Assessment of seismic performance of RC frame structure with masonry infill panels partially uncoupled from the surrounding frame members

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Abstract. The present study numerically analyses the influence of physical and mechanical properties of the materials used for masonry infill panels upon the seismic response of low rise reinforced concrete frame structure. A four-storey residential building (benchmark), located in Timisoara, a moderate seismic area, has been designed according to the current Romanian design codes. Then, infill panels considered uncoupled from the frame members along their lateral and upper edges, have been added to the structure. Infill panels have been investigated in four variants, by using 2 types of masonry units (hollowed ceramic blocks and AAC), alternatively built with mortars specific for regular bed joints (G) and thin bed joints (T), for which a comparative modal response spectrum analysis has been carried out. The seismic behaviour of buildings in all these cases has been analysed in terms of peak inter-storey drifts under two limit states and of the out-of-plane strength of infill panels. The results show that the peak inter-storey drifts reductions compared to the benchmark structure are up to 59% at SLS, and 61% at ULS. Regarding the out-of-plane behaviour of the infill panels it was noted that safety verification is fulfilled only for one of the abovementioned cases. As a final remark, the results obtained in this study highlight the importance of physical and mechanical properties of the masonry infill panels in the assessments of seismic response of frame structure buildings.

1. Introduction

The infill walls for reinforced concrete frame structures are widely used in seismic areas all over the world [1, 2], due to their good thermal properties, low density and cost. Their role is to separate interior and outer space and enhance at the same time the energetic performance of the building.

Field observations after recent earthquakes have shown numerous damages to infill wall panels. The costs of repairs were high and sometimes exceeded the cost of structural members strengthening [3], [4], and their failure can threaten the occupants’ life [5].

The masonry infill undertakes the own weight and could be seismically designed in two different ways: first, interacting with the surrounding frame members in order to improve their strength and lateral stiffness [6] and secondly, with partial interaction with the frame members, by providing gaps in between on one or more edges [7], with low increase of building stiffness.

The technical literature provides numerous studies on the seismic behaviour of frame structures interacting with infill panels, concerning the development of various simplified computational techniques (diagonal strut) [8], appraisal of the influence of panels upon the seismic response, investigation of possible types of unfavourable collapse mechanisms (short columns, soft storey...
mechanisms) [7], the influence of openings dimensions and positions, the influence of vertical and horizontal irregularities, damage assessment etc. [9]. Instead, it has been investigated the behaviour of infill panels isolated from the main structure by means of various materials and construction details, when subjected to earthquake excitations, in fewer experimental and numerical studies [5, 10, 11].

The paper aims to investigate the influence of materials properties used for masonry infill panels, restrained by the surrounding frame members only at the bottom edge, upon the seismic response of low rise reinforced concrete frame structure.

2. Materials and Methods

The reinforced concrete frame structure of a building placed in Timisoara, was designed with medium ductility (DCM), in compliance with the provisions of code P100/1-2013 [12] and standard SR EN 1992-1 [13]. First, the bare structure (benchmark) has been designed according to the usual design practice with uniformly distributed load on beams (figure 1a), instead of modelling the infill panels.

In plane, the structure has two bays of 5.7 m along Y direction and five bays range between 3.2 m and 4.6 m along X direction, the storey height being 3 m.

![Figure 1. Reinforced concrete frame structure: benchmark (a), with infill panels (b).](image)

The seismic action has been considered by modal response spectrum analysis. The main features of the design response spectrum are the following: seismic ground acceleration ($a_g = 0.20 \text{ g}$); corner period ($T_c = 0.7 \text{ s}$); behaviour factor ($q = 4.725$). The columns have square cross section (40x40 cm), and the beams have rectangular cross section (30x40 cm) in both, longitudinal and transversal direction. Their dimensions have been established considering stiffness, ductility and fire requirements. The concrete class is C20/25 and steel grade S500.

In the second version, infill panels have been added to benchmark structure (BS) with 45 mm wide gap at the frame-infill interface, established from inter-storey drifts and tolerance consideration, in order to avoid the interaction (figure 1b).

In Romania, various materials are used for masonry infill panels, their choice and wall thickness depending on seismic and climatic zones.

Two types of masonry units and mortars have been used for masonry infill walls, as follows:
- hollowed ceramic blocks (with normalized compressive strength $f_b = 10 \text{ N/mm}^2$, density $\rho = 850 \text{ kg/m}^3$) and mortar class M5 in regular bed joints (compressive strength $f_m = 5 \text{ N/mm}^2$) (case 1) and respectively in thin bed joints (case 2).
• infill panels made of AAC, with compressive strength $f_c = 3 \text{ N/mm}^2$, $\rho = 500 \text{ kg/m}^3$ and mortar class M5 in regular bed joints (case 3), respectively with $f_m = 5 \text{ N/mm}^2$ and mortar in thin normal bed joints (case 4).

The mechanical properties of masonry have been calculated according to CR6-2013[14], resulting the following:

• design compressive strengths ($f_d$): 1.92 N/mm² (case 1); 2.79 N/mm² (case 2); 1.07 N/mm² (case 3); 0.83 N/mm² (case 4);
• design flexural strength of masonry, with the plane of failure parallel to the bed joints ($f_{d1}$): 0.126 N/mm² (case 1); 0.079 N/mm² (case 2); 0.055 N/mm² (case 3); 0.053 N/mm² (case 4);
• short term secant modulus of elasticity ($E_s$), of 3653 N/mm² (case 1); 5300 N/mm² (case 2); 1628 N/mm² (case 3); 1259 N/mm² (case 4).

The structures have been analysed by using Finite Element Method (FEM) with SAP 2000 Educational software [15]. Shell elements have been used for the modelling of infill panels.

3. Results and discussions
The safety verifications of infill panels partially decoupled from the surrounding frame members are in terms of inter-storey drifts at two limit states (Serviceability Limit State - SLS and Ultimate Limit State - ULS) and their out-of-plane strength.

3.1. Inter-storey drifts
Figure 2 illustrates the lateral displacements along Y direction for the benchmark (figure 2a), respectively with infill panels - case study 2 (figure 2b).

![Figure 2](image)

Figure 2. Lateral displacements along Y direction: benchmark (a), with infill—case study 2 (b).

In each of the analysed cases the maximum lateral displacements of all storeys along the X and Y directions have been extracted. The inter-storey drifts in SLS and ULS have been computed with the previous values. Considering that the masonry ductility is lower than that of reinforced concrete, the inter-storey drifts of the infill have been corrected with the ratio between the behaviour factors of the structural and non-structural members.

In figures 3-4, the inter-storey drift profiles for benchmark and the four cases are displayed.

In comparison with the reference structure, the addition of infill panels has reduced the peak inter-storey drifts at SLS by: 36.47% - 49.55% along X direction and 38.92% - 56.84% along Y direction for case 1; 43.15% - 58.78% along X direction and 43.94% - 65.06% along Y direction for case 2; 34.4% -
51.04% along X direction and 42.12% - 59.58% along Y direction for case 3; 38.4% - 51.93% along X direction and 42.12% - 58.29% along Y direction for case 4.

Figure 3. Inter-storey drift of benchmark and structures with infill panels at SLS: along Y (a) and X directions (b).

Figure 4. Inter-storey drift of benchmark and structures with infill panels at ULS: along Y (a) and X directions (b).

For ULS, slightly lower decrease has been obtained: 32.03% - 46.02% along X direction and 34.65% - 53.82% along Y direction for case 1; 39.17% - 55.90% along X direction and 40.57% - 60.89% along Y direction; 29.81% - 47.61% along X direction and 38.07% - 56.75% along Y direction; 34.09% - 48.56% along X direction and 38.07% - 55.37% along Y direction.

The amount of the previously mentioned reductions is due to different elastic moduli (E_z) and specific weights of the materials.

From the above figures it can be seen that the reductions obtained for the cases 3 and 4 are similar, explained by the fact that the physical and mechanical characteristics of the materials used for infill walls are not very different, E_z being slightly higher in case 3, while the specific weight is slightly higher in case 4.

Analysing the variation of reductions along the structure height, it can be observed that in all cases and for both limit states, the maximum values for decrease have been recorded at the intermediate floors.
and the smallest one at the ground floor and at the top floor. It is worth mentioning that in the case of reference structure, the maximum displacement appears on the 2nd floor, while for the infill frame structures, the maximum displacement is reached at the first floor. The values of the previously mentioned reductions result because of the different elastic moduli \( E_z \) and specific weights of the materials.

By analysing the obtained results, it can be seen that inter-storey drifts along Y direction are higher than those along X direction, both for SLS and ULS. It should also be mention that inter-storey drifts of infill panels and columns are different, but lower than the width of the gap, so the interaction between them is avoided.

### 3.2. Out-of-plane verification of infill panels

The out-of-plane strength of the infill panel is a key issue for the seismic performance of buildings. Due to the forces of inertia generated by ground motions, infill panels could be expelled from the structure in the out-of-plane direction, which pose a threat to human lives because of the falling of rubble and can lead to substantial economic losses, as demonstrated during recent earthquakes.

Figure 5 shows the values of the normal stresses perpendicular to the bed joints.

![Figure 5](image-url-normal-stresses.png)

**Figure 5.** Normal stresses perpendicular to the bed joints: case 1 (a); case 2 (b); case 3 (c); case 4 (d).
The maximum values of the normal stresses perpendicular to bed joints at each floor of the 4 analysed cases are summarized in Table 1.

**Table 1. Maximum values of the normal stresses [N/mm²] perpendicular to bed joints at each floor of the 4 cases.**

| Floor | Case 1 | Case 2 | Case 3 | Case 4 |
|-------|--------|--------|--------|--------|
| 1     | 0.042  | 0.028  | 0.008  | 0.018  |
| 2     | 0.051  | 0.044  | 0.013  | 0.023  |
| 3     | 0.087  | 0.072  | 0.037  | 0.051  |
| 4     | 0.104  | 0.091  | 0.053  | 0.089  |

The out-of-plane strength of infill panel is verified by comparing the maximum normal stresses with design flexural strength of masonry, with the plane of failure parallel to the bed joints (f\textsubscript{ad}). In all cases the maximum normal stresses appear at the base of the 4th floor; the highest values being recorded along Y directions.

The verifications in cases 1 and 3 are fulfilled on both directions. In case 2, the verification is not fulfilled at the base of the 4th floor, on a length of about 1m starting from corners, along Y direction. In case 4 the verifications are not satisfied on the base of the 4th floor, on the entire length along Y directions and on a length of about 80 cm starting from corners along X direction.

4. Conclusions

Nowadays, on the market there are a wide range of building materials with various physical and mechanical properties that can be used for infill in case of frame structures. Their seismic performance depends on the perimeter restraining conditions. In Romania and in other Eastern European countries the infill panels are usually restrained at the base and free on the other three sides. The gaps between the panels and the surrounding members of the frames are filled with various insulation materials (foams, polystyrene etc.) thus, their interactions during seismic events are prevented, therefore the major issue is the out-of-plane verification of these panels.

In seismic design practice the structure is modelled as a bare frame, with uniformly distributed load on perimeter beams, hence the stiffness of infill panels is neglected, and their out-of-plane verifications are omitted. The disadvantages of this simplified design method could be avoided by modelling the infill panels. In this case, the frame-infill interaction could be verified, as well as the inter-storey drift reductions and the contribution of infill panels to the lateral stiffness of the building. Also, out-of-plane infill failures could be highlighted, making possible to strengthen the weak zones during the building’s execution. The results obtained in the present research have shown that seismic response of buildings is influenced by the materials properties (units and mortars) and masonry type (with regular or thin bed joints).

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