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Evaluation in probabilistic terms of behaviour of existing RC structures equipped with friction pendulum devices including presence of masonry infills

D. Gino, P. Castaldo, G. Amendola, and L. Giordano

Politecnico di Torino, Turin, Italy

Abstract

The safety assessment of existing structures in areas with a relevant seismic hazard is one of the major topics for engineers since many existing reinforced concrete structures have been realized disregarding seismic design and providing poor detailing in comparison to the current specifications. In this context, the seismic assessment is a primary issue in order to identify the best retrofitting solution with the aim to upgrade the performance level of existing structures. In order to enhance the seismic response of existing RC structures, over the years, the isolation system adopting friction pendulum devices turned out to be one of the most diffused and efficient.

The aim of this work is to investigate the effectiveness of the retrofitting intervention using single-concave friction pendulum devices on the seismic performance of an existing 3D reinforced concrete building located in central Italy, which is an area with a high seismic hazard. After the characterization of the geometrical features and material properties according to the "knowledge levels" approach, a non-linear numerical model of the structure has been defined using fiber-based finite elements. 3D non-linear dynamic analyses have been performed considering 21 natural ground motions with the three accelerometric components to assess the seismic response of the building with and without the retrofitting intervention composed of the FP isolators. The influence of infill masonry panels on the overall behaviour of the structure has also been evaluated. The results from the non-linear dynamic analyses have been useful to evaluate the effectiveness of the retrofitting intervention to improve the seismic performance.

Keywords: seismic isolation, infills, existing structures, probabilistic analysis, non-linear dynamic analysis, reinforced concrete.

1 Introduction

The safety assessment of existing structures and infrastructures placed in areas with a relevant seismic hazard is one of the challenges for engineers over the last years [1]. In particular, during the 60's and 70's many existing reinforced concrete (RC) structures have been realized disregarding seismic design and providing poor detailing in comparison to the current specifications ([2]-[3]).

In order to enhance the seismic response to seismic actions of existing RC structures, over the years, the isolation system adopting friction pendulum (FP) devices turned out to be one of the most diffused and efficient ([4]-[5]).

The aim of this work is to investigate the influence of the retrofitting intervention performed using single-concave friction pendulum devices on the seismic response on an existing framed reinforced concrete building located in central Italy. The existing building presents both in plane and in elevation irregularities also related to disposition of masonry infills (Figure 1 and 2).

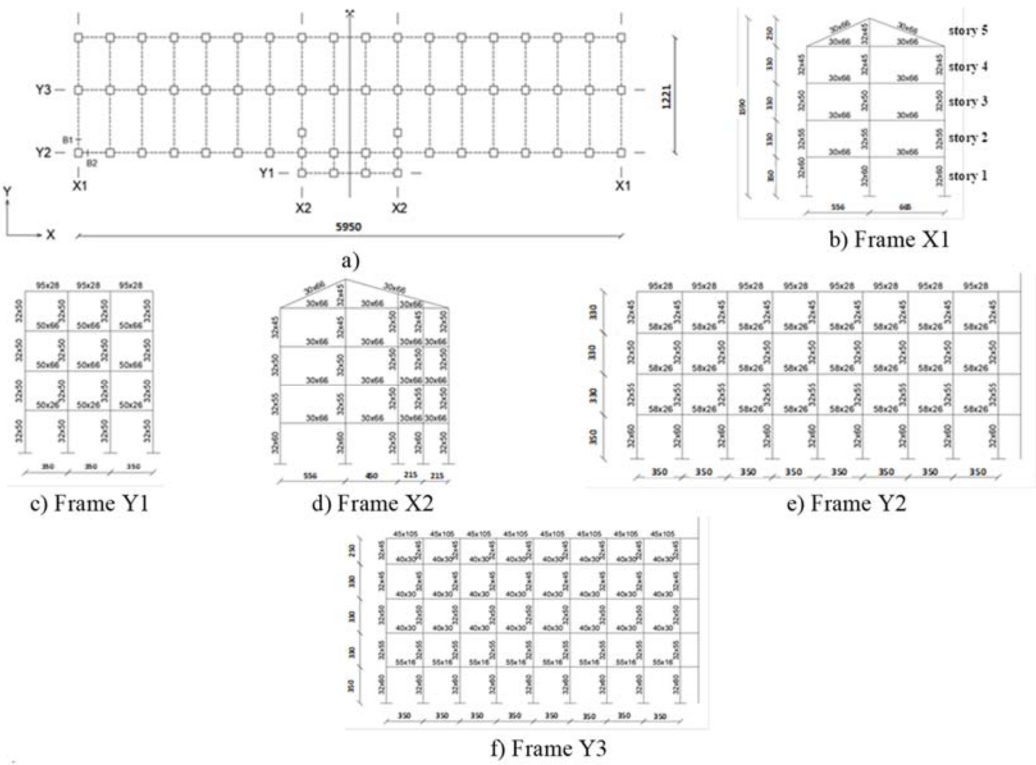

Figure 1: Geometry of the investigated existing RC building. Measures in cm.

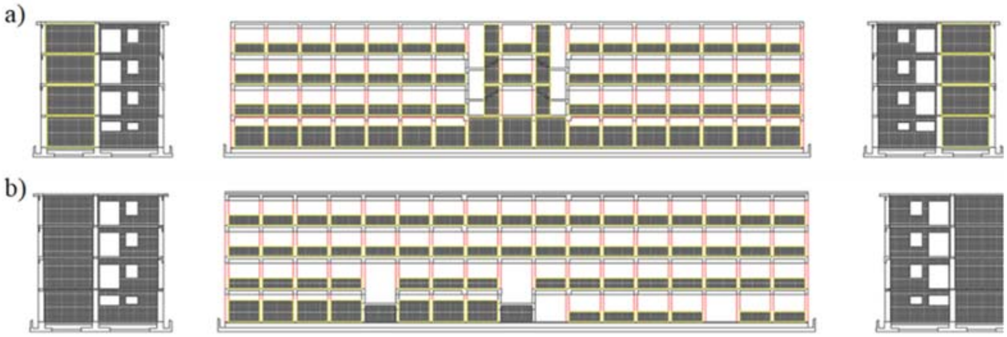

Figure 2: Configuration of external masonry infills.

After the characterization of the geometrical features and material properties according to the “knowledge levels” approach ([3]), a non-linear numerical model of the structure has been defined using a fiber-based finite elements using SAP2000 [6]. Non-linear dynamic analyses have been performed considering 21 natural ground motions [7] with the three accelerometric components to assess the seismic response of the building with and without the retrofitting intervention composed of the FP isolators. Moreover, the influence of masonry infills on the seismic performance has been investigated.

In particular, the fixed-base (FB) and base-isolated (BI) structure has been both analysed with and without the presence of masonry infills. The local effects of the infill-frame interaction have been examined.

The results from the non-linear dynamic analysis have been useful to evaluate the effectiveness of the retrofitting intervention to improve seismic performance. The inter-story drift index (IDI) and horizontal relative displacement of the FP devices has been adopted as output variables. The output variables have been modelled according to mono-variate and bi-variate lognormal distribution (i.e., including correlation between in plant orthogonal directions) [8]. Finally, the probabilities of exceedance for different values of the output variables are evaluated and compared with thresholds requirements from literature [9].

2 Methods

The FP devices allow to disconnect the superstructure to the foundation level and are able to absorb the main part of the displacement demand due to seismic actions and provide also energy dissipation by friction [4]. These devices are realized by means of an articulated slider which moves on a concave surface, characterized by a specific curvature radius R [10] and friction coefficient [11].

The overall mechanical behaviour of single-concave FP devices can be idealized according to non-linear hysteretic model proposed by [10]. Regarding the dynamic friction coefficient, its non-linear variation in function of the sliding velocity can be described according to [11].

The masonry panels are able to interact with the surrounding RC structural frame in the presence of significant lateral actions [12]. In fact, although the overall stiffness of the structural system turns out to be increased, the presence of infills leads to a reduction in the natural period with related increase of the seismic demand [13]. In the present investigation the non-linear macro-modelling approach of for totally infilled panels is adopted according to [14]. With reference to the macro-modelling of the partially infilled masonry panels, they have been reproduced by means of a single-strut model with elastic behaviour in order to take into account unfavourable effects related on shear demand on columns.

The numerical model of the RC framed building has been established using the software SAP2000 [6] adopting fiber-modelling approach. The mechanical properties of the fibers in each cross-section have been defined differentiating between core, cover and longitudinal reinforcements including stirrups confinement. The constitutive model of the reinforcement has been defined with an elastic-plastic law. The mechanical non-linearity is developed in each fiber of the cross-section within the plastic hinge length of the element [15].

The seismic demand in terms of elastic pseudo-acceleration Sa is evaluated considering the elastic design response spectrum related to 50 years reference period, life safety limit state according to [3]. The seismic inputs adopted to perform the 3D non-linear dynamic analyses are represented by 21 natural accelerograms [8] (3 accelerometric components) selected from European Strong Motion Database [7] and then scaled in X direction with respect to the Intensity Measure related to the elastic response spectrum in correspondence of the fundamental period of vibration for both FB and BI structures with and without masonry infills.

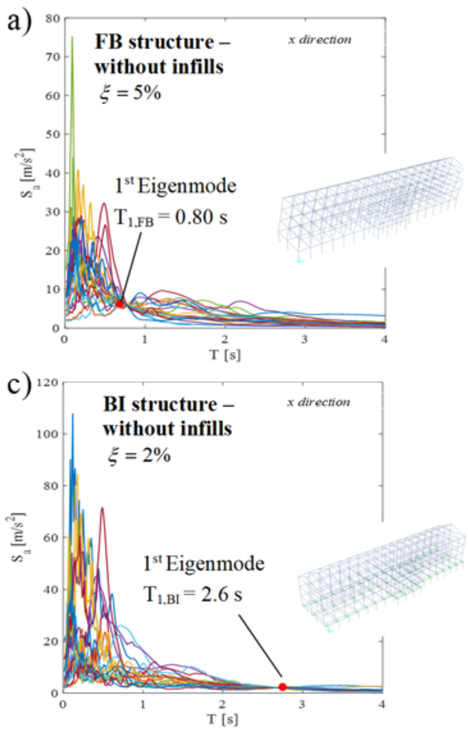

Figure 3: Scaled spectra of pseudo-acceleration for FB (a)-(b) and BI (c)-(d) structure of the 21 real ground motion records in X direction (a)-(c); Y direction (b)-(d). Numerical models without infills.

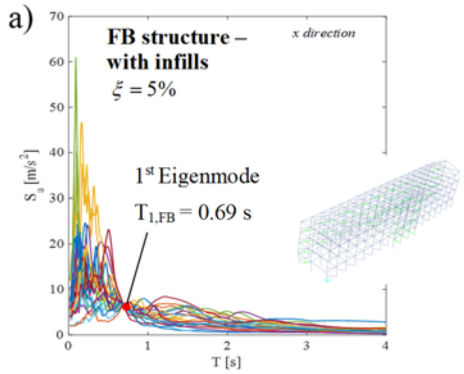

Figure 4: Scaled spectra of pseudo-acceleration for FB (a)-(b) of the 21 real ground motion records in X direction (a); Y direction (b). Numerical models with infills.

The non-linear dynamic analyses have been performed adopting the direct integration of the motion equations [16] considering all the non-linearities.

3 Results

The results from the 3D non-linear dynamic analyses in terms of interstory drift index (IDI) and horizontal relative displacement for the FP devices d_{FPS} have been useful to perform probabilistic evaluation of performance of FB structure and BI structure. The mentioned above parameters have been probabilistically modelled using a lognormal distribution [4].

The mono-variate lognormal distributions, by making a comparison between the FB and BI structure, are shown in the following Figure 5 with reference to generic limit state threshold. Table 1 reports the limit state (LS) thresholds in terms of IDI for both FB structure and BI structure [5],[9].

It is then possible to estimate the probability P_f exceeding different values of IDIs and d_{FPS} (Figure 6-7).

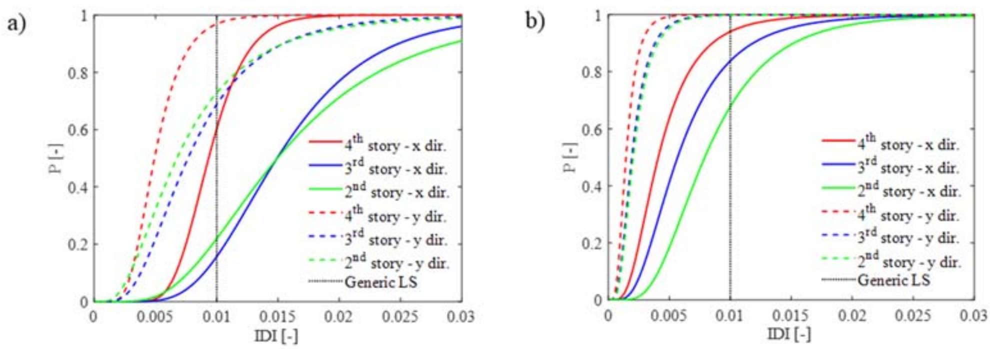

Figure 5. Lognormal mono-variate CDFs for the IDIs in X and Y direction: FB model (a), BI model (b) (without masonry infills).

Limit state	IDI [%] for FB structure	IDI [%]for BI structure
Fully operational limit state LS1	0.50	0.33
Operational limit state LS2	1.00	0.67
Life safety limit state LS3	1.50	1.00
Near-Collapse limit state LS4	2.00	1.33

Table 1. Limit states thresholds in terms of IDI (FB and BI structure) [5],[9].

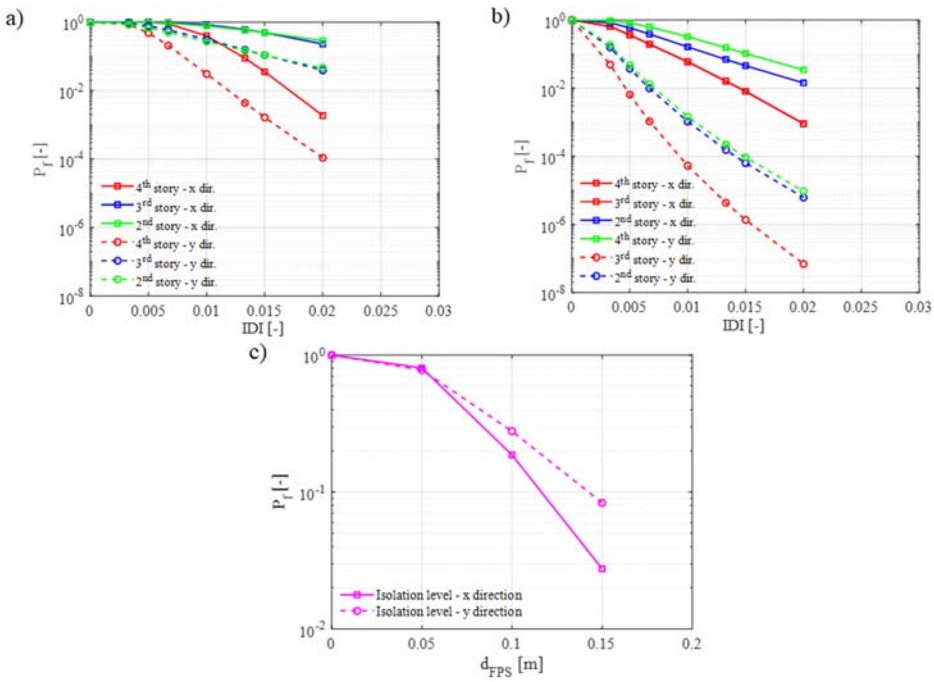

Figure 6. Exceeding mono-variate probabilities (logarithmic scale): FB model (a); BI model (b); Isolation level for BI model (c); (without masonry infills).

Furthermore, with the main purpose of assessing the three-dimensional response of either the FB structure and the IB one, by mainly evaluating the degree of correlation between the abovementioned parameters and d_{FPS} along the two directions x and y of the planar scheme of the structure, the joint log-normal distributions have been computed according to [4] (Figure 8).

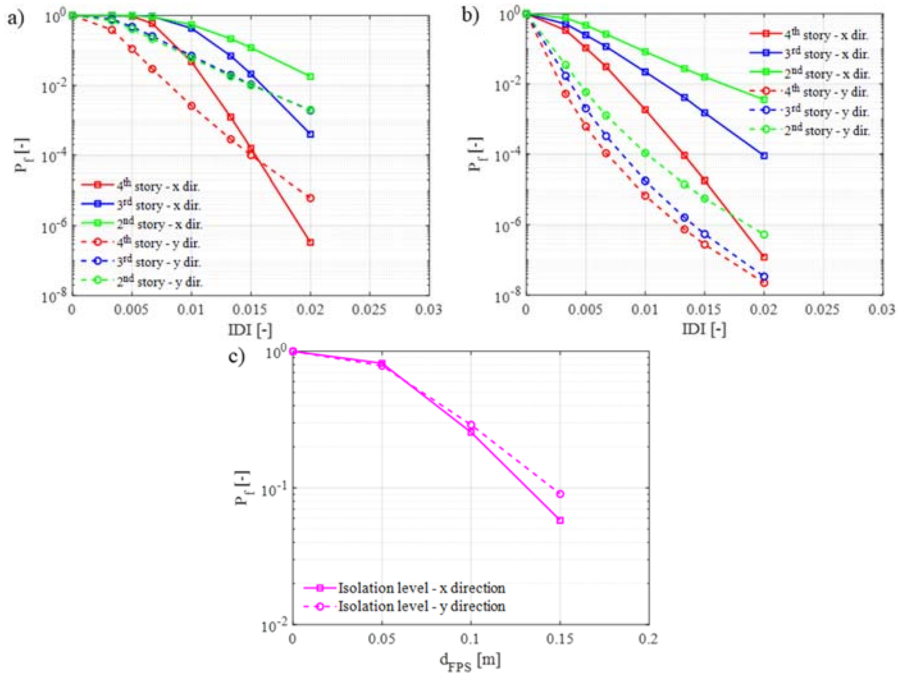

Figure 7. Exceeding mono-variate probabilities (logarithmic scale): FB model (a); BI model (b); Isolation level for BI model (c); (with masonry infills).

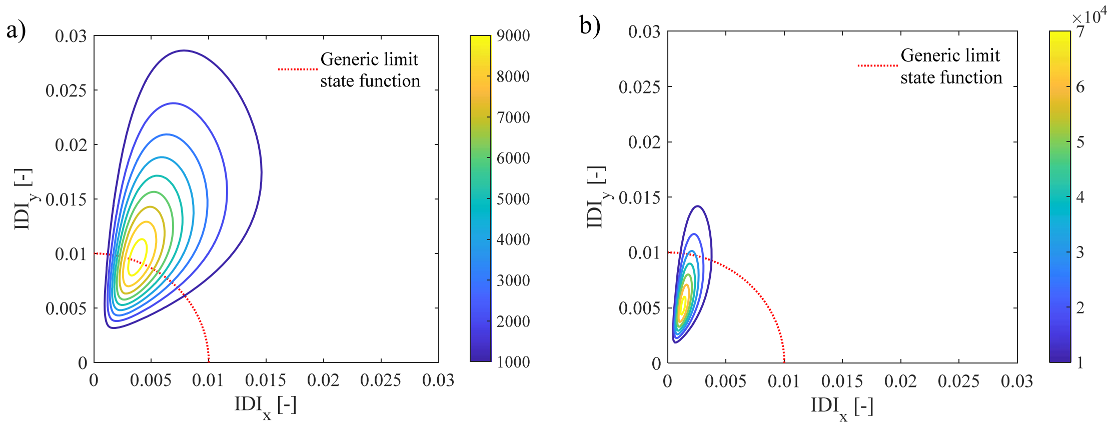

Figure 8. Level curves of the joint PDF for the 2nd storey with a generic limit state: FB model (a); BI model (b) (without masonry infills).

Similarly, it is possible to estimate the probability P_f exceeding different values of IDIs and d_{FPS} (Figure 9-10) with bi-variate probabilistic modelling.

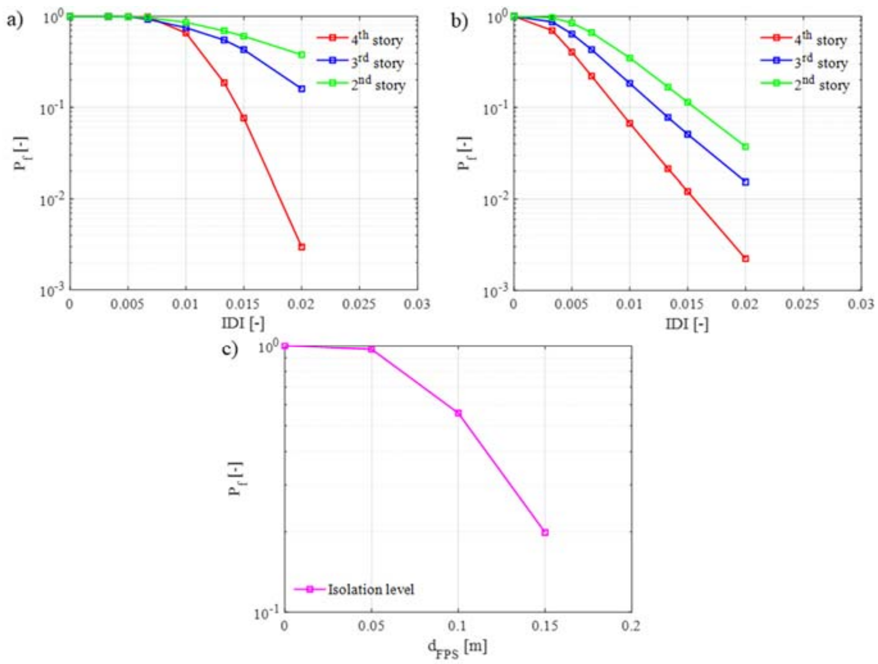

Figure 9. Exceeding bivariate probabilities (logarithmic scale): FB model (a); BI model (b); Isolation level for BI model (c); (without masonry infills).

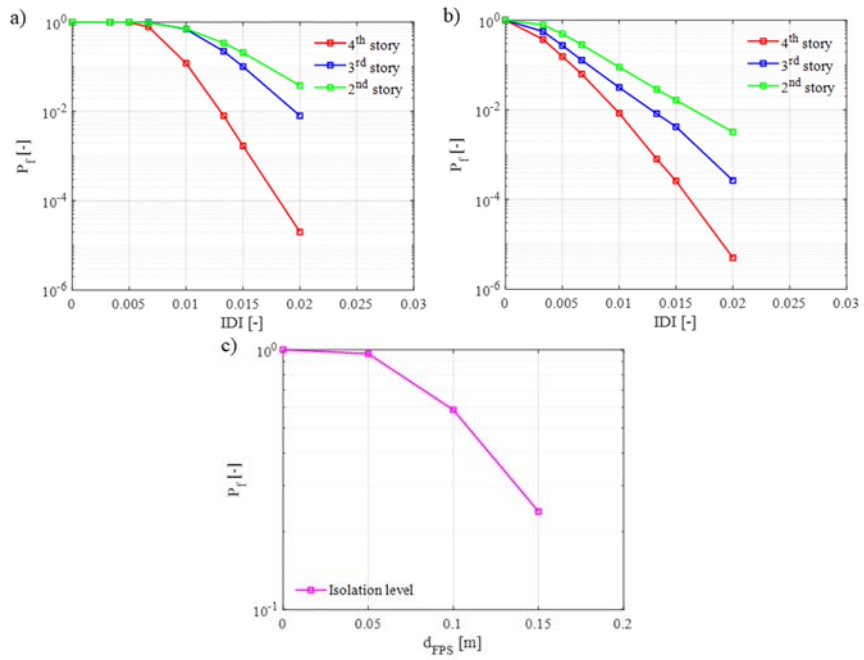

Figure 10. Exceeding bivariate probabilities (logarithmic scale): FB model (a); BI model (b); Isolation level for BI model (c); (with masonry infills).

4 Conclusions and Contributions

The present investigation aims to evaluate the influence of the seismic retrofitting of an existing 3D RC building using single-concave FP devices in probabilistic terms. After a characterization of both geometry and materials, non-linear numerical models of the structure have been defined using fiber cross-sections approach for the FB and BI system with and without the infills. 3D non-linear dynamic analyses have been carried out accounting 21 natural seismic events with the 3 components. The results of the non-linear dynamic analyses highlight the effectiveness of the retrofitting intervention in the reduction of the values of the interstory drift ratios avoiding the occurrence of brittle shear failure in columns. The presence of the infills improves the effectiveness of the isolation system by reducing the displacement demand. These abovementioned effects are then quantified in probabilistic terms by computing the lognormal distribution functions on the interstory drift index and displacement at the level of the isolation devices. The probabilities of exceedance show a reduction of more than 1 order of magnitude between the FB structure and the structure retrofitted by means of single-concave FP devices, also in presence of the infills. This aspect is fundamental for the safety of the structure.

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