Analysis of Influence of Hinge Condition on Overall Mechanical Performance of Hollow Slab Beam

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Abstract: The concrete hinge joint is a widely used connection method for the assembled hollow slab bridge, and it is also a place where the disease is extremely easy to appear. Through the study of four different simplified calculation modes of the hinge joint, the transverse distribution coefficient of the hollow slab beam under different working conditions is compared and analyzed, and the influence of the hinge joint on the overall mechanical performance of the structure under different working conditions is obtained. It is found that the difference of the simplified mode has a great influence on the calculation of the lateral distribution of the bridge; the complete failure of the joint will lead to a drastic change in the lateral distribution coefficient of adjacent hollow slab beams, and even the phenomenon of single beam appear. At the same time, combined with the research results, reasonable suggestions for the design stage and actual operation stage of hinge joint of the hollow slab beam are put forward.

1. Overview 

Concrete tongue-and-groove connection is a common connection method of assembled hollow slab girder bridge. Between two hollow slabs, cast-in-place concrete connects two hollow slabs into one piece, which is a concrete joint. This type of connection is approximately considered as hinge in the stressed system. Commonly used three types of concrete tongue-and-groove hinge form by the three: round, diamond and funnel.

![Figure 1 common form of concrete tongue-and-groove hinge](image)

Practice shows that hinged joints of hollow slab are easy to crack due to the structure, construction quality and other reasons and cannot effectively transfer shear force. For precast slabs bridge hinged joint disease common phenomenon, there were some scholars for the study of this kind of problem, part of the researchers from the aspects of design theory, assuming the hollow board hinged joints only vertical shear, and not under bending moment, by simplifying theory combined with experimental research on a series of hollow slab are obtained hinged joint shear calculation, strength calculation and...
construction of very useful conclusions; Another part of scholars took the experimental research as the focus, analyzed the causes of diseases of transverse hinged joints, gave corresponding prevention measures, put forward a set of experimental research methods, and obtained the corresponding improvement methods and maintenance and reinforcement methods for the transverse hinged joints of hollow slab. The following is a detailed introduction of the main research results in these aspects. In 1980, Fengkang He and Yaokeng Zhu [1] combined the basic theoretical formulas of elastic mechanics and structural mechanics, put forward the calculation method of shear force distribution based on elastic thin plate theory, and deduced the calculation formula of long side vertical shear force of simply supported plate. In 1985, Zhenkun Xi[2] improved the half-chord positive wave load commonly used in the shear force distribution and peak calculation of hinge joints, expressed it in the form of triangular series, and suggested that the influence value on the shear force at hinge joints multiplied by a peak increase coefficient. In 2004, Dongke Wang[3] proposed that the upper surface of hollow slab bridge should be gouged and cleaned, and the structure of deck pavement should be enlarged to improve the ability of transverse connection. In 2007, Siyu Sun [4] summarized the main manifestation and occurrence mechanism of the hollow slab girder bridge disease, and suggested that the existing bridge deck pavement and hinge-joint concrete should be chisel away, and the new transverse joint reinforcement effect would be better. In 2009, Changjiu Yu[5] considered that hinge joints' shape had no adverse effect on the force of hinge joints. Based on the bond test of new and old concrete, it was concluded that the bond of new and old concrete was a major reason for the strength reduction of hinge joints.

In this paper, the transverse distribution coefficient analysis is carried out for a span of 13m simply supported hollow plate girder bridge when hinge joints are in different working conditions, so as to know the influence of hinge joints on the mechanical performance of structural finishing.

2. Finite element model
In order to analyze the influence of hinged joints on the overall mechanical performance of hollow slab, we establish a spatial girder model with a span of 13m as the research object. The simulation of hinged joints is simulated by releasing the rotational degrees of freedom at the beam end. The number of hollow slab is 1#~8# hollow slab starting from a side beam. The spatial lattice finite element model is as following.

![Figure 2 Finite element rendering](image)

3. Analysis of lateral distribution coefficient
After applying unit force to each beam, we can obtain and compare the transverse distribution coefficients of each beam are. Considering the symmetry of the structure, only 1 ~ 4# beams are extracted. The damage of hinge joints is simulated by the shear stiffness reduction of transverse virtual beam. Failure of hinge joints is studied by considering the following conditions, I: hinge joints are intact; Case II: no. 1 hinge joint fails; Case III: failure of no.2 hinge joints; Case IV: no. 3 hinge joint failure. The transverse distribution of each beam of the structure is calculated by applying the unit concentrated force in the middle of the span. The following equation is the most accurate according to the definition of the transverse distribution coefficient:
\[ m_i = N \frac{D}{\sum_{i=1}^{n} D_i} \]

Where \( m_i \) is the lateral distribution coefficient of vehicle load; \( N \) is the number of lanes; \( D_i \) is the deflection value of the mid-span section of plate \( i \).

**Figure 3** Transverse distribution when applied to beam 1

**Figure 4** Transverse distribution when applied to beam 2
As can be seen from the figure, after the complete failure of a hinge joint, the transverse distribution coefficient of adjacent hollow plate girder will change dramatically. In extreme cases, the distribution coefficient of one hollow plate girder is close to 1, while that of other hollow plates is close to 0.

4. Conclusion
Based on the grillage model, different simplified calculation models of hinged joints are studied, including four simplified models of hinged joints, rigid joints, cast-in-place layer hinged joints and cast-in-place layer rigid joints. The influence of the degree of deterioration of hinge joints on the transverse distribution was emphatically studied, and the concentrated force was applied, and the following conclusions were obtained:

Different simplified calculation models have great impacts on the calculation of the transverse distribution of the bridge. The influence line coefficients of the transverse distribution from beam 1 to
beam 4 (side beam to middle beam) differ by 11.6%, 14.1%, 13% and 18.3%, respectively. Therefore, it is necessary to select appropriate simplified calculation mode in the process of calculation and design. In order to reflect the reality more accurately, we should adopt the rigid connection method and consider the contribution of the cast-in-place layer.

Under the action of a single concentrated force, the results show that after a joint joint fails completely, the transverse distribution coefficient of adjacent hollow slab beam changes drastically. In extreme cases, the distribution coefficient of a hollow slab beam is close to 1, and the distribution coefficient of other hollow slabs are close to 0. Therefore, it is suggested to avoid the stress of the single slab in the actual operation of the bridge. The transverse distribution under vehicle load is slightly better than that under unit force, but the transverse distribution will still change dramatically after the hinge joints are damaged or shed, resulting in the increase of single beam stress.

References
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