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Masonry In-Fill Modeling and Its Influence on RCC Framed Structure under Lateral Loads

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Abstract:
Design of masonry infill is an issue that has attracted the attention of several researchers in the past, both from the experimental and analytical points of view. Many buildings are constructed with masonry infill walls. Masonry infill walls are widely used as partitions worldwide. For many years the infill walls formed an integral part of buildings. Field evidence has shown that continuous infill masonry walls can help reduce the vulnerability of a reinforced concrete structure. In design of new buildings, the structural behavior of masonry elements is of interest mostly in case of infill frames. The masonry infill frames show larger ductility than isolated masonry walls. The parametric study on masonry infill framed structures lead to propose a strut-and-tie model that provides a novel simplified expression for the failure of infill walls belonging to frames subjected to lateral loading. In this study, an effect of nonstructural masonry infill on the diagonal strut model is adopted for modeling masonry infill. The most simple equivalent frame system with reduced degrees of freedom is proposed for handling multi-story multi-bay in-filled frames. The frame is composed of a homogenized continuum for the reinforced concrete members braced with unilateral diagonal struts for each bay, which are only activated in compression. In this project, the linear static analysis is used to evaluate the effect of brick-infill panels on the progressive potential of a RC building. The present computational study aims at developing finite element modeling techniques for Reinforced-concrete building frames *with* and *without* masonry infill wall under lateral load performance assessment. A 2 Bay-10storied RCC framed structure is used in this investigation using a powerful Finite Element Software ANSYS (version 10.0).

Keywords: Reinforced cement concrete, Bending Moment, Degree of freedom, Axial Force, Shear Force.

I. INTRODUCTION

Modern design philosophy of Civil Engineering structures under extreme loading conditions aim to ensures fulfillment of both structural as well as functional requirements and predicts its behavior. Prediction of this behavior ultimately requires extensive experimentation or advanced analytical techniques. In many cases, analytical methods are more economical and expedient than laboratory or field testing. Many a number of researchers have extolled the potential of using finite element analysis to predict building frame response with reinforced-concrete frames. In many countries reinforced concrete frames are in-filled by brick masonry panels. Although the infill panels significantly enhance both the stiffness and strength of the framed structure. But, the contribution of masonry infill is often not taken in to account in the analysis and design, mainly because of the lack of knowledge of the RCC behavior of the frame and the infill. However, extensive experimental and semi-analytical investigations have been made. Recently, it has been shown that there is a strong interaction between the infill masonry wall and the surrounded frame as detailed below.

a. Behavior of a RCC frame depends not only on the relative stiffness of the frame, the infill and the frame geometry; but also on strength properties of the masonry.
b. Considerable reduction of the probability of collapse; even in cases of defective in-filled framed structures, if designed properly.
c. Computational complexity: The particulate infill material and the ever-changing contact conditions along its interface to concrete constitute additional sources of analytical burden. The real behavior of an in-filled frame is a complex statically indeterminate problem according to Smith.

d. Structural uncertainties: The mechanical properties of masonry, as well as its wedging conditions against the internal surface of the frame, depend strongly on local construction conditions.
e. The non-linear behavior of in-filled frames depends on the separation of masonry infill panel from the surrounding frame.

Development of commercial finite element codes, which provide a unique program interface to analyze a system, has helped practitioners attain a better appreciation for both the usefulness and limitations of finite element modeling of reinforced concrete. Evaluation of specific applications, such as reinforced-concrete building frames, can be handled using these codes. However, to identify possible modeling discrepancies and to verify the accuracy of these computer codes, results from nonlinear finite element analyses need to be compared with those from actual experiments. This may be achieved only if the analysis can account realistically for the material and geometric properties of the various components of a structure and the interaction among them. In the present study, the ANSYS finite element program is used to simulate the behavior of reinforced concrete beam with masonry wall. This model can help to confirm the theoretical calculations as well as to provide a valuable supplement to the laboratory investigations of behavior. An essential factor in making a sound decision is knowledge of the strength of the building in its existing form.

OBJECTIVE AND SIGNIFICANCE

In order achieve first objective, finite element modeling of RCC frame with and without masonry infill and find the deformations of high raised buildings. This thesis is aimed at utilizing finite element modeling techniques to evaluate the Performance of reinforced concrete frame with and without masonry wall. A specific objective of the analytical evaluation included the development of a finite element model that could correctly represent global building behavior and accurately predict displacements, stiffness, shear force and bending moment in the RCC frames. The aims of this study, the following objectives are fulfilled:

1) Perform a comprehensive review on the reinforced concrete frame with masonry wall.
2) Establish a methodology for applying computer modeling to reinforced concrete beams and buildings.
3) Compute deformations, stiffness, shear force and bending moment.
4) Examine the structural behavior of RCC frame with masonry wall.

PURPOSE AND SCOPE

The primary objective of this study was to establish and demonstrate a convenient, reliable, and accurate methodology for analyzing reinforced-concrete structures with particular emphasis on reinforced-concrete building frames with masonry wall. Finite element method (FEM) models were developed to simulate the behavior of RCC frame with masonry wall using the ANSYS program. Modeling simplifications and assumptions developed during this research are presented.

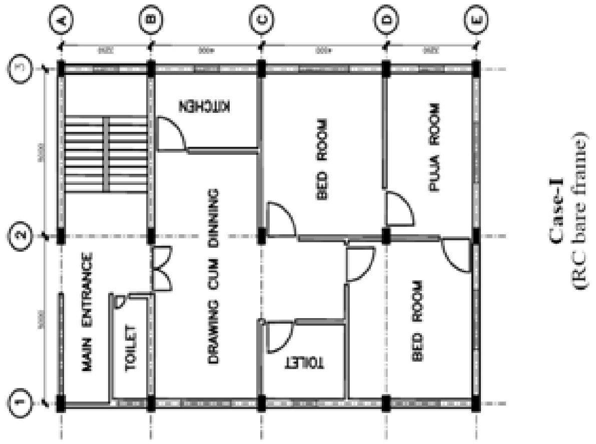


Figure.1. Plan of an RCC 2-Bay-10 Storied Structure

INTRODUCTION OF MASONRY WALLS

Masonry is an integral component of building from ancient to modern history. Masonry is one of the most common building medium used for construction. Masonry may be defined as the construction of building units bonded together with mortar. In brick masonry bricks are used as the building units. Masonry walls are used almost in all the buildings. They may be either load bearing walls or partition walls. Unless otherwise specified, a wall may be defined as vertical load-bearing member, the width (i.e. length) of which exceeds four times of thickness. Load bearing walls are structurally efficient when the load is uniformly distributed and when the structure is so planned that eccentricity of loading on the wall is small as possible.

Load bearing wall:

A wall carrying a vertical load in addition to its own weight is called load bearing wall. All conventional walls which support roofing or other load transfer components of a structure are examples of Load bearing wall.

Non-Load bearing walls: Walls which carry their own load but do not carry any imposed load bearing walls. Partition walls are examples of non load bearing walls.

IMPORTANCE OF MASONRY STRUCTURES

The application of structural engineering principles to design of masonry structures in recent times has resulted in the increased use of structural masonry especially for multi storied buildings. While the design based on thumb rule results in thick section, the applications of principles of structural engineering results in slender sections. In India some load bearing structures of 4 to 5 storeys with one brick thick walls. Generally the masonry structures are designed such that no tensile stresses are developed in the cross section, the maximum compressive stress must be within the safe stress of the materials, the shear force is not greater than the natural friction between the masonry.

STABILITY OF MASONRY STRUCTURES

In order to ensure stability of masonry structures; the following requirements should be satisfied.

1. There should be no tension produced across the cross section due to eccentric loads, wind pressure or inclined thrusts.
2. The maximum compressive stress developed must be within the safe permissible stress for the material.
3. The shear force should not be greater than the natural friction between the masonry.
4. The restoring moment must be greater than the over turning limits.

SLENDERNESS RATIO FOR WALLS

As the masonry infill is effective along the compression diagonal. Where there is compression, there is a possibility of buckling. The phenomenon of buckling is governed by slenderness ratio. It is defined as the ratio of the effective height to the effective thickness of the wall or effective length of the wall whichever is less. The effective height of the wall is the height to be considered for designing the thickness of the wall and for determination of its slenderness ratio.

FINITE ELEMENT METHOD IN MODELING MASONRY INFLL

In this investigation, finite element method is used as a tool to simplify problem solving efforts by making use of its versatilities. Hence it is thought of appropriate to give salient features of Finite Element Method for the sake of completeness and benefit of reader. This chapter is exclusively meant for explaining the finite Element Method and principles involved as detailed below. Also, in this chapter, it is explained how masonry infill in RCC frame is modeled by verifying/ comparing the results from finite element analysis and experimental. Already available experimental results are made use of in the project. The finite element method overcomes the difficulty of the variational methods because it provides a systematic procedure for the derivation of the approximation functions. The method is endowed with two basic features, which account for its superiority over other competing methods. First; a geometrically complex domain of the problem is represented as a collection of geometrically simple sub domains, called finite elements. Second; over each finite element the approximation functions are derived using he basic idea that any continuous function can be represented by a linear combination of algebraic polynomials. With the rapid advancement of technology, the complexity of the problem to be dealt by a design engineer is also increasing. This scenario demand speedy, efficient and optimal design from an engineer. To keep pace with the development and ensure better output, the engineer today resorting to numerical methods. For problems involving complex shapes, material properties and complicated boundary conditions, it is difficult and in many cases intractable to obtain analytical solutions. Numerical methods provide approximate but acceptable solutions to such problems. The finite Element method (FEM) has now become a very important tool of engineering analysis. Its versality is reflected in its popularity among engineers and designers belonging to nearly all the engineering disciplines. It is not that these problems remained unproved before the finite element method came into vogue; rather this method has become popular due to its relative simplicity of approach and accuracy of results. Actually Finite Element Method was originated as a method of stress analysis. But today the applications are numerous. Now days, each and every design is developed through Finite Element Analysis. The various areas of applications include design of buildings and bridges, electric motors, heat engines, aircraft structures, spacecrafts etc. With the advances in Interactive CAD systems complex problems can be modeled with relative ease. Although the Finite Element Method was originally developed for structural analysis, the general nature of the theory on which it is based has also made possible its successful application for solutions of problems in other fields of engineering. Finite Element Method (FEM) has become one of the most widely used techniques, for analyzing mechanical loading characteristics in modern engineering components.

Traditional analysis techniques can only be satisfactory applied to a range of conventional component shapes and specific loading conditions. Unfortunately, the majority of engineering loading situations are not simple and straight forward therefore traditional techniques often need to be modified and compromised to suit situations for which they were not intended. The basic premise of the finite element method is that a solution region can be analytically modeled or approximated by replacing it with an assemblage of discrete elements. The Finite element method is a numerical technique for obtaining approximate solutions to a wide variety of engineering problems. Although originally developed to study stresses in complex frame structures, it has since been extended and applied to the broad field of continuum mechanics. The basic idea in Finite element Method is to find the solution of a complicated problem by replacing it with a simpler one. Since the actual problem is replaced, it is able to find only an approximate solution but not the actual solution. The power of Finite Element method resides principally in its versatility.

The body analyzed can have arbitrary shape, loads and support conditions. The mesh can mix elements of different types, shapes and physical properties. This great versatility is contained within a simple computer program. User prepared input data controls the selection of problem type, geometry, boundary conditions, element selection and so on. Another feature of finite element method is the close physical resemblance between the actual structural and finite element model. Although the name finite Element Method was given recently, the concept has been used several centuries back.

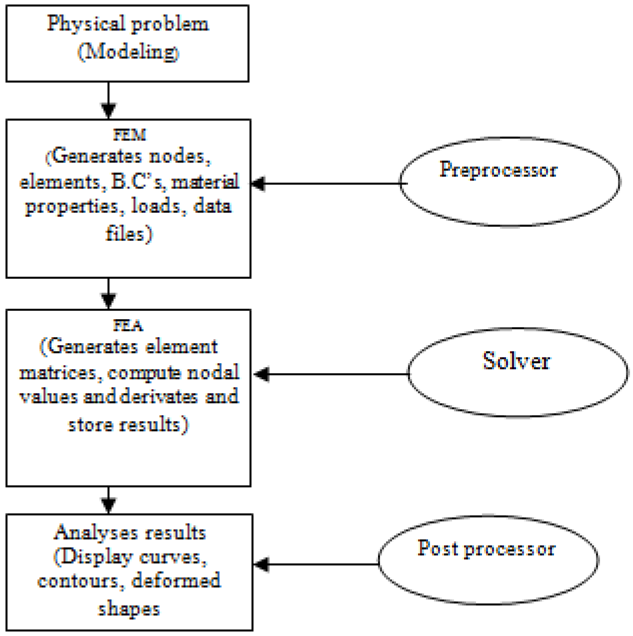


Figure.2. Flow chart about Finite Element Analysis procedure

MODELING OF MASONRY IN-FILL

In general structures are broadly classified as discrete structures and continuous. Trusses (pin jointed structures) and RCC framed structures (rigid jointed) comes under the category of discrete structures. In general RCC framed structures are analyzed and designed without considering the effect of masonry in to account. Analysis and design of rigid framed structure is based on the assumption that all loads on the structure is taken care of by the RCC frame itself, which is a conservative/ uneconomical. It is very obvious that masonry in-fill contribute a lot to stiffness of RCC framed structure; especially under lateral loads, like wind/earthquake/ blast loads. Researchers all over the world attempted in this direction leaving much scope for working in this area of research. Modeling of masonry in-fill has not been found attempted in the literature. Therefore, in this investigation, it is attempted to study with the following objectives.

1. To model the masonry in-fill.
2. To study the effect masonry in-fill on performance of RCC framed Structure.

A 2 BAY-10 STORIED RCC FRAMED STRUCTURE

In order to assess influence of the masonry in-fill and model it; a 2 bay-10 storied RCC plane frame is considered in this investigation. As masonry is brittle in nature; it is strong in compression and weak in tension. Therefore, tension in masonry is neglected. Under lateral loading; masonry in RCC framed structure is effective in compression along diagonal direction. The details of the structure considered are given below.

a) Details of RCC Frame structure:

Width of bay…………………………………..= 5 m
Height of each storey…………….…………….= 3 m
Height of stilt floor…………………………….= 4 m
Width of beam and column (b) ………………..= 300 mm
Depth of beam and column (d)……………….. = 450 mm
Moment of inertia of beam and column (I)= 2.278 x 10^9 mm^4
Elastic modulus of frame (E_f) ………… = 5000√25 N/mm^2
Elastic modulus of steel (E_s)……………....= 2 x 10^5 N/mm^2
Characteristic strength of concrete (f_{ck})……. …= 25 N/mm^2
Poison's ratio (μ)……………………………….. ...= 0.25
Load (w)…………………………………….. ……= 100kN

Element type…………………………..= Beam 2D Elastic 3.

b) Properties of masonry in-fill:

Thickness of the in-fill wall (t)…………………..…= 230 mm
Elastic modulus of masonry wall (E_m)…….= 13800 N/mm^2
Poison's ratio (μ)…………………………………..……= 0.15
Element type …………………..= Solid brick 8 node 45
Equivalent strut width…………………………..……= 0.90 m
Equivalent strut Element type…………….= link 2D spar 1

Under lateral loading on the RCC framed structures; part of masonry wall along one of its diagonal is effective under compression. Along the other diagonal, it is under tension which is considerably small and hence neglected. As there is no monolithic action between masonry wall and RCC frame, and masonry wall along the diagonal with limited width acts as strut. Therefore, the effective portion of the masonry along the diagonal is to be modeled as strut element. The frame considered in the study is shown in Figure 4.

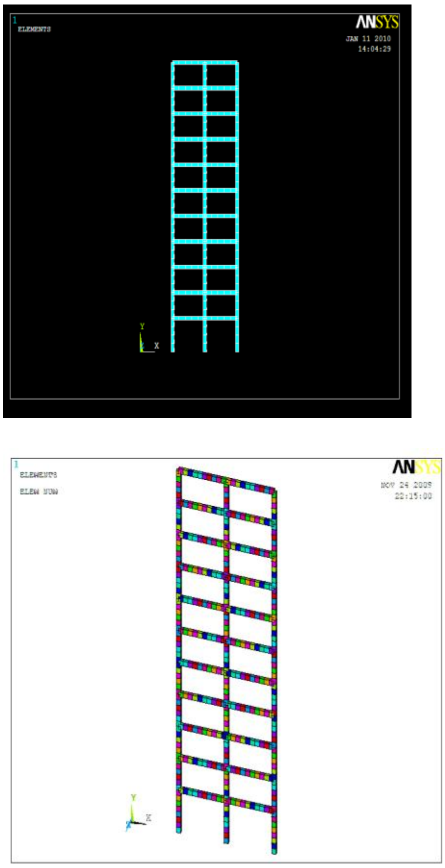


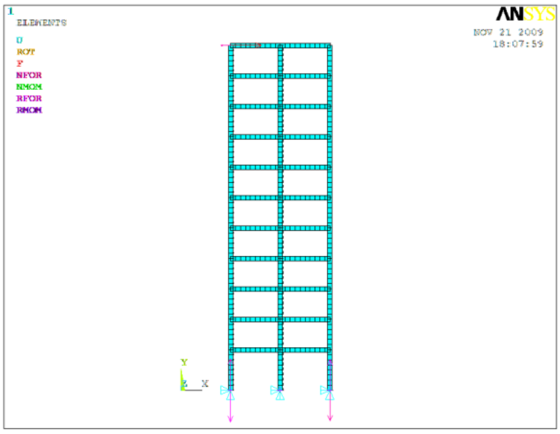
Figure.3. Bay-10 Storied RCC Framed structure modeled in ANSYS

ANALYSIS OF 2 BAY-10 STORIED RCC FRAMED STRUCTURE

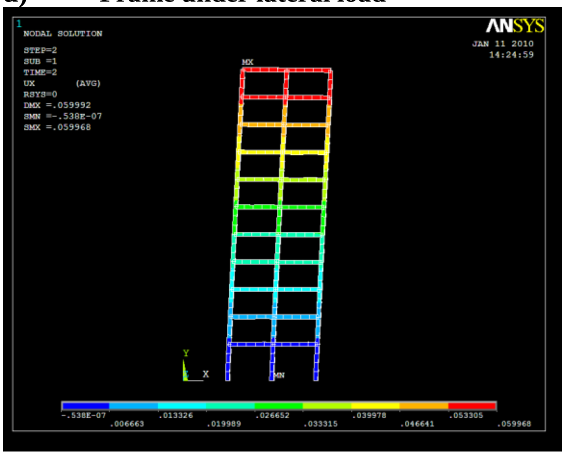
In order to study the effect of masonry in-fill on performance of an RCC framed structure under lateral loading; a 2 Bay-10 Storied RCC plane frame is considered in this study as shown in Figure 4. ANSYS software is used to analyze the frame both with and without masonry in-fill. Loading on the structure is kept constant throughout the analysis. Here, a point load of 100 kN is applied at the top of the frame for all cases. The study is carried

ANALYSIS OF 2 BAY-10 STORIED RCC FRAME WITHOUT MASONRY IN-FILL

A 2 Bay-10 Storied RCC plane frame without masonry in-fill (bare frame); as shown in Figure 4(a); is modeled in ANSYS software by using appropriate elements. A load of 100 kN is applied at the top of the frame. Then out of the structure in terms of deflections, forces in all the members are noted. Deflected profile of the frame is as shown in Figure 4(b). From the deflection at the top, where load is applied, stiffness of the structure is computed based on the definition of stiffness.



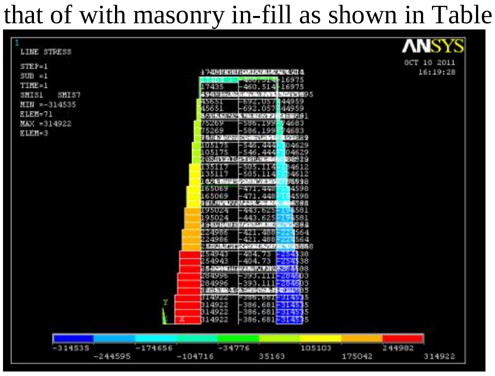
a) Frame under lateral load



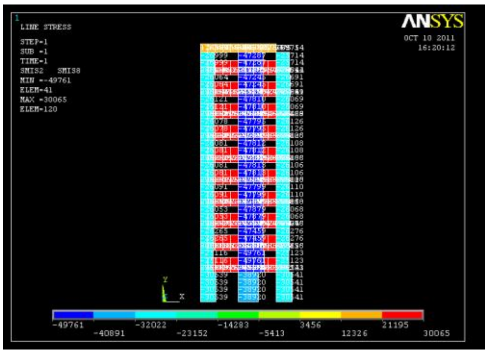
b) Deformed profile of the frame

Figure.4. 2bay-10 Storied RCC frame without masonry in-fill under lateral load

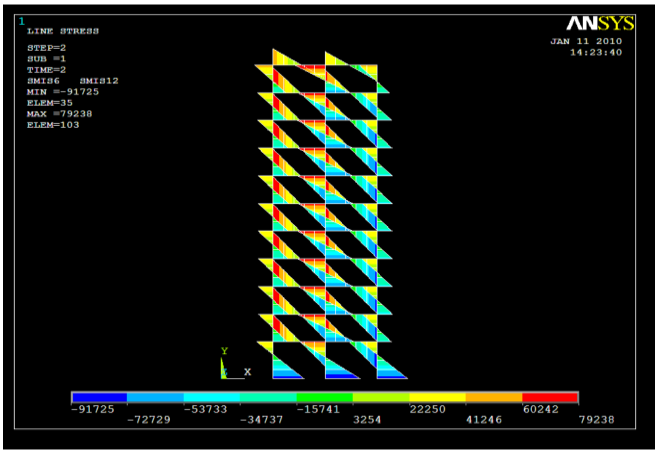
The force in various members can be viewed from graphical view of the frame as shown in figure 5. It is obvious from Figure 5(a) that axial force increases towards the bottom members. Bending moments also are observed to be increasing towards bottom members. However, it shear forces in all the members almost remain constant. The exteriors column members in 1st storey, 2nd storey 3rd storey are designated as C_{o1}, C_{o2}, C_{o3} respectively with C_{o10} corresponding to topmost column. The interior column members in 1st storey, 2nd storey 3rd storey are designated as C_{i1}, C_{i2}, C_{i3} respectively with C_{i10} corresponding to topmost column. Beams from 1st storey, 2nd storey 3rd storey are designated as B_1, B_2 and B_3 respectively with B_{10} corresponding to topmost beam. The same notation is followed throughout. The results are tabulated together with that of with masonry in-fill as shown in Table I.



a) Axial Force



b) Shear Forces

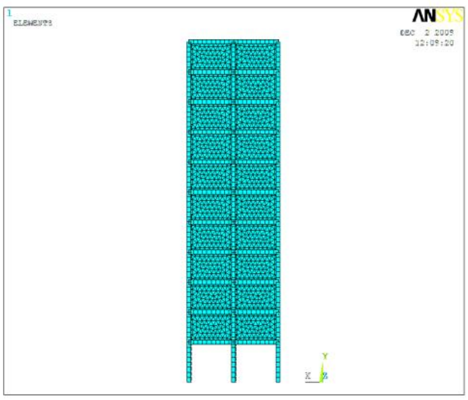


c) Bending Moments

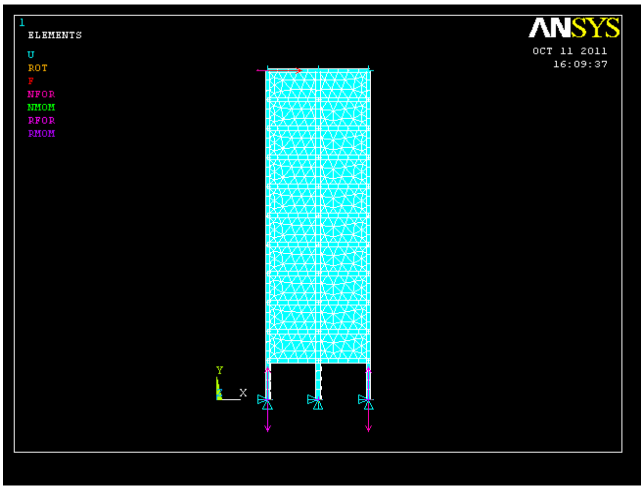
Figure.5. Forces in Frame without masonry wall

ANALYSIS OF 2 BAY-10 STORIED RCC FRAME WITH MASONRY IN-FILL.

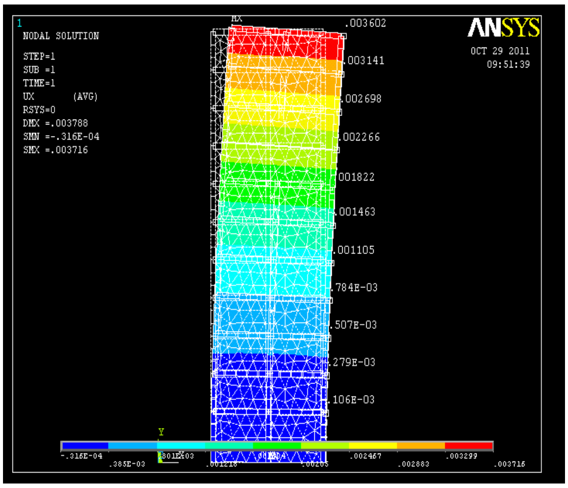
The 2 Bay-10 storied RCC plane structure with masonry in-fill is modeled in ANSYS subjected to a point load of 100 kN at the top of the frame as has been done in case of bare frame. Here masonry wall enclosed by columns and beams all around; is fully modeled. The material properties and geometry are incorporated correspondingly in modeling. The common nodes between RCC members and masonry in-fill are merged. RCC members are modeled using beam elements; whereas solid45 elements are used in modeling. Output of the results is graphically shown in Figure 4. The forces in various members of the RCC frame with masonry in-fill are noted and tabulated on Table I. Influence of the in-fill is observed to be remarkable. Deflection at the top of the frame is also noted. It is observed that deflection of the RCC frame with masonry in-fill is found to be lesser that that of bare frame. Hence it can be inferred that presence of in-fill stiffened the structure. It is also observed that forces in the members are affected as it can be evidenced from Table I.



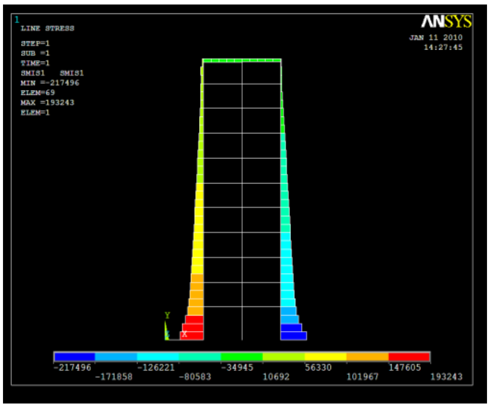
a) RCC frame with masonry in-fill



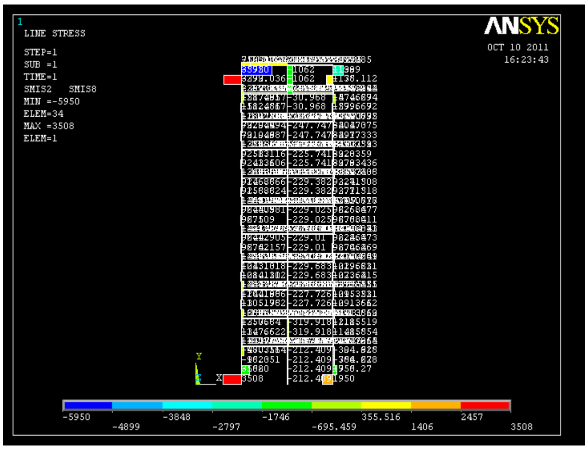
b) RCC frame with in-fill under lateral loading



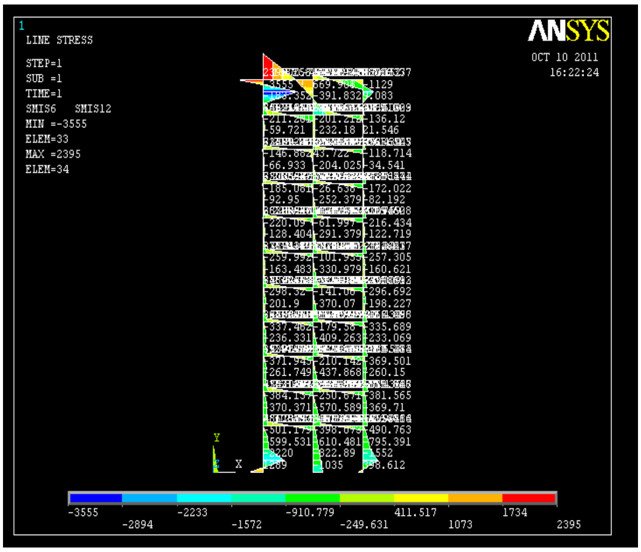
c) Deformed profile



d) Axial forces



e) Shear forces



f) **Beniding moments**

Figure.6. Forces in RCC Frame with masonry in-fill/ wall

ANALYSIS OF RCC FRAME WITH EQUIVALENT STRUT

A 2Bay-10 storied RCC plane frame with equivalent effective strut width as calculated above has been analyzed. Performance of the frame is quantified and compared with that of masonry infill frame. The results from frame with equivalent strut and frame with masonry infill are compared and found to be almost same. The forces in all the members of the RCC frame with equivalent strut and actual masonry infill frame have been tabulated as given in the Table I. The values from the table is clear evidence that masonry infill can be modeled as an equivalent strut.

Table .1. Bending Moments in Beams

BEAM	Floor	Height (m)	$M_{without\ infill}$ (kN.m)	$M_{with\ infill}$ (kN.m)	$M_{with\ struct}$ (kN.m)	$M_B=M_{in\text{-}fill}/M_{without\ infill}$
B_{11}	11	34	47.37	2.37	0.37	0.05
B_{10}	10	31	73.65	0.52	0.13	0.01
B_9	9	28	77.29	0.52	0.13	0.01
B_8	8	25	78.02	0.35	0.17	0.00
B_7	7	22	78.11	0.31	0.18	0.00
B_6	6	19	78.13	0.33	0.18	0.00
B_5	5	16	78.14	0.33	0.19	0.00
B_4	4	13	78.15	0.34	0.19	0.00
B_3	3	10	78.19	0.36	0.21	0.00
B_2	2	7	78.17	1.01	0.22	0.01
B_1	1	4	79.23	12.05	0.22	0.15

Table.2. Bending Moment in Outer Column

COL. no	Floor	Height (m)	$M_{without\ in\text{-}fill}$(kN.m)	M_{infill}(kN.m)	$M_{with\ struct}$(kN.m)	$M_B=M_{in\text{-}fill}/M_{without\ in\text{-}fill}$
C_{o11}	11	34	33.67	3.55	0.18	0.11
C_{o10}	10	31	39.16	0.21	0.05	0.01
C_{o9}	9	28	39.23	0.14	0.06	0.00
C_{o8}	8	25	39.44	0.18	0.09	0.00
C_{o7}	7	22	39.57	0.21	0.12	0.01
C_{o6}	6	19	39.67	0.25	0.16	0.01
C_{o5}	5	16	39.79	0.29	0.2	0.01
C_{o4}	4	13	39.84	0.33	0.23	0.01
C_{o3}	3	10	40.49	0.45	0.26	0.01
C_{o2}	2	7	37.57	6.04	0.37	0.16
C_{o1}	1	4	49.95	72.43	1.28	1.45

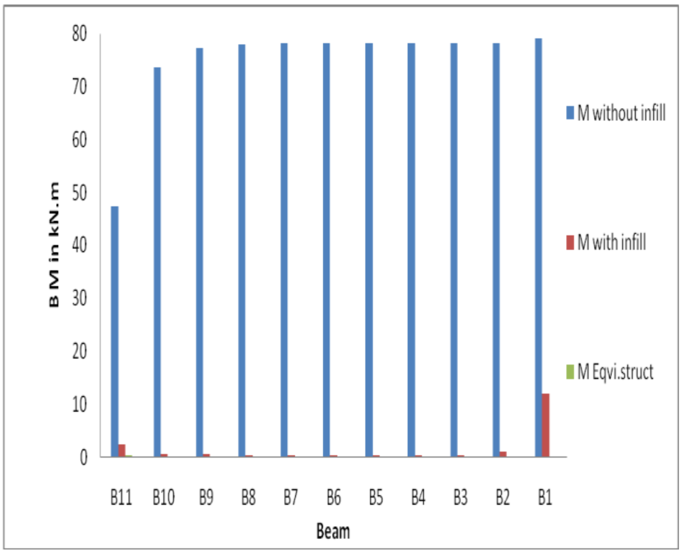


Figure.7. Bar Chart Showing Bending Moments in Beams

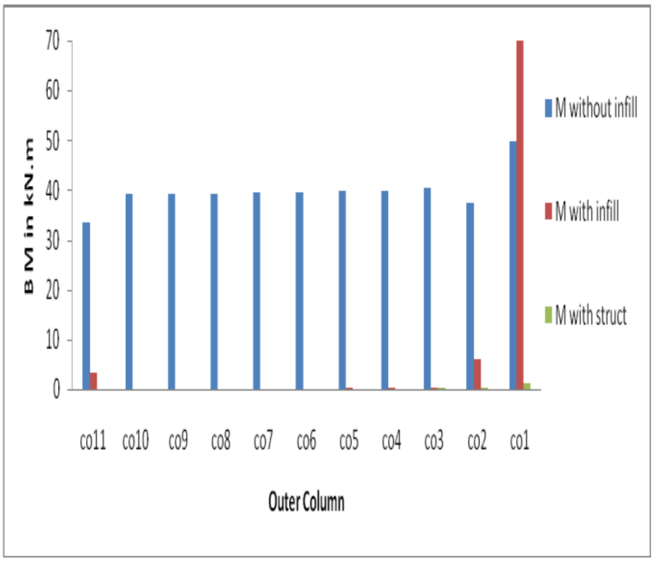


Figure.8. Bar Chart Showing Bending Moments in Outer Columns

Table.3. Bending Moment in Inner Column

COL.NO	Floor	Height (m)	$M_{without\ in\text{-}fill}$ (kN.m)	$M_{with\ in\text{-}fill}$ (kN.m)	$M_{with\ struct}$ (kN.m)	$M_B = M_{in\text{-}fill} / M_{without\ in\text{-}fill}$
c_{i11}	11	34	62.94	0.66	0.39	0.01
c_{i10}	10	31	70.16	0.23	0.21	0.00
c_{i9}	9	28	71.77	0.2	0.21	0.00
c_{i8}	8	25	72.02	0.25	0.25	0.00
c_{i7}	7	22	72.16	0.29	0.29	0.00
c_{i6}	6	19	72.27	0.32	0.33	0.00
c_{i5}	5	16	72.34	0.39	0.37	0.01
c_{i4}	4	13	72.62	0.22	0.41	0.00
c_{i3}	3	10	71.77	1.87	0.43	0.03
c_{i2}	2	7	76.84	10.12	0.57	0.13
c_{i1}	1	4	52.8	71.03	1.03	1.35

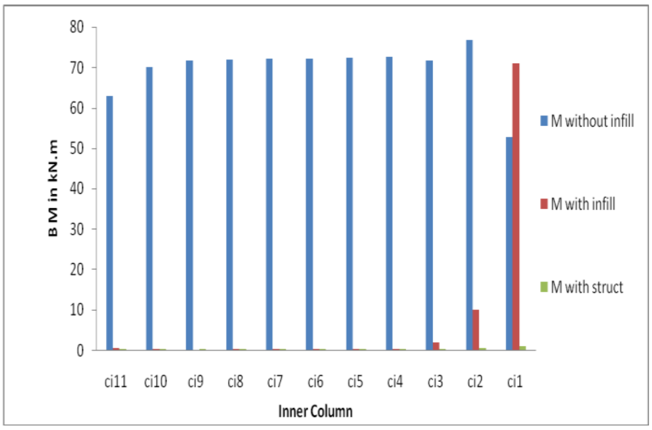


Figure.9. Bar Chart Showing Bending Moments in Inner Columns

In this investigation, it is attempted to study the effect of masonry infill on the performance of RCC framed structure. Further, it is proposed to model the effect of the infill in the analysis of the framed structure. The results of the RCC frame with masonry reveal that masonry infill stiffened the RCC framed structure and influences its member forces. This is chapter is exclusively for discussion of the results as presented in the preceding sections.

EFFECT OF MASONRY INFILL ON STIFFNESSOF RCC STRUCTURE

According to reported earthquake damage studies, the reinforced concrete frames with masonry in-fills present a high level of damage. Under these conditions, the references quoted question the appropriate building authorities on why the reinforced concrete framed buildings with masonry infill walls are allowed and still continuing to be allowed in such a wide range. Thus, it becomes the responsibility of all parties involved with the planning, design and construction process to advocate for safer buildings. This research presents a simple analytical method of micro-modeling the complicated behavior of in-filled frames under lateral loads. Using this technique, the behavior of RCC frame with masonry in-fill frames under lateral loads has been investigated. The choice of beam materials for the assembly has a large effect on its stiffness.

The proposed statically equivalent strut system for in-fill frames which is represented by linear finite elements with unilateral diagonal strut yields reasonable predictions with considerable reduction in the numerical operations. Buildings should have sufficient strength, stiffness design should follow the guidelines given in IS: 1893:2002. This research presents following findings as discussed below.

EFFECT OF MASONRY INFILL ON BENDING MOMENTS

The bending moments in various beams and columns of the 2 Bay-10 Storied RCC frame with, without masonry infill and equivalent strut results are presented in the Tables I, II and III. The results are compared graphically as shown in Figures 7, 8 and 9 from which the following observations are made.

1. The results reveal that the effect of masonry infill results in considerable reduction in bending moments of beams as can be seen from Figure 7.
2. It can be evidences from Figures 8 and 9 those moments in both inner and out columns are reduced to almost too nil (negligible) owing to masonry infill /equivalent strut.
3. The moment in out columns are almost doubled as evidenced from Figures 8 and 9.
4. Further, Figures 7, 8 and 9 evidence that the whole masonry infill can be replaced by its equivalent strut, while modeling the infill in finite element software; there by computational efforts can be minimized.

CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

Modeling masonry infill in RCC frame and its effect on the performance of the RCC structure are carried out in this investigation. The modeling infill and the research findings are presented in the preceding chapters. Conclusions and scope for further research in this area is presented in this chapter. Out of the discussion of the results, the valuable conclusions are drawn as enlisted in the succeeding section.

II. CONCLUSIONS

The essence or gist of the present study is presented in the form of conclusions as given below.

1) All the sheer force, bending moment is taken by masonry in-fill wall.
2) Due to masonry infill in RCC Frame inner and outer columns axial force decrease up to 50%.
3) Due to masonry infill; stiffness of RCC Framed structure is considerably improved about 17 times.
4) Equivalent strut in RCC frame can replaces the masonry infill panel in terms of effect, for analysis purpose.
5) Infill influence on the deformations related to lateral load is found to depend on frame features such as number of stories and number of bays as well as infill amount and position.
6) Infilling bottom floors of RCC frames provide more stiffness for the frame as compared to that of upper floors.

SCOPE FOR FURTHER RESEARCH

All the model / scientific findings in the world of research are bound to have their limitations and constraints. Within the limitations alone the model works out. There is end of perfection and improvements. The present study also has its limitations within which it is workable. In this study, a 2bay-10storied plane is considered. The results and conclusions are valid for the structure under consideration. Authenticity of the conclusions for other structures can be verified. Therefore the present work can be extended as suggested below.

1. The study can be extended for dynamic analysis under both gravity and lateral loads.
2. The study can be extended for space frame structures under static analysis both for gravity and lateral loads.
3. The study can be extended for space frame structures.

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