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Concrete Repair, Rehabilitation and Retrofitting

Chapter 173. Comparing the behaviour of reinforced HSC beams with AFRP bars and confined HSC beams with AFRP sheets under bending

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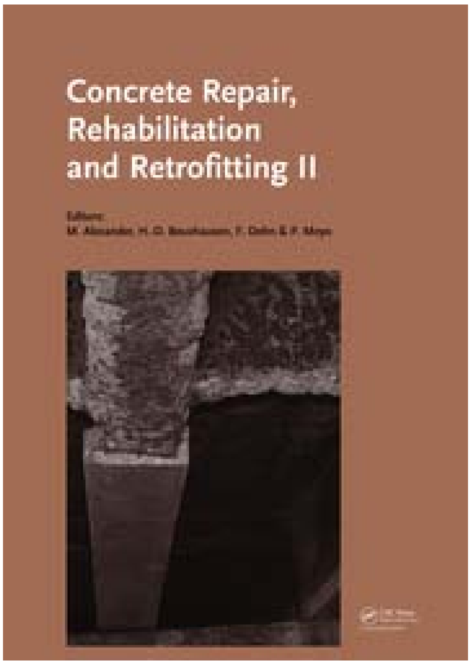

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Comparing the behavior of reinforced HSC beams with AFRP bars and confined HSC beams with AFRP sheets under bending

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ABSTRACT: By increasing the use of FRP composites in civil engineering, they seem highly essential to be studied. The purpose of the study is comparison of the behavior of AFRP reinforced HSC beams (reinforced with AFRP bars) and steel reinforced HSC beams which confined with AFRP sheets under bending. eighteen beams have been modeled with ANSYS. Three beams are HSC which reinforced with AFRP bars. After modeling, the results have been compared with experimental results and then software has been calibrated. Then twelve steel reinforced HSC beams which confined with AFRP sheets (with different number of laminates) have been modeled. In addition three simple steel reinforced HSC beams have been modeled as the base of comparison. At the end behavior of aforementioned beams has been compared and corresponding graphs have been sketched.

1 INTRODUCTION

Fiber-reinforced polymers (FRP) are using in the form of sheets or laminates to confinement and bars to reinforcement the concrete members. In both they have some advantages to steel jackets and steel bars. Steel is an isotropic material and its modulus of elasticity is high, thus the steel jackets stand the great part of axial forces which lead to buckling of steel. On the other hand, Poisson ratio of steel is greater then concrete, thus the two materials act separately. Corrosion and hard performance are the other problems of steel jackets. [1]

Although using the FRP bars as the main reinforcement isn't common yet, it seems they will play an important role as a main reinforcement. Fiber-reinforcement polymers (FRP) in the form of bars or sheets, usually made from one of the three basic types of fibers such as Aramid (AFRP), Carbon (CFRP), and glass (GFRP), represent one of the most promising new developments in the area of structural concrete. High strength, but lightweight fibers encapsulated in a polymer matrix possess non-corrosive, non-conducting, and nonmagnetic purpose structures. The non-corroding characteristics of FRP reinforcement could also significantly increase the service life of ordinary concrete structures. [2,7]

In the case of flexure, the very high strength FRP bars, which exhibit elastic response up to failure, could perhaps be effectively used in combination with high strength concrete (HSC). However the majority of reported research works (Cosenza et al 1997 [5]; Toutanji and Saafi 2000 [11]) dealt only with normal strength concrete ($f'_c \leq 41$ Mpa), while some other (Benmokrane et al. 1996 [12]; Masmoudi et al. 1998 [6]; Grace et al. 1998 [13]) considered concrete with maximum compressive strength (f'_c) of up to 70 Mpa. Only The'riault and Benmokrane (1998) [14] used concrete with (f'_c) as high as 100 Mpa. Some other researchers worked on the effect of confinement of RC beams (Dathinh and Starnes [4]). In this study behavior of HSC beams reinforced and confined with AFRP under bending have been compared. ANSYS 9 has been used for modeling the beams.

2 MODELING WITH ANSYS

ANSYS is suitable software for nonlinear analysis. Designing with ANSYS has three parts; preprocessor, solution, and postprocessor [8]. Between more than 100 elements exist in the software, concrete 65; link 8 and solid layer 45 have been used for modeling of concrete, bars or stirrups and sheets respectively. [9]

3 MODELED BEAMS AND MATERIAL PROPERTIES

18 HSC beams all 3 meters length (Fig.2) have been modeled. Three beams are in first group AF2, AF3, and AF4. In these beams tensile bars are AFRP bars but compressive ones are steel because compressive strength of AFRP is less than 20% of its tensile strength. The number in the names determines the number of tensile bars. As supplied by manufacturer the tensile strength and the modulus of elasticity of AFRP bars are 1760 Mpa and 53 Gpa, respectively. More properties of these beams are shown in table 1.

Second group has three beams too; ST2, ST3, and ST4. They have steel tensile bars and the number in the names determines the number of tensile bars. This group is the base group and the other groups' beams have been compared with these beam. Tensile strength and modulus of elasticity of steel are 533 Mpa and 2.1×10^5 Mpa respectively. More properties of these beams are shown in table 2.

The last group has twelve beams which have steel tensile bars and AFRP sheet(s) attached at the bottom of the beams. The tensile strength and modulus of elasticity of AFRP sheets are 2900 Mpa and 120 Gpa respectively. The third group name is SmCn. S and C imply Steel and Confine and m and n are two numbers that determine number of tensile bars and number of AFRP sheet layers respectively. More properties of these beams are shown in table 3.

All layers of AFRP have 0.3 mm thickness. All the compressive bars are steel. 26 steel stirrups have been distributed monotonously along the beams. Compressive strength of concrete (f'_c) has been considered 84.5 Mpa in all beams.

More details are shown in figure 2.

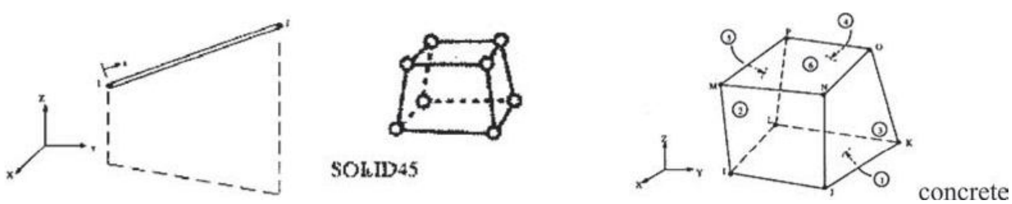

Figure 1. Used elements.

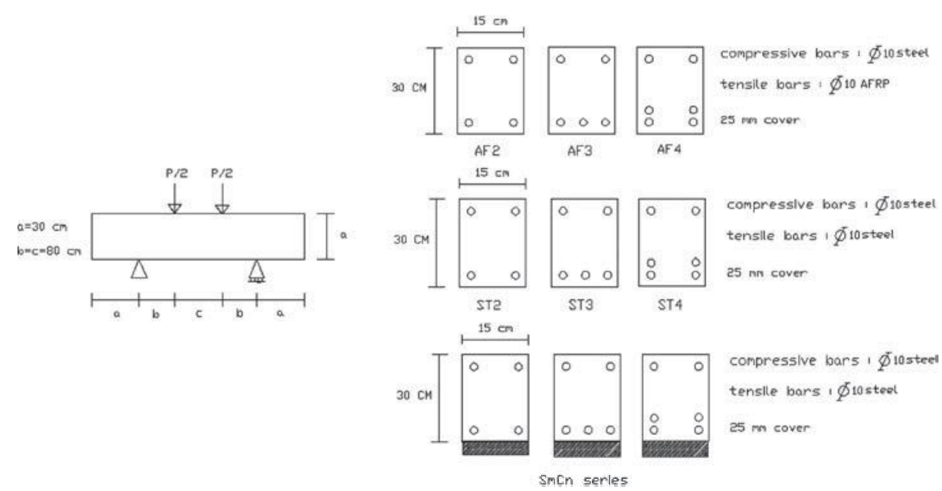

Figure 2. Modeled beams.

Table 1. First group properties.

	AFRP bars properties		Compressive steel bars properties		Concrete properties		
Name	Tensile strength(Mpa)	Modulus of elasticity(Mpa)	Yielding strength(Mpa)	Modulus of elasticity(Mpa)	Compressive strength(Mpa) f'_c	Modulus of elasticity(Mpa)	Tensile strength(Mpa)
AF2	1760	53000	533	2.1×10^5	84.5	45962	5.05
AF3	1760	53000	533	2.1×10^5	84.5	45962	5.05
AF4	1760	53000	533	2.1×10^5	84.5	45962	5.05

Table 2. Second group properties.

	Steel bars properties		Concrete properties		
Name	Yielding strength(Mpa)	Modulus of elasticity(Mpa)	Compressive strength(Mpa) f'_c	Modulus of elasticity(Mpa)	Tensile strength(Mpa)
ST2	533	2.1×10^5	84.5	45962	5.05
ST3	533	2.1×10^5	84.5	45962	5.05
ST4	533	2.1×10^5	84.5	45962	5.05

Table 3. Third group properties.

	AFRP bars properties			Steel bars properties		Concrete properties		
Name	Number of layers	Modulus of elasticity (Mpa)	Tensile strength (Mpa)	Yielding strength (Mpa)	Modulus of elasticity (Mpa)	Compressive strength (Mpa) f'_c	Modulus of elasticity (Mpa)	Tensile strength (Mpa)
S2C1	1	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S3C1	1	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S4C1	1	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S2C2	2	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S3C2	2	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S4C2	2	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S2C3	3	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S3C3	3	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S4C3	3	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S2C4	4	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S3C4	4	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05
S4C4	4	12×10^4	2900	533	2.1×10^5	84.5	45962	5.05

4 SOFTWARE CALIBRATION

Before modeling of main beams, two experimental results of beams compared with ANSYS results. It can help to check the software. AF-control beam is a represent of first group. It has AFRP bars as tensile bars and its experimental results have been shown by Rashid et al. [7]. (DF3T1).

Figure 3 compares the results of experimental and modeling beams. After the formation of great cracks, the software

Couldn't converge the equations and couldn't continue up to complete failure. STC-control beam is a represent of third group. It has steel tensile bars and a layer of FRP attached at the bottom. Its experimental results have been shown by Sader momtazi et al. [10]

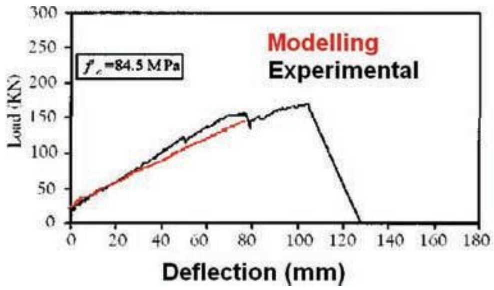

Figure 3. AF control beam.

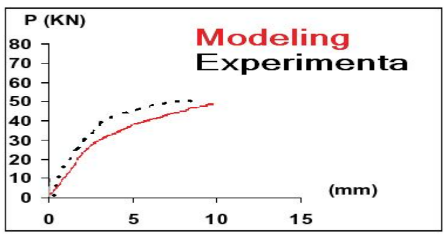

Figure 4. STC control beam.

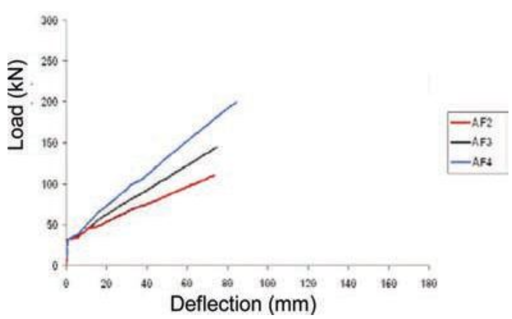

Figure 5. First group beams.

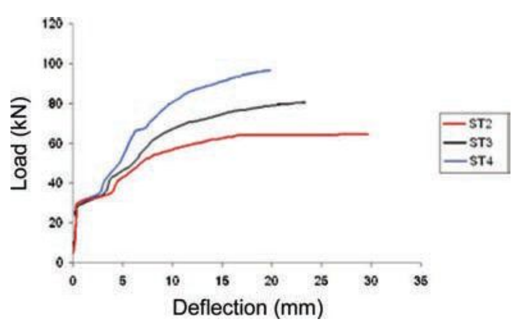

Figure 6. Second group beams.

(G1). Figure 4 compares the results of experimental and modeling beams.

5 COMPARING THE BEHAVIOR OF BEAMS

HSC beams which reinforced with AFRP exhibit elastic response up to failure. Figure 5 compares the response of AF2, AF3, and AF4 (First group). HSC beams which reinforced with STEEL exhibit non-linear behavior after yielding. Figure 6 compares the

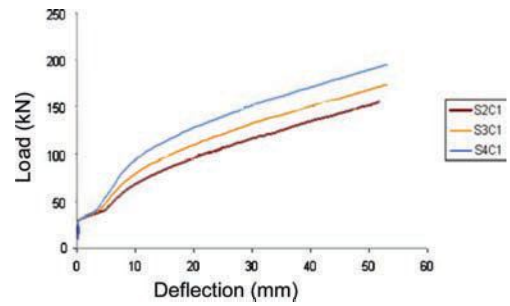

Figure 7. Third group with one layer.

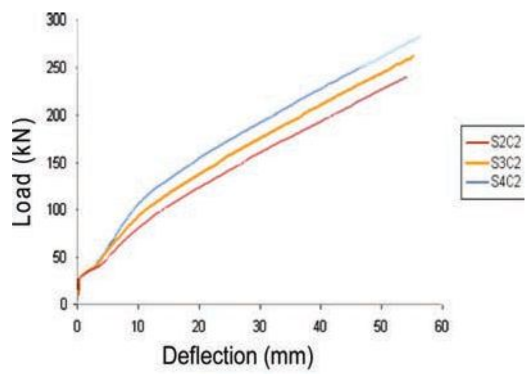

Figure 8. Third group with two layers.

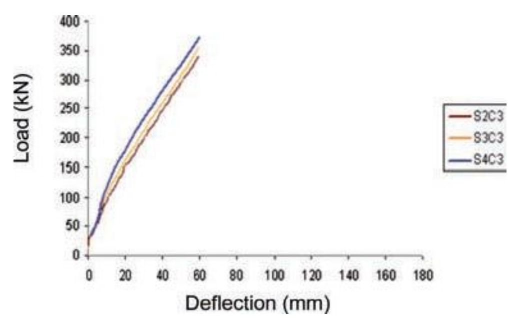

Figure 9. Third group with three layers.

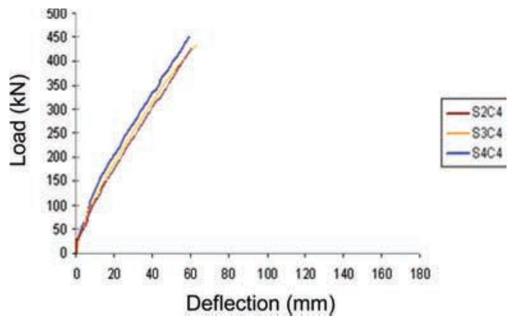

Figure 10. Third group with four layers.

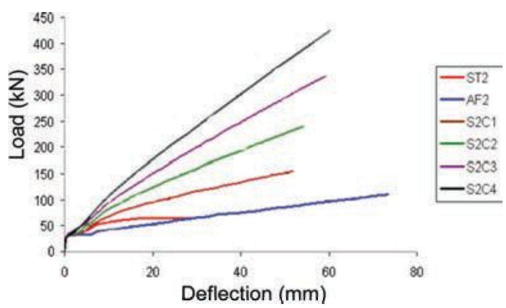

Figure 11. Beams with two tensile bars.

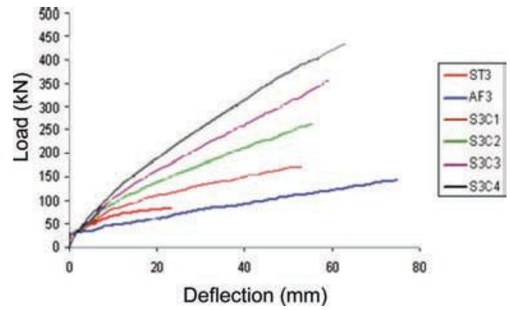

Figure 12. Beams with three tensile bars.

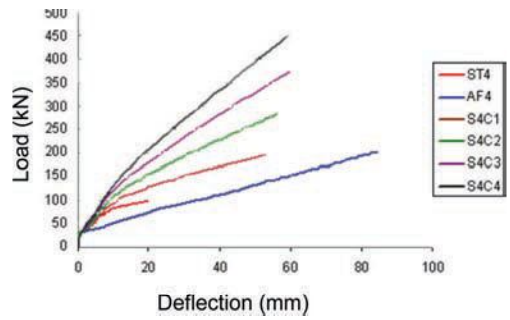

Figure 13. Beams with four tensile bars.

Table 4: Details of results.

Name	Tensile bars	AFRP layers	Compressive strength of concrete (f'_c) (MPa)	Maximum deflection (mm)	Ductility $(\mu = \frac{\Delta u}{y})$	Failure force (KN)	Increase of tensile bars effect on failure force (%)
ST2	STEEL	–	84.5	29.69	7.81	64.6	–
ST3	STEEL	–	84.5	26.35	8.78	80.5	24
ST4	STEEL	–	84.5	19.88	7.95	96.5	20
AF2	AFRP	–	84.5	73.37	–	110	–
AF3	AFRP	–	84.5	74.78	–	144	30
AF4	AFRP	–	84.5	84.62	–	200	39
S2C1	STEEL	1	84.5	51.73	10.34	155	–
S3C1	STEEL	1	84.5	53.03	13.25	174	12
S4C1	STEEL	1	84.5	53.09	17.69	195	12
S2C2	STEEL	2	84.5	54.17	12.03	240	–
S3C2	STEEL	2	84.5	55.29	18.43	261.8	9
S4C2	STEEL	2	84.5	56.28	23.312	282.2	7
S2C3	STEEL	3	84.5	59.40	14.85	338.2	–
S3C3	STEEL	3	84.5	59.21	19.73	355.77	5
S4C3	STEEL	3	84.5	59.70	23.88	373.52	5
S2C4	STEEL	4	84.5	60.27	17.22	425	–
S3C4	STEEL	4	84.5	62.97	25.18	434.1	2
S4C4	STEEL	4	84.5	59.18	29.59	450	3

response of ST2, ST3, and ST4 (second group). Comparing the behavior of third group beams is shown in figures 7, 8, 9, 10 which show third beams with one, two, three and four AFRP covering layers respectively.

Figure 11, 12 and 13 show the comparing of beams with 2, 3 and 4 tensile bars respectively. More details of results are shown in table 4.

6 CONCLUSIONS

1. Beams reinforced with AFRP bars (first group) have linear behavior up to failure. Their fracture is in brittle manner that can be a disadvantage but They have large deflection before failure which can be a caution.
2. Maximum deflection in HSC beams covered or reinforced with AFRP is higher than HSC beams reinforced with steel bars. Furthermore increase the number of bars.
   Furthermore increasing the number of tensile bars increases the Maximum deflection tensile bars increases the Maximum deflection of AFRP reinforced and covered beams (first and third groups) but decreases it in steel reinforced beams second group).
3. Failure force of AFRP reinforced and covered HSC beams are much higher than steel reinforced. Effect of tensile bars increasing on failure force in AFRP reinforced HSC beams is higher than AFRP covered and steel reinforced ones, furthermore it would be increased by increasing the number of tensile bars in first group and be decreased by increasing the number of bars in second and third groups.
4. Failure force in AFRP reinforced HSC beams is less than even one layer AFRP covered HSC beams.
5. Failure forces in third group are higher than first group and in all cases their maximum deflections are less than first group. Furthermore in third group effect of tensile bars increasing on failure force is less than the other groups. The mentioned effect become less and less when the number of AFRP layers increased because higher amounts of load are bearing by AFRP covers and number of tensile bars has less effect.
6. HSC beams with AFRP covers (third group) have higher ductility than uncovered beams (second group). Ductility factor (μ) increases by increasing the number of AFRP covers.

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