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The Influence of the Seismic Action on the RC Infilled Frames

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ABSTRACT: *The effects of the masonry panels on the seismic performance of the reinforced concrete frames depend on different factors: the building geometry, the mechanical characteristics of the infill, the intensity of the seismic action. The infills can provide an important contribution to the overall strength and stiffness, saving the building from collapsing in case of high intensity earthquakes. The paper presents a comparative study between infilled RC frames, with different number of stories (from four to seven), subjected to different seismic intensities.The study refers to three structural systems: the bare frame; the infilled frame, with the masonry panel that is isolated from the structure; the infilled frame that interact with the masonry wall. The study consists on carrying-out nonlinear static pushover analysis for each case and comparing the resulting capacity curves*.

KEYWORDS: *capacity curves, infill walls, masonry, push-over analysis*

I. INTRODUCTION

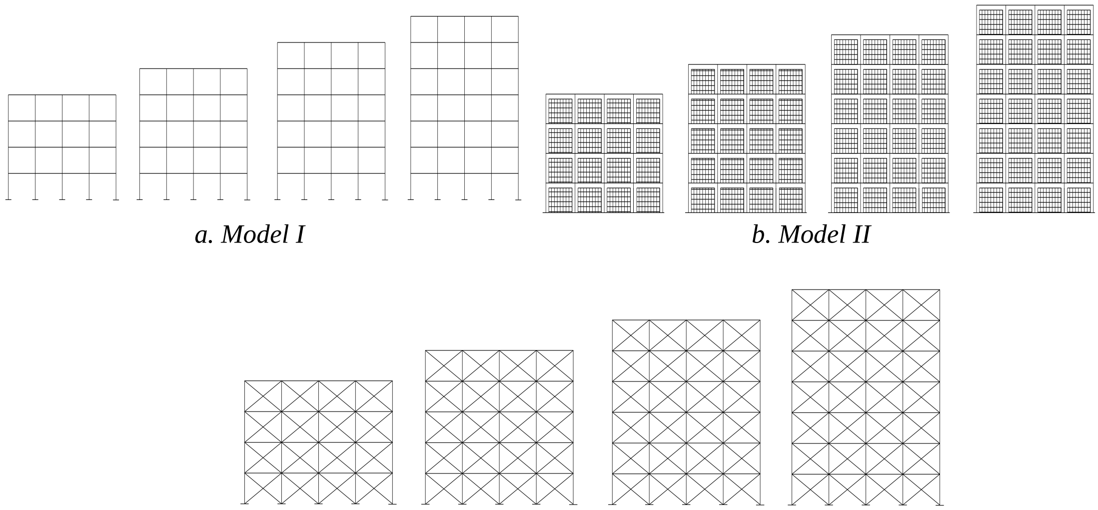
Masonry infilled frames are often encountered in zones with relatively high seismicity from countries such Romania, Greece, Portugal, Italy. Most of them are designed according to old standards, or even without following any specific rule of seismic design, and their safety assessment is a concern for modern structural engineering. Besides this, the design of the new buildings aims high performance and low costs, and hence studying the seismic response of the concrete frames with masonry infills is a must.Usually, because of the difficulties of identifying the infills' influence upon the structure, the design approach considers the infills as non-structural elements. This perspective is a simplistic and approximated one, as it has been observed that, under the action of seismic loads, the masonry infills can decisively influence the overall response of the structure. The effects of the masonry are generally positive, as the increase of the global stiffness and strength [1],[2]. The experience of the previous earthquakes revealed the fact that the masonry panels saved the concrete frame from collapsing in many situations, due to the energy dissipation through the cracking of the masonry. Negative effects could also be encountered: brittle failures due to frame-infill interaction (shear splitting, damages of the joints), or caused by a non-uniform distribution of the infills in the structure [3].

The execution of the masonry infills can follow two different approaches. The first one considers full contact between the concrete frame and the infill panel. The second approach consists of separating the wall from the frame thought joints, and using special devices (ties, belts, posts and shear connectors) to anchorage the infill. The paper presents a comparative study between concrete frames without masonry and frames provided with infills in the two situations mentioned above: masonry in contact with the frame and separated from the frame respectively. The study aims to evaluate the seismic performance of these structural systems, their load-carrying capacity, stiffness and ductility. The structures are considered to be located in Bucharest, being designed according to P100/2006 [4] and to P100/2013 [5], respectively. The frames are subjected to two different seismic intensities, according to the old and the new Romanian seismic standard. The resulting capacity curves highlight the difference in strength and stiffness of the infilled frames towards the frames without masonry walls.

II. ANALYTICAL MODELLIG

The numerical study consists of carrying out non linear static analysis for a number of 24 plane frames of different heights (from four to seven floors). The length of the frames bays is equal to 5m. The structures are modeled in three different situations:

- bare frames, with no masonry, with walls made of light materials (Fig. 1a. – Model I);
- frames with walls that are separated through joints from the concrete frame (Fig. 1b – Model II);
- frames that are in full contact with the infills and co-operate with them in absorbing the seismic lateral forces (Fig. 1c – Model III).



a. Model I *b. Model II*

c. Model III

Fig. 1 – Different cases of masonry infill frames

The beam and column sections are 0.5x0.25m and 0.5x0.5m, respectively, for all cases. The storey height is 3m, and the slab thickness is 0.13m. The masonry walls thickness is 0.25m. In the case that the infills are separated from the frame, the masonry is introduced in analysis only as an additional vertical load, having no contribution to the absorbing of the lateral loads. In the situation of assuming the co-operation between frame and infill (Fig. 1c), the masonry is modeled as a compressed diagonal strut. This method, known in the scientific literature as the "equivalent strut" method [6], [7], is based on the observation that the load path within the infill panel mainly follows the diagonal. This approach is quite effective and relatively simple to apply, reasons for which is widely used. The fundamental factors that govern the equivalent strut model are the geometrical and mechanical characteristics of the strut. The strut width is an important parameter, for which different proposals have been made. One approach defines the width as a function of diagonal length [8],[9] and other approach provides more refined numerical formulations [10], [11]. In the present paper it has been used the relation determined by Paulay and Priestley [12], which calculate the strut width as a fourth of the diagonal length, adopted in other studies [13], [14]. The strut width value for all structures is 1.29 m.

Table 1. The reinforcement of the columns

	a_g=0.24g		a_g=0.30g	
	Model I	Model II+Model III	Model I	Model II+Model III
P+3E	4Φ20+8Φ16	4Φ20+8Φ16	12Φ20	12Φ20
P+4E	12Φ20	12Φ20	12Φ20	4Φ25+8Φ20
P+5E	12Φ20	12Φ20	12Φ25	12Φ25
P+6E	12Φ20	12Φ20	12Φ25	12Φ28

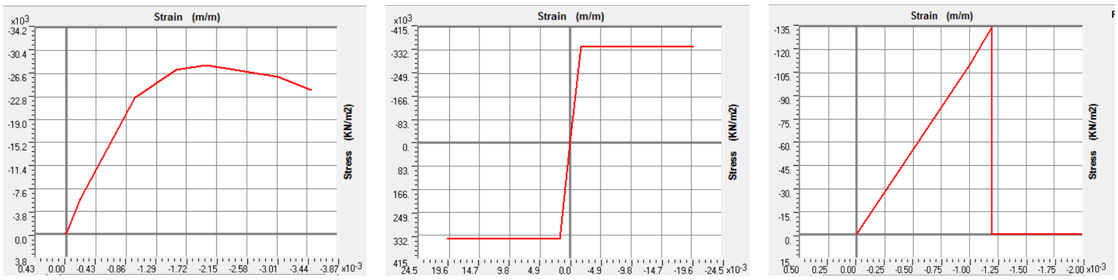
The reinforcement bars in columns are continuous along their entire length. Their number and diameter for all the studied cases are presented in Tabel 1.The reinforcement bars in beams are the same, in number and diameter, both in the fields and the bearings, being reduced in the top stories. The frames with masonry infills (Model II and III) have the beams reinforcement increased with aprox 50% towards the bare frames (Model I).
For the structures that co-operate with the masonry panels (Model III), the stresses resulted from linear elastic analyses are smaller than those obtained for the frames isolated from the masonry (Model II). Nevertheless, Model III frames have been designed similarly to Model II, because the concrete structure should resist to the seismic loads after the infills collapse.

The properties of the materials are given in Table 2.

Table 2. The properties of the materials

Materials	Modulus of elasticity [kN/m^2]	Poisson coefficient	Mean compressive strenght [kN/m^2]	Design compressive strenght [kN/m^2]	Yield strenght [kN/m^2]	Design tensile strenght [kN/m^2]	Strain - maximum force	Ultimate strain
Concrete-C20/25	E_b=30x10^6	0.2	f_{cm}=28000	f_{cd}=13300			ε_{c1}=0.002	ε_{cu1}=0.0035
Steel-PC52 (S 345)	E_a=200x10^6				f_{yk}=345000	f_{yd}=300000		
Masonry	E_z=4.5x10^6	0.19		f_d=1990				

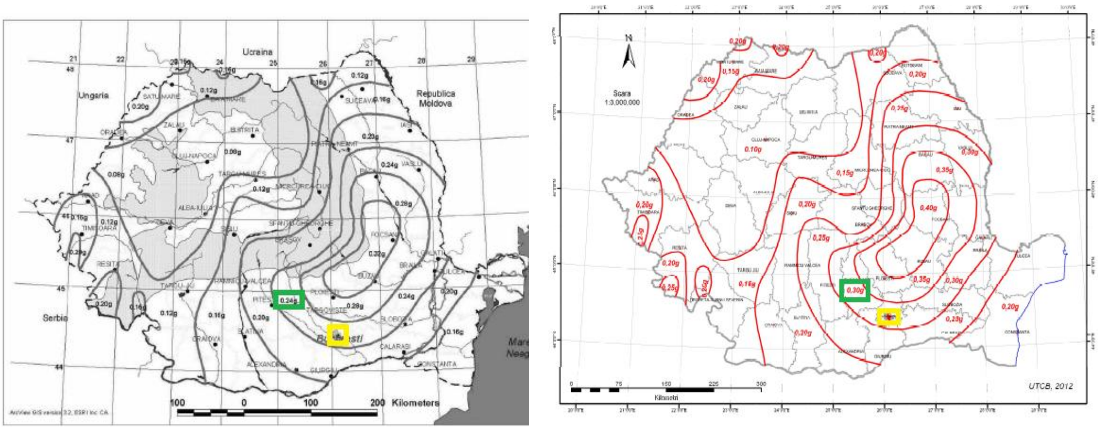
The stress-strain curves, are presented in Fig. 3. The force-displacement relation in Fig. 3c. describes the behavior of the masonry infill on the diagonal direction, and not the behavior of the masonry to the compression effort. The maximum force in the diagonal strut was considered to be 135 kN, associated to a displacement of 0.0012 m [13].



a. *b.* *c.*

Fig. 2 – The stress-strain curves: a. concrete; b. steel; c. masonry

The structures are considered to be located in Bucharest (marked in yellow in Fig. 3) , Romania's capital, in a zone with high seismicity. The Romanian standards are in a continuous process of improvement and therefore the characteristics of the seismic zones have changed. According to the old seismic code –P100/2006, the ground peek acceleration a_g is equal to 0.24g (g- gravitational acceleration) but P100/2013 provides a value of 0.32g, considering that the seismic intensity is higher. The study aims to make a comparison between the structures designed and loaded according to both standards.



a. P100/2006 b. P100/2013

Fig. 3 – The design ground acceleration according to Romania's map

III. RESULTS AND DISCUTIONS

The frames were subjected to an increasing lateral force using NEFCAD software. The results of the nonlinear pushover analyses are the capacity curves which represent the variation of the base shear force related to the displacement to the top of the structure. On each diagram in Fig. 4 are presented the force-displacement curves for all the three models for a specific storey number (from ground floor and three stories to ground floor and six stories) and a specific seismic intensity.

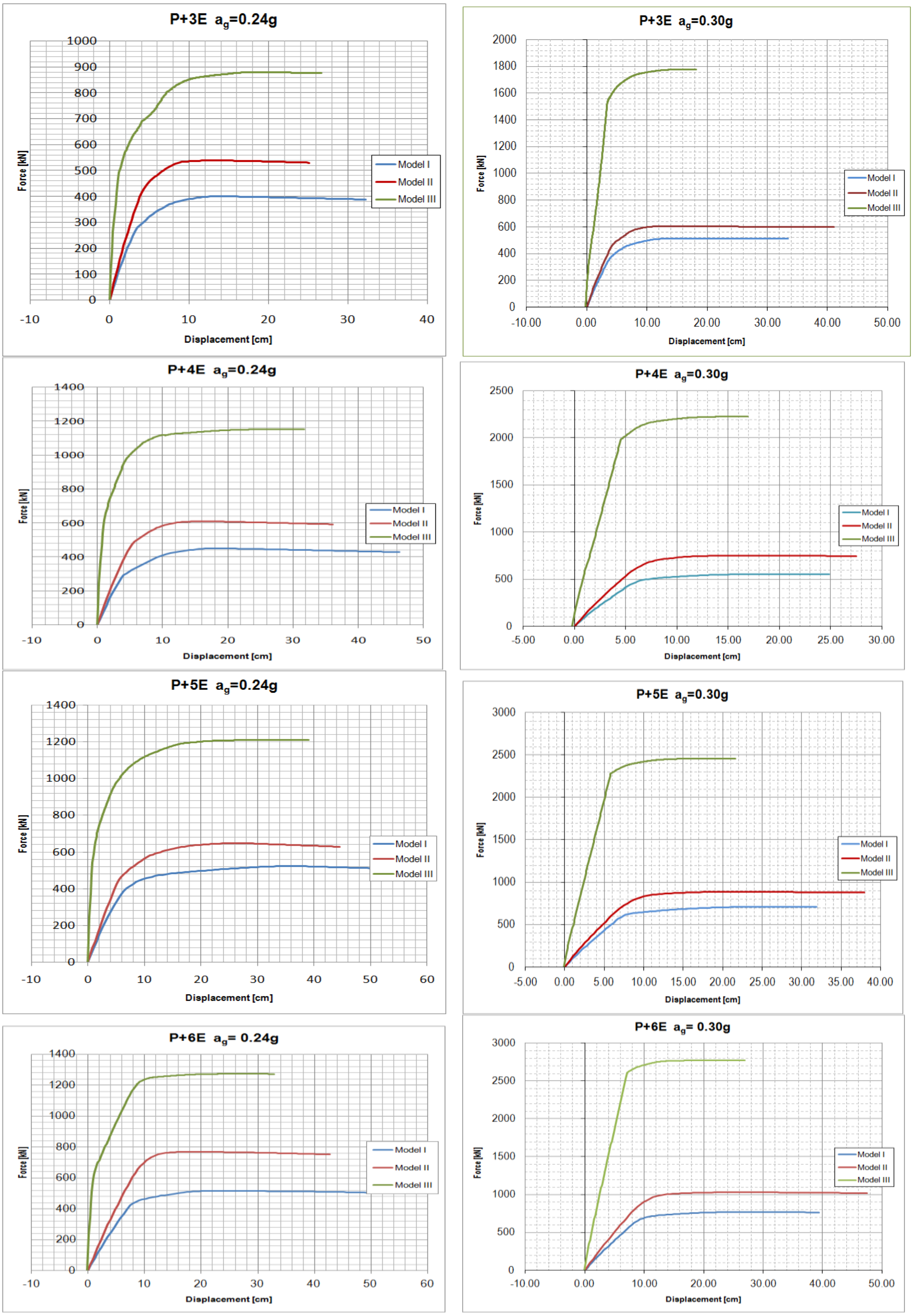


Fig. 4 – Capacity curves

Important information revealed by the capacity curves is that the frames with masonry infills (Model II and Model III) have a higher structural capacity than the structures without masonry (Model I). The increase of load carrying capacity is about one third for the frames with isolated masonry. In the case of the frames in contact with the masonry the increase is of 138% for a seismic intensity corresponding to a_g=0.24g, and of 263% for a_g=0.30g (Fig. 4). These results confirm the positive influence of the masonry infills upon the concrete frames, especially in the case that the walls interact with the frames. Hence the recommendation to use the structural system in which the infills co-operate with the frames in absorbing the seismic force (Model III).

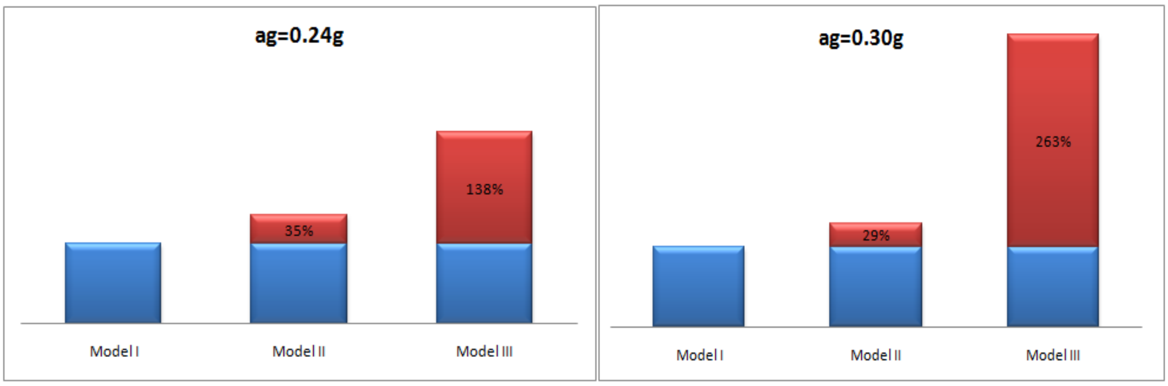


Fig. 4 – The comparison of the structures' capacity

Regarding the stiffness of the structures, it can be observed that infilled frames curves have a higher inclination of the linear elastic segment which means they are stiffer. The increase is not very high for Model II structures, but as for Model III frames, the stiffness is substantially higher. For a specific value of the force, the displacement is much smaller for Model III structures than for the other two models.

IV. CONCLUSION

[1] The presence of the masonry infills can decisively change the behavior of the concrete frames and neglecting their contribution can leads to higher costs and negative effects.

[2] The two possibilities of execute the infill walls are the full contact between the frame and the masonry and the separation through joints of the wall from the concrete frame.

[3] The structural capacity of the infilled structures is much higher compared to the bare frames. The increase of the strength is about 30% for the structures with separated masonry and about 200% for the frames that interact with the infilled walls.

[4] Another positive effect of the masonry infills is the increase of the structures' stiffness which is higher for the frames in contact with the infills than for the frames separated from the masonry.

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