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INFLUENCE OF INFILL MATERIAL ON THE OVERALL BEHAVIOR OF A REINFORCED CONCRETE FRAME STRUCTURE

BY

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Abstract. Reinforced concrete frame structures are a wide spread structural system all around the world. Considered to be flexible structures, they are strongly recommended in areas with height seismicity. The main principle is to create weak breams and strong column, in order that the failure mechanism to be beams and then columns. Severe problems appear due to the supplementary stiffness the non-structural elements bring. Among them is the infill masonry that can be made of several materials and can influence the overall behavior of the structure. The present paper presents the influence of the infill material on the overall behavior of the structure. Numerical simulation in two different computer software is performed. The authors present also a solution to make the infill material to work in the same way as the structural system.

Key words: infill material; reinforced concrete frame structure; polyurethane; stiffness.

1. Introduction

Reinforced concrete (RC) frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multi-family

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residential uses in seismic regions worldwide. Often, the infill walls are not taken into consideration during the design process because the final distribution of these elements may be unknown, or because masonry walls are regarded as non-structural elements (Olteanu, 2011). Masonry infill typically consists of brick, clay tile or concrete block walls, constructed between columns and beams of an RC frame. Nevertheless, the presence of masonry walls have a significant impact on the seismic response of an RC frame building, increasing structural strength and stiffness, in comparison with a bare RC frame, but, at the same time, introducing brittle failure mechanisms associated with the wall failure and wall-frame interaction. Separation between masonry walls and frames is often not provided and, as a consequence, walls and frames interact during strong ground motion. This leads to structural response deviating radically from what is expected in the design (Fig. 1) (Elwood *et al*., 2000).

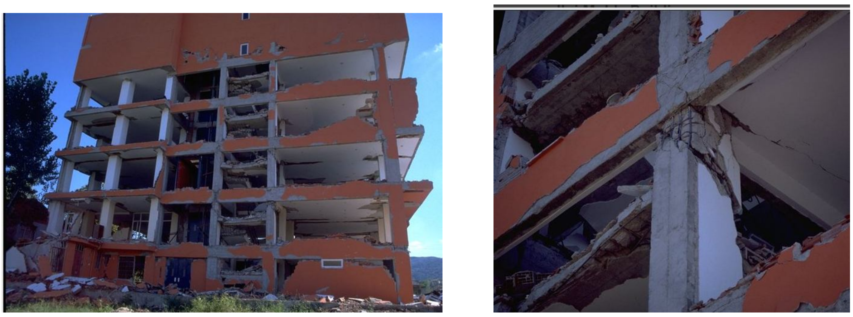


Fig. 1 – Damaged RC frame with hollow clay tile infill masonry, Izmit 1999 (Elwood *et al*., 2000).

Previous experimental research concerning the response of RC frames with masonry infill walls subject to static and dynamic lateral cyclic loads have shown that infill walls lead to significant increases in strength and stiffness in relation to bare RC frames (Alper, 2011).

Polyako,v (1960) conducted experimental tests on masonry-infilled frames, first proposing that the infill system works as a braced frame, with the wall forming compression “struts”. Following this approach, Klingner & Bertero, (1978), tested a one-third scale 3.5 story representation of an 11-story 1970s-era RC apartment building, concluding that reinforced infill panels reduce the risk of incremental collapse, compared to a bare RC frame. Mehrabi *et al*., (1996), tested twelve 1/2-scale single-story single-bay frame specimens and observed that the frames with infill showed better seismic performance than the bare frames.

Analytical methods to model masonry infill panels have advanced alongside experimental research. Based on infill tests by Polyakov, (1960), and others, Holmes, (1961), proposed a linear equivalent strut model for computing maximum strength and stiffness of masonry walls.

Stafford-Smith & Carter, (1969), developed analytical techniques to calculate the effective width of the strut, and cracking and crushing loads, as a function of the contact length between frame and wall elements. Dhanaskar & Page, (1986), modeled an infilled frame using nonlinear finite brick elements, comparing the results with several half-scale experiments. Mehrabi and Shing, (1997), used a smeared-crack finite element model to represent masonry units and RC frames, developing a constitutive model for mortar joints. Stavridis & Shing, (2009), have developed a complex nonlinear finite element model for RC frames with masonry infill, combining the smeared and discrete crack approaches to capture different failure modes observed in experiments.

More recent research has combined analytical and experimental methods to evaluate the seismic performance of RC frames with masonry infill more generally. Dolsek & Fajfar, (2008), used concentrated plasticity beam-column model elements with equivalent strut wall elements to evaluate the seismic performance of masonry-infilled RC frames, looking at “damage limitation”, “significant damage” and “near collapse” limit states. Dymiotis *et al.*, (2001), assessed the seismic vulnerability of a 10-story infilled RC frame at “serviceability” and “ultimate” limit states. Madan & Hashmi, (2008), evaluated the performance of 7 and 14-story RC frames with masonry infill subjected to near-fault ground motions (Sagttar & Liel, 2010).

Pujol & Fick, (2010), conducted tests on a three story full scale flat plate structure which was designed to resist gravity loads only. The purpose of the study was to investigate the possible positive and negative effects of the partition walls. Therefore, the study was concentrated on the response of full scale RC frame with and without partition walls. In this report response was assessed by strength, stiffness and displacement capacity of the system. It was concluded that partition walls can be expected to help control inter-story drift, provided that measures are taken to prevent out-of-plane failure of the infill and the shear failure of the columns.

It is recognized that infill materials significantly affect the seismic performance of the resulting in-filled frame structures. The study focuses on the effect of types of infill materials (commonly used and a new one) on the seismic performance of in-filled RC frames compared using SAP2000 and Axis.

2. FlexyBricks

The paper proposes the use of polyurethane in order to obtain an innovative brick to be used for the envelope of RC frame structures and partition walls. The authors named the new brick as *FlexyBrick*.

Polyurethane is a resilient, flexible and durable manufactured material that can replace rubber, metal or wood in thousands of applications. Can be manufactured in any colour, can take any shape, size or geometrical complexity. Since its invention during the 1940s, polyurethane has been used in a wide range of items.

In Romania, the polyurethane was introduced in 1978 and it is manufactured by Oltchim SA. In 2007, polyurethane consumption was more than 12 million metric tons, the annual average increase being of approximately 5%.

Polyurethane is used in construction since 1950 in the shape of insulation panels for roofs, walls, ceilings and floors. Metal-faced polyurethane sandwich panels (Fig. 2) are widely used for large industrial buildings, refrigerated and other warehouses, office blocks, exhibition halls, fair pavilions, schools and sports halls. Prefabricated sandwich wall and lightweight roofing consist of metal facings bonded tightly together by a core of rigid polyurethane foam.

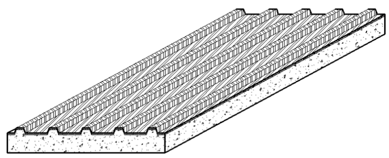


Fig. 2 – Sandwich panel.

Polyurethane foam sandwich panels are recommended for facilities where a constant temperature or strict hygiene maintenance is required.

Polyol and isocyanate are the main components of polyurethane, which have to be mixed mechanically at a temperature of 25°C. The mixture expands and because of the limited dimensions of the mold, physical properties of the polyurethane bricks are obtained.

FlexyBricks are made using a mold and a special machine with a dosing device, in order to obtain the required mechanical characteristics.

FlexyBricks can be produced in a variety of sizes, depending on the construction site, the destination of the building and the size of the reinforced concrete frames structure. In Fig. 3 a prototype is shown for a polyurethane brick that has fiber cement boards on both faces, in order to increase the mechanical strength. The brick can be produced as a hallow one, with empty or filled gaps with various materials – ceramics, polystyrene, wood, in order to reduce the costs and increase the mechanical resistance.

By creating an appropriate mold, FlexyBrick can be produced with circle cross section, simmilar with wood material. Polyurethane concrete block can replace logs used for constructions in the country-house.

To improve the quality of the polyurethane bricks and to increase compressive and flexure strength, reinforcement can be used for FlexyBrick, also. In addition to this, the amount of polyurethane will be reduced, and thus, the costs. In order to find the ideal reinforcement material, bricks with various type of reinforcement have been tested in the faculty laboratory at bending in 3 points test and compression test (Fig. 4). The materials used as reinforcement are: fiberglass mesh, chopped rubber, mesh geogrid, wire mesh and chopped glass shards form (Fig. 4 *b*).

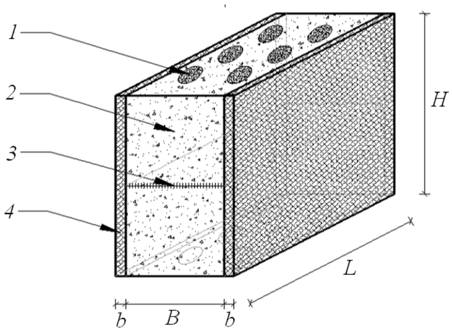
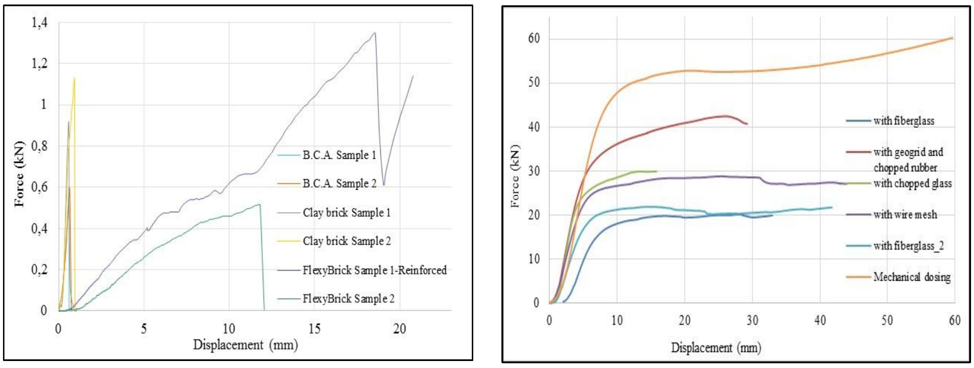


Fig. 3 – FlexyBrick: *1* – gaps; *2* – polyurethane; *3* – reinforcement mesh; *4* – cement plates.



a *b*

Fig. 4 – Results obtained in the laboratory tests: *a* – bending in 3 points test; *b* – compression test for FlexyBrick with different reinforcement

3. Software Analyses

In order to compare the behavior of bared RC frame with that having infill of different materials, static, modal and nonlinear analysis were performed, using computer software AxisVM and SAP2000. Both of them are based on the finite element method.

A 2-D RC frame structure was considered, with 3 stories, each level of 3 m high and opening of 6 m. The dimensions of the columns are 50 cm × 50 cm, and for the beam, 30 cm × 50 cm. The structure was loaded only with self weight. Four cases were considered: the bared RC frame and 3 cases with different infill bricks – made of clay tile, aerated light weight concrete (A.A.C) and FlexyBrick. The material characteristics are presented in Table 1.

Table 1
Materials Characteristics

Material	Modulus of elasticity, *E*, [N/mm^2]	Poisson coefficient, *ν*	Unit weight, [kg/m^3]
Concrete, C20/25	29,000	0.2	2,500
Brick	1,210	0.2	2,700
A.A.C.	2,500	0.1	1,100
FlexyBrick	100	0.2	180

3.1. Static Analysis

In the static analysis the total internal efforts were evaluated. These values determine the structural system elements dimensions for the cross

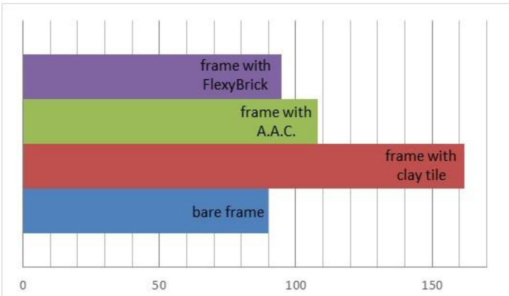


Fig. 5 – Axial force values at the base of the frame in different situations.

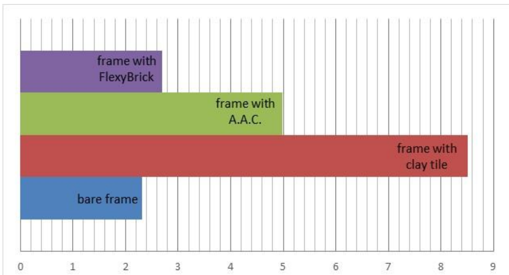


Fig. 6 – Shear force values at the base of the frame in different situations.

section and for the reinforcement. The values for the axial force and shear force at the base of the frame are shown in Figs. 5 and 6.

These results are directly proportional with the weight of the considered structures, which are shown in Fig. 7. The weight's values were extracted from SAP2000. The main conclusion from this analysis is that the proposed brick, FlexyBrick, brings the smallest load to the structural system.

If the maximum stresses that appears in the masonry are compared, it can be noticed, in Fig. 8, that even though the distribution is similar in all 3 cases, the maximum values for the clay infill is 13 times higher than the values obtained for FlexyBrick and the case in which we consider A.A.C. infill, the values are only 6 times higher.

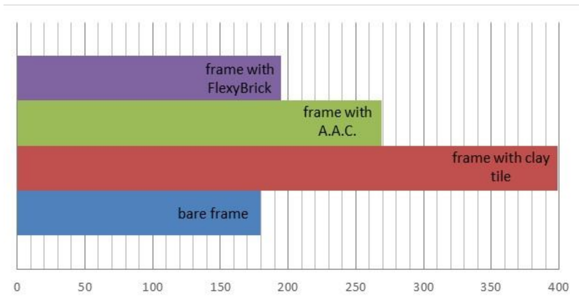
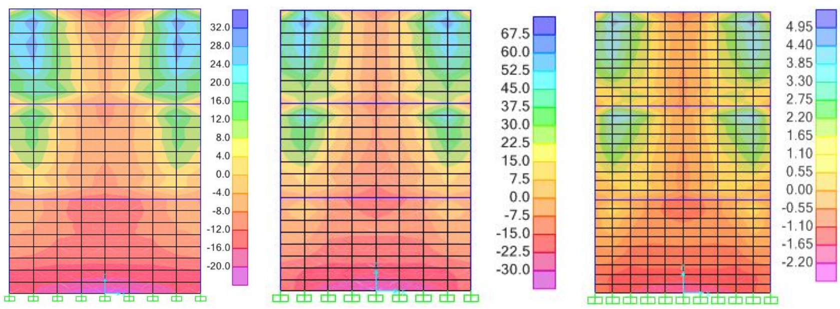


Fig. 7 – Structure weight, *G*, [kN].



a *b* *c*

Fig. 8 – Maximum stresses in the masonry of: *a* – A.A.C., *b* – clay and *c* – FlexyBrick.

3.2. Modal Analysis

The results of this analysis are: characteristics of the models considered – periods of vibration, frequencies, eigenvalues, percentage of participation of the masses, adding modal participation rates and structural modal participation factors.

The first comparison realized was for horizontal displacement at the top of the structure (Fig. 9). The maximum value is for the bare frame (0.36 mm) and the minimum one is for the case in which the infill material is clay. In this case the displacement reaches 0.23 mm. It can be observed that the displacements for the first mode of vibration in case of a frame with FlexyBrick infill and a bare frame, are similar, differing only with 5%.

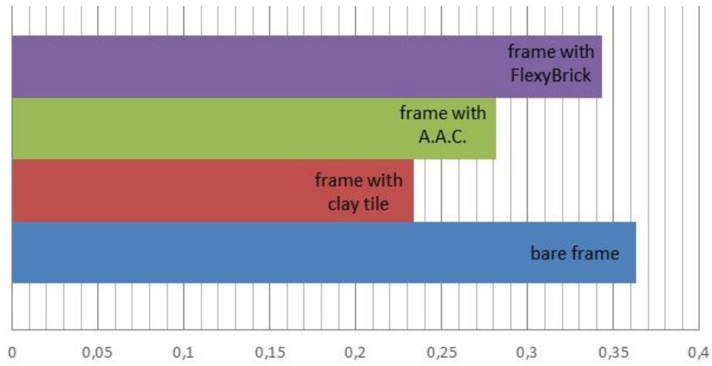


Fig. 9 – Horizontal displacement at the top of the structure, [mm].

The modal analysis was performed in SAP200 and Axis software. It appears that differences in values between the two computer programs vary between 0.24% and 5%, differences that may be considered negligible. The model with FlexyBrick infill has the closed fundamental period with the bare frame case.

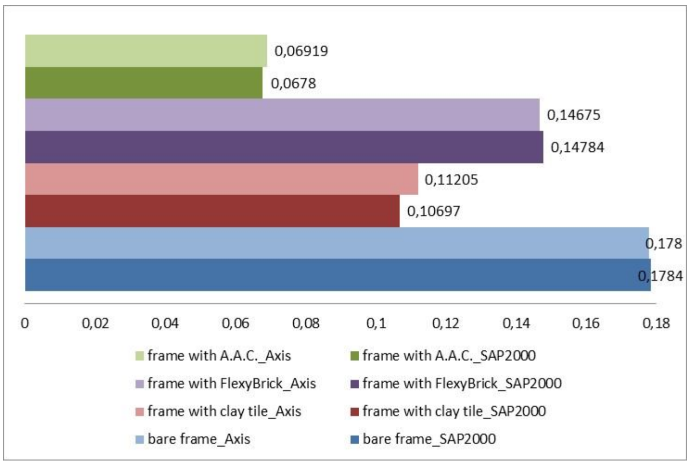


Fig. 10 – Period for first mode of vibration in SAP200 and Axis, [s].

Comparing the stiffnesses for the four considered cases it is observed that the A.A.C. has the higher value, and the FlexyBrick has the lowest one. This is in accordance with the initial hypothesis that the proposed infill material will bring for the structural system sufficient stiffness without changing the failure mechanism. Beside this the FlexyBrick infill is recommended for the envelope because of it's thermal insulating properties.

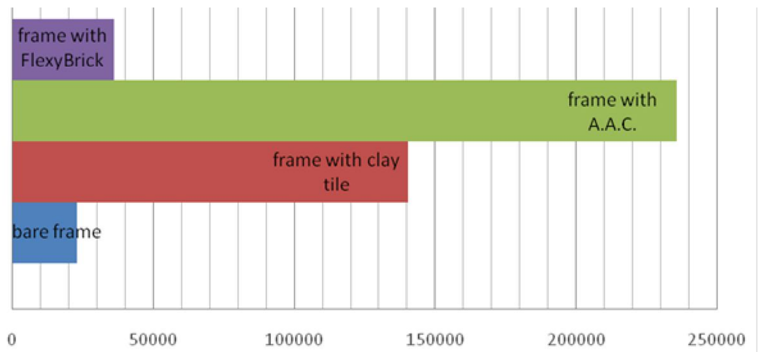


Fig. 11 – Assembly stiffness comparison, *k*, [kN/m].

4. Conclusion

The main conclusion is that the behavior of reinforced concrete frame structures can be improved by changing the material characteristics of the infill. The proposed polyurethane brick have a flexible behavior, with good properties for thermal insulation and mechanical ones. The main advantage is the low unit weight, respectively the low load that is transmited to the structural system.

Further analyses will be made in order to determine physical properties, costs and detailed behavior with nonlinear analysis for the FlexyBrick product.

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INFLUENȚA TIPULUI DE MATERIAL DIN UMPLUTURĂ ASUPRA COMPORTAMENTULUI GLOBAL AL STRUCTURILOR ÎN CADRE DIN BETON ARMAT

(Rezumat)

Structurile în cadre din beton armat sunt foarte răspândite în întreaga lume. Considerate a fi structuri flexibile sunt recomandate şi în zone cu seismicitate ridicată. Principiul de bază constă din a proiecta grinzi slabe, stâlpi puternici, astfel încât mecanismul de cedare să caracterizeze mai întâi elementele secundare şi apoi cele principale. Cu toate acestea probleme grave pot apărea din cauza aportului de rigiditate adus de elementele secundare. Printre acestea este şi umplutura sistemului structural care poate fi realizată din diferite materiale. Lucrarea îşi propune să cerceteze influența tipului de material asupra comportamentului global al structurii. În aceast scop au fost efectuate diferite analize numerice. Se prezintă, de asemenea, un material nou care poate fi folosit ca material de umplutură, ale cărui proprietăți sunt considerate a fi superioare celor existente în prezent pe piață.