Analysis of Parametric Influence on Anchorage of Cable-stayed Bridge

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Abstract. In the cable-beam anchorage structure with tensile anchor plate of cable-stayed bridges, there is obvious stress concentration in the local area and the weld position of the anchor plate, which is prone to plastic failure and leads to the reduction of the bearing capacity of the anchorage zone. In order to analyse the mechanical behaviour and optimize the local structure of the anchorage, the finite element simulation technology is used to study the mechanical performance and bearing capacity of the anchorage. The stress distribution law and transmission path of the anchorage structure are defined, and the influence of structural parameters on mechanical performance is analysed. In order to reduce the stress concentration level and improve the bearing capacity of the anchorage, the optimum structural measures of anchorage structure are put forward.

1. Introduction
Cable-beam anchorage structure with tensile anchor plate are mainly composed of anchor plate (AP), anchor padding plate (APP), anchor tube (AT) and stiffening plate (SP) (Fig.1(a)). The cable force is transmitted to the AT then transmitted to the AP by the welding seam between them, and finally transmitted to the main beam through the weld between the AP and the top surface of the flange of the steel box girder. During this process, the weld joint connecting the AP and the two sides of the AT is subjected to a large cable force, and a plastic zone will appear at the root of the weld, which easily causes the AP to be damaged[1,2]. Therefore, it is vital to clarify the stress state of the AP and optimize its local structure to improve its bearing capacity.

Pan Ping et al. analysed the structural parameters of the AP. The results show that increasing the thickness of the AP or the SP and increasing the length of the shear weld are beneficial to reducing the stress level of the AP and improving the stress state of it[3]. Wei Xing carried out the full-scale static test of the cable-beam anchorage structure. The anchorage structure is in elastic working state under the design load of 1.0 times, and under the action of 1.7 times design load, some place of the AP and the AT would yield[4]. Existing research has not yet clarified the influence of structural parameters on the main mechanical properties of anchorage structure. Taking the anchorage structure of the cable-stayed bridge of Lancang River as an example, the mechanical properties of the structure was analysed.
The influence of structural parameters is clarified through the parametric analysis, which has important reference significance for the design of the subsequent anchorage.

2. Mechanical characteristics analysis.

2.1. Establishment of finite element model

The Lancang River Bridge is a double-tower and double-surface-cables hybrid composite cable-stayed bridge with a span of 40.5+42.5+67+400+67+42.5+40.5m. The edge span of the main beam is in the form of concrete beam, and the middle span adopts the bilateral "上"-shaped steel main beam combined with the concrete bridge deck structure.

The anchorage corresponding to the maximum cable force under the limit state of the load capacity is selected as the research object. The maximum cable force of the cable Z14 is 4,814 kN, and the corresponding anchorage structure is MLB-Z14. The anchorage model was established by using the finite element software ABAQUS. The calculation model is shown in Fig. 1 (b).

(a) Schematic diagram of anchorage structure     (b) Finite element model of anchorage structure

Figure 1. Anchorage structure

2.2. Stress distribution of each plate of anchorage structure

It can be seen from Fig.2: (a) there is obvious stress concentration at the arc transition of the AP, the maximum stress is 180.2 MPa. As the main force transmission path, the stress concentration is very serious, and the AP is easily broken. (b) Severe stress concentration occurs in the joint between the APP and the AT, and the stress here is the largest in the entire structure, reaching 270.7 MPa. It is generally considered that stress exceeding the standard or yielding of the local micro-region does not affect the strength and safety of the anchoring structure as a whole. (c)(d) The stress concentration occurs at the position where the SP and the AT are connected to the APP, but the stress level is lower than the stress of the AP and the APP. The impact of the overall force could not be considered.
To further clarify the mechanical behaviour of the anchorage structure, on the basis of the above-mentioned 4,814 kN, the load is increased by 200 kN per stage. Fig. 3 shows the relationship between stress and load of the AP and the APP.

**Figure 3. Diagram of the relationship between load and stress**

As can be seen from Figure 3:(1) When loading to 6814 kN, the stress of the APP is close to 345 MPa, the yield stress of the material is reached, and component enters the plastic state, but still has a large bearing capacity, which has little effect on the overall force of the structure. (2) After the APP enters the plastic state, the stress on the AP is little affected; when the load changes from 4814 kN to 9414 kN, the stress of the AP is almost linear with the load, and the structure is in elastic working state. After the load exceeds 9414 kN, the AP is plastically damaged. Fig. 4 shows the stress cloud diagram of the AP and the APP after the anchorage structure enters the plastic state.

**Figure 4. Stress cloud diagram of anchor plate and anchor padding plate in plastic state**
It can be seen from Fig. 3 and Fig. 4 that when the anchorage structure enters the plastic state, the stress of the AP and the APP is maintained at a yield load of 345 MPa for a long time; as the load increases, the plastic zone is also significantly enlarged: it expands to the periphery along the welds 1, 2 of the AP, and extends circumferentially along the arc cut of the APP.

Based on the above analysis results, the failure load of the AP is 9814kN, and the anchorage structure is first damaged at the arc-shaped incision of the anchor APP. The failure load is about 1.4 times of the design load. When the APP is broken, it does not affect the overall structure.

2.3. Analysis of weld stress

In the structure, a part of the cable force is directly transmitted from the APP to the AP, and the remaining part is respectively transmitted from the APP to the AT and the SP, and then transferred to the AP through the weld between the AT and the AP, the SP and the AP, and finally transmitted to the steel main beam via the butt weld of the AP and the steel main beam web. In the following, three main welds (Fig. 5) are taken as the analysis objects, and the variation law of the stress along the path is analysed.

![Diagram of the selected position of the weld](image)

**Figure 5.** Diagram of the selected position of the weld

From Figure 6: (a) The stress mainly appears as shear stress at the starting end of the arc, and the tensile stress is almost zero. The equivalent stress is the largest at the root and the tail is small. It is rapidly attenuated in the front part, and the middle part is evenly reduced, and finally it tends to be gentle. From the stress distribution and size, when the curve drops to 0.3L, the stress is reduced by about 1/2, indicating that the stress transfer in this segment is more efficient. (b) The initial stress is relatively large, mainly because the anchorage structure and the steel main beam are connected to the initial section of the weld bead 3 with an arc-shaped notch, and there will be stress concentration. At the distance 1000mm–3000mm away from the starting point of weld 3, the stress gradually decays and then tends to be gentle. This distance is between weld 1 and weld 2. It is the area of cable force, so the stress will gradually decrease and eventually become gentle. At the end of the weld 3, the stress is almost zero.

![Changes along the path of welds 1, 2](image)

![Changes along the path of weld 3](image)

**Figure 6.** Changes along the path

3. Analysis of Structural parameters
3.1. Structural parameters selection

It can be seen from the previous section that the stress concentration of the APP is the most obvious, and the arc transition of the AP is the prone area of plastic failure of the anchorage. Therefore, taking P1 (the arc transition zone of the AP) and P2 (stress concentration point of the APP) as the research object to analyze the influence of the thickness of the APP and the AT, the radius of the arc transition zone, the length of the weld between the APP and the AP on the stress levels of P1 and P2. The change of the value is shown in the following figure.

3.2. Influence rules of structural parameters

The Mises stress of P1 and P2 changes with the value of each parameter, and the change rule is shown in Fig. 7(a) ~ (d)

![Figure 7](image)

**Figure 7.** Changes in the stress of P1 and P2 with various parameters

Fig. 7: (a) While the thickness of the APP is between 40mm and 65mm, the stress drop of P1 is 12.4%, and the stress drop of P2 is 20.4%. After the cable force is transmitted to the APP, it will be transmitted to the AP. Increasing the thickness of the APP can increase the length of the weld between the APP and the AP, so that the cable force shared by the APP increases. The force on the arc-shaped transition zone of the AP is also better improved. (b) The stress of P1 decreases slightly with the increase of the thickness of the AT; the stress of P2 changes significantly with the increase of the thickness of the AT, and the stress are reduced from 290.5 MPa to 228.6 MPa, a decrease of 21.3%. As the thickness of the AT increases, the contact area between the APP and the AT increases, and the force transmitted from the APP to the AT increases accordingly. (c) Increasing the length of the joint weld between the APP and the AP has little effect on the stress of P1, but has a greater influence on P2. When the weld length is increased from 220mm to 320mm, the stress of P2 is reduced by 14.6%. The length of the force transmission weld between the APP and the AP is increased, the cable force
transmitted from the APP to AP is increased, and the cable force transmitted to the AT is reduced. (d) The radius of the arc transition zone has a relatively large influence on its equivalent stress. When the radius increased to 100mm, the equivalent stress decreased from 311MPa to 176.3MPa. After increased to 100mm, the equivalent stress tends to be gentle.

3.3. Structural optimization measures
Based on the results of the above parameter analysis, increasing the size of these three components can optimize the effect. The parameters of the components of the anchorage structure of the Langcang River Bridge are shown in the following table, which can be used as a reference for the design of the anchorage structure of the cable-stayed cable girder in the future.

| Parameter name                        | Value (mm) |
|---------------------------------------|------------|
| Thickness of anchor plate             | 48         |
| Thickness of anchor tube              | 60         |
| Thickness of anchor padding plate     | 40         |
| Thickness of stiffener                | 36         |
| Weld length of anchor padding plate   | 262        |
| Radius of arc transition zone         | 100        |

4. Conclusion
(1) The maximum stress occurs at the position where the APP is connected with the AT. The failure load of the APP is 6814kN, and of the AP is 9814kN. The anchorage structure was first destroyed at the arc cut of the APP, and the damage load was about 1.4 times of the design load.
(2) The equivalent stress is transmitted efficiently between the three main welds, and nearly 1/2 stress is transmitted in the first half, and the stress reduction in the latter half is relatively flat, and eventually approaches 0 MPa.
(3) Reducing the radius of the plastic zone of the AP can reduce the stress concentration of the AP and improve the mechanical performance of the plastic zone; increasing the thickness of the AT and the length of the weld between the APP and the AP can effectively reduce the stress level of the APP; increasing the thickness of the AP can simultaneously reduce the equivalent stress of the AP and the APP to achieve the best effect.

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