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Research on Anchorage Performance of New CFRP Plate Anchorage Based on Displacement Control

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Abstract. The anchorage characteristics of CFRP plate anchors are controlled by anchorage deformation. The anchoring efficiency of anchors under tension and the force mechanism of CFRP plates are studied. The preliminary design of splint anchors is carried out by ANSYS general software. The deformation and stress of the CFRP plate under the displacement control of the different splint edges are analyzed, and the corresponding splint displacement is 0.55mm when the anchoring efficiency is 100%. At the same time, the finite element analysis results were compared by the anchor static test, and the stress loss and relative slip of the CFRP plate were analyzed. The research shows that: from the test results, when the total displacement of the splint reaches 0.55mm, the CFRP plate undergoes longitudinal splitting failure; when the total displacement of the splint reaches 0.50mm, the test anchoring performance is the best, the anchoring efficiency is 82%; the total displacement of the splint is 0.30~0.55. When mm is used, the slip amount of CFRP plate is 0.69~3.31mm. The better the anchoring performance is, the smaller the slip amount is. The loss of stress caused by CFRP plate retraction and anchorage deformation is recommended to be 7.5% of the total tensile stress.

1. Introduction

With the rapid development of China's economy and the progress of society, traditional bridges are increasingly unable to meet the needs of development, and there are many hidden dangers due to long construction time, imperfect technology and large environmental impact. In addition, blind dismantling will bring material waste, so the search for a reasonable material and reinforcement method[1] is the best policy, so Carbon Fiber Reinforced Plastics (CFRP)[2] came into being. This material has high tensile strength[3] and is excellent in corrosion resistance and is being applied more and more to road bridges. The common structural forms of carbon fiber composites are carbon fiber ribs, carbon fiber cloth[4] and carbon fiber reinforced plastics. Considering the wide range of beam reinforcement for road bridges and the prestressing of existing bridges for main beams, the most common applications are currently applied. A wide variety is carbon fiber sheets. However, since the carbon fiber is a brittle material, the shear strength of the laminated carbon fiber sheet[5] is poor, and if it is not used properly, its performance advantage cannot be exerted. Therefore, a reasonable anchoring measure[6] is sought to solve the carbon fiber board shearing. The problem of cutting and destroying has become the focus of many scholars.



Wu Zhipin[7] studied the anchoring performance of prestressed carbon fiber slab anchors, and the control method was torque control. The study found that the anchoring efficiency of flat carbon fiber anchors can reach 70%, and the final form of carbon sheets is mostly slip. Deng Langni[8] studied the force mechanism and anchoring performance of wedge-shaped clip anchors, and found that the anchor length and wedge angle of wedge anchors are the main factors affecting the anchoring performance of carbon fiber sheets. Wang Zhizhen[9] studied the anchoring performance of prestressed carbon fiber slab circular slab anchors. The investigation shows that reasonable tooth depth, pitch and tangential angle can improve the anchoring performance of anchors. Li Weijie[10] explored the anchoring performance of the wave curve anchors and found that the anchoring efficiency was affected by the corrugated shape and the bolt preload, and the strain loss was explored. Fan Xiaosan[11] studied the anchoring performance of wave anchors on carbon fiber sheets, taking the bolt pre-tightening torque as a variable, and focused on the characteristics of the anchor port. It was found that the lateral force of the carbon fiber board was uneven, and the lateral port was affected. The force is larger and the displacement is smaller, and the middle force is smaller and the displacement is larger.

In summary, it is not difficult to find that due to the size of carbon plates, the form of force and the impact of engineering cost and practical application, the most widely used anchors are still pre-tightened by bolts to achieve pre-tightening and controllable effects. The carbon fiber board is increased in friction with the anchor by the pre-tightening force of the bolt, but the actual operation is controlled by a torque wrench or other tightening device, which makes the correspondence between the tightening torque and the pre-tightening force difficult. It is determined that although there is a certain correspondence, but the quality of the bolts processed by the factory is different, the accuracy is often not high. Therefore, this paper combines the force performance of carbon plates to explore a new type of carbon plate surface anchors, and analyzes the force mechanism through displacement control. And anchoring efficiency, the results have a strong guiding significance for engineering development.

2. Specimen Design and Finite Element Simulation

2.1. Test Piece Design

The anchor is made of Q345B steel. The components are divided into two parts: the clamp and the limit plate. The specific dimensions are shown in Figure 1. The design principle of the clip is to increase the contact area with the carbon plate by contacting the curved surface to improve the friction force; to reduce the shear stress of the port by using the flared port; the displacement control is to increase the vertical extrusion degree by controlling the thickness of different limit plates. To achieve better pre-tightening effect and improve anchoring efficiency. The carbon plate has a cross-sectional dimension of 100 mm x 2 mm and a length of 600 mm. The material properties of the anchors are shown in Table 1. The material properties of the carbon plates are shown in Table 2. The properties of the bolt materials are shown in Table 3. The three-dimensional model of the anchor carbon plate is shown in Figure 2.

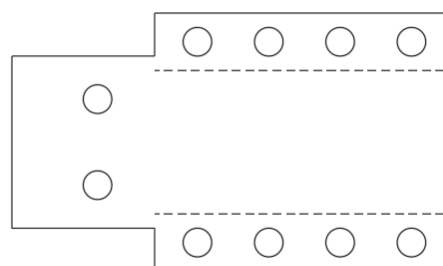


Figure 1. Anchor dimension drawing

Table 1. Carbon fiber board material characteristics

Carbon plate size(mm)	Fiber volume content	Modulus of elasticity(GPa)	Ultimate tensile strength(MPa)	Ultimate bearing capacity(kN)	Interlaminar shear strength(MPa)	Ultimate elongation
2x100	55%	160	2400	480	50	1.5%

Table 2. Anchor ply material properties

Splint material	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus(GPa)	Poisson's ratio
Q345B steel	500	345	206	0.32

Table 3. Bolt material characteristics

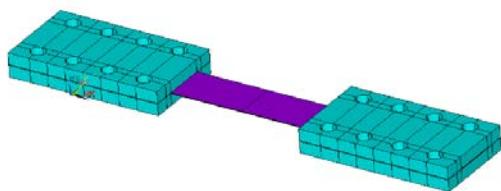
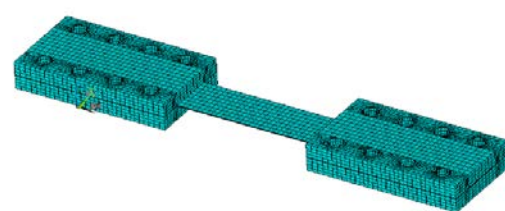
Bolt grade	Bolt type	Quantity	Yield strength(MPa)	Nominal diameter (mm)	Nominal area (mm ²)	Single bolt maximum preload(KN)
12.9	Hexagon	16	1080	20	245	185
12.9	inner hexagon	4	1080	20	245	185

2.2. Finite Element Model

2.2.1 Building a model

This chapter will use ANSYS[12] for modeling. The optimal anchor in this chapter is modeled in a bottom-up manner. Modeling in this way is divided into two steps: establishing geometric models and netting. Considering that the splint joint only serves as a joint, the limit plate acts to restrain the lateral deformation of the carbon plate, and has no effect on the force, so the model is simplified and not considered in the modeling.

The finite element[13] model establishment is the main point of calculation. The model uses mapping grid division[14], and sets the corresponding contact pairs. The carbon fiber splint test is divided into two stages, the extrusion stage and the tension stage. To simplify the calculation, only $\frac{1}{4}$ of the model is calculated. The geometric model is shown in Figure 2, and the finite element model is shown in Figure 3.

**Figure 2.** ANSYS geometric model diagram**Figure 3.** Finite element model diagram

2.2.2 Extraction and analysis of finite element results

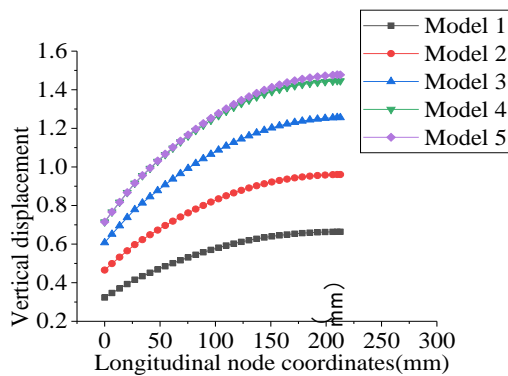
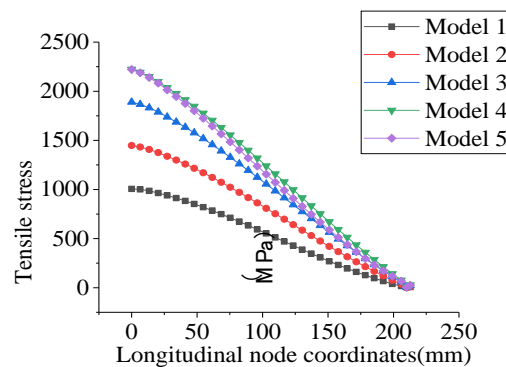
In order to explore the relationship between the displacement of the lateral edge of the splint and the corresponding pre-tightening degree, the finite element adopts the parametric comparison of different displacement control. After preliminary analysis, the relationship between the total displacement of the upper and lower splint edges and the pre-tightening force is extracted. Table 4.

Table 4. Relationship between the displacement of the splint edge and the preload

Model Node	Plywood edge total displacement(mm)	Load preload ^a (kN)
1	0.30	60-85-85-60
2	0.40	92-120-120-92
3	0.50	109-135-135-109
4	0.55	126-147-147-126
5	0.60	156-188-188-156

^aThe loading preload data sequence is arranged along the longitudinal direction of the splint.

In order to further judge the relationship between the degree of deformation of the splint edge and the longitudinal deformation of the carbon plate during the tensioning stage and the anchoring efficiency, the longitudinal displacement and longitudinal tensile stress data of the middle tension stage of different model carbon plates are extracted as shown in Figures 4 and 5. Wherein, the longitudinal node coordinates are arranged in the order from the load end to the free end of the carbon plate anchorage zone.

**Figure 4.** Longitudinal displacement of carbon sheet tensioning stage**Figure 5.** Tensile stress of carbon sheet tensioning stage

It can be seen from Figure 4 that the degree of longitudinal deformation of the carbon plate changes logarithmically, the degree of deformation of the anchorage zone is smaller, and the degree of deformation of the free end of the anchorage is larger; and as the total displacement of the edge of the splint increases, the longitudinal direction The displacement is also increasing, but the longitudinal displacement of Model 4 and Model 5 is relatively close, that is, the total displacement of the edge of the splint is not changed after reaching 0.55mm; the maximum displacement of Model 1-5 is 0.65mm, 0.95mm, respectively. 1.25mm, 1.35mm, 1.40mm, the maximum deformation of all model carbon fiber sheets does not exceed 2mm, which can meet the actual engineering requirements.

It can be seen from Figure 5 that the stress change of the carbon plate from the anchor receiving end to the anchor free end is opposite to the displacement, and the smaller the degree of deformation, the greater the stress, which is consistent with the theory. The larger the total displacement of the splint edge, the greater the tensile stress in the longitudinal direction. The longitudinal tensile stress of the model 4 and the model 5 are basically the same. Since the tensile strength of the carbon plate is 2400 MPa, the anchorage corresponding to the model 1-5 can be seen from the data in the figure. The efficiency is 45%, 65%, 85%, 100%, 100%, so it is determined that the anchorage efficiency is reliable when the edge displacement of the splint is 0.55 mm.

3. Anchor Static Load Test

After finite element comparison analysis, it can be seen that the pre-tightening force of the splint by the edge of the splint is feasible and further discovers the relationship between the anchoring

efficiency and the anchoring efficiency. In order to verify the anchoring efficiency of the actual anchor, the static tensile test is carried out on the anchor.

3.1. Test Process

The test was carried out in a structural laboratory, and a total of 4 sets of 8 tests were carried out. The test piece table is shown in Table 5. Torque is applied to the bolt by the action of the torque wrench and the adjustable wrench. The fit of the edge of the splint and the limit plate is measured by a vernier caliper. The simplified and physical diagrams of the completed test piece are shown in Figures 6 and 7.

Table 5. Test piece table

Test piece group	Test piece number	Limit plate thickness (mm)	Control the total displacement of the splint edge(mm)
First group	N1	1.70	0.30
	N2	1.70	0.30
Second Group	N3	1.60	0.40
	N4	1.60	0.40
The third group	N5	1.50	0.50
	N6	1.50	0.50
Fourth group	N7	1.45	0.55
	N8	1.45	0.55

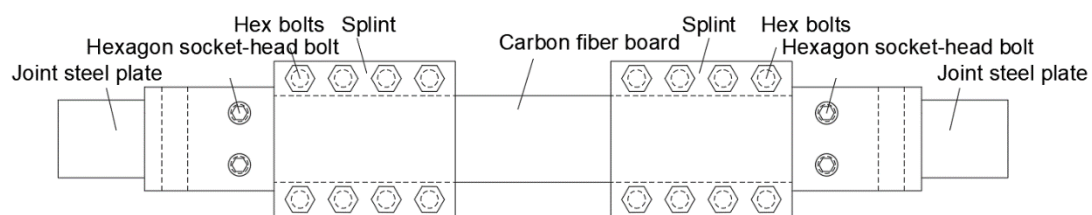


Figure 6. Sketch of the assembly of the test piece



Figure 7. Physical diagram of the assembly of the test piece

The test is carried out by a microcomputer-controlled electro-hydraulic servo universal testing machine. The carbon plate is subjected to an initial tensile load of 3 kN to straighten the carbon plate before tensioning, and the longitudinal displacement of the carbon plate due to inelastic deformation is reduced. Then, using grading loading, before the 75% of the tensile strength of the carbon plate is reached, the control loading rate is 0.5kNs^{-1} , the load per stage is 48kN, and the load is 2 min after reaching each stage load; after reaching 75%, it is 50MPa. Loaded for intensity increments, each intensity increment is held for 3 min. The displacement of the anchor is arranged on the carbon plate and the clamp plate by a displacement meter. The strain and displacement are collected by the

DH3820 static strain test analysis system. The strain gauge and the displacement gauge are arranged as shown in Figure 8.

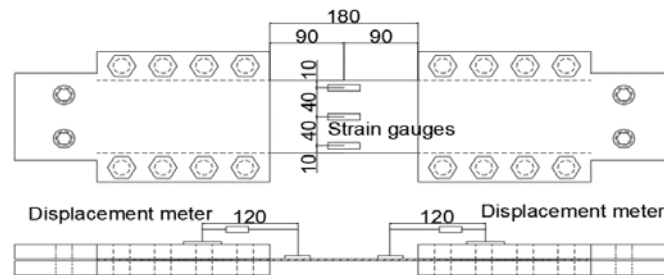


Figure 8. Schematic diagram of strain gauge and displacement gauge (mm)

3.2. Test Results

3.2.1. Analysis of anchoring performance

After the test, the failure modes of the first two sets of specimens were slipping from the anchors, and the non-carbon fiber sheets were broken. The third group of specimens exploded, and the specific process was the first partial explosion from the lateral sides of the carbon fiber sheets. Destruction, and gradually transfer the middle part, the middle part of the final destruction, instead of the carbon fiber board as a whole is broken; the fourth group of specimens in the lateral edge of the longitudinal splitting damage, the middle part is not broken. The carbon plate damage is shown in Figures 9 and 10. The carbon plate test results of the four sets of test pieces are summarized in Table 6.



Figure 9. Carbon plate explosion damage



Figure 10. Carbon plate longitudinal splitting failure

Table 6. Summary of test results of carbon fiber board

Test piece Node	Limit plate thickness (mm)	Control splint edge total displacement (mm)	Carbon fiber plate theoretical damage tensile force (kN)	Test machine maximum tensile force (kN)	Actual tensile force to theoretical value ratio	Carbon plate final failure form
N1	1.70	0.30	480	191	39.79%	Slip off
N2	1.70	0.30	480	198	41.25%	Slip off
N3	1.60	0.40	480	245	51.04%	Slip off
N4	1.60	0.40	480	267	55.63%	Slip off
N5	1.50	0.50	480	387	80.63%	Explosive
N6	1.50	0.50	480	399	83.13%	Explosive
N7	1.45	0.55	480	213	44.38%	Splitting
N8	1.45	0.55	480	226	47.08%	Splitting

From the actual tensile ratio of each group in Table 6, it can be seen that the proportion of each group is lower than that of the finite element analysis, which may be related to the uncertainty of the actual test piece production, installation and stretching. The anchoring efficiency of the first two groups was about 40% and 52%, and the failure mode was normal. The anchoring efficiency of the third set of N5 and N6 specimens is about 82%, which is similar to the finite element analysis value of 85%, but the explosive damage with better effect occurs. The reason is due to the lateral non-uniformity of the carbon plate, first in the lateral direction. Longitudinal cracks appear, which affect the overall performance of the material and gradually break down. The anchoring efficiency of the fourth set of test pieces is relatively low, only about 45%, which is larger than that of the finite element. The reason may be that the total displacement of the edge of the splint is the largest, so that the lateral compression of the carbon plate is not uniform, resulting in damage, early loss of anchoring performance. It can be seen from the above that the anchoring performance of the control splint is preferably 0.5 mm.

3.2.2. Carbon plate strain and stress loss

The data of three sets of strain gauges along the longitudinal direction of the carbon plate in the test were extracted, and the maximum strain, strain average and corresponding strain loss of the carbon plates in the four sets of tests were selected, and are summarized and summarized as shown in Table 7 below.

Table 7. Test specimen strain change and loss table

Test piece Node	Maximum strain at point A ($\mu\epsilon$)	Maximum strain at point B ($\mu\epsilon$)	Maximum strain at C point ($\mu\epsilon$)	Average strain ($\mu\epsilon$)	Average strain loss ($\mu\epsilon$)	Strain loss ratio
N1	2513	2126	2411	2350	165	7.02%
N2	2416	1987	2373	2259	172	7.61%
N3	3644	3083	3496	3408	207	6.07%
N4	3503	2881	3441	3276	216	6.59%
N5	5634	5130	5828	5531	486	8.79%
N6	5350	4774	5530	5218	428	8.21%
N7	2764	2339	2652	2585	199	7.70%
N8	2658	2186	2610	2485	202	8.13%

From the strain change and strain loss table of the four sets of specimens, it can be seen that the three-point strain, the strain values of point A and point C are larger than those of point B, and the difference between point A and point C is not obvious. This is because the two points of A and C are located near the lateral edge of the carbon plate, and the pre-tightening force on both sides is large, resulting in less deformation, and the central pre-tightening force is small, resulting in large deformation. Therefore, the stress and strain on both sides are large, and the intermediate stress and strain value are small. The average strain of the first set of N1 and N2 specimens is similar to that of the fourth set of N7 and N8 specimens. The third group of N5 and N6 has the largest average strain and the maximum strain is 5531×10^{-6} . The average strain of each test piece in each group was not much different, and the strain loss ratio was within 10%, and the loss was small. Combined with the overall strain-stress situation, it is recommended that the prestressed carbon plate retraction stress loss rate of the anchor is 7.50%.

3.2.3. Overall displacement, strain and slip relationship of the test

In order to explore the relationship between the displacement, strain and slip amount of the test, the data such as the slip amount and the test displacement are summarized as shown in Table 8.

Table 8. Table of specimen displacement, material deformation and slip

Specimen Node	Overall displacement (mm)	Actual maximum strain corresponding to material deformation (mm)	Finite element calculation Material deformation ^a (mm)	Calculated slip amount(mm)
N1	4.64	1.41	1.30	3.23
N2	4.42	1.36	1.30	3.06
N3	4.05	2.04	1.80	2.01
N4	3.92	1.97	1.80	1.95
N5	4.12	3.32	2.50	0.80
N6	3.90	3.13	2.50	0.77
N7	4.53	1.55	2.70	2.98
N8	4.50	1.49	2.70	3.01

^a Since the finite element only calculates $\frac{1}{4}$ of the model, the total deformation is twice the calculated data.

It can be seen from the above table that the total displacement of the four sets of test pieces is less than 5 mm, and the total displacement is small. The actual maximum strain corresponding to the material deformation is larger than the material deformation obtained by the finite element calculation, which is due to the uneven material properties. The third group of specimens measured the minimum amount of slip, which was about 0.78mm. It can be seen that the anchorage is relatively firm when the edge of the splint is 0.5mm. The slip amount of the first group and the second group of specimens is large, which is due to insufficient anchoring preload. In the fourth group, the displacement preload is too large due to the excessive displacement of the edge of the splint, so that the lateral unevenness of the carbon plate is large, which causes the carbon plate to split and the slip amount is large.

4. Conclusion

After finite element calculation and actual test loading, it is proved that the method of preloading the clamping plate by displacement can be feasible. For the anchor of this test, when the edge of the splint is displaced by 0.5mm, the best anchoring effect can be obtained, and the highest anchoring efficiency is 82%. It can be met the actual requirements of the project.

For the four test pieces of this test, the average carbon plate strain loss rate is 7.50%. It is recommended that the stress loss accounted for 7.50% due to the deformation of the anchor and the carbon plate retraction.

According to the situation that excessive compression will cause the carbon plate to split, it is instructed from the experiment that the lateral non-uniformity of the carbon plate will also have an important influence on the anchoring efficiency of the anchor. This is of great significance for further research in the future.

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