Effect of Tension at Early Age on Bearing Capacity of PC Continuous Girder Bridge

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Abstract. In order to study the influence of prestressed steel bundles on the bearing capacity of bridges in the early age of concrete, a new 5×20 m prefabricated continuous box girder bridge is used as the engineering background, and MIDAS/CIVIL simulation is used. When the age of precast box girder concrete is 3d (working condition 1), 5d (working condition 2), 7d (working condition 3), the steel bundle is tensioned. The ultimate state check and prestress loss analysis of the mid-span middle beam after tensioning at different ages are analyzed. The results show that the positive section bending capacity of working condition 1 and working condition 2 decreased by 13.15% and 6.51% respectively and the earlier the tensile age, the greater the prestress loss value of the steel bundle. Combined with the simulation analysis, the load test is carried out on the bridge (the actual construction is tensioning at 5d): the strain check coefficient is between 0.599 and 0.753, and the deflection check coefficient is between 0.596 and 0.705. The results show that when the concrete age is 5d, the steel bundle is tensioned, and its bearing capacity can still meet Highway Class I requirements

1. Introduction
The modern construction method is committed to minimizing the construction period [1-2]. However, compared with the low strength of the early age concrete, the smaller force may cause greater damage, so it is necessary to pay attention to the tensile prestressed steel of concrete at early age.

The early age of concrete refers to the stage of no more than 7 days of age. Regarding the mechanical properties of the early age of bridge construction, many scholars have carried out related research work. Wu Jia [3] and others studied the construction control parameters of early age about C55 high-performance concrete for bridges; Wei Ya [4] and others established a tensile and creep model of early age concrete and derived the three-dimensional spatial stress increment and strain increment relationship, which is helpful for the correct assessment of early cracking risk. For the influence of the load on the structure in the early age, Ye Jianxiong [5] studied the effects of the age and loading stress on the early deformation and strength of the concrete, and found that the loading stress is more affected than the loading age. The prestressed steel bundles in the early age are actually the prestressed loads of concrete in the early age. Xiong Wei [6] used the combination of laboratory test and finite element analysis to design two tensioning schemes at early age, comparing prestress loss and main beam deflection under different schemes; Li Ziang [7] proposed prestressed tension and load test of prestressed concrete simply supported beam in early age, and proposed a new type of tension to improve the bearing capacity of concrete beams; Wu Yuegang [8] passed the bending test on the
specimen beam subjected to external force at the early age, which proved that the early age stress has
no significant effect on the bearing capacity of the structural use stage, and the effect on reducing the
deformation ability is more significant. In the related literature, the influence of prestressed steel
bundles on the bearing capacity of bridges in the early age of concrete has not been studied. This paper
takes a newly built 5x20m prestressed continuous box girder bridge as example. For the engineering
background, the construction duration is urgent due to weather and construction requirements. During
the construction of the box girder, the prestressed steel bundle was pretensioned by the post-tensioning
method in advance, compared with the design document (7d), to 2 days. The MIDAS/CIVIL space
finite element analysis software was used to establish the single beam calculation model. Only the age
of the concrete when the prestressed steel bundle was tensioned was changed, and the influence on the
bending capacity of the normal section and the prestress loss were analyzed. And through the real
bridge load test, further assess the bearing capacity of the bridge after the early age tension, and
provide reference for the scientific and reasonable tension and tension of the similar bridge design and
construction.

2. Bridge structure analysis modeling

2.1 Bridge overview
The total length of the bridge is 129m, the bridge width is 1.5 m (sidewalk) +1 m (non-motorized
vehicle lane) + 7 m (laneway) +1 m (non-motorized vehicle lane) + 1.5 m (sidewalk) = 12 m, and the
bridge span is 5x20m. The prestressed steel strand adopts a low-relaxation high-strength steel strand
with a tensile strength standard value pkf=1860MPa and a nominal diameter d=15.2mm. The bridge
cross section is shown in Figure 1.

![Figure 1. The bridge cross section (unit: cm).](image)

2.2 Main beam construction plan
The upper structure of the bridge adopts prefabricated hollow slab hoisting construction, first forming
a simple supported structure, and then casting the continuous section concrete construction method.
The main beam bending moment steel beam tensioning sequence is N2→N1. When the strength and
elastic modulus of the hollow slab concrete reach 85% of the design strength, and the concrete age is
not less than 7d, the prestressed steel bundle can be stretched, but due to the weather and the
construction period, the construction party tensiled the prestressed steel bundle at the age of 5d.
According to the characteristics of the structure and the actual construction conditions, three working
conditions are set. The specific construction phase is divided into Table 1.

| Construction stage                  | Concrete age/d | Construction duration / d |
|-------------------------------------|----------------|--------------------------|
| Main beam pouring                   | —              | 28                       |
| Tensile steel bundle                | 3 (Working condition 1) | 10                       |
|                                     | 5 (Working condition 2) |                       |
|                                     | 7 (Working condition 3) |                       |
| Hoisting and setting up temporary support | 28          | 30                       |
| Cast-in-place continuous section concrete | 58          | 20                       |
2.3 Finite element analysis calculation model
According to the construction plan and the actual force of the structure, the spatial finite element analysis model under three working conditions was established by MIDAS/CIVIL for the middle beam. The model has 121 nodes, 120 units, and 2 material properties. The three-dimensional finite element model of the bridge is shown in Figure 2.

3. Analysis of the influence of tension on the early age of concrete

3.1 Analysis of bearing capacity of bridges
Tensioning the pre-stressed steel bundle in the early age of the concrete will have a certain impact on the bearing capacity of the bridge. Regarding the evaluation of the bearing capacity of bridges, the combination of cross-section checking and load testing is currently used. The calculation of the force-controlled section is carried out by calculating the ratio of the effect of load effect to the value of structural resistance. The positive bending moment influence line (Figure 3) can be used to determine the force control section as the midspan cross-section. That is to say, the I-end and J-end of the No. 60 and No. 61 units are subjected to the ultimate design of the bearing capacity limit state under different working conditions. The load combination of the cross section check is as follows,
Combination 1: Basic combination (permanent load):
\[1.2 \cdot (cD) + 1.2 \cdot (cTS) + 1.0 \cdot (cCR) + 1.0 \cdot (cSH)\]
Combination 2: Basic combination:
\[1.2(cD) + 1.2(cTS) + 1.0(cCR) + 1.0(cSH) + 1.4M\]
Combination 3: Basic combination (permanent load):
\[1.0 \cdot (cD) + 1.0 \cdot (cTS) + 1.0 \cdot (cCR) + 1.0 \cdot (cSH)\]
Combination 4: Short-term combination:
\[1.0(cD) + 1.0(cTP) + 1.0(cTS) + 1.0(cCR) + 1.0(cSH) + 0.7/ (1+\mu) M\]
Note: cD is the constant load, cTP is the effect of the tensile force of the steel bundle on the internal force of the section core, cTS is the secondary effect of the steel bundle caused by the statically indeterminate structure, cCR is the actual creep internal force effect caused by the creep deformation, cSH For the actual contraction internal force effect caused by shrinkage deformation, M is an eccentric load.

The ultimate cross-section bending test results of the ultimate capacity of bearing capacity are shown in Table

| Unit number | Location (node number) | biggest/smallest | Load combination | \(rMu(\text{KN}^*\text{M})\) |
|-------------|------------------------|-------------------|-----------------|---------------------|
|             |                        |                   | Working condition 1 | Working condition 2 | Working condition 3 | Mn(\text{KN}^*\text{M}) |
| 60          | I[60]                  | biggest           | combination2     | 1324.5310           | 1210.1260           | 1098.161     | 1845.2756       |
2. (Note: Maximum/minimum refers to the maximum and minimum bending moments generated by different load combinations). It can be seen from Table 2 that with the advance of the tensile age, the value of rMu at the same position is increasing. The maximum value of rMu under each working condition is the effect value considering the structural importance coefficient, and Mn is the resistance effect value. The model analysis results show that the tension at early age will increase the effect value of the load and have no effect on the resistance effect of the structure. The ratio of the effect value to the resistance is used as the index to evaluate the limit state of the bearing capacity. In the case of working condition 1, the value of \[\max(rMu)/Mn\] is 77.17%, the working condition 2 is 70.53%, and the working condition 3 is 64.02%. The analysis shows that the tensile strength of the normal section of the prestressed steel bundle is reduced by 13.15% at 7d when the concrete age is 3d, and the tension is decreased by 6.51% at 5d.

3.2 Prestress loss analysis
When prestressed steel bundles are tensioned in the early age of concrete, the total prestress loss after bridge formation will change. The prestress loss of steel bundles N1 and N2 under different working conditions is shown in Figure 4 and Figure 5. With the advance of the tensile age, the prestress loss value of the steel bundle will increase, and the prestress loss at the mid-span position will reach the maximum value. When the concrete age is 3d, the prestress loss value of the tensioned steel bundle N1 is increased by 19.24MPa compared with 7d, the tensile loss value is increased by 7.56Mpa at 5d; when the steel bundle N2 is tensioned at 3d, the prestress loss value increased by 16.38Mpa and the value increased by 6.72Mpa at 5d.

| 60 | I[60] smallest combination3 | 603.9948 | 550.7227 | 499.2742 |
| 60 | I[61] biggest combination1  | 745.8024 | 679.8470 | 616.2216 |
| 60 | I[62] smallest combination3 | 610.4310 | 650.5156 | 508.3110 |
| 61 | I[61] biggest combination2  | 1423.9580 | 1301.4912 | 1181.3510 |
| 61 | I[62] smallest combination3 | 614.4308 | 560.5154 | 508.3110 |
| 61 | I[62] biggest combination1  | 732.5239 | 667.4508 | 604.8204 |
| 61 | I[62] smallest combination3 | 603.9938 | 550.7203 | 499.2727 |

Figure 4. Steel bundle N1 prestress loss.

Figure 5. Steel bundle N2 prestress loss.
3.3 Load test verification

3.3.1 Measuring point arrangement
The test load is equivalently converted according to the most unfavorable effect value such as force and displacement in the control section generated by the design standard live load (Highway Class I). After calculation, it is determined that a total of three three-axle trucks with a total weight of 520kN are required for this test. The strain and deflection measurement point arrangement is shown in Figure 6 and Figure 7.

![Figure 6. Strain measurement point arrangement.](image)

![Figure 7. Deflection measurement point arrangement.](image)

3.3.2 Test data analysis
It can be seen from Figure 8 that the strain check coefficient of the mid-section beam bottom measuring point is between 0.599 and 0.753, which satisfies the normal range of the strain check coefficient of the prestressed concrete bridge from 0.5 to 0.8, indicating that the strength of the mid-span section under the test load meets the design requirements.

![Figure 8. Strain test result.](image)

It can be seen from Figure 9 that the deflection check coefficient of each measuring point in the mid-span section is between 0.596 and 0.705, which satisfies the normal range of the deflection check coefficient of the prestressed concrete bridge from 0.5 to 1.0, indicating that the stiffness of the mid-span section under the test load meets the design requirements.
4. Conclusion
Taking the pre-tensioned prestressed steel bundle in the early age construction process of a newly built PC continuous box girder bridge as the engineering background, a spatial finite element model was established for 3d (working conditions 1) 5d (working conditions 2) and 7d (working condition 3), in which the normal section bending capacity under load capacity limit state is checked, and the total pre-stress loss of the steel bundle after the bridge is analyzed. The analysis shows that: (1) compared with working condition 3, working condition 1 has a load capacity reduction of 13.15%, and working condition 2 has a load capacity reduced by 6.51%; (2) the actual tension construction of the bridge is to tension the prestressed steel bundle at the concrete age of 5d, which is 2d ahead of the design document. It is necessary to carry out load test on the midspan of the bridge and the results show that the strain check coefficient of each measuring point is between 0.599 and 0.753, the deflection check coefficient is between 0.596 and 0.705, and the bearing capacity meets the requirements of Highway Class I; (3) the prestress loss value of working condition 1 is higher than that of working condition 3 by 19.24 MPa, and the prestress loss value of working condition 2 is higher than that of working condition 3. The maximum increase is 7.56 MPa. Early age tension will reduce the bearing capacity of the bridge structure and increase the prestress loss. However, under good curing conditions, the prestressed concrete can still meet the operational requirements of highway bridges.

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