Glass Fiber versus Carbon Fiber Grid used in Textile Reinforced Mortar Strengthening of Precast RC Walls

C. Toduț, V. Stoian, and I. Demeter

Abstract—**The experimental study presented hereis based on the seismic performance investigation of precast reinforced concrete wall panels (PRCWP), post-damage strengthening using different materials and different anchorage systems. Both wall panels have an initial small window opening, but the second panel has the opening enlarged into a large window opening in order to investigate also the cut-out effect. The behavior and failure details are presented and analyzed for both unstrengthened and post-damage strengthened situations. The economic aspect will also be discussed for each of the strengthening systems used.**

Index Terms—**Textile reinforced mortar, strengthening, reinforced concrete, wall.**

I. Introduction

Precast reinforced concrete large wall panel buildings proved good seismic behavior, but these structures affected by time and several interventions on them such as cut-outs made in walls due to several reasons must have weakened their load bearing capacity. In the field of retrofitting or strengthening of structural elements a large variety of applications are available today, still the selection of the strengthening system used is more often based on the financial aspect. Since few literatures are known on this economic aspect, in this paper the strengthening costs will be analyzed and discussed for both TRM systems.

II. Experimental Program Description

The experimental walls were laterally loaded, reversed cyclic - displacement controlled. As the height of the wall is 2150 mm, 21.5 mm corresponds to 1% drift ratio. The displacement control has its unit a drift ratio of 0.1% (2.15 mm), while two cycles per drift were made. The test was stopped when the specimen lost 20% of its load bearing capacity. The boundary conditions consist of restrained rotation and out of plane displacement prevention [1]. The compressive strength (cubic measured) for the panels was 27.25 MPa for the PRCWP (10-L1) specimen and 27.25MPa for the PRCWP (11-L1/L3) specimen. The instrumentation part in the experimental test consisted of three measuring quantities, namely displacements using displacement transducers, unit strains (using strain gauges) and forces (using piezo-resistive transducers).

III. The Strengthening Strategies

The strengthening strategies presented here are based on the TRM technique, one using glass fiber grid and the other one using carbon fiber grid. The TRM technique provides a viable alternative to “classic” FRP interventions without compromising strength and ductility increase [2]. Other advances in this type of strengthening system are offered by Papanicolaou, C.G., Triantafillou, T.C., Bourn as, D.A and Lontou, P.V. [3]-[4], Thomas Blanksvärd [5], J.T. San-José [6] and others.Besides the grid material used, two types of anchorage system were used in order to assure the workability and the bond strength between the strengthening system and the concrete substrate.

A. PRCWP (10-L1/L3-T/R)

In the case of the post-damage strengthened wall having a small window opening enlarged to a large window opening, the strategy applied was based on TRM using GF grid and a punctual type of anchorage using threaded rods. After repairs, the surface of the wallwas polished, 8 mm holes were drilled for the threaded rods, the corners of the opening were rounded 20 mm and the wall surface was vacuum-cleaned. First, the threaded rods (6 cm length) were fixed using resin through the panel. According to the retrofitting plan (Fig. 1), the SikaWrap 350 G grid was cut using scissors considering their dimensions. The bonding primer(SikaMonotop 910 N)was then applied on the surface of the wall, followed by the first layer of mortar, the GF grid (Fig. 2) and last the second layer of mortar (Fig. 3) “to be published” [7].The mortar from the TRM system was a 1-componentmortar, mixed with water (SikaMono Top 722 Mur). The material consumption here comprised 18 m^2 of glass fiber grid, 98 threaded rods, 1 kg of resin for the anchorage, 35 kg bonding primer and 175 kg component mortar in TRM. Strain gauges were mounted on steel reinforcement for the unstrengthened wall and on the GF grid for the strengthened wall.

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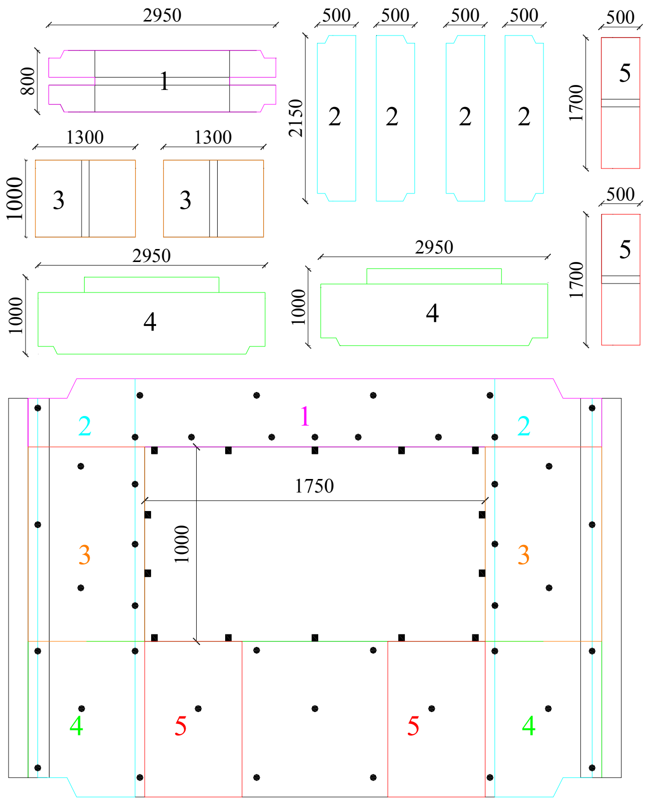

Fig. 1. Retrofitting strategy for the PRCWP (10-L1/L3-T/R) specimen

Fig. 2. Glass fiber grid and punctual anchorage application

Fig. 3. Second layer of mortar application

B. PRCWP (11-L1-T/R)

In the case of the post-damage strengthened wall having a small window opening the strategy applied was based on TRM using MapeGrid C170carbon fiber grid and a surface type of anchorage using MapeWrap S Fiocco, a high-strength steel fiber cord. The strategy applied intended to increase the initial load bearing capacity of the element. After repairs, the surface of the wall was polished, 16 mm holes were drilled for the steel fiber cord anchorage, the corners of the opening were rounded about 20 mm and the surface of application was vacuum-cleaned. The cracks from the experimental test of the unstrengthened specimen were injected with epoxy resin (Epojet) using Sika mechanical injection packers, MPS type, 115 mm length. In this case the mortar for the TRM system was Planitop HDM, a two-component, high-strength, cement-based mortar with fine-grained aggregates, special admixtures and synthetic polymers (blended with a liquid, giving high bonding strength. The material consumption here comprised 15 mechanical packers, 2.5 kg epoxy resin for crack injection, 7.95 m steel fiber cord, 6 kg of resin for cord preimpregnation, 6 kg of resin for cord fixing through wall, 23.40 m^2 of carbon fiber grid and 396.5 kg component mortar in the TRM system. Strain gauges were mounted on steel reinforcement for the unstregthened wall and on the carbon fiber grid for the post-damage strengthened wall. In Fig. 4 is presented the strengthening strategy in this case.

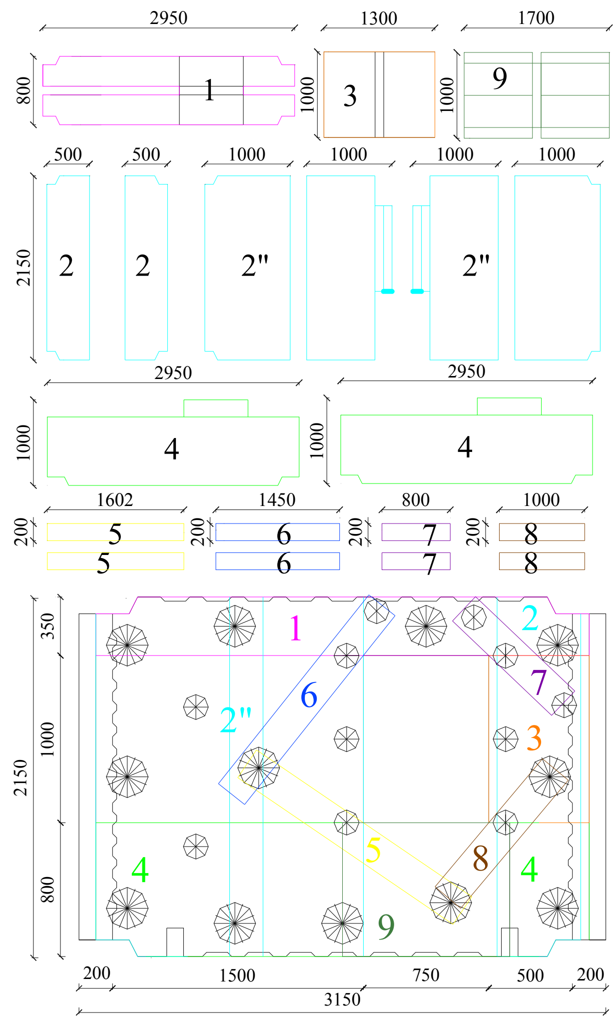

Fig. 4. Strengthening strategy for the PRCWP (11-L1-T/R) specimen

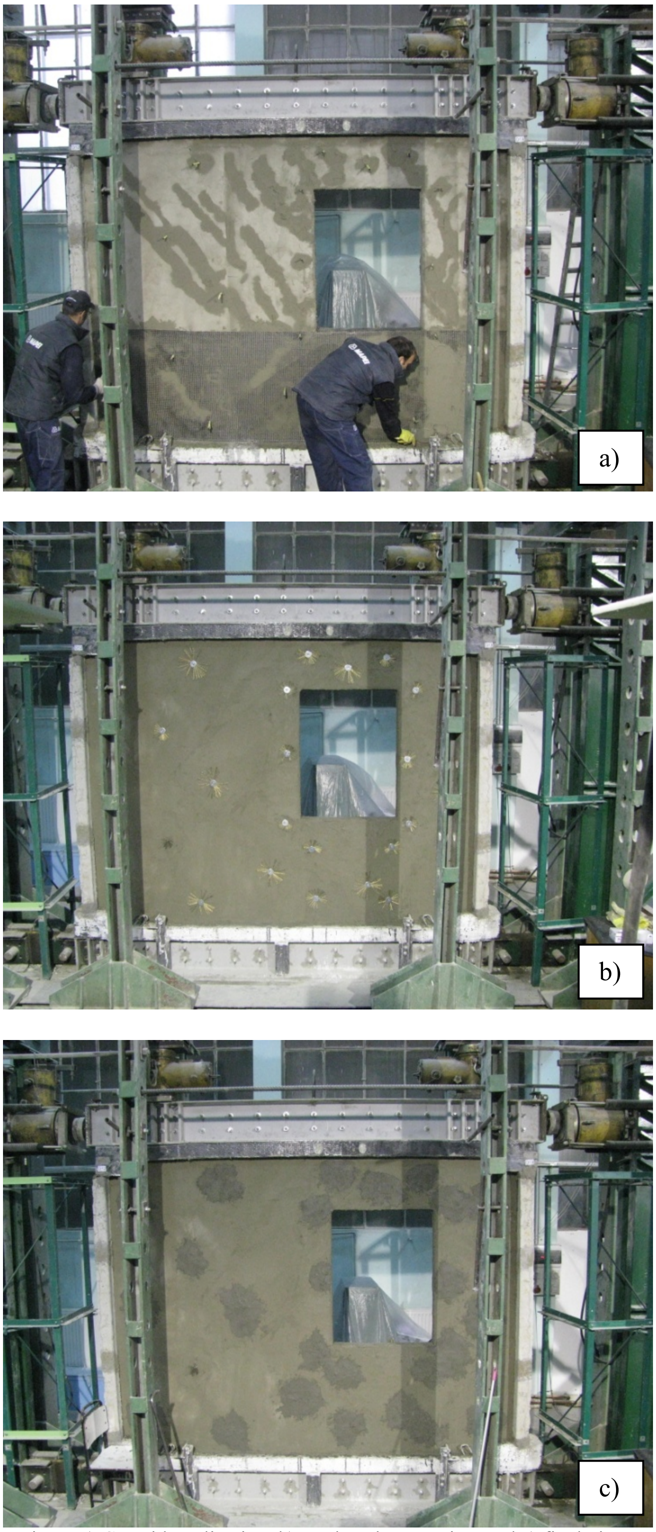

Fig. 5. a) CF grid application, b) steel anchorage view and c) final view

Fig. 5 shows the experimental post-damage strengthened wallhaving a small window opening in different views: a) when the carbon fiber (CF) grid was applied, b) a view of the steel anchorage system and c) the final phase when the strengthening was realized. The steel filaments of the anchorage were fixed to the wall using washers and concrete nails beaten in resin. The dark spots over the anchorage represent a high strength mortar (Mapegrout Easy Flow GF) which was applied in order to prevent debonding of the anchorage system. In comparison with the retrofit of the other panel, here was paid a much more attention on the anchorage type used and also the cracks were injected using mechanical packers and a hand pump, fact also leading to higher costs.

IV. Failure Details of the Strengthened Specimens

During the experimental test, the PRCWP (10-L1/L3-T/R) recorded debonding of the TRM system between the threaded rods (Fig. 6a) and diagonal cracks with mortar crushing (Fig. 6b). When the test was finished, parts of the TRM system were removed and in Fig. 6c one can remark the concrete crushing and severe diagonal cracks. Fig. 6d represents a piece of the TRM system debonded containing glass fiber grid, mortar, bonding primer and no concrete substrate.

In the case of the unstrengthened wall having a small window opening (11-L1-T) recorded multiple cracks on the entire surface, cast in place mortar crushing and concrete crushing in the parapet (Fig. 7a). For the post-damage strengthened wall having a small window opening (11-L1-T/R) a few diagonal cracks were recorded in the piers, parapet and coupling beam. The specimen could not be taken to failure in this case due to the available testing facility which could impose lateral loads up to 100 tones.

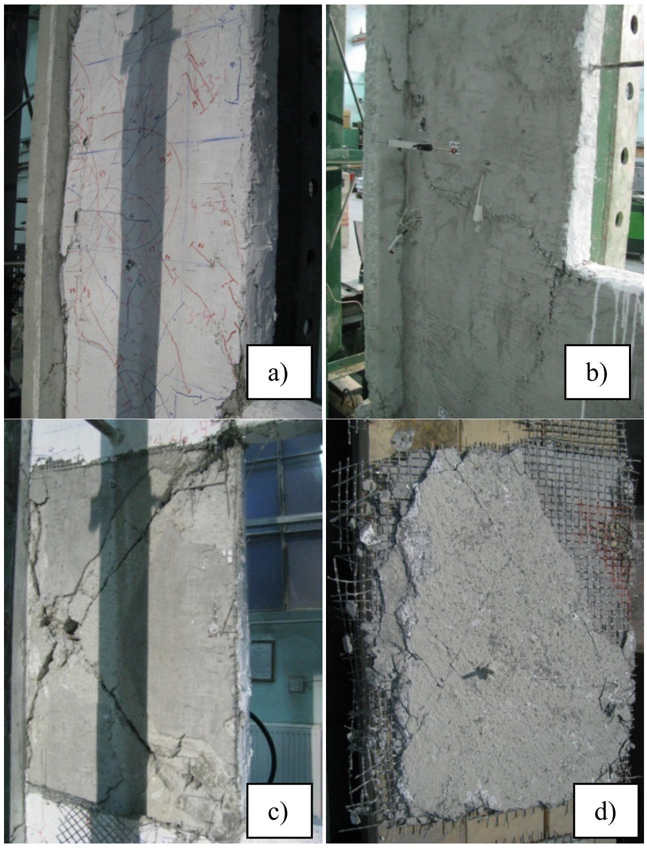

Fig. 6. Failure details for the PRCWP (10-L1/L3-T/R)

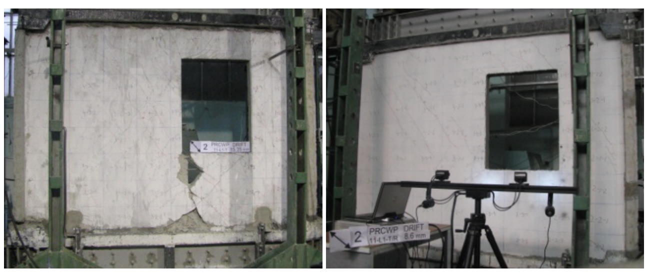
Fig. 7. a) PRCWP (11-L1-T) and b) PRCWP (11-L1-T/R)

V. RESULTS

Fig. 8 represents the load-displacement envelopes for the four experimental tests performed on the precast RC wall panels, while Fig. 9 shows the stiffness degradation curves. Fig. 10 and Fig. 11 show the strain-displacement diagrams.

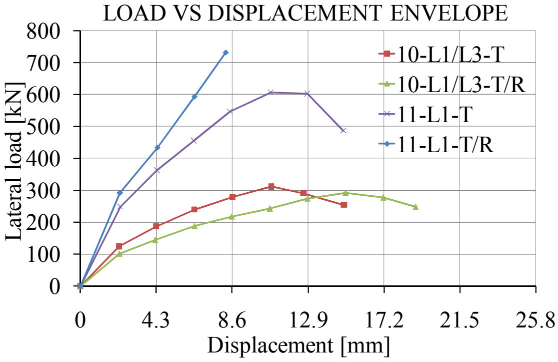

Fig. 8. Load-displacement envelope curves

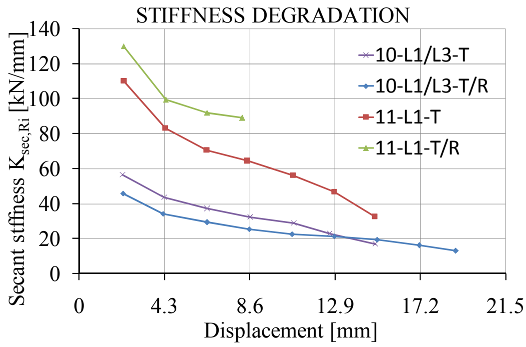

Fig. 9. Stiffness degradation curves

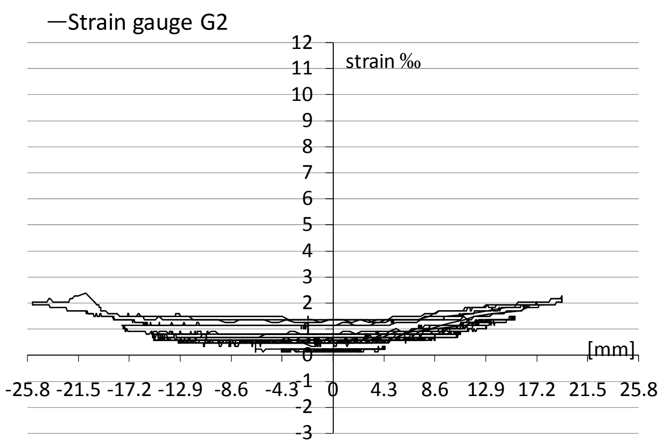

Fig. 10. Strain-displacement diagram for G2 (10-TR)

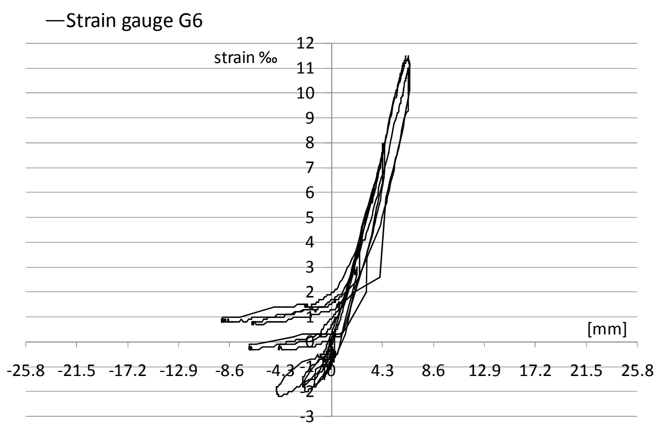

Fig. 11. Strain-displacement for G6 (11-TR)

TABLE I: PRCWP (10-L1/L3-T/R)

PRCWP 10-L1/L3-T/R				
MATERIAL	DETAILING	UM	QUANTITY	TOTAL PRICE [EUR]
Sika wrap 350 G (1000 mm x 50 m)	Glass fibre grid	roll	0.36	191.51
Sika Monotop 722 Mur (25 kg)	Mortar for TRM	kg	7	243.04
Sika Monotop 910 N (25 kg)	Bonding primer for TRM	kg	1.4	47.74
Sika sikadur 30 (6 kg)	Resin for rods	kg	0.17	1.69
Threaded rod, nut and washer	Anchorage for grid	pieces	98	18.23
Sika Monotop 614 (25 kg)	Repair mortar	kg	1.5	44.64
LABOR	DETAILING	UM	QUANTITY	TOTAL PRICE [EUR]
Structural repair for RC wall	including formwork	hours	2	9.42
Concrete surface polish	including disc damping	m^2	9.2	171.12
Hole drilling in concrete	including drill	hours	1	11.16
Concrete surface blowing using compressed air	including air pump damping	m^2	9.2	11.41
Concrete surface vacuum-cleaning	including vacuum bag	m^2	9.2	11.41
Glass fiber grid cut	including foil support	m	18	11.16
Resin application	including spatules, gloves	pieces	98	12.15
TRM application	primer, mortar,	m^2	9.2	45.63
TOTAL PRICE FOR RETROFIT				830.31

TABLE II: PRCWP (11-L1-T/R)

PRCWP 11-L1-T/R				
MATERIAL	DETAILING	UM	QUANTITY	TOTAL PRICE [EUR]
Mapegrid C170 (1.0 m x 50 m)	Carbon fiber grid	roll	0.47	1748.40
Planitop HDM (30.5 kg)	Mortar for TRM	kg	13	688.32
Mapegrout easy flow GF(25 kg)	Repair mortar	kg	2	58.90
Epojet (4 kg)	Resin for crack injection	pieces	0.625	67.27
Adesilex PG2 (6kg)	Steel fiber cord preimpregnation	pieces	1	83.33
Mapewrap 11 (6kg)	Resin for cord fixing	pieces	1	79.61
Mapewrap S fiocco (25 m)	Steel fiber cord	m	0.32	238.08
Sika mechanical packers (MPS)	Packers for crack injection	pieces	15	42.41
LABOR	DETAILING	UM	QUANTITY	TOTAL PRICE [EUR]
Structural repair for RC wall	including formwork	hours	3	22.32
Concrete surface polish	including disc damping	m^2	11.2	208.32
Hole drilling in concrete	including drill	hours	1	11.16
Concrete surface blowing using compressed air	including air pump damping	m^2	11.2	13.89
Concrete surface vacuum-cleaning	including vacuum bag	m^2	11.2	13.89
CF grid cut	including foil support	m	23.4	14.51
Anchorage application	including spatules, gloves	pieces	98	30.38
TRM application	mortar, grid	m^2	11.2	55.55
TOTAL PRICE FOR STRENGTHENING				3095.85

Fig. 10 represents the strain-displacement diagram for G2 strain gauge (PRCWP 10-L1/L3-T/R) on glass fiber grid, and Fig. 11 for G6 (PRCWP 11-L1-T/R) on carbon fiber grid. Table I and Table II show the TRM strengthening costs for PRCWP (10-L1/L3-T/R) using glass fiber grid and PRCWP (11-L1-T/R) using carbon fiber grid. All the results will be discussed in the conclusion section.

VI. Conclusion

In terms of maximum load supported by the element the unstrengthened PRCWP (10-L1/L3-T) recorded 344 kN while the post-damage strengthened one (10-L1/L3-T/R) 320 kN. Drift level corresponding to the maximum load was 12.93 mm for the unstrengthened wall while for the post-damage strenghtened one was 14.98 mm. The maximum load supported by the unstrengthened PRCWP (11-L1-T) was 793.5 kN, while for the post-damage strengthened one 1007.5 kN. Drift level corresponding to the maximum load was 12.59 mm for the unstrengthened wall while for the post-damage strengthened one was 8.02 mm. Investigating the cut-out effect made in the wall panel due to the window enlargement we obtain a decrease in load bearing capacity of 56%. In the case of PRCWP (10-L1/L3) the initial load bearing capacity of the element was almost restored. The PRCWP (11-L1) could not be taken to failure due to the available capacity of the testing facility, but analyzing the data one can remark that at a displacement level of 8.02 mm we have an increase in load bearing capacity of 60%. Strain gauge G2 located on glass fiber grid (right pier, midpoint) ranged only up to approximately 2.4 ‰ in tension. Strain gauge G6 applied on carbon fiber grid (at the left upper corner of the opening on an inclined strip, number 6) ranged from approximately -2.2 ‰ in compression until +11.5 ‰ in tension. Concerning the economical aspect, we obtained a cost per square meter of 90.25 EUR/m^2 for PRCWP (10-L1/L3-T/R) using glass fiber grid and 276.42 EUR/m^2 for PRCWP (11-L1-T/R) using carbon fiber grid. The prices given in tables are valid for Romania, for the current period. The strengthening using TRM with carbon fiber grid proved to be the most expensive, but we have to take into consideration the fact that the crack injection was not performed in the other case, the steel fiber cord is a high performance anchorage type and its price is in accordance with it, and also the idea of strengthening versus retrofitting implying the carbon fiber grid wraps raised the total price. Both systems proved to be efficient, except the punctual type of anchorage which reduced the costs but led to debonding.

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