SEISMIC RETROFIT OF PRECAST RC WALL PANELS WITH CUT-OUT OPENINGS USING FRP COMPOSITES

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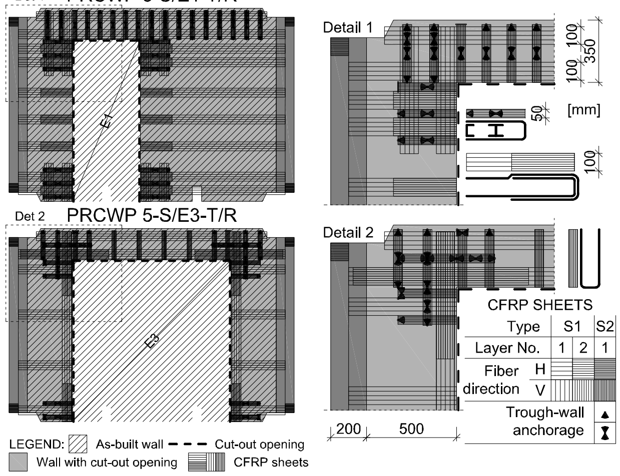
1 INTRODUCTION

The present study was conceived in order to investigate the shear behaviour of the Precast Reinforced Concrete Wall Panels (PRCWP) with cut-out openings subjected to in-plane seismic loading conditions and to assess the shear capacity gain obtained using Fiber Reinforced Polymer (FRP) composites as retrofit solution. The structural system of Precast Reinforced Concrete Large Panels (PRCLP) was extensively used in Romania, from 1950 to 1990, for housing buildings with 5 and 9 stories [1]. Cut-out openings are often required to facilitate direct access from outside or between adjacent apartments, predominantly at the ground floor, where both gravity and seismic capacity demand is maximum. However, cut-out openings performed in structural walls results in the modification of the internal force flow paths, loss of load bearing capacity and reduced structural safety.

Similar experimental researches are scarce in the literature. The earthquake resisting behaviour of Reinforced Concrete (RC) structural walls with openings, strengthened by Carbon FRP (CFRP) sheets and grids, was investigated in the post-damage repair and strengthening case [2]. The shear and flexural strengthening effect of differently oriented CFRP sheets was examined on cantilever type RC shear walls in both prior-to-damage and post-damage situations [3]. Experimental research was performed on high slenderness RC walls with door openings distributed on four height levels, strengthened with CFRP sheets [4].

2 EXPERIMENTAL SPECIMENS

The experimental program consisted of eight 1:1.2 scaled wall specimens, including three single and five double tests. The geometric dimensions, reinforcement arrangement and material properties of the wall panels were inherited from an actual PRCLP building, according to a typical plan. The experimental variables were represented by the opening type (without opening, i.e. solid wall, narrow door, and wide door), the opening nature (as-built, and cut-out) and the strengthening state (not strengthened, post-damage, and prior-to damage). In this paper the discussion was focused on two double tested elements, see Figure 1.



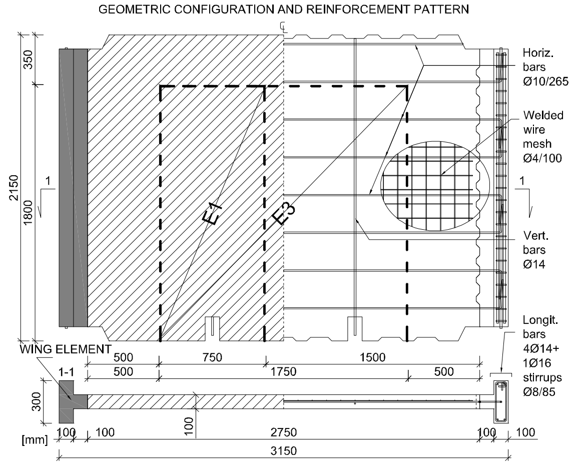


Fig. 1 The strengthened experimental specimens. **Fig. 2** Geometrical and reinforcement details.

Table 1 Variables of the experiment.

Test No.	Element No.	As-built / cut-out opening type	Strengthening state	Element designation
1	3	solid wall / narrow door (S/E1)	not strengthened (T)	PRCWP 3-S/E1-T
2	3	solid wall / narrow door (S/E1)	post-damage strengthened (T/R)	PRCWP 3-S/E1-T/R
3	5	solid wall / wide door (S/E3)	not strengthened (T)	PRCWP 5-S/E3-T
4	5	solid wall / wide door (S/E3)	post-damage strengthened (T/R)	PRCWP 5-S/E3-T/R

Both experimental specimens were obtained from a solid wall (S), by cutting out a narrow door (E1) for element No. 3, and a wide door (E3) for element No. 5, respectively. The geometric configuration and the reinforcement arrangement of the solid wall, as well as the cut-out openings were represented in Figure 2. In order to ensure the out-of-plane stability, the wall panels were constructed with wing elements along the vertical edges. The experimental elements were tested twice: first the bare RC wall panels were damaged, thereafter repair and strengthening was carried out and the second test was performed. The designation pattern of the specimens corresponds to the described experimental variables, see Table 1.

3 TEST SET-UP, LOADING STRATEGY AND INSTRUMENTATION

The test set-up, see Figure 3, was designed to reproduce the in-situ boundary and seismic loading conditions of a wall panel at the ground floor of an actual PRCLP building. Two composite steel-reinforced concrete beams were used as force transmitter (upper) and as foundation (lower) element. The horizontal joint gap between the beams and the wall specimen was poured with high-strength mortar. The vertical (gravity) and in-plane horizontal (seismic) forces were induced by four hydraulic cylinders supported by reaction frames. The novelty of the test set-up lay in the supporting conditions: in order to stimulate shear failure, the vertical tensile forces (ensued as a result of the rocking rotation of the laterally loaded wall) were transferred from the direct path (through the experimental specimen) to an indirect path (through the vertical reaction frames) toward the ground floor.

The experimental elements were subjected to pseudo-constant axial and in-plane reversed cyclic lateral forces, simulating the seismic loading conditions at a quasi-static rate. The initial axial loads were computed considering a normalized axial stress of 0.056. The lateral loading history was defined in terms of constant displacement increment of 2.15 mm (corresponds to 0.001 rad storey drift angle) and two cycles on each displacement level. The rocking rotation of the wall panels was restrained by the displacement control of the two vertical hydraulic cylinders, at a rate of 100 kN/mm. The failure criterion was assigned to the displacement level, where a 20% lateral load capacity drop was observed. A detailed presentation of the loading strategy was reported in [5].

The instrumentation for the experiments consisted of displacement transducers, strain gauges and pressure transducers, see Figure 3.

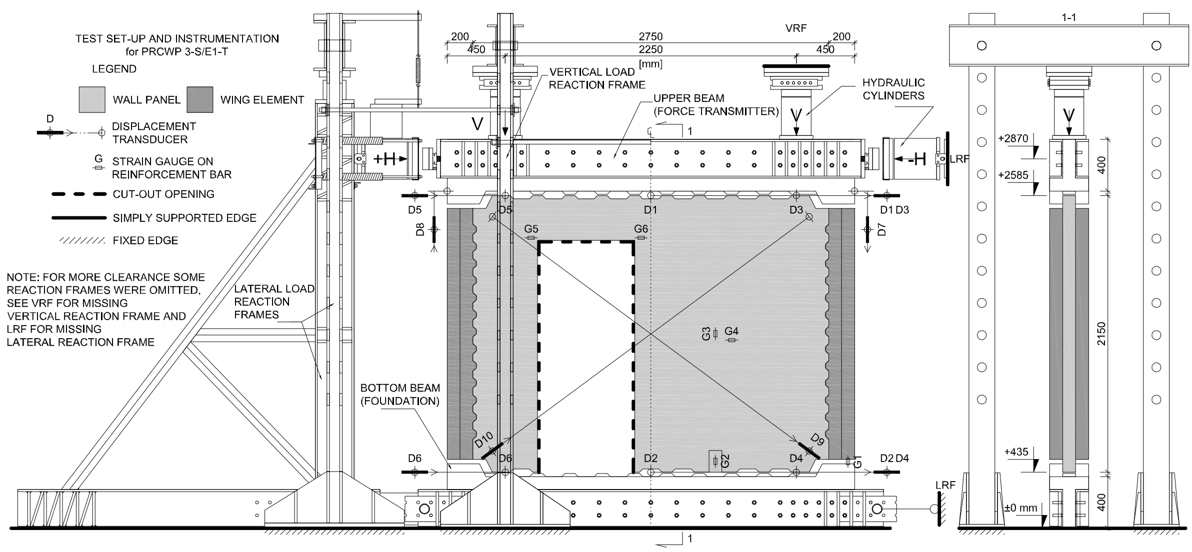


Fig. 3 Test set-up and instrumentation.

Table 2 Material properties.

Concrete(1)			**Repair mortar**(2)		**Steel reinforcement**(3)				**CFRP**(2)	CF (Carbon Fiber)		Impr. resin	
Element No.	3	5			Type	mesh	longit.	stirr.	Sheet type	S1	S2	S1	S2
Compressive strength (f_{ck}) MPa	10.54	17.11	Compressive strength (at 7 day) MPa	48÷52	Diameter mm	4	10; 14; 16	8	Thickness mm	0.122	0.337	n/a	n/a
					Yield strength MPa	490	355	255	Areal weight g/m^2	220	610		
					Modulus of elasticity (E) GPa	210			Tensile strength MPa	4100	3900	30	45
									Tensile modulus GPa	230		4.5	3.5

Note: (1) experimentally determined by the authors; (2) given by the producer; (3) according to the product standard.

4 DAMAGE ASSESSMENT AND STRENGTHENING PROCEDURE

During the tests on the bare wall specimens (test No. 1 and No. 3), the development of diagonal cracks was observed, which indicated shear behaviour mode. Nevertheless, the final failure mode was governed in both tests by the local crushing of concrete in compression. This was attributed to the lack of transverse reinforcement and to the local increase of the compression forces at the corners of the cut-out openings. After the first test series, the crumbled concrete was replaced by high-strength mortar and the walls were strengthened by CFRP fabrics, using the Externally Bonded Reinforcement (EBR) technique. For details on the FRP sheet arrangement and material properties see Figure 1, and Table 2, respectively. The strengthening strategy was threefold: to provide confinement effect at the cut-out opening corners, to increase the shear capacity of the sleeve walls and to offer flexural capacity along the vertical and horizontal edges of the cut-out opening. The strengthening was carried out symmetrically on both faces of the walls.

In the second test series (test No. 2 and No. 4), the development of the diagonal cracks continued and the final failure occurred at an increased displacement level. The element No. 3 failed by concrete crushing at the lower-right corner of the wide sleeve-wall, where no confinement was provided, and CFRP confinement fracture at the lower-left corner. The element No. 5 failed by sliding shear between the right sleeve-wall and the adjacent wing element, after the debonding of the shear CFRP sheets.

5 EXPERIMENTAL RESULTS

The load – displacement hysteresis diagrams of the experimental specimens were presented in Figure 4. The characteristic shear behaviour mode of the wall panels was exhibited by the pinched hysteresis loops. As the displacement level was increased, the stiffness diminished gradually, but more significantly around the zero displacement value and less at the peak displacement.

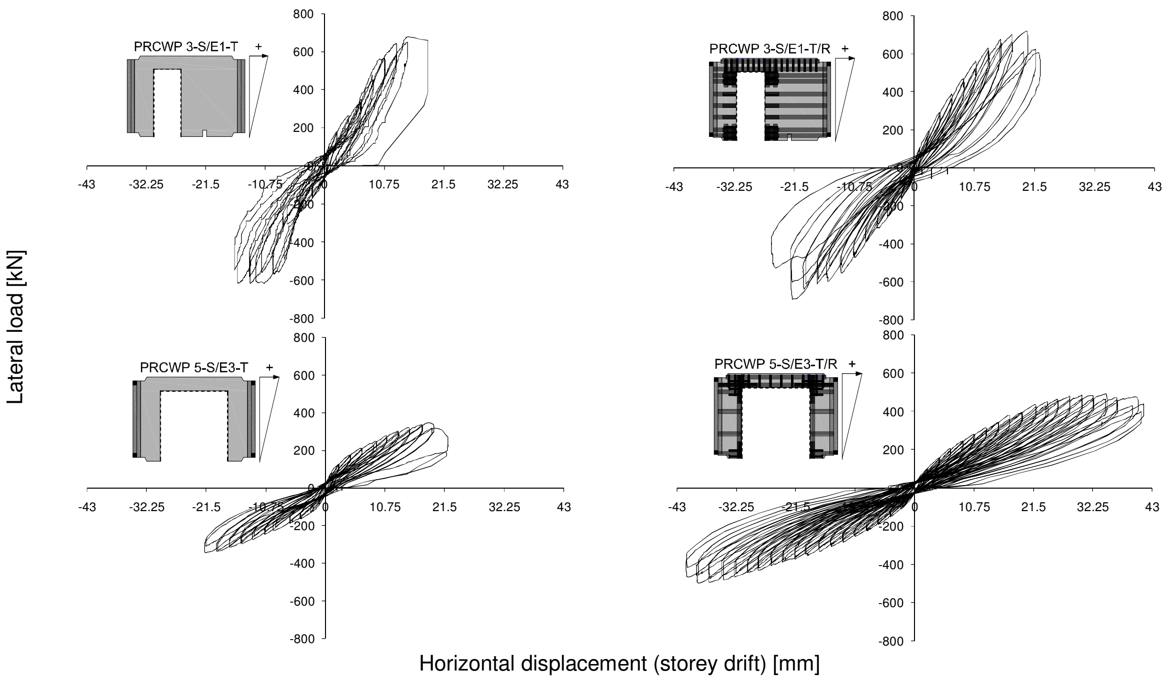


Fig. 4 Load – displacement hysteresis diagrams.

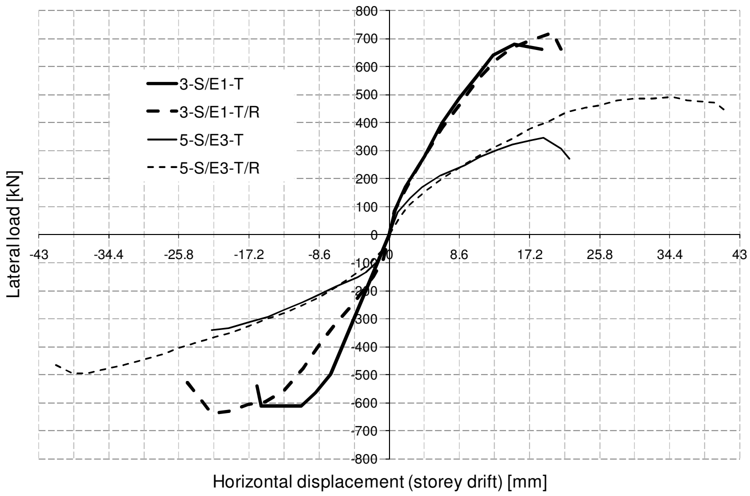


Fig. 5 Load – displacement envelope curves.

The influence of the considered experimental variables on the behaviour of the specimens was represented by the load – displacement envelope curves, Figure 5. By increasing the cut-out opening width from 75 cm (S/E1) to 175 cm (S/E3) the lateral load bearing capacity of the bare specimens was halved, from 679 kN (3-S/E1-T) to 346 kN (5-S/E3-T). The strengthening of the damaged wall panels resulted in a lateral load bearing capacity increase of 6% for element 3-S/E1-T/R (720 kN), and 43% for element 5-S/E3-T/R (494 kN), while the displacement capacity gain was 57% and 90%, respectively.

6 CONCLUSIONS

The presented experimental research was performed on precast RC wall panels in order to assess the shear capacity decrease, caused by cut-out openings, and to investigate the effectiveness of the externally bonded FRP composite materials as simple and efficient retrofitting solution. The wall specimens were previously damaged, to simulate the post-seismic strengthening situation. The tests on the strengthened elements indicated increased horizontal displacement capacity and the same or higher lateral load bearing capacity in comparison with the bare walls.

ACKNOWLEDGEMENTS

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