RETROFIT OF CONCRETE PANELS WITH PREFABRICATED HPFRCC PLATES

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ABSTRACT :
The main goal of this study is to develop a convenient strengthening technique for retrofitting of beam-column joints against shear forces. For this purpose the considered retrofitting technique was studied by utilizing a simple testing method for experimental analysis. Experimental study included tests of reference specimens and tests of specimens retrofitted with high performance fiber reinforced cementitious composite (HPFRCC) panels. The HPFRCC panels were either only bonded on the specimens using epoxy mortar or anchored to the specimen by steel bolts as well as bonding. The behavior of the specimens under vertical monotonic load was investigated with a theoretical study by employing non-linear finite element analysis (FEM). The retrofitted members were found to exhibit much better performance in terms of strength and deformation capability. The anchorage application was found to positively affect this improved performance. Experimental results and theoretical results obtained from FEM analysis were also compared. It was seen that finite element analysis is successful to predict the load carrying capacity of the original and the retrofitted specimens as well as the vertical load–vertical strain relationship of the original specimen.

KEYWORDS:
Concrete panels, FEM analysis, Retrofitting, Steel fibers.

1. INTRODUCTION

Many existing reinforced concrete structures do not meet the requirements given by current building design codes by various aspects. Lack of adequate shear strength of beam-column joints is among the most common deficiencies. Research conducted on the shear behavior of the beam-column joints strengthened with innovative materials is rare, [1-8]. Research on the shear behavior of retrofitted concrete panels is also limited, [9-10].

The primary purpose of this study is to develop a convenient technique to improve the shear behavior of beam-column joints. For this purpose the core of beam-column joints are represented by concrete panels. A simple representative testing method was utilized for experimental analysis of shear behavior of low strength concrete panels. To carry out the experimental study eight concrete panel elements were constructed with low quality concrete. Two specimens, which were tested without strengthening, were used as reference specimens. Six specimens were strengthened using HPFRCC panels with different connection details. The specimens were intentionally cast using low strength concrete for representing majority of relatively old existing reinforced concrete structures, particularly in developing countries. The main parameters were thickness of the HPFRCC panel and presence of the mechanical anchorage. All panel specimens were tested under diagonal tension stresses. Average displacements in principle directions were measured in different gage lengths, as well as HPFRCC strains in different directions and locations. The test results are evaluated in terms of specimens' performances in terms of strength, ductility and deformation characteristics, as well as failure patterns. According to the obtained results, retrofitting with HPFRCC panels increased the shear strength of concrete panels and changed the very brittle failure mode to less brittle. The behavior of reference and HPFRCC retrofitted specimens were also predicted theoretically. The analysis results and experimental data are in satisfactory agreement in terms of strength, while deformation characteristics could not be predicted satisfactorily for the retrofitted specimens.

2. EXPERIMENTAL STUDY

2.1. Diagonal Shear Test

A simple test technique was used for evaluating comparative shear strengths of low strength concrete panels either before retrofitting or after retrofitting with HPFRCC panels of different thickness and connection details to the specimens. An Amsler universal testing machine was used to apply the load to the diagonal direction of the specimens as shown in Figure 1. Main target of using this simple test setup was to make a comparative evaluation of specimen performances, rather than obtaining their pure shear behavior.

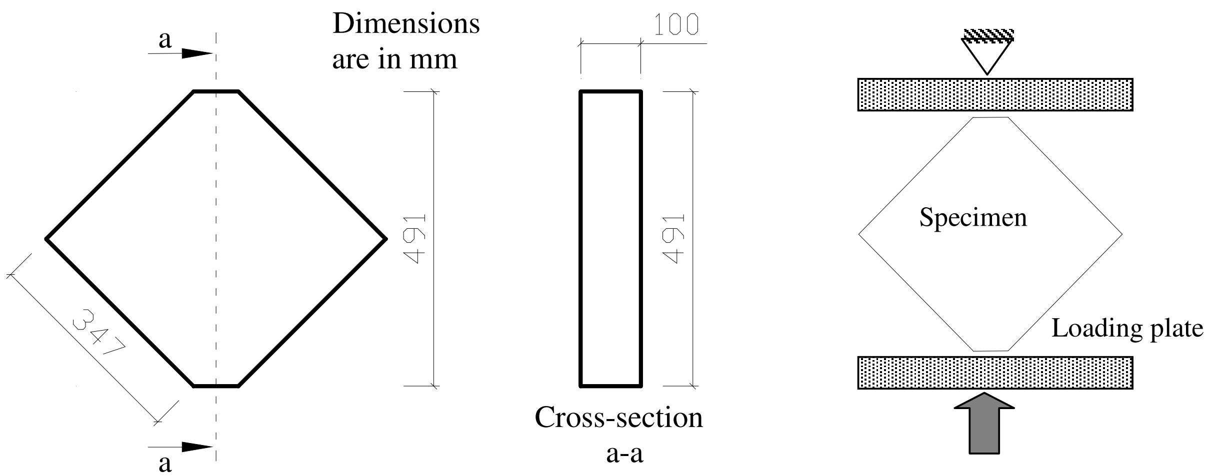


Figure 1 Specimen dimensions and the loading system.

2.2. Details of Test Specimens

Experimental study included eight specimens with 400×400×100 mm dimensions. Six specimens were retrofitted with HPFRCC plates, while two specimens without retrofit were used as reference specimens. The details of specimens are given in Table 1. For construction of specimens, specially designed ready mixed low strength concrete with water/cement ratio of 1.17 was used. Ordinary Portland cement class 42.5 was used in the mixture. Maximum aggregate size of powdered stone, sand and gravel was 4, 4 and 8 mm, respectively. Concrete mix-proportion is presented in Table 2. The average compressive strength and elasticity modulus of concrete at the day of testing was around 8 and 14000 MPa, respectively. The mix-proportion of HPFRCC is given in Table 3. To obtain mechanical characteristics of HPFRCC, standard cylinder compression and disk splitting tensile tests were carried out. The compressive and tensile strengths of HPFRCC around testing days were found to be approximately 135 MPa and 17 MPa, respectively. Construction of the specimens is shown in Figure 2. For strengthening, HPFRCC panels were used with different thickness. The HPFRCC panels were either only bonded on the specimen or anchored to the specimen by steel bolts as well. Before bonding the prefabricated HPFRCC panels on the specimens, surface preparation procedure was carried out, which included sanding, cleaning. Epoxy based adhesive which had the tensile strength of 25 MPa and compressive strength of 75 MPa at the age of 7 days was used for bonding HPFRCC panels on the specimens. The prefabricated panels were cast in wooden forms and the forms were placed on a vibration table to ensure satisfactory compaction. The panels were removed from their forms after one day and were cured in 90 ^{0}C water for 3 days and in 20 ^{0}C water for 25 days. To obtain an optimum mix-proportion and high tensile strength an experimental study was carried out. Details of that study and more information related to steel fiber reinforced concrete can be found in reference [11]. The retrofitting steps are shown in Figure 3 and anchorage application is shown in Figure 4.

Table 1 Specimen details.

No	Specimens	Thicknesses (mm)	Anchorage
1	DS-O-a	-	-
2	DS-O-b	-	-
3	DS-HPFRCC-2	20	No
4	DS-HPFRCC-2-A	20	Present
5	DS-HPFRCC-3	30	No
6	DS-HPFRCC-3-A	30	Present
7	DS-HPFRCC-4	40	No
8	DS-HPFRCC-4-A	40	Present

Table 2 Concrete mix-proportion (kg/m^3).

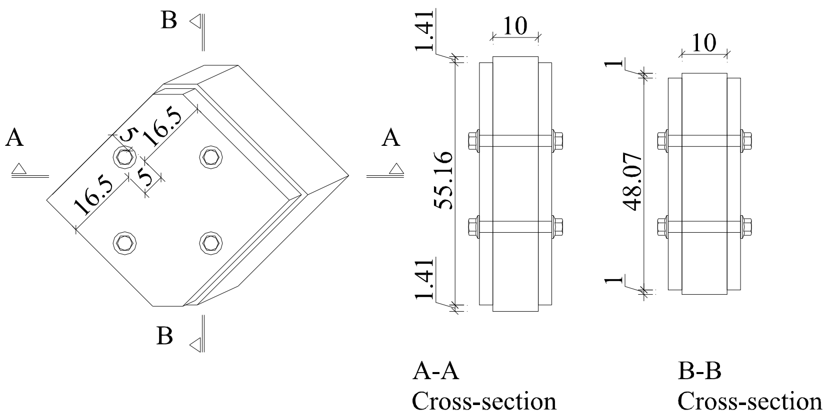
Cement	Water	Sand	Gravel	Powdered stone	Superplasticizer
180	210	650	880	337	2.10

Table 3 HPFRCC mix-proportion (kg/m^3).

Cement	Water	Microsilica	Silica sand	Sand	Steel fiber	Admixture
925	204	186	557	278	314	33.6

Figure 2 Construction of specimens.

Figure 3 Retrofitting of specimens.



The HPFRCC panels are positioned with a distance of 1 cm to the edges of the concrete specimens in order not to resist vertical loads directly. Diameter of the steel bolt is 16 mm.

Figure 4 Anchorage applications (dimensions in cm).

2.3. Details of Test Setup

The loading setup can be seen in Figure 5. An Amsler universal testing machine with the capacity of 5000 kN was used for applying concentric compressive loads on the specimens. External vertical displacements at the loading plates were measured with 8 displacement transducers. The average deformations of specimens in two principal directions were measured at around 400 mm gage length. For measurement of the displacements and strains at different locations on the specimen, pi-type displacement transducers and strain gages were used in addition to linear variable displacement transducers. Locations of the strain gages, pi-type displacement transducers and linear variable displacement transducers on the specimens are shown in Figure 6.

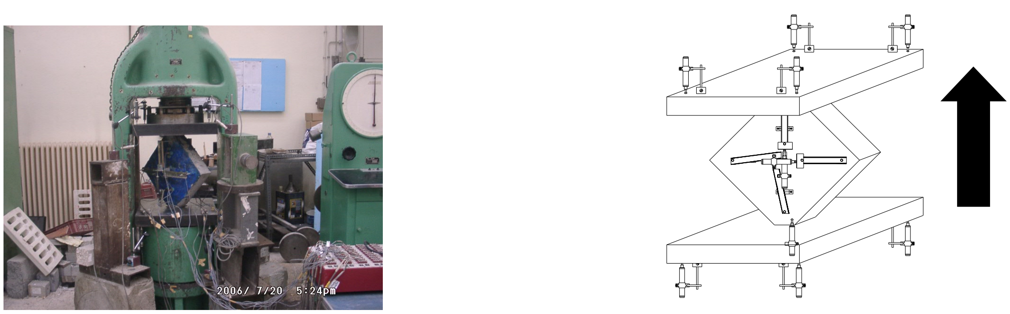


Figure 5 Test machine and schematic view of loading setup.

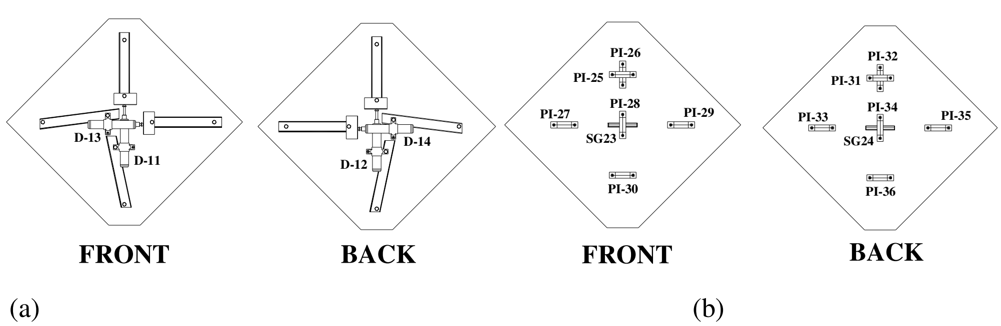
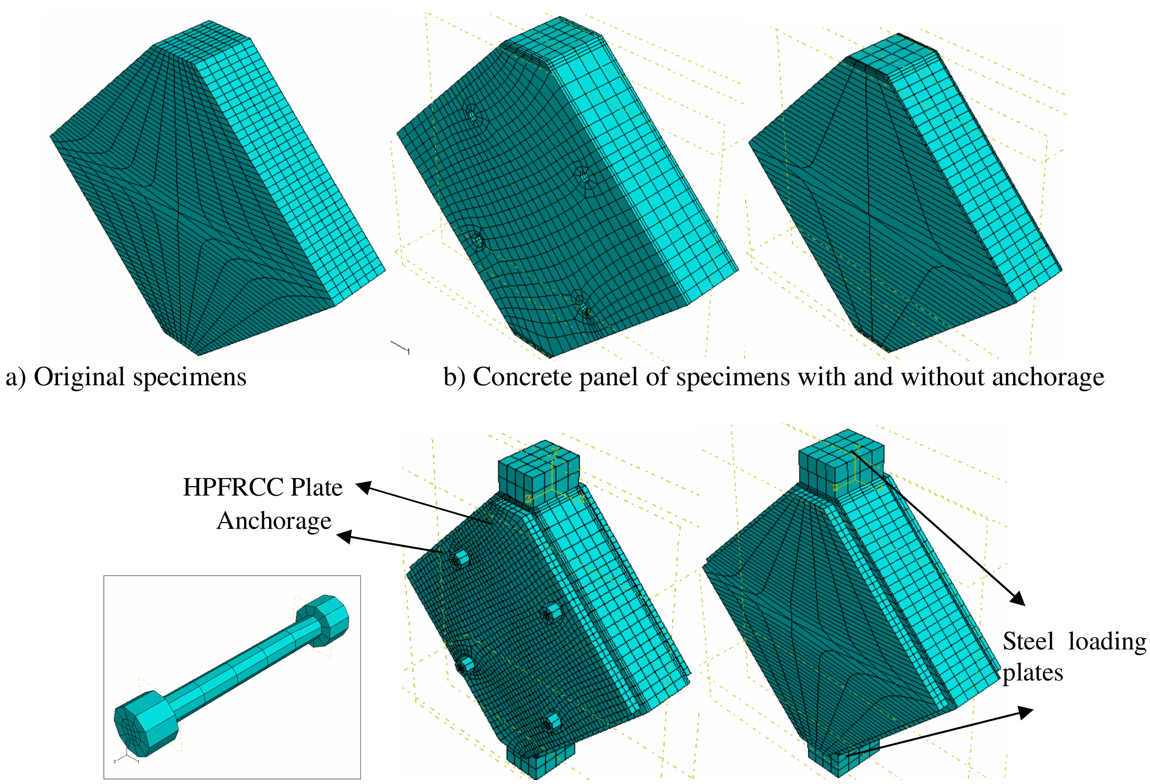


Figure 6 Measuring system a) linear variable displacement transducers b) pi-type displacement transducers and strain gages.

3. FINITE ELEMENT ANALYSIS

The behavior of the original and HPFRCC retrofitted specimens under vertical load was investigated with a theoretical study by employing non-linear finite element analysis. ABAQUS [12], finite element analysis software, was run to carry out finite element analysis. Finite element models for the original and retrofitted specimens are shown in Figure 7.a-d. To represent the actual loading setup of the tests, two thick steel plates were used to load and to support the specimens. Meshes were refined at the transition surfaces in order to get more precise transition of stresses between pieces.

In analysis process "concrete damaged plasticity model" was applied as a concrete model. Mechanical characteristics and stress-strain relationship of the concrete were obtained from the analysis of standard cylinder tests. A C3D8R (8-node linear brick), 8 node linear element, was used as a finite element. During tests, no relative deformations were observed between connected pieces such as concrete panel, HPFRCC plate and anchorage. Since all the contact surfaces worked perfect and all dislocations were observed on concrete panel, all the contacts between pieces were defined as tie-constraint. According to definition of tie-constraint, the relative deformation between connected pieces are prevented.



a) Original specimens b) Concrete panel of specimens with and without anchorage

c) Anchorage d) Specimens with and without anchorage

Figure 7 Finite element models.

4. EXPERIMENTAL AND THEORETICAL RESULTS

4.1. Experimental Results

Experimental results are summarized in Table 4. As seen in this table, the behavior of all retrofitted specimens was improved in different extents, depending on the applied retrofitting scheme. In this table, shear strength, vertical strain for the achieved maximum loads and vertical strain corresponding at 85% of the maximum load on the descending branch are presented. In Table 4, the abbreviation CF is used for cleavage of panel at its middle vertical axis, DB1 is used for the loss of bond between HPFRCC and concrete causing peeling of concrete surface followed by cleavage of panel and CC is used for concrete crushing.

As it can be seen in Table 4, the shear strengths increased between 45 and 150% for HPFRCC retrofitted specimens. Enhancements in vertical strain correspond to the load level of 85% of the maximum load on descending branch of the load-vertical strain relationships are 34-780% for HPFRCC retrofitted specimens. It is important to note that no enhancement in strength is possible by only increasing the thickness of the HPFRCC panel, unless appropriate anchoring of the panel is made to the concrete specimen.

Load-vertical deformation relationships are presented in Figure 8 for evaluating global performances of specimens in terms of their load carrying and deformation capacities. As seen in this figure, retrofitting, not only increased load carrying and displacement capacities, but also enhanced the toughness characteristics. Deformation measurements showed that the horizontal tensile stresses were concentrated around the mid portion of the specimen. Horizontal strains were much smaller on the right and left sides of the specimen, like the horizontal strains at the top and bottom parts of the specimen.

Table 4 Test results.

Specimen	Failure mode	Maximum load (kN)	Shear strength (MPa)	Vertical strain at maximum load	Vertical strain at 85% of maximum vertical load on descending branch
DS-O-a	CF	104	1.73	0.0031	0.0032
DS-O-b	CF	113	1.86	0.0030	0.0031
DS-HPFRCC-2	DB1	155	2.60	0.0058	0.0062
DS-HPFRCC-2-A	DB1/CC	166	2.93	0.0113	0.0254
DS-HPFRCC-3	DB1	155	2.73	0.0042	0.0043
DS-HPFRCC-3-A	CC	228	4.02	0.0137	0.0281
DS-HPFRCC-4	DB1	155	2.69	0.0041	0.0043
DS-HPFRCC-4-A	CC	259	4.53	0.0181	0.0230

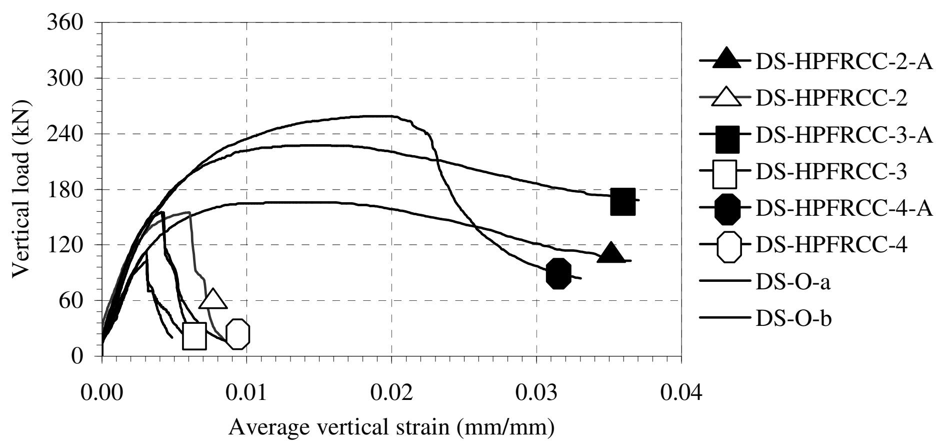


Figure 8 Comparison of vertical load-average vertical strain relationships for all specimens.

4.2. Comparisons of Experimental and Theoretical Results

A non-linear finite element analysis carried out using ABAQUS software confirmed the experimental findings related with the load carrying capacities. As it is seen in Table 5, the vertical load capacities of the specimens calculated using non-linear finite element analysis are in good agreement with experimental data. Figure 9 shows the good agreement of vertical load-vertical strain relationships obtained experimentally and theoretically for reference specimens. As seen in Figure 10, for the retrofitted specimens, although the initial parts of the experimentally obtained vertical load-vertical strain relationships are in good agreement with theoretical results, the other parts of the curves do not match. Consequently, it is clear that the finite element model for the retrofitted specimens need to be further developed.

Table 5 Vertical load capacities.

	P_{max} (kN)		
Specimens	Experiment	ABAQUS	ABAQUS/Experiment
DS–O–a	104	99.4	0.92
DS–O–b	113		
DS–HPFRCC–2	155	206	1.33
DS–HPFRCC–3	155	232	1.49
DS–HPFRCC–4	155	238	1.53
DS–HPFRCC–2–A	166	204	1.23
DS–HPFRCC–3–A	228	244	1.07
DS–HPFRCC–4–A	259	275	1.06
		Average	1.23

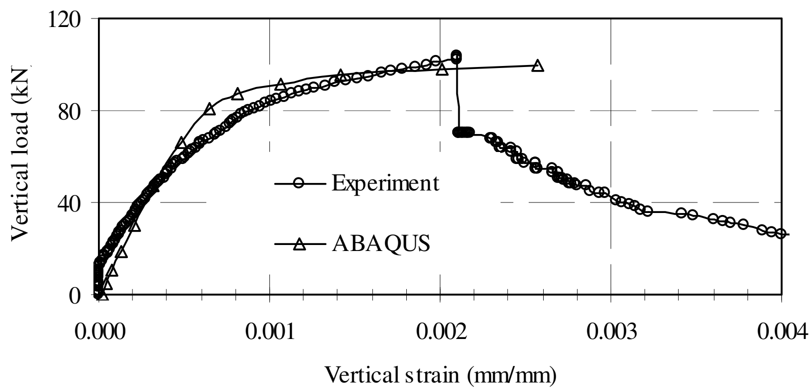


Figure 9 Vertical load-vertical strain relationships of reference specimen.

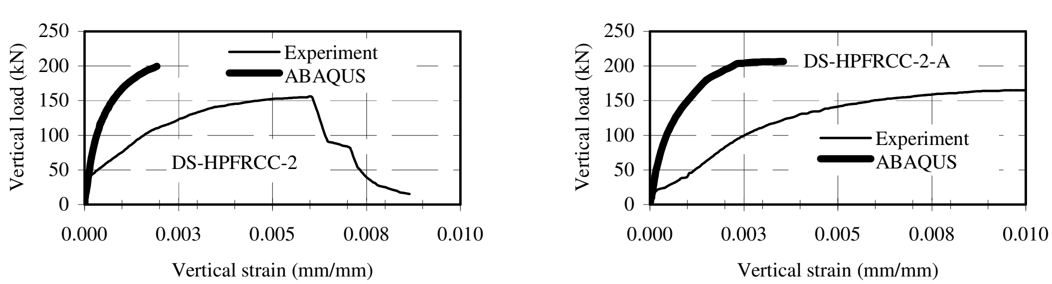


Figure 10 Vertical load-vertical strain relationships of retrofitted specimens with HPFRCC.

5. CONCLUSION

In this study, a new retrofitting technique through utilization of prefabricated HPFRCC panels that can be used for beam-column joint retrofitting is investigated by utilizing a simple testing method for experimental analysis. Low strength concrete diagonal panels were tested under diagonal tension before and after retrofitting with prefabricated HPFRCC panels. According to test results, remarkably higher shear strength and deformability were possible through this retrofitting application, particularly when the prefabricated HPFRCC panels were anchored to the concrete specimens properly. To predict experimental behavior of reference and HPFRCC retrofitted specimens, non-linear finite element analysis was carried out. Theoretical results were in agreement with experimental data in terms of strengths, while the vertical load–vertical strain relationships of the retrofitted specimens could not be predicted accurately.

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