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A STUDY ON INFLUENCE OF CORE WALL IN FRAME STRUCTURE UNDER SEISMIC LOAD

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Abstract: Seismic load is crucial for the structural design of multistoried buildings. The study delves to evaluate performance of core wall in the building frame under seismic loading. Two models are compared in this research. One is typical frame structure without any shear wall i.e. model 1 and another one is frame structure with core wall, i.e. model 2. The study found that frame structure with core wall (model 2) have much lower story drift in comparison with frame structure without shear wall (model 1). Vis-à-vis, frame structure with core wall (model 2) experiences lower column reactions, shear forces, base shear and overturning moments compare to the frame structure without shear wall (model 1) under seismic load. Therefore, the core wall incorporated in multistoried building plan can against withstand seismic load with better performance.

Keywords: *Core wall, building frame, seismic load, Bangladesh National Building Code 2017, drift.*

1. INTRODUCTION

Shear walls are effective structural elements used in multistoried buildings to provide adequate resistance against seismic loadings. Those are constructed usually at a centrally located position in a building plan as a reinforced concrete core wall. Core wall in a multi-story building is often used as lift facilities. Provision of core wall is widely accepted in the construction of multi-story building. In high rise buildings, it is crucial to ensure adequate lateral stiffness to resist seismic load. Other lateral loads, such as, wind load which depends on building height, wind flow, surrounding exposure and building shape—it is also significant for multistoried building. However, this is beyond the scope of this study. As per BNBC 2015 [1], building having more than 10 story or 33m height from reference datum is designated as high rise building. Now a days earthquake resistant designs draw special attention in design of any type of structure. Earthquake is the shaking of the surface of the Earth generating seismic waves which is occurred due to sudden release of energy in the Earth's lithosphere. Yang et al. [2] studied influence of core wall system in multistoried building under earthquake. Their study showed that gravity system of beam-column-slab without core wall subject to larger axial column load under combined gravity and earthquake effects. Değer et al. [3] investigated effects of seismic load on core wall with the moment resisting frame systems using finite element model. They found that dual system, i.e. core wall with moment resisting frame has low inter-story drift and subject to less damage under different earthquake intensities.

Over the past hundred years, researchers are investigating on earthquake resisting building frame systems. Suitable building frame system can reduce earthquake vulnerability in terms of human life loss, property damage and building collapse. Those also can reduce post-earthquake repair and replacement expenditure. Therefore, Structural Engineers used to choose appropriate building system to analysis and design multistoried building which can dissipate seismic load efficiently. Reinforced concrete core wall are widely adopted as elevator shaft in multistoried buildings over many years. Hence, our study investigates the behavior and efficiency of core wall to resist earthquake.

This study explores seismic response of frame structure with and without core wall for a 10 story RCC building located in Dhaka city. Two building models are analyzed; one is typical frame structure without any shear wall i.e. model 1 and another one is frame structure with core wall, i.e. model 2 as shown in Figure 1 and 2. It compares the seismic performance of these two building models in terms of story drift, shear and moment at bottom of stories, base shear, overturning moment due to earthquake intensities as per Bangladesh National Building Code (BNBC) 2015 [1]. The research assesses influence of core wall under seismic load and conduct in-depth study of seismic load as per BNBC 2015 [1]. It also investigates effect of seismic load on column bending moments and reactions. The research evaluates performance of core wall to resist and control story drift due to seismic load. It performs parametric study on seismic load and analyzes column reaction force, which can be used for foundation design as well.

2. LITERATURE REVIEW

Geographically, Dhaka city is situated in the earthquake vulnerable zone. Several studies have been marked that massive catastrophe may occur by

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moderate to high intensity earthquake in the city. Ahmed and Morita [4], Rahman et al. [5] and Bhuiya et al. [6] researched on assessing earthquake vulnerability of Dhaka city extensively. Sadat et al. [7] performed rapid visual screening to evaluate earthquake vulnerability of Dhaka city. Al-Hussaini [8] emphasized on better earthquake resistant design in buildings to minimize earthquake losses. The numbers of multistoried building in Dhaka are increasing rapidly. Since, there is possibility to occurrence of earthquake, the multistoried buildings are on the threat due to earthquake drift occurrence.

Multistoried structures need to be constructed considering the effect of drift due to seismic load, otherwise it causes huge loss of life and damage of properties. Sindel et al. [9], Chang and Lin [10] worked on analytical models related to story drift control. Story drift is the difference of displacements between two successive stories divided by the height of that story. It is the amount of side sway between two adjacent stories of a building caused by lateral loads, such as, wind and seismic loads.

Number of studies have been investigated utilization of core wall as an alternatives to resist seismic load in building frame. Rahman et al. [11], Cheng et al. [12] and Rathi et al. [13] performed analysis on core wall frame structure system under seismic load. Rahman et al. [11] conducted nonlinear response history analysis to estimate seismic effect on multistoried core wall frame structure. Cheng et al. [12] studied Fourier amplitude spectrum and response spectrum to investigate behavior of core wall under earthquake. Rathi et al. [13] revealed core wall curtailment in multistoried building poses severe vulnerability. Hashmi and Narender [14] revealed that position of elevator core wall caused torsional irregularity and changed seismic behaviour of building frame. Story displacement is much higher in building frame without core wall. Hosseini et al. [15] showed that shear wall enhance lateral stiffness and suitable to resist seismic load in multistoried building.

3. FORMULATIONS

In this research, parametric study has been carried out between core wall building frame and without any shear wall building frames. Seismic loads are calculated as per Bangladesh National Building Code (BNBC) 2015 [1].

Firstly, Fundamental period of vibration (T) is calculated in second,

$$T = C_t h_n^{3/4} \qquad (1)$$

Where, c_t= Moment resisting factor and h_n =Height of building above GL, in meter.

Secondly, Numerical co-efficient (C) is determined by,

$$C = \frac{1.25s}{T^{2}/_{3}} \qquad (2)$$

Where, T = Fundamental period of vibration and S = Site co-efficient.

Thirdly, base shear (V) is calculated from the following relation:

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

Where, V = Base Shear, Z = Seismic zone co-efficient, W = Total dead load in a floor, I = Importance Factor and R = Response Reduction Factor

Finally, the remaining portion of the base shear (V-F_t), shall be distributed over the height of the building according to the relation:

$$F_x = \frac{(V-F_t)w_x h_x}{\sum w_i h_i} \quad (4)$$

Where, W_i = Seismic Weight of floor i, h_i = Height of floor i from base.

The concentrated force, F_t acting at the top of the building shall be calculated as follows:

F_t =0.07TV ≤ 0.25V [for T › 0.7 sec] or F_t = 0 [for T ≤0.7 sec] (5)

4. MODEL DESCRIPTION

Two frame structure are analyzed to observe effects of earthquake load as per BNBC 2015. Models are of three 16’ span in X- direction and three 14’ span in Y-direction. Both the buildings are 10 storied. Column size are calculated considering 2% reinforcement. Dead load and live load are calculated for the building frame as per BNBC. Live load is 40 psf for residential building. Wall load is 50 psf and floor finish load is 25 psf. Size of edge columns are 16”x16” and corner columns are 12”x12”. The sizes of middle column are 20”x20”. Dimension of beams are considered 12”x15” and slab thickness 6” based on thumb rule calculation. Details of key parameters of modeling are presented in Table I.

Model 1: Building frame without shear wall. There are 16 columns and the building is beam-column frame structure. There is no shear wall to resist lateral load.

Model 2: Building frame with core wall. Four shear walls are located at central portion of the building. Two core walls are 16’ and other two core walls are 14’. The thickness of core walls are 5”. The minimum thickness of core wall is 1/25th of unsupported height or length nor less than 5”, whichever is smaller as per BNBC 2015 [1]. Both of the two buildings have same 16 columns as shown in Figure 1(a) and 2(a).

Figure 2 shows the plan and elevation of Model 2. The core shear walls are located at B2 to B3, B3 to C3, C2 to C3 and B2 to C2 span. All shear walls are located at the middle or central position of the building plan.

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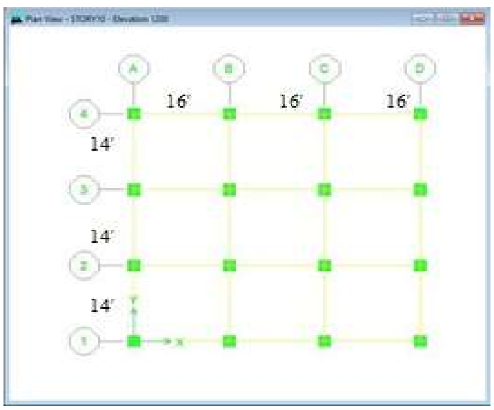
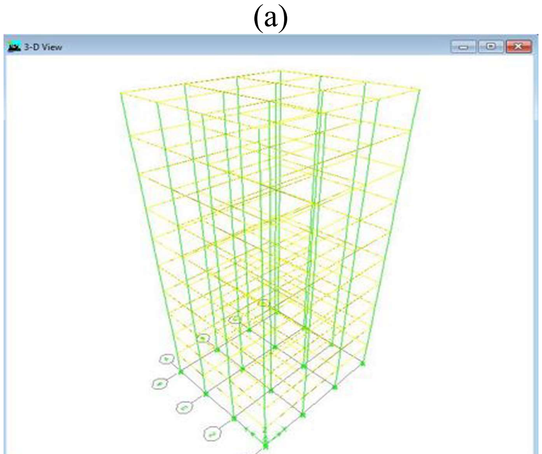
TABLE I. Key parameters of modeling

Parameters	Values
Compressive strength of concrete (fc')	3000 psi
Rebar grade	60 grade
Story height	10'
Beam size and arrangement	12"x15" all directions along column gridline.
Slab thickness	6"
Support condition	Fixed support
Mesh size and type	Auto Mesh, maximum element size = 48
Opening in core wall	One opening of 4'x7'
Pier Definition	P1
Spendrel Definition	S1
Analysis condition	Static analysis

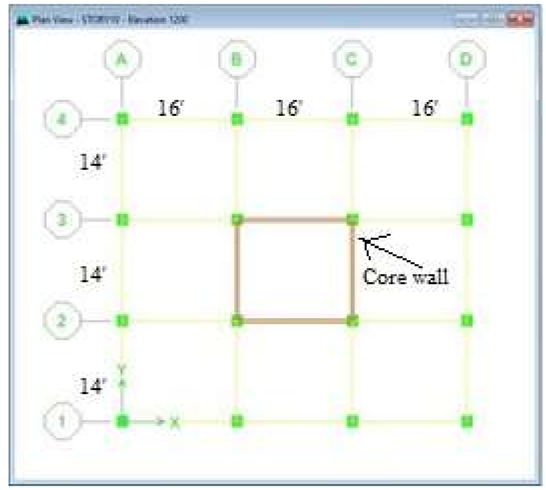


(a)

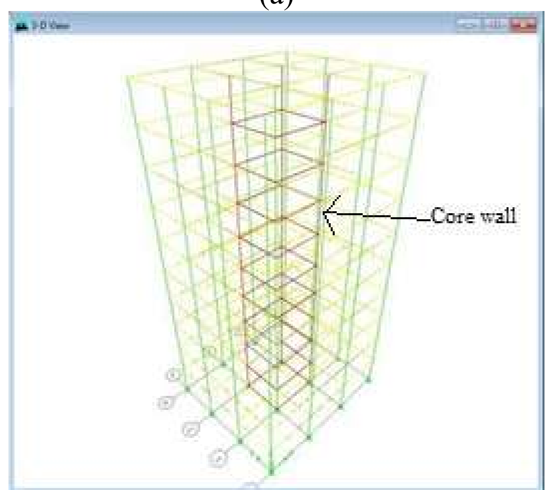


(b)

Fig. 1. (a) Plan and (b) 3D view of Building frame without shear wall (Model 1)



(a)



(b)

Fig. 2. (a) Plan and (b) 3D view of frame structure with core wall (Model 2)

5. DATA ANALYSIS

Drift, axial force and bending moment of columns are studied in this research. ETABS v 17.0 software is used for the structural analysis. Reaction of columns are also analyzed. Static seismic analysis is performed as per BNBC 2015 [1].

A. Story drift

Frame structure with core wall (model 2) have much lower story drift in comparison with frame structure without shear wall (model 1) which is shown in Figure 3. Story drift is low in bottom stories, high in middle stories and decreases towards top stories in model 1. On contrary, story drift increase with the height of building up to 10m, after that the drift is uniform up to the top stories in model 2. Maximum story drift in model 1 is 0.000589, on contrary, maximum story drift in model 2 is 0.000105. Story drifts reduce from 49.48% to 88.85% at various floor levels inserting core wall in the building plan. Since, only difference in between the two models is core wall at central span. Hence it is clear that, core wall control drift and reduce story-wise drift significantly. Maximum allowable story drift is 0.005 times height of the story as per BNBC 2015 [1]. Hence, the calculated allowable drift for the proposed building models are 0.15m, which is lower than this allowable limit.

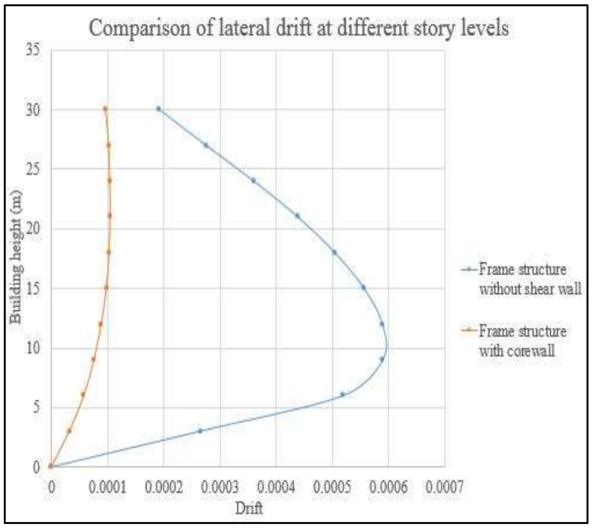


Fig. 3. Comparison of story drift at different levels between models

B. Base shear

Hashmi and Narender [14]; Youssef et al. [16] showed comparison of base shear occur due to seismic load for the core wall or shear wall frame structure with the structure without shear wall. ETABS v 17.0 analysis shows that, due to seismic load base shear in frame structure without shear wall (model 1) and frame structure with core wall (model 2) are 80.93kip and 53.6kip respectively. Base shear reduces by 50.99% in model 2 under seismic load. Therefore, core wall resist base shear produced by earthquake load with greater percentage.

C. Overturning moment

Overturning moment is crucial feature of a frame structure performance under seismic loading. Overturning moment in frame structure without shear wall (model 1) is 5765.65kip-ft, on the other hand, same for frame structure with core wall (model 2) is 3820.64kip-ft as shown in Figure 5. Overturning moment adding up to 33.73% in the model 1, since there is no core wall in the structure.

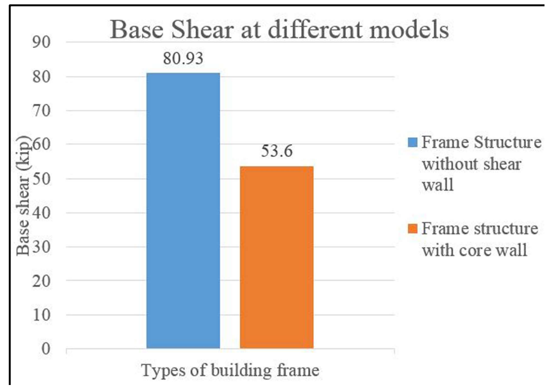


Fig. 4. Comparison of base shear at different models

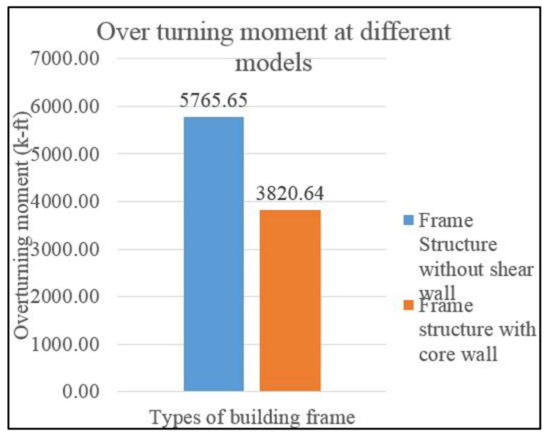


Fig. 5. Graphical representation of overturning moment at different models

D. Reaction at different columns

Corner column at left most portion of the building plan A1, edge column at A3 and central column at B2 (position of columns are shown in Figure 1 and Figure 2) are considered for observing column reaction due to seismic load. Reactions due to seismic load in corner and edge column is less in case of frame structure with core wall. The reactions in corner column and edge column in frame structure with core wall are 4.74kip and 7.37kip respectively. On the other hand, reactions in corner column and edge column in frame structure without shear wall are 24.1kip and 28.94kip respectively. Reaction force at corner A1 column reduce by 80.33% in frame structure with core wall and same for edge column A3 by 74.33%. Hence, column reaction exerts by earthquake load decreases by introducing core wall at center location of building plan. Shear wall carries significant amount of the shear force occurred due to seismic load. As a result, reaction on columns decrease. However, central column which is adjacent to core wall subjected additional reaction force. It needs special attention while structural design.

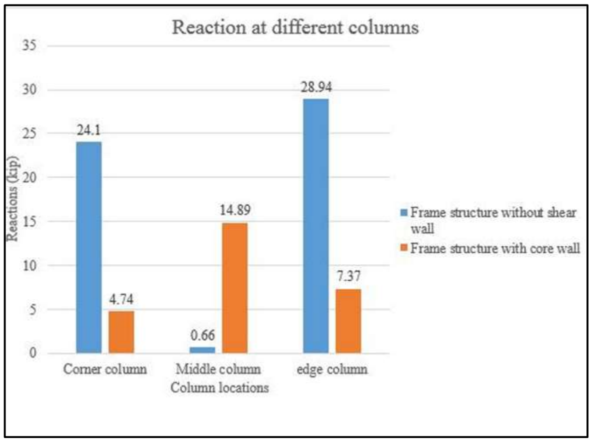


Fig. 6. Reaction due to earthquake load at various columns

E. Maximum bending moment at different columns

Similar to column reaction, bending moment is necessary for the structural design of column. We consider, corner column A1, central or middle column B2 and edge column A3 for the in depth study as shown in Figure 1 and Figure 2. Maximum bending moments produce by seismic load at corner, edge and middle columns varies from 48.65kip-ft to 54.63kip-ft in the frame structure without shear wall, i.e. model 1. On the other hand, maximum bending moments produce by seismic load at corner, edge and middle columns are 1.96kip-ft, 2.34kip-ft and 2.22kip-ft in the frame structure with core wall, i.e. model 2 respectively (Figure 7). Amount of maximum bending moment at columns decrease by approximately 95% in all three types of columns. Hence, column bending moments generated by earthquake load are taken significantly by the core wall in the model 2.

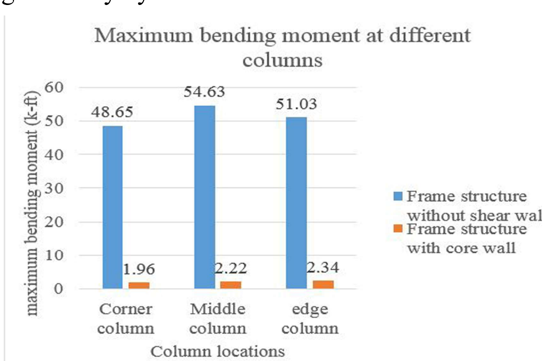


Fig. 7. Maximum bending moment at different columns

6. CONCLUSION

From the above study, it is evident that inclusion of core wall in building frame can control drift and reduce story-wise drift considerably. In addition, base shear is less in frame structure with core wall (model 2) compare with the frame structure without any shear wall (model 1) under seismic load. Furthermore, edge and corner column reaction forces are higher in model 1 in comparison with model 2 due to load exerted by same earthquake intensity. However, central column near to core wall experience more reaction force, which requires special consideration while structural design.

In this study, seismic load calculated in this research are based on BNBC 2015 only. Other code provisions regarding seismic analysis can be conducted. The study limited to static analysis only. Dynamic analysis under seismic load can be performed. The location of seismic study is only for Dhaka area. The studied buildings are used only for residential purpose. The study is limited to medium dense clay soil only.

The study can be extended for industrial and commercial buildings. Impacts of seismic load on irregular shape frame can be studied. Moreover, influences of other lateral forces, such as, wind load can be investigated. Effects of earthquake loading on double core wall and periphery shear wall may provide valuable information. The study can be extended for other building systems, such as, masonry building and composite structures. Cost-benefit study can be performed considering core wall in the frame structure system also.

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