Study on shear behavior of FRP strengthened concrete beams

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Abstract. There are many researches on concrete bending beams reinforced with FRP, and the beam section of the bending strength is enhanced, it is necessary to carry out an oblique section bearing capacity review, if the bearing capacity is insufficient, it is also necessary to strengthen, so as to ensure the ductility of the beam and meet the needs of Engineering safety. In this paper, four concrete beams strengthened with different fibers (CFRP, HFRP and GFRP) were used to study the stress characteristics, failure forms, reasonable reinforcement methods, beam strain conditions, bearing capacity, stiffness and deformation capacity of shear behavior of concrete beams strengthened with different fibers and different forms of reinforcement. The experimental results showed that the FRP reinforcement can not only improve the shear bearing capacity and ultimate deformation of beam, but also increase the stiffness of the beam, reduce the bending deformation under the same load beam, and delay the extension of diagonal cracks.

1. Shear Test of FRP Strengthened Reinforced Concrete Beams

1.1. Introduction

When FRP material is used to reinforce RC beams, the FRP sheet is attached to the bottom of the beam for bending reinforcement. On the other hand, FRP can be applied to the beam side for shear reinforcement. In many practical projects, there is a shortage of the shear bearing capacity of beam oblique section and the beam need to be strengthened due to the reasons of low strength, insufficient amount of stirrup, use load increase, structural system change. If the bending strength of the beam is enhanced, it is necessary to carry out the recheck of the bearing capacity of the oblique section. If it is insufficient, it also needs to be reinforced so as to ensure the ductility requirement of the beam and meet the engineering safety requirements.

1.2. Experimental study on shear behavior of concrete beams reinforced with FRP

In the experiment, four specimens were tested, all of which had the same shape. Reinforcement with FRP used a total of four sheets and the basic mechanical properties of FRP showed in Table 1. Specimen reinforcement details showed in Figure 1. FRP of C-C1, C-CG have the same U strip width and spacing and the width and spacing of C-C2 U strip is slightly dense.

Figure 1. Specimen reinforcement details. Figure 2. Experimental setup and details.
Table 1. The basic mechanical properties of FRP.

| No. | Reinforcement ratio | Reinforcement method | Fiber fraction | Remarks |
|-----|---------------------|----------------------|----------------|---------|
| C-1 | 0.31                | Not reinforced       | 0              | contrast|
| C-C1| 2 layers CFRP sheets(C1), 120 mm in width, 4 | 0.29         | |
| C-C2| 2 layers CFRP sheets(C2), 100 mm in width, 5 | 0.32         | |
| C-CG| 1 layers CFRP sheets(C1), 1 layers GFRP sheets(G1), 120 mm in width, 4 | 0.70         | |

The method of the counter force frame upside down hydraulic jack was taken in the test and the loading method was single point loading at the top of the beam span controlled by the sensor. Experimental setup and details of test was showed in Figure 2. When the concrete was crushed or the fiber was broken, the test was terminated.

2. Test results and analysis

2.1. Destructive form
Due to the fact that the C-1 beam was not reinforced, it occurred a typical shear stress failure. The failure process of the three reinforcement members was largely the same. When the critical oblique fracture extended toward Intersection of the loading point and the fiber strip, the U-shaped strip began to peel away from the upper end as the load increasing. Finally, the entire side was completely peeled off, the concrete was crushed at the loading point and the components were destroyed. The reason of the fiber strip stripping wasn't that the bond surface was destroyed, but it occurred shear failure between the concrete protection layer and the core concrete.

2.2. The load displacement curve of component
The load displacement curves of the four components measured in the test are plotted as shown in figure 3. The following conclusions can be drawn from the diagram:
1) In addition to C-CG, the ultimate load and displacement of FRP strengthened members are significantly improved compared with those of the corresponding members.
2) The stiffness of FRP strengthened members is obviously higher than that of the contrast members.
3) Reinforcement with relatively narrow and dense form have the best effect.[1]

![Figure 3. Beam lord-span displacement.](image)

2.3. Bearing capacity
As shown in Table 2, the shear capacity of the C-C1 beam and the C-C2 beam increased by 31% 55% respectively and the fiber strength and elastic modulus of C2 are both lower than that of C1. So U-shaped fiber strips using narrow and dense paste form to improve the carrying capacity is more effective.[1]
Table 2. Comparison of ultimate load (Pu) and shear capacity (Mu) of beam.

| No. | C-1   | C-C1  | C-C2  | C-CG  |
|-----|-------|-------|-------|-------|
| $P_u$ (kN) | 55.0  | 72.0  | 85.0  | 50.0  |
| $M_u$ (kN·m) | 55.0  | 72.0  | 85.0  | 50.0  |
| Increase ratio | -     | 31%   | 55%   | -9%   |

2.4. Deformation capacity
As can be seen from Table 3, although the mechanical property of C2 is lower than that of C1, the limit displacement of C-C2 is larger than that of C-C1. It is obvious that the U shaped fiber strip is more effective in the improvement of the limit displacement by the narrow and dense paste method.

Based on the above test results, the shear-strengthened FRP strip is most likely to be stripped and damaged without effective anchoring measures. When the reinforcement fails, the fiber bar is intact, and the material fails to play its full role. Therefore, reasonable anchoring measures should be taken.

Table 3. Comparison of the beam ultimate displacements.

| No. | C-1   | C-C1  | C-C2  | C-CG  |
|-----|-------|-------|-------|-------|
| Ultimate displacement (mm) | 2.70  | 3.63  | 3.97  | 2.52  |
| Increase ratio | -     | 34%   | 47%   | -6.7% |

3. Shear capacity analysis of beam oblique section
The ultimate failure sign of FRP shear strengthening of concrete members is that the concrete in the compression zone is crushed. But before this happens, fiber stripe may occur stripping damage or be pulled off and the efficiency of the later is higher than that of the former. That means that the effect of reinforcement is entirely dependent on the effective strain of the fiber bars when the member is damaged.

Failure form I: The strips used for shear reinforcement were stripped and gradually out of work, the critical inclined crack develops rapidly, the concrete in the shear zone is crushed and the member is destroyed.

Failure form II: The fiber strips used for shear reinforcement were pulled off, the critical inclined crack develops rapidly, the concrete in the shear zone is crushed and the member is destroyed.

4. Comparison shear capacity of beam between calculated value and experimental value
The test beams C-C1 and C-C2 were calculated and compared with the experimental results. The value of $V_f$ is the shear capacity that FRP can provide when the failure form II happens but the failure form of the two components is failure form I in the experiment, the reaction of calculated values $V_f$ is that the shear capacity of FRP can be provided when fiber stripe occur stripping damage. The ratio of the two components shows the effectiveness of the fiber when the test strip is stripped under the anchoring conditions of the test member. According to the comparison results, it is better to use the relatively narrow and dense paste arrangement to enhance the anti-stripping strength of FRP.

5. Conclusion
The following conclusions can be drawn through the experimental analysis and comparison:

1) The FRP reinforcement can not only improve the shear bearing capacity and ultimate deformation of beam, but also increase the stiffness of the beam, reduce the bending deformation under the same load beam, and delay the extension of diagonal cracks.

2) The ultimate failure sign of FRP shear strengthening of concrete members is that the concrete in the compression zone is crushed. But before this happens, fiber stripe may occur stripping damage or be pulled off and the efficiency of the later is higher than that of the former. That means that the effect of
reinforcement is entirely dependent on the effective strain of the fiber bars when the member is damaged.  
3) In order to improve the effective strain and shear reinforcement efficiency of FRP, some effective anchoring measures should be taken at the fiber ends.  
4) The shear reinforcement effect is relatively good with the form of using relatively narrow and dense fiber paste.[1]

Acknowledgement
The authors acknowledge the financial support provided by the Natural Science Foundation of Shandong Province of China (No. ZR2014EEM036) and the School of Civil Engineering and Architecture at the University of Jinan.

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