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A Comparative Study on Beam Slab and Flat Plate Building Frame under Seismic Load

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Abstract

The study delves to evaluate the performance of beam slab and flat plate slab in the building frame due to seismic load. Two models of the same layout plan and story levels were compared under seismic load as per BNBC 2016—one was a typical frame structure with beam slab i.e., model 1 and another one was a frame structure with a flat slab, i.e., model 2. Frame structure with beam slab (model 1) reduced story drift varying from 16.34 to 66.67% at various floor levels compared to a frame structure with a flat slab (model 2). It is evident that beam slab can control drift and reduce story-wise drift significantly. Story-wise column shear force decreased in presence of beam in the building frame under earthquake load. Story-wise bending moment at the bottom of column decreased with the rise of story height under seismic load in both models. However, the bending moment at different story levels was much lower in frame structure with beam slab. Column reaction at the corner and middle columns under seismic load decreased to 19.08% and 70.20% respectively in the beam slab frame. Since there was no beam in the structure, overturning moment adding up to 55% in model 2 compared to model 1.

Keywords: Beam slab, BNBC 2016, flat plate slab, seismic load, story drift

INTRODUCTION

A flat plate slab system is advantageous over an alternative conventional beam slab system providing adequate architectural flexibility, easier formwork, shorter construction time, and lower building height. However, flat plate slab buildings are vulnerable to earthquakes due to larger transverse displacements. This results in excessive deformation, damage of non-structural members, and produce unbalanced moments between slab and column. In addition, a flat plate slab is susceptible to reduced stiffness compared to an alternative beam slab under an earthquake. Most of the studies do not recommend flat plate systems alone in the high seismic hazard zone. Since Dhaka is situated in the moderate-intensity seismic zone as per Bangladesh Building Code 2016 [1], it is required to investigate the seismic behavior by comparing flat plate and beam slab building frames thoroughly.

Several studies have been performed to compare the behavior of flat slab and beam slab structures under seismic load. Flat slabs were subjected to punching shear failure and disproportionate collapse under dynamic load [2]. Dynamic loads such as, seismic load changeover time very quickly in comparison with the structure's natural frequency, and producing an overall structural response. Pahwa et al. [3] analyzed the behavior of multistoried buildings with flat slabs and two-way slabs under seismic loads for different seismic zones in India. Because of the absence of a lateral load resistance system, a flat slab structure subjected to greater story displacements compared to a beam slab structure [4]. A study conducted by Nayyashree and Sahana [5] found that lateral

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displacements of flat plate structures were 28 to 57% higher compared to the alternate beam slab structure. Sable et al. [6] investigated the seismic behavior of beam slab and flat slab buildings for different story heights. They found that the base shear of the beam slab structure was less than the flat slab of alternate structures. Coelho et al. [7] performed a full-scale laboratory test on three-story flat slab model under seismic load and observed flexural and torsional cracks around the exterior column-slab connections. They suggested combining shear walls with flat slab buildings in order to provide a stiffer structural system under seismic load. Medasana and Chintada [8] found that column moments and shear forces under various load combinations were high i.e., 68 to 95% and 14 to 35% respectively in flat slab structure compared to beam slab at different story levels. Story displacement and story shear were higher in flat slab structures than alternate beam slab structures [9]. Prior research investigated the effects of seismic load on core wall-frame structure in the context of Dhaka City [10].

Several researches were based on seismic load calculations as per different countries' building codes and soil conditions. For instance, Pahwa et al. [3], Navyashree and Sahana [5], Spoorthy and Reddy [9] considered Indian code (IS) and Coelho et al. [7] used Euro code for seismic load calculation. However, researches comparing beam slab and flat plate structures considering seismic load and soil condition of Dhaka city are yet to be explored. The novelty of this study delves to compare the flat plate and alternative beam slab structures considering the soil condition of Dhaka city and seismic load as per BNBC2016 [1].

SEISMIC LOAD FORMULATIONS

Seismic loads were calculated as per BNBC 2016 in this study. The steps of seismic load calculation were shown in the following:

Step 1: Fundamental period of vibration (T) was determined in second,

$$T = c_t h_n^{3/4} \quad (1)$$

where, c_t= Moment resisting factor and h_n=Height of building from base, in meter.

Step 2: Numerical co-efficient (C) was calculated from the following relation,

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

where, T = Fundamental period of vibration and S = Site coefficient

Step 3: Base shear (V) was determined by,

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

where, V = Base shear, Z = Seismic zone coefficient, W = Total dead load in a floor, I = Importance factor and R = Response reduction factor

Step 4: The remaining portion of the base shear (V-F_t), shall be distributed over the height of the building as per the following:

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

where, W_i = Seismic weight of floor i, h_i = Height of floor i from the base.

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

$$F_t = 0.07TV \leq 0.25V \text{ [for T >0.7 sec] or } F_t = 0 \text{ [for T } \leq 0.7 \text{ sec]} \quad (5)$$

MODEL ANALYSIS

Two alternative frame structures of the same plan (Figure 1) were analyzed in ETABS v. 9.6 to observe the effects of earthquake load as per BNBC 2016. Both of the buildings were six storied. Dead load and live load were calculated for the building frame as per BNBC 2016. The size of corner, edge, and middle columns were 12″×12″, 16″×16″ and 20″×20″ respectively in both models, and beams were considered 12″×18″ for Model 1. Slab thickness in Model 1 and Model 2 were 5″ and 7″ respectively as per ACI 318 code [11].

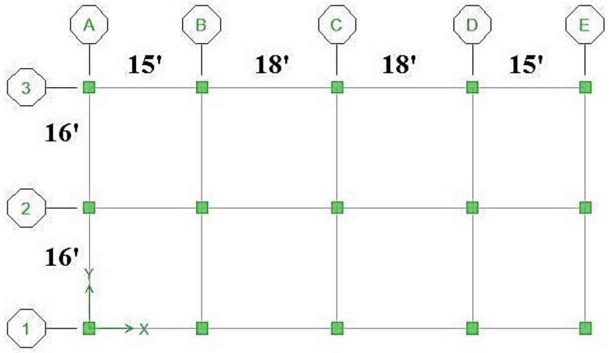
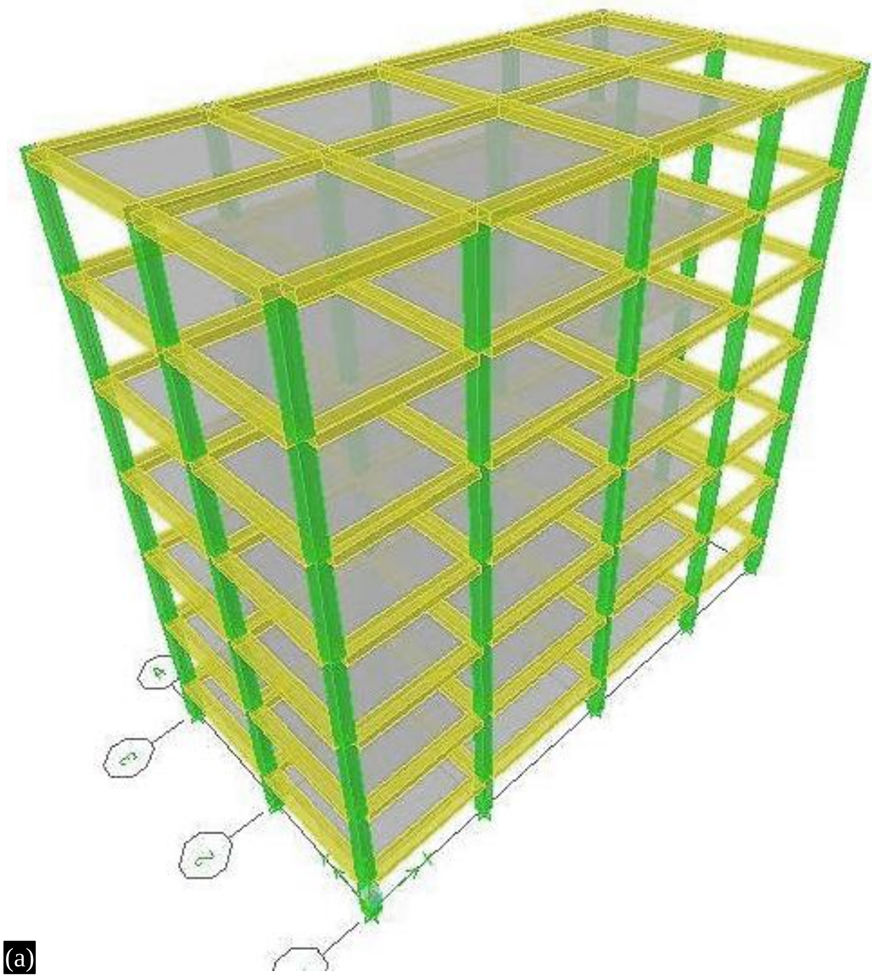
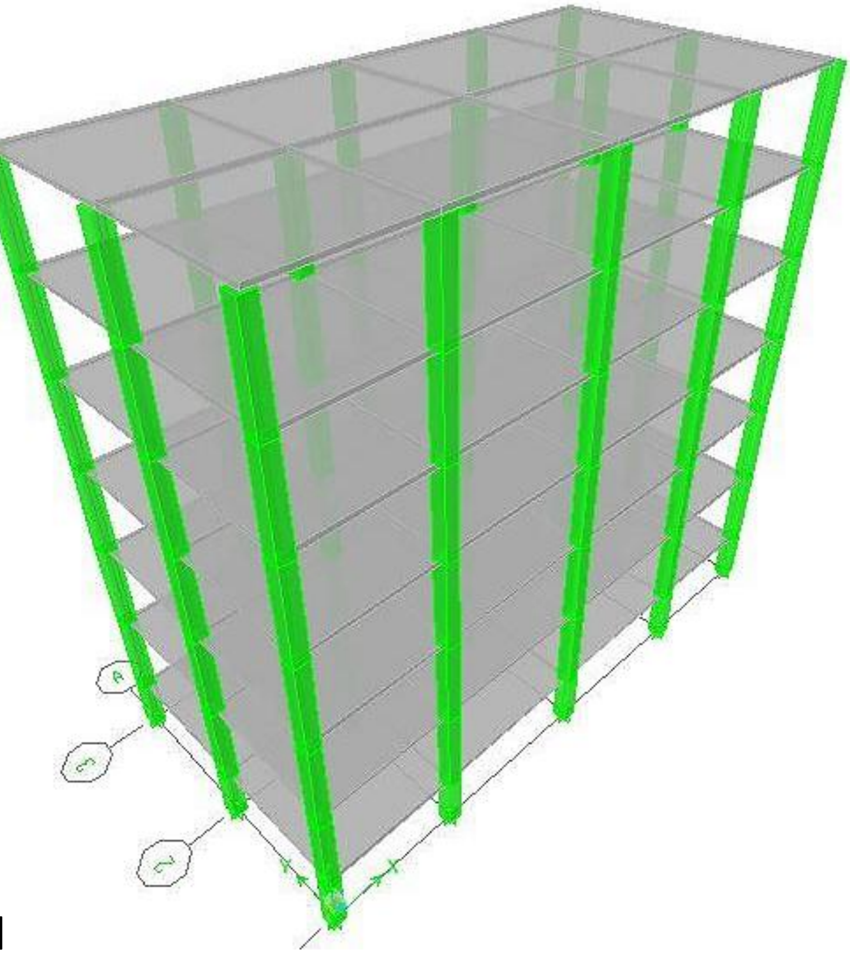


Figure 1. Building plan of model 1 and model 2.

Model 1 was a building frame with a beam slab and Model 2 was a building frame with a flat plate slab as shown in Figure 2.





(b)

Figure 2. 3D view of the building. (a) Model 1: Beam slab frame structure,
(b) Model 2: Flat plate frame structure.

RESULTS AND DISCUSSION

Drift, axial force, and bending moment of columns were studied in the research. Reactions of columns were also analyzed. Only seismic load in X and Y directions was taken into consideration. Story drift, story overturning moment, the moment at edge column, and column reactions were observed to conduct the comparative study.

Story Drift

Story drift is the amount of side sway in-between two adjacent stories of a frame structure caused by lateral loads. Frame structure with beam slab (Model 1) exerted much lower story drift in comparison with frame structure with flat slab (Model 2). Story drift increased in frame with flat plate slab (Model 2) by a maximum of 66.67% at base and increased by a minimum of 16.34% compared to the frame with beam slab (Model 1).

Story Overturning Moment

Maximum overturning moment in Model 1 and Model 2 was found to be 1743.89 kip-ft and 2702.03 kip-ft respectively. Story overturning moment decreases up to 55% due to the presence of beam frame in Model 1.

Moment at the Bottom of A2 Column

A2 column is located at the edge of the building plan as shown in Figure 1. Story bending moment at the bottom of the column decreases with the rise of story height under earthquake load in both cases (shown in Figure 3(a and b)). However, bending moment at the bottom of the column at different story levels was much lower in the beam slab frame structure. Reduction of story-wise bending moment varied from 56.79 to 112.99% in Model 1 compared to Model 2.

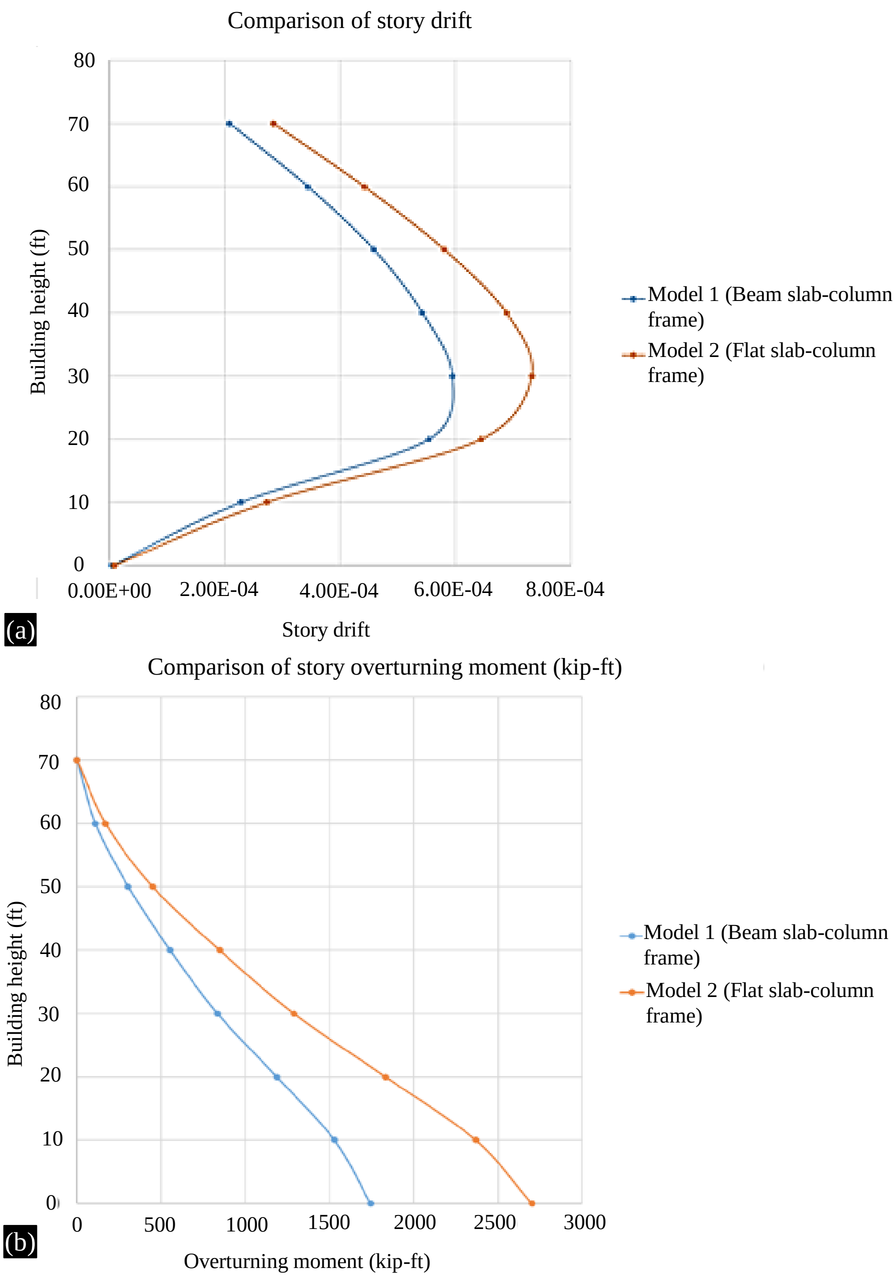
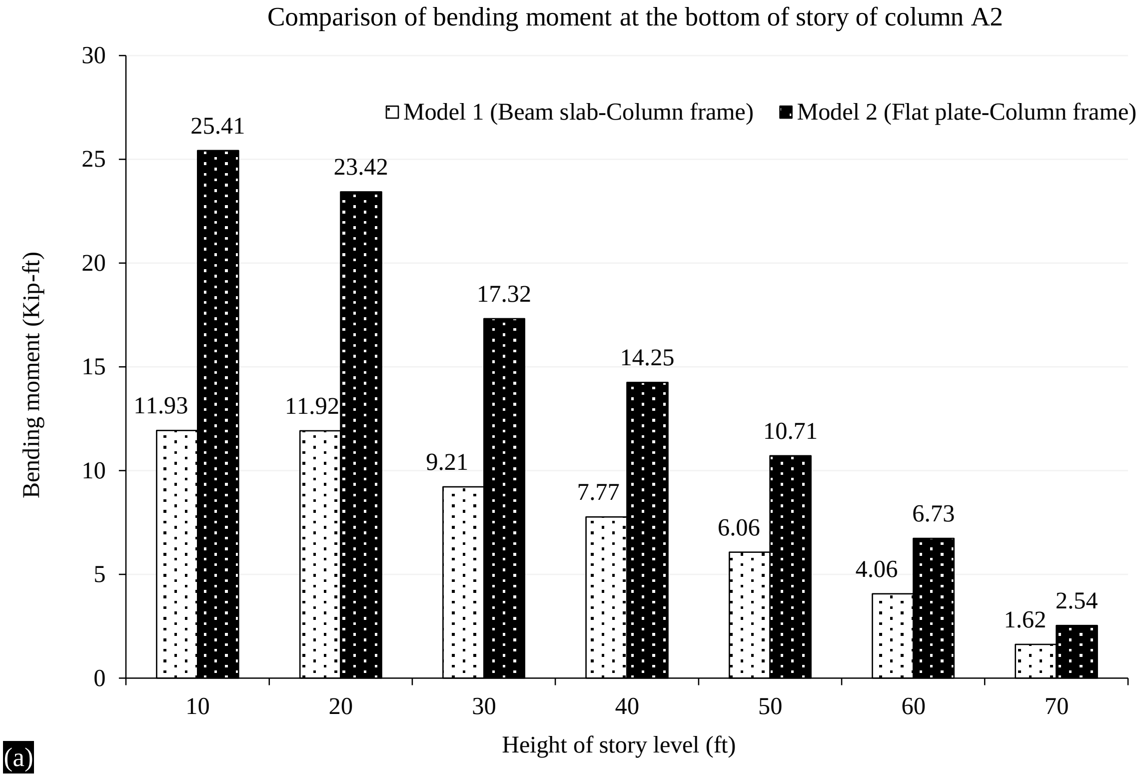


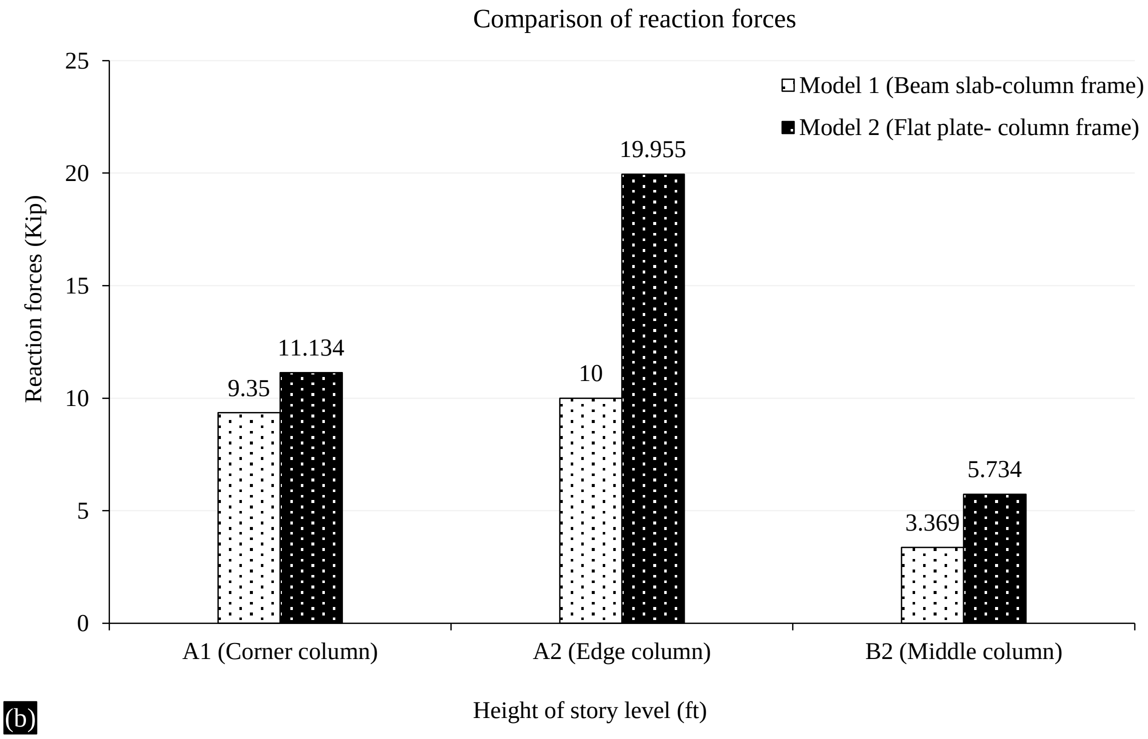
Figure 3. Comparison between beam slab and flat plate slab frame structures in terms of (a) story drift and (b) story overturning moment.

Reaction at Different Columns

Corner column at (leftmost portion of the building plan) A1, edge column at A2, and central column at B2 were considered for observing column reactions under seismic load. Reactions due to seismic load in corner, edge, and middle columns were less in the case of a frame structure with beam slab compared to frame structure with flat plate slab. Reaction force at corner A1 column reduced by 105.72% in a frame structure with beam slab and same for edge column A2 and middle column B2 decreased by 112.91% and 106.45% respectively Figure 4 (a and b).



(a)



(b)

Figure 4. Comparison between beam slab and flat plate slab frame structures in terms of (a) Column bending moment at the bottom and (b) Reaction forces.

CONCLUSIONS

It is evident from our study that beam slab can control drift and reduce story-wise drift significantly. In addition, column bending moment and overturning at different story levels are much lower in frame structure with beam slab under seismic load. Besides, column reaction exerted by earthquake load decreased in beam slab frame compared to flat plate slab frame. Dhaka City is situated in an earthquake vulnerable zone because of geological features, dense population, and an increasing number of high-rise buildings, this risk many folds. It is recommended to construct a beam slab building rather than an alternative one. However, proper provision of lateral displacement controls, such as shear wall and cross-bracing can be combined with flat plate building frame to avoid the risk of earthquake vulnerability.

The location of seismic study can be extended to other cities of Bangladesh. The study can be extended to industrial and commercial buildings. Besides, the impacts of seismic load on irregular shape frames can be studied. Effects of earthquake loading for different locations may provide valuable information. The study can be extended for other building systems, such as masonry building and composite structures. A cost-benefit study can be performed considering beam slabs and flat slabs in the frame structure system.

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