Effect of Transverse Damage on Transverse Load Distribution of Bridge Side Beam under Moving Load

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Abstract. In order to study the variation of transverse load distribution of T-beam bridge with transverse damage under moving load. In this paper, nine kinds of working conditions are proposed for the possible failure modes and the different locations of the failure, and relevant finite element models are established. Through simulation, the lateral load distribution of middle beams under nine working conditions is obtained and compared with that under non-damage condition. The results show that the transverse load distribution capacity of T-beam bridge under moving load will be greatly affected after the transverse connection damage of the diaphragm beam occurs. When the location of transverse damage is different, the influence of T-beam bridge will be different.

1. Introduction
With the continuous development of China, bridge construction has developed rapidly. As we all know, the fabricated simply supported T-beam bridge has been widely used because of its simple structure, convenient installation and clear structural stress. Therefore, many scholars have carried out extensive research on the transverse distribution characteristics of the simply supported T-beam bridge[1-2].

Due to planning, economic and many other reasons, most of the existing bridges in service with damage can not be demolished and rebuilt. Therefore, it is of great significance to study the numerical model of bridge structure with damage, as well as the concrete influence of damage on bridge and its development law [3-4].

2. Verification of finite element model

2.1. Establish the finite element model
The finite element model established in this paper is referred to [5]. It is a reinforced concrete simply supported T-beam bridge. The upper structure is assembled and spliced by five T-beams, and there are five diaphragms in the transverse direction of the bridge. The standard span is 19.5m. The main beam is rigidly connected with the flange plate. The section form of the main beam and the diaphragm beam is shown in Fig.1 (unit cm). The main beam is made of C40 concrete, and the reinforcement is HRB335. The reinforcement arrangement is shown in Fig. 2, and the main beam is longitudinally arranged. There are 6 bars with diameter of 36 mm and 4 bars with diameter of 25 mm. The spacing of stirrups in transverse densification area of main beam is 100 mm, and that of other beam sections is 250 mm, and the diameter of stirrup is 10 mm.
The finite element model is established by using the finite element software ABAQUS according to the parameters mentioned above, as shown in Figure 3. The relative slip between the reinforcement and the concrete is not considered in the model. In the modeling process, the longitudinal load-bearing reinforcement is established according to the separated model, and the three-dimensional solid element is adopted. The moving load is applied to the girder. According to the highway engineering technical standard, the moving load speed is selected as 40km / h.

2.2. Simulation verification without damage

The model is composed of five T-beams. The adjacent T-beams have reliable lateral connection, and the width span ratio of each girder is $B / L = 9 / 19.5 < 0.5$, which can be regarded as a narrow bridge. Therefore, the modified eccentric pressure method can be used to solve the lateral load distribution of each girder. The calculated values are compared with the results of the finite element model. The comparison of the lateral load distribution is shown in Fig. 4-6.

By observing fig.4-6, it can be found that the results of finite element simulation and theoretical solution fit well, most of the data error is small, the error of finite element method is within the allowable range of the project, and the comparison curve of each main beam is in good agreement, which proves the validity and rationality of the established model, which indicates that the finite element model can be used for relevant simulation analysis.
Fig. 3 Finite element model of T-beam Bridge

Fig. 4 Comparisons of Load Transverse Distribution of Beam No.1

Fig. 5 Comparisons of Load Transverse Distribution of Beam No.2

Fig. 6 Comparisons of Load Transverse Distribution of Beam No.3

3. Comparative analysis

3.1. Division of transverse distribution damage condition

The main girder of assembly type simply supported T-beam bridge is generally transported to the bridge location for assembly after processing, and the transverse connection of main beam is completed by the transverse connection structure between flange plate and diaphragm beam in later stage. Because the transverse connection of prefabricated bridge can not be poured with the main beam at the same time, it is easy to damage in its practical application. However, the damage of the connection is easy to be ignored in the early stage of its occurrence, but with the continuous expansion of bridge use and damage, it is easy to cause greater harm [6-8]. The transverse damage is divided into three cases according to its location. The damage condition number is shown in Table 1.

| Damage form | Location of transverse connection damage |
|-------------|------------------------------------------|
| A           | B                                       | AB | AC | AD | BC | ABC | ABD | ABCD |
| ①           | I-1                                     | II-1 | III-1 | IV-1 | V-1 | VI-1 | VII-1 | VIII-1 | IX-1 |
| ②           | I-2                                     | II-2 | III-2 | IV-2 | V-2 | VI-2 | VII-2 | VIII-2 | IX-2 |
| ① + ②      | I-3                                     | II-3 | III-3 | IV-3 | V-3 | VI-3 | VII-3 | VIII-3 | IX-3 |

Note: ABCD refers to the damage location, as shown in Fig. 1; ① indicates the damage of T-beam flange connection; ② represents the damage of diaphragm connection; ① + ② indicates that both flange connection and diaphragm connection are damaged; according to the damage location, the working conditions are classified as I, II, III... IX.
Based on the model, the failure of bridge lateral connection is simulated by adjusting the coupling mode of nodes, and the lateral load distribution of middle beam under various working conditions is calculated.

3.2. Load simulation and analysis
Taking No.3 beam (middle beam) as a representative, this paper analyzes the variation of load transverse distribution coefficient of simply supported T-beam bridge under transverse damage. The transverse load distribution coefficient and its variation of beam bridge under various working conditions are compared and analyzed, as shown in Fig. 7. Abscissa is the number of girder under moving load.

![Graphs showing load distribution](image)

Under the condition of type I, the lateral load distribution value of No. 2 beam is significantly increased, while that of No. 1 beam decreases, which indicates that after the damage at a in Fig. 1, the transverse transmission of load in the bridge is hindered, and the No. 2 beam bears a larger load.

![Graphs showing load distribution](image)

It can be seen from Fig. 7 (b) (c) and (d) that when the load acts on the middle span of No. 1 beam, the transverse load distribution of No. 1 beam drops sharply and approaches to 0; when the load acts on the No. 3 beam itself, the increase of the transverse distribution value is obvious, which indicates that the middle beam bears a large load due to the serious obstruction of load transfer.

V condition is shown in the figure. The results show that the distribution of the numerical value is almost symmetrical with the No.3 beam as the center, because the damage is evenly distributed on both sides of the bridge center in V condition. The transverse distribution of the load acting on the No.1 and No.5 beams is hindered, and only a small part of the load can be transferred to the No.3 beam, while the load acting on the No.3 beam and its adjacent beams can be normally distributed between these beams along the transverse direction.
Compared with V condition and VI condition, it can be found that the change trend is almost the same, but the fluctuation amplitude of class VI working condition curve is relatively large, which is mainly reflected in that when the load acts on No. 3 beam, the maximum increase rate increases from 29.65% to 89.45%. The reason is that the damage distribution of two transverse connections in class VI condition is more concentrated. Generally speaking, when the number of transverse joint damage is fixed, the damage density has a great influence on the numerical value.

Working conditions VII, VIII and IX are mainly shown as follows: the curve shapes of the three working conditions are almost completely symmetrical, which is similar to the performance of V and VI conditions. This is because the transverse connection damage of the above-mentioned working conditions is symmetrically distributed around the No. 3 beam. In addition, through the comparison, it
can be found that the variation range of the curve (load acting on the No. 3 beam) shows an increasing trend (IX > VI > V).

4. Conclusion

The results show that the transverse distribution of the middle beam will be greatly affected by the damage of the transverse connection

   (1) After the lateral failure, the lateral distribution of load has obvious change compared with that without damage. The main performance is: when the load acts on the middle beam itself and adjacent main beams, the load transverse distribution value increases, especially when the load acts on the middle beam; when the load acts on the side beams, the load transverse distribution value of the middle beam decreases.

   (2) The variation law of transverse load distribution of main beam is related to the failure mode of transverse connection. The change is the smallest when the flange joint of main beam is damaged alone, followed by the diaphragm connection with single damage, and the change range is the largest when the flange and diaphragm are damaged together, but the situation of diaphragm connection with single damage and joint damage is similar.

   (3) When the load action point is close to the damage location or the load directly acts on the middle beam itself, the above influence on the transverse distribution of the middle beam load will further increase. In a word, the transverse connection damage of T-beam bridge will also have adverse effects on the transverse load distribution of the middle beam, and this effect is still related to the form, quantity and location of the transverse connection damage.

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