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A STUDY OF EFFECT OF INFILL MATERIAL ON SEISMIC PERFORMANCE OF RC BUILDINGS

Ms. Rajashri A. Deshmukh [*], Dr. P. S. Pajgade
[*]Student, Department of Civil engineering, Prof. Ram Meghe Institute of Technology and
Research Badnera, Amravati, Maharashtra 444701 India
Professor, Department of Civil engineering, Prof. Ram Meghe Institute of Technology and Research
Badnera, Amravati, Maharashtra 444701 India

ABSTRACT

The construction of RC buildings with unreinforced infill wall is a regular practice in India. Infill panels have usually been made of heavy rigid materials, such as clay bricks or concrete blocks. However, more lightweight and flexible infill options such as AAC (aerated light weight concrete) blocks are now obtainable in India to be used as masonry infill (MI) material in reinforced concrete (RC) framed buildings. It has been accepted that infill materials considerably influence the seismic performance of the infilled framed structures. Number of researchers studied the behaviour of infilled RC frames experimentally and analytically. Most of the research work carried out in this area was paying attention on parameters such as the variation of distribution of masonry infill and the stiffness of frame elements. Though it has been implicit that the infill's play important role in enhancing the lateral stiffness of complete structures. There are plenty of researches done so far for infilled frames, however variation in infill materials are still the topic of interest. In the present study an investigation has been made to study the behaviour of RC frames with both AAC block and conventional clay bricks infill with varying percentage of opening subjected to seismic loads.

KEYWORDS: *AAC blocks, diagonal strut, infill wall with opening, ETABS v 9.6.0*

INTRODUCTION

Earthquakes represent the largest potential source of causalities and damage for inhabited areas due to natural hazard. Although the location varies, the pattern is the same: an earthquake strikes without warning, leaving cities in rubble and killing tens to thousands of people. They can cause landslides and slips however the majority of earthquake related deaths are due to failures of buildings. This is the reason why earthquake study is so important, as it is the only way in which engineers will fully understand how buildings and structures behave. Masonry walls are provided for functional and architectural requirements in RC structures. The term infilled frame is used to represent a composite structure formed by the combination of a moment resisting RC frame & Infill walls.

It has been accepted that infill materials considerably influence the seismic performance of the infilled framed structures. Number of researchers studied the behavior of infilled RC frames experimentally and analytically. Most of the research work carried out in this area was paying attention on parameters such as the variation of distribution of masonry infill and the stiffness of frame elements. Though it has been implicit that the infill's play important role in enhancing the lateral stiffness of complete structures. The study of the effect of types of infill materials used on the seismic performance of infilled RC frames is however still inadequate. There are plenty of researches done so far for infilled frames, however variation in infill materials are still the topic of interest.

Infills have been commonly measured as non-structural elements & their influence was ignored during the modeling phase of the structure, leading to significant inaccuracy in predicting the actual seismic response of framed structures. The performance of the structure can be considerably improved by the increase in strength and dissipation capacity due to the masonry infill's even if it is increasing in earthquake inertia forces.

Autoclaved Aerated Concrete Block

As the infill wall is inseparable aspect of our construction in India. Being a tropical country we required high insulating partition material. Now a day's green buildings and eco friendly material is widely chosen by designers and owners. One of the most famous eco-friendly materials used is AAC blocks as a replacement to traditional masonry infill material. AAC (Autoclaved Aerated Concrete) block is an infill material developed by an architect Dr. Johan Eriksson in 1923 at the Royal Technical Institute in Stockholm, Sweden, and was patented for manufacturing in 1924. These are light-weight and pre-cast building materials that simultaneously provide structure, insulation, and fire resistance. One of the major advantages of AAC over other cementacious construction materials is its lower impact on environment. It has no efflorescence emission (white salt appearance) at large. It is highly thermal insulating product used for both internal and external construction. It is easy and quick to install since the material can be routed, and cut to size on site using standard carbon steel band saws, hand saws, and drills.AAC production industry is growing rapidly in Asia due to strong demand in housing and commercial space. China, Central Asia, India, and the Middle-East are the biggest markets in terms of AAC manufacturing and consumption.

Fig.-1-AAC Blocks

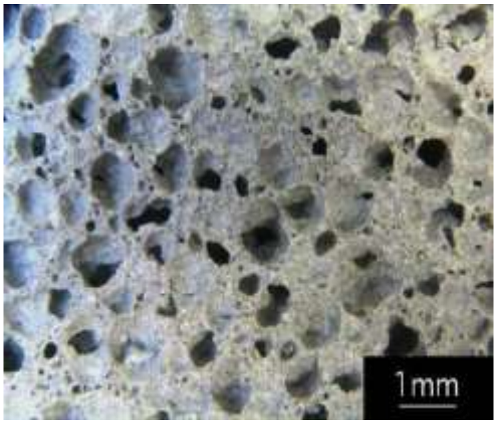

Fig.2-Porous structure of AAC Block

From the existig literature it was observed that the study of the effect of different type of infill materials used on the seismic performance of in-filled RC frames is however still limited. Now a day's use of this lightweight AAC block increased tremendously but the research done on AAC block infilled structures is insufficient .A very limited research work has been done on the performance of RC structures with AAC blocks. This clearly indicates the need for more attention, mainly on the in-plane behavior of AAC block masonry infilled subjected to lateral loads.

Seismic Analysis of RC Frames with infill walls

While analyzing multi storey buildings, designers usually neglect the contribution of masonry infill in resisting loads. They consider only dead weight of masonry and analysis is done by bare frame method. It is very common now days to construct multi-storyed buildings with open ground storey. Since there is a sudden change in stiffness at first floor level, ground floor columns will attract greater horizontal force and hence they should be designed for a larger force than that obtained using bare frame analysis. As per IS 1893:2002, the columns and beams of the soft storey are to be designed 2.5 times the storey shears and moments calculated under seismic loads.

Masonry infill walls are laterally much stiffer than the RC frames, and therefore, the initial stiffness of the masonry infilled RC frames largely depends upon the stiffness of masonry infill walls. Accordingly, it is quite important to have a reliable method to estimate the stiffness of the MI walls. Investigations showed that, one of the most appropriate ways of analyzing the masonry infilled concrete frames is to use single equivalent diagonal strut.

Determination of equivalent strut width gives a chance to estimate the behavior of infilled frame. With known value of equivalent width, the strength and the stiffness of frame with infill wall may be included in the lateral load resistance of the structure. More than one parameter affects the equivalent strut width. First one is geometric properties of infill. Panel proportion and panel height are important parameters.

The NEHRP Guidelines for the seismic rehabilitation of buildings FEMA-273, 1997 is an extensive document for use in the design and analysis of seismic rehabilitation projects. FEMA-273 includes design criteria, analysis methods, and material specific evaluation procedures. Section 7.5 addresses masonry infills systems. FEMA-273 specifies that masonry infill panels shall be represented as equivalent diagonal struts.

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf} \quad \text{….Eqn. 1}$$

Where,
λ= Coefficient used to determine equivalent width of infill strut which is given by equation 2.

$$\lambda_1 = \left[\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}}\right]^{\frac{1}{4}} \quad \text{…..Eqn. 2}$$

Where

hcol= Column height between centerlines of beams, in.
hinf= Height of infill panel, in.
Efe = Expected modulus of elasticity of frame material, psi
Eme = Expected modulus of elasticity of infill material, psi
Icol= Moment of inertia of column, in4
Linf= Length of infill panel, in.
rinf= Diagonal length of infill panel, in.
tinf = Thickness of infill panel and equivalent strut, in.
θ = Angle whose tangent is the infill height-to-length aspect ratio, radians

Infills Frame With Opening

Area of opening, Aop is normalized with respect to area of infill panel, Ainfill and the ratio is termed as opening percentage (%)

$$\text{Opening percentage (\%)} = \frac{\text{Area of openning } (A_{op})}{\text{Area of infill}(A_{infill})}$$

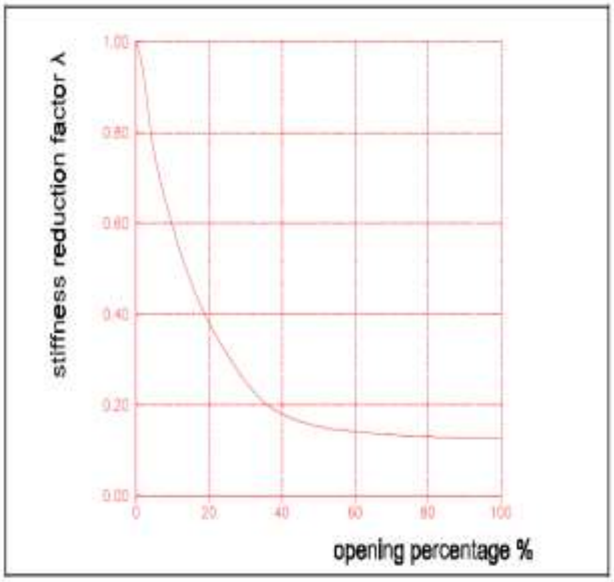

Fig.3-Stiffness Reduction Factor λ'for Infilled Frame In Relation To Opening Percentage

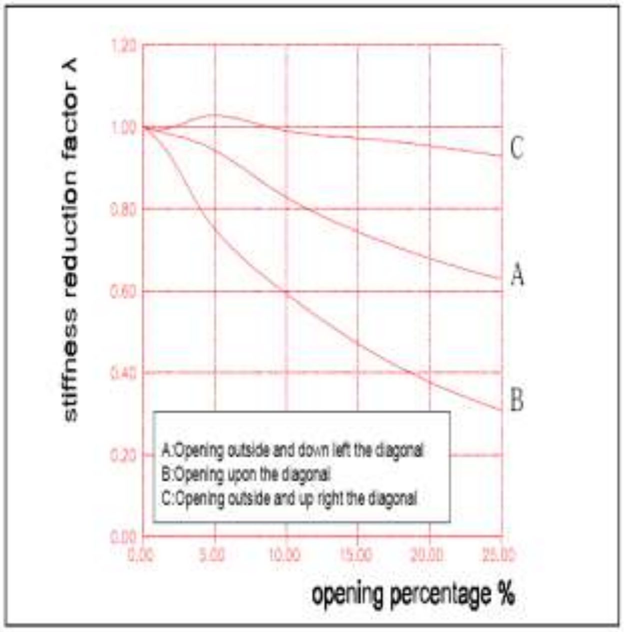

Fig.4-Stiffness Reduction Factor λ' Of The Infilled Frame In Relation To The Opening Percentage (A,B,C)

Analysis of the frame

The following load combinations are considered in the analysis as per IS: 1893-2002.

$$1.5(DL+IL)$$
$$1.2(DL+LL\pm EL)$$
$$1.5(DL\pm EL)$$
$$0.9Dl\pm 1.5EL$$

The above equations, DL is self-weight of beams, columns, slab, floor finish and infil; and IL is imposed load. As per IS: 1893-2002, the design base shear V_B on the frame is given by,

$$V_{B=}WA_h \qquad \text{......Eqn. 3}$$

Where, W is the seismic weight of the building, which is calculated as full DL plus 25% of IL if IL is less than 3 kN/m^2, else 50% of it. A_h is the design horizontal seismic coefficient, which is calculated as below.

$$A_h = \frac{Z\,I\,S_a}{2\,R\,g} \qquad \text{......Eqn. 4}$$

Where,
z = Zone factor, which is 0.10, 0.16.0.24 and 0.36 for zone II, III, IV and V respectively.
I = importance factor taken as 1.0 for residential building;
R = response reduction factor taken as 5.0 for special RC MRFs when detailed as per IS 13920
Sa/g = Average response acceleration coefficient

The design lateral force *Q*, at the floor *i* is obtained by

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{N} W_j h_j^2} \qquad \text{......Eqn. 5}$$

Analysis Example

For this study, a G+5 building with 3.2 meters height for each storey, regular in plan is modeled. The rectangular plan of all buildings measures 19m x 11m. This building consists of five spans in X direction and three spans in Y direction. Infill walls were modeled using two different materials. These buildings were designed in compliance to IS-1893:2002-Indian Code of Practice for Seismic Resistant Design of Buildings.

The buildings are assumed to be fixed at the base and the floors acts as rigid diaphragms D1. The sections of structural elements are rectangular and their dimensions are changed for different buildings. Storey heights of buildings are assumed to be constant including the ground storey. The plan of the building model are given in fig.5.

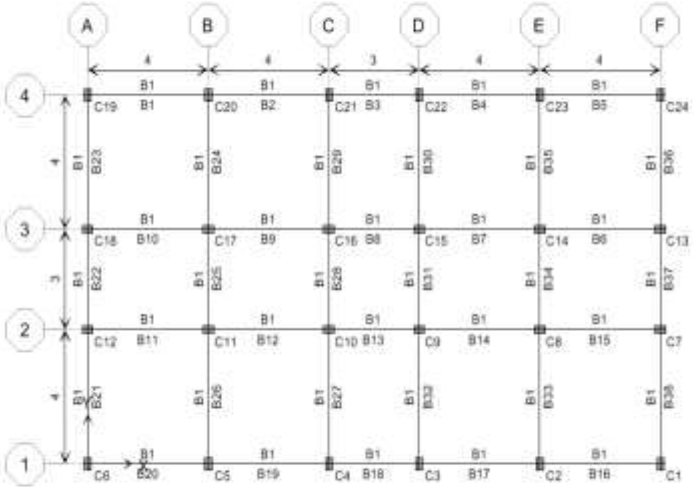

Fig.5-Plan of building

Table 1. Structural Details of Model

TYPE OF STRUCTURE	COMMERCIAL BUILDING (G+5)
ZONE	III (Moderate Zone Z= 0.16)
FOUNDATION LEVEL TO GROUND LEVEL	2 M
FLOOR TO FLOOR HEIGHT	3.2 M
HEIGHT OF BUILDING	21.2 M
GRADE OF CONCRETE	M25
EXTERNAL WALL	230 MM
LIVE LOAD	4 kN/M2
MATERIAL	M25 AND Fe415
SIZE OF COLUMN	C1= .230X.350 M ,C2=.230X.400 M
SIZE OF BEAM	B1=0.230X0.350 M
DEPTH OF SLAB	150 MM

The analysis has been carried out for dead load (DL), live load (LL), and earthquake load by standard computer package ETABS v 9.6.0. The combinations of the above loads have been made according to CL 6.3 of IS1893-2002.

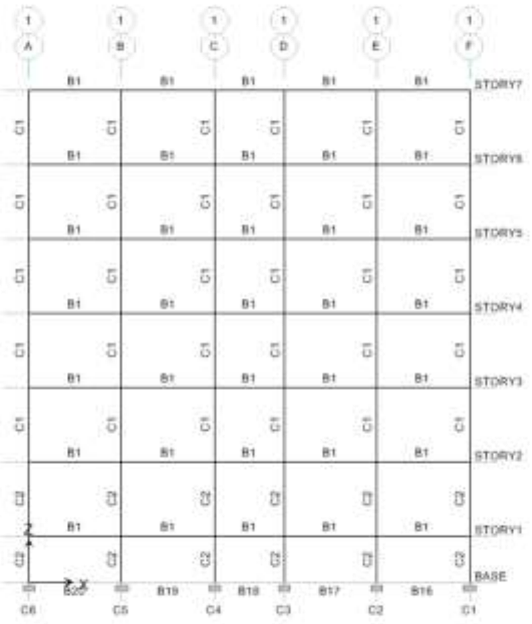

Fig.6-Elevation for Bare Frame Model

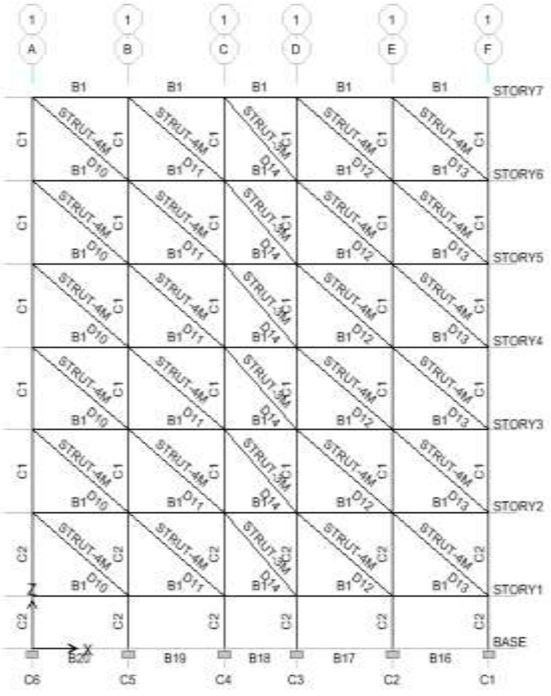

Fig.7-Elevation for Infilled Frame Model

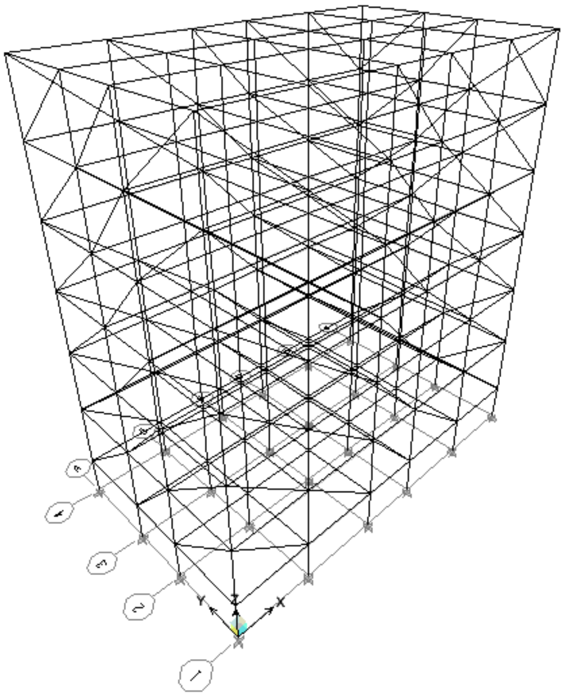

Fig.8- 3D-view of Infilled Model

In this study G+5 (21.2 m high) model located in zone III are analyzed for brick masonry and AAC masonry. For modeling different cases are considered ,which are as described below

i. Case A: Bare frame with considering loading of infill but the stiffness of infill is ignored.
ii. Case B-1: Frame (fully infilled by brick masonary) in which the load and stiffness of infill is taken into consideration.
iii. Case B-2: Frame (fully infilled by brick masonary & 15 % opening below diagonal) in which the load and stiffness of infill is taken into consideration.
iv. Case B-3: Frame (fully infilled by brick masonary & 15 % opening on diagonal) in which the load and stiffness of infill is taken into consideration.
v. Case B-4: Frame (fully infilled by brick masonary & 20 % opening below diagonal) in which the load and stiffness of infill is taken into consideration.
vi. Case B-5: Frame (fully infilled by brick masonary & 20 % opening on diagonal) in

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which the load and stiffness of infill is taken into consideration.

vii. Case C-1: Frame (fully infilled by AAC Block masonary) in which the load and stiffness of infill is taken into consideration.

viii. Case C-2: Frame (fully infilled by AAC Block masonary & 15 % opening below diagonal) in which the load and stiffness of infill is taken into consideration.

ix. Case C-3: Frame (fully infilled by AAC Block masonary & 15 % opening on diagonal) in which the load and stiffness of infill is taken into consideration.

x. Case C-4: Frame (fully infilled by AAC Block masonary & 20 % opening below diagonal) in which the load and stiffness of infill is taken into consideration.

xi. Case C-5: Frame (fully infilled by AAC Block masonary & 20 % opening on diagonal) in which the load and stiffness of infill is taken into consideration.

RESULTS

a)Base Shear

It has been observed that brick case 1(B-1) model was 510.89 kN whereas for AAC case 1(C-1) model it was 394.72 kN which is 77.26 % of brick case 1. Also the base shear for model case 3(B-3) with bricks infill panel with 15 % opening on diagonal was 418.60 kN whereas for model with AAC infill panel(C-3) it was 305.39 kN which is 72.96 % of brick case 3(B-3). The seismic weight of brick case 1(B-1) model is 17242.26 kN whereas it is 13499.77 kN for AAC case 1(C-1) model. Thus the lateral forces experienced by model with AAC infill panel are less as compared with model with conventional clay bricks. Also the dead load on building with AAC infill panels is less as compared to model with bricks infill panels.

Table 2-Base shear for various models with brick infill panels and AAC infill panels

Case	V_B in X Direction (kN) (Brick infill)	V_B in X Direction (kN) (AAC infill)
WALL WITHOUT OPENING	510.89	394.72
15 % OPENING BELOW DIAGONAL	470.70	349.51
15 % OPENING ON DIAGONAL	418.60	305.39
20 % OPENING BELOW DIAGONAL	457.52	340.76
20 % OPENING ON DIAGONAL	385.45	286.50

b)Design lateral force and story shear

The design lateral force in X -direction for Case brick infill case -1(B-1) & AAC infill case-1 (C-1) is shown in figure 9.

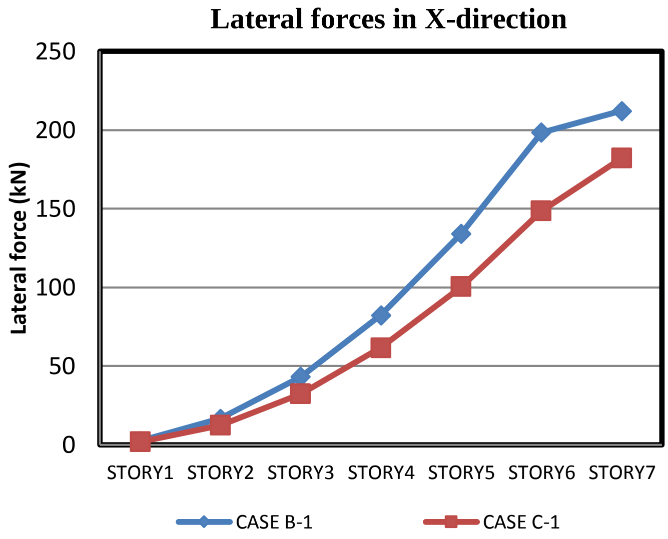


Fig.9 Design lateral force in X-direction

In the case of brick case 1(B-1) model predicts the maximum lateral force of about 212.27 kN at the terrace level which is reduced by about 14.12 % to about 182.30 kN in the case of AAC case 1(C-1)model. Thus due to lesser weight of AAC blocks the lateral forces generating on building with AAC blocks is less as compared with brick infill panels.

c)Displacement

The effect of infill on the lateral displacement was studied for all the cases. The lateral displacements in X- direction are presented in fig. 10.

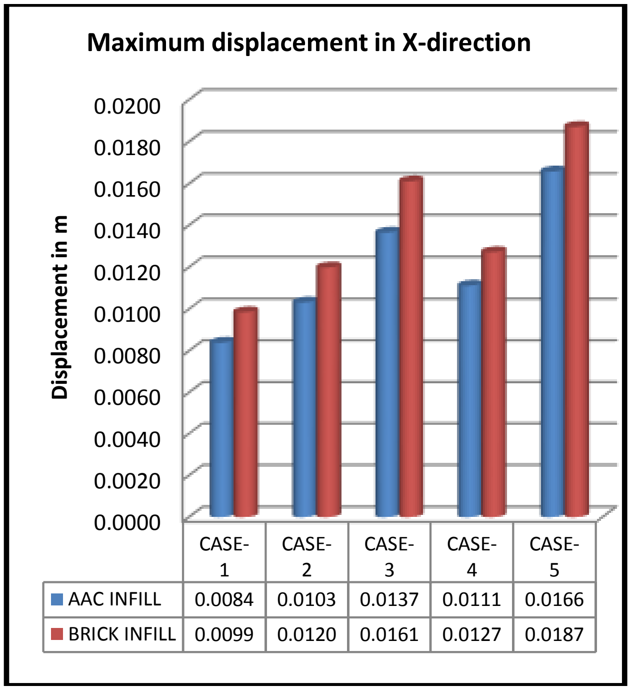


Fig. 10 Maximum Lateral displacement and in X-direction

Figure 10 show the comparative study of lateral displacement amongst all types of brick infilled model and AAC infilled frame model. The increase in the top displacement in brick case 2(B-2) model and brick case 3(B-3) model compared to brick case 1 (B-1)model was 82% and 61% respectively. Whereas the increase in the top displacement in AAC case 2 (C-2)model and AAC case 3(C-3) models compared to AAC case 1(C-1)model was 81.2 % and 61.4 % respectively.

Figure 11 show the comparative study of lateral displacement at every story levels amongst AAC infilled model all cases. The curves represent displacement in cases C-1, C-2, C-3, C-4 & C-5 at each story level. AAC case 2 (C-2)model with 15 % opening below diagonal and AAC case 3(C-3) model with 15 % opening on diagonal compared to AAC case 1 (C-1)model displacement increased by 18% and 38 % respectively. AAC case 4(C-4) model with 20 % opening below diagonal and AAC case 5 (C-5)model with 20 % opening on diagonal compared to AAC case 1 (C-1)model displacement increased by 24 % and 49 % respectively. The results obtained from analysis shows opening below diagonal shows better result than opening on diagonal.

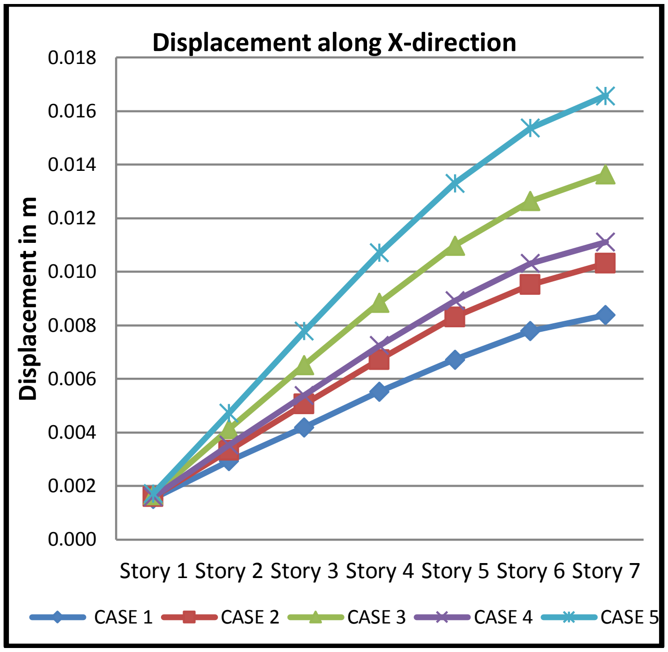


Fig. 11 Displacement in X-direction

d) Member forces

The effect of infill on forces acting on members was studied. In general the axial force in model with AAC infill panel was found to be less as compared with model with brick infill panels. The results obtained for all the models were compared for major and minor bending moments in columns. Thus, the effect of infill panel is to change the predominantly a frame action of a moment resisting frame system towards truss action. The floor wise axial forces for the column C1 for the seismic load case are presented in Table 3.

Table 3 Axial forces for column C1 for seismic load cases

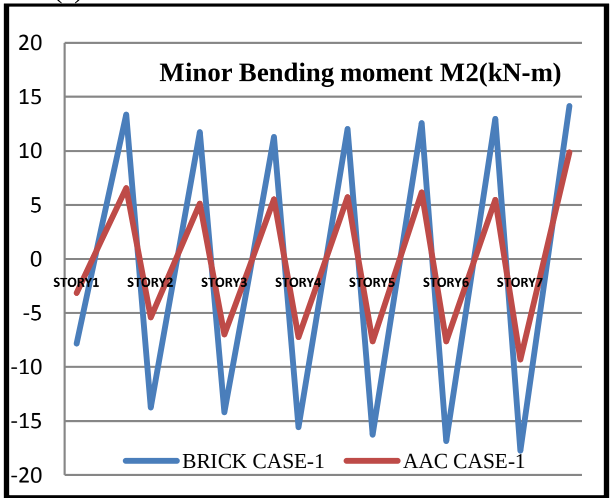
Story No.	Axial force brick case 1 (kN)	Axial force AAC case 1 (kN)
STORY 7	93.80	73.26
STORY 6	271.37	191.10
STORY 5	445.39	308.27
STORY 4	615.60	408.53
STORY 3	781.03	505.19
STORY 2	939.12	596.04
STORY 1	1098.75	674.47

For the bottom floors where the axial force is large, model with AAC infill showed 38.61 % decrease in axial force. Whereas at the 3rd floor there was a decrease of 35.32 % for model with AAC infill panel as compared with the model with AAC infill panels. Whereas at the Top floor there was a decrease of 21.90 % for model with AAC infill panel as compared with the model with AAC infill panels.

e) Bending moments in columns

To study the effect of infill panels on the member force of a moment resisting RC frame structure. One typical column was selected for the study; C1 column. The bending moment M2 & M3 in column C1 for various cases are presented in Figure 12.

(a) Brick case 1 vs AAC case 1



(b) Brick case 1 vs AAC case 1

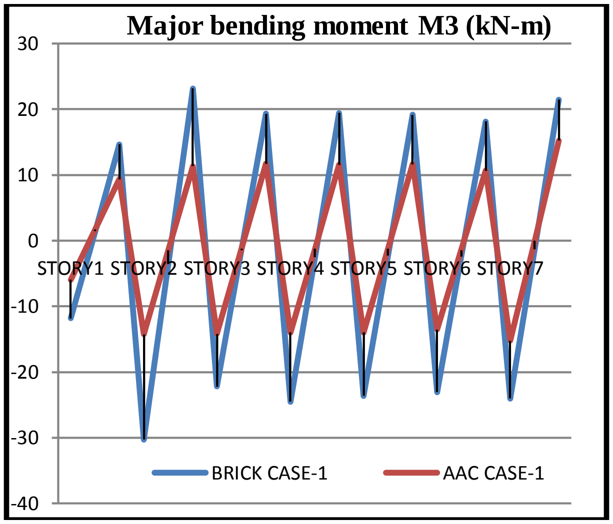


Fig. 12 Comparison of M2 & M3 in column C1

In the case of C1 column, brick case 1(B-1) model predicts the maximum moment of about 17.754 kN-m at the top floor which is reduced by about 47 % to about 9.33 kN-m in the case of AAC case 1(C-1) model. Whereas in the case brick case 1(B-1) model predicts the maximum moment of about 13.361 kN-m at the bottom floor which is reduced by about 51 % to about 6.54 kN-m in the case of AAC case1 (C-1)model.

CONCLUSION

This work is a small attempt towards the understanding of the effect of AAC infill masonry and brick infill masonry on the seismic behavior of RC structures. In this work, the seismic behavior of brick infill panels and AAC infilled panel was studied and compared in a systematic manner.The main conclusions are summarized below:

i. The bare frame for all models showed lower strength, initial stiffness and ductility, as compared to fully infilled models.

ii. In column, considering AAC infill wall effect, the value of axial force, bending moment, Ast is less compared to brick infill frame. Because of infill wall effect, there is drastic decrease in the value of axial force in column. Maximum Axial Force is at the foundation level

iii. The effect of infill wall is to change the predominantly a frame action of a moment resisting frame structure towards a truss action.

iv. It has been observed that the base shear, lateral forces and story shear for a structure with AAC blocks is significantly less as compared with the structure infilled with brick masonry due to low weight density of AAC blocks. Lesser base shear will result in lesser lateral forces and as the weight density of AAC blocks is less as compare with brick masonry the dead load of AAC block masonry is less as compared brick masonry and hence economy in design can be achieved by replacing brick masonry with AAC block masonry.

v. The deflection and drift of structure with AAC block in all cases was less as compared with the corresponding cases of structure with brick masonry.

vi. The Axial force in columns is significantly reduced for structure with

AAC block masonry as compared with the structure with brick masonry.

vii. The response of a structure in terms of bending moments is greatly improved in an infill model. The bending moments is reduced greatly by the introduction of infill panels. The bending moments for members of structure with AAC block in all cases were less as compared with corresponding cases of structure with brick masonry.

In general, The performance of AAC block infill was found to be superior to that of Conventional brick infill in RC framed structures. Therefore, the AAC block material can basically be used to replace conventional bricks as infill material for RC framed structures built in the earthquake prone region.

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