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A Review of Experimental Studies on the Mechanical Properties of Grouting Connections of Steel Pipe Sleeves

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Abstract

The prefabricated concrete structure is widely used in practical engineering due to its short construction period, energy saving and environmental protection, and with the continuous integration of Internet technology and the construction industry and the rapid development of the concept of ecological building, and the connection technology of concrete-filled steel tube column joints in the prefabricated structure is more complex, the connection technology of steel pipe sleeve grouting connection is proposed. The experimental study of bending mechanical properties, compression mechanical properties and fatigue mechanical properties, the analysis of their force mechanisms, experimental conclusions, and personal opinions on the experiments provide a convenient and reference for the related mechanical research of steel pipe sleeve grouting in the future.

Keywords

Prefabricated Concrete Structure; Grouting Connection of Steel Pipe Sleeve; Mechanical Properties; Connection Technology.

1. Introduction

The connection of the steel structure is usually welded, bolted, rivet connection, but this link mode can not meet the requirements of its mechanical properties in the special connection technology environment, such as in the construction of the rigid node of the offshore platform, the construction of the mine support structure, the construction of the wind power pile foundation and other special projects, the traditional connection technology obviously can not meet its safety and reliability, feasibility, durability and other factors, in order to solve these worries, scholars at home and abroad continue to conduct in-depth research, with the passage of time, the steel pipe sleeve grouting connection technology came into being, this connection technology has penetrated into the field of construction.

The grouting connection of the steel pipe sleeve is a combination assembled by a steel pipe, a sleeve, a grout material and a shear key, and a connection method that relies on the bonding occlusion between the material and the shear key by injecting the grouting material between the sleeve and the steel pipe and attaching a shear key. This connection method can not only resist the corrosion of steel pipes, but also improve its stiffness, increase its bearing capacity and fatigue resistance, so as to ensure the safety and reliability of the structure, so it is of great significance to carry out experimental research on the mechanics related to the grouting connection of steel pipe sleeves.

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2. Study of Axial Mechanical Properties

Scholars at home and abroad analyzed the factors affecting the bearing capacity, the load-displacement curve of the specimen, the failure process of the specimen, and the stress-strain distribution by carrying out axial loading on the specimen.

Teng Lirong et al. [1] studied the bearing capacity and failure of four groups of grouting sleeve connectors, and analyzed the influence of shear keys, the length of grouting connections, and the conical form on the axial bearing capacity and failure of steel pipe sleeve grouting The length of the grouting connection section has no obvious influence on the bearing capacity, and the cylindrical shear key is better than the conical one, and when the load is large, the setting of the shear key greatly improves the bearing capacity, but the stress concentration is easy to appear at the shear key at both ends of the connecting section, it is recommended to implement strengthening measures at both ends, and the increase of the length of the connecting section will resist the displacement under the same load, and the conical form grouting connection is better; Li Wei et al. also designed four kinds of specimens, namely "shorter with and without shear bonds", "longer with shear bonds" and "tapered with shear bonds", and the conclusions obtained by applying axial loads to them were equivalent to those of Teng Lirong et al., both of which showed that the setting of shear keys and the grouting connection of tapered shape are helpful to improve the axial bearing capacity.

Wang Guoqing et al. [2] (2017) studied the variation of the bearing performance of grouting sleeves under different shear key height-to-pitch ratios and different connection diameters by carrying out two sets of 30 grouting connection model specimens axial load-bearing performance tests. According to the analysis of the test results of the small-diameter grouting sleeve, when the diameter of the casing is constant, the height (height and spacing) ratio of the shear key is not proportional to the bearing capacity, but there is an optimal shear key height and distance ratio, and the shear bearing capacity reaches the maximum value at this time, when the diameter is increasing, the change of diameter and the radial restraint stiffness of the casing have a greater impact on the axial bearing capacity, while the height and distance ratio of the shear key at this time has little influence.

Lamport et al. [3] (1991) tested the bearing capacity of grouting sleeve connections on 10 specimensThe results show that the difference in the thickness of the grouting material in the grouting sleeve structure has no obvious effect on its bond strength, and the paper only analyzes the influence of the thickness of the grouting material, and does not study the influence of the grouting strength, grouting length and other factors, so a control experiment should be set up for further study.

Hawileh et al. [4] conducted an experimental study of axial bearing capacity by using five sets of grouting sleeve connectors. The influence of different steel pipe wall thicknesses and different sleeve wall thicknesses on the bearing capacity is studied, and the comparative analysis of experimental and calculated results shows that within a certain range, the sleeve wall thickness has a significant effect on the bearing capacity, while the steel pipe wall thickness has little effect on itWhen the axial pressure is applied, only one direction is applied in this experiment, and the influence of the reciprocating static load axial experiment on the mechanical properties needs to be further studied.

Wang Qiuyu et al. [5] conducted a research test on the compression and bending capacity of the grouting connection of the steel pipe sleeve, and he divided it into two groups, one for the axial compression test and the other for the compression and bending test. The authors analyzed the failure process of the specimens, and used steel pipes with an outer diameter of 168 mm × 8 mm. The axial compression test by Wang Qiuyu et al. was carried out on a 200-ton testing machine, and the steel pipe was filled with C40 self-compacting concrete. The experimental phenomenon shows that in the early stage of loading, there is no obvious phenomenon, with the increase of load, the steel pipe and the sleeve begin to have a small relative vertical displacement, when the load value increases to 70%~90% of the ultimate load, the relative vertical displacement increases, and the specimen emits a small cracking sound. When the load is about 1600KN, the relative vertical displacement increases sharply, accompanied by a large cracking sound of grouting material, which indicates that the

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specimen reaches the limit of compressive bearing capacity. The average ultimate bearing capacity of the axial compression test is 1559 KN.

Wu Liwei et al. [6] conducted experimental research on the axial compression performance of the steel pipe grouting sleeve connection, and studied the influence of factors such as connection length and grouting material strength on the mechanical properties of the steel pipe sleeve grouting process. The bond and radial stress continue to increase, when the grouting material is partially damaged, the internal stress of the structure changes, and the axial stress does not increase with the increase of load, while the radial stress on the steel pipe and sleeve increases suddenly, and the bond stress distribution gap of the contact surface is significant.

Zhong Weiqiu et al. [7] carried out experimental research and numerical simulation analysis on the grouting connection technology between pile foundation and jacket, and studied the mechanical properties under axial load with or without shear bonds. The experimental and simulation results are in good agreement, the results show that the setting of the shear key enhances the axial bearing capacity, and the grouting connection effect is significantly improved, and the compressive, friction and shear stress on the contact surface between the steel pipe and the sleeve are compared and analyzed, and it is found that the setting of the shear key can promote the transmission effect of axial force.

To sum up, the research results of the scholars are in good agreement, the setting of the shear key, the grouting connection section of the conical shape, the length of the grouting connection, the increase of the strength of the grouting material, the increase of the thickness of the sleeve wall, can enhance the axial bearing capacity of the specimen, at the same time, the setting of the shear key will also enhance the transmission of axial force, and the high distance ratio of the shear keyWith the increase of axial load to the failure of the grouting material, the stress and strain inside the specimen continue to increase, and after the failure of the grouting material, the bonding stress is unevenly distributed, the axial stress stops increasing, and the radial stress increases significantly, and the bond strength has nothing to do with the thickness of the grouting material.

3. Study on Flexural Performance

The study of the flexural properties of components is one of the important indicators of mechanical properties, and scholars at home and abroad have conducted in-depth research on the stress mechanism and the factors affecting the flexural bearing capacity.

Yang Lidong et al. [8] analyzed the force mechanism of the grouting connection under the action of bending moment, and used numerical simulation analysis method to obtain the relevant conclusions of shear and tensile stress generated on the contact surface of the steel pipe and grouting material, and the bending moment and shear force generated by wind load. The results show that the compressive stress and friction on the contact surface transmit the bending moment and shear force, and when the grouting material produces horizontal cracks, as long as the grouting material can transmit the compressive stress, the transmission of the bending moment of the connection section is not obvious, and the axial bearing capacity is significantly improved when the shear key is set, but the bearing capacity of the bending moment is not obvious. The shape and height and spacing of the shear key are affected by other factors, so the experiment should be supplemented.

Ma Ye et al. [9] analyzed the force mechanism of the grouting casing connection section under the action of bending moment, and deduced the corresponding formula. At the same time, ANSYS simulation analysis is carried out, and the experimental results show that under the action of wind load, the transmission of bending moment in the connection section is mainly related to the compressive stress and friction of the contact surface, and has little influence on whether there are cracks in the grouting materialThe shear key has a great effect on the axial bearing capacity, but has little effect on the bending moment bearing capacity, and the influence of the dynamic load on the bending bearing capacity performance is not analyzed, and the actual engineering load has a change, so it is of great significance for its research.

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Han Xu et al. [10] studied the flexural performance of round concrete-filled steel tube components under different connection forms, and analyzed the bearing capacity, stiffness, and stiffness of the bending specimensThe analysis results show that the stiffness of the steel pipe sleeve grouting connection specimen is higher than that of the integral steel tube concrete component, the initial and use stage is increased by more than 15%, and the ultimate bending stiffness is increased by 64.3%, so the flexural bearing capacity and ductility of the steel pipe sleeve grouting connection specimen exceed that of the overall steel tube concrete specimen, and the influence of pure bending is only studied in this paper, and in practice, it will be affected by axial force, bending moment, torque, etc., so the mechanical properties of its different connection forms should be further studied and analyzed.

Tao Chen et al. [11] conducted a study on the flexural performance of grouting joints of offshore turbine support structures. The effects of different eccentricities, eccentricities, sleeve thicknesses, lap lengths, etc., on the flexural capacity, stiffness and ductility of the structure were studied. The experimental results show that the magnitude of different eccentricities has little effect on the flexural capacity, stiffness and ductility of the components, but the increase of eccentricity causes radial cracks to appear inside the grouting material, which will have a significant impact on the fatigue bending performance of the structure. The increase of the thickness of the sleeve will increase the bending stiffness of the specimen, reduce the peak bending capacity and yield displacement, but does not affect its ductility.

Li Kaiqiang et al. [12] studied the flexural performance of the connection section of the new grouting sleeve of offshore wind power foundation, and analyzed the stress mechanism of the grouting connection section under the action of bending moment. The experimental results show that the transmission of the bending moment of the new grouting connection section mainly depends on the contact pressure and friction between the steel pipe and the grouting material. However, whether to set the shear key in the connection section has little effect on the transmission capacity of the bending moment, under the influence of the bending moment load, within a certain range, with the increase of the connection length, the stress of the contact surface also increases, if the grouting length is too large to reduce the corresponding mechanical performance, its length should be 1.5 times the diameter of the steel pile; when the grouting thickness is between 90mm-100mm, the contact surface stress is smaller, and the stress in other intervals fluctuates greatly with the grouting thickness.

Nikolaos I. Tziavo et al. [13] performed a nonlinear finite element analysis of a sleeve grouting connection under large bending moments. The results show that the connection with shear key shows better mechanical properties than the connection without shear bond, and setting a higher shear key height can not significantly improve the bending capacity of the connection, and the layout of the shear key is very important to improve the bending capacity of the connection, and the analysis also proves that it can continue to transfer the load even after the grouting material is broken, but the paper does not analyze the bearing capacity distribution on the shear key, which should be further studied experimentally.

To sum up: the author's experimental results are in good agreement, the bearing capacity of the bending moment of the connecting section of the steel pipe grouting sleeve and whether the grouting material produces horizontal cracks, whether the shear key is not set is not obvious, and the compressive stress, friction, eccentricity, shear key layout position, eccentricity, sleeve thickness, lap length on the contact surface are closely related, and the grouting thickness is 90mm- At 100mm, the internal force on the steel pipe and grouting material is small, and the bending bearing capacity of the steel pipe sleeve grouting connection specimen is higher than that of the overall concrete-filled steel tube specimen.

4. Research on Compression and Bending Performance

Tao Chen et al. [14] studied the mechanical properties of grouting sleeve joints under compression-bending loads, and the authors used numerical methods and python to analyze the effects of grouting thickness, shear bond height and spacing ratio, and length-diameter ratio of pipes on compression-

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bending bearing capacity, and the results showed that the given axial compression ratio was n=In the case of 0.1, when the grouting sleeve connection specimen reaches the ultimate flexural capacity, the stress correlation coefficient is ηCOR varies between 1.2 and 2.0, and in the bending capacity analysis, the bending capacity provided by the shear key is the largest, followed by the contact pressure between the steel pipe and the grouting material, then the vertical friction between the grouting material, and finally the bending bearing capacity provided by the horizontal friction between the grouting material, but the first two together account for about 7 flexural bearing capacity6%.

Wang Qiuyu et al. [5] et al. carried out a test study on the compression-bending bearing capacity of the grouting connection of the steel pipe sleeve, and analyzed the factors such as compression-bending capacity, displacement, failure mode, sleeve strain, hysteresis curve, etc., and the experimental results showed that under the action of compression-bending load, the axial pressure increased from 0. When 2N0 increases to 0.6N0, the stiffness increases, the energy dissipation and ductility deteriorate, and the horizontal bearing capacity decreases by 30%, but the stiffness increases slowly above 0.4N0, and the grouting material near the two ends of the connection is easy to crush and the shear key is easy to fail, and through the calculation and simulation, it can be seen that the smaller the axial pressure, the more likely it is to produce bending failure, and the larger the axial compression, the more easy the specimen is to be damaged by compression.

Qi Fang et al. [15] carried out a numerical study on the compressive bending performance of grouting joints of marine engineering structures, used ABAQUS to simulate the mechanical properties of the specimens under axial force and bending load, and used Python to derive the stress distribution, and the experimental analysis showed that the contact pressure and shear key of the contact surface had a great influence on the bending bearing capacity, accounting for 75% of the bearing capacity When the axial compression ratio increases from 0 to 0.18, the peak bending moment decreases by about 39%, the initial stiffness decreases by 37.8%, the secant stiffness decreases by 18.9%, and the ductility decreases by 23.6%. Moreover, the bearing capacity of the shear key is uneven under the compression-bending load, so the follow-up research should pay attention to it.

In summary, the research on the compression-bending performance of steel pipe sleeve grouting continues to deepen, under the action of compression-bending load, the bearing capacity provided by the stress between the shear key and the grouting material accounts for the largest proportion, and with the increase of axial pressure, the stiffness of the specimen increases, but the energy dissipation capacity becomes weaker, and the more susceptible to compression failure, with the increase of the axial compression ratio (0-0.18).The peak bending moment, stiffness and ductility all decrease, and due to the action of bending moment, the shear key is not uniformly stressed, the stress near the two ends of the connection section becomes larger, the grouting material is easy to crush, and the shear key is easy to fail, so it should be reinforced at both ends to further study the relevant mechanical properties.

5. Fatigue Performance Study

The complexity of the marine environment determines the complexity of the structural force, and the fatigue performance determines the service life of the steel pipe sleeve grouting structure, and the factors affecting the fatigue life include stress state, component form, load, etc., so it is of great significance for its research.

Li Kaiqiang et al. [12] used theoretical analysis and numerical simulation to analyze the mechanical and fatigue properties of the new grouting connection section of offshore wind power foundation, and the results showed that the stress concentration occurred at the position of the shear bond, resulting in a fatigue life of107 magnitude, and the specification requirements are 108 magnitude, do not meet the design specifications, the study finds that the new grouting connection section with wavy groove is evenly stressed, resulting in a fatigue life of 109 magnitude, to meet the requirements of the specification, and under the bending moment load, with the increase of the length of the connecting section, the stress on the steel pipe and the grouting material continues to increase, when the ratio of

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the grouting length and the diameter of the steel pipe is 1.5, the mechanical performance of the connecting section, The fatigue performance is good, but only the static wind pressure on the blade is considered in the experiment, and the influence of vibration on the fatigue performance is not considered, and further analysis and research should be carried out.

Boswell et al. [16] carried out relevant mechanical studies on the connection section of offshore grouting sleeves, studied the fatigue resistance of specimens with different grouting strengths, tested 9 samples, and used 0.1HZ and 0.5Hz loading frequencies, and the experimental results showed that the fatigue performance of the high-strength grouting material was relatively poor, and the fatigue limit of high-strength grouting was about 20.7% of the ultimate strength The fatigue limit of low-strength grouting is 32.5% of the ultimate strength, which is half of the critical value predicted by other literatures.

To sum up, scholars have conducted detailed research on fatigue performance, and the changes in the load, component form, and grouting thickness of the specimen have a great influence, which provides a theoretical basis for subsequent research.

6. Epilogue

By reading and summarizing the relevant literature at home and abroad, it is found that significant development has been made in the field of steel pipe sleeve grouting connection over the years, but there are still the following problems that need further research. When the grouting connection is applied at sea, under the action of repeated loads, the area near the shear key often withdraws from work in advance due to fatigue damage, and has a special environment, and the influence of water corrosion and other factors on the mechanical properties, durability and feasibility of the connector needs to be studied; The failure mode and the factors affecting the torsional resistance need to be further studied.

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