

Numerical Study on Section Constitutive Relations of Members Reinforced by Steel-BFRP Composite Bars

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Abstract. Steel-Basalt FRP Composite Bar (S-BFCB) is a new kind of substitute material for longitudinal reinforcement, with high elastic modulus, stable post-yield stiffness and excellent corrosive resistance. Based on mechanical properties of S-BFCB and the plane cross-section assumption, the moment-curvature curves of beam and column members are simulated. Some parameters such as equivalent rebar ratio, postyield stiffness, concrete strength and axial compression ratio of column were discussed. Results show that the constitutive relation of the cross section is similar with RC member in elastic and cracking stages, while different in post-yield stage. With the increase of postyield stiffness ratio of composite bar, the ultimate bearing capacity of component improved observably, member may turn out over-reinforced phenomenon, concrete crushing may appear before the fibers are fractured. The effect of concrete strength increase in lower postyield stiffness ratio is not obvious than in higher. The increase of axial compression ratio has actively influence on bearing capacity of column, but decreases on the ductility.

1. Introduction

Traditional reinforced concrete structure suffering an earthquake is characterized by rapid increase of deformation, essentially constant bearing capacity and secondary stiffness close to zero in yielding stage. The structure gets damaged rapidly with high residual plastic deformation in this stage, thus hard to be repaired after earthquake.

For the purpose of achieving the earthquake fortification goal that buildings do not fall down after a major earthquake or are repairable after a medium earthquake, Chinese and overseas scholars have investigated a lot to ensure the concrete structure to have a stable secondary stiffness and control the residual deformation after an earthquake. Such researches include tactfully mixing unbonded reinforcement with bonded reinforcement for use [1], applying a prestress on bridge piers [2], using CFRP bars for column bases [3] and using high strength reinforcement to strengthen concrete frames [4]. In recent years, fiber reinforced polymer (FRP) bars are a competitive option in civil engineering. The use of FRP reinforcement is attractive for structures that operate in aggressive environments, such as in coastal regions, or for buildings that host magnetic resonance imaging (MRI) units or other equipment sensitive to electromagnetic fields [5]. FRP has high strength, a low elastic modulus, poor ductility and good durability, while steel is the opposite. Combining the advantages of the two materials is expected to have outstanding comprehensive properties. A hybrid rod made with fiber-reinforced polymer (FRP) skin over a steel core was first proposed by Nanni et al. (1993) [6] to achieve good anti-corrosion performance for concrete beams. Based on the abovementioned research, a new kind of hybrid rebar named Steel-fiber Composite Bar was proposed by Wu et al. (2010) [7] (Figure 1). S-BFCB is a kind of longitudinal bar wrapped by fiber reinforced polymer (FRP) in



longitudinal direction, which is a compound of elastic-plastic steel and linear elastic FRP with stable postyield stiffness [8-10].

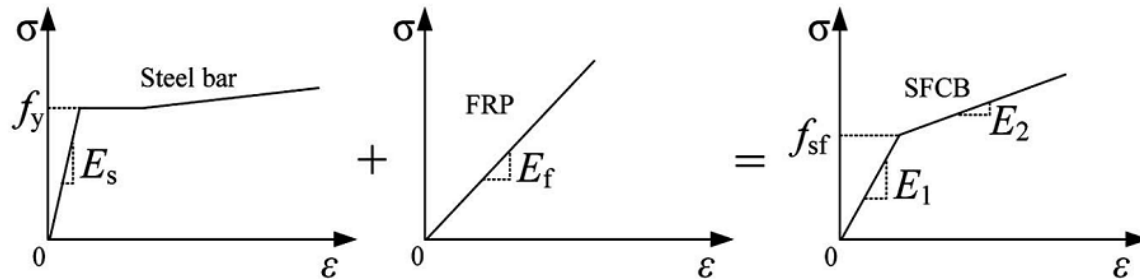


Figure 1. Stress-strain relation of Steel and FRP

2. Material constitutive relation model

Steel-Basalt FRP Composite Bar (S-BFCB) is a material of tension and compression asymmetry constitutive relation [11]. Relevant program is compiled by OpenSees software open platform, concluding the proposed S-BFCB tension and compression asymmetry material constitutive relation. The moment-curvature curve of beam and column is simulated, S-BFCB member is compared with RC member by equal stiffness and strength principle and some parameters such as concrete strength are also discussed.

2.1. Constitutive relation of bars

This paper adopts the reinforcingsteel01 material as the steel constitutive model, its tensile model is Chang and Mander model. It is completed by defining the steel yield point, harden point position, hardening stiffness and strength of the limit point. For composite bar concrete members, composite bar is divided into steel bar and FRP to simulate respectively, which is used in FRP and linear elastic elements.

2.2. constitutive relation of concrete

For the constitutive relation of the cross section, concrete constitutive relation is divided into the core concrete bounded by stirrups and concrete of protective layer. Concrete constitutive relation uses the concrete02 material, which seeks a balance between simplified and the precision. This paper adopts the correction of Kent - Park model [12].

3. Moment-curvature curve of beam

Material and geometrical parameters are as follows: the cross section size of beam is 300 mm * 200 mm, compressive and extensive strength standard values of C30 concrete are $f_{ck} = 20.1 \text{ MPa}$ and $f_{tk} = 2.01 \text{ MPa}$. Yield strength and ultimate strength of steel bar are 400 MPa and 540 MPa, and the corresponding strains are 0.002 and 0.08 respectively. The ultimate strength of Basalt fiber is 1540 MPa and nominal yield and ultimate strains are $\varepsilon_{sfy} = \varepsilon_y = 0.002$ and $\varepsilon_{sfu} = 0.022$.

In Figure 2, the bearing capacity of S10B20 and S10B138 is more than S10 beam due to the fiber, S10B20 beam is correspond to S12 beam by the equal-strength principle design while S10B138 beam is correspond to S12 beam by the equal-stiffness principle design. In the pre-yield stage, stiffness is relatively consistent, but the bearing capacity of S10B138 beam improved significantly while the section ductility is not significantly lower.

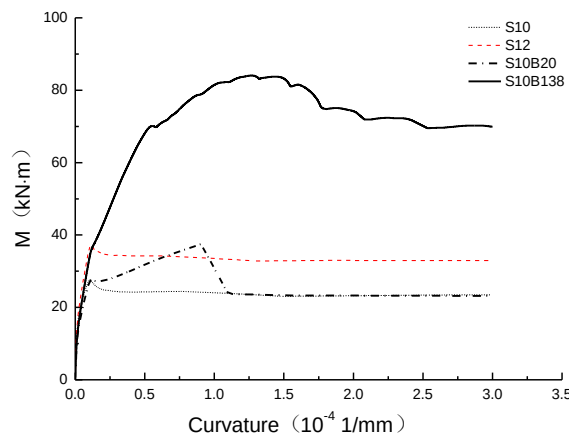


Figure 2. M- ϕ relationship of RC and S-BFCB concrete beam

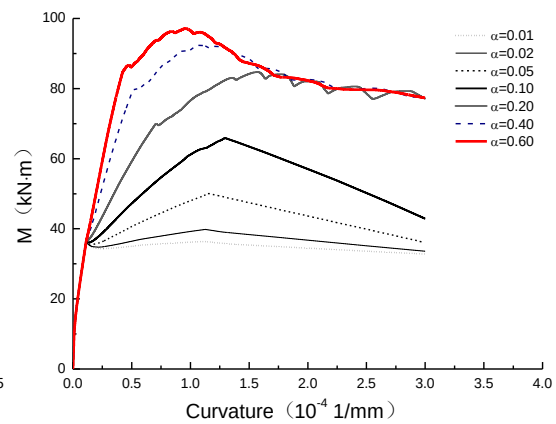


Figure 3. M- ϕ curve of beam in different stiffness ratio

Parameter α in Figure 3 is the reinforcement materials elastic modulus ratio of post yield to pre-yield, with the range from 0.01 to 0.60. The ultimate bearing capacity improved obviously with the increment of parameter α .

4. Moment-curvature curve of column

Material and geometrical parameters of column are as follows: section size is 300 mm $\times$ 300 mm, concrete compressive strength and tensile strength standard values of C30 are $f_{ck} = 20.1 \text{ MPa}$ and $f_{tk} = 2.01 \text{ MPa}$, axial compression ratio of column is 0.2. The material mechanics performance of steel, basalt fiber and composite bars equal to the value of beam section.

Contrast curve in Figure 4, S10B24 column is correspond to S14 column by the equal-strength principle design while S10B163 column is correspond to S14 column by the equal-stiffness principle design. In the pre-yield stage, stiffness is relatively consistent, but the bearing capacity of S10B163 column improved significantly while the section ductility is not significantly lower. In Figure 5, it shows that with the increases of axial compression ratio from 0 to 0.6, the bearing capacity of S12B24 column improves obviously but the ductility of column members is reduced.

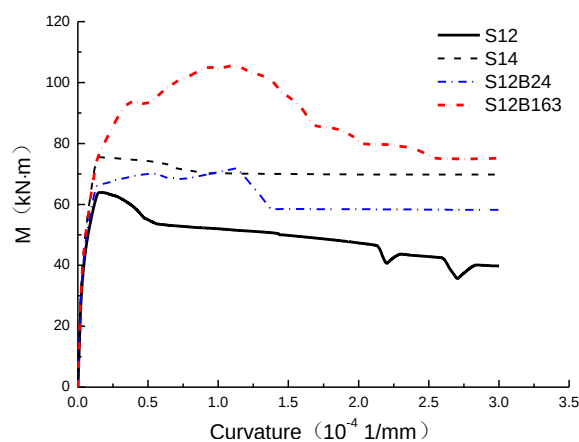


Figure 4. M- ϕ curve of RC and S-BFCB column

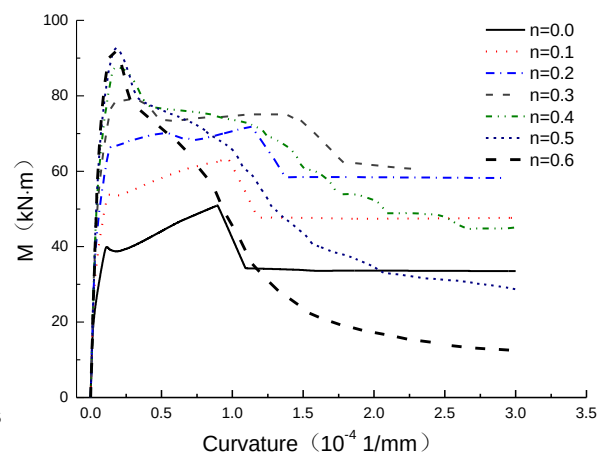


Figure 5. M- ϕ curve of column in different axial compression ratio

In Figure 6, with the increase of parameter α from 0 to 0.60, M- φ curve of column is similar with the curve of beam, but when reach the ultimate compressive strain of concrete, the effect of bearing capacity improvement is limited and the decline period is coincide. With the increase dosage of fibers, column may appear the phenomenon of overreinforced, concrete crushing may occur before fiber being pulled break. Figure 7 shows that with the improvement of concrete strength, the ultimate bearing capacity of S10B24 column improves not obvious.

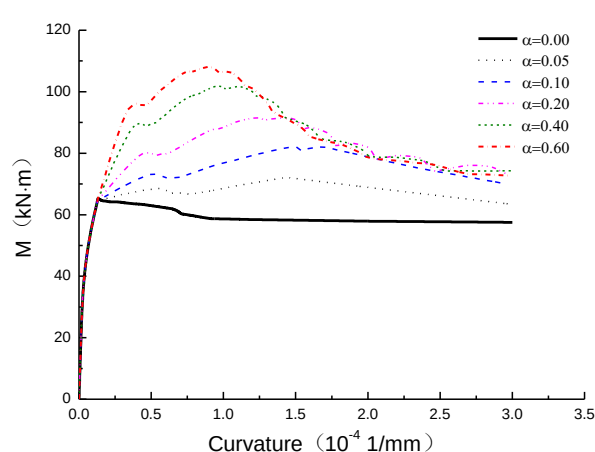


Figure 6. M- φ curve of column in different postyield stiffness

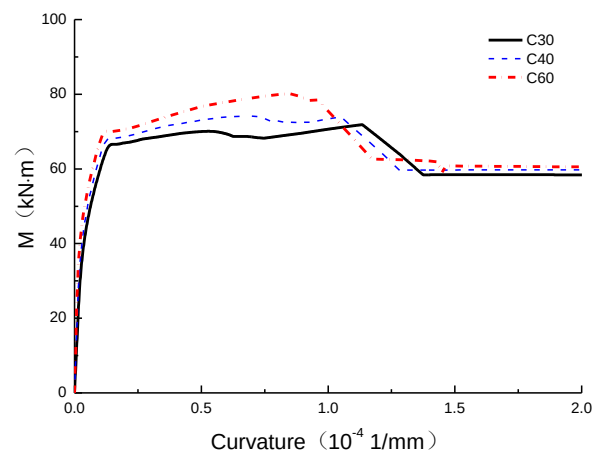


Figure 7. M- φ curve of column in different concrete strength

By the contrast of numerical simulation in this paper, secondary stiffness of composite reinforcement material improve the bearing capacity of composite reinforced concrete members, but the performance of the composite reinforced concrete member not only depends on the composite reinforcement material, but also related to the strength of the concrete. Blindly increase the secondary stiffness reinforced materials need more basalt fiber, the member design should be considered not only the ratio of reinforcement and fiber, but also concrete strength index, to ensure the best comprehensive performance.

5. Summary

From the comparison of data, the conclusion in this paper is confirmed as follows:

Based on mechanical properties of S-BFCB and the plane cross-section assumption, the moment-curvature relationship of beam and column members have been analyzed by numerical simulation. The relationship relevant to some parameters such as equivalent rebar ratio, postyield stiffness, concrete strength and axial compression ratio of column were discussed. Results show that the constitutive relation of the cross section is similar with RC member in elastic and cracking stages, while different in post-yield stage. With the increase of postyield stiffness ratio of composite bar, the ultimate bearing capacity of component improved observably, member may turn out overreinforced phenomenon, concrete crushing may appear before the fiber is snap. The effect of concrete strength increase in lower postyield stiffness ratio is not obvious than in higher. The increase of axial compression ratio has actively influence on bearing capacity of column, but decreases on the ductility. S-BFCB has good prospects for engineering applications.

6. Acknowledgements

The authors would like to acknowledge financial support from the National Natural Science Foundation of China (No. 51078077), the National Science and Technology Pillar Program during the 12th Five-Year Plan Period (2012BAJ14B02) and Nanjing Institute of Technology Foundation of China (No. YKJ201511).

References

- [1] Iemura H, Takahashi Y, Sogabe N. Two-level seismic design method using post-yield stiffness and its application to unbounded bar reinforced concrete piers [J]. *Structural Engineering/Earthquake Engineering, JSCE*. 2008, **23(1)**: 109s-116s.
- [2] Ou, Y C, Chiewanichakorn M, Aref A J, et al. Seismic performance of segmental precast unbounded posttensioned concrete bridge columns [J]. *Journal of Structural Engineering, ASCE*, 2007, **133**: pp 1636-1647.
- [3] Xie X, Bu Z Y. Elementary study on usefulness of carbon fiber for controlling bridge pier seismic damage [J]. *Journal of Zhejiang University (Engineering Science)*. 2005, **(10)**: pp 131-137. (in Chinese)
- [4] Zhang X, Wei H, Ye L P. Experimental study on seismic performance of RC frames reinforced with high-strength steel [J]. *China Civil Engineering Journal*. 2009, **(05)**: 74-78. (in Chinese)
- [5] Hany Jawaheri Zadeh, Antonio Nann. Design of RC Columns Using Glass FRP Reinforcement. [J]. *Journal of Composites for Construction*, **17**, No. 3, June 1, 2013.
- [6] Nanni A. Flexural behavior and design of RC members using FRP reinforcement. [J] *Structure Engineering*, 1993; **119(11)**: pp 3344-3359.
- [7] Wu G, Luo Y B, Wu Z S, Hu X Q, et al. Experimental and theoretical studies on mechanical properties of steel-FRP composite bars (SFCB) [J]. *China Civil Engineering Journal*. 2010, **43(3)**: pp 53-61. (in Chinese)
- [8] Luo Yun-biao. Performance Study on Steel Fiber Composite Bars and Its Strengthened Concrete Structure [D]. *Master's Degree Thesis of Southeast University*, Nanjing, 2008. (in Chinese)
- [9] Sun ZY, Wu G, Wu ZS, et al. Seismic behavior of concrete columns reinforced by steel-FRP (fiber-reinforced polymer) composite bar. *J Compos Constr* 2011; **15(5)**: pp 696-706.
- [10] SUN Zeyang, XIAO Wenchao, WU Gang, et al. Preliminary Study on Moment-curvature Behavior of Concrete Beams Reinforced by Steel-Fiber Reinforced Polymer Composite Bars [C]. *The 9th national construction engineering application of FRP academic communication*: 2015:5. (in Chinese)
- [11] Xiao Tongliang, Qiu Hongxing, Sun Lanxiang. Experimental and Theory Study on the Basic Tensile and Compression mechanical properties of Steel-Basalt Fiber Composite Bars, *Journal of southeast university (Natural science edition)*, 2014, **44(4)** pp 805-810. (in Chinese)
- [12] Scott B D, Park R, Priestley M J N. Stress-strain behavior of concrete confined by overlapping hoops at low and high strain rates [J]. *ACI Journal*, 1982, **79(1)**: pp 13-27