International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 9 (October 2014) www.ijirae.com

Validation of a FE Micro Model for RC Frames

T.C. Nwofor[1] , M.E. Ephraim[2]
[1]*Department of Civil Engineering,*
University of Port Harcourt,
P.M.B 5323 Port Harcourt,
Rivers State, Nigeria
[2]*Department of Civil Engineering,*
Rivers State University of Science and Technology,
P.M.B 5080 Port Harcourt,
Rivers State, Nigeria

Abstract-- The contribution of infill panels to the shear response of RC frames subjected to lateral in-plane loads has been the subject of numerous experimental investigations, while a good number of attempts to model it analytically have also been reported. In this work a basic micro modeling approach which uses a finite element approach is validated using available data from experimental test where the accuracy of the model is verified by comparison of a load-deflection profile. The micro model is an explicit two dimensional finite element method that also considers the effect of the opening size of the infill panel on the shear response of the structure. It was generally observed that the one-strut macro model was able to model the infilled RC frames with opening up to a reasonable failure load.

Key words: Infill panel, Finite element model, one strut model, Load and Displacement.

I. INTRODUCTION

The present practice of design for structural infilled frames is to treat the masonry infill as a non-structural element neglects the strength and stiffness contribution of the infill. Therefore, the whole lateral load is assumed to be resisted by the frame only. One basic disadvantage of neglecting the effect of the infill is that the structure can have both horizontal as well as vertical irregularities due to uncertain position of infill and opening in them. Most times also, these infill walls are usually rearranged to suit the changing function of the occupants without considering the adverse effect on the overall structural behaviour. Infill panels generally enhance the stiffness and shear strength of framed structure but their contribution are often neglected in the analysis and design. Experience has shown that frames with fills have more strength and rigidity than bared frames, hence it would be reasonable to used infilled frames for tall and medium buildings subjected to strong lateral loading.

The idea of equivalent strut at the compressed diagonal (Polyakov, 1960) and (Homes, 1961) has been adopted in which the infill panel is replaced with equivalent diagonal struts and the properties of the struts determined. Since the first attempts to model the response of the composite infilled frames structures, experimental and conceptual observations have indicated that a diagonal strut with appropriate geometrical and mechanical characteristics could possibly provide a solution to the problem. Another set of researchers (Smith,1966) , (Smith and Carter 1969) related the width of the equivalent diagonal strut to the infill/frame contact lengths using an analytical equation which has been adapted from the equation of the length of contact of a free beam on an elastic foundation subjected to a concentrated load (Hetenyi, 1946). Based on the frame/infill contact length, alternative proposals for the evaluation of the equivalent strut width have been given, (Maintone, 1971) and (Kadir, 1974).

Several researchers (Reflak and Fajfar, 1991; Saneinejad and Hobbs, 1995; Mosalam et al., 1997; Buonopane and White, 1999; and El-Dakhakhni et al., 2003) have suggested that the bending moments and shear forces in the frame members cannot be replicated using a single diagonal strut connecting the two loaded corners. These researchers have proposed more complex macro-models, using more than one diagonal strut to produce better estimations of the bending moments and shear forces in the frame members. As the macro-model becomes more complex, the number of parameters involved increases, for example, the proportions of stiffness and strength between the struts need to be calibrated for the three strut model.

The main purpose of this research is to formulate a reliable finite element micro model for the shear strength resistance of lateral loaded infilled reinforced concrete frame structure which accounts for the effect of openings in the infill panel and validate it against available experimental data. This will help overcome some assumptions unavoidably made while utilizing the macro models

II. DEVELOPMENT OF THE THEORETICAL FRAMEWORK

The consideration of the infill panel in the design of RC frame structures results in a complex modeling problem because of the large number of interacting parameters and the many possible mode of failure that needs to be evaluated with a high degree of uncertainty. Therefore it is not surprising that no consensus has emerged leading to a unified approach for the proper design of infilled frame structure. Even when it is generally accepted that under the action of lateral loads an infill panel acts as a diagonal strut connecting the two loaded corners, it has severally been applied to cases of infill walls without openings.

In this paper, the micro modeling method would be used to investigate the effect of openings in the infill panels of a RC frame structure. A two-dimensional finite element model for the micro-modeling of infilled structures using constant strain triangular elements will be developed to analyze the shear strength response of the masonry infilled reinforced concrete frame structure with different sizes of openings and validated against available experimental and numerical data for nonlinear static analysis of infilled frames subjected to in-plane lateral loading. The finite element method of structural analysis is a method in which a modified structural system consisting of discrete (finite) elements is substituted for the actual continuum and thus represents an approximation which is of a physical nature. The basic principle of this method is that the continuum is divided into a finite number of elements inter connected at node points situated on their boundaries. For the purpose of the finite element analytical study of masonry structure, the triangular elements shall be used and the formulation that would be adopted is the displacement approach. In using this method the nodal displacements are the basic unknown, from which the stresses can be obtained.

1. Derivation of the Triangular Element of Stiffness Matrix

This investigation shall be carried out using the constant strain three node triangular elements. Hence the masonry infilled frame continuum shall be divided into constant strain triangular elements which shall include elements in the infill panel and reinforced concrete frame.
The element stiffness matrix $[K^e]$ would be a 6 x 6 matrix for this plane elasticity triangle, because there exist a two degree of freedom (DOF) at each node of the triangular element hence the Nodal force vector $[F^e]$ can be related to the displacement vector in equation 1

$$\{F^e\} = [K^e]\{\delta^e\} \qquad (1)$$

If there exist a two degree of freedom at each node, as can be seen in figure 1, then lets consider two displacement patterns expresses in terms of two linear polynomials.

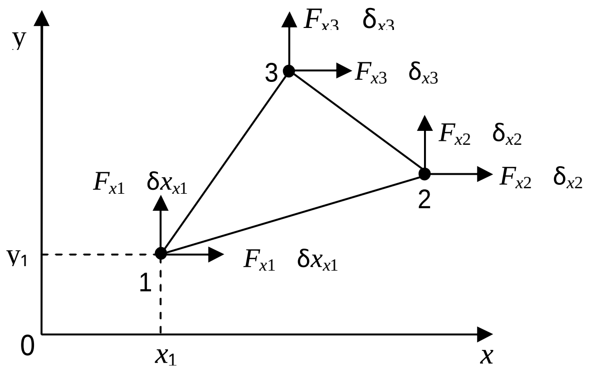


Figure 1: A two-dimensional triangular element typical of that used in plane stress problems.

$$\delta_x = \delta_1 + \delta_2 x + \delta_3 y \qquad (2)$$
$$\delta_y = \beta_1 + \beta_2 x + \beta_3 y \qquad (3)$$

where δ and β are constants which may be determined from the co-ordinates of the nodal points of the elements.
Simplifying

$$\{\delta\} = |C|\ \{\delta\beta\}$$

Rearranging

$$|C|^{-1}\ \{\delta\} = \{\delta\beta\} \qquad (4)$$

Express strains in the elements as a function of its geometry.

$$\{\varepsilon\} = [H]\ \{\delta\beta\} \qquad (5)$$

Where [H] is the stress matrix
Combining equation (4) and (5)

$$\{\varepsilon\} = [H]\ |C|^{-1}\ \{\delta\} \qquad (6)$$

Simplifying further

$$[\beta] = [H]\ |C|^{-1} \qquad (7)$$

Where [β] is a matrix dependent on the geometric size and shape of the element.
The stress-strain relationship depends on the material property of the element, hence adopting the material stiffness matrix.

$$|D| = \begin{bmatrix} d_{11} & d_{12} & o \\ d_{21} & d_{22} & o \\ o & o & d_{33} \end{bmatrix} \qquad (8)$$

Where for plane stress
$d_{11} = d_{22} = E/(1-v^2)$
$d_{12} = d_{21} = E/(1-v^2)$
$d_{33} = E/2(1+v)$

The overall interrelationships between the nodal forces and the applied stresses be written in matrix form as follows

$[F] = |A| [\sigma]$ (9)

Where |A| makes up arbitrary constants and σ is the component of normal stress (σ_x and σ_y) and shear stress (τ_{xy}).
From the foregoing the stiffness matrix [k] for a basic plane strain triangular element from equation (1) can be obtained since matrix |A|, |B| and |D| are available from equation (9), (8) and (7).

$|K^e| = |A| |D| |B|$ (10)

Where $|K^e|$ represents a 6x6 matrix which can be obtained from the co-ordinates of the elements and the material property.

II. COMPUTER PROGRAM ALGORITHM

In order to implement the finite element method, a computer programme for two dimensional finite element analysis developed by the author would be used. The computer program is divided into two parts (subroutines). The first part consists of the routines for the control numbers and data input modulus, the second part consists of routines for tabulations nodal displacements and element stresses. The basic steps to obtain the element stiffness matrix $[K^e]$ and stress matrix [H] are integrated in the program. The processes are well built up in the subroutines to take care of the overall analysis. The input data consists of specifying the geometry of the idealized structure, its mechanical properties, the loading and the support condition. The data also includes certain control numbers that would help the efficiency of the program such as the total number of nodes and elements.

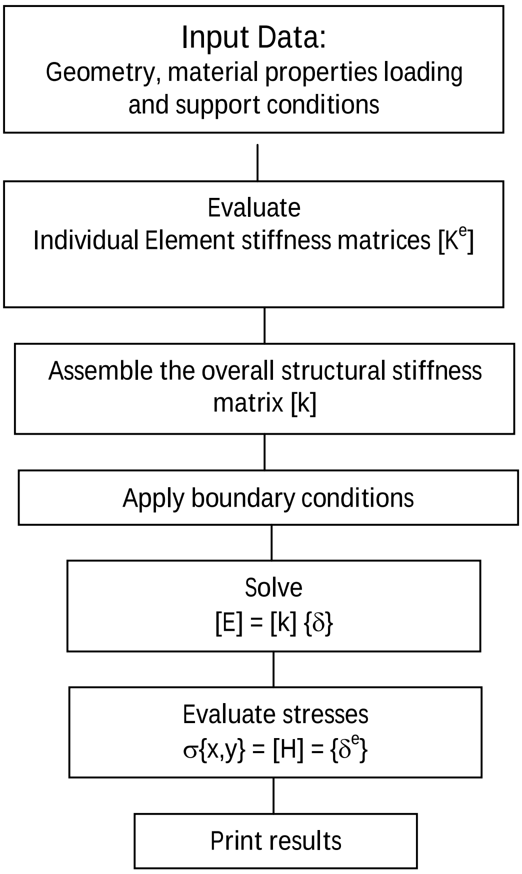


Figure 2: Computer programme flow chart diagram for finite element analysis of micro-model

III. VERIFICATION OF THE FINITE ELEMENT MODEL

The developed finite element model is employed here to simulate the in-plane behaviour of masonry-infilled frames tested by previous researchers. Detailed experimental results of the specimens have been summarized by Dawe et al. (1989). Among several specimens tested under lateral load in their investigation specimen WC3 would be singled out for this present investigation. The specimen is a structural panel of 3600mm long by 2800mm high masonry infilled frame with a central opening. The basic method was to allow a horizontal load applied at an upper corner of the frame and increment up to the failure load level. From the foregoing stress path obtained from finite element analytical modeling of the model which is similar to the WC3 model was compared against the stress path from results of experimental data by Dawe and Seah as shown in Figure 3 in order to validate the finite element programme for the micro-modeling of masonry infilled concrete frame structure with openings.

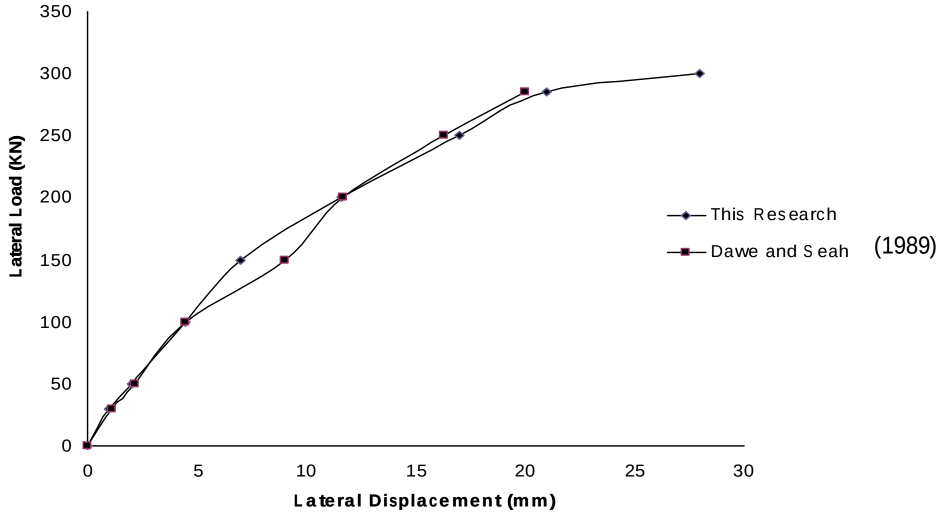


Figure 3:Lateral load-displacement curves

There was reasonable agreement between the experimental collapse loads of 285kN and the numerical result of 295kN and a good correlation coefficient of $c_r = 0.9$ was obtain between the experiment and the numerical results. Also another researcher Tasnimi and Mohebkhah, 2011 carried out an experimental test on the non-linear behaviour of some brick masonry infilled frames at the building and Housing Research center (BHRC). In the test program, six large scale single-storey single bay frames were constructed and tested under lateral in-plane loading. All specimens were 2400mm long by 1870mm high. Infill panels consisting of solid clay bricks with average size of 219 x 110 x 66mm and placed in running bond with 22 courses within a surrounding moment resistance. One of the frames tested was a bare (without infill panel); one had a solid infill panel, while the rest has various degrees of symmetrical window and door openings. The structural specimens were tagged SW which represents a solid infilled frame, while PW1 – PW4 represents infilled frames with different configurations of window openings. The mechanical properties of the masonry panel and their constituents required for the FE analysis is shown in Table 1, while figure 4 illustrates the geometry and dimensions of the test specimens.

TABLE 1:

Characteristics	Brick	Mortar	Brickwork		
			SW, PW 1	PW2, PW3	PW 4
Modulus of elasticity (N/mm^2)	8442	1000	5194	4900	5984
Poisson's ratio			0.22	0.20	0.20

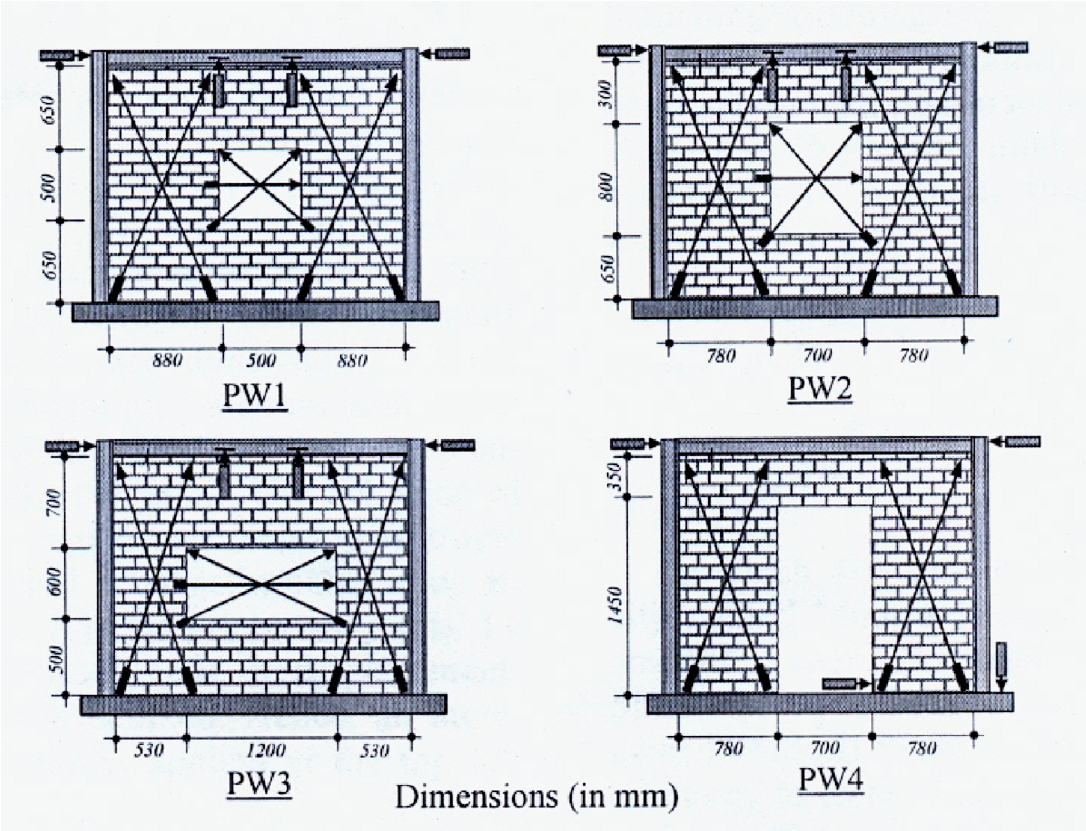
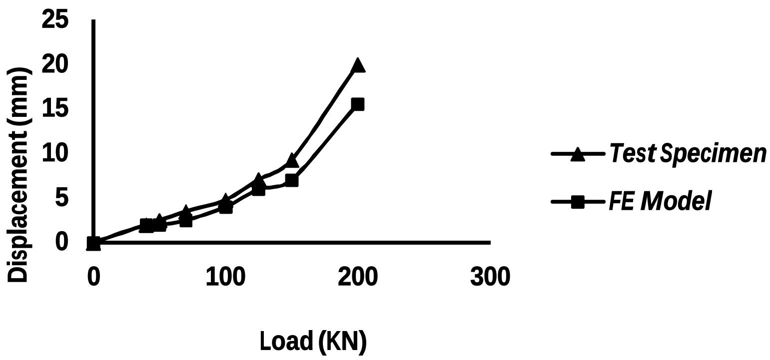


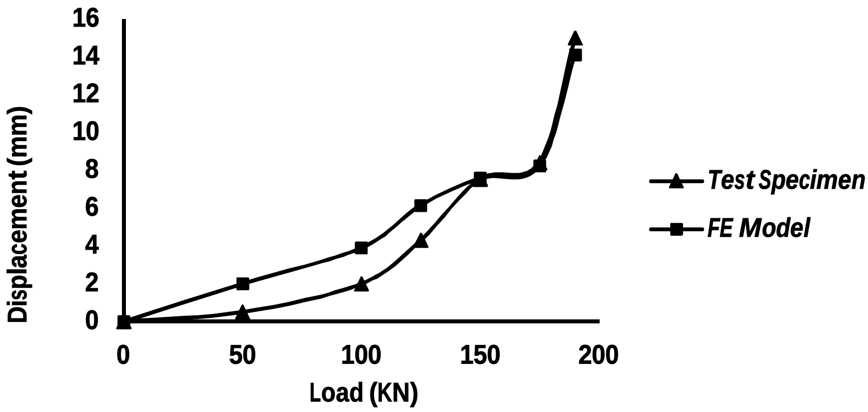
Figure 4: Configuration and position of test specimens [A.A. Tasmini and A. Mohebkhah, 2001]

These specimens are modeled using the finite element procedure enhanced by the programme software already developed. Thus an incremental horizontal load was applied at the top left hand corner of the models, adopting a displacement controlled boundary condition for determination of the specimen. Figure 5 illustrates the comparison between the load-displacement relationships of all the test specimens and that of the FE analysis up to failure mechanism formation.

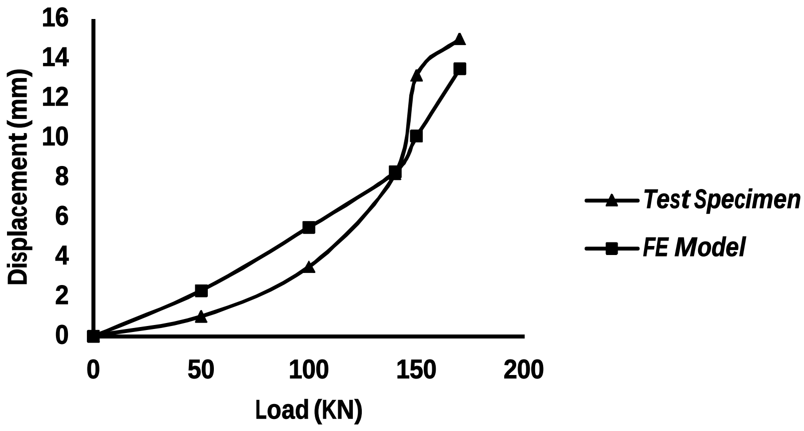
(a)



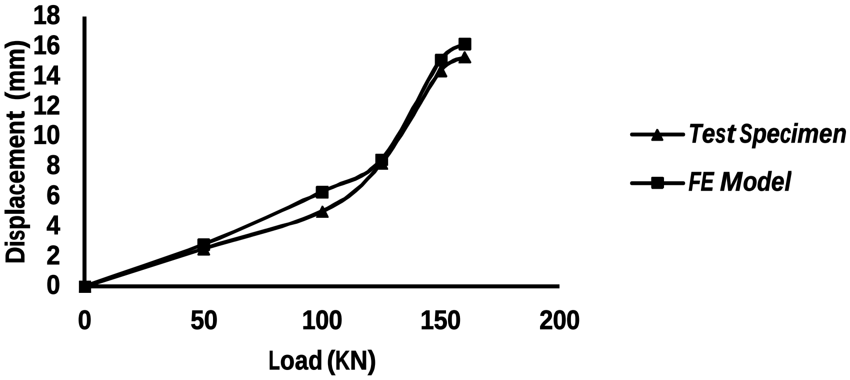
(b)



(C)



(d)



(e)

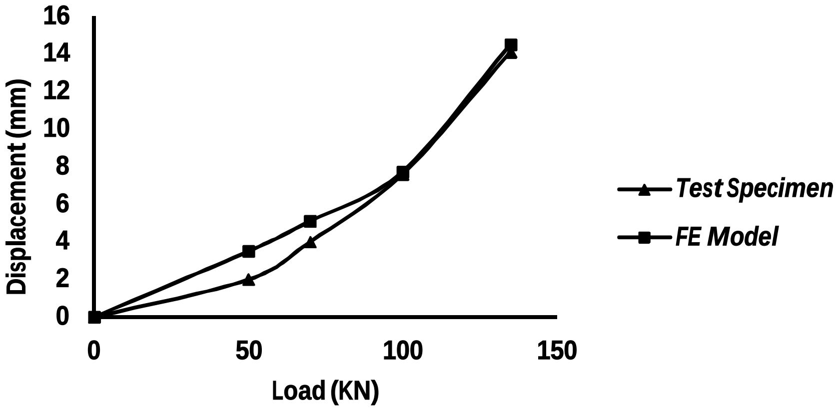


Fig 6: Comparison Lateral load- displacement diagrams for the different Specimens (a) SW, (b)PW1, (c)PW2, (d)PW3, (e)PW4.

The load peaks on the curve indicates the state at which a new joint cracking occurs or when plastic failure takes place in the infill masonry. It can be clearly be deduced that the experimental and numerical results show good correlation. The wide difference in the failure load of some specimens can be attributed to premature failure of the week bricks which may have induced an early diagonal shear cracking failure of the slender piers leading to a low shear capacity. Hence the two dimensional finite element model developed for the nonlinear analysis of the masonry infilled frames has proved to be a useful micro-modeling approach as it was found to properly simulate the non-linear behaviour of such frame throughout the loading process leading to failure.

IV. CONCLUSION

This work is an effort towards the understanding of the effect of infill wall, both full and partial to the shear resisting RC framed structure under lateral loading condition. The finite element analytical technique supported by useful computer programme software developed by the author was validated with results from the adopted experimental test procedures. With this verification, the shear strength response of masonry infilled frames with varying opening ratio of the infilled panel and the different configuration of openings can be investigated using the FE model developed.

REFERENCES

1. Buonopane, S. G., and White, R. N. (1999). ''Pseudodynamic Testing of Masonry-infilled Reinforced Concrete Frame.'' J. Struct. Eng., 125(6), 578–589.
2. Dawe J.L. and Seah C.K., (1989), "Behavior of Masonry Infill Frames," in *Canadian Journal of Civil Engineering, v*ol. 16, 865-876.
3. El-Dakhakhni W., Mohamed E. and Ahmad H. (2003) "Three-Strut Model for Concrete Masonry-Infilled Steel Frames." Journal of Structural Engineering, Vol. 129, No. 2,: 177-185.
4. Hendry, A. (1981). Structural Brickwork, Macmillan, London.
5. Hetenyi, M. (1946) "*Beams on elastic foundations",* University of Michigan Press.
6. Holmes, M. (1961). ''Steel Frames with Brickwork and Concrete Infilling.'' Proc., Inst. Civ. Eng., Struct. Build., 19, 473–478.
7. Kadir, M.R.A. (1974). *The structural behaviour of masonry in fill panels in framed structures*, PhD thesis, University of Edinburgh.
8. Mainstone, RJ. (1971). On the stiffnesses and strengths of in filled Frames, *Proc., Instn. Civ. Engrs.*, Supp. (iv), 57-90.
9. Mosalam, K., White, R. N., and Gergely, P. (1997). ''Computational Strategies for Frames with Infill Walls: Discrete and Smeared Crack Analyses and Seismic Fragility.'' Rep. No. NCEER-97-0021.
10. Polyakov, S.V. (1960). On the interaction between masonry filler walls and enclosing frame when loading in the plane of the wall, *Translation in earthquake engineering, Earth quake Engineering Research Institute,* San Francisco, 36-42.
11. Reflak, J. and Fajfar, P. (1991), "Elastic Analysis of Infilled Frames Using Substructures," Proceedings of 6th Canadian Conference on Earthquake Engineering, Toronto, 285–292.
12. Saneinejad, A. and Brian H., (1995). "Inelastic Design of Infilled Frames." Journal of Structural Engineering, Vol. 121, No. 4,: 634-650.
13. Smith, B.S. (1966). Behavior of Square Infilled Frames. Proceeding of the American Society of civil Engineering Journal of Structural Engineering, ASCE, 92 (ST1): 381-403.
14. Smith B.S. and Carter C. (1969). A method of analysis for infilled frames, Psoc. lustn. Civ. Engrs. 44, 31 – 48
15. Tasnimi, A.A. and Mohebkh, A. (2011), "Investigation on the behavior of brick-qEng Struct., vol.33, pp.968-890.