Sustainable development in drift control of tall buildings: study of the structural parameters

M.M. Islam & A. Siddique
Ahsanullah University of Science and Technology, Dhaka, Bangladesh

A. Murshed
Multiplan Ltd., Dhaka, Bangladesh

ABSTRACT: In civil engineering projects sustainability is a very important aspect to consider in designing structures for expected service life. In general the low rise buildings (below ten storied) are designed according to the required design criteria with a loading system not considering much of the wind loads. 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. In this paper, increasing of floor thickness, moment of inertia of beams and columns, thickness of shear walls and providing outriggers in tall buildings are analyzed to control the drift. Increase of the moment of inertia i.e. depth of beam has a significant effect in reducing the drift tall building. Increase of the thickness of shear walls and depth of outriggers are also found effective in drift control. The increase of slab thickness and moment of inertia of columns are found to be less effective in controlling drift of tall buildings.

1 INTRODUCTION

In recent times, construction materials have been improved rapidly resulting into smaller cross-section and more flexible than before. These improvements and changes in condition of practice have made the deflection analysis more important. Moreover, adequate lateral stiffness is a major consideration in the design of a tall building. One simple parameter to estimate the lateral stiffness of a 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 (Smith & Coull, 1991). 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. Tall and slender buildings are strongly wind sensitive (Lam et. al 2009). The lateral loading due to wind or earthquake is the major factor that causes the design of high-rise buildings to differ from those low-rise to medium-rise buildings. For up to 10 stories and of typical proportions, the structure is rarely affected by wind loads (Smith & Coull, 1991). Structures which are usually tall or slender, respond dynamically to the effects of wind (Mendis et. al. 2007). An important problem associated with wind induced motion of building is concerned human responses to vibration and perception of motion. At this point this will suffice to note that the humans are surprisingly sensitive to vibration to the extent that motions may feel uncomfortable even if they correspond to relatively low level of stress and strain. Therefore, the serviceability considerations govern the design for tall buildings, not the strength issues (Mendis et. al. 2007).

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 & Coull, 1991). 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 objectives in choosing the structural form of a tall building to support the gravity, dead and live loading and to resist external horizontal load, shear, moment and torque with adequate strength and stiffness.

Reinforced concrete planar solid or coupled shear walls have been one of the most popular systems used for high-rise construction to resist lateral forces caused by wind and earthquakes. Shear walls are treated as vertical cantilevers fixed at the base. Shear walls used in tall office buildings are generally located around service and elevator cores and stairwells. In fact, in many tall buildings, the vertical solid core walls that enclose the building services can be used to stabilize and stiffen the building against lateral loads. The outrigger-braced system is regarded as one of the most effective ways for increasing structural stiffness and has been widely used in tall building structures (Wu & Li 2003). Outrigger systems have been historically used by sailing ships to help resist the wind forces in their sails, making the tall and slender masts stable and strong (Mendis et. al. 2007). The core in a tall building is analogous to the mast of the ship, with outriggers acting as the spreaders and reduces the overturning moment in the core that would otherwise act as pure cantilever. The reduced moment is transferred to the outer columns through the outriggers connecting the core. Drift of tall buildings due to wind loads may be estimated by wind tunnel testing of the prototype of tall building, numerical simulation techniques, approximate methods etc.

In this paper, sustainable development in drift control are analyzed regarding the performance of the shear walls, outriggers, beams, columns and slabs of tall building by approximate method (Smith & Coull, 1991) and numerical simulation technique.

2 EXPERIMENTAL PLANS AND NUMERICAL MODELING

A 3D shear wall-frame structure is modeled using structural analysis software STAAD.Pro-2006 for the building plan shown in Figure 1 (“OR” represents beams acting as outriggers). The tall building is modeled considering 20 stories with story height 12.5ft. The thickness of the shear walls are considered 12in. The sizes of the beams are 12in x 20in and columns are 24in x 24in. The slab thickness is considered 6in. The wind load is applied as per BNBC (1993) considering exposure condition A and wind velocity 210 km/hr. To investigate the drift of the building, the structural parameters, i.e. thickness of shear wall, moment of inertia of beams and columns, thickness of slab and moment of inertia of outriggers are varied and top displacements are estimated from numerical simulations. The thicknesses of shear walls are considered 12in, 14in, 16in, 18in and 20in. The beam sizes are considered 12in x 15in, 12in x 20in, 12in x 24in, 12in x 27in and 12in x 30in. The column sizes are considered 18in x 18in, 21in x 21in, 24in x 24in, 27in x 27in, 30in x 30in and 33in x 33in. The depths of outriggers are considered 20in, 24in, 30in, 36in, 42in and 48in. The slab thicknesses are considered 6in, 7in, 8in and 10in. Drift index due to the changes are estimated and compared.

3 APPROXIMATE ANALYSES

According to approximate analysis, the shear rigidity, (GA) of the frames (including shear wall) 1, 3, 4 and 6 (Fig 1a) are calculated according to Equation 1 and frames (without shear wall) 2 and 5 (Fig 1a) are calculated according to Equation 2.

$$(GA)_I = \frac{1}{2}\frac{12EI_g(2a+2\alpha L_m)^2}{(2\alpha L_m)^3 h} \tag{1}$$

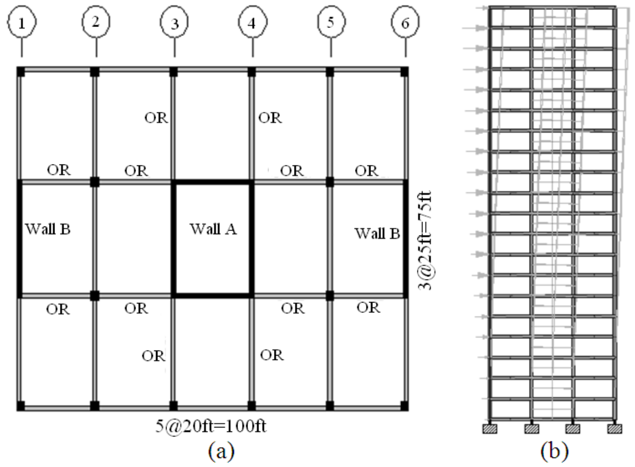
$$(GA)_{II} = \frac{12E}{h\left(\frac{1}{G}+\frac{1}{C}\right)} \tag{2}$$

where $(GA)_I$ = story-height averaged shear rigidity of the frames 1, 3, 4, 6 (Fig 1a), $(GA)_{II}$ = story-height averaged shear rigidity of the frames 2 and 5 (Fig 1a), E=modulus of elasticity of concrete (3000ksi), I_g= moment of inertia of girders, α= dimensionless parameters representing the rigidity of wall-frame structure and calculated using Equation 3, 4 & 5 for m=1 (no. of shear walls in a frame), h=storey height, $G=\sum I_g/L$, $C=\sum I_c/h$, L=span, L_m=length of girder connecting to shear-wall, a= half width of shear wall (Fig 2), I_c= moment of inertia of columns. Total shear rigidity is (GA)=4$(GA)_I$ +$(GA)_{II}$.

$$\alpha = 0.566 + 0.024\ln(\eta) + 0.0424\beta \tag{3}$$

$$\eta = \frac{a}{L_m} \tag{4}$$

$$\beta = \frac{EI_g}{EI_c} \tag{5}$$



(a) (b)

Figure 1. (a) Plan of the tall building. (b) elevation of the tall building with deflected shape due to wind loading.

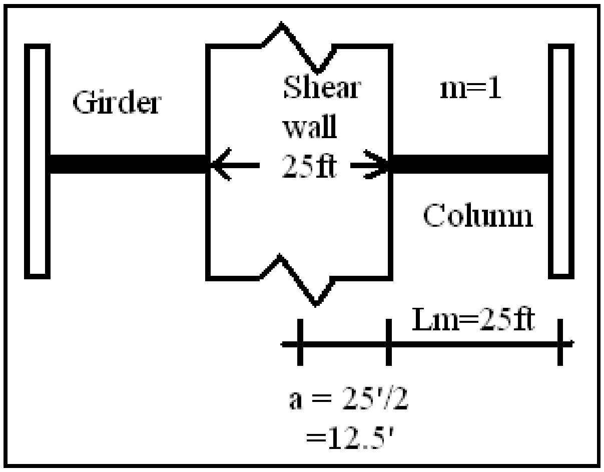


Figure 2. Story of planar wall-frame structure with connecting beams

The deflected shape is a function of the dimensionless parameter αH which represents the structural properties of wall-frame and calculated using Equation 6.

$$\alpha H = H\sqrt{\frac{(GA)}{EI}} \tag{6}$$

where H=total height of the building. Top deflection is measured using Equation 7.

$$y(z) = \frac{wH^4}{8(EI)}K_1 \tag{7}$$

where w=wind load, z=elevation from base of the building, K_1= a function of only αH and z/H (for αH=1.16 and z/H=1.0, K_1 =0.69) that represents the distribution expression in the braces and I=moment of inertia of shear walls. To calculate top deflection, z is considered as $z=H$ and z/H=1.0. Maximum story deflection (at top) is found (using Equation 7) 0.803ft or 9.636in which is very close to the numerical results. The drift index for the building is 0.00321.

4 NUMERICAL RESULTS AND DISCUSSION

Vigorous numerical analysis is done with changing structural parameters to observe the effect on the drift (lateral deflection) of the tall building. Figure 3 shows the effect of shear wall thickness on the lateral deflection of tall building. The lateral deflection significantly reduced with increasing shear wall thickness. The effect of increase in beam depth is clearly visible in Figure 4. Extensive reduction is observed in the lateral deflection due to increase of beam depth i.e. moment of inertia of beams. Effects due to increase of slab thickness and column size are presented in Figure 5 & 6 and are found less efficient to control the drift. Figure 7 shows the performance of outriggers with increasing depth and found to be effective in controlling the lateral deflection. Figure 8 presents the comparative investigation of the performances of the structural parameters in reducing drift index. The reduction of drift index is sharper for beams with increasing moment of inertia. The increase of the thickness of shear walls is found to be in the next position in reducing drift. Outriggers are found less effective compared to shear walls. The effects of slab thickness and column size are found very low control on drift of tall buildings.

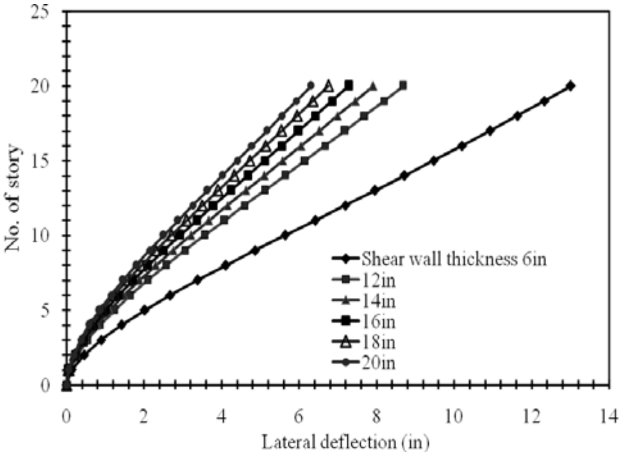


Figure 3. Effect of shear wall thickness on lateral deflection.

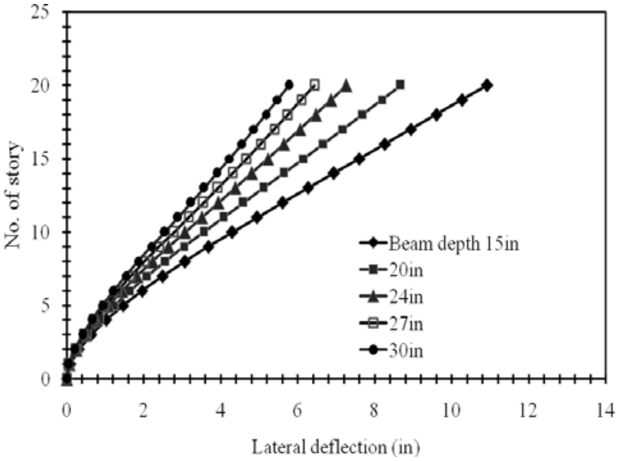


Figure 4. Effect of beam depth on lateral deflection.

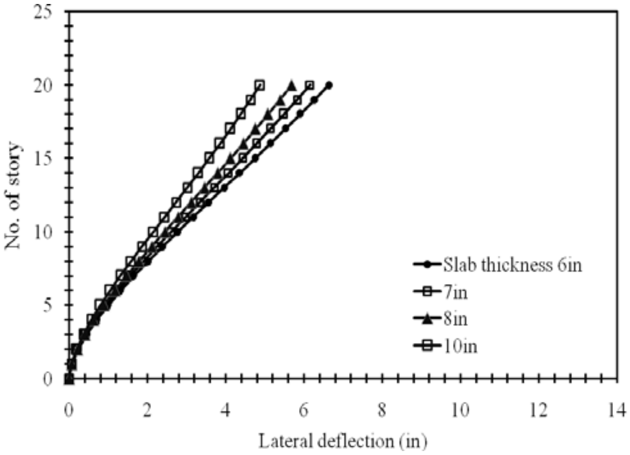


Figure 5. Effect of slab thickness on lateral deflection.

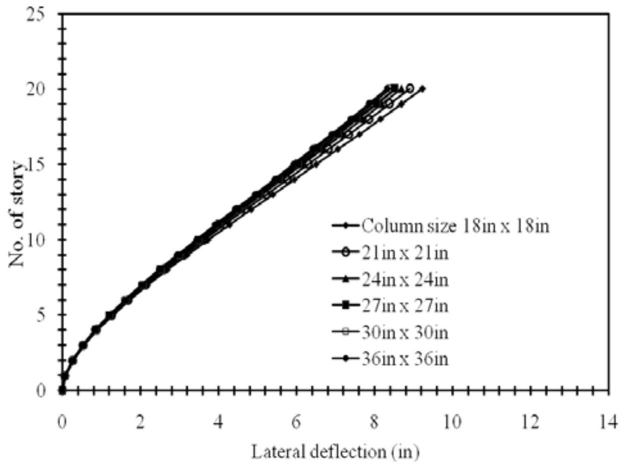


Figure 6. Effect of column size on lateral deflection.

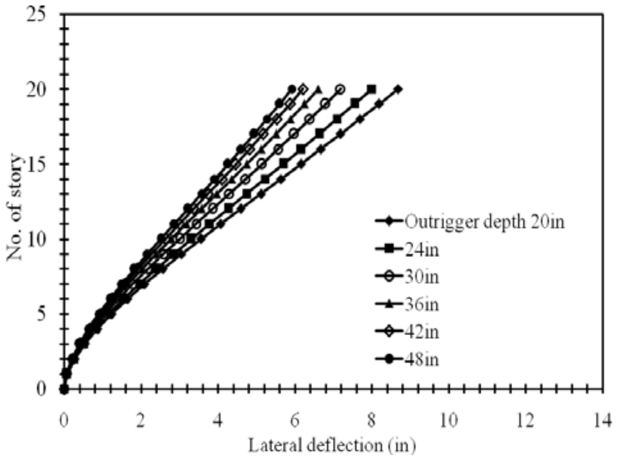


Figure 7. Effect of the depth of outriggers on lateral deflection.

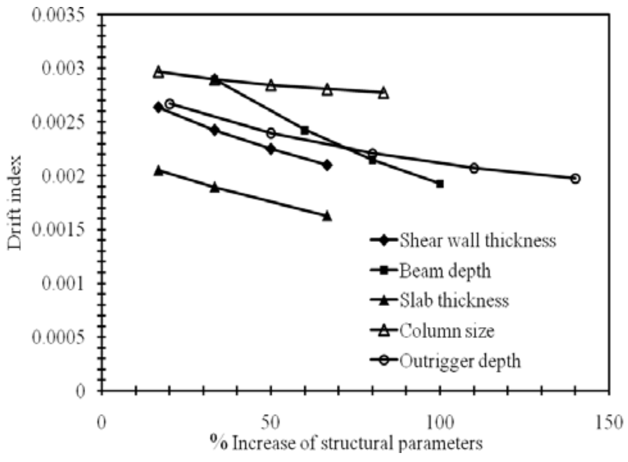


Figure 8. Effect of structural parameters on drift index.

5 CONCLUSION

Among the different measures, most sustainable approach of reduction of drift is increasing the moment of inertia i.e. depth of beams is the most effective. Shear walls provide significant resistance to lateral deflection of tall buildings. Introducing the outriggers is also a very effective method to reduce the drift. The modification in moment of inertia of columns and increasing slab thickness has a very small effect on the reduction of drift.

In order to build and design a sustainable structural system, every tall building should contain adequate beam sizes and at least one or more shear walls at suitable and required positions.

REFERENCES

Bangladesh national building code (BNBC), 1993

Lam. K.M., Wong. S. Y. & To. A. P. 2009. Dynamic wind loading of h-shaped tall buildings. The seventh asia-pacific conference on wind engineering, Taipei. Taiwan.

Mendis, P. Ngo, T. Hariots, N. Hira, A. Samali, B. Cheung, J. 2007. Wind loading on tall building. EJSE special issue: loading on structures. pp 41-54.

Smith, B.S. & Coull, A. 1991. Tall building structures: analysis and design. Singapore: John wiley & sons, Inc.

Wu, J.R. & Li, Q.S. 2003. Structural performance of multi-outriggerbraced tall buildings. The structural design of tall and special buildings, struct. design tall spec. build. 12, pp 155–176. Published online in wiley interscience (www.interscience.wiley.com). DOI:10.1002/tal.219.