

Experimental Verification of Glass Fiber Sleeve Reinforced Bridge Pile Foundation

Xinlei Chen¹, Yujun Cai¹, Rui Wang^{1,*}, Shigang Luo², Fengning Li²

¹School of Mechanical Engineering, Tianjin University of Technology and Education, Tianjin, China

²Carbon Technology Group Co., Ltd, Tianjin, China

*Corresponding author

Abstract

Aiming at the corrosion problem of steel pile foundation, this paper analyzes the characteristics and advantages of glass fiber sleeve reinforcement technology, and introduces the application of glass fiber sleeve reinforcement technology in the maintenance and reinforcement of steel pile foundation combined with the reinforcement project of Anyang Road Bridge over Hai River. Through the design test, it is verified that the measured bearing capacity is greater than 600 kN, which meets the requirement of single pile bearing capacity of steel pipe pile in the design scheme of bracket reinforcement.

Keywords

Reinforcement Technology; Steel Sheet Piling; Glass Fiber Sleeve; Special-shaped; Bearing Capacity.

1. Introduction

With the improvement of steel production capacity and the continuous progress of bridge construction technology, a large number of steel structure trans-river and sea Bridges have been greatly developed, and a higher request is also put forward for the bearing performance of bridge pile foundation. However, in the seawater environment, chloride ions in the water will lead to steel corrosion [1], especially the corrosion of steel structure in the splash area is faster, which seriously affects the service life of steel pile foundation and leads to premature failure of pile foundation structure [2].

Anyang Road Haihe Bridge is located in Haihe River, an important geographical location. Due to the unsealable waterway, the bridge cannot be closed, resulting in increasing corrosion of steel pipe pile supports located in the middle of Haihe River, especially those in the splash-wave section. In order to ensure the overall safety and stability of the load-bearing support, it is necessary to carry out necessary detection and reinforcement measures for the main structure. The working condition of Anyang Road Bridge across Haihe River is shown in Figure 1.

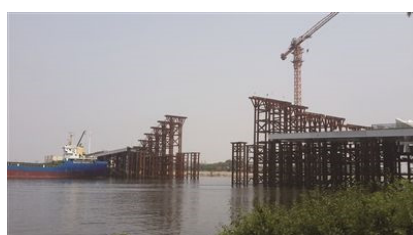


Figure 1. Reinforcement project of the Anyang Road Crossing the River Bridge

At present, the anti-corrosion reinforcement methods for steel structure buildings include glass fiber composite reinforcement method, brush anticorrosive coating reinforcement method [3], steel casing protection reinforcement method, etc. The anticorrosive coating has certain pollution to the water environment and poor durability, which makes it impossible to carry out secondary reinforcement of the steel structure. The construction cost of the steel sheath is high and the construction cycle is long [4]. Compared with the above two methods, glass fiber composite reinforcement method has become an ideal material choice for repairing steel structures due to its lightweight, high strength, good corrosion resistance and excellent fatigue performance [5], and it has been widely used in the repair and reinforcement of existing buildings in recent years. The glass fiber sleeve reinforcement technology is finally selected in this project. This technology can not only meet the reinforcement requirements of the cylindrical steel pile structure, but also has the advantages of convenient construction technology, shortening the reinforcement period, and large-scale production capacity. It can be applied to the repair and reinforcement projects of similar special-shaped building structures in the future.

2. Reinforcement Performance Verification Experiment of Glass Fiber Sleeve

In order to test the safety and reliability of construction technology and determine the bearing capacity of glass fiber sleeve reinforced steel pipe pile, the performance of the reinforcement scheme must be verified. At present, many researchers at home and abroad have studied the axial compressive properties of composite columns such as GFRP tube-concrete-steel tube and CFRP/ FRP-concrete-steel tube [6]-[12], so that the actual field conditions can be simulated for axial compression tests, and the failure bearing capacity and mechanical properties of specimens from the elastic stage, loading to the design load can be studied.

2.1 Experimental Base Material

The experimental substrate mainly includes steel pipe pile, glass fiber sleeve, underwater epoxy grouting material and related accessories (including supporting fastening belt, sealing ring, stainless steel nail, underwater epoxy sealing glue, underwater epoxy capping, etc.). The specimens used $\Phi 630$ mm*8 mm steel pipe piles of the same material size as those in the engineering.

2.2 Experimental Base Material

According to the working condition, the corrosion height of pile foundation tends to 100 mm, and the corrosion depth is about 4 mm. The design of this specimen takes into account the ultimate bearing capacity of steel pile reinforced with glass fiber sleeve when the corrosion thinning is reduced to 4 mm. The specific design is as follows:

Disconnect the steel pipe pile from the middle position with a spacing of 200 mm; A section of steel pipe with the same diameter is spot-welded in the middle position of steel pipe pile, and the wall thickness of steel pipe is 4 mm; Then weld the temporary support channel steel at the four corners of the pressing plate above and below the steel pipe pile, and wrap the glass fiber sleeve (sleeve length 1.2m, thickness 5 mm) in the middle area. The force transmission length between the steel pipe and the underwater epoxy grouting material was calculated as 0.5m, the grouting material pouring thickness between the sleeve and the steel pile was 20 mm, and the bearing capacity of the glass fiber sleeve reinforcement system was checked according to the vertical bearing capacity of a single 600kN in actual working conditions. The channel steel was sawed off before the pressure test began.

2.3 Experiment Part Parameter Design

In the anti-pressure experiment of glass fiber sleeve, the bearing capacity of the specimens mainly includes steel pile, grouting material and sleeve, and the failure form is mainly deformation and falling off of each part. Therefore, it is necessary to calculate the bonding and compressive bearing capacity between the materials of each part and determine the minimum theoretical bearing capacity. The material property parameters required by the experiment are shown in Table 1.

Table 1. Material performance parameters required for the experiment.

Materials/Mechanical properties	Parameter value
Steel tube	
Steel pipe diameter	0.63 m
Transmission length	0.5 m
Residual wall thickness of steel pipe	0.004 m
Glass fiber sleeve	
Thickness of glass fiber sleeve	0.005 m
Strength of extension	400 MPa
Modulus of elasticity in static bending	20 GPa
Underwater epoxy grout	
Thickness of grout material	0.02 m
Section area of grout material	0.0408 m ²
Calculated length	0.5 m
Compressive strength	100 MPa
Bond strength of epoxy grout to steel	1.2 MPa
Bond strength between epoxy grout and glass fiber sleeve	2.5 MPa

The bearing capacity results are shown in Table 2. It can be seen from the results that the weakest link in theory is the bonding bearing capacity link of steel pipe grouting material. The minimum theoretical bearing capacity is 1188 kN, which meets the bearing demand of a single pipe of 600 kN in actual working conditions.

Table 2. Calculation result of bearing capacity

Property	Parameter value
Bond capacity of glass fiber sleeve grouting material	2631 kN
Bond capacity of steel pipe grouting material	1188 kN
Calculate the compressive capacity of grout material	3264 kN
Calculation of compressive capacity of glass fiber sleeve	4241 kN
Residual wall thickness bearing capacity of steel pipe	1691 kN

2.4 Test Piece Measuring Point Arrangement

In order to measure the strain value of the glass fiber sleeve under static loading, resistance strain gauges were uniformly arranged at the measuring points from S1 to S5 along the longitudinal direction, and a transverse resistance strain gauge (S6) was arranged at section S3. There were 6 resistance strain gauges in total.

2.5 Experimental Testing Method

The static loading test is carried out on the hydraulic servo long column test machine, and the curve of load displacement is displayed intuitively through the testing machine. The reinforced steel pipe column was hoisted onto the hydraulic testing machine. In order to prevent eccentric compression, the center of the sample was aligned with the center of the lower pressing plate of the testing machine during the hoisting process. In order not to affect the force of the component, the temporary supporting Angle was sawed off from the middle position.

3. Results and Discussion

3.1 Experimental Phenomenon

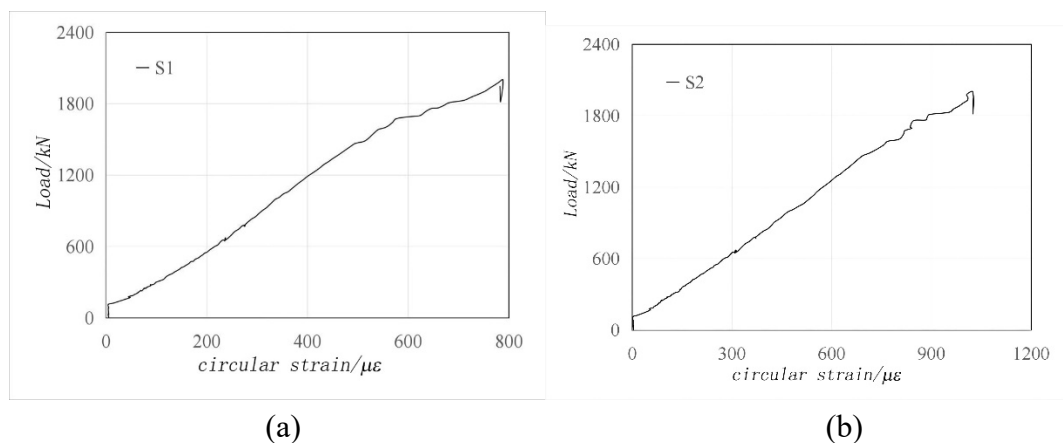
The simulated corrosion degree of the specimen is relatively low. When the load is loaded to 1667 kN, the specimen makes a slight sound, and the load value quickly rises after a small reduction. When the load was loaded to about 1900 kN, the specimen made a small breaking sound for many times. At the end of the test, no obvious damage occurred to the cylinder body and sleeve of the steel pipe, as shown in Figure 2.



Figure 2. Failure photo of sample

3.2 The Load-strain Curve of Sample

Figure 3 and 4 respectively reflect the load-circumferential strain curves and load-axial strain curves of specimens. Before reaching the maximum adhesive failure load, the load of the hoop increases in a roughly linear relationship with the circumferential strain and axial strain. When the specimen reaches the maximum adhesive failure load of 1701.85kN, the upper and lower column segments slip, and the annular and axial strains in the simulated corrosion zone (S3) increase sharply. After reaching the maximum adhesive failure load, the load of the specimen still rises. The above shows that the simulated corrosion degree of the specimen is small, the bearing capacity is large, and the hoop is involved in the force transfer between the upper and lower steel pipes. With the increase of the load, the strain of the hoop also increases, and the restraint effect of the hoop is also enhanced, but it is far less than the ultimate strain, indicating that the material strength of the hoop is not fully used.



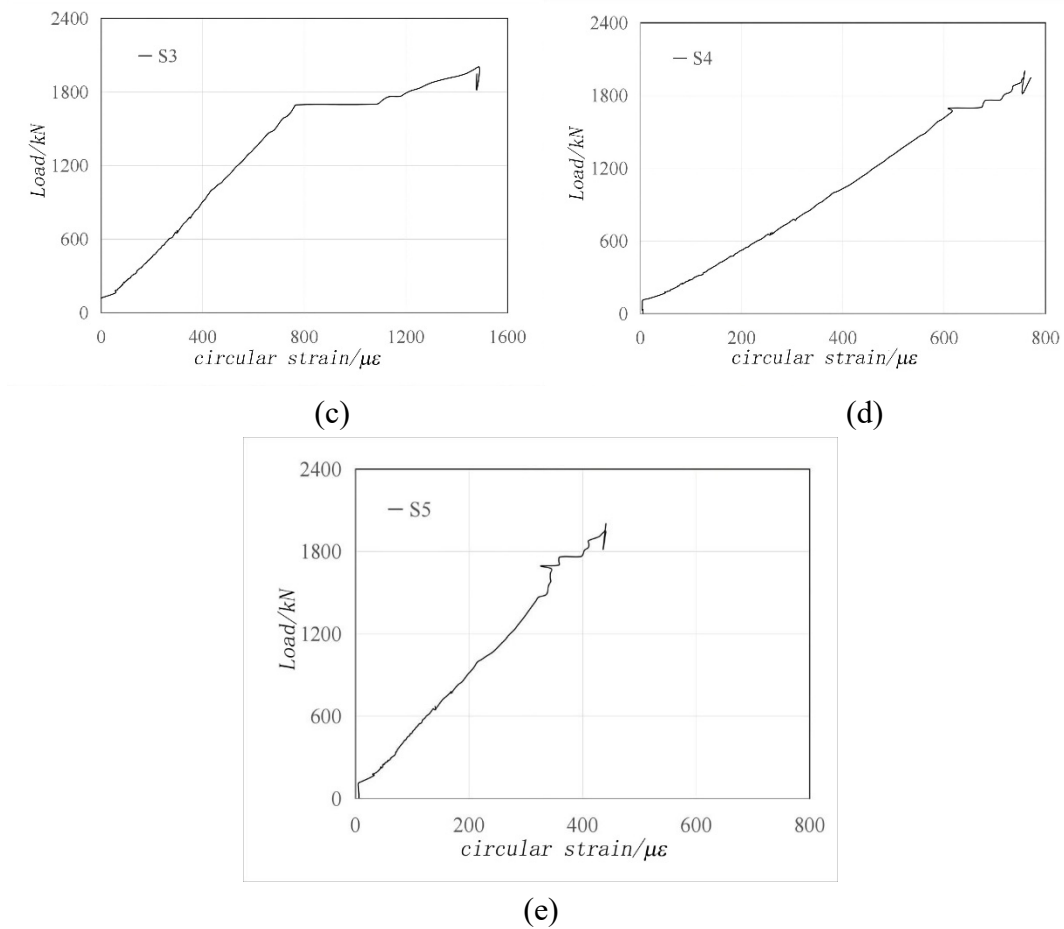


Figure 3. The load-circular strain curve of sample

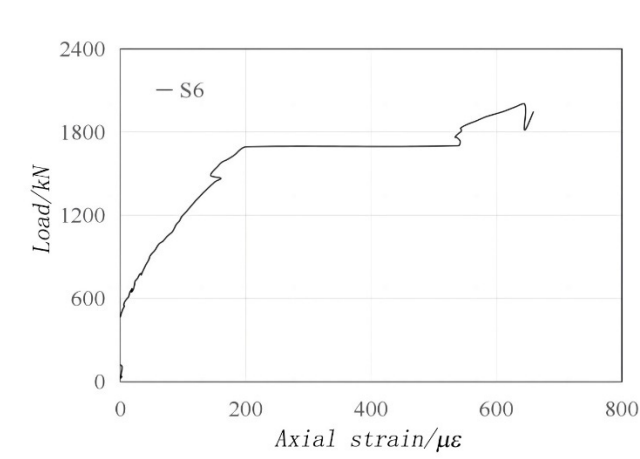


Figure 4. The load-axial strain curve of sample

4. Failure Form and Cause Analysis

After cutting the outer collar, it was found that the epoxy grout layer was intact without any cracks, as shown in Figure (5-a). After cutting out the local epoxy grout, it was found that there was a local void between the epoxy grout and the steel pipe wall (see Figure (5-b)). The thin steel plate between the upper and lower steel pipes is buckling (see Figure (5-c)), indicating a large relative displacement between the upper and lower steel pipes. When the epoxy grouting material was released from the pipe wall, it was found that no epoxy grouting material remained on the pipe wall (see Figure (5-d)), indicating that the interface between the two was a weak area. At the same time, it was found that the back of the shed epoxy grouting material was covered with rust (see Figure (5-e)), resulting in a

smaller actual force contact area between the epoxy grouting material and the steel pile. According to the investigation, the main reason that the rust floating on the base surface did not meet the requirements is that the test pile underwent a whole treatment before the year, but the sleeve was not covered and the grouting material was not poured because the connection mode of the upper and lower steel pipes was not determined. After the connection mode was determined, the rust removal operation was not carried out. The idle period of nearly 2 months resulted in a large area of rust regrowth.

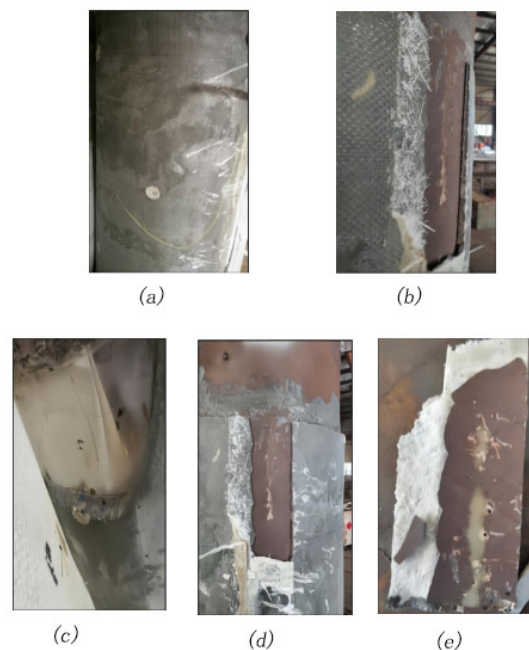


Figure 5. Failure image of test sample

5. Conclusion

Through the research and analysis of steel pile foundation, the method of glass fiber sleeve reinforcement and experimental verification are proposed, and the following conclusions are obtained:

- (1) Combined with the actual situation of steel pile foundation of Anyang Road cross-Haihe Bridge, the method of glass fiber reinforcement for pile reinforcement is proposed;
- (2) The performance verification experiment of the special-shaped glass fiber sleeve reinforcement system is designed. The results show that the actual bearing capacity of the specimen is greater than 600 kN, which meets the requirement of the vertical bearing capacity of single steel pipe pile designed in the bracket reinforcement design scheme of 600 kN.
- (3) The failure form shows that the interface between epoxy grouting material and pipe wall is a weak area, so in the subsequent construction process, the surface rust floating should be cleaned to increase the contact area between epoxy grouting material and the actual force of steel pile.

References

- [1] Zhao, S. C. Study on Environmental Action Zoning of tidal affected Area Based on Durability of Concrete Structures [J]. Journal of Highway Communication Technology, 2010, 27(7):61-64.
- [2] Wei,M.H., Yan,F. Application of glass fiber Sleeve Reinforcement Technology in High pile Wharf maintenance Engineering [J].Marine traffic engineering,2017(9):202-205.
- [3] Lu,G., Wei,W.J., Screening of anticorrosive Coatings for Repairing and Protecting Reinforced Concrete Pipe Support [J].Coating industry,2008(02):40-42.

- [4] Chen,H.Z., Comparison between Reinforcement of traditional Steel Sheath by Increasing Section and Reinforcement of underwater glass fiber Sleeve [J].Technology Outlook,2016, 26(17): 176.
- [5] Xiao,Y.H., Research on strengthening technology of underwater glass fiber sleeve [J]. Urban roads and Bridges and flood control, 2017(7): 146-149.
- [6] Zhang,Y.R.,WEI,Y.,BAI, J.W.,et al. Stress-strain model of an FRP-confined concrete filled steel tube under axial compression[J]. Thin-Walled Structures ,2019, 142(9): 149-159.
- [7] Wang,Y.L.,YU,T.,Teng,J.G.,et al. Behavior of FRP-confined concrete in annular section columns[J]. Composites:Part B, 2008, 39(3) : 451-466.
- [8] Li,S.B., Pan,X.N.,Chen,Y.N.,Qin,K.,Experimental study on axial compressive properties of concrete-filled steel tube stiffened mixed column restrained by GFRP tube [J].Concrete, 2022(05):31-36.
- [9] Tan,S.Z.,Jiao,C.J.,et al. RPC compression test of CFRP-steel tube[J].Concrete, 2017(7): 146-149.
- [10]Kiank, Michael, J., et al. Testing and modeling of a novel FRP-encased steel–concrete composite column[J]. Composite Structures,2011,93(5):1463-1473.
- [11]Qian,J.R.,Liu,M.X.,et al., Experimental Study on Axial Compression of FRP-Concrete-Steel Double-wall Hollow Tube Short Column[J].Journal of Building Structures , 2008, 29(2): 107 -113.
- [12]Shakir, A. S., Guan, Z. W. Jones, S. W. Lateral impact response of the concrete filled steel tube columns with and without CFRP strengthening[J]. Engineering Structures, 2016, 116: 148 -162.