Simulation Studies on the Non-uniform Temperature of Steel Members by the Solar Radiations

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Abstract—The thermodynamic analysis of long-span structure can be very complicated with the numerous members and high-degree indeterminate. In this paper, a typical spatial grid model with 4.5 x 4.5 meters plane is simulated, through the numerical simulation study on grid temperature field by solar radiation in winter and summer. The results show that: solar radiation can cause a non-uniform temperature field on grid model, of which the maximum temperature in summer is up to 52°C, temperature rising is 20°C, the maximum temperature difference among members is up to 14°C, In winter the overall temperature of the component is low; The azimuth of the chords has little effect on the temperature change law, which has great influence on the change of the web member temperature.

Keywords—grid model; high-degree indeterminate; non-uniform temperature field; temperature difference; steel structure

I. INTRODUCTION

With the development of urban modernization and the increase of population, in order to meet the vast housing and site demand, the long-span, large-space, super-high have been a development direction of architectural construction. With huge geometric size, numerous members, complex structure, and high-degree indeterminate, the secondary thermal stress of space steel structure caused by redundant constraint can be very complicated. During the surface construction process, the non-uniformity solar temperature load takes an important part or even become the controlling factor in the structure design and closure processing [1].

The research on temperature effects on structure has some achievements since the problem raised up. However at present, the constructional code does not consider the role of non-uniform temperature effects. The analysis method in code gives a uniform temperature method with the use of the maximum, minimum, and the initial average temperature of structure determined by the theory of engineering thermodynamics, which is based on the mean monthly temperature 50-year recurrence interval[2].

Present foreign scholars working on non-uniform temperature field analysis mainly focus on such structures like bridge[3-5], dam[6-7], radio telescope[8], and for special structure like stadiums, Exhibition Center and terminal space structure, experience is limited and further study is needed. As to domestic circumstance, tests and numerical simulations of steel components are mainly research issues[9-13], but for scaled model there is almost blank. As stated previously, measurement and the accuracy verification of simulation method of spatial grid scaled model on the non-uniform temperature is of utmost importance.

In this paper, the experimental research focus on the non-uniform temperature field numerical simulation of the grid scaled model in summer and winter, and get the typical distribution law of them.

II. THE NUMERICAL SIMULATION

A. Finite Element Model

According to the geometric dimension and material thermal physical properties of each component, as shown in Fig. 1, the finite element software ANSYS is adopted to establish the finite element model of the component temperature field, element list as shown in Table 1.

TABLE 1: ANSYS Simulation elements

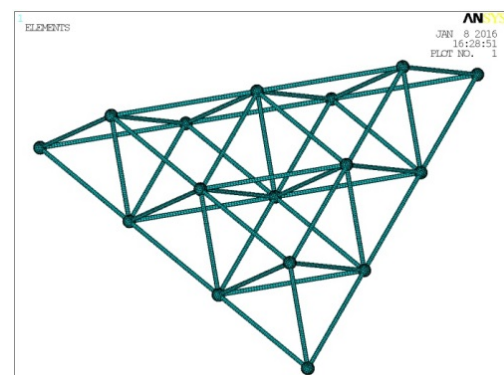| transfer type	ANSYS Simulation elements
Thermal conduction.	SHELL57(3 dimensional shell element)
Thermal convection	SURF152(surface effect element)
Thermal radiation	LINK31(3 dimensional two-node radiating element)

Fig. 1. Finite element model for thermal analysis

B. Solar Radiation Intensity

Solar radiation intensity is the main heat load of the space structure under the sunlight. Chose Dilger model to calculate the solar radiation intensity, the formula is:

$$S_d = 0.90^{mp} J \qquad (1)$$

J: solar radiation intensity
m: Atmospheric optical quality modified by atmospheric pressure
p: Atmospheric turbidity factor

Sun shading is an important factor affecting the distribution of direct solar radiation on the surface of the structure. For the grid model in this paper, the shadow is caused by two parts: the bar self-occlusion and that from other bars. For the self-occlusion, the judgment method is to judge the angle between the shell element normal and the sun ray vector. For the mutual occlusion, the ray-casting algorithm is adopted. The steps are as follows:

Step 1: In ANSYS software, the finite element model is established by the global coordinate system, and the element size must be small enough to get the accurate result.

Step 2: Transform the coordinates of the global coordinate system to the analytical coordinate system, make the Z axis parallel with the rays of the sun.

Step 3: Determine the sun ray equation by the azimuth angle and the solar altitude angle. The intersection points between the element central line equation and the projection plane (Z=0 plane) is created as the new nodes.

Step 4: For the area of shell element in projection surface, selected the new nodes created in step 3. Judge the element is occluded if Z coordinate is larger than that of new node of the shell element, then this unit is blocked, and vice versa.

Fig. 2 shows the shading distribution of the grid, the red represents the sun, blue represents the shadow area.
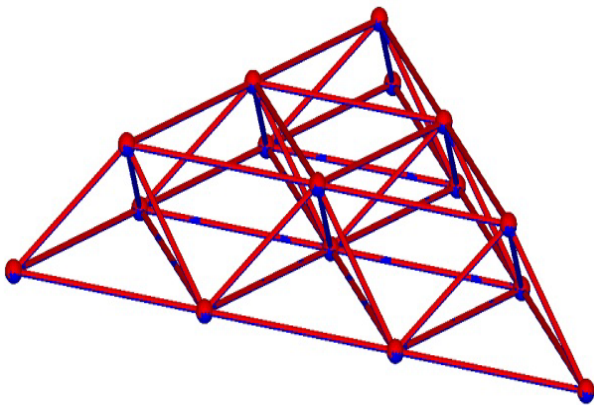

Fig. 2.   Grid shading distribution layou

C. Other Influence factors

In this paper, to simulate the temperature condition in summer and winter, the summer solstice and winter solstice are chose as the typical data. The simulation parameters are shown in Table 2. Data in brackets is that of the winter solstice.

TABLE 2: Simulation parameters list

parameters	Value
The latitude	36.5 north
wind velocity	1m/s(2m/s)
Surface albedo	0.3
temperature daily change function	30.5+3.5sin(15t-105) (6.5+3.5sin(15t-105))
Radiation absorption	0.8
Atmospheric turbidity factor	2 (3)
solar declination	23.45 (4.6)
solar radiation intensity	1416.58 W/m^2

III.   RESULTS AND ANALYSIS

A. Grid Temperature Field in Summerand Winter

Fig. 3 and Fig. 4 shows the temperature field distribution of grid model at 11:00~14:00 in summer and winter, through which can be seen:

(1) The maximum temperature of members in summer appears at 12:00 and in winter the time is 13:00. The sun grid temperature field distribution is not uniform in both summer and winter and which is varying with time, the temperature difference between different members up to a maximum of 14 °C in summer, 11°C in winter.

(2) Grid temperature maximum value appeared at the solder balls, which is due to the welding ball have larger section area. The followed are the outer rings of the bottom chords of which the second highest temperature is caused by the solar radiation reflected by the sun visors. The inner rings of bottom chords have lower temperature by the effect of occlusion. The temperature change curves are not same for the web members with different azimuth. When the angle between web member and solar radiation vector is larger, the temperature rise is higher. The more parallel between bars and sun rays, the lower temperature is.

a) 11:00

a) 11:00

b) 12:00

b) 12:00

c) 13:00

c) 13:00
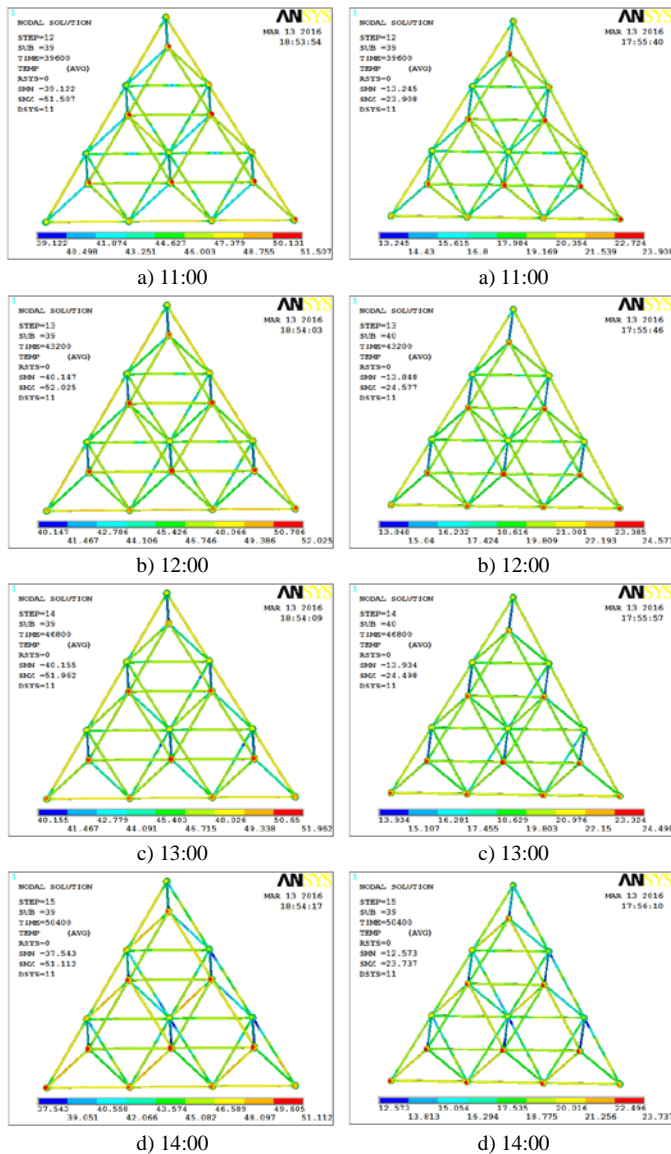

d) 14:00

d) 14:00

Fig. 3. Grid temperature field pattern
in summer

Fig. 4. Grid temperature field pattern
in winter

Fig. 5 is the maximum and minimum temperature history curve of the grid in summer and winter, it tells that:

(1) The maximum and minimum temperature history curve is similar to sinusoid. In summer, the maximum temperature can reach to 52°C with maximum temperature rise 20°C, the maximum temperature difference is 14°C. In winter, the maximum temperature is 25°C with maximum temperature rise 15°C, the maximum temperature difference is 11°C.

(2) The maximum and minimum nocturnal grid temperature is both 2~3°C less than the atmospheric temperature which is decreased by the radiation heat transfer between members and ground; In winter the overall temperature of the component is low but the non-uniform temperature field is still obvious, which should be considered in the actual grid design work.
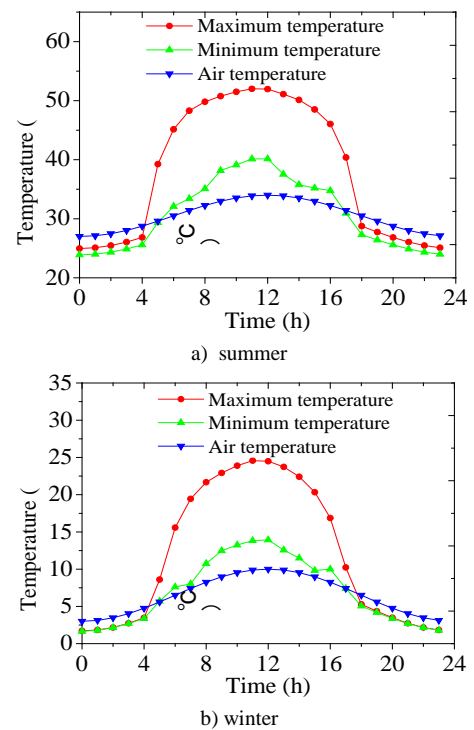

a) summer

b) winter

Fig. 5. The maximum and minimum temperature history curve

B. Member Azimuth Effect to Temperature Field

One of the main factors that cause the uneven temperature field is the azimuth of the spatial structure member. In this paper, the temperature field of chord member and web member with the same and different azimuth are analyzed. Each of three elements of gird top chord, web member and bottom chord were extracted, The location of each element is shown in Fig. 6 , The definition of three elements of chord are T1, T2, T3, web members are W1, W2,W3, bottom chord are B1, B2, B3.
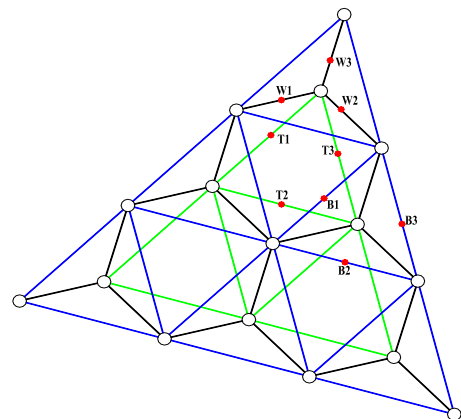

Fig. 6. Position of extraction elements

Fig. 7 shows the temperature rise curve of grid top chord and bottom chord with the different azimuth in summer, from which we can see: the temperature rise curve of measuring point put on top of the bar T1~T3, B1~B3 almost coincide with that of bottom side, except very individual difference

more than 2°C, the temperature difference of rest bars with different azimuth is all less than 2°C. So that leads us to the conclusion that: to the structure member at the same height and same plane but with different azimuth, the temperature regularities are the same.
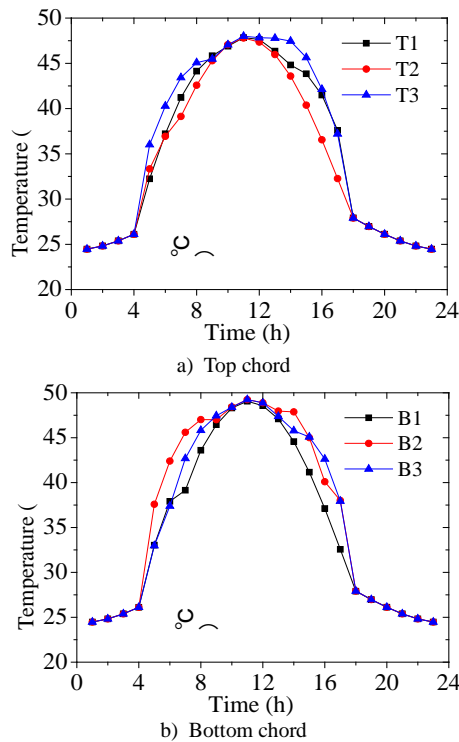

a) Top chord

b) Bottom chord

Fig. 7.   Chord Members temperature time history curve

Fig. 8 is the comparison temperature rise curve of bars with different azimuth, it tells that: web members with different azimuth have different temperature change law and non-uniform temperature field exist during different time of which the highest difference reach to 12°C.
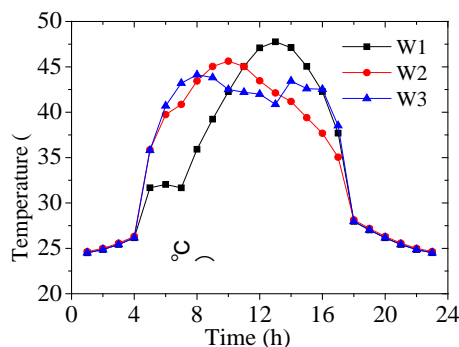

Fig. 8.   Web Members temperature time history curve

IV.   CONCLUSION

In this paper, through the numerical simulation study on grid temperature field by solar radiation in winter and summer, we get the following conclusions:

The grid model has Non-uniform temperature field under sunlight, and the maximum temperature of member in summer can reach to 52°C with the temperature rise 20°C, the maximum temperature difference 14°C. In winter the overall temperature of the component is low but the maximum temperature difference can reach to 11°C, which also should be considered in the actual grid design work; the azimuth of the chords has little effect on the temperature change law, which has great influence on the change of the web member temperature.

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