Selection of Optimum Structural System in the Design of Reinforced Concrete High-Rise Building under the Effect of Seismic Load

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Abstract. Due to the infrequency of spaces in megacities, it is highly required to construct high rise buildings. In high rise buildings, the effect of seismic lateral forces is significant to be studied. The stiffness of lateral force-resisting elements of the building should be enough to stay safe during an earthquake. Providing the required stiffness by only enlarging the size of columns will cause congestion in space. Shear wall and/or bracing positioned at a lucrative location in frame, contribute to the structure and serve as lateral load resisting systems. Hence, Optimization for the selection of proper structural systems is vital in the structural engineering profession. This study deals to investigate the consequences of the shear wall and RC bracing on the reduction of earthquake lateral forces in the building. Including a moment-resisting frame, nine models of G+14 Storeys RC building with various structural systems and configurations are analysed and compared using Response Spectrum Method, as per IS 1893 (part 1); 2016. The comparison among all the models is carried out based on the storey displacement, base shear, storey drift, fundamental period, storey stiffness, force demand, and modal period. Based on the comparison of all building models with various configuration, it was found that out of all models, the model M-1 (moment-resisting frame) is not desirable, while the model M-5 (shear wall at the corners of the periphery) will have an upmost seismic performance and the model M-8 (bracing at the middle of the periphery) has indicated better execution during an earthquake.

Abbreviations: IS, Indian Standard; G+14, Ground plus Fourteen; RC, Reinforced Concrete; M-1, Model-1; M-2, Model-2; M-3, Model-3; M-4, Model-4; M-5, Model-5; M-6, Model-6; M-7, Model-7; M-8, Model-8; M-9, Model-9; DL, Dead Load; LL, Live Load; EQX, Earthquake Static Load in X-direction; EQY, Earthquake Static Load in Y-direction; RSX, Response Spectrum Load in X-direction; RSY, Response Spectrum Load in Y-direction, (X) Modes of Oscillation in X-Direction, (Y) Modes of Oscillation in Y-Direction, (T) Torsion.

1. Introduction
The ground acceleration is time-dependent; it can deliver different levels of damages to various types of structures, due to inadequate stiffness the reinforced concrete buildings were damaged or collapsed [1, 2]. It is a must to build safe buildings with stability in seismic waves [3] The major perspectives to build a building that is resistant to seismic forces are (a) selection of lateral load resisting system, (b)
configuration of the proposed lateral load resisting system, (c) their basic dynamic characteristics, and (d) their quality of construction [1, 4, 5]. RCC buildings are sufficient for resisting both vertical loads and horizontal forces acting on them [6, 7]. When the buildings are tall, the lateral force is a concern, the size and reinforcement of the column and beam need to be enlarged, which causes column-beam junction to function quite heavy. There could be a big crowd at beam-column joints, placing and vibrating concrete at such joints are very difficult, and the joints might not properly be filled with concrete, which fact, cannot contribute to building’s safety [8, 9]. Such practical difficulties call for the introduction of the lateral load resistance system which is very useful [10]. To resist the lateral load (earthquake & wind) acting on buildings, various types of structural systems mentioned in IS1893 2016 Part 1 [11]. When lateral load resisting elements are selected and configured in an advantageous place in the building, they take active and efficient participation against lateral loads originated from earthquake load or wind load [12-19]. The concept of seismic-resistant design of structures should be on the bases of lateral stiffness and strength, ductility and deformability of the structure with limited and less damage but no collapse [20, 21]. Comparing to the shear wall, the concrete columns have less stiffness and resistance to seismic forces. Shear wall has enough bearing capacity, ductility and stiffness, which can resist both vertical and horizontal loads [22, 23]. The energy dissipation capacity of shear wall is not as good as bracing [24] Shear wall configuration has great influence in building’s response to lateral forces [25]. X bracing, is found to be very effective in minimizing the deflection, displacement, storey drift in comparison with all other bracing types [26-29]. The structural weight of shear wall is more as compared to the weight of bracing [30].

2. Research Significance
The ground shake or earthquake is counted very dangerous for the people living on the earth. People are not killed by the earthquake, but by the buildings. It is necessary to establish a safe living environment. The high rise buildings are sensitive to the lateral forces and tend to be subjected under the earthquake lateral forces, in such a case the building should be pre-equipped with enough lateral stiffness, strength, ductility, less lateral displacement, and less deformability. Such provisions call for lateral load resisting elements. There are significant consequences of shear wall and bracing configuration in the building, the location of the shear wall and bracing in the building has its direct influence on the behaviour and force demand of a building. This paper aims to investigate the optimum structural system with a lucrative position of shear wall and bracing elements.

3. Method
3.1. Selected Method of Seismic Analysis
The recommended procedures those are mentioned in the code are for determining the horizontal force on the basis of approximation influences, yielding might be enumerated via the design spectrum for the building’s linear analysis. Dynamic Analysis is carried out conforming to (IS 1893 (Part 1) 2016) [11].
3.2. Applied Loads: In this research work the following loads have been considered for the analysis.
3.2.1. Dead Load: the dead loads conforming to IS-875 (Part-1) [31], are considered by software.
3.2.2. Live Load: The live load conforming to IS 875 (Part-2): 1987, Table-1 (clause 3.1) [32] has been considered separately for the cells of the building as shown in Table1.
3.2.3. Seismic loading: The seismic load is calculated as per the guidance mentioned in IS 1893 part 1; 2016 [11].
3.2. Load Combinations
After generating the models of computations and assigning the loads, the models are checked for each loading case. The members' internal forces like axial forces, shear forces and bending moment are combined for Seismic Loads, Dead Loads and Live Loads as per IS 1893 Part 1, 2016 and IS 875 Part 5[33]. All the members are designed for the most critical force of members among them. The load
combination is as per new code [11] IS 1893; Part 1, 2016 and per IS-875 (Part-5): [33]1987 – clause 8.0, the below load combinations are considered for this research work.

1. 1.5 DL  
2. 15(DL + LL)  
3. 1.2 (DL + LL ± EQX)  
4. 1.2 (DL + LL ± EQY)  
5. 1.5 (DL ± EQX)  
6. 1.5 (DL ± EQY)  
7. 0.9DL ± 1.5EQX  
8. 0.9DL ± 1.5EQUY  
9. 1.2 (DL + LL + R SX)  
10. 1.2 (DL + LL + R SY)  
11. 1.5 (DL + R SX)  
12. 1.5 (DL + R SY)  
13. 0.9DL + 1.5RSX  
14. 0.9DL + 1.5RSY

3.3. Software Used
Etabs Software 2017
Linear response spectrum method (dynamic) is the main focus in this research work. Therefore, the ETABS software has been chosen as computer program for performing of the analysis.

3.4. Problem of the Study
Three structural systems such as the moment-resisting frame, frame with the shear wall system, and frame with the bracing system are selected for the analysis. Nine structural systems namely M-2 to and M-9 together with moment-resisting frame as a base model (M-1) have been modelled for the analysis and compare the result of all these models with M-1, the aim of this study is to analyse these models for fundamental period, storey drift, base shear, storey stiffness, force demand of columns, and storey displacement. These models are configured with lateral load resisting elements by introducing bracing and shear wall at various locations.

3.5. Structural Details and Input Parameters
Followings are the details of structure and input parameters which are applied on all the models.

| Name                        | Details                  | Name                        | Details           |
|------------------------------|--------------------------|------------------------------|-------------------|
| Plan Dimension               | 24m x 20m                | Grade of Concrete            | M30               |
| Number of Stories            | 15                       | Poisson’s ratio              | 0.2               |
| Width of bay along X Direction | 4 &5 m                   | Slab thickness               | 150mm             |
| Width of bay along Y Direction | 4 m                      | Thickness of interior wall   | 125mm             |
| Floor height                 | 3 m                      | Thickness of shear wall      | 230mm             |
| Grade of Steel               | Fe 415                   | Seismic Zone                 | V                 |
| Thickness of parapet wall    | 125mm                    | Type of frame                | SMRF              |
| Size of Beam-1               | 230mm x 450mm            | Importance Factor, I         | 1.2               |
| Size of Beam-2               | 250mm x 450mm            | Response Reduction Factor    | 5                 |
| Size of Column-1             | 600mm x 450mm            | Damping                      | 5                 |
| Size of Column-2             | 450mm x 450mm            | Soil Type                    | II-Medium         |
| Size of bracing              | 300mm x 300mm            | Building Models              |                   |
| Density of Concrete          | 25k N/m²                 | Moment Resisting Frame       | M-1               |
4. Modeling and Analysis

| Density of infill wall | 19\(k\) N/m\(^3\) | Frame with Core Shear Wall | M-2 |
|-----------------------|-----------------------|----------------------------|-----|
| Floor Finishes        | 1\(k\) N/m\(^3\)     | Frame with Bracing at Middle of Periphery | M-3 |
| Live Load             | 3\(k\) N/m\(^3\)     | Frame with Shear Wall At Middle of Periphery | M-4 |
| Thickness of exterior wall | 250mm | Frame with Shear Wall at Periphery Corners | M-5 |
| Roof Load             | 1.5\(k\) N/m\(^3\)   | Frame with bracing at Periphery Corners | M-6 |
| Wall load             | 12\(k\) N/m          | Frame with Two Shear Walls at Periphery Middle | M-7 |
| Type of Building      | Residential           | Frame with Two Bracings at Periphery Middle | M-8 |
| Zone Factor, Z        | 0.36                  | Frame with Bracing at the core | M-9 |

**Figure 1.** Building Models (M-1 – M-9) Considered in the analysis
5. Results and Discussion

In this part of the research, all the models namely, M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are analysed along the X and Y directions for base shear, fundamental time period, storey stiffness, storey lateral displacement, storey drift, and force demand of structural elements and the relevant results of each model are compared with the reference model (M-1), as discussed below.

5.1. Base Shear

| Building Model |
|----------------|
| M-1            |
| M-2            |
| M-3            |
| M-4            |
| M-5            |
| M-6            |
| M-7            |
| M-8            |
| M-9            |

Table 2: Seismic Weight and Base Shear

| Building Model | M-1   | M-2   | M-3   | M-4   | M-5   | M-6   | M-7   | M-8   | M-9   |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Seismic Weight (KN) | 80202.89 | 83004.68 | 81507.51 | 81591.87 | 88068.06 | 83028.94 | 82056.10 | 83028.94 | 81507.51 |
| X-Direction     | 1745  | 2451  | 2176  | 1944  | 3674  | 2695  | 3360  | 2802  | 2146.78 |
| Y-Direction     | 1833  | 2430  | 2282  | 2042  | 3316  | 2543  | 3024  | 2648  | 2258.03 |

Table 3: Seismic Weight and Base Shear in Percentage

| Building Model | M-1   | M-2   | M-3   | M-4   | M-5   | M-6   | M-7   | M-8   | M-9   |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Seismic Weight (KN) | 100   | 103.49 | 101.62 | 101.73 | 109.80 | 103.52 | 102.27 | 103.52 | 101.62 |
| X-Direction     | 100   | 128.81 | 119.81 | 110.27 | 152.51 | 135.27 | 148.07 | 137.73 | 118.73 |
| Y-Direction     | 100   | 1124.56 | 119.68 | 110.24 | 144.72 | 127.91 | 139.37 | 130.78 | 118.82 |

Figure 2. (right image) Base Shear in X-Direction, (left image) Base Shear in Y-Direction

After employing the lateral load resisting elements (shear wall and bracing) with various configurations, the base shear value alters for each model. The highest base shear is interrelated to the type of lateral load resisting element and a lucrative position of lateral load resisting elements. The base shear along X direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are considerably increased by 28.81, 19.81, 10.27, 52.51, 35.27, 48.07, 37.73, and 18.73% as compared to the reference model (M-1) or model without shear wall and the bracing system as shown in Table 2 and 3 and plotted in Fig. 2a. Similarly the results for base shear along Y-direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are significantly enhanced by 24.56, 19.68, 10.24, 44.72, 27.91, 39.37, 30.78, and 18.82%, respectively as shown in Table 2 and 3 and plotted in Fig. 2b. In both directions, the model M-5 has the maximum value for the base shear.
5.2. Fundamental Time Period

Table 4: Time Period Calculated by ETABS Software

| Model | M-1 | M-2 | M-3 | M-4 | M-5 | M-6 | M-7 | M-8 | M-9 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| X-Dir | 2.251 | 1.658 | 1.834 | 2.054 | 1.173 | 1.508 | 1.196 | 1.451 | 1.853 |
| Y-Dir | 2.142 | 1.672 | 1.748 | 1.956 | 1.3 | 1.599 | 1.329 | 1.535 | 1.765 |

The estimated fundamental period for each model varies, it seems that use of each lateral load resisting element with various configuration has its type of influence on the building’s period; the fundamental period along X direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are considerably decreased by 26.34, 18.53, 8.75, 47.90, 33.00, 46.87, 35.54, and 17.68% as compared to the reference model (M-1) or model without shear wall and the bracing system as shown in Table 4 and plotted in Fig. 3a. Similarly, the results for fundamental period along Y-direction for models M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are significantly reduced by 21.94, 18.39, 8.68, 39.31, 25.35, 37.95, 28.34, and 17.60% respectively as compared to reference model (M-1), as shown in Table 4 and plotted in Fig. 3b. In both directions, the model M-5 has the minimum value for the fundamental time period.

5.3. Storey Stiffness

As it can be observed in Fig.4 (a & b) and the table 5, the lateral stiffness of the building decreases when the height of the building is increased. The lateral storey stiffness of the building was enhanced after applying the lateral load resisting elements (shear wall and bracing), increase or decrease in the storey stiffness value is directly proportional to the type, configuration and positioning of the
mentioned elements. The storey stiffness along X direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are considerably increased by 75.53, 53.21, 72.92, 90.91, 71.26, 89.43, 71.28, and 52.00% as compared to the reference model (M-1) or model without shear wall and the bracing system as shown in Table 5 and plotted in Fig. 4a. Similarly, the results for storey stiffness along Y-direction for models, No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are significantly enhanced by 64.11, 51.04, 71.01, 87.02, 66.71, 84.69, 68.87, and 50.07% respectively as shown in Table 5 and plotted in Fig. 4b. In both directions, the model M-5 has the maximum value for the storey stiffness. Among various configurations of shear walls and bracing, it is observed that locating shear wall and bracing at the exterior corner of the building enhances the lateral stiffness and strength of the building against the lateral forces.

| Table 5. Maximum-Storey Stiffness Percentage in X & Y Directions (Increment) |
|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Model           | X-Dir  | Y-Dir  | X-Dir  | Y-Dir  | X-Dir  | Y-Dir  | X-Dir  | Y-Dir  |
| M-1             | 100    | 100    | 100    | 100    | 100    | 100    | 100    | 100    |
| M-2             | 175.53 | 164.11 | 175.53 | 164.11 | 175.53 | 164.11 | 175.53 | 164.11 |
| M-3             | 153.21 | 151.04 | 153.21 | 151.04 | 153.21 | 151.04 | 153.21 | 151.04 |
| M-4             | 172.92 | 171.01 | 172.92 | 171.01 | 172.92 | 171.01 | 172.92 | 171.01 |
| M-5             | 190.91 | 187.02 | 190.91 | 187.02 | 190.91 | 187.02 | 190.91 | 187.02 |
| M-6             | 171.26 | 166.71 | 171.26 | 166.71 | 171.26 | 166.71 | 171.26 | 166.71 |
| M-7             | 189.43 | 184.69 | 189.43 | 184.69 | 189.43 | 184.69 | 189.43 | 184.69 |
| M-8             | 171.28 | 166.87 | 171.28 | 166.87 | 171.28 | 166.87 | 171.28 | 166.87 |
| M-9             | 151.00 | 150.07 | 151.00 | 150.07 | 151.00 | 150.07 | 151.00 | 150.07 |

5.4. Storey Lateral Displacement

| Table 6. Top-Storey Lateral Displacement Percentage in X & Y Directions (Decrement) |
|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Model           | X-Dir  | Y-Dir  | X-Dir  | Y-Dir  | X-Dir  | Y-Dir  | X-Dir  | Y-Dir  |
| M-1             | 100    | 100    | 100    | 100    | 100    | 100    | 100    | 100    |
| M-2             | 68.20  | 70.24  | 68.20  | 70.24  | 68.20  | 70.24  | 68.20  | 70.24  |
| M-3             | 70.76  | 71.23  | 70.76  | 71.23  | 70.76  | 71.23  | 70.76  | 71.23  |
| M-4             | 78.64  | 79.89  | 78.64  | 79.89  | 78.64  | 79.89  | 78.64  | 79.89  |
| M-5             | 55.16  | 61.68  | 55.16  | 61.68  | 55.16  | 61.68  | 55.16  | 61.68  |
| M-6             | 62.52  | 68.13  | 62.52  | 68.13  | 62.52  | 68.13  | 62.52  | 68.13  |
| M-7             | 55.75  | 62.32  | 55.75  | 62.32  | 55.75  | 62.32  | 55.75  | 62.32  |
| M-8             | 60.18  | 65.67  | 60.18  | 65.67  | 60.18  | 65.67  | 60.18  | 65.67  |
| M-9             | 71.03  | 71.42  | 71.03  | 71.42  | 71.03  | 71.42  | 71.03  | 71.42  |

![Figure 5.](image1.jpg) **Figure 5.** (right image) Storey Lateral Displacement in X-Direction, (left image) Storey Lateral Displacement in Y-Direction

Employing any lateral load resisting elements (bracing and shear wall) reduces the lateral displacement at the top of the building, various configurations have various influences (stiffness) on the decrement of the building's lateral displacement. The minimum lateral displacement at the top storey is proportional to high stiffness, and mass which will be obtained by an ideal and lucrative configuration of the shear wall or bracing at the building. The storey lateral displacement along X direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are considerably reduced to 68.20, 70.76, 78.64, 55.16, 62.52, 55.75, 60.18, and 71.03% as compared to the reference model (M-1) or model without shear wall and the bracing system as shown in Table 6 and plotted in Fig. 5a.
Similarly, the results for the lateral displacement along Y-direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are significantly decreased to 70.24, 71.23, 79.89, 61.68, 68.13, 62.32, 65.67, and 71.42% respectively as shown in Table 6 and plotted in Fig. 5b. In both directions, the model M-5 has the minimum value for the storey lateral displacement. It was observed that the model M-5 functions with minimum and M-1 functions with maximum displacement As compared to all other models.

5.5. Storey Drift

| Model | M-1 | M-2 | M-3 | M-4 | M-5 | M-6 | M-7 | M-8 | M-9 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| X-Dir | 100 | 68.27 | 72.80 | 78.93 | 53.53 | 62.42 | 54.30 | 60.14 | 73.21 |
| Y-Dir | 100 | 65.04 | 66.78 | 73.36 | 55.13 | 62.58 | 55.98 | 60.32 | 67.14 |

The storey drift is larger in the mid-floor levels in the building, and again it decreases towards the top floor. Various configurations of bracing and shear wall have shown a positive influence in storey drift reduction. The storey drift along X direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are considerably decreased to 68.27, 72.80, 78.93, 53.53, 62.42, 54.30, 60.14, and 73.21% as compared to the reference model (M-1) or model without shear wall and the bracing system as shown in Table 7 and plotted in Fig. 6a. Similarly the results for storey drift along Y-direction for models No. M-2, M-3, M-4, M-5, M-6, M-7, M-8, and M-9 are significantly reduced to 65.04, 66.78, 73.36, 55.13, 62.58, 55.98, 60.32 and 67.14%, respectively as shown in Table 7 and plotted in Fig. 6b. In both directions, the model M-5 has the minimum value for the storey drift. Amongst the bracing systems model (M-3, M-6, M-8, & M-9), the model M-8 has the minimum value of storey drift. Comparing the results in both X and Y directions for the models (M-2 to M-9), there were not significant increment or decrement in the value of storey drift, because there are not many differences in lengths of X and Y directions.
5.6. Modes of Oscillation

| Mode  | Building Models | M-1 | M-2 | M-3 | M-4 | M-5 | M-6 | M-7 | M-8 | M-9 |
|-------|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mode1 |                 | 2.251(X) | 1.863 (T) | 1.834(X) | 2.054(X) | 1.3(Y) | 1.599(Y) | 1.329(Y) | 1.535(Y) | 1.874(T) |
| Mode2 |                 | 2.142(Y) | 1.672(Y) | 1.748(Y) | 1.956(Y) | 1.173(X) | 1.508(X) | 1.196(X) | 1.451(X) | 1.853(X) |
| Mode3 |                 | 2.059(T) | 1.658(X) | 1.425(T) | 1.55(T) | 0.81(T) | 1.071(T) | 0.912(T) | 1.096(T) | 1.765(Y) |

As it can be observed in the Table 8, the moment-resisting frame system has the largest modal period at its first and second mode shapes, as well as it has the largest torsion in third mode. The mode shape values have been decreased after applying the bracing and shear wall systems with various configurations. Each configuration has an altered number of mode shapes and torsion, and it shows the effectiveness of the selected location for the shear wall or bracing systems in comparison with M-1. In this comparison, amongst all models, the model M-5 has the minimum modal period at both X and Y – Directions, whereas the models M-2 and M-9 have the worst modes of oscillation due to having the torsion in their first modes of oscillation.

5.7. Force Demand of Structural Element

The objective is to investigate the structure's force demand before and after employing the lateral load resisting elements (shear wall and bracing). M-1, M-5, and M-8 are considered to study their demand for shear force, axial force, and bending moment.

| Element Type | Shear Force (kN.m) | M-1 | M-5 | M-8 |
|--------------|--------------------|-----|-----|-----|
|              | Storey 1st | Storey 15th | Storey 1st | Storey 15th | Storey 1st | Storey 15th |
| Column C-1   | 9.28      | 32.02     | 93.97     | 5.82      | 8.93      | 34.58      |
| Column C-2   | 54.98     | 51.78     | 4.65      | 43.49     | 19.65     | 42.37     |

Figure 7. Shear Force in Moment Resisting Frame (M-1), Frame with Shear Walls at Periphery Corners (M-5) and Frame with Bracings at Middle of Periphery (M-8)
The investigation is carried out on the corner and middle columns at first and last floors. The force demand on members is checked for the most severe load combination 1.2(DL+LL+RSX). As it is shown in Table 9 and Fig.7, the shear force demand for the periphery columns is great at the base floor in M-1. It increases through the height of the building. As well the shear force demand is almost constant through the entire length of the building for the columns located at the middle portion of the building. From the M-5 it can be observed that the shear force is resisted by in-plane action of shear walls, but it is less at the top. The amount of force is getting expanded from the 2nd floor, and then it decreases through the height of the building. As most of the shear force is resisted by the shear wall, therefore, fewer amounts of shear forces are acting on the column. In M-8 as it can be observed, the force value gets enlarged from base to top of the building, but the bracings have less affect for minimizing the shear force in moment resisting frame, in M-8 the demand for shear force in moment resisting frame having bracing is less as compared to moment resisting frame with no bracing (M-1).

**Table 10. Axial Force Demand on Members of Buildings**

| Element Type | Axial Force (kN.m) | M-1 | M-5 | M-8 |
|--------------|---------------------|-----|-----|-----|
|              | Storey | Storey | Storey | Storey | Storey | Storey |
| Column C-1   | 1st    | 15th   | 1st    | 15th   | 1st    | 15th   |
|              | 1972.13 | 98.54  | 329.76 | 42.59  | 958.25 | 88.17  |
| Column C-2   | 2731   | 127.43 | 2270.13| 86.58  | 2702   | 111    |

![Figure 8. Axial Force in Moment Resisting Frame (M-1), Frame with Shear Walls at Periphery Corners (M-5) and Frame with Bracings at Middle of Periphery (M-8)](image)

**Table 11. Bending Moment Demand on Members of Buildings**

| Element Type | Bending Moment (kN.m) | M-1 | M-5 | M-8 |
|--------------|-----------------------|-----|-----|-----|
|              | Storey | Storey | Storey | Storey | Storey | Storey |
| Column C-1   | 1st    | 15th   | 1st    | 15th   | 1st    | 15th   |
|              | -13.27 | 42.95  | 42.52  | 3.60   | -13.94 | 45.90  |
| Column C-2   | 187.42 | 77.16  | 34.25  | 101.82 | 78.67  | 88.50  |
Figure 9. Bending Moment in Moment Resisting Frame (M-1), Frame with Shear Walls at Periphery Corners (M-5) and Frame with Bracings at Middle of Periphery (M-8)

As shown in the Table 11 and Figure 9, in M-1, the middle portion columns of the periphery in the lower storeys have maximum demand for bending moment. While it is fewer on the columns at the periphery, however, its value decreases through the length of the building. The maximum bending moment demand in M-5 is mostly on the base portion of the shear walls, and it decreases along with the height. The shear wall has absorbed most of the bending moment in first floor columns at middle of periphery after it was applied to the building; however, it is not same for the corner columns. The bending moment in M-8 is greater in the columns located at the middle portion of the periphery. The columns at the corners have lesser demand for bending moment as the bracing contribute them. The results show that the shear wall and bracing have directly influenced reducing the bending moment demand in columns of the building, which the model M-5 is efficient as compared to model M-1 and model M-8.

6. Conclusions
Based on the analytic studies, the following conclusion can be drawn.
1. The lateral force resisting capacity of the building is enhanced after employing the shear wall and bracing systems. The maximum stiffness in M-5 and M-8 obtained 90.91% and 71.28%, respectively. Comparing both systems’ capabilities in providing enough stiffness to the building, model M-5 has more stiffness, which is due to its best in-plane Stiffness action and mass of the building against the induced shear force.
2. After employing the shear wall and bracing systems, the storey drifts were reduced; the minimum storey drifts in the model M-5 and M-8 obtained by 53.53% and 60.14%, respectively. Comparing both systems’ functions, it can be observed that the model M-5 is more efficient due to proper position of shear walls.
3. Lateral displacement is directly proportional to the lateral stiffness and induced lateral force on the building. Absence of displacement prohibits the energy to be dissipated, and when the displacement is over the limit, the probability of structural damage and collapse is more. Comparing with model M-1, the model M-5 has the minimum storey lateral displacement (55.16%) for the shear wall system, and the model M-8 has the minimum percentage of storey lateral displacement (60.18%) for the bracing system. Among both models, the model M-5 has the least lateral displacement percentage, in which the displacement is controlled by shear wall due to its proper position and increased mass and in-plane stiffness.
4. Based on the overall comparison after applying the shear wall and bracing along the X and Y directions in the building, the maximum base shear values are obtained for the models M-5 and M-8 in both systems. In which the model M-5 is more stable against the lateral forces due to the proper configuration and variation in seismic weight of the building due to weight of shear wall.
5. The moment resisting building M-1 has the maximum fundamental period. Adding or removing any lateral load resisting system will alter the period of the structure. The fundamental period in model M-5 and M-8 were reduced by 47.90 and 39.31%, respectively as compared to model M-1. Comparing both models’ period, the model M-5 oscillates with the least period which is safe during an earthquake. This is due to the proper position of shear wall in the building.

6. The force demand comparison of moment-resisting frame, frame with shear wall system and frame with the bracing system has shown that the moment-resisting building (M-1) has the greatest demand of forces, while the force demand in the model M-8 is less due to the applied bracing system at the middle of the periphery. Similarly, in the model M-5, it was observed that most of the axial force, shear force, and bending moment are directed to the shear walls and fewer amounts of these forces observed in the columns. The model M-5 has found as a suitable structural system. It can be attributed to the in-plane action and participation in taking the induced forces on the frames.

7. Configuration of the bracing and shear wall systems should be done with no stiffness eccentricity. To avoid the early torsion in the building, the torsional stiffness of the building has to be increased. Such preparation can be achieved by proper configurations of shear wall and bracing. Models M-2 and M-9 have torsion at their first mode of oscillation due to openings in shear wall, which is not safe. In some models, the modal period was large in the long direction, which was due to ineffective configuration and variable span. In both directions the model M-5 has least modal period.

8. Shear wall twists the coupling beam due to its inappropriate configuration, for which the cross-section of the beam should be enlarged along with increase in reinforcement.

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