EFFECT OF INFILL MASONRY PANELS ON THE SEISMIC RESPONSE OFFRAME BUILDINGS

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ABSTRACT

This paper presents the results of an experimental program investigating the behaviour of frame with masonry infill panels subjected to cyclic loadings. Two types of masonry frequently used were tested. The effects of the infill panels on the seismic response of frame buildings were evaluated. The experimental results have been used to develop an analytical model for the determination of the stress-strain relationship to predict the inelastic behaviour of each type of infill. A linear (spectral) and non linear (step by step) analysis have been carried out on currently used prototype frames. The results obtained show that the infill has an effect on the seismic response of frame buildings and it should be considered in the analysis of such a type of structures.

KEY WORDS

Infill panels, seismic behaviour, cyclic loading, modelling, frames. Fundamental period, base shear

1. INTRODUCTION

Reinforced concrete frame buildings with masonry infill walls are a type of construction widely used in Morocco .and throughout many countries. Hollow clay tile blocks and hollow concrete blocks are used for infill. The masonry panels, which are required to build the partition and enclose the structure, are generally considered as non-structural components. Therefore, the commonly accepted hypothesis in the design of frame structures is to neglect the structural role of the infill panels, This hypothesis does not seem to correspond with the reality when the structure is subjected to seismic lateral loads. As a matter of fact, the behaviour of the structures is affected by these non-structural elements in earthquake horizontal loads. Some skeleton failures observed during earthquakes have been, indeed, attributed to the action of the infill panels placed in the frames. The goal of this paper is to bring a contribution to the knowledge of the effect of infill panels on earthquake response of frame buildings. From the experimental point en view, two types of infill panels confined in frame have been tested. The test results are used in theoretical analysis. Experimental and numerical investigations are briefly presented.

2. EXPERIMENTAL INVESTIGATIONS

Two different types of infill panels confined in frame have been tested. Panels are made of hollow clay tile blocks, and hollow concrete blocks. The tests have been made under quasi static alternate loading (ref 1). Loads were high enough to crack the masonry panels without yielding the steel frame. Because of the limited length of the article the results of the experimental tests are briefly summarized.

2.1 Stiffness

Infilling panels are found to increase stiffness of the structure as observed in Figs. 1 and 2. The increase in initial stiffness, obtained for small strains, can reach 7 times that of bare frame. Experimental data show that after the first shear cracking, appreciable stiffness degradation occurs. This decrease continues when the displacement increases. However, the stiffness of the infill frame remains higher than that of the bare frame even after the collapse of the masonry panel as shown in Fig. 3.

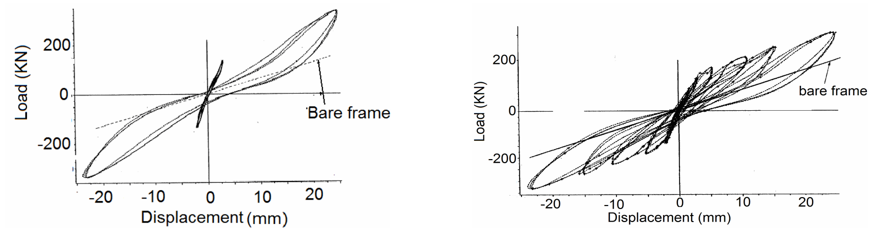


Figure 1 Load versus displacement curves

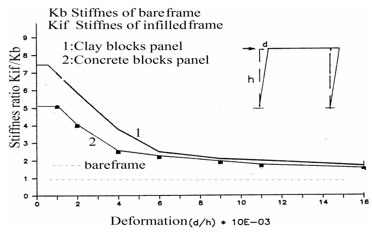


Figure 2 Degradation of panel stiffness

2.2 Strength

The infill panel acts as a lateral load resisting structural element and results in an increase in strength of the frame.The ultimate strength has increased to 1.9 times that of the bar frame as shown in fig. 2. As it can be observed, there is no reduction in the strength of the infill frame, in spite of the degradation of the panel. Load levels depend on the type and thickness of the panel of masonry.

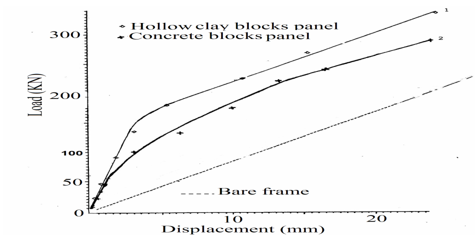
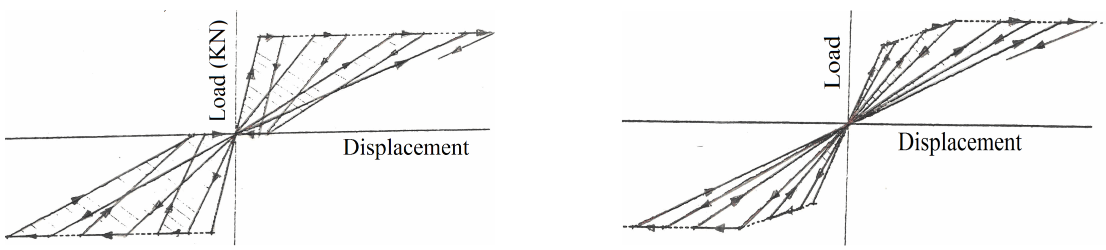


Fig. 3 Experimental strength envelop vs displacement curves

2.3 Hysteretic modelling of infill panel

Dynamic inelastic analysis of frame buildings with masonry infill walls requires realistic conceptual model of these walls that can simulate there strength, stiffness, and energy-dissipation characteristics. The experimental hysteretic load-displacement curves have been used to develop a model of the global behaviour of each type of infill panel. It's a set of rules that define the branches of loading, unloading, and reloading under reversed cyclic loading. Detail of the hysteretic model of each type of panels is given in ref (2). The two models are shown in figs. 4. These models can be used in non linear seismic analysis.



(a) Hollow clay blocks

(b) Hollow concrete blocks

Figure 4: Hysteretic model of infill panel

3. NUMERICAL INVESTIGATIONS

The purpose is to illustrate the effect of infill panel on the overall structural response. The experimental results have been used in the theoretical study. For covering the range of short, medium and tall buildings, the 5, 10, 15 and 20 floors frames were selected. The locations of infill walls were changed in horizontal direction. The full details of member sizes and other specifications of all models are given in ref. (3). Dynamic time history analyses were carried out, assuming a nonlinear behaviour of masonry panels, by using the proposed hysteretic model of each type of masonry. The computer program, NODYNA was used. The program contains the proposed models of the types of the masonry panels. All of the in filled frames were analyzed with this program and subjected to EL Centro and Taft ground motions records. The structures were analyzed for the first fifteen seconds of the records.

3.1 The modelling of frame buildings

Based on the commonly accepted approach in the design of frame building, an analytical macro-model was used. The panel is idealised by a compression diagonal strut opposing the lateral deformation of the structure as shown in. Fig.5. When the building is subjected to horizontal seismic forces the masonry panel is replaced by two compression diagonal trusts as shown in. Fig.6 thus frames with masonry confined panels are modelled as equivalent braced frames by assuming the frame members and diagonal struts to be pin jointed as shown in fig.7. This approach is simple and computationally attractive.

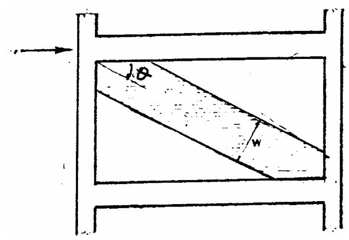


Fig 5 Idealisation of masonry Infill panel

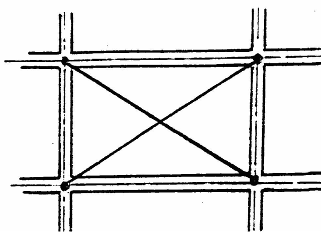


Fig 6 Idealisation of infill for dynamic analysis

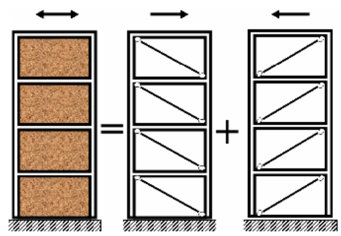


Fig 7 Idealisation of in filled frame building

There are expressions for dimensions that should be considered for the equivalent diagonal strut. The expression taken from ref (4) and the test results ref (1) were used to evaluate the width W of the equivalent strut replacing the masonry panel fig 5. This width is given by the equation. 1.

$$W = = 0.135D\,\beta^{-0.4} \qquad (1)$$

Where:

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

D is the length of the strut, E_c, I_c , H are the elastic modulus, the modulus of inertia and the height of the column panel respectively. θ ,t, H_i are the angle defining diagonal strut with the horizontal, the thickness and the height of the infill panel respectively. The elastic in-plane stiffness of a masonry infill panel is represented with a compression strut of width W. The initial lateral stiffness K_i of a diagonal strut is given by the following expression:

$$K_i = \quad E_i\, w\, t \cos^2\theta \;/ D \qquad (3)$$

If the beam and column sections do not change drastically from floor to floor and story heights throughout major part of the building are fairly constant, the story lateral stiffness of a bare frame can be given by the following expression;

$$K_b = 12E_c \sum(I_c) / H^3(1+2\alpha) \quad (4)$$

with

$$\alpha = L.\sum(I_c) / H \sum(I_b) \quad (5)$$

Where H and L are the high of the column and the length of he beam respectively. The moment of inertia of the column and the beam are denoted by I_c and I_b respectively. The initial lateral stiffness of the building in each story, denoted by K_{if}, can be estimated by the following expression:

$$K_{if} = m K_i + K_b \quad (6).$$

m is the number of infill panels in a story. The ratio of the initial story panel stiffness to the story equivalent stiffness of the bare frame is denoted by:

$$\mathbf{r} = K_i / K_b \quad (7)$$

r is used as a parameter for evaluation of the effects of infill masonry on structural behaviour of the frame building subjected to seismic loading. Results regarding the fundamental period, the base shear, maximum displacement and the distribution of forces in the frame elements are presented.

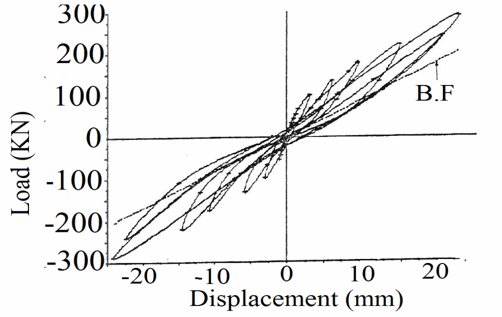
3.2 Hysteretic models of diagonal struts

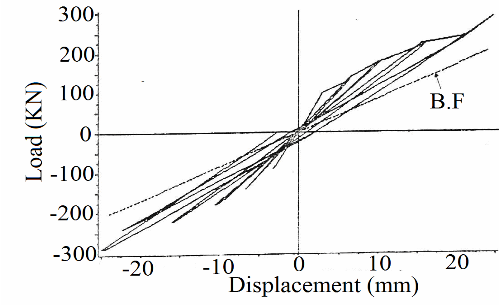
The proposed hysteretic models of the global behaviour of each type of infill panel have been used to develop a hysteretic relationship stress-strain of the strut replacing the panel. Each strut is characterized by a hysteretic model, that can simulate strength, stiffness degradation, and energy-dissipation characteristics Figs.8 and 9.These hysteretic models have been implemented in the non linear dynamic analysis program NOLIDAP. Fig. 10 shows a comparison of experimental and analytical results using the proposed hysteretic models of diagonal struts. The experimental curves correlate with the analytical curves obtained by using the proposed hysteretic models of diagonal struts..

Fig 8 Hysteretic model stress-strain of diagonal strut

(a) Experimental curves (b) Numerical curves

Fig 9 Load versus displacement curves





(a) Experimental curves (b) Numerical curves

Fig; 10 Comparison of experimental and numerical results

3.2Fundamental period

The fundamental period is an important design parameter that plays a significant role in the computation of design base shear. The first natural periods of the building are estimated using an eigenvalue analysis, applying the initial elastic stiffness matrix. The inclusion of the masonry panels rigidity in structural modelling changes the fundamental periods of the model by stiffening the structure, and in turn affects considerably the overall response of the building to earthquake ground motion. Fig. 11 shows that when the stiffness provided by the infill panels was included in the analysis, the structure periods decrease considerably. In some cases the periods of frame buildings when the infilling panels are neglected are 2 to 3 times larger than the actual building periods when panels are taken into account in the calculation.

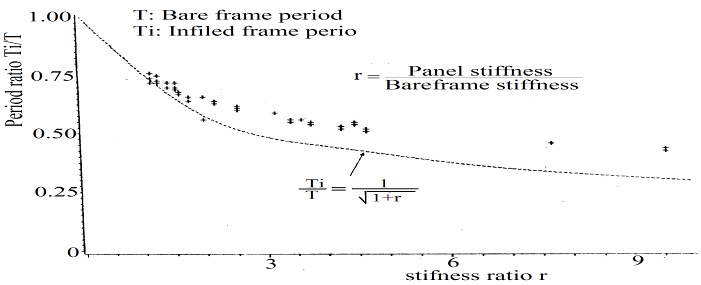


Fig 11 Effect of infill panel on the fundamental period

3.3 Horizontal seismic base shear force.

Figure 12 illustrates the variation of computed base shear forces with the amount of lateral bracing expressed in terms of the ratio of infill panel stiffness to bare frame stiffness. The behaviour of infill panels is assumed linear elastic. 28 buildings with tree spans and different levels, 5-10-15-20 floors, have been studied.

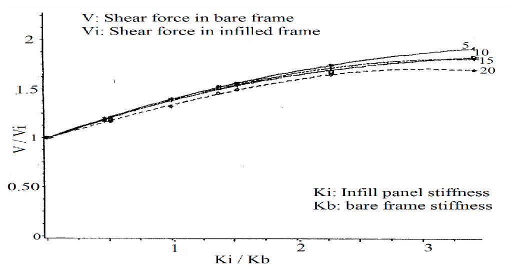


Fig 12 Effect of infill panels on the seismic base shear force

To evaluate the base shear force when the infill panels develop nonlinear behaviour, time-history analyses have been carried out on 20 frame buildings which were subjected to El Centro N-S 1940 and Taft 1950 records. Figures 13 and 14 show the results of typical structure of ten stories and tree bays The central bay is filled by hollow clay blocks panels The initial stiffness of the building is 1.7 times more than that of bare frame. The peak horizontal ground acceleration was taken for the two records (0.20g). The hysteretic model of the diagonal strut, presented above, was used. The members frame behaviour remains linear. As shown in the fig. 13 it is clear that the presence of the infill panels results in increase of the base shear. The maximum base shear occurs under the El Centro earthquake record. The shear force in filled frame is 1.53 times that in bare frame. Thought the used value of peak ground acceleration was the same for the two ground motion records, the shear force in the building subjected to Taft record was only 1.29 times that of the bare frame. This is because of difference in frequency continents of the records. Thus maximum base acceleration is not necessarily a representative measure of the intensity of an earthquake.

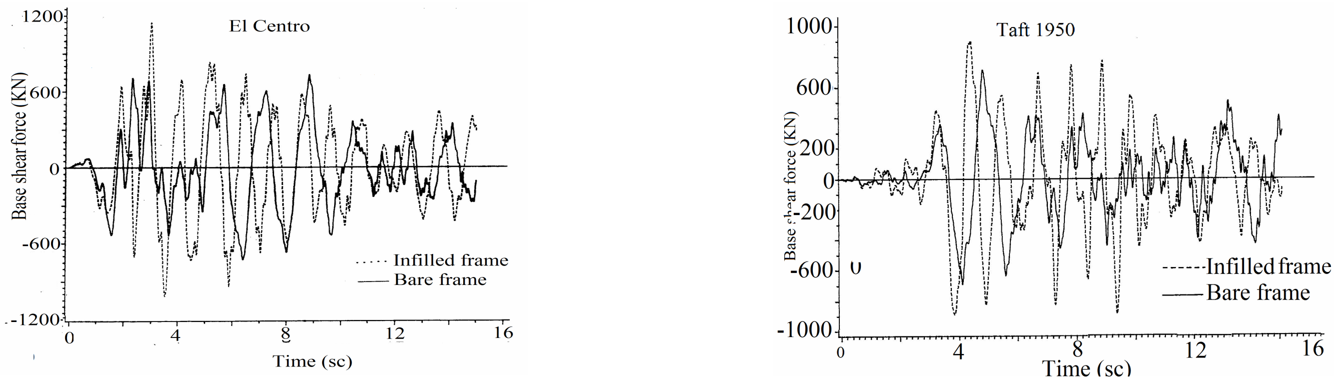


Fig 13 Effect of infill panels on the seismic base shear force

3.4 Lateral displacement

The maximum floor displacements at different levels, when the behaviour of the confined masonry panel is linear elastic are depicted in Fig. 14. for different values of the factor **r** = K_i / K_b . It can be seen that the displacements decrease with the presence of the masonry panels in the frame. In some cases the displacement can be reduced by 40%.

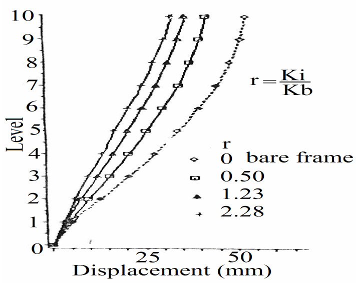
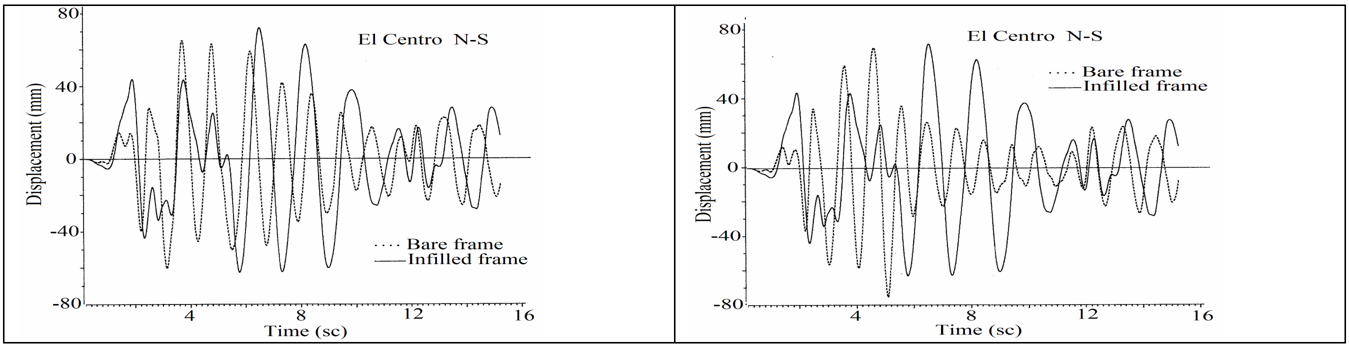


Fig 14 Maximum floor displacements (Taft earthquake)

In order to evaluate the displacement when the infill panels develop nonlinear deformations, the structure was subjected to El Centro and Taft ground motion records. The hysteretic model of diagonal strut replacing the panel mad of hollow clay blocks was used. Two initial panels stiffness ratios were used (Ki/Kb = 1.70 and 3.3). As shown in fig 15, the waveforms are not similar they depend on the initial stiffness. It was found that there is a reduction in the top level displacement of the structure for Taft ground motion record In the case of El Centro record, the amplitude displacement was close to that of bare frame. It was reduced by 10% with a ration r of 1.70 fig. 15 (a) and increased by 7% when the ratio was of 3.3, fig. 15 (b). This small change in the top level displacement can be explained by the increase in the horizontal seismic forces due to the increase in initial stiffness of the structure and because as the stiffness change, the frequencies of the structure change and may fell into the vicinity of the frequencies of the recorded data. Hence, the structure may be close the state of resonance.

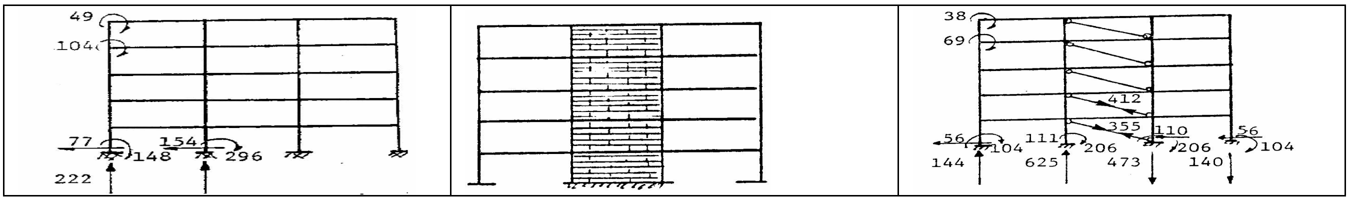


(a) r =1.7 (b) r = 3.3

Fig. 15 Top level displacements

3.5 Modification of frame member forces.

The presence of infill panels transform the rigid frame into braced frame. Therefore the structural behaviour is different from that assumed by the analysis. Flexural effects will decrease substantially. Fig.17 shows clearly a typical example of the drastic changes in bending moments and axial forces obtained when a masonry panel is included in the analysis of a frame or when it is neglected. Obviously, the design of the frame elements with the moments and forces obtained without the panel is useless. Because of this modification of frame member forces some damage may be expected when the structure is subjected to earthquake. This damage usually take place in the angular columns adjacent to the panel due to the additional shear forces from the diagonal strut as shown in Fig 18. It may also happen that the failure of the panel leads to the creation of short columns which causes shear failure of them selves, Fig, 19.



V= 462 KN (shear base force) V= 650KN

Fig. 17 Chang in internal forces

Fig 19 failure of angular column

Fig 19 Creation of short column AlHoceima 2004

4. CONCLUSION

The experimental results show that infill panels increases the lateral stiffness and strength of the bare frame. The increase in initial stiffness, can reach 7 times that of bare frame. This stiffness decreases when the displacement increases but it still remains higher than that of the bar frame in spite of the degradation of the masonry. The increase of the lateral strength can reach 1.9 times that of the bare frame. The test results were used to propose a hysteretic model of diagonal strut for each type of infill that can simulate initial stiffness, strength, stiffness degradation. The numerical analyses show that the inclusion of the masonry panels reduces the fundamental periods of the structures. There is a significant increase in the horizontal base shear forces due to reduction of fundamental period. The displacement may be reduced or increased depending on the frequency contents. The equivalent diagonal representing the confined panels transform the rigid frame into trussed frame, and there is a definite change in the form in which the frame will resist lateral loads; flexural effects will decrease substantially. There is a drastic change in bending moments and axial forces. Then the presence of infill should be considered in the design of the frame structures in order to profit from its positive contribution to the strength of the structure and to avoid the possible harmful effects.

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