IOP Conference Series: Earth and Environmental Science

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To cite this article: Shuqin Li *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **643** 012060

Study on the length of cable-free zone of wide cantilever cable stayed bridge with low pylon

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Abstract: Low pylon cable-stayed bridge is a new type of composite bridge between girder bridge and traditional cable-stayed bridge. Because of its good mechanical properties, economic benefits and beautiful shape, low pylon cable-stayed bridge is widely used in highway and urban landscape bridges. In this paper, a wide and low pylon cable-stayed bridge under construction is taken as the research background, and the numerical simulation model is established by using the finite element analysis software MIDAS CIVIL. The influence of the length of the cable-free zone is studied. By changing the length of cable-free zone at the tower root and the length of cable-free zone in the middle of span, the influence of the length of non-cable zone on the deformation, bending moment, internal force and cable force of low pylon cable-stayed bridge at the completion stage is studied. The reasonable value range of non-cable zone length is obtained. The research results will provide theoretical guidance for the design and construction of similar projects.

1. Introduction

Low pylon cable-stayed bridge is a new type of bridge in recent years, its main beam stress is between continuous beam bridge and cable-stayed bridge. Ganter bridge designed by French engineer Christian Menn is the predecessor of low pylon cable-stayed bridge. The first low pylon cable-stayed bridge in the real sense is Japan's Ogata Yuangang bridge. Subsequently, the low tower cable-stayed bridge has been better developed and applied in Japan [5-6]. Although the low pylon cable-stayed bridge started late in China, it has developed rapidly. In recent years, the application of low pylon cable-stayed bridge in China is more and more extensive.

The main girder of low pylon cable-stayed bridge is the main flexural compression member, which bears about 70% of the total load, and the stay cable bears about 30% of the load[7]; Compared with the conventional cable-stayed bridge, the number of stay cables of low pylon cable-stayed bridge is less, and the vertical load of stay cables is far less than that of cable-stayed bridge; The main tower of the low pylon cable-stayed bridge is relatively low, and the height of the pylon is generally 1/12~1/8 of the main span [4]; Different from the conventional cable-stayed bridge, the obvious feature is that there are three cable-free areas on the main girder: tower root, middle span and end of side span. The distance between stay cables and the length of cable-free zone have a direct impact on the stress of the

IOP Conf. Series: Earth and Environmental Science **643** (2021) 012060 doi:10.1088/1755-1315/643/1/012060

main girder. This paper studies the length of the cable-stayed bridge without cable, analyzes the mechanical performance of the main beam under the condition of the length change of the non-cable area, and obtains the reasonable length of the non-cable area, so as to provide theoretical guidance for the engineering design.

2. Project Support and Calculation Model

2.1 Project support

This paper takes qingliuhe bridge as the research background. The span of the bridge is 77 + 135 + 77m, and the tower height is 32.5m. The bridge has 3.0% longitudinal slope and 2.0% cross slope. The total width of double deck is 60.5m, the width of single deck is 30m, and 0.5m central divider is set. The main beam adopts a single box three chamber cantilever structure, and the cantilever length is 5.5m. The beam height at the tower root is 4.78m, and the beam height in the middle of the span is 2.78m (excluding the 36cm higher than the partition belt). The height of the beam at the tower root 3m away from the tower root gradually changes to the beam height of the standard section in the form of quadratic parabola. The side webs are inclined webs. The anchorage points of stay cables are arranged at the diaphragm of the middle chamber of the box girder, and the cross section of the main beam is shown in Fig. 1.

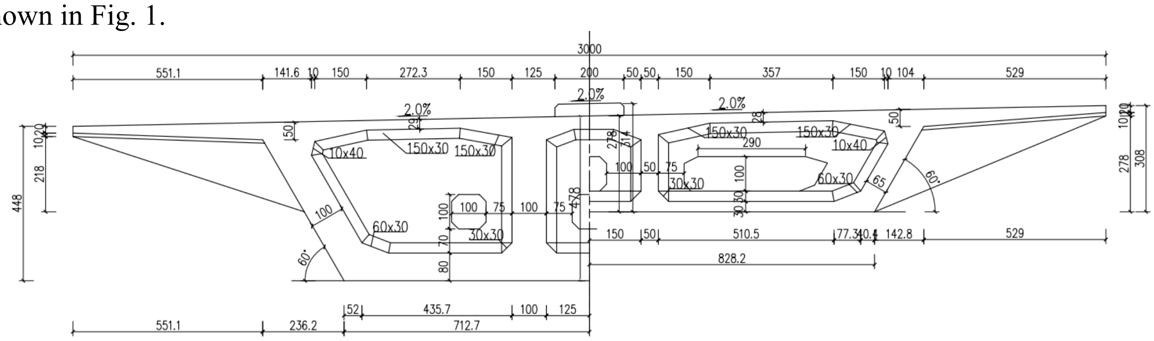

Figure 1. Structural drawing of main beam fulcrum and mid span cross section

The stay cable adopts the form of double row single cable plane. The cable spacing of the main beam is 4m, and the cable spacing of the main tower is 1.5m. The stay cable is anchored on the main tower through the wire pipe anchorage structure. The main tower is set at the separation zone, and the stay cable is arranged at the main beam separation zone. The standard strength of stay cable is 1860Mpa, and the cable group anchor system with steel strand is adopted. The length of cable-free zone at the end of side span is 15m, that of tower root is 18m and that of midspan is 11m. There are 24 stay cables with single cable plane and 96 stay cables in total. The upper structure adopts the structure system of tower beam consolidation and tower pier separation, as shown in Figure 2:

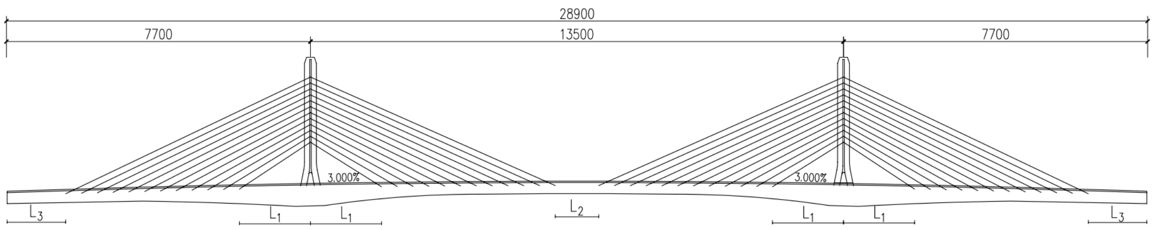

Figure 2. Layout of Qingliu River Bridge

2.2 Computational Model

The finite element software MIDAS civil is used to establish the numerical model. The variable section beam element is used to simulate the main beam, the truss element is used to simulate the stay cable, and the weight of diaphragm is replaced by the node load. There are 241 nodes and 236 elements in the whole bridge. The main tower is simulated by 40 beam elements and the stay cables are simulated by 48 truss elements. The connection between stay cable and main beam is simulated by elastic connection, and tower beam consolidation is replaced by general support. Based on the minimum bending energy method [1-2], the unknown load coefficient of MIDAS civil and the amplitude adjustment function of cable internal force are used to fine tune the cable force. Considering the reasonable completion state of the bridge under the action of dead weight, second stage dead load and prestress, a group of relatively reasonable cable forces are obtained. The finite element model of the whole bridge is shown in Fig. 3.

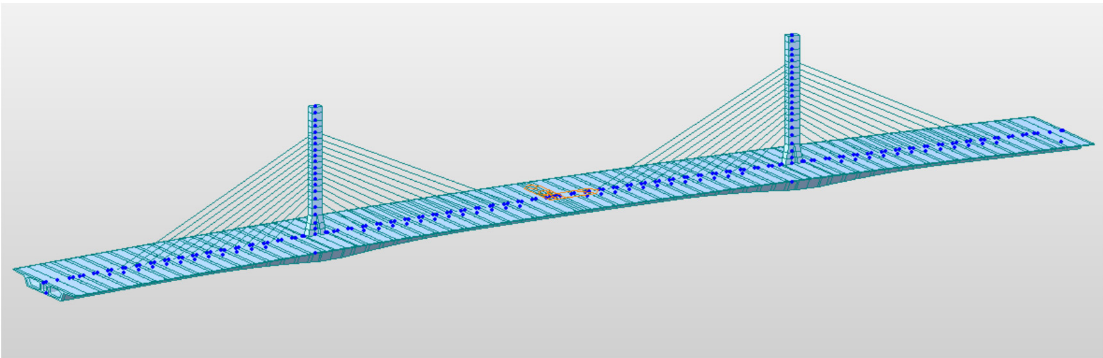

Figure 3. Finite element model of structural analysis

3. Length analysis of cable-free zone of tower root

By controlling the tower height, main beam section, total area of stay cable [3], cable spacing and other parameters of low pylon cable-stayed bridge, only changing the length of cable-free zone at the tower root to analyze the force of the bridge. Taking bending energy as the objective function, the maximum deflection of main beam, the maximum compressive stress of upper and lower flange of main beam, the maximum positive bending moment of main beam, the minimum negative bending moment of side and middle span and the average cable force are selected as the length objective of analysis of cable-free zone[8]. The number of stay cables is changed by increasing or decreasing the length of stay cables. The change range is 4m, the length of the cable-free zone at the tower root increases from 10 m to 26 m, and the corresponding number of stay cables is 14, 13, 12, 11 and 10 respectively. The ratio of the length of the cable-free zone at the tower root to the midspan is 0.074, 0.104, 0.133, 0.163 and 0.193, respectively. Each group of finite element models are established to compare and analyze the influence of the length of the cable-free zone of the tower root on the static performance of the structure.

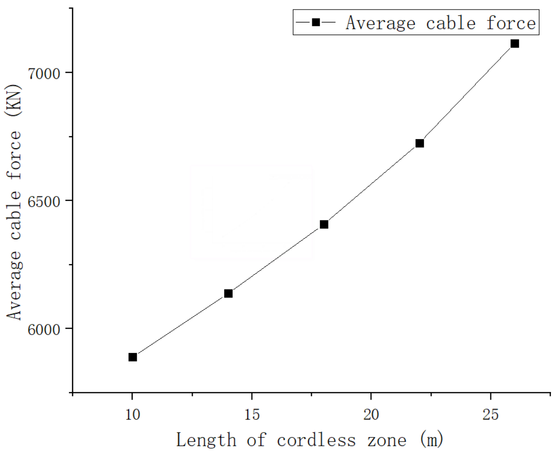

Figure 4. Change of average cable force

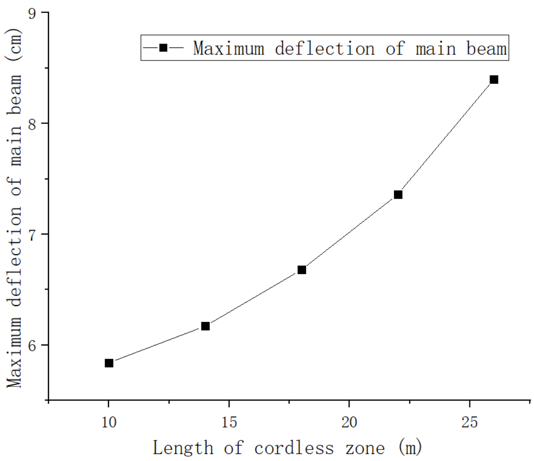

Figure 5. The maximum deflection of main beam does not change

It can be seen from Figure 4 that the average cable force of stay cable increases with the increase of the length of cable-free zone, and the change is close to linear change. The average cable force increases from 5890KN to 7155KN, increasing by 20.80%. The increase of the average cable force is due to the decrease of the number of stay cables with the increase of the length of the cable-free zone, which leads to the gradual increase of the cable force of a single stay cable with the increase of the length of the cable-free zone at the tower root. With the increase of the length of the cable-free zone of the tower root, the maximum deflection of the main beam increases from 5.84cm to 8.4cm, and the change trend is increasing.

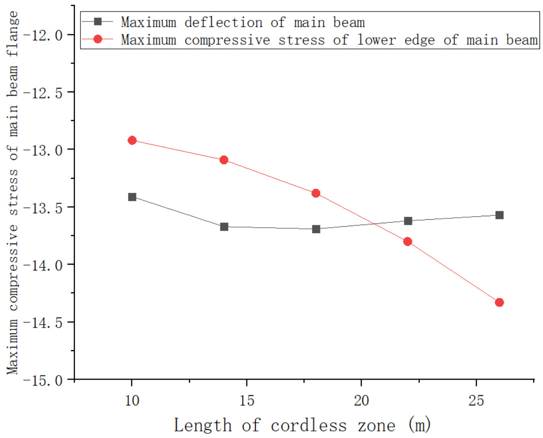

Figure. 6 Variation of maximum compressive stress at upper and lower edges of main beam

According to the results of finite element model analysis, the maximum compressive stress occurs near the tower root. It can be seen from Fig. 6 that the maximum compressive stress of the upper flange of the main beam increases first and then decreases with the increase of the length of the cable-free zone of the tower root. When the length of the cable-free zone reaches 18m, the maximum compressive stress on the upper edge of the main beam reaches the maximum of 13.69Mpa, which is only 0.15% lower than that of 10m of the tower root; The maximum compressive stress of the lower flange of the main beam occurs in the middle of the mid span. With the increase of the length of the cable-free zone at the tower root, the maximum compressive stress of the lower flange of the main beam increases by 10.91% with the increase of the length of the cable-free zone from 10m to 26m. The influence of the length of the cable-free zone of the tower root on the lower flange of the main beam is much greater than that on the upper flange of the main beam. The maximum compressive stress difference between the upper and lower edges of the main beam is 0.49Mpa, 0.58Mpa, 0.31Mpa, 0.18Mpa and 0.76Mpa, respectively. When the length of the cable-free zone of the tower root is 18~22m, the maximum compressive stress of the upper and lower edges of the main beam is relatively close, and the stress distribution of the main beam is more uniform .

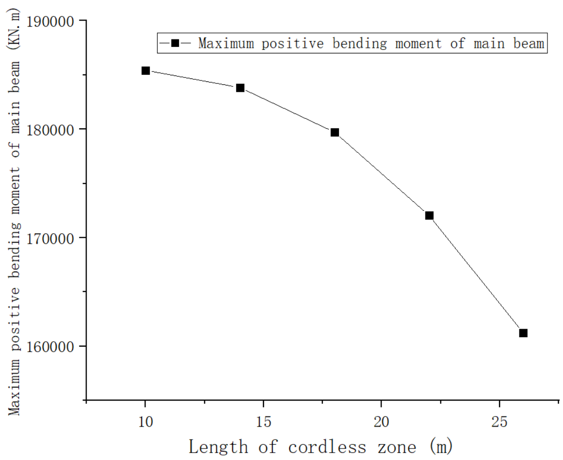

Figure 7. Variation of maximum positive bending moment of main beam

It can be seen from Figure 7 that with the increase of the length of the cable-free zone at the tower root, the maximum positive bending moment of the main beam decreases from 185428KN.m to 161213KN.m. The maximum positive bending moment of the main beam occurs in the middle span of the mid span, with a decrease of 13.06%. With the increase of the length of the cable-free zone of the tower root, the maximum positive bending moment of the main beam decreases more and more, and the influence on the maximum positive bending moment of the main beam is also greater and greater.

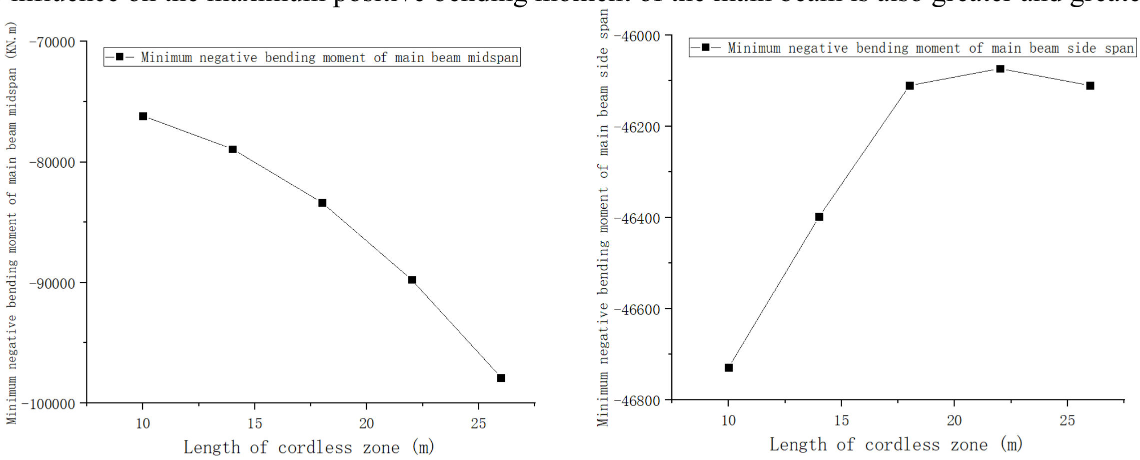

Figure 8. Variation of minimum negative bending moment at side and middle span of main beam

It can be seen from figure 8 that the minimum negative bending moment of the main beam midspan is reduced from -76175KN.m to -97881KN.m, with a decrease of 28.49%; The absolute value of the minimum negative moment of the main beam side span decreases with the increase of the length of the cable-free zone at the tower root. When the length of the cable-free zone at the tower root is 22m, the minimum absolute value of the minimum negative bending moment of the side span of the main beam reaches 46073KN.m, subsequently, the absolute value of the minimum negative bending moment of the side span of the main beam tends to increase. To sum up, the change of the length of the cable-free zone at the tower root can effectively adjust the bending moment of the main beam at the tower root and the middle span, which has little effect on the bending moment of the side span. When the bending moment of the main beam at the tower root decreases, the absolute value of the bending moment in the middle span of the mid span increases; when the length of the cable-free zone at the tower root is within 18~22m, the bending moment of the main beam is more uniform.

4. Analysis of length of cable-free zone in midspan

Taking the bending energy as the objective function, the parameters such as the spacing of stay cables on the main beam, the section of the main beam, and the stiffness of the stay cables are controlled. The length of the non-cable area in the middle of the span is changed by increasing or decreasing the number of stay cables. The length of the non-cable area in the middle of the span is 3m, 11m, 19m, 27m and 35m respectively, and the corresponding numbers of stay cables are 14, 13, 12, 11 and 10 respectively. The spacing of stay cables is 4 m, and the length of cable-free zone at tower root remains 14 m. The Influence of length variation on the maximum deflection of main beam, maximum positive bending moment of main beam, mid span bending moment of side span, and maximum compressive stress of upper and lower flange of main beam are studied. See Figure 8 ~ Figure 12 for details.

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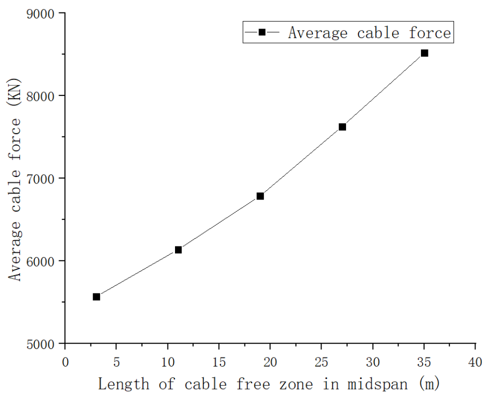

Figure 9. Variation of average cable force

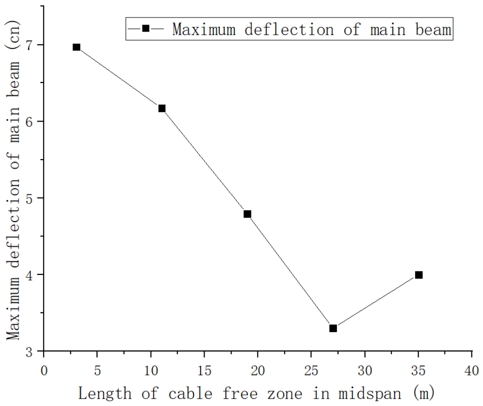

Figure 10. Variation of maximum deflection

It can be seen from Fig. 9 that with the increase of the length of the cable-free zone in the middle of the span, the average cable force of the stay cable changes nearly linearly, and the average cable force increases from 5568KN to 8518KN, an increase of 52.98%. The deflection analysis of the main girder shows that the maximum deflection of the first four models occurs in the middle of the middle span, and the maximum deflection of the main beam occurs in the middle of the side span when the length of the cable-free zone in the middle of the span is 35m. The change trend of the maximum deflection of the main beam is that the maximum deflection of the main beam decreases with the increase of the length of the non-cable area in the middle of the span. When the length of the non-cable area in the middle of the span is 27m, the maximum deflection of the main beam reaches the minimum of 3.3cm. When the length of the non-cable area in the middle of the span increases from 27m to 35m, the maximum deflection of the main beam increases. Therefore, when the length of the cable-free zone in the middle span is 27m, the stiffness of the main beam is the most favorable.

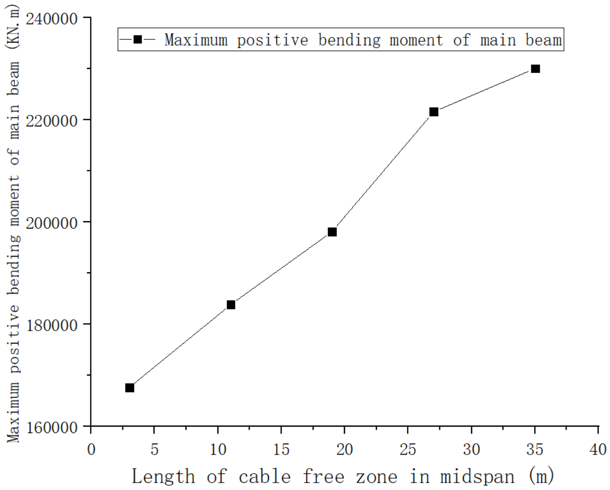

Figure. 11 Variation of maximum positive bending moment of main girder

It can be seen from Figure 11 that the maximum positive bending moment of the main girder increases from 167601KN.m to 230095KN.m, with an increase of 37.29%. The increase increases continuously when the length of the mid span cable-free zone increases from 3m to 27m, and the increase tends to be moderate from 27m to 35m. It can be seen that the length of the cable-free zone in the middle of the span has a great influence on the positive bending moment of the main beam.

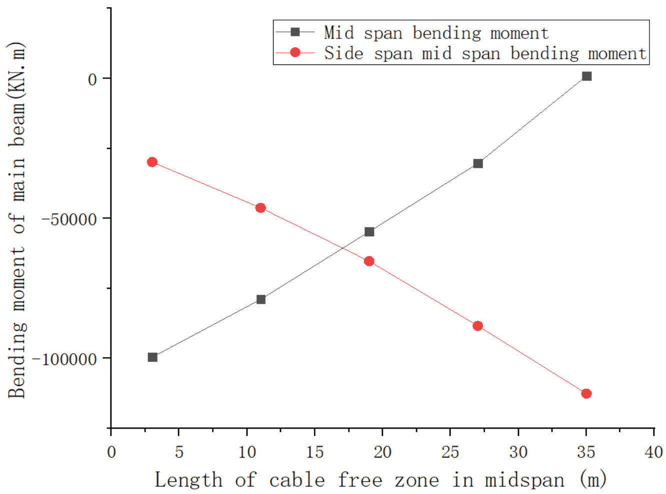

Figure 12. Bending moment variation of side and middle span of main beam

With the increase of the length of the cable-free zone in the middle of the span, the bending moment of the side span decreases and the bending moment of the middle span increases. When the length of the cable-free zone in the middle span is 35m, the mid span bending moment increases to 837KN.m. The mid span bending moment of the main beam increases from -99561KN.m to 837KN.m; the bending moment of side span decreases from -29867KN.m to -112546KN.m. When the length of cable-free zone reaches 19m, the difference of bending moment between side and middle span, that is, the minimum negative bending moment, reaches the minimum, and the stress on the side and middle span of main beam is more uniform.

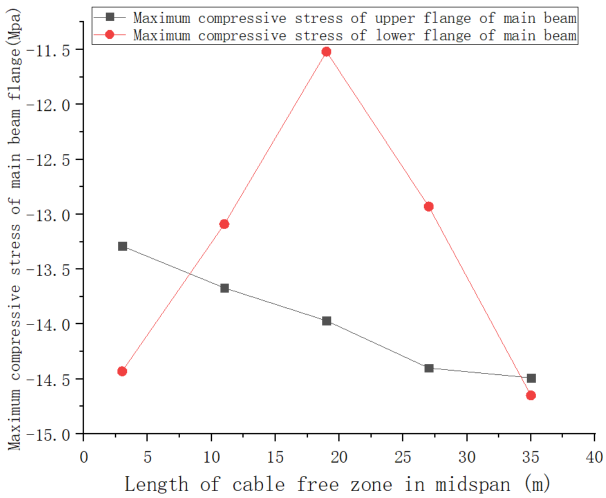

Figure. 13 Maximum compressive stress of upper and lower flange of main beam

It can be seen from Figure 13 that the maximum compressive stress on the upper flange of the main beam increases by 9.03% with the increase of the length of the non-cable area in the middle of the span; the maximum compressive stress of the lower flange of the main beam first decreases and then increases with the increase of the length of the non-cable area in the middle of the span, and the minimum maximum compressive stress of the lower flange of the main beam is 11.52Mpa when the length of the mid span cable-free zone is 19m. From the slope of the curve in the figure, it can be seen that the influence of the length of the middle span cable-free zone on the maximum compressive stress of the lower flange of the main beam is significantly greater than that of the upper flange of the main beam. When the length of no cable zone is 19m, it is more reasonable.

To sum up, adjusting the length of the cable-free zone in the middle of the span has a great influence on the bending moment of the main beam, which can effectively improve the bending moment of the main beam. Considering the deflection, bending moment and stress of the main girder, the reasonable range of the length of the non-cable zone in the middle of the span is 11~19m.

5. Conclusion

With the change of the length of the cable-free zone, the characteristic values reflecting the stress of the main beam show different trends. In order to make each eigenvalue within a reasonable range, it is very necessary to study the length of the cable-free zone .

- It is feasible to optimize the low pylon cable-stayed bridge only by changing the length of the cable-free zone without changing the tower height, girder section and cable amount.
- Through the above analysis, it is concluded that the influence of the length of the cable-free zone on the bending moment of the main beam is more obvious. If the peak bending moment in the middle of the main beam is large, the measures to improve the stress of the main beam can be taken by increasing the length of the cable-free zone at the tower heel or reducing the length of the cable-free zone in the middle of the span.
- Considering the deflection, bending moment and the maximum compressive stress of the upper and lower flange, it is concluded that the length of the cable-free zone at the tower root is 18~22m, the ratio of the length of the cable-free zone at the tower root to the span of the main beam is in the range of 0.13~0.16; the length of the cable-free zone in the middle of the span is suitable to be 11~19m, and the ratio of the length of the cable-free zone in the middle of the span to the span of the main beam is in the range of 0.08~0.14.

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