A Study on the Maximum Flexural Strength of RC Beams with Steel Rebars and CFRP Bars by Using FEM Analysis

Nihon University JSCE Member Ming-Chien HSU
Nihon University JSCE Member Tetsukazu KIDA
Nihon University JSCE Member Tadashi ABE
Nihon University JSCE Member Toshiaki SAWANO
National Taipei University of Tech. University (Taiwan) Yeou-Fong Li

1. Introduction

Over the years, RC structures become damaged by natural weather, earthquake, and overloading. The most critical effects to the RC structures are chloride contamination and corrosion of rebars, which mostly affect the steel rebars in the RC structures. Therefore, finding a substitute material for the steel rebars is one of the focuses of researchers. The new material of fiber reinforced plastic (FRP) has been considered one of the best substitute materials since it has anti-corrosion, lightweight, as well as high strength and high elastic modulus properties. In this paper, the authors used CFRP bars as the reinforcement at the tensile side of the RC beams [1] instead of steel rebars. The maximum flexural strength of the RC beam with CFRP bars and its comparison with regular steel rebar RC beams were calculated in this paper. In the end, the finite element method (FEM) is proposed for future study.

2. Preparation of Experimental Specimens

2.1 Materials used for experimental specimens: Normal concrete with the compression strength of 22.45 N/mm^2 was used for the RC beams in the experiment. D16 was used as the main steel rebars and D10 was used as the stirrup steel rebars. The CFRP bars, similar in size to D10 steel rebars, were used in the tensile side of the RC beams. The properties of concrete, steel rebars and CFRP bars are shown in Table 1 and Table 2[1].

2.2 Specimen size and steel rebar arrangement: The RC beams were 180×220×1350 mm in size. The steel rebar were arrangeed wtih two D16 located at the tensile side and two D16 located at the compression side. The D10 stirrup steel rebars were included in the RC beams with a distance of 80 mm between each other. However, the stirrup steel rebars were not placed within a 300 mm range at the center of the RC beams. Fig. 1 (a) shows the dimensions and steel rebar arrangements of the RC beams.

For RC beams with CFRP bars, the dimensions and rebar arrangement of RC beams were the same as the RC beam with steel rebars. However, the tensile side was replaced by two CFRP bars. Fig. 1 (b) shows the dimensions and steel rebar arrangements of the RC beams' with CFRP bars.

Hereafter, the RC beams with steel rebars were named N-S2S2, and the RC beams with CFRP bars were named N-C2S2. The N indicates the normal concrete. The numbers indicate the number of rebars located at the tensile side and the compression side.

2.3 Experimental method: The static load experiment was carried out so that the loading area was 300×180 mm at the center of the span, the point where the maximum bending strength occurs. The load was increased until the experimental specimens failed.

3. FEM Analysis

The models for the RC beams were half of the original RC beams' size in 3-D model by the FEM program Diana [2]. The modeling property for the concrete, the steel rebars and CFRP bars were done in the laboratory mostly. However, for the unknown properties, some of the concrete properties were adopted from the specification for concrete structures in Japan [3]. Moreover, the rebar modeling for both steel and CFRP were fully bonded in the models. Fig. 2 shows the properties of the concrete, steel rebars, and CFRP bars. Furthermore, the plasticity used for the concrete was Drucker-Prager [2]. The steel rebars' plasticity was Von Mises [2].

4. Maximum Flexural Strength

The failure condition and results are list in Table 3. Fig. 3 shows the experimental and FEM results.

4.1 Experimental results: For steel rebars N-S2S2-1 and N-S2S2-2, the RC beams had the maximum flexural strength of 137.79 kN and 172.27 kN, respectively. The failure conditions were bending failure and shear failure for N-S2S2-1 and N-S2S2-2, respectively.

For CFRP bars, the RC beams N-C2S2-1 and N-C2S2-2 had the maximum flexural strength of 108.00 kN and 117.46 kN, respectively. The failure conditions were bending failure for N-C2S2-1 and N-C2S2-2, respectively.

4.2 FEM results: For steel rebars, the RC beams N-S2S2

Key words: RC beams, CFRP bars, Steel rebars, and maximum flexural strength.
Address: 1-2-1 Izumi-Chou, Narashino-Shi, Chiba, 275-8575, Japan; Civil Engineering Dept., College of Industrial Tech., Nihon University; Tel: 047-474-2460

had the maximum flexural strength of 117.00 kN. For CFRP bars, the RC beams N-C2S2 had the maximum flexural strength of 98.00 kN.

5. Conclusion

Comparing the experimental results with the FEM results, the maximum experimental flexural strengths of Specimens N-S2S2-1 and N-S2S2-2 were 18% and 47% greater than the FEM results, respectively. Similarly, the maximum experimental flexural strengths of Specimens N-C2S2-1 and C-C2S2-2 were 10% and 20% greater than the FEM results, respectively. As seen from Fig. 3, the FEM results show that the FEM calculations have similar pattern as the experimental results. In other words, the FEM input parameters should be reconsidered again and the interface alone the rebars should be included in future studies.

Table 1 Concrete and steel rebar properties

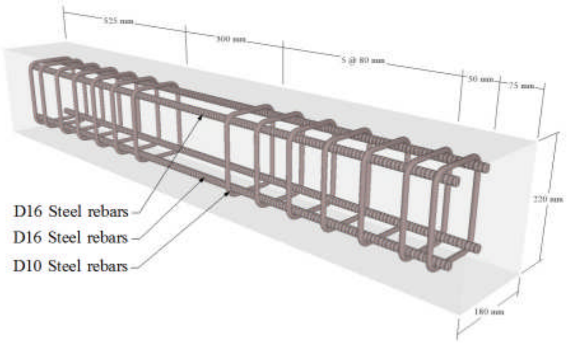
Test specimen	Concrete: Compressive strength (N/mm^2)	Concrete: Young's modulus (N/mm^2)	Steel rebar (SD295A / D16): Yield strength (N/mm^2)	Steel rebar (SD295A / D16): Young's modulus (kN/mm^2)
N-S2S2 N-C2S2	22.45	5600	395.71	200

Table 2 CFRP rebar's properties

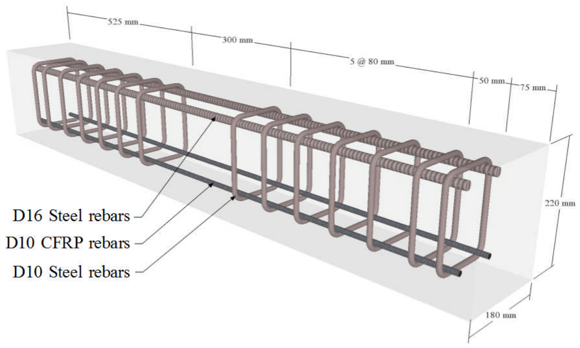
Name of CFRP	Cross Section (mm^2)	Tensile strength (N/mm^2)	Young's modulus (kN/mm^2)
CFRP re-bars	72.48	854.72	92.12

Table 3 Maximum flexural strength and failure condition

Specimen	Rebars arrangement	Maximum flexural strength (kN): Experiment	Maximum flexural strength (kN): FEM	Experiment / FEM	Failure Condition
N-S2S2		137.79	117.00	1.18	Bending
		172.27		1.47	Shear
N-C2S2		108.00	98.00	1.10	Bending
		117.46		1.20	Bending



(a) Steel rebars (N-S2S2)



(b) CFRP bars (N-C2S2)

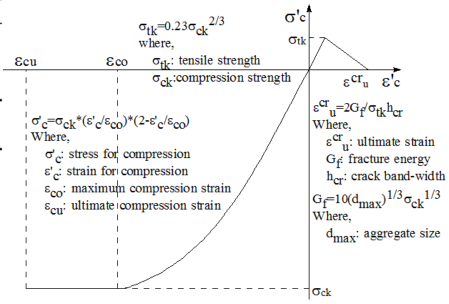
Fig. 1 The dimension and rebars arrangement of RC beams [1]

References:

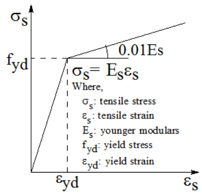
[1] Yeou-Fong LI, Chih-Tsung LIN, Wen-Chen JAU, Kuo-Shuan LO: A Feasibility Study on the Flexural RC Beams Us GFRP Rebars as Main Reinforcement, Structural Engineering (Taiwan), Vol. 22, No. 4, pp. 113-128. (Dec. 2007)

[2] DIANA Finite Element Analysis User's Manual, TNO Building and Construction Research.

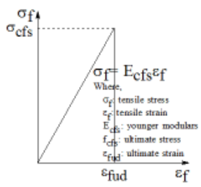
[3] Japan Society of Civil Engineers: Standard Specifications for Concrete Structures - 2002, Structural Performance Verification. (2002)



(a) Concrete

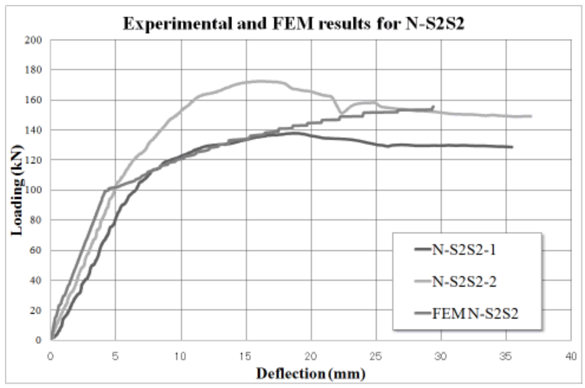


(b) Steel rebars

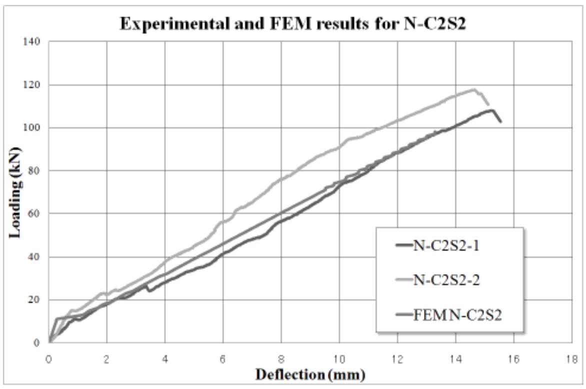


(c) CFRP bars

Fig. 2 The constitutive models for FEM analysis [3]



(a) Steel rebars (N-S2S2)



(b) CFRP bars (N-C2S2)

Fig. 3 The comparison between the experimental and FEM results