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A Comparative Investigation to Control Drift in Tall Buildings by Study of Structural Parameters

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Abstract—The rapid growth of urban population and the consequent pressure on limited space have considerably influenced city residential development, which eventually initiated the construction of high-rise structures. For such structures, deflection analysis is very important. Moreover, adequate lateral stiffness is a major consideration in the design of a tall building. In this regard, determination of drift and drift index have become of major significance for designing such structures. In this study, a high-rise R. C. C twenty storied building is investigated for drift analysis due to wind load by means of analytical analysis as well as numerical analysis. Comparative study is made to observe the differences of the drift values found from both methods. From the comparative study, it is found that drift values from analytical analysis (Approximate Method) are conservative where numerical analysis tends to overestimate drift values. To observe the drift values for changes of different structural parameters, increasing of slab thickness, moment of inertia of beams and columns and thickness of shear walls are analyzed. Increase of the moment of inertia i.e. depth of beam has a significant effect in reducing the drift of tall building. Increases of moment of inertia of columns are also found to be effective in reducing drift of tall structure. On the other hand, effects due to increase of slab thickness and shear wall thickness are found less efficient to control the drift.

Keywords: Drift, Drift Index, Approximate Method, Numerical Analysis, Parametric Study, Tall Building.

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1. Introduction

In civil engineering projects, sustainability is a very important aspect to consider in designing structures for expected service life. The lateral loading due to wind or earthquake is the major factor that causes the design of high-rise buildings to differ from that of the low-rise to medium-rise buildings. In this regard, Mendis *et al.* [1] showed that structures which are usually tall or slender, respond dynamically to the effects of wind.

In case of tall buildings, the wind load is a major form of lateral loading and plays a vital role as it tends to deflect the whole structure. One simple parameter to estimate the lateral stiffness of a tall building is the drift index, defined as the ratio of maximum deflection at the top of the building to the height due to lateral forces. For conventional structures the preferred acceptable range is 0.0015 to 0.003 and sufficient stiffness must be provided to ensure that the top deflection does not exceed the value under extreme loading condition. In addition of estimating drift index, the inter-story drift index gives a measure of possible localized excessive deformation. The control of lateral deflection is of particular importance for modern high-rise buildings in which the traditional reserves of stiffness due to heavy internal partitions and outer cladding have largely disappeared. The amount of lateral deflection must be limited to prevent second-order P-Delta effects due to gravity loading being of such a magnitude as to precipitate collapse.

Rahman *et al.* [2] analyzed the drift for lateral loads (both earthquake and wind loads) and conducted a comparative study on drift involving three types of high rise structures: such as- rigid frame, coupled shear wall and wall frame structures by means of programming language C (version C++ 4.5). Their study showed that strength is satisfied by limit stresses, while serviceability is satisfied by drift limits in the range of H/500 to H/1000. On the other hand stability is satisfied by sufficient factor of safety against buckling and P-Delta effects. So every tall structure should include the drift due to earthquake load as well as wind load. In a research on drift, Kamruzzaman *et al.* [3] used the 'Displacement Participation Factor (DPF)' Approach to identify the members, which contributes significantly to drift. Besides a computer program was also developed to compute the deflection, strain energy and DPF of the members. Their study showed that considerable reduction in drift can be achieved by increasing the moment of inertia (stiffness) of 2nd to 5th floor beams up to 30 story frames. From the structural engineering's point of view, the determination of the structural form of tall building would ideally involve only the selection and arrangement of the major structural elements to resist most efficiently the various combination of vertical and horizontal loading (Smith and Coull [4]).

In reality, however the choice of structural form is usually strongly influenced by other than structural considerations. The range of factors that has to be taken into account in deciding the structural form includes the internal planning, the material and method of construction, the external architectural treatment, the planned location and routing of service system, the nature and magnitude of horizontal loading, the height and proportion of the building. The taller and more slender a building, the more important the structural factors become and proper choice of appropriate structural form become necessary. The principal objective in choosing the structural form of a tall building is to support the gravity, dead and live loading and to resist external horizontal load, shear, moment and torque with adequate strength and stiffness.

In this paper, drift has been determined at each floor of a commercial twenty story building by means of analytical method as well as numerical analysis and the drift values of each floor found from both methods have been compared. Also, a parametric study has been conducted to observe the most effective measure for minimizing drift involving modifying the moment of inertia of beams and columns, thickness of slab and shear wall.

2. Methodology of Analytical and Numerical Analysis

Drift is a dominant feature in tall building design. Drift problem as the horizontal displacement of tall buildings is one of the most serious issues in tall building design, relating to the dynamic characteristics of the building during earthquakes and strong winds. Drift is usually caused by the accumulated deformation of each member, such as columns, beams, braces and shear walls. Lateral loads (i.e. wind or earthquake loads) are mainly responsible for drift, which very often dictates the selection of structural systems for high rise building.

The present study investigates drift analysis of a real project (the BULUS CENTER, Gulshan Avenue, Plot no-1, Block-1, Gulshan-2, Dhaka). The building consists of twenty stories with each story height 10 ft. It is a 3D shear wall-frame structure which is analyzed using Approximate Method and numerical analysis to determine drift of each story. The layout plan of the building (with directions) is shown in Figure-1. In X-direction, there are eight frames, denoted by A, B, C, E, F, G, H, and I. Two shear walls are located along 2A to 3A and along 2I to 3I line in frame A and frame I respectively. Similarly, in Y-direction, there are five frames, denoted by 1, 2, 3, 4 and 6.

2.1 Approximate Method

The analytical analysis involves theoretical determination of drift of the present structure due to wind load along both long and short direction by means of Approximate Method. In this type of analysis, at first shear rigidity of all the frames in each direction is determined. In case of long direction, there are two types of frames (including shear wall at grid A-2,3 & I-2,3 and excluding shear wall at grid B,C,E,F,G,H). Similarly in short direction, two types of frames are found (excluding lift core-frames 1, 2, 3 and 4; lift core wall at grid D, E-5,6). The shear rigidities of different types of frames and flexural rigidities of shear walls as well as of lift core (cross section of the lift core has been shown in Figure-2) have been evaluated by means of formulas mentioned below in the example calculation.

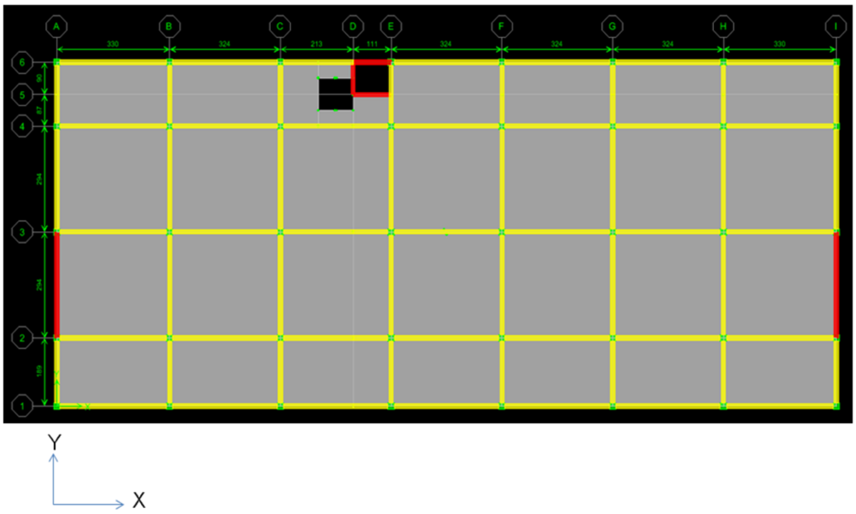


Figure 1: Lay-out Plan of the BULUS CENTER

Example Calculation

The purpose of this article is to address the drift and drift index of the structure studied. Hence, a sample calculation of evaluating the drift and drift index of the structure has been demonstrated below:

***Problem Statement*:** The plan of the building under study is presented in Figure-1, which is a 20 story, 200 ft high, wall frame structure. The horizontal resistance to wind acting on its long side is provided by eight rigid frame bents (the leftmost and rightmost bent each consisting of a shear wall) and a lift-core. The summary of input data are listed in Table-1. It is required to determine deflection at each story, maximum story drift and drift index.

Table-1: Input data for the present problem

Frame	Interior Column (inch)	Exterior Column (inch)	Girder (inch)
Type-1 (without shear wall)	21×21	21×21	12×20
Type-2 (including shear wall)	21×21	21×21	12×20

Thickness of shear wall: 14″

Dimensions of lift core: 126″× 108″

Slab thickness: 7″

Elastic Modulus of Concrete, E: 3605 ksi

Solution: The desired outputs for the present problem have been determined by means of the equations according to Smith and Coull [4].

Determination of Effective Shear Rigidity *(GA)*:

- For frame type-1 (without shear wall):

$$(GA)_1 = \frac{12E}{h\left(\frac{1}{G}+\frac{1}{C}\right)} \quad \text{...(i)}$$

Now, $G = \sum \frac{I_g}{L} = 8000 \times \left[\frac{1}{189} + \frac{2}{294} + \frac{1}{177}\right] = 141.95 in^3$

$$C = \sum \frac{I_c}{h} = \frac{5 \times 16206.75}{120} = 675.28 in^3$$

$$(GA)_1 = \frac{12 \times 3605}{120 \times \left(\frac{1}{141.95} + \frac{1}{675.28}\right)} = 42283.06\,kips$$

From equation no-(i),

❖ For frame type-2 (including shear wall):

$$(GA)_2 = (1/2)\left(\frac{12EI_g(2a + 2\alpha L_m)^2}{(2\alpha L_m)^3 h}\right) \qquad \text{..............................(ii)}$$

For m = 1, (where, m = number of shear walls in a specific frame)

$$\alpha = 0.566 + 0.024\ln(\eta) + 0.0424\beta \qquad \text{..............................(iii)}$$

Here, $\eta = \frac{a}{L_m} = 0.5$ $\beta = \frac{EI_g}{EI_c} = 0.494$

From equation no-(iii), $\alpha = 0.566 + 0.024\ln(0.5) + 0.0424 \times 0.4936 = 0.5703$

So, from equation no-(ii)

$$(GA)_2 = 15145.666\,kips$$

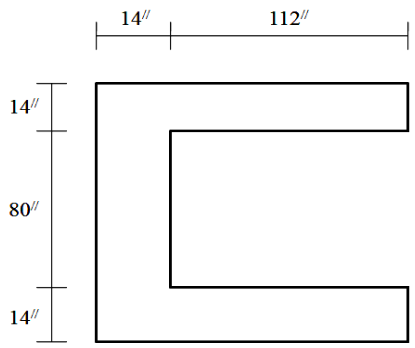
Therefore,

$$(GA)_t = 6 \times (GA)_1 + 2 \times (GA)_2 = 283989.6651\,kips$$

$$\alpha H = H\sqrt{\frac{(GA)_t}{(EI)_t}} = 2.645$$

Determination of Flexural Rigidity of Shear walls and Lift-cores $(EI)_t$:

$$(EI)_t = (EI)_w + (EI)_c \qquad \text{..(iv)}$$



Now, inertia of each shear wall, $I_w = 29647548 in^4$

Inertia of lift-core, $I_{xx(core)} = 5569839.161328\ in^4$

So, from equation no-(iv),

$$(EI)_t = 3605 \times (5569839.161328 + 2 \times 29647548)$$

$$= 233837831796.85 k - inch^2$$

Figure 2: Cross-section of lift-core

<u>Drift and drift index for reference stories:</u>

For story-9:

$$z = 1080\, inch$$

$$\frac{z}{H} = \frac{1080}{2400} = 0.45$$

For the given structure, the wind loading per unit height, (calculated following BNBC-2006 [5]),

$$w = 39.4 kips/inch$$

For $\alpha H = 2.645$ and $\frac{z}{H} = \frac{1080}{2400} = 0.45$

$K_1 = 0.12$

So, horizontal displacement,

$$y(z) = \frac{wH^4 K_1}{8(EI)_t} = \frac{39.4 \times (2400)^4 \times 0.12}{8 \times 233837831796.85} = 83.85 inch$$

Maximum story drift occurs at the topmost story, i.e. the 20th story, which is found 263.37 inch (where, $w = 55 kips/inch$).

And, story drift index, $\frac{dy}{dx}(\max) = \frac{wH^3}{6(EI)_t} K_2(\max)$

$$= \frac{55 \times (2400)^3 \times 0.23}{6 \times 233837831796.85}$$

$$= 0.1246 = \frac{1}{8}$$

2.2 Numerical Analys

Numerical analysis involves the drift analysis of the structure using ETABS software (version 9.7). The height of each story is taken as 10 ft. The thickness of each shear wall is considered as 12″. The cross-sectional dimensions of the beams are 12″×15″ and columns are 18″×18″. The slab thickness is considered 6″. The wind load is applied as per BNBC-2006 [5] considering exposure condition "A" and wind velocity 210 km/hr for Dhaka region. To investigate the drift of the building, the structural parameters, i.e. moment of inertia of beams and columns, thickness of slab and thickness of shear wall are varied and story displacements are estimated from numerical simulations. After the analysis, the drift values at each story and drift index (at the topmost story) is determined. Finally, drift index due to the changes in structural parameters is also determined.

The input data for the analysis have been summarized in Table-2:

Table 2: Input data for numerical analysis

Structural component	Unit	1st trial	2nd trial	3rd trial	4th trial	5th trial	6th trial
Beam	inch	12 × 15	12 × 20	12 × 24	12 × 27	12 × 30	-
Column	inch	18 × 18	21 × 21	24 × 24	27 × 27	30 × 30	33 × 33
Thicknesses of Slab	inch	6	7	8	10	-	-
Thicknesses of Shear Walls	inch	12	14	16	18	20	-

Figure-3 represents deflected shape of the tall building with elevation due to wind load acting on short (Y) direction.

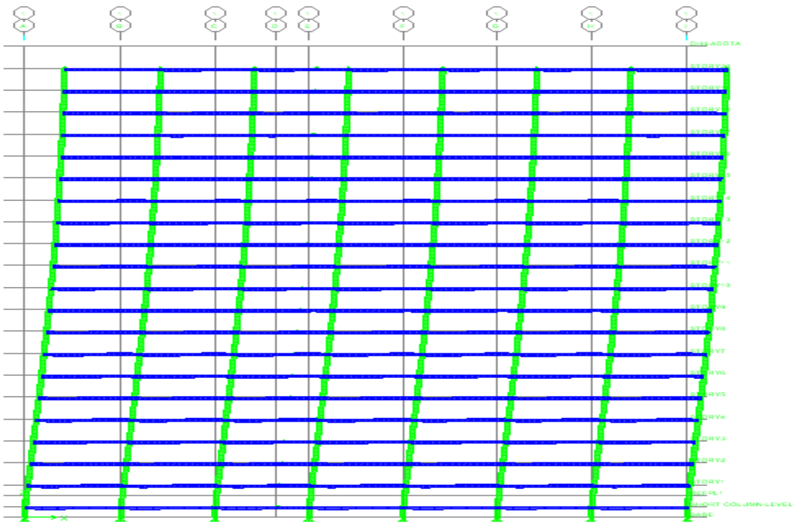


Figure 3: Deflected shape of the tall building with elevation due to wind load acting on short dimension.

3. Results and Discussions

In this paper, drift values of each story of the building under consideration have been determined using both Approximate Method and numerical analysis by changing beam depth, column cross-section, slab thickness and thickness of shear wall. After that, the drift values found by both methods for change of any of the structural component (beam, column, slab or shear wall) have been compared for better understanding.

The different graphs associated with the results of both Approximate Method and numerical analysis has been represented in this article. At first, the results of the comparative study between Approximate Method and numerical analysis have been represented and then the effects of change of structural parameters on drift values have been demonstrated graphically.

(i) Presentation of Comparative Drift Values obtained from Numerical Analysis and Approximate Method

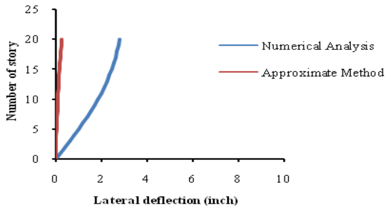


Figure 4: Comparative drift values for beam depth 30″ in long direction

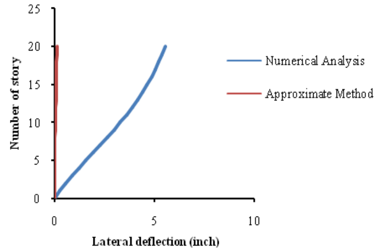


Figure 5: Comparative drift values for c cross-section (30″ × 30″) inch in long di

From Figure-4 and Figure-5, it has been observed that there are extensive differences between drift values obtained from numerical analysis and Approximate Method in long direction due to beam depth 30″ and column cross-section 30″×30″ respectively. For example, from Figure-4, at 20th floor, drift value from numerical analysis is 3″ and that from Approximate Method is 0.2″; from Figure-5, drift value from numerical analysis is 5.85″ and that from Approximate Method is 0.8″.

This difference between numerical analysis and Approximate Method is because of the fact that, in Approximate Method, for the drift formulas, ideal conditions for beams, columns, shear walls etc. are assumed. But in reality, the overall condition changes varying from load values to member imperfection, eccentricity etc, which are usually accounted in numerical analysis.

(ii) Presentation of Drift Values Obtained from Numerical Analysis due to Change in Dimensions of Structural Components

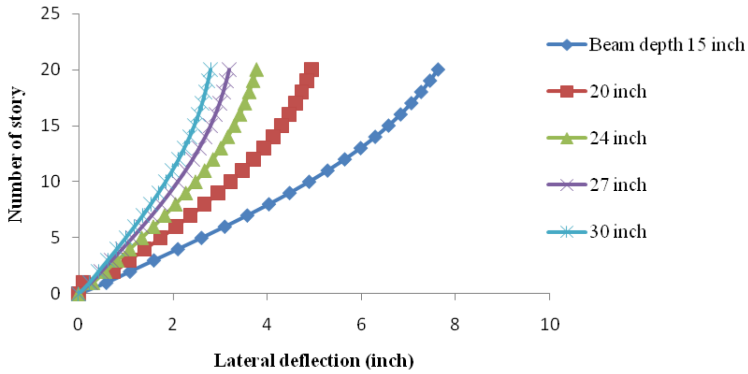


Figure 6: Variation of lateral deflection due to change in beam depth in long direction

In Figure-6, the effect of the change of beam depths on drift values have been demonstrated. It has been observed that, for every beam depth, lateral deflection increases gradually with the increase of number of story from ground floor. It is clear from the demonstration that, with the increase of beam depths, the overall lateral deflection values of each story decreases.

For example: the rightmost graph shows the lateral deflection of the 20th story of the building (in long direction) is 7.626″ for beam depth 15″. With the beam depth values 20″, 24″, 27″ and finally 30″, the drift values of the same story are found to be 4.941″, 3.765″, 3.201″, and 2.805″ respectively. So, it is clear that, the lateral deflection graphs shift to the left (near the number of story axis) indicating the gradual overall decrease of lateral deflection values of the building.

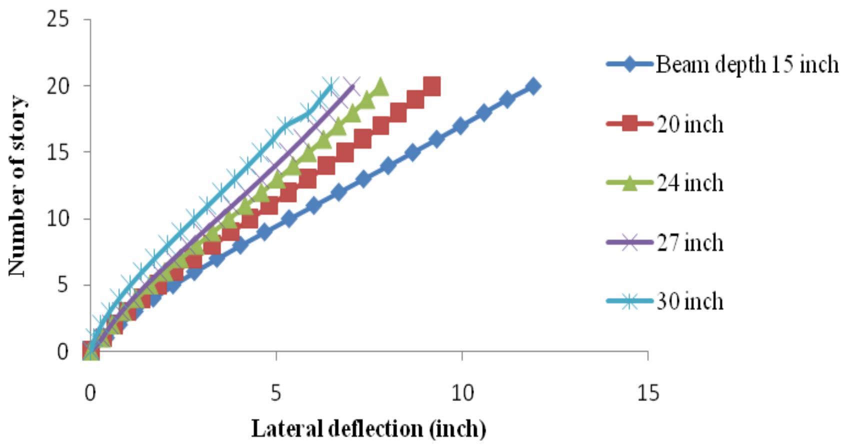


Figure 7: Representation of lateral deflection of the building due to variation of beam depth in short direction

From Figure-7, it has been observed that, like Figure-6, for every beam depth, lateral deflection increases gradually with the increase of number of story from ground floor. For increase of beam depths from 15″ to 30″, the lateral deflection graphs show similar trend as is Figure-6. With the beam depth values 15″, 20″, 24″, 27″ and finally 30″, the drift values of the 20th story are found to be 11.9″, 9.192″, 7.801″, 7.044″ and 6.465″ respectively. It has been observed that the building shows larger drift values in short direction than those in long direction.

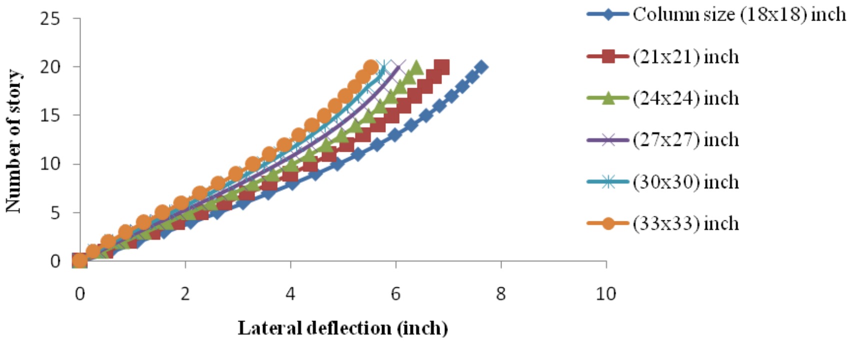


Figure 8: Representation of lateral deflection of the building due to variation of column size in long direction

From Figure-8, and Figure-9, it is clear that, with the increase of column sizes, the overall lateral deflection values of each story decreases. But, unlike the cases for changes in beam depth, the effect of change in column cross-section on drift values is less significant.

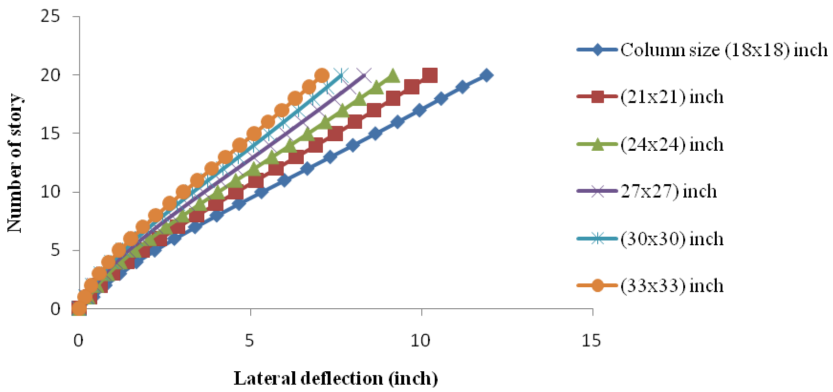


Figure 9: Representation of lateral deflection of the building due to variation of column size in short direction

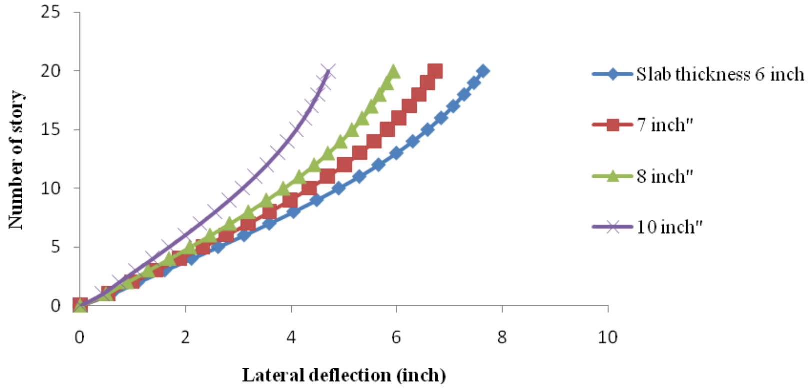


Figure 10: Representation of lateral deflection of the building due to variation of slab thickness in long direction

From Figure-10 and Figure-11, it has been observed that, for every slab thickness, lateral deflection increases gradually with the increase of number of storey from ground floor. It is clear from the demonstration that, with the increase of slab thickness, the overall lateral deflection values of each story decreases.

For increase of slab thickness from 6″ to 10″, the lateral deflection (drift) graphs follow the same pattern like Figure-8 and Figure-9. The changes in drift values is significant in long direction (Figure-10) compared to the drift values in short direction (Figure-11).

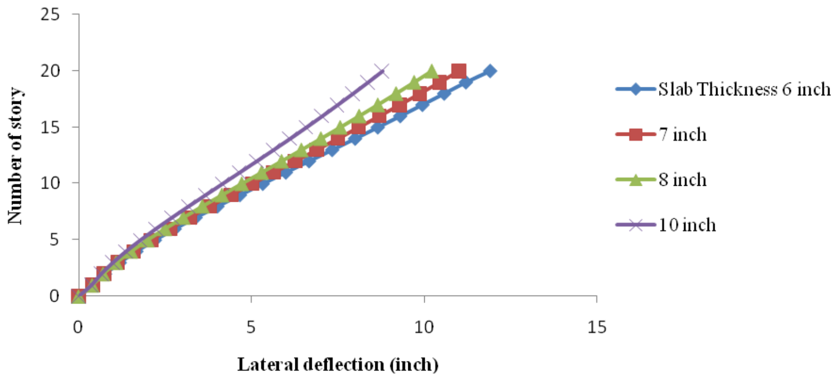


Figure 11: Representation of lateral deflection of the building due to variation of slab thickness in short direction

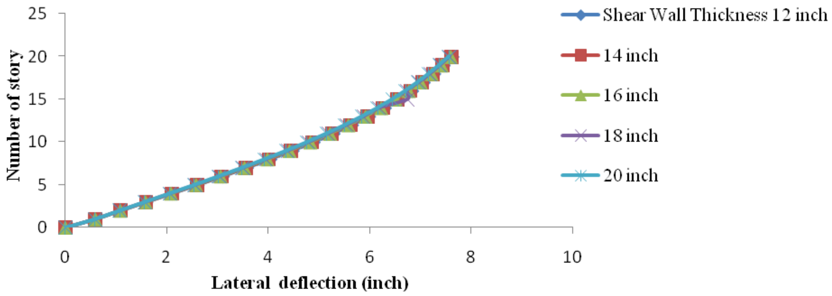


Figure 12: Representation of lateral deflection of the building due to variation of shear wall thickness in long direction

From Figure-12 and Figure-13, it has been observed that, for every shear wall thickness, lateral deflection increases gradually with the increase of number of story from ground floor. It is clear from the demonstrations that, in long direction change of shear wall thickness has a very negligible effect on drift values. On the contrary, in short direction the lateral deflection graphs shift slightly to the left for the increase of shear wall thicknesses.

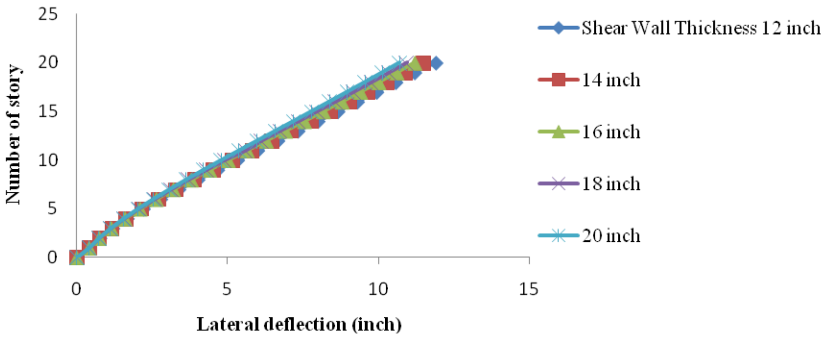


Figure 13: Representation of lateral deflection of the building due to variation of shear wall thickness in short direction

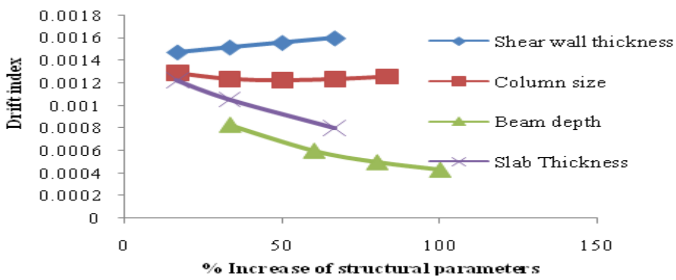


Figure 14: Drift index for increase of structural parameters at long direction

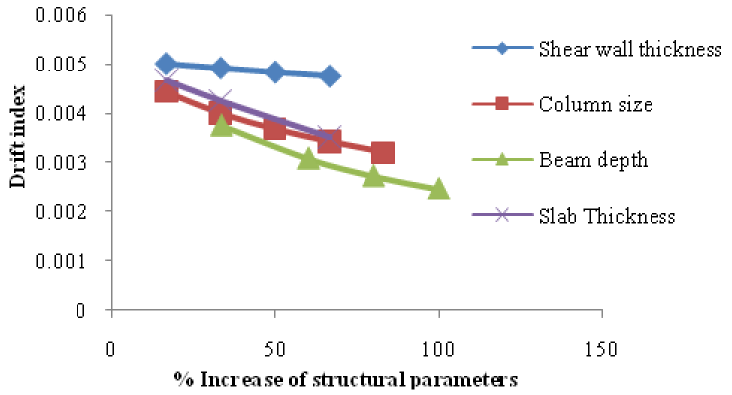


Figure 15: Drift index for increase of structural parameters at short direction

Figure-14 and Figure-15 present the comparative investigation of the performances of different structural parameters in reducing drift index. The reduction of drift index is sharper for beams with increasing moment of inertia. The increase of column size is found to be in the next position in reducing drift.

For the 1st trial set of input data as mentioned in Table-2, maximum story deflection (at topmost floor) from Approximate Method is 1.63 inch which differs with the drift value found from Numerical Analysis (11.9 inch) where results from both methods have been found to be within allowable drift value of 12 inch for the 20-story building (according to BNBC-2006 [5] (from sec-1.5.6.1)). The drift index for the building is found as 0.001598 (for the 1st trial of input data), which is within the usual range (0.0015 to 0.003) for conventional structures.

4. Conclusion

On the basis of present study, it can be concluded that among different measures, most sustainable approach of reduction of drift is increasing the moment of inertia of beams i.e. increase of depth of beams is the most effective measure. The modification in moment of inertia of columns have also been proved to be effective in controlling drift. The increase in shear wall thickness and slab thickness have very small effect on reduction of drift. In order to build and design a sustainable structural system, every tall building should contain adequate beam sizes and proper column sizes at suitable and required positions.

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