International Journal of Frontiers in Engineering Technology
ISSN 2706-655X Vol.4, Issue 9: 50-54, DOI: 10.25236/IJFET.2022.040909

Study on reinforcement methods for 0# block of long-span prestressed continuous rigid frame bridges

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Abstract: *Long-span continuous rigid frame bridges are widely used due to their good overall performance, small deformations and good seismic properties. However, quality is difficult to guarantee during construction, which affects the bearing capacity of the bridge and the safety and durability of the structure. In order to improve the mechanical performance of continuous rigid frame bridges, the extended cross section method and the external prestressing method are discussed based on an engineering example. By comparing before and after reinforcement, the results show that the internal stresses of the reinforced structures by the two methods meet the bearing requirements. After the comparative analysis, it was concluded that the extended section method can be applied to the reinforcement of continuous rigid frame bridges under certain conditions, which can serve as a reference for other bridge reinforcement projects.*

Keywords: *Continuous rigid frame bridges, Reinforcement, Expanded section method, External prestress*

1. Foreword

As our country has a long history of development, the construction of bridges also has a long history. Our country has the most bridges in the world. Nowadays, bridge construction technology also advances with The Times, and the span of bridges is also increasing. Long-span continuous rigid frame bridge has a good overall performance, small deformation, seismic performance is good, the characteristics of low cost, operation and maintenance and continuous beam and beam pier consolidation, makes the continuous rigid frame bridge without expansion joint, the vehicle can run smoothly, nor does it support at the same time, don't need conversion system, and there is a lot of along the bridge to the bending stiffness and lateral torsional stiffness, These advantages make it develop rapidly in recent decades, and it has become a type of long-span prestressed concrete bridge[1]. However, because the construction quality of long-span continuous rigid frame bridge is difficult to be guaranteed in the construction process, a variety of diseases will appear in the long-term operation state, affecting the bearing capacity of the bridge and the safety and durability of the structure[2].

In this paper, a prestressed concrete continuous rigid frame bridge is used as an example. Midas software was used to simulate a finite element analysis of the bridge and specific recommendations were made to improve the bridge's load-bearing capacity.

2. Project overview and pre-existing issues

2.1. Bridge Overview

The total length of the bridge is 268.02 m, with (65 + 120 + 65) m continuous rigid frames. The cross-sectional layout of the main bridge is: 2m sidewalk +8m roadway +2m sidewalk =12m, using the form of single-box and single-room section, the continuous steel superstructure adopts C55 prestressed concrete, the double thin-wall slab piers and cover beams adopts C40 reinforced concrete, the prestressed steel reinforcement adopts the standard strength of 1860MPa steel strand, the bridge deck pavement structure layer: 9cm asphalt concrete + waterproof layer +8cmC50 concrete. Vehicle loads are taken from the freeway-I level lanes, which are arranged in a two-lane arrangement. The transverse reduction factor is 1.0 according to the specification.

2.2. Existing Problems

Concrete poured during bridge construction is not good. The 0# strength of Pier 1 is 41Mpa and that of Pier 2 is 45Mpa, according to the results of concrete cementing tests. The material used for the continuous rigid frame superstructure is C55 prestressed concrete with a standard value of 55Mpa for compressive strength. This can lead to cracks in the construction or use of the bridge structure and mismatches in the entire prestressed system, reducing the bearing capacity of the bridge and affecting the bridge's service life.

3. Analysis of the finite element simulation

In order to further analyze the current situation of the bridge and formulate a reasonable bridge reinforcement scheme, the original structure was calculated based on the original design specifications.

In this paper, Midas Civil, a professional bridge software, is used for modeling calculations.

3.1. Model Establishment

The unit partition of the bridge model is partitioned according to the construction section. The purpose is to define later stages of construction for easy division and viewing. The whole bridge unit is divided into 243 nodes and 237 units (including piers and caps) according to the construction stage.

The bridge is a continuous rigid frame bridge with piers in the form of double thin-walled piers. General support is established at the end of the beam and at the bottom of the cap as boundary constraints, respectively, and the pier top is connected to the main beam by rigid connections.

3.2. Parameter Definition

Add concrete material to the "Material Characteristic Value" option of Midas Civil and define the strength of block 0# concrete of Pier 1 as 41Mpa, block 0# concrete of pier 2 as 45Mpa, and the rest of the main beam as 55Mpa.

3.3. Analysis of the results of the calculations

(1) Check in the construction stage

Through the normal stress checking calculation of the normal section in the construction stage, the maximum allowable stress of each section is basically positive, indicating that the concrete is under pressure, can meet the maximum stress effect, so the normal stress checking calculation of the normal section in the construction stage meets the requirements. However, as the strength of the block 0# decreases, the normal stress excess of the block 0# decreases during construction, which should be noted during construction.

(2) Normal section bending checking calculation in operation stage

The bearing capacity of each cross section can satisfy the combined effect of maximum bending moment. The lowest coefficient of bending occurs at the mid-span position, where it is 1.25, and at the top of the pier, where it is 1.39. The bending coefficient of the normal section of the primary beam is in accordance with the requirements.

(3) Shear checking calculation of oblique section in operation stage

The shear bearing capacity of each section can satisfy the maximum shear joint action. The minimum drag coefficient for the shear capacity of the main beam appears at the mid-span root, which is 1.34. Shear-check calculations of the tilt profile of the primary beam are in line with the requirements.

(4) Check the compressive stress of the normal section in the permanent condition

The compressive stress of the concrete and the tensile stress of the prestressed steel rods are examined. The compressive stress of the normal section of the prestressed concrete flexural member and the tensile stress of the prestressed steel bar at the stage of use shall be in accordance with the following:

The maximum compressive stress of concrete in the compressive zone of an uncracked member:

$$\sigma_{kc} + \sigma_{pt} \leq 0.50 f_{ck} \quad (1)$$

The maximum tensile stress of a prestressed steel bar is in the tensile region of the uncracked member when the internal prestressed strand is aligned as follows:

$$\sigma_{pe} + \sigma_{p} \leq 0.65 f_{pk} \quad (2)$$

In the formula:σ_{kc}. σ_{kt}-- normal compressive stress and tensile stress of concrete;

σ_{pt}-- Normal tensile stress of concrete generated by prestressing.

The section at the top of Pier 1 had a maximum stress of 13618Kpa, slightly greater than the permitted stress of 13400Kpa. The maximum allowable stress for the other sections can satisfy the maximum stress effect, so the compressive stress calculation for the normal section of the main beam is checked to be essentially as required.

The reduced strength of the 0# block and the reduced allowable stress of the cross section make the local stress of the normal cross section of the 0# block appear relatively large in the permanent condition, slightly exceeding the allowed stress of the cross section, which should be noted.

(5) Checking the principal compressive stress of the inclined section in the permanent condition

The compressive stress of the flexural members of the inclined section of the prestressed concrete and the tensile stress of the prestressed steel rods shall be in accordance with the following:

$$\sigma_{cp} \leq 0.60 f_{ck} \quad (3)$$

The maximum allowable stress for each section can satisfy the maximum stress action, so the compressive stress check calculation for the tilted section of the main beam meets the requirements. It should be noted that the maximum principal stress excess of the oblique profile decreases as the intensity of the 0# block decreases.

4. Reinforcement design and effect analysis

4.1. Comparison of reinforcement design schemes

4.1.1. Extension of the Section Method

In view of the permanent condition of the bridge, the local stress of the normal section compresses the 0# block beyond the allowed stress of the section. Based on the construction drawings and site survey, this paper intends to increase the cross-sectional area of the 0# block by filling it with concrete, thereby enhancing the cross-sectional bearing capacity, increasing the cross-sectional stiffness and reducing stress.

4.1.2. External prestressing

In order to increase the completeness of the original structure and improve the distribution of the internal forces, the scheme of adding external prestress was considered. The use of external prestressing technology to strengthen the bridge can delay the continuous deflection in the span, improve the bridge deck, strengthen the compressive stress reserve of the main beam section, and has the advantages of short construction period and little influence on the traffic [3]. However, the construction was difficult due to the location of the construction near 0#block, and the addition of auxiliary structures around 0#block would affect the beauty of the entire bridge.

Regarding the condition of the bridge, the proposed reinforcement scheme is as follows.

The inner webbing of the 0# box girder of the main bridge was laid with external prestressed steel bundles, which were bent downward through steel steering blocks and anchored to the 4# side spans. The two sides of the box girder were lined with four $\varphi_s 15.2$ mm steel bundles and one spare bundle, for a total of ten bundles. The tension control stress under the anchor is taken $0.75 f_{pk} = 1395 \mathrm{N/mm^2}$.

4.2. Analysis of the reinforcement effect

4.2.1. Expanding the method of section

The reduction factor should be fully considered in the calculation of reinforcement by the expanded section method according to the current national standard "Code for Design of Reinforcement of Concrete Structures" (GB50367-2013)[4].

The compression bearing capacity of the normal section shall be determined according to the following formula when increasing the section used to strengthen the reinforced concrete member:

$$N \leq 0.9\varphi[f_{c0}A_{C0} + f'_{y0}A'_{s0} + \alpha_{cs}(f_cA_c + f'_yA'_s)] \tag{4}$$

In the formula: N--The design value of axial pressure after reinforcement (KN);

φ--Member stability coefficient, according to the reinforced section size, according to the current national standard "Code for Design of Concrete structures" GB 50010 specified value;

A_{c0}、A_c--Section area of concrete before reinforcement and section area of newly added concrete after reinforcement (mm^2);

$f'_y.f'_{y0}$--The design value of the compressive strength of the new longitudinal reinforcement and the original longitudinal reinforcement (N/mm^2);

A'_s--Section area of the newly added longitudinal compression steel bar (mm^2);

α_{cs}--Considering the reduction coefficient of strength utilization degree of newly added concrete and reinforcement comprehensively, the value is 0.8.

The bearing capacity of the reinforced bridge is obtained by analyzing the operation of the original bridge model by modifying the 0# cross-section parameters and computing the parameters.

(1) Normal section bending checking calculation in operation stage

The bearing capacity of each cross section can satisfy the combined effect of maximum bending moment. The lowest bending coefficient occurs at the mid-span position, at 1.246, and at the top of the pier, at 1.409. The bending coefficient of the normal section of the primary beam is in accordance with the requirements.

(2) Shear checking calculation of oblique section in operation stage

The shear bearing capacity of each profile can satisfy the maximum shear joint action. The minimum drag coefficient for the shear capacity of the primary beam appears at the mid-span root, which is 1.388. Shear-check calculations of the tilt profile of the primary beam are in line with the requirements.

(3) Check the compressive stress of the normal section in the permanent condition

The maximum stress of the section at the top of the pier is 12424KPa, which is less than the allowable stress of the section at 13400KPa. The maximum allowable stress for each section can satisfy the maximum stress effect, so the compressive stress calculation for the normal section of the main beam is checked to satisfy this requirement.

(4) Checking the principal compressive stress of the inclined section in the permanent condition

The maximum allowable stress for each section satisfies the maximum stress action, so the compressive stress check calculation for the sloped section of the main beam meets the requirements.

4.2.2. External prestressed reinforcement

(1) Normal section bending checking calculation in operation stage

After the reinforcement, the resistance coefficient of the flexural bearing capacity of the normal section of the bridge decreases, and the bearing capacity of each section can satisfy the combined effect of maximum bending moment. The lowest bending coefficient occurs at the mid-span position, at 1.203, and at the top of the pier, at 1.328. The bending coefficient of the normal section of the main beam is in accordance with the requirements.

(2) Shear checking calculation of oblique section in operation stage

After the reinforcement, the resistance coefficient of the flexural bearing capacity of the normal section of the bridge decreases, and the shear bearing capacity of each section can satisfy the maximum shear binding effect. The minimum drag coefficient for the shear capacity of the main beam appears at the mid-span root, which is 1.222. Shear-check calculations of the tilt profile of the primary beam are in line with the requirements.

(3) Check the compressive stress of the normal section in the permanent condition

The section at the top of the pier has a maximum stress of 12,405KPa, which is less than the allowable stress of 13,400KPa for this section, and a resistance factor of 1.080 to meet the requirements of the maximum stress action. The compressive stress of the normal section of the main beam was checked to be calculated as required.

(4) Checking the principal compressive stress of the inclined section in the permanent condition

After the reinforcement, the bearing capacity of the sloped sections is increased, the maximum allowable stress of each section can meet the maximum stress action, and the compressive stress calculation of the sloped sections of the main beam is checked to meet the requirement.

4.2.3. Comparison of the reinforcement effects

By comparing the reinforcement effect of the augmented profile method with that of the external pre-stressed reinforcement method, we can see that:

(1) After adopting these two reinforcement methods, the bridge can be strengthened to a reasonable state;

(2) Both of these two reinforcement methods can ensure that the normal section stress of the main beam has a certain safety reserve. The maximum cross-sectional stress at the top of the pier strengthened by the expansion cross-section method was 12424KPa, and the maximum cross-sectional stress at the top of the pier strengthened by the outer treatment was 12405KPa.

(3) The bearing capacity of the Bridges is improved after the reinforcement with the expanded section method; ater the external pre-stressed reinforcement method, the bearing capacity of the permanent condition is increased, and the flexural and shear capacity of the operation stage is decreased, but both are able to meet the maximum joint effect.

5. Conclusion

In this paper, we use the Midas Civil program to examine the theory of continuous steel bridges with problems in the construction process. Because of the reduced strength of the 0# block, the maximum allowable stress of the section is reduced, which will affect the normal stress of the concrete during the construction phase. The bending and shear bearing capacity of the normal section decreases with decreasing strength. When the normal section stress of the permanent condition is checked, the strength of the 0# block decreases and the allowable stress of the section decreases, which makes the local stress of the 0# block of the normal section stress of the permanent condition relatively large, slightly exceeding the allowable stress of the section.

The bridge was simulated and calculated using the method of filled concrete widening sections and external prestress strengthening. The results show that the two reinforcement methods can improve the strength, durability and bearing capacity of the bridge structure. Through the comparative analysis, it is proved that the extended section method has a better application effect on the reinforcement of the continuous rigid frame bridge under certain conditions, which provides a reference for other bridge reinforcement projects.

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