Sabri Attajkani, Abdellatif Khamlichi, Abdellah Jabbouri / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 1, January -February 2013, pp.1178-1183

Modelling the Effect of Infill Walls on Seismic Performance of Reinforced Concrete Buildings

Sabri Attajkani*, Abdellatif Khamlichi*, Abdellah Jabbouri*
*Department of Physics, Abdelmalek Essaâdi University, M'hannech 2, Tetouan, Morocco

ABSTRACT

Infill walls contribute to lateral stiffness and resistance of buildings they stuff. These variations of rigidity and strength are dependent on the mechanical properties of the material used for the infill and also on the interaction existing between this last and the frame. In this work, masonry like infill walls were modeled by using the equivalent diagonal strut concept in order to asses their involvement in seismic resistance of regular reinforced concrete building. Pushover analysis was performed by means of ZeusNL software package. Various scenarios of infilled frames that include weak story arrangements at different storey levels were considered. Comparison between complete infilled building, partially infilled with a weak story and bared buildings was performed. The obtained results have shown that infill walls have considerable effect on the lateral stiffness and resistance of reinforced concrete buildings when subjected to the static equivalent seismic loads. It was found also that infill enhances seismic performance. This enhancement is however largely affected by the distribution of infill through the building stories. The soft storey mechanism was found to be more severe when the bared storey is located in the inferior part of the building. For non infilled higher stories an unusual equilibrium state can be reached showing very high lateral resistance.

Keywords - masonry infills, reinforced concrete buildings, seismic performance, pushover, equivalent diagonal strut

1. INTRODUCTION

It is well known that infill walls enhance the lateral behavior of the frames they fill up. In common situations, the infill stiffens the frame laterally by an order of magnitude and increases its ultimate strength to very high values. These variations of stiffness and strength are dependent on the mechanical properties of the material used for the infill: masonry, concrete blocs, reinforced concrete, etc. The interaction between the frame and the infill wall is also strongly affected by the extension of the infill in the frame. It is also influenced by the ratio between the horizontal and vertical applied loads and the infill characteristics: mortar used, reinforcements, type of junction with the frame members, etc.

Because of the complexity to take into account the infill effect on the frame behavior, many researches have attempted at simplifying the modelling of the infill effect on the frame response by introducing simple analytical models. Extensive experimental investigations were used to identify these approximate models. In this context, infilled steel frames were studied at first. On the basis of experimental evidence showing that detachment of the frame from the infill occurs, Holmes [1] has proposed replacing the panel by an equivalent diagonal strut made of the same material as the infill and having a width equal to 1/3 of the infill diagonal length. Based on experimental investigation on diagonally and laterally loaded square infilled steel frames, Stafford Smith [2] has subsequently developed furthermore the idea of an equivalent strut as suggested by Holmes, and provided a numerical procedure to evaluate its dimensions.

The procedure proposed in [2] for the evaluation of the geometrical dimensions of the equivalent strut that represents the stiffening effect of the infill is nowadays well accepted. It was found to be sufficient in many situations, in spite of neglecting some mechanical aspects of the infill-frame interaction [3-5]. Other refined models that embody the effect of infills walls can be found in the literature [7-10].

The equivalent strut characteristics are identified according to Mainstone model [9] and used after that for pushover analysis of the infilled frames, where all the walls are replaced by their equivalent diagonal struts. ZeusNL [11] software package is employed in this analysis. The objective is to assess the influence of infills on seismic capacity of buildings. A four-storey three-bay reinforced concrete building will be studied and the weak-story effect investigated.

2. EQUIVALENT STRUT MODELS FOR INFILLED FRAMES

In FEMA 273 [6], FEMA 306 [7] and FEMA 356 [8] it is suggested that the stiffness of the infills is represented in the structural model by equivalent diagonal struts based on the work of Mainstone [9]. The equivalent strut width is given by

$$w = 0.201 \frac{\sqrt{H'^2 + L'^2}}{H^{0.4}\left(E_d\, s \sin(2\theta)\right)^{0.1}} \left(E_f I_c H'\right)^{0.1} \quad (1)$$

with

$$\theta = \tan^{-1}\left(\frac{H'}{L'}\right) \quad (2)$$

where s is the actual infill thickness that is in contact with the frame, d' the diagonal length of the infill, E_d is the Young modulus of the infill along the diagonal, E_f the Young modulus of the reinforced concrete, H and L are the height and the length of the frame, and H' and L' are the height and the length of the infill as shown in Fig.1, finally I_c is the entire inertia moment of the cross-sectional area of the column.

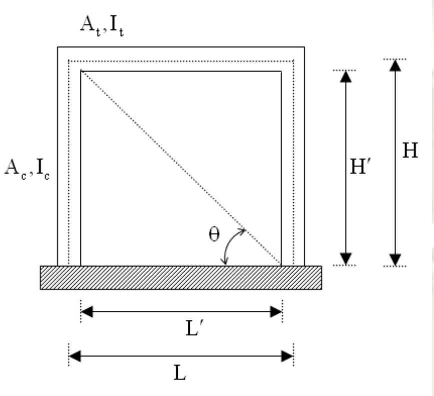


Figure 1. Scheme of the infilled-frame showing the equivalent strut median fibre

3. Static nonlinear pushover analysis by means of ZeusNL software

ZeusNL is an open source software package [11] which provides an efficient way to run structural analyses such as conventional and adaptive pushover and nonlinear dynamic time-history. The modelling takes into account both geometric and material nonlinear behaviour. Common concrete and steel material models are available, together with a large library of elements that can be used with a wide choice of typical pre-defined steel, concrete and composite section configurations. The applied loading can include constant or variable forces, displacements and accelerations.

In the conventional pushover analysis which is used in the following, the applied loads vary proportionally according to a predefined pattern. The post-peak response is obtained with a displacement control procedure.

Modelling static pushover under ZeusNL software requires entering configuration of members sections, material properties, applied loadings and analysis protocol.

In the present analysis, the concrete behaviour was chosen to be described by the nonlinear concrete model with constant active confinement modelling (con2), Fig.2. This enables accurate uniaxial concrete behaviour description where a constant confining pressure is assumed in order to take into account the maximum transverse pressure from confining steel. This is introduced on the model through a constant confinement factor, used to scale up the stress-strain relationship throughout the entire strain range. To enter this concrete model during simulations, four parameters are required: compressive strength f_c, tensile strength f_t, crushing strain ε_{co} and confinement factor k.

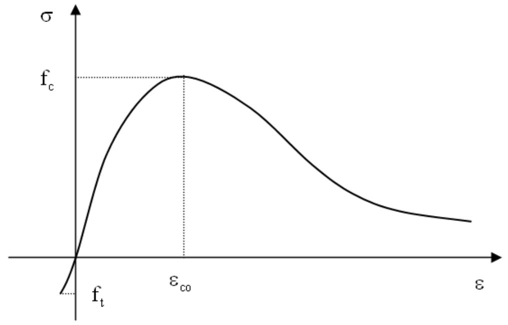


Figure 2. Uniaxial constant confinement concrete model

The reinforcement steel behavior was assumed to be a bilinear elastic plastic model with kinematics strain-hardening (stl1), Fig.3. This model is applied for the uniaxial modelling of mild steel. To enter this model during simulations, three parameters are required: Young's Modulus E, yield strength σ_y and kinematic strain-hardening μ.

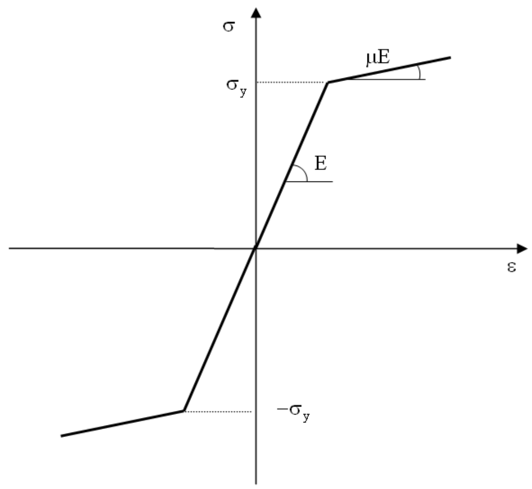


Figure 3. Uniaxial bilinear elastic-plastic law with kinematic strain-hardening modelling mild steel

Static pushover analysis was conducted by taking the most adverse seismic direction when the building structure is assumed to be a plane gateway frame. Response control protocol was chosen to monitor the nonlinear analysis. This refers to the situation where the displacement of the building roof is specified by the user and is incrementally increased. The loading applied as well as the deformations of the other nodes are determined by the solution of the program.

4. PRESENTATION OF THE CASE STUDY

A reinforced concrete building consisting of a regular framed structure having four stories and three bays is considered. The inter-storey height is $3\,\text{m}$, the bay length is $4\,\text{m}$. Fig.4 shows the portal frame which is equivalent to this building when subjected to static lateral equivalent loading along the most adverse seismic direction.

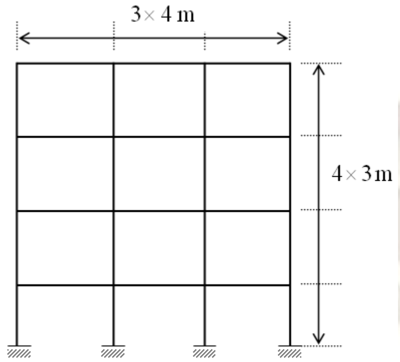


Figure 4. Vertical elevation of the four-storey reinforced concrete structure in the seismic direction

All the columns are assumed to be identical and all the beams equal. Fig. 5 and Fig.6 show respectively the columns and beams sections.

Columns characteristics are: section height $h = 400\,\text{mm}$, height of the confined part $h_c = 350\,\text{mm}$, section width $b = 300\,\text{mm}$ and width of the confined part $b_c = 250\,\text{mm}$. Table 1 gives the reinforcements sections and their locations.

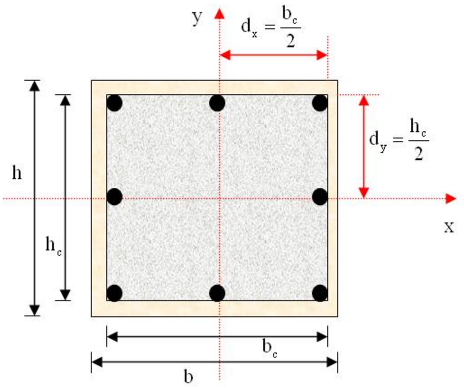


Figure 5. Columns reinforced section; pushover is considered along the y-axis while x-axis is the other horizontal direction

Beam characteristics are as follows: compressed span height $h = 200\,\text{mm}$, height of the confined part of compressed span $h_c = 200\,\text{mm}$, height of the beam $H = 600\,\text{mm}$, height of the confined part of the beam $H_c = 600\,\text{mm}$, effective width of the compressed span $B = 1250\,\text{mm}$, width of confined part of the compressed span $B_c = 1200\,\text{mm}$, width of the beam $b = 300\,\text{mm}$ and width of the confined part of the beam $b_c = 250\,\text{mm}$. Table 2 gives the steel reinforcements bar sections and their positions on the transverse beam sections.

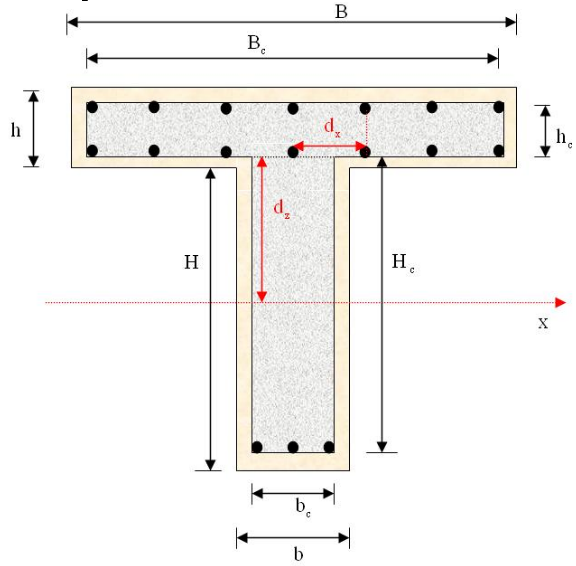


Figure 6. Beams reinforced section; pushover is considered along the horizontal y-axis while x-axis is the other horizontal direction

Table 1. Steel reinforcements section and their locations in columns transverse sections

Section mm^2	Distance d_x mm	Distance d_y mm
255	125	175
127.5	0	175
127.5	125	0

Table 2. Steel reinforcements section and their locations in beams transverse sections

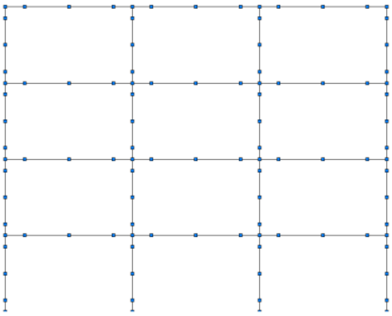
Section mm^2	Distance d_x mm	Distance d_z mm
255	25	125
255	775	125
127.5	25	0
127.5	775	0

Material behavior for steel reinforcement bars is chosen to be such that $E = 2.1\times10^{11}$ Pa, $\sigma_y = 500\times10^6$ Pa and $\mu = 0.05$. For confined concrete, the following characteristics are assumed to hold: $f_c = 20\times10^6$ Pa, $f_t = 2.2\times10^6$ Pa, $\varepsilon_{co} = 0.002$ and $k = 1.2$. The unconfined concrete is assumed to have the same properties as for confined concrete except that $k = 1.02$. Material of struts that are equivalent to infills is assumed to be like that of concrete with the following properties:

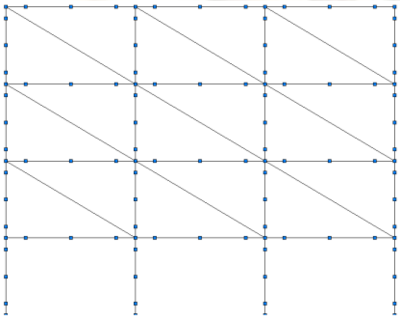
$f_c = 10\times10^6$ Pa , $f_t = 1.1\times10^6$ Pa , $\varepsilon_{co} = 0.001$ and $k = 1.02$.

5. RESULTS AND DISCUSSION

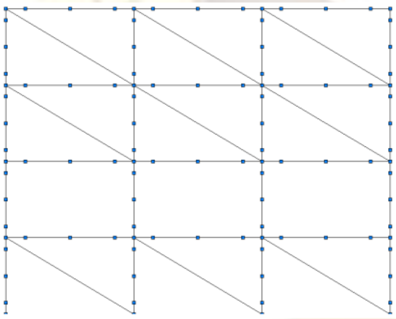
The infill section is considered to be uniform over all the infilled stories of the building. Fig.7 gives the different configurations of infills that are considered. These include the bare frame (a), variable level weak storey (b)-(e) and the complete infilled frame (f).



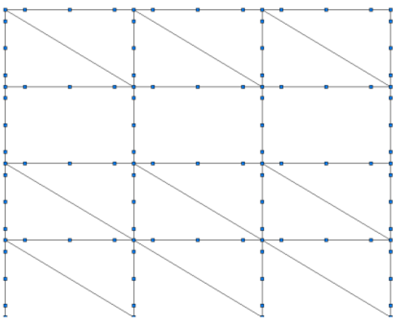
(7a)



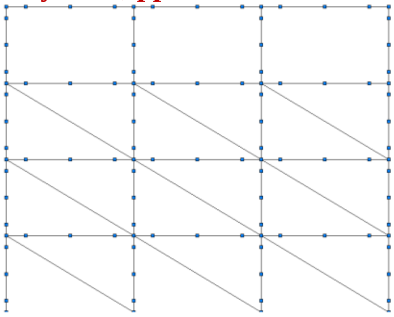
(7b)



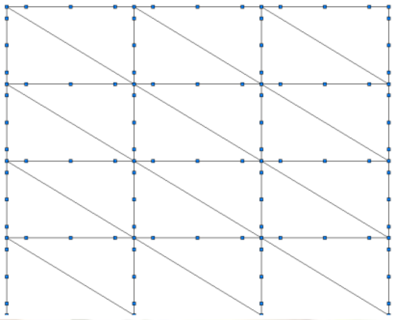
(7c)



(7d)



(7e)

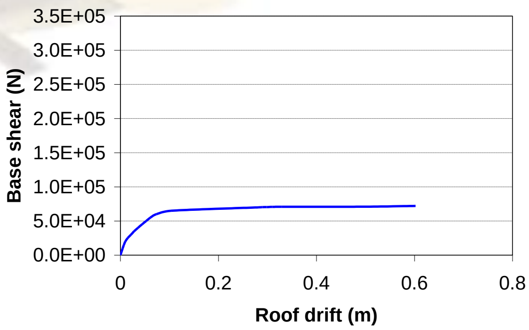


(7f)

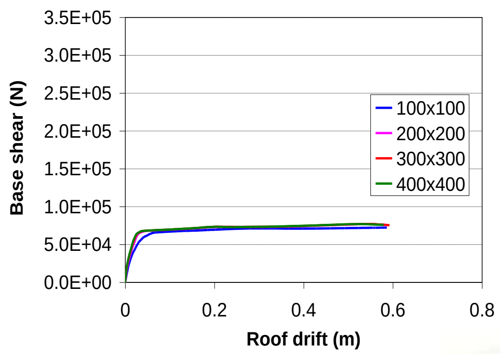
Figure 7: Considered frame infilled configurations; (a) bared frame; (b) bared first storey; (c) bared second storey; (d) bared third storey; (e) bared fourth storey and (f) completely infilled frame

Fig.8 gives pushover curves, as they were computed by ZeusNL for the different infilled frame configurations and given infill section. These last have been varied in the set $\{100\times100;\ 200\times200;\ 300\times300;\ 400\times400\}$. This parametric study is intended to determine the effect of infill section for a given infilled configuration. It enables to answer the question about which weak storey will have a minor effect on seismic performance?

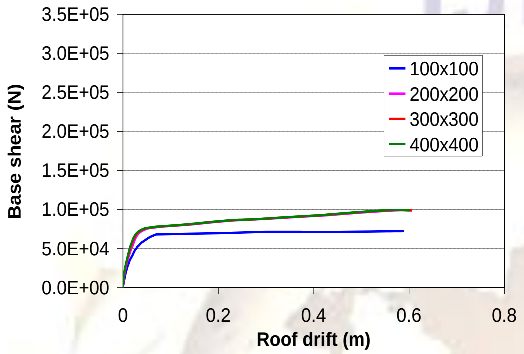
Fig.9 gives pushover curves, but this time as function of the infilled configuration for the different infill section taken in the set $\{100\times100;\ 200\times200;\ 300\times300;\ 400\times400\}$. This is to determine for a given infilled section which configuration performs the best?



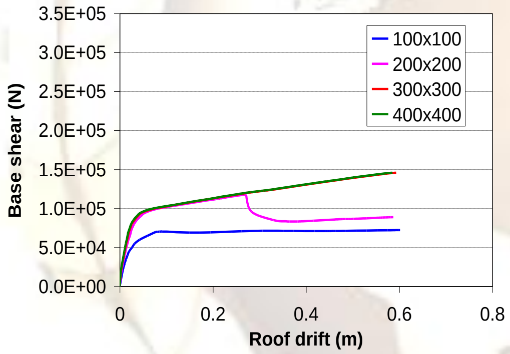
(8a)



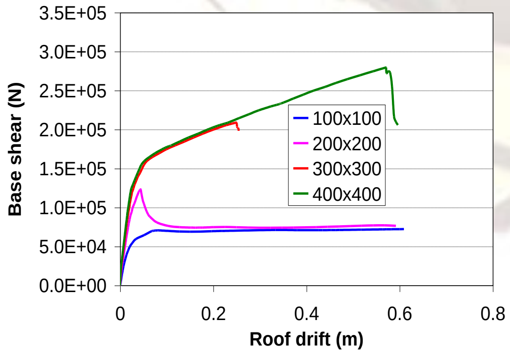
(8b)



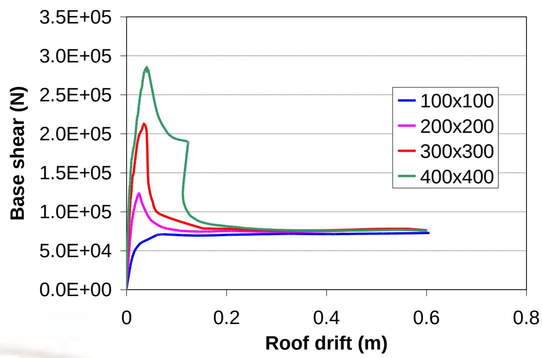
(8c)



(8d)



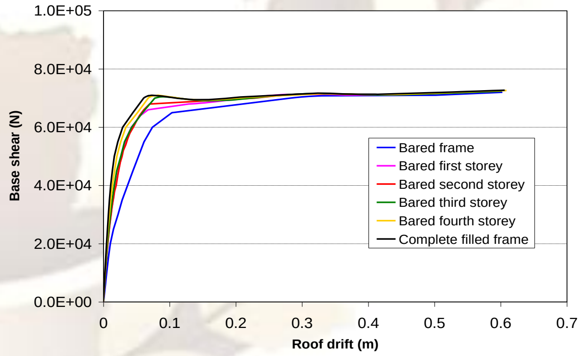
(8e)



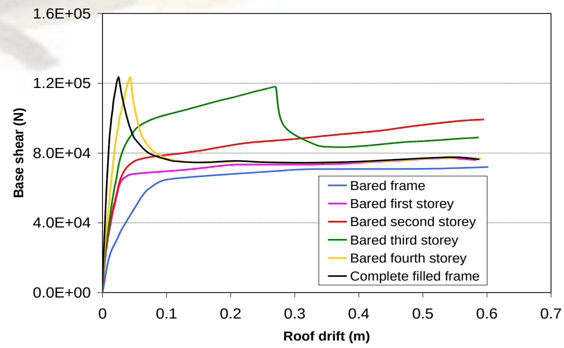
(8f)

Figure 8: Pushover curves as function of infill sections for the different infilled configurations; (a) bared frame; (b) bared first storey; (c) bared second storey; (d) bared third storey; (e) bared fourth storey and (f) completely infilled frame

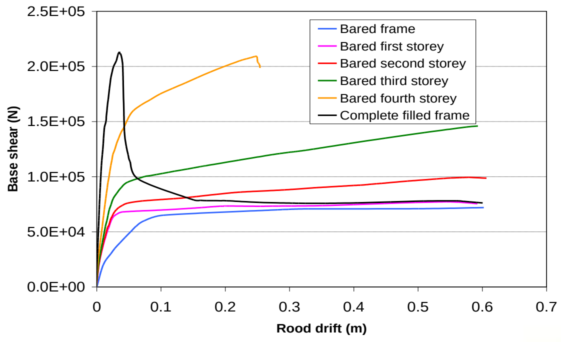
Fig.8 and Fig.9 show that infill has always a benefit effect of the lateral seismic behavior of the portal frame as the obtained capacities are always higher independently of where the infill has been placed. As this can be seen from Fig.8b, if the first storey is not infilled, then there is no need to seek enhancing the seismic behavior of the building, by inserting infills in the upper stories. Also, as seen from Fig. 9a, if the infill quantity is not enough, only insignificant changes will be observed on the capacities independently from where the weak storey exists. The infill will affect in this case only the initial stiffness and insignificant variations appear in the lateral capacity.



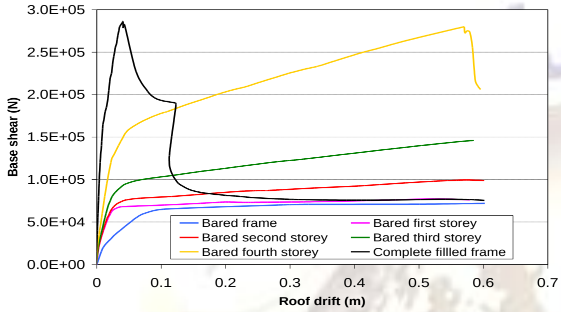
(9a)



(9b)



(9c)



(9d)

Figure 9: Pushover curves as function of the infilled configuration for different infill sections; (a) 100×100; (b) 200×200; (c) 300×300; (d) 400×400; (e) bared fourth storey and (f) completely infilled frame

Some frame configurations with partially infilled stories are more advantageous than the complete infilled frame in terms of ductility as this can be seen from Fig.8e, Fig.8f , Fig.9c and Fig.9d. The bared fourth storey will have quantitatively higher ductility than the complete infilled frame even if the initial stiffness shows the reverse behavior. This behavior can be beneficial if confirmed by experimental tests in order to increase seismic performance of buildings. It can be assessed also through a dynamic modelling of the building, as irregularity from bared stories can have a drastic effect on the results that could not be assessed through only nonlinear static analysis.

6. CONCLUSION

The effect of infills on seismic performance of reinforced concrete building was analyzed. This was achieved through using the concept of equivalent compression diagonal strut that enables to model the infill mechanical behavior. Considering regular buildings for which the seismic response can be sought by means of the equivalent portal frame subjected to lateral static equivalent loads to seismic action, pushover curves were derived by using ZeusNL software package.

The obtained results have shown that infill enhances always seismic performance. This enhancement is however largely affected by the distribution of infill through the levels of the building stories. For infill to be beneficial, the lower stories should be first infilled and the infill quantity should be significant.

The obtained results have shown also that some infill configurations with bared stories are more advantageous than the complete infilled frame in terms of ductility, while the highest stiffness is always achieved by the configuration where all the stories are infilled.

REFERENCES

[1] H. Holmes. Steel frames with brickwork and concrete infilling. Proceedings of the Institute of Civil Engineers 1961; 19:473-478.

[2] B. Stafford Smith. Behaviour of the square infilled frames. *Journal of Structural Div. ASCE* 1966; 92:381-403.

[3] R.E. Klingner, V.V. Bertero. Earthquake resistance of infilled frames. *Journal of Structural Engineering, ASCE* 1978; 104:973-989.

[4] T.N. Valiasis, K.C. Stylianidis, G.G. Penelis. Hysteresis Model for weak brick masonry infills in R/C frames under lateral reversals. *European Earthquake Engineering* 1993; 1:1–9.

[5] T.B. Panagiotakos, M.N. Fardis. Seismic response of infilled RC frames structures. *Proceedings of the 11th World Conference on Earthquake Engineering*, Acapulco, Mexico. Paper no. 225. Oxford: Pergamon, 1996.

[6] Applied Technology Council. *NEHRP Guidelines for the seismic rehabilitation of buildings*. FEMA 273, prepared by ATC (project 33) for the Building Seismic Safety Council. Washington (DC): Federal Emergency Management Agency; 1997.

[7] Applied Technology Council. *Evaluation of earthquake damaged concrete and masonry wall buildings - basic procedures manual*. FEMA 306, prepared by ATC (project 43) for the Partnership for Response and Recovery. Washington (DC): The Federal Emergency Management Agency; 1998.

[8] ASCE. *FEMA 356 Prestandard and commentary for the seismic rehabilitation of buildings*. Reston (VA): American Society of Civil Engineers; 2000.

[9] R.J. Mainstone. On the stiffnesses and strengths of infilled frames. *Proc Inst Civil Eng 1971*(Suppl. iv):57-90 [7360 S].

[10] B. Stafford Smith. Behavior of square infilled frames. *Journal of Structural Engineering, ASCE* 1966:381-403.

[11] A.S. Elnashai, V.K. Papanikolaou, D.H. Lee, 2008. *Zeus NL A system for inelastic analysis: User Manual, Version 1.8.7*, University of Illinois at Urbana Champaign, Mid- America Earthquake Center.