

Seismic Performance Evaluation of Residential Building in Dhaka City

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Abstract— Bangladesh is situated in a moderate earthquake-prone region. Major metropolitan cities of our country are under serious threat because of faulty design and construction of structures. So, structural engineers nowadays are more concerned about different procedures. According to Bangladesh National Building Code, the buildings are designed according to the equivalent static force method, response spectrum method, and time history analysis. But these methods can hardly find the actual performance of a structure. The nonlinear analysis provides a better understanding of the actual behavior of the systems during earthquakes. The nonlinear elastic analysis has a wide range of applications in the seismic evaluation and retrofitting of structures. This research mainly follows the procedures of ETABS 9.5.0 software in evaluating the seismic performance of residential buildings in Dhaka, Bangladesh. The present study investigates as well as compares the performances of bare, full-infilled, and soft ground story buildings. For different loading conditions resembling the practical situation of Dhaka city, the performance of this structure is analyzed with the help of a deflection, drift, and base shear. The performance of an infilled frame is found to be much better than a bare frame structure. It is seen that consideration of the effect of the infilled leads to a significant change in the capacity. Investigation of buildings with soft stories shows that the soft story mechanism reduces the performance of the structure significantly and makes them the most vulnerable type of construction in earthquake-prone areas.

Keywords— *Earthquake; Nonlinear elastic analysis; Infilled frame; soft ground story, irregular structure.*

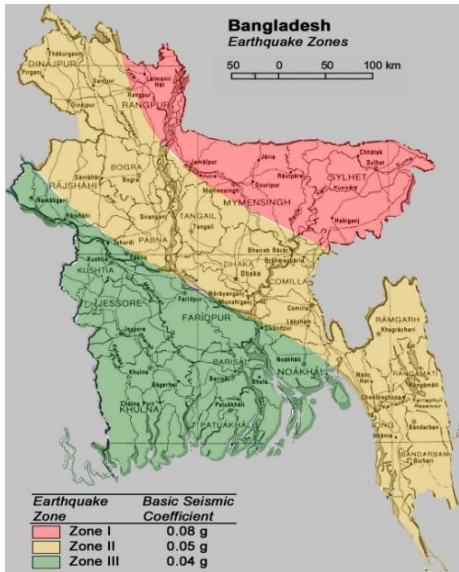
I. INTRODUCTION

Earthquake engineering has come a long way since its birth and seems to grow rapidly as it gains experience. Each time an earthquake happens, something new is available to learn and the profession grows to accommodate it. Both research and practice used to be mostly concerned with the design of structures that would be safe, in the sense of surviving a seismic event with the minimum number of casualties structure designed to higher standards, chosen to meet the specific needs, and able to remain functional after a small but relatively frequent event and being safe in a rare destructive earthquake costs slightly higher but still preferred nowadays by building owners. Nonlinear analysis is the simplified elastic method to find the behavior of the structure in the earthquake.

In the last few years, the widespread damage to RC buildings during earthquakes generated greater demand for seismic evaluation and retrofitting of existing buildings in Dhaka. Furthermore, most of our buildings built in the past two decades are seismically deficient because of the lack of awareness regarding structural behavior during earthquakes and the reluctance to follow the code guidelines. The structures, whose performance was evaluated in this study, are designed with the provisions from BNBC, 2006. BNBC equivalent static force method of determining earthquake force is limited to structures having a height of fewer than 20 meters. Hence this study deals with medium-rise buildings (six-storied). The purpose of the paper is to summarize the basic concepts on which the nonlinear elastic analysis is based, perform a linear analysis of medium-height residential RC buildings as seen in Dhaka city and investigate the changes in structural behavior due to different infill configurations. Therefore, the study aims to study and compare the deflection, drift, and base shear characteristics of different infilled conditions i.e. fully infilled, particular floor empty, and soft ground story conditions.

II. ANALYTICAL APPROACH

This study represents the performance evaluation of different types of existing buildings according to Bangladesh National Building Code (BNBC) 2006. BNBC, 2006 has some specific provisions for the calculation of earthquake load and analysis procedures for structures subjected to earthquakes. The most commonly used analytical method is the Equivalent Force Method, in which the dynamic earthquake effect is represented by an equivalent static load at different levels in proportion to mass at that level. According to BNBC, 2006 this process divides the country into three regions of possible earthquake ground response (0.075g, 0.015g, and 0.25g) as Zone 1, Zone 2, and Zone 3 respectively.



The total design base shear for a seismic zone is given by,

$$V = \frac{ZICW}{R}$$

Where,

Z = Seismic zone co-efficient

I = Structural importance co-efficient

R = Response modification co-efficient

W = Total seismic dead load

C = Numerical co-efficient = $1.25S/T^{2/3}$

S = Site co-efficient and

T = Time period = $C_t (h_n)^{3/4}$

Where, $C_t = 0.083$ for moment resisting frame

= 0.073 reinforced concrete and eccentric still frame

= 0.049 for all other structural analysis respectively.

Fig. 2.1: Seismic Zone of Bangladesh acc. to BNBC 2006

Lateral force calculated from the above equation known as base shear V, shall be distributed along the height of the structure.

III. MODELING OF THE STRUCTURE

The modeling of in-filled frames by the equivalent strut method and some other special features used in the modeling of in-filled panels is discussed in this chapter. Procedures and detailed calculations of equivalent strut width are also included here.

Equivalent strut method: Strength predictions of in-filled frames are a complex, statically indeterminate problem. The strength of an in-filled frame system is not only the summation of the infill properties but also those of the frame. Great efforts have been invested, analytically and experimentally, to better understand and estimate the composite behavior of masonry in-filled frames. Polyakov (1960) (work back to the early 1950s), Stafford Smith (1962, 1966, 1969), Mainstone (1971), and Klinger and Sertero (1976, 1978), to mention just a few, formed the basis for understanding and predicting in-filled frame in-plane behavior. Their experimental testing of in-filled frames under lateral loads resulted in specimen deformation shapes similar to the one illustrated in Fig 3.1.

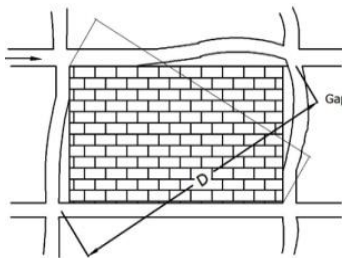


Fig 3.1: Deformed shape

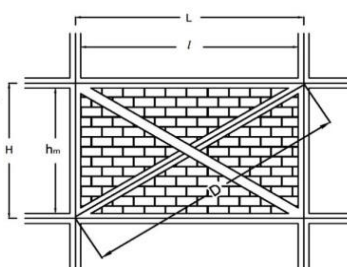


Fig 3.2: Strut geometry

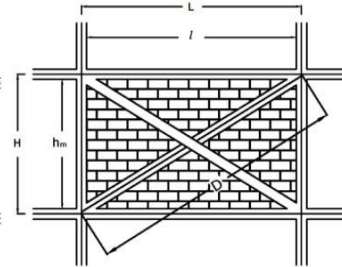


Fig 3.3: Placement of strut

During testing of the specimens, diagonal cracks developed in the center of the panel, and gaps formed between the frame and the infill in the non-loaded diagonal corners of the specimen, while full contact was observed in the two loaded diagonal corners. This behavior, initially observed by Polykov, led to a simplification in the in-filled frame analysis by replacing the masonry infill with an equivalent compressive masonry strut as shown in Fig 3.2. The equivalent masonry strut of width a, with the same net thickness and mechanical properties (such as modulus of elasticity, E_m) as the infill itself, is assumed to be pinned at both ends to the confining frame.

Equivalent Strut Width: The evaluation of the equivalent width varies from one reference to the other. The most simplistic approaches presented by Paulay and Pristlay (1992) and Angel et al. (1994) have assumed constant values for the strut width, a, between 12.5 to 25 percent of the diagonal dimension of the infill, with no regard for any infill, or frame properties. Stafford Smith and Carter (1969), Mainstone (1971), and others derived complex expressions to estimate the equivalent strut width, a, that consider parameters like the length of contact between the column/beam and the infill, as well as the relative stiffness of the infill to the frame. Expressions used in this chapter have been adopted from Mainstone (1971) and Stafford-Smith and Carter (1969), for their consistently accurate prediction of in-filled frame in-plane behavior when compared with experimental results (Mainstone, 1971; Stafford-Smith and Carter, 1969; Klinger and Bertero, 1978; and Al-Chaar, 1998). The masonry infill panel will be represented by an equivalent diagonal strut of width, a, and net thickness, t_e , as shown in Fig 3.2.

The equivalent strut width a , depends on the relative flexural stiffness of the infill to that of the columns of the confining frame. The relative infill-to-frame stiffness shall be evaluated using Eq. 3.1 (Stafford- Smith and Carter, 1969):

$$\lambda_1 = H [(E_m t \sin 2\theta / (4E_c I_{col} h_w))]^{1/4} \dots\dots (3.1);$$

Where, t is the thickness of masonry wall.

Using this expression, Mainstone (1971) considers the relative infill-to-frame flexibility in the evaluation of the equivalent strut width of the panel as shown in Eq. 3.2

$$a = 0.175 D (\lambda_1 H)^{-0.4} \dots\dots (3.2)$$

If there are opening present, existing infill damage, and/or FRP overlay, However, the equivalent strut must be modified using

$$A_{mod} = a (R_1)_i (R_2)_i \xi_1 \dots\dots (3.3)$$

Where $(R_1)_i$ = reduction factor for in-plane evaluation due to presence of openings

$(R_2)_i$ = reduction factor for in-plane evaluation due to existing of damage

ξ_1 = strength increase factor due to presence of FRP overlay

Although the expression for equivalent strut width given Eq. 3.3 was derived to represent the elastic stiffness of an infill panel, this study will extend its use to determine the ultimate capacity of in-filled structures. The strut will be assigned a strength parameter consistent with the properties of the infill it represents.

Eccentricity of Equivalent Strut: The equivalent masonry strut is to be connected to the frame members as depicted in Fig. 3.3, where the bold double-sided arrow represents the location of the strut in the structural model. The infill forces are assumed to be mainly resisted by the columns, and the struts are placed accordingly. The strut should be pin connected to the column at a distance l_{column} from the face of the beam. This distance is defined in Eq. 3.3 and Eq. 3.5 and is calculated using the strut width, a , without any reduction factors.

$$l_{column} = a / \cos \theta_{column} \dots\dots (3.4)$$

$$\tan \theta_{column} = \{ h_m - (a / \cos \theta_{column}) \} / l \dots\dots (3.5)$$

Using this convention, the strut force is applied directly to the column at the edge of its equivalent strut width, a . Figure 3.3 illustrate this concept.

IV. DESCRIPTION OF THE STRUCTURE

BARE, AN IN-FILLED STRUCTURE, A SOFT STOREY STRUCTURE, A STRUCTURE WITH NO PARTITION WALLS ON A PARTICULAR FLOOR

The model structure of this study is a 6-story 3x3 bays residential building, located in Dhaka which is shown in Fig. 4.1. Length of each bay is 3.7 meters. The slab thickness is 125 mm and the column sizes are 500x500 mm for interior columns and 400x400 mm for exterior columns. All the beams are of the same size with a width of 300 mm and depth including slab thickness of 500 mm. The typical story height is 3 m. The total floor area is 123.21 m². Fig. 4.2 represents the elevation of bare and infilled structures with all these mentioned properties. The foundation of the building is a mat foundation.

A regular structure that has all the story heights the same was designed first and then to use the ground floor as a car parking its partition walls were removed which is shown in Fig. 4.3 as a soft story structure. And Fig. 4.4 indicates a regular structure that has an infill masonry panel on all the floors was designed first and then to use the third floor as a commercial hall, its partition walls were removed and this structure can be said as irregular structure. Loading condition, material property, and salient features of these structures are as same as the full in-filled structure described previously.

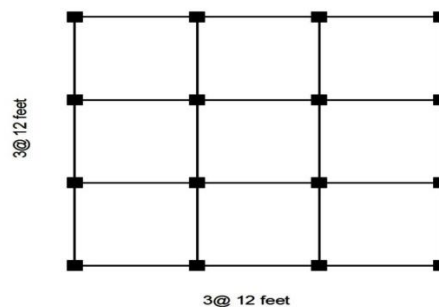


Figure 4.1: Plan of the building

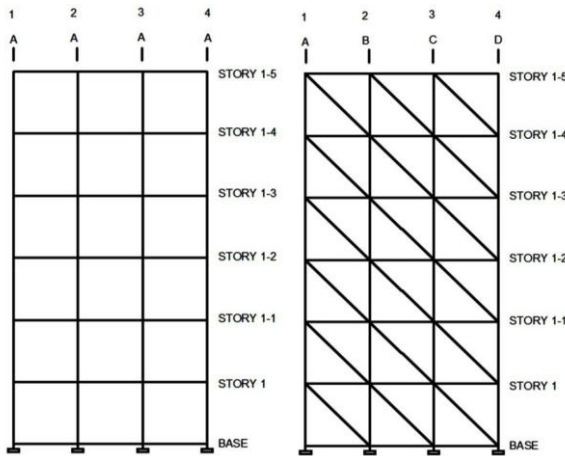


Fig. 4.2: Bare and In-filled structure

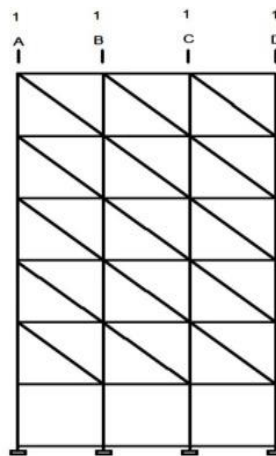


Fig. 4.3: Soft storey structure

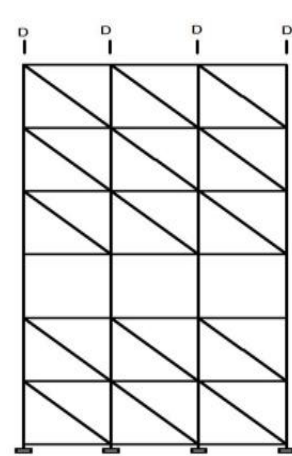


Fig. 4.4: Irregular structure

Design Details

Table 3.1: Properties of slab, beam & column

Member	Slab	Beam	Exterior Column	Interior Column
Size(mm)	125	300x500	400x400	500x500

Table 3.2: Properties of equivalent brace

Dimension	Width (mm)	Thickness (mm)	Area (mm ²)
Size(mm)	485	125	2425

V. RESULT AND DISCUSSION

Comparison of bare and an in-filled structure: The performance of a bare frame and infilled structures is evaluated based on the comparison of base shear, lateral drift and lateral displacement.

Base Shear: The maximum tolerable base shear of a bare structure is 356 kN which is lower than that of an in-filled structure about 370 kN illustrated in Fig. 5.1. And Table 5.1 is indicating that the addition of infill increases the base shear characteristics of infilled frame structure about 3.78% than that of the bare frame structure.

Lateral Drift: Story drift is maximum for the ground floor as shown in Fig. 5.2. From the Figure, it is seen that displacement of a different story for the in-filled frame is less than that of a bare frame and each story deforms uniformly. From Table 5.1 it is seen that the story drift ratio of the infilled frame structure is 78.92% smaller than that of the bare frame structure.

Lateral Displacement: From Fig. 5.3 it is seen that the maximum displacement of infilled frame structure and bare frame structure is 1.76 mm and 7.88 mm respectively. It is also observed from Table 5.1 that the maximum displacement of the infilled frame structure is 77.66% smaller than that of the bare frame structure.

After comparing the base shear, story drift, and lateral displacement of the infilled and bare frame structures, the results from the graphs and table indicate the addition of infill actually helps to increase the base shear while reducing the story drift and displacement for infilled structures more than the bare frame. So the performance of bare frame structures can be improved by placing in-filled masonry panels in it, which contributes to the stability of the structure against earthquakes.

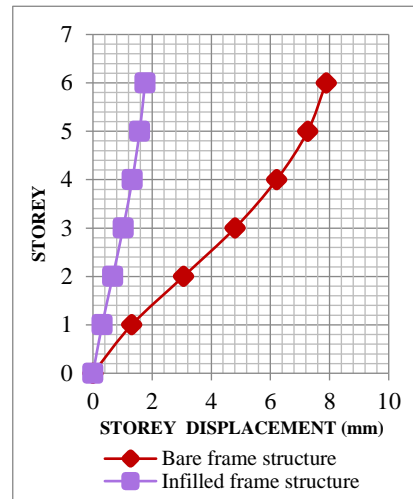
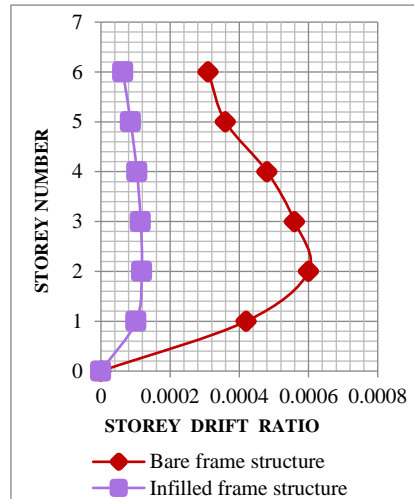
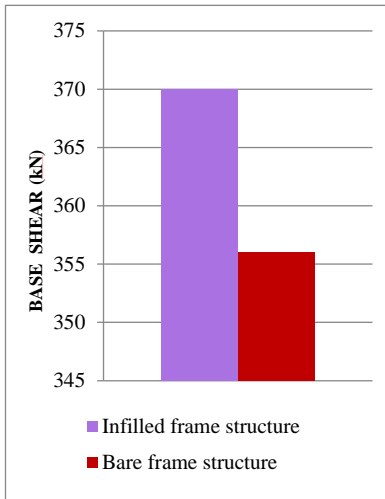


Fig 5.1 Comparison of base shear Fig 5.2 Comparison of storey drift Fig 5.3 Comparison of storey displacement

Table 5.1 Comparison of base shear, storey drift, storey displacement between infilled and bare frame structure

Frame type	Base shear (kN)	% Variation	Maximum storey drift ratio	% Variation	Maximum displacement (mm)	% Variation
Infilled frame structure	370	3.78	0.000118	78.92	1.76	77.66
Bare frame structure	356		0.00056		7.88	

Comparison of soft storey and an in-filled structure:

If one level of a building is significantly more flexible or less stiff in lateral load resistance than the stories above it or the foundation below it refers to a Soft story. The formation of soft stories is caused by the story stiffness difference with the upper stories. The stiffness difference between stories is mainly caused by having bare ground floor have in-filled masonry panels. This is the most common case in residential buildings and could be in earthquakes.

Base Shear: Fig 5.4 indicates that the base shear of infilled frame structure and soft ground story structure is 370 kN and 84 kN respectively. It is also observed that the base shear of the infilled frame structure is 77.30% higher than that of the soft ground story structure from Table 5.2.

Lateral Drift: From Table 5.2 and Fig. 5.5 it is seen that the story drift ratio of infilled frame structure and Soft ground story structure is 0.000118 and 0.000344 respectively which represents that the story drift ratio of the infilled frame structure is 65.70% smaller than that of the bare frame structure.

Lateral Displacement: The maximum displacement of infilled frame structure and soft ground story structure is 1.76 mm and 2.54 mm respectively seen in Fig 5.6 and Table 5.2. The observed maximum displacement of the infilled frame structure is 30.71% smaller than that of the soft ground story structure.

A comparison between infilled and soft story structures' different properties such as base shear, lateral drift, and displacement indicates that increases in infill can improve the base shear characteristics while decreasing the amount of drift and displacement. Again, infill can give better performance in earthquake regions rather than soft stories.

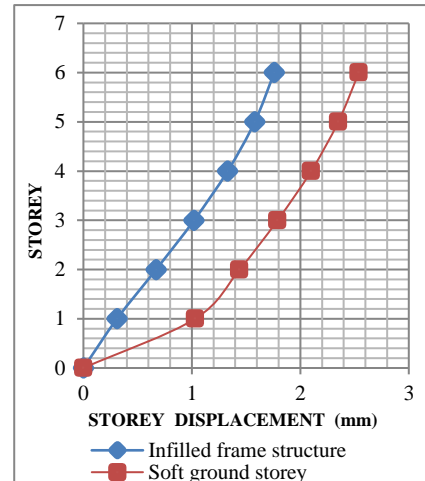
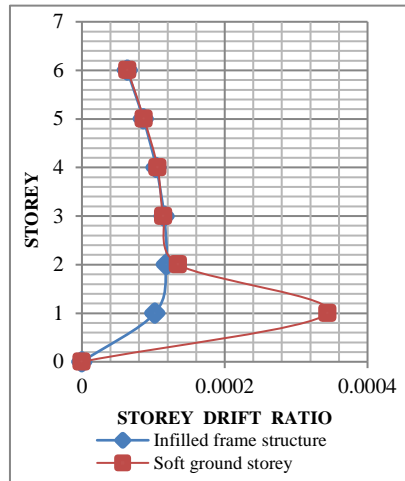
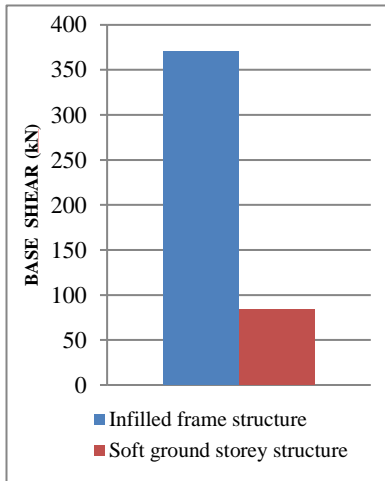


Fig 5.4 Comparison of base shear Fig 5.5 Comparison of storey drift Fig 5.6 Comparison of storey displacement

Table 5.2 Comparison of base shear, storey drift, storey displacement between infilled frame and soft storey structure

Frame type	Base shear (kN)	% Variation	Maximum storey drift ratio	% Variation	Maximum displacement (mm)	% Variation
Infilled frame structure	370	77.30	0.000118	65.70	1.76	30.71
Soft Ground Storey	84		0.000344		2.54	

Comparison of a structure with no partition walls on a particular floor and an in-filled structure:

Sometimes for use in commercial purposes, like party halls or offices, the partition walls of a particular floor of a multistoried building are removed. This is common in the case of multistoried buildings used for various purposes. Such irregularity may cause a change in the capacity of the structure against earthquake

Base Shear: Fig. 5.7 and Table 5.3 it is seen that the base shear of infilled frame structure and irregular structure is 370 kN and 83 kN respectively. The base shear of the infilled frame structure is 77.57% higher than that of an irregular structure. This is because the reduction of infill in a particular floor reduces base shear characteristics.

Lateral Drift: The story drift ratio of the infilled frame structure is lower than that of the irregular structure which is 0.000118 and 0.000397 respectively shown in Fig. 5.8. Table 5.3 calculated that the story drift ratio of infilled frame structure is 70.28% smaller than irregular structure.

Lateral Displacement: Fig 5.9 represents the comparison between lateral displacement values of both infilled and irregular structures. The maximum displacement of the infilled frame structure is 1.76 mm which is 34.57% smaller than that of the irregular structure shown in Table 5.3.

Comparing the infilled and irregular structures it can be said that the addition of infill reduces the lateral drift and displacement for infilled structures whereas base share characteristics are increasing. So again, infilled structures are showing better performance than irregular structures with the assistance of increasing infilled members.

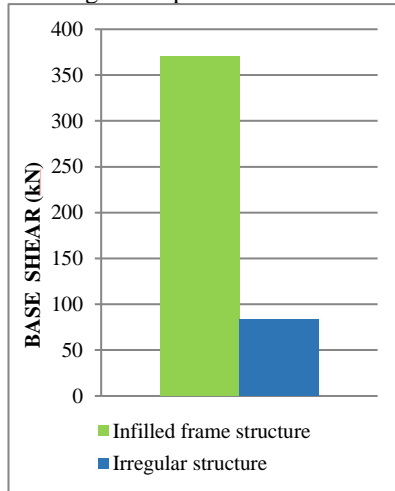


Fig 5.7 Comparison of base shear

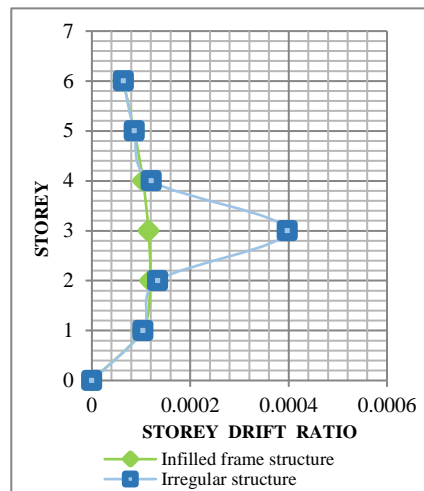


Fig 5.8 Comparison of storey drift

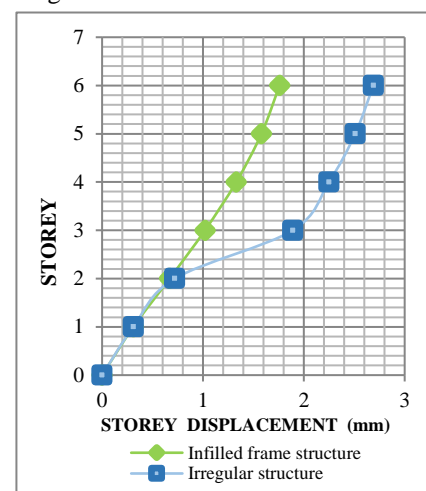


Fig 5.9 Comparison of storey displacement

Table 5.3 Comparison of base shear, storey drift, displacement between infilled frame and irregular structure

Frame type	Base shear (kN)	% Variation	Maximum storey drift ratio	% Variation	Maximum displacement (mm)	% Variation
Infilled frame structure	370	77.57	0.000118	70.28	1.76	34.57
Irregular structure	83		0.000397		2.69	

IV. CONCLUSIONS

In this chapter different cases which are most common in structural design and construction are discussed. The reinforced concrete buildings are frequently modeled as frame structures due to simplicity, but it is evident in the above discussion that the performance is improved significantly due to the modeling of infill and its effect should be considered. The failure of RC building due to soft story mechanism is also fatal and enough consideration.

There are some desired levels of seismic performance when the building is subjected to specified levels of seismic ground motion. Acceptable performance is measured by the level of structural and nonstructural damage expected from the earthquake shaking.

The main goal of the study was to analyze the deflection, drift, and base shear characteristics of bare frames, infilled frames, and different infilled frames and compare them with each other.

Based on the study the main conclusions can be summarized as follows:

- The seismic performance of full-infilled frames has been observed to be better than that of bare frames. The deformation pattern of a fully infilled frame is uniform and total deformation is small than any other type analyzed.
- The addition of infill in the upper stories leaving the ground floor open makes an extremely soft story case and causes a significant reduction in the capacity of the structure.
- For the three types of structure considered (bare, full infilled, and soft ground story), roof displacement is highest for the bare frame, and ground floor displacement is highest for the soft ground story.

IV. RECOMMENDATIONS

The following recommendations for future work are suggested:

- The thesis concentrated its study mainly on medium-rise buildings. The performance of high-rise buildings can be studied further.
- The effect of partial infill on the same floor level can be studied.
- The effect of the type of foundation and soil on the earthquake response of a building can be investigated.
- Further studies can be performed on existing old RC structures to improve their performance against earthquakes by adding a shear wall, braced frame, etc.

V. REFERENCES

- [1] "Building Code Requirement for Structural Concrete", American Concrete institute, ACI Committee 318, Detroit, 2002.
- [2] "Seismic Evaluation and Retrofit of concrete Building (volume 1)", Report (ATC-40), Applied Technology Council (ATC), California, USA, 1996.
- [3] "Bangladesh National Building Code (BNBC)", Housing and Building Research Institute, Mirpur, Dhaka, Bangladesh, 2006.
- [4] Chopra, A.K., "Dynamic of Structure –Theory and Application of Earthquake Engineering", Second Edition, Prentice-Hall of India, New Delhi, India, 2003.
- [5] Computer and Structure Inc. ETABS Nonlinear version 9.5.0. California, USA.
- [6] FEMA 356, 273 - Pre-standard and Commentary for the seismic Rehabilitation of Buildings. Federal Emergency Management Agency, Washington D.C., USA, 2002.
- [7] Nilson, A.H., Darwin, D. and Dolan, C. W., "Design of Concrete Structure (Thirteenth edition)", McGraw Hill, New York, USA, 2003.
- [8] Stafford- Smith, B., "Behavior of square In-Filled", Journal of the structural Division, ASCE, vol. 92, February 1966.
- [9] Stafford-Smith, B. and C. Carter, "A Method of Analysis for Infill Frames", Proceedings of the institution of Civil Engineers, vol. 44, 1969.
- [10] Shahrin, R., "Seismic Performance Evaluation of RC Building by Pushover Analysis", B.Sc. Engg. Thesis, Department of Civil Engineering, Bangladesh University of Engineering & Technology, 2009.