Flexural performance of Reinforced Concrete One-way Slabs Strengthened by FRP Grid

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Abstract: Fiber reinforced polymer (FRP) grid is a kind of two-way fiber material. Its transverse reinforcement and longitudinal reinforcement have the same physical characteristics. Experiments on the reinforced concrete one-way slabs strengthened by FRP grid were conducted to study the influences of bonding area and FRP anchors on its flexural performance. The results showed that the flexural capacity of reinforced concrete one-way slabs strengthened by FRP grid is increased by 7% - 21%. FRP grid can effectively slow down the crack expanding, increases the stiffness and improve the flexural behavior of the slab.

1. Introduction
Fiber reinforced polymer (FRP) has the characteristics of light weight, high strength, corrosion resistance, fatigue resistance and good durability [1,2]. FRP grid is a bidirectional fiber material, its transverse reinforcement has the same physical properties as longitudinal reinforcement. FRP grid also has good anti-stripping performance and fire resistance performance [3,4]. Therefore, this paper studies the flexural performance of reinforced concrete one-way slabs reinforced by FRP grids.

Schmeckpeper [5] evaluated the applicability of reinforced concrete structures reinforced by FRP grids, and analyzed the bending properties of FRP grid reinforced concrete beams. The test results showed that the stiffness of the FRP grid reinforced concrete beam is greatly improved. Edwin R [6] used FRP grid to reinforce large-span concrete bridge decks. The results show that the main failure mode is punching failure. It is recommended that the ultimate bending strength of FRP should be controlled by concrete crushing rather than reinforcement damage, and the structure may be over-reinforced. The final balanced design should be considered. Smith [7] conducted an experimental study on the flexural reinforcement of reinforced concrete beams with FRP anchors. The results show that the load and deflection of beams strengthened with FRP slabs and FRP anchors are increased by 30% and 110%, respectively, compared with unanchored FRP beams, anchors with smaller spacing can reduce the speed of crack propagation.

At present, there is little research on the reinforcement of reinforced concrete slabs by FRP grid and FRP grid + FRP anchor. Therefore, in this paper, the flexural performance test of reinforced concrete one-way slabs strengthened by FRP grids and FRP anchors will be used to research the mechanical properties and failure characteristics of RC one-way slabs strengthened by FRP grids. Hope to provide a reference for future engineering design.
2. Test Overview

2.1 Specimen design
In this test, 8 pieces of reinforced concrete one-way slabs were produced, which were divided into 2 groups for testing. Each group consisted of 4 test pieces. Among them: (1) unreinforced reinforced concrete one-way slabs; (2) all paste 1 layer FRP grid; (3) all paste 1 layer FRP grid + FRP anchor; (4) partially paste 1 layer of FRP grid + FRP anchor. In Table 1 for the design parameters of the test piece.

| Specimen number | Type of reinforcement                      | Reinforced area /mm² |
|-----------------|--------------------------------------------|----------------------|
| B-1-1  B-1-2    | unreinforced RC board                      |                      |
| B-2-1  B-2-2    | all paste 1 layer FRP grid                 | 1800x500             |
| B-3-1  B-3-2    | all paste 1 layer FRP grid + FRP anchor    |                      |
| B-4-1  B-4-2    | partially paste 1 layer of FRP grid + FRP anchor | 1800x250             |

Each one-way slab have the same reinforcement and C30 commercial concrete. The specific size of the specimen is span \(L = 2000\text{mm}\), calculated span \(L_0 = 1800\text{mm}\), slab width \(b = 500\text{mm}\), slab height \(h = 100\text{mm}\), and the bottom of the slab is equipped with tensile reinforcement \(4\Phi 8 \text{ @120}\) and distribution bars \(\Phi 8@250\), the reinforcement ratio is 0.49%, the reinforced are all HPB300 round reinforced, and the yield strength is measured \(f_y = 419\text{Mpa}\), the concrete compressive strength measured \(f_c = 51\text{Mpa}\), the thickness of the protective layer is 15mm, and the specific size of the test piece is shown in Figure 1.

Figure 1. Dimensions and reinforcements skeleton of specimens

The FRP bundle anchors are made with CFRP sheet. According to the effective bonding length of CFRP sheet and concrete, slab width, slab thickness, concrete protective layer thickness and related literature [7], the design of CFRP sheet is 200mm long and 120mm wide, the drilling depth is 30mm, the diameter is 14mm, the specific dimensions of FRP anchors are shown in Figure 2.
In order to make the FRP grid damage first when the weaker side is strengthened so as to observe the test phenomenon, half of the reinforced slab is reinforced with FRP strips, so only the FRP grid and reinforced data on the weaker side of the slab reinforcement are collected. The schematic diagram of specimen reinforcement is shown in Figure 3. In the test, the FRP grid is a 20mm × 20mm bidirectional equal-strength carbon fiber grid, the theoretical cross-sectional area of the unidirectional FRP bundle is 47mm²/m, and the paste resin glue is sikadur-330CN two-component epoxy carbon sheet impregnated glue. The mechanical properties of the materials are shown in Table 2.
Table 2. Material properties of FRP grid and glue

| Material            | Tensile strength  | Elastic Modulus | Thickness | Elongation at break (%) |
|---------------------|-------------------|-----------------|-----------|-------------------------|
| CFRP grid           | 4300              | 240             | 0.3       | 1.49 1.50               |
| Carbon fiber sheet  | 4153              | 242             | 0.167     | 1.72                     |

2.2 Specimen production
The reinforcement steps of reinforced concrete one-way slabs with FRP anchors are: (1) Draw line positioning; (2) Clean the concrete surface; (3) Drilling (4) Clear holes, glue injection, and put in FRP anchor; (5) Brush the bottom resin glue; (6) Paste the CFRP grid; (7) Unfold the FRP anchor. Reinforcement slabs anchored without FRP bundles only carry out steps (1) (2) (5) (6).

2.3 Test method and measuring point layout
The test measures and collects data such as reinforced strain, FRP grid strain, concrete strain and displacement. It adopts four-point bending static load, and the test uses displacement control. The loading rate is 0.3mm/min. The test is loaded until the slab breaks. The loading diagram are shown in Figure 4.

![Figure 4. Loading diagram](image)

3. Test results and analysis

3.1 Test phenomenon and failure mode
The failure modes of the reinforced slabs are all bending failures caused by the FRP grid breaking at the mid-span crack, which is shown as the FRP grid partially breaking at the main crack of the mid-span, except for B-3-1 and B-3-2, the other reinforcement The tensile reinforced under the slabs all reached the yield strength. In addition, the deflection of all test panels in mid-span is too large, which exceeds 1/50 of the calculated span of the panels, and far exceeds the value specified in the code. The deformation is obviously no longer suitable to withstand greater loads. The failure is ductile, and the failure mode is shown in Figure 5.

![Figure 5. Failure mode](image)
3.2 Bearing capacity analysis

The results of the cracking load, ultimate load and mid-span deflection of each test piece are shown in Table 3, and the load-displacement curve of each test slab is shown in Figure 6. As can be seen from the chart, after using FRP grid reinforcement and FRP grid + FRP anchors to reinforce the reinforced concrete one-way slab, the cracking load of the slab can be increased by 10%-53%, and the yield load can be increased by 11%-20%, the limit load can be increased by 7%-21%. The biggest increase in the ultimate load is B-3-1 and B-3-2, with an average increase of 21.08%, followed by B-2-1 and B-2-2, with an average increase of 12.28%, B-4-1 And B-4-2 increased by 7.08% on average. This shows that the use of FRP grid and FRP anchors reinforcement can improve the flexural performance of reinforced concrete one-way slabs, and under the same paste area, the use of FRP anchors has a better lifting effect. The same anchors measures are adopted, the larger the FRP grid paste area, the more obvious the increase in bearing capacity.

From the two sets of load-deflection curves in Figure 6, we can see that before the cracking of the concrete slab, each material is in the elastic stage, and the FRP-reinforced slab has better rigidity. After the slab reaches the cracking load, the stiffness of the test slab gradually decreases, but the stiffness of the FRP-reinforced slab is still greater than that of the unreinforced control slab. The reinforced of B-2-1 and B-2-2 subsequently entered a yield state, and suddenly fell a little after the load reached the limit load. At this time, the FRP grid resin glue at the crack was peeled off, and some fibers in the FRP grid bundle were broken. After that, the FRP grid continues to be stretched, but it can still continue to play a role, inhibit the development of cracks, and improve the deformation ability of the test slab, so the test slab load can still have room for improvement, but with the expansion of the crack and the FRP fiber gradually fracture, the load gradually began to decline slowly; B-3-1 and B-3-2 no obvious yield phenomenon, the tensile strength of the longitudinal reinforcement did not reach the yield strength during the entire loading process, and compared with the sudden drop in B-2-1 and B-2-2, the FRP anchors in the reinforced slab delay the load drop rate, suppress the crack propagation and the speed of FRP grid fiber breakage, thereby increasing the bending capacity of the slab. Since the FRP grid and FRP anchors are not completely destroyed, they can continue to function. The load slowly decreases after slowly lifting, the mid-span deflection of the slab exceeds 40mm, and the deformation is obvious; B-4-1 and B-4-2 the FRP grid has a small amount of reinforcement, its effect of inhibiting crack propagation is not obvious. Therefore, it is similar to the development trend of the unreinforced contrast slab. The load slowly increases to the limit load and then decreases, but the FRP grid and FRP anchors are jointly tensile. Under the effect of, the load is still slightly increased, and the deflection is also significantly increased.

Table 3. Test results

| Specimen number | Crack Yield | Peak Yield | Peak Load |
|-----------------|-------------|------------|-----------|
| Test value (kN) | average value (kN) | improvement (%) | Test value (kN) | average value (kN) | improvement (%) | Test value (kN) | average value (kN) | improvement (%) |
| B-1-1 | 7.8 | 8.96 | _ | 20.95 | 21.06 | _ | 23.55 | 23.58 | _ |
3.3 Crack analysis

The cracks of the specimen are shown in Table 4. Compared with the unreinforced slab, the number of cracks in the reinforced slab increases, the average spacing of the crack decreases, the overall width of the cracks is thinner. This is because the FRP grid and FRP anchors started to work after the slab cracked. The bonding stress between the FRP and concrete interface slowed down the cracks. The small and dense cracks promoted the bonding stress between the FRP and concrete interface. The distribution is more uniform, which improves the utilization rate of FRP strength and suppresses the development of slab cracks, thereby improving its bending capacity. Under the same reinforcement area, the board using FRP anchors slowed down the crack development speed and reduced the occurrence of cracks, which shows that the addition of FRP anchors can improve performance of reinforced concrete one-way slabs.

| Numbering | Average crack spacing (mm) | Number of cracks on board side (strip) |
|-----------|---------------------------|---------------------------------------|
|           | Test value | average value | Test value | average value |
| B-1-1     | 311        | 309           | 5          | 5             |
| B-1-2     | 306        | 306           | 5          | 5             |
| B-2-1     | 99         | 114           | 14         | 12            |
| B-2-2     | 128        | 114           | 10         | 12            |
| B-3-1     | 256        | 256           | 6          | 7             |
| B-3-2     | 256        | 256           | 7          | 7             |
| B-4-1     | 168        | 202           | 7          | 7             |

Figure 6. Test slab load-deflection curve

Table 4. Crack test data of each slab
3.4 FRP grid strain analysis

In order to study the stress of the FRP grid during loading, the FRP grid strain distribution diagram and the load-strain curve of the reinforced under different load levels are drawn, as shown in Figure 7.

![Figure 7. FRP grid strain distribution](image)

It can be seen from Figure 7 that before the load reaches 0.5Pu-0.6Pu, the strain value of the FRP grid is small and develops slowly. At this time, the concrete in the tension zone mainly bears most of the tensile force. After the load is from 0.6Pu, the FRP grid strain growth rate of the grid is gradually accelerating. As the concrete cracks and the reinforced enters the yielding state, the FRP grid bears a continuously increasing load, resulting in the rapid development of the FRP grid strain value. In the limit state, the strain value of the FRP grid is greater than the strain value of the longitudinal tensile reinforcement, which means that during the loading process, the FRP grid bears more tensile force than the longitudinal tensile reinforcement. The strain changes of the FRP grid at the loading point and mid-span are more significant. This is due to the combined effect of shear force and bending moment at the loading point, while the bending moment at the mid-span is larger and the deformation and deflection continue to increase after the formation of the main crack. So that the FRP grid is continuously stretched due to the large tensile force.

4. Conclusion

(1) Reinforced concrete one-way slabs reinforced by FRP grid and FRP grid + FRP anchors can improve its flexural performance. The cracking load, yield load, ultimate load and stiffness of the reinforced slab have been increased to varying degrees, among which the ultimate load can be increased by 7%-21%.

(2) Compared with the unreinforced contrast slab, the slab reinforced by FRP grid and FRP grid + FRP anchors has obvious crack sound before the failure, and the ultimate deflection of the slab exceeds
40mm, which is far beyond the allowable deflection of the standard design. Before the failure of the test slab, there are obvious signs, belonging to ductile failure, and has certain safety.

(3) The bending cracks of reinforced concrete one-way slabs reinforced by FRP grid and FRP grid + FRP anchors are obviously denser and finer than those of unreinforced contrast slabs, which makes the bonding between the FRP grid and the concrete interface The stress distribution is more uniform, which in turn improves the bending capacity of the slab.

References
[1] Nanni A, Tumialan J G. Fiber-Reinforced Composites for the Strengthening of Masonry Structures[J]. Structural Engineering International, 2003, 13(4): 271-278.
[2] Feng Peng, Ye Lieping. Applications and development of fiber-reinforced polymer in engineering structures [C]. Proceedings of the 2nd China Fiber Reinforced Plastics (FRP) Concrete Structure Academic Exchange Conference, 2002.
[3] Wang Wenwei. Study on Flexural Behavior of Reinforced Concrete Beams Strengthened with Fiber Reinforced plastics (FRP) [D]. Dalian: Dalian University of Technology, 2003.
[4] Wu Gang, Wu Zhishen. A New Technology of Strengthening Concrete Structures with FRP Grids and Its Application[J]. Construction Technology, 2007, 36(12): 98-99.
[5] Schmeckpeper E R. Performance of concrete beams and slabs reinforced with FRP grids[E]. University of New Hampshire, ProQuest Dissertations Publishing. 1992.
[6] Joseph Robert Yost, Edwin R. Strength and Service Ability of FRP Grid Reinforced Bridge Desks[J]. Journal of Bridge Engineering. 2001, 6(6): 605-612.
[7] Scott T. Smith, Shenghua Hu, Seo Jin Kim, Rudolf Seracino FRP-strengthened RC slabs anchored with FRP anchors[J]. Engineering Structures, 2011, 33: 1075–1087.