The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 06 || Series I || Pages || PP 50-56 || 2020 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

A Study on Elastic Behavior of RC Regular Rectangular Building for Different Slab Systems under lateral loads

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ABSTRACT

Now-a-days, the construction of high-rise building is ever increasing due to the limitation of space in horizontal direction in urban areas. Even the vertical extension can be commonly seen in urban areas of developing countries like Bangladesh. However, Bangladesh is situated at earthquake prone region. Therefore, it is important to consider lateral loads in designing high-rise building emphasized on storey drift. In this present study, a ten-storied RC regular rectangular building has been studied under lateral loads-seismic and wind-using finite element based computer software ETABS (version 9.6) for five different slab systems. Five slab systems are edge supported slab with deep beams, column supported slab with interior shallow beams, flat plate with edge beams and without cantilever portion, flat plate with cantilever portion and without edge beams, and flat plate without cantilever portion and without edge beams. Storey drift for every storey and inter storey drift index have been calculated for lateral loads for all five conditions and compare with allowable drift limitations. The result shows, the building with flat plate without cantilever portion and without edge beams may be vulnerable under lateral loads.

Keywords: *Ten-storied RC building; slab systems; lateral loads; storey drift; inter storey drift index*

Date of Submission: 28-05-2020 | Date of Acceptance: 14-06-2020

I. INTRODUCTION

High rise building construction with flat plate slab systems has been increased in recent time in the towns and cities especially in the densely populated countries like Bangladesh, China, India and Singapore etc. In the structural aspect the building without deep beam is not recommended in high rise structure as these structures are vulnerable under lateral loads –seismic and wind. In the earthquake prone areas, the structures are almost prohibited predicting probable disaster due to lateral loads. Structural engineers, specialists and researchers have suggested to add shear walls to mitigate the problem reducing vulnerability and improving strength passing lateral loads through it. But in the developing countries, a considerable portion of high rise building have been constructed with flat plate without any shear walls, that is vulnerable under all kinds of lateral loads-seismic and wind.

Building with flat plate slab systems with and without shear walls was started to practice in the beginning of the 1960s for medium to high rise buildings in cities and town areas in USA, Japan, Canada, Chile, Romania, Turkey, Colombia, etc. Later the construction technique was adopted in the other parts of the world and now in almost all metropolitan towns and cities experienced this. Owners and construction authorities prefer flat plate systems for the easiness to arrange rooms and aesthetic views. As the construction pattern is almost new, a few well established research articles can be found in available sources. As making a prototype of high rise building coping with actual environment is much more expensive, hard work and sometime impossible, most of researchers used finite element based computer software ETABS [3], ABAQUS, SAP-2000 and STAAD.pro to analyze their studies.

Some research have been found over drift and displacement of civil structures considering various structural conditions-heights of the structure, beam-column connections, shear wall length and positions. A significant numbers of researchers investigated about drift and displacement of building, with and without shear walls [9, 28], by arranging shear walls at various locations and configurations in the structural framing system [18], considering the ratio of strength to steel weight and their ductility [24], performance of steel place shear walls [11] and size of opening [17]. Another major group of researchers [6, 12, 21, 23, 25, 26, 27, 29] studied about suitable position in both the global and local directions chaining locations in RC building with shear walls and observed displacement and drift (elastic and plastic behaviors) of the building under laterals loads.

Several others significant studies have been carried out over the time to investigate the strength of structure considering various structural properties such as shear wall length variations [14], shear wall height [20], corner slab-column connections [10], initial punching shear failure [16, 22] and to find optimum design reinforcement concrete flat slab with drop panel [19].

However, a few researchers studied to find lateral drift and displacement using conditional variations of slabs. Lateral drift and displacement was investigated under lateral loads considering effective bean width [13], comparing with flat slabs with drops to the two way slabs with beams in multi storey buildings [15], column supported slab with interior shallow beams [7] and typical flat slab building [8].

In this study, storey drift and displacement of a ten-storied RC regular rectangular building under lateral loads-seismic and wind- has been investigated under five slab conditions. Five considered slab systems are edge supported slab with deep beams, column supported slab with interior shallow beams, flat plate with edge beams and without cantilever portion, flat plate with cantilever portion and without edge beams, and flat plate without cantilever portion and without edge beams. Finite element based computer software ETABS (version 9.6) has been used to analyzed data.

II. LITERATURE REVIEW

Wind and seismic (earthquake) loads are considered as the lateral loads on a tall building. During the design in Bangladesh and most other countries, some specific equations are followed. Here, equations are followed according to BNBC 2006 [1], design guide for Bangladesh.

2.1 Wind Load

Wind pressures are generally calculated for two types-sustained wind pressure and design wind pressure.

Sustained wind pressure, q_z on a building surface at any height z above ground can be calculated from the following equation.

$$q_z = C_c \times C_i \times C_z \times {V_b}^2 \qquad (1)$$

Here, q_z, sustained wind pressure at height z , (KN/m), C_c, velocity to pressure conversion coefficient, C_i, structural importance coefficient, C_z, combined height and exposure coefficient, V_b , basic wind speed in Km/hr[1].

Again, design wind pressure, P_z for a structure or an element of a structure at any height, z above mean ground level can be determined from below equation.

$$P_z = C_G \times C_P \times q_z \qquad (2)$$

Here, P_z, design wind pressure at height z (KN/m), C_G, gust coefficient, C_p, pressure coefficient for structures or components, q_z, sustained Wind pressure [1].

2.2 Seismic Load

Based on the height, location and other properties of structures, two methods are available to calculate seismic load. Those methods are equivalent static force method and dynamic response method. Considering the properties of out structure, equivalent static force method is used here to calculate earthquake load and to distribute them in different height.

Following the method mentioned above, design base shear is determined using following equation.

$$V = \frac{ZIC}{R} W \qquad (3)$$

Here, V, design base shear, Z, seismic zone coefficient, I, structural modification coefficient, R, response modification coefficient for structural system, W, total seismic dead load, C, numerical coefficient.

Numerical coefficient, C, can be found from the equation.

$$C = \frac{1.25\,S}{T^{2/3}} \qquad (4)$$

Here, S, site coefficient for soil characteristics, T, fundamental period of vibration in seconds, of the structure for the direction under consideration.

Fundamental period of vibration in seconds of the structure, T, can be known using the formula.

$$T = C_t (h_n)^{3/4} \qquad (5)$$

Here, h_n, height in meters above the base to top level n and C_t, constant based on the structural properties.

C_t = 0.083 for steel moment resisting frames,

= 0.073 for reinforced concrete moment resisting frames and eccentric braced steel frames.

= 0.049 for all other structural system.

The base shear, V, is distributed along the height of the structure according to the following equation.

$V=F_i+\sum F_t$ (6)

Here, V, base shear, F_i, lateral force applied at the storey level i, F_t, concentrated load at the top of the building in addition to the force F_n.

$F_t=0.07TV\leq 0.025V$ when T>0.7 second

$F_t=0$ when $T\leq 0.7$ second

The remaining portion of the base shear ($V-F_t$) shall be distributed over the height of the building included level n, according to the following equation [1].

$$F_x=\frac{(V-F_t)w_x h_x}{\sum_{i=1}^{n} w_i h_i} \quad (7)$$

2.3 Drift

Total lateral displacement at any storey is called total drift of the storey. The relative lateral displacement between two consecutive levels is known as inter storey drift.

Storey drift, Δ, shall be limited as according to the following rules.

$\Delta \leq 0.04h/R \leq 0.005h$ for T<0.7 second

$\Delta \leq 0.03h/R \leq 0.004h$ for $T\geq 0.7$ second

$\Delta \leq 0.025h/R$ for unreinforced masonry structures

Here h, height of the building structure and T, time period in second.

The period, T, used here, is same as that used for determining the base shear. The limits involving R in shall be applicable only when earthquake forces are present.

Inter storey drift index limitations are used 0.001 to 0.005 [2]

The Inter storey drift index limitations can be calculated from the above equations. According to the BNBC, 2006 code,

Inter storey drift index limitations = Storey drift/height of the storey

III. DATE PREPARE

3.1 General Data

A ten-storied regular rectangular (60ft ×40ft) building studied here considering five cases. The five cases are edge supported slab with deep beams (Case-1), column supported slab with interior shallow beams (Case-2), flat plate with edge beams (Case-3), flat plate with cantilever portion and without edge beams (Case-4), and flat plate without cantilever portion and without edge beams (Case-5). Properties of five cases are given below in table 1.

Table 1: Case properties of the building

Case	Interior Beam Dimension	Edge Beam Dimension	Slab Thickness	Length of Cantilever
Case-1	12in×30in	12in×30in	5in	No
Case-2	18in×15in	12in×30in	5in	No
Case-3	No	12in×30in	9in	No
Case-4	No	No	9in	4ft
Case-5	No	No	9in	No

Other properties of the building are listed in table 2.

Table 2: Other properties of the building

Storey Height Per floor	Length Global X- direction	Length Global Y- direction	Column Dimension	Material
10 ft	60 ft	40 ft	21 in × 21 in	Reinforced Concrete

3.2 Material Properties

a Compressive strength of Concrete, f_c' = 4000 psi

b Yield stress of steel, f_y = 60,000 psi

c Modulus of elasticity of concrete, E = 3,600,000 psi

3.3 Plan Layout
The conventional high rise building structures contain very complex layout but here in this study a simple layout (Figure 1) is considered.

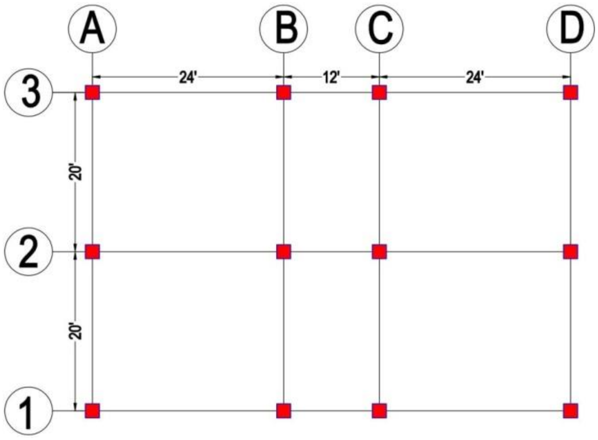

Figure-1: Typical floor plan without beams

3.4 Load Applied
Vertical Loads Applied on the building is shown in table 3.

Table 3: Loads applied on the building

Load Type	At the roof (psf)	Rest of the Storey (psf)
Dead Load	112.5	162.5
Live Load	0	40

3.5 Lateral Load (Wind)
Wind load has been calculated in global X and Y directions using the equations (1) and (2) (literal review) using excel sheet following the direction of Bangladesh National Building Code (BNBC 2006) and data is listed in table 4.

Table-4: Wind Load in global X and Y directions

Storey	Height from GL (m)	Force in X direction		Force in Y direction	
		KN	Kip	KN	Kip
1	3.04	293.58	66.00	308.02	69.25
2	6.08	333.79	75.04	350.20	78.73
3	9.12	399.52	89.82	419.17	94.23
4	12.16	453.93	102.05	476.26	107.07
5	15.2	501.16	112.67	525.81	118.21
6	18.24	543.36	122.15	570.08	128.16
7	21.28	581.81	130.80	610.43	137.23
8	24.32	617.31	138.78	647.67	145.60
9	27.36	650.34	146.20	682.33	153.39
10	30.4	681.45	153.20	714.97	160.73

3.6 Lateral Load (Seismic)
According to UBC 1994, earthquake load is calculated in excel sheet considering the following conditions using the equations (3) to (5) (literature review).
a Zone coefficient, Z= 0.25 (Considering seismic zone 3).
b Site coefficient, S= 1.5 (as soil condition is unknown).
c Structural importance coefficient, I = 1 (Standard occupancy structures).
d C_t = .073 (for concrete moment resisting frames).
e Response coefficient R = 12 (for special moment resisting frames concrete).
The calculated load is distributed along the storey level using the equations (6) and (7) and has putted into ETABS at point load.

3.7 Drift
Limited storey drift and inter storey drift index were calculated using equations in section 2.3.

IV. RESULT ANALYSES

4.1 Lateral Drift

Lateral drifts were calculated using data in section 3 and ETABS (version 9.6) and presented here in graph-vertical storey level and horizontal lateral drift in inch.

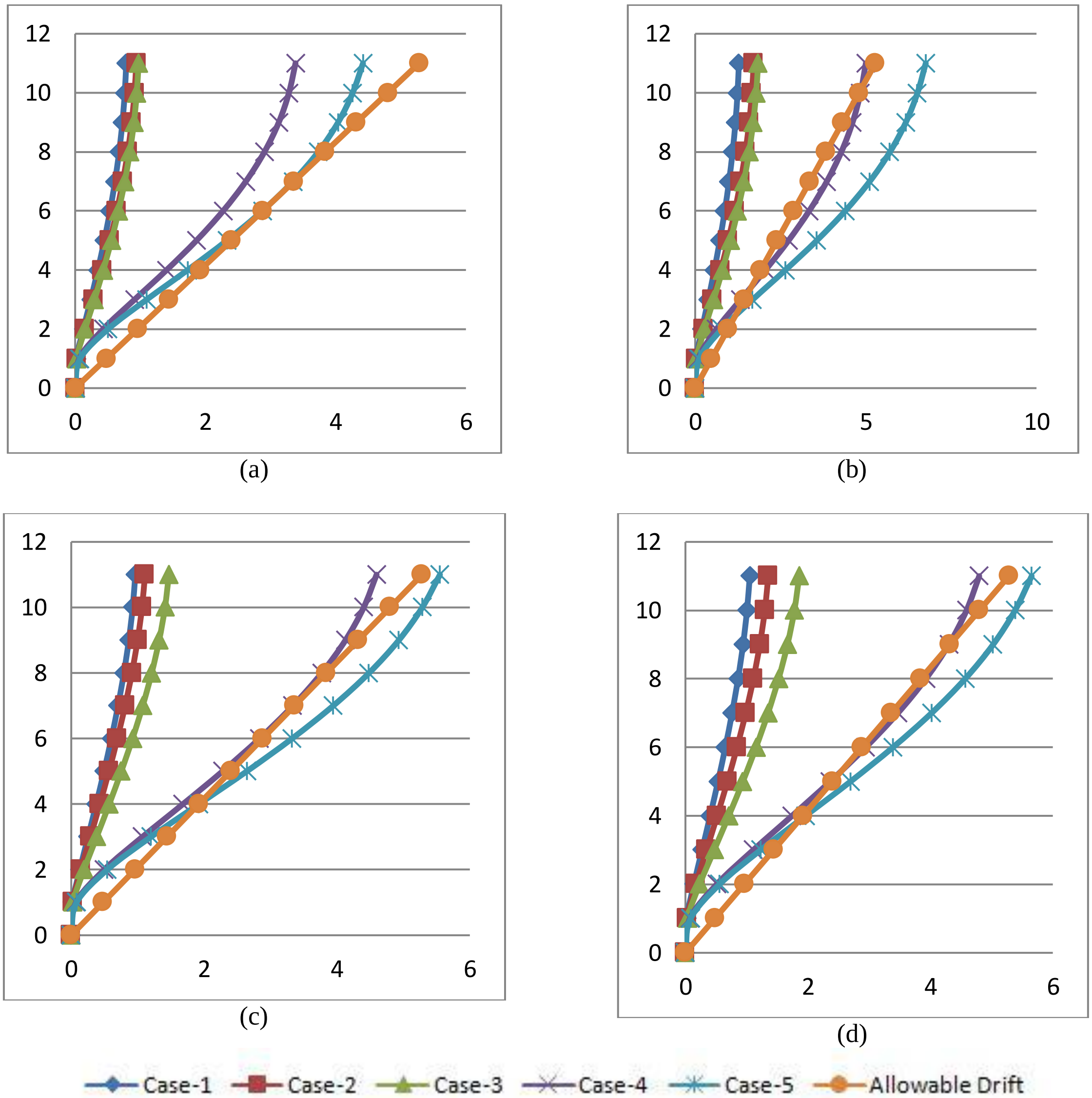

Figure-2: Lateral drifts in inch (a) in global X-direction, (b) in global Y direction for wind load and (c) in global X direction, (d) in global Y direction for earthquake load.

From above figures (Figure -2), it is seen that drift increases with height of the building. Case-1 shows the lowest value for both wind and seismic load and gradually increases in next cases. The magnitude of drifts along the short direction found slightly higher than long direction. The drift due to wind load in global X direction (long direction) for all five cases don’t exceed allowable limits but the drifts due to wind load in global Y direction (short direction) and drift due to earthquake loads in both directions exceed allowable limits for case 4 (flat plate with cantilever portion and without edge beams) and case 5 (flat plate without cantilever portion and without edge beams).

4.2 Inter storey drift index

Inter storey drift indexes were calculated using data in section 3 and presented here in graph-vertical storey level and horizontal lateral drift index in inch per inch.

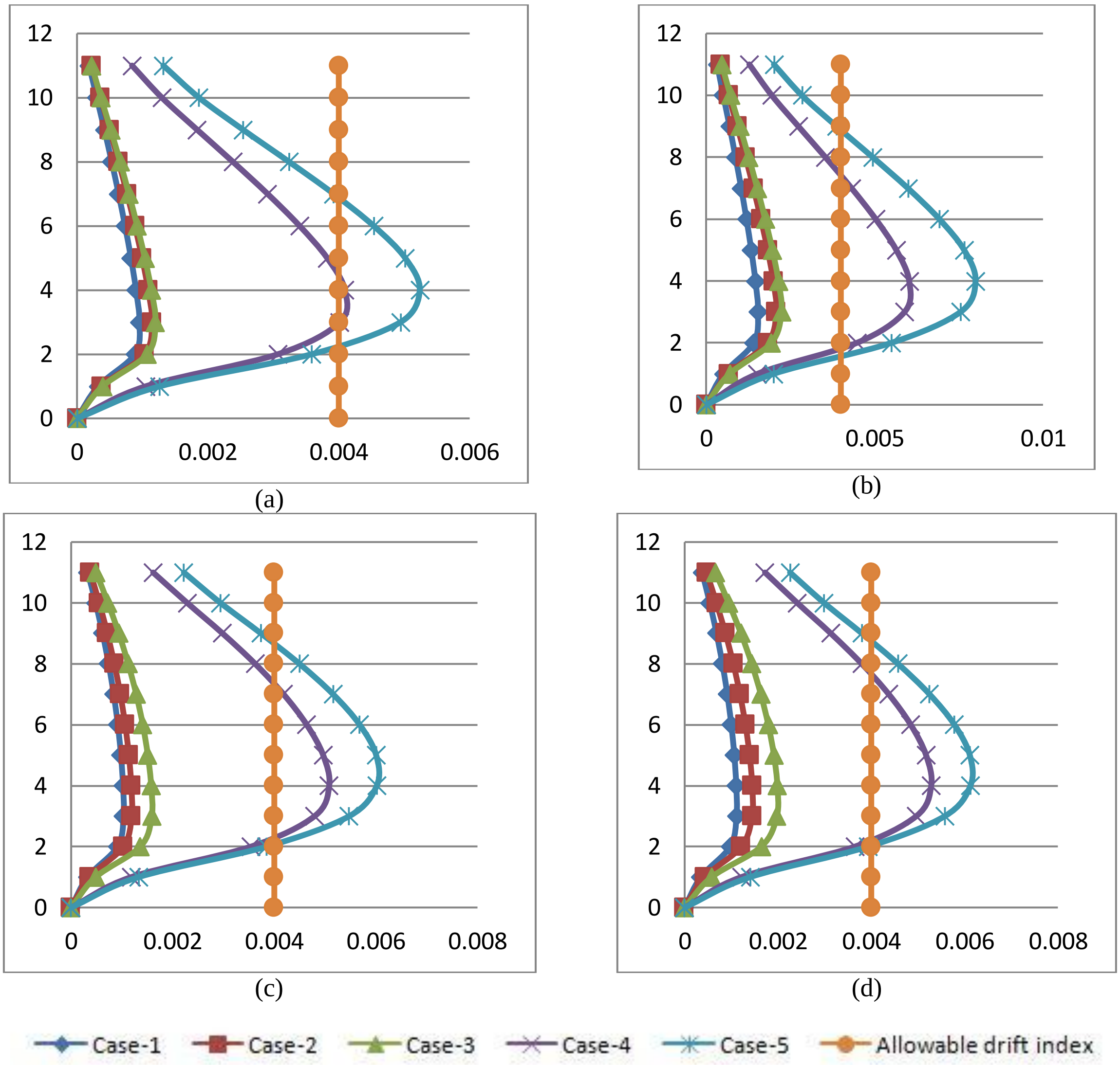

Figure-3: Inter storey drift index in inch per inch (a) in global X-direction, (b) in global Y direction for wind load and (c), in global X direction, (d) in global Y direction for earthquake load.

From above figures (Figure 3), it is seen that inter storey drift index is maximum in the middle portion of the building. Case-1 shows the lowest value for both wind and seismic load and gradually increases in next cases. The drift index for case 4 (flat plate with cantilever portion and without edge beams) and case 5 (flat plate without cantilever portion and without edge beams) exceed allowable limits in both directions for both wind and earthquake loads.

V. DISCUSSIONS AND CONCLUSION

The study have considered five different slab systems--edge supported slab with deep beams (Case-1), column supported slab with interior shallow beams (Case-2), flat plate with edge beams and without cantilever portion (Case-3), flat plate with cantilever portion and without edge beams (Case-4), and flat plate without cantilever portion and without edge beams (Case-5) to compare lateral drift and inter storey drift index. Building with beam supported slabs (Case 1, Case 2, Case 3) shows lower lateral drifts and drift indexes rather than other two slab systems where there is absence of beams. Lateral drifts and drift indexes are almost same in both global directions (Global X and Y directions).

The drifts and inter storey drift indexes in the building with no beam slab systems (Case 4, Case 5) due to both wind and earthquake loads exceed allowable limits in both directions while other three slab systems show acceptable magnitude. So, it can be concluded that, the building of slab systems without beams are vulnerable under high winds and moderate and high earthquake prone areas and are not recommended.

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Abbas Ali, et. al. "A Study on Elastic Behavior of RC Regular Rectangular Building for Different Slab Systems under lateral loads." *The International Journal of Engineering and Science (IJES)*, 9(6), (2020): pp. 50-56.