EXPERIMENTAL TESTS OF R/C FRAMES WITH MASONRY INFILL

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ABSTRACT:
Structural frames are often filled with masonry serving as partitions or cladding. Studies have demonstrated that infilled frames perform better than corresponding bare frame but the only feasible way to account for the effects of infill is to directly include the infill in the analytical model used for design.
In order to test the numerical models and to define a simple method for analyzing the behavior of reinforced concrete frames with infill in earthquake regions we have done a series of tests with the aim to investigate the behavior of infilled r/c frames under seismic loads. Model frames represent part of a model structure. They were designed according to the EC8, modeled in a scale 1:2.5, infilled with three types of masonry and tested under constant vertical and cyclic horizontal loading. Presented is the relationship between drift capacity and properties of the frame-wall system controlling drift capacity.

Keywords: r/c frames, infilled frames, masonry infill, in-plane loading, experimental tests

1. INTRODUCTION

The vulnerability of unreinforced masonry to earthquake became evident to industrial society as early as in Naples, 1857, and Messina, 1908. Specific flaws in unintentional frame-wall systems were identified in the aftermath of the Skopje Earthquake of 1963. They were: (1) weakness introduced by openings in the wall, (2) captive columns, (3) out-of-plane collapse of walls, and (4) column failures under reversals of combinations of shear and tensile or compressive forces. These flaws have continued to cause tragic consequences in subsequent urban earthquakes with the most recent examples occurred in profusion in Wenchuan (2008) and L'Aquila (2008).
A review of the literature on infilled-frames shows that consensus on the effects of the interaction between frames and in-plane masonry walls is lacking. Some researchers have suggested that infill walls have led to collapse of buildings and that infill walls may affect the response of frames detrimentally. Some others have suggested that masonry infill panels may be beneficial.
Dolsek and Fajfar (2008) captured the essence of the problem stating: "The infill walls can have a beneficial effect on the structural response, provided that they are placed regularly throughout the structure, and that they do not cause shear failures of columns."
The existence of contradictions in the views of the research community have led to the deconstruction of the frame-wall system by many regional building codes that contain warnings about the interaction of frames and walls but are mostly silent on providing recommendations and bounds on their proper proportioning. That has been the driving reason for the proposed project.
In multi-story construction, the most important attribute of the structure is its capability to [-] retain its integrity at story drift ratios on the order of 1.5%-2%. The results of neural-network analysis (Sigmund-Kalman,2009) based on approximately 100 tests of one-bay one-story infilled frames available in literature have demonstrated that drift ratios of that magnitude can be achieved by a

reinforced concrete frame with solid filler walls provided the columns have the ability to sustain the required shear force under reversals of shear and axial forces.

In frame-wall systems with competent and uniformly distributed walls, the infill walls stiffen the frame and reduce the first-mode period leading to a reduction in drift response to strong ground motion. At the same time, the addition of the masonry wall to the frame tends to increase the base-shear response and reduce the drift capacity of the structure. The increase of lateral force and reduction of drift capacity leads to serious vulnerabilities unless proper proportioning is exercised.

The objective of the project, whose part are these tests, has been to investigate the safety and behavior of buildings with masonry-infilled RC frames through pseudo-dynamic tests of structural assemblies and components and by full scale tests on the shake-table (if possible). The overall goal is to develop pragmatic methods for evaluating the safety of existing buildings and for design of new buildings. Because frame-wall systems serve both architectural and structural demands efficiently, people in seismic regions live and will continue to live in buildings of this type. An organized solution of the safety of such construction is essential.

2. TEST SPECIMENS

The behavior of the infilled frame under seismic loading is difficult to predict by analytical methods unless the analytical models are supported and revised by using the experimental data. Therefore, we have built nine r/c frames and filled them in with three types of masonry infill: (a)strong infill made of hollow clay brick blocks with nominal strength of 10MPa (Opeka), (b)medium strong infill with hollow clay blocks with strength of 5Mpa (Eurotherm) and (c)weak infill with Autoclaved Aerated Concrete blocks with strength of 2,5MPa (Ytong). For every infill type we have had three specimens.

In this paper presented are results obtained through in-plane cyclic loading tests of a bare frame and three frames infilled with three different infill types. The specimens are a scaled part of a model 7-story building (middle frame of the „Tsukuba“ building) located in the ground floor and constructed in a scale 1:2.5 as shown on Figure 1.

Reinforced-concrete frames were designed according to EC2 and EC8 rules as frames with non-structural infill and made of concrete C30/37 and reinforced with steel bars B400/500H according to the design requirements. Column longitudinal reinforcement ratio was 2,36%, beam longitudinal reinforcement ratio in the field was 1,31 % and on the support 3,27 %. Frame elements were made first and then the masonry infill walls were added with frame and infill in close connection without spacing. They were made of fired clay perforated bricks (a and b having nominal strength of 10 and 5MPa respectively), mixed mortar (cement: lime: sand in volume proportion 1:1:5 and nominal strength of 3MPa) with thicknesses of horizontal joints of 1 cm and completely filled vertical joints in a manner typically used in Croatia. Masonry infill made of Aerated Autoclaved Concrete blocks were made with prescribed AAC glue (with nominal strength of 13.9MPa) in horizontal joints. After 28 days infilled frames have been tested under vertical and reversed in-plane cyclic loading.

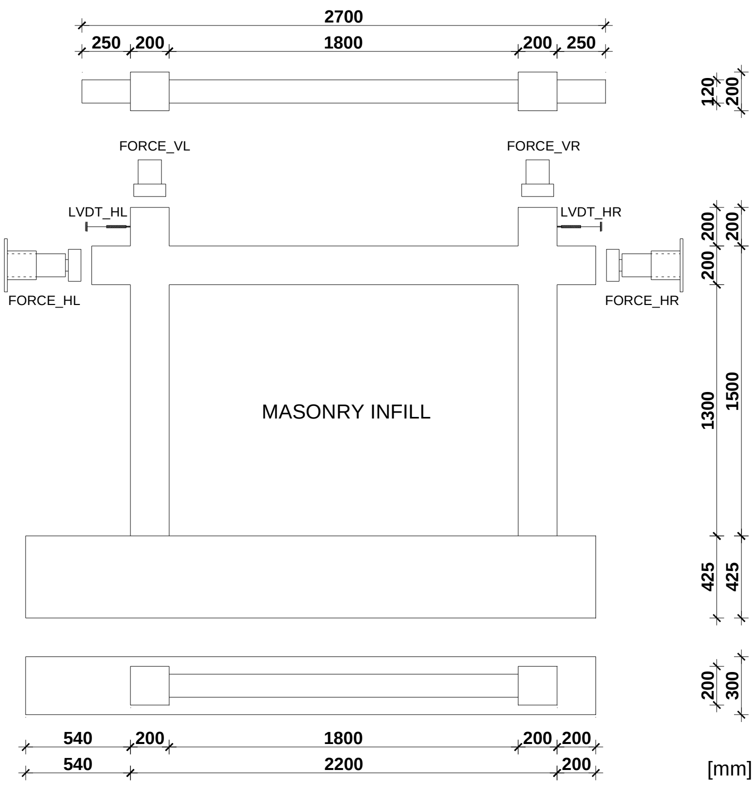

Figure 1. Outline of the test specimens

3. TEST PROCEDURE

Columns of the test specimens were loaded with constant vertical load that replaced the stories above. Scaled load applied at the column tops was 350kN in each column. Horizontal loading has been applied in-plane as reversed cyclic load. It steadily increased by increment of 10kN as shown on Figure 2. Vertical load oscillated during the test due to the additional moment introduced to the frame by horizontal load. During the test measured were: loads at each point, vertical and horizontal displacements at top, sliding of foundation and elongation of diagonals, deformations in the columns and beams.

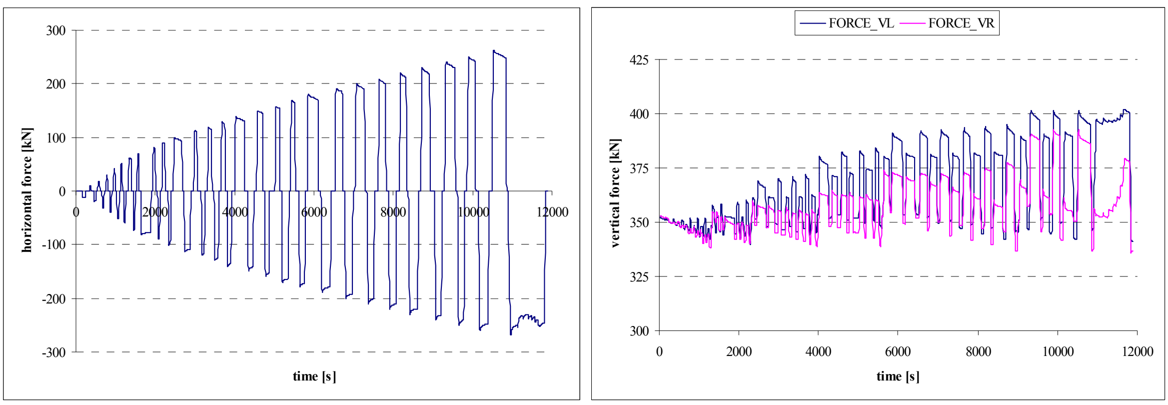

Figure 2. Applied horizontal cyclic loading and changes of vertical forces due to specimen rotation

Figure 3. R/C frames infilled with Opeka and Eurotherm hollow clay blocks

Figure 4. R/C frame infilled with Ytong blocks and Reference bare frame

4. TEST RESULTS

Part of the measured results is present in a form of Base shear vs. Horizontal displacement of the frame in both directions for bare frame and frames with all three infill types. In the Table 4.1 presented are values of the horizontal load, displacement and drift for the points of three-linear primary curve, namely cracking and yielding points.

Table 4.1 Base shear and attributed top displacement for cracking and yielding points

R/C frame with	Crack No.	H_{cr} [kN]	δ_{cr}[mm]	DR %	H_y [kN]	δ_y [mm]	DR %
Bare frame		70	1,38(-1,02)	0,09(-0,07)	220	14,28	0,95
		80	1,83(-1,46)	0,12(-0,10)			
		100	2,80(-2,50)	0,19(-0,17)			
		110	3,13(-2,83)	0,21(-0,19)			
		137	(-5,72)	(-0,38)			
		149	(-6,20)	(-0,41)			
Opeka	1	100	0,58(-0,31)	0,04(-0,02)	220	2,30	0,15
	2	110	-0,36(0,56)	-0,02(0,04)	260	4,78	0,32
Eurotherm	1	70	-0,26(0,25)	-0,02(0,02)	218	2,28	0,15
	2	80	-0,29(0,29)	-0,02(0,02)	237	6,00	0,40
Ytong	1	137	0,87(-0,80)	0,06(-0,05)	207	8,49	0,57
	2	149	-0,68(0,74)	-0,05(0,05)	218	10,13	0,68

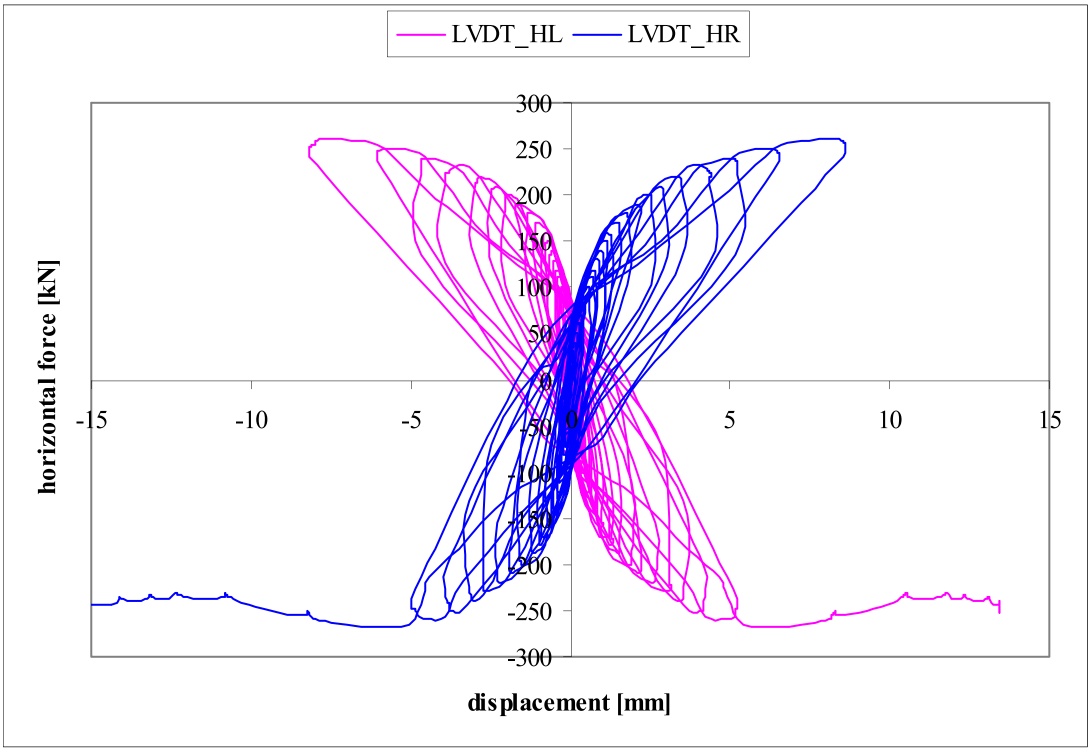

Figure 5. Base shear vs. Top displacement for frame with OPEKA infill

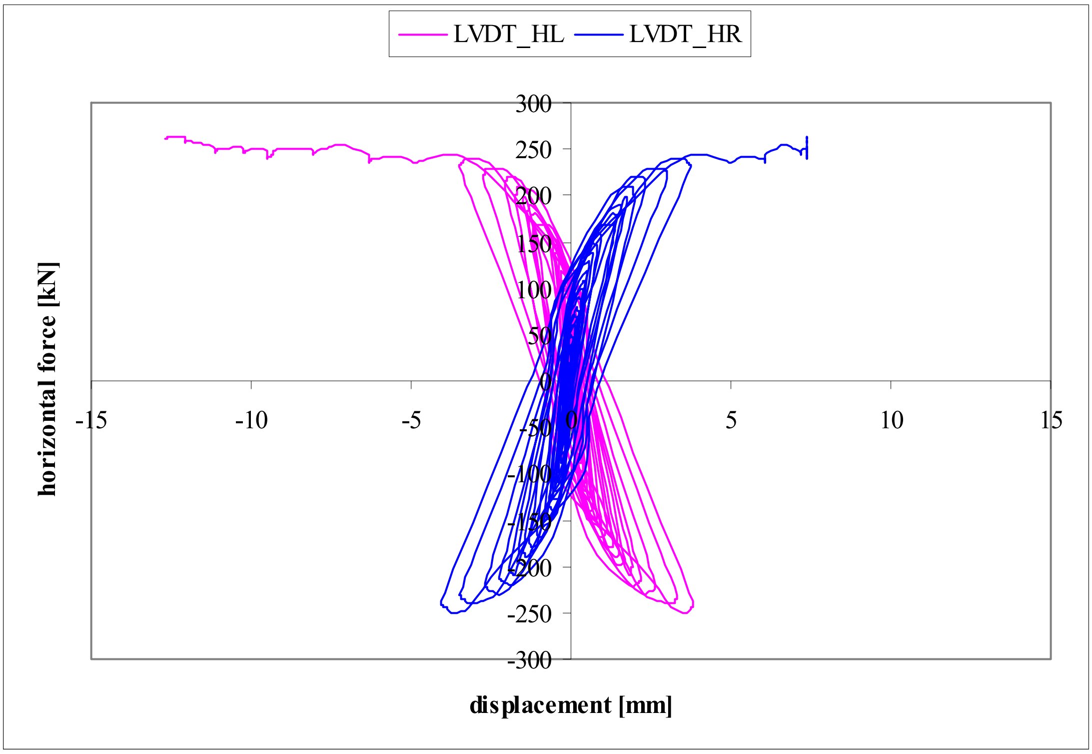

Figure 6. Base shear vs. Top displacement for frame with Eurotherm infill

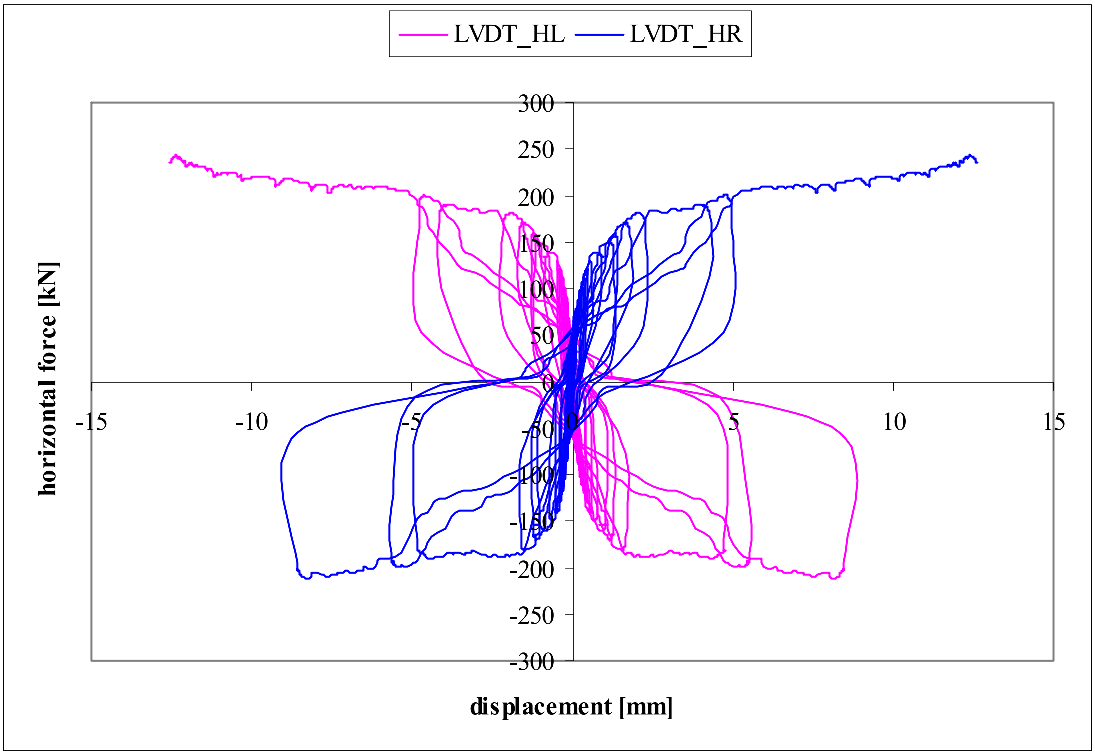

Figure 7. Base shear vs. Top displacement for frame with YTONG infill

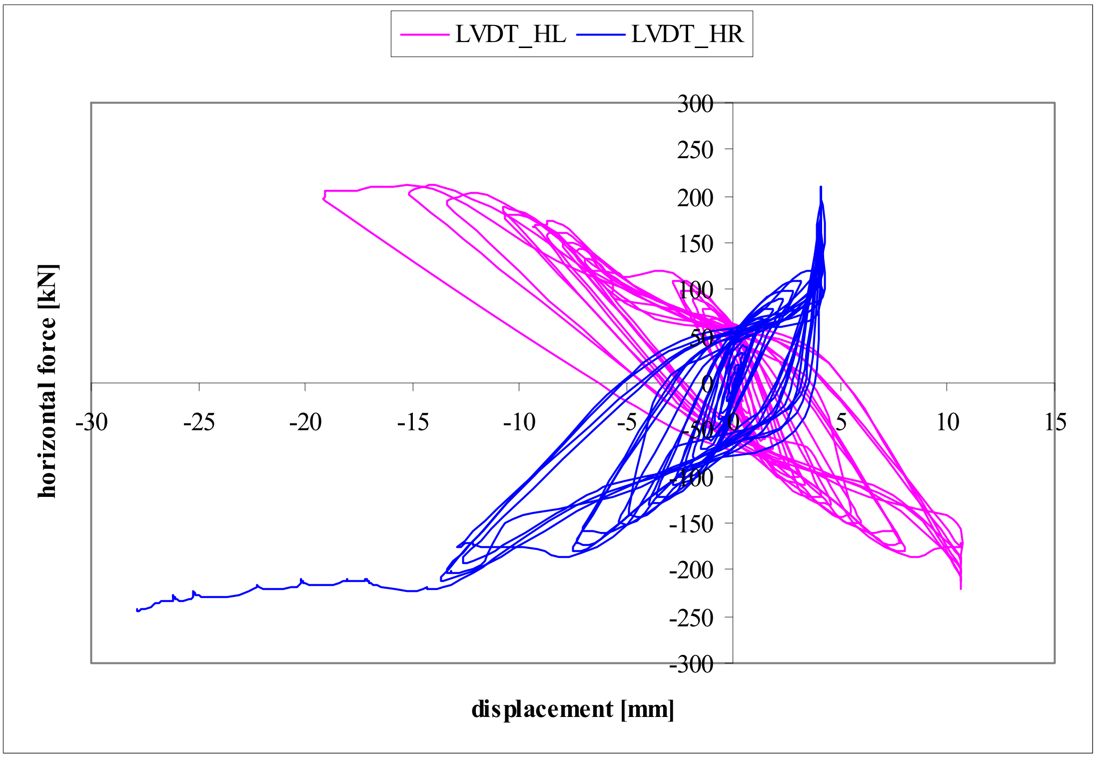

Figure 8. Base shear vs. Top displacement for bare frame

The envelopes of hysteretic curves (primary curves) are presented in the following Figure 9.

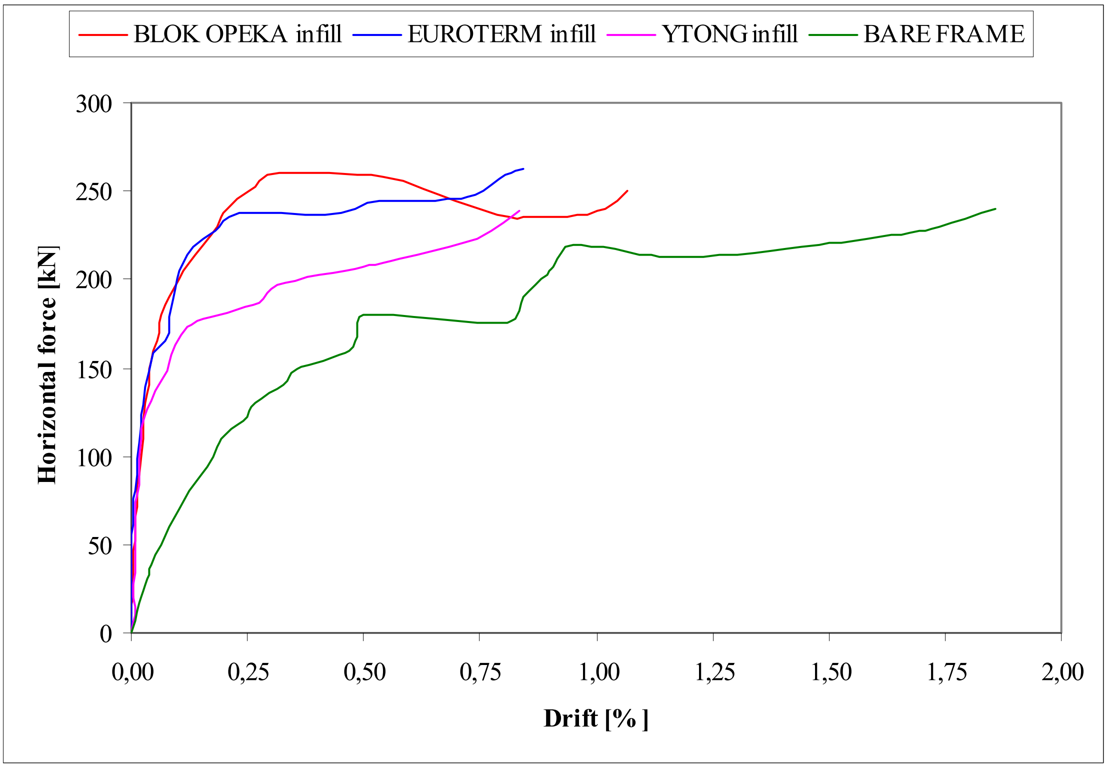

Figure 9. Base shear vs. Drift Ratio for the bare frame and all three infill types

5. CONCLUSION

The behavior of the infilled frame under seismic loading is difficult to predict by analytical methods unless the analytical models are supported and revised by the experimental data. Within the scope of a larger project we have tested nine r/c frames infilled with three types of masonry infill, namely: (a)strong, (b)medium strong and (c)weak infill. The frames were made with standard materials and procedures as used in Croatia.

Frome the measured results could be observed that infill of any type enhances the initial stiffness of a composite structure for about 60%. Increase in the load carrying capacity depends on the type of infill and brings from 5 to 25% in the increase. First cracking in the infill occurred at inter-story drift of 0,05%, while infill fall-out happens at the drift ratio of 01,5 to 0,60% depending on the type of infill.

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