Hydraulic and Civil Engineering Technology VII
M. Yang et al. (Eds.)

doi:10.3233/ATDE220907

Comparative Study on Ultimate Stress Test and COMSOL Analysis of Steel Beam of Pull-Up Cantilever Scaffold

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Abstract. Combined with the actual project, the mechanical properties of the cantilever steel pipe scaffold system are tested by model test, including the bending stress, vertical shear stress and vertical deformation displacement of the test steel beam. The stress state of the cantilever steel pipe scaffold system is analyzed, and the mechanical properties of the cantilever steel pipe scaffold system are simulated by COMSOL numerical simulation software. By comparing the results of numerical simulation and ultimate load test, the variation law of stress and vertical deformation displacement of the steel beam with the pull-up cantilever frame in the loading process is obtained, which provides necessary experimental and theoretical basis for monitoring and early warning of the pull-up cantilever scaffold.

Keywords. Pull-up cantilever scaffold, stress test, finite element analysis

1. Introduction

At present, the design load of cantilever outer frame in China is based on the Safety Technical Specification for Fastener Steel Pipe Scaffolding in Construction. JGJ 130—2011 [1], which specifies the load type, load partial coefficient, load value, load combination principle, length of cantilever end and fixed end, anchorage method, etc. that should be considered in the design of cantilever outer frame system [2]. In addition, the theoretical calculation and numerical simulation of cantilever scaffold have been relatively perfect in China, but it is very rare to test the ultimate stress and vertical deformation displacement of the steel beam of the cantilever outer frame. Therefore, this paper mainly focuses on the scientific research on the ultimate mechanical properties of steel cantilever beam of cantilever scaffold, and at the same time, combined with COMSOL finite element software [3] to simulate the cantilever outer frame system model, analyzes the stress changes of cantilever outer frame steel in the loading process [4], which provides necessary experimental and theoretical basis for monitoring and early warning of cantilever scaffold.

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2. Test Scheme of Cantilever Outer Frame Bearing Capacity

I-beam cantilever end length is divided into 1.2m, vertical pole distance of 1.5m, horizontal pole distance of 0.8m and vertical pole step distance of 1.8m. Difficulty of test: 1) The weather conditions have great influence on the data sensitivity of strain gauge test when the test is carried out outdoors; 2) The number of test points is large, and the site workers' operation is easy to damage the test points. Before loading, it is necessary to test the accuracy of the test point data many times; 3) Test 7 shows that the load is large and the duration is long.

In the test area of the cantilever outer frame, the normal and shear stresses of the section steel are tested by installing the resistance strain gauge at the root of the fixed end; Set a dial indicator at the free end and 30cm away from the root of the free end to test the deflection and deformation of I-beam during loading.

2.1. Preparation of Test Materials

The materials and instruments required for the full-scale test of cantilever frame are shown in table 1.

Table 1. Test Materials and Instruments.

Material name	Quantity	Material name	Quantity
Alcohol	1 bottle	Cyanoacrylate Glue/Adhesive	5 boxes
Electric Iron	5	Notebook	1 set
Rosin	5 boxes	Torque Wrench	1 put
Tin Solder	1 volume	Dial indicator	4
Tweezers	5	BZ2205 Resistance Strain Gauge	1 set
Insulating Tape	20 volumes	Camera	1 set
Wire Stripper	2	Video Recorder	1 set
Absorbent Cotton	500g	Standard Brick	200 horses
Multimeter	2	Steel Tape Measure	1 put
Handheld Grinding Wheel Grinder	2	Lead	100m
Scissors	5	75 Glue	5 boxes

2.2. Specimen and Material Requirements

According to the actual situation at the site, steel pipe 48×3.0 is selected as the material, and the model is Q235 steel pipe. The design value of compressive strength of vertical steel pipe is 215N/ mm^2, and the elastic modulus is 205N/mm^2. Before the test, it shall be inspected according to the requirements of Code for Acceptance of Construction Quality of Steel Structures (GB50205—2011 [5]), and the test can be carried out only after it is qualified.

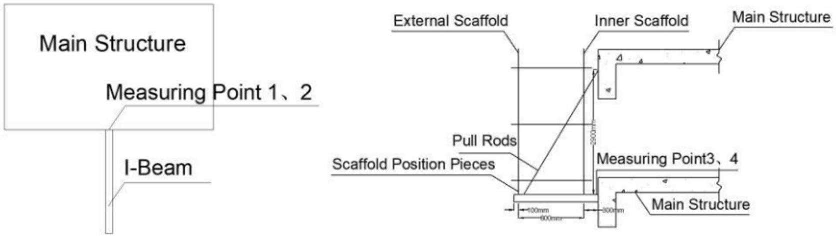
Test that the tightening torque of all fasteners is ≥ 40N m, and shall not be greater than 65N· m. All fasteners shall be corrected one by one by torque wrench.

15mm × 800mm wood pattern is used for hard protection, with the design value of bending strength of 17N/mm^2 and elastic modulus of 404N/mm^2. Before the test, it shall be inspected according to the requirements of Code for Acceptance of Construction Quality of Timber Structure Engineering (GB50206-2012 [6]), and the test can be carried out only after it is qualified.

Weld the anti-slip positioning piece on the section steel, and weld the vertical rod and the positioning piece into a whole to ensure that the frame body will not overturn during the loading process.

2.3. Test Model

Pull-up cantilever external frame scheme: the length of I-beam is 1.5m vertical pole, 0.8m horizontal pole and 0.8m vertical pole step. Two I-beams are selected as test objects, numbered 1 and 2 respectively, and the layout of measuring points on the plane and elevation of the cantilever outer frame is shown in figure 1. Four measuring points are arranged at the fixed end of I-beam, three strain gauges are attached to the front measuring point and three strain gauges are attached to the side measuring point of each steel beam, and dial indicators are respectively set at the free end and 30cm away from the fixed end for reading the vertical displacement value of steel beam.



1) Layout of Plane Measuring Points 2) Layout of Side Measuring Points

Figure 1. Layout of Measuring Points of Steel Beam of Pull-up Cantilever frame.

2.4. Long-term Loading Scheme

Manual material transportation is adopted, and the loading is symmetrical from the middle to both ends from bottom to top. The loading process is shown in figure 1. Loading sequence: 1) Load 20kN for the first time and stop for 30min to collect data; 2) Load 10KN for the second time and stop for 30min to collect data; 3) Load 10KN for the third time and stop for 30min to collect data; 4) Load 10KN for the fourth time and stop for 30min to collect data; 5) Load 10KN for the fifth time and stop for 30min to collect data.

3. Numerical Simulation Method of Bearing Capacity of Cantilever Outer Frame

In this paper, COMSOL finite element software is used to determine the stress and deformation state of the steel beam of the pull-up cantilever scaffold, and the boundary conditions are imposed at the fixed end of I-beam by the method of zero linear displacement in three directions. The loading mode of the full-scale model is that the load borne by I-beam is applied to the top of the inner and outer vertical poles on average and vertically downwards, and the I-beam bears the construction average wiring load of 0.27KN/m, as shown in figure 2.

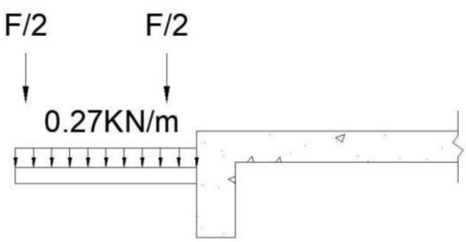
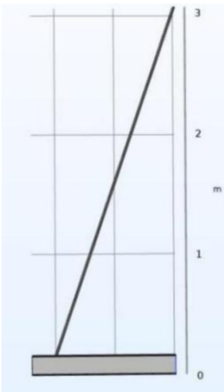


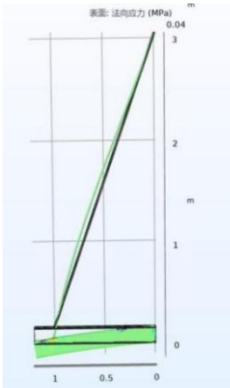
Figure 2. Schematic Diagram of Steel Beam Bearing Load.

3.1. Finite Element Simulation of Cantilever Outer Frame

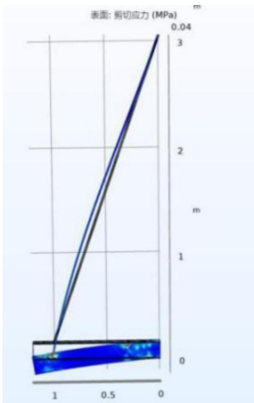
The finite element diagram, element node diagram, vertical displacement deformation diagram and normal stress under 20KN load are shown in figure 3.



1) Model



2) Normal Stress and Vertical Deformation Displacement



3) Shear Stress and Vertical Deformation Displacement

Figure 3. COMSOL Finite Element Simulation.

4. Test Results and Analysis

According to the analysis of the normal stress of section steel given in figure 4, the difference between the normal stress of No.1 and No.2 section steel is obvious, and with the increase of the upper load, the measured values of No.1 and No.2 section steel are 25.4% and 13.3% larger than the COMSOL simulation results, respectively. Analysis of reasons: (1) During the loading process, the stress on both sides of the section steel is uneven, which leads to the inconsistency of the measured normal stress; (2) During the loading process, the center of gravity of the structure keeps moving towards the free end due to the deflection of the free end, while the center of gravity of COMSOL numerical simulation remains unchanged, resulting in the measured value being larger than the simulated value.

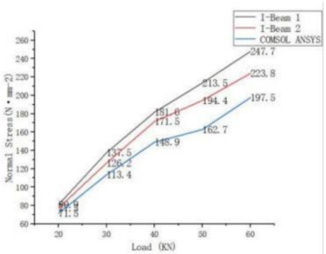


Figure 4. COMSOL Simulation and Field Measured Normal Stress.

By analyzing the shear stress of section steel given in figure 5, the simulated value of COMSOL and the measured value rise alternately, with a good coincidence degree. It can be seen that the shear stress of section steel is less affected by the shift of center of gravity during loading.

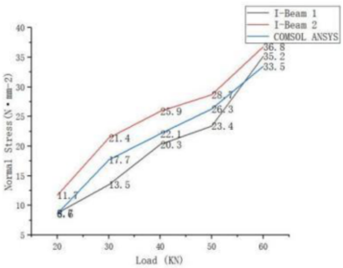


Figure 5. COMSOL Simulation and Field Measured Shear Stress.

By analyzing the vertical displacement of section steel shown in figure 6, it is found that the deflection deformation of No.1 and No.2 section steel is quite different, and the COMSOL simulation value is 11.7% and 15.2% smaller than the measured value of No.1 and No.2 section steel, respectively. Cause analysis: (1) During the loading process, the stress of the steel sections on both sides is uneven, resulting in inconsistent deflection values measured; (2) During the loading process, the center of gravity keeps moving forward, while the center of gravity of COMSOL simulation remains unchanged, and the simulated value is smaller than the measured value.

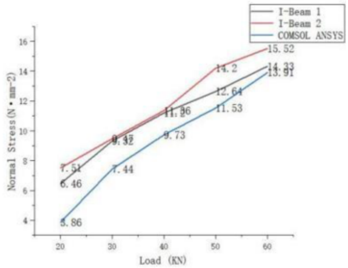


Figure 6. COMSOL Simulation and Field Measurement of Vertical Deformation of Free End.

Under the action of 60KN load, the measured value of vertical deformation at 20cm from the fixed end of I-beam (see figure. 7) does not follow the trend of formula νmax = 5q'lb4 /(384EI) in Code for Design of Steel Structures GB50017-2003, but obvious shear deformation occurs. Cause analysis: During the test, it was found that the concentrated load exerted by the inner pole of the cantilever outer frame on the section steel was very large, resulting in the concentrated stress generated by the shear stress near the fixed end of the section steel, which resulted in obvious shear deformation at the root of the section steel.

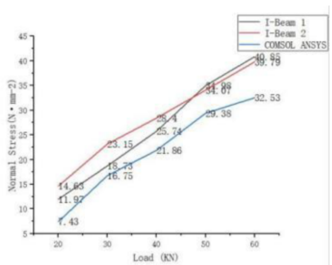


Figure 7. Measured Value and COMSOL Simulation Value of Vertical Deformation at 20cm of Fixed End of Section Steel.

By querying the I-beam material report, the allowable value of normal stress of I-beam is 215MPa. When the load reaches 60KN, the normal stress of No.1 and No.2 I-beams exceeds the allowable value. Stop loading and observe the cantilever end state of No.1 I-beam. It is found that the shape steel itself begins to deform, as shown in figure 8.

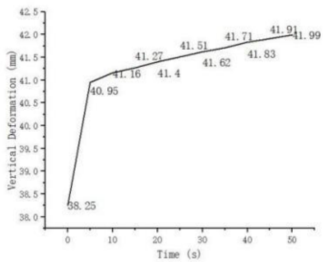


Figure 8. Field Measured Value of Vertical Deformation at Free End.

The deformation rate of I-beam is the highest in 0~5s, and then the deformation development rate of section steel gradually slows down. In the engineering site, a large number of materials are often piled up on the outer frame, and the live load piled up for a long time is likely to cause the above-mentioned test phenomenon. Therefore, it is suggested that the inspection and management of the project site should be strengthened to ensure that a large amount of materials are piled up in the cantilever outer frame for a short time, so as to avoid excessive deformation of the shaped steel and reduce the probability of high-altitude safety accidents.

5. Conclusion

As can be seen from the test above, cantilever scaffold erection or loading deviation will lead to inconsistent stress and deformation of section steel, especially when a large number of loads are piled up illegally on the site, it is easy to happen in the test, that is, a certain I-beam is the first to lose stability, which leads to the overall collapse of cantilever scaffold. Therefore, cantilever scaffold erection and load stacking in engineering practice should be strictly in accordance with the design and specification requirements.

During the loading process, the center of gravity of the upper scaffold moves to the free end due to the deformation of the section steel, which increases the vertical deformation of the section steel itself. However, during the COMSOL simulation process, the center of gravity and load direction of the scaffold are unchanged, resulting in the simulated value being smaller than the measured value, which is also the need to improve the finite element numerical simulation, so some errors should be considered in the numerical simulation process.

Under the condition of exceeding the limit load, the measured results show that obvious deformation occurs near the fixed end of I-beam. Therefore, the safety management and patrol should be strengthened at the project site to ensure that the live load of the steel cantilever outer frame will not pile up for a long time, and it will be hoisted with the release.

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