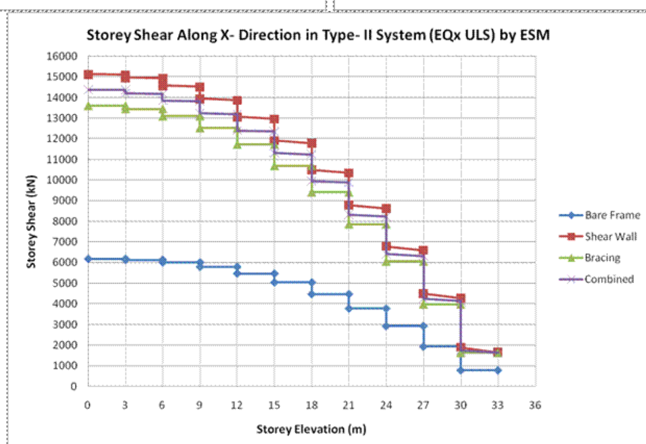

X-Direction Diaphragm Max Over Avg Drifts in Combined System (RSx ULS) by RSM
(Max/Avg) Drift
Storey Elevation (m)
Type I
Type II
Type III
Type IV
Type V

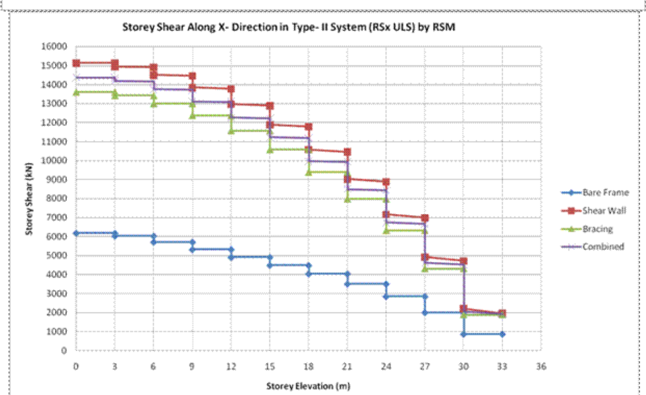

Maximum Storey Displacement Along X- Direction in Type- II System
(EQx ULS) by ESM
Max Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

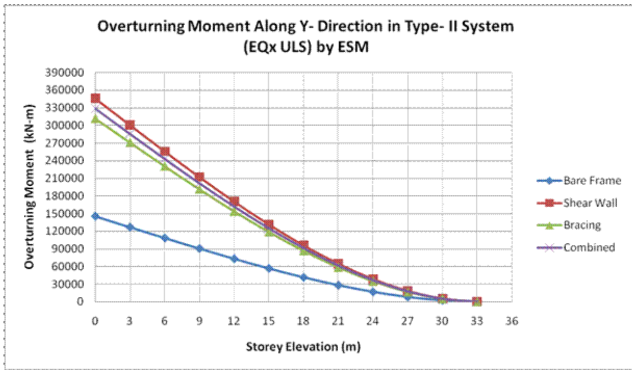

Maximum Storey Displacement Along X- Direction in Type- II System
(RSx ULS) by RSM
Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

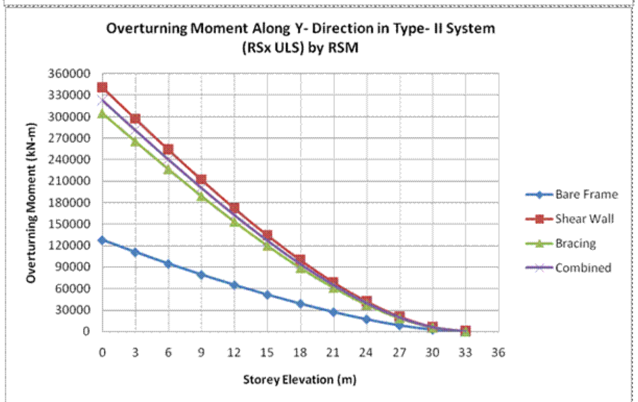

Maximum Storey Drift Along X- Direction in Type- II System (EQx ULS)
by ESM
Max Storey Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

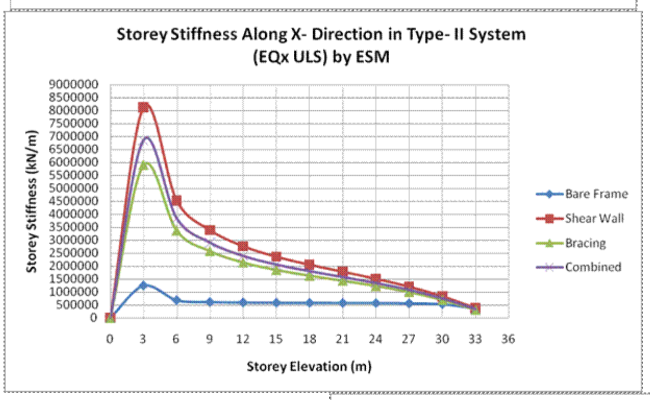

Maximum Storey Drift Along X- Direction in Type- II System (RSx ULS)
by RSM
Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

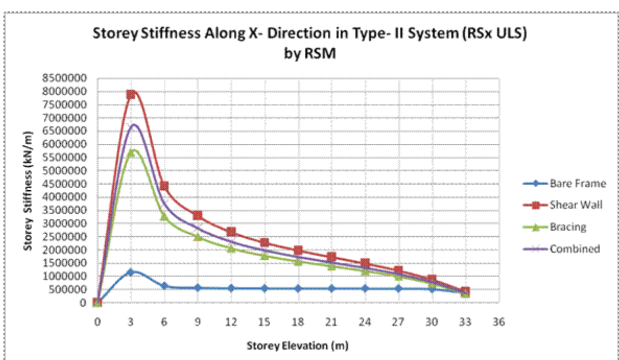

Storey Shear Along X- Direction in Type- II System (EQx ULS) by ESM
Storey Shear (kN)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

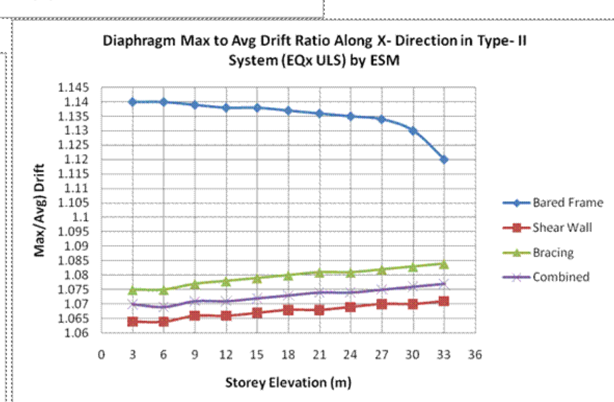

Storey Shear Along X- Direction in Type- II System (RSx ULS) by RSM
Storey Shear (kN)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

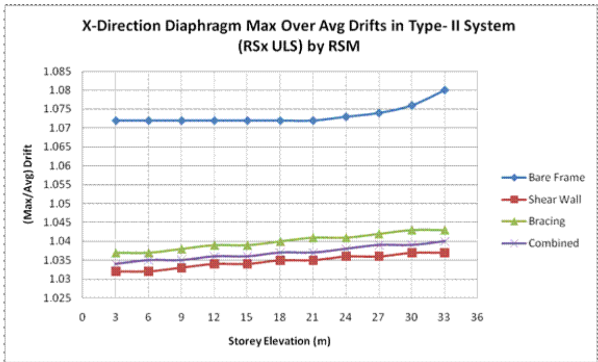

Overturning Moment Along Y- Direction in Type- II System (EQx ULS) by ESM
Overturning Moment (kN-m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

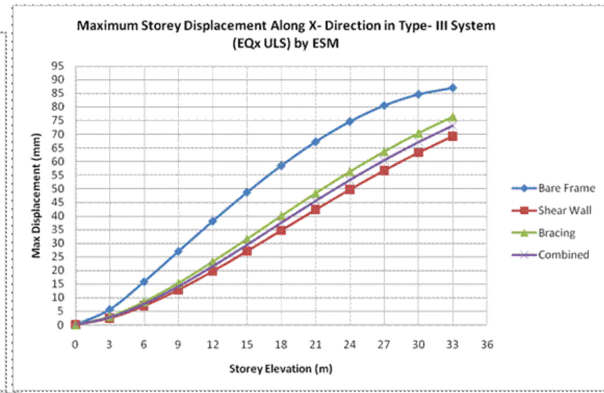

Overturning Moment Along Y- Direction in Type- II System (RSx ULS) by RSM
Overturning Moment (kN-m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

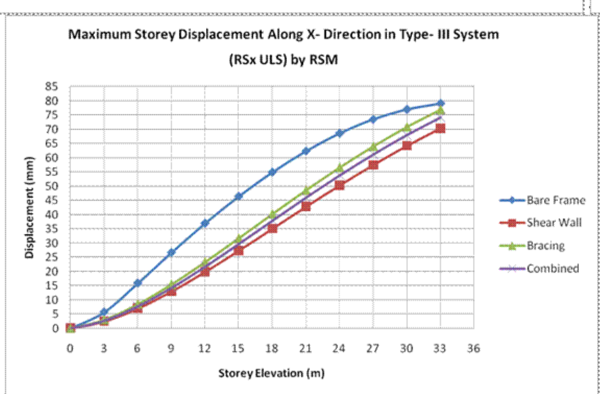

Storey Stiffness Along X- Direction in Type- II System (EQx ULS) by ESM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

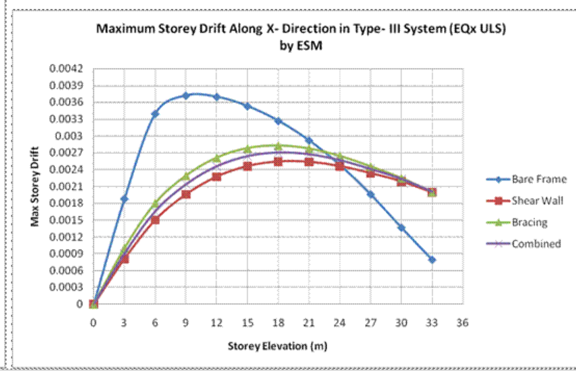

Storey Stiffness Along X- Direction in Type- II System (RSx ULS) by RSM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

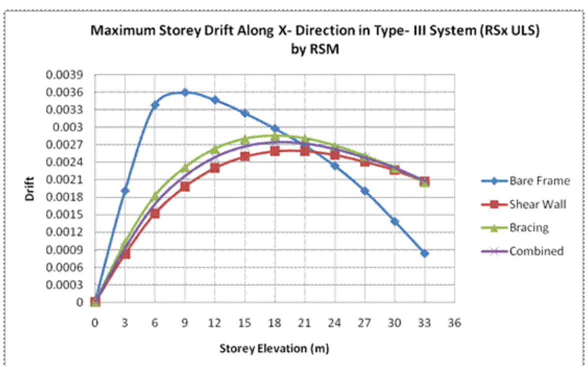

Diaphragm Max to Avg Drift Ratio Along X- Direction in Type- II System (EQx ULS) by ESM
Max/(Avg) Drift
Storey Elevation (m)
Bared Frame
Shear Wall
Bracing
Combined

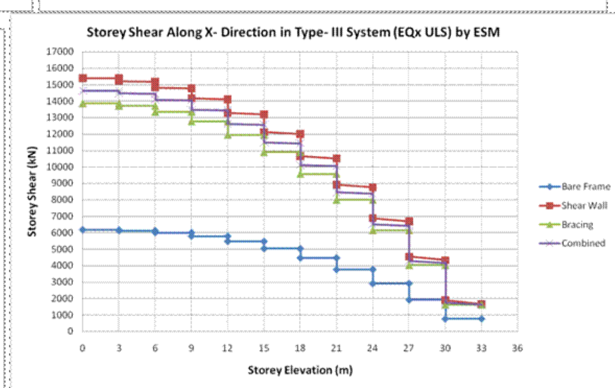

X-Direction Diaphragm Max Over Avg Drifts in Type- II System
(RSx ULS) by RSM
(Max/Avg) Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

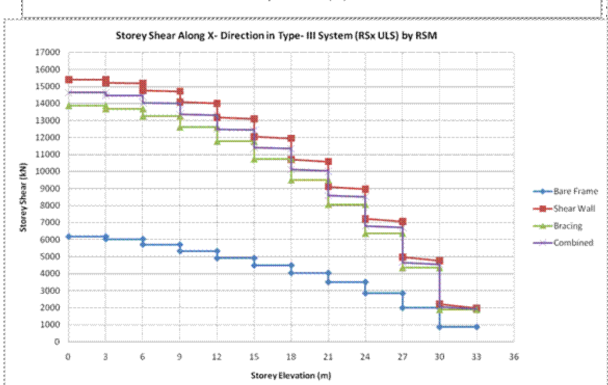

Maximum Storey Displacement Along X- Direction in Type- III System
(EQx ULS) by ESM
Max Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

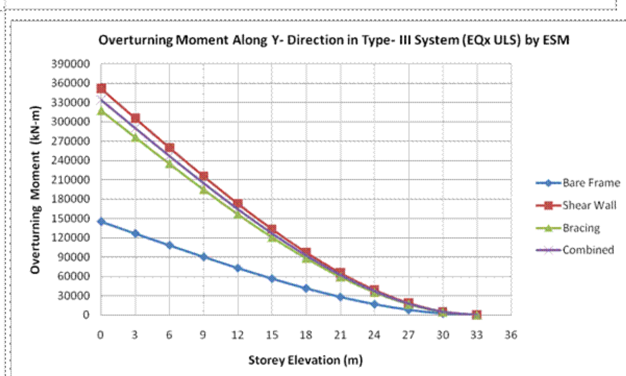

Maximum Storey Displacement Along X- Direction in Type- III System
(RSx ULS) by RSM
Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

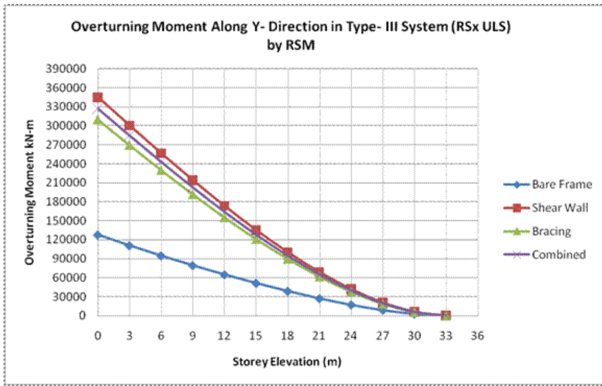

Maximum Storey Drift Along X- Direction in Type- III System (EQx ULS)
by ESM
Max Storey Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

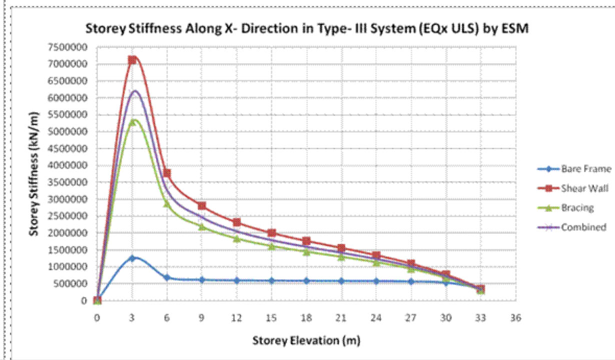

Maximum Storey Drift Along X- Direction in Type- III System (RSx ULS)
by RSM
Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

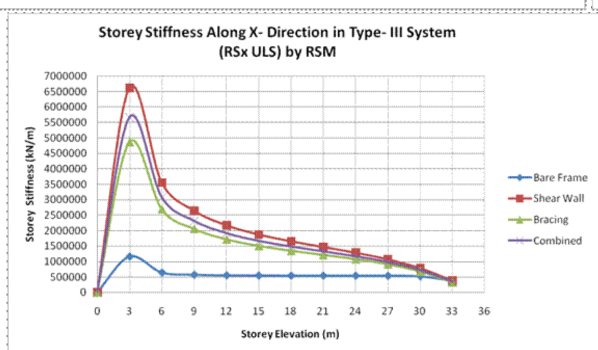

Storey Shear Along X- Direction in Type- III System (EQx ULS) by ESM
Storey Shear (kN)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

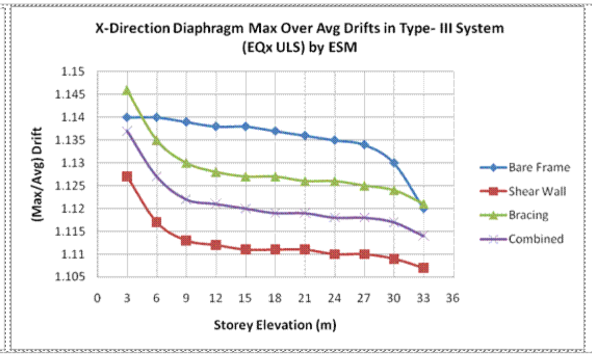

Storey Shear Along X- Direction in Type- III System (RSx ULS) by RSM
Storey Shear (kN)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

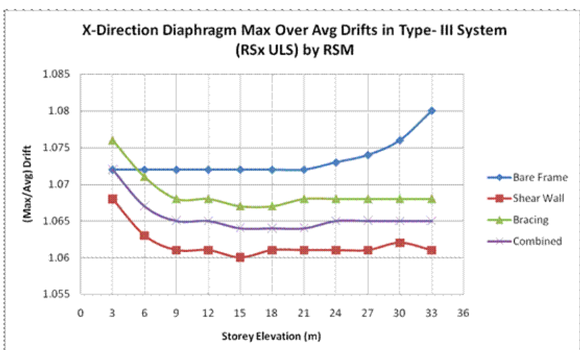

Overturning Moment Along Y- Direction in Type- III System (EQx ULS) by ESM
Overturning Moment (kN-m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

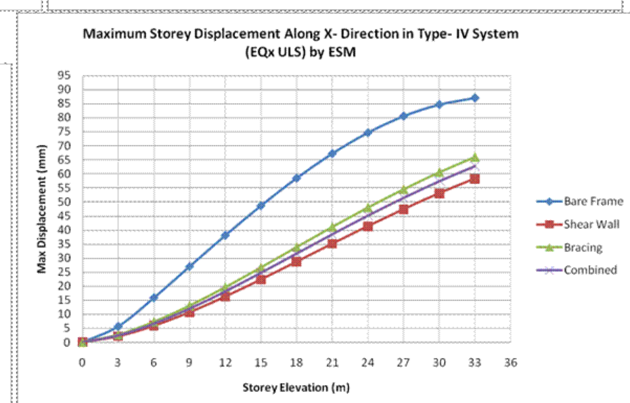

Overturning Moment Along Y- Direction in Type- III System (RSx ULS) by RSM
Overturning Moment kN-m
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

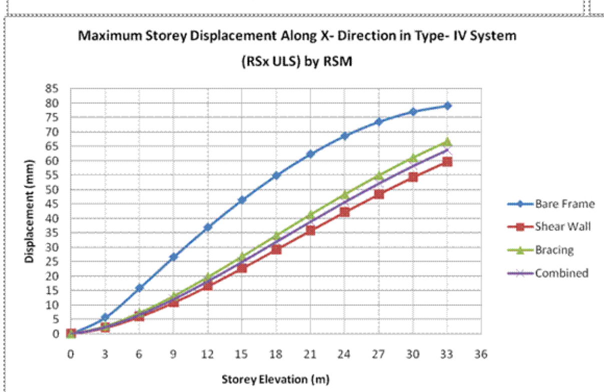

Storey Stiffness Along X- Direction in Type- III System (EQx ULS) by ESM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

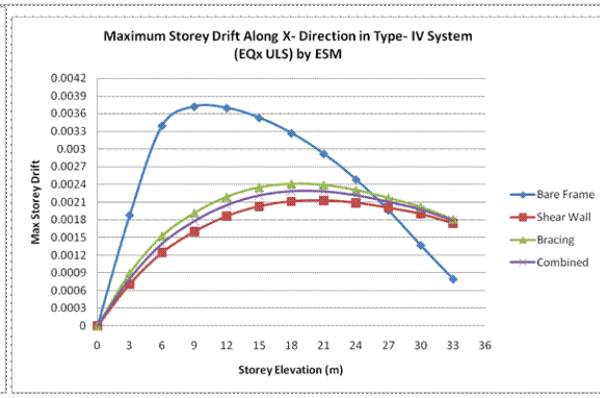

Storey Stiffness Along X- Direction in Type- III System (RSx ULS) by RSM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

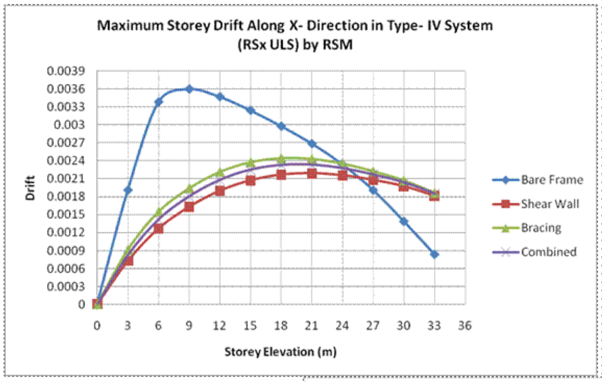

X-Direction Diaphragm Max Over Avg Drifts in Type- III System (EQx ULS) by ESM
(Max/Avg) Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


X-Direction Diaphragm Max Over Avg Drifts in Type- III System (RSx ULS) by RSM
(Max/Avg) Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Maximum Storey Displacement Along X- Direction in Type- IV System (EQx ULS) by ESM
Max Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Maximum Storey Displacement Along X- Direction in Type- IV System (RSx ULS) by RSM
Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Maximum Storey Drift Along X- Direction in Type- IV System (EQx ULS) by ESM
Max Storey Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined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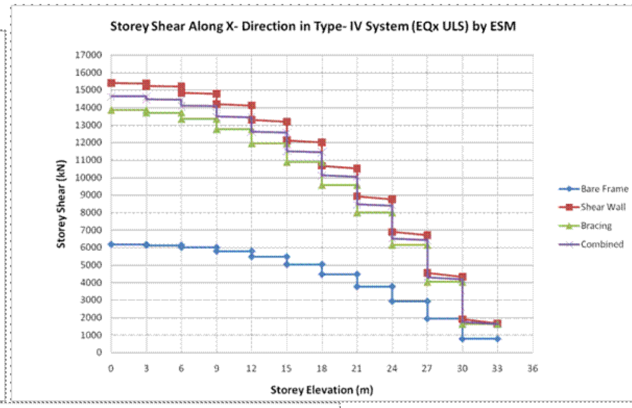
(RSx ULS) by RSM
Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined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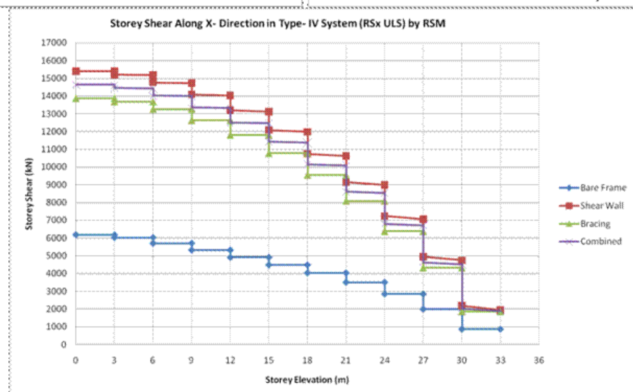
Storey Shear (kN)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined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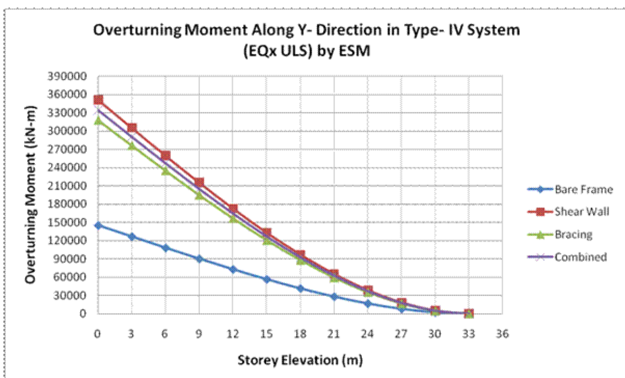
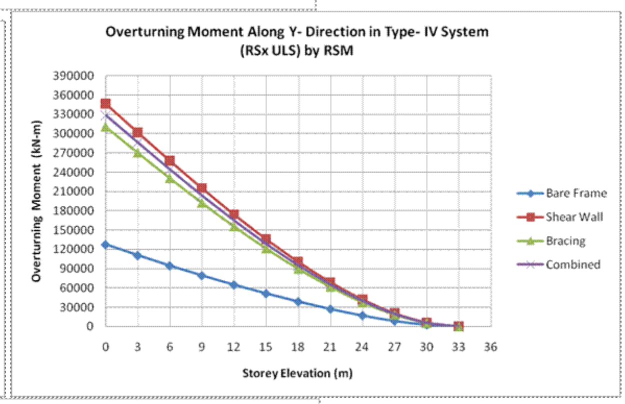
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Overturning Moment Along Y- Direction in Type- IV System
(EQx ULS) by ESM
Overturning Moment (kN-m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Overturning Moment Along Y- Direction in Type- IV System
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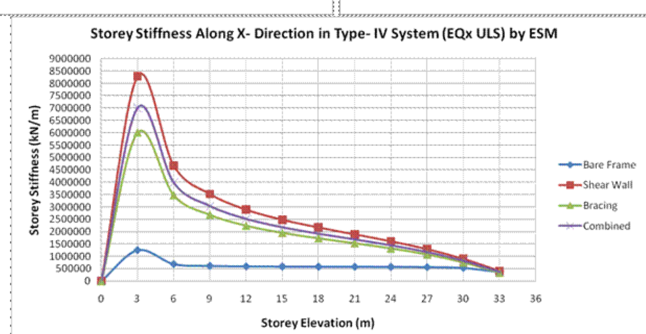
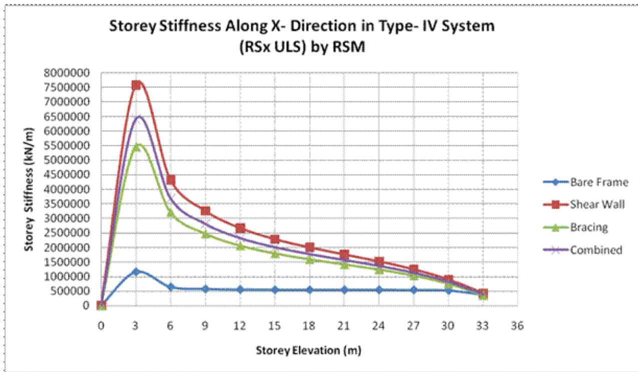
Bracing
Combined


Storey Stiffness Along X- Direction in Type- IV System (EQx ULS) by ESM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined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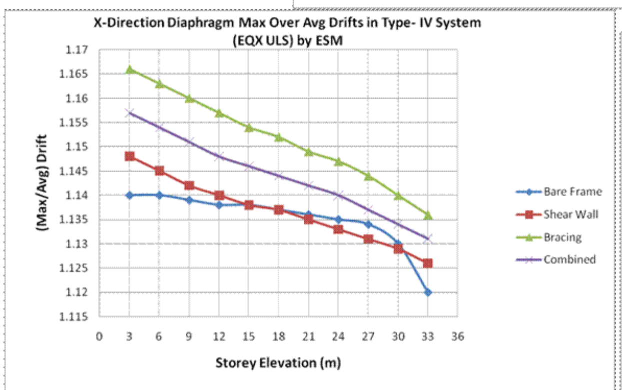
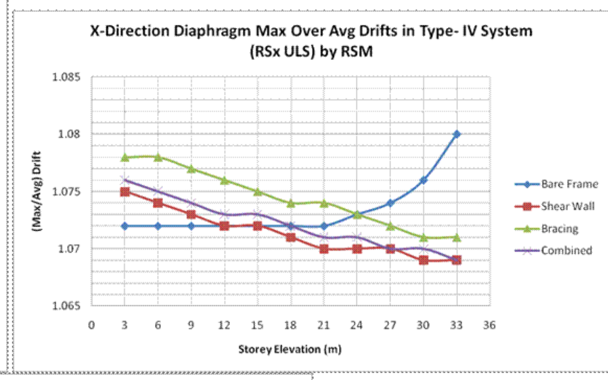
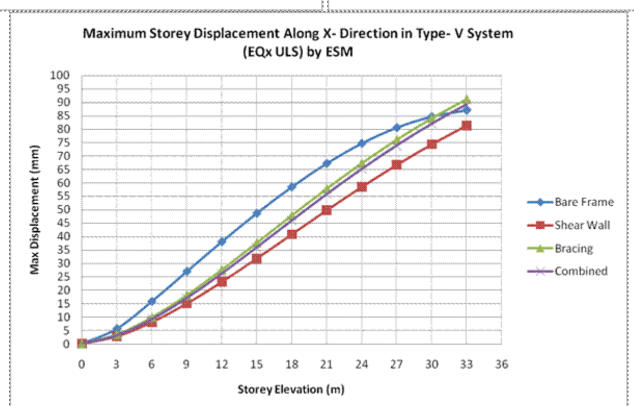
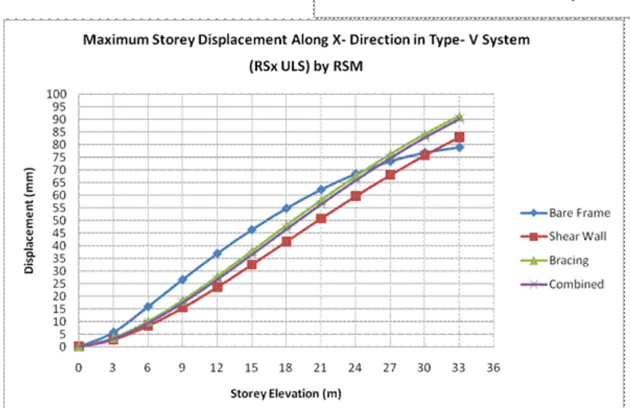
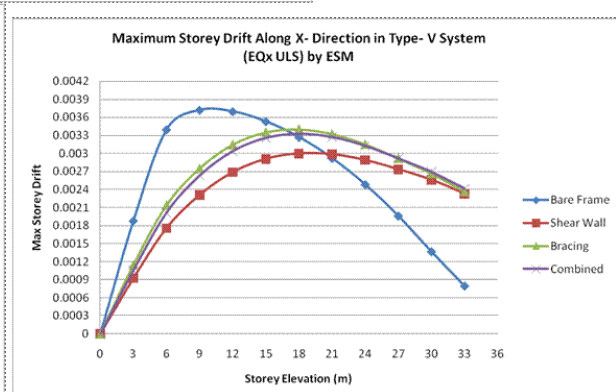
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

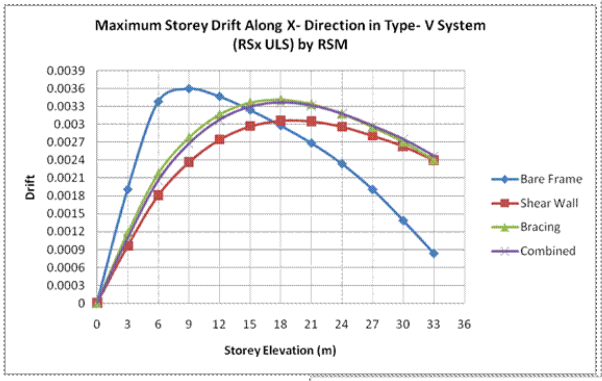

X-Direction Diaphragm Max Over Avg Drifts in Type- IV System
(EQX ULS) by ESM
(Max/Avg) Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

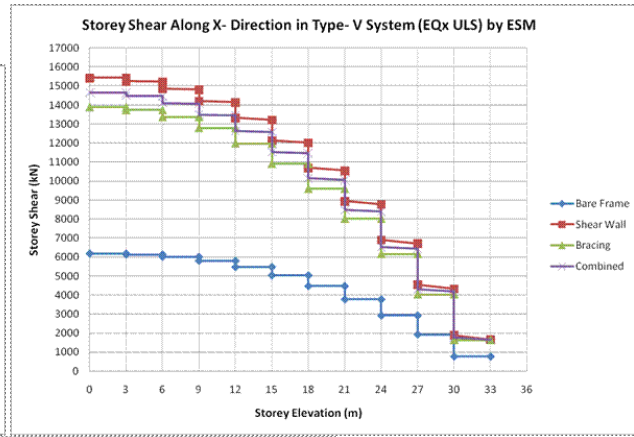

X-Direction Diaphragm Max Over Avg Drifts in Type- IV System
(RSx ULS) by RSM
(Max/Avg) Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined

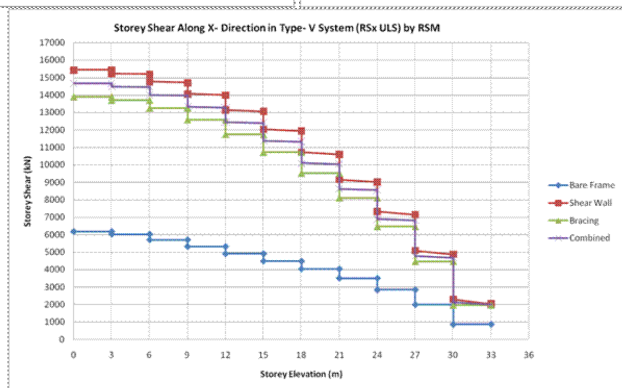

Maximum Storey Displacement Along X- Direction in Type- V System
(EQx ULS) by ESM
Max Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Maximum Storey Displacement Along X- Direction in Type- V System
(RSx ULS) by RSM
Displacement (mm)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Maximum Storey Drift Along X- Direction in Type- V System
(EQx ULS) by ESM
Max Storey Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Maximum Storey Drift Along X- Direction in Type- V System (RSx ULS) by RSM
Drift
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Storey Shear Along X- Direction in Type- V System (EQx ULS) by ESM
Storey Shear (kN)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined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Storey Shear (kN)
Storey Elevation (m)
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Bracing
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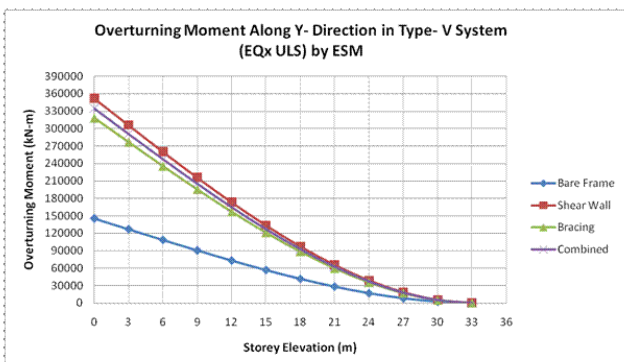
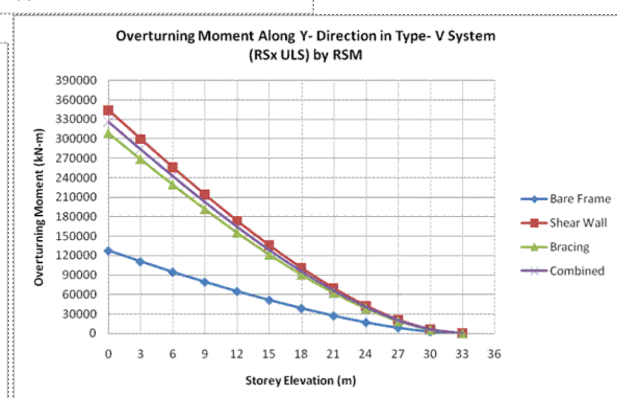

Overturning Moment Along Y- Direction in Type- V System (EQx ULS) by ESM
Overturning Moment (kN-m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Overturning Moment Along Y- Direction in Type- V System (RSx ULS) by RSM
Overturning Moment (kN-m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
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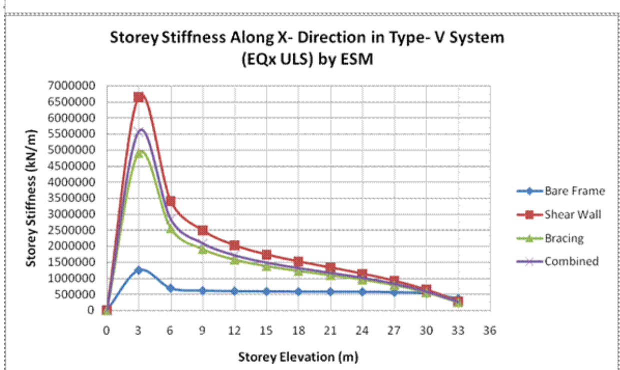
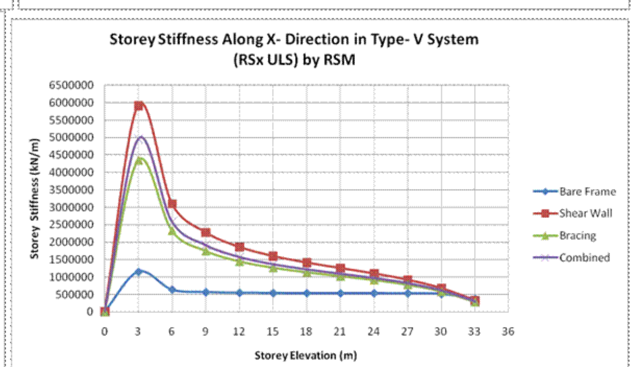

Storey Stiffness Along X- Direction in Type- V System (EQx ULS) by ESM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
Bracing
Combined


Storey Stiffness Along X- Direction in Type- V System (RSx ULS) by RSM
Storey Stiffness (kN/m)
Storey Elevation (m)
Bare Frame
Shear Wall
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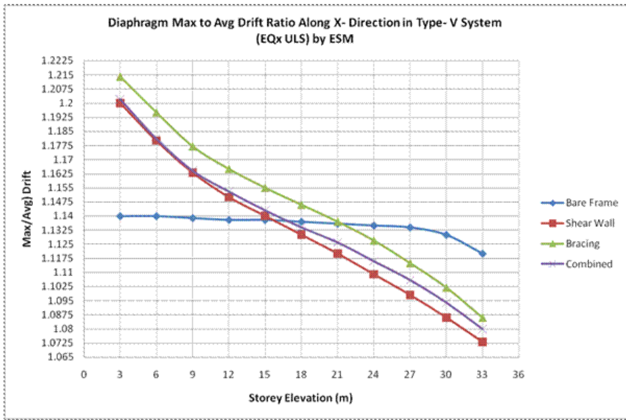

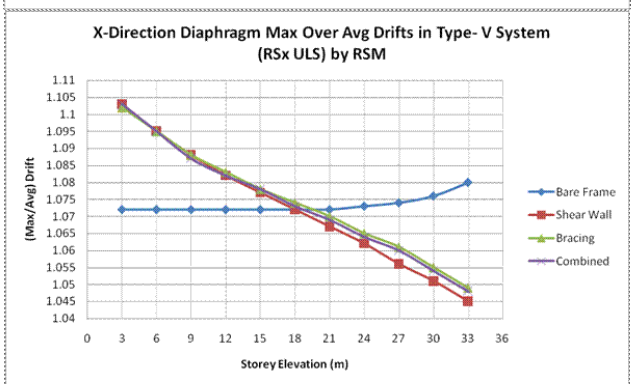

B. DISCUSSION

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:

1. The displacement of all models remains below the limit of 0.004 times the building height.
2. It is seen that when the seismic force is in X-direction, the model having the shear wall system only in each type of arrangements/locations shows the better performance than other systems. Similar case is for Y-direction too, as the structural system being symmetric and regular.
3. In terms of location or type, the order of increasing storey stiffness values in ESM is type-V, type-I, type-III, type-II, and type-IV, while in RSM it is type-V, type-I, type-III, type-IV, and type-II.
4. Observations indicate that a combined system consisting of shear wall and bracing exhibits lower displacement, drift, and maximum to average drift ratio, as well as higher storey shear, overturning moment, and stiffness when compared to a bracing system alone.
5. It is observed that in each system, type- II and type- IV shows almost similar performance in terms of all analyzed parameters.

6. In all types/locations of any system there is no considerable difference in the distance between center of mass and center of rigidity.
7. 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.
8. 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.
9. Outer sides (periphery) central location (Type- II position) of each system has better performance in terms of all considered parameters than other four type of location.
10. 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 reduction in top storey displacement are 27.35%, 18.46% and 21.95% respectively, percentage reduction in maximum storey drift are 41.22%, 34.50% and 37.06% respectively, percentage increase in base shear are 144.87%, 120.13% and 132.50% respectively, percentage increase in overturning moment are 167%, 138.93% and 152.97% respectively, percentage increase in maximum value of storey stiffness are 581.07 %, 392. 14% and 474.26% respectively and percentage decrease in maximum value of diaphragm maximum to average drift ratio are 3.98%, 3.43% and 3.70% respectively.

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

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 27.35% and maximum storey stiffness can be increased by 581.07% compared to a bare frame model.
2. 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.
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.

B. Recommendations

Different assumptions and limitations have been adopted for simplicity in modeling the proposed building. Thus all the factors which may influence on the behavior of the structures should be considered in the modeling.

The following suggestions are proposed for future studies to obtain more thorough and improved results.

1. In the current study, the analysis was conducted using ESM and RSM. Time History Analysis and Pushover Analysis can potentially provide more accurate results.
2. The study focused on a regular medium-rise building, but a comparison with low and high-rise buildings can also be conducted.
3. Since the structure analyzed was regular, the analysis was only conducted in one direction (X-direction). For an irregular structure, the analysis should be conducted in both directions.
4. An additional system called concealed bracing shear wall can be used for further analysis.
5. Soil-structure interaction analysis can be performed for cases involving high-rise and irregular buildings.

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