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ANTISEISMIC STRENGTHENING OF COMPOSITE STEEL-CONCRETE SHEAR WALLS USING HIGH PERFORMANCE STEEL FIBER REINFORCED CEMENTITIOUS COMPOSITES

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Abstract: *The present paper describe the nonlinear behaviour of composite steel-concrete structural walls, under lateral loads, applied in a cyclic loading procedure, simulating the effect of an earthquake, which were tested initially up to full failure and after then, strengthened using a high performance steel fiber reinforced cementitious composite material and retested to full failure, being described aspects such: sectional configurations and geometry of tested elements, materials used and also the results obtained from the tests carried out in laboratory.*

Key words: *hybrid steel-concrete walls, strengthening, nonlinear behaviour, cyclic loads.*

1. Introduction

In the last years, researches made in concrete are focused to develop materials with small rate of cracking under stresses and with high tension resistance, materials such steel fibers reinforced concrete and especially high-performance steel fibers grouts, developed commonly to retrofit or strengthen the damaged elements with lower bearing capacity. This type of materials is having high mechanical properties and good rate of energy dissipation, presenting many advantages over a traditional reinforced concrete.

The fiber reinforced concrete consist of a concrete matrix reinforced by a specified percentage of discrete steel fibers embedded randomly in the concrete mass. Some technological objectives refer to the possibility to replace the traditional steel bars of the traditional reinforced concrete elements with such materials described above. The material is also used to increase the durability and ductility of structural members. Most studies made on strengthening reinforced concrete elements, using high performance steel fiber materials, indicate a significant increase of bearing capacity with at least 25% than initially, material being usually applied in a relatively thin layer on the contour of

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the damaged elements. This type of research related to the topic of structural members strengthening using fiber reinforced materials deals mostly with strengthening of slabs, beams, columns, very limited researches dealing with strengthening of structural concrete walls being performed.

2. Experimental Program

The experimental program is performed on steel-concrete hybrid walls, being part of an extended research program. Main objective of the experimental research program was to study the performance and non-linear behaviour of the composite steel-concrete hybrid walls in comparison with traditional reinforced concrete shear walls considered as reference [1]. The study consists of testing the traditionally reinforced concrete walls (RCW) and a various hybrid steel-concrete shear walls with specific design and detailing (CSRCW - composite steel concrete shear walls with encased steel profiles and reinforced concrete; CSFRCW - composite steel fibre reinforced concrete shear walls made from steel fibre reinforced concrete and encased steel profiles). Extensive assessment of the performance of the tested elements have been made. The main objective of this research is to study the non-linear behaviour of strengthened composite steel-fibre shear walls (CSFRCW) using high performance steel fibers reinforced cementitious composites (HPSFRCC), a material described by very good mechanical performances. Specimens were strengthened with 25 mm thin jacket of HPSFRCC and then retested up to the failure. The results obtained on one strengthened specimen (CSFRCW - 4) are presented in this paper.

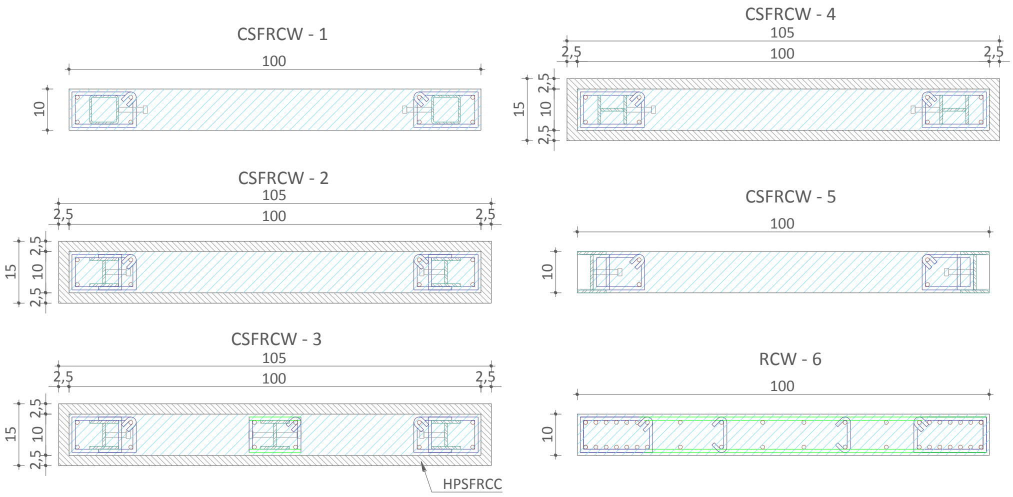

Fig. 1. *Details of the strengthened specimens and sectional configuration of them*

Characteristics of the encased steel profiles Table 1

Specimen labels	Steel shape	Encasement level	b_f [mm]	t_f [mm]	h_w [mm]	t_w [mm]
CSFRCW-1	2□	full	70.0	5.0	70.0	5.0
CSFRCW-2	2工	full	70.0	7.0	56.0	7.0
CSFRCW-3	2工	full	70.0	7.0	56.0	7.0
CSFRCW-4	2H	full	70.0	7.0	56.0	7.0
CSFRCW-5	2工	partially	70.0	7.0	86.0	7.0

3. Geometrical Characteristics

Before strengthening, the geometrical characteristics of the specimens were 3000 mm height, 1000 mm width and 100 mm thickness. Specimens were representative for a lateral resisting system with shear walls being reduced at a 1:3 scale due to the limited conditions of the load setup laboratory equipment. After strengthening, the walls had the same height, but 1050 mm width, and 150 mm thickness. The specimens were fixed into a heavily reinforced concrete foundation to avoid any type of failure at this level of encasement. The encased structural steel profiles were connected to the concrete web by headed shear studs of 13 mm diameter and 75 mm length placed at every 150 mm on the length/height of the profiles. The reinforcement placed around each steel profile consist of 4 vertical bars of 10 mm diameter and horizontal stirrups of 8mm diameter spaced at 75 mm.

3.1. Materials

Structural embedded steel profiles are made from welded steel plates and correspond to S355 (f_{yk}= 355 MPa) steel grade quality. The reinforcements were produced from S500C (f_{yk}= 500 MPa) steel grade. The concrete corresponds to a C30/37 strength class (f_{ck}= 43.06 MPa). For disperse reinforcement of the concrete, hooked steel fibers with 60 mm length and 0.8 mm diameter were used with a minimum tensile strength of 1100 MPa. For strengthening the CSFRCW group of specimens, a self-compacting high-performance steel-fiber reinforced cementitious mortar was used (HPSFRCC).

HPSFRCC is a self-compacting, bi-component mortar and a commercially available product, being manufactured by a specialised company in high-technology repairing materials for damaged structural elements. Material consist of: brass coated steel fibres which have 13 - 15 mm length, 0.2 mm diameter and a pre-dosed powder grout made of ultra-high strength cement, aggregates and special admixtures. The mixing formula consist of 6.5% steel fibre weight of the pre-dosed grout used. The mechanical properties of the material were determined based on the tests performed on 3 cubes and 6 prismatic samples. The compressive strength of the material was 121 MPa and the tensile strength indicates values from 5.46 MPa up to 9.57 MPa. The mechanical properties of this material indicate higher value than a usual concrete or grout used predominantly for structural members.

4. Test Set-Up and Loading Procedure

The specimens were subjected by vertical load (100 kN) provided by a hydraulic jack placed at the top of the walls and by quasi-static reversed cyclic lateral loads, applied alternatively left-right, using two hydraulic jacks placed at 400 mm below the top of the specimens. The specimens were anchored in the main reaction floor with steel bolts anchors and some steel connecting devices. The recommended ECCS short testing procedure was used for cyclic tests. Minimum four cycles were performed before the elastic limit of the elements was reached. The tests were performed in displacement control mode. For monitoring the behaviour of the specimens, displacement and pressure transducers were used.

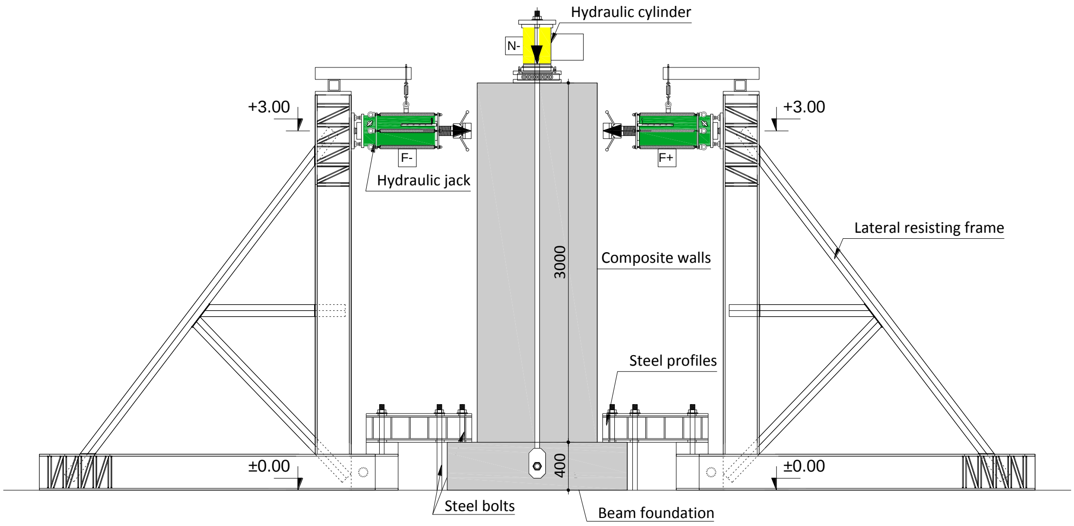

Fig. 2. *Experimental stand set-up*

5. Experimental Results

5.1. CSFRCW group of specimens - before strengthening

The main objective of the research performed on the CSFRCW group of specimens in initial case, was to investigate if the traditional reinforcement placed in the central part of walls could be successfully replaced by the steel fibers, with a similar percentage of embedded steel fibers mixed in the concrete core of the wall [2,3]. The experimental tests, leads, to the conclusion that the concrete steel fibers mixture, was not able to supply the tension resistance of the missing traditional reinforcements, tested specimens developed brittle failure modes. All the specimens reached the failure at a maximum value of drift, 30-40 mm. Failure was triggered by central diagonal splits, characteristic to shear failure modes. Specimens shown a low rate of dissipated energy. This kind of behaviour is not recommended in the seismic areas. At the end of the tests, the specimens showed an advanced state of degradation as are illustrated in Figure 3.

Fig. 3. *Encountered type of failure - CSFRCW group of specimens - shear failure*

5.2. Strengthening of tested specimens using HSPFRCC

Strengthening procedure was performed in two different phases, in the first one, a preliminary repair of the specimens was made. Damaged concrete zones were removed and remade with a new high strength repairing mortar, the small cracks were filled up by injecting liquid epoxy resin and the surface of the wall was mechanically prepared, to assure the adhesion of the new material. The second phase consisted in jacketing of the specimens using the HPSFRCC material. The strengthening consists in applying a 25 mm thin jacket of the material on the entire perimeter and height of the walls. The material was cast gravitationally into a classic formwork. The mixing formula of the HPSFRCC material consist in introducing of 1.625 kg of brass-coated steel fibers in 25 kg of grout powder using maximum 3.20 litres of water. The recommended time for mixing the components was between 10÷12 minutes. The structural connection of the HPSFRCC jacket with the concrete foundation block was ensured by chemically anchored steel rods (5 bars of 12 mm diameter) which were distributed on the two long sides of the walls. Rods had 600 mm length, 100 mm inside the foundation and 500 mm outside of it and were made from S355 (fyk= 355 MPa) steel grade.

Fig. 4. *Phases from strengthening procedure - inserting steel rods and repairing the damaged concrete with high performance repairing grouts*

Fig. 5. *Walls before / after jacketing using HPSFRCC material*

5.3. CSFRCW specimens - after strengthening

After strengthening and retesting to full failure, shear wall reveals a better behaviour in comparison with initial situation, with an increased rate of dissipated energy and yielding in tension of the encased steel profiles, before the failure of specimen encountered. Was encountered also local damage on the beam foundation.

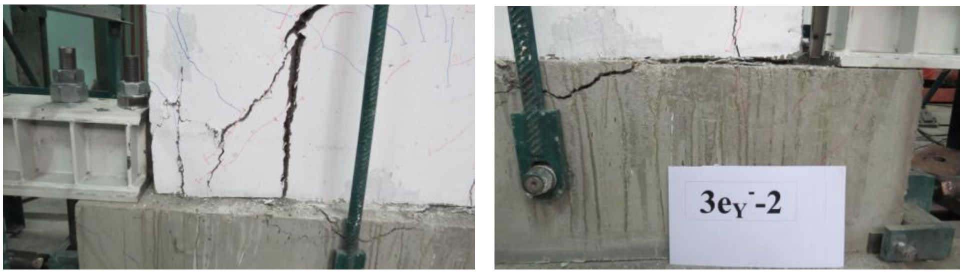

Fig. 6. *Level of damage encountered in beam foundation and at the base of the wall*

Tested specimen develops many cracks oriented in a random direction, being multiple on the area of the wall with spread propagation. Cracks was monitored on opening and marked on each step of loading. The visible cracks started developing only at 15 mm level of drift and at a distance of 15 cm from the edge of the wall (which correspond to the internal face of the steel profile and vertical bars) then extending to the centre, forming a group of inclined cracks, on the first 20 mm level of drift, with a maximum 0.15÷0.20 mm value in opening. This fact shows that the jacket is active from the first cycles of loading helping with the overall dissipation rate of induced energy.

Before strengthening the elastic limit of the wall was reached at 21.84 mm value of drift, 195.8 kN value of lateral force, while after strengthening, at this level of induced force, wall behaviour curve keeps the slope of an elastic behaviour. Chemically mounted steel rods completed the transfer of stresses from the jacket of HPSFRCC into the foundation beam of the wall. After the elastic limit was reached, on the initial situation, existing cracks lead to a brittle failure of the steel fiber reinforced concrete, stiffness of the wall being reduced drastically for the last two cycles of loading. The strengthened wall failed in the same manner (shear failure), but at a higher value of drift and lateral force. The failure diagonal crack of strengthened specimen had another path than the initial situation, revealing that the HPSFRCC jacket had good bond to the fiber reinforced concrete. The behaviour of both specimens under the loading procedure could be better observed by studying the hysteretic curves (Fig.7).

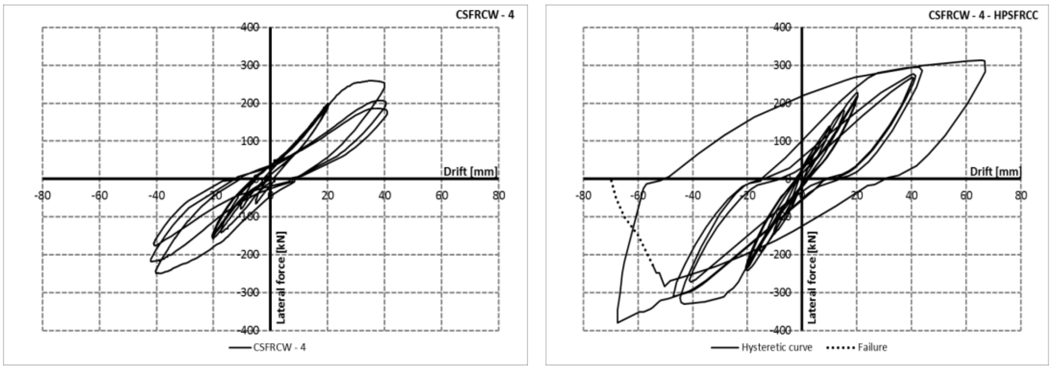

Fig. 7. *Hysteretic curves of tested specimens - before / after strengthening*

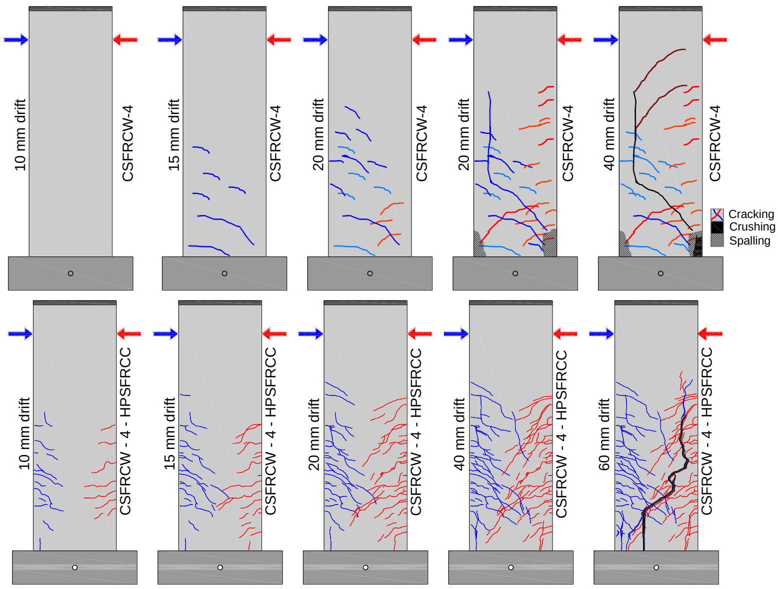

Fig. 8. *Behaviour of the tested specimens before / after strengthening*

6. Conclusions

Based on the experimental study, the conclusion is that the strengthened wall with HPSFRCC material showed a better behaviour in comparison with the initial one, under the cyclic load procedure. The strengthening procedure can be considered successful as the initial performance of the wall in term of load bearing was restored. Moreover, a significantly increased rate of energy dissipation, ductility and stiffness was observed, even if the failure mode of the specimen was quasi similar. The strengthening solution could be a viable alternative in choosing the best solutions for retrofitting damaged structural members.

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