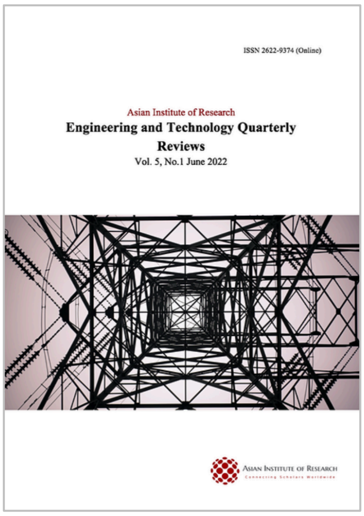
ISSN 2622-9374 (Online)

Asian Institute of Research

Engineering and Technology Quarterly Reviews

Vol. 5, No.1 June 2022

Engineering and Technology Quarterly Reviews

Mociran, H. A. (2022), Influence of Masonry Infill Panels Mechanical and Physical Properties on the Seismic Performance of RC Frame. In: *Engineering and Technology Quarterly Reviews*, Vol.5, No.1, 9-16.

ISSN 2622-9374

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The Asian Institute of Research

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The Asian Institute of Research
Engineering and Technology Quarterly Reviews
Vol.5, No.1, 2022: 9-16
ISSN 2622-9374

Influence of Masonry Infill Panels Mechanical and Physical Properties on the Seismic Performance of RC Frame

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Abstract
The paper investigates numerically the influence of masonry infills properties on the seismic response of RC frame structures. A five-story plane RC frame with infill panels (benchmark), part of a residential building, situated in Piatra Neamț, was considered for this aim. The benchmark was designed according to the current design practice and based on current Romanian seismic design codes, thus the infills were modelled as uniformly distributed gravitational loads on beams. Two more cases of the same structure were examined: case 1, with infill panels made of hollowed ceramic blocks and case 2, with infills made of AAC. In both cases, infills panels were modelled through diagonal struts. Comparative nonlinear time history analyses of the structures were performed. In both cases, compared to benchmark, the results show that peak inter-story drift ratios, peak bending moments of columns and beams were reduced significantly, peak axial forces of columns had a small variations and base shears were slightly increased.

Keywords: Infill Panel, RC Frame, Mechanical Property, Diagonal Strut, Time History analysis

1. Introduction

In Romania, as well in other earthquake prone countries, infill panels are frequently used in the case of multi-stories buildings with RC frame structures due to their advantages: thermal conductivity, low bulk density and an affordable cost (Dautaj et al., 2018; Mociran & Cobârzan, 2021a; Pallares et al., 2021).

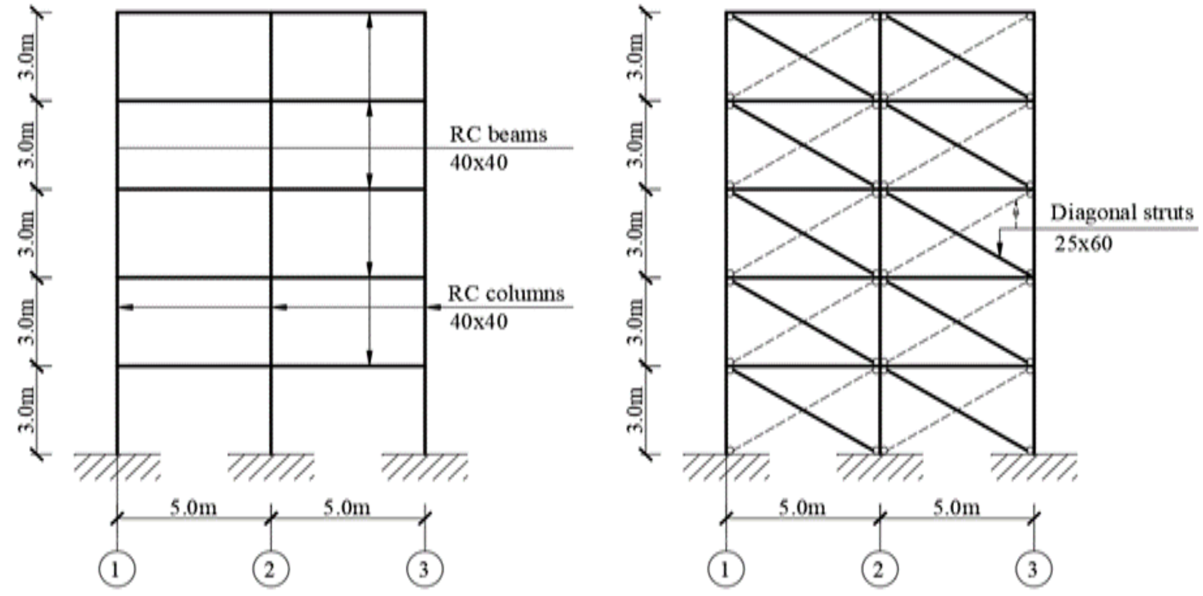
Major seismic events of the past have shown that although RC frame structures have an adequate response, non-structural components of buildings (infill panels, mechanical equipment etc.) have suffered important damages (Dolce & Goreti, 2015). Consequently, material damages have been much more significant in the case of non-structural components, in comparison with those of the structure (Gaudio et al., 2016; Trapani et al., 2020). In addition, the collapse of non-structural components is a danger to people's lives.

Field observations of buildings affected by earthquakes, as well as numerous experimental and numerical studies have highlighted that masonry infills panels in full contact with the surrounding frames, interact with them, significantly influencing the seismic response of the structure (Alwashali, 2019; Fiore et al., 2012). The masonry infills panels provide the structure with extra strength and stiffness, which depend on the mechanical properties of the infill panels and on the ratio between their strength and the strength of the frames (Penelis & Penelis, 2014; Peng et al., 2018; Perrone et al., 2017; Santos, 2007).

The paper aims to investigate numerically the influence of masonry infills properties, for two types of masonry units frequently used in Romania, on the seismic performance of a typical low-rise RC frame structure, located in a moderate seismic area.

2. Description of Case Studies

A five-story plane RC frame (benchmark), part of a residential building, has been chosen for this study. The building is in Piatra Neamț, a moderate seismic zone of Romania, and has been designed by Mociran and Cobîrzan (2021b), according to Romanian seismic design code, (*P100-1/2013*, 2013), and Romanian standard for design of concrete structures, *(SR EN 1992-1*, 2006), considering a dissipative behavior with ductility class medium (DCM). It is important to highlight that in the design of benchmark structure, the infills have been modelled as uniformly distributed gravitational loads on beams, according to current design practice. The geometry of the frame is shown in Figure 1.



(a) (b)

Figure 1: Elevation view of RC frame: benchmark (a), with infill panels (b)

The seismic load has been established by modal response spectrum analysis. The main parameters of the design response spectrum have been considered: design ground acceleration (a_g=0.25g), corner period (T_c=0.7s) and behavior factor (q=4.725). The dimensions of all columns and beams sections are 40x40cm and 30x40cm, respectively. The concrete class C25/30 has been used for all structural members.

To assess the influence of masonry infills mechanical and physical properties on the seismic performance of RC frame structures, two more cases have been considered:

- Case 1, with infill panels made of hollowed ceramic blocks (with normalized compressive strength in the direction of the applied action $f_b = 11.38N/mm^2$ and density $\rho = 760N/mm^2$) and mortar class M5 in regular bed joints (compressive strength $f_m = 5N/mm^2$).
- Case 2, with infill panels made of AAC (with normalized compressive strength in the direction of the applied action $f_b = 5N/mm^2$ and density $\rho = 600N/mm^2$) and mortar class M5 in regular bed joints (compressive strength $f_m = 5N/mm^2$).

It is worth mentioning that the selected types of masonry units are frequently used in Romania for infills. In both cases, the geometry and dimensions of the structural members are the same as in the benchmark. The infill panels have been considered in full contact with the surrounding frames and have been modelled through diagonal struts. The width of all diagonal struts has been taken one tenth of the diagonal of infill frame, according to *P100-1/2013*. Thus, the dimensions of all strut sections are 25x60cm.

By using *CR6/2013* and *P100-1/2013*, the mechanical properties of masonry have been obtained:

- Case 1: design compressive strength in the direction being considered $f_d = 2.1N/mm^2$, design value of the shear strength under no compression $f_{vd0} = 0.11N/mm^2$, short term secant modulus of elasticity $E_z = 4000N/mm^2$.
- Case 2: design compressive strength in the direction being considered $f_d = 1.4N/mm^2$, design value of the shear strength under no compression $f_{vd0} = 0.07N/mm^2$, short term secant modulus of elasticity $E_z = 2270N/mm^2$.

3. Numerical Analyses

The seismic performance of the building is assessed by nonlinear time history analyses using *SAP 2000 Educational software*. The seismic input is represented by a set of seven semiartificial accelerograms of Vrancea 1977 NS component type, compatible with the elastic response spectrum for Piatra Neamț. The accelerograms have been generated in *Seismo Match program*. The following seismic response parameters have been investigated: peak inter-story drift ratios at two limit states (Serviceability (SLS) and ultimate (ULS)), peak axial forces and bending moments (at edge and interior columns and beams, respectively) and peak base shears.

3.1 Inter-story Drift Ratios

Figures 2 and 3 show the distribution of the peak inter-story drift ratios over the height of structure at SLS and ULS, respectively.

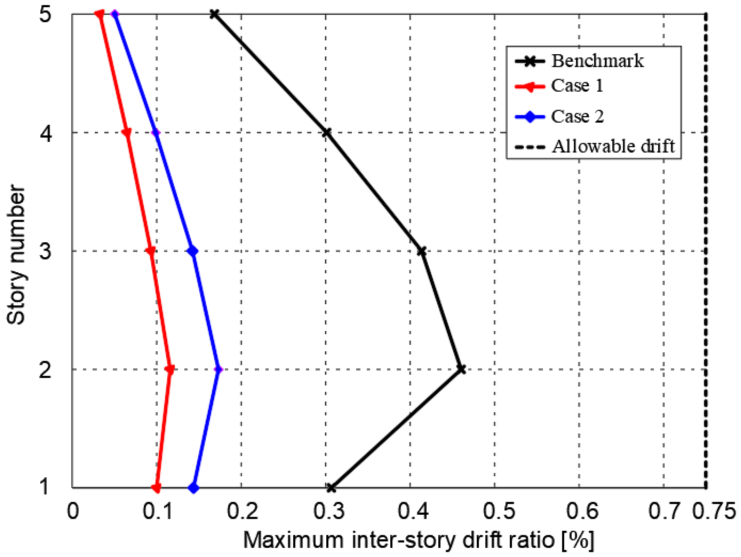


Figure 2: Distribution of peak inter-story drift ratios over the structures' height at SLS

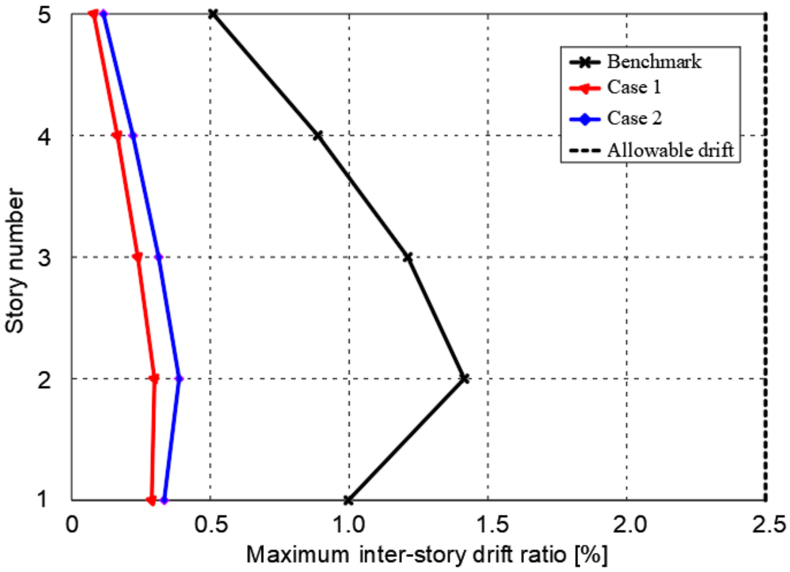


Figure 3: Distribution of peak inter-story drift ratios over the structures' height at ULS

The benchmark structure satisfies the *P100-1/2013* SLS and ULS requirements for inter-story drifts of 0.005h and 0.025h, respectively. In the previous expressions, h represents the height of the story (3m). In the case of benchmark, the maximum magnitude of the inter-story drift ratios has been recorded at the second story, at both limit states. It can be remarked that all inter-story drift ratios of the structures with infills have been significantly reduced compared to benchmark. The reductions slightly increased on the height of the structure from the first to the last story and have been in the range of 65.76-80.59% at SLS and 71-84.3% at ULS for case 1 and 53.15-70.1% at SLS and 66.59-77.5% at ULS for case 2.

3.2 Axial Forces and Bending Moments

It is examined the influence of masonry infills mechanical properties on the peak axial forces and moments of an edge and interior column and on the peak bending moments of the beams.
Figures 4 and 5 plot the distribution of maximum bending moments for an edge and interior column, over the height of structures, at ULS.

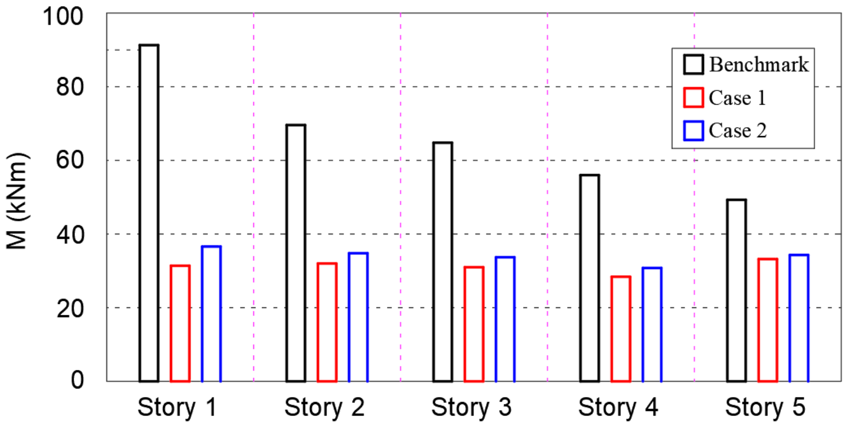


Figure 4: Distribution of peak bending moments for an edge column over the structures' height

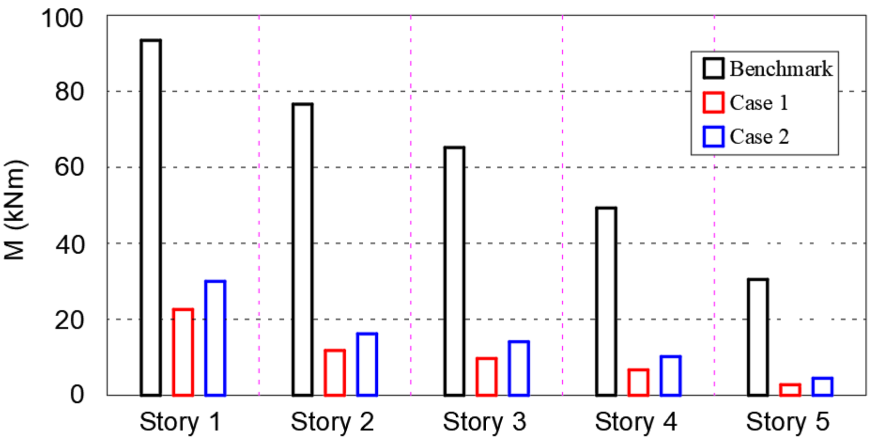


Figure 5: Distribution of peak bending moments for an interior column over the structures' height

In the benchmark, the peak bending moments of the edge columns decrease from the first to the top story. By adding infill panels, the maximum bending moments have been pronouncedly reduced compared to benchmark and became approximately uniformly distributed over the height of the building. Higher reductions (65.66-32.68%) have been achieved for the structure with infills panels made of hollowed ceramic blocks compared to the structure with infill panels made of AAC (59.9-30.4%). In both cases, the maximum reductions took place on the first floor, and the minimum at the top story.

In the benchmark, the peak bending moments of the interior columns decrease from the first to the top story. In cases 1 and 2 important decreases have been obtained, compared to the benchmark: up to 90.86% and up to 85.38%, respectively. Unlike the edge column, the maximum decreases have been recorded at the top story and the minimum decreases at the first story, such that peak bending moments of the cases 1 and 2 decrease from the first to the top story, like in the benchmark.

Figures 6 and 7 show the distribution of maximum axial forces for an edge and interior column, over the height of structures, at ULS.

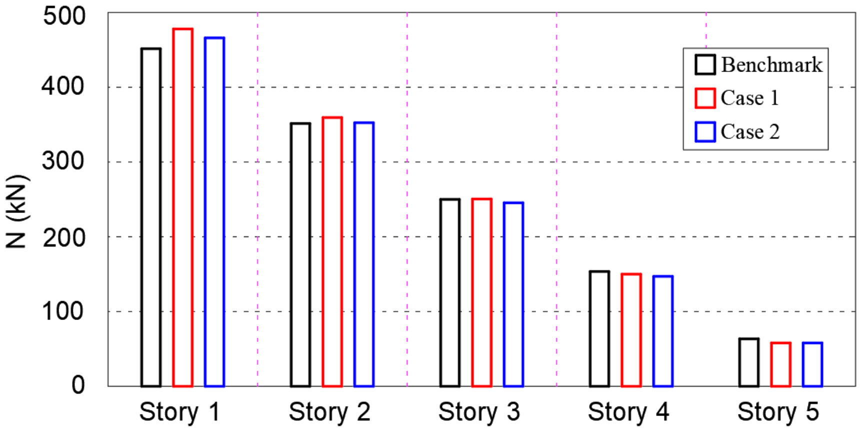


Figure 6: Distribution of peak axial forces for an edge column over the structures' height

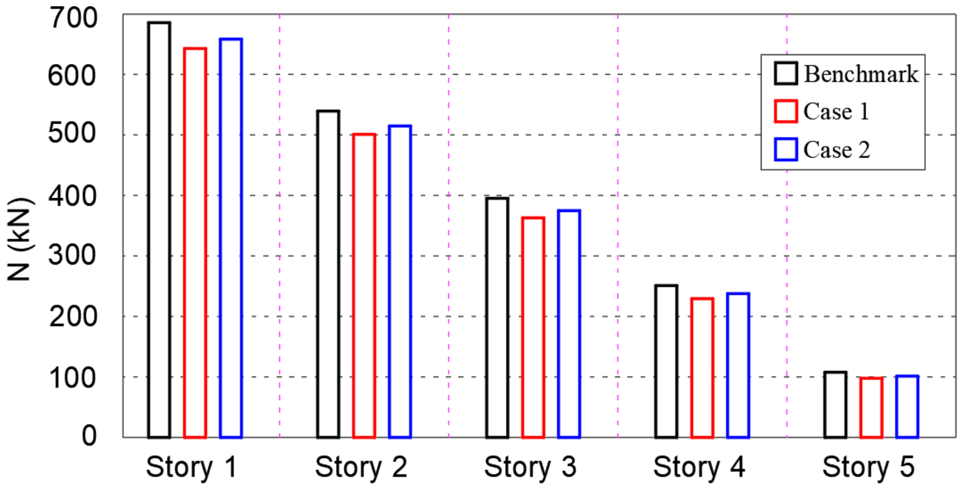


Figure 7: Distribution of peak axial forces for an interior column over the structures' height

In the case of columns, insignificant variations of bending moments have been observed compared to benchmark. For edge column, small increases have been noticed in the lower stories (up to 5.87% in case 1 and up to 2.84% in case 2) and slight decreases in higher stories (up to 8.3% in case 1 and up to 8.52% in case 2). For interior column, slight decreases have been seen (up to 9.27% in case 1 and up to 6.3% in case 2).
Figure 8 illustrates the distribution of the maximum bending moments at beams, over the height of structures, at ULS.

In the benchmark, the peak bending moments of the beams decreases from first story to top story. It can be observed that all bending moments of the structures with infill panels have been reduced compared to benchmark by up to 49.53% in case 1 and by up to 73.78% in case 2. Higher reductions have been achieved at the lower stories, and lower reductions at upper stories.

By analyzing the obtained results, it can be concluded that by explicit modeling of infills panels through diagonal struts, the behavior of structure changes from a moment resisting frame into a truss type structure.

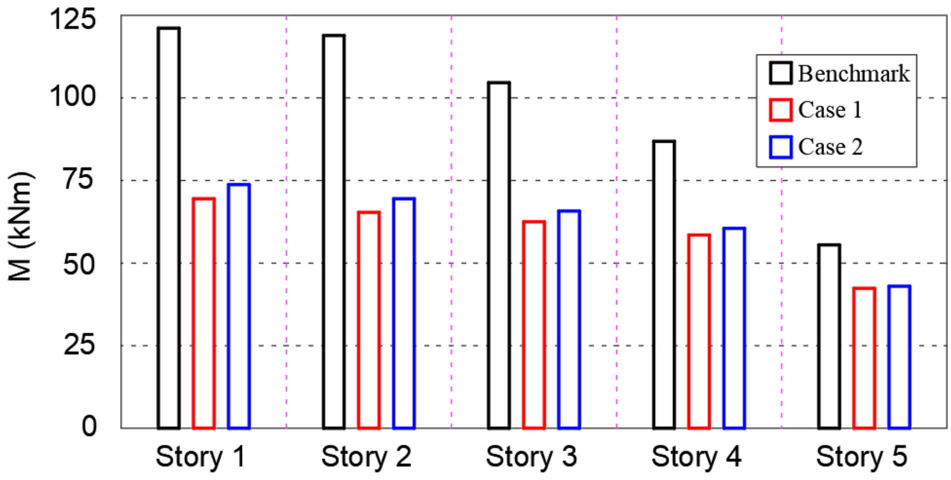


Figure 8: Distribution of peak bending moments for a beam over the structures' height

3.3 Base Shears

Figure 9 displays the average value (of the seven time history analyses) of the maximum values of the base shears at ULS, for the considered cases.

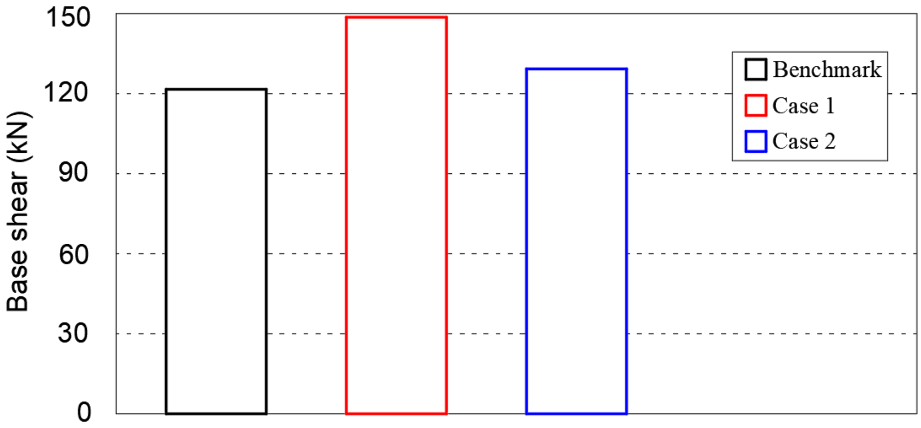


Figure 9: Peak base shears

It can be observed, that by adding infill panels to the benchmark, the values of the maximum base shears have been increased, since the stiffness of the benchmark has been increased. The maximum base shear has been increased by 22.19% in case 1 and by 6.25% in case 2.

4. Conclusions

The following conclusions can be drawn from the present numerical study:

- The peak inter-story drift ratios have been substantially reduced at all stories of the structures by 65.76%-80.59% at SLS and by 71%-84.3% at ULS in case 1 and by 53.15%-70.1% at SLS and by 66.59%-77.5% at ULS in case 2, compared to benchmark. This is explained by the supplemental stiffness added by the infill panels.
- The peak bending moments of the edge and interior columns have been reduced at ULS by 32.68%-90.86%, in case 1 and by 30.4%-85.38%, in case 2, compared to benchmark. At the same time, the values of axial forces in the columns had a small variation (up to 10%), compared to benchmark. The sizes of the sections of structural members can be diminish by considering the internal forces and moments obtained by explicit modeling of infill panels through diagonal struts, with benefits on execution costs.
- The magnitude of reductions of maximum inter-story drift ratios and of peak bending moments of columns and beams is highly influenced by values of elastic modulus and bulk density of masonry.
- Peak base shears have been increased by 22.19% in case 1 and by 6.25% in case 2, compared to benchmark. Neglecting this additional base shear at the design of structure can lead to brittle failure of columns at their ends.

The results obtained in this study have pointed out the importance of modeling the infill panels through diagonal struts and have shown that the seismic performance of the building depends on the mechanical and physical properties of the materials used for infills.

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