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Seismic Analysis of Infill Reinforced Concrete Building Frames

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Abstract*: This study is devoted towards numerical analysis of a high rise masonry infill RC building in order to evaluate seismic performance. In this regard, frame is designed by linear beam and column elements. An 8-storey RC frame structure with different amount of masonry infill walls and bare frame were considered. Modeling of masonry infill walls had been done by diagonal strut approach. Infill panels are modeled by truss elements and the boundary condition at the support is considered restrained in all direction and linear material properties are used. The observation of the response of building structures shows that there is significant contribution of infill in the characterization of their seismic behavior. During modeling of a structure the influence of infills are generally neglected as usually those are classified as non- structural elements. As a result, it become unattainable to calculate the actual seismic response of framed structures. In this study, story displacement curves and storey drift curves are found from static analysis, response spectrum analysis and time history analysis which are used in comparing the effects of different configuration of masonry infill wall in structure. Regarding with the analysis results, the effects of infill are determined in the structural behavior under earthquake.*

Keywords*: RC building, masonry infill, irregularity, static analysis, response spectrum analysis, time history analysis.*

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I. INTRODUCTION

A composite structure which combines moment resisting plane frame and infill walls is known as infilled frame. Use of this frames is the most widely construction practice all over Bangladesh in cities as well as in rural areas. Infill refers to masonry walls made of bricks, concrete blocks or stones. Usually in Bangladesh bricks made from clay soil are used as non-structural partition wall and outside wall. As Bangladesh is an over populated developing country, construction of midrise building is increasing day by day. Moreover gradual increment in the needs of parking facilities bounds people to provide an open first storey in buildings though it is vulnerable to earthquake forces. As Bangladesh lies within an active seismic zone, it is exigent to determine the earthquake force on a structure and run a proper seismic analysis. Bangladesh national building code, BNBC provides guidance for seismic analysis of structures, which is based on static analysis. Though static analysis is simple, it cannot provide accurate result like dynamic analysis. Moreover considering structural component like infill wall in analysis shows different result than bare frame analysis.

In this study bare frame and other two different configuration of infill frames (100% infilled and irregularly infilled) have been considered (Shown in Fig 3). Both static analysis and dynamic analysis (response spectrum analysis and time history analysis) have been carried for all frames. The main objectives of this study were to review and compare static and dynamic analysis of different frames and also investigate and compare the performance of different frames when subjected to seismic force.

MODELING OF MASONRY INFILL

Basically modeling of masonry infill can be individualized into two types. One is micro modelling and other one is macro modelling. In micro modelling, analysis is done considering all the local effects. Because of considering all possible modes of failure micro-modelling is comparatively complex method and the use is limited as it is more time consuming and needs greater computational effort. On the other hand macro modeling is comparatively easier method of analysis. In macro modelling an equivalent pin-jointed diagonal strut system is used to replace the infill walls in structural analysis (Fig 1).It is very much important to calculate the equivalent width of this diagonal strut as it affects the strength and stiffness. Many formulas have been developed by many researchers to calculate the width of equivalent diagonal strut. (Catherin, et al.,2013).

Table 1: Equations for strut width value for full infill by various researchers (Prachand, 2012)

Researchers	**Strut width (w)**	**Remark**
Holmes	$0.333\ d_m$	d_m is the length of diagonal
Mainstone	$0.175\ D\ (\lambda_1\ H)^{-0.4}$	$\lambda_1\ H = H[E_m t Sin2\theta/4\ E_f I_c h_m]^{1/4}$
Liauw and Kwan	$0.95\ h_m\ Cos\ \theta/\surd(\lambda h_m)$	$\lambda = [E_m t Sin2\theta/4 E_f I_c h_m]^{1/4}$
Paulay and Priestley	$0.25\ d_m$	d_m is the length of diagonal
Hendry	$0.5[\alpha_h + \alpha_L]^{1/2}$	$\alpha_h = \pi/2[E_f I_c h_m/2E_m t sin2\theta]^{1/4}$ and $\alpha_L = \pi[\ E_f I_b L/\ 2\ E_m t sin2\theta]^{1/4}$
Recommended by MSJC	$0.3/\ \lambda_1 Cos\ \theta$	$\lambda_1 = [E_m t Sin2\theta/4\ E_f I_c h_m]^{1/4}$

Parametric study have shown that these different formulae proposed by several researchers lead, given the same geometry, to large variability in results, with up to 81% differences. In general we have considered the equations proposed by Hendry in 1998 (adopted by the Canadian Standard (CSAS304.1-04))

Description of Structural Model: The selected building prototype is eight-storey building frame located in city of Chittagong. This building has a square plan dimensions with length and width of 20 meters. It has a height of 24m. A typical plan of the building, which is identical at all stories.

Material Properties and Structural Details: Compressive strength of concrete, f_c = 20 MPa;Tensile strength of steel, f_y = 275.6 MPa; Poisson's ratio of concrete = 0.2; Poisson's ratio of brick wall = 0.17; Unit weight of brick masonry = 1920.7 kg/m^3; Compressive strength of infill wall, f_w = 10.14 MPa; Column section (0.508m X 0.381m); Beam section (0.41m X 0.254m); I_b = 0.00146 m^4; I_c = 0.00416 m^4; Elastic modulus of masonry infill wall, E_m = 15921.68 MPa; Elastic modulus of frame material (concrete) , E_f = 22360.67 MPa.

Following three different models were considered in the study (Fig 3)

Model 1: Bare frame

Model 2: 100% Infilled in outer periphery with soft storey

Model 3: Infilled at 1st 3rd 6th and 7th floor

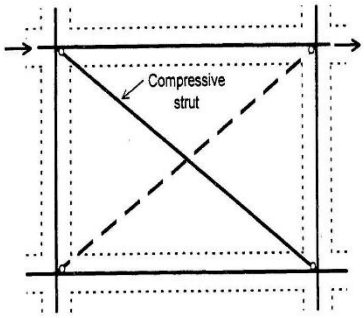


Fig.1 Diagonal Strut Model for Infilled Frames (N.AL-Mekhlafy, et al., 2013)

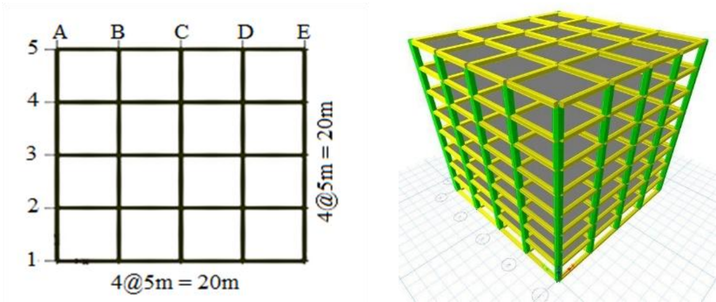
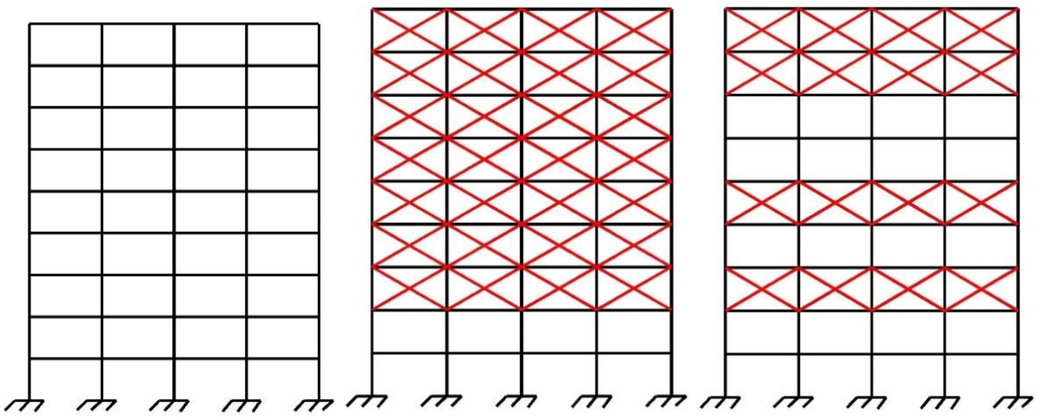


Fig 2: Plan and 3D elevation of eight-storey building frame.



Model 1 Model 2 Model 3

Fig 3: Front elevation of different models.

ANALYTICAL METHODS:

Based on relationship of static and kinematic parameters such as stress-strain relationship and force-displacement relationship the analysis method can be classified into linear and non-linear. If serviceability of structure need to be analyzed, then mechanical, geometrical and constraint non-linearities can be omitted. (Rajen, 2016)

In this study linear static analysis according to BNBC 1993, Response Spectrum analysis and Linear Time History analysis based on El Centro Earthquake had been carried out by using ETABS 2015.

Equivalent Diagonal Strut Width: Stafford (1966) developed the formulations for α_h and α_L on the basis of beam on elastic foundation. The following equations are proposed to determine α_h and α_L which depend on the relative stiffness of the frame and infill and on the geometry of the panel.

$$\alpha_h = \frac{\pi}{2} * \sqrt[4]{\frac{4E_f I_c h}{E_m t \sin 2\theta}} \quad (1)$$

$$\alpha_L = \pi * \sqrt[4]{\frac{4E_f I_b L}{E_m t \sin 2\theta}} \quad (2)$$

Where,

E_m and E_f are Elastic modulus of the masonry wall and frame material respectively

t, h, L are thickness , height and length of the infill wall respectively

I_c,I_b are Moment of inertia of the column and beam of the building frame respectively

$$\theta = \tan^{-1}\frac{h}{L} \quad (3)$$

Hendry (1998) has proposed the following equation to determine the equivalent or effective strut width w, where the strut is assumed to be subjected to uniform compressive stress

$$w = \frac{1}{2}\sqrt{\alpha_h{}^2 + \alpha_L{}^2} \quad (4)$$

Height of the infill wall, h = 3 – 0.41 = 2.59 m; Length of the infill wall, L = 5 – 0.508 = 4.49 m

Thickness of infill wall, t = 0.13 m; $\Theta = \tan^{-1}(h/L) = 29.98^0$

According to the equation (1),(2), and (4), α_h = 1.345 m& α_L= 2.376 m;

Equivalent strut width, $w = 0.5[\alpha_h{}^2 + \alpha_L{}^2]^{1/2}$= 1.16 m

Storey Drift

Storey Drift is one the most commonly used damage parameter.

$$SD_i = (\Delta_i - \Delta_{i-1}) / h_i \quad (5)$$

Where $(\Delta_i - \Delta_{i-1})$ is the relative displacement between successive storey and h_i is the height of storey.

Base Shear and Lateral Load Distribution

Location: Chittagong

Type of building: Ordinary Moment Resisting Frame

Occupancy: Residential

Soil Type: S_3

Base shear, $V = \frac{ZIC}{R}W$ (6)

Response factor, R = 8

Seismic zone coefficient, Z = 0.15

Structural Importance coefficient, I = 1

Now, $C = \frac{(1.25)S}{T^{2/3}}$ (7)

Where, $T = C_a(h_n)^{3/4}$ = 0.073*$24^{3/4}$ = 0.792 sec (8)

So, C = 2.19

From Eq. (6) , Base Shear V = 884 KN

$F_t = 0.07\,TV \;\; for\; T > 0.7\; sec$ (9)

$F_t = 0 \; for\; T \leq 0.7\; sec$ (10)

Here, T = 0.792 sec. So, F_t = 49 KN

Now, $F_x = \frac{(V - F_t)\, W_x h_x}{\sum W_i h_i}$ (11)

From equation (11) At floor 1, F_1= 23.49 KN; At Floor 2, F_2 = 46.98 KN; At Floor 3, F_3 = 70.47 KN; At Floor 4, F_4 = 93.97 KN;At Floor 5,F_5 = 117.46 KN; At Floor 6, F_6 = 140.95 KN; At Floor 7, F_7 = 164.44 KN; At Floor 8, F_8 = 225.35 KN

COMPARISON OF RESULTS

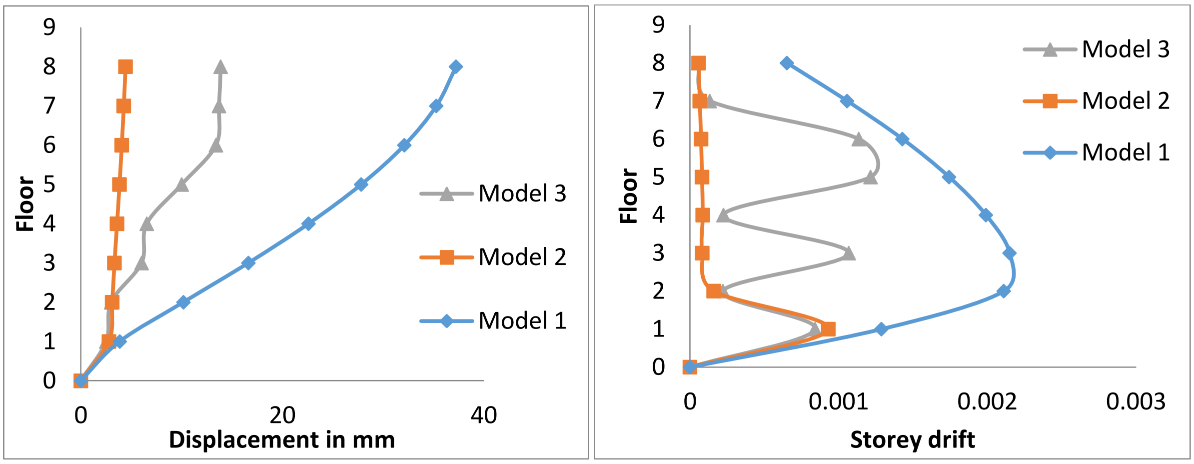


Fig 4: Graph for Static Analysis.

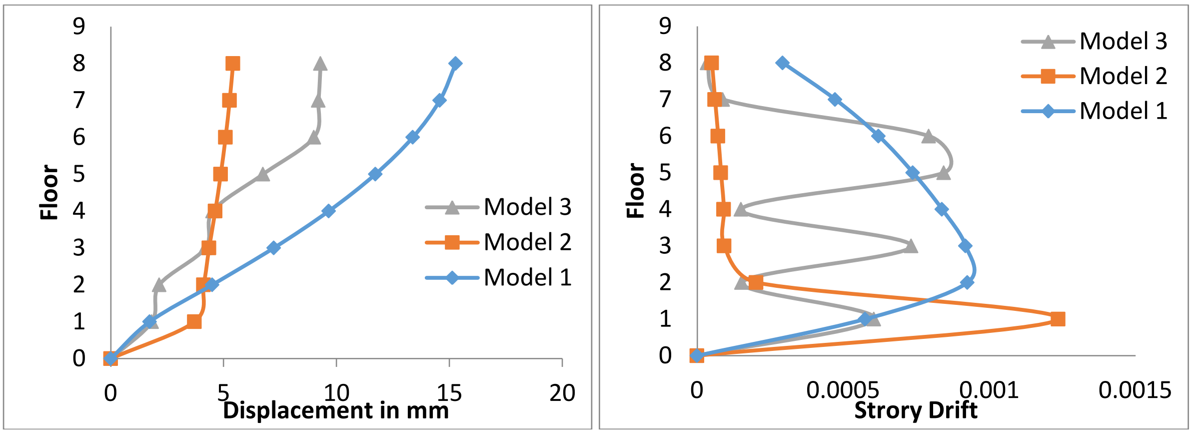


Fig 5: Graph for Response Spectrum Analysis.

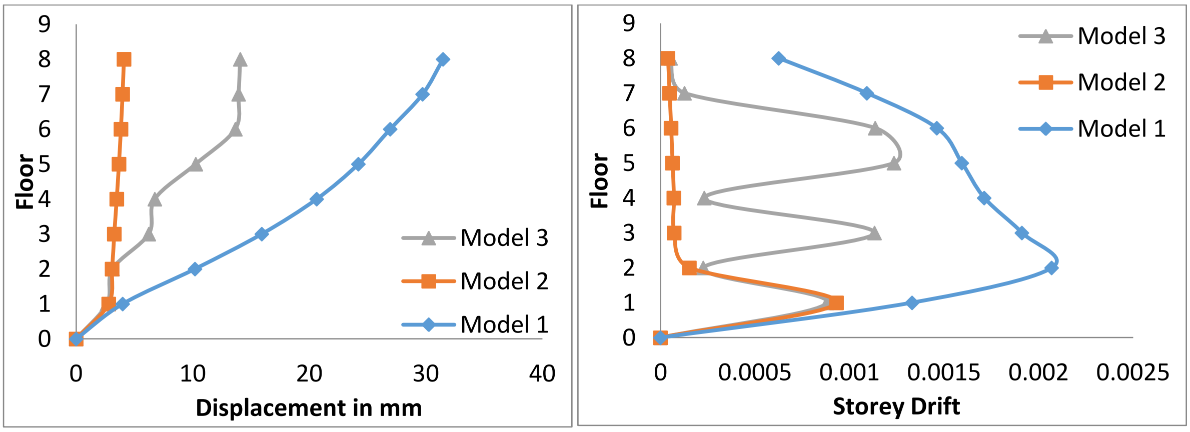


Fig 6: Graph for Time History Analysis

Fig (4), (5), (6) consent to a decision that in all three analysis methods Model 1 indicates higher top displacement than both Model 2 and Model 3. Moreover Model 1 and Model 2 refer to a proportional relation between floors and displacement except soft storey, whereas Model 3 offers a zigzag graph.

In case of storey drift, Model 2 indicates a steeper slope and nearly constant decrement in between the floors except soft storey. On the contrary, Model 1 and Model 2 indicate flatter and zigzag graph respectively.

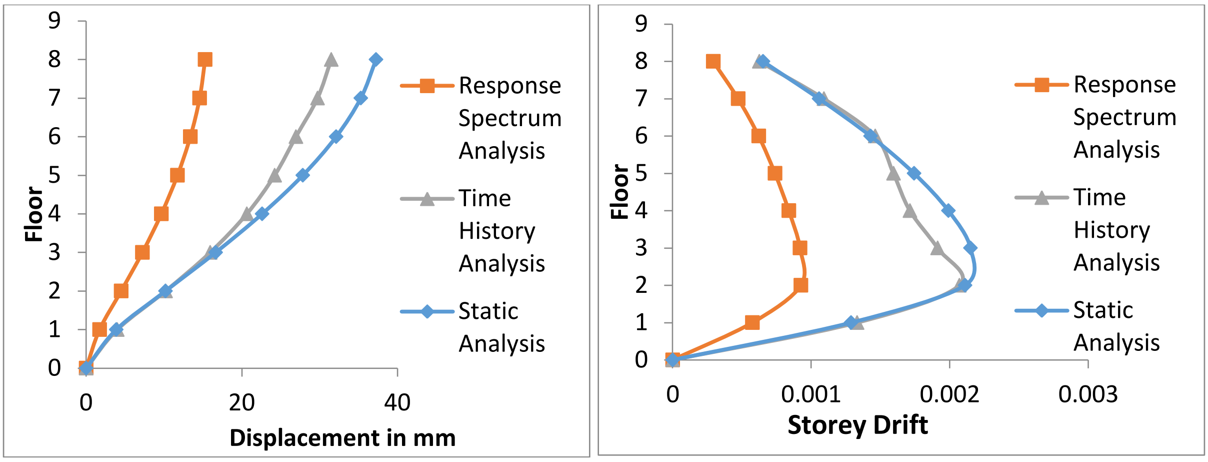


Fig 7: Comparison between Analysis Methods for Model 1

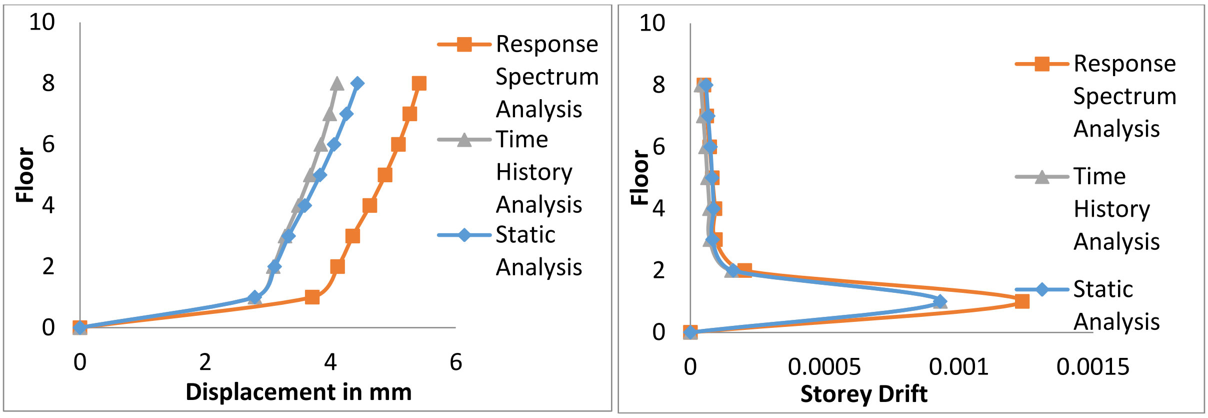


Fig 8: Comparison between Analysis Methods for Model 2

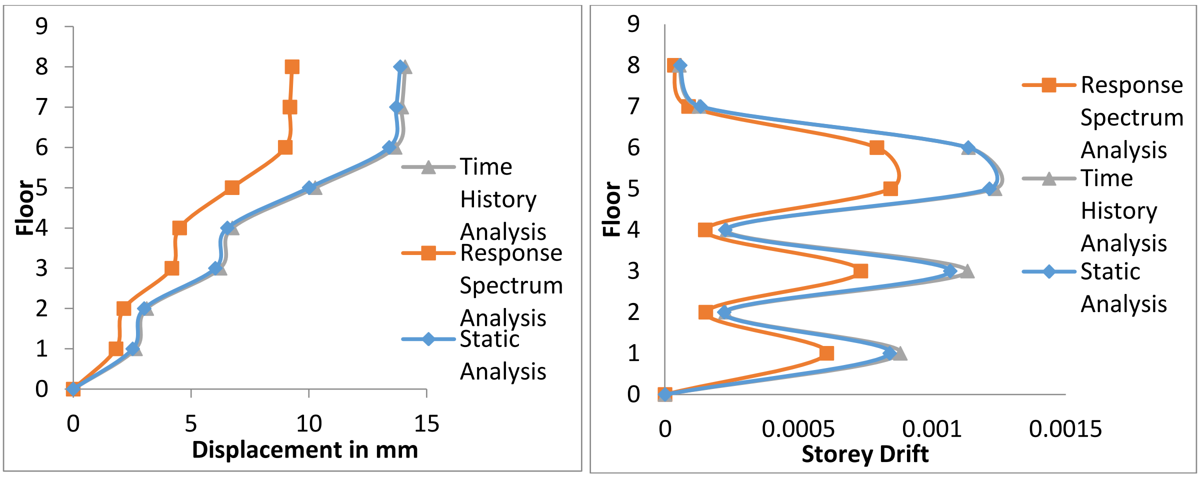


Fig 9: Comparison between Analysis Methods for Model 3

Fig (7), (8), (9) apprise that all the analysis methods show nearly similar graph pattern for each model. Response Spectrum Analysis points out less displacement values than Static and Time History Analysis with an exception in case of Model 2. Static and Time History Analysis point out nearly similar values of displacement and story drift all each models but a slightly unusual behavior has been noticed in case story drift graph for Time History Analysis of Model 1.

II. CONCLUSION

This paper addresses the effects of infills in RC frames and also evaluates the efficiency of different analysis methods. Modeling of masonry infills were carried out using equivalent diagonal strut method and analyses were done using ETABS 15. The main conclusion emerging from the paper are as follows:

1. It is evident that introducing infill reduces the top displacement value. But irregular configuration of infill's behavior is hard to predict. So we must introduce infill panel in all over the structure not in irregular configuration.
2. As an earthquake is a dynamic loading and different earthquake have different intensity so static analysis can't be able to give us proper result. Hence for seismic design purpose dynamic analysis like response spectrum analysis, time history analysis etc. have to be performed by engineers to get desired result.
3. Variation of displacement in successive floors is little in case of regularly infilled structure than irregularly infilled structure. Fully infilled configuration will give more lateral strength to the structure.

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