SEISMIC PERFORMANCE ASSESSMENT OF MULTISTORY BUILDINGS WITH NON-STRUCTURAL HOLLOW CLAY TILE INFILLS

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ABSTRACT

In recent years, walls made by Hollow Clay Tiles (HCT), have been used as a common partitions in Iran and other countries. These partitions are generally thought as non-structural elements and hence not considered in analysis and design of buildings; this is due to the lack of information about the seismic performance of partitions. In this study, based on experimental tests, a new analytical backbone curves are proposed to simulate the performance of HCT partitions. Partitions considered in this study have two types of overlays (plaster + browning plaster and cement), R.C. frames are in 3 and 6 stories and OpenSees software is used for non-linear modelling.

The effect of presence of this type of partitions in seismic performance of R.C. frames is investigated by modal and nonlinear push-over analysis. It has been observed that the presence of the wall makes a significant reduction in fundamental period of frames while the changes in mode shapes are not considerable. On the other hand, the deformation capacity of the frames decreases.

INTRODUCTION

Nowadays the use of Hollow Clay Tile (HCT) partition in buildings is a common practice; but, these partitions are generally thought non-structural and hence not considered in the analysis and design of buildings. The background of neglecting infill walls in the analysis process is partly the result of incomplete knowledge on behaviour of such partitions, particularly those made by HCT. In recent years, some experimental and analytical researches have been conducted on seismic response of HCT infills and the lack of information in this field is dissipated. Seismic performance of three HCT walls with different overlays was investigated in a series of experimental tests by Khanmohammadi et al. (2011). Overlays used in this study (Khanmohammadi et al. 2011) are plaster + browning plaster, cement and tile + grout and seismic responses are reported. In current research an analytical investigation is performed and analytical backbone curve are proposed for this type of infills. To investigate the effect of presence of partitions on response of R.C. buildings, two R.C. frames in 3 and 6 stories, are designed conforming with ACI 318-05 (ACI 2005) and ISIRI 2800-05 (ISIRI 2005). An interior frame of the designed building is modelled in 2D by OpenSees ver. 2.0.0 (OpenSees, 2002) and 3D demand effects is considered according to FEMA-356 (FEMA 2000). The partitions are modelled as nonlinear zero-length spring element in OpenSees. The force-deformation relationship of infills is prescribed in horizontal shear direction based on analytical backbone curve. The effect of non-structural partitions on dynamic characteristics of frames is studied by Modal & Nonlinear Push-Over analysis

PROPOSED MODEL FOR MODELING HOLLOW CLAY TILE WALLS

Strong dependence of wall behaviour to material properties and its manner of making, limits the use of different models proposed for wall modelling; and it seems necessary that the validity of existing models should be examined or an appropriate model to be presented in accordance with the target materials and execution. For this reason, based on the analysis done on the walls made by Hollow Clay Tiles (Khanmohammadi et al. 2014) on a series of experimental data (Khanmohammadi et al. 2011), a modelling approach is proposed for modelling of masonry wall shown in Fig.1. This model is based on compression strut behaviour, which has been extensively employed by other researchers[1], except that the strut element is considered as a rigid element and nonlinear behaviour of wall is assigned to horizontal spring elements at the end of the strut. The advantage of this model compared to previously presented models is the elimination of the vertical force exerted on the beam-column connection .Such an assumption on the behaviour of the walls seems reasonable, regarding the execution-style of non-structural walls which typically a small gap remains between the last row of brickwork and its overhead beam. Typical walls non-linear force-deformation relations shown in Fig.2.

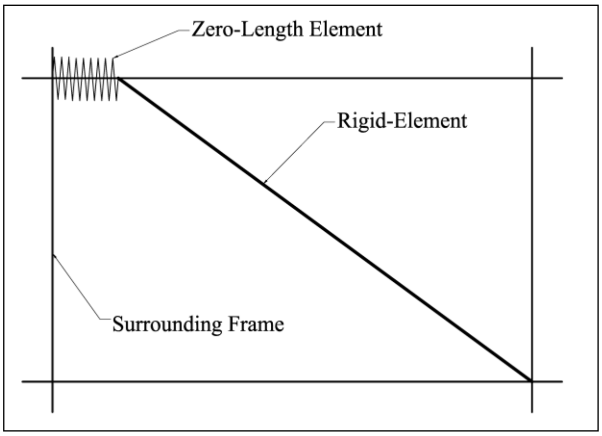


Figure 1. Rigid strut and shear spring model for wall modelling

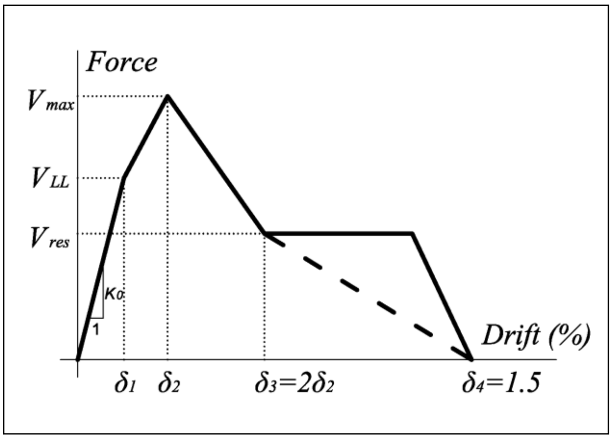
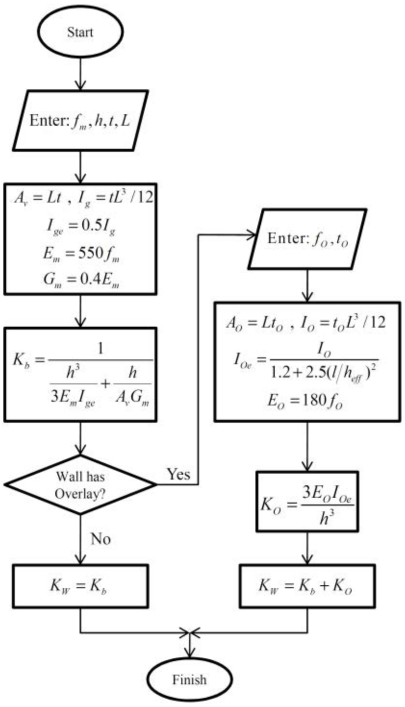


Figure 2. Typical non-linear force-deformation relation of non-structural walls developed based on experimental tests.

To define this relation, different parameters are required such as initial stiffness (k_0), linear limit strength (V_{LL}) and corresponding drift (δ_1); maximum strength ($V_{\max}$) and corresponding drift (δ_2), residual strength (V_{res}), drop point drift (δ_3) and ultimate drift (δ_4). The following steps are proposed to define this parameters and the force-deformation relation:

1. Up to 70% of maximum strength, the wall shows a linear behaviour; with a slope equal to the initial stiffness. The initial stiffness (k_0) and maximum strength ($V_{\max}$) is determined by proposed analytical equations shown in Fig.4 and Fig.5.

1.(Polyakov, 1960),(Holmes, 1961), (Smith, 1967), (Mainstone, 1974), (Liauw & Kwan, 1984), (Paulay & Pristley, 1992), (Flanagan & Bennett, 2001)



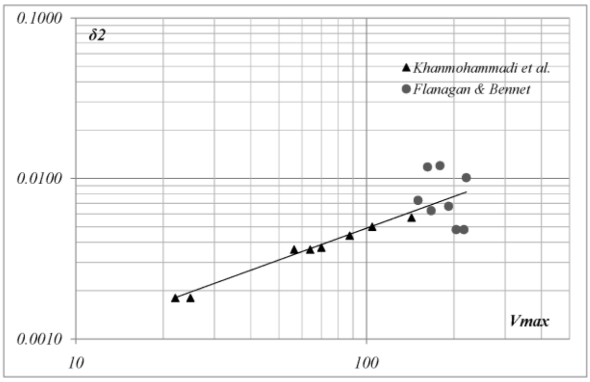


Figure 3. Relation between $V_{\max}$ (kN) and δ_2

Figure 4.Initial stiffness determination flowchart

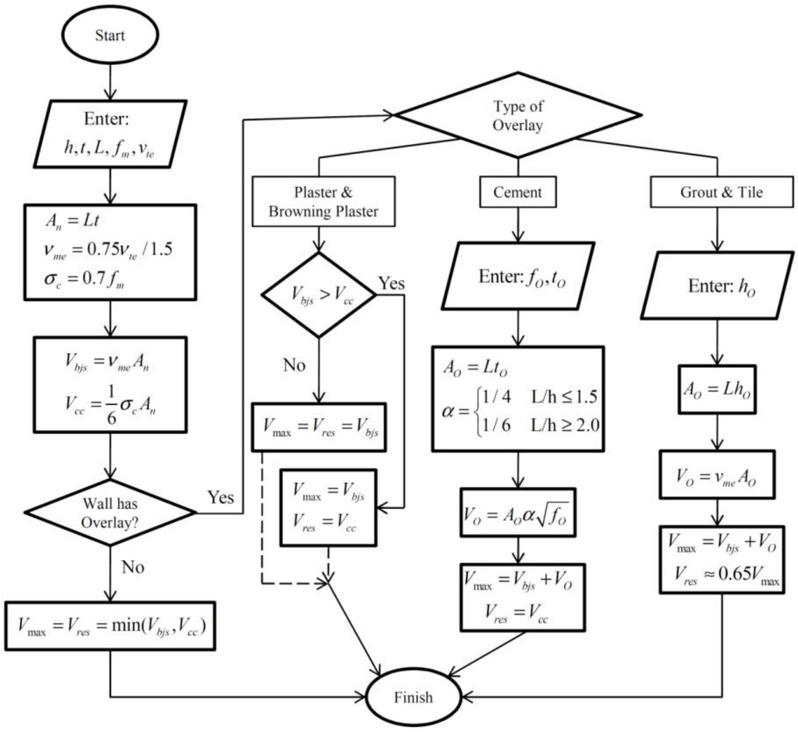


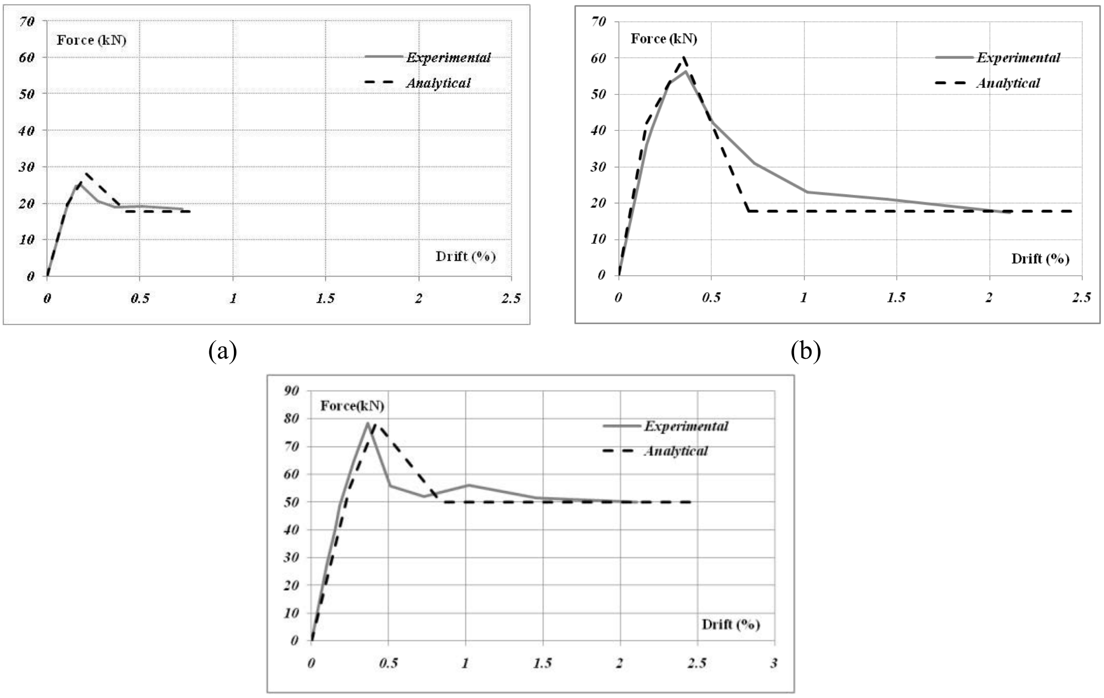
Figure 5. Maximum strength determination flowchart

2. Maximum strength point is determined by $V_{\max}$ and corresponding drift (δ_2), which can be calculated by Eq.(1).
3. Drift corresponds to resistance loss (δ_3) is twice maximum strength drift (δ_2) and strength of this point can be calculated by proposed analytical equations shown in Fig.4.
4. The ultimate drift (δ_4) is considered to be 1.5%.

According to experimental studies (Khanmohammadi *et al.*,(2011) , Flanagan & Bennet, (2001)), good correlation can be seen between maximum strength ($V_{\max}$) and corresponding drift (δ_2) in a log-log graph (Fig.3). Accordingly, Eq.(1) is proposed to determine δ_2 .Average ratio of predicted drift (based on this relationship)to the actual drift is equal to 1.04 with correlation coefficient equal to 0.09.

$$Log(Dir) = 0.656 Log(V_{max}) - 3.623 \quad (1)$$

In the flowcharts presented in Fig.5 and Fig.6, L , h and t are the length, height and thickness of wall panel, f_m is compressive strength of masonry, f_O and t_O is the compressive strength and thickness of overly. In Fig.6 experimental and analytical push curves are compared with experimental data taken from Khanmohammadi *et al.* (2011).



(a) (b)

(c)

Figure 6. Comparison between experimental and analytical push curves
(a) wall with plaster and browning plaster overlay (b) wall with cement overlay
(c) wall with tile and grout overlay

FRAMES CONSIDRATIONS AND NON-LINEAR MODELLING

To investigate the effect of presence of partitions on response of R.C. buildings, two RC frames in 3 and 6 stories, are designed conforming whit ACI 318-05 (ACI 2005) and ISIRI 2800-05 (ISIRI 2005). Story heights are equal to 3.2 meters and spans length is assumed to be 4 meters in one direction and 5 meters in another direction. Plane of designed structure is shown in Fig.7. Structural system is intermediate moment resisting frame. An interior frame of the designed building is modelled in 2D by OpenSees ver. 2.0.0 and 3D demand effects is considered according to FEMA-356 (FEMA 2000). Modified beam-column manner is used in order to non-linear modelling of R.C. frame.

HTC walls are assumed to have thickness of 10 cm with two types of overlays: plaster+browning plaster (wall type 1) and cement (wall type 2). Non-linear modelling of walls is performed as presented in pervious sections. Relevant data have been presented in Table 1. Push curves of both type of walls and related data have been presented in Fig. 8 and Table 2.

For each type of frame and wall, five models, as detailed in Table 3, have been studied by modal and static nonlinear pushover analysis. An eigenvalue (modal) analysis was carried out to investigate the effect of the wall panels on the modal periods and mode shapes of the frames .Moreover, static nonlinear pushover analyses of the models were performed to investigate the lateral base shear and roof displacement relationship of the frames. For the static pushover analysis in this study, the applied reference forces vary linearly over the height of the frames. The reference forces are applied to the beam-column nodes of the moment-resisting frames.

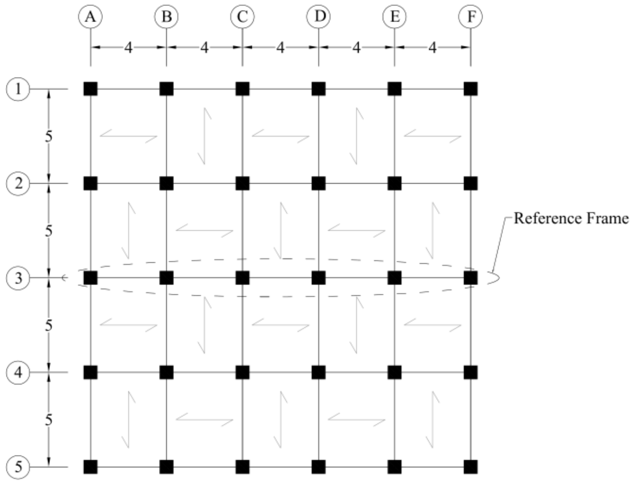


Figure 7. Designed frames floor plane

Table 1.Walls Strength and Stiffness Calculating Data

Input Data			*Calculated Data for Stiffness*			*Calculated Data for Max. Strength*		
h	***(mm)***	3200	***A_v***	***mm^2***	4.00E+05	***A_n***	***mm^2***	400000
L	***(mm)***	4000	***I_g***	***mm^4***	5.33E+11	***v_me***	***MPa***	0.155
t	***(mm)***	100	***I_ge***	***mm^4***	3.56E+11	***σ_c***	***MPa***	0.735
t_o	***(mm)***	14	***E_m***	***Mpa***	577.5	***A_o***	***mm^2***	56000
f_m	***(Mpa)***	1.05	***G_m***	***MPa***	231	***α***	***-***	0.25
f_o	***(Mpa)***	25.56	***A_o***	***mm^2***	5.60E+04	***V_bjs***	***kN***	62.00
v_te	***(Mpa)***	0.31	***I_o***	***mm^4***	7.47E+10	***V_cc***	***kN***	39.20
			I_oe	***mm^4***	1.46E+10	***V_o***	***kN***	70.78
			E_o	***Mpa***	4600.8			
			K_b	***kN/mm***	11.39			
			K_o	***kN/mm***	6.16			

Table 2. Push Curves Parameters of Walls

	with Gypsum overlay	**with Cement overlay**
K0 (kN/mm)	11.39	17.55
V_cr (kN)	43.40	92.95
δ1 (%)	0.12	0.17
V_max (kN)	62.00	132.78
δ2 (%)	0.36	0.59
V_res (kN)	39.20	39.20
δ3 (%)	0.71	1.18
δ4 (%)	1.5	1.5

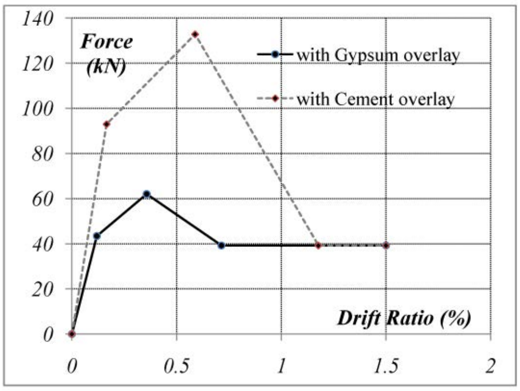


Figure 8. Push Curves of Walls

Table 3. Details of Models for Each 3 & 6 Story Frames

Model Id.	Wall Type	Infilled Bays	Model Id.	Wall Type	Infilled Bays
A1	1	1	**A2**	2	1
B1	1	1+2	**B2**	2	1+2
C1	1	1~3	**C2**	2	1~3
D1	1	1~4	**D2**	2	1~4
E1	1	1~5	**E2**	2	1~5

RESULTS OF MODELING AND ANALYSIS

Analysis of a building's mode shapes gives insight into the deformed shape of the building during an earthquake. Depending on the properties of the ground motion, one or more of the modes is activated, and the deformed shape can be a superposition of the mode shapes. The first three mode shapes are shown in Fig.9-Fig.12. The first, second and third mode shapes of the models are virtually identical, indicating that the wall does not have much of an effect on the free vibration displacements caused by higher modes.

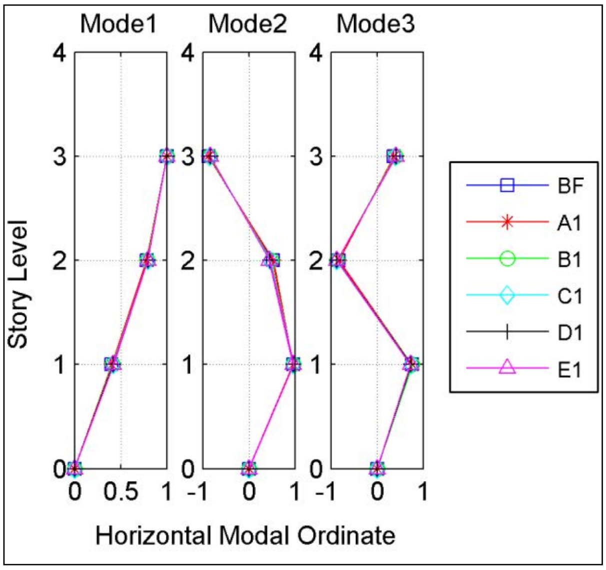


Figure 9. First Three Mode Shapes
(3 Story Frame, Wall Type 1)

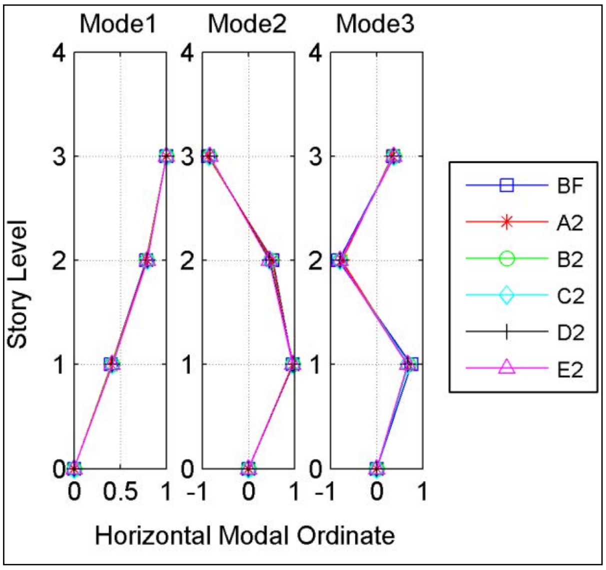


Figure 10. First Three Mode Shapes
(3 Story Frame, Wall Type 2)

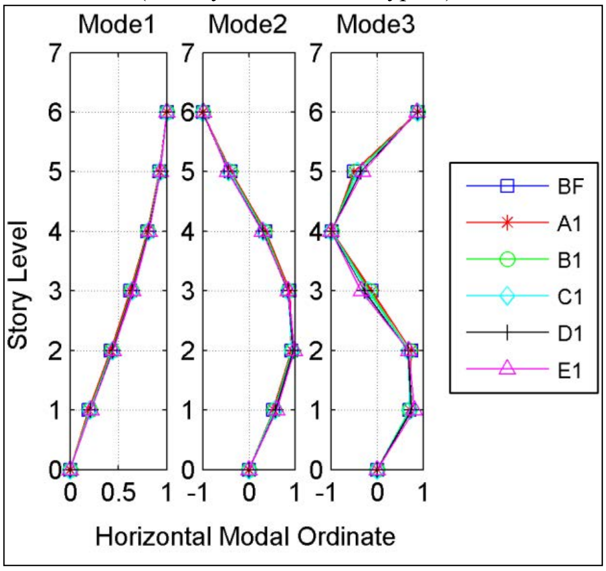


Figure 11. First Three Mode Shapes
(6 Story Frame, Wall Type 1)

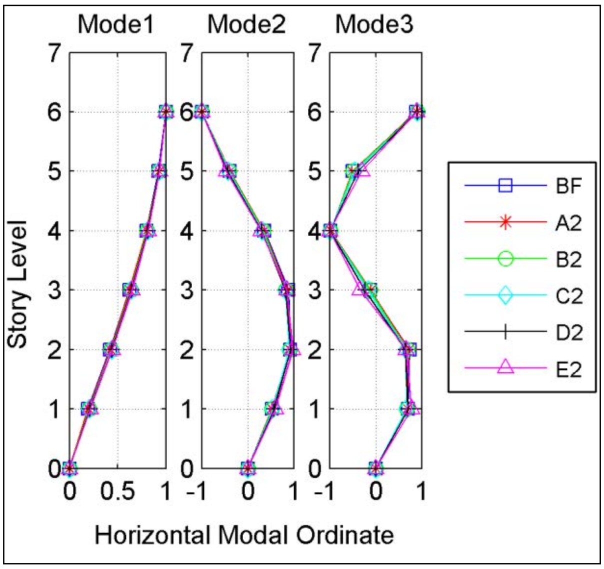


Figure 12. First Three Mode Shapes
(6 Story Frame, Wall Type 2)

As well as analysis of building's vibration periods provides information on how the building might respond to lateral excitation, depending on the predominant frequency of the ground motion. The first modal periods of models are shown in Fig. 13 and Fig.14. It is shown that due to the wall effect, modal periods decreases drastically and type of wall is effective in this reduction. In comparison with empirical period recommended by seismic loading code (ISIRI 2005), (i.e. 0.3 sec. and 0.6 sec. for 3 and 6 story buildings respectively), it is concluded that, both of buildings with one bay infill have the period same as empirical period and for more infilled bays, the resulted periods are less then empirical ones.

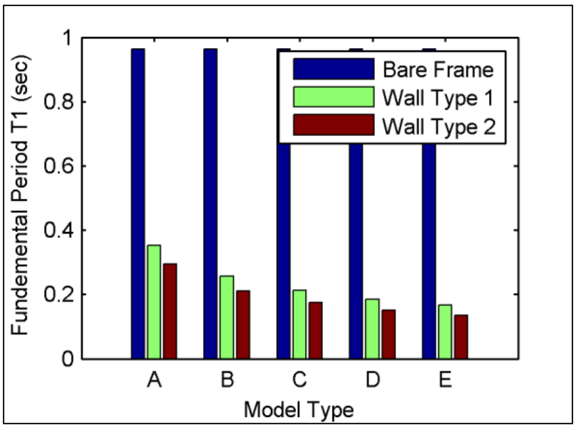


Figure 13. First Modal Periods of 3 Story Frame

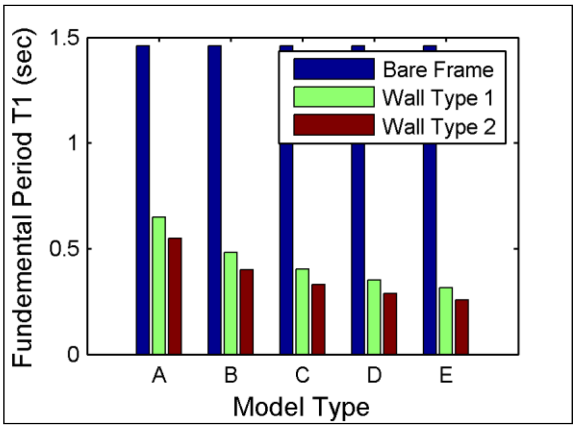


Figure 14. First Modal Periods of 6 Story Frame

The base-shear versus roof drift capacity (pushover) curves are shown in Fig.15-Fig.18. The roof drift is normalized with respect to the overall frames height (9.6 m for 3 story frame and 19.2 m for 6 story frame). All curves show that initial stiffness and strength increase considerably and immediate strength degradation is happened suddenly after developing maximum strength. On the other hand, with degrading strength of non-structural elements, the residual strength tends to bare frame strength. With increasing the number of infilled bays from one to five, due to change in hinging mechanism of structure, deformation capacity of frames decreases drastically and instability accelerate. The derived results show that neglecting non-structural element in design of new buildings leads to conservative design from point of immediate occupancy limit state and cause reduction in collapse margin ratio.

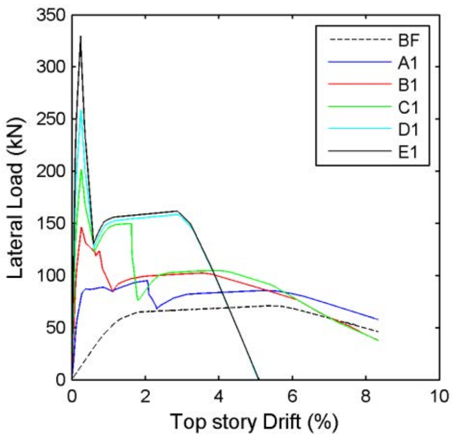


Figure 15.Push Curves (3 Story Frame, Wall Type 1)

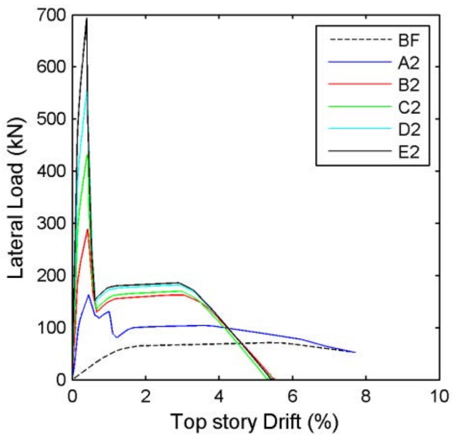


Figure 16. Push Curves (3 Story Frame, Wall Type 2)

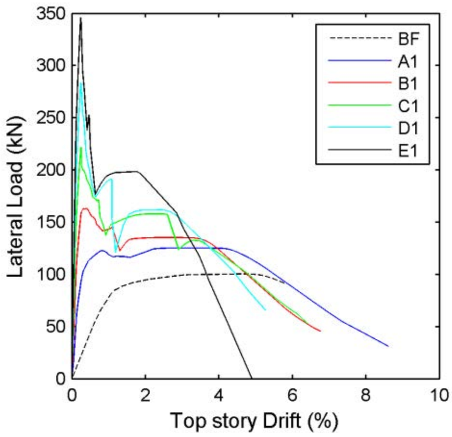


Figure 17. Push Curves (6 Story Frame, Wall Type 1)

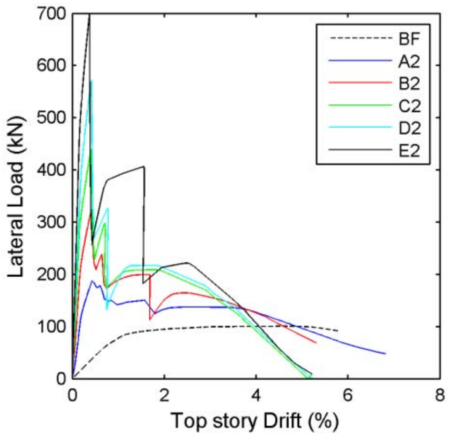


Figure 18. Push Curves (6 Story Frame, Wall Type 2)

CONCLUSIONS

Analytical and experimental studies have shown that non-structural partition panels have a major influence on behaviour of structures. However, in seismic analysis and design, engineers typically ignore the additional stiffness and strength that the partitions may provide, which could prove to be beneficial or detrimental to the buildings. The purpose of this research was to study the effect that Hollow Clay Tile (HCT) partitions has on structural response of buildings. Thus two R.C. frames in 3 and 6 stories was modelled in OpenSees and the effect of two types of HCT walls, with various overlays, on seismic behaviour of frames was investigate by modal and non-linear pushover analysis. In order to non-linear modelling of HCT walls a backbone curve and an appropriate model was proposed on the basis of experimental data. The results showed that the fundamental mode shapes remain unchanged, initial stiffness and strength is increased considerably, performance limit state is different from those expected for new designs. Therefore, effect of non-structural partitions should be considered particularly for life safety and collapse limit states of new designs.

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