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Influence of Masonry Panels on Seismic Performance of Reinforced Concrete Buildings

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Abstract

Generally considered as partition or infill, masonry panels were never considered in the design, while their presence affects the structural response illustrated by the failure mechanism. Many experimental and analytical studies showed that the presence of masonry panels have significant impact on the seismic response of reinforced concrete frame buildings, increasing structural strength and stiffness but at the same time introduce brittle failure mechanism like soft story and short columns. In addition, the mutual interaction between these two structural elements with antagonistic behaviour (ductile frame-rigid masonry) increases the demand for structural resistance and reduces the demand for deformation. The work undertaken focuses on the evaluation of seismic performance through a nonlinear static analysis (Pushover) of bare frame, partially-infilled and fully infilled frames designed in accordance with the Algerian code (RPA99 V2003). Discussion of the results obtained showed the influence of masonry structural response and many resulting conclusions were issued.

Key words: masonry panels, failure mechanism, seismic performance, pushover

INTRODUCTION

Generally considered as partition or infill element, masonry panels are not taken into account in the design and structures are designed as bare frames. In this paper, three buildings: fully infilled, partially infilled and bare frame have been analyzed for showing effect of masonry infill on the seismic performance of reinforced concrete frame buildings. Using nonlinear pushover analysis, it has been observed that infills increase stiffness and strength of the structure while the deformation capacity gets reduced. It has been observed too, that infill panels fail before frame elements. Modeled as diagonal compression strut, infill panels interact with frame when buildings are subjected to lateral loads and four types of failure modes can be observed:

- Tension failure of tension side of the column
- Sliding shear failure of the masonry along horizontal mortar bed joint causing shear hinges in the columns
- Compression failure of the diagonal strut
- Diagonal tension cracking of the panel (1)

These panels are generally considered as architectural components. The presence of masonry walls has a significant impact on the seismic response of a RC frame building, increasing structural strength and stiffness, but at the same time introducing brittle mechanisms associated with the wall failure and wall-frame interaction. Studies have shown that different arrangements of stiffness, mass and strength by each other can have significant effect on structure behavior. One of the most failure modes of structures in earthquakes is soft story which causes by discontinuity of lateral force resisting elements such as braces, shear walls or infill walls in the first story. Other failure mode is short column that is common mode in concrete structures. The asymmetrical arrangement of infill walls produce high torsional moment. Existence of the infill walls can change the structural behavior from flexural action into axial action.

Strength and stiffness contribution of infill walls are often neglected and self weight of infill wall is modeled as uniformly distributed load. In reality, presence of the infill wall in the frame changes the lateral load transfer mechanism into truss actions leading to stress concentration in the ground floor (3)

The assessment of RC frames with infill walls is dependent on the material constituting the infills and the geometry of both frame and infill. The possible effects of infills on frames are the followings:

- Presence of infills doesn't affect the structural response if they are very light or completely isolated from RC frame or so brittle that a total failure is expected even for a moderate ground motion.
- The infills have a significant contribution on the response, they are expected to remain in elastic range only
- The infills have an important contribution to the response. They are expected to suffer significant damage during seismic event and probably soft story will be born

In order to decide which the case will be taken into account, the following parameters should be examined: details of connections between infill and frame, ratio of stiffness of the infilled wall and the stiffness of the bare frame, ratio of the shear strength between infilled walls and frame (4)

The observation of post-earthquakes damages buildings has clearly shown that the presence of non structural elements like infill walls may significantly affect the seismic performance of buildings both in terms of seismic demand and capacity. The objective of the paper is to point out some observations and recommendations about the introduction of infill walls in the structural models and the consequent possible altercation of the global response. (5)

Modeling of Masonry Infill Walls

Analytical modeling of infilled frames exhibit nonlinear inelastic behavior, resulting from interaction of the masonry infill panel and the surround frame. The modeling approaches for masonry infills can be grouped into micro-models which capture the behavior of infill and its interaction with the frame and macro-models which try to capture the gross behavior of the infill.(1) among the different approaches proposed in the recent scientific literature. The most widely adopted methods are based on the observation that within a masonry panel the compressive stress follows the diagonal path and thence are oriented at describing their contribution through one or more equivalent struts with proper geometrical and mechanical properties.(6). FEMA 356 (7) has proposed the diagonal strut model of infill by considering deformation controlled action with specified properties. In this paper, a RC infilled frame building is considered as a case study. A significant reference frame is selected and modeled in the plane for the application of nonlinear static analysis. Three configurations are analyzed: bare frame, partially-infilled frame and fully infilled frame in order to perform a critical comparison and deduce some observations about the modeling of the infill panels. 30% reduction in the weight of infills has been done to take into account the presence of openings (windows and doors).

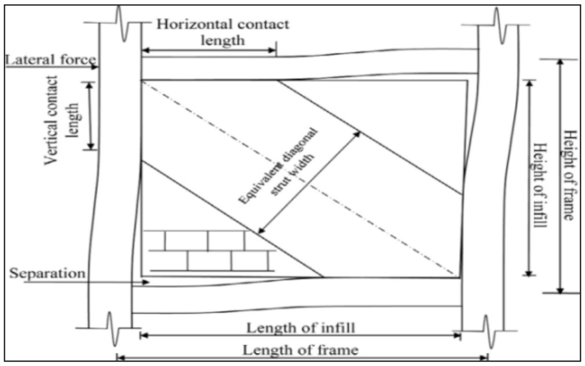

Figure 1. Modeling of masonry infill

Under progressive increasing loads, a detachment between the panel and the frame happens at the nodes determining a stress increase in the panel. However, on the opposite corners that are still in contact with the frame, axial stress become relevant and for this reason infill panel is represented as diagonal compressive strut. The fundamental factors that govern the equivalent strut model are:

- The width bω of the strut
- The constitutive relationship of the panel
- The number of struts introduced

The length of contact between the beam and the infill was approximately equal to half the span. The implication of this observation is that the behavior of the infill is completely independent of the beam section. However the large increase in lateral stiffness response of the infills resulting from the increased lengths of contact against the columns, which are due in turn to the increased column section.

The thickness of strut is usually assumed to be the same of infill panel whereas many expressions are giving for determination of width of the equivalent strut which must be greater at the beginning in order to represent the initial stiffness of the uncracked panel and then decrease with crushing of the corners or sliding of the bed joints.

Stafford Smith was the first who introduce a parameter λ expressing the relative stiffness of the frame and infill panel in the equation of width of the equivalent strut giving below:

$$b_w = 0.175(\lambda_h . H)^{-0.4}\sqrt{H^2 + L^2} \quad (1)$$

Where

$$\lambda_h = \sqrt[4]{\frac{E_i \, t \sin 2\theta}{4 \, E_c \, I_c \, H_i}} \quad (2)$$

H and L are height and length of the frame, Ec and Ei are elastic modulus of column and infill panel, t is the thickness of infill panel, θ is the angle defining diagonal strut, Ic is the modulus of inertia of the column and Hi is the height of the infill panel.(8)

It is important to take into account the progressive degradation of stiffness and strength of infill panel during the cyclic loading but variability of materials and constructive techniques made the task so difficult (mechanical parameters, geometrical configuration and the presence of openings in infill panel). However for simplicity the effect of openings on stiffness and strength has been ignored.

Before modeling infill panel as diagonal strut, mechanical properties must be defined especially Young's modulus of masonry materials. The values of this module for 15kg/cm^2 compressive stress are listed in the following table:

Table 1. Elasticity modulus for equivalent masonry struts

Reseacher	**Modulus of elasticity**	**E_m (kg/cm^2)**
Sahlin		11000
Paulay and Priestley		11000
Sanbartolome		7500 (min)
Sinha and Pedreschi		160000
Hendry		25000 (max)
Some others		15000

Infill panels were modeled by diagonal struts which can carry loads only in compression. Each strut is assigned a force-displacement relationship showed in the figure below.

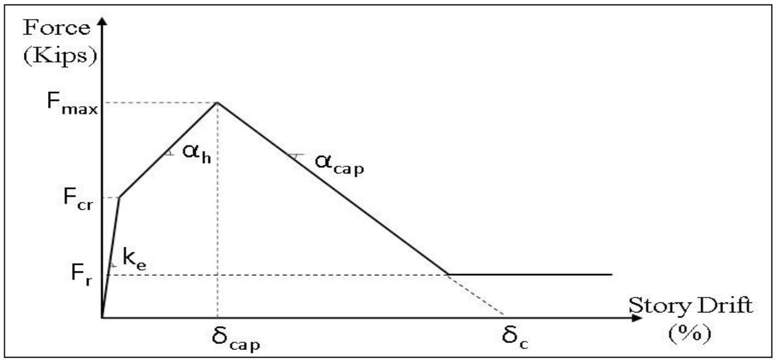

Figure 2. Modeled force-displacement behavior for infill strut material

The curve shown in figure above given by Panagiotakos and Fardis for the equivalent strut is composed by four segments. The first segment represents the initial shear behavior of the uncracked panel. The second corresponds to the formation of the equivalent strut in the panel after detachment of the infill from the surrounding frame (F_m). The third describe the softening response of the panel after critical displacement. The last horizontal segment defines the final state of the panel and is characterized a constant residual resistance. The main problem is how to determine the hysteretic behavior of diagonal equivalent strut. Many different proposals have been made for the determination of stiffness and strength of infill. The initial stiffness of the masonry infill panel k_e is taken as:

$$k_e = 2\left({}^{E_w b_w}/_{L_w}\right)(\cos\theta)^2 \tag{3}$$

Where **L** is length of the diagonal strut. Another equation for calculating the initial shear stiffness of the uncracked panel is:

$$K_e = \frac{G_w L_{in} t_w}{H_{in}} \tag{4}$$

Where $\mathbf{G_w}$ is the shear modulus of the wall, determined experimentally; $\mathbf{L_{in}}$**,** $\mathbf{H_{in}}$ are length and height of the infill respectively and $\mathbf{t_w}$ is thickness of the wall. (9)

For determination of the strength of the infill wall, simplified form of the expression proposed par Zarnic and Gostic was used:

$$F_{max} = 0.818\frac{L_{in} t\, f_{tp}}{C_I}\left(1+\sqrt{C_I+1}\right) \tag{5}$$

$$C_I = 1.925\frac{L_{in}}{h'} \tag{6}$$

Where f_{tp} is the cracking strength of the infill obtained from diagonal compression test.

CASE STUDY

The case study is 4 stories reinforced concrete frame building with fully infilled, partially infilled and bare frames located in medium seismic risk area (in Constantine at north east of Algeria) . The building is regular both in plan and elevation with typical interstory height of 3.06 m. Beams are all rectangular section of 30x40 cm^2 and columns are square sections with 40 cm for each side. The yield stress of reinforcement is f_y = 400 Mpa and the compressive stress of the concrete is f_{c28} = 25 Mpa. Masonry panel made of hollow bricks and represented by equivalent strut has 15 cm height and a Young's modulus equal to E_m = 3800 Mpa for moderate infill and shear modulus G= 1233 Mpa.

The nonlinear behavior of beams and columns was described according to a lumped plasticity approach. According to this, the post elastic behavior is modeled by introducing plastic hinges in which all non-linearity is located at the ends of structural elements (beams and columns). The non-linearity of the plastic hinge is defined by M-φ relationship including as a parameter the shear span which enters in the calculation of the plastic length L_p according to expression giving by Park & Paulay: $L_p = 0.08L_v + 0.022d_b.f_y$ where

L_p: plastic length

L_v: shear span

d_b: longitudinal bars diameter

f_y: yield stress of reinforcement

The analytical results are given in table below representing base shear forces versus top displacements for different frames taken in the case study:

Table 2. Analytical results of different case study

Analytical results	Base Shear force	Top displacement	Effective period
Bare frame	491.63	0.089	1.356
Partially infilled frame	756.81	0.052	0.911
Fully infilled frame	2213.09	0.019	0.298

DISCUSSION OF THE RESULTS

In order to assess the dynamic behavior of the building, a non linear static analysis was performed with hypothesis of rigid floor. The infill panels were modeled with a single equivalent strut which its width was calculated using Stafford Smith expression. Many interesting results can be deduced and are that

- The presence of strong infill panels can alter the post seismic behavior of building.
- The presence of infill determines a redistribution of the horizontal actions and of plastic hinges where position of critical hinge may vary
- Presence of the infill walls can alter the formation of plastic hinges within the frame with a possible negative consequence on the global structural ductility
- The period of the system decreases when changing from the bare frame to infilled frame
- By eliminating the infill from the first story for partially infilled frame, the top displacement decrease but increase at all other floors
- In fully infilled frame, hinges form firstly in infill and then in frame element
- Due to strut action of infill panels, columns of infilled frame fail earlier than those of bare frame
- The results confirm that the presence of infill in the RC frame induces a reduction of natural period of the structure and a significant diminution of horizontal displacements as consequence of stiffening.
- At the same time we can see that base shear for fully infilled frame is 4 times that of bare frame which is natural consequence of increasing strength.
- The detachment of infill masonry from the surrounding frame determines a concentration of the load transfer in the contact area between infill panel and the frame favorating shear behavior of structural elements.
- The distribution of stirrups within the structural elements is typically poor and ineffective especially in the column-beam nodes they are completely absent.
- Two distinct modes of infill failure can be observed: tensile cracking failure along loaded diagonal which started in center of infill panel and extend to the ends of corners and compressive failure in one of the loaded corners
- It means that tensile cracking failure or compressive failure of the infill panel is independent of the beam stiffness.

CONCLUSION

- Structural infill walls have very important effects on structural behavior under earthquake. Effect results of pushover analysis show an increase in initial stiffness, strength and energy dissipation of the infill frame compared to the bare frame despite the wall's brittle failure modes. The better collapse performance of fully-infilled frames is associated with the larger strength and energy dissipation of the system associated with the added walls.
- The partially-infilled frames fails in a soft story mechanism due to much lower strength and stiffness at the first floor because on the configuration of infill walls
- The infilled frames experienced less damage than either the bare frame or partially-infilled buildings due to higher stiffness and strength.
- Results of pushover analysis show an increase in initial stiffness, strength and energy dissipation of the infilled frame by developing more plastic hinges than developed in bare frame.
- Because of high stiffness of the infill walls considered as structural elements leads the initial stiffness of buildings to increase. These elements show high strength at first step of seismic load, but by reaching to the maximum strength the infill wall fail and high loss of strength occur in small drift. Presence of these walls in buildings causes big eccentricity between center of mass and center of stiffness which cause high torsional effect
- The masonry infill walls strongly influence the structural seismic response and contribute to the overall stiffness, to the hysteretic dissipation capacity and can modify the development of the failure mechanism in the frames
- Algerian seismic code doesn't take the effect of presence of infill panels in structures and give expression to calculate the total base shear which is find overestimate along the height of the frame.

Considered as diagonal strut, several expressions for determining the mechanical and geometrical characteristics of this strut were established. The contribution of the masonry panels in the structural modeling frames can alter the post-seismic behavior and failure mode. Their presence (infill walls) can change the structural behavior from bending behavior to axial behavior. This change reduces the contribution of the frame to horizontal actions. In the other side the change of behavior has negative effects such as: increasing the axial load on the columns and foundations and therefore a concentration of shear forces at their level. The presence of the masonry increases the strength and rigidity of the structure and capacity of energy dissipation, but against part, significantly reduces its ability to deformation due to structural irregularities. From the above, we can say that the participation of the masonry in seismic behavior significantly influences the structural performance of frame structures and that both alternatives are required: disconnect the masonry panels by a separating joint between the two constructions and avoiding to consider it as non structural elements, or consider the masonry as a structural element involved in seismic response of the structure.

REFERENCES

1. Y.Singh, D.Das, 4th international conference on earthquake engineering paper n° 064 october 12-13 (2006) Taipei, Taiwan
2. K.,A,Korkmaz, F,Demir and M.Sivri, International Journal of Science and Technology, vol 2, pp 155-164, 2007
3. P. Tuladhar MEE 07158 Engineer, Dept on Urban Development & Building Construction, Govt. of Nepal
4. E.Vaseva, 11th national congress on theoritical and applied mechanics, 2-5 sept 2009 Borovets,Bulgaria
5. G.Uva, F.Porco, A.Fiore,Eng Struct Vol 34 2012, pp 514-526
6. A.Fiore, F.Porco, D.Raffaele, G.Uva, , Soil Dynamic and Earthquake Engineering Vol 39, 2012, pp 11-22
7. Prestandard and commentary for the seismic rehabilitation of buildings, FEMA 356, (2000)
8. Bryan Stafford Smith, Build Sci. Vol 2, pp 247-257. Pergamon Press 1967. Printed in Great Britain
9. G.Uva, D.Raffaele, F.Porco, A.Fiore: On the role of equivalent strut models in the seismic assessment on infilled RC buildings. Engineering structures 42, 2012 83-94
10. M.Dolsek, P.Fajfar, Engineering Structure, Vol 30, 2008, pp 1991-2001
11. S.Cattari, S.Lagomarsino, First European Conference on Earthquake Engineering and Sismology. Geneva, Switzerland 3-8 sept 2006, paper n° 927.

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