Finite Element Analysis of Influencing Factors of Micro Round Steel Pipe Pile Based on Pure Bending Orthogonal Test

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Abstract. Based on the pure bending orthogonal test of different diameter grouting micro circular steel pipe, the influence of the parameters such as steel ratio, steel yield strength, the type and strength of filling material on the bending performance of the grouting steel pipe pile was simulated by the finite element software. The results show that the error between the ultimate bearing capacity of the cast-in-place steel pipe pile simulated by the finite element method and the test data is between 6.4\% and 13.6\%, which is in good agreement and can be used for simulation calculation; under the pure bending action, the steel content of the cast-in-place steel pipe component has a great influence on its bearing capacity; the yield strength of the steel pipe has a significant effect on improving the bending bearing capacity of the micro steel pipe pile; the filling core material of the steel pipe The influence of strength on flexural capacity is less, so the core filling material with low compressive strength can be used to reduce the investment.

Keywords: Micro round steel pipe pile; Orthogonal test; Numerical analysis; Bending performance.

1. Introduction

Grouting micro steel pipe pile is widely used in Landslide Control Engineering in China [1-3], but there are few researches on bending resistance. Jibohai [4] carried out experimental research on flexural performance of circular steel tube lightweight aggregate concrete members, sun Shuwei [5] carried out comparative analysis on the anti sliding characteristics of micro piles and common anti sliding piles, Zhou Depei [6] studied the combined anti sliding structure of micro piles and its design theory, Wang Shaojie [7] carried out experiments on the basic static performance of 89mm diameter steel tube bending functional micro piles In this paper, Yan Jinkai [8] carried out an experimental study on the engineering model of landslide micro pile group reinforcement, and Chen Lanxiang [9]used ABAQUS software to analyze the mechanical properties of section steel circular steel tube concrete. In these studies, the grouting micro steel pipe pile is regarded as the pile foundation under horizontal stress, and the design calculation is mainly based on the test results of concrete-filled steel tube, while the research on the influencing factors of the bending performance of the grouting micro steel pipe pile is less. However, because the diameter of steel pipe used for grouting micro steel pipe pile is generally between 40-150 mm, and the internal grouting material is pure water slurry or mortar, which is significantly different from the conventional steel pipe concrete with large diameter and the internal concrete material
contains coarse aggregate, it is very necessary to conduct a special study on the bending performance and influencing factors of grouting micro steel pipe pile, so as to provide a basis for the actual engineering design. In this paper, nine micro steel tubular pile members determined by orthogonal test are tested to study the relevant factors. Due to the relatively small number of test pieces, the ABAQUS finite element software is used to establish the numerical model.

2. Bending Test

2.1. Specimen Design and Parameters

Q235 seamless steel pipe is used for grouting steel pipe test piece. The length of the test steel pipe is 1.35m, and the calculated length is 1.20m. One end of the steel pipe shall be welded and sealed with steel plate, and the core filling material shall be pure water slurry or mortar. During fabrication, the slurry materials shall be evenly mixed by machinery, and fully vibrated during pouring to ensure the slurry density inside the steel pipe, and the corresponding material strength test shall be carried out according to the requirements. The relevant parameters of each test piece are shown in Table 1.

Table 1 Parameters of test piece

| specimen number | steel pipe diameter × thickness (mm) | i  | $\xi$ | $f_y$ / MPa | $f_{ck}$ / MPa | Filling material | ways of strengthening |
|----------------|-----------------------------------|----|------|-------------|---------------|-----------------|---------------------|
| CS57-3.5-A     | 57×3.5                            | 0.300 | 3.761 | 295         | 23.5          | mortar          | built in $\varnothing$ 22 steel bars |
| CS57-3.5-B     | 57×3.5                            | 0.300 | 3.310 | 295         | 26.7          | cement          | cement slurry outsourcing |
| CS57-3.5-C     | 57×3.5                            | 0.300 | 3.310 | 295         | 26.7          | cement          | cement slurry outsourcing |
| CS89-4.5-A     | 89×4.5                            | 0.238 | 2.599 | 292         | 23.5          | cement          | reinforcement $\varnothing$ 25+Cement slurry outsourcing |
| CS89-4.5-B     | 89×4.5                            | 0.238 | 2.953 | 292         | 23.5          | cement          | cement slurry outsourcing |
| CS89-4.5-C     | 89×4.5                            | 0.238 | 2.953 | 292         | 23.5          | cement          | cement slurry outsourcing |
| CS108-5.5-A    | 108×5.5                           | 0.240 | 3.029 | 297         | 26.7          | Mortar          | reinforcement $\varnothing$ 25 |
| CS108-5.5-B    | 108×5.5                           | 0.240 | 2.666 | 297         | 23.5          | Mortar          | cement slurry outsourcing |
| CS108-5.5-C    | 108×5.5                           | 0.240 | 2.666 | 297         | 26.7          | Mortar          | cement slurry outsourcing |

Note: 1) steel ratio: $i = A_s / A_c$, $A_s$ is the cross-sectional area of steel pipe, $A_c$ is internal slurry material respectively;
2) Stirrup tightening coefficient: $\xi = f_y / f_{ck}$ is the yield strength of steel, $f_{ck}$ is the axial compressive strength of mortar (cement paste);
3) The outer grouting material is the same as the inner grouting material, and the outer thickness is 30mm.

2.2. Test Loading Device

During the test, the load is applied by hydraulic jack, and the loading force is measured by pressure sensor. The longitudinal strain of steel pipe is measured by resistance strain gauge, and the data is collected by static strain tester. The loading measurement and strain gauge sticking of pure bending test specimens of micro steel tubular pile components are shown in Fig. 1. During the loading, the load is carried out according to the pre estimated ultimate bearing capacity, and the load stays for more than 2 minutes between all levels. When the deformation of the test piece approaches the maximum range of the strain gauge, the load is stopped.

Figure 1. Loading of test piece and sticking diagram of strain gauge (unit: mm).
3. Test Result

3.1. Analysis of Load Strain Curve
Select the typical specimen CS89-4.5-C to draw the load-strain curve as shown in Fig. 2. It can be seen from the analysis of Fig. 2 that the initial stage of loading is the stage of elastic deformation, the readings of each strain gauge are basically linear, the strain gauge readings at the upper and lower edges of the midspan change the most, and the strain at the corresponding parts of the upper and lower parts of the steel pipe is basically symmetrical to the neutral axis distribution; with the increase of loading, when the strain at the upper and lower edges of the steel pipe reaches the yield strain of the steel, the growth rate of the readings of the external strain gauge is faster than that of the external load. The load-strain curve deviates from the original straight line obviously after the steel pipe yielding. It can be seen from the analysis of the three and seven strain gauges in the center of the pasted steel pipe that the change of the two increases and the values are both positive, which indicates that the sum axis of the grouted steel pipe pile moves up continuously during the loading process.

![Figure 2. Load strain curve of typical test piece.](image)

3.2. Load-Deflection Curve
The load-deflection curve of 9 micro steel tube piles with different diameters is shown in Fig. 3. It can be seen from Fig. 3 that the larger the section size is, the greater the bending capacity of the micro steel pipe pile will be; when the diameter of the steel pipe is the same, the load deflection curve of the filled cement slurry or mortar is basically the same, indicating that the type of the internal filling material has little impact on the bending capacity of the component; adding a layer of external slurry on the outer edge of the steel pipe can not effectively increase the bending capacity of the micro steel pipe pile; adding reinforcement it can improve the bending capacity of the micro steel pipe pile by 14.5% - 31%, and the larger the increase is with the increase of the size of the test piece; even if the deflection of the middle section reaches $L/30$, the external load on the test piece can still increase, which shows that the ductility of the micro steel pipe pile component is better.

![Figure 3. Comparison of load-deflection curves of each test piece.](image)

4. Finite Element Analysis and Calculation

4.1. Model Building
The numerical simulation is carried out by ABAQUS finite element numerical calculation software [10].

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When modeling, the steel pipe and mortar unit type is C3D8R, and the reinforcement unit type is T3D2. Take CS-89-4.5-C as an example, the model with 22186 nodes and 16075 units. According to the actual situation of the test, one end of the bottom node of the test piece is constrained by the degrees of freedom in the x-axis and z-axis directions, and the other end of the bottom node is also constrained by the same conditions.

4.2. Analysis of Finite Element Calculation Value and Test Result

In order to verify the rationality of the finite element software in the simulation of the mechanical behavior of the micro steel pipe pile, CS-89-4.5-C micro steel pipe pile is selected for analysis. When the load of the micro steel pipe pile component is calculated to a certain extent by the finite element simulation, the stress nephogram of the micro steel pipe pile component is checked after the nonlinear solution (Fig. 4). The stress of the steel pipe at the outer edge of the tension area and the compression area of the micro steel pipe pile component is quite large, and the stress distribution is roughly symmetrical to the neutral axis, because the steel pipe is filled with a single cement mortar No local yielding of steel tube is found in the drawing.

![Figure 4. Stress diagram of component loading.](image1)

At the same time, the load deflection curve calculated by the finite element simulation is compared with the test results (Fig. 5). Through the comparison of the curves, it can be seen that the load deflection curve of the micro steel tubular pile members calculated by the finite element simulation is more consistent with the load deflection curve obtained by the test.

The test results and finite element analysis results of ultimate bearing capacity of each test piece are shown in Table 2.

| specimen number | test value(kN) | calculated value of finite element (kN) | error (%) |
|-----------------|---------------|----------------------------------------|-----------|
| CS57-3.5-A      | 25.6          | 22.3                                   | 12.9      |
| CS57-3.5-B      | 21.0          | 19.2                                   | 8.6       |
| CS57-3.5-C      | 19.8          | 18.1                                   | 8.6       |
| CS89-4.5-A      | 85.9          | 80.4                                   | 6.4       |
| CS89-4.5-B      | 71.5          | 62.3                                   | 12.8      |
| CS89-4.5-C      | 65.4          | 60.0                                   | 8.3       |
| CS108-5.5-A     | 125.3         | 115.7                                  | 7.7       |
| CS108-5.5-B     | 83.6          | 72.2                                   | 13.6      |
| CS108-5.5-C     | 78.5          | 71.1                                   | 9.4       |

Note: the ultimate bearing capacity is taken as the load corresponding to the strain in the tensile zone of the steel pipe when it is 10000 \( \mu \varepsilon \).

![Figure 5. Load deflection curve of component.](image2)

![Figure 6. Effect of steel ratio on P-F curve.](image3)
According to table 2, the error between finite element simulation and test is between 6.4% and 13.6%. Although the conditions of finite element model simulation test are different from the actual situation, the error is still within the acceptable range.

To summarize, it can be seen that the element selection, grid division and boundary conditions of the model material are more reasonable. Therefore, when there are few test pieces, the finite element method can be used to simulate and analyze the influence of the relevant parameters of the grouting micro steel pipe pile on the bending resistance.

4.3. The influence of parameter change on load deflection curve

4.3.1 Influence of steel content change. The influence of the change of steel content on the micro steel pipe pile is shown in Fig. 7, and the last number of the sample number in the figure is the steel content. Analysis of Fig. 7 shows that: when the steel ratio increases from 0.237 to 0.269, the flexural capacity of the component increases by 23%; when the steel ratio of the component increases from 0.269 to 0.302, the flexural capacity of the component only increases by 11%. This shows that the increase of steel content has a significant effect on the initial flexural rigidity of the component, and it is an important parameter affecting the flexural capacity of the micro steel pipe pile; the steel bars can be inserted into the steel pipes with larger sections to increase the steel content and enhance the strength of the component degree.

4.3.2. Influence analysis of steel pipe yield strength. The influence of the change of steel yield strength on the micro steel pipe pile is shown in Fig. 8. It can be seen from the figure that: when the load is before 40kN, the change of steel yield strength has a weak influence on the deflection change, indicating that the yield strength of steel pipe has little influence on the flexural rigidity of the member at the initial and service stages; when the yield strength is increased from 235MPa to 298MPa, the flexural bearing capacity of the member is increased by 21%, and when the steel content of the member is increased from 298 MPa to 345 MPa, its flexural strength is increased. The results show that the yield strength of the steel pipe has a significant effect on the bending capacity of the micro steel pipe pile. With the increase of the yield strength of the steel pipe, the bending capacity of the micro steel pipe pile also increases.

4.3.3. The influence of the strength of filling material. The influence of the change of the strength of the core filling material on the micro steel pipe pile is shown in Fig. 9. It can be seen from the figure that when the strength of the core filling material changes from 10.1 MPa to 36.7MPa, but the load deflection curve of the component is consistent with each other, indicating that the influence of the strength of different core filling materials on the bending capacity of the component is very small. Therefore, in order to save cost and reduce project cost, it is necessary to reduce the strength of core filling material of grouting micro steel pipe pile.

5. Conclusion

1) The comparison between the finite element calculation results and the test results shows that the error between the ultimate bearing capacity calculated by the finite element simulation and the test value is
between 6.4% and 13.6%, and the load deflection relationship curve simulated by the finite element simulation is also consistent with the test results. It can be seen that the selection of model materials, grid division and determination of boundary conditions are more reasonable, so when the test data is insufficient, the finite element method can be used to simulate the analysis.

2) The increase of steel content has a significant effect on the initial bending stiffness of the component, which is an important parameter affecting the bending capacity of the micro steel pipe pile; when the steel content of the micro steel pipe pile is high, the increase of steel content has no obvious trend to increase the bending capacity.

3) The yield strength of steel pipe has a significant effect on improving the bending capacity of micro steel pipe pile. With the increase of the yield strength of steel pipe, the bending capacity of micro steel pipe pile also increases.

4) Under the condition of different strength of core filling material, the flexural capacity of the component changes little. Therefore, in order to save cost and reduce project cost, it is necessary to reduce the strength of core filling material of grouting micro steel pipe pile.

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Reference
[1] Liu Kai, Liu Xiaoli, Su Yuanyuan. Application and development of micro anti slide pile [J]. Geotechnical mechanics, 2008 (added): 675-679.
[2] Tang Xianyuan, Gao Xiangdong. Analysis on the causes of embankment cracking in expansive soil area and treatment technology [J]. Highway engineering, 2014, 39 (5): 13-16.
[3] Tang Xianyuan, Li Yongpeng. Comprehensive treatment technology of embankment landslide caused by instability of expansive soil foundation [J]. Highway, 2011 (12): 6-10.
[4] Jibohai, Hu Zhengqing, Chen Jiashu, et al. Experimental study on flexural behavior of lightweight aggregate concrete members with round steel tubes [J]. Journal of civil engineering, 2007, 40 (8): 36 – 42.
[5] Zhu Benzhen, Sun Shuwei, Zheng Jing. In situ experimental study on micro pile group reinforcement of accumulative landslide [J]. Journal of rock mechanics and engineering, 2011, 30 (5): 2858-2864.
[6] Zhou Depei, Wang Huanlong, Sun Hongwei. Anti sliding structure of micro pile combination and its design theory [J]. Journal of rock mechanics and engineering, 2009, 28 (7): 1353-1362.
[7] Wang Shaojie, Liu Fusheng, Duan Xusheng, et al. Experimental research and application of bending functional micropiles [J]. Architectural science, 2009, 25 (11): 73-75.
[8] Yan Jinkai, Yin Yueping, men Yuming, et al. Study on model test of landslide micro pile group reinforcement engineering [J]. Journal of civil engineering, 2011 (4): 120-128.
[9] Chen Lanxiang, Guan Ping, Liu Qingqing. Analysis of mechanical properties of steel-circular steel tube concrete based on ABAQUS [J]. Journal of water conservancy and construction engineering, 2015, 13 (2): 15-19.
[10] JUSTO E, MANUEL V B, LUIS J J, et al. An elastoplastic model for the analysis of a driven pile extended with a micropile[J]. Computers and Geotechnics, 2017, 87(1):10-19.
[11] Chen Zaiqian, Pu Shuxi, Guo Guo, et al. Bending resistance of micro concrete filled steel tubular members Performance of numerical simulation[J]. Journal of Chongqing Jiaotong University (Natural Science), 2018, 37 (1): 72-79.
[12] Liu Zhan. ABAQUS finite element analysis from introduction to mastery [M]. Beijing: People's post and Telecommunications Press, 2015.