A COMPARATIVE STUDY OF THE EFFECT OF INFILL MATERIALS ON SEISMIC PERFORMANCE OF REINFORCED CONCRETE BUILDINGS

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Abstract

A reinforced concrete building with masonry infill is most common type of construction in India. Traditionally, conventional clay bricks or concrete blocks which are heavy rigid materials have been used as Infill wall. Though, AAC (aerated light weight concrete) blocks which are lightweight, flexible building materials that provides insulation and fire resistance and have lower impact on environment, can be used as masonry infill (MI) material in buildings. AAC blocks are now also available in India. A number of researchers have studied the behavior of AAC in-filled reinforced concrete (R/C) frames experimentally. The experimental result have shown that the AAC blocks infilled RC frame exhibits better performance subjected to lateral loads than that of conventional bricks infilled frames. The study of the effect of types of infill materials used on the performance of RC infilled frames is still limited. Hence in present report, comparative study of the effect of type of infill wall material on seismic response of structure has been presented. AAC blocks and conventional clay bricks materials are used for the comparison. To check the behavior of RC frames with both AAC block and conventional clay bricks infill, analysis has been done using ETABS. Three models are considered for comparison. One is bare frame, 2nd is infill frame and third is infill frame with open ground storey. To model the infill analytically, equivalent diagonal strut method is used. The ends of diagonal strut are pin jointed. Infill behaves like compression strut between column and beam and compression forces are transferred from one node to another. The analysis has been carried out for dead load (DL) live load (LL), and earthquake load. The results have shown that AAC block infill material behaves better under seismic loading than conventional brick.

Index Terms: AAC block, Infill frame, Equivalent strut model

I. INTRODUCTION

Reinforced concrete building with masonry infill is most common type of construction in India. Masonry walls are provided for functional and architectural point of view and thus they are generally considered as nonstructural elements. Hence interaction of infill with bonding frame is neglected in the design. Though an infill panel interacts with bonding frame and may induce a load resistance mechanism when subjected to lateral loads. Influence of infill is ignored in modeling of the RC structure which leads to inaccuracy in guessing the actual seismic behavior of framed structures. Infilled frame shows a composite structure which is made by the combination of both RC frame and Infill walls. The Infill walls in infilled frame may be of conventional clay brick, concrete block or AAC block. The study of the influence of types of infill materials on the seismic response of infilled RC frames is still limited. Thus, in present study focus is given on the effect of type of material on seismic performance. AAC blocks and clay bricks are used as infill in RC frame. AAC blocks are light-weight building materials that provide insulation and fire resistance and have lower impact on environment. The experimental results have shown that the AAC blocks infilled RC frame exhibits better performance subjected to lateral loads than that of conventional bricks infilled frames.

Behaviors of in-filled RC frames have been studied by number of researchers experimentally and analytically. Conclusion is made by them that infill materials influence the seismic response of the in-filled frame significantly. Infill materials improve the performance of RC frame structure. An infill wall decreases lateral deflections, storey drift and bending moments in the frame and increases axial forces in the column thus reduce the probability of collapse. Hence, considering the infill leads to slender frame members in design, reducing the overall cost of the structural system.

II. SCOPE AND OBJECTIVES OF STUDY

Following are the object of this study:
1. To study the effects of infill materials on the behavior of RC frame under lateral loading.

2. To evaluate the behavior of RC frames in-filled with AAC blocks as the lightweight materials and clay brick simulating earthquake forces and compare the results in terms of Displacement, Column forces, Beam forces, Storey shear, Base shear and Storey drift.

3. To find out green and environmentally safe materials such as AAC blocks which can be used in place of conventional bricks and perform better in seismic prone areas.
4. To find out effect of infill masonry frame in reinforced concrete buildings compared to bare frame under seismic prone area.5. To compare the different parameters such as deflection, storey drift, storey shear, axial forces and base shear in bare frame and infill frame.

Scope of the Study:

- The present study involves the influence of types of infill materials used (i.e. AAC block versus conventional brick masonry) on the seismic response of infilled RC frames.
- In this project, three different types of models have been analyzed for both brick masonry and AAC block masonry.
- A 10 storey building with and without infill and infill with soft ground storey is analyzed under seismic load which is located in seismic zone-III and Linear static analysis is carried out using ETAB to find out the results.
- To consider stiffness of infilled frames, modeling of infill is done as "Equivalent diagonal strut method".

III. METHODOLOGY AND SIMULATION OF BUILDING IN ETAB

1. Geometry

In the present study, A typical Ten storey RC framed type of building with five bays in longitudinal X direction and three bays in transverse Y direction have been considered with the plan dimension as 25 m × 15 m. All stories including ground storey having 3.2m floor to floor height is considered for the analysis. The width of bay is taken as 5m along X as well as Y direction. The thickness of masonry wall is taken as 300mm. The building is kept symmetric in both orthogonal directions in plan to avoid torsional response under lateral force. The column is kept square having size 500x500mm and size of the column is taken to be same throughout the height of the structure. The size of beam is taken as 300x450mm having 150mm thick Floor and roof slab for all the spans. The base is considered to be fixed. The building is located in zone III and Medium Type of soil is considered. A response spectrum is considered as per IS 1893(Part-1):2002. Response reduction factor for the special moment resisting frame is taken as 5.0 (assuming ductile detailing).Damping of structure is taken as 5 percent and Importance factor is taken as 1. Superimposed dead and live loads are applied on slab and beams as per IS 875 and Earthquake loads are applied as per IS 1893 (Part -1) 2002.

2. MATERIAL PROPERTIES

Grade of concrete is taken as M-25 and for reinforcing steel, Fe 415 grade of steel is used for all the model cases considered in this study. The unit weight of concrete is taken as 25kN/m3. The unit weight for brick masonry infill and AAC block masonry infill are taken as 20kN/m^3 and 6.5 kN/m^3 respectively. The modulus of elasticity for concrete is taken as [5000 $(fck)^{0.5}$] which is equal to 25000MPa (as per IS: 456-2000) and poison ratio is 0.2. The modulus of elasticity for brick masonry infill and AAC block masonry infill are taken as 2640MPa and 2040MPa respectively. The poison ratio for brick masonry is 0.16 and that of AAC block masonry is 0.25. The live load on floors is taken to be 3 kN/m^2 and $1kN/m^2$ live load is taken as floor finishes respectively. In seismic weight calculations, 25 % of the floor live loads are considered because live load on floor is equal to 3 kN/m^2 as given in IS code 1893:2002.

3. Modelling of Infill Walls

As FEMA 356(2000) stated that the elastic in plane stiffness of a masonry infill panel shall be denoted with an equivalent diagonal compression strut prior to cracking. The width of equivalent diagnoal strut is computed as

$$W = 0.175(\lambda h)^{-0.4} d$$

Where

$$\lambda = \left(\frac{E_i t \sin(2\theta)}{4 E_f I_c s} \right)^{1/4}$$

E_i = modulus of elasticity of infill material

E_f = modulus of elasticity of frame material

L = beam length between center lines of columns

L' = length of infill wall

h = column height between center lines of beams

s = height of infill wall Ic = moment of inertia of column

t = thickness of infill wall

d = diagonal length of strut

θ = angle between diagonal of infill wall and the horizontal in radian

Currently only single strut model suggested by Mainstone and week is used in linear static analysis of RC frames with infill walls. Contact length parameter which is given by Stafford Smith and his associates has been used.

The infills are modelled by single equivalent diagonal strut approach and its thickness is equal to infill wall thickness. The ends of strut are pin jointed which are connected to frame and releases moments at ends. A pin jointed end of strut avoids transfer of moment from frame to strut. Considering Mainstone and week diagonal strut width expressions for modeling the infill, width of strut for brick infill and AAC block infill is calculated which has been represented in following table. Contact length parameter is based on Stafford Smith.

Table-1: Width equivalent of strut

Strut	**Brick infill**	**AAC block infill**
Width (mm)	700	750
Thickness(mm)	300	300

IV. RESULTS AND DISCUSSION

In this chapter, The seismic analysis for all the RC frame models which consist of bare frame (M-1), model with full infill (modeling infill as a strut element) (M-2) and full infill with soft ground storey (M-3) has been done for both the infill materials i.e. for brick masonry infill and AAC block masonry infill by using software ETABS and the results are presented below. The parameters which are to be studied are Base Shear, Displacement, Beam Forces, Column Forces, Storey Shear and Storey drift by changing the material of infill as Brick infill and AAC block infill.

1. Displacement (mm)

The decrease in the displacement in AAC block masonry is found 31% in case 1 for bare frame model , 8% in case 2 for full infill masonry and 22 % in case 3 for full infill ground soft storey . Thus Displacement in AAC block is less than that of Brick infill in every cases due to its light weight .From the results it is found that the lateral displacement is very large for bare frame model compared to other models while masonry infill have least displacement.

Table-2: Displacement (mm) at Various Storey Level

Storey	Brick masonry			AAC block masonry		
	Bare frame	Infill frame	Infill with ground soft storey	Bare frame	Infill frame	Infill with ground soft storey
	M-1	M-2	M-3	M-1	M-2	M-3
10	125	14	19	97	13	17
9	121	13	18	93	12	16
8	113	12	17	87	11	15
7	103	10	16	78	9	14
6	90	9	14	68	8	12
5	75	7	12	57	7	10
4	59	5	11	44	5	9
3	42	4	9	32	3	7
2	25	2	8	19	2	6
1	9	1	6	7	1	4

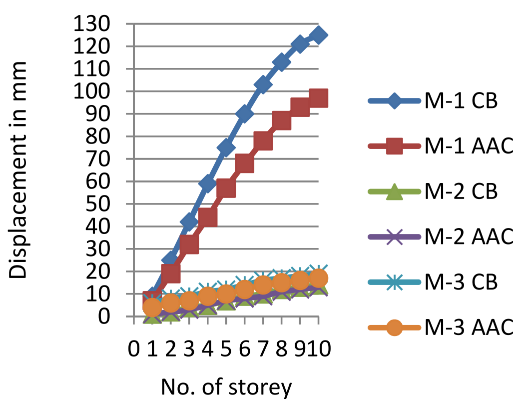

Chart-1: Displacement in X direction for all models

2. Storey drift (mm)

Storey drift in AAC block in every case is lower than Brick masonry. Model 1 shows highest storey drift then the other models. The decrease in the storey drift in AAC block masonry is found 29% in case 1 for bare frame model ,6% in case 2 for full infill masonry and 10 % in case 3 for full infill ground soft storey.

Table-3: Storey drift (mm) at Various Storey Level

Storey	Brick masonry			AAC block masonry		
	Bare Frame	Infill frame	Infill with ground soft storey	Bare frame	Infill frame	Infill with ground soft storey
	M-1	M-2	M-3	M-1	M-2	M-3
10	0.001377	0.000239	0.000239	0.001165	0.000222	0.000222
9	0.002383	0.000369	0.000368	0.00192	0.000336	0.000335
8	0.003339	0.00047	0.000468	0.002616	0.000425	0.000425
7	0.004104	0.000533	0.000531	0.003168	0.000483	0.000482
6	0.004672	0.000563	0.00056	0.003577	0.000514	0.000513
5	0.005061	0.000563	0.00056	0.003857	0.00052	0.000519
4	0.005287	0.000538	0.000536	0.004017	0.000505	0.000505
3	0.005316	0.000491	0.000474	0.004034	0.000474	0.000464
2	0.004899	0.000432	0.000624	0.003714	0.000433	0.000587
1	0.002794	0.0003	0.001796	0.002117	0.000308	0.001336

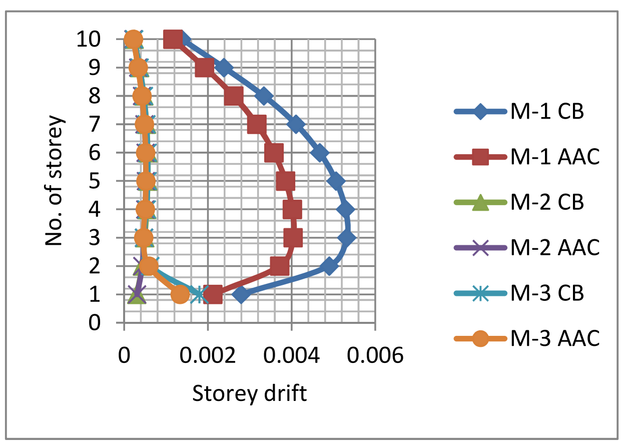

Chart-2: Storey drift in all models

3. Storey shear (KN)

The decrease in the storey shear in AAC block masonry is found 28% in case 1 for bare frame model ,35% in case 2 for full infill masonry and 34% in case 3 for full infill ground soft storey.

Table-4: Storey shear at Various Storey Level

Storey	**Brick masonry**			**AAC block masonry**		
	Bare Frame	**Infill frame**	**Infill with ground soft storey**	**Bare frame**	**Infill frame**	**Infill with ground soft storey**
	M-1	**M-2**	**M-3**	**M-1**	**M-2**	**M-3**
10	672.85	725.79	722.5	618.22	636.42	635.08
9	672.85	725.79	722.5	618.22	636.42	635.08
9	1514.92	1653	1645.52	1225.5	1272.26	1269.56
8	1514.92	1653	1645.52	1225.5	1272.26	1269.56
8	2180.25	2385.61	2374.82	1705.33	1774.64	1770.89
7	2180.25	2385.61	2374.82	1705.33	1774.64	1770.89
7	2689.64	2946.52	2933.19	2072.7	2159.28	2154.72
6	2689.64	2946.52	2933.19	2072.7	2159.28	2154.72
6	3063.89	3358.61	3343.42	2342.6	2441.88	2436.71
5	3063.89	3358.61	3343.42	2342.6	2441.88	2436.71
5	3323.79	3644.79	3628.3	2530.03	2638.12	2632.54
4	3323.79	3644.79	3628.3	2530.03	2638.12	2632.54
4	3490.12	3827.94	3810.62	2649.99	2763.72	2757.87
3	3490.12	3827.94	3810.62	2649.99	2763.72	2757.87
3	3583.69	3930.97	3913.18	2717.46	2834.37	2828.37
2	3583.69	3930.97	3913.18	2717.46	2834.37	2828.37
2	3625.27	3976.76	3958.76	2747.45	2865.77	2859.7
1	3625.27	3976.76	3958.76	2747.45	2865.77	2859.7
1	3635.66	3988.2	3969.65	2754.95	2873.62	2867.37

4. Base shear (KN)

Table-5: Base shear for various models

MODEL	**V_B in X Direction (KN) (BRICK infill)**	**V_B in X Direction (KN) (AAC infill)**
M-1	3635.66	2754.95
M-2	3988.2	2873.95
M-3	3969.65	2867.37

5. Axial forces (KN)

For comparison column C1 has been chosen and the axial forces at the mid height of column C1 are found which are presented below.

Table-6: Axial forces at Various Storey Level in column C1

Storey	**Brick masonry**			**AAC block masonry**		
	Bare frame	**Infill frame**	**Infill with ground soft storey**	**Bare frame**	**Infill frame**	**Infill with ground soft storey**
	M-1	**M-2**	**M-3**	**M-1**	**M-2**	**M-3**
10	195.61	352.23	352.97	167.34	266.99	267.46

9	471.85	771.56	773.17	365.72	556.98	557.98
8	721.98	1162.15	1164.76	544.13	825.63	827.2
7	951.27	1529.37	1533.09	707.28	1077.3	1079.49
6	1162.68	1875.09	1880.02	857.15	1313.05	1315.9
5	1359.48	2200.56	2206.84	996.08	1533.74	1537.31
4	1544.34	2505.93	2513.51	1125.92	1739.45	1743.75
3	1719.75	2790.16	2801.33	1248.47	1929.53	1935.63
2	1890.83	3052	3035.59	1367.46	2102.97	2090.94
1	2072.06	3280.1	3279.27	1493.86	2254.83	2263.63

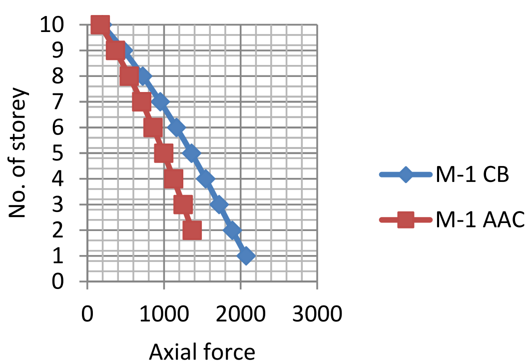

Chart-3: Axial force in bare frame

6. Bending moment (KN-m)

For comparison Beam B1at every floor has been selected and the Bending moment at a distance 0.25m from the end is found out and results are presented below in the form of bar chart. The all Bending moments are shown here in the table with (-) sign but for comparison point of view only amplitude is considered.

Table-7: BM (KN-m) at various storey level in Beam B1

Storey	**Brick masonry**			**AAC block masonry**		
	Bare Frame	**Infill frame**	**Infill with ground soft storey**	**Bare frame**	**Infill frame**	**Infill with ground soft storey**
	M-1	**M-2**	**M-3**	**M-1**	**M-2**	**M-3**
10	86.794	71.912	71.961	73.699	63.063	63.105
9	123.786	106.98	107.041	95.357	83.308	83.359
8	119.453	106.355	106.417	91.016	81.603	81.655
7	117.78	107.855	107.921	89.709	82.556	82.611
6	114.505	108.373	108.447	86.931	82.497	82.556
5	110.5	108.55	108.63	83.621	82.192	82.255
4	105.602	108.25	108.35	79.592	81.48	81.555
3	99.66	107.326	107.363	74.749	80.262	80.308
2	93.436	106.289	107.143	69.644	78.967	79.436
1	83.244	103.765	93.116	61.599	76.109	68.528

V. CONCLUSIONS

The following conclusions can be enumerated point wise as follows:

1. From the results, it has been noticed that displacement of the structure with AAC block in all the three Model cases is found less than that of conventional brick masonry.

2. When displacement results of Model 1 and Model 2 in the both type of masonry infill as AAC blocks and brick infill are compared,

Model 2 is preferred than Model 1 because displacement is least in case of Model -2. This is because, In Model 2 strength and stiffness of the masonry panel is considered by modeling infill panel as equivalent diagonal strut which reduces the lateral deflection of the structure.

3. The results of Model 2 and Model 3 are comparable with very less increase in displacement in Model 3 compared to Model 2 because of soft ground storey.

4. From the results, it can be observed that storey drift of the structure is found less in AAC block masonry infill in all the three model cases with the corresponding model cases of brick masonry. Model 1 shows highest storey drift then the other models in both types of masonry infill panels.

5. Storey drift in model 2 is less than model 1 and 3 because stiffness is taken into consideration in model M-2. The results of model 2 and model 3 are comparable expect ground storey. The storey drift of first storey in model M-3 is very large than the upper stories due to absence of infill walls in the first storey.

6. It is observed from the results that storey shear with AAC is significantly less as compared to brick masonry infill panel. It is because of light weight of AAC blocks.

7. Model M-2 has more storey shear than M-1 and M-3 because Storey shear is depend on stiffness of the frame. The struts in masonry infill resist the lateral seismic forces through axial compression along the strut. The contribution of infill increases the stiffness of the frame this resulting increase in seismic forces. Model M-1 has the least value of storey shear with both type of infill materials because stiffness has not been considered in case M-1.

8. Base shear in case of AAC block masonry is also less in all the three models compared to brick masonry panels. This is because of light weight of AAC blocks. Less base shear results lesser lateral forces. Due to reduced base shear, member forces are also reduced which leads to reduction in amount of area of steel in various members

9. Base shear in model 2 is more than model 1 and model 3 because of increased mass of structure.

10. From the results it is observed that axial forces in columns are reduced with AAC block masonry than that of conventional brick masonry. Axial Force is found maximum at the foundation level.

11. Masonry infill increases the axial forces in columns and it can be seen from the results also that axial forces are min. in model M-1 because in this model stiffness is not considered, only load of the infill is considered. Due to presence of infill the stiffness also increases in frame with increase of axial forces in column.

12. The bending moment and shear forces in beam members of AAC block masonry structure is found less as compared to brick masonry.

13. As the density of AAC block masonry is less ($1/3^{rd}$ of brick) as compared to brick masonry, the dead load of the structure is reduced in AAC block masonry and hence economy may be achieved in design by replacing brick masonry with AAC block masonry.

14. From all the analysis results it is found that seismic analysis should be performed by considering the infill walls in analysis. Due to presence of infill wall, stiffness of the reinforced concrete frame increases and infill wall changes frame action of a moment resisting frame to a truss action which affect the seismic response of the building.

15. From all the results it can also be concluded that if infill is not considered in the design then seismic analysis of the bare frame structure will lead under estimation of base shear and this will lead to collapse during earthquake.

Thus the AAC blocks masonry perform superior to that of brick masonry therefore AAC blocks can be used to replace the conventional brick masonry which is usually used in India in seismic prone area. It also concluded that seismic analysis should be performed by considering the infill walls in analysis. Due to presence of infill wall, stiffness of the reinforced concrete frame increases and decrease in displacement, storey drift will occur.

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