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Effect of Edge Beam and Shear Wall on the Structural Behavior of Flat Plate Multistoried Building: A Computing Modeling for lateral load Analysis

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Abstract: *A computing modeling approach has been carried out to understand the rigid frame structural behavior of eight storied commercial building due to incorporation of edge beams and shear walls into the flat plate structure. In this study, numerical analysis based on finite element method for reinforced concrete building materials and static lateral loading conditions has been conducted The lateral loads including earthquake and wind loads were applied using ETABS software package to the building model along both long and short direction as per Bangladesh National Building Code 2006 (BNBC). Based on computing modeling output data, a comparative study has been performed to understand the effect of edge beam and shear wall on the structural behavior of flat plate buildings. The results show that lateral displacements as well as lateral drifts are found smaller in case of edge beam and the smallest for shear walls while compared to flat plate building only. It is also found that in case of shear wall the maximum axial compressive force at interior column is reduced by 10.6 % but this reduction is about 2.9 % in case of edge beam while compared with flat plate system.*

Keywords: *Flat plate slab, Lateral drift, Edge beam, Shear wall.*

1. Introduction

Concrete slabs are often used to carry vertical loads directly to walls and columns without the use of beams. Such a system is called ‘Flat Plate’ whose spans are not large and at the same time loads are not heavy to transfer. Flat plate slabs are solid concrete slabs of uniform depth that transfer loads directly to the supporting columns without the aid of beams, column capitals or drop panels. They are probably the most commonly used slab system today for multi-storey reinforced concrete hotels, motels, apartment houses, hospitals and dormitories. Flat plate slabs are generally constructed for a thickness of 125

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to 250 mm for spans of 4.5 to 6m (F.A. Sayed et.al, 2012). This floor system has an advantage of introducing an edge beam at the periphery of the panel to reduce the deflection of the exterior panel. The main disadvantage of this floor system is their lack of resistance to lateral loads. Hence special features like shear walls, structural walls are to be provided if they are to be used in high rise constructions. Flat plate system is widely adopted by engineers as it provides many advantages such as flexibility in room layout, reduction of floor height, shorter construction time. These advantages further result in reduction in material cost. In the flat plate system, slab-column connection is always subjected to combination of high bending moments and shear stresses. H.S. Kim and D.G. Lee (2005) studied a review about the flat plate system which has been adopted in many buildings constructed recently due to the advantage of reduced floor heights to meet the economical and architectural demands. Viswanathan T.S et. al. (2012) carried out a study on the shear stress distribution of flat-plate using Finite Element Analysis.

Shear walls are specially designed structural walls incorporated in buildings to resist the lateral forces that are produced in the plane of the wall due to wind, earthquake forces. In an earthquake, heavy wind affected prone zones the infill wall panels attract large lateral forces and are damaged, or the perimeter columns, beams and their connections fail. It is always advisable to incorporate them in buildings built in regions likely to experience earthquake of large intensity or high winds. They are usually provided between columns, in stairwells left wells, toilets, utility shafts etc. Their thickness can be as low as 150 mm, or as high as 400 mm in high rise buildings (F.A. Sayed et.al, 2012). Shear walls are usually provided along length and width of the buildings. Shear walls are like vertically oriented wide beams that carry lateral loads downwards to the foundation. L.G. Jaeger et. al. (1973) studied the structural analysis of tall buildings having irregularly positioned shear walls. Husam Omar and Glenn Morris (1991) studied a review about a procedure which is described for performing a linear structural analysis of laterally loaded three-dimensional flat plate structures, with or without shear walls. F.A. Sayed et.al (2012) performed a comparative analysis of flat plate multistoried frames with and without shear walls under wind loads. The study revealed that the column moments for flat plate floor system with shear walls are decreased by 69.17% when compared with flat plate system only. It has also been found that the column axial forces are less in flat plate system with shear wall compared to flat plate system only.

The main objective of the present study is to investigate the structural behavior of reinforced concrete flat plate building subjected to static load, lateral wind and earthquake loading. At first, eight storied flat plate building has been modeled and then linear static analysis has been performed due to dead load, super dead load, live load, wind and earthquake load. Three different cases have been considered for the study. Those cases are Building with Conventional Flat plate floor system; Flat plate system with Edge beam; Flat plate system with Shear Wall. Finally a comparative study has been made to understand the effect of edge beam and shear wall on the structural behavior of flat plate structure. This comparative study has been mainly carried out on lateral storey displacement, lateral drift, storey shear, column axial forces and bending moments at different storey level of the building.

2. Modeling Approach

In the present study, eight storied Reinforced Concrete (RC) commercial building has been modeled and then analyzed using ETABS software package. The total height of the building considered for the study is 86 ft. The height of each storey is 10 ft and all the floors are considered as typical floors. The plan area of the structure is 126 ft ×100 ft with columns spaced at 18 ft from centre to centre in long direction and at 20 ft from centre to centre in short direction. The plan view of the structure is shown in Figure 1.

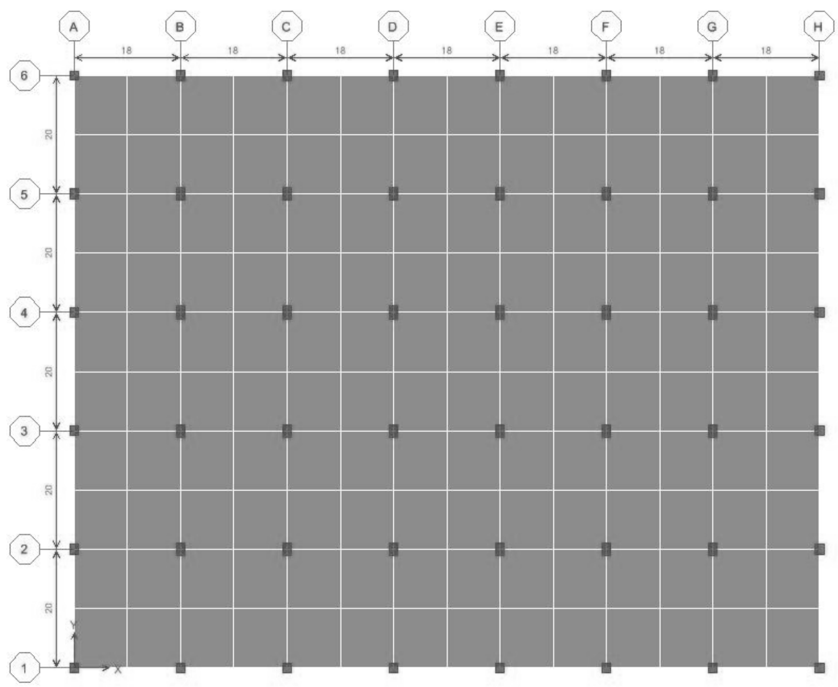

Figure 1: *Layout Plan of Flat Plate building*

The location of the building is assumed to be at Dhaka city of Bangladesh. In modeling, the material properties and geometric properties used for the structure have been given in Table 1 and 2 respectively.

Table 1: Material properties used in Flat Plate RC buildings

Type of Material	Properties	Unit	Value
Concrete	Modulus of elasticity	ksi	2900
	Density	pcf	150
	Poisson's ratio	----	0.15
	Damping ratio	----	5%
	Compressive Strength	ksi	4
Steel	Yield strength	ksi	60

Table 2: Geometric properties of the buildings

Name of parameter	Value	Unit
Number of stories	8	---
Each Storey height	10	ft
Total height of the structure above base	86	ft
Length in long direction	126	ft
Length in short direction	100	ft
Thickness of Slab	8	inch
Column size Corner: Exterior: Interior:	 18×18 18×20 18×26	inch × inch
Edge Beam size	16 × 28	inch × inch
Grade Beam size	12 × 18	inch × inch
Thickness of Shear wall	10	inch

The following three cases have been considered for the study:Case I: Conventional Flat plate floor system; Case II: Flat plate floor system with Edge beam; Case III: Flat plate system with Shear Wall.

All those cases are considered for comparison with respect to the height of the structure. Comparison was made with lateral displacement, storey drift, storey shear, column axial forces, bending moments. Each Flat plate panel of the building is properly meshed and the size of the meshes is maintained closer to aspect ratio 1. 3D view of the flat plate building with edge beams has been shown in Figure 2. Layout plan and 3D view of flat plate structure having lift cores are also shown in Figure 3 and 4 respectively.

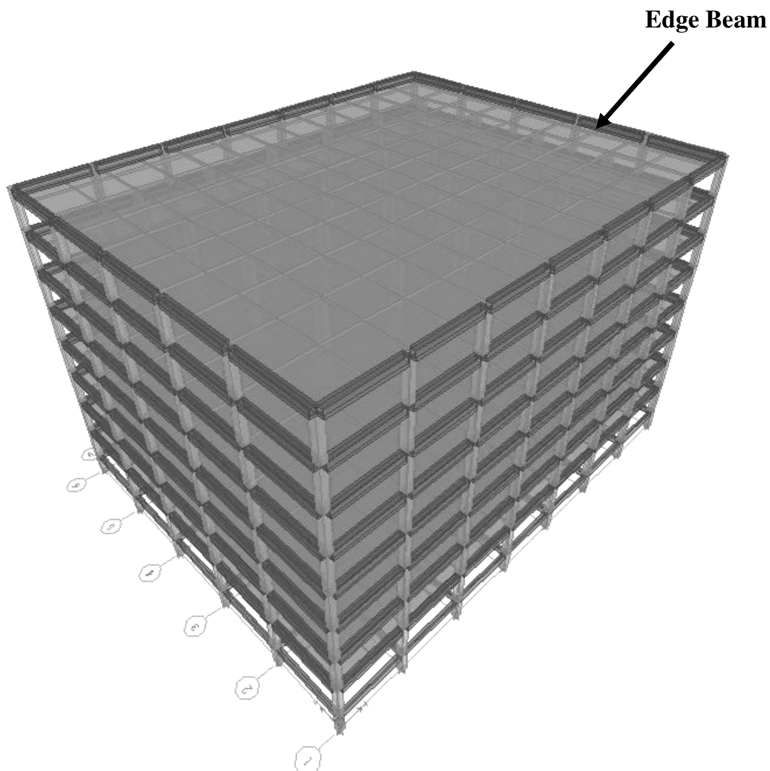

Figure 2: *3D view of Flat Plate building with Edge Beam*

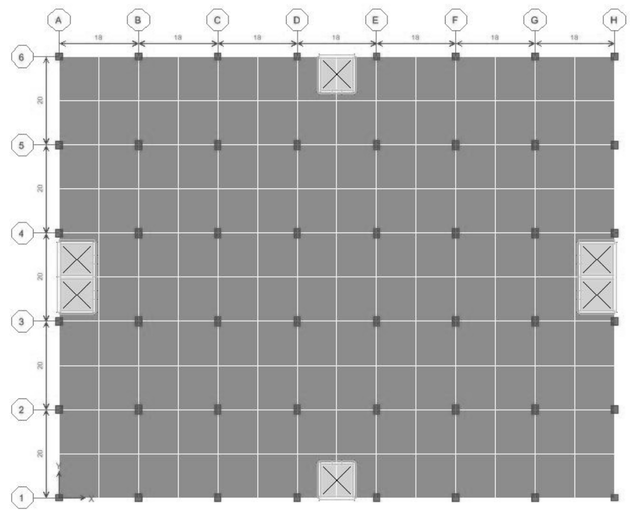

Figure 3: *Layout Plan of Flat Plate building with lift cores at four different positions*

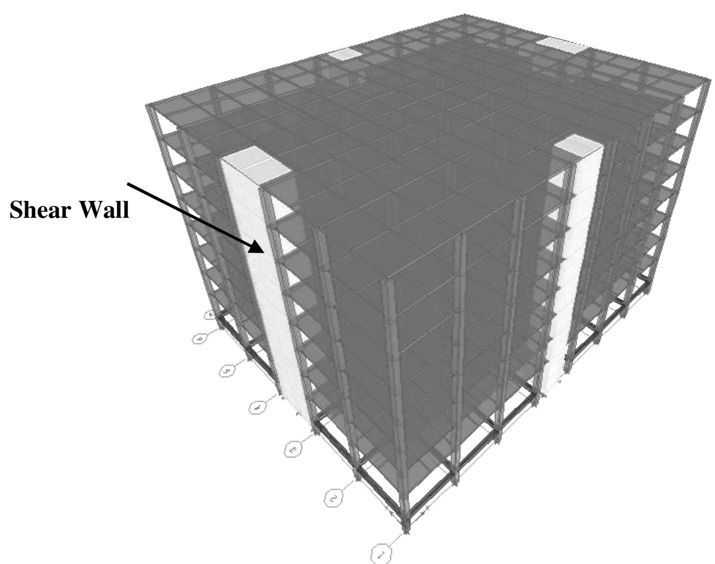

Figure 4: *3D view of Flat Plate building with Shear Wall*

3. Loading Approach

Different loads that are applied on the slab of the structure are given in the following Table 3.

Table 3: Applied loading on the slab

Type of load	Name of Load	Value	Unit
Super Dead Load	Partition Wall	100	psf
	Floor finish	30	psf
	Lime concrete on roof	30	psf
Live load (LL)	Live load	60	psf

For the analysis, the wind and earthquake loading was calculated as set forth by the provision of Bangladesh national building code (BNBC, 2006).According to the following Tables 4 and 5, different coefficients and parameters have been used for the wind (W) and earthquake (Eq) loading that have been applied to the structure.

Table 4: Different coefficients taken into account for the calculation of seismic load

Name	Symbol	Value	Description
Seismic Zone Coefficient	Z	0.15	Zone 2 (Dhaka)
Structural Importance Coefficient	I	1	Standard occupancy Structure
Site Coefficient	S	1.2	Soli profile type S2 (deep cohesionless or stiff clay)
Response Modification Co-efficient	R	8	Intermediate Moment Resisting frame

Table 5: Coefficients or parameters taken into account for the calculation of wind load

Name	Symbol	Value	Description
Terrain Exposure Category	A	---	Urban and sub-urban areas
Basic wind speed	V_b	210 km/hr	Dhaka city
Structural Importance Coefficient	C_I	1	Standard occupancy Structure (Commercial)

4. Results and Discussion

4.1 Lateral Displacement

The variation of lateral displacement along short direction with storey level has been clearly shown in Figure 5.

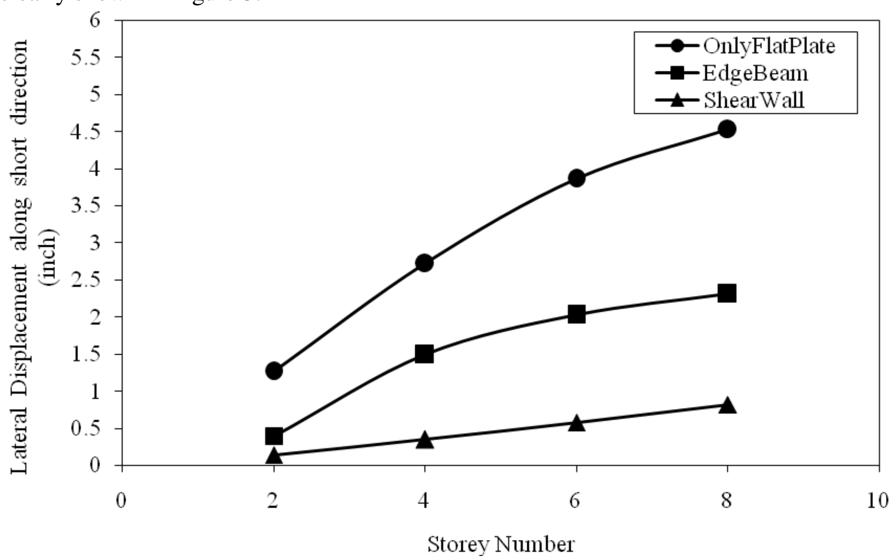

Figure 5: *Lateral displacement along short direction at different storey for 1.05 DL+ 1.275LL+1.4EqY*

From Figure 5 it has been observed that maximum lateral displacement is decreased by 47% in case of edge beam whereas the reduction is nearly 81% for shear wall while compared to flat plate structure. Here only the maximum effect has been considered for the comparison. F.A. Sayed et.al (2012) performed a comparative analysis of flat plate multistoried frames with and without shear walls under wind loads. The study shows that due to static load including dead, live and wind load the maximum lateral displacement for flat plate floor system with shear walls is decreased by 75% when compared with flat plate system only. Thus it has been obtained from both of the studies that the lateral displacement is significantly reduced due to the presence of shear walls.

4.2 Storey drift

The variation of lateral Drift along short direction with storey level has been clearly depicted in the following Figure 6.

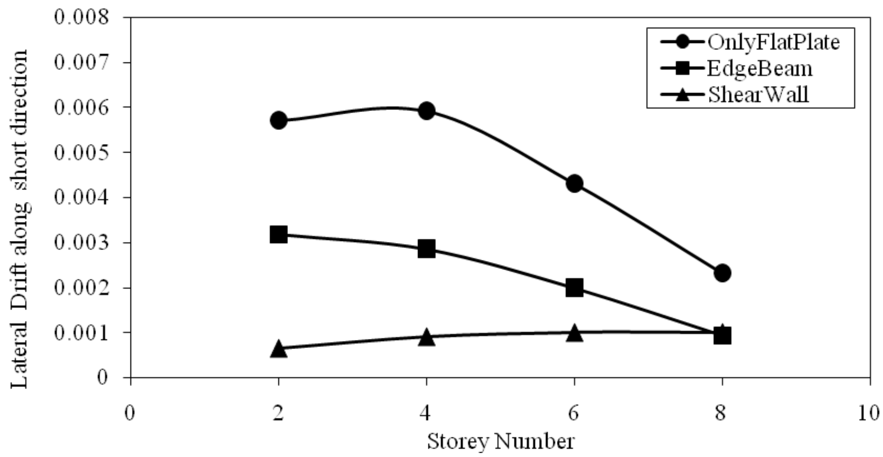

Figure 6: *Lateral drift along short direction at different storey for 1.05 DL+ 1.275LL+1.4EqY*

Figure 6 shows that lateral drift is greatly reduced due to shear wall and it can be clearly seen that storey drifts are nearly same throughout the height of the building in case of shear wall. However lateral drift is also reduced in case of edge beam but the reduction is not as much as shear wall. In addition, it has been found that maximum storey drift occurs at fourth storey in case of flat plate floor system which is 0.0059. According to BNBC, the maximum storey drift is limited to 0.03 h/R which is 0.104 where h is the height of the building structure in metre. It is to be noted here that the obtained maximum storey drift is well below this limiting value. F.A. Sayed et.al (2012) performed a comparative analysis of flat plate multistoried frames with and without shear walls under wind loads. The study shows that the maximum lateral drift for flat plate floor system with shear walls is decreased by 65.77% when compared with flat plate system only. In the present study, it has been found that in case of shear wall lateral drift is reduced by 83.33 % while compared with flat plate system only. Thus it has been obtained from both of the studies that the lateral drift is significantly reduced due to greater lateral stiffness of the shear walls.

4.3 Storey Shear

The variation of Story shear with storey level has been clearly shown in following Figure 7.

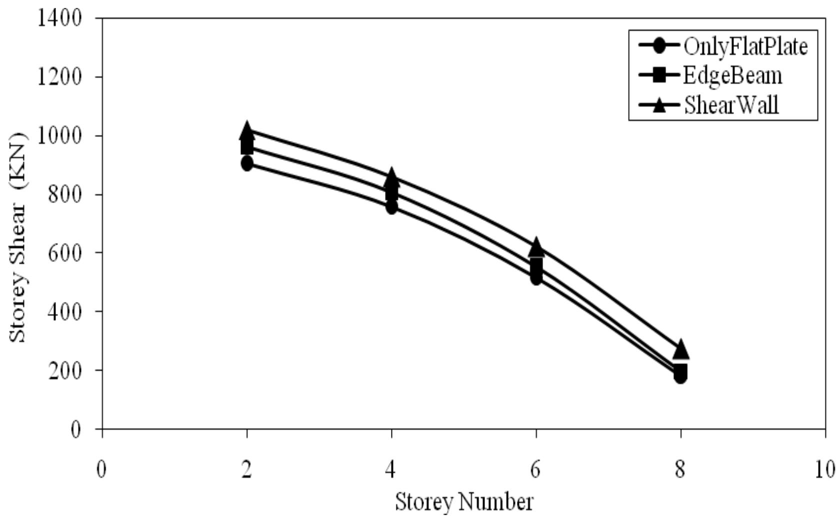

Figure 7: *Storey Shear along long and short direction at different storey for 1.05 DL+ 1.275LL+1.4Eq* $_{X\ or\ Y}$

From Figure 7, it is evident that storey shears are the largest in case of flat plate building with shear walls as logically expected. It has also been found that the reducing trend of storey shear is almost same for all cases. It is also needed to add here that the storey shears remain same along both long and short direction for those load cases.

4.4 Column Axial Forces

Under factored dead and live load the axial forces at the base of the column is the highest in all of the cases. The variation of axial forces in interior column (5D position near lift core) and exterior column (2A position) with storey level have been shown in Figure 8 and 9 respectively.

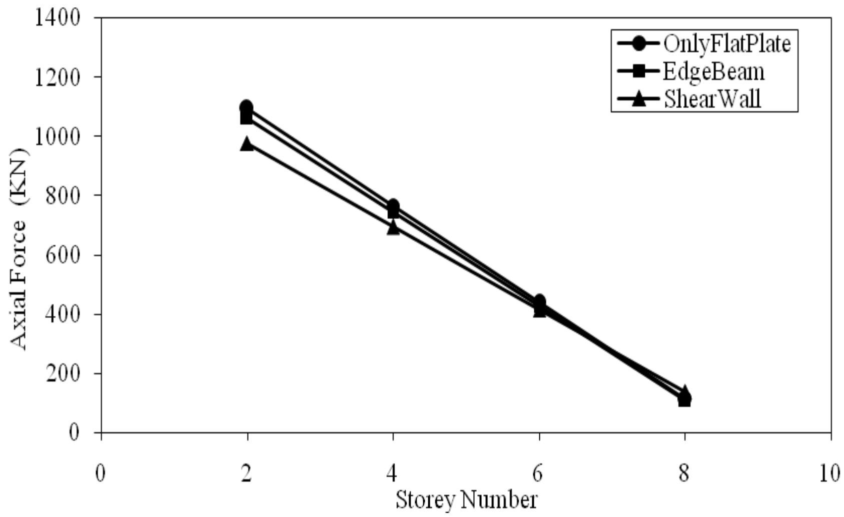

Figure 8: *Axial force in Interior Column (5D position) at different storey for 1.4DL+1.7LL*

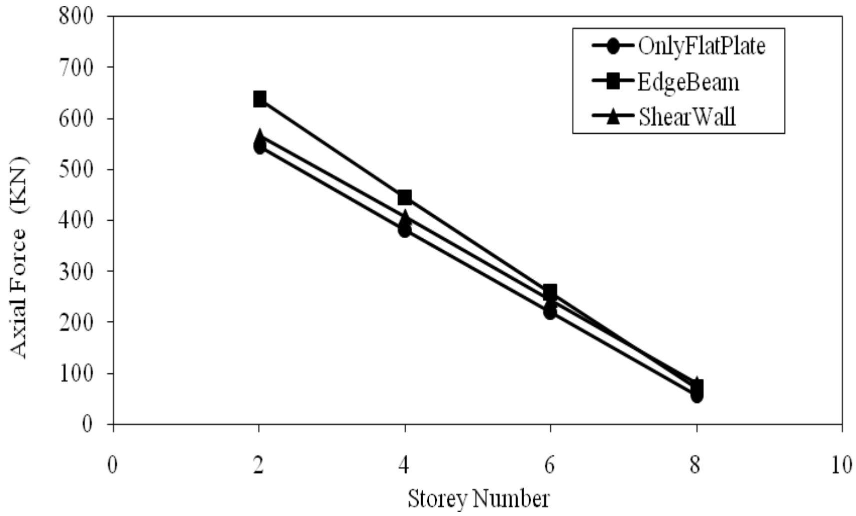

Figure 9: *Axial force in Exterior Column (2A position) at different storey for 1.4DL+1.7LL*

From Figure 8, it can be noted that in case of flat plate system with shear wall the maximum axial force at interior column, which is very close to the lift core, is the lowest among three cases. This is because shear walls are considered as an integral element of the building and as such it contributes towards sharing of some of the axial force. Furthermore, it can be said that column axial forces in case of edge beam are little less when compared to flat plate system only. Most importantly, in case of shear wall the maximum axial compressive force is reduced by 10.6 % and this reduction is about 2.9 % in case of edge beam when compared with flat plate system only. In another figure 9, it is clear that axial forces in exterior column are the largest in case of edge beam as logically expected. It has also been obtained that the column axial forces in flat plate system with shear wall are very close to that of flat plate system only. F.A. Sayed et.al (2012) performed a comparative analysis of flat plate multistoried frames with and without shear walls. The study shows that the column axial forces for flat plate floor system with shear walls are decreased by 28.57% when compared with flat plate system only due to dead and live load. Thus it has been obtained from present and previous studies that column axial forces are notably decreased due to the shear walls.

4.5 Column Bending Moments

The variation of bending moments in interior column (5D position near lift core) and exterior column (2A position) with storey level have been shown in Figure 10 and 11 respectively.

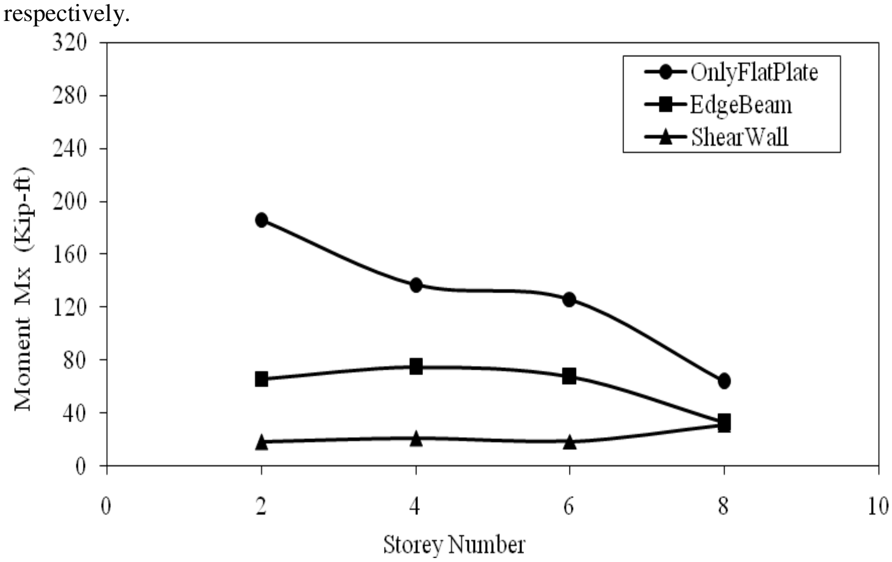

Figure 10: *Maximum Moment M_x in Interior Column (5D position) at different storey*

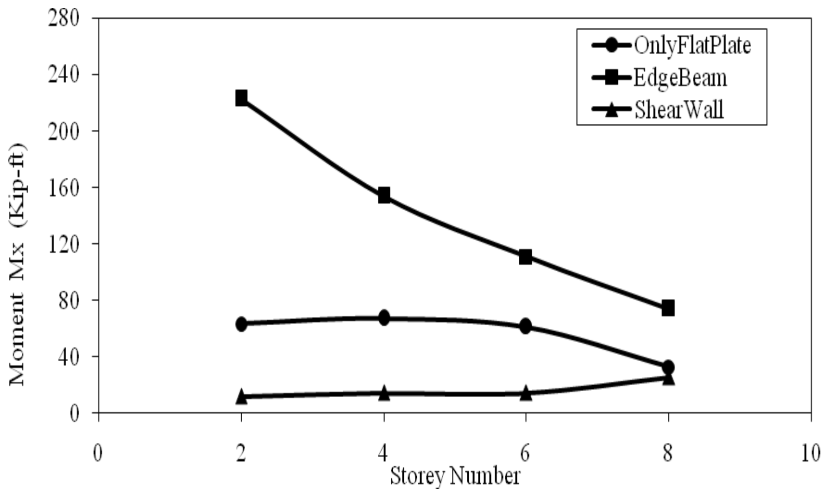

Figure 11: *Maximum Moment M_x in Exterior Column (2A position) at different storey*

From Figure 10 an 11, it is quite apparent that in case of flat plate system with shear wall the bending moments about x-axis (M_x) in both exterior and interior column are the smallest among three cases. It is also observed that in case of edge beam bending moment in interior column is also less than that of flat plate system but in exterior column it is greater than flat plate system as logically expected. F.A. Sayed et.al (2012) performed a comparative analysis of flat plate multistoried frames with and without shear walls under wind loads. The study shows that the column moments for flat plate floor system with shear walls are decreased by 69.17% when compared with flat plate system only due to static load including dead, live and wind load. In the present study, it has been found that in case of shear wall column moment at exterior column is reduced by 89 % while compared with flat plate system only due to static load including dead, live, wind and earthquake load. Thus it has been obtained from the aforementioned studies that shear walls do cause the substantial amount of reduction in column bending moments. Hence it is clear that flat plate building with shear wall is very much strong in resisting lateral loading.

5. Conclusion

The following conclusions have been drawn from the present study:

- Flat plate floor system with shear walls helps in reducing maximum lateral displacement by 81 % whereas the reduction is nearly 47 % in case of edge beam while compared to flat plate building. Hence it can be said that shear wall provides greater lateral stiffness to the structure.

- Although edge beam reduces lateral drift considerably but this reduction is huge in case of shear wall when compared to flat plate floor system. It has been found that in case of shear wall lateral drift is reduced by 83.33 % while compared with flat plate system only but this reduction is about 46.67 % in case of edge beam when compared to flat plate system.
- In case of flat plate building with shear wall, the maximum axial compressive force at interior column near lift core is reduced by 10.6 % and this reduction is about 2.9 % in case of edge beam when compared to flat plate system. As the column axial forces are very much reduced in case of flat plate building with shear walls hence the design of column becomes more economical if shear walls are incorporated in flat plate building.
- In case of flat plate system with shear wall, the reduction in column bending moment is great in both exterior and interior column while compared to flat plate system only.
  It has been found that in case of shear wall column bending moment at exterior column is reduced by 89 % while compared with flat plate system only.

Finally, it can be concluded from the present study as well as from structural point of view that under lateral loading the structural response of flat plate structure as rigid frame system can be very much improved by incorporating edge beams or shear walls. However, it is evident from the present study that in flat plate system with shear walls the lateral drifts and column reactions such as axial forces and bending moments are considerably less than that of the structure with edge beams. Therefore it can be strongly suggested that provision of flat plate system with shear walls is one of the best choices to safeguard against lateral loading.

Recommendations

For future work the following suggestions may be considered:

- Structural analysis of flat plate floor system considering the overhanging slab at the outer perimeter can also be done to see the overall effect on the structural behavior.
- The study of the flat plate system including both the edge beam and shear wall can also be carried out for better understanding of the combined effect of shear wall and edge beam on flat plate structure.

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