BEHAVIOR OF ACB MASONRY IN-FILLED RC FRAME UNDER CYCLIC IN-PLANE LATERAL LOAD

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Abstract - One of the major disadvantages of Conventional masonry is its dead weight. There have been attempts to reduce the dead weight of masonry by replacing conventional masonry units with hollow units. Of late the use of extremely light weight Aerated Concrete Blocks (ACB) have started becoming popular. The process of aeration, has led to the unit weight being as low as $6KN/m^3$. Thus the self weight of the structure reduces significantly. However there have been scanty studies on its application as a load bearing structure. The study also indicated that ACB masonry may find useful application as an in-fill material in RC framed structures. In the present investigation an attempt has been made to study the performance of ACB masonry in-filled RC frame under cyclic in-plane lateral loads. Prior to testing of the half scaled frame, the strength and elastic properties of ACB masonry and its constituents obtained through a series of experiments. The half scaled model was subjected gradually increasing magnitudes of cyclic lateral loads. The specimen was tested up to failure. Linear finite element analysis has been carried out to know the nature of stresses developed in the RC (reinforced concrete) frame and ACB masonry in-fill. The properties used for finite element analysis were based on the experiments. The analysis indicated the region of initiation of failure.

1. Introduction

Masonry in-fills are normally considered as non-structural elements and their stiffness contributions are generally ignored in practice. However, in-fill walls tend to interact with the frame when the structure is subjected to lateral loads, and also exhibit energy-dissipation characteristics under seismic loading. Masonry walls contribute to the stiffness of the in-fill under the action of lateral load. The term 'in-filled frame' is used to denote a composite structure formed by the combination of a moment resisting plane frame and in-fill walls.

The composite behavior of an in-filled frame imparts lateral stiffness and strength to the building. The interaction of MI(masonry infill) with RC frames under excessive lateral loads may result in complicated failure mechanisms such as shear failure of columns, cracking of masonry mortar joints, crushing of masonry units etc., these failure mechanisms pose significant challenge in modeling and performance of MI- RC frame.

In-fills interfere with the lateral deformations of the RC frame; separation of frame and in-fill takes place along one diagonal and a compression strut forms along the other. Thus, in-fills add lateral stiffness to the building. The structural load transfer mechanism is changed from frame action to predominant truss action.

When in-fills are non-uniformly placed in plan or in elevation of the building, a hybrid structural load transfer mechanism with both frame action and "truss" action may develop. In such structures, there is a large concentration of ductility demand in a few members of the structure. For instance, the *soft-Storey effect* (when a Storey has no or relatively lesser in-fills than the adjacent storeys), the *short-column effect* (when in-fills are raised only up to a partial height of the columns), and *plan-torsion effect* (when in-fills are un-symmetrically located in plan), cause excessive ductility demands on frame columns and significantly alter the collapse mechanism.

In-fills possess large lateral stiffness and hence draw a significant share of the lateral force. When In-fills are strong, strength contributed by the in-fills may be comparable to the strength of the bare frame itself.

Table 1: Modes of failure of masonry in-filled RC frames

| Description	Weak Infill	Strong Infill
Weak Frame		Diagonal cracks in in-fill Plastic hinges in columns
Frame with Weak Joints and Strong Members	Corner crushing of in-fills Cracks in beam-column joints	Diagonal cracks in in-fill Cracks in beam-column joints
Strong Frame	Horizontal sliding in in-fills	

2 Materials and Methodology

Aerated/foamed concrete can either be produced by introducing air entraining agents, foaming agents or combination of both. Using air entraining Agents, gas forming chemicals which are aluminium powder, hydrogen peroxide/bleaching powder and calcium cabbie which liberate hydrogen, oxygen and acetylene respectively, are mixed into the lime or cement mortar during the liquid or

plastic stage. This results in a mass of increased volume when the gas is produced, which leaves a porous structure. Among these, aluminium powder is the most commonly used aerating agent. The density of Aerated concrete blocks varies from 300 to 900 Kg/m³. All the basic mechanical properties of aerated concrete block evaluated in a series of lab test. An attempt has been made to compile the information on the absorption characteristics, flexural strength, dry and wet compressive strength and density of aerated concrete blocks and properties of mortar used for masonry. The recommendation as given by IS: 2185-1979 (part 1 & part 2) were followed for carrying out the tests. As per IS 1905-1987 the height to thickness h/t of prisms is between 2 to 5. The tests on blocks and prisms are conducted to determine the strength and elastic properties of masonry.

Table 2: Aerated concrete block test results

| SL NO	PERTICULARS	TEST	CODE BOOK	TEST RESULTS
1	Aerated concrete cube - 200x200x200mm	Initial rate of absorption	IS: 2185(part-I) 1979	2.375 kg/m2/min
2	Aerated concrete block- 600x200x200mm	Block density test	IS: 2185(part-I)-1979	626.94 kg/m3)
3	ACB cube - 200x200x200mm	Water absorption test	IS: 2185(part-I)-1979	23.20%
4	ACB cube - 200x200x200mm	wet Compressive strength	IS: 2185(part-I)-1979	3.743 N/mm²
5	Cement mortar cube- 70.6x70.6x70.6mm	Compressive strength	IS: 2250-1981	4.74 N/mm² for 14 days
6	Cement mortar cube- 70.6x70.6x70.6mm	modulus of elasticity	IS: 2250-1981	9.59 N/mm² for 28 days
7	ACB block- 400x200x200mm	flexural strength	IS: 2185(part-I)-1979	0.525 N/mm²
8	ACB triplets	Shear strength	IS: 2185(part-I)-1979	0.061 N/mm²
9	Aerated concrete cube - 200x200x200mm	dry Compressive strength	IS: 2185(part-I)-1979	5.867 N/mm²
10	Aerated concrete cube - 200x200x200mm	modulus of elasticity	IS: 2185(part-I)-1979	3316.9 N/mm²
11	ACB masonry Prisms - perpendicular to bed joints	dry Compressive strength	IS:2185-1979 (part 1 & part 2) & IS 1905-1987	2.654 N/mm²
12	ACB masonry Prisms - perpendicular to bed joints	modulus of elasticity		1129.7 N/mm²
13	ACB Prisms - parallel to bed joints	dry Compressive strength	IS:2185-1979 (part 1 & part 2) & IS 1905-1987	2.18 N/mm²
14	ACB Prisms - parallel to bed joints	modulus of elasticity		2341.6 N/mm²
15	ACB prisms	flexural bond stress	BS: 5628-1992	0.125 N/mm²
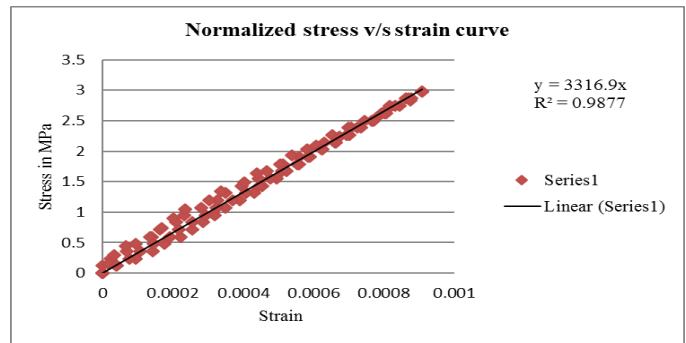
Figure 1: Normalized Stress v/s Strain curve for blocks
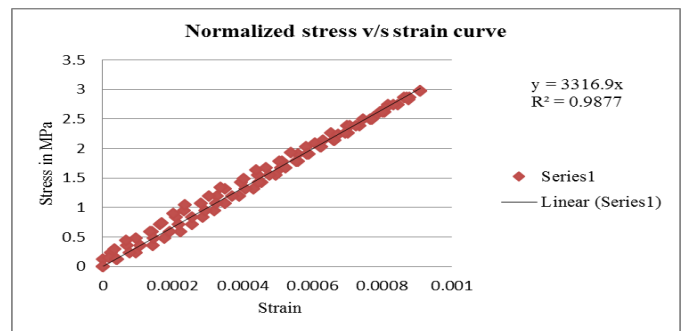
Figure 2: Normalized Stress v/s Strain curve for blocks
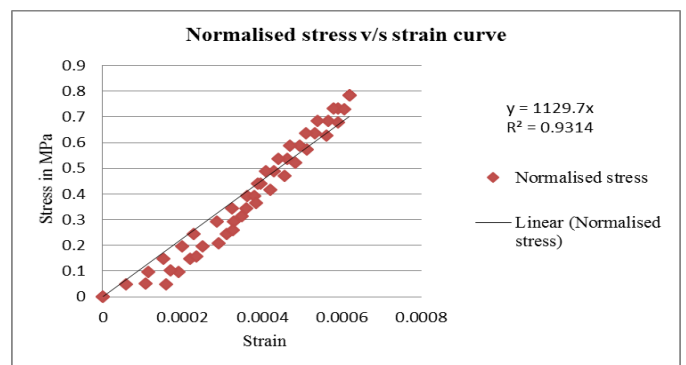
Figure 3: Normalized Stress v/s Strain curve for masonry prisms (Perpendicular to bed joints)
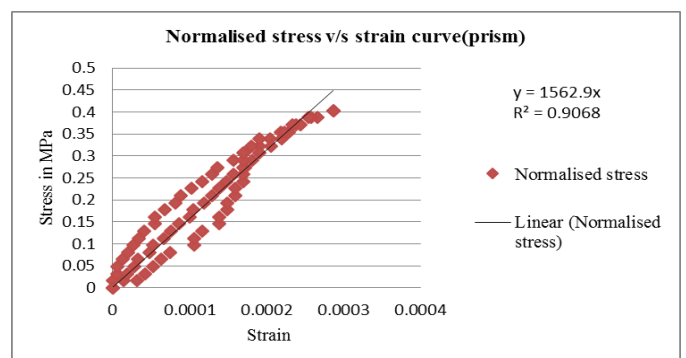
Figure 4: Normalized Stress v/s Strain curve for masonry prisms

3 BEHAVIOR OF ACB MASONRY IN-FILLED RC FRAME UNDER CYCLIC IN-PLANE LATERAL LOAD - EXPERIMENTAL INVESTIGATION

3.1 INTRODUCTION

Masonry in-filled RC framed structures have become one of the most popular structural systems for multi-storied buildings, especially in the urban context. It offers a wide range of relative advantages. Two of them are;

a) Bare RC frame can be constructed at a faster rate and later the in-fill can be introduced.
b) Provision for flexibility in plan forms.

However, very often the strength, stiffness and load carrying capacity of the in-fill material is seldom considered. If the in-fill material is heavy, it only adds to the self-weight and reduces the structural efficiency. On the other hand if the in-fill is light weight and if it's lateral stiffness is significant than the structure becomes more efficient. One such in-fill material which possesses both the above mentioned property is ACB masonry. Ideally testing a full-scale prototype is preferred. However the cost of testing and the sophistication involved is very high. Hence one has to resort to testing of geometrically scaled models. In this present investigation a half scale model depicting single-bay single storey structure, has been tested under cyclic in-plane lateral load

3.2 CONSTRUCTION OF HALF-SCALE MODEL

In the present investigation half scaled single bay single storied RC frame has been constructed. The RC frame of 2.1mX1.6m with outer to outer dimension and inner clear dimension of 1.9mX1.4m to fit within in the loading frame for testing. The model is constructed for testing, in loading frame of 2000KN capacity. The experimental set up done to test the RC frame with ACB in-fill for cyclic in-plane lateral load. For the RC frame of cross section 100mmX100mm, it is very difficult to pour the concrete in the formwork and compact in the presence of congested reinforcements. Here SCC is adopted to eliminate compaction process. The SCC mix designed for characteristic compressive strength of 20MPa for 28 days.

3.3 ACB MASONRY IN-FILL

The ACB blocks were supplied by m/s Ultratech Private limited. The Aerated concrete blocks of 200mm breadth, 200mm depth and 600mm in length respectively. These AC blocks were sawn using wooden saw manually to required length and breadth. For mortar zone-II river sand and OPC 53 grade cement is used. The masonry in-fill constructed in stretcher bond. The construction of ACB masonry in-fill with 100mm thickness.

3.4 EXPERIMENTAL SET-UP

The RC frames were provided with the RC flanges of 100mmx100mm in cross section and length of 450mm at the bottom on either side of the columns to facilitate fixed support condition at the base. The test set-up model is as shown in the fig. 5

These RC flanges were secured firmly to the base of the loading frame using adequate mild steel channels and clamps which were welded to the steel base of loading frame. The test set-up is made using jacks, dial gauge and proving ring. The small rigid steel plate is pasted at the top of column at one end; the digital dial gauge is fixed at that end and all the readings were note down from same end for both loading directions. The jack and proving ring of 50KN capacity are used to load the model. The jack and proving ring is shifted to opposite side to apply cyclic load. The precautionary measures were taken so that applied lateral cyclic loads are in-plane. The white wash is done to RC frame ACB in-fill masonry to show clear indications of cracks while testing.
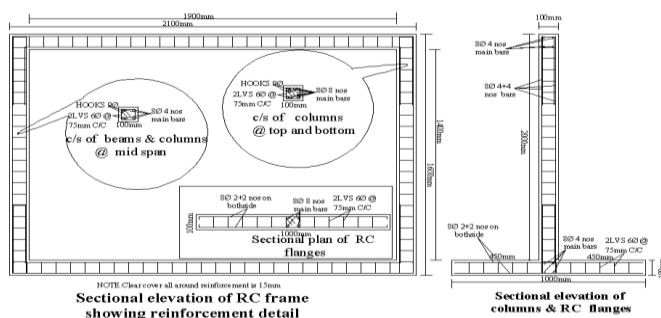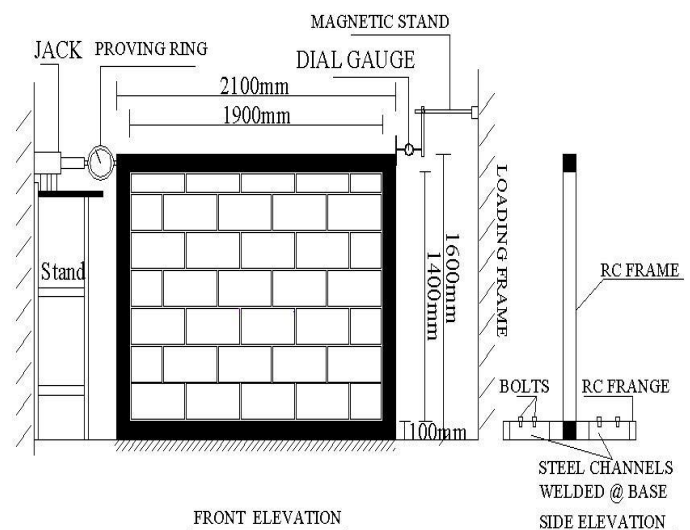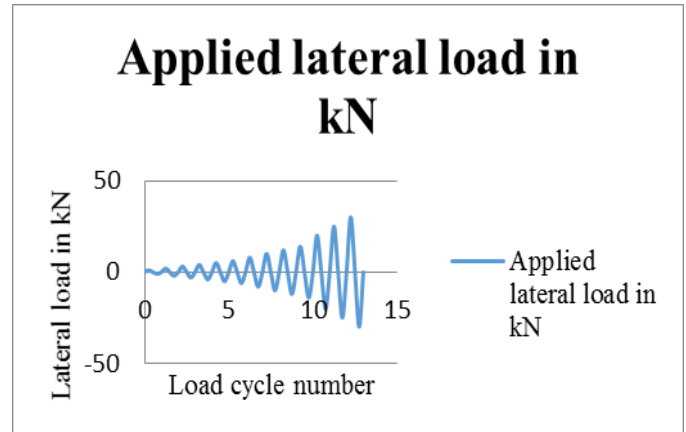

Figure 5: Test set-up for ACB in-fill masonry RC frame for cyclic lateral in-plane loading.

Figure 4: Detailing of reinforcement

Table 3: Shows the peak deflection and effective stiffness for each cycle of load

Load cycle	Load in kN	Peak deflection in mm		Effective stiffness in kN/mm
		positive	negative	
1	1	0.06	-0.07	14.7
2	2	0.12	-0.15	12.658
3	3	0.09	-0.19	21.739
4	4	0.16	-0.24	18.867
5	5	0.23	-0.31	16.666
6	6	0.3	-0.37	16.666
7	8	0.4	-0.54	15.87
8	10	0.53	-0.73	14.93
9	12	0.75	-0.86	14.285
10	14	1.15	-1.18	11.36
11	20	2.96	-2.99	6.71
12	25	6.4	-5.67	4.03
13	30	24.53	-14.9	1.56

Figure 6: Test set-up for ACB in-fill masonry RC frame

3.5 TEST PROCEEDINGS AND OBSERVATIONS

3.5.1 LOADING HISTORY FOR ACB IN-FILLED MASONRY RC FRAME

The model is tested under the 2000KN loading frame for reversed lateral in-plane cyclic loads. The model is subjected to lateral loads using jack which is mounted at top beam centre level and the loads were recorded using proving ring of 50KN capacity. The story drift recorded using digital dial gauge. The known increasing magnitudes of reversed cyclic in-plane lateral loads were applied up to the failure of the frame. The white wash of the model facilitated the visual observation of cracks. The crack pattern and its progress were recorded and photographed.
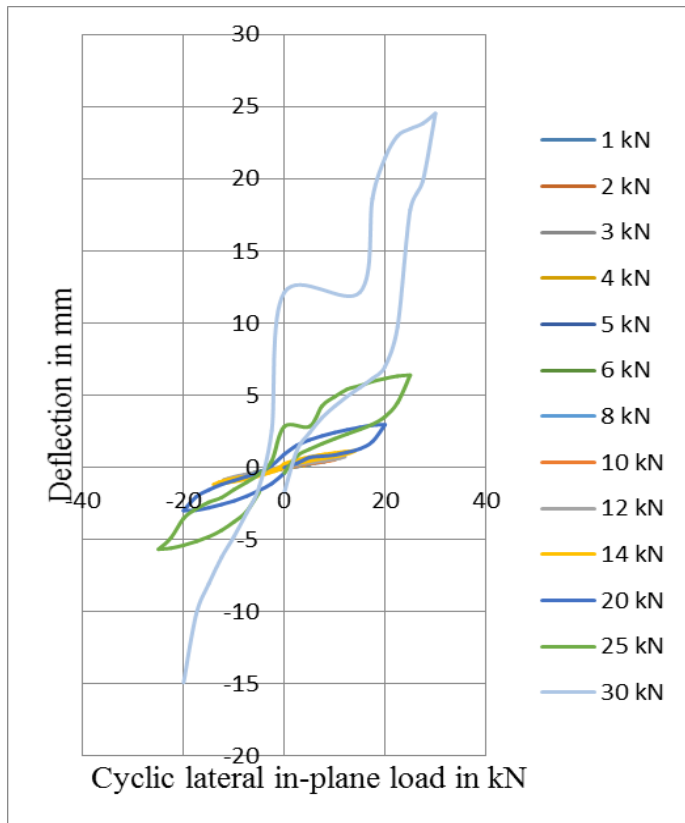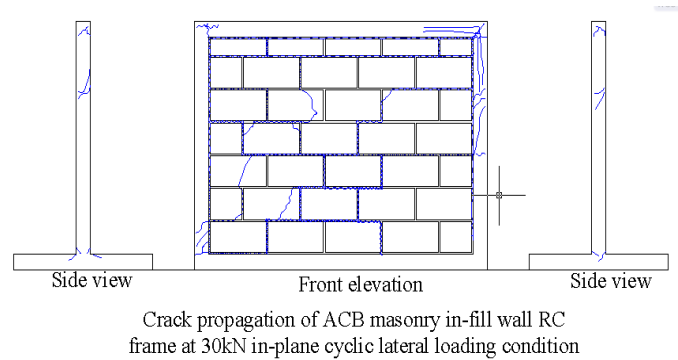

Figure 7: Loading history for RC frame with ACB in-fill masonry

3.5.2 OBSERVATIONS

During the first cycle, 1kN of load was applied at an interval of 0.2kN. The load-deflection response clearly noticed that the system is behaving almost perfectly linearly. The peak deflection was found to be 0.07mm. The effective stiffness was found to be 14.7kN/mm. During the 2nd cycle of load the system went into slight non-linearity after a deflection of about 0.07mm. During this cycle of load there was a separation of masonry at the horizontal interface between the bottom of the beam and top of masonry. This crack also propagated vertically at the vertical interface between inner face of column and ACB masonry to a depth of about 2 courses. It was later observed that this crack sustained till the 11th (20kN) cycle. During the 11th cycle of load there was a huge dissipation of hysteretic energy. The specimen went into a permanent offset. This is clearly noticed in figure 9.

During the 11th cycle beam-column junction at one end started developing plastic hinges and the cracks were noticed up to the point where the beam reinforcement was L-bent into the column. A minor crack at toe of the specimen.

3.5.3 FAILURE PATTERN

During the 12th cycle the typical diagonal crack in the ACB masonry was noticed. During the 13th cycle there was a diagonal crack in the other direction also. A few of the ACB unit also developed cracks in the joints. During this cycle there is crushing of concrete at both the toes. The specimen had almost developed mechanism. It ceased to take any further load. It can be deemed that this corresponds to the failure load. Figures 10, 11 and 12 shows the failure pattern.

Figure 8: Load v/s deflection curve for all cycles

Crack propagation of ACB masonry in-fill wall RC frame at 20kN in-plane cyclic lateral loading condition
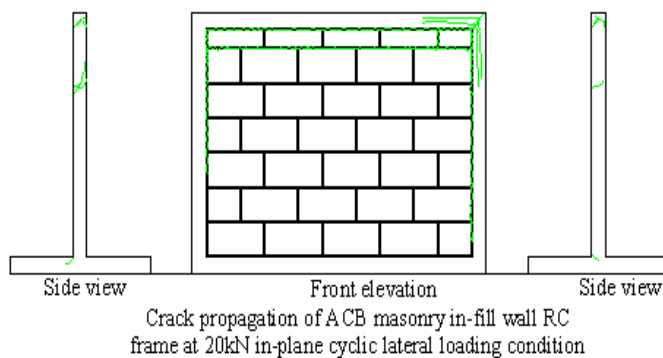
Figure 9: Crack propagation at 11th cycle

Crack propagation of ACB masonry in-fill wall RC frame at 25kN in-plane cyclic lateral loading condition

Figure 10: Crack propagation at 12th cycle

Crack propagation of ACB masonry in-fill wall RC frame at 30kN in-plane cyclic lateral loading condition

Figure 11: Crack propagation at 13th cycle
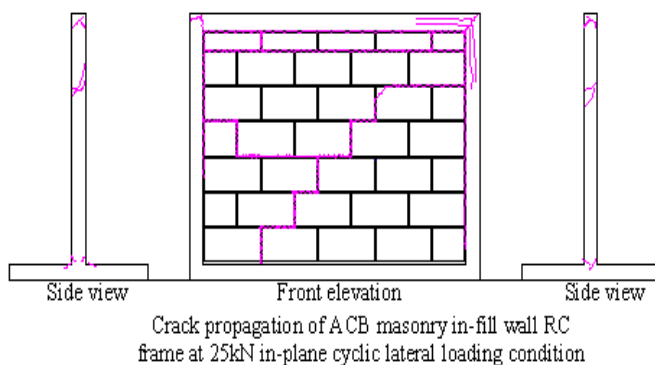

Figure 12: Crack developed at 13th cycle loading

4.0 ANALYSIS OF ACB MASONRY IN-FILLED RC FRAME UNDER IN-PLANE LATERAL LOAD

4.1 INTRODUCTION

Masonry In-filled RC framed structures are indeed very complex to analyze, especially when they are subjected to In-plane lateral loads. The In-fill masonry experiences significant shear mode of deformation, it compatible with RC, else the diagonal may respond as a strut element. One way of understanding the behavior of MI-RC frame is by Finite Element Analysis (FEA). In this project an attempt has been made to understand the stresses developed in ACB MI-RC frame, through linear FE analysis. A commercially available general purpose FE package is used for the analysis. This program (NISA) has an advantage of a pre-processer and post-processer which is user friendly. The objective of the analysis is to identify the vulnerable region in ACB MI-RC frame, under cyclic In-plane lateral load.

4.2 FE MODEL OF RC FRAME

Table 3 gives the properties used for FE analysis. The RC frame was modeled as 2D beam elements, while the ACB In-fill masonry was modeled as homogeneous plane stress elements. To establish the compatibility between masonry and RC, the base was assumed to be clamped. The load was applied at the appropriate location as done in the experiments.

Table 4: Properties used for FE analysis

| Sl. no	Material/Description	Compressive strength in (MPa)	Modulus of elasticity (MPa)
1	Aerated concrete blocks	5.867(dry) 3.743(wet)	3316
2	ACB masonry prisms Parallel to bed joints	2.180	1562
3	ACB masonry prisms perpendicular to bed joints	2.654	1129
4	Concrete cubes	47.85	34587
5	Cement mortar cubes	9.59	-
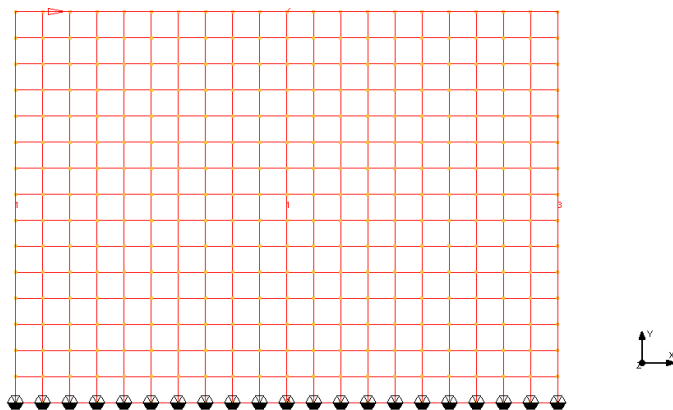
Figure 13: Shows the view of the discretized FE model

4.3 RESULTS AND DISCUSSIONS

### 4.3.1 LATERAL DEFORMATION

Figure 14 shows the lateral deformation profile from the FE analysis. The peak deformation observed is 0.456mm which is far lesser than the experimental value. It is very obvious that linear analysis does not reflect the behavior of the model. However, the objective of linear analysis is to evaluate the stress patterns in the model. The following section discusses about the stresses developed in the FE model.
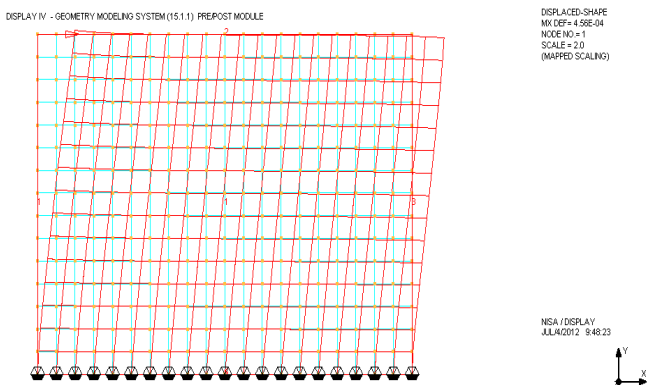

Figure 14: Lateral deformation of FE model

4.3.2 STRESS DISTRIBUTION

Figure 15 shows the σ_{yy} contour (The normal stresses perpendicular to bed joints). It can be noted that the maximum tensile and compressive stresses is 0.06MPa and 0.057MPa respectively. This is lower than the respective strength of ACB masonry. Hence it can be concluded that toe crushing or tensile failure at the heel may not occur. Even in the experiments tensile and compressive failures were not noticed. Similarly stresses parallel to bed joints σ_{xx} contour (The normal stresses parallel to bed joints) also indicated maximum stresses within the limit. Figure 16 shows σ_{xx} contours. The stress contour for shear stresses developed is interesting. The maximum shear stress developed is 0.133MPa which is much higher than the shear strength. It can also be noted from figure 17 that a significant portion of ACB masonry has developed shear stresses exceeding the limit. It can also interesting to note that the two principal stresses indicate the diagonal tensile stress exceeding the limit. It can also interesting to note that the two principal stresses indicate the diagonal tensile stress exceeding the limit from figure 18 &19. Table 4.2 gives the bending moment and shear force developed at the joints of RC frame.
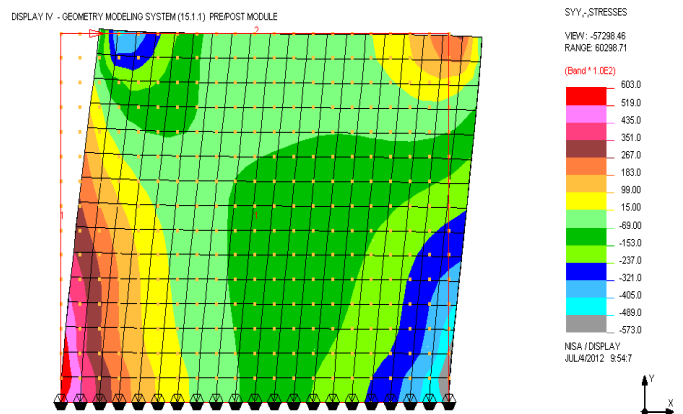
Figure 15: Shows the σ_{yy} contour (The normal stresses perpendicular to bed joints).
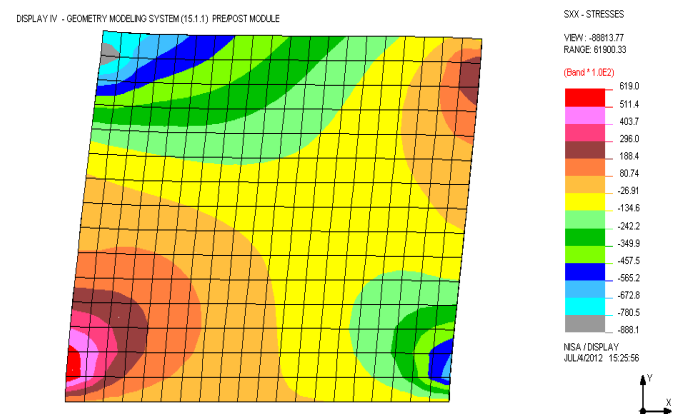
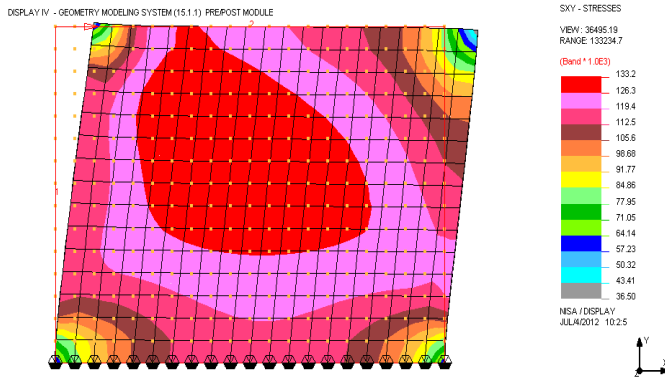**Figure 16: Shows the σ_{xx} contour (The normal stresses parallel to bed joints).**
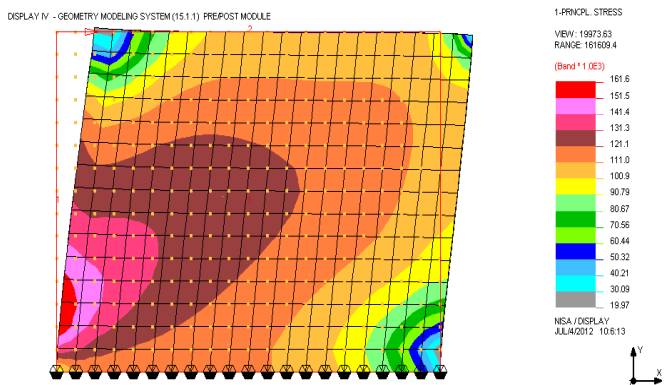
Figure 17: Stress contour for shear stresses

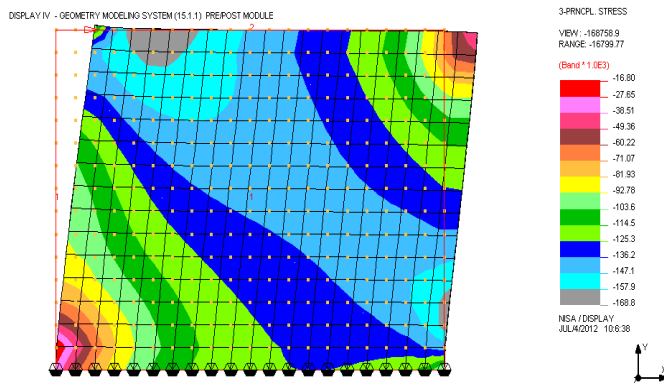
Figure 18: Stress contour for 1st principal stress

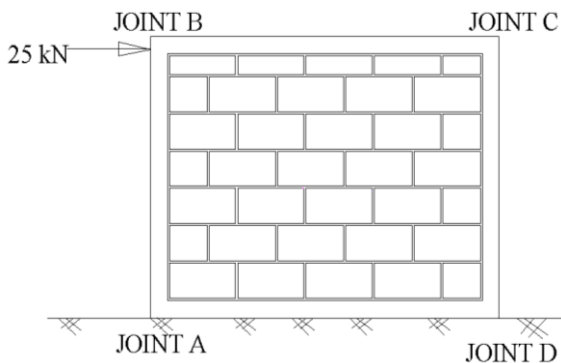**Figure 19: Stress contour for 3rd principal stress**

Figure 20: Bending moment and shear force

Table 5: Bending moment and shear force at joints

Joint	Maximum axial force in kN	Maximum shear force in kN	Maximum bending moment in kN.m
A	16.77	2.09	0.492
B	21.98	1.62	0.394
C	1.42	1.13	0.262
D	0	6.36	0.501

5.0 SUMMARY AND CONCLUSIONS

5.1 SUMMARY

In-filled RC framed structures have become one of the most common construction practice for a majority of buildings in recent times. They are known to perform in a rather complicated manner when subjected to in-plane lateral loads. The masonry in-fill influences the strength, stiffness and overall ductility of the structure. Of late there is an effort to adopt light weight masonry units as in-fill material so as to reduce the self-weight. Aerated concrete block masonry is possesses extremely low unit weight and relatively high stiffness. Thus ACB masonry may perhaps be an ideal material for in-fill. In this project an attempt has been made to evaluate the;

- Strength and elastic properties of ACB and its constituents
- Structural behavior of ACB masonry in-filled RC frame under in-plane cyclic lateral load

5.2 CONCLUSIONS

Based on the experimental and analytical studies, the following broad sets of conclusions are highlighted;

1. The average Initial rate of absorption (IRA) for ACB is found to be 2.375 kg/m²/min. It is within the permissible limits similarly to that for IRA of bricks specified in BIS codal provisions.

2. The average block density of the ACB is found to be 626.94 kg/m³. It is very low as compared to other masonry units.

3. The average water Absorption of ACB is found to be 23.2%. This is very high when compared with any other masonry unit. This is also not permissible as per the codal provisions.

4. The average wet compressive strength of ACB was found to be 3.743 MPa.

5. The average flexural strength of ACB was found to be 0.525 MPa.

6. The average compressive strength and Modulus of elasticity of ACB was found to be 5.867 MPa and 3316 MPa respectively.

7. The ACB triplets were tested for shear and the average shear strength was found to be 0.061 MPa.

8. The average compressive strength and Modulus of elasticity of ACB prisms tested under perpendicular to bed joints was found to be 2.654 MPa and 1129 MPa respectively.

9. The average compressive strength and Modulus of elasticity of ACB prisms tested under parallel to bed joints was found to be 2.18 MPa and 1562 MPa respectively.

10. The average flexural bond stress for ACB prisms was found to be 0.125MPa.

11. The half-scale single bay single storeyed ACB masonry in-filled RC frame was able to withstand 13 cycles of in-plane cyclic lateral load with the load magnitude increasing from 1kN to 30kN. After every cycle there was a reduction in stiffness which is an indication of the energy dissipation capabilities.

12. The mode of failure was a combination of plastic hinge developed at RC joints and diagonal shear failure of ACB masonry in-fill.

13. The linear FE analysis clearly indicated that the shear failure of ACB in-fill precedes the crushing failure of ACB. The analysis also indicated the vulnerability of the RC joints.

It can be concluded that ACB masonry in-fill has a potential of being a good alternative to conventional masonry in-fill. However there is a need to carry out further investigation to come out with important design parameters particularly for lateral loads.

5.3 FURTHER SCOPE OF RESEARCH

➤ The studies can be extended to carrying out experiments on two storey frames with a combination of soft-storey and openings.

➤ There is a need to carry out non-linear analysis to estimate the failure loads.

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