- Technical Paper -

TENSILE BEHAVIOR OF THE CFRP GRID WITH INTERSECT-TYPE ANCHORAGE METHOD IN THE MORTAR

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ABSTRACT

A new anchorage method of the CFRP grid in the mortar named intersect-type anchorage method was proposed in this paper. Single-direction pull-out tests and bidirectional pull-out tests were conducted to investigate the anchorage behaviour of the CFRP grid in the mortar. The number of nodes and anchorage conditions were selected as changing parameters. Based on the experimental results, the number of nodes for full use of the tensile strength of the CFRP grid was analysed. Besides, the failure mechanism was discussed.

Keywords: CFRP grid, mortar, intersect-type anchorage method, failure mechanism, pull-out test

1 INTRODUCTION

Carbon Fiber Reinforced Plastic (CFRP) grid is a kind of strengthening material for concrete structures. It has been widely applied in the concrete structure in Japan [1]-[4]. For the strengthening of concrete slabs, tunnels, columns and some other structures, sometimes two parts of CFRP grids have to be assembled for the dimensional limit and the constructional requirements. It is clear that the reliable anchorage of the CFRP grid in the assembling part is essential to the strengthening effect. The traditional anchorage method is lapping two parts of CFRP grids, as shown in Fig.1. For this method, because two parts of CFRP grids in the assembling area are not located in the same layer, the CFRP grid is easy to move and slide. This would make the void and cause the failure of the assembling part easily. In this paper, a new anchorage method named intersect-type anchorage method was proposed. As shown in Fig.2, the main procedure of this new method is cutting the middle part of the horizontal bar between two adjacent vertical bars and assembling two parts of CFRP grids by intersecting with a certain number of nodes. For this new anchorage method, because two parts of CFRP grids are located in the same layer, it is easier to fix the CFRP grid on the surface of the existing concrete by the sprayed mortar compared with the lap-type anchorage method.

In this paper, the main purpose is to investigate the tensile behaviour of the CFRP grid with intersect-type anchorage method in the mortar. It has been clarified that the anchorage action of the CFRP grid in the mortar is composed of two parts: one part is the resistant action of the horizontal bar; the other part is the bond action of the vertical bar. And the resistant action is the dominant anchorage action of the CFRP grid in the mortar [5]. However, the ultimate resistant action of the horizontal bar in the CFRP grid hasn't been obtained. In this study, two stages of pull-out tests were conducted. The single-direction pull-out tests were conducted to obtain the ultimate resistant action of the CFRP grid with different number of nodes first. And then the bidirectional pull-out tests were conducted to investigate the tensile behaviour of intersect-type CFRP grids in the mortar. Sketches of simplified mechanical models for these two stages of pull-out tests are shown in Fig.3.

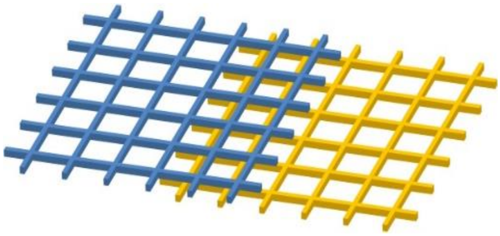

Fig. 1 Sketch of lap-type anchorage method

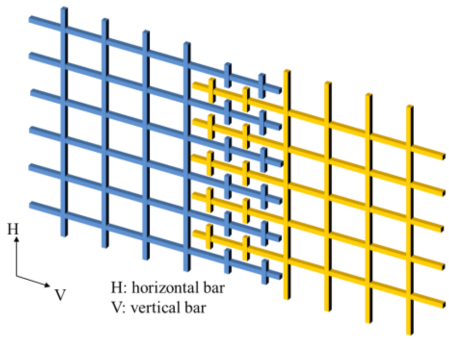

Fig. 2 Sketch of intersect-type anchorage method

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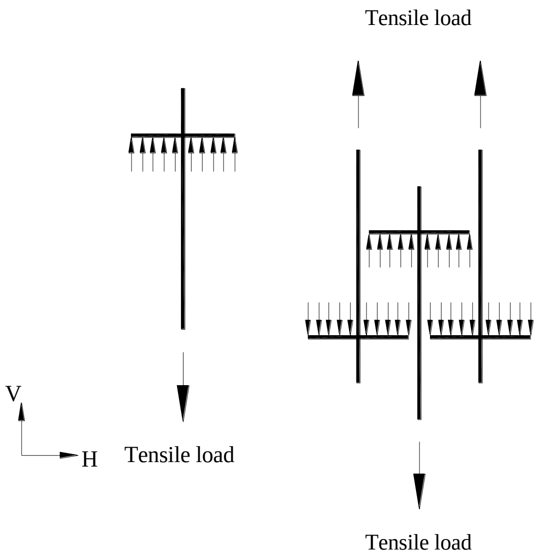


(a) single-direction pull out model (b) bidirectional pull out model

Fig.3 Sketches of simplified mechanical models for two types of pull-out tests (under no-bond condition)

2 SINGLE-DIRECTION PULL-OUT TESTS

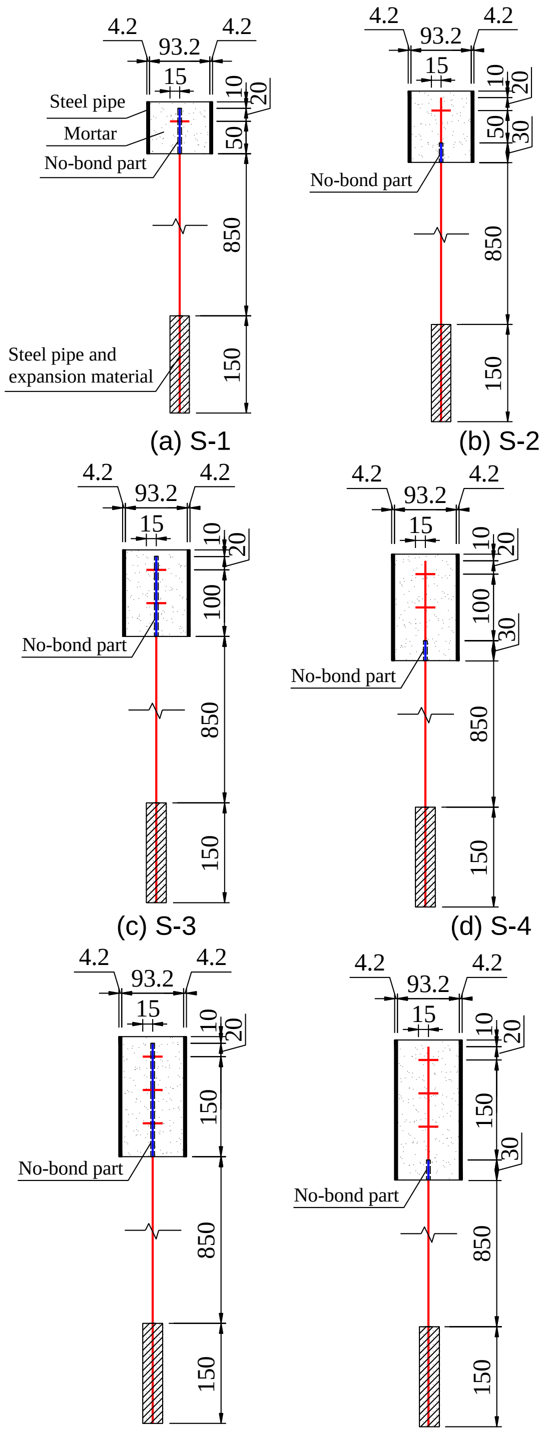
2.1 Experimental program

(1) Specimens

The main aim of this experimental program was to obtain the ultimate resistant action of the CFRP grid with different number of nodes in the mortar. Accordingly, the mortar should not fracture before the tensile failure of the CFRP grid. In order to avoid the fracture of the mortar during the loading process, the high strength mortar and the steel pipe were applied. Table 1 shows the types of specimens. Fig.4 shows the dimensions of specimens. Three identical specimens were manufactured for each specimen design. The total number of specimens is 3 (number of nodes)×2 (anchorage condition)×3 (sample), which is equal to 18. The no-bond condition was constructed by wrapping smooth tape around the vertical bar (S-1, S-3, S-5). In order to reduce the adverse effect of the local pressure of the mortar near the loading part, 30mm-length no-bond parts were conducted for the specimens under bond condition (S-2, S-4, S-6). The loading part of the specimen was fabricated by the small steel pipe and expansion material. Fig.5 shows the fabricated CFRP grids, steel pipes and a representative specimen.

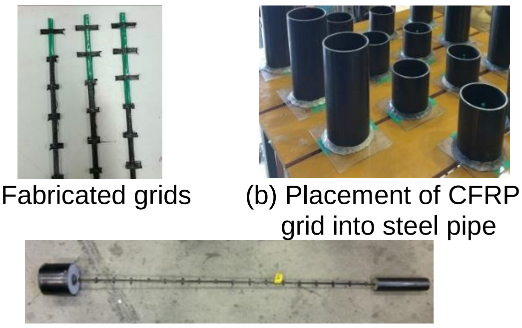
Table 1 Types of specimens

Type	CFRP grid	Number of nodes	Anchorage condition
S-1	CR5@50	1	No-bond
S-2			Bond
S-3		2	No-bond
S-4			Bond
S-5		3	No-bond
S-6			Bond



(a) S-1 (b) S-2 (c) S-3 (d) S-4 (e) S-5 (f) S-6

Fig.4 Dimensions of specimens (mm)



(a) Fabricated grids (b) Placement of CFRP grid into steel pipe

(c) Representative specimen

Fig.5 Fabrication of the specimen

(2) Material properties

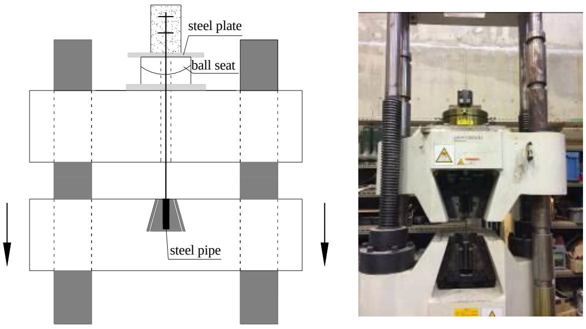
Table 2 shows the mix proportions of the mortar. The average compressive strength of the mortar at 65 days was 106.3MPa. The pull-out tests were carried out at the same age. For CFRP grids (CR5), the test results showed that the average maximum tensile load was 24.5kN.

Table 2 Mix proportions of the mortar (kg/m^3)

Cement	Water	Sand	Expanding material	Water reducer
1000	309	1000	50	2

(3) Loading program

Fig.6 shows the experimental loading method and the test setup. The displacement-control loading method was applied and the loading rate was set as 1.5mm/min. Load and displacement data were acquired during the loading process.



(a) Loading method (b) Test setup

Fig.6 Loading method and test setup

2.2 Experimental results and analysis

(1) Maximum loads and failure modes

Table 3 shows the maximum loads, the tensile strength utilization and failure modes. The tensile strength utilization μ of the CFRP grid was calculated by **Eq.1**. It can be used to estimate the anchorage reliability of CFRP grid in the mortar. Because the design value of the material strength in practical engineering is always taken as the 70% of the test value. And in this study, the tensile strength utilization was calculated based on the test results. Accordingly, it was regarded that the tensile strength of CFRP grid is fully used when the tensile strength utilization is larger than 70%.

$$\mu = \frac{P_u}{24.5} \times 100\% \quad (1)$$

Where,

24.5kN: the test maximum tensile load of CR5;

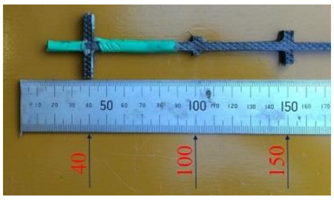
P_u: the average maximum load of each specimen, as shown in Table 3.

The calculation results of tensile strength utilization showed that: in order to make full use of the tensile strength of CFRP grid, under no-bond condition, two nodes at least were needed; under bond-condition, one node at least was needed.

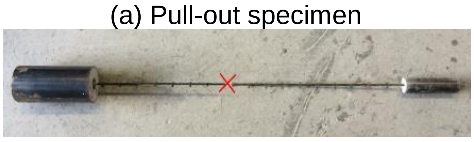
Two types of failure modes were observed for all specimens: (a) pull-out failure mode: it means that the vertical bar was pulled out; (b) rupture failure mode: it means that the vertical bar broke. Fig.7 shows the representative failure photos.

Table 3 Experimental results

Type		Maximum load (kN) Single	Average	μ (%)	Failure modes
	1	13.2			Pull out
S-1	2	10.1	11.2	45.6	Pull out
	3	10.2			Pull out
	1	19.7			Pull out
S-2	2	18.5	19.2	78.2	Pull out
	3	19.3			Pull out
	1	18.3			Pull out
S-3	2	19.5	18.1	74.0	Pull out
	3	16.5			Pull out
	1	23.1			Rupture
S-4	2	24.0	23.6	96.1	Rupture
	3	23.6			Rupture
	1	19.4			Pull out
S-5	2	19.4	19.1	77.9	Pull out
	3	18.4			Pull out
	1	22.9			Rupture
S-6	2	24.7	22.8	93.0	Rupture
	3	20.9			Rupture



(a) Pull-out specimen



(b) Rupture

Fig.7 Failure modes

(2) Analysis of the experimental results

The experimental results showed that the mortar kept intact after the loading. It means that the maximum loads of specimens S-1, S-3 and S-5 can reflect the ultimate resistant action of the CFRP grid with one node, two nodes and three nodes, respectively. Moreover, the maximum tensile load of the specimen S-1 can be used to estimate the tensile strength of the crossing point in the CFRP grid. It showed that the crossing point was the weak part of the CFRP grid under the tensile load, and it was only about 45.6% of the tensile strength of the CFRP grid.

It was found that the maximum loads of specimens S-2 and S-4 were reasonably larger than those of specimens S-1 and S-3, respectively. But the maximum loads of specimens S-5 and S-6 were not so different from those of specimens S-3 and S-4, respectively in spite of more nodes. This is because the maximum load is not the linear increase with the increasing number of nodes. When the number of nodes reaches a certain amount, the maximum load will not increase significantly and it will be more and more close to the maximum tensile load of the CFRP grid. The specific increasing mechanism of the maximum load with the increasing number of nodes is rather complicated, due to the bearing mode of the resistant action of the horizontal bar in the CFRP grid with multiple nodes and the coupling effect between the resistant action and the bond action.

3 BIDIRECTIONAL PULL-OUT TESTS

3.1 Experimental program

(1) Specimens

The aim of this experimental program was to investigate the tensile behaviour of bidirectional intersect-type CFRP grids in the mortar. Table 4 shows the types of specimens. Three identical specimens were manufactured for each specimen design. The total number of specimens is 2 (number of nodes)×2 (anchorage condition)×3 (sample), which is equal to 12. The no-bond condition was constructed by wrapping smooth tape around the vertical bar. In order to ascertain the practical tensile behaviour of the bidirectional intersect-type CFRP grids in the mortar, a special mortar was applied in this experiment. The average compressive strength of the mortar at 20 days was 61.2MPa. The pull-out tests were carried out at the same age.

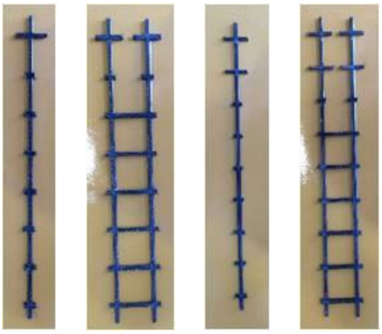
Table 4 Types of specimens

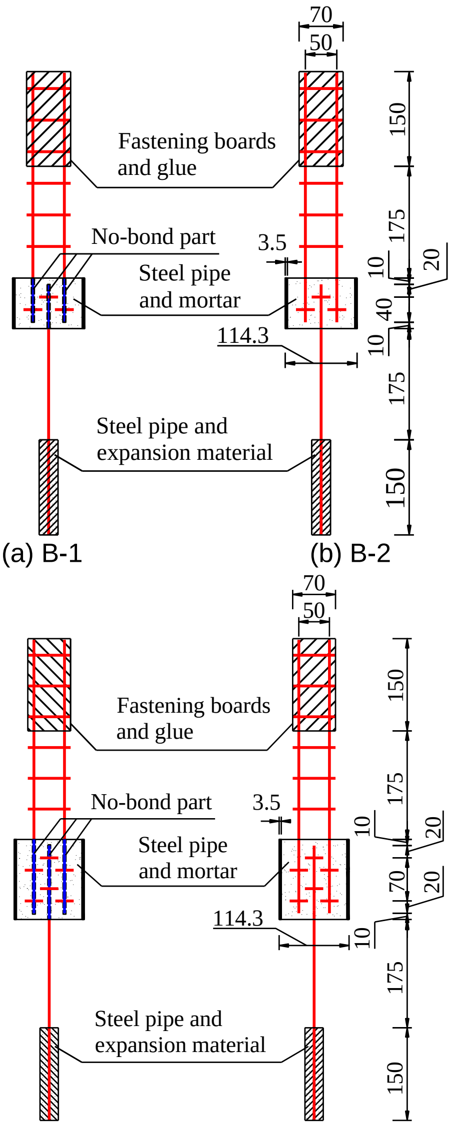
Type	CFRP grid	Number of nodes	Anchorage condition
B-1	CR5@50	1	No-bond
B-2			Bond
B-3		2	No-bond
B-4			Bond

Fig.8 shows the fabricated CFRP grids. Fig.9 shows the dimensions of specimens. The steel pipe was applied in the experiment. The internal diameter and thickness of the steel pipe are 107.3mm and 3.5mm, respectively. Fig.10 shows a representative specimen.

(2) Loading program

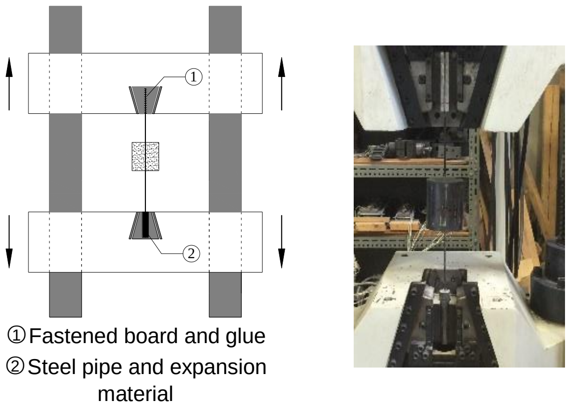
Fig.11 shows the experimental loading method and the test setup. The displacement-control loading method was applied and the loading rate was set as 1.5 mm/min. Load and displacement data were acquired during the loading process.


(a) (b) (c) (d)
Fig.8 Fabricated CFRP grids



(a) B-1 (b) B-2
(c) B-3 (d) B-4
Fig.9 Dimensions of specimens (mm)


Fig.10 Representative specimen



(a) Loading method (b) Test setup
Fig.11 Loading method and test setup

3.2 Experimental results and analysis

(1) Maximum loads and failure modes

The tensile strength utilization of the CFRP grid was calculated by Eq.1. Table 5 shows the maximum loads and the tensile strength utilization. It showed that the tensile strength utilization of specimens B-2 and B-4 were larger than 70%. It meant that: under no-bond condition, two nodes were not enough to make full use of the tensile strength of CFRP grid; under bond condition, one node at least was needed for full use of the tensile strength of CFRP grid.

Table 5 Maximum loads and the tensile strength utilization

Type		Maximum load (kN)		μ (%)
		Single	Average	
B-1	1	6.4	4.7	19.2
	2	3.1		
	3	4.6		
B-2	1	16.2	17.4	71.0
	2	18.7		
	3	17.2		
B-3	1	9.2	9.3	38.0
	2	8.5		
	3	10.2		
B-4	1	23.6	24.6	100
	2	25.6		
	3	24.5		

Table 6 shows the failure modes described from two perspectives (the grid and the mortar).

Table 6 Failure modes

Type	Failure mode of the grid	Failure mode of the mortar
B-1	The grid in the single-grid side was pulled out.	Kept intact.
B-2	The grids in both sides were pulled out. The pull-out distance in single-grid side is less than that in double-grid side.	The mortar of both sides fractured.
B-3	The grid in the single-grid side was pulled out.	Kept intact.
B-4	The grid ruptured.	The mortar of the double-grid side fractured.

It showed that: (a) under no-bond condition, the mortar kept intact after the loading, while under bond condition, the mortar fractured; (b) under bond condition with two nodes, the grid broke because the maximum tensile load reached the ultimate tensile load of the CFRP grid; under other conditions, the CFRP grids were all pulled out. But the pull-out characteristic was different. For specimens under no-bond condition, only the grid in the single-grid side was pulled out, while for specimens under bond condition, the grids in both sides were pulled out.

(2) Analysis of the experimental results

In order to clarify the tensile behaviour of bidirectional intersect-type CFRP grids in the mortar clearly, the comparative analysis between the single-direction pull-out tests and the bidirectional pull-out tests were made. The experimental results showed that the maximum loads of specimens B-1 and B-3 were much smaller than those of specimens S-1 and S-3, respectively. While the maximum loads of specimens B-2 and B-4 were close to those of specimens S-2 and S-4, respectively. This indicates that the maximum loads of bidirectional pull-out specimens under no-bond condition are smaller than those of single-direction pull-out specimens with the same number of nodes. Because it has been clarified that the maximum loads of the single-direction pull-out specimens under no-bond condition can reflect the ultimate resistant action of horizontal bar in the CFRP grid. Accordingly, it means that the resistant action of the horizontal bar in the CFRP grid under the bidirectional pull-out condition are not fully used. It can be revealed from the failure mechanism of these two types of pull-out specimens. It is clear that the main differences between these two types of pull-out tests are the loading method and the strength of mortar. Preliminary analysis suggests that both of these two factors can be regarded as the influence factors on the support of the node from the mechanical perspective.

For these two types of pull-out specimens, the demand of support for the node must increase with the increasing of the tensile load, and it can be depicted by "Demand curve" in Fig.12. While for the capacity of support for the node, they are different. For the single-direction pull-out specimen, because the specimen was set on the steel plate (as shown in Fig.6), besides, the strength of the mortar is rather high, the deformation of the support is very small during the loading process. It means that the support is strong enough to bear the tensile load. It can be depicted by the "Capacity curve Ⅰ" in Fig.12. Accordingly, the failure of the single-direction pull-out specimen is controlled by the tensile strength of CFRP grid and the crossing point. In other words, the ultimate resistant action of the horizontal bar in the CFRP grid can be fully used. The tensile load corresponding to the peak point A in the "Demand curve" is the maximum load of the single-direction pull-out specimen. For the bidirectional pull-out specimen, the double-grid part could be regarded as the support of the single-grid part. With the increasing of the tensile load, the tensile deformation of the vertical bar and the pull-out deformation of the crossing point in the double-grid part increase gradually. Besides, the mortar may fracture under the high tensile load. These will result in the decrease of the capacity of support, and it can be depicted by "Capacity curve Ⅱ" in Fig.12. Accordingly, the failure of the bidirectional pull-out specimen is controlled by the capacity of support for the node. As shown in Fig.12, the tensile load corresponding to the crossing point B of the "Capacity curveⅡ" and the "Demand curve" is the maximum load of the bidirectional pull-out specimen. It is obvious that F_b is smaller than F_s.

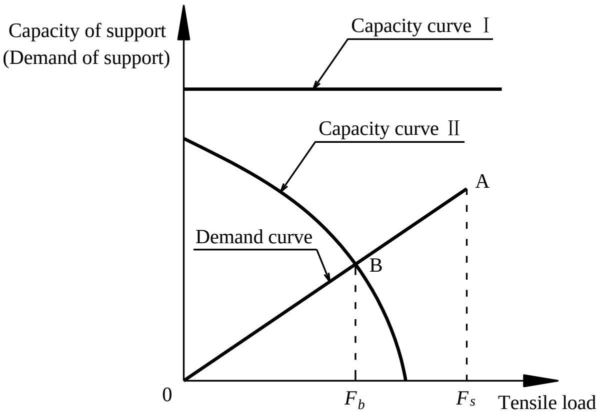


Fig.12 Capacity and demand curves of the support corresponding to two types of pull-out specimens

4 CONCLUSIONS

From the experimental work conducted in this study, the following conclusions can be drawn:

(1) The experimental method of the single-direction pull-out test in this study can be used to obtain the ultimate resistant action of horizontal bar in the CFRP grid under tensile load. For CR5@50, the ultimate resistant actions of the CFRP grid with one node, two nodes and three nodes were 11.2kN, 18.1kN and 19.1kN, respectively. The crossing point was the weak part of the CFRP grid under the tensile load, and it was only about 45.6% of the tensile strength of the CFRP grid.

(2) For the single-direction pull-out specimen, in order to make full use of the tensile strength of CFRP grid, two nodes at least were needed under no-bond condition; one node at least was needed under bond-condition.

(3) For the bidirectional pull-out specimen, under no-bond condition, two nodes were not enough to make full use of the tensile strength of CFRP grid; under bond condition, one node at least was needed for full use of the tensile strength of CFRP grid.

(4) From the perspective of the capacity and demand curves of the support for the node, the failure mechanism of the specimens under no-bond condition was discussed. The failure of the single-direction pull-out specimen is controlled by the tensile strength of CFRP grid and the crossing point. The ultimate resistant action of the horizontal bar in the CFRP grid can be fully used. The failure of the bidirectional pull-out specimen is controlled by the capacity of support. The capacity of support decreases with the increasing of the deformation of the CFRP grid in the double-grid part and the fracture of the mortar. When the capacity of support is equal to the demand of support, the tensile load reaches the maximum value.

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