Influence of Vertical Prestressed Tensioning Process on Box Girder Web

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Abstract. In order to study the effect of vertical prestressing tension timing and sequence on the vertical stress change of concrete box girder webs, an ANSYS finite element model was established with a large-span continuous rigid frame bridge to simulate the different tensioning sequence of the vertical prestressing steel strands. This paper analyzed the reasonable time of vertical prestressed tension, the stress variation of web plate under different ways of vertical prestressed tension, and the influence of secondary vertical prestressed tension on web crack resistance. The vertical compressive stress at the bottom of the adjacent beam section is obviously smaller than that at the middle of the beam section during segmental tensioning, which leads to the problem that the difference between the free end section and the vertical compressive stress at the end of the beam section is large. During the vertical prestressing of the two lagging sections, the vertical normal stress of the web is more uniform. The maximum vertical compressive stress is 2.7% larger than the overall tension, which is 32.3% less than the maximum vertical compressive stress of the segmented tension. In the case of vertical prestress loss in the initial tension, the reasonable use of the secondary tension construction process can significantly increase the cracking load of the beam.

1. Introduction
During the operation of long-span prestressed concrete box girder bridge, the web is prone to produce diagonal cracks, which seriously affects the safety and durability of the structure, and the loss of vertical prestress of the web is the key factor causing the diagonal cracks. At present, the requirements for the tension of vertical prestressed tendons are not clearly specified in highway bridge design specifications, construction technical specifications, and quality inspection and evaluation standards. In the process of vertical prestressing tension, the time lag should not exceed that of the three cantilever beams. The tensioning sequence of prestress is not clearly defined. In order to ensure that the main tensile stress of web does not exceed the limit in the construction process, the common construction process is segmented and batched tensioning, but the research on section length and batch tensioning proportion is less. The current code does not take into account the cantilever pouring process of the box girder when calculating the vertical compressive stress on the web. In the practical engineering application, the vertical prestressed tendon is tensioned in sections and batches, and the vertical prestressed tendon is tensioned at the same time of the longitudinal prestressed tendon. If the vertical prestress is tensioned in a synchronized manner with the longitudinal prestressed steel beam, the vertical prestressing of the previous beam segment will not affect the subsequent beam segment. Stress can affect the box girder in the previous beam section, causing uneven compression and deformation of the concrete in the previous beam section, resulting in uneven stress in the box girder.
web. Aiming at the phenomenon that the quality of vertical prestressed construction is unstable and highly discrete, the vertical prestressed tensioning process is researched to optimize the tensioning process and improve the tensioning technology to reduce excessive prestressing losses due to construction factors.

2. Establishment of finite element model
The ANSYS finite element model was established to simulate the tension sequence of the vertical prestressed reinforcement and analyze the reasonable time of the vertical prestressed tension. The concrete box girder was simulated by solid 65 element, and the nonlinear analysis of reinforced concrete structure can be carried out by using the element characteristics and material parameters. Link 8 bar element was used to simulate the vertical prestressed reinforcement. 3D bar element has the functions of elasticity, plasticity, creep, expansion, large deformation, stress rigidity, etc. In this paper, the method of coupling the degree of freedom of the joints is used to simulate the coordinate stress relationship between the vertical prestressed reinforcement and the concrete.

![Finite element model of box girder](image1)

![Vertical prestressing model](image2)

In order to simulate the stress of the box girder web during construction, the model consolidated the interface between the 4# beam section and the 3# beam section. The longitudinal prestress was extracted after the 4#, 5#, 6# blocks in the Midas/Civil overall model were stretched. The effective prestress of the cantilever end section is used as the basis for the longitudinal prestress application of the ANSYS local model (as shown in Table 1). The solid force bars are used to simulate the cooling method, and the vertical prestress is applied by cooling.

3. Tension mode

3.1. Integral tensioning
The overall tension construction of vertical prestressed reinforcement shall be analyzed according to the construction sequence shown in Table 1.

| Construction stage | Activation unit | Load                      | Boundary conditions         |
|--------------------|-----------------|---------------------------|----------------------------|
| first stage        | 4#–6# beam section | Dead weight, longitudinal prestress | 4# Section solid end restraint |
| second stage       | 4#–6# beam section | Vertical prestress         | 4# Section solid end restraint |

The cross-section stress calculation points are selected as four typical locations A, B, C, and D in Figure 3-a. Point A indicates the position of the interface between the top plate and the web; point B indicates the position of the peak bending shear stress of the web; point C indicates the position of the interface between the web and the bottom plate; and point D indicates the chamfer of the bottom plate. The calculation position of the longitudinal stress of the longitudinal bridge is shown in Figure 3-b. The cross section and the middle position of each beam section at a distance of 0.5 m from the edge of the cross section are selected.
Figure 3. Schematic diagram of stress calculation locations

The vertical compressive stress of the box girder web along the longitudinal bridge changes, as shown in Figure 4.

Figure 4. Vertical normal stress of the vertical tensioned front web as a whole

It can be seen from Figure 4 that the vertical compressive stress at points A and B in the middle and upper part of the box girder web is significantly greater than point C at the lower part of the box girder web and point D at the chamfer of the web floor; The vertical compressive stress distribution of the plate is relatively uniform. Tensile stresses appear at points C and D. The maximum tensile stress is 0.65 MPa. The change of vertical compressive stress along the longitudinal bridge to the box girder web is shown in Figure 5:

Figure 5. Vertical normal stress of the web after vertical prestressing

It can be seen from Figure 5 that after the vertical prestress is stretched as a whole, the vertical compressive stress increases significantly. The three stress calculation points of A, B, and C increase by 4.5MPa on average. At about 1.5 MPa, the tensile stress disappeared. The vertical compressive stress at the beam height 0.5 times from the consolidation section is small, about 1.0-1.2 MPa, and the stress distribution along the longitudinal bridge to other parts is uniform.
3.2. Sectional tension
In order to study the characteristics and regularity of the compressive stress distribution of the web, the vertical prestressed steel bars are stretched in sections, and the vertical normal stress along the longitudinal bridge is plotted as a line chart, as shown in Figure 6.

![Figure 6. Vertical normal stress of the web after vertical prestressed section tensioning](image)

It can be seen from Figure 6 that the vertical normal stress distribution in the middle of the box beam web is extremely uneven and has a wavy feature. The maximum compressive stress appears at the end of each beam segment and the maximum value is -7.33 MPa. The minimum value of the head end is -1.72 MPa, and the maximum normal stress and the minimum normal stress in the contact area are different by 300%. The vertical normal stress fluctuations at the top and bottom of the web are small. The comparison of the vertical normal stress at the point A of the box girder web in the one-time tensile construction and the segmented tension construction of the vertical prestressed steel bars is shown in Figure 7.

![Figure 7. Vertical normal stress in the middle of the segmented and integrated tensioned webs](image)

It can be seen from Figure 7 that the maximum value of the vertical compressive stress in the middle region of the segmented tensile vertical prestressed box girder web is more than 1.5 times the overall tension, and the minimum is only 37% of the overall tension, and the stress distribution is extremely uneven.

3.3. Lag tension
Lag tensioning is the vertical prestressing of a certain beam segment before cantilever construction of several beam segments. The vertical pressure can be better transmitted to both sides of the beam section, and the vertical pressure transmitted from the adjacent beam section can also be received, which overcomes the shortcoming of the uneven distribution of the vertical normal stress of the web along the longitudinal bridge. Because the three prestressed beam sections are stretched vertically, the
tensile stress may exceed the limit for untensioned beam sections. According to the influence of the cantilever pouring construction hanging basket, this article uses two lagging beam sections for tensile analysis. In order to quantitatively analyze the difference of the three tension methods on the web stress, the change of the vertical normal stress at the calculation point A of the 4 # beam section web under the three tension methods is calculated, as shown in Figure 8.

![Figure 8. Vertical distribution of vertical normal stress on the web A at three tensioning modes](image)

Figure 8. Vertical distribution of vertical normal stress on the web A at three tensioning modes

It can be seen from Figure 8 that the vertical normal stress of the web generated by tensioning the vertical prestressed steel bars with two lagging beam sections is relatively uniform, consistent with the overall tensile distribution. The maximum vertical compressive stress of the segmental tension is reduced by 32.3%.

4. Effect of secondary tensioning on web crack resistance

The vertical prestressing adopts the secondary tensioning technology, the first tensioning ensures the structural safety during the construction period, and reduces the loss of prestressing caused by the factors such as the unclean cleaning of the anchor base plate, the compression deformation of the concrete, the retraction of the anchorage device, etc. The results show that the loss of instantaneous and long-term prestressing can be reduced by using the secondary tensioning of vertical prestressing tendons, and the loss of prestressing can be reduced by more than 50% by using the secondary tensioning 24h after the initial tensioning. Considering the discreteness of construction during prestressed tension, assuming that the loss of primary tension of vertical prestress is 10%, 15%, 20% and 30%, the influence of secondary tension on the crack resistance of box girder web is calculated.

The calculation model adopts the right-end consolidation, and the top of the webs on both sides of the box beam adopts uniform load. In order to reduce the stress concentration caused by the constraint conditions, a web with a distance of 5m from the consolidation end was selected as the research object, and the first crack load was used as the cracking load. The effects of different prestress losses on the crack resistance of the web were compared and analyzed.

![Figure 9. ANSYS model of web cracking](image)

Table 2 shows the size of the uniform load applied to the web when it cracks for the first time at a distance of 5 m from the consolidation end.
Table 2. Comparison of cracking loads of box girder webs

| Serial number | Vertical prestressing loss% | Calculation of cracking load(kN/mm²) | Cracking load ratio |
|---------------|-----------------------------|-------------------------------------|---------------------|
| ①            | 10                          | 523.94                              | 1                   |
| ②            | 15                          | 501.47                              | 0.957               |
| ③            | 20                          | 495.68                              | 0.946               |
| ④            | 30                          | 421.57                              | 0.805               |

If the loss of the vertical prestressed reinforcement is up to 20%, the cracking load of the beam body will be increased by 5.7% after the reasonable use of the secondary tensioning; if the loss of the primary tensioning prestress is up to 30%, the cracking load of the beam body will be increased by 18.9% after the reasonable use of the secondary tensioning, which proves that the reasonable use of the secondary tensioning construction technology is of great significance to improve the cracking load of the beam body.

5. Conclusions
The calculation and analysis of several ways of the vertical prestressed reinforcement after the closure of the bridge, such as the overall tension, the sectional tension and the lag two beam end tension, show that the overall tension box girder web is the most reasonable stress, but the safety of the bridge structure cannot be guaranteed; the sectional tension will appear a large range of "stress blank" area at the junction of the two ends; the lag two beam end tension vertical prestressed can not only ensure the stress uniformity of web can ensure the safety of bridge structure and effectively reduce the "stress blank" defect of sectional tension.

The influence of the loss of vertical prestress on the cracking resistance of the box girder web is studied. The results show that the cracking resistance of the box girder web is obviously improved by using the secondary tension. For the case of the loss of vertical prestress of the initial tension of 20%, the cracking load of the beam body can be increased by 5.7% by using the secondary tension, and 18.9% by using the secondary tension for the case of the loss of the initial tension of 30%.

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