

Analysis of the Temperature Effect During the Lifting Stage of The Main Arch Ring of The Strong Skeleton

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Abstract: In this paper, a finite element model of the main arch ring of the strong skeleton is developed in order to analyse the stress and deflection response of the strong skeleton under the action of uniform temperature during the lifting stage. Uniform temperature action was found to have a significant effect on the stresses and deflections of rigid skeletal stringers. The effect of the huddle on the stress and deflection of the skeleton at the non-design reference temperature was further investigated, and the results showed that the changes of the stress and deflection of the skeleton were directly proportional to the relative temperature difference (the difference between the huddle temperature and the design reference temperature). In addition, a reasonable value for the jointing temperature was analysed, and it was suggested that a value of 2°C slightly lower than the average annual temperature be used as the jointing temperature.

Keywords: Main arch ring with strong skeleton, temperature effect, closing temperature, stress, deflection.

1. Introduction

The strong skeleton arch bridge is more and more widely used in various regions due to its strong spanning capacity and convenient construction, etc. The strong skeleton main arch ring will produce corresponding temperature distribution due to the influence of solar radiation and ambient temperature in the construction process, which will affect the internal force and line of the main arch ring in the construction process, however, the construction process of the strong skeleton main arch ring and the form of the box cross-section without flange are different from the traditional reinforced concrete box girder, so the temperature effect in the construction needs further in-depth study. Therefore, the temperature effect in the construction of the main arch ring of strong skeleton needs further in-depth study.

Studies in the literature^{[1][10]} on the temperature field and temperature effects of box girder structures have revealed many important phenomena and laws. It has been shown that the temperature gradient distribution pattern of box girders under solar radiation is closely related to the geometry of the structure, material properties, and radiation intensity. In addition, it was found that the effect of ambient temperature changes on the internal temperature field of box girders is significantly time-delayed and non-uniform.

Studies in the literature^{[11]-[14]} on the temperature effect on the lifting stage of the stiffening skeleton mainly focuses on the influence of the temperature change on the buckling cable force, deflection angle and the elevation of the lifted section during the lifting process of the stiffening skeleton.

The strong skeleton of the concrete arch bridge is mostly constructed by the diagonal pulling and buckling cantilever assembly method, the temperature in this method is a key factor that can not be ignored, during the cantilever assembly of the segments, the temperature change has a greater effect on the linearity of the skeleton, and the increase of span and the extension of

buckling cables will make the temperature impact on the axis of the arch bridge even more significant, which is critical in the process of the strong skeleton lifting and stress adjustment after the joining process.

2. Finite Element Analysis

2.1. Introduction to Bridge Examples

The bridge is a main span 236m top-bearing reinforced concrete arch bridge, the main arch ring for the strong skeleton box section form, in which the strong skeleton using diagonal buckling, cable suspension method of erection. Total 6 limbs of the upper and lower chords of the strong skeleton are made of Q390D steel, and the pipes are filled with self-compacting non-shrinkage C70 concrete. The strong skeleton of the whole bridge has 13 sections, the inner diameter of the main steel pipe is 400mm, the wall thickness is 16mm, the total length of the pipe is 276m, the sagittal height is 59m, and the sagittal span ratio is 1:4.

Reference 15 uniform temperature under the action of the calculation parameters to take the value of the study, for the merging temperature to take the value of the calculation formula: $T = T_{28} + (D - 0.85) / 0.2 + T_0$ is reliable, the calculation of the stiffening skeleton merging temperature of 6.1°C. For the alpine climate with large temperature difference at the bridge site, it is more reasonable to take the maximum effective temperature as the local daily maximum temperature +2°C, and the minimum effective temperature in winter as the local daily average of the minimum temperature -2°C for calculation, and the daily average of the minimum temperature in January 2022 at the bridge site is -12°C, and the daily maximum temperature in July is 29°C. Therefore, the highest effective temperature is taken as 31°C, the lowest effective temperature is taken as -14°C, and the merging temperature is taken as 6°C, so the temperature difference of the system is 25°C, and the temperature difference of the system is 20°C.

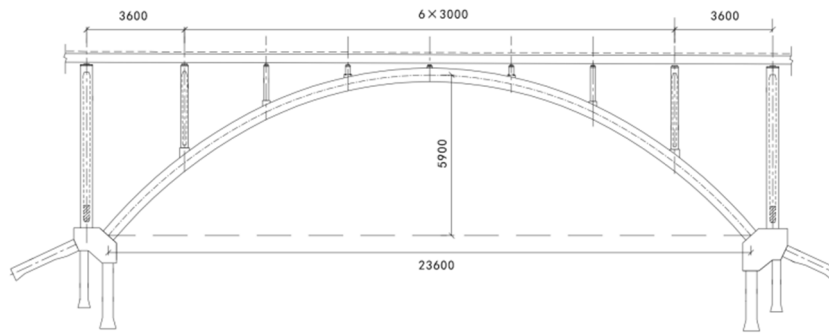


Figure 1. Bridge Elevation

2.2. Introduction to Finite Element Modelling

The construction phase simulation analysis of the main arch ring of the strong skeleton of this bridge was carried out using Midas/civil finite element computational simulation software. The main arch ring model of the strong skeleton mainly includes: the strong steel skeleton, the outer concrete of the main arch ring, and the buckling anchor cable of the

cable buckling system, in which the strong skeleton is simulated by the beam unit, the buckling anchor cable is simulated by the truss unit, and the outer concrete is simulated by the plate unit, and the coupling between the beam unit of the strong skeleton and the plate unit of the outer concrete is carried out by the common unit nodes, and the finite element model of the main arch ring is as shown in Figure 2.

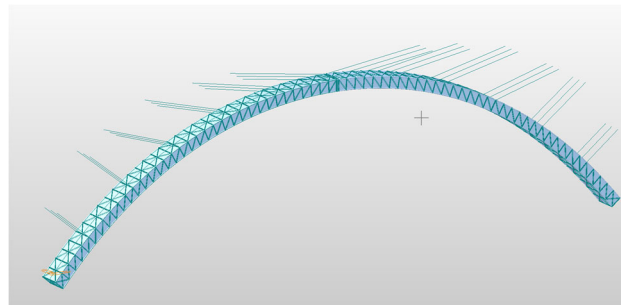


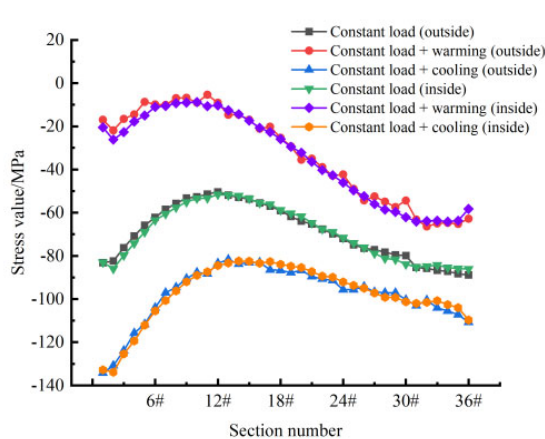
Figure 2. Finite element calculation model of main arch ring of strong skeleton

2.3. Finite element result analysis

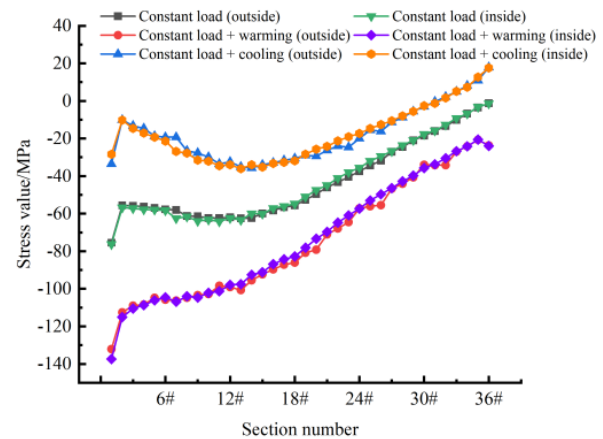
2.3.1. Skeleton Stress Analysis

The stress changes of the key sections of the upper and lower chord pipes under various load conditions, including constant load, constant load+uniform temperature rise of

25°C, and constant load+uniform temperature drop of 20°C (referred to as constant load+temperature rise, constant load+temperature drop in the following charts and analysis), after the lifting and closure of the rigid skeleton and pouring of concrete inside the pipe, are shown in Figure 3.



(a) Upper chord stress



Lower chord stress

Figure 3. Finite element calculation model of main arch ring of strong skeleton

From Fig. 3, it can be seen that for the top chord pipe, the

stresses in each cross-section are compressive stresses only

under constant load, and their value decreases and then increases from the foot of the arch to the top of the arch, and reaches the maximum at the top cross-section of the arch, which is 88.9MPa. Under the action of constant load + uniform warming, the compressive stresses on the upper chord are reduced, so the uniform warming action produces tensile stresses on the upper chord, which is the largest in the section of the arch foot, with a value of 66.2MPa, accounting for 79.6% of the value of the stresses under the action of constant load; Under the action of constant load + cooling, the compressive stresses on the top chord bar are increased, so the uniform cooling action in the top chord tube produces all the compressive stresses, the maximum is at the foot of the arch, which is 51.0MPa, accounting for 61.3% of the value of the stresses under the action of constant load. The most unfavourable loading condition for the upper chord is the constant load + uniform cooling condition, and the maximum compressive stress at the foot of the arch is 134.2MPa.

The lower chord is subjected to tensile stress under the action of uniform warming (cooling) and the upper chord is opposite, so the action of uniform warming produces compressive stress in the lower chord, the largest in the section of the foot of the arch, 61.1MPa, reaching 80.0% of the value of the stress under the action of the constant load; the action of uniform cooling produces tensile stress in the lower chord, and also the largest in the foot of the arch, 47.9MPa, reaching 62.8% of the value of the stress under the action of the constant load. The most unfavourable load on the lower chord tube. The most unfavourable loading condition of the lower chord is the constant load + uniform warming condition, and the maximum compressive stress at the foot of the arch is 137.4MPa.

2.3.2. Skeleton deflection analysis

According to the reference^[12], it can be concluded from the force analysis during the hoisting construction of the rigid skeleton that, 6 # section lifting completion of the maximum cantilever stage force is more unfavourable, take the 6 # section lifting stage to analyse the deflection change of the key section of the strong skeleton under the action of uniform temperature as shown in Figure 4.

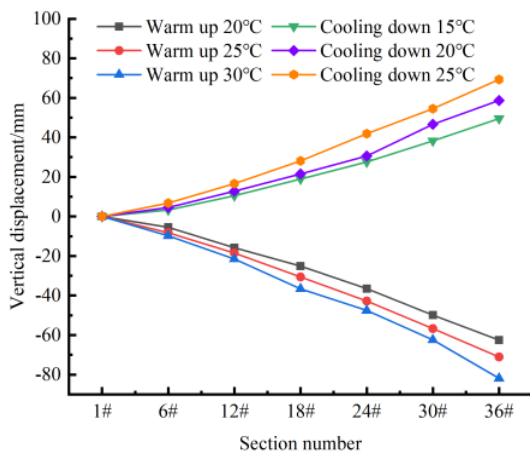


Figure 4. section deflection during lifting stage of section 6#

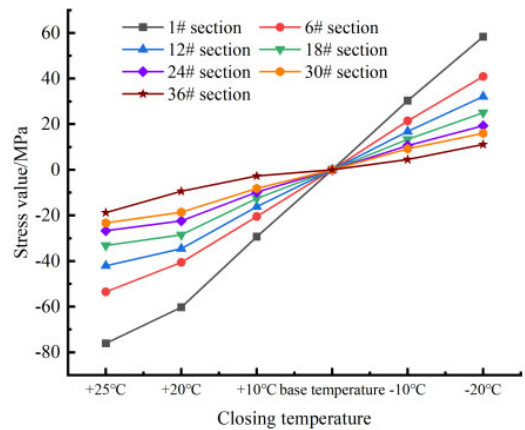
According to Fig. 4, the deflection generated under the effect of uniform temperature rise and fall gradually increases from 1# cross-section to 36# cross-section, basically showing a linear distribution. Under the effect of uniform temperature

rise, the deflection value is proportional to the temperature difference, when the temperature difference increases by 5°C, the downward deflection of 36# section increases by about 10mm. Under the effect of uniform cooling, the absolute value of deflection is proportional to the cooling temperature difference, when the cooling temperature difference increases by 5°C, the upward deflection of 36# section increases by about 10mm. In this paper adopts the lifting temperature working condition, uniform heating 25°C, in the 36# cross-section of the downward deflection of 71.1mm, which is superimposed with the deflection under the constant load, the structure is unfavourable; uniform cooling 20°C, in the 36# cross-section of the upward deflection of 58.7mm, which can offset some of the constant load under the structure of the downward deflection.

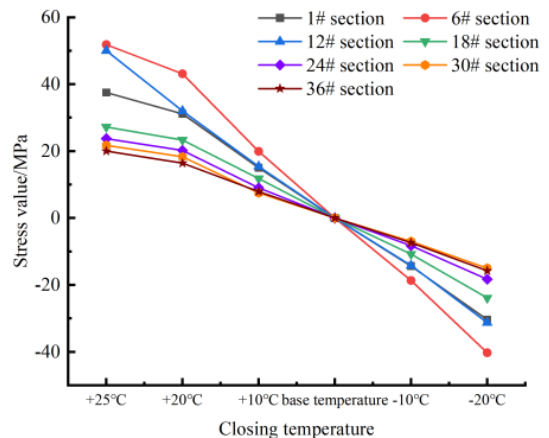
3. Temperature Effect of Non-design Base Temperature Merging

3.1. Effect of Different Closing Temperatures

Due to the environment and construction conditions, the temperature during the actual construction can not be strictly in accordance with the design temperature, resulting in a certain difference between the force and linearity of the strong skeleton after joining and the design. So according to the range of values of effective temperature at the bridge site, and taking the design merging temperature as the base temperature, +25°C, +20°C, +10°C, -10°C, -20°C, (the difference between the actual merging temperature and the calculated merging temperature) were taken for analysis.



(a) Stress in each section of the top chord



(b) Stress in each section of the lower chord

Figure 5. Skeleton upper and lower chord stresses

According to Fig. 5, it can be seen that, for the upper chord tube, when the stiffening skeleton joint temperature is higher than the design reference temperature, the stresses on each key section of the chord tube are all compressive stresses and decrease with the difference between the actual joint temperature and the design joint temperature, and the stresses at the same temperature gradually decrease from the foot of the arch to the top of the arch, in which the values of compressive stresses at the foot of the arch, the 18# cross-section (about 1/4L cross-section), and the top of the arch cross-section decrease with the difference of temperature by 5°C, and then the values are 15MPa, 7MPa, and 4MPa, respectively. 15MPa, 7MPa, 4MPa;The opposite is true when the temperature is lower than the design reference temperature, the stresses on the chord tube are all tensile stresses, and the tensile stresses on the foot of the arch, the 18# section (about 1/4L section), and the top of the arch section increase by 14MPa, 7MPa, and 3MPa, respectively, with the temperature difference increasing by 5°C; It can be seen that the stresses in each critical section of the upper chord tube vary essentially linearly with the value of the merging temperature.

For the lower chord pipe, the temperature stress at the same temperature increases and then decreases from the foot of the arch to the vault, and it is the largest at the 6# section. When the joint temperature is higher than the design reference temperature, the stresses on each key section of the chord pipe are tensile stresses, and the opposite is true for the lower section, and the stresses at the foot of the arch, the 6# section (the section with the largest temperature stresses), and the vault increase by 7MPa, 9MPa, and 4MPa, respectively, when the temperature difference is increased by 5°C. The stress of each key cross-section of the lower chord is also basically linearly changing with the value of the merging temperature.

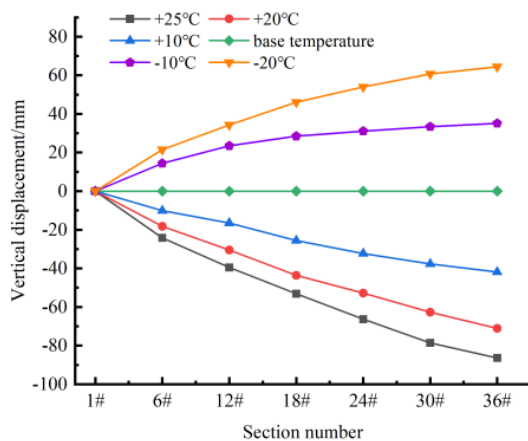


Figure 6. Skeleton vertical displacement

As can be seen from Fig. 6, when the actual merging temperature is higher than the design reference temperature, i.e., when the relative temperature difference is positive, each cross-section of the strong skeleton produces downward deflection, and the larger the relative temperature difference is, the larger the downward deflection is, and the deflection and the value of the relative temperature difference are basically positively correlated, and for every increase of 5°C in the relative temperature difference, the downward deflections of the 18# cross-section (about 1/4L cross-section) and the top of the arch cross-section are increased by about

12mm and 16mm, respectively. When the relative temperature difference is negative, each cross-section of the strong skeleton produces upward deflection, and the larger the relative temperature difference is, the larger the upward deflection is, for every 5°C increase in the relative temperature difference, the upward deflection of the 18# cross-section (about 1/4L cross-section) and the vault cross-section increases by about 10mm and 15mm. For the strong skeleton joining, considering the downward deflection generated by the self-weight of the skeleton, choosing a lower temperature joining can correspondingly reduce the downward deflection generated by the skeleton due to self-weight, which is more favourable to the structure.

3.2. Reasonable Values for the Temperature of the Joints

In construction, the arch bridge closing time is directly related to the internal force of the arch, generally will not choose to close at the lowest temperature, and will not choose to close at the highest temperature, so in the actual construction process of the arch ribs, from the aspect of reducing the internal force of the temperature considerations, should choose the appropriate time to close to get a reasonable value of the closing temperature. For this reason, the temperature internal forces were analysed for different values of closing temperature to obtain a reasonable closing temperature of the arch ribs, and the closing temperatures were taken to be -3, 5, 7, 12, and 17°C to analyse the stresses at the foot of the arch and the top of the arch cross-section under the temperature variations, respectively.

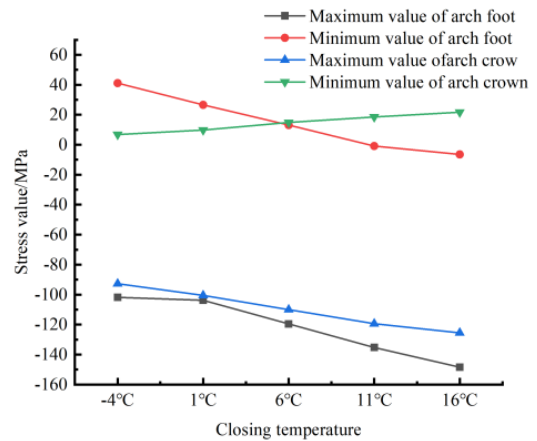


Figure 7. Stresses in foot and vault sections

As can be seen from Fig. 7, the higher the temperature of the strong skeleton joint the higher the minimum compressive stress value at the foot of the arch and the arch cross-section decreases, i.e., the maximum compressive stress increases, the maximum stress at the foot of the arch cross-section decreases gradually, and the tensile stress decreases gradually to the compressive stress, while the maximum stress at the arch cross-section increases gradually, and the maximum stress at the arch cross-section decreases gradually, and the maximum stress at the arch cross-section increases gradually. By comparison, when the temperature is taken as 2~7°C, the maximum and minimum stresses of both sections are smaller, and considering the effect of the previous temperature on the deflection, it can be seen that the lower

temperature should be chosen to reduce the deflection of the skeleton, and it is more appropriate to take 2°C as the temperature of the strong skeleton and the dragon, which is slightly lower than the average annual temperature at the site of the bridge and the bridge site is 5.5°C.

4. Conclusion

(1) The effect of uniform temperature action on the stress of the skeleton string tube is more significant, the effect of uniform warming and cooling action on the stress of the skeleton is different due to the location of the string tube and the location of the cross-section, the tensile and compressive stresses on the upper and lower string tubes at the same cross-section are inversely significant, and the tensile and compressive stresses on different cross-section of the same string tube are the same, and the values are quite different. The most unfavorable load conditions for different chord sections are also different. The maximum tensile stress generated by uniform heating on the upper chord is 66.2MPa, accounting for 79.6% of the stress value under constant load at the arch foot section, 51.0MPa of the maximum compressive stress generated in the lower chord, and 61.3% of the stress value under constant load at the arch foot section; The effect of uniform cooling on the stress of the upper and lower chord pipes is opposite, with slightly smaller values due to the temperature difference between cooling and heating. The deflection of the skeleton is directly proportional to the temperature difference between lifting and lowering.

(2) When the rigid skeleton is closed at different temperatures and then raised or lowered to the design reference temperature, the stress of each key section of the upper and lower chord pipes basically changes linearly with the closing temperature value, and the deflection of each section is positively correlated with its relative temperature difference. For every 5°C increase in relative temperature difference, the upward deflection of the 18 # section (about 1/4L section) and the arch crown section increases by about 10mm and 15mm. Considering the influence of the maximum and minimum stress and deflection of the skeleton arch foot and arch crown after closure, it is more reasonable to choose 2°C slightly lower than the annual average temperature as the closure temperature.

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