

Study the Reinforced Concrete Frame with Brick Masonry Infill due to Lateral Loads

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Abstract — In the building construction, framed structures are frequently used due to ease of construction and rapid progress of work. Masonry infill panels have been widely used as interior and exterior partition walls for aesthetic reasons and functional needs. When infill walls are omitted in a particular storey, a soft storey is formed compared to much stiffer other stories. The masonry infill has been modeled by equivalent struts. Normally in structural analysis it is considered that the Equivalent Static Analysis is more conservative against ground shaking for regular structures or structures of smaller height. In this paper the behavior of reinforced concrete (R.C.) frames with brick masonry infill for various parametric changes have been studied to observe their influences in deformation patterns of the frame. The present study is also aimed at findings out the effect of soft storey on frame structures due to horizontal loading. In both cases of wind and earthquake loads, if number of bay increases, then the deflection eventually decreases. As the story level of a building frame increases, deflection due to lateral loads naturally increases due to additional lateral loads. Deflection increases linearly if the span of bay increases linearly because of linearly increased loads. Deflection for a soft storey building frame is 1.4 to 2.0 times greater than that observed excluding the soft storey effect. Deflection for R.C. frames with 5 inch wall thickness is observed 10 to 20% higher than that for frames with 10 inch wall thickness. As the beam and column size increases, deflection pattern decreases with increased stiffness. Two different theories for modeling the equivalent struts (Mainstone and Saneinejad theory) have used in this work and these two different theories of Equivalent Strut Method have little bearing on the variations of results.

Key words: infill, soft story, Equivalent Static Analysis, equivalent struts, Saneinejad Theory, Mainstone Theory.

1.0 INTRODUCTION

The behavior of masonry in filled frame structures has been studied in the last four decades in attempts to develop a rational approach for design of such frames. Present code of practice does not include provision of taking into consideration the effect of infill. It can be understood that if the effect of infill is taken into account in the analysis and design of frame, the resulting structures may be significantly different. Therefore, a study is undertaken which will involve the finite element analysis of the behavior of High-Rise reinforced concrete (R.C.) frame with brick masonry infill. Again when a sudden change in stiffness takes place along the building height, the story at which this drastic change of stiffness occurs is called a soft story. According to BNBC [1] a soft story is the one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stores above. The infill components increase the lateral stiffness and serve as a transfer medium of horizontal inertia forces. From this conception the floors that have no infill component has less stiffness regarding other floors. The major objectives of the research work are as follows:

- To find out the influence of masonry infill wall panel in Reinforced Concrete framed Structures in terms of deformation.
- To study the behavior of frame with brick masonry infill by modeling masonry infill as a diagonal strut. The Finite Element package ANSYS 5.6 [2] is to be used for the development of the model.
- The present study is aimed at findings out the effects of various parameters on frame structures due to horizontal loading. The various parameters are number of bay, span of bay, number of story, beam and column geometry and wall thickness.

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- Two different theories (Mainstone and Saneinejad theory) have been described in this paper and comparisons of results are also made.

Previous experimental research on the response of RC frames with masonry infill walls subject to static and dynamic lateral cyclic loads [3 - 9] have shown that infill walls lead to significant increases in strength and stiffness in relation to bare RC frames. Within conventional seismic design, which focuses on accelerations and strength, it may be difficult to recognize the benefits of increases in stiffness. However, research and field evidence [10 – 12] has shown that increases in stiffness are beneficial because they lead to reductions in the magnitude of the deformations induced by ground motions.

2.0 METHODOLOGY OF THE WORK

Finite element technique is a powerful and versatile tool for the analysis of problems of structural and continuum mechanics. In this study a linear finite element analysis has been performed using the package ANSYS to predict the inelastic behavior of R.C. high-rise frame with brick masonry infill. The finite element analysis of infilled frames includes modeling of beams and columns, modeling of masonry infill, calculations of wind and earthquake load according to BNBC code, generation of finite element mesh with infill.

Finite Element Discretization

The ultimate purpose of finite element analysis is to predict mathematically the behavior of actual engineering system. In complete modeling, BEAM44 3-D Elastic Beam element has been used to represent beams and columns. LINK10 3-D spar element has been used to model masonry infill as a diagonal strut against lateral load. This model has comprised all nodes, elements, material properties, geometrical properties, boundary conditions and other features that have used to represent the physical system. 2-D analysis has performed in this study. Since the analysis has been based on nonlinear elastic material response, it provides the information about the nature of stress distribution and deformation rather than the ultimate behavior of the structure.

For appropriate modeling of R.C member two types of elements, one for concrete and other for reinforcement are required and two types of material properties are also required for both these elements but in this analysis, reinforced cement

concrete frame has assumed as a homogeneous and isotropic material. To model the R.C frame, Beam44 3-D elastic beam has been selected from ANSYS element library. For Beam44 3-D elastic beam, reinforced concrete properties have been used. In R.C high-rise frame, in addition to the use as partition walls, the infill can also be used for increasing stability and reducing displacement against lateral load. To model brick masonry infill, it has been considered masonry infill to be act as a diagonal strut against lateral load according to the equivalent strut method. Since the tensile strength of masonry is negligible, only compression diagonal strut is liable to resist the lateral load. In this analysis the element LINK10 3-D spar has been used to represent equivalent diagonal strut.

First to model the equivalent diagonal strut in this study, the width of the equivalent strut has been calculated by taking into accounts the formulations developed by Mainstone [13]. Also in another method of equivalent strut formulation, where the area of diagonal strut has been found 66450 mm^2 by Saneinejad and Hobbs [14] formula. In this study a 10 storied building frame has been analyzed. The cross sections of columns and beams have been taken as $305 \text{ mm} \times 305 \text{ mm}$. For analysis, 3.0 and 2.0 percent reinforcement have been considered in columns and beams respectively.

3.0 DATA TABULATION

Properties of the Elements Used

In modeling Plane frame, the following material properties and geometrical properties have been used for beam, columns, masonry infill.

Beam and Columns

Material properties: The following material properties of normal weight concrete have been provided for finite element analysis of building frames:

- Density, $w_c = 8.68\text{e}^{-2} \text{ lb/in}^3$
- Compressive strength, $f_c = 4000 \text{ psi}$
- Young's modulus of elasticity, $E_c = 3\text{e}6 \text{ psi}$
- Poisson's ratio, $\nu_c = 0.15$

Geometrical properties: The following sectional properties have been used for beams and columns:

Column: Cross-section = $12 \text{ in} \times 12 \text{ in}$

Beam: Cross-section = $12 \text{ in} \times 12 \text{ in}$

Masonry infill:

Material properties: The following material properties have been used for masonry infill:

- Density, $w_c = 6.94\text{e}^{-2} \text{ lb/in}^3$
- Compressive strength, $f_c = 1740 \text{ psi}$
- Young's modulus of elasticity, $E_c = 1.2\text{e}6 \text{ psi}$
- Poisson's ratio, $\nu_c = 0.16$

Geometrical properties: Thickness of infill = 5 in

Loads

In the present investigation, wind load and earthquake load has been chosen as the source of lateral loading on the building frame as set forth by the provision of Bangladesh National Building Code (BNBC, 1993). A 10-storied building has been selected to carry out this study. Fig. 1 shows the plan of the building. The structure is 48ft x 36ft in plan dimension and per floor storey height of the building has considered as 10ft. Loads are shown in Fig. 2 and Fig. 3.

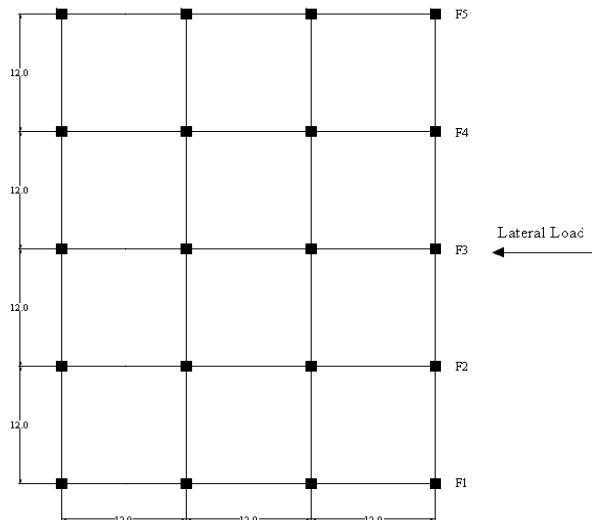


Fig. 1: Plan of the building

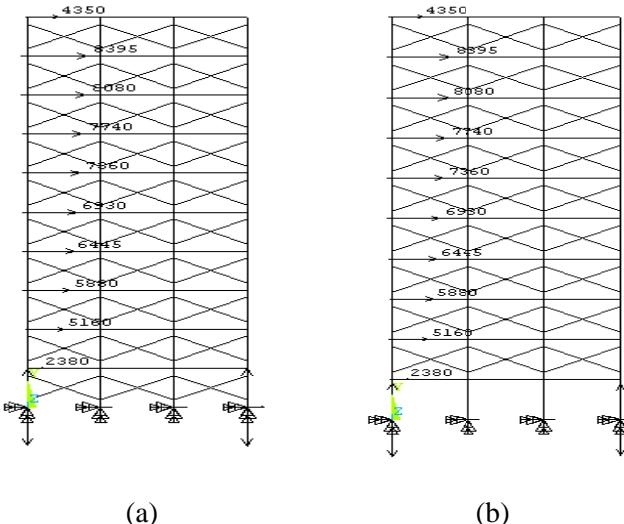


Fig. 2: Elevation of 10-story building frame (F2) with calculated wind load at each floor level (a)without soft story effect, (b)with soft story effect.(Loads are in kips)

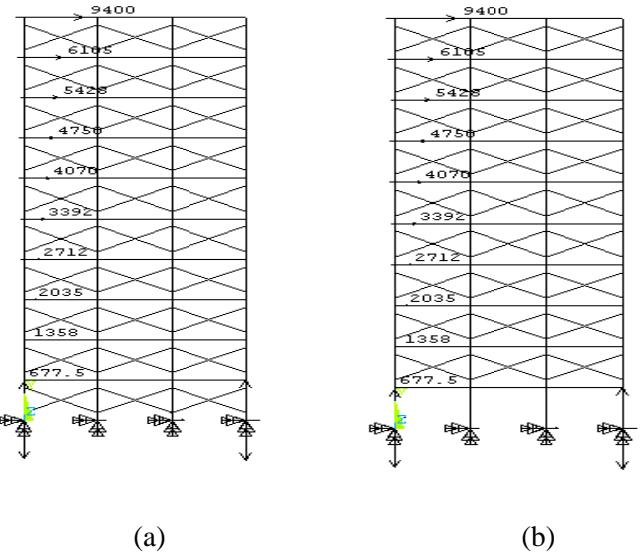


Fig. 3: Elevation of the building frame (F2) with calculated earthquake load at each floor level (a) without soft story effect, (b) with soft story effect. (Loads are in kips)

4.0 RESULTS AND DISCUSSIONS

The main objective of this investigation is to study the effect of horizontal loading on reinforced concrete frames with brick masonry infill for different conditions (without soft story effect/ with soft story effect). In this section only the results obtain from the analysis and their discussions are presented. In this analysis the frame is assumed to be restrained at ground floor level. Deflections are one of the most important parameter to be considered in the design and analysis of a tall building. Therefore deflections for lateral loads (wind and earthquake loads) have been studied according to Mainstone theory of equivalent strut method for different cases and comparisons are also made. The different cases are: deflections for various no. of bay, deflections for different story building and deflections for various spans of bay.

In this study comparison of deflections of a 10-story 3-bay building frame for different geometrical properties of beam, column and infill has been made. Also deflections have been measured for two different theories of equivalent strut method (Mainstone theory and Saneinejad theory) and comparisons are also made.

4.1 Effect of number of bays

In this analysis, a 10-story building frame of 12 ft bay length has been used and analysis has been done for both wind and earthquake loads. For different no. of bays, the lateral loads at every story level remain same. But as the

no. of bays increases, the stiffness of the frame for resisting lateral loads increases. As a result, the maximum top deflection of the frame decreases gradually. Comparison of deflections of the frame for different conditions (without soft story effect/ with soft story effect) and for different no. of bays have been graphically shown in Fig. 4.

4.2 Effect of number of story

In this analysis, a 3-bay building frame of 12 ft bay length has been used and analysis has been done for both wind and earthquake loads. As the no. of story level increases, there are additional lateral loads added for increased story level. As a result, the maximum top deflection of the frame increases gradually. Comparison of deflections of the frame for different conditions (without soft story effect/ with soft story effect) and for different no. of story have been graphically shown in Fig. 5.

4.3 Effect of various spans of bay (in both parallel and perpendicular to lateral loads)

In this analysis, a 10-story 3-bay building frame has been used and analysis has been done for both wind and earthquake loads. As span of bay increases in both directions, the lateral wind load increases at every story level because of contact surface of wind increases. As a result, deflection increases. Similar behavior appears for lateral earthquake loads because of dead loads of the structure increases with span of bay. So, the maximum top deflection of the frame increases gradually. Comparison of deflections of the frame for different conditions (without soft story effect/ with soft story effect) and for different spans of bay has been graphically shown in Fig. 6.

4.4 Effect of various spans of bay (in parallel to lateral loads)

In this analysis, a 10-story 3-bay building frame of constant bay size in perpendicular to lateral loads has been used and analysis has been done for both wind and earthquake loads. The lateral wind load remains same at each story level as the contact surface remains same. But as the bay size changes in parallel to wind direction, stiffness of the frame changes accordingly. But in case of earthquake, loads increases as the dead load of the frame increases with span of bay. Comparison of deflections of the frame for different conditions (without soft story effect/ with soft story effect) and for different spans of bay has been graphically shown in Fig. 7.

4.5 Effect of various spans of bay (in perpendicular to lateral loads)

In this analysis, a 10-story 3-bay building frame of constant bay size in parallel to lateral loads has been used and analysis has been done for both wind and earthquake loads. In both cases, the lateral load increases linearly with linearly increased bay size. As a result, deflection also increases quite linearly. Comparison of deflections of the frame for different conditions (without soft story effect/ with soft story effect) and for different spans of bay has been graphically shown in Fig. 8.

4.6 Effect of various geometrical properties of beams, columns and infill

In this analysis, a 10-story 3-bay building frame has been used and the span of each bay is 12 ft. Analysis has been done for both wind and earthquake loads and according to Mainstone theory of equivalent strut method. Now for various geometrical properties of beams, columns and infill, maximum top deflection of the frame is measured for different conditions (without soft story effect/ with soft story effect). The following sectional properties have been used:

For beams and columns:

- Size 1: 10 inch X 10 inch,
- Size 2: 12 inch X 12 inch,
- Size 3: 14 inch X 14 inch,
- Size 4: 16 inch X 16 inch

For infill masonry wall:

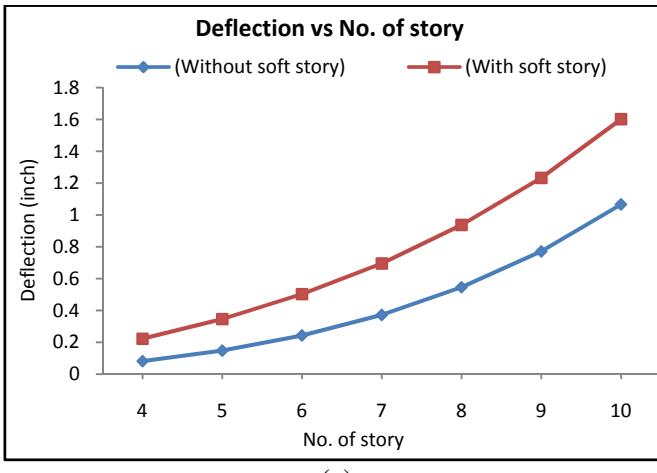
Thickness of the wall = 5 inch, Thickness of the wall = 10 inch

As the cross-section of beams and columns increase the deflections of the frame decrease because of increased stiffness. Also deflections decrease for 10 inch wall thickness than that for 5 inch wall thickness. Comparison of deflections of the frame for different conditions (without soft story effect/ with soft story effect) and for different geometrical properties of beams, columns and infill have been graphically shown in Fig. 9.

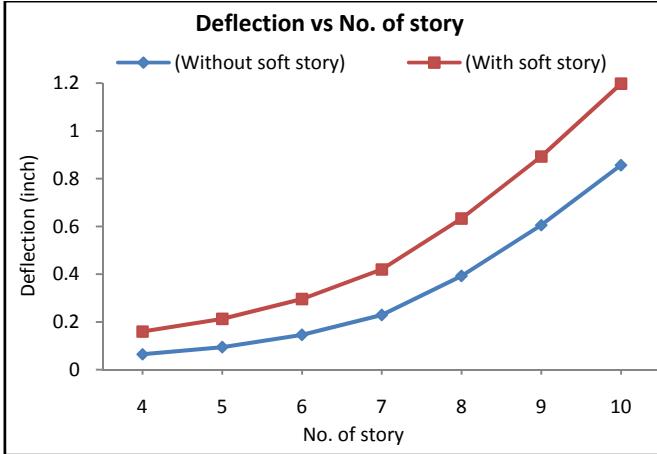
4.7 Comparison of deflections for two different theories of equivalent strut method

In this analysis, a 10-story of 20 ft bay span building frame has been used for various no. of bays. In this case, two different theories of equivalent strut method that is Mainstone theory and Saneinejad theory are applied. The maximum top deflections of the frame for these two different methods are quite similar. Comparison of deflections of the frame for different conditions (without

soft story effect/ with soft story effect) and for different theories has been graphically shown in Fig. 10.



(a)



(b)

Fig. 4: Maximum top deflection of a 3-bay @ 12ft building frame for wind loads (a), earthquake loads (b) for various no. of story.

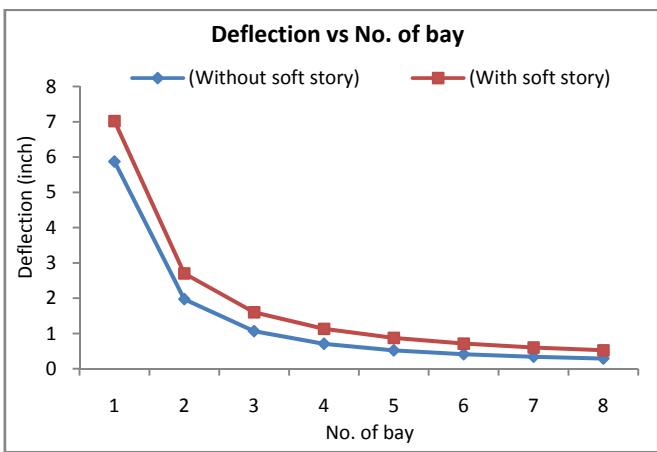


Fig. 5: Maximum top deflection of a 10-story 12ft bay building frame for wind load for various no. of bay parallel to wind direction (similar diagram for earthquake loads)

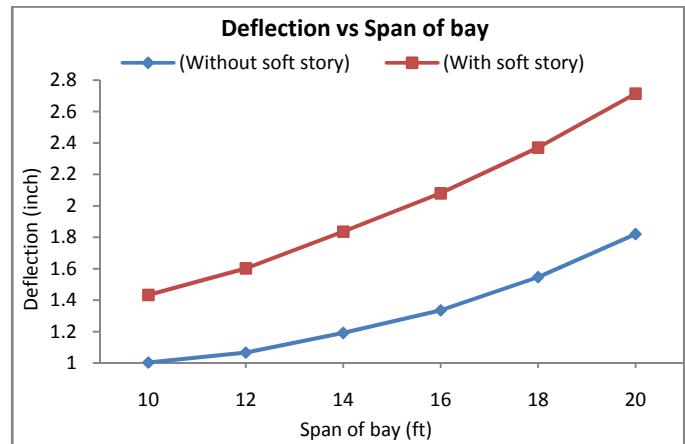


Fig. 6: Maximum top deflection of a 10-story 3-bay building frame due to wind load for various span of bay in both direction (similar diagram for earthquake load)

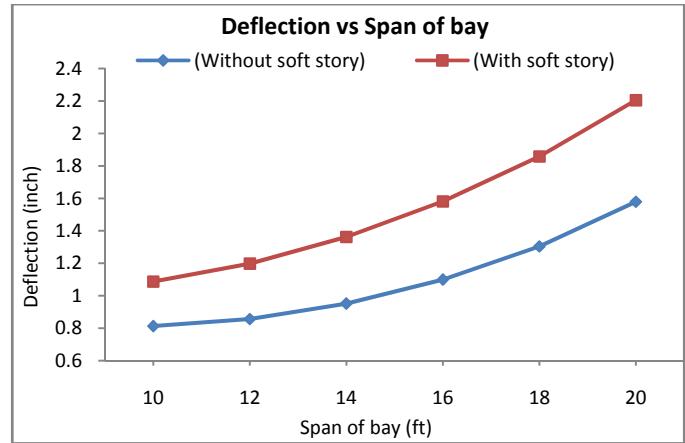


Fig. 7: Maximum top deflection of a 10-story 3-bay building frame due to earthquake load for various span of bay in parallel to earthquake direction (similar diagram for wind load)

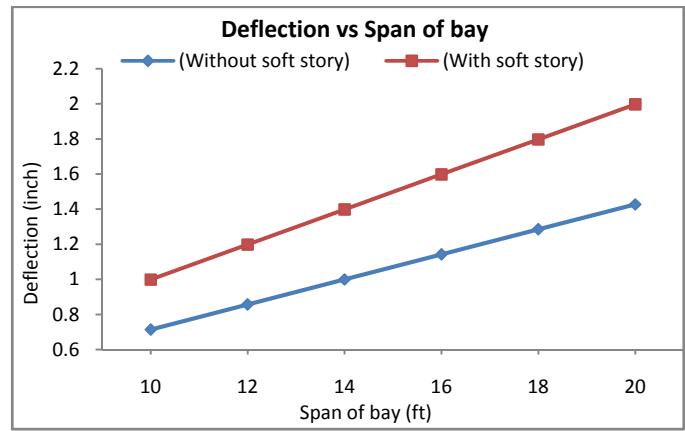


Fig. 8: Maximum top deflection of a 10-story 3-bay building frame for earthquake load for various span of bay in perpendicular to earthquake direction (similar diagram for wind loads)

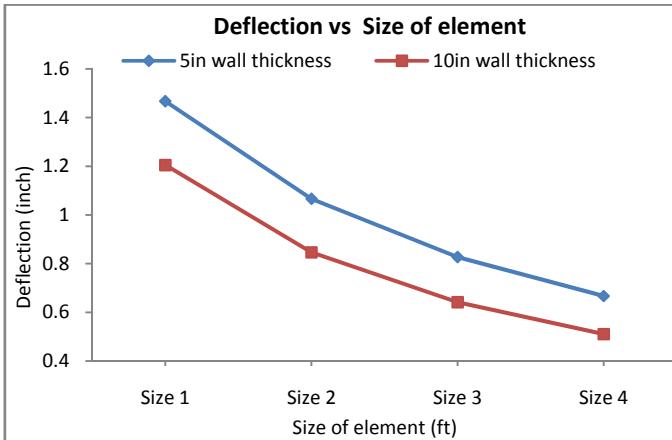


Fig. 9: Maximum top deflection of a 10-story 3@12ft-bay building frame without soft story effect for wind load for various element geometry (**similar diagram for soft story effect and also for earthquake loads**)

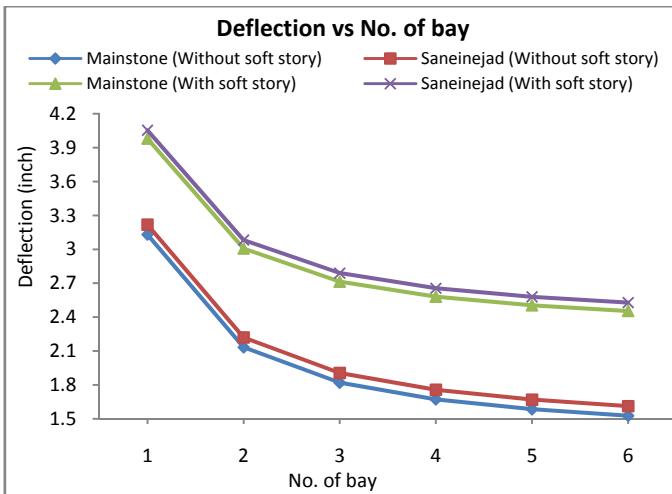


Fig. 10: Maximum top deflection of a 10-story 20ft bay building frame for wind load for various no. of bay and for different theories (**similar diagram for earthquake loads**)

5.0 CONCLUTIONS AND RECOMMENDATIONS

The present study may be regarded as a preliminary work for an extensive research work on the effect of various parameters on infilled frames due to horizontal loading. Therefore, some guidelines for future theoretical and experimental study on this topic may be recommended. The recommendations are:

- Effect of dynamic loading on the behavior of masonry infilled R.C frame may be investigated.
- Instead of brick masonry infill other types of infill such as concrete block can also be considered for such type of investigation.
- This analysis may be performed by using non linear property of brick material.

A cost-benefit analysis may be carried out to find out the relative economy that may be achieved if infill is considered as structural element.

REFERENCES

- [1] Bangladesh National Building Code (BNBC). Housing and Building Research Institute and Bangladesh Standards and Testing Institutions, 1993.
- [2] Manual of ANSYS 5.6, Elan Computer Group, Inc., USA(1997).
- [3] Fiorato, A. E., Sozen, M. A., Gamble,W. L. (1970). An Investigation of the Interaction of Reinforced Concrete Frames with Masonry Filler Walls. Civil Engineering Studies, University of Illinois, Urbana, IL, 525p.
- [4] Brokken, S.; Bertero, V.V. (1981). Studies on Effects of Infills in Seismic Resistant RC Construction. *Report UCB/EERC, 81-12, University of California, Berkeley, CA.*
- [5] Calvi G. M., Bolognini, D. (2001). Seismic Response of Reinforced Concrete Frames Infilled with Masonry Panels Weakly Reinforced. *Journal of Earthquake Engineering* **5**: 2, 153-185.
- [6] Negro P., Verzeletti, G. (1996). Effect of Infills on the Global Behaviour of Frames: Energy Considerations from Pseudodynamic Tests. *Earthquake Engineering and Structural Dynamics*, **25**: 8, 753-773.
- [7] Zarnic R, Gosti S, Crewe AJ, Taylor CA (2001). Shaking Table Tests of 1:4 Reduced-Scale Models of Masonry Infilled Reinforced Concrete Frame Buildings. *Earthquake Engineering and Structural Dynamics* **30**:6, 819-834.
- [8] Al-Chaar, G., 2002. *Evaluating strength and stiffness of unreinforced masonry structures*, ERDC/CERL TR-02-1, US Army Corps of Engineers, Construction Engineering Research Laboratories.
- [9] Hashemi, A., Mosalam, K. M. (2006). Shake-Table Experiment on Reinforced Concrete Structure Containing Masonry Infill Wall. *Earthquake Eng. Struct. Dyn.* **35**: 14, 1827–1852.
- [10] Shimazaki K, Sozen M., Strong Ground Motion Drift and Base Shear Coefficient for RC Structures. Proc. 9th World Conference on Earthquake Eng., Tokyo and Kyoto, Japan, **5**, 165-170.
- [11] Wood S. (1991). Performance of Reinforced Concrete Buildings During The 1985 Chile Earthquake : Implications for the Design of Structural Walls. *Earthquake Spectra*, **7**:4, 607-639.
- [12] Lepage A. (1997) A Method for Drift-Control in Earthquake-Resistant Design of RC Building Structures. PhD Thesis, University of Illinois, Urbana, 251p.
- [13] Mainstone, R. J. On the Stiffness and Strengths of Infilled Frames. Proceeding of the Institute of Civil Engineers, 1971.
- [14] Saneinejad, A. and Hobbs, B. Inelastic Design of Infilled Frame. American Society of Civil Engineers, (ASCE), Journal of Structural Engineering, Vol.121, No.4, 1995, pp 634-643.