Experimental Research On Static Strength of C-shaped Steel Structure in Photovoltaic Agricultural Greenhouse

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Abstract. Based on the research characteristics of the C-shaped steel structure of the photovoltaic agricultural greenhouse, the stress and strain under the design load of the solar cell module support are tested. Compared with the ANSYS simulation and test data, the test results are in good agreement with the simulation analysis results. The maximum stress measured by the main steel frame structure under the required load is far less than the steel stress value, the structural safety strength is high, there is a big reduction Heavy margin. The research results can provide a reference for the engineering design of the photovoltaic agricultural greenhouse steel frame structure.

1. Introduction

With the development of economy and the strengthening of national environmental protection awareness, China's demand for clean energy is increasing. Under the background of shutting down the construction of thermal power plants with high energy consumption and high pollution, China vigorously develops photovoltaic power generation projects, especially photovoltaic agricultural projects[1]. Large-scale photovoltaic agricultural projects require large steel structures for construction and support. The steel structures that make up these photovoltaic module systems are huge, up to 1000m in length, with complex structural layout and stress conditions, small cross section size of the rods, and numerous joint connections[2]. At present, in China's photovoltaic industry, there are not enough effective analysis and design methods for large steel structures, most of which are imported from foreign greenhouses and photovoltaic steel structures[3].

In photovoltaic power generation system, the weight of steel frame accounts for about 80% of the total weight of the system, so the design of steel structure has great potential in saving steel and reducing cost[4-5]. In this study, the stress system of c-section steel frame structure of agricultural science and technology greenhouses in Jimo Photovoltaic Town was studied. On the basis of ensuring safety and reliability, an economical and reasonable photovoltaic support was designed.

2. Experimentation

2.1. Support structure

The steel structure and size of the solar cell module bracket are shown in Fig.1, and the unit is mm. Tab.1 shows the details of components that make up the solar cell module bracket.
2.2. Loading device
Loading equipment mainly includes triangular bracket, 48 vertical load barrels, horizontal load barrel, 24 wooden modules of solar panels, and loading ropes, as shown in Fig.2.

2.3. Test equipment
The test equipment mainly includes the computer, wireless communication controller, acquisition and transmission modules, and signal transmission shielding lines, as shown in Fig.3.
3. Experimental program

3.1. Test load and the location of displacement measurement point
Generally, vertical loading is adopted in truss experiments. The test load is from the dead weight of solar panels, snow load, wind load and other live loads. 48 vertical load drums are used to simulate the vertical load of the truss, and the triangular bracket (including 1 fixed pulley) and horizontal load drums are used to simulate the horizontal load. According to GB50009-2001 load code for building structures, the load under left wind was selected for the test, with a total load of 4966.28kg. The test loads are shown in Tab.2 and Tab.3.

| Tab.2 Vertical load |
|---------------------|
| The serial number   | Vertical load (mm) | Distance (mm) | Spacing (mm) | Load (kg) | The initial load (kg) | Vertical load (kg) |
| A                   | 1515.3             | 741.6         | 4085         | 113.33    | 53.33              | 906.65             |
| B                   | 1417.65            | 741.6         | 4085         | 105.78    | 45.78              | 846.28             |
| C                   | 1320               | 741.6         | 4085         | 98.24     | 38.24              | 785.91             |
| D                   | 1222.35            | 741.6         | 4085         | 90.69     | 30.69              | 725.53             |
| E                   | 1124.7             | 741.6         | 4085         | 83.15     | 23.15              | 665.16             |
| F                   | 1027.05            | 741.6         | 4085         | 75.60     | 15.60              | 604.79             |
| G                   | 929.4              | 741.6         | 4085         | —         | —                  | 4534.32            |

The loading scheme and the distribution of displacement measuring points are shown in Figure 4. The test piece consists of three trusses of trusses. Since the theoretical calculation strength is mainly conducted on the middle trusses, this test adopts 1 triangular bracket and 1 horizontal load barrel to simulate the horizontal load of the middle trusses. In the figure, points A, B, C, D, E and F are displacement measuring points, among which the B, D and F are measuring points of the middle steel frame inclined beam, and A, C and E are the middle measuring points of purlin.

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3.2. Arrangement of stress and strain measuring points
The resistance strain gauge is used to measure the strain of truss members. The arrangement of measuring points and the number of strain gauge are shown in Figure 5. In the figure, B, D and F are
the positions of displacement measurement points. The pre-loading test is carried out before the test to eliminate gaps between components and adjust the position and wiring of strain gauge.

4. Full load simulation and test calculation of greenhouse

Full load test was carried out on agricultural greenhouses to measure stress values at different positions. ANSYS software was used for the comparison and verification of simulated calculation and test measurement data.

4.1. Greenhouse full load simulation calculation

4.1.1. Geometric model

![Fig. 6 The model of solar cell module bracket](image)

4.1.2. Simulation results

According to the simulation results, the maximum deformation position was in the middle part of 1-2 span a-row purlin, and the total deformation distance was 31mm. The maximum equivalent stress is 186.6MPa. The position near the left diagonal brace connection on the 2 rows of inclined beams is less than the specification requirements (the inclined beam is Q235 steel with tensile and compressive strength of 215MPa). The maximum bending moment is 5211N, which is located at the connection between the 2nd row main steel column and the diagonal bracing. The maximum positive axial force is 17900N, and the position is on the 2 rows of inclined beams. The minimum negative value is -29893N and the position is on 2 rows of main steel columns under compression. The maximum shear force is 8844.5N, and the position is in contact with the left diagonal brace on the 2 rows of inclined beams.

![a. Deformation cloud map of photovoltaic bracket model](image)

![b. Deformation vector diagram of photovoltaic bracket](image)

![c. Equivalent stress diagram of photovoltaic support](image)

![d. Bending moment diagram of photovoltaic bracket](image)
4.2. Greenhouse full load simulation calculation

4.2.1. Vertical displacement data of test piece steel frame
The experiment on the location of the measuring point, the test data of the vertical displacement of the test piece steel frame (unit: mm) are shown in Tab. 4 below.

| Serial number | 1030-1 | 1030-2 | 1030-3 | 1030-4 | Average value |
|---------------|--------|--------|--------|--------|---------------|
| A             | 10     | 11     | 13     | 10     | 11            |
| B             | 10     | 8      | 8      | 12     | 9.5           |
| C             | 13     | 11     | 10     | 15     | 12.25         |
| D             | 3      | 1      | 2      | 1      | 1.75          |
| E             | 31     | 30     | 31     | 30     | 30.5          |
| F             | 29     | 23     | 26     | 25     | 25.75         |

4.2.2. Stress and strain test data of the test piece steel frame
The stress and strain test data of the test piece steel frame are shown in Tab. 5.

| Serial number | 1029-0 | 1029-1 | 1029-2 | 1029-3 | 1029-4 | average value | Safety factor |
|---------------|--------|--------|--------|--------|--------|---------------|---------------|
| CH1           | 49.37  | 39.85  | 42.60  | 43.34  | 43.68  | 43.77         | 4.91          |
| CH2           | -35.78 | -40.80 | -38.24 | -38.06 | -37.63 | -38.10        | 5.64          |
| CH3           | 87.06  | 76.70  | 82.97  | 82.17  | 81.40  | 82.06         | 2.62          |
| CH4           | -63.53 | -66.58 | 71.45  | -70.54 | -68.80 | -68.18        | 3.15          |
| CH5           | 78.03  | 61.95  | 64.69  | 62.69  | 73.76  | 68.22         | 3.15          |
| CH6           | -36.33 | 30.77  | -31.65 | -42.61 | -26.99 | -33.67        | 6.39          |
| CH7           | -83.46 | -80.34 | -81.30 | -93.42 | -78.01 | -83.31        | 2.55          |
| CH8           | -53.20 | -55.75 | -56.91 | -56.36 | -55.5  | -55.54        | 3.89          |
| CH9           | -45.44 | -46.70 | -46.25 | -43.3  | -44.5  | -45.24        | 4.63          |
| CH10          | -31.79 | -43.46 | -42.30 | -35.76 | -38.50 | -38.36        | 5.49          |
| CH11          | -20.31 | -25.43 | -23.60 | -25.59 | -18.55 | -22.7         | 13.66         |
| CH12          | 8.72   | 8.50   | 9.28   | 7.28   | 9.3    | 8.62          | 35.97         |
| CH13          | 35.12  | 36.34  | 35.8   | 34.48  | 34.49  | 35.25         | 8.99          |
| CH14          | -53.87 | -50.56 | -51.56 | -51.25 | -51.01 | -51.65        | 6.06          |
| CH15          | 19.62  | 34.90  | 26.53  | 29.69  | 32.50  | 28.65         | 10.82         |
| CH16          | -39.12 | -57.84 | -48.64 | -51.66 | -49.59 | -49.37        | 6.28          |

5. Conclusion
In the experimental scheme, 6 vertical displacement measurement points were set, including 3 main steel frame and 3 purlin, 35 stress-strain measurement points were set, including 30 main steel frame
and 5 purlin. In this round of 5 tests, the displacement values at 6 displacement measuring points and the stress values at 22 stress measuring points on the main steel frame were measured. The static test reached the three targets set as expected, and the design load was evaluated for the greenhouses under construction.

The analysis shows that the data in the table have good repeatability, and the measured points have been tested many times, which proves the reliability of the measured data. According to data analysis, the maximum stress measured under the load of the main steel frame structure is 108.23 MPa, far less than the steel stress value of 315 MPa. The structure has high safety strength and a large weight loss margin.

Specimen vertical maximal displacement occurred in steel purlin center is 30.5 mm, compared to steel structure before and after the point load test data of the displacement of the applied value and can be speculated that one reason may be caused by steel installation process, steel oblique beam and support has been playing well in advance before installation mounting holes, easy cause artifacts in the assembly process, the internal stress or virtual contact between suggestion for the key component assembly to demand higher, with the method of field of fittings for installation.

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**References**

[1] Yan Feng. Application of solar Photovoltaic in Agriculture [J]. Modern Agricultural Science and Technology, 2015(12): 205-207.

[2] Qi Fei, TONG Genshu. Stability design method for steel structure frame of greenhouse [J]. Journal of Agricultural Engineering, 2009, 25(9):202-209.

[3] Yuan Tao, Liu Shanliang, WANG Shigang. Wind Load time-history response Analysis of photovoltaic steel structure supports [C]. The 12th CAE Engineering Analysis Technology Annual Conference of China,2016, 178-182.

[4] Hu Xuelian, LI Zhengliang, Yan Zhitao. Wind Load Simulation of long-span bridge structures [J]. Journal of Chongqing Jianzhu University, 2005, (27): 63-67.

[5] Experimental Study on the carrying capacity of fixed PHOTOVOLTAIC bracket [J]. Journal of Solar Energy, 2020, 41(4): 7-13.

[6] Research on photovoltaic light steel shed strength and flow field temperature field based on finite element analysis [D]. Jinan: Shandong University, 2019.