CHAPTER 1

INTRODUCTION

1.1 OVER VIEW OF INFILL FRAME

Masonry infilled panels considered as interior and exterior walls in framed structures. Beam-column members and the filler walls are major component of infill frames. Although the infill walls are mostly considered as non-structural elements, it is known that they have important impact on the behavior of the frames. The presence of masonry infills in framed structure significantly modifies the structural response to strong ground motion; however, the interactive behavior is complex and cannot be quantified easily. Due to lack of simple analytical modals and the uncertainty due to large number of variables involved, the contribution of masonry infill is disregarded in conventional design practice. However this practice has been questioned over time and studies made to investigate the contribution of infills and incorporate it in the design of new building and the evaluation of the existing ones. The abundance of such framed structures with unreinforced masonry infills in earthquake prone areas necessitates that further effort be directed towards developing and understanding the behavior of such infills under repeated in-plane and out-of-plane cyclic loading.

During recent earthquakes reinforced concrete buildings with masonry infills have demonstrated superior behavior compared with buildings without infills when subjected to seismic loads. Reinforced concrete frames without infill possess low lateral stiffness and may exhibit excessive lateral drifts during earthquakes. Masonry being a stiff but brittle material is weak in shear but can sustain significant in-plane compression if properly confined. The masonry infill provides significant lateral stiffness thus reducing lateral drift, while the frame furnishes confinement and ductility to the frame system. The infill acts as a stiff bracing element and reduces the deformation of the framed structure when subjected to lateral loads. However the masonry infill contributes additional mass and stiffness to the system which causes it to attract large seismic forces and reduces the period of vibration of the system. This considerably alters the dynamic response of the structure from that of the bare frame structure without infill. It is therefore important that the interaction of the masonry infills with the confining frames be appropriately accounted for analyzing existing or designing new buildings.

Masonry infill has effect on global seismic response of R/C frame. On the other hand, they improve the global resistance to lateral load and the energy dissipation capacity. They also increase the lateral stiffness of the structure. Due to irregular arrangement, the infill with opening makes the short column effect, torsional or the story effect.

To ensure the effect of the infill on the structural system, considerable work has been done in past few decades. Many researchers agree that the infill increases strength in vertical loading. The wall and floors are effective in resisting lateral load caused by wind and earthquakes. The wall may act as vertical bracing to transfer the lateral load to the ground. It also acts as diagonal bracing to transfer the lateral load to the ground. It may also acts as diagonal bracing to the frame, which helps to reduce moment, allowing a more economical elastic design. (B.S Smith et al 1962).

Past earthquakes results show that the buildings, which are constructed traditionally, and having thick walls are found less damaged compare to the frame with less partition wall. The infill is economical and provides lateral strength on the structures, so instead of additional RCC to bear lateral load the inclusion of infill wall is worthy.

To study the actual behavior of structures through the scale model, the considerations on the selection of the model should be compatible to prototype. To understand the behavior of individual and whole components in symmetrical loading patterns as they face susceptible conditions, infill should be included in analysis and design. In analysis the neglect of contribution or effect of the wall seems to be poor judgment with understand of actual behavior.

Currently, masonry walls are constructed under different configurations, such as solid panels, panels with window and/or door openings. The in-plane capacity of these masonry walls has not been clearly established, nor the in-plane lateral capacity of infilled masonry wall. Though the only reliable way to obtain the capacity of these structures in their weak direction is by performing experimental tests, but this research is focused in carrying out analytical analysis and to develop various relationships for infilled masonry subjected to cyclic lateral loading.

Typically, residential reinforced concrete walls are infilled with masonry walls in their weak direction, which are commonly used as partition walls (figure A1). Normally, designers consider the masonry concrete block walls as non structural elements during the design of these residential houses. Therefore, interaction of the masonry infill walls with its surrounding elements during the seismic events is neglected. In seismic ignoring the composite action is not always on the safe side, since the interaction between the infill panel and the surrounding elements under lateral loads changes dramatically the stiffness and the dynamic characteristics of the composite structure and consequently, its response to seismic loads. In order to obtain information about how these structures in their weak direction, this investigation is focused in conducting analytical investigation on the behavior of the infilled frames under lateral loading and studies the possible scenarios of failure.

1.2 OBJECTIVES OF THE STUDY

The Primary objective of this thesis is to investigate effect of brick masonry infills on the strength and stiffness characteristics of reinforced concrete frames when subjected to in-plane lateral loading. The inelastic behavior of masonry infills was investigated in order to study their mode of failure under in-plane lateral loading.

The supporting objective includes:

i. To develop a simplified analytical model to represent the infill behavior.
ii. To study how the presence of unreinforced masonry infills modifies the stiffness, strength and energy dissipation characteristics of reinforced concrete frames,
iii. To develop moment rotation relation.
iv. To develop comparative results on load deformation relation.

v. To investigate the effect of variation in frame stiffness relative to the infill, on the in-plane lateral load behavior of masonry infill.
vi. To study overall response of laterally loaded infill frames and masonry panel.

1.3 SCOPE AND LIMITATION

Analytical model has to be prepared, material properties has to be assigned, analysis of the model has to be carried out and results have to be interpreted carefully, to achieve the objective of study,. The scope of this thesis work will be as per follows:

i. Study has been concentrated on only one panel with the different arrangement of openings of one thirds models.
ii. Material properties have been taken from standard literature.
iii. Analysis has been carried out using software SAP 2000 and BINAP.
iv. The mortar has been modeled as link elements. The non linearity in the link element has been considered assigning link element. (Though the mortar will not behave in this way, the link is selected to approximate the non linearity which is the best option available in SAP 2000.)
v. Bond strength between mortar and brick and mortar and concrete has been assumed same.

1.4 METHODOLOGY

The detail methodology is described in chapter 3, while the summarized methodology is presented here.

Literature review is carried out on related field. Material properties are taken from previous researchers.

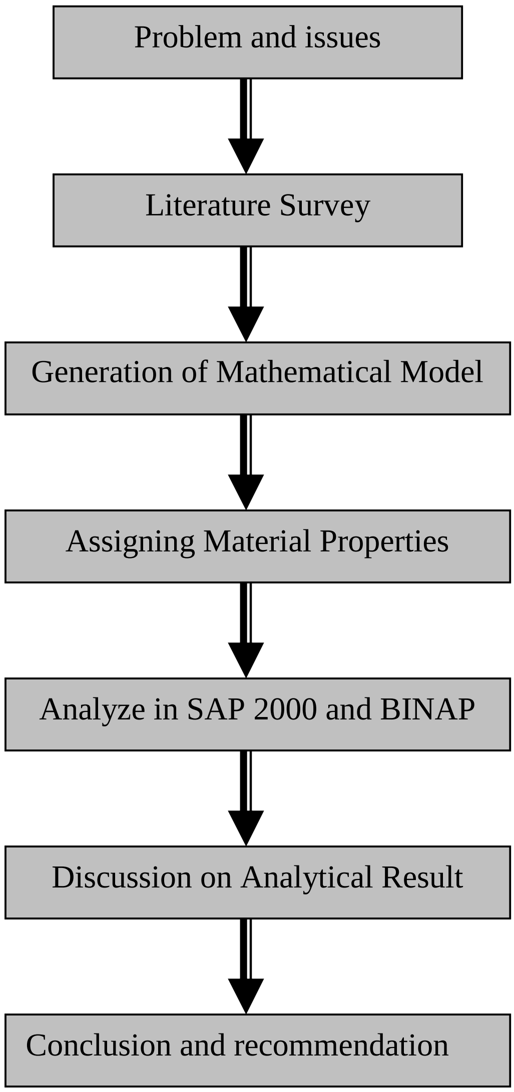
For analysis five FEM models with different percentage of opening are made and analysis is carried with SAP 2000 and BINAP after that the results have been studied systematically and interpretation of results has been carried out.

The material properties are critical input data. For input of these data collection have been made from previous research conducted in IOE laboratory.

After analyzing the models, extensive discussion and appropriate conclusion is carried out.

Flow Chart of Methodology

METHODOLOGY



1.5 ORGANIZATION OF THESIS

This research paper is organized into seven chapters.

Chapter One:	Introduce the basic information about subject matter. Brief discussion on objectives, scope, limitations and Methodology.
Chapter Two:	Includes the literature review on subject matter.
Chapter Three:	Gives the numerical modeling of infilled frame
Chapter Four:	Focus on analytical Methodology.
Chapter Five:	Discussion of analytical model.
Chapter Six:	Ends with summary, conclusion and further recommendation.

The appendix includes relevant data:

Appendix A:	List of Figures
Appendix B:	List of Output Graphs and charts

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Various research activities, analytical and experimental, have been developed in the last five decades to investigate the in-plane lateral load response of masonry infilled frames. The experimental investigations have been carried out to examine the responses of full or scaled structures subjected to monotonic or cyclic loading and simulated earthquakes. Analytical investigations have been performed to predict the observed behavior of the infilled frames during experimental tests and seismic events. This section presents a series of analytical investigation of the lateral static load response of masonry infilled frames.

2.2 REVIEW OF LITERATURE

The disagreement within analysis and construction practice of the structure is omission and existence of infill in the frame structure. The study of infill behavior is divided into two types, first assuming masonry as heterogeneous material and second homogenous material. While brick masonry is taken as heterogeneous materials it is into two elements having the joint between them.

In homogeneous model analysis of the structures, a suitable property of the infill is given in combined state. Doing do the infill is represented as a member, which governs the behavior of the brick masonry and this makes less effort for analysis.

Using finite element approach, idealizing brick and mortar having two different material properties, firstly large computational effort arises in simple structures. In second, brick and mortar joints require further degree of freedom for each brick and it should be modeled at lease one element.

The available literature on the behavior of the infill frames can be divided into two parts. One parts deals with the analytical research on the modeling of the infill in building frames and the other part with the experimental work on the study of actual behavior of the infill frames under lateral static load.

Polyakov (1950) Investigated on the behavior of pin-jointed masonry infilled steel frames with and without opening. He found that the separation between frame and the infill except at two compressive corners and proposed the concept of diagonal struts assuming that the infill behave as a diagonal strut. In 1956 he introduce the concept of equivalent diagonal struts in which system was deemed to behave as a diagonally braced frame with compression strut; he suggested that stresses from the frame to infill are only transmitted in the compression zone of infill to the frame interface.

Tezcan and Ipek (1996) found that the masonry walls of three and four story houses collapsed immediately during the 1995 Dinar, Turkey earthquake. The masonry houses constructed using bearing walls made of hollow core brick tiles collapsed due to insufficient wall rigidities, improper wall thicknesses, and wall openings. However, when the bearing walls were constructed from solid brick walls or stones, and they were one or two-story high, the masonry buildings survived the earthquake with minor cracks.

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Flanagan et al. (1996) investigated the performance of masonry infills during the Northridge earthquake. They found that the collapse of the masonry infills during the earthquake was due to diagonal cracking, cracking around the infill perimeter, and corner crushing. However, in spite of the damage of the masonry infill, the buildings remained useable and stable after the earthquake.

Sezen et al. (2000) analyzed the role of infill walls in the response of moment-frame buildings during the 1999 Kocaeli, Turkey earthquake. Their found that many buildings collapsed due to soft stories. Irregular placement of infill masonry walls produced stiffness discontinuities, which concentrated the deformation in the first story, and led to the failure of the ground floor columns.

Humar et al. (2001) investigated the performance of buildings during the 2001 Bhuj earthquake in the Kachchh region of the province of Gujarat in India. They concluded that the presence of masonry throughout the height of the buildings prevented the collapse of many buildings even though such infills were neither reinforced nor positively tied to the boundary elements.

2.3 ANALYTICAL INVESTIGATION

Macro-models and micro-models are those two different approaches on which analytical investigation was done. The micro-models are based on the theory of elasticity, equilibrium, and energy approach, plastic analysis and lately the finite element method. The macro-models are based on simple analytical models such as equivalent frame and equivalent strut.

2.3.1 Micro-Modals

Achyutha et al. (1986) proposed a simple iterative finite element method w to investigate the infilled frames with openings, and with or without stiffeners around the openings. The method takes into consideration the separation, slip, and frictional loss at the interface of the infill and the frame. The bounding frame members were represented by prismatic beam elements having three degrees of freedom at each node. The continuum infill panel was modeled by two-dimensional four-node rectangular plane stress elements having two degree of freedom at each node. The interface between the frame and infill was represented by short stiff beam elements having three degrees of freedom at each node. The analytical results demonstrated that for cases of window opening area greater than 50% of the solid infilled area the lateral stiffness of the infill panels with openings can be neglected when compared to that of solid infilled frames.

May and Naji (1991) presented a nonlinear finite element program to simulate the behavior of steel frames infilled with concrete panels subjected to monotonic and cyclic loading. The infilled frame was modeled using panel elements, frame elements and interface elements. The program was validated by using experimental results of the tests conducted by May and Ma (1984), and Liauw and Kwan (1982). For the analysis of the infilled frame under monotonic loading, the analytical results represented the different modes of behavior observed experimentally. When the infilled frame was subjected to cyclic loading, the analytical results showed a good agreement with the test results for the first cycle of loading. For other cycles, the hysteretic loops predicted by the program were narrower than those of the tests.

Mehrabi and Shing (1997) investigated the lateral load resistance of masonry-infilled frames R/C frames using finite element models. The finite element models considered the fracture behavior of R/C frames, masonry units, mortar joints, and frame-panel interface. The tension and compression behavior of the concrete frame and masonry units were modeled with smeared crack element, while the fracture of the mortar joints, the separation of the frame-panel interface, and the shear cracks in the concrete columns were modeled using interface elements. The models were validated with results of experimental tests conducted by Mehrabi (1994) on half-scale, single-story, R/C frames infilled with concrete masonry units. The analytical results showed an acceptable correlation with the experimental results, thus allowing the use of the analytical models to evaluate the influence of different design parameters on the performance of infilled frames (figure 2.1).

Ghosh and Amde (2002) presented a new finite element model for infilled frames, in which the interface between the frame and the infill and the mortar joints surrounding the blocks of masonry were simulated by using a non associated interface model based on test data on masonry joints. The cracking in tension and plasticity in compression of the infill were modeled by using smeared crack model and the plasticity model, respectively. The finite element model was validated by comparison with the results of the experimental tests carried out by other researchers. The results obtained by the finite element model showed that the numerical models were capable of providing detailed information on the failure mode, ductility, and cracking.

2.3.2 Macro-Modals

Stafford (1967) developed the equivalent strut concept to predict the lateral stiffness and strength of multi-story infilled frames. The equivalent strut concept was developed by considering that the frame members are rigidly connected to each other and that the infills which are not bonded to the frame and are made of homogenous and isotropic material. In the equivalent strut concept, the structure is modeled as a braced frame where the infill walls are replaced by equivalent pin-jointed diagonal strut. As a result of the analytical investigation, Smith proposed a theoretical relation to determine the effective width of the diagonal strut based on the relative stiffness of the infill and frame. Also, he concluded that the lateral load that produces a compressive failure of the infill depends on the relative stiffness of the columns to the infill, and it is independent of the length/height proportions of the infill and the beam stiffness.

Liauw (1972) presented the concept of the equivalent frame for the analysis of infilled frames with or without opening. This concept was developed by transforming the infilled framed in to an equivalent frame whose members have the properties of the composite sections of the actual structure. The analytical results obtained by the equivalent frame concept were compared with the experimental results obtained from an elastic model experiment. The comparison between the experimental and analytical results showed a good agreement when the openings are more than 50 percent of the full infill area. When the openings are less than the 50 percent of the full infill area, the equivalent frame concept is on the conservative side.

Sobaih and Abdin (1988) used a concept of equivalent strut for the linear analysis of infilled multi-story frame subjected to earthquake excitations. The method was presented in the computer program SAPF (Seismic Analysis of Plane Frame). The program was used to simulate 13 cases of bare and infilled frames in order to investigate the effect of different factors such as the presence and continuity of infill panels, the height of the structure, infill material, panel rectangularity ratio, and width of the equivalent strut. The results showed that infill panels increase the stiffness of the structure and the stresses on columns, but decrease the lateral displacement of the frame.

Saneinejad and Hobbs (1995) developed a method based on the equivalent diagonal strut approach for the analysis and design of steel frames with concrete or masonry infillings walls subjected to in-plane forces. The method takes into account the elastic and plastic behavior of infilled frames considering the limited ductility of infill materials. The method provides a rational basis for predicting the lateral strength and stiffness of infilled frames as well the infill diagonal cracking load. Various governing factors such as the infill aspect ratio, the shear stress at the infill-frame interface and relative beam and column strength are accounted for in this development. To represent masonry infill panels in nonlinear analysis of frame structures, an equivalent strut integrated with a smooth hysteretic model was proposed by Reinhorn et al. (1995) and Madan et al. (1997). The model is based on an equivalent diagonal strut with a hysteretic force-deformation that includes the strength and stiffness degradation as well as pinching resulting from opening and closing of masonry gaps. The equivalent strut model was implemented in the computer program IDARC Version 4.0. The macro modeling approach does not permit to study local effects such as frame-infill interaction within the individual infilled frame subassemblies. However, the proposed approach allows for the evaluation of the nonlinear force-deformation response of the structure and individual components under seismic loading.

Force equilibrium of a frame with an infill wall under lateral load is shown below in figure 2.1.

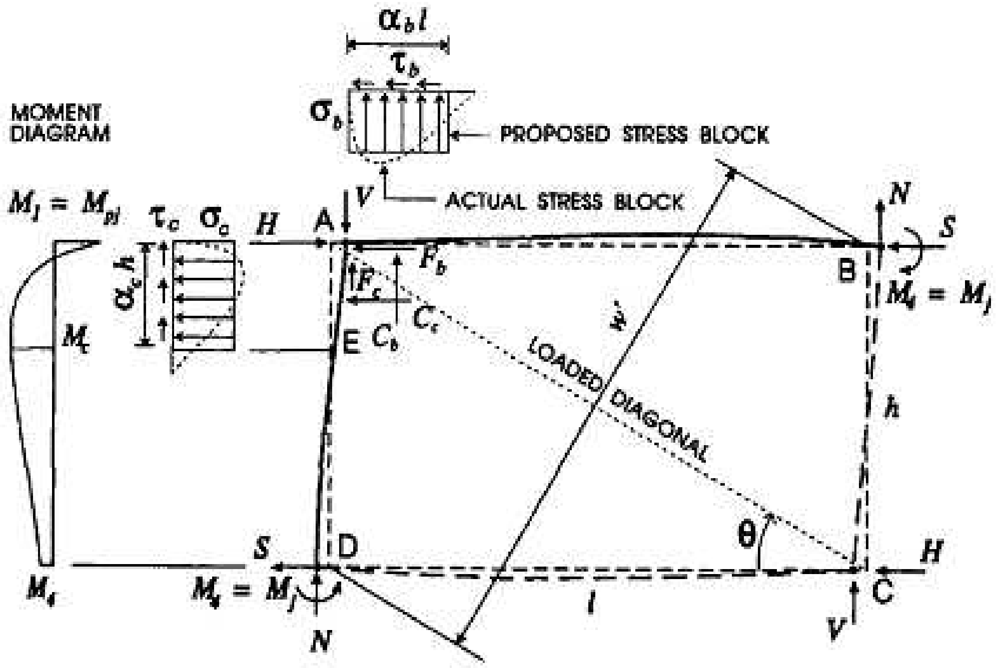


Figure 2.1-Frame Force Equilibrium, Saneinejad & Hobbs

Saneinejad & Hobbs have calculated the collapse load as:

$$M = \pm_c t(1 - \sim_c)\sim_c h + {}^2{}_b t \sim_b l + 2\frac{(M_{pj} + M_j)}{h} \qquad (2.1)$$

Here $\pm_c$ and ${}^2{}_b$ are the uniform frame infill contact normal and shear stresses, respectively; $\sim_c$, $\sim_b$ are the normalized contact lengths of the column and beam, respectively; *h*, *l* and *t* are the height, length and the thickness of the infill, respectively; M_{pj} is the joint resisting plastic moment on load corner and M_j is the moment at the unloaded corner at collapse load level.

For multistory structures Saneinejad & Hobbs have proposed a pin connected equivalent diagonal strut with the cross-sectional area given as:

$$A_d = \frac{(1 - \sim_c)\sim_c th\frac{\pm_c}{f_c} + \sim_b tl\frac{{}^2{}_b}{f_c}}{\cos^{-}} \qquad (2.2)$$

In equation (2.2) f_c represents uniform compressive strength. This equation was further modified for stability of infill and shear sliding of masonry infilled frames according to ACI 312.1-89 and ACI 530-88 respectively. Later Madan et al. extended this model with hysteric rule that accounts for strength and stiffness degradation as well as pinching resulting from opening and closing of gaps between the infill and bounding frame.

Ei-Dakhakhni et al (2003) presented a simple method for estimating the stiffness and the lateral load capacity of concrete masonry-infilled steel frames failing in corner crushing mode. The method consisted in replacing each masonry panels by three struts with force-deformation characteristics based on the orthotropic behavior of the masonry infill. In order to determine the bending moments and shearing forces in the frame members, a single diagonal strut is connected between the two loaded corners, and the other two struts are located off-diagonal at the points of maximum field moments in the beams and the columns. They concluded that three struts do not fail simultaneously, which is the case in actual infill panels, because the crushing starts at the corners and keeps propagating in the corner region leading to failure of the panel. El-Dakhakhni proposed three equivalent struts which have a total area given as:

$$A = \frac{(1 - \sim_c)\sim_c ht}{\cos -} \qquad (2.3)$$

Distribution of total area among the diagonal struts is shown in figure 2.2. it was stated that the three-strut model had better simulated the moment distribution along beams and columns. It should be noted, however, that this method only considers the infill corner crushing which is the most common type of failure mode in infill steel frames.

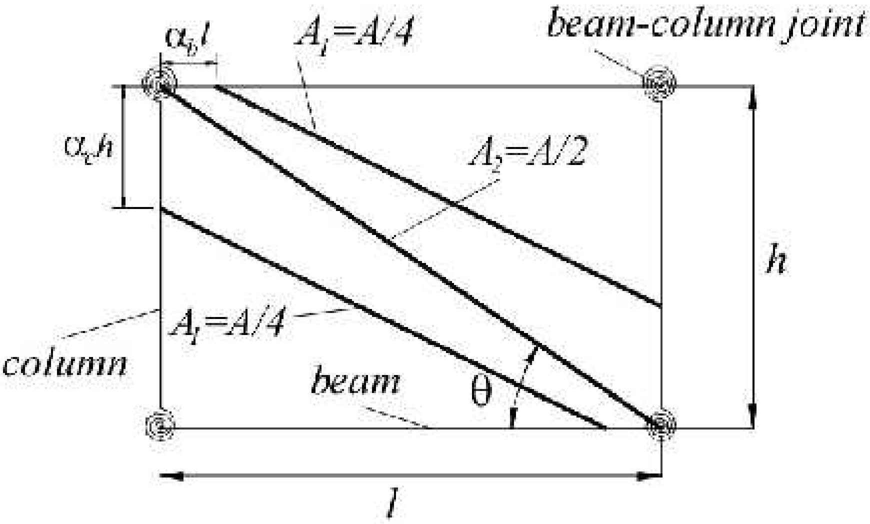


Figure 2.2-Concrete masonry-infilled steel frame model Ei-Dakhakhni et al

Perera (2005) proposed a damage model based on the equivalent strut for the characterization of masonry walls subjected to lateral cyclic loads. The strut element is modeled as a simple longitudinal inelastic spring simulating equivalent bracing acting directly between the two compressed corners of the frame, and its constitutive law is formulated by using the concepts and principles of continuum damage mechanics. For this, the axial force versus deformation relation is formulated through the effective stress concept and the strain equivalence principle. Using this approach, a scalar damage variable is introduced in the constitutive equations for characterizing damage processes. The damage variable considers the progressive decrease of the effective width of the diagonal compression strut, due to the cracking occurring in the infill panel by tension effects.

2.4 FAILURE MECHANISM

Shing P.B. and Mehrabi A.B. stated that no single analytical model can account for all possible load resistance mechanisms. It was also noted that the limit analysis methods that account for a variety of possible failure modes are the most promising approaches. It was also stated that the mechanism that results in the lowest lateral resistance is the dominant failure mechanism and the corresponding load determines the maximum lateral load. Mainly, five failure mechanisms and the corresponding frame and infill load resistances proposed by Shing and Mehrabi.

2.4.1 Sliding failure

This mechanism corresponds to horizontal sliding failure of the infill at mid-point. The lateral resistance in this case is the sum of the shear forces in the columns and the residual shear resistance of the wall. The resistance of the frame is governed by the hinges formed at one end and the mid-height of each column. **(Figure A4)**

2.4.2 Shear failure

Here, the shear failure develops at one or more locations in the columns. This is the main distinction form the mechanism 1. Lateral resistance is the sum of the ultimate shear resistance of the windward column, the shear force in the leeward column and the residual shear resistance along the horizontal crack of infill**. (Figure A5)**

2.4.3 Crushing Failure

In this mechanism masonry reaches the crushing strength along the wall to frame interface. Also, plastic hinges develop near the beam-to-column joints and at points B as shown in Figure. **(Figure A6)**

2.4.4 Compressive Failure

Infill reaches its compressive strength at corners and plastic hinges are formed at both ends of the column. The wall-to-column interface has a parabolic distribution along the contact length. **(Figure A7).**

CHAPTER 3

MODELLING OF INFILL FRAMES

3.1 GEOMETRICAL CONFIGURATION OF PROPOSED MODELS

Geometric modeling of the proposed model are presented in this chapter. Five infill models and three masonry panels with different percentage of central opening are carried out as presented below

3.1.2 Case-1

Two dimensional RC framed single story single bay models are carried out with zero percent central opening. The models story height is 1.04 m with column and beam of 75X75 mm and similarly the wall of 75mm.

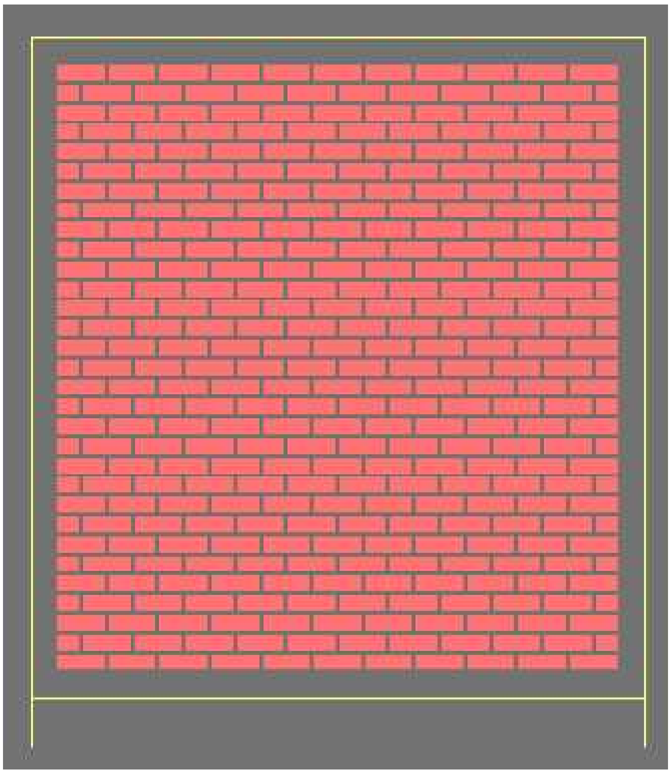


Figure 3.1-infill wall micro model with 0% opening

3.1.2 Case-2

Two dimensional RC framed single story single bay model is carried out with thirty percent central opening. The models story height is 1.04 m with column and beam of 75X75 mm and similarly the wall of 75mm. (figure A8)

3.1.2 Case-3

Two dimensional RC framed single story single bay model is carried out with sixty percent central opening. The models story height is 1.04 m with column and beam of 75X75 mm and similarly the wall of 75mm (figure A9)

3.1.2 Case-4

Two dimensional RC framed single story single bay model is carried out with ninety percent central opening. The models story height is 1.04 m with column and beam of 75X75 mm and similarly the wall of 75mm (figure A10)

3.1.2 Case-5

Two dimensional RC framed single story single bay model is carried out with hundred percent central opening. The models story height is 1.04 m with column and beam of 75X75 mm and similarly the wall of 75mm (figure A11)

3.1.6 Case-6

The masonry wall without RC frame with opening of zero, thirty and sixty percent of above dimensions are modeled for the comparison of lateral stiffness of infill masonry against masonry panel without RC frame. (figure 12-14)

3.2 MODELING OF DIFFERENT COMPONENT

Micro modeling was carried out for the focused infill panel of the building and approximate modeling was carried out for other panels. The modeling features are as follows:

i. The bricks were modeled as 4-noded rectangular shell element. Each brick is divided into three shell elements.

ii. The mortar was represented by non-linear springs that connect adjacent units at nodes.

iii. The surrounding columns and beams were modeled as solid elements with sufficient sub-divisions so that the nearby bricks can be connected by springs at corresponding nodes.(Ref Figure 3.2)

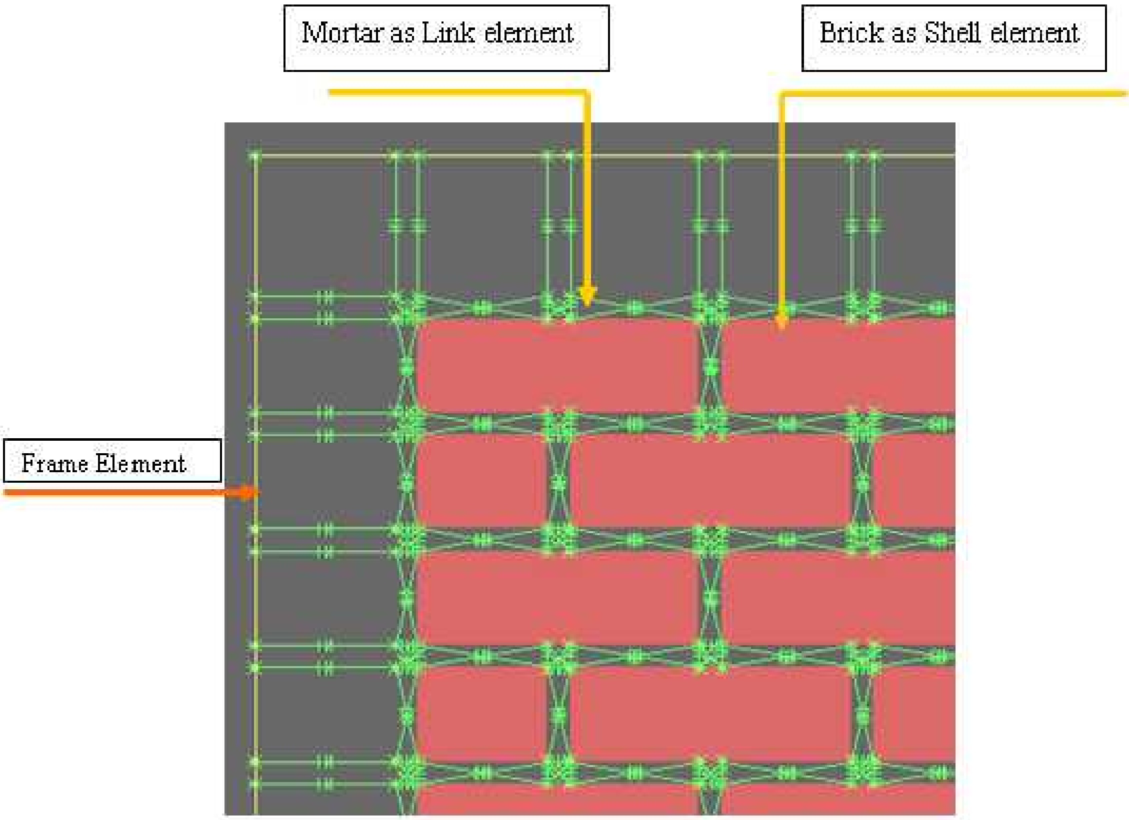


Figure 3.2-Micro modeling of different component

NONLINEAR MODELING : PLP FIT MODEL

(P.L Pradhan, 2008)

In this model, the instantaneous modulus of elasticity E is assumed to remain constant up to yield limit (Figure 3.3) and curvilinear (i.e. second order polynomial) thereafter given by:

$$\pm = a£^{2} + b£ , \quad (1.1)$$

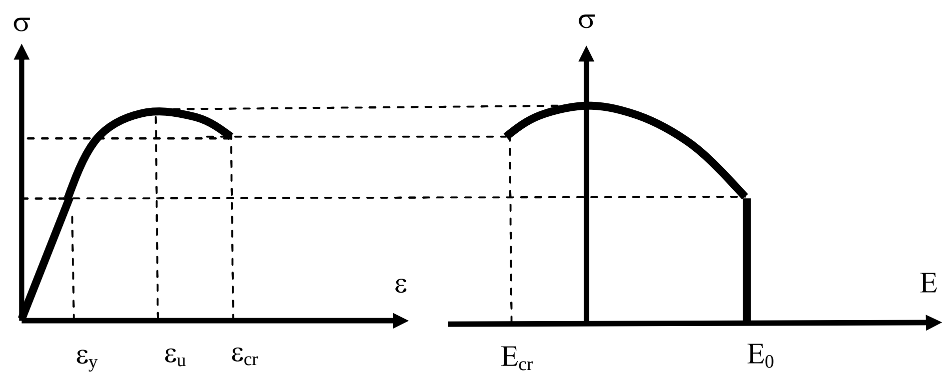


Figure 3.3: Parabolic model of stress-strain curve

where a and b are constants determined by the constraining points (σ_y, ε_y) and (σ_u, ε_u):

$$a = \frac{\sigma_u \varepsilon_y - \sigma_y \varepsilon_u}{\varepsilon_u \varepsilon_y \left(\varepsilon_u - \varepsilon_y\right)}, \text{ and} \tag{3.2}$$

$$b = \frac{\sigma_y}{\varepsilon_y} - \frac{\sigma_u \varepsilon_y - \sigma_y \varepsilon_u}{\varepsilon_u \left(\varepsilon_u - \varepsilon_y\right)}. \tag{3.3}$$

Thus, the stress-strain relation becomes.

$$\sigma = \sigma_u - \left(\sigma_u - \sigma_y\right)\left(\frac{\varepsilon_u - \varepsilon}{\varepsilon_u - \varepsilon_y}\right)^2. \tag{3.4}$$

From Eq. (6), the general expression for instantaneous modulus of elasticity E becomes:

$$E = \frac{2\left(\sigma_u - \sigma_y\right)\left(\varepsilon_u - \varepsilon\right)}{\left(\varepsilon_u - \varepsilon_y\right)^2}. \tag{3.5}$$

Also,

$$E_{cr} = \frac{2\left(\sigma_u - \sigma_y\right)\left(\varepsilon_u - \varepsilon_{cr}\right)}{\left(\varepsilon_u - \varepsilon_y\right)^2}. \tag{3.6}$$

From Eq. (3.4), the general expression for strain can be obtained as,

$$\pounds = \begin{cases} \pounds_u - (\pounds_u - \pounds_y)\sqrt{\dfrac{\pm_u - \pm}{\pm_u - \pm_y}} & if \;\; \pm_{\mathrm{y}} \le \pm \le \pm_{\mathrm{u}} \\ \pounds_u + (\pounds_u - \pounds_y)\sqrt{\dfrac{\pm_u - \pm}{\pm_u - \pm_y}} & if \;\; \pm_u \le \pm \le \pm_{\mathrm{cr}} \end{cases} \tag{3.7}$$

where,

$$\pounds_u = \frac{2(\pm_u - \pm_y)}{E_0} + \pounds_y \text{, and} \tag{3.8}$$

$$\pounds_{cr} = \pounds_u + (\pounds_u - \pounds_y)\sqrt{\frac{\pm_u(1-\sim)}{\pm_u - \pm_y}} \, . \tag{3.9}$$

In this research work, ~ is taken as 0.85. The idealized and experimental data of infill materials (brick, mortar and masonry) are shown in Figures 2 and 3.

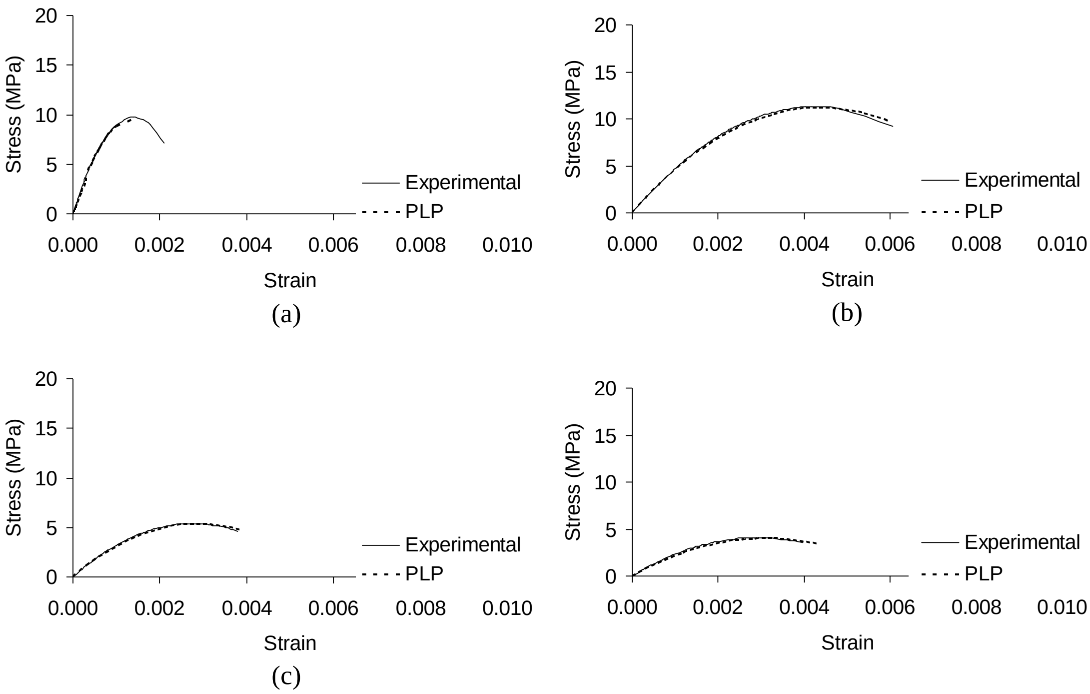


Figure 3.4 : PLP Fit model of stress-strain curve compound with experimental stress-strain curve for concrete and mortar samples: (a) Concrete M7, (b) Mortar 1:3, (b) Mortar 1:4, and (d) Mortar 1:6, PL Pradhan

CHAPTER 4

ANALYTICAL METHODOLOGY

4.1 ANALYTICAL METHODS FOR INFILLED FRAME

While analyzing of any structure, its appropriate model representing its all parameter is necessary. This can be done only if there are appropriate design and analysis tools to model the structure. To some extent, the modeling of structure for analysis is depending on the approach of analysis, which is related to the type and size of structure. The formation of model and procedure of analysis should be rapid and result should be fairly well.

Following method of modeling are widely adapted different methods from different researcher used to study behavior of infill frame with their silent features.

Stress Function Method (Polyakov 1960): In this method the panel and the frame elements of infill panel are assumed to resist a percentage of lateral loads. The loads carried by infill and frame are estimated through an iterative approach. The analysis is carried out using hand calculation and method is approximate.

Equivalent Diagonal Strut Method (Smith 1967): The infill is idealized as diagonal strut and the frame modeled as a beam or truss element. Frame analysis techniques are used for analysis assuming that there is no bond between frame and infill.

Finite Element Method (Riddington and Smith 1977): To simulate structural interface infill-frame system is idealized as panel elements, beam elements and interface elements. In this method interface condition should be properly assigned to have better result. The analysis requires the use of computer.

Plastic method of analysis (Liauw and Kawn 1984,1985): Infill-frame system is idealized either integral, or semi-integral or non integral frame depending on the interface condition and plastic collapse load corresponding to different possible mechanism is determined.

Non-Linear Analysis (Liauw and Kwan 1984): The infilled frame is idealized for analysis by finite element method the response of system is traced by increment the load. Effect of geometric and material nonlinearity can be accounted in the analysis.

4.2 STRUCTURAL MODEL

4.2.1 Bare Frame Model

This type of model does not reflect the reality. In this method bare frame is only considered for analysis and design.

4.2.2 Diagonal Strut Model

The bar element known as strut represent the masonry panel and its behavior are taken from the masonry panel. The diagonal strut model is simple and capable of representing the influence of representing the influence of masonry in a global sense. The model, however, cannot describe the local effects resulting from the interaction between the infill panel and the surrounding frame. As a result, the bending moments and shear forces in he frame members are not realistic and the location of potential plastic hinges cannot be adequately predicted. For this reason single diagonal strut, it has been modified by different researchers. Though it gives overall behavior of the frame system and makes significant results on the stiffness and deformation.

4.2.3 Modified Diagonal Strut Model

The model consist of a moment resisting frame with a number of pin jointed diagonals to represent the shear and axial stiffness of the masonry infill was developed by Triuvebgdam for the dynamic analysis of infill frames. In order to take into account the partial separation at the panel-frame interfaces, the contact length is calculated and those ineffective struts are removed. In the similar way, the effect of opening can be considered by removing the struts crossing the opening area.

4.2.4 Equivalent Frame Approach

The modified properties of the infill with or without opening are idealized. The properties of equivalent frame are computed using the procedure recommended by Liauw (1972). It should be noted that the corner parts of the infill are used twice to calculate the moment of inertia of the beam and column of the frame. This tends to increase the stiffness of the frame, since the corners of the infill stiffen both the beams and columns. The transformed section of the equivalent frame normally consists of deep beams and wide columns, calculating needs to account for strain energy. It also can account for the presence of opening in the infill while calculating the section properties of the equivalent frame members.

4.2.5 Plastic Analysis For Infill Frames

T.C Liauw and K.H Kwan experimented on the infill frames and study the behavior of interface condition. The stress redistribution towards collapse and the condition at the infill-frame interface are taken account. The theory is compared with the experimental results and gives good agreement. In plastic analysis of infill-frames the stress redistribution due to the development of cracks together with the crushing of the infill towards collapse, and the shear strength at the infill-frame interface depending upon the interface condition.

Though the experiments were done in micro concrete infill, here try we have tried to investigate under the brick infill.

4.3 PROPOSED ANALYTICAL APPROACH FOR THIS RESEARCH

For our study purpose, reduced scaled model is created using SAP 2000 using the numerical technique described in chapter 3. The scaled model behaviour can be transferred to the prototype model, which represents the dimensions as the actual construction practice is called prototype. Here in our study we tried to study the behaviour of numerical model and compare with the properties of physical model behaviour of previous.

After creating the model in SAP the work was carried out with the help of BINAP and SAP.BINAP is Nonlinear Analysis Program, was developed for as a pre-processor to SAP2000 for nonlinear analysis of brick infill reinforced concrete frames with micro-models. This program considers many possible modules for the analysis of brick infill frames with micro-modelling. In research studies software, like SAP2000, DIANA, ETABS, have been extensively used. In this study, a major challenge was to incorporate nonlinear contacts after separation between frame wall interfaces, mortar, and bricks. Similarly, another challenge is incorporating strength degradation of infills after loading, cracking and/or crushing of infills. Thus, for the effective analysis, in the present study both SAP2000 and BINAP are used in tandem. BINAP provides the modified structure considering the above issues, whereas SAP2000 does the nonlinear analyses as in figure 4.1. (PL Pradhan 2008).

The masonry panel was investigated using only SAP 2000 under lateral static load case only.

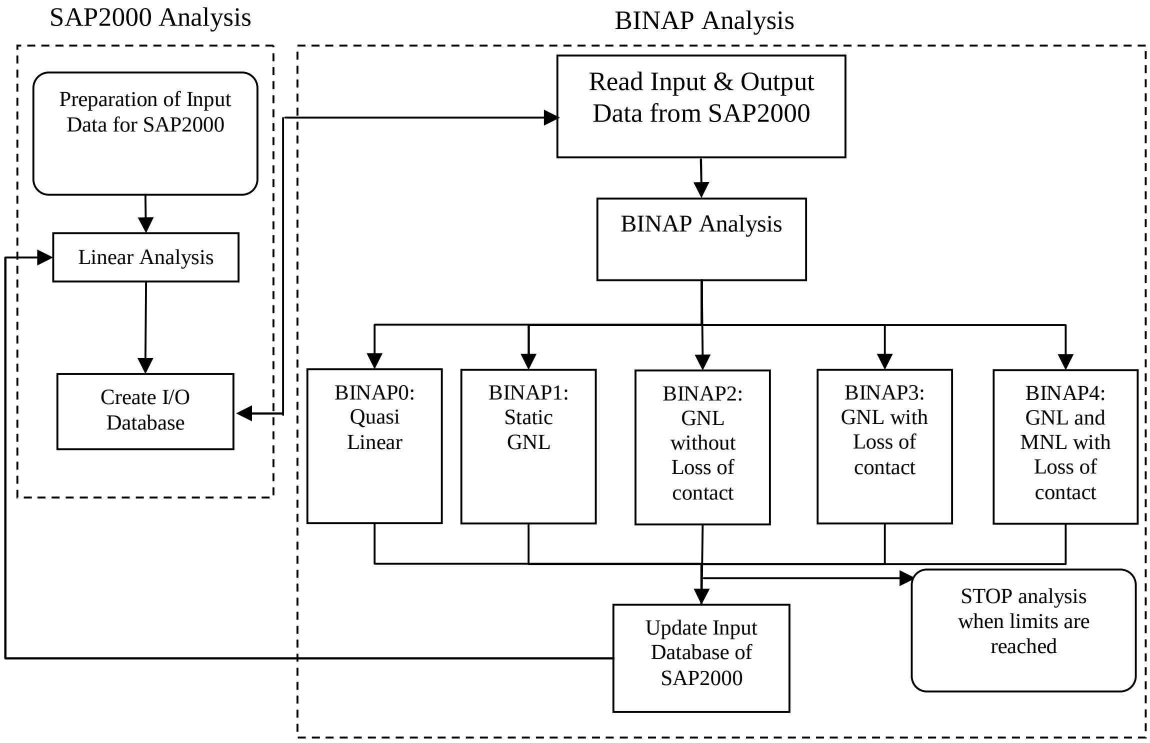


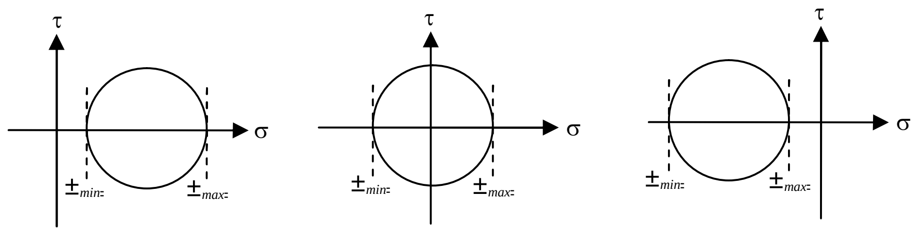
Figure 4.1 Analysis model using SAP2000, PL Pradhan

4.3.1 Geometric and Material Nonlinear Analysis with Loss of Contact

When structural materials reach yielding the stress-stain behaviour becomes nonlinear. Hence, this module uses the idealised stress-strain curve defined in section 3.3; the element starts to behave nonlinearly. The mortar and brick elements, which have low tensile and shear strengths, quickly loose their strength and separate.

In general, loss of contact is considered along with geometric nonlinearity. Initially, the program checks for the frame members exceeding yield limits of stress and strain values and updates the nodal coordinates associated to these frame members. Further, mortar elements are checked for exceeding the yield limits of compressive strength and changes the nodal coordinates related to the mortar elements. For the vertical and horizontal mortar elements (perpendicular and parallel to the bed joints, respectively), the program checks for tension and immediately removes the element, ensuring that all existing mortar elements are no tension elements.

Also, for all the diagonal mortar elements in the model, both the tension and shear limits are checked. Accordingly, the cracks and separations are simulated. The similar operation is performed with the brick elements as well. As the brick element consists of four nodes, the program evaluates principle stresses for checking the limiting values. The three possible cases as shown in Figure 4.2 (Possible cases for principle stresses) are incorporated in the program.



(a) $\pm_{max}>\pm_{min}>0$ (b) $\pm_{min}<0$ and $\pm_{max}>0$ (c) $\pm_{min}<\pm_{max}<0$

*Figure 4.*2 Possible three cases of principle stresses, *PL Pradhan*

The , the program not only considers the idealised stress-strain curve, but also updates the material degradation factor by changing the basic parameters of material characteristics like modulus of elasticity, compressive and tensile strengths, which in turn is updated in SAP2000 material characteristics input data (Figure 4.3). For this, it is assumed that the number of elements and the materials sets are same. This module also performs additional updating of material data. Besides these, this module updates the resizing factor for frame elements. It is assumed that frame elements when strained, the cross sectional size of the frame members changes when strained i.e., area of cross section and second moment of area change. (P.L Pradhan, 2008)

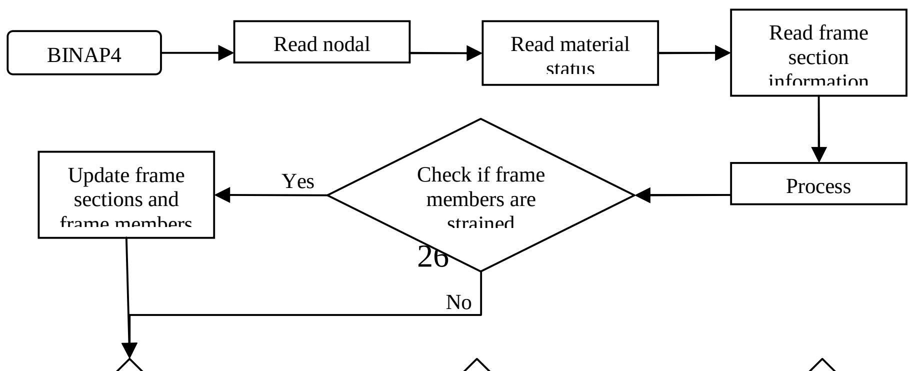


Figure 4.3: *Module BINAP4 for Geometric and Material Nonlinear Analysis with Loss of Contact, PL Pradhan*

4.4 MATERIAL PROPERTIES USED FOR ANALYTICAL STUDY

Material properties are carried out from a series of review. The modulus of elasticity of brick masonry is taken as secant modulus of elasticity. The modulus of elasticity of masonry shall be determined by secant method in which slope of line for the modulus of elasticity is taken from $0.05f_m$ to a point on the line curve at $0.33f_m$.(Uniform Building Code) so the moduli for masonry may be established as $E_m = 750*f_m$.

Beam/Column

Property	Type	Value	Unit

Concrete	Mass per unit volume	2.24	KN/m^3
	Weight per unit volume	24	KN/m^3
	Poisson's ratio,υ	0.15	
	Compressive strength, f_{ck}	7000	KN/m^2

Infill

Property	Type	Value	Unit
Brick Masonry	Mass per unit volume	1.83	KN/m^3
	Weight per unit volume	18	KN/m^3
	Poisson's ratio,υ	0.11	
	Thermal Expansion	9.9*1E-6	

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 ANALYTICAL RESULTS

The behavior of masonry panel and infill is analyzed in this chapter. As described in chapter four, masonry infill RC frame and three masonry panel with different percentage of central opening is analyzed and study is carried out.

5.1.1 Discussion

After modeling the wall non-linear analysis was carried out using software SAP 2000 and BINAP. The analysis has been carried out at regular lateral load incensement. The node where load has been applied and the concern node where outputs are expected are shown in figure 5.1.

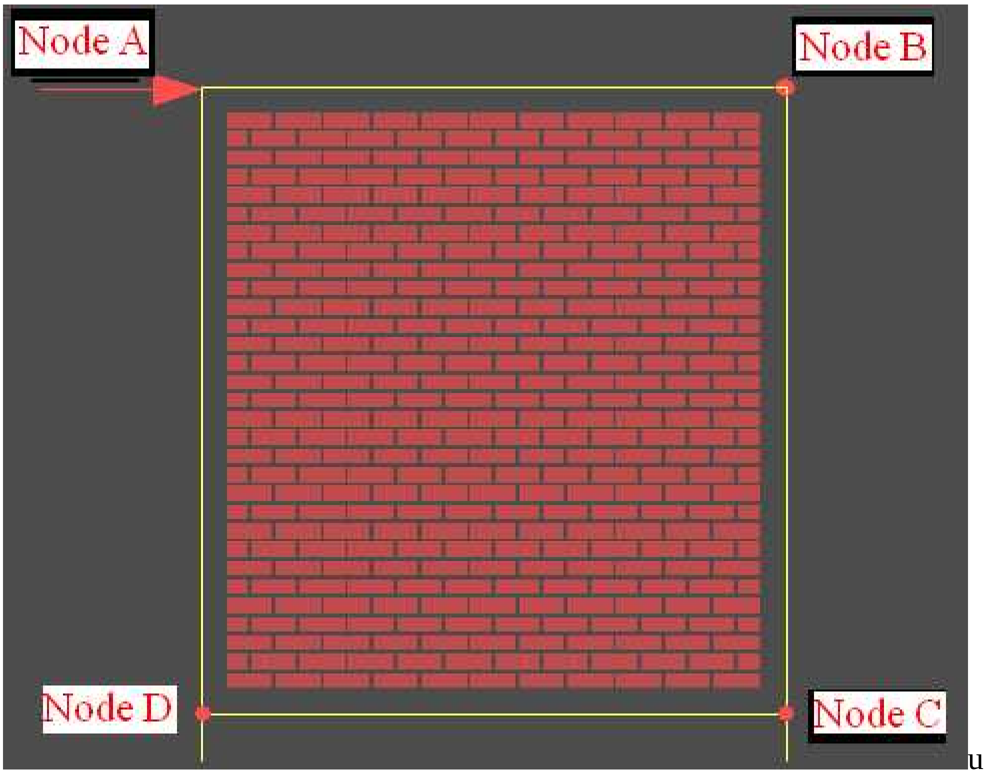


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Figure 5.1, Node

Lateral load is applied at Node A and deflection at node B is carried out. For moment rotation relationship node A and Node C are observed.

5.1.2 Load-Deflection

The load is applied until almost the collapse of the frame. The deflection with almost regular interval of loading is graphed as in figure 5.2. It shows the deflection is linear at first stage afterward the deflection increases rapidly. Slope of load displacement curve is inversely proportional to the opening percentage clearing that the slope decreases with increase in opening.

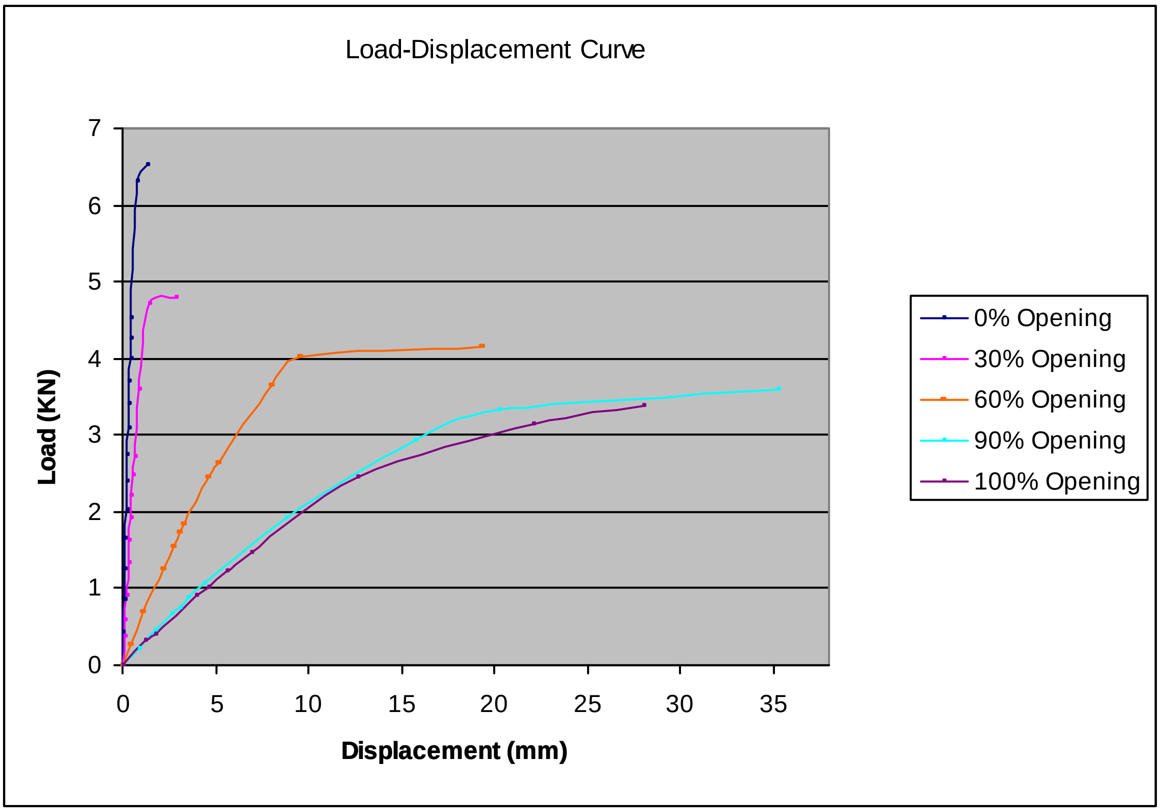


Figure 5.2- Load Deflection Curve

Figure 5.3 shows the load carrying capacity opening percentage. Load carrying capacity of infill panel with zero percentage opening (ie full infill) is 6.3 KN and that of bare frame is 1.8 KN. It shows the load carrying capacity of full infill is almost four times more than that of bare frame. The decrease in load carrying capacity occurs almost linearly with the increase in opening percentage. This shows the frame with infill can carry more lateral load than the bare frame.

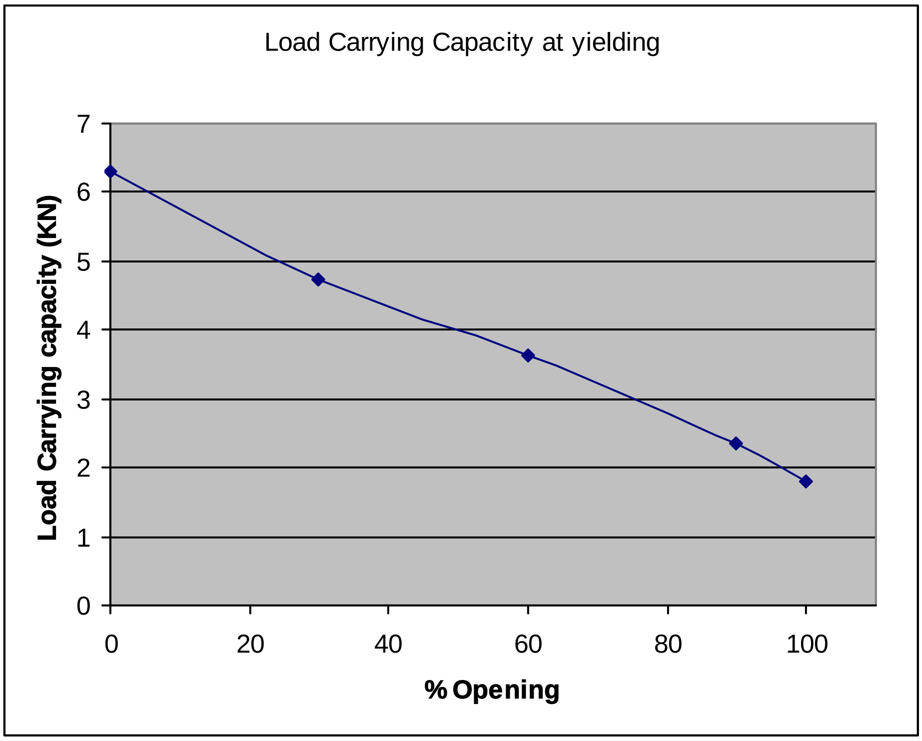


Figure 5.3-Load Carrying Capacity Chart

5.1.3 Infill Stiffness

Results are plotted as figured in terms of stiffness of infill frame with opening/ Stiffness of full infill with respect to opening percentage. The stiffness in fully infill frame bears more than rest. Stiffness curves are decline with the interval of opening figure 5.4. Stiffness of infill panel with thirty percent opening is almost forty percent of full infill and the panel with zero percent opening is almost twelve times stiffer than the infill with hundred percent opening.

Here K_o indicates the stiffness of infill frame with opening and K_f indicates the stiffness of full infill.

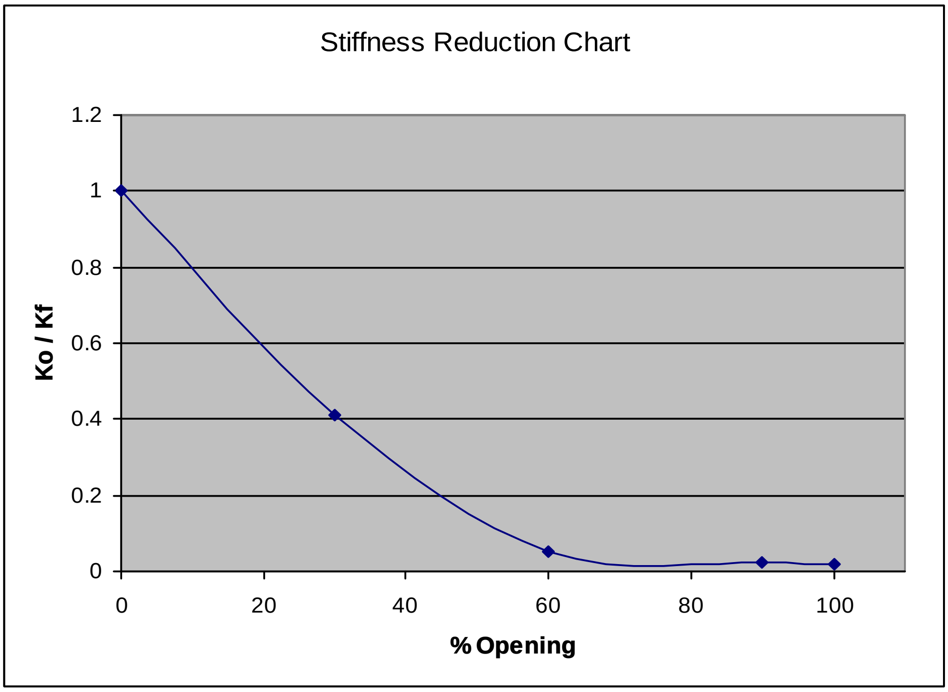


Figure 5.4-Stiffness Reduction Chart

5.1.4 Moment-Rotation

Figure 5.5 shows the moment rotation chart of right bottom node (Node C). Moment and rotation is obtained running the programs at every lateral load steps at Right Bottom Node (Node C). Moment rotation curve is linear at initial stage and then nonlinearity starts. It shows lesser the opening higher the slope of moment rotation curve. Figure 5.6 rotational stiffness decreases with increase in opening. It concludes that higher the opening higher the rotation governing to decrease in rotational stiffness.

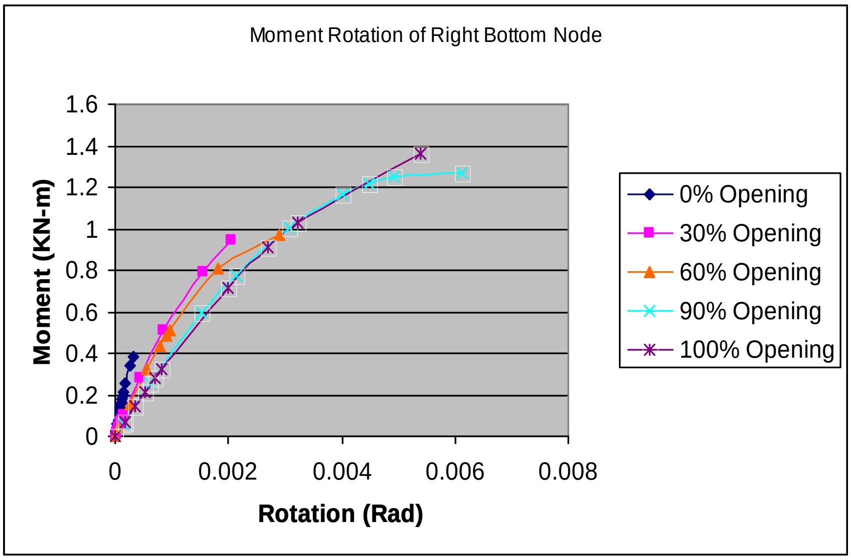


Figure 5.5-Moment Rotation chart of right bottom node.

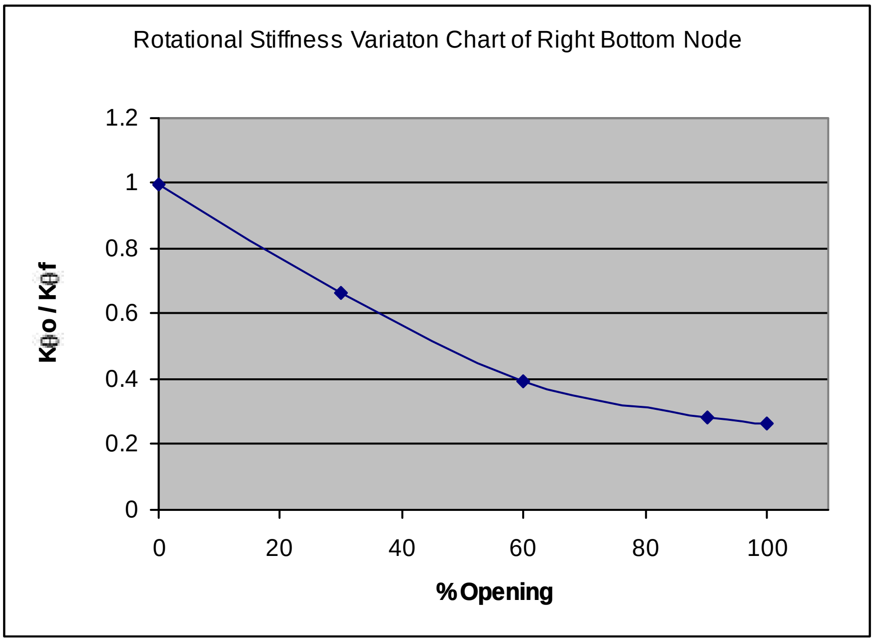


Figure 5.6 Rotational Stiffness Variation Chart of Right Bottom Node

5.1.5 Lateral Stiffness of Infill Frame Vs Masonry Panel without RC Frame

Figure 5.9 shows the lateral stiffness comparison chart of lateral stiffness of infill frame and masonry panel without RC frame. Stiffness is significantly improved by RC frame in masonry panel. At zero percent opening stiffness is six times more in case of infill frame with respect masonry panel without RC frame. Similarly it is nine times at thirty percent opening. It shows that after thirty percent opening influence of RC frame increases rapidly.

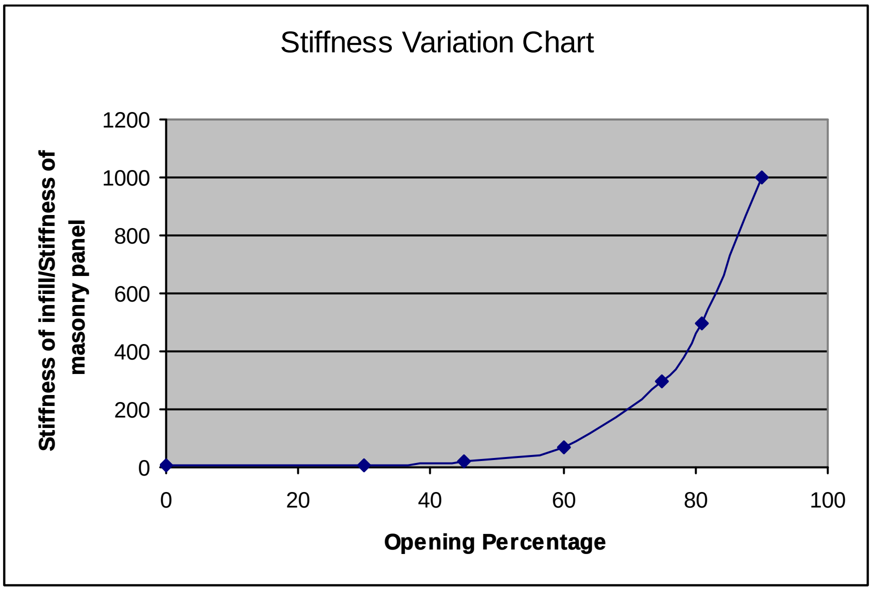


Figure 5.9 Lateral Stiffness variation Chart of Infill Masonry and Masonry Panel without RC Frame

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMARRY

In present trend, due to not having proper explanations and tedious job in the analysis, the contribution of infill to carry lateral load is though significant, it is neglected in analysis and design, which is unfair. The study carried out in this thesis work is a small effort in the direction of preparing an analytical model to incorporate the development of appropriate design provision considering the effect of partial infill subjected to lateral load.

In this work five models of infill frame are analyzed. The primary interest was to observe the load-deflection pattern in different opening. Compare with bare frame, the full infill frame resist almost six times higher load capacity. The frame with 30% opening found to have almost four times greater load than that of bare frame.

Lateral load capacity of the frame was observed by increasing the lateral load till the failure of the frame occurred. The first crack was observed in the adjacent of the corner opening and the crack increases towards the column-beam interaction.

Moment rotation is also graphed during works. Moment of concerned node increases with increase of opening percentage. This was due to the contribution of infill which reduces the moment but rotational stiffness decreases with as rotation increases with opening.

Rotational stiffness almost varies linearly with opening. Rotational stiffness of infill frame is two times that of thirty percent opening, two and half at sixty, five times at ninety and seven times at hundred percent opening.

Similarly RC frame increases the stiffness considerably. At zero percent opening stiffness is six times more in case of infill frame with respect masonry panel without RC frame. Similarly it is nine times at thirty percent opening. It shows that after thirty percent opening influence of RC frame increases rapidly.

6.2 CONCLUSIONS

A. The study shows that the deflection in the bare frame is controlled by infill and infill frame are effective in load carrying capacity.

B. Increase in opening size rapidly decreases the load carrying capacity. The relation between the load carrying capacity and opening was found to be almost linear.

C. From stiffness reductions chart the stiffness of infill with thirty percent opening 0.4times that of full infill and at sixty percent opening it is 0.05times and 0.021 and 0.018times for ninety and hundred percent opening of full infill. It shows that up to forty percent opening stiffness decreases linearly with sharp slope and after that with lesser slope.

D. Moment at concerned node decreases with opening size. Moment of right bottom node of thirty, sixty, ninety and hundred percent opening was 1.31, 1.70, 2.29 and 2.65 times that of full infill. This was due to the contribution of infill. Almost similar result was obtained for left top node.

E. Rotational stiffness decreases with opening percentage. This was due to increase in rotation with opening size.

F. Decrease in translational stiffness with opening is more than rotational stiffness.

G. In summary the opening size reduces the load carrying capacity and also rotational stiffness considerably.

6.3 RECOMMENDATION FOR FUTURE WORKS

I. In present study the static analysis was carried out considering the load deflection and moment rotation effect. For the same dynamic analysis may also be carried out.

II. Central opening with different percentage was concerned in this study. The opening with different location may provide valuable information

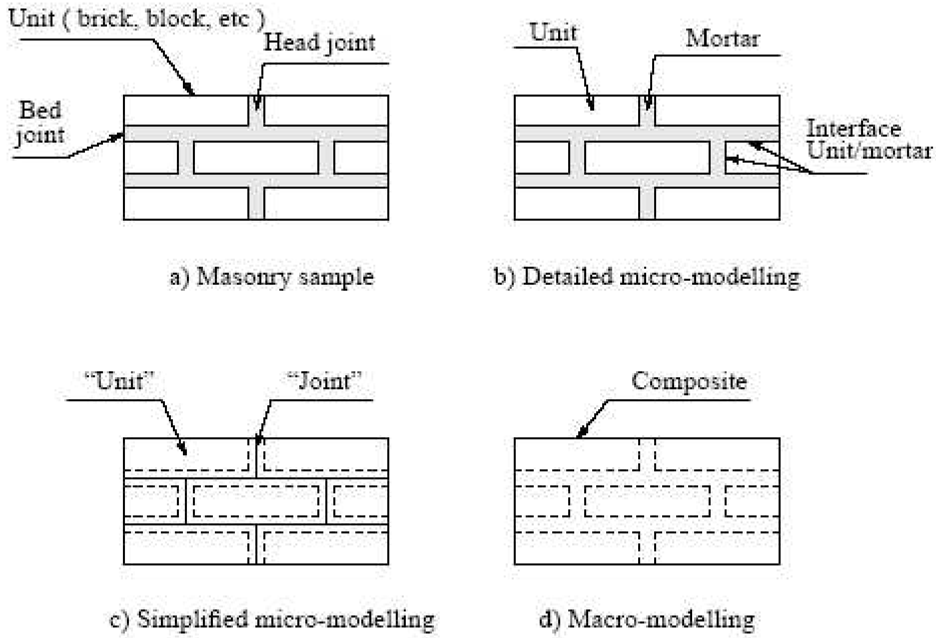
III. Study on irregular pattern of brick infill may provide useful information.

<u>Appendix A</u>

LIST of FIGURES

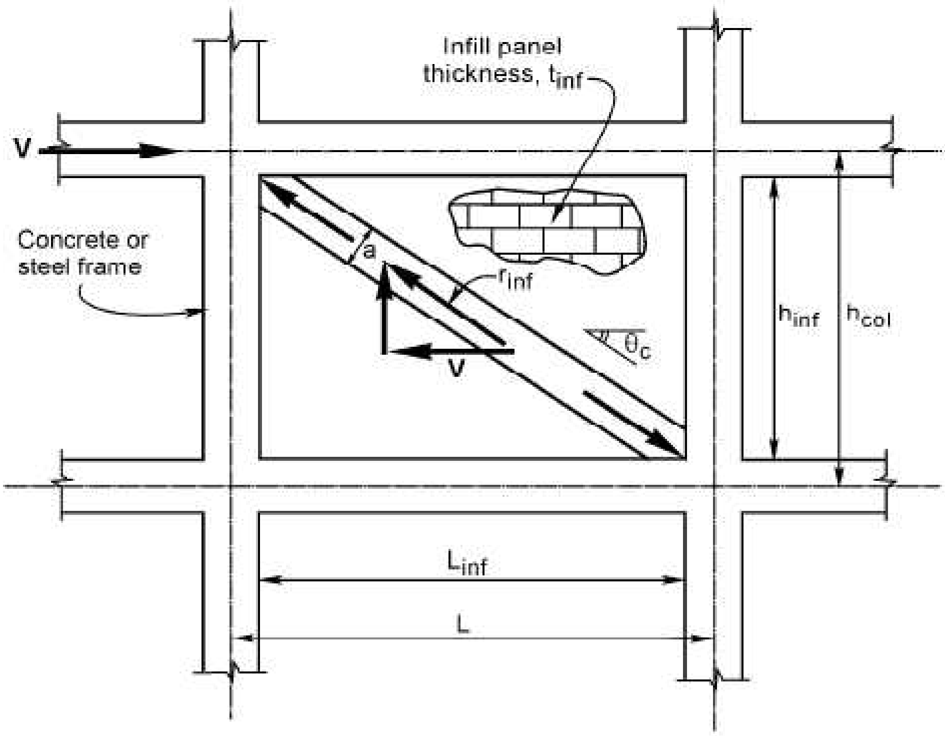
Typical collapse mechanism of infilled structures (T.d Dottorato)

<u>Figure-A1</u>

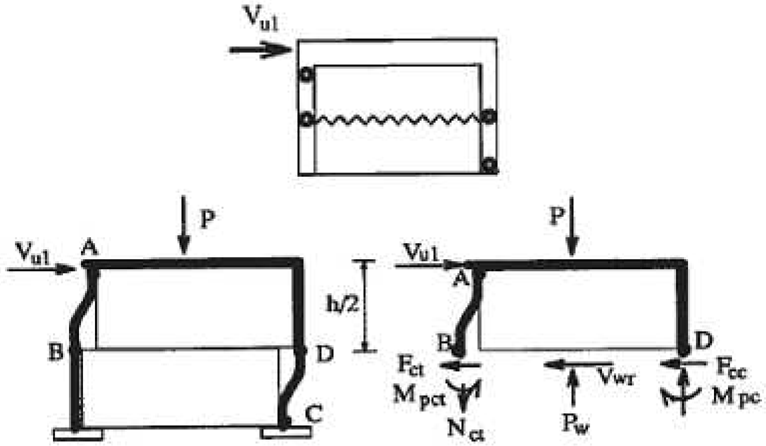


Different modeling techniques of masonry wall adopted in literature

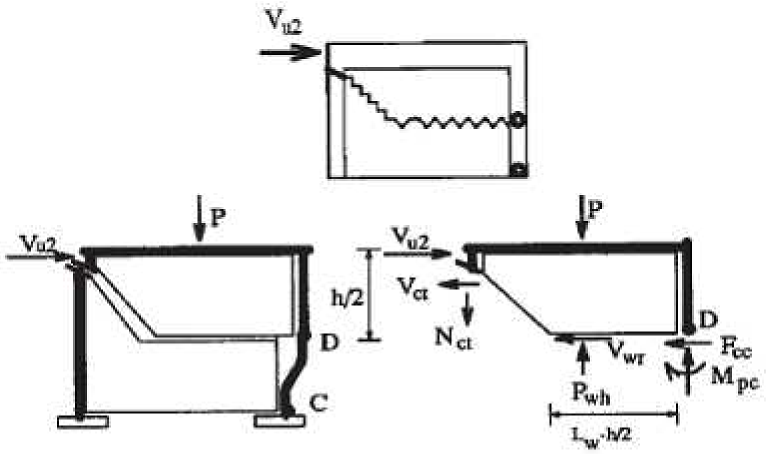
Figure-A2



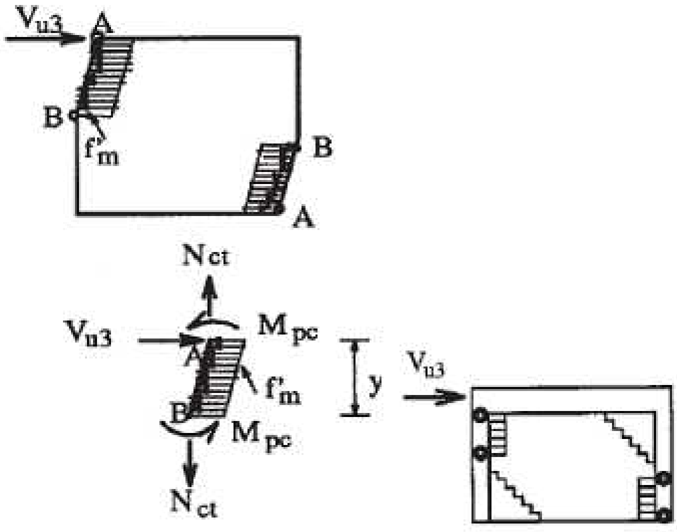
Modeling the infill panel as an equivalent strut (FEMA 306)
Figure-A3



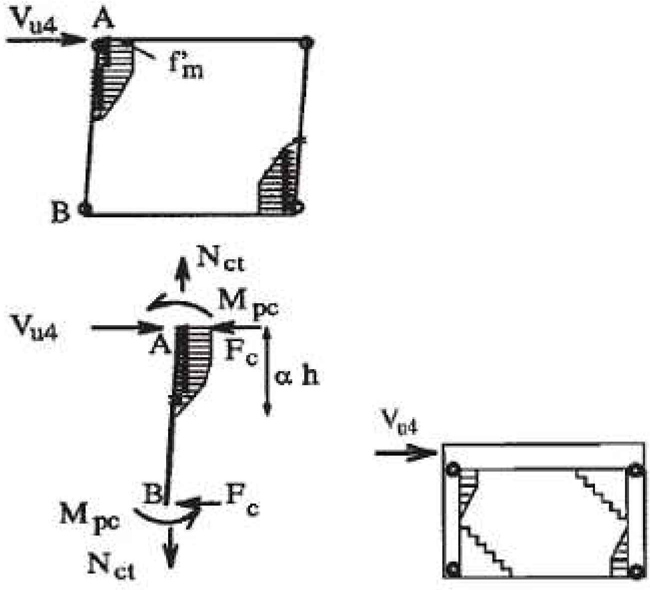
Sliding Failure
Figure-A4



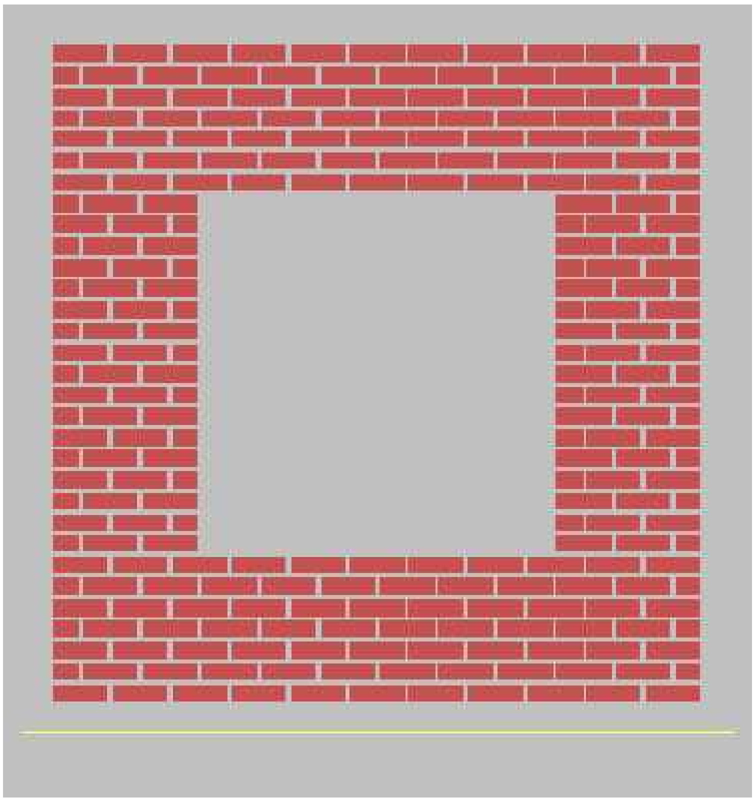
Shear Failure
Figure-A5



Crushing Failure
Figure-A6

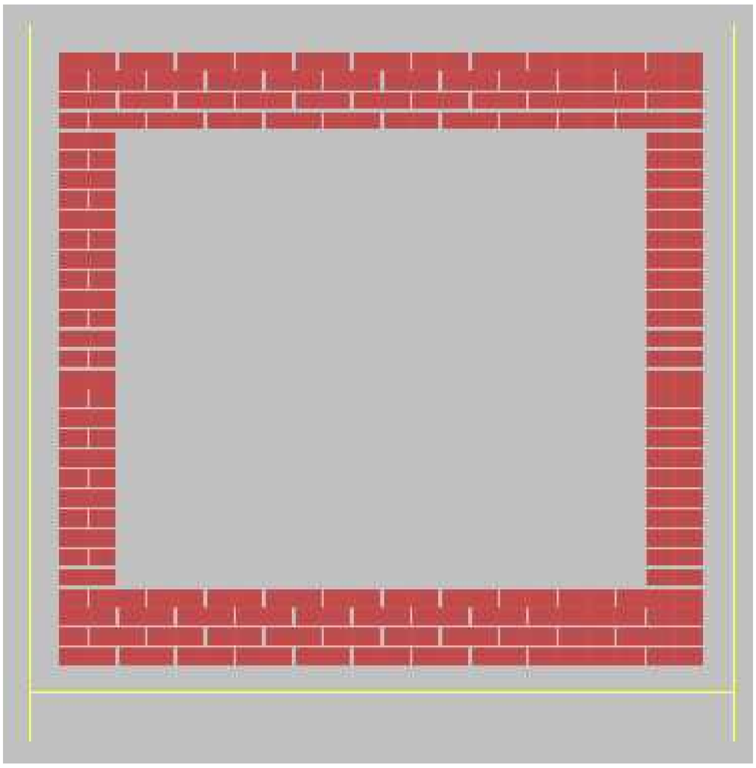


Compressive Failure
Figure-A7



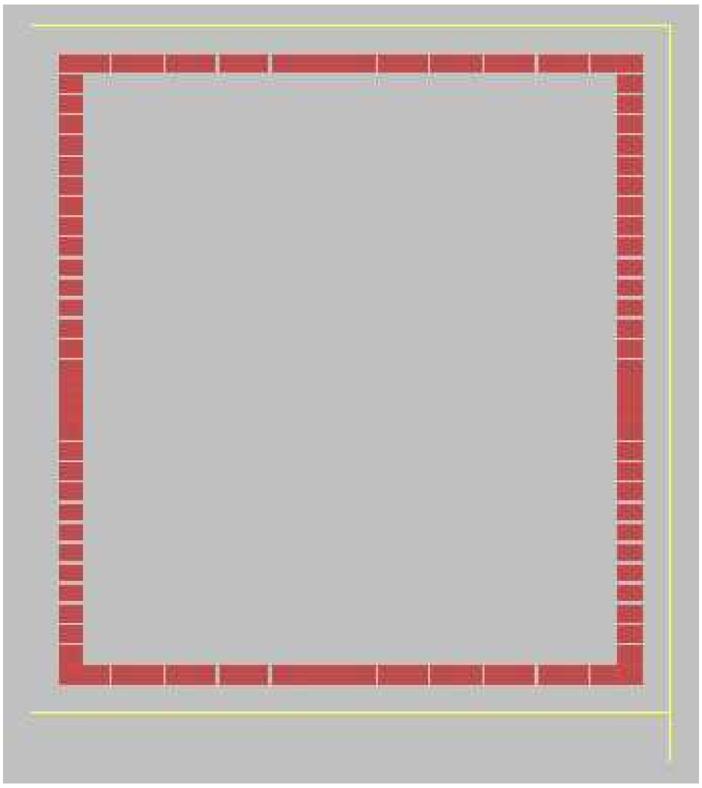
Infill wall model with 30% Opening

Figure-A8



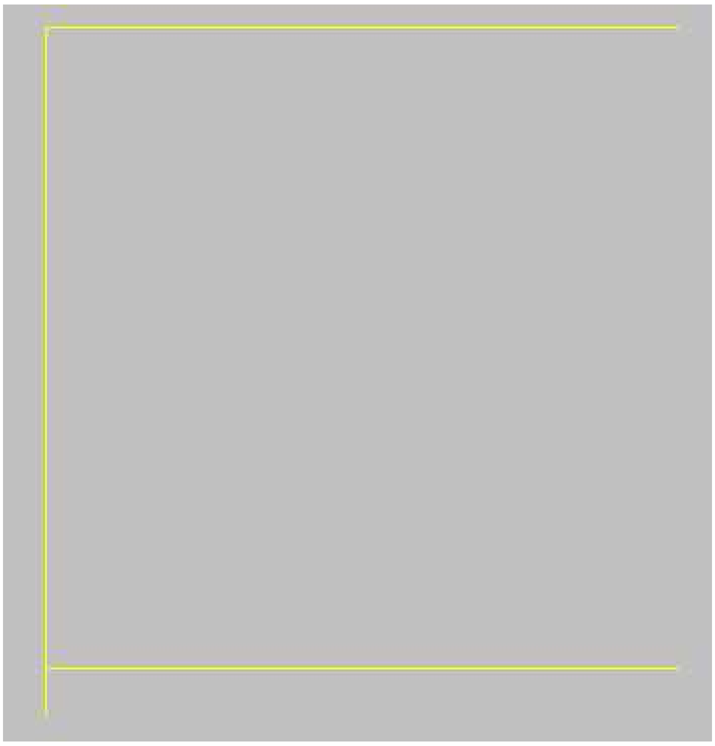
Infill wall model with 60% Opening

Figure-A9



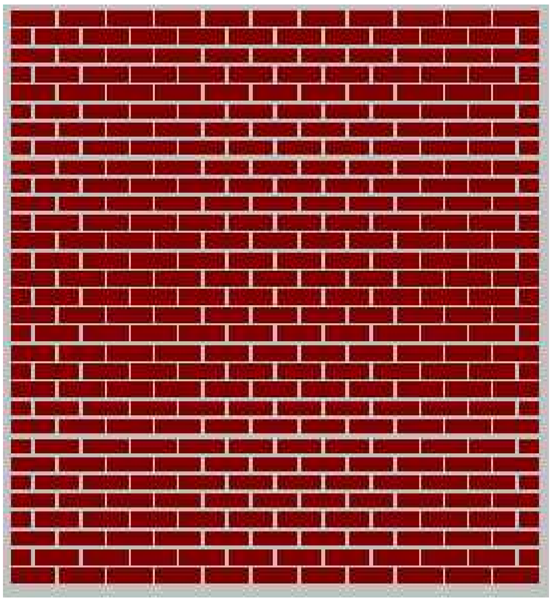
Infill wall model with 90% Opening

Figure-A10



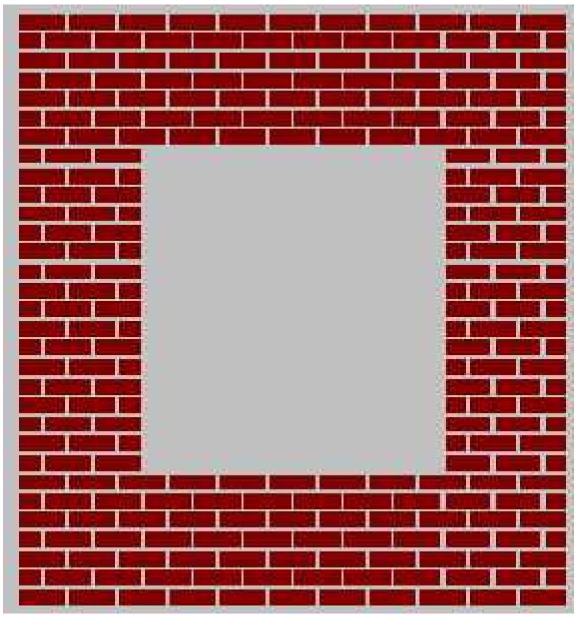
Infill wall model with 100% Opening

Figure-A11



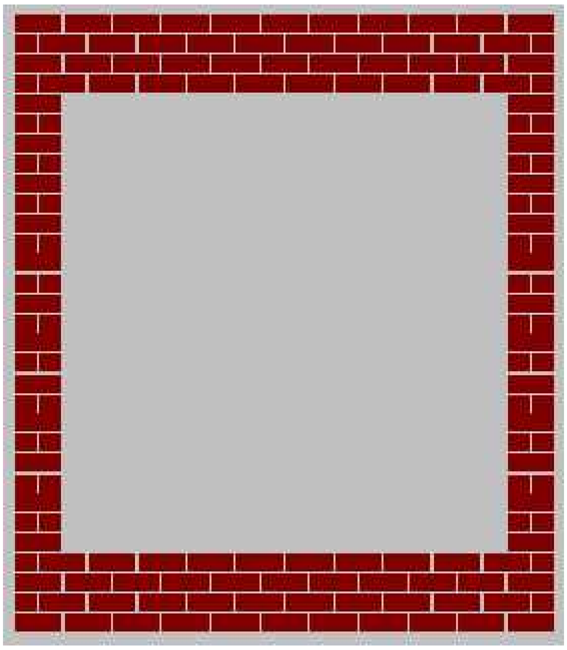
Full wall model with out Opening

Figure-A12



Wall model with 30% Opening

Figure-A13



Wall model with 60% Opening

Figure-A14

APPENDIX - B

OUTPUT GRAPHS AND CHARTS

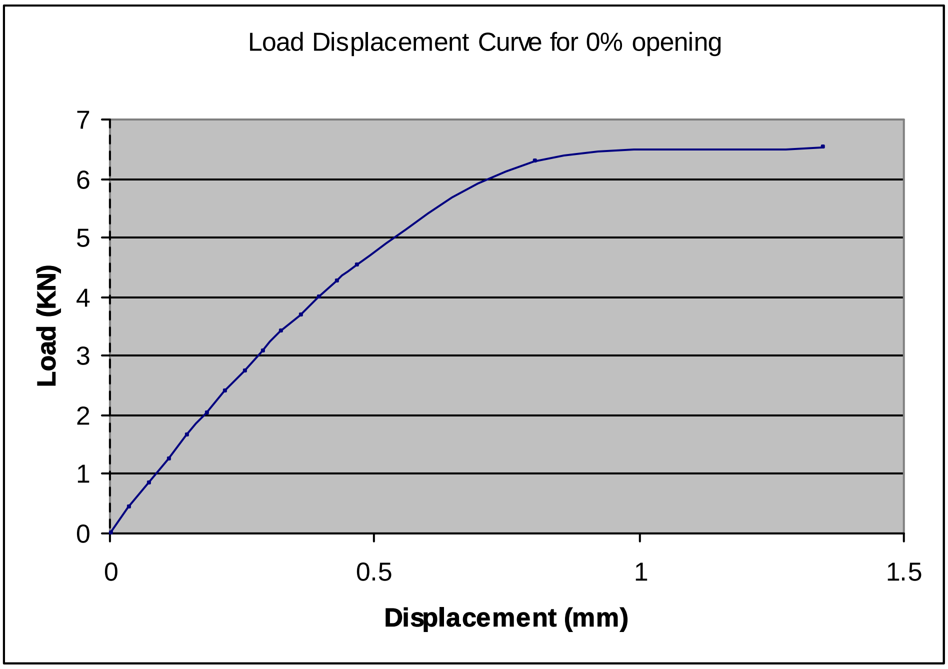

Load Displacement Curve for 0% opening
Load (KN)
7
6
5
4
3
2
1
0
0
0.5
1
1.5
Displacement (mm)

Fig-B1

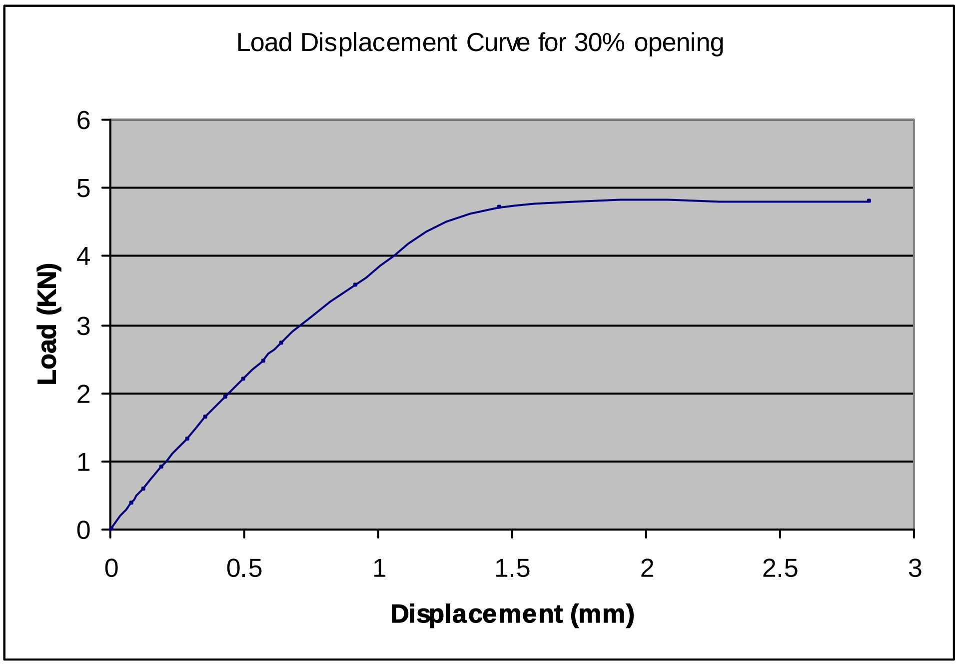

Load Displacement Curve for 30% opening
Load (KN)
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
Displacement (mm)

Fig –B2

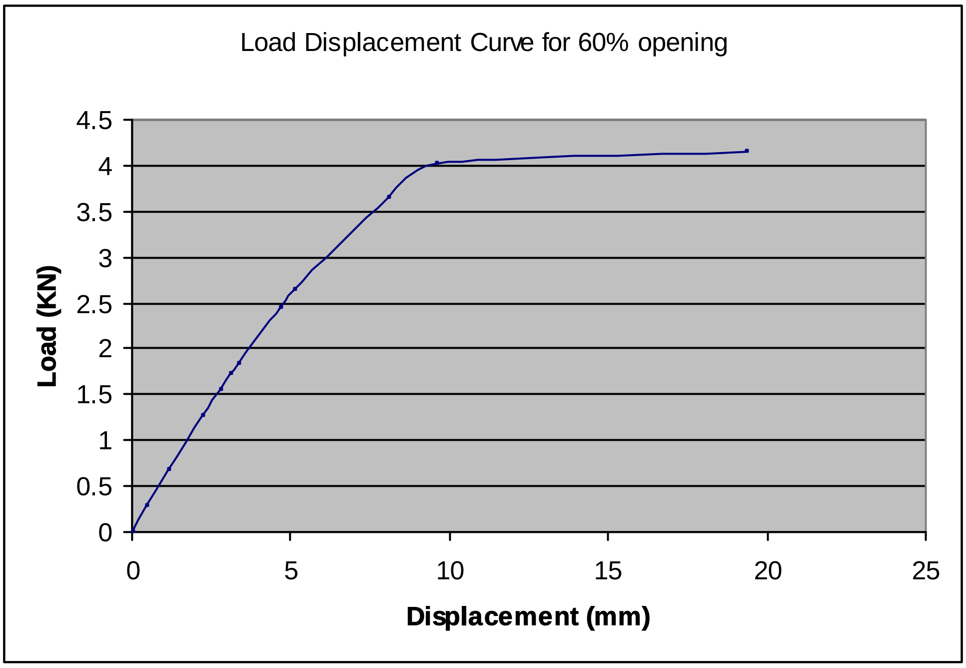

Load Displacement Curve for 60% opening
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Load (KN)
0
5
10
15
20
25
Displacement (mm)

Fig-B3

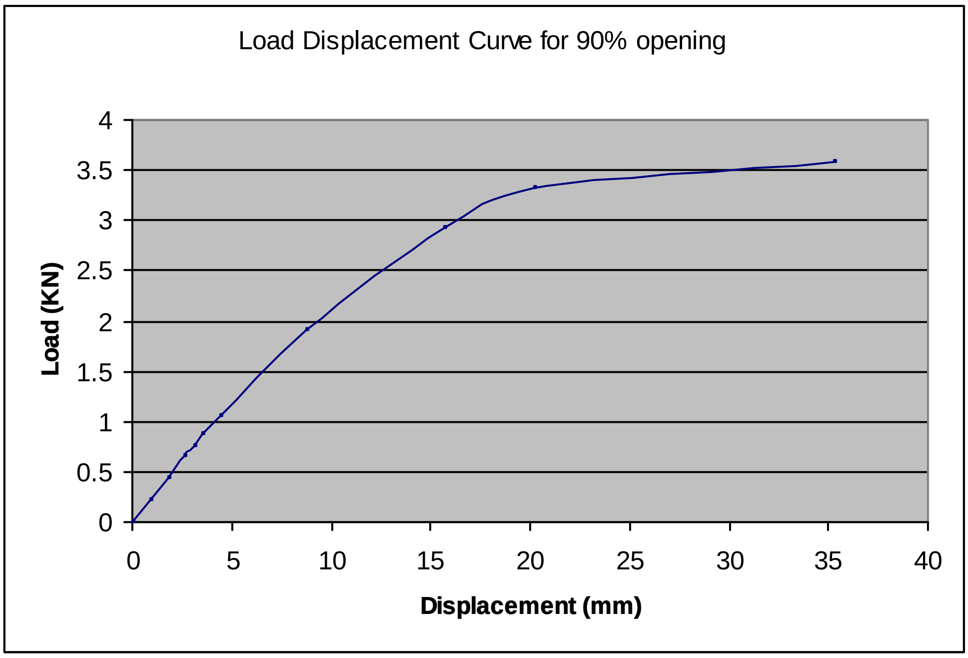

Load Displacement Curve for 90% opening
4
3.5
3
2.5
2
1.5
1
0.5
0
Load (KN)
0
5
10
15
20
25
30
35
40
Displacement (mm)

Fig-B4

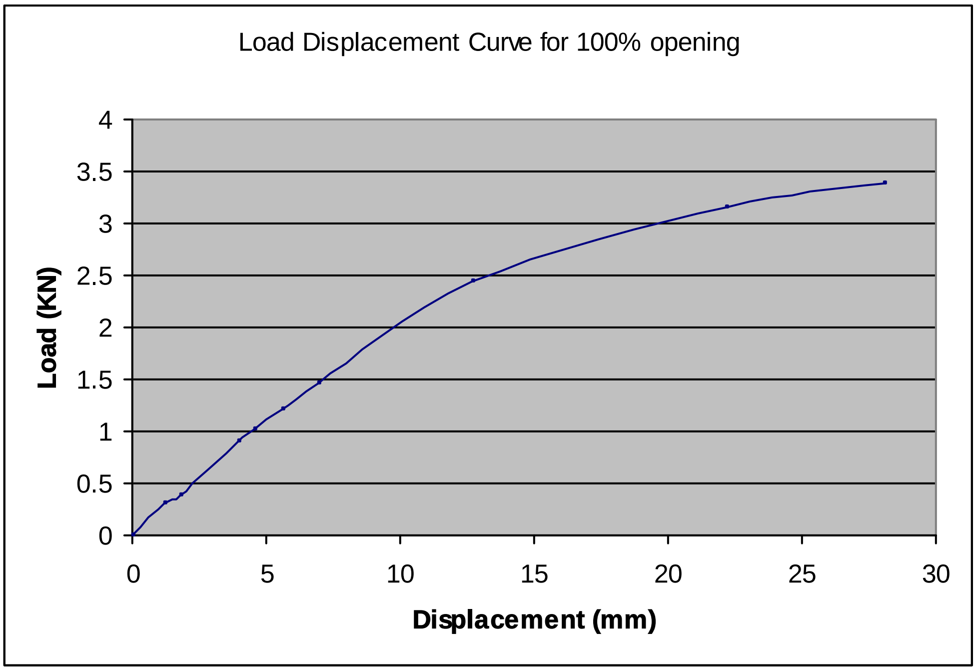

Load Displacement Curve for 100% opening
Load (KN)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
Displacement (mm)

Fig-B5

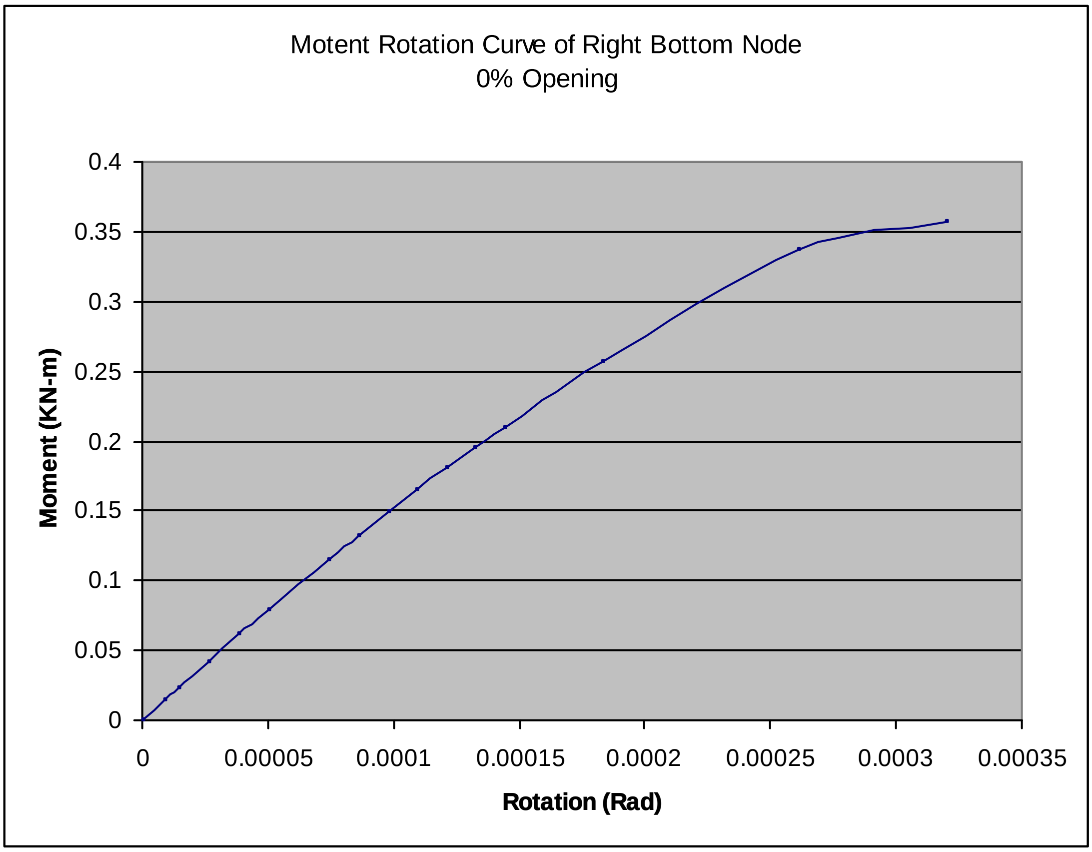

Motent Rotation Curve of Right Bottom Node
0% Opening
Moment (KN-m)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.00005
0.0001
0.00015
0.0002
0.00025
0.0003
0.00035
Rotation (Rad)

Fig-B6

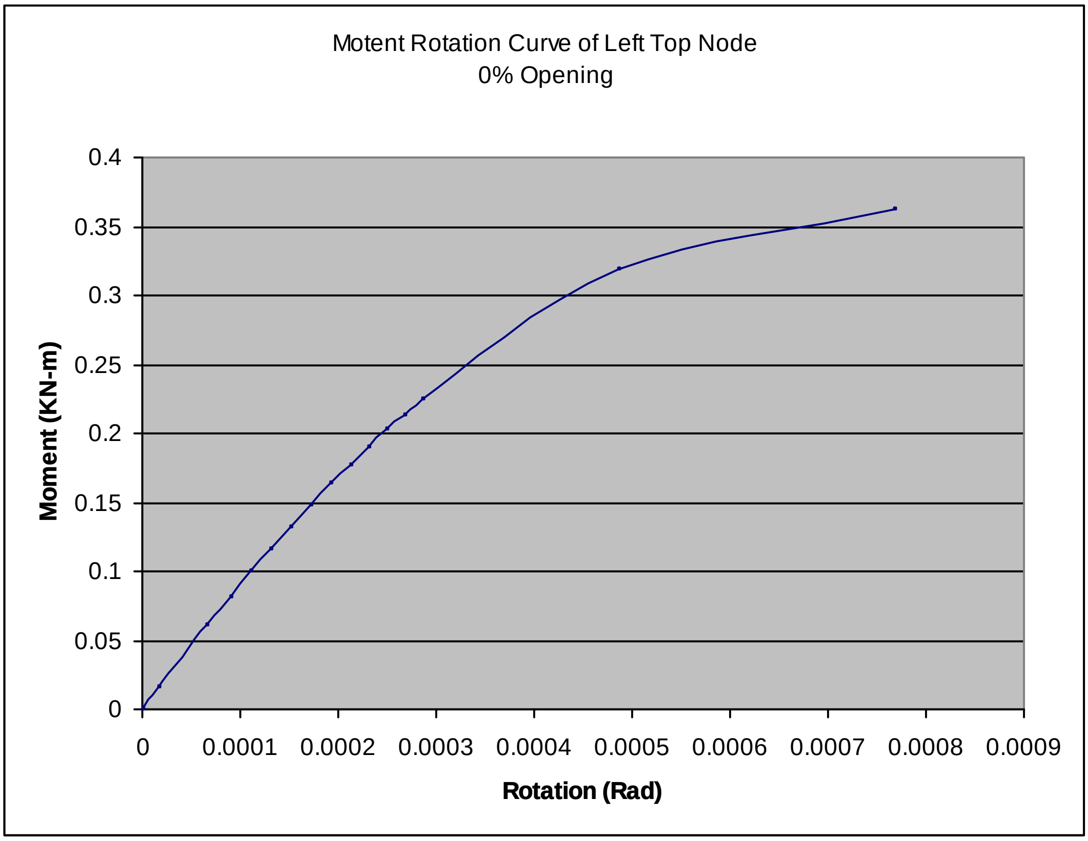

Motent Rotation Curve of Left Top Node
0% Opening
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Moment (KN-m)
0
0.0001
0.0002
0.0003
0.0004
0.0005
0.0006
0.0007
0.0008
0.0009
Rotation (Rad)

Fig-B7

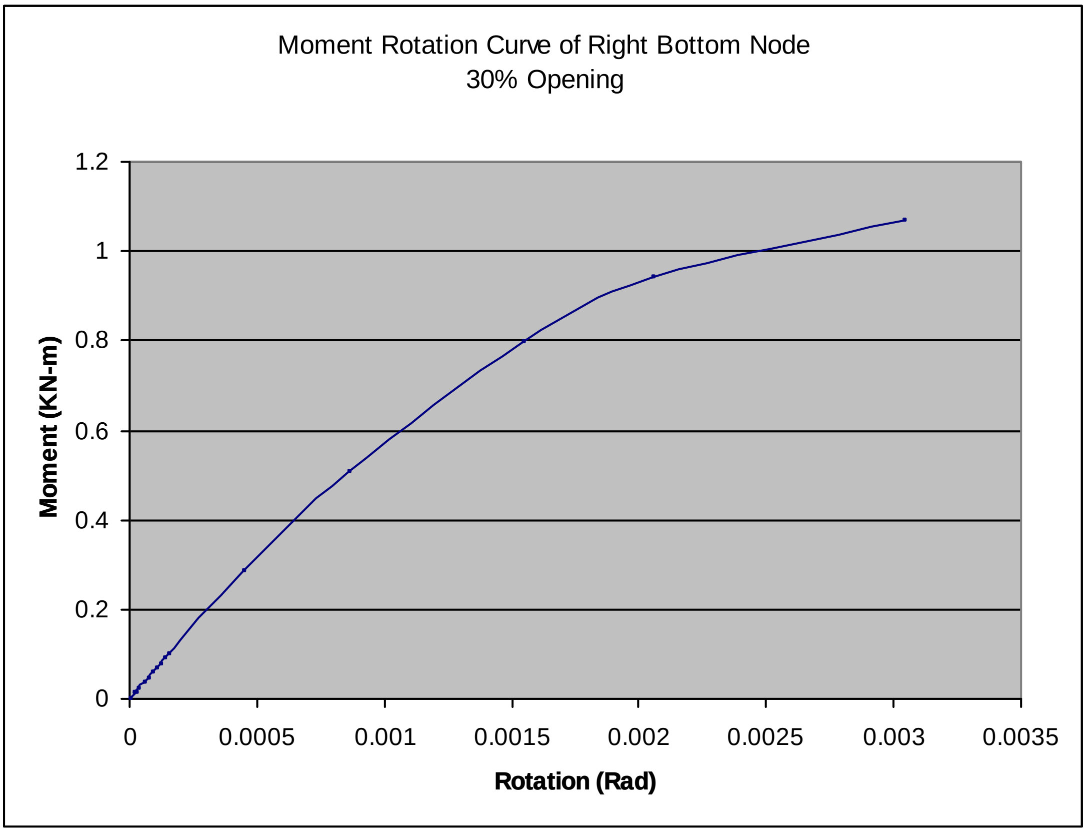

Moment Rotation Curve of Right Bottom Node
30% Opening
1.2
1
0.8
0.6
0.4
0.2
0
Moment (KN-m)
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
Rotation (Rad)

Fig-B8

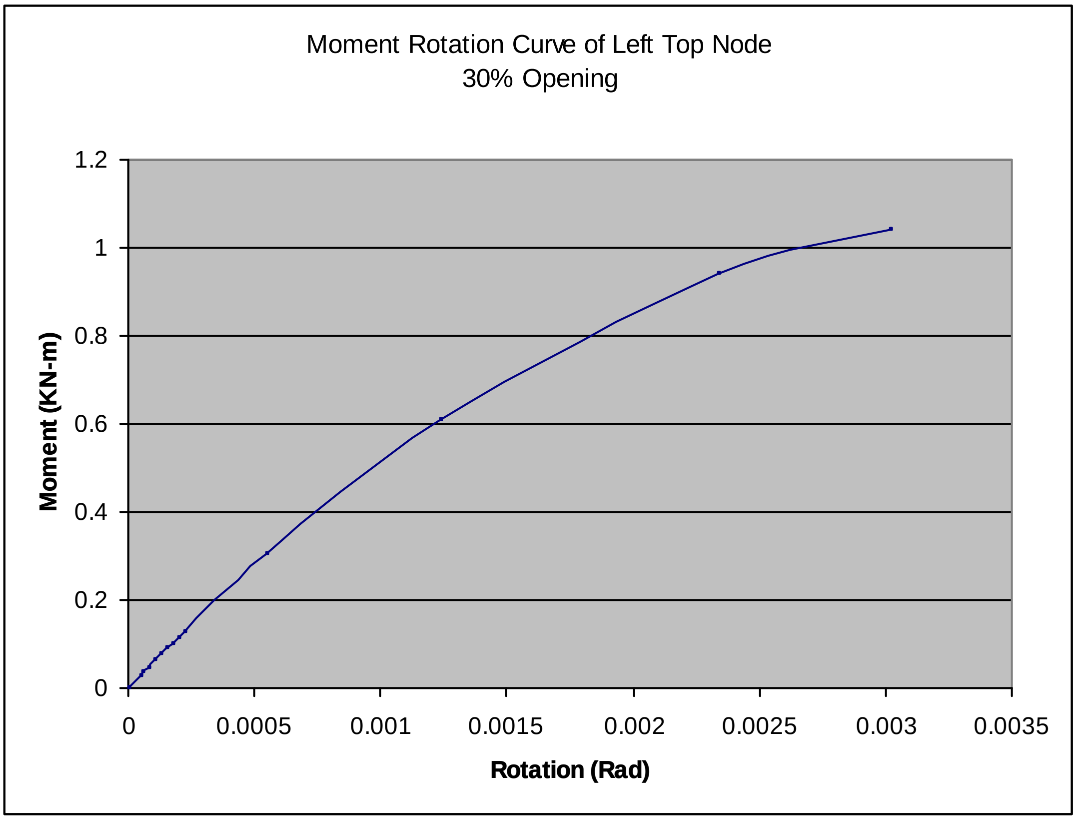


Fig-B9

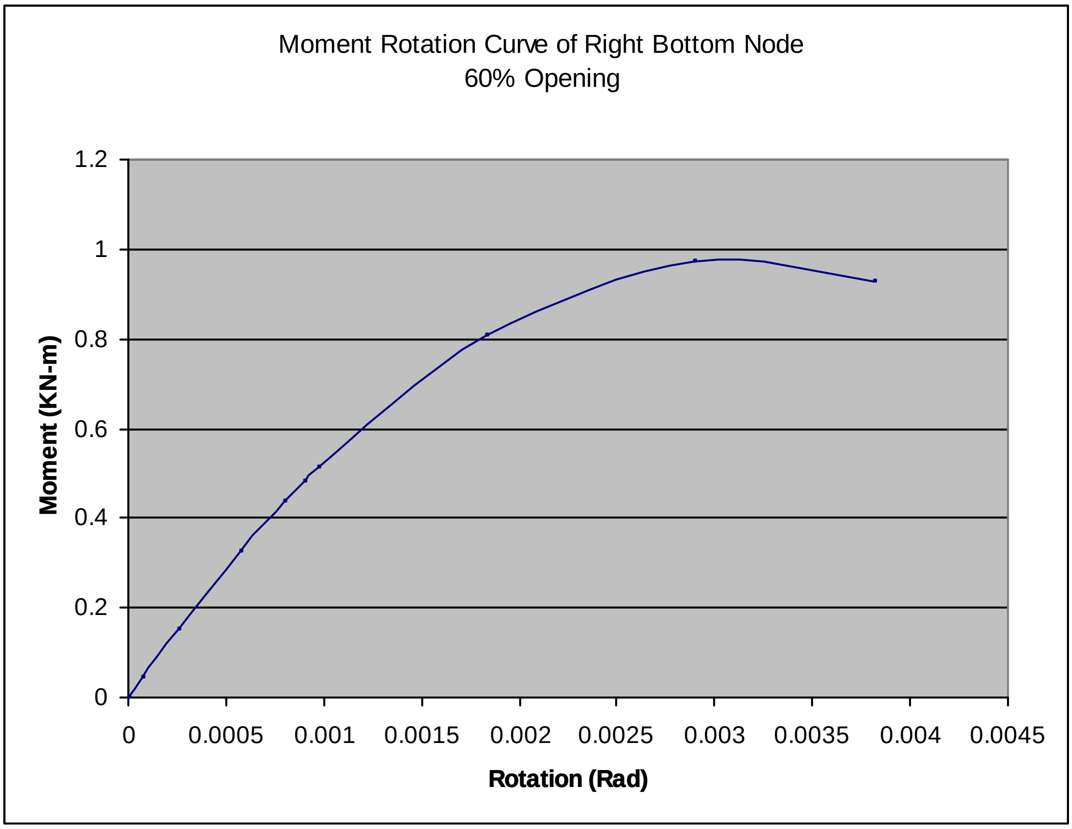


Fig-B10

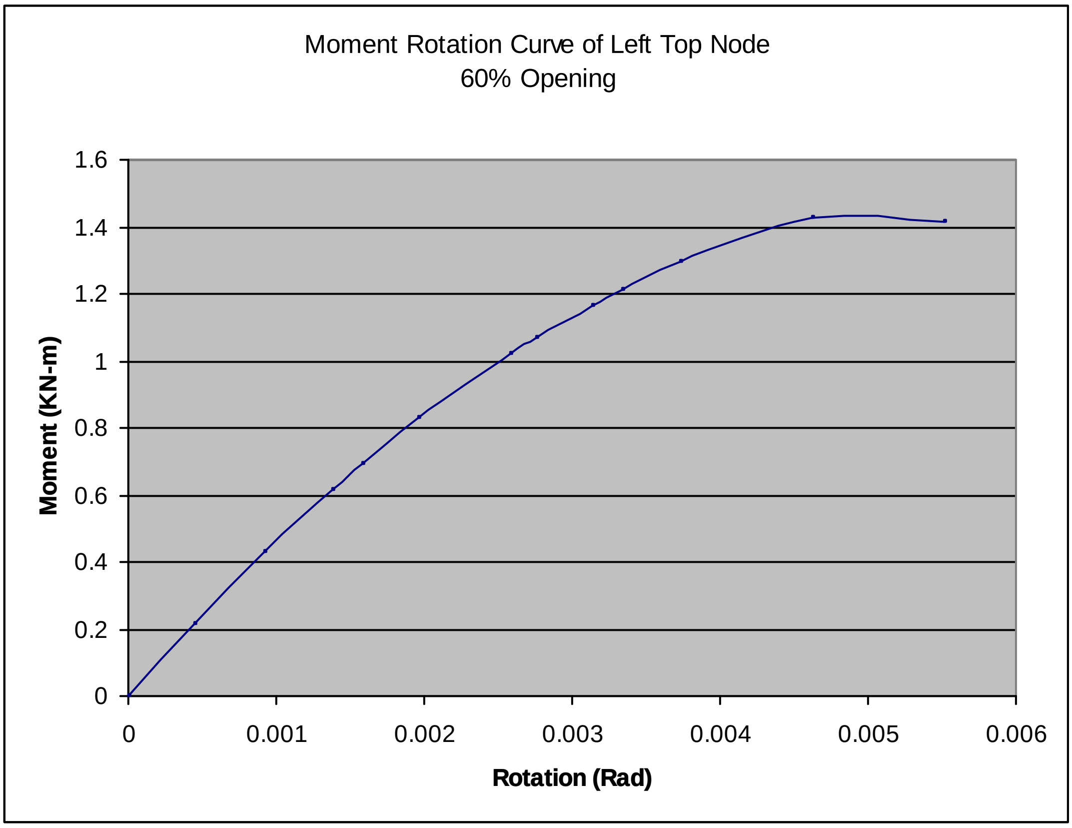


Fig-B11

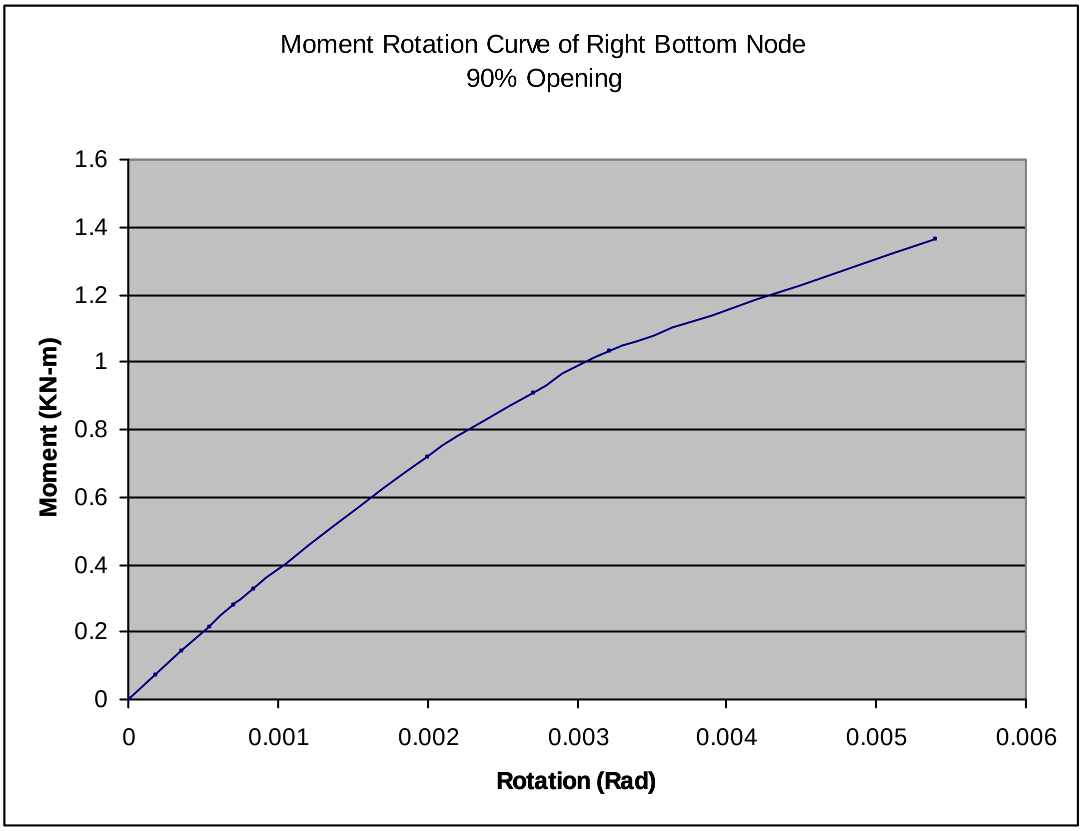


Fig-B12

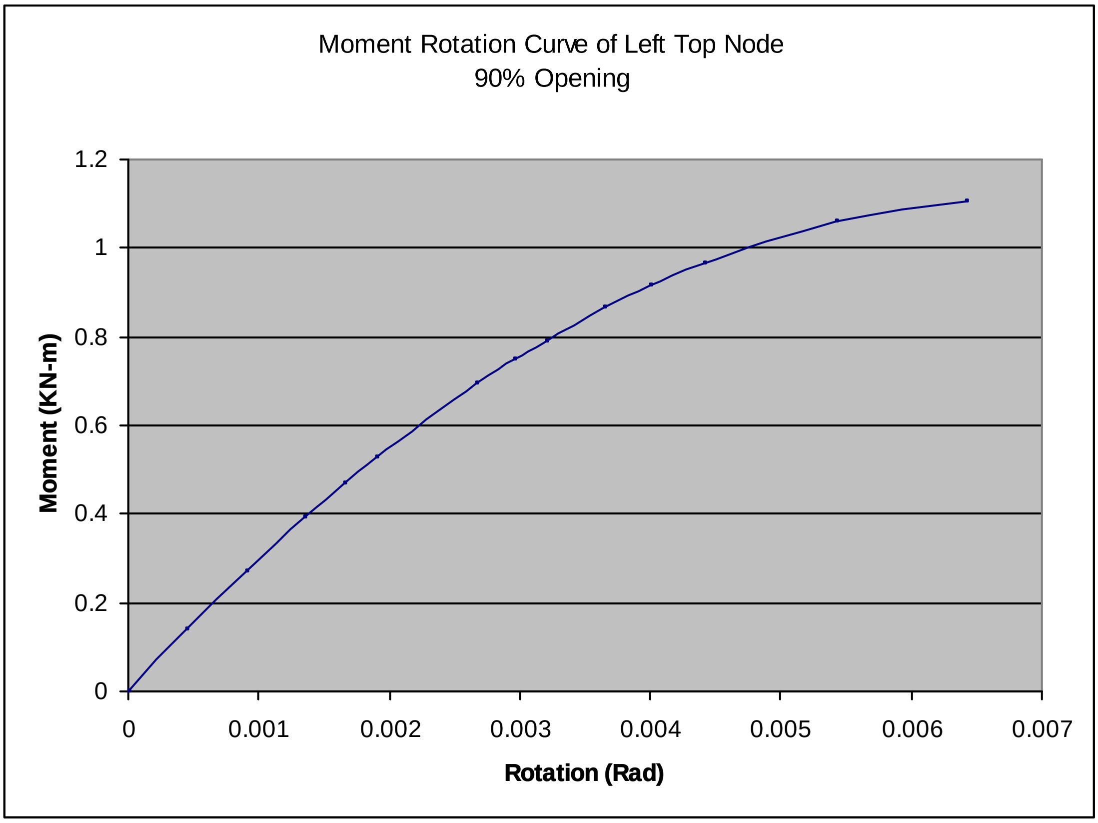


Fig-B13

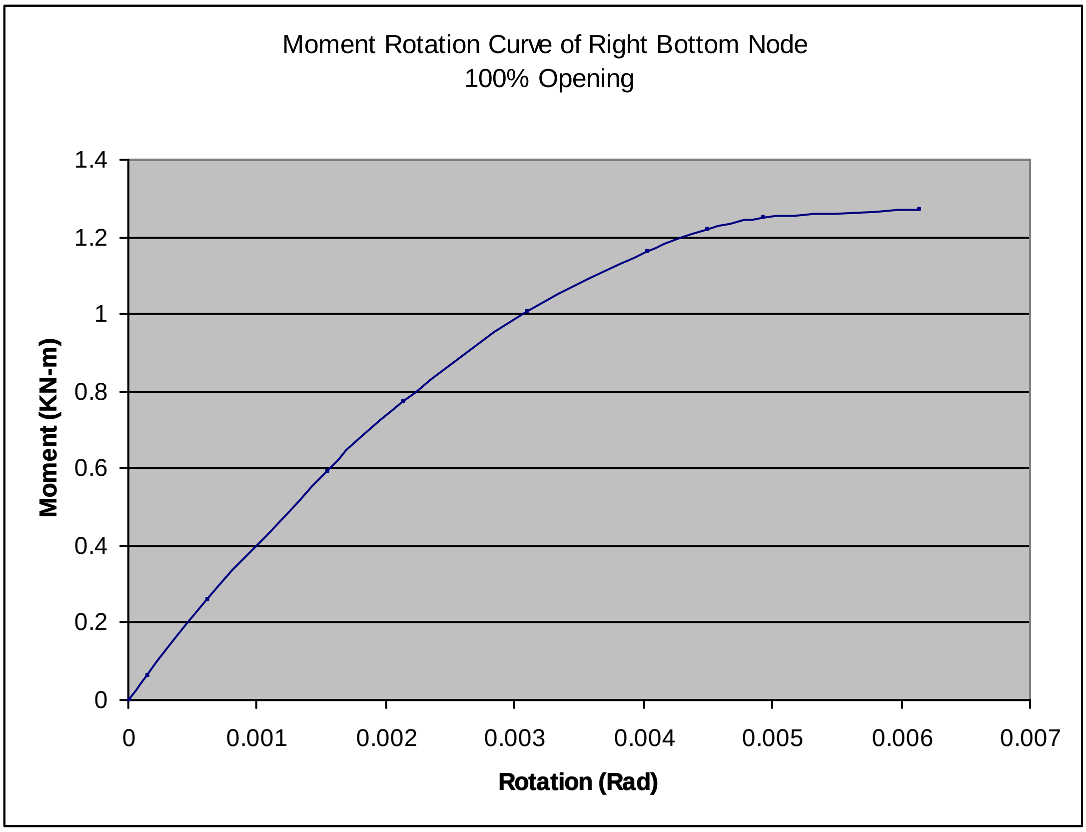


Fig-B14

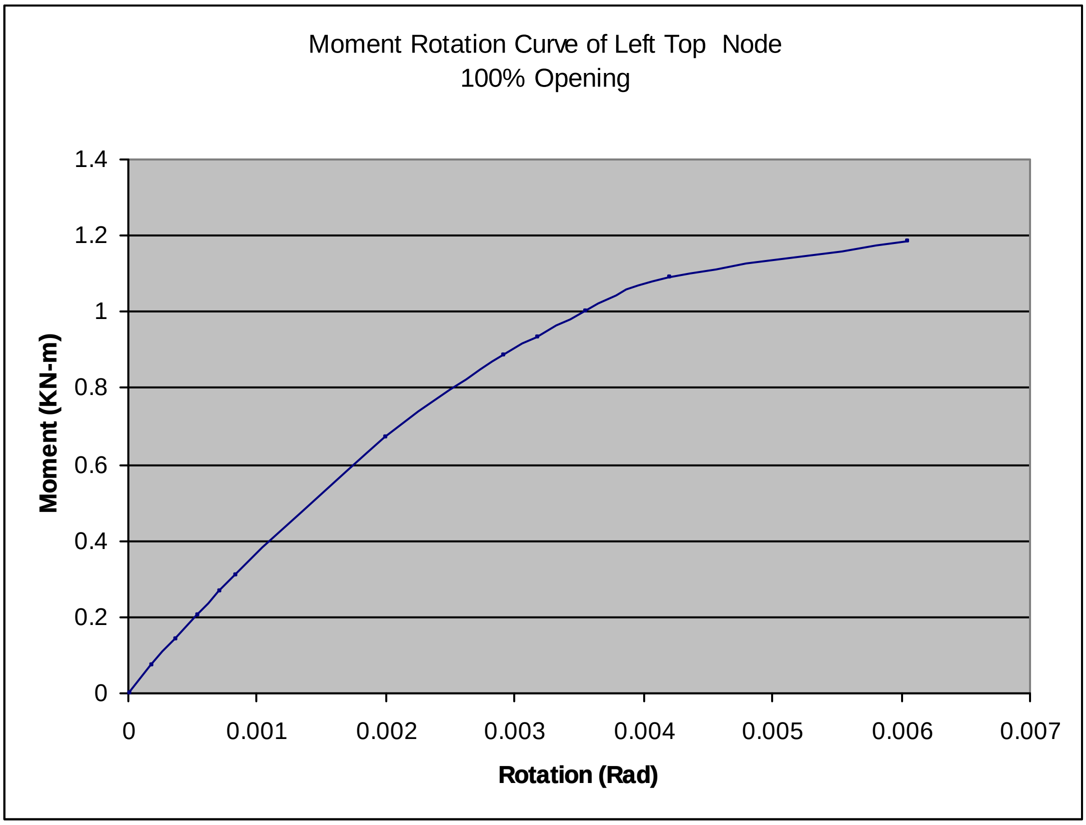


Fig-B15

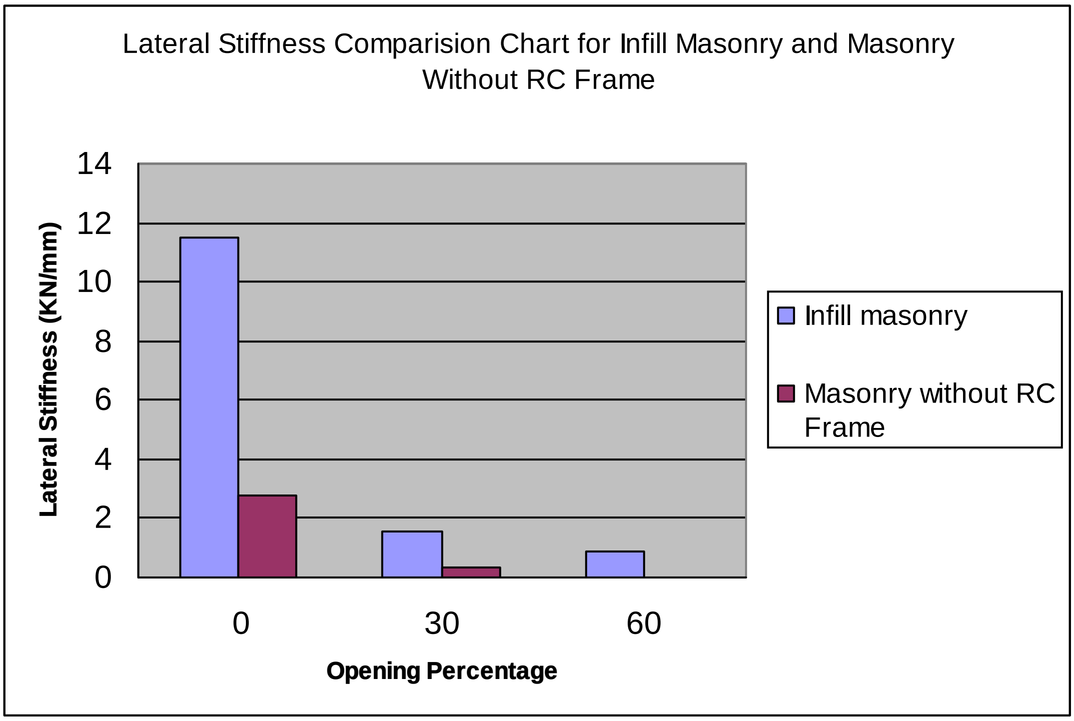


Fig-B16

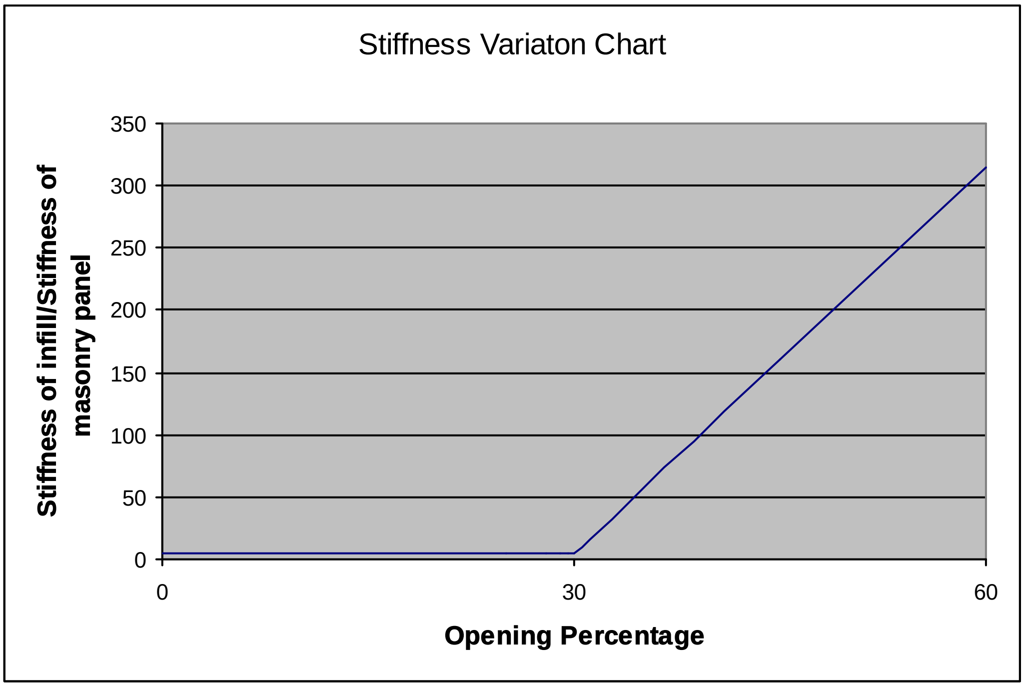

Stiffness Variaton Chart
Stiffness of infill/Stiffness of masonry panel
350
300
250
200
150
100
50
0
0
30
60
Opening Percentage

Fig-B17

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