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EXPERIMENT STUDY ON THE INFLUENCES OF LENGTH ERRORS OF CABLES AND STRUTS ON SPATIAL CABLE-TRUSS STRUCTURE WITHOUT INNER RING CABLES

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ABSTRACT

Spatial cable-truss structure without inner ring cables (SCSWIRC) belongs to tensile structure, which is composed of three kinds of cable, strut and stiff ring-beam, and its stiffness generates from the pre-stresses of cables. The manufacturing errors of the three kinds of components determine the final formed state and ultimate bearing capacity, so it is essential to study the influences of manufacturing errors of three kinds of components on the mechanical property of structure. The influences of manufacturing errors on SCSWIRC have been studied from four aspects that include elongation or shortening of cable and strut, different pre-stresses states, different cable-truss frames and external loads. The relations of manufacturing errors and four aspects have been studied based on finite element model and experimental model. The results show that the elongation and shortening of components has little influence on sensitive indexes of components when the elongation or shortening of components is the same. The manufacturing errors have the different influences on the mechanical property of structure under the different pre-stress states. The closer cable-truss frame is to the error position, the larger influence the error has on cable-truss frame. The external loads have not changed the basic mechanical property of SCSWIRC, but the external loads make upper chord cables easier to loose and make sensitive indexes change more greatly. The research contents reveal the influences of manufacturing errors on the mechanical property of SCSWIRC from the four aspects.

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Mechanical property

1. Introduction

Tensile structures are one important type of large-span spatial structures, which is generally composed of cables, struts and stiff ring-beam [1-2]. Tensile structures share these advantages of light weight, considerable-spanning ability, rapid construction speed and favorable appearance. Cable-truss tensile structures (CTTS) are one of the most comparative structural types, which share the same advantages as the tensile structures. Spatial cable-truss structure without inner ring cables (SCSWIRC) belongs to the kinds of CTTS, and it is a new kind of CTTS. At present, the main researches about SCSWIRC mainly focus on simulation analysis, theoretical research and model experiment [3]. There are still no any engineering cases in the world, so it is necessary to further study SCSTWRC.

At present, the form-finding analysis of SCSWIRC was studied and the improved force iteration method based on rational shape design was proposed to solve the form-finding problem of SCSWIRC [4]. The model experiment of SCSWIRC with a diameter of 17.15 m was carried out, and the experiment values agree with the simulation values that further reveal the static property of SCSWIRC [5]. Lu et al. [6] proposed the simplification method based on grid-jumped layout to simply SCSWIRC, and the simplification method can simplify structural system and save the project costs. The progressive collapse ability of SCSWIRC was studied by using LS-DYNA, which reveals the progressive collapse mechanism of SCSWIRC [7]. Lu et al. [8] studied the influences of film-covering on SCSWIRC, and the research results show that the film-covering effect is obvious. But there are hardly any references about construction control of SCSWIRC, and construction control determines the final forming state at the same time. The final forming state also further determines the mechanical property and ultimate bearing capacity, so it is necessary to study the construction control problem of SCSWIRC.

Some scholars have studied the construction control problem about other kinds of tensile structures. Tian et al. [9] proposed a method of solving the control criteria of cable length error based first-time and second-order moment reliability indexes. Gao et al. [10] used the orthogonal test design method to analyze the deviations of the experimental model and finite element model of rigid bracing cable dome. Deng et al. [11] introduced an uncomplicated sensitivity method to statistically evaluate the pretension deviation of tensile structures and revealed that different tensioning schemes take different effects on controlling the pretension deviations. A shape control framework which consisted of multi-objective search and reinforcement learning was experimentally validated on an active tensegrity structure by Adam and Smith [12-13]. Korkmaz et al. [14] investigated the active control performance of a tensegrity bride to assess the practicability of an active tensegrity structure in practice. Liang et al. [15] proposed an active control algorithm based on a nonlinear force method and the method was also used to prevent the failure of cable domes due to slackening of the ridge cables and excessive displacements of the central section of the cable dome. Sun et al. [16] proposed the small elastic modulus method to analyze the random error analysis of combining cable length and cable force, and the control index in practical engineering was ensured. Jin et al. [17] proposed the global sensitivity analysis method of parameters and then come to the conclusion that the cable cross-sectional area has the largest impact on the cable net structure of FAST (Five-hundred-meter aperture spherical radio telescope). Sun et al. [18] studied the influences of cable length errors and other parameters on cable force and then the deviation of cable length is the largest impact on the cable force. Shen et al. [19] systematically studied the independent error analysis and multiple error coupling analysis of cable-length error, active-cable tension error and outer-node coordinate of FAST based on the random error analysis method of normal distribution. Based on the above research contents, there are few scholars to study the influences of manufacturing errors on SCSWIRC.

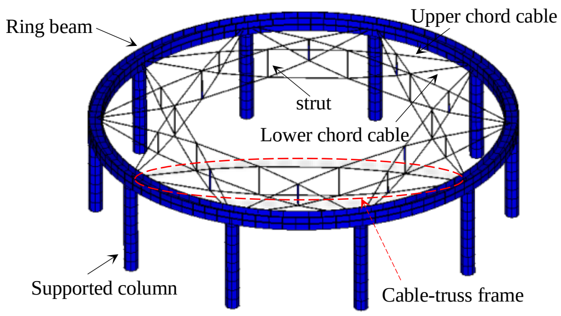
In the paper, four aspects about manufacturing errors of components are studied based on experimental model and finite element model (FEM). Firstly, the influences of the elongation or shortening of cables on structures are studied based on manufacturing errors. Secondly, the influences of different pre-stresses states on structures are studied. Thirdly, the influences of manufacturing errors on different cable-truss frames are studied. Fourthly, the influences of manufacturing errors on structure under the external loads are studied. Finally, the conclusions of the paper are given at the end of the paper.

2. Design of experimental model

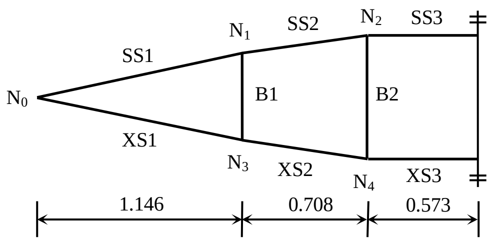
In order to study the influence of manufacturing errors on SCSWIRC, the experimental model of SCSWIRC with a span of 6 m is built. The experimental model is consisted of 10 planar cable-truss frames with winding and interwoven. Namely, the ring equivalent fractions are 10. The outer shapes of upper and lower chord cables conform to parabola shape and the equations of parabola are shown in Eq. (1). It can be known from Ref. [20] that the optimal rise-span ratios of upper and lower chord cables are 1/25 to 1/20 and 1/20 to 1/15, respectively. So, the rise-span ratios of upper and lower chord cables for the experimental model are selected as 1/24 and 1/16. Based on structural control parameters including Eq. (1), span, ring equivalent fractions and rise-span ratios, the coefficients of Eq. (1) are solved; Namely, A_1=-0.091778, B_1=0.075665, A_2=0.137668, B_2=-0.113497. The program of solving the nodal coordinates is compiled based on structural control parameters and Fortran Language. The FEM is built by the nodal coordinates, and then the integral FEM is built considering ring beam and supported column, shown in Fig. 1a. The size and element number of the half planar cable-truss frame is shown in Fig. 1b. The feasible pre-stress values are solved by using the method from Ref. [4], which is shown in Table 1.

$$\begin{cases} y_1 = A_1 x_1^2 + B_1 \\ y_2 = A_2 x_2^2 + B_2 \end{cases} \quad (1)$$

For Eq. (1), x_1 and x_2 stand for x-coordinate values, and y_1 and y_2 stand for y-coordinate values when cable-truss frames are in planar.



(a) Integral FEM of SCSWIRC



(b) Size of half planar cable-truss frame

Fig. 1 Integral FEM of SCSWIRC and Size of half planar cable-truss frame

Table 1
Feasible self-stress mode of FEM

Element number	Cable						Strut	
	SS1	SS2	SS3	XS1	XS2	XS3	B1	B2
Cable length/m	1.157	0.710	1.146	1.163	0.711	1.146	0.354	0.463
Non-stress cable length/m	1.153	0.709	1.142	1.161	0.709	1.144	-	-
Self-stress mode/kN	1.000	0.993	0.993	0.837	0.829	0.827	-0.139	-0.138

Table 2
Material properties of cable and strut

Element Type	Size	Area/mm^2	Elastic modulus/MPa	Broken force/kN
Cable	Φ6	21.487	1.21×10^5	36
Strut	P20×3	141.300	2.05×10^5	52.02

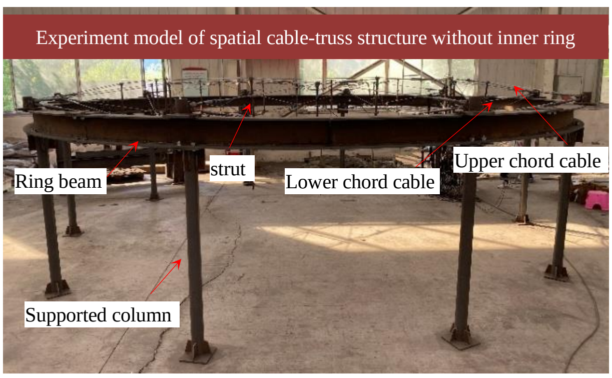


Fig. 2 Integral experiment model of SCSWIRC

Based on FEM, the integral experimental model is designed including main cable system structure, cable-strut joint, cable-beam joint, ring beam and supported column, shown in Fig. 2. The material properties of experimental model are gained by material test shown in Table 2. The real material properties are used in FEM in order to make the FEM and experimental model the same.

3. Influences of elongation or shortening of cable and strut on sensitive indexes of SCSWIRC

The cable length can be shortened or elongated in the manufacturing process. In numerical analysis, the elongation of cable and strut can be simulated by applying negative temperature (NT) to cable and strut, and the shortening of cable and strut can be simulated by applying positive temperature (PT) to cable and strut. But there are no relative references about how the elongation and shortening of cable and strut affect the internal forces of cable and strut.

The influences of elongation or shortening of cable and strut on internal forces of components are studied. The influence magnitude can be expressed as internal force variation (δ). In Fig. 1b, it is assumed that the initial cable force of SSi is σ_{ssi}, and the corresponding cable force is σ'_{ssi} when the variation of cable length SSi is $\triangle l$. The internal force variation of cable SSi can be expressed as

$$\delta_{ssi}=\sigma'_{ssi} - \sigma_{ssi} \quad (2)$$

For Eq. (2), SSi srands for the ith upper chord cable.
The sensitive indexes of cable and strut can be expressed as

$$\delta_{ssi}=(\sigma'_{ssi} - \sigma_{ssi})/(\triangle l) \quad (3)$$

Similarly, the sensitive indexes of other components can be gained by the same analysis method as Eq. (3).

The planar diagram and nodal number of SCSWIRC are shown in Fig. 3. The nodal numbers 1 to 10 are the boundary constraints and the nodal numbers 11 to 30 are the upper chord nodes and the nodal numbers 31 to 50 are the lower chord nodes. As the SCSWIRC is a centrosymmetric structure, the cable-truss frame 1-4 is selected as the research objective to study the influences of elongation and shortening of cable and strut on structure.

Based on the data in Table 1, the corresponding FEM and experimental model are built, respectively. In FEM, the elongation or shortening of cables and struts are simulated by applying positive or negative temperature to cables and struts. In the experimental models, the elongation or shortening of cables are completed by adjusting the threaded sleeves of the terminal or middle of cable and strut. The threaded sleeves are installed in the monitoring positions in advance, which are shown in Fig. 4a. The strain gauges are attached to the threaded sleeves to monitor the internal forces of cables. As the symmetry of cable-truss frame, the half cable-truss frame 1-4 is monitored shown in Fig. 4b.

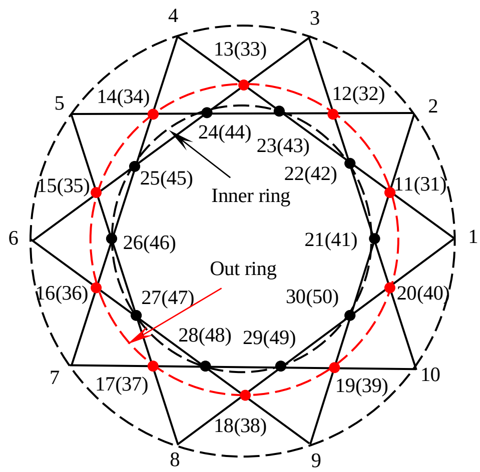
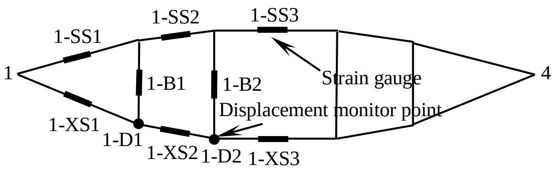


Fig. 3 Planar diagram and nodal number of SCSWIRC

(a) Threaded sleeves of cable and strut



(b) The monitoring points of internal forces and displacements

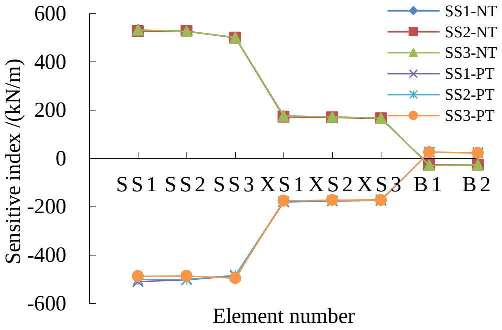
Fig. 4 Threaded sleeves and monitoring points

When the cables and struts of cable-truss frame 1-4 are shorten or elongated by 3mm, the comparison results of sensitive indexes are solved by Eq. (3), shown in Fig. 5.

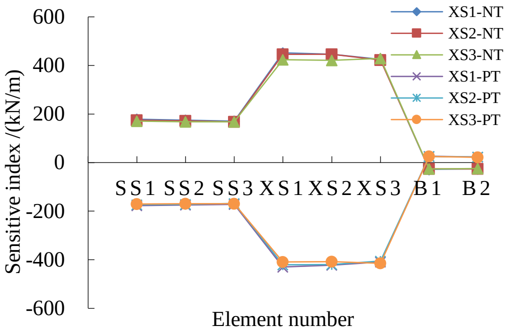
It can be known from Fig. 5 that the sensitivity indexes of cable and strut caused by negative temperature (NT) or positive temperature (PT) are the same. For the upper chord cables SS1 to SS3, the difference of sensitive indexes caused by negative temperature and positive temperature is in the range of 3.43 to 7.55%. For the upper chord cables XS1 to XS3, the difference of sensitive indexes caused by negative temperature and positive temperature is in the range of 3.84 to 6.31%. For the upper chord cables B1 to B2, the difference of sensitive indexes caused by negative temperature and positive temperature is in the range of 4.25 to 7.71%. The research results show that the negative or positive temperature has the same influences on the sensitive indexes of cable and strut in the linear elastic state. So one of two types of applying temperature to cable and strut can be selected in the solution process of sensitive problem.

4. Influences of manufacturing errors under different pre-stress states on internal forces of cable and strut

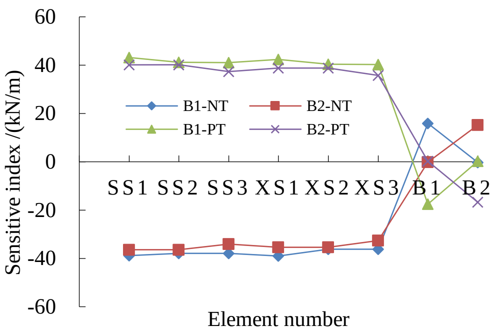
The influences of cable length errors under three different pre-stress levels on the internal forces of components are studied. The planar diagram and nodal number of SCSWIRC are shown in Fig. 3. As the SCSWIRC is a centrosymmetric structure, the cable-truss frame 1-4 is selected as the research objective. The three types of feasible pre-stress states are shown in Table 3. The P1, P2 and P3 stand for the feasible pre-stress levels 1 to 3, respectively.



(a) Upper chord cable SS1 to SS3



(b) Lower chord cable XS1 to XS3



(b) Lower chord cable XS1 to XS3

Fig. 5 Influences of elongation and shortening of cable and strut on sensitive indexes of SCSWIRC

Table 3
Three types of feasible pre-stress states

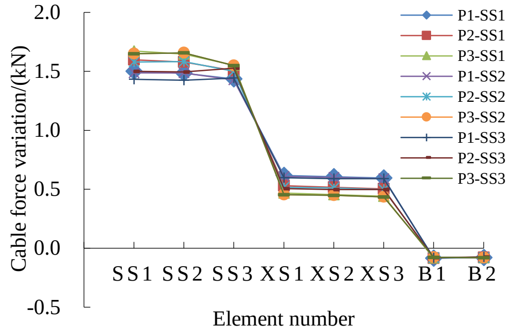
Nodal number	Cable						Strut	
	SS1	SS2	SS3	XS1	XS2	XS3	B1	B2
Feasible pre-stress state 1 /kN	1.4616	1.452	1.4515	1.2596	1.2471	1.2449	-0.2067	-0.2053
Feasible pre-stress state 2 /kN	2.4565	2.4404	2.4394	2.0745	2.0537	2.0502	-0.3439	-0.3414
Feasible pre-stress state 3 /kN	3.4511	3.4285	3.4270	2.8897	2.8608	2.8559	-0.4810	-0.4776

Table 4
Relative variations of internal forces of cable (SS1) for FEM and experimental model

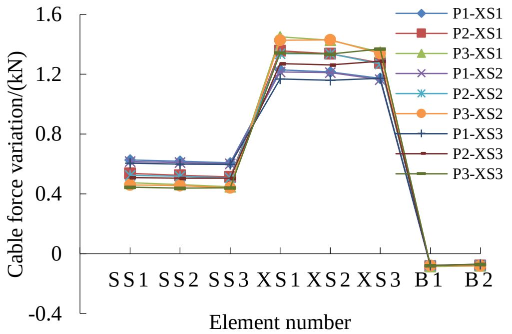
Element number	Relative variation between P2 and P1			Relative variation between P3 and P2			Relative variation between P3 and P1		
	Simulation values	Experiment values	Errors	Simulation values	Experiment values	Errors	Simulation values	Experiment values	Errors
XS3	-18.25	-17.43	4.48	-14.52	-15.32	5.55	26.15	24.87	4.90
XS2	-17.27	-18.32	6.05	-13.52	-13.23	2.13	24.89	22.94	7.84
XS1	-16.71	-18.01	7.80	-12.84	-11.93	7.08	24.07	23.43	2.64
SS3	4.66	4.98	7.01	3.07	2.89	5.72	-8.20	-8.72	6.32
SS2	5.88	5.53	5.95	4.23	4.45	5.27	-10.94	-11.73	7.23
SS1	6.13	6.34	3.41	4.47	4.18	6.49	-11.52	-10.76	6.54
B1	-1.13	-1.21	6.74	-0.37	-0.35	5.84	1.49	1.52	2.39
B2	-0.99	-0.92	6.66	-0.36	-0.34	4.27	1.33	1.34	1.14

Errors=abs (simulation values-experiment values)/simulations values

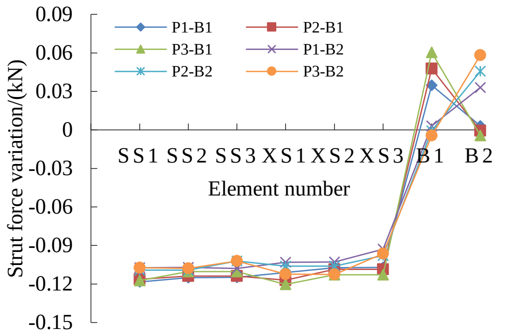
Based on the data in Table 1, the corresponding FEM and experimental model are built, respectively. It is assumed that the length of cable and strut is shortened by 3 mm. The variations of internal forces of cable and strut can be gained by Eq. (2). The variations of internal forces of cables and struts are shown in Fig. 6 and Fig. 7. As there are too many components, the SS1 is selected as the research objectives and the relative variations of internal forces of cable SS1 under three different pre-stress states are shown in Table 4.



(a) Error positons at cables SS1 to SS3

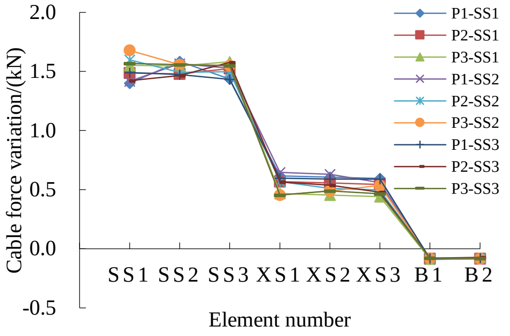


(b) Error positons at cables XS1 to XS3

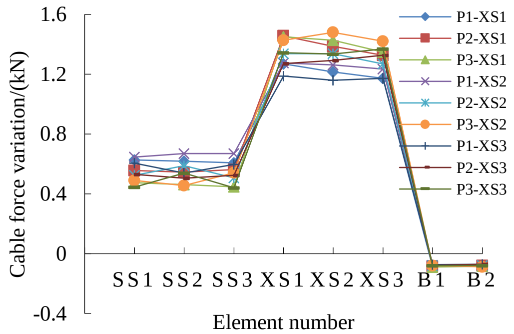


(c) Error positons at struts B1 to B2

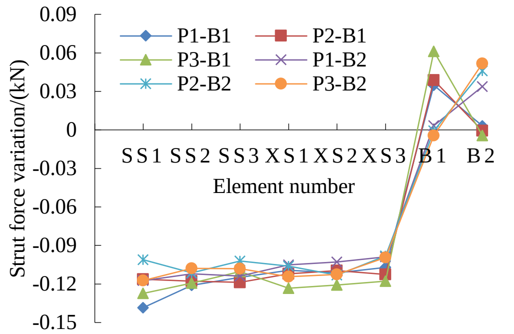
Fig. 6 Variation of internal forces for FEM



(a) Error positons at cables SS1 to SS3



(b) Error positons at cables XS1 to XS3



(c) Error positons at struts B1 to B2

Fig. 7 Variation of internal forces for experimental model

It can be seen from Fig. 6 and Fig. 7 that the simulation values agree with the experiment values. The most error between simulation values and experiment values is about 6%, which shows the correctness of experiment data. The variations of internal forces for all components under the three types of pre-stress states are different. The variations of internal forces of cables and struts gradually increase with internal force increase when the cable length errors are located at upper chord cables and struts, and the variations of internal forces of cables and struts gradually decrease with the increase of internal forces when the cable length errors are located at lower chord cables. The phenomenon shows that the influences of length errors of cable and strut on internal forces of components have certain influences. The larger the pre-stresses change, the larger the variations of internal forces are. It can also be seen from Table 4 that the simulation values agree with the experiment values and the most errors are within 8%. The relative variations of internal forces of cables and struts gradually increase with the increase of the difference of two kinds of pre-stress level. So the different kinds of pre-stress states should be considered in design.

5. The influences of length errors on the cable-truss frames at different positions

In order to study the influences of cable length errors on the cable-truss frames of different positions, four different types of cable-truss frames are designed. The four cable-truss frames include cable-truss frame 1-4, cable-truss frame 3-10, cable-truss frame 1-8 and cable-truss frame 7-10 in Fig. 3, respectively. According to the correlation of four types of cable-truss frames, the cable-truss frame 1-4 can be named as cable-truss frame itself (CTF1) and the cable-truss frame 3-10 can be named as near cable-truss frame (CTF2) and the cable-truss frame 1-8 can be named as interval cable-truss frame (CTF3) and the cable-truss frame 7-10 can be named as interval two cable-truss frame (CTF4), which is shown in Fig. 8. The sensitive indexes of cable is the Eq. (3). Similarly, the sensitive indexes of sturts can be gained by using the same way as Eq. (3).

The sensitive indexes of cables and struts for four types of cable-truss frames are gained based on the pre-stress state 2 in Table 3 when the errors of cables and struts are located at cable-truss itself. The solved sensitive indexes are shown in Fig. 9. The sign “SS1-CTF1” refers to the sensitive indexes of CTF1 (cable-truss frame itself) when the error is located at SS1, and other signs can be expressed by the same way.

It can be seen from Fig. 9 that length errors of cable and strut have great influence on the cable-truss frame itself (CTF1) and have little influence on the other three cable-truss frames (CTF2 to CTF4). When the cable length errors are located at SS1 to SS3, the most sensitive index of CTF1 is 532.50 kN/m and the most sensitive index of CTF2 to CTF4 is 49.97 kN/m. When the cable length errors are located at XS1 to XS3, the most sensitive index of CTF1 is 452.00 kN/m and the most sensitive index of CTF2 to CTF4 is 65.33 kN/m. When the cable length errors are located at B1 to B2, the most sensitive index of CTF1 is 39.00 kN/m and the most sensitive index of CTF2 to CTF4 is 5.47 kN/m. It can be seen from the analysis results that cable length errors have much greater influence on SCSWIRC than strut length error, so the strut length error can be ignored in design and mechanical analysis. Meanwhile, the sensitive indexes of cables can be recognized as “sensitive component” and the sensitive indexes of struts can be recognized as “insensitive component”. The classification method helps to simplify the calculation process and distinguish the importance of components.

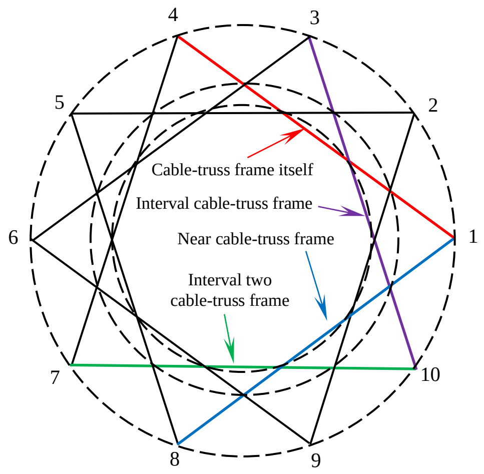
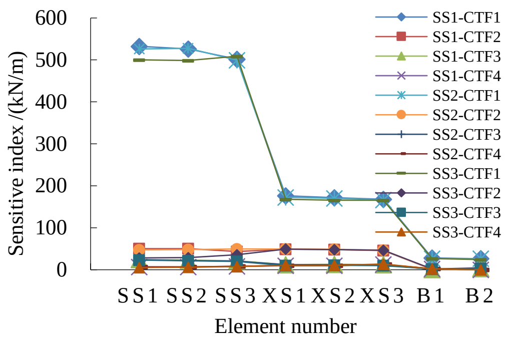
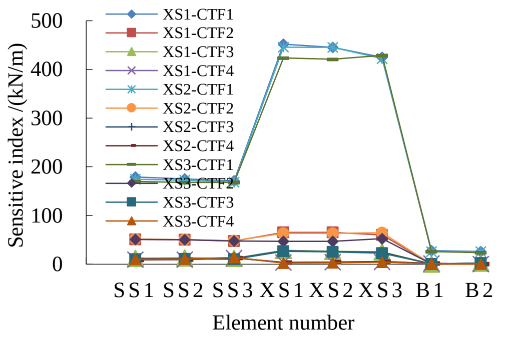


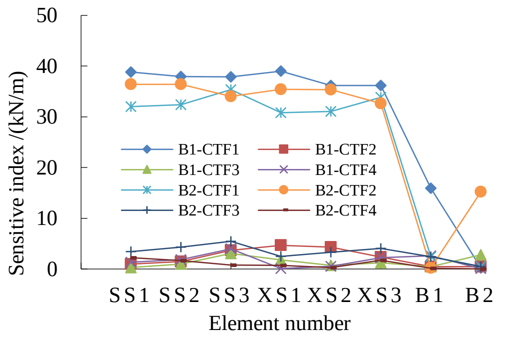
Fig. 8 Positions of four kinds of cable-truss frames



(a) Error position at cables SS1 to SS3



(b) Error position at cables XS1 to XS3

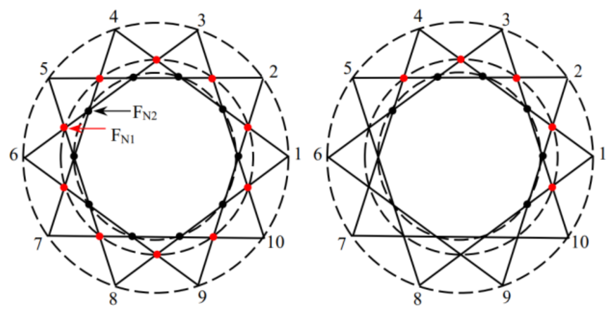


(c) Error position at struts B1 to B2

Fig. 9 Sensitive indexes when errors are located at cable-truss frame itself (CTF1)

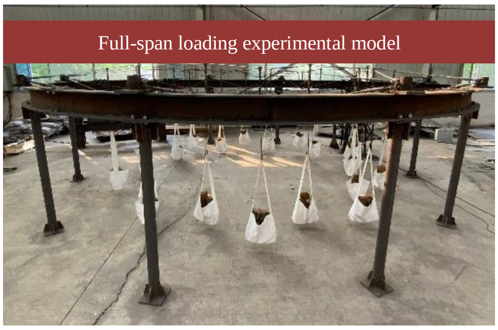
6. Influence of manufacturing errors on the mechanical property of SCSWIRC under external loads

In order to further study the influence of manufacturing errors of components on the mechanical property of SCSWIRC under external loads, the sensitive analysis of all kinds of components are studied by numerical analysis and experiment research. The external loads can be divided into two types of full-span loads and half-span loads, shown in Fig. 10. The two types of loads are applied to the experimental model and FEM by the form of five loading levels. The external loads applied to the structure can be transformed into the equivalent nodal load, and the equivalent nodal load can be calculated by Ref. [1]. The equivalent nodal load can be expressed as F=[F_{N1}, F_{N2}]=[-0.429, -0.361] kN shown in Fig. 10, and the negative sign stands for the vertical direction. The five levels of loading can be written as 0.4F, 0.6F, 0.8F, 1.0F, 1.2F. In the experiment, the external loads are replaced with the iron block and the experimental models under the full-span load and half-span load are shown in Fig. 11. It can be known from Section 3 that manufacturing errors have great influence on cable-truss frame itself and have little influences on the other three kinds of cable-truss frames, so cable-truss frame itself is taken as the research objective. The monitoring points are shown in Fig. 4b. The length of cables and struts are shortened by 3 mm for FEM and experimental model, respectively.



(a) Full-span load (b) Half-span load

Fig. 10 Planar layout diagram of full-span and half-span loads



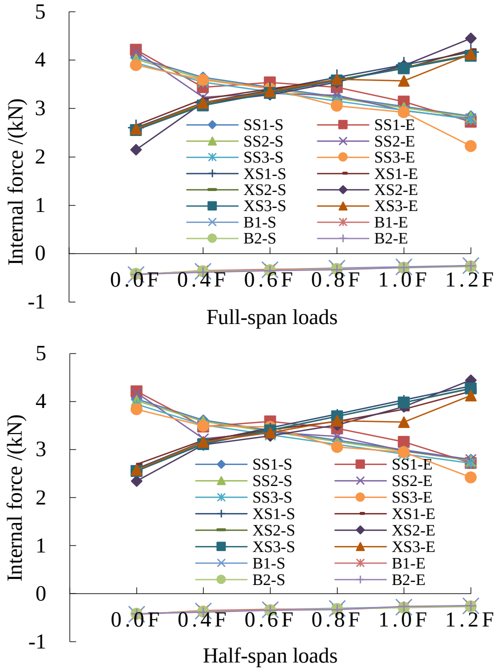
(a) Full-span loading experiment

(b) Half-span loading experiment

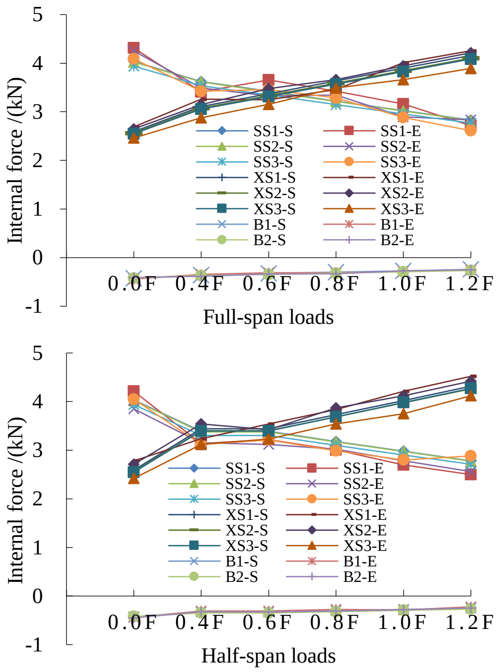
Fig. 11 Full-span and half-span loading experimental model

6.1. Cable length errors of upper chord cables

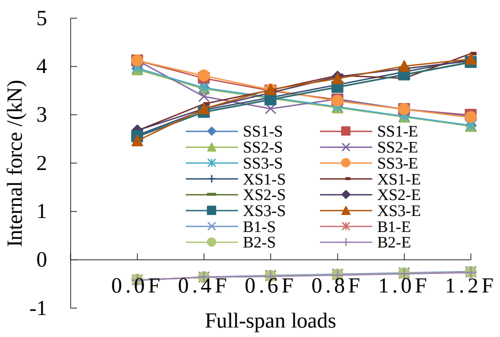
When manufacturing errors are located at SS1 to SS3, the solved sensitive indexes under full-span loads and half-span loads are shown in Fig. 12. The symbol “S” stands for “simulation value” and “E” stands for “experiment value”, the same below.

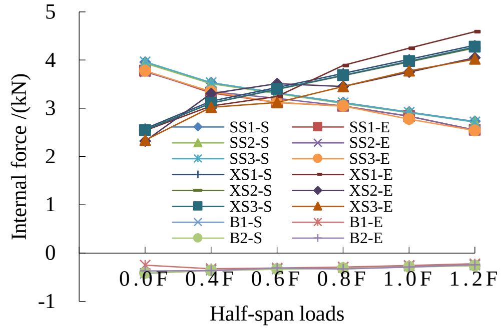


(a) Error position at SS1



(b) Error position at SS2





(c) Error position at SS3

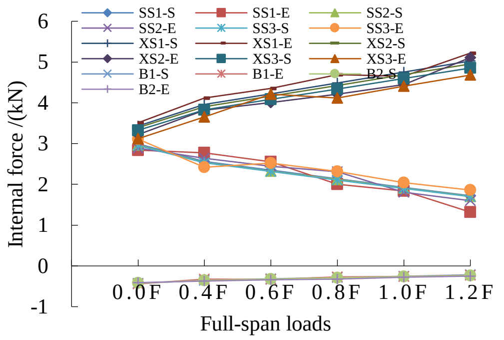
Fig. 12 Internal forces under full-span and half-span loads when error positions are located SS1 to SS3

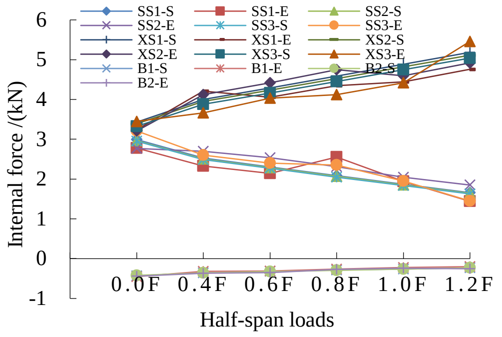
It can be seen from Fig. 12 that the experiment values agree with the simulation values when the errors are located at SS1~SS3 and the most errors are in the range of 2.34% to 6.25%. With the increase of full-span loads and half-span loads, the internal forces of SS1 to SS3 and B1 to B2 gradually decrease and the internal forces of XS1 to XS3 gradually increase, which shows that the external loads do not change the structural basic mechanical property when the components have the manufacturing errors. The internal forces of SS1 to SS3 under half-span loads are slightly less than those of SS1 to SS3 under full-span loads, and the internal forces of XS1 to XS3 under half-span loads are slightly greater than those of XS1 to XS3 under full-span loads. Namely, the internal forces of the upper and lower chord cables change significantly and the upper chord cables are easier to loose under the half-span loads and half-span load is more unfavorable to structures. Meanwhile, the internal forces of B1 to B2 gradually increase with external load increase, but the amplitude is slight. So the half-span loads have great influences on the internal forces of SCSWIRC. The change laws of upper and lower chord cables also show that cables belong to "sensitive component" and the struts belong to "insensitive component", which conforms to the conclusions in Section 4. It can further be known from Eq. (3) that the sensitive indexes under half-span loads are slightly greater than those of full-span loads. Meanwhile, the main reasons of producing error include four aspects: (1) There are a certain differences between the FEM and experimental model; (2) The strain gauges are slightly drifting in measurements; (3) The measuring instrument will produce some errors; (4) The surrounding temperature has some influences on the experimental model.

6.2. Cable length errors of lower chord cables

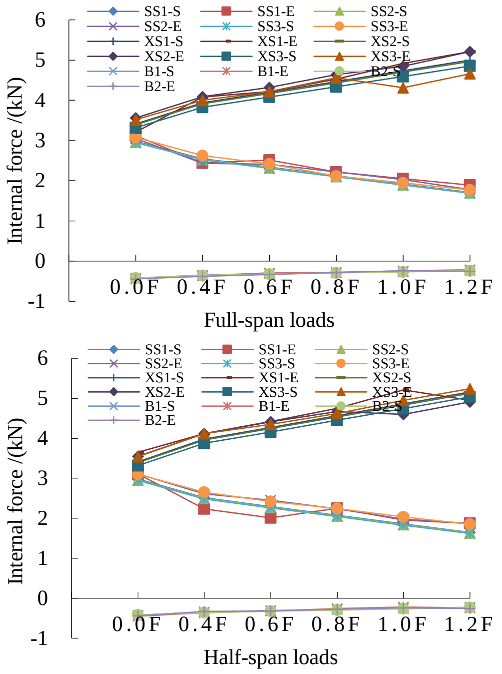
When manufacturing errors are located at XS1 to XS3, the solved internal forces are shown in Fig. 13.

It can be seen from Fig. 13 that the experiment values agree with the simulation values when the errors are located at XS1 to XS3 and the most errors are in the range of 3.15% to 5.87%. With the increase of external loads, the internal forces of SS1 to SS3 and B1 to B2 linearly decrease and the internal forces of XS1 to XS3 linearly increase, which shows that the external loads do not change the basic mechanical property of structure when the components have the manufacturing errors. The internal forcecs of SS1 to SS3 under half-span loads are slightly less than those of SS1 to SS3 under full-span loads and the internal force of XS1 to XS3 under half-span loads are greater than those of XS1 to XS3 under full-span loads, which shows that upper chord cables are easier to loose and the half-span loads have greater influences on SCSWIRC. Meanwhile, the reasons of producing errors are similar to Section 5.1, so do not repeat it again.

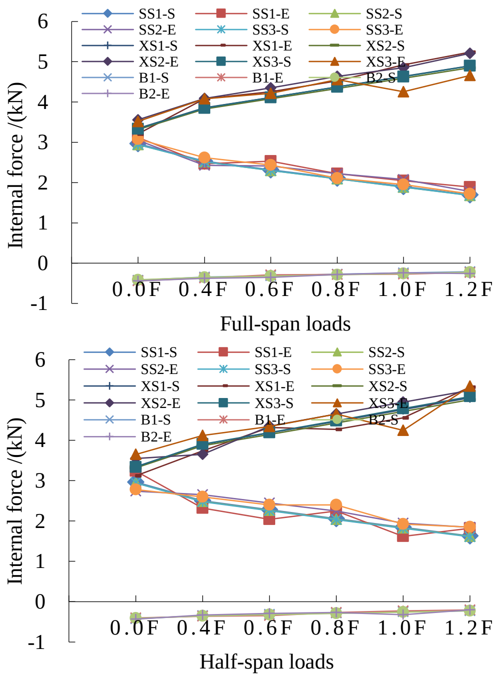




(a) Error position at XS1



(b) Error position at XS2



(c) Error position at XS3

Fig. 13 Internal forces of XS1~XS3 under full-span and half-span loads

6.3. Manufacturing errors of ring-beam and ear-plate

Although the installation and manufacturing errors of ring-beam and ear-plate are difficult to be simulated in Finite Element Software, the kind of errors will directly result in the elongation of upper and lower chord cables. So the installation and manufacturing errors of ring-beam and ear-plate can be equivalent to the errors of upper and lower chord cables. When the errors are located at ring-beam and ear-plate, the corresponding internal forces can be gained shown in Fig. 14.

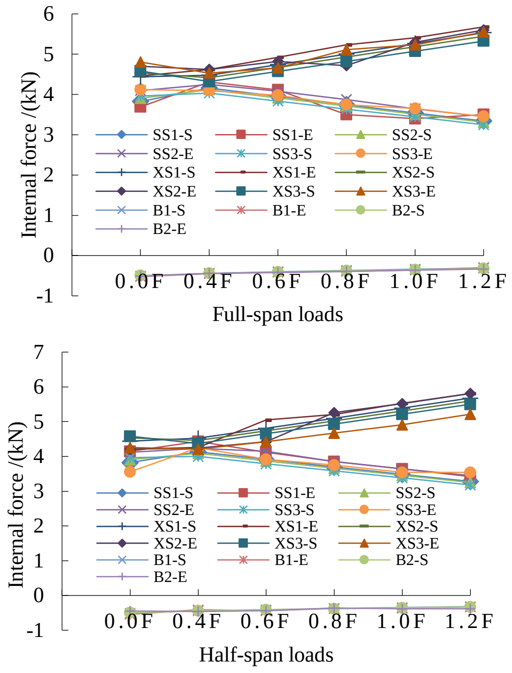


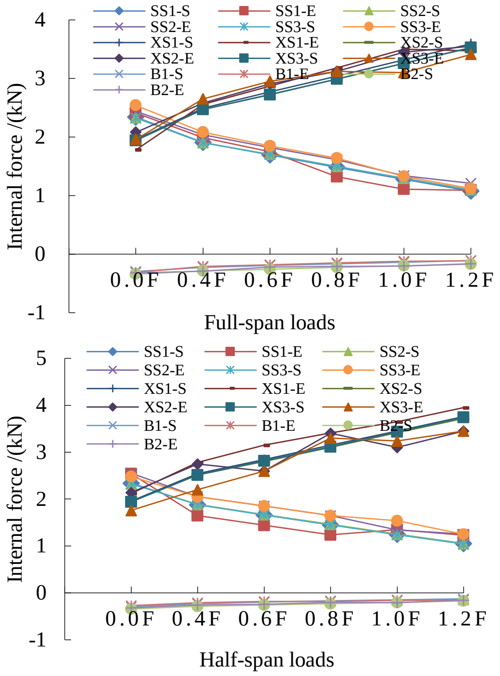
Fig. 14 Internal forces of ring-beam and ear-plate under full-span and half-span loads

It can be seen from Fig. 14 that the experiment values agree with the simulation values and the most errors are in the range of 2.65% to 7.21%. The reasons of producing errors are similar to Section 5.1 and Section 5.2. With the increase of external loads, the internal forces of upper chord cables linearly decrease and the internal forces of lower chord cables linearly increase, which shows that the external loads do not change the structural basic mechanical property when the components have the manufacturing errors. The variations of internal forces under half-span loads are larger than those of full-span loads. When error positions are located at ring-beam and ear-plate, the internal force variations under external loads are far greater than those of non-loads.

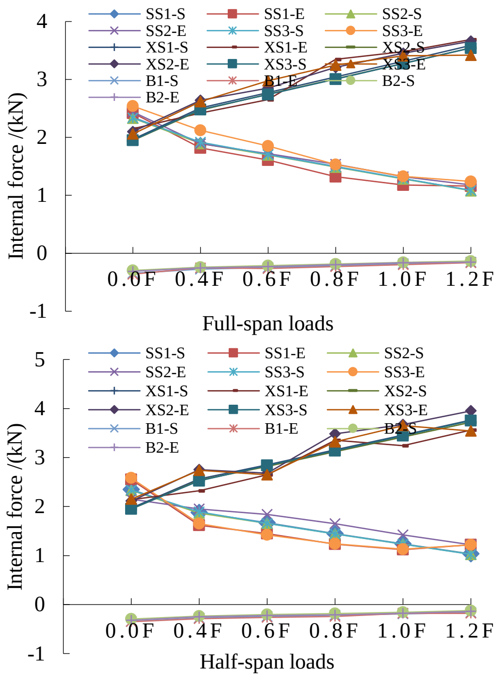
6.4. Manufacturing errors of struts

When the errors are located at ring-beam and ear-plate, the corresponding internal forces can be gained shown in Fig. 15.

It can be seen from Fig. 15 that the experiment values agree with the simulation values and the most errors are in the range of 1.79% to 5.47%. With the increase of external loads, the internal forces of upper chord cables gradually decrease and the internal forces of lower chord cables gradually increase, which shows that the external loads do not change the basic mechanical property of the structure when the components have the manufacturing errors. Meanwhile, the internal forces of B1 to B2 gradually increase with the increase of external loads, but the amplitude is slight. The change laws of upper and lower chord cables also show that cables belong to "sensitive component" and the struts belong to "insensitive component", which conforms to the conclusions in Section 4. The internal force variations of upper and lower chord cables under half-span loads are greater than those of full-span loads, which shows that the half-span loads are unfavorable to the structure. The main reasons of producing errors are the same, so there are no more repeat again.



(a) Error position at B1



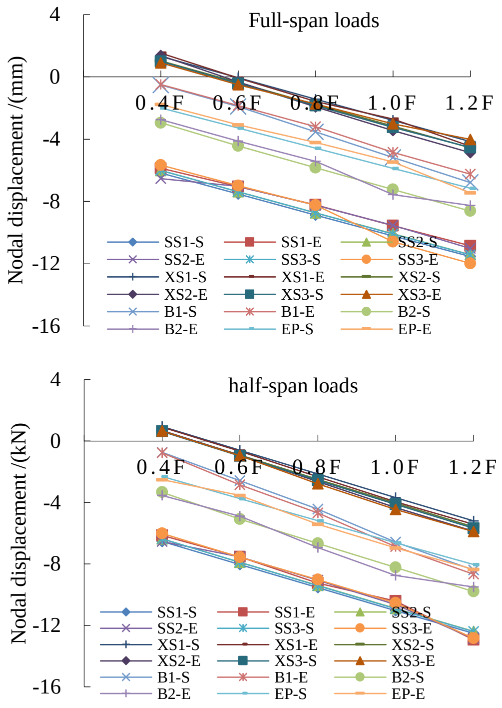
(b) Error position at B2

Fig. 15 Internal forces of B1 amd B2 under full-span and half-span loads

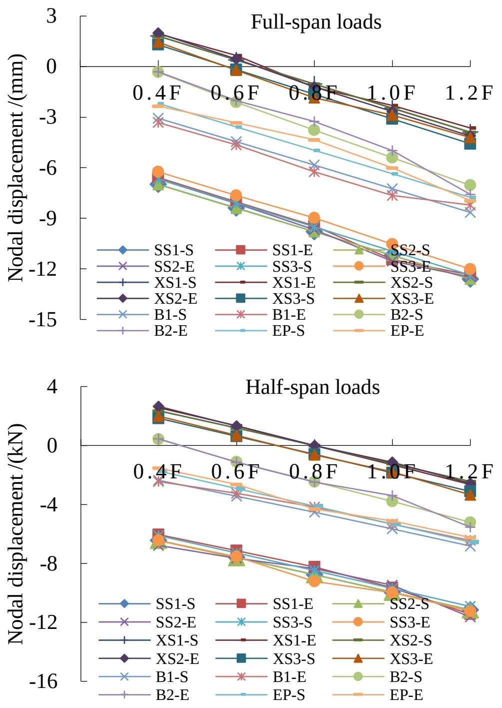
6.5. Influences of manufacturing errors on nodal displacements

When the error positions are located at SS1 to SS3, XS1 to XS3, B1 to B2 and ring-beam and ear-plate, the nodal displacements of N1 and N2 are gained under the external loads. The results are shown in Fig. 16.

It can be seen from Fig. 16 that the experiment values agree with the simulation values and the most errors are in the range of 2.25% to 6.37%. The nodal displacements gradually increase with the external loads. The nodal displacements under the external loads of 0.4F and 0.6F are the positive values when the error positions are located at lower chord cables (XS1 to XS3), which shows that the shortening of upper chord cables can make the SCSWIRC up toward. Similarly, the elongation of lower chord cables can make the SCSWIRC down. Meanwhile, the nodal displacements under half-span loads are greater than those of full-span loads, which shows that the half-span loads are unfavorable to the structure.



(a) Node N1



(b) Node N2

Fig. 16 Nodal displacements under full-span and half-span loads when errors are located at SS1 to SS3, XS1 to XS3, B1 to B2 and ear-plate

7. Conclusions

Based on ACCTS, the influences of manufacturing errors on structural mechanical property are studied from four aspects. The main conclusions as follows:

(1) The elongation or shortening of cable and strut has little influences on the sensitive indexes of cable and strut in the linear elastic state.

(2) The manufacturing errors have the different influences on the mechanical property of structure under the different pre-stress states, so the rational pre-stress level should be selected in practical engineering cases.

(3) The component errors have great influences on cable-truss frame itself and have little influences on the other cable-truss frames. Namely, the closer cable-truss frame is to the error position, the larger influence the error has on cable-truss frame.

(4) The external loads do not changed the basic mechanical property of structure, but the external loads make upper chord cables easier to loose and make sensitive indexes change more greatly. So the influences of external loads on structure should be considered in design.

Meanwhile, there are some problems in the paper. Such as, when cable-strut joints slip, there are no scholars to study the influences of joint slip on the manufacturing errors of structure. The author will continue to study how joint slip effects the structural mechanical property based on the manufacturing errors.

Acknowledgments

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