Detection and Reinforcement of A Bridge

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Abstract: Combined with the disease situation of a certain bridge, through the longitudinal and transverse checking calculation of the bridge structure, after fully grasping the stress condition of the structure, a targeted reinforcement design scheme is developed, and the comprehensive analysis and checking calculation of the reinforced structure are carried out to confirm the reinforcement effect, which provides a reference for similar engineering design.

1. Introduction
With the rapid development of traffic construction in our country, the traffic density and tonnage are increasing, the load of bridges is aggravating day by day, and many bridges are damaged seriously, which affects the normal use of bridges. It is necessary to rebuild or strengthen them. Considering the cost of construction, most of them are reinforced on the basis of old bridges, therefore, the old bridge reinforcement technology is widely used in bridge reinforcement.

2. General situation of engineering
A bridge is 577.32m in length and 14 spans in total. The span arrangement is 4*30+65+110+65+7*30. The main bridge of the bridge is 5-7 spans. The design load of the bridge is over-20, hanging-120, design speed is 100 km/h, and the total width of the bridge deck is 26 meters. The bridge deck composition is 0.5 meters (guardrail)+11.5 meters (lane)+1.5 meters (middle). Central dividing zone) +11.5 (lane) +0.5 m (guardrail) = 26 m; earthquake intensity is VI; design flood frequency: 1/300 years.

3. Major diseases
1) Transverse cracks at the bottom of the middle span girder of the main bridge: located at the middle joint of the sixth span (1 upper and 1 lower); the width of the upward cracks is 0.02 mm, the length of the cracks is 2.85 m, and the depth of the cracks is 3-7.5 cm; the width of the downward cracks is 0.1-0.17 mm, and the transverse length of the cracks extends to 55-70 cm above the webs on both sides, and the depth of the cracks is 3-7.5 cm.
2) Maximum deflection in span: 5.6 cm upward and 6.4 cm downward.
3) Longitudinal cracks in the roof of box girder: there are more than 810 longitudinal cracks in the top of box girder of the main bridge upstream and downstream, and the distribution of cracks in other parts is more uniform except near the top of pier. 57 of them are larger than 0.15 mm. The maximum crack width is 0.36 mm. The longest crack is 7.6 M. The depth of the crack is 1-6 cm. Most of the cracks do not span segments.
4) Oblique web cracks: 123 whole bridges (upstream and downstream), most of which are located near the middle to 1/4 span of the sixth span. The width of the cracks is 0.02-0.11 mm, and the maximum length of the cracks is 1.3 M.
5) Damage of concrete surface or diseases such as rust, bulging and dew bars, honeycomb, etc.

4. Checking analysis

4.1 Vertical check of the original bridge
Combining with the engineering practice, the original structure is analyzed and checked, and the stress condition of the existing structure is comprehensively grasped. Then, a specific reinforcement scheme is formulated. Five kinds of models are used to control the calculation, and the comparison with the original design condition without considering the additional loss of prestressing force is made

1) 1.2 times the overload coefficient, the vertical prestress loss is 20%; the longitudinal prestress has no additional loss, and the mid-span floor section is reduced by 5%;
2) 1.2 times the overload coefficient, the loss of vertical prestressing force is 20%, the additional loss of longitudinal prestressing force is 10%, and the section of mid-span mid-floor is reduced by 5%.
3) 1.2 times overload factor, the loss of vertical prestressing force is 20%, the additional loss of longitudinal prestressing force is 20%, and the section of mid-span mid-floor is reduced by 5%.
4) 1.2 times the overload coefficient, the loss of vertical prestressing force is 20%, the additional loss of longitudinal prestressing is 30%, and the section of mid-span mid-floor is reduced by 5%.
5) The loss of vertical prestressing force is 20%, the additional loss of longitudinal prestressing force is 20%, and the section of roof and floor is reduced by 5%.

Five kinds of hypothetical damage checking results are shown in Table 1

| Assumed damage condition | Maximum Normal Stress (MPa) | Minimum Normal Stress near Mid-span and Mid-floor | Maximum Principal Tensile Stress of Middle Span L/4-L/2 | Midspan of the Fifth Span Bridge | Midspan of Sixth Span Bridge | Midspan of Seventh Span Bridge |
|--------------------------|-----------------------------|-----------------------------------------------|------------------------------------------------|-------------------------------|-----------------------------|--------------------------------|
| Original design          | 16.61                       | 1.16                                         | -2.32                                        | -13.4                         | -68.3                       | -13.4                         |
| Hypothesis 1             | 16.48                       | 0.30                                         | -2.50                                        | -15.0                         | -75.8                       | -15.0                         |
| Hypothesis 2             | 16.06                       | -1.23                                        | -2.66                                        | -33.5                         | -98.5                       | -33.5                         |
| Hypothesis 3             | 15.12                       | -2.78                                        | -2.87                                        | -64.7                         | -136.0                      | -64.7                         |
| Hypothesis 4             | 15.07                       | -4.60                                        | -3.66                                        | -78.2                         | -157.3                      | -78.2                         |
| Hypothesis 5             | 15.63                       | -2.79                                        | -2.79                                        | -53.8                         | -123.5                      | -53.8                         |

4.2 Transverse check of the original bridge
There are many longitudinal cracks in the lower edge of box girder roof. In order to simulate the transverse existing damage state of the bridge, the vertical prestress loss of 20% and the section weakening of 5% are considered for modeling and analysis. The maximum resistance and maximum resistance are 601.3 kN m and 72.8 kN m respectively in the original design; the minimum resistance and minimum resistance are -769.4 kN m and -169.4 kN m respectively; the maximum compressive stress of the roof edge is 8.09 MPa, the maximum tensile stress is -1.86 MPa, the maximum compressive stress of the lower edge of the roof is 5.95 MPa and the maximum tensile stress is -2.19 MPa. The maximum resistance and maximum resistance are 572.9 kN m and 73.9 kN m respectively when the section is weakened, and the minimum resistance and minimum resistance are -722.9 kN m and -167.2 kN m respectively; the maximum compressive stress at the top edge is 8.35 MPa, the
maximum tensile stress is - 2.82 MPa, the maximum compressive stress at the bottom edge of the roof is 5.61 MPa and the maximum tensile stress is - 3.35 MPa.

### 4.3 Analysis of results

Through several hypothetical damage checking calculations, it can be seen that 1.2 times overload coefficient, 20% loss of vertical prestressing force, 20% additional loss of longitudinal prestressing force, 2.78 MPa of midspan tensile stress, 2.87 MPa of principal tensile stress near 1/4-3/4 span, exceeding the limit value of 2.7 MPa of 85 code [3], transverse cracks occur with the bottom plate of the fifth span, and larger principal tensile stress occurs. The position of force basically coincides with the crack position and shape of the bridge. At the same time, according to the test report, the transverse length cracking at the bottom of the box girder at the mid-span joint, the diagonal cracking of more than 100 webs near the 1/4-1/2 span of the box girder and the deflection of the main girder are compared and analyzed with the calculation results. It is assumed that the normal tension stress and the principal tension stress of the main girder under the action of load combination (considering overload) are the damage condition 3. The material limit of 85 bridge gauge has been reached, which will inevitably lead to structural cracking. According to the stress results and the crack distribution map in the detection, the regions with larger values of principal tensile stress can basically correspond to the actual crack areas. Through the above analysis, it can be seen that the cracking and deflection of the main girder of the bridge are the result of the combined action of prestress loss, concrete shrinkage and creep, and vehicle overload, which leads to the transverse cracking of the floor and the development of oblique cracking of the web.

In summary, the theoretical analysis results of bridge diseases are basically consistent with those under assumed condition 3. Therefore, the corresponding damage condition 3 of bridge diseases is determined as damage condition, and the reinforcement checking and design will be based on it.

### 5. Reinforcement design

Combining with the present structural calculation and the basic condition of crack distribution of the bridge, according to the causes of the disease, the following reinforcement design schemes are put forward:

1) By adding longitudinal external prestressing tendons of box girder, the stress reserve of main girder is increased, the durability of structure is improved, and the deflection of main girder is restrained.

2) By pasting oblique steel plates on the middle span of the main bridge from 1/4 to 3/4, the shear resistance of the main girder is improved and the development of oblique web cracks is restrained.

3) By redesigning bridge deck pavement and transversely pasting steel plates on the roof, the stiffness and transverse bearing capacity of the box girder roof are increased, the development of longitudinal cracks in the roof is delayed, and the durability of the structure is improved. Other diseases such as cracks and concrete defects are dealt with accordingly according to the specifications.

### 6. Comparative analysis of results before and after reinforcement

After reinforcement, the special software for bridges is used to analyze and calculate the strengthened bridges comprehensively. The flexural strength, shear strength, stress and deflection of the bridges are compared and analyzed as shown in Fig.1-5 and Tables 2.
Fig 1. Flexural capacity of the fifth and seventh spans before mid-span reinforcement

Fig 2. Flexural capacity of the fifth and seventh spans after mid-span reinforcement

Fig 3. Flexural Bearing Capacity of Sixth Span before Reinforcement

Fig 4. Flexural Bearing Capacity of Sixth Span before Reinforcement
Comparing the stress and deflection of the structure before and after reinforcement, it can be seen that the stress state of the main girder has been greatly improved after reinforcement, the stress reserve at the lower edge of the mid-span section has increased by about 1.84 MPa, the maximum principal tensile stress of the main girder has decreased by about 0.51 MPa, and the mid-span deflection of the main girder has been improved after reinforcement, and the structural stiffness has been improved. The theoretical calculation shows that the main girder will displace about 4.3 cm upward after reinforcement, effectively restraining the further development of mid-span cracks.

7. Conclusions and Suggestions
After maintenance and reinforcement, the ultimate bearing capacity and structural stiffness of the main bridge are effectively improved, the stress reserve of the main girder is increased, and the durability of the structure is improved, which provides a reference for the reinforcement design of similar projects. Considering that the bridge is strengthened on the old bridge of the original expressway, in order to ensure the safety of the bridge in the construction process, it is suggested to control the construction of the bridge during tension prestressing, to obtain the displacement and strain of the control section, and to control the structural safety of the bridge in the reinforcement construction process at any time. After the reinforcement of the bridge is completed, the load test of the main bridge is carried out to evaluate the reinforcement effect of the bridge more accurately, and to provide a basis for the observation and maintenance of the bridge in the future.
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