Experimental Study on Residual Bearing Capacity of Existing Prestressed Concrete Hollow Slab Beam

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Abstract. Through the reconstruction and expansion of expressway, it has become the new normal of expressway construction in China to improve the traffic capacity and operation service level of the existing road. However, the reconstruction and expansion of expressways are faced with problems such as the degradation of the existing bridge performance and the original design bearing capacity that can’t meet the current load standards, which restrict the full utilization of the existing expressway bridges. Based on the reconstruction and expansion project of Beijing-Shanghai Expressway (Shandong section), this paper selects the prefabricated and prestressed concrete (PC) simply supported slab bridge with span of 10m and 13m. It evaluates the bearing capacity of HSB based on technical condition checking calculation and load test, and carries out the ultimate bearing capacity test at the same time. According to the checking calculation of bearing capacity and test results, it is concluded that the technical condition of the existing bridges in the expressway (Shandong section) is evaluated as class 1 prefabricated simply supported slab bridge. By adding 150mm integral cast-in-place pavement, the bending capacity of the HSB in the mid of span section meets the current load standard, while the shear capacity of supporting point section does not meet the current load standard, but the difference is within 5%. After the reconstruction and expansion of expressway, the existing bridges mainly bear the load of small vehicles, the load effect is far lower than the current load standard, the bearing capacity meets the current load standard, and can be fully utilized in its original state.

1. Introduction
At present, the traffic volume of expressways in China is becoming more and more saturated, the traffic pressure is increasing day by day, and the existing bridge engineering diseases along the line are increasingly appearing, which restricts the traffic capacity of the expressway and even affects its safe operation. Through the reconstruction and expansion of existing expressways, it is used to improve the road capacity and operation service level, which has become the new normal of expressway construction in China.
In the reconstruction and expansion of expressway, there are many common diseases of existing bridges and performance degradation, which affect the bearing capacity and durability of the structure. The design method of some prefabricated bridges is not perfect, and the construction quality control is not strict, which leads to the poor integrity of the structure. In particular, with the promulgation and implementation of JTG D60-2015, the original design load standard of existing bridge beam in expressway reconstruction and expansion is lower than the current load standard, which makes the bearing capacity of upper beam and slab of some existing prefabricated bridges unable to meet the current design requirements. If all the beams and slabs are removed, on the one hand, it will increase the project cost, and produce certain environmental pollution in the bridge demolition and waste treatment. At the same time, the new bridge will further consume a lot of building materials, causing secondary development damage of resources, which is not in line with the national green development concept. Therefore, in the expressway reconstruction and expansion project, it is necessary to carry out the relevant test research on the bearing capacity of the existing bridge. Scientifically and reasonably evaluate the service performance of the existing bridge, so as to provide theoretical and technical guidance for the full use of the existing bridge.

According to the current expressway reconstruction and expansion project, the guiding opinions and suggestions of highway reconstruction and expansion are proposed. JTG/T L11-2014 [1] put forward that the design scheme of bridges and culverts for expressway reconstruction and expansion should be determined comprehensively according to the characteristics of reconstruction and expansion projects, so as to meet the requirements of safety, reliability, durability, applicability, economy, rationality and overall coordination. Many scholars at home and abroad have carried out the experimental research on the bearing capacity of bridges, but there are few researches on the bearing capacity of existing bridges in the reconstruction and expansion of expressways. Li et al. [2] carried out the experimental study on the ultimate bearing capacity of the old reinforced concrete T-beam bridge. Through the failure test, it was concluded that the ultimate bending bearing capacity was greater than the bearing capacity based on technical condition assessment and load test. Meanwhile, it was considered that although the bridge diseases were serious, the ultimate bearing capacity still meet the operation requirements. Liu [3] analyzed the theoretical optimal thickness of HSB reinforced by integral pavement, and considered that the composite effect of integral layer was considered in the fabricated HSB bridge, and different integral pavement thickness for different span bridges could meet the requirements of bearing capacity of HSB. Liu et al. [4] carried out the research on the current situation and bearing capacity of the reconstruction and expansion of the HSB bridge, and considered that the cast-in-place concrete layer in the compression zone of the HSB can improve the bending and shear bearing capacity of the HSB, meanwhile the improvement of the bending bearing capacity is more obvious. Valenzuela et al. [5] considered the comprehensive effect and the actual damage of bridges, and proposed the comprehensive index method to evaluate the bearing capacity of bridges. Talko et al. [6] based on the technical status information of regular bridge inspection, and carried out the bridge bearing capacity prediction from the aspects of dynamic test, modal identification, finite element modeling, etc..

2. Theoretical analysis of bearing capacity of prestressed concrete HSB beam (PCHSB)

2.1. Checking calculation of bearing capacity of PCHSB
Combined with the reconstruction and expansion project of Beijing-Shanghai Expressway (Shandong section), the existing prefabricated simply supported HSB is selected to test the technical condition and flexural bearing capacity when the solid beam and slab were demolished. Based on the current load standards, the flexural capacity of the mid span section and the shear capacity of the fulcrum section are evaluated.

In this paper, the PCHSBs with span of 10m and 13m which have been in operation for 22 years are selected as the research objects. The precast slab height is 40cm and 55cm, and the standard slab width is 99cm. The detailed geometric dimensions of 10m and 13m PCHSBs are shown in Fig. 1.
According to the design principle of bearing capacity limit state method, the bending bearing capacity of mid span and shear bearing capacity of fulcrum section are checked and calculated according to the current load standard. In this paper, the calculation of bearing capacity takes into account two working conditions: bare slab and overlay 150mm integral cast-in-place bridge deck pavement. The calculation results of bending capacity of HSB and shear bearing capacity of fulcrum section are shown in Fig. 2.

It can be seen from Figure 1 that the bending bearing capacity of the mid span section and the shear bearing capacity of the fulcrum section of the PCHSB with the span of 10m and 13m are not in line with the current load standard. Considering the 150mm integral cast-in-place pavement, the bending bearing capacity of the mid span section meets the current load standard, but the shear bearing capacity of the fulcrum section does not meet the current load standard.

2.2. Research on bearing capacity based on veneer technology
The prefabricated and PCHSB with span of 10m and 13m in Beijing-Shanghai expressway (Shandong section) is selected as class 1 slab (retaining the original 150mm integral cast-in-place pavement layer). After demolition, the detailed technical condition inspection and evaluation shall be carried out, and the checking coefficient of bearing capacity of veneer can be determined based on technical condition detection. According to JTG/J21-2011 [7], the bearing capacity evaluation of old highway bridges (beams and slabs) is determined according to the following formula:

$$ R = R(f_d, \xi_e, a_{dc}, a_{dr})Z_1(1-\xi_e) $$  

(1)

where, $R$ denotes structural resistance effect function; $f_d$ - design value of material strength; $a_{dc}$ denotes geometric parameter value of member concrete; $a_{dr}$ denotes geometric parameter value of member reinforcement; $Z_1$ denotes checking coefficient of bearing capacity of HSB, which depends on its appearance quality, concrete strength and structural modal parameters; $\xi_e$ denotes deterioration
coefficient of bearing capacity of HSB, which depends on its apparent defect, corrosion potential of reinforcement and concrete resistivity, carbonation depth, protective layer thickness, chloride ion content and concrete strength, etc.; $\xi_c$ denotes reduction coefficient of HSB section, which depends on material weathering, carbonation and physical, chemical damage; $\xi_s$ denotes reduction coefficient of reinforcement section, which depends on the crack width of concrete.

After checking and calculating, the checking coefficient of bearing capacity of HSB based on technical condition is determined as show in Table 1. The table shows the variation live load influence coefficient of actual traffic vehicle load. Considering that the existing bridge after expressway expansion is mainly driven by cars, its value is taken as 1.0.

| Span/m | $Z_1$ | $\xi_c$ | $\xi_s$ | $\xi_e$ | $\xi_q$ |
|--------|-------|---------|---------|---------|--------|
| 10m    | 1.15  | 1.00    | 1.0     | 0.01    | 1.0    |
| 13m    | 1.15  | 1.00    | 1.0     | 0.01    | 1.0    |

According to formula (1), the bending bearing capacity of the mid span section and the shear bearing capacity of the fulcrum section are calculated based on the technical conditions. The calculation results are shown in Fig. 3.

![Figure 3](image)

**Figure 3.** Calculation results of bearing capacity based on technical condition of veneer.

It can be seen from the table that the existing PC HSB with the span of 10m and 13m in Beijing-Shanghai Expressway (Shandong section) meets the current load standard according to the bending bearing capacity of the mid span section, while the shear bearing capacity of the fulcrum section does not meet the current load standard, but the difference is within 5%.

3. Experimental study on bearing capacity of HSB

3.1. Loading scheme

According to the above-mentioned technical status of the HSB, the bearing capacity of the solid slab is tested by MTS, and the bearing capacity of the HSB based on the load test is evaluated. At the same time, the ultimate bending capacity of the existing HSB in the mid-span section is obtained by destructive test. Two point loading is used in the mid span bending capacity test of HSB (as show in Fig. 4). The pure bending section of 10m span HSB is 2m, and that of 13m span HSB is 3m. Displacement sensors are set up in the middle and the fulcrum of the HSB to measure the deflection of the HSB during the loading process.
3.2. Failure mode
At the initial stage of loading, vertical cracks first appear at the lower flange of the web. With the further increase of load, the cracks gradually develop towards the roof, and there are several vertical cracks in the middle of the span. When the load reaches the ultimate strength, the concrete in the middle of the span will be crushed which in the compression zone, and the failure mode is shown in Fig. 5.

3.3. Test result
In order to reasonably determine the load validity coefficient of existing HSB, the flexural bearing capacity test of 10m and 13m HSB was carried out, and the mid span load deflection curve was obtained as shown in Fig. 6.

According to the analysis in Fig. 3, when the HSB with a span of 10m is loaded to the current design load standard (208kN), the measured deflection in the middle of the span is 19mm, and the theoretical deflection value is 36mm, so the corresponding mid span deflection validity coefficient is
0.55. When the HSB with a span of 13m is loaded to the current design load standard (216kN), the measured deflection in the middle of the span is 20mm, and the theoretical deflection value is 30mm, then the corresponding mid span deflection validity coefficient is 0.6. According to the formula (2), the bending capacity of the mid span section and the shear capacity of the fulcrum section based on the single plate load test are calculated, and the calculation results are shown in Fig. 7.

\[ R = R\left( f_d, \xi_d, a_d, \xi, a \right) Z_2 \left( 1 - \xi \right) \]  

(2)

where, \( Z_2 \) denotes checking coefficient of bearing capacity of HSB based on load test, in which the value is 1.17 when the load validity coefficient is 0.55, and 1.15 when the load validity coefficient is 0.6. The meaning of other symbols is the same as before.

![Figure 7. Bearing capacity based on single plate load test.](image)

It can be seen from Fig. 7 that the technical condition of existing PCHSBs of Beijing-Shanghai Expressway (Shandong section) is evaluated as class 1, the bending bearing capacity of mid-span section based on load test meets the current load standard, and the safety reserve is large. The shear bearing capacity of fulcrum section does not meet the current load standard, but the difference is less than 5%. It can be seen from Fig. 6 that the maximum failure load of the HSB with a span of 10m is 415kN, and the corresponding ultimate flexural bearing capacity of the mid span is 1,038kN\cdot m. The maximum failure load of the HSB with the span of 13m is 455kN, and the corresponding ultimate flexural capacity is 1,479kN\cdot m. It can be seen that the mid span ultimate flexural capacity of prefabricated simply supported slabs with spans of 10m and 13m is far greater than the effect under the current load standard.

4. Bearing capacity evaluation of HSB

According to the test results of mid span flexural bearing capacity and ultimate bearing capacity based on technical condition checking calculation, mid span bending bearing capacity and ultimate bearing capacity test results of prefabricated simply supported slab with span of 10m and 13m (paved with 150 mm integral cast-in-place pavement), the load effect and bearing capacity comparison diagram of prefabricated simply supported slab with span of 10m and 13m are drawn, as shown in Fig. 8.
4.1. Evaluation of flexural capacity of mid-span section

It can be seen from Fig. 8 that the bending capacity of mid-span section can be greatly improved by adding 15cm integral cast-in-situ pavement layer for 10m and 13m span prefabricated simply supported slab. Among them, the safety reserve factor of flexural capacity of 10m and 13m HSB based on technical condition checking and load test is greater than 1.5, the safety reserve factor of ultimate flexural bearing capacity of 10m HSB is 2.0, and that of 13m span HSB is 2.1. It can be seen that the existing prefabricated HSB bridge of expressway can fully meet the requirements of flexural bearing capacity of mid-span section under the current load standard by adding 15cm integral cast-in-place pavement.

4.2. Evaluation of shear bearing capacity of fulcrum section

Through paving 150mm integral cast-in-place pavement layer with span of 10m and 13m, the shear bearing capacity of fulcrum section based on technical condition checking calculation and load test still can not meet the requirements of current load standard bearing capacity, but the insufficient value is within 5%. Considering that the traffic lane of the existing bridge girder is mainly used as a car in the fast lane after the reconstruction and expansion of the expressway, the actual load effect will be significantly reduced. At the same time, the shear bearing capacity can be further improved by integrating the fulcrum section and cast-in-place pavement with high-strength concrete. Therefore, the existing prefabricated HSB bridge of expressway can fully meet the requirements of shear bearing capacity of fulcrum section under the current load standard by adding 15cm integral cast-in-place pavement.

Based on the above analysis, the existing prefabricated and PC simply supported slab bridge with span of 10m and 13m in the reconstruction and expansion project of Beijing-Shanghai Expressway (Shandong section) ,and HSB with technical status evaluated as class 1. The flexural bearing capacity of the mid span section and the shear bearing capacity of the fulcrum section can meet the requirements of the current load standard, and the HSB is determined to be fully utilized.

5. Conclusion

The existing prefabricated and PC simply supported slab bridge in the reconstruction and expansion project of Beijing-Shanghai Expressway (Shandong section) has a span of 10m and 13m, and its technical condition is evaluated as class 1 HSB. By adding 15cm integral cast-in-place pavement, its mid span section bending bearing capacity meets the current load standard. Considering the lightening of the traffic load of the existing bridge after reconstruction, the shear bearing capacity of the fulcrum section can also meet the current load standard. The full use of this part of HSB saves a lot of...
engineering construction resources and further reduces the project cost. At the same time, it avoids the environmental damage caused by the secondary development of building materials and the environmental pollution caused by the demolition of beam and slab, which reflects the concept of green development.

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