COMPARISON BETWEEN THE EFFECT OF LINTEL AND LINTEL BAND ON THE GLOBAL PERFORMANCE OF LOAD BEARING WALLS AND MASONRY INFILLED RC FRAMES

by

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COMPARISON BETWEEN THE EFFECT OF LINTEL AND LINTEL BAND ON THE GLOBAL PERFORMANCE OF LOAD BEARING WALLS AND MASONRY INFILLED RC FRAMES

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ABSTRACT

Improperly designed brick masonry walls cause undesirable effects under seismic loading in both brick masonry in-filled reinforced concrete (RC) frames and masonry load bearing wall structures. Doors and windows (openings) are unavoidable components in brick masonry in-filled RC structures and masonry load bearing wall structures because of its functional and ventilation requirements. The presence of openings in brick masonry walls reduces the lateral stiffness and strength of the wall in both RC and load bearing structures, which changes the actual behavior of structure. If these openings are located in the restricted zones like areas within middle two thirds of a wall wall, then the wall needs to be strengthened by providing necessary horizontal/vertical (bands) structural elements such as lintel or lintel bands around them. Lack of such structural elements may cause the structure to undergo severe damage during the earthquake event. In this paper, two case studies, (a) the presence of openings in infill wall with or without lintel and lintel band (b) the presence of openings in load bearing wall with or without lintel and lintel band is studied, to know the nonlinear response of brick masonry in-filled RC frame and load bearing wall under seismic loading. To understand the behaviour of the infilled frames and load bearing wall, a two dimensional (2D) infilled frame and load bearing wall is modeled and analyzed using a tool based on Applied Element Method (AEM). Nonlinear static pushover (SPO) is performed to estimate capacity of the models.

Keywords*:* Horizontal/Vertical bands, Non-Linear Static Pushover Analysis and Applied Element Method.

I. INTRODUCTION

Brick Masonry is primarily used as infill in framed structures or primary unit in load bearing structures. The in-plane shear resistance and the out-of-plane bending capacity of the walls are primary qualities of brick masonry to safeguard the structure during earthquake event. The shear and bending capacities of brick walls are, dependent on the ability of the horizontal mortar joints (bed joints) and the vertical mortar joints (head joints) to transfer the loads through the brick units; they also depend on mode of failure of the wall [13].

During strong ground motions, the brick masonry may lose its stability, leading to change in seismic behavior of a building as a whole. Various studies have been carried out to understand the behavior of brick masonry; but the effect of openings (i.e., Door(s) and window(s)) and presence of lintel or lintel bands above the openings are not much studied / rather neglected in the analysis and design procedures. In this paper, to study effect of openings in the brick masonry, full wall, with opening, with lintel and with lintel band models are considered with constant mechanical properties. Since inelastic behaviour is intended in most of the structures subjected to infrequent earthquake loading, the use of nonlinear analysis is essential to capture the behaviour of brick masonry under seismic effects. Therefore nonlinear static procedure is adopted in this study.

II. METHODOLOGY

a) AEM

For the purpose of modeling lintel and lintel beam, discrete element approach i.e., Applied Element Method (AEM) [17] is used. Applied Element Method was first developed by Tagel-Din Hatem [17] on RC frames and later continued by Bishnu Pandey [15] for its applicability to brick masonry units. In this methodology, the brick masonry is considered as combination of brick units and mortar units. The interaction between the brick units and the masonry units is established with the help of assumed virtual pair of springs in two directions; one normal and the other shear as shown in (Fig.1.(a)). Each spring is defined with a failure criteria specified on principal stresses (Fig.1. (b)). The forces/stresses in the elements are calculated using the forces/stresses in springs connected between them. The global stiffness matrix generated using connectivity matrix is used to calculate the deformation in three degrees of freedom defined at the centre of each element for a 2D problem.

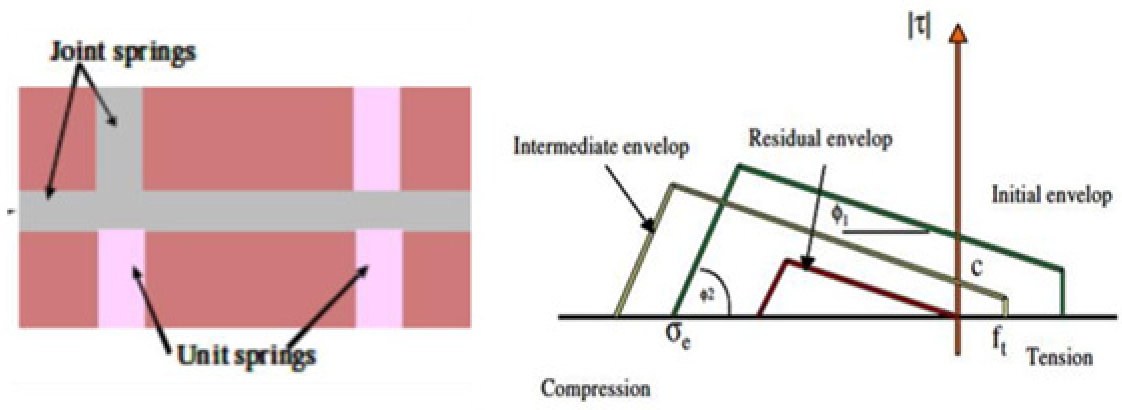


Fig.1. (a) Discretization of brick masonry using unit springs and joint/mortar springs (b) Failure criteria for joint/mortar springs

b) Pushover Analysis

The Pushover analysis (POA) is an incremental static analysis used to determine the force displacement relationship, or the capacity curve for a structure. The analysis involves applying horizontal loads, in a prescribed pattern onto the structure incrementally; pushing the structure and plotting the total applied lateral force and associated lateral displacement at each interval, until the structure achieves predefined target. A plot of the total base shear versus roof displacement in a structure is obtained from this analysis would indicate any premature failure or weakness.

In present study, Displacement controlled POA is carried out on eight AEM based models; with a target displacement of 0.048m (1.5% drift) is applied in positive x direction which is distributed [3] as shown in Fig.2 and 3, to know the performance and damage pattern of brick masonry.

III. NUMERICAL MODELING

In this study, two cases (a) a single bay single storied non-ductile in-filled RC frame, (b) Masonry load bearing wall, are considered and for each of the case further four different cases are considered as shown in Fig.2 & 3.

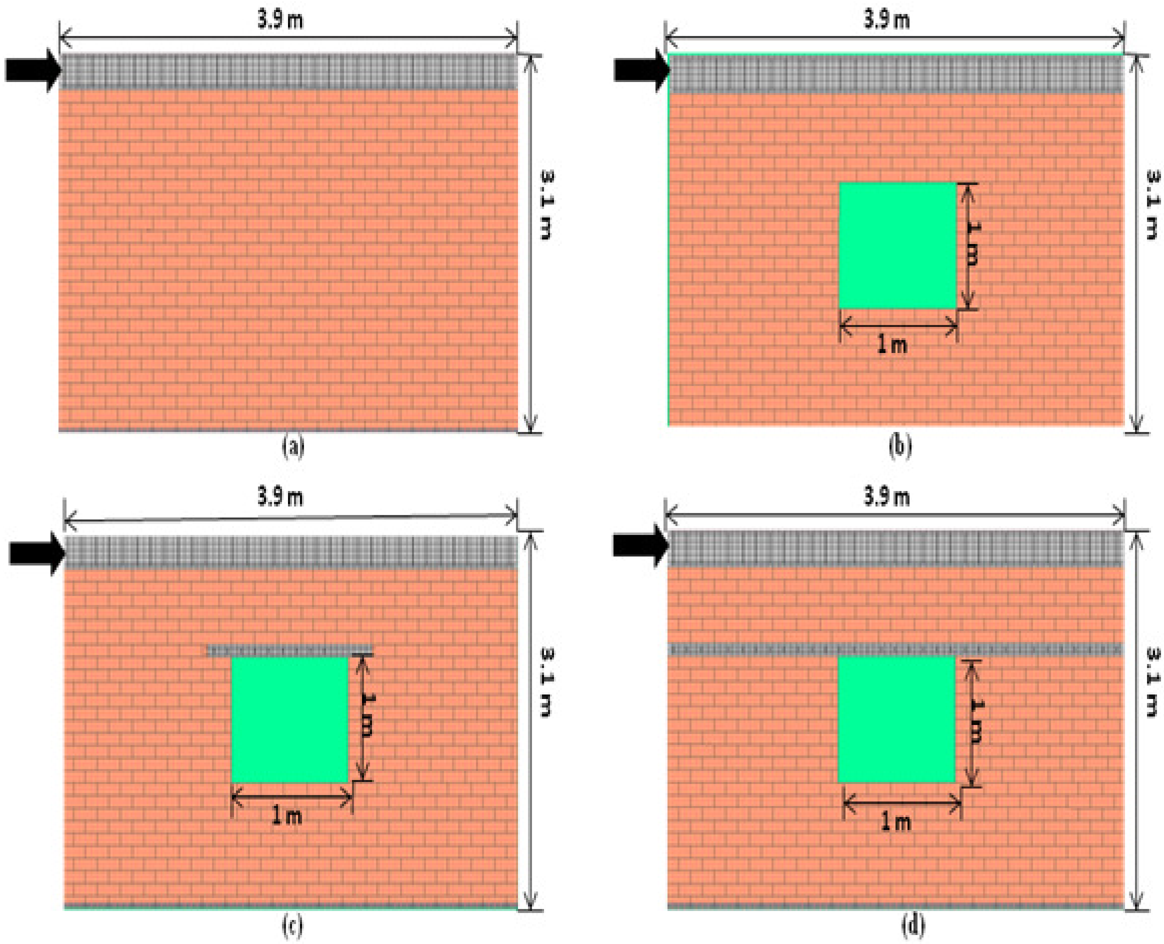


Fig.2. AEM based models of load bearing wall (a) Full wall (b) with opening (c) with lintel above opening (d) with lintel band above opening

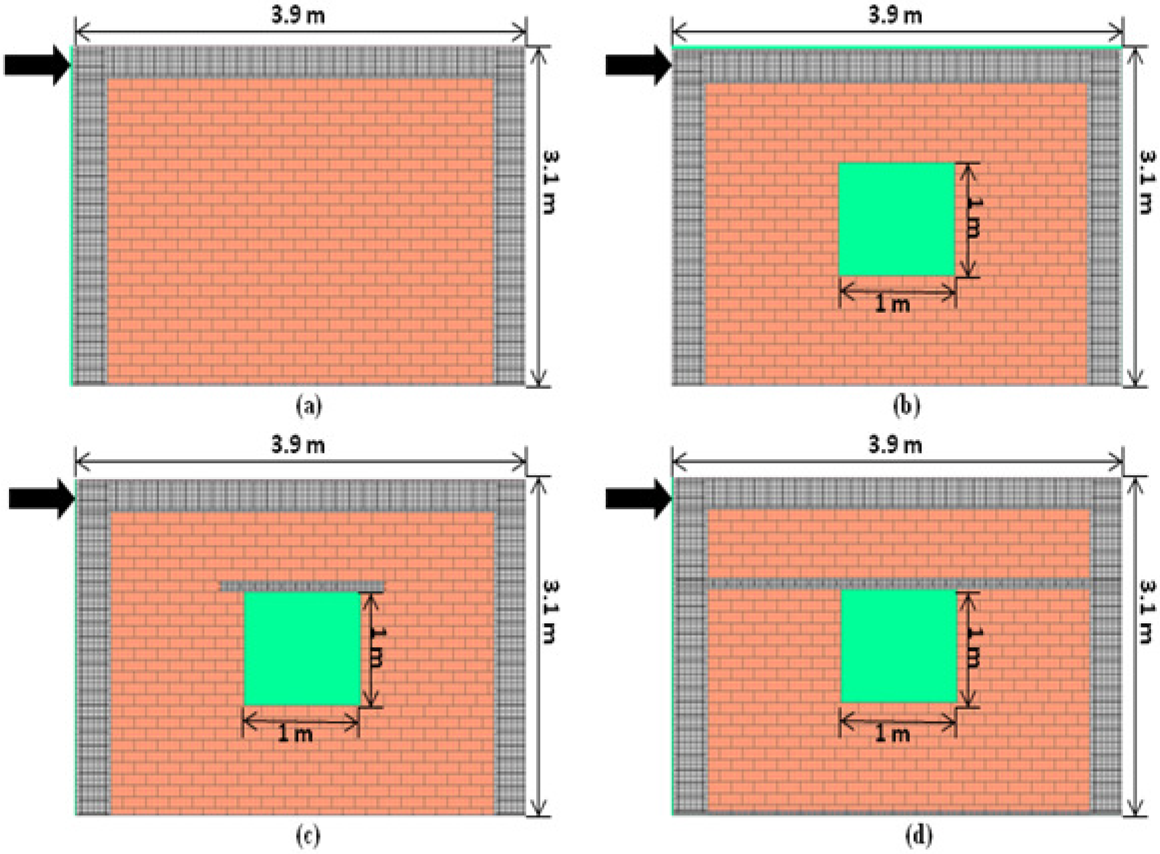


Fig.3. AEM based models of RC masonry infilled frame (a) full wall (b) with opening (c) with lintel above opening (d) with lintel band above opening

Table 1: Material Properties

S.No	Material Type	Properties
1.	Grade of concrete for Beams, Columns and Slab	M 25
2.	Grade of concrete for Lintel	M 15
3.	Grade of steel	Fe 415
3.	Brick Compressive strength (MPa)	5
4.	Young's Modulus of Elasticity of brick E_b (N/mm^2)	3.38E6
5.	Mortar Compressive strength (MPa)	3.5
6.	Mortar Thickness (mm)	10
7.	Friction [14]	0.75
8.	Cohesion of masonry (MPa) [14]	0.25

Table 2: Geometry of the Structure

S.No	Element Type	Geometry
1.	Beam Dimension	0.23 m x 0.3m
2.	Column Dimension	0.3m x 0.3m
3.	Lintel Dimension	0.23m x 0.1m
4.	Wall Thickness	0.23m
5.	Slab Thickness	0.1m

IV. RESULTS AND INTERPRETATION

In this study, responses of all the 8 models are compared from pushover/ capacity curves. The behaviour of the structure at different stages of pushover analysis is tabulated in Table 3 and Table 4 in sequence of different response. The location of the crack is indicated by white colored lines which are highlighted within the red colored circle shown on the brick masonry wall.

a) Discussion of Brick masonry infilled RC frame results

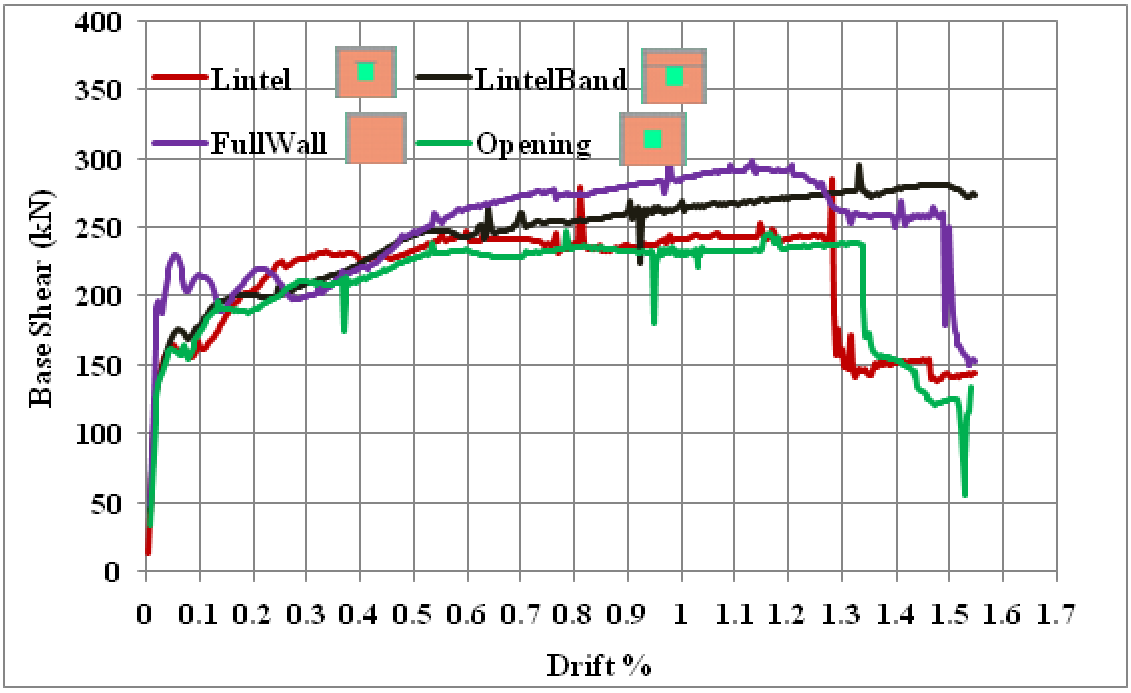
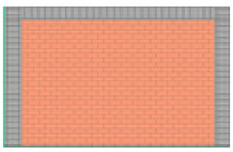
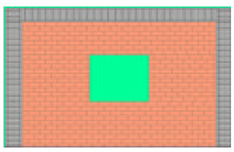
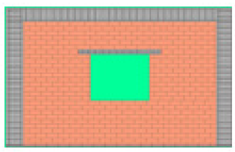
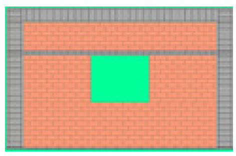
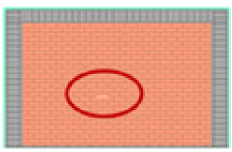
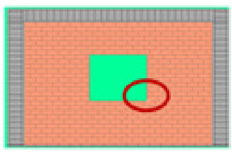
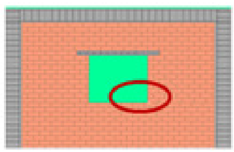
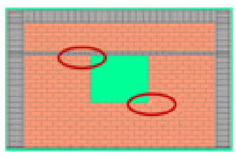
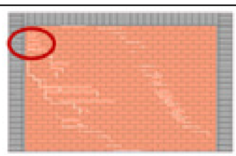
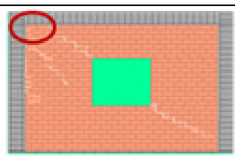
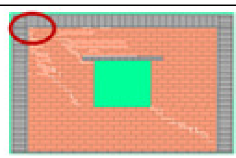
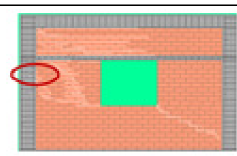
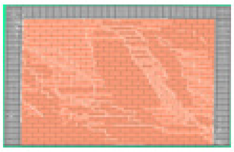
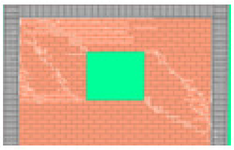
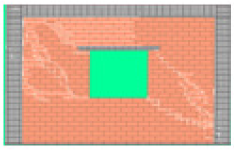
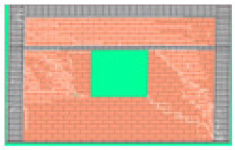
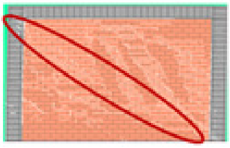
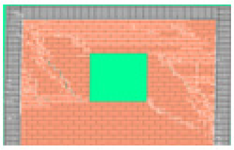
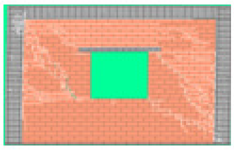
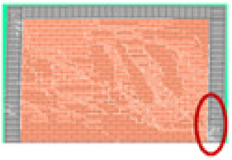
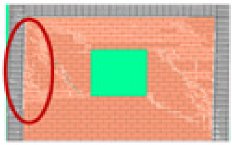
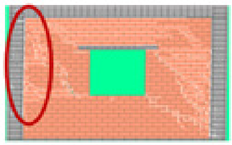


Fig.1. Pushover Curves for RC Infilled Frames

Under lateral in-plane loading of an infilled RC frame without opening, high compressive stresses are concentrated on the diagonal of an infill. As a result, yielding is observed at 0.5mm displacement (0.016% Drift) with base shear 185.1kN. At this stage there is no formation of crack in the model (Table 3) and capacity curve is linear as shown in Fig.2. Similar behaviour is seen in other three models (opening, opening with lintel and opening with lintel band) but with 30% to 35% of reduced base shear when compared with full wall model. Reason for the above mentioned variation is due to presence of opening with/without strengthening structural elements. Perpendicular to diagonal principal compressive stresses and strains are the tensile strains. The tensile strain exceeds the cracking strain of the infill wall material at the displacement 1.8mm (0.058% Drift) with shear force 226.7kN leading to diagonal cracking, (Table 3). Similar behaviour is seen in other three models but with 30% to 35% of reduced base shear compared to full wall model. This crack commence at the centre of the infill and propagates parallel to the compression diagonal (Table 3), due to which capacity curve drops down at the drift 0.058% as shown in Fig.2. As inter-story drift increases, the diagonal crack tend to propagate until it extends from center to one corner to the diagonally opposite corners, (Table 3). This common form of cracking with bed joint sliding is evident in infill walls with opening, opening with lintel and opening with lintel band as shown in Fig.2 when subjected to lateral loads (Table 3). Bed-joint sliding is likely to occur when the bounding frame is strong and flexible. The mortar beds are relatively weak compared to the adjacent brick masonry units, near the mid-level of the infill wall a plane of weakness forms and damage is in the form of bed joint crack. Corner compression occurs because of the high stress concentrations at each corner of the compression diagonal. As concrete frame's resistance to the applied force is less, corner crushing is more extensive and the damage propagates into the concrete frame. At the displacement 6.1mm (0.197% Drift) and base shear 218.5kN crack propagates into column (Table 3), due to which capacity curve drops down at drift 0.197% as shown in Fig.2. In the case of lintel band model, crack propagates at higher displacement due to presence of lintel band. RC in-filled frame without opening reaches maximum strength at 35.5mm displacement (1.145% Drift) with base shear 298.2kN. Similarly other models reach maximum strength with 6% to 20% of reduction in base shear at different drift values (Table 3). As inter-story drifts increases, corner crushing becomes more pronounced (Table 3). When this happens, crushing propagates towards the center of the column leading to strength degradation (Table 3). Therefore, energy is continuously dissipated following Coulomb friction law. It is evident from Fig.2 that the ductility of in-filled frame with lintel band is more compared to the in-filled frame with lintel.

Table 3: Comparison of parameters for RC infilled Frames

Damage Stage	Full Wall	Opening	Lintel	Lintel Band
Yielding Point	 (185.1kN, 0.016%)	 (120.3 kN, 0.016%)	 (121.5 kN, 0.016%)	 (125.7 kN, 0.016%)
Crack Initiation	 (226.7 kN, 0.058%)	 (150.6 kN, 0.032%)	 (153.4 kN, 0.031%)	 (161.8 kN, 0.039%)
Crack Propagation into Column	 (218.5kN, 0.197%)	 (183.7 kN, 0.18%)	 (219.5 kN, 0.26%)	 (216.4 kN, 0.33%)

Max-Base Shear (kN)	 (298.2kN,1.145%)	 (237.2kN,0.6%)	 (253.6 kN, 0.6%)	 (278.1 kN, 1.54%)
Displacement at 85% strength degradation (mm)	 (253.9 kN, 1.36%)	 (201.62 kN, 1.34%)	 (222.7 kN, 1.3%)	-
Ultimate Stage	 (193.5 kN, 1.5%)	 (236.9 kN, 1.33%)	 (239.4 kN, 1.26%)	

In case of RC in-filled framed models, full wall model performs better than the other three models. Eventually opening with lintel band model performs better than opening with lintel and opening model.

b) Discussion of load bearing wall results

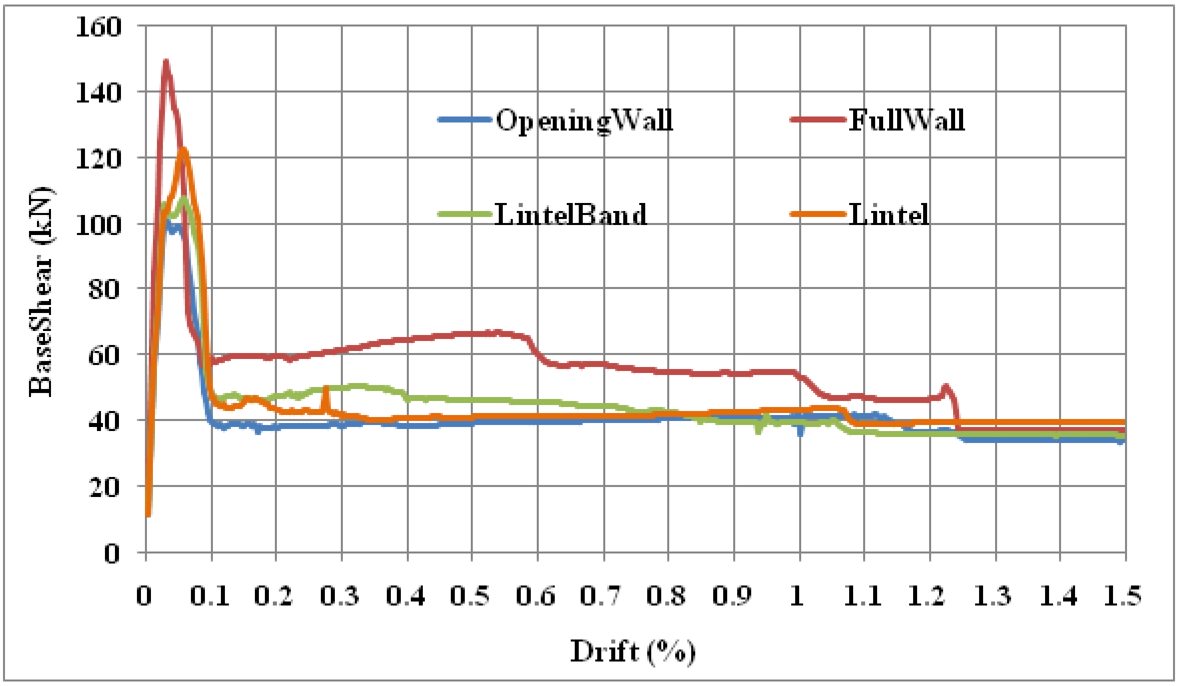
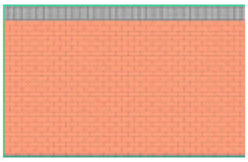
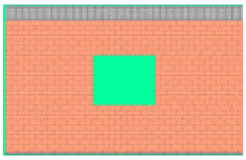
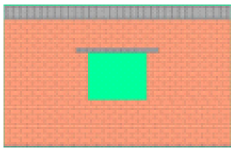
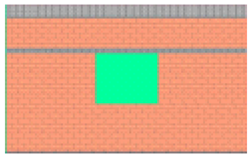
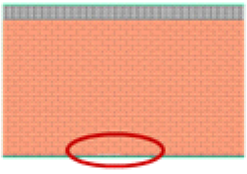
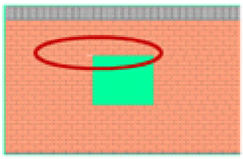
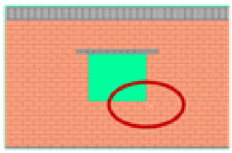
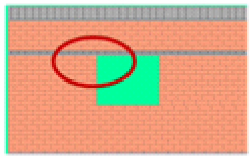
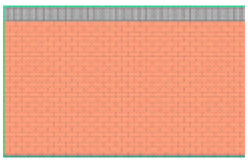
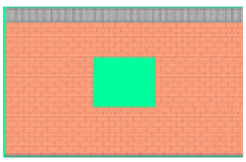
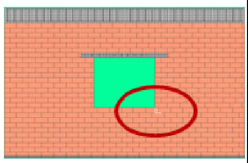
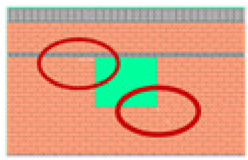
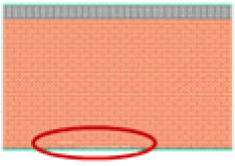
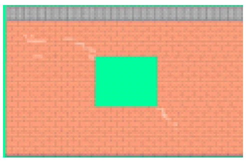
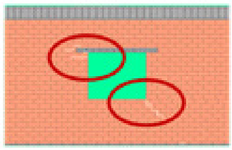
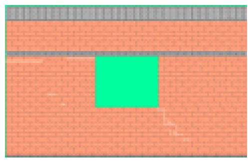
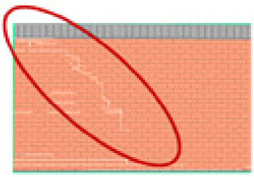
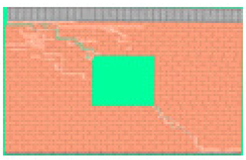
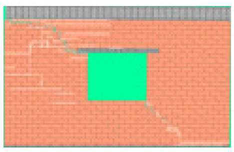
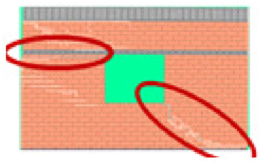


Fig. 2. Pushover curves for load bearing walls

Under lateral in-plane loading of a load bearing wall without opening, high compressive stresses are formed across the diagonal of an infill, As a result model starts yielding at 0.6mm displacement (0.019% Drift) with base shear 124.7kN. At this stage there is no formation of crack in the model (Table 4) and capacity curve is linear as shown in Fig. 3. Similar behaviour is seen in other three models (opening, opening with lintel and opening with lintel band) but with 28% to 33% of reduction in base shear compared to full wall model. Perpendicular to these principal compressive stresses and strains are tensile strains. The tensile strain exceeds the cracking strain of the infill wall material at the displacement 1.3mm (0.042% Drift) with shear force 135.3kN leading to diagonal cracking, (Table 4). Similar behaviour is seen in other models but with 10% to 25% of reduced base shear compared to full wall model. This crack commences at the base of the infill and propagates parallel to the compression diagonal (Table 4) due to which capacity curve drops down at drift 0.042% as shown in Fig. 3. As inter-story drift increases, the diagonal crack tends to propagate until it extends from one corner to the diagonally opposite corner (Table 4). Load bearing wall without opening reaches maximum strength at 0.9mm displacement (0.03% Drift) with base shear 149.4 kN. Similarly other models reach to 18% to 33% of reduced maximum base shear compared to full wall model. As inter-story drifts increase, corner crushing becomes more pronounced (Table 4).

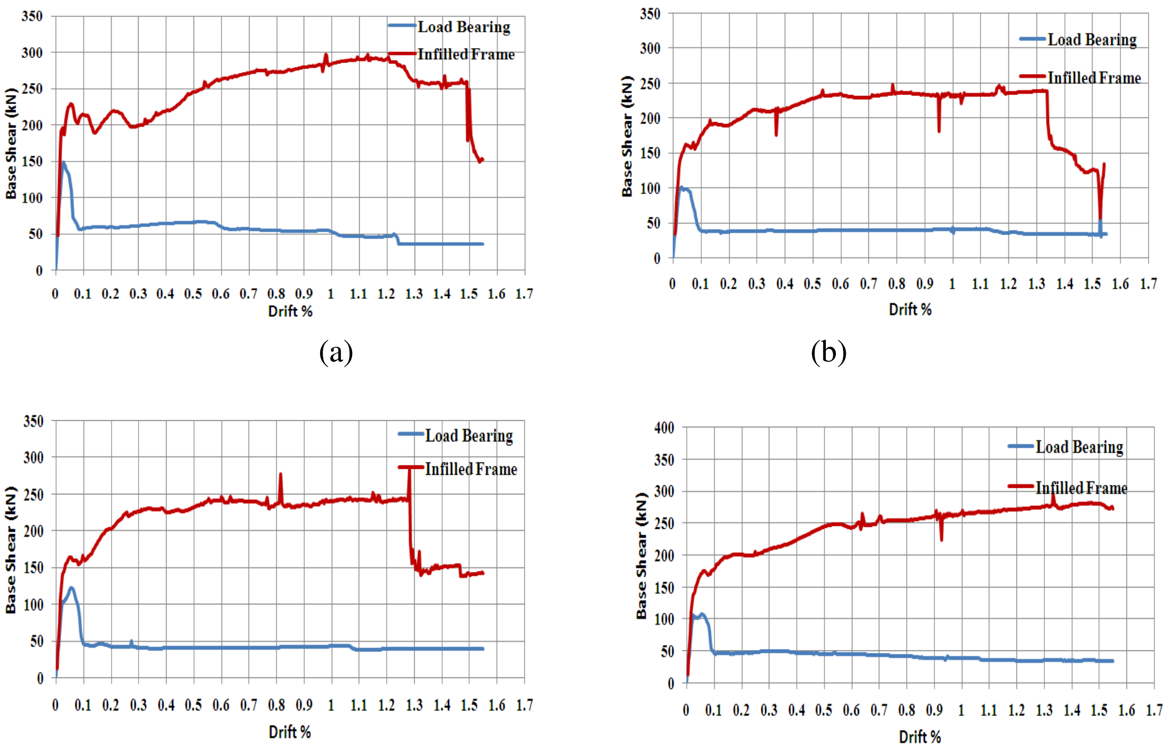
Table 4: Comparison of parameters for load bearing wall

Damage Stage	Full Wall	Opening	Lintel	Lintel Band
Yielding	 (124.7 kN , 0.019%)	 (82.6 kN, 0.019%)	 (86.6 kN, 0.019%)	 (89.18 kN, 0.019%)
Crack Initiation	 (135.3 kN, 0.042%)	 (100.8 kN, 0.032%)	 (120.8 kN, 0.051%)	 (102.4 kN, 0.042%)
Max-Base Shear (kN)	 (149.4 kN ,0.03%)	 (101.4 kN, 0.03%)	 (122.5kN, 0.058%)	 (108 kN,0.058%)
Displacement at 85% strength degradation (mm)	 (124.5 kN, 0.052%)	 (83.26 kN, 0.067%)	 (101.6kN, 0.077%)	 (88.26 kN,0.081%)
Undulations in curve	 (64.9 kN, 0.58%)	 (41.6 kN, 1.1%)	 (43.71 kN, 1.06%)	 (39.3 kN, 1.042%)

In case of Load bearing models, full wall performs better than the other three models. Eventually opening with lintel model performs better than opening with lintel band and opening model (Table 4).

c) Comparison of Infilled frame and load bearing wall results

Pushover curves of all eight models are compared to know their behaviour under seismic loading (In Plane loading at the roof).



(a) (b)

(c) (d)

Fig. 3. Pushover curve for 8 AEM models (a) full wall (b) with opening (c) with lintel above opening (d) with lintel band above opening

From the above graphs Fig.6 it is clear that the performance of the in-filled RC frame models is better than load bearing unframed wall model due to the frame action.

In Tables 3 and 4 opening with lintel band model clearly shows the effect of frame on the performance of structure. In RC in-filled frame, crack commences above lintel band at drift 0.1%, whereas in load bearing wall crack starts above lintel band after drift 0.33% which leads to strength degradation. From this it is clear that performance of lintel band is better in the case of RC in-filled frame compared to load bearing wall.

V. CONCLUSIONS

In this paper four brick masonry infilled RC frames and four brick masonry load bearing walls (i.e., Full wall, with opening without lintel and lintel band, opening with lintel and opening with lintel band) have been considered. Displacement based pushover analysis is conducted on each of these frame to understand the effect of lintel and lintel band on overall capacity of the infilled RC frames and load bearing walls. Following observations are made in this study.

1. The results showed that strength and stiffness reduction observed due to opening in masonry infill. Presence of Lintel and Lintel band improved the infill's failure mechanism and also ductility capacity of the frame.
2. In-filled RC frame model response is better than Load bearing bare wall. This is due to confinement effect of the frame.
3. Lintel band presence is more effective in the case of in-filled RC frame compared to load bearing wall. This is because the interaction of frame and lintel band increases the overall stiffness and the same comes into picture after the appearance of diagonal cracks.
4. In the case of load bearing wall, performance of lintel model is better than the response of lintel band model.

Therefore, in higher seismic zone areas, providing lintel bands for infilled RC structures is suggested rather than providing lintels and lintels for brick masonry structures.

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