Static load test of RC T-beam bridge flexural strengthening with externally bonded steel plates

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Abstract. Externally bonding steel plates is a common method for strengthening old bridges. Structural features and diseases of T-beam bridge are described. The strengthening project of Erdao River Bridge was taken as an example. Based on static load test, changes of deflection and stress are studied at the bottom of RC T-beams strengthened by externally bonding steel plates in the loading process. Numerical simulation is also carried out. The results of static test show that bearing capacity, bending stiffness and deformation can be improved of T-beams strengthened with bonding steel plates. This paper provides good engineering practice experience for the reasonable application of bridge with externally bonding steel plate strengthening method.

1. Introduction

Bridges play an important roles of traffic engineering, and they are important infrastructures for national economic and social development. By the end of 2019, China has 878300 bridges with a mileage of 60634600 meters, ranking first in the world. Bridges in service are aging and service conditions are deteriorating. Therefore, many old bridges do not meet current specifications, and there are initial defects in the design. In view of the above situation, more attention should be paid to the strengthening and maintenance of old and dangerous bridges.

Externally bonding steel plates method refers to bonding steel plate on the surface of the original concrete member, which indirectly increases strengthening ratio of original structure and improves its bearing capacity. Surfaces of original structure are connected with steel plates by glue, then high-strength bolts are used to compress steel plates. It has the advantages of mature technology, wide application range, less wet operation on the construction site, short strengthening, and basically unchanged size of the original structure.
In this paper, a RC T-beam bridge is flexural strengthened with externally bonding steel plates. Static load test is carried out before and after the strengthening. The effects of strengthening are analyzed by comparing deflection and strain data.

2. Engineering background
Taking Erdao River bridge in Hulan District of Harbin City as the engineering background, the original design load is car-20 and trailer-100, now it needs to be upgraded to highway class II. Layout of Erdao River bridge is shown in Fig. 1.

3. Strengthening scheme
In order to improve bearing capacity of T beam, steel plates are bonded to normal section within a certain range of the middle span, as shown in Fig. 2.
The main steps of strengthening are as follows:

1. Concrete surface treatment and drilling. Before drilling, steel bar position locator should be used to detect, so that drilling position can avoid steel bar and prevent damage to original beam steel bar.

2. Bonding steel plate. Steel plate is pasted to concrete surface by glue, and then the high-strength bolts are tightened for anchoring.

3. Anti corrosion treatment of steel plate. After removing oil and rust on the surface of steel plate, apply anti rust paint.

4. Static load test

4.1. Test program

The layout of measuring points is shown in Fig. 3. Deflection measuring points M1-M7 are arranged at bottom of web of the midspan section. Strain measuring points S1-S7 are arranged at the bottom of web of the midspan section.

![Fig. 3. Layout of measuring points](image)

In the original bridge test before strengthening, test load vehicles are 324.8kN and 339.4kN, respectively. During the test after strengthening, test load vehicles is 320.0 kN and 325.5 kN, respectively. The detailed axle weight of vehicles is shown in Table 1.

| Vehicle ID. | P1(kN) | P2(kN) | P3(kN) | P(kN) | Vehicle diagram |
|-------------|--------|--------|--------|-------|----------------|
| Before      | 64.96  | 129.92 | 129.92 | 324.8 |                |
| strengthening | 67.88  | 135.76 | 135.76 | 339.4 |                |
| After       | 64.00  | 128.00 | 128.00 | 320.0 |                |
| strengthening | 65.10  | 130.20 | 130.20 | 325.5 |                |

Static load tests of the bridge before and after strengthening are carried out according to the following conditions:

Case 1: Load vehicles are located at the midspan section, which are is symmetrically distributed in the transverse direction, as shown in Fig. 4.

Case 2: Load vehicles are located at the midspan section, which are is eccentric distributed in the transverse direction, as shown in Fig. 5.

![Fig. 4. Symmetric loading](image)  ![Fig. 5. Eccentric loading](image)
4.2. Finite element model

Finite element model of simply supported T-beam bridge is established by using professional bridge analysis software MIDAS Civil. Finite element results of displacement for load case 1 and 2 are shown in Fig. 6.

![Finite element results of displacement](image)

(a) Load case1  
(b) Load case2

Fig. 6. Finite element results of displacement

5. Test results and analysis

5.1. Deflection results and analysis

Comparisons between theoretical values and measured values of deflections of T-beams under test load before and after strengthening are shown in Table 2.

| Load Case | Measuring point | Before strengthening | After strengthening | Reduction rate of measured value (%) |
|-----------|-----------------|----------------------|---------------------|-------------------------------------|
|           | Theoretical value (mm) | Measured value (mm) | Verification coefficient | Theoretical value (mm) | Measured value (mm) | Verification coefficient |                      |
| M1        | 7.4             | 7.6                  | 1.03                | 4.6                | 3.8                | 0.82                | 0.50                |
| M2        | 8.1             | 8.2                  | 1.01                | 5.3                | 4.6                | 0.86                | 0.44                |
| M3        | 9.8             | 10.3                 | 1.05                | 5.9                | 4.9                | 0.83                | 0.52                |
| M4        | 9.8             | 10.6                 | 1.08                | 5.9                | 5.2                | 0.88                | 0.51                |
| M5        | 8.1             | 8.7                  | 1.07                | 5.3                | 4.7                | 0.89                | 0.46                |
| M6        | 7.4             | 7.6                  | 1.03                | 4.6                | 4.0                | 0.87                | 0.47                |
| M7        | 6.1             | 6.2                  | 1.02                | 4.5                | 4.1                | 0.90                | 0.34                |
| M1        | 14.2            | 15.6                 | 1.10                | 8.9                | 7.1                | 0.80                | 0.54                |
| M2        | 11.8            | 12.5                 | 1.06                | 8.2                | 6.8                | 0.83                | 0.46                |
| M3        | 9.5             | 10.6                 | 1.12                | 6.1                | 5.4                | 0.89                | 0.49                |
| M4        | 7.1             | 8.0                  | 1.13                | 4.8                | 4.2                | 0.88                | 0.48                |
| M5        | 4.7             | 4.8                  | 1.02                | 3.3                | 3.0                | 0.90                | 0.38                |
| M6        | 2.4             | 2.8                  | 1.17                | 1.8                | 1.6                | 0.87                | 0.43                |
| M7        | 1.3             | 1.4                  | 1.08                | 1.2                | 1.1                | 0.89                | 0.21                |

According to Table 2, it can be seen that under the test load before strengthening, measured deflection values are greater than theoretical calculation values. The deflection verification coefficient is between 1.01 and 1.17. It indicates that structural stiffness of the bridge does not meet the design requirements and there is not enough safety reserve. After strengthening, measured deflection values are less than theoretical calculation values. The deflection verification coefficient is within the range of 0.80 ~ 0.90. It is in line with the provisions of the code that the calibration coefficient is less than 1.0, indicating that the structural stiffness of the bridge meets the requirements of highway class II load.
Under the condition of symmetrical load, the measured deflection decreases by 52.41%, and the average deflection decreases by 46.59%; Under the condition of eccentric load, the measured deflection is reduced by 54.42% at most, and the average deflection is reduced by 43.22%.

Compared with the theoretical value, the reduction percentage of deflection is slightly larger than the theoretical value, because the cracks of the original bridge are also repaired in the process of strengthening, which also improves a small part of bearing capacity to a certain extent.

It indicates that bonding steel plate method is feasible, and the effect of improving the structural stiffness is obvious.

5.2. Strain results and analysis

Comparisons between theoretical values and measured values of strains of T-beams under test load before and after strengthening are shown in Table 3.

| Load Case | Measuring point | Before strengthening | After strengthening | Reduction rate of measured value (%) |
|-----------|-----------------|----------------------|---------------------|--------------------------------------|
|           | Theoretical value (με) | Measured value (με) | Verification coefficient | Theoretical value (με) | Measured value (με) | Verification coefficient |
| S1        | 113             | 95                   | 0.84                | 93                     | 70                   | 0.75                 | 26.32                  |
| S2        | 172             | 150                  | 0.87                | 149                    | 105                  | 0.70                 | 30                     |
| S3        | 255             | 235                  | 0.92                | 202                    | 145                  | 0.72                 | 38.3                   |
| S4        | 298             | 255                  | 0.86                | 218                    | 165                  | 0.76                 | 35.29                  |
| S5        | 253             | 240                  | 0.95                | 201                    | 155                  | 0.77                 | 35.42                  |
| S6        | 169             | 175                  | 1.04                | 143                    | 100                  | 0.70                 | 42.86                  |
| S7        | 114             | 115                  | 1.01                | 92                     | 65                   | 0.71                 | 43.48                  |
| S1        | 339             | 310                  | 0.91                | 297                    | 235                  | 0.79                 | 24.19                  |
| S2        | 302             | 255                  | 0.84                | 255                    | 190                  | 0.75                 | 25.49                  |
| S3        | 243             | 200                  | 0.82                | 203                    | 160                  | 0.79                 | 20.00                  |
| S4        | 201             | 190                  | 0.95                | 156                    | 110                  | 0.71                 | 42.11                  |
| S5        | 166             | 150                  | 0.90                | 135                    | 100                  | 0.74                 | 33.33                  |
| S6        | 132             | 105                  | 0.80                | 104                    | 85                   | 0.82                 | 19.05                  |
| S7        | 101             | 105                  | 1.04                | 76                     | 50                   | 0.66                 | 52.00                  |

According to Table 3, it can be seen that, under the test load before strengthening, the verification coefficient of strain value is between 0.59 and 1.15, indicating that the structural strength of the bridge does not meet the design requirements and there is not enough safety reserve.

The measured strain values after strengthening are less than the theoretical calculation values, and the strain verification coefficient in the span is 0.53-0.91, which conforms to the requirements of the calibration coefficient less than 1.0 in the specification, indicating that the structural strength of the bridge meets the requirements of highway class II load.

The conclusion can be drawn from the above data processing, after the structure is strengthened, the structure is more safe under the symmetrical load or the off load condition. Therefore, the steel plates are used to enhance the structural strength obviously.

6. Conclusions

Based on load tests of Erdao River bridge before and after strengthening, the strengthening effect of T-beam bridge with bonding steel plates method is studied. The conclusions are as follows:
(1) Under the symmetrical load condition, the measured deflection decreases by 52.41%, and the average deflection decreases by 46.59%. Under the eccentric load condition, the measured deflection is reduced by 54.42%, and the average deflection is reduced by 43.22%.

(2) Under the symmetrical load condition, the measured strain decreases by 43.48% and 35.95% on average. Under the eccentric load condition, the measured strain decreases by 52.00% at most and 30.88% on average.

(3) The deflections and strains of T-beams are reduced to some extent after strengthening with externally bonding steel plates. The bearing capacity of T-beams can meet the requirements of highway - class II load.

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