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# Seismic Performance Assessment of a RC Building Considering High, Low Quality Infill and Bare Frame

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**Abstract:- Bangladesh is a moderately seismic active region in the world. Due to the unplanned pattern of construction, many buildings have been built without proper seismic consideration. In this situation, it is necessary to evaluate the seismic performance of the existing buildings.**

**The study aims to evaluate the seismic performance of Reinforced Concrete (RC) frame buildings considering the effect of infill brick masonry designed by the previous code. In Bangladesh, the load-bearing capacity of masonry walls is not considered during structural design. But masonry infills have a vital role in the seismic performance of RC frame buildings. This study compares the building performance of infilled walls using non-linear static pushover and response history analysis using STERA software. RC structures are considered to get analytical results of story drift due to the application of artificial ground motions. Also, capacity spectrum method is conducted after considering the hysteresis damping effect to determine the performance point. Therefore, all the simulations and analyses have been performed as per both previous and updated seismic codes.**

**From this study, it was obtained that the quality of masonry infill walls significantly affects building performance. Instead of being a brittle element, the infill masonry walls change the seismic behavior and influences the seismic capacity, story drift, and displacement. Therefore, consideration of masonry walls is advisable for both the new design of buildings and the assessment of existing structures.**

***Keywords:-*** *Seismic Performance, Masonry Infill, Seismic Code, Artificial Ground Motion.*

## I. INTRODUCTION

Bangladesh is a moderately seismic-active region around the world. It is located where three tectonic plates meet: the Indian plate, the Eurasian plate, and the Burmese plate. The Indian plate is moving northeast, slowly colliding with the Eurasian plate. This collision formed the Himalayan Mountains, and they are still rising. There are some active faults along this boundary, such as the enormous Dauki fault that borders northern Bangladesh. Movement along this fault formed the large Shillong Plateau to the east, and the Burmese plate pushes west against the Indian plate. In recent years, the construction of high-rise buildings has increased as part of the ongoing development of Bangladesh. The high population density in the capital, Dhaka, is a catalyst for the present trend of high-rise buildings. Unplanned and haphazard pattern development due to the rapid construction of new structure is a problem. For the structural design of mid to high-rise buildings in the city, earthquakes are of vital concern.

Masonry infill RC frame structures are widespread throughout Bangladesh, like the other developing countries. In general, infill can be grouped into two different categories: isolated infill and “regular” infill (sometimes referred to as shear infills). Isolated infill is not anchored with the frame of the building. In Bangladesh, the masonry infill is isolated from structures. Most buildings in Bangladeshi cities have been built without following any proper codes and seismic guidelines.

For this reason, even moderate level earthquakes could result in catastrophe, especially in cities where multistoried masonry infill buildings with soft ground stories are typical. Bangladesh is an earthquake-prone area. But there is always a tendency among people not to abide by the rules and regulations of the building code. Using infill masonry walls has been prohibited by modern codes of developed countries unless a special technique has been taken to ensure that they can withstand lateral loading. To mitigate expected earthquake damage, developing an effective strategy for changing the current system is also necessary.

In our country, the first building code was published in 1993 (act issued in 2006). The building code has been updated recently. The revised code was published in 2020 (and came in effect in February 2021). In the new code, Bangladesh has been divided into four seismic zones. The value seismic zone coefficient has been 1.5 times larger than the previous one. A school building has been analyzed in this study to evaluate the seismic performance of this building considering masonry infill. The model building was designed and constructed before the publication of the updated code. In this study, a comparative analysis of the building will be performed to understand its behavior considering the previous and new ones. Moreover, the effect of masonry walls having different strength will be discussed.

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Reinforced concrete (RC) frame buildings with infill walls are commonly built throughout the world. Infill walls are widely used as partitions in RC framed building construction work throughout Bangladesh. These are being considered non-structural elements; these walls affect both the structural and non-structural performance of RC buildings. This study is therefore of vital importance for the seismic assessment procedure of buildings in Bangladesh. As the behavior of the infill depends upon several unknown parameters. Thus, there is a growing need to carry out an evaluation of their seismic performance.

➢ *In Recent Years there has been a Good Deal of Research in Infill-Masonry Buildings. in Bangladesh, many Buildings are:*

- *Seismically vulnerable*
- *Containing non-structural masonry walls*
- *Need to be strengthened.*

This study is of vital importance for seismic assessment procedures in Bangladesh.

## II. METHODOLOGY

*A. Numerical Model of Frame*

By using computer software, a model is prepared considering hysteretic behavior corresponding to materials of structure, design parameters and loading patterns. In order to computer analysis, STERA 3D (ver. 10.8) software is used for simulation. As the model incorporates inelastic member behavior under cyclic lateral loading, the nonlinear time history analysis explicitly simulates hysteretic energy dissipation in the nonlinear range.

*B. Specification of Building*

The main purpose of this study is the seismic performance evaluation and response analysis of building structures in Bangladesh. As buildings in Bangladesh are usually constructed with infill brick masonry, this masonry wall significantly affects the performance of the building.

The building is in Gazipur, the adjacent city of the capital, Dhaka. The zone co-efficient of this location was 0.15 according to the previous building code, BNBC 2006. But in the updated building code, BNBC 2020, the zone co-efficient is increased and its value is 0.28.

Table 1 Specification of Building

| **Number of floors** | **:06** |
|---|---|
| Response modification factor | :8 |
| Height of the building | :19.2 meter |
| Area of each floor | :195 sqm |
| Type of footing | :Isolated foundation |
| Concrete Compressive strength | :20 MPa |
| Tensile strength of steel | :275 MPa |
| Column, C1 | 300 x 450 mm |
| Column, C2 | 300 x 500 mm |
| Beam, B1 | 300 x 375 mm |
| Beam, B2 | 300 x 450 mm |

*C. Numerical Model of Building*

For the analysis, the target building was modeled in STERA 3D (ver. 10.8), which is integrated software for seismic analysis of steel and reinforced concrete structures developed by Professor Taiki Saito of Toyohashi University of Technology (Saito, T., STERA 3D ver.10.8).

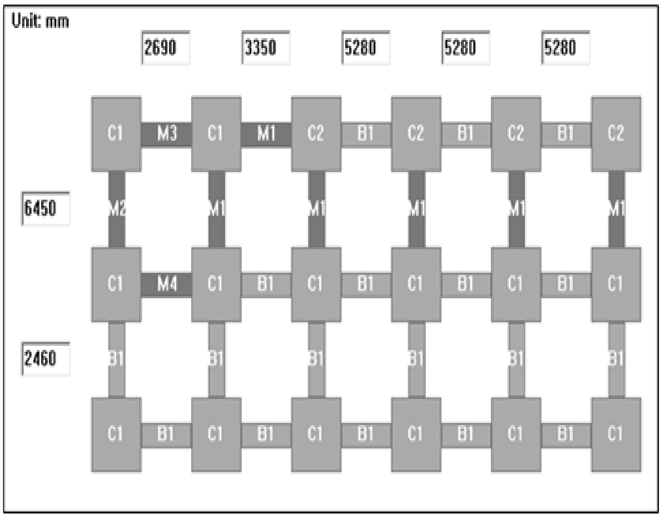

Fig 1 Plan in STERA 3D

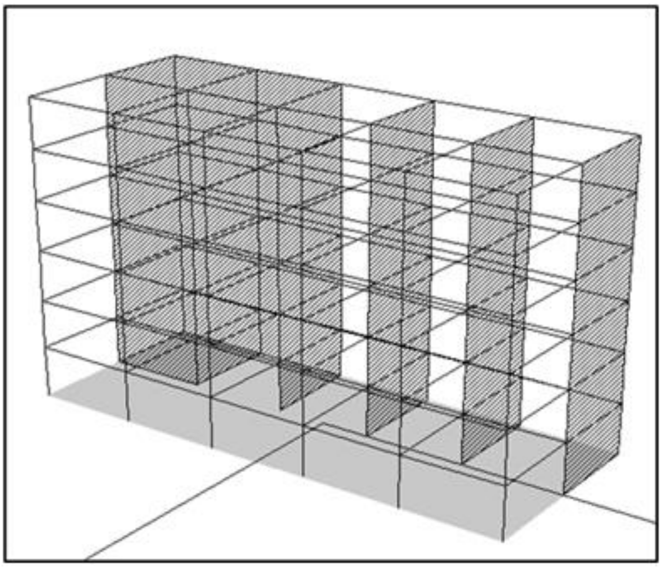
Fig 2 Three-Dimensional View of Full Structure

Live load at a classroom is considered as 2.0 $KN/m^2$ and in the corridor area is 3.8 $KN/m^2$. Moreover, applied live load at stair is 4.8 $KN/m^2$. Superimposed dead load for each floor is considered as 2.0 $KN/m^2$.

## III. ANALYSIS PROCEDURE

Pushover analysis is a simplified nonlinear technique which can be used to estimate the seismic performance of a structure by analyzing the relationship between base shear and structural deformation.

On the other hand, it can be an incremental static analysis used to determine the force versus displacement relationship of an existing or a new building structure.

*A. Capacity Spectrum Method (CSM)*

The Capacity Spectrum Method (CSM), a performance-based seismic analysis technique, is a widespread procedure for the assessment of building behavior due to ground motion.

CSM is used for the assessment of building behavior due to the ground motion. In this procedure, the resistance capacity of a building to an earthquake which is described by the capacity curve represents the demand of an earthquake. An intersection point can be determined considering the ductility of the building. The equations required in this procedure are as follows.

$$S_a = \frac{2 * ZICs}{3}$$

$$S_d = \frac{Sa}{\omega^2}$$

*B. Determination of Performance Point*

The capacity spectrum method initially characterizes seismic demand using an elastic response spectrum. This spectrum is plotted in spectral ordinates showing the spectral acceleration as a function of spectral displacement. This format allows the demand spectra to intersect on the capacity spectrum for the building. The intersecting point of the demand and capacity spectra would define the displacement for the structure; however, this is not normally the case as most analysis includes some inelastic behaviors.

To find the point where demand and capacity are equal, a point on the capacity spectrum needs to be selected as an initial estimate. Using the spectral acceleration and displacement defined by this point, reduction factors may be calculated to apply to the 5% elastic spectrum to account for the hysteretic energy dissipation or damping.

The response spectral acceleration and displacement are reduced by the following equation,

$$F_h = \frac{1.5}{1+10heq}$$

Where $h_{eq}$ is the equivalent damping ratio= $h = \frac{1}{5}\left(1 - \frac{1}{\sqrt{\mu}}\right)$.

*C. Response History Analysis (RHA)*

Non-linear time history analysis is performed by applying artificial ground motions. An input ground motion is synthesized by scaling existing ground motions and spectral fitting with response spectrum considering seismic design codes of different regions. The recorded ground motions from past earthquake records can be considered input earthquake ground motions for designing and assessing of the building. Where there are no records of earthquake ground motions, artificial simulated ground motions can be used. To perform response history analysis in my study, two sets of spectral accelerations are used. One set of spectral acceleration is obtained from the previous seismic code of Bangladesh. The other set is found from the updated building code. These data of spectral acceleration differ due to different values of seismic zone co-efficient.

In the target RC structure, artificial ground motion is applied. STERA wave is used to generate artificial ground motions in which acceleration response spectra is compatible with the target acceleration response spectra. There are two options to create the phase spectrum; one option is to use uniform random numbers and an envelope function, and the other option is to use the phase spectrum of real ground motion records.

Multiple ground motions are required to provide the satisfactory result of the demands due to the inherent randomness in earthquake ground motions. Different seismic codes suggest different opinions to consider several ground motions. ASCE 7 requires analysis for at least seven ground motions (or ground motion pairs for three-dimensional analysis) to determine mean values of demand parameters for design. Building standard law of Japan suggests at least three or more notification motions simulated from the acceleration response spectra. To conduct nonlinear earthquake response analysis, three phases of artificial ground motion data are conducted in this study. These phases of data are applied to the transverse direction of the target building in STERA 3D. After applying artificial ground motion data, comparative results of story drift for each floor will be obtained.

All the above phases are applied for high and low qualities of brick and mortar and for the bare frame of full structure to obtain seismic performance of RC structure.

*D. Allowable Deflection and Story Drift According to the Current Seismic Code in Bangladesh*

According to BNBC-2020, the deflections (δx) of level x at the center of the mass shall be determined in accordance with the following equation:

$$\delta x = \frac{Cd\delta xe}{I}$$

$C_d$ =Deflection amplification factor
$\delta_{xe}$ = Deflection determined by an elastic analysis
I = Importance factor defined

The design story drift at story x shall be computed as the difference of the deflections at the centers of mass at the top and bottom of the story under consideration:

$$\Delta x = \delta_x - \delta_{x-1}$$

Here, $\delta_x$ is deflection at the top story and $\delta_{x-1}$ is deflection at the bottom story.

The provision for allowable story drift according to the present code, BNBC-2020 is as follows.

Table 2 Allowable Story Drift

| Structure | Occupancy category | | |
|---|---|---|---|
| | I and II | III | IV |
| Structures, other than masonry shear wall structures | $0.025h_x$ | $0.020h_x$ | $0.015h_x$ |
| Masonry cantilever shear wall structures | $0.010h_x$ | $0.010h_x$ | $0.010h_x$ |
| Other masonry shear wall structures | $0.007h_x$ | $0.007h_x$ | $0.007h_x$ |
| All other structures | $0.020h_x$ | $0.020h_x$ | $0.020h_x$ |

*Ref: Table 6.2.21, BNBC-2020, hx is the story height

## IV. RESULTS AND DISCUSSION

This chapter describes comparison and discussions based on seismic performance of the target building with masonry infill. The existing building was constructed in 2018 and designed according to BNBC-2006. The building code, along with the seismic code, was updated in 2020. Due to the revision of the seismic zoning map, the seismic zone co-efficient of the location of the building has changed from 0.15 to 0.28. In this study, two sets of spectral acceleration are obtained from two different values of zone co-efficient. The strength of brick and mortar has a significant effect on the performance of the building. Comparative analyses of three tested specimens (one bare and two fully infill) have been studied in this research.

### *A. Results from Nonlinear Static Pushover*

Pushover analysis is quasi-static nonlinear analysis where the lateral displacement is incrementally increased in order to find the weak point and shear displacement at the ultimate stage. Non-linear pushover analysis can determine the displacement changing behavior performed in this study.

➢ *Drift-Shear Relationship*

Drift-shear relationship of each floor for various (two masonry infill structures and one bare frame) specimens are obtained by applying static pushover analysis.

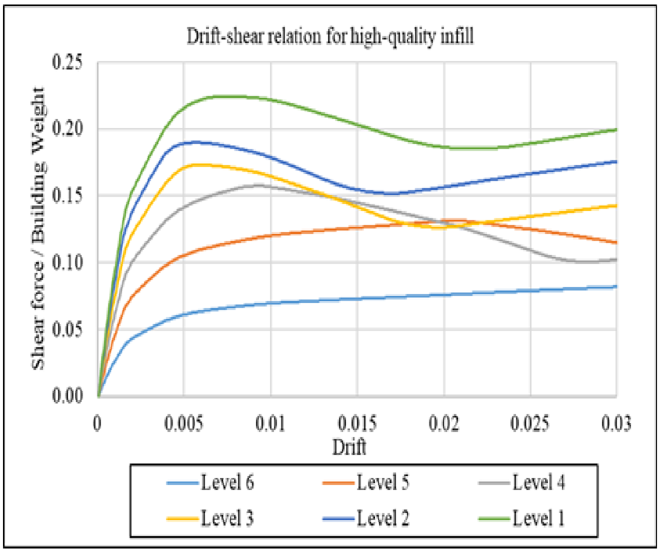


Fig 3 Drift vs. Shear Co-Efficient Graph for High Strength Infill

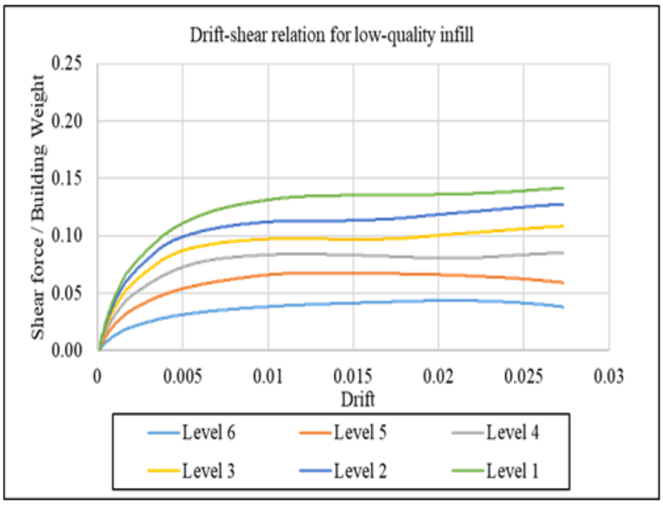


Fig 4 Drift vs. Shear Co-Efficient Graph for Low Strength Infill

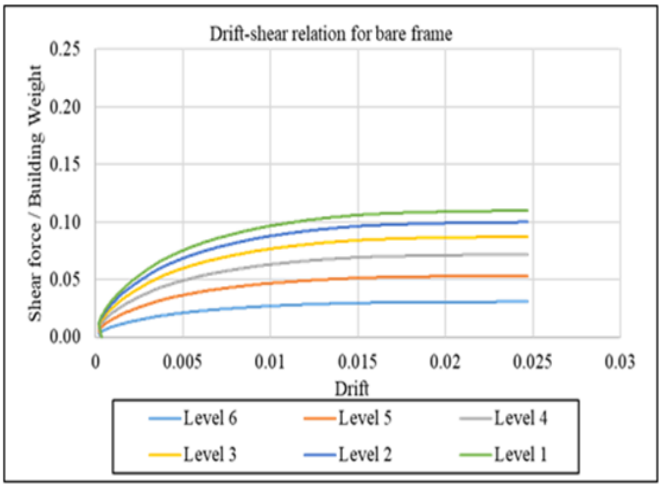


Fig 5 Drift vs. Shear Co-Efficient Graph Considering Bare Frame

➢ *Determination of Performance Point by CSM*

In the following figure, the capacity curves of three specimens intersect the demand spectra of hysteresis damped effect. This graph represents the performance points for three types of frames by following the current seismic code.

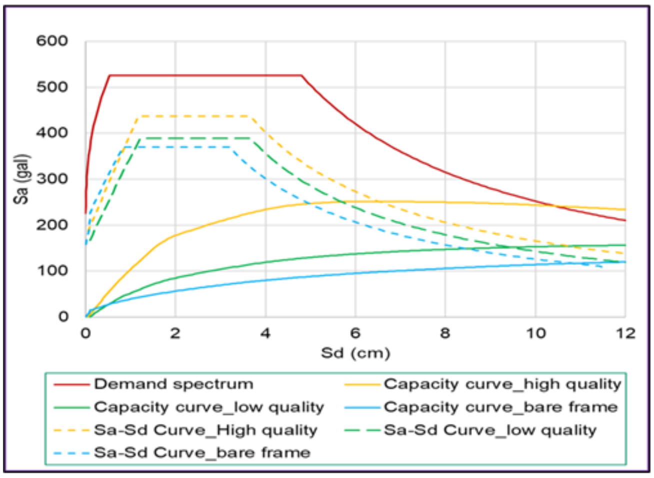


Fig 6 Graph for Capacity Curve and Demand Spectra for Current Code

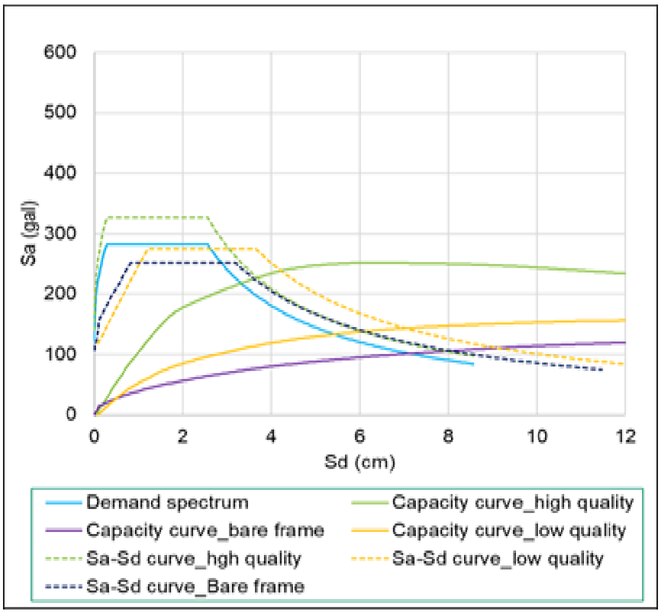


Fig 7 Graph for Capacity Curve and Demand Spectra for Previous Code

From the above graph, performance point for three types of frames can be obtained. Table of performance points is given below.

Table 3 Performance Point

| Type of Frame | According to Current Code | According to Previous Code |
|---|---|---|
| High quality infill | 6.96 cm | 4.12 cm |
| Low quality infill | 9.19 cm | 5.19 cm |
| Bare frame | 10.72 cm | 6.04 cm |

➢ *Maximum Story Drift by Pushover Analysis*

The parameters of story drift are important parts for understanding the displacement behavior of a building. Non-linear pushover analysis and response history analysis can determine this behavior as performed in this study. Story drift is defined as the ratio of the total lateral displacement that occurs in a single-story divided by the height of that story.

$$\text{Story drift} = \frac{\text{Displacement at story 2} - \text{Displacement at story 1}}{\text{Story height}}$$

Pushover analysis uses a mathematical model that directly shows the nonlinear load versus deformation relation pattern of a building structure or structural elements. The push-over analysis of this target building is conducted by STERA 3D software. The response of the building is obtained after applying lateral load in transverse direction up to average story drift of 1/50. The following graphs indicate maximum story drift corresponding to story numbers due to the pushover analysis.

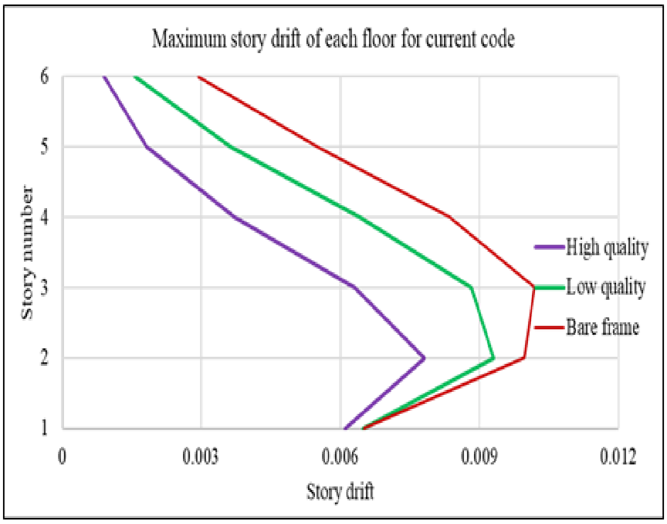


Fig 8 Maximum Story Drift vs. Story Number for Current Code

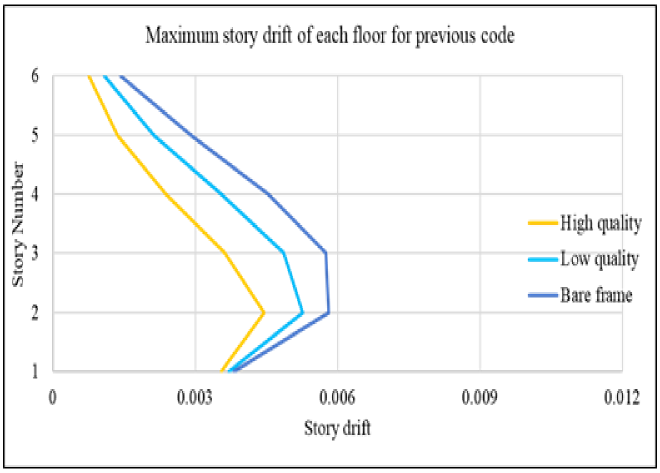


Fig 9 Maximum Story Drift vs. Story Number for Previous Code

*B. Target Spectra vs Response Spectra by Artificial Ground Motion:*

Nonlinear pushover analysis and response history analyses have been performed to investigate the performance level of the building according to the previous code (BNBC-2006) and the current one (BNBC-2020). Two real earthquake phases are obtained from the 1968 Hachinohe EW and the Kobe Earthquake phase to generate artificial ground motions. Again, another simulated graph of the acceleration response spectra is attained from random phase for 120 seconds.

The following figure demonstrates simulated acceleration spectra vs. target spectra by three artificial ground motions for the current seismic code of Bangladesh.

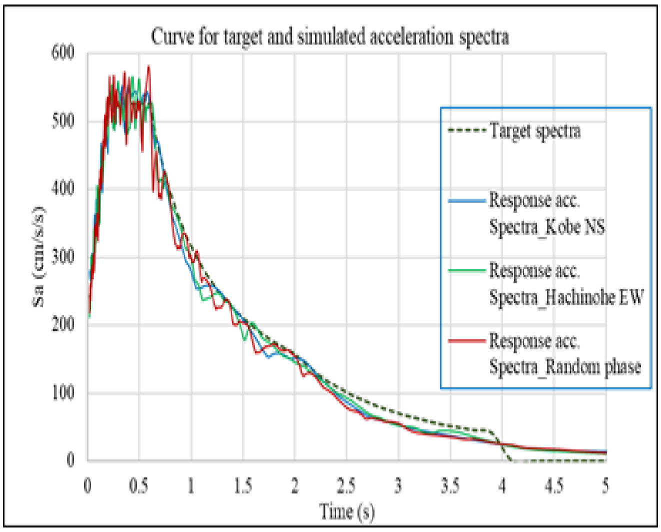


Fig 10 Graph for Target and Simulated Spectra Following Current Seismic Code

The following graph depicts simulated acceleration spectra vs. target spectra by same artificial ground motions for the previous seismic code.

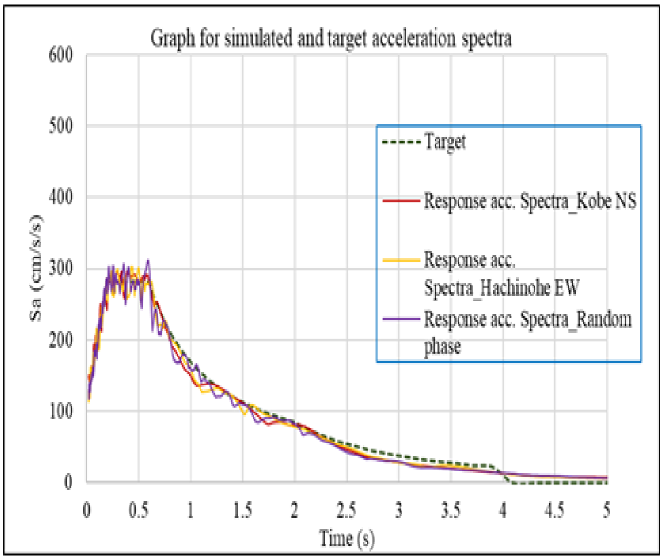


Fig 11 Graph for Target and Simulated Spectra Following Current Seismic Code

*C. Results from Response History Analysis*

In this study, to conduct response history analyses, three sets of artificial ground motions were applied to the transverse direction of the structure. Three cases (High, low-quality brick infill and bare frame) are simulated in computer software for analysis. For masonry infill with higher-quality material, the strength of brick and mortar is considered as 14 MPa and 10 MPa, respectively. On the other hand, in the case of low-quality masonry infill, the compressive strength of brick is 4 MPa and, the strength of mortar is 2 MPa.

➢ *Maximum Story Drift vs Story Number Graph by RHA*

The following graphs illustrate maximum story drift corresponding to story numbers due to the application of artificial ground motions considering the current seismic code in Bangladesh.

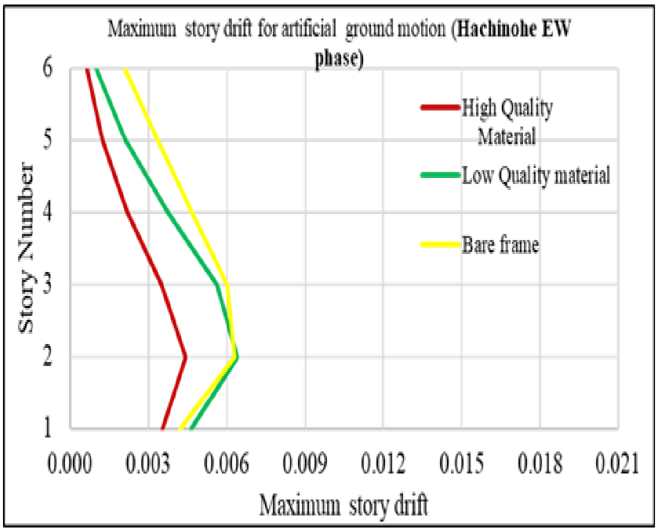


Fig 12 Maximum Story Drift for Real Earthquake Phase Considering Current Code

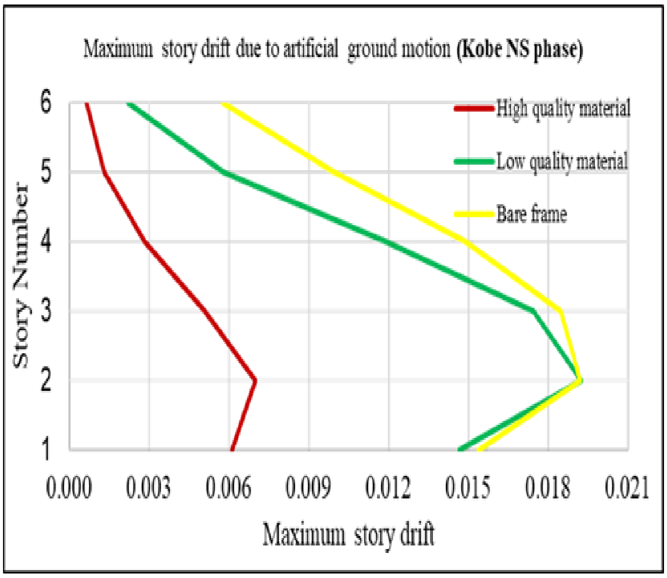


Fig 13 Maximum Story Drift for Real Earthquake Phase Following Current Code

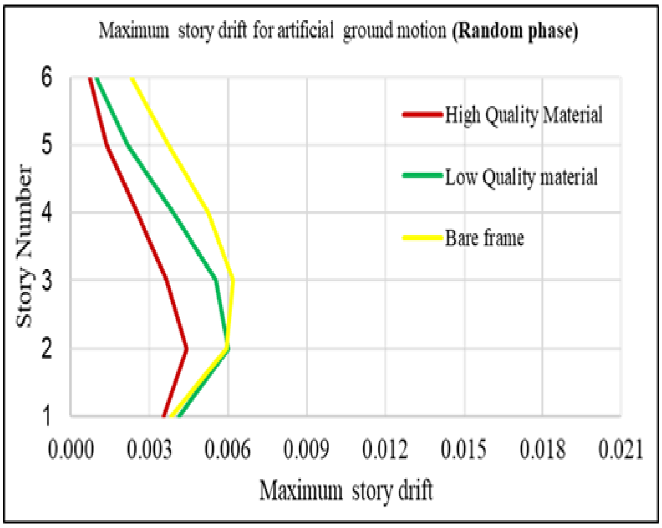


Fig 14 Maximum Story Drift for Random Earthquake Phase (120s) for Current Code

From the above figures, it is observed that the masonry infill of higher-quality brick has less drift value comparative to the others. For all the above cases, story drifts show highest value in level 02 among all the floors. Gradual changes in displacement ensure structural stability, uniform stiffness, and decrease the probability of forming non-uniform plastic hinges. In case of low strength materials and bare frames, there is a sudden change of story drift. So, the behavior of bare frame and low-quality infill are found to be the worse.

The following graphs are for maximum story drift corresponding to the number of story due to the application of artificial ground motions considering the previous seismic code (BNBC-2006).

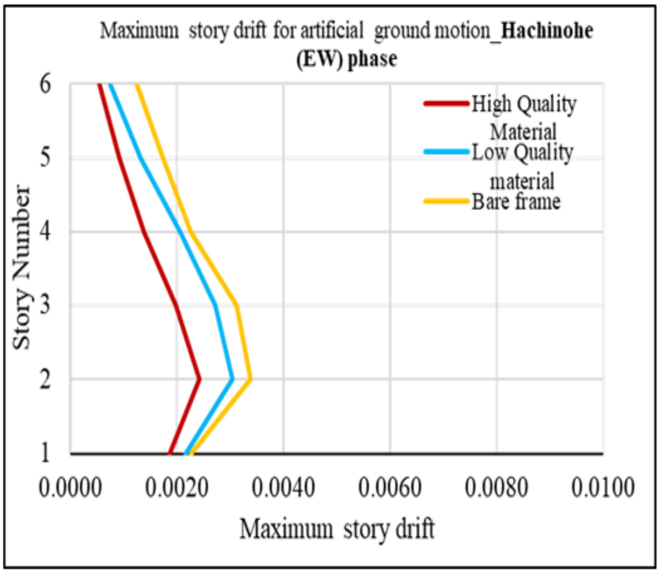


Fig 15 Maximum Story Drift for Real Earthquake Phase Following Previous Code

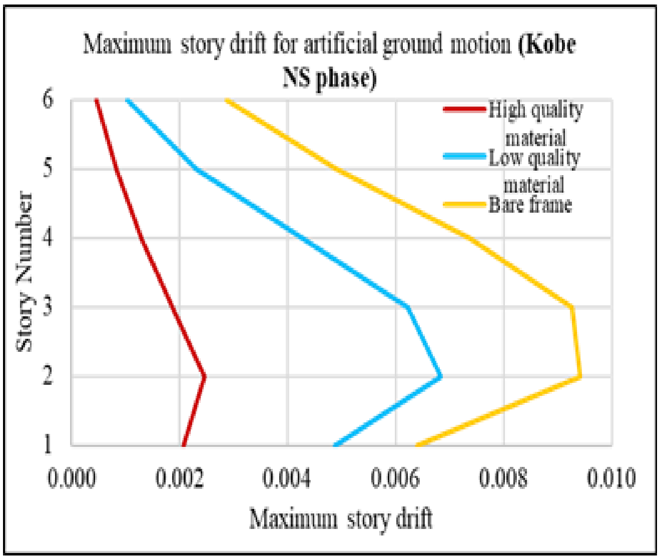


Fig 16 Maximum Story Drift for Real Earthquake Phase Following Previous Code

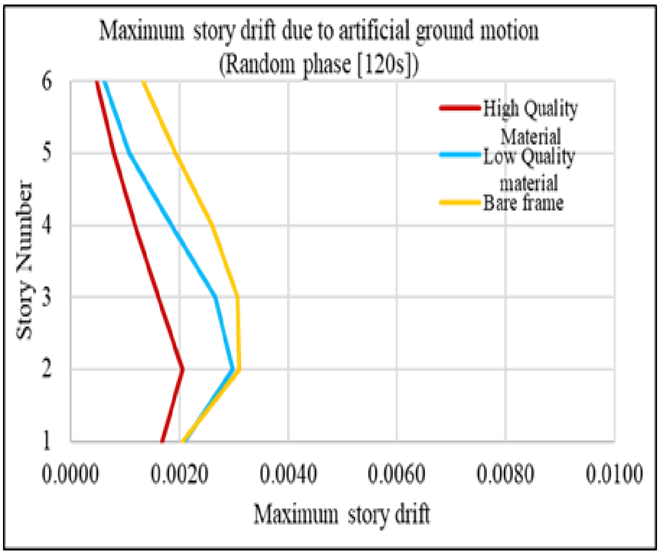


Fig 17 Maximum Story Drift for Random Phase Considering Previous Code

From the above graphs, it can be stated that it shows almost similar results to the graphs following the current code. Compare with the bare frame; the lateral drift is less in the higher-quality masonry infill. The overall seismic capacity is very low both in the bare frame and the low-quality masonry infill. The masonry infill has influences on seismic capacity and displacement. Moreover, the masonry infill of good quality has a significant effect over the bare frame.

- *Time vs. Top Displacement Graph for Hachinohe and Kobe EQ Phase*

Due to the application of 1968 Hachinohe EW and Kobe earthquake phases, the relation between time and top displacement can be obtained by constructing graphs.

- *The Graphs for Three Specimens Corresponding to Two Ground Motions are Presented below.*

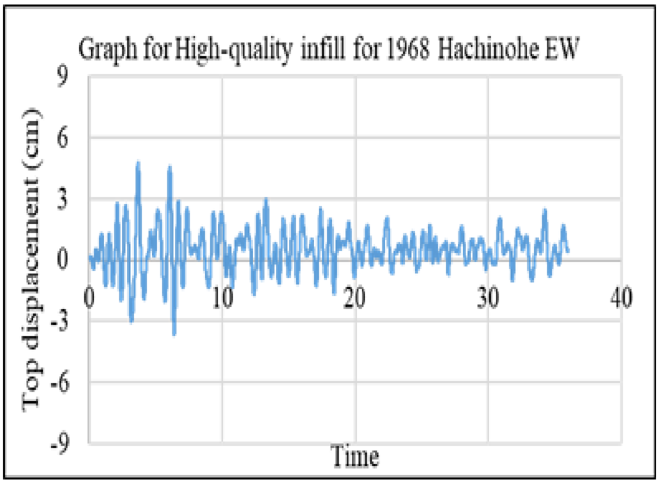


Fig 18 Top Displacement of High-Quality Infill for Hachinohe EW Phase

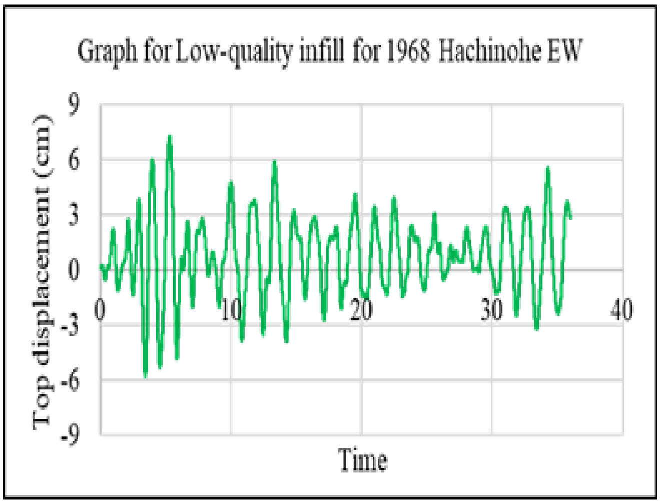


Fig 19 Top Displacement of Low-Quality Infill for Hachinohe EW Phase

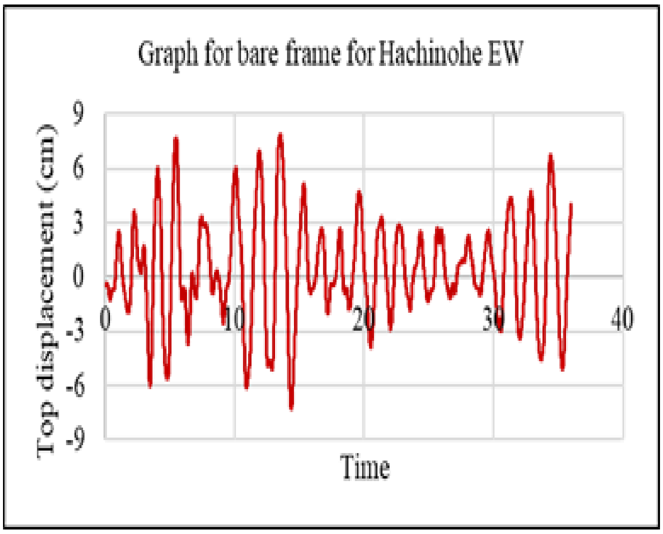


Fig 20 Top Displacement of Bare Frame for Hachinohe EW Phase

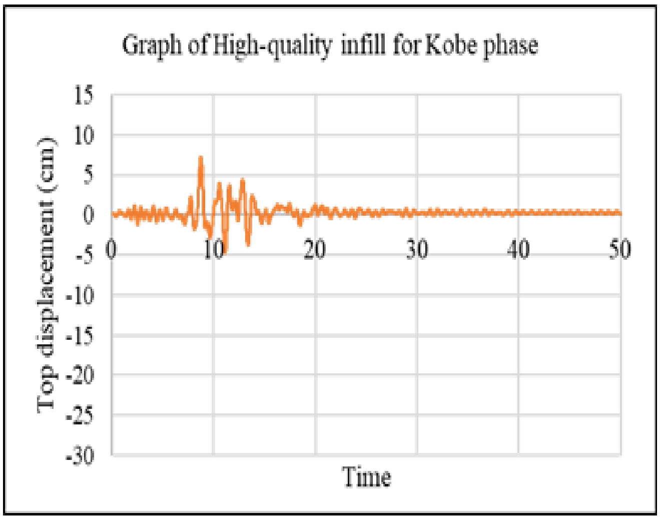


Fig 21 Top Displacement of High-Quality Infill for Kobe NS Phase

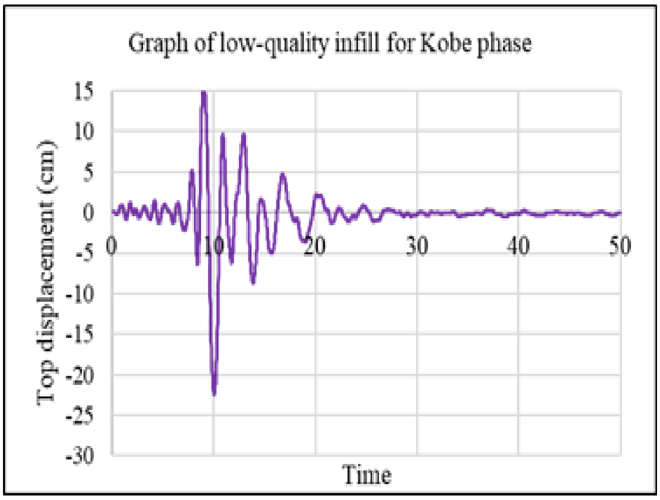


Fig 22 Top Displacement of Low-Quality Infill for Kobe NS Phase

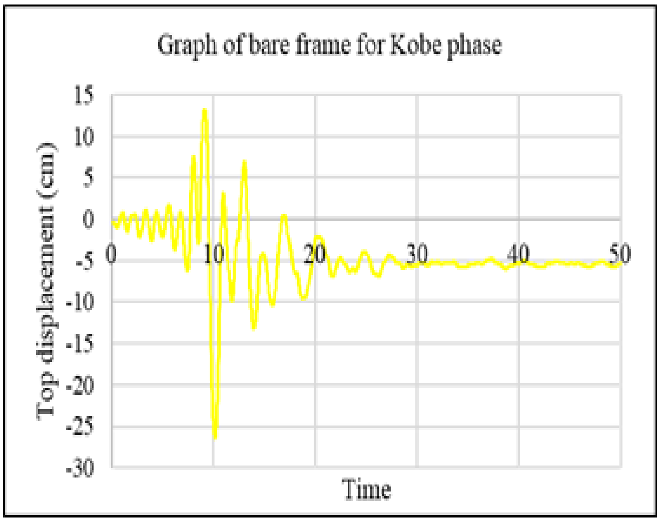


Fig 23 Top Displacement of Bare Frame with Time for Kobe NS Phase

## V. CONCLUSIONS

In this study, non-linear pushover and time history analyses have been performed to investigate the seismic performance of the building. Three different simulated ground motions have been used in this study for non-linear time-history analysis in dynamic analysis. Dynamic analyses are performed with three different types of specimens and compared with the obtained results. This section provides findings from this research work in addition to suggestions for further work in this area and better understanding of the seismic behavior of RC buildings with masonry infill buildings. Finally, it can be stated that this study will provide a better understanding of the behavior of RC buildings with high strength masonry infill during severe earthquakes in Bangladesh.

➢ *The Findings from the Study can be Summarized as follows:*

- The analysis showed that masonry infill had a positive influence on the behavior of RC frames in terms of displacement, drift, stiffness of the structure, and overall structural performance. Therefore, the effect of masonry walls in building designs and assessment of structure should be considered.
- It is necessary to consider the effect of infill walls during structural designs. In fact, it can contribute some strength to the building.
- RC Buildings having low-quality infill material do not exhibit adequate ductile behavior or proper seismic performance.
- It is observed from the results of drift vs. story number graphs that high strength masonry infill will not collapse even after following the current seismic code.
- It has been concluded that this study provides analytical approaches to determine the vulnerability of existing RC buildings as well as the preliminary design of new buildings in Bangladesh

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