

# Stability analysis of the super tall tower in the arch rib hoisting construction process

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**Abstract:** This paper expounds the importance of the stability analysis of the super high tower frame in the lifting stage of the arch rib. Then the arch rib turning stage is divided into 0 degrees, 30 degrees, 60 degrees, 90 degrees, 102.8 degrees five conditions, respectively carried out the force analysis of sling and tower under different conditions. Finally, calculated the stability safety factor of the tower structure, proved the tower structure meet the requirements of stability during the whole course of the arch rib.

## Introduction

Bridge construction method mainly includes the support construction method, cable hoisting construction method, swivel construction method and integral lifting method of arch rib<sup>[1]</sup>. The whole lifting method has little effect on the navigation, reduce the danger of aerial work, short duration, etc<sup>[2]</sup>. But the premise condition of integral lifting method is to set up a temporary tower structure, to ensure the safety of the construction process must ensure the stability of the tower during construction. The integral lifting method of the arch rib mainly consists of two stages: arch rib flipping and arch rib lifting. When the arch rib is flipped to a different angle, the cable and arch rib have different angle, the stress of the tower is different too, so the effect of arch rib flip stage of tower is relatively large, integral lifting stage of arch rib has little effect for the tower. This paper mainly studies the stability problem of the tower in the process of the arch rib flipping.

## basic principles

The basic idea of structural stability analysis is to write down the equilibrium equation of the structure, then the characteristic equation of the structure is listed, finally, the structure stability safety factor is solved.

### structure characteristic equation

The stiffness equilibrium equation (equilibrium equation) of the structure is:

$$[K_E]\{d\} + [K_G]\{d\} = \{F\} \quad (1)$$

Among them,  $[K_E]$ 、 $[K_G]$  respectively are the elastic stiffness matrix and geometric stiffness matrix of the structure,  $\{d\}$  is the displacement of the structure,  $\{F\}$  is the load of the structure, the geometric stiffness matrix of the structure is obtained by the addition of the geometric stiffness matrix of the various elements, That is:

$$[K_G] = \sum [K_G]^e \quad (2)$$

By formula (1) can be known,when the load  $\{F\}$  is determined,we can find the structural displacement  $d$  .If  $\{F\}$  increases  $I$  times, then the structural stiffness matrix  $[K_G]$  also increased by  $I$  times, so there is an equation:

$$[K_E]\{d\}+I[K_G]\{d\}=I[F] \quad (3)$$

When the structure reaches the equilibrium state,  $\{d\}$  change into  $\{d\}+\{\Delta d\}$  , so there is:

$$([K_E]+I[K_G])(\{d\}+\{\Delta d\})=I[F] \quad (4)$$

In order to satisfy the equation (3) and (4), there are:

$$([K_E]+I[K_G])(\{\Delta d\})=0 \quad (5)$$

Equation(5) is the characteristic equation for calculating the stability safety factor.If the equation (5) is the  $n$  order equation, the equation is bound to exist  $N$  characteristic value  $I_1, I_2, \dots, I_n$  .But in practical engineering problems,only the smallest eigenvalue and the minimum of the stability safety factor are meaningful,at this moment the load is the critical load  $I_{cr}\{F\}$  ,the characteristic value is  $I_{cr}$  ,feature vector is the buckling mode.For solving the eigenvalue problem of the stability characteristic equation,only need to find a minimum eigenvalue,this characteristic value is describe the stability coefficient of the structure to achieve the lowest order instability<sup>[3]</sup>.

Using the inverse iteration method to solve the problem,turn the formula (5) into:

$$[K_E]\frac{1}{I}\{d\}=-[K_G]\{d\} \quad (6)$$

Then the inverse iteration method is solved in the form of:

$$[K_E]\frac{1}{I}\{d\}^{i+1}=-[K_G]\{d\}^i \quad (7)$$

The stability safety factor of the structure can be obtained by solving the stability characteristic equation.

## The establishment of finite element model

### The establishment of tower model

The tower use steel pipe fastener type bracket,in order to ensure the tower and arch rib in the process of Arch rib flipping,at the foot of the 33m respectively set up the tower.The tower height is 75m,consisting of 2 truss elements,each truss element is 6m long, 4m wide, 3m high,the truss element model is shown in Figure 1. Each tower unit is composed of four truss unit,each plane is used with a diagonal brace,bolted connection between upper and lower units,truss with Q235 steel pipe,the outer diameter of the pipe is 63mm,wall thickness is 18mm.Figure 2 shows the total tower model with 560 nodes, 2605 truss unit.

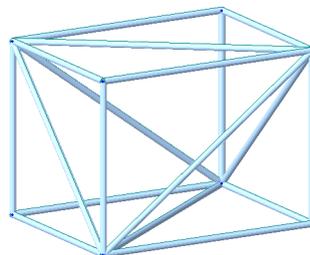


Fig. 1 Schematic diagram of truss element model



Fig. 2 Schematic diagram of the tower model

**sling and cable set**

The hoisting sling using GB/T8918-1996 "wire rope" 6×19-Φ32-1770 wire rope, each hanging point selection of six slings and its technical parameters as shown in Table 1:

Table 1 technical parameters of wire rope

|                                              |          |
|----------------------------------------------|----------|
| Nominal tensile strength of steel wire ropes | 1770Mpa  |
| per meter Weight of Wire rope                | 3.45Kg/m |
| Wire rope diameter D                         | 32mm     |

Because the arch rib is in the turning, the force of the tower is large, in order to ensure the stability of the tower in the lifting process of arch rib, to prevent the occurrence of the overturning of the tower, so consider increasing wind resistance cables around the tower, and guarantee cable and tower not affect each other in the course of the arch rib flipping, in the tower height of 45m and 60m on both sides of the tower set 3 cables, both sides are symmetrically arranged, the side view of the tower and cable layout as shown in figure 3, normal view of the arrangement of the first order (45m) and two order (60m) cable as shown in figure 4 and figure 5. Cable and the sling is the same type wire rope.

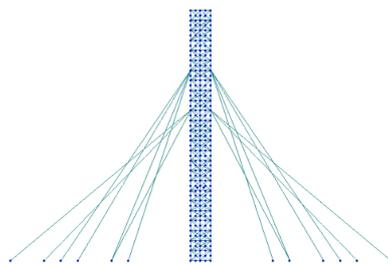


Fig 3. The wind cable layout (side view).

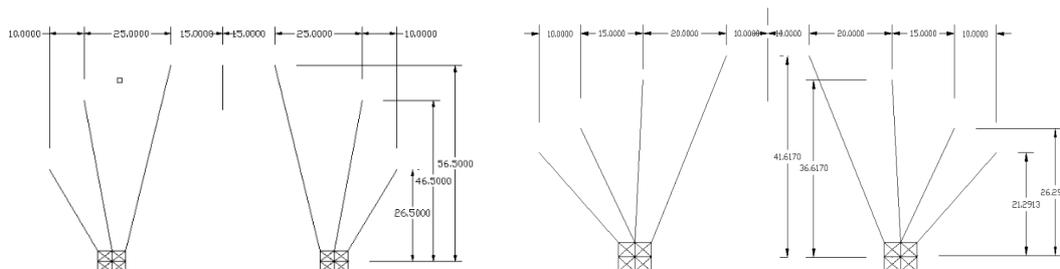


Fig. 4 First order wind cable layout (45m) Fig. 5 Two order wind cable layout (60m)

### hanging point layout

Whether the arrangement of the hanging point is reasonable, in relation to the stress and deformation of arch rib in the course of the arch rib flipping. In order to control the deformation of the arch rib in the turning process, at the same time, as far as possible to reduce the technical difficulty of construction, after many trial and error, finally, the 5 hanging points are arranged on both sides of the single arch rib, and the left and right symmetrical arrangement. The distance between the five hanging points and the center line of the arch rib is respectively 5.54m, 21.41m, 33.13m, 43.14m, 51.86m, and give each hanging point position a number, the center line of the arch rib left for 1#-5#, the center line of the arch rib to the right is 6#-10#, as shown in figure 6.

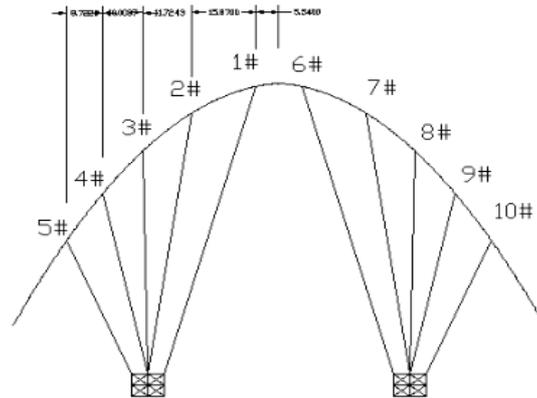


Fig. 6 Position of hanging point

### temporary support of the arch rib foot

For the arch bridge in this project, before the main arch closure, make an ideal roll axis hinge, it can play the role of adjusting the arch axis before the closure, after the closure of the vault then seal the hinge, and then form the structure without hinge<sup>[4]</sup>. In fact, for this kind of span arch bridge, due to the presence of hinges, so that when the arch rib is assembled, stability greatly reduced. Therefore, the bridge was assembled after the vault, then the foot is fixed. Finally, the arch foot hinge is only bear a part of internal force.

### The stability of tower example

#### Stress analysis of sling

According to the turning angle of the arch rib, the arch rib turning stage is divided into 0 degrees, 30 degrees, 60 degrees, 90 degrees, 102.8 degrees five conditions.

Under five different conditions, we carried out the stress analysis of the sling by the finite element software MIDAS, the stress analysis of the sling is shown in figure 7 to figure 11.

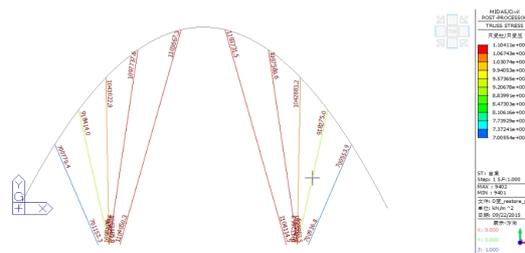


Fig. 7 When the arch rib is flipped 0 degrees, Stress sling

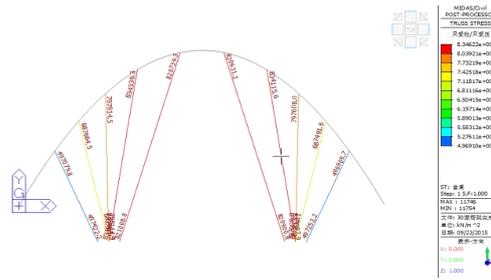


Fig.8 When the arch rib is flipped 30 degrees, stress sling

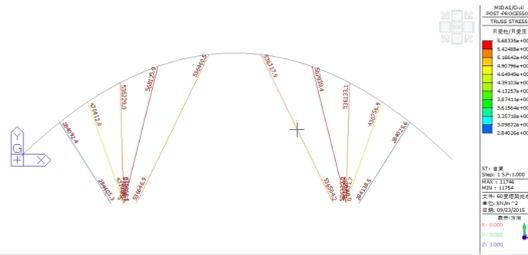


Fig. 9 When the arch rib is flipped 60 degrees, stress sling

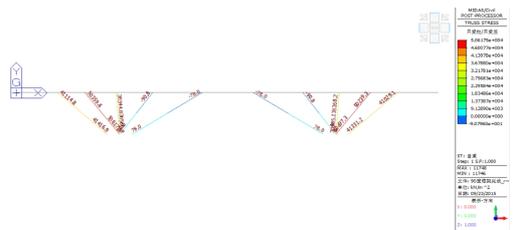


Fig.10 When the arch rib is flipped 90 degrees, stress sling

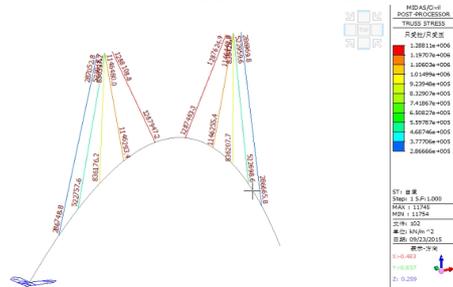


Fig. 11 When the arch rib is flipped 102.8 degrees, stress sling

Table 2 under different conditions, the maximum tensile stress of the sling

|                 | 0°      | 30°     | 60°     | 90°     | 102.8°  |
|-----------------|---------|---------|---------|---------|---------|
| $s_{\max}$ /MPa | 1104.11 | 834.622 | 568.335 | 50.6175 | 1288.11 |

Table 2 shows that the arch rib is flipped from 0 degrees to 90 degrees, the sling stress is gradually reduced, the arch rib is flipped from 90 degrees to 102.8 degrees, the sling stress increases rapidly. We can see from Figure 11, when the arch rib flip 102.8 degrees, the sling has the largest tensile stress at 1# and 6# sling hanging position, the maximum tensile stress is 1288.11GPa. The 2.3.2 section shows that the sling is used in 6×19-Φ32-1770 type wire rope, the nominal tensile strength of steel wire ropes is 1770MPa, and the maximum tensile stress is greater than the maximum tensile stress of the sling, so the sling in arch rib turning stage can meet the capacity requirements.

## Stress analysis of the tower

Stress analysis of the tower under five conditions as shown in figure12 to figure16:

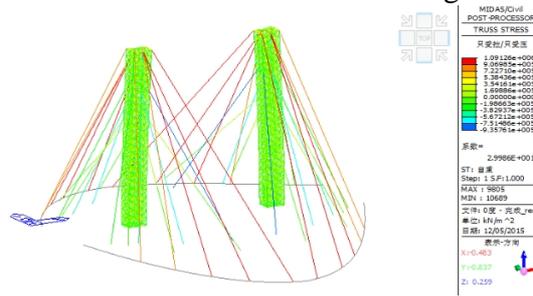


Fig. 12 Arch rib flip 0 degrees, the stress of the tower

As shown in Figure 12, when the arch rib is flipped to 0 degrees, the maximum tensile stress of the tower section is 198MPa, the maximum pressure stress is 340MPa, the tower is used Q345 seamless steel tube, tensile strength of the Q345 seamless steel tube is 490-675MPa and its yield strength is 345. So the arch rib has just begun to flip, the tower structure meets the requirement of stability.

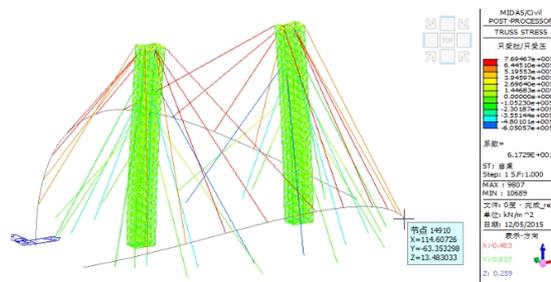


Fig. 13 Arch ribs flip to 30 degrees, the stress of the tower

As shown in Figure 13, arch rib flip to 30 degrees, tower structure of maximum tensile force is 209MPa, the maximum compressive stress is 329MPa, less than Q345 seamless steel pipe yield strength. So the tower structure satisfies the stability requirement.

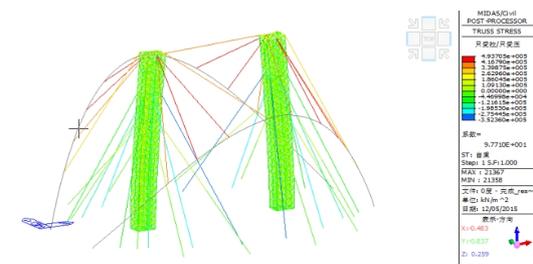


Fig. 14 Arch ribs flip to 60 degrees, the stress of the tower

As shown in Figure 14 above, the arch rib turnover to 60 degrees, the maximum tensile stress of the tower structure is 134MPa, the maximum compressive stress is 192MPa, less than the yield strength of Q345 seamless steel tube, so the tower structure satisfies the stability requirement.

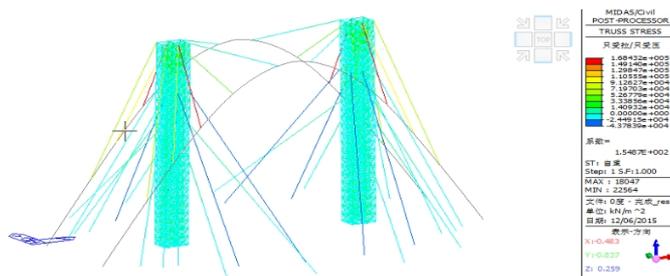


Fig. 15 Arch ribs flip to 90 degrees, the stress of the tower

Figure 15 shows that when the arch rib flip to 90 degrees, the maximum tensile force of the tower structure is 45.8MPa maximum rate of pressure stress is 31.7mpa, less than the yield strength of Q345 seamless steel tube, so tower structure meet the stability requirements.

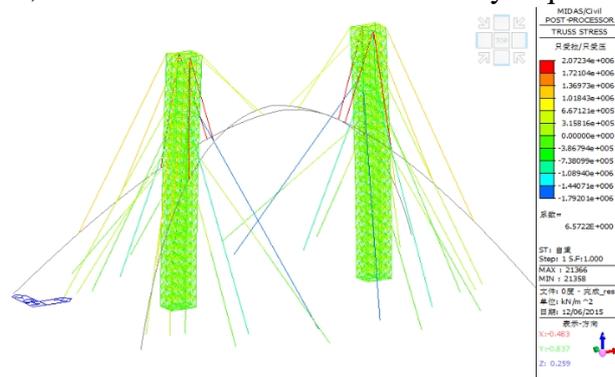


Fig. 16 Arch ribs flip to 102.8 degrees, the stress of the tower

Figure 16 shows that when the arch rib is flipped to 102.8 degrees, the maximum tensile force of the tower structure is 456mpa, the maximum compressive stress is 325 MPa, are less than the yield strength of Q345 seamless steel tube, so the tower structure meet the stability requirements.

Table 3 under different conditions, the maximum stress of the tower

|                         | 0°  | 30° | 60° | 90°  | 102.8° |
|-------------------------|-----|-----|-----|------|--------|
| Maximum tensile stress  | 198 | 209 | 134 | 45.8 | 456    |
| Maximum pressure stress | 340 | 329 | 192 | 31.7 | 325    |

Table 3 shows that when the arch rib flip from 0 degree to 90 degree, the maximum stress of the tower decreases. When the arch rib flip from 90 degrees to 102.8 degree, the maximum stress of the tower increased gradually. The arch rib started turning, the maximum compressive stress of the tower is 340MPa, smaller than the compressive strength of the tower structure, arch rib flip to 102.8 degrees, the maximum tensile stress of tower is 456mpa, less than the tensile strength of the seamless steel pipe, so the structure is safe.

Table 4 lists the stability safety factor K of the tower in the course of the arch rib flipping, it can be seen that the K value of the arch rib is fluctuations in the range of 42 to 52, the structure is stable, and has a large safety reserve.

Table 4 The stability safety factor K of the tower under different working conditions

| Arch rib Flip angle/° | 0     | 30    | 60    | 90    | 102.8 |
|-----------------------|-------|-------|-------|-------|-------|
| K                     | 44.69 | 46.13 | 48.19 | 51.15 | 42.56 |

## Conclusions

- (1) In the course of the arch rib from 0 degrees to 90 degrees, stress sling reduced gradually, in the turning process of the arch rib from 90 degrees to 102.8 degrees, the sling stress increased significantly. Maximum stress occurs when the arch rib is turned to 102.8 degrees, maximum tensile stress is 1288.11MPa, less than the sling tensile strength of 1770 MPa, therefore in the arch rib for turnover construction, sling selected to satisfy construction requirements.
- (2) In arch rib turning stage, the stress of the tower is first decreased and then increased. The arch rib from 0 degrees to 90 degrees in the turning process, the tower stress decreases gradually, the arch rib from 90 degrees to 102.8 degrees in the turning process, the tower stress and a rapid increases

rapidly. When the arch rib is flipped 102.8 degrees, the maximum tensile stress of tower is 456MPa, less than the tensile strength value of the seamless steel pipe, so the arch rib in the turning process, the tower stress satisfy the stability requirement.

(3) Through the calculation of stability safety factor of the tower structure, at the turning stage of the arch rib, the K values are in the range of 42 to 52, the tower structure is stable, and has a large safety reserve. So the tower structure satisfy the stability requirement.

### **Acknowledgements**

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