

# Experimental study on the connection property of full-scale composite member

Cao Panpan<sup>1</sup> and Sun Qing<sup>2</sup>

1 Department of Civil Engineering, Xi'an Jiaotong University, China

E-mail: 574093483@qq.com

2 Department of Civil Engineering, Xi'an Jiaotong University, China

E-mail: sunq@mail.xjtu.edu.cn

**Abstract.** The excellent properties of composite result in its increasingly application in electric power construction, however there are less experimental studies on full-scale composite member connection property. Full-scale experiments of the connection property between E-glass fiber/epoxy reinforced polymer member and steel casing in practical engineering have been conducted. Based on the axial compression test of the designed specimens, the failure process and failure characteristics were observed, the load-displacement curves and strain distribution of the specimens were obtained. The finite element analysis was used to get the tensile connection strength of the component. The connection property of the components was analyzed to provide basis of the casing connection of GFRP application in practical engineering.

## 1. Introduction

Because of its high specific strength, good fatigue performance and strong design ability, fiber composite material has been gradually popularized in the field of structural engineering [1-3], especially in power construction in recent years [4-6]. Compared with other types of composite materials, such as carbon fiber reinforced plastic (CFRP), aramid fiber reinforced plastic (AFRP), glass fiber reinforced polymer (GFRP) is of better toughness (breaking elongation of 2.5%~3%) and economy, which results in its broader engineering application as a force component [7-9]. However, the application in structural construction still requires the development of reliable and convenient connection approaches, especially for tubular sections [10].

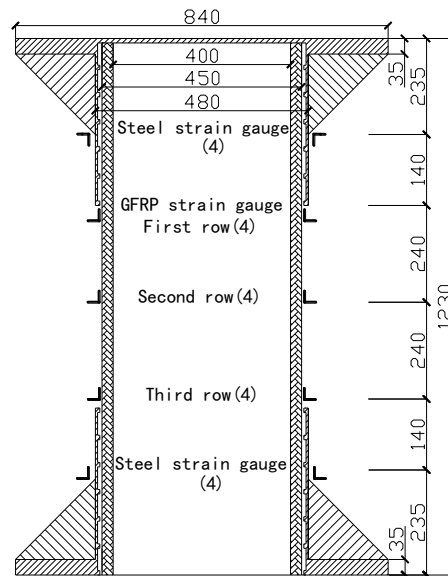
At present, there is less research in structural engineering field about the GFRP component, and the research is mainly focused on the material properties and the performance of components under small size. As for the composite component, the connection occupies a very important position, which is similar to the steel structural member. In this paper, the extruding test of bonded steel sleeve connection for full-scale GFRP component is carried out, the connection property between GFRP and steel sleeve is studied as well. Besides that, finite element (FE) analysis of the component under tension force is also conducted to estimate the joint capacity. The research could provide the design basis for engineering application of glass fiber composite materials.

## 2. Experiment condition



### 2.1. specimen details

The specimen was made up of two components. The epoxy resin was used as the matrix, and the glass fiber was used as the strengthening material. The form of the thin wall ring was adopted, and the forming process was winding forming. Between the sleeve and the GFRP pipe, the high strength adhesive was utilized to fix. In addition, the sleeve was grooving in the interface so as to improve the performance of the connection. The specimen size and arrangement of measuring points are shown in figure 1.

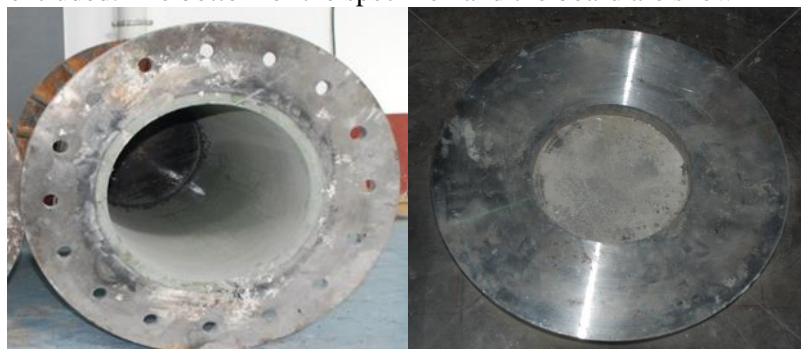


**Figure1** The specimen size and arrangement of measuring points

### 2.2. Load scheme

The YAW-10000E microcomputer controlled electro-hydraulic servo pressure testing machine was used as the loading device. Compression test adopted load control before the pressure reached 4000kN. The loading speed was 5kN/s. Each level load was 100kN, and the loading interval of each level load was 30s. When the pressure was greater than 4000kN, the displacement control was adopted until the specimen lost bearing capacity. The loading speed was 2mm/min, each level of displacement was 1mm, and the loading interval of each level load was also 30s.

The extruding test needed an appropriate board at the end of the specimen, which is necessary for the GFRP pipe to be extruded. The bottom of the specimen and the board are shown in figure 2.

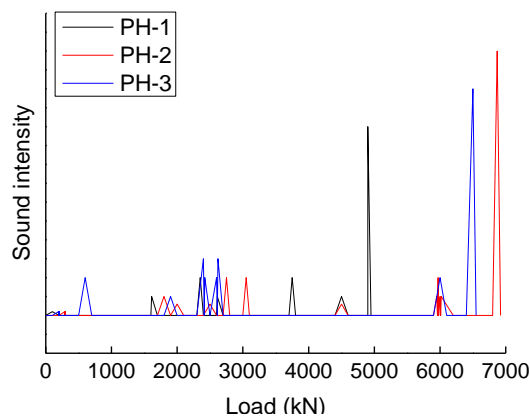


**Figure 2** The bottom of the specimen and the board

### 3. Experimental phenomenon

The phenomenon observed in the course of the experiment is shown in the Fig. 3. There was no phenomenon but some sounds appearing on the specimens during the loading process. Set specimen PH-1 as an example to demonstrate how the figure shows. When the loading force was 100kN, the specimen made a faint sound. When the loading force was 1610kN, the specimen made a medium sound. When the loading force was 2350kN and 2610kN, the specimen both made a larger sound. When the loading force was 3750kN, the specimen made a medium sound. When the loading force was 4500kN, the specimen made a faint sound. When the loading force was 4950kN, the specimen was broken with a very big sound. Through further observation, the connection of specimen was broken before the GFRP pipe was destroyed by sudden impact. As we can see from the three curves, the concentration of sounds occurred between 1500kN and 3000kN. It can be inferred that the adhesive part was beginning to break.

The failure of the specimen is shown in Fig.4. The GFRP pipes of the three specimens were all extruded, PH-1 was pressed out 12mm, PH-2 was 20mm and PH-3 was 2mm. In addition, the GFRP pipes were damaged, which proved that the strength of the connection was equal to the damage strength of the material under the compression experiment.



**Figure 3** The sound record



(a) PH-1 specimen



(b) PH-2 specimen

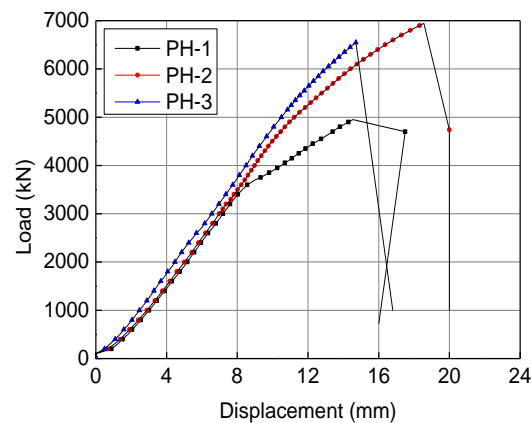


(c) PH-3 specimen

**Figure 4** Destroyed specimens

### 4. Test result and analysis

The load-displacement curve of specimen is shown in Fig.5. As can be seen from the load-displacement curve of the three specimens, the curve can be divided into three phases, the linear segment, the broken line segment and the descending segment. There is a turning point between the linear and the broken line segment for each specimen, and when the load is greater than this value, the slope of the curve drops. When the load reaches limit finally, load-displacement curve falls sharply and specimen is damaged.



**Figure 5** The load-displacement curve

As we can see from the curve slope, the component of the overall stiffness is larger at the beginning, after a certain load, the component of the overall stiffness decreases. The load-displacement curve is basically linear, which shows that the component is brittle and the destruction is sudden without any sign.

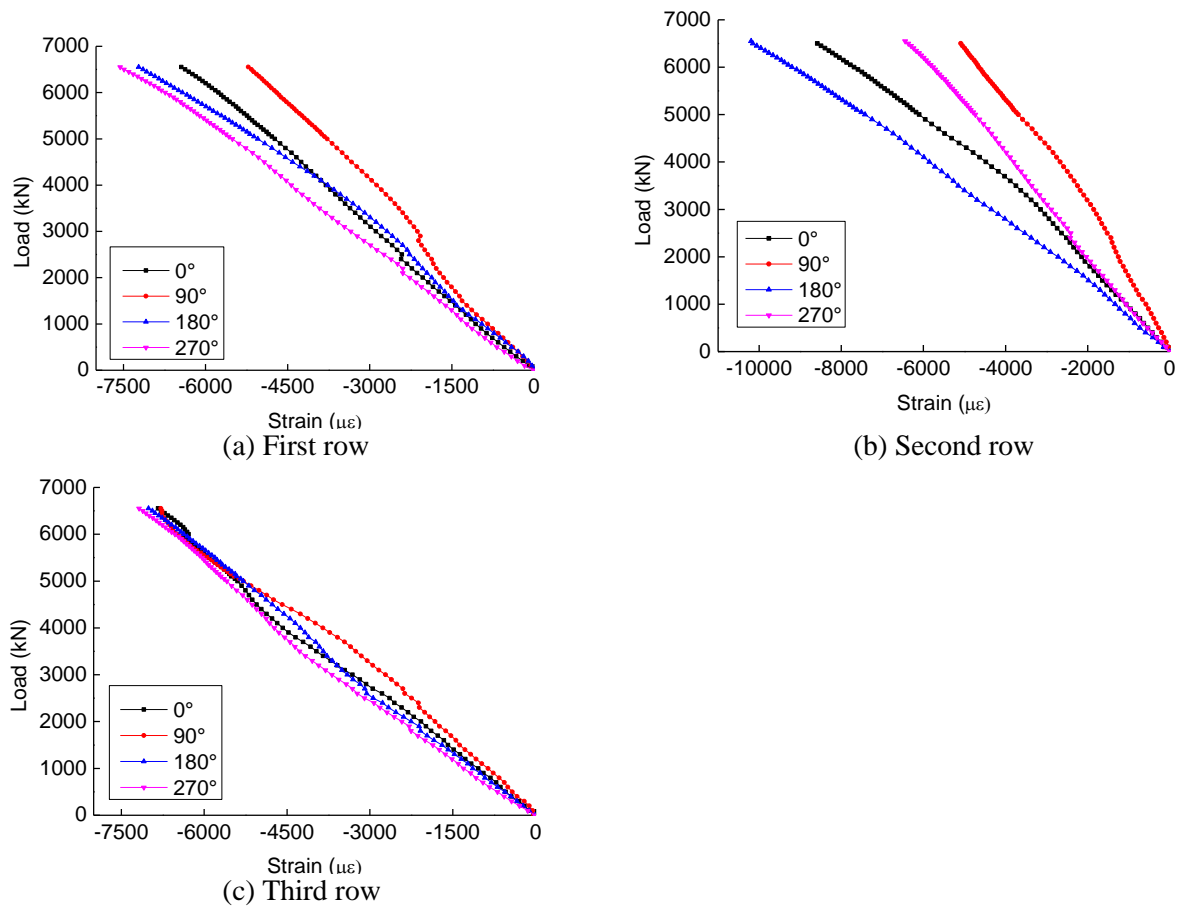
The performance of the specimen is analyzed and summarized in table 1. The critical load of the specimens is between 4950kN and 6950kN, the mean value is 6150kN, and the mean of compressive strength is 184.34Mpa. The standard deviation of the test data of the ultimate bearing capacity of the component is 1058.3kN, which shows that the dispersion of connection performance is quite large.

If the adhesive area is supposed to be equivalent to the projection of the GFRP pipe to calculate the strength, the shear strength of the adhesive is 11.61MPa.

Table 1: Test specimen bearing capacity and test specimen adhesive strength

specimen	section size (mm•mm)	bearing capacity (kN)	average bearing capacity (kN)	standard deviation	equivalent adhesive area (mm <sup>2</sup> )	adhesive strength (Mpa)	average adhesive strength (Mpa)
PH-1	Φ450•25	4950	6150	1058.30	529875	9.34	11.61
PH-2		6950				13.12	
PH-2		6550				12.36	

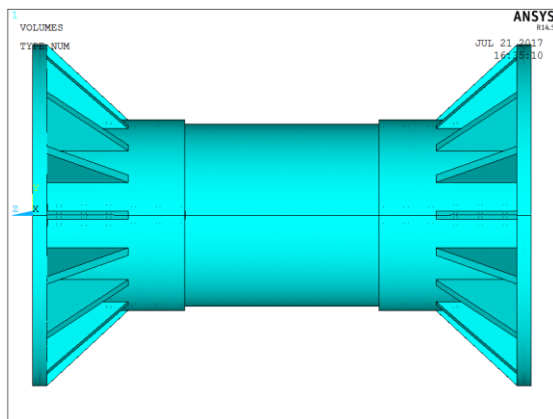
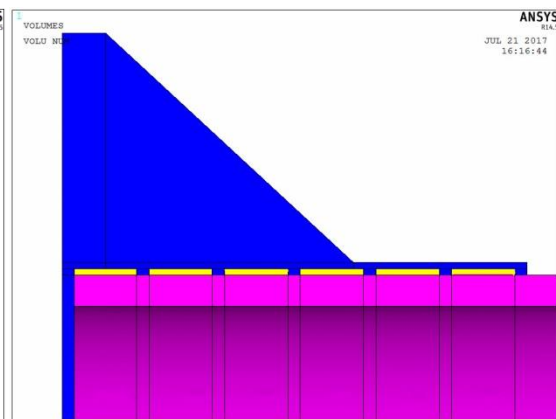
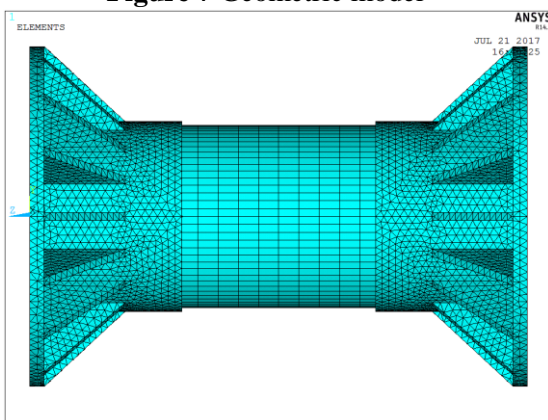
The longitudinal maximum strain of the PH-1 GFRP pipe is  $-8524 \mu \epsilon$ , the PH-2 is  $-9318 \mu \epsilon$  and the PH-3 is  $-10030 \mu \epsilon$ . The GFRP pipe is in the elastic stage from applying load to the failure, the load and strain remains generally a linear relationship. The strain increases with the increase of load. The load-longitudinal strain curve of the PH-3 is shown in the figure6. For the steel sleeve, far from the yield value, the longitudinal strain values are less than  $800 \mu \epsilon$ . Because the steel sleeve and the GFRP pipe are bonded together, the adhesive damages in the process of loading test and then sleeve will appear stress redistribution, stress situation was complex.



**Figure6.** The GFRP load-longitudinal strain curve of PH-3

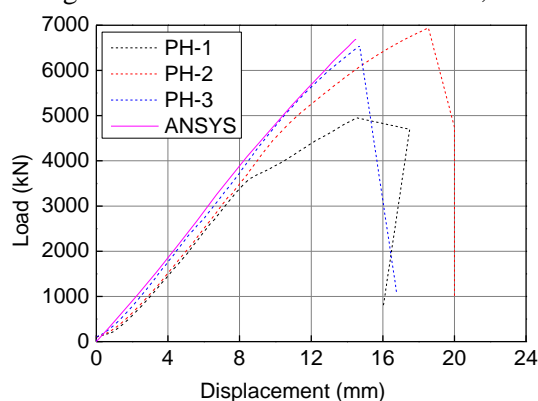
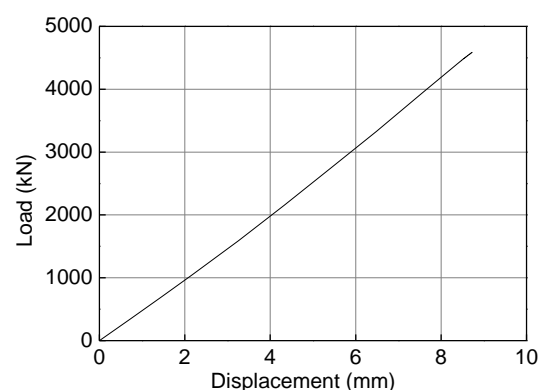
## 5. Finite element analysis

In this paper, the tensile strength of the same specimen is obtained by the finite element simulation. Before that the compression simulation of the same model was carried out, and the correctness of the finite element model is verified by comparing with the experimental results. The material test had been carried out before the production of specimen design. The mechanical property parameters of GFRP pipe:  $E_1=43.15\text{GPa}$ ,  $E_2=E_3=14.32\text{GPa}$ ,  $\nu_{12}=\nu_{13}=0.283$ ,  $\nu_{23}=0.091$ ,  $G_{12}=G_{31}=2.48\text{GPa}$ . The mechanical property parameters of steel sleeve:  $E=201.5\text{GPa}$ ,  $\nu=0.241$ . The mechanical property parameters of adhesive:  $E=5\text{GPa}$ ,  $\nu=0.25$ . The bond strength between steel and adhesive is  $16.5\text{MPa}$ , and the bond strength between GFRP and adhesive is far greater than that between the steel and adhesive, so the failure of the connection between GFRP and adhesive is not considered. The geometric model established is shown in figure 7 and the details of the binding site are shown in figure 8. Because the steel sleeve model is complex, it is divided by tetrahedral mesh. GFRP and adhesive are divided into hexahedral meshes. The finite element model is shown in the figure 9. Because the specimen is short column, the effect of slenderness ratio is not considered. The constraint conditions of compression and tensile simulation are all fixed on one end, and the longitudinal constraint is relaxed and the longitudinal axial force is exerted on the other end.

**Figure 7** Geometric model**Figure 8** Details of the binding site**Figure 9** The finite element model

As for the axial compression component, the ultimate bearing capacity of finite element simulation is 6688kN. The comparison of load–displacement curves between experimental and FE result are shown in figure 10. It can be seen from the figure that the finite element analysis results are similar to that of the actual test, which demonstrates the finite element analysis method is valid.

As for the axial tension component, the ultimate bearing capacity of finite element simulation is 4589kN. The load-displacement curve of the finite element analysis is shown in figure 11. The tension ultimate bearing capacity is less than the compression capacity, which is in line with the common sense of gusset connection. On the one hand, it also shows the correctness of simulation.

**Figure 10** Comparison of load–displacement curves between experimental and FE result**Figure 11** Load-displacement curve of tension FE result

## 6. Conclusion



In this paper, axial compression experiment of the connection property between full-scale composite member and steel sleeve was conducted. The tensile connection strength of the component was obtained through the FE method. The main conclusions are as follows:

- (1) As for the axial compression experiment, the ultimate bearing capacity of the component is between 4950kN and 6950kN, the mean value is 6150kN. The standard deviation of the test data of the ultimate bearing capacity of the component is 1058.3kN, which shows that the dispersion of connection performance is quite large. The longitudinal strain of the steel sleeve connecting the fiberglass composite material is about 8000 to 10000  $\mu\epsilon$ , the steel sleeve strain is less than 800  $\mu\epsilon$ , which is still in the elastic stage.
- (2) As for the tension analysis, the ultimate bearing capacity of the component is 4589kN. The failure of the component also results from the failure of the adhesive. The tensile ultimate bearing capacity of the component is less than the extrusion bearing capacity.
- (3) Bonded steel sleeve connection for full-scale composite member can better exert the strength of the composite material, for the connection strength is close to the compression strength of GFRP. The connection mode is capable to meet general engineering requirement.

## 7. References

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