Study on the destructive test of T-beam strengthened by external prestressing

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Abstract. Three T-beams with severe cracks in the operation were selected for the approach bridge of the Yellow River Bridge of a national highway. Three pieces of external T-beams were used for reinforcement and the destructive tests were carried out on the strengthened T-beams. The test results of the T-beam test of the approach bridge are analyzed to evaluate the bearing capacity. The main conclusions are as follows: The strengthened T-beam has greatly improved the mechanical performance, improved the cracking load of the T-beam, and slowed the crack development. The change of beam deflection is divided into three stages: 0~30t, 30~66t, 66~134t. The deflection value increases gradually, and the turning point of deflection changes basically corresponds to the crack development. The stiffness and ultimate load carrying capacity of the T-beam are greatly improved, which greatly improves the safety of the T-beam. Due to the lack of space at the bottom of the beam, the test beams of the three pieces of reinforcement were loaded to the final failure, and the maximum crack width has reached the loading termination condition. This indicates that the elastic stress stage of the T-beam is increased after the reinforcement, and the T-beam has a strong T-beam. Deformation recovery capability. It provides some reference for the reinforcement and transformation of similar T-beams and the evaluation of bearing capacity.

1. Introduction

With the rapid development of the economy and the increase in traffic volume, a large number of active bridges, due to the effects of concrete temperature stress, corrosion of steel bars, and overloading, have caused structural cracks or excessive deformation, or due to the requirements of highway bridge load upgrade Reinforcement, using external prestressing reinforcement is one of the most effective methods. Chen Xiaoying and others used CFRP and external prestressed beam to strengthen a small span T beam [1]. Gao Rongxiong and others analyzed the mechanical characteristics of external prestressed reinforcement of T beams, and discussed the free length control of external prestressed steel cables [2]. Gao Rongxiong and others carried out external prestressed reinforcement design engineering practice for simply supported T-beam bridges, and conducted a comparative analysis of the mechanical properties before and after reinforcement [3].
It is an effective method for improving the bearing capacity of bridges through external prestressed beam reinforcement. Huang Guanping, Ma Lin, etc. to evaluate the bearing capacity of the bridge through destructive tests on single beams [4-5].

In this paper, three 40m T beams of the approach bridge of a national highway Yellow River Bridge are selected for external prestressing reinforcement, destructive destructive tests performed and compared with previously unreinforced T-beams, analysis of T beam failure phenomenon and test results.

2. Project Overview
The upper structure of the approach bridge of a national highway Yellow River Bridge is a prestressed concrete T-shaped simply supported beam, 7 beams arranged horizontally, the bridge deck is continuous. A total of 11, 6 × 40m each joint, 6 × 50m five joints, 7 × 40m five joints. Through crack detection, divide 40m T beam into three parts, 1-13 span, 14-27 span, 67-80 span, the cracks of 14-27 spans are obviously serious, Therefore, it is decided to select representative T-beams from 14-27 spans for load test.

By checking the structure of the approach bridge, it is found that the bending capacity of the T-section of the approach bridge is insufficient, and the shear capacity of the fulcrum can not meet the requirements of the code. In order to improve the flexural and shear bearing capacity and the service performance of the structure, the T-beam was strengthened by adding 14 Φ 15.24 epoxy spraying unbonded steel strand external bundle, and the severely damaged T-beam was replaced; Figure 1 for the reinforcement method of T-beam's longitudinal external beam.

![Figure 1. Test beam reinforcement](image)

3. Test loading

3.1. Test items and methods

3.1.1. Deflection of beam and settlement measurement of pier and abutment. Use the precise level to read the T-beam scale, and measure the load deflection value of the beam and the test bench.

3.1.2. Strain measurement of key section. In the middle of the beam span and the webs on both sides of the T-beams of L / 4, 3L / 4, L / 8 and 3L / 8 sections, bridge strain gauges are arranged along the height direction for measurement, and the data are collected by the "JC-4A" acquisition device.

3.1.3. Fracture observation and failure form record. Before the test, the initial condition of T-beam shall be checked carefully, the original crack shall be marked, and the crack length, width, starting point coordinate, etc. shall be marked after each level of loading.
3.2. Loading device and test site preparation
The loading device adopts the reaction frame Jack to load, uses the expanded concrete block as the anchoring foundation, and carries out the force transmission through the finish rolling screw steel and the transverse steel frame.

4. Analysis of test results
The test beam is a middle beam, which is loaded to 133.9t of a single jack. During the loading process, the maximum deflection of the T beam reaches 31.49cm, the maximum crack width is 1.93mm, and the residual deflection after unloading is 3.5cm. Due to the lack of space at the bottom of the beam, the loading of the test beam has not reached the final failure, but the maximum crack width has reached the condition of loading termination, which shows that the strengthened T beam has a strong ability of deformation recovery.

4.1. Analysis of displacement results
4.1.1. Deflection change of test beam. In this paper, the results of displacement load in the process of twice loading are given. Fig. 2 show the load deflection results of the first and second loading respectively.

![Figure 2. Deflection curve of test beam in T-stage loading process](image)

It can be seen from the displacement load curve of the test beam that in the first loading condition, the displacement load is linear at the stage of 0 ~ 30t, which basically coincides with the theoretical calculation value; In the stage of 30 ~ 60t, the measured stiffness of T-beam decreases, the deflection value in the middle of span accelerates, the stiffness is lower than the theoretical value, and the displacement load in the whole stage changes linearly; In the 60 ~ 66t stage, the rigidity of T-beam decreases again, but there is no sharp decrease in the loading process.

In the limit loading condition, the displacement load curve shows three stages, the 0 ~ 45t stage is curve section, and the deflection trend increases gradually; In the 45 ~ 89 stage, the displacement load shows a linear relationship, and there is a sudden change of deflection at 45t, and the deflection tends to increase; In the last stage of 89 ~ 89, there is a linear relationship between the displacement load and the deflection. Compared with the changing joint of crack width and spacing, the stiffness degradation has a strong correlation with the changing rule of seam.

The final deflection value of the test beam is 31.49cm, L / 127, the residual deflection value is 3.55cm, and the relative residual is 11.3%.
4.1.2. Comparison between test beam and before reinforcement. In this paper, the load deflection curves of 1/4 of the ultimate bearing capacity and midspan of the unreinforced test beams are compared. See Fig. 3-4 for the load deflection curves of 1/4 and midspan.

![Figure 3. Curve of ultimate load](image1)

![Figure 4. Deflection curve of 1/4L ultimate load](image2)

In the ultimate loading condition, the bearing capacity of the two beams is obviously different. The stiffness of the structure is improved by adding external prestressing tendons, and the bearing capacity of the strengthened T-beam is obviously improved.

4.2. Analysis of strain results

Due to the cracking of concrete in the process of loading, only the strain values of measuring points in the compression area are analyzed to determine the change trend. In this paper, the data table of the strain at the test point of the first loading compression zone of the test beam is given, The strain curves of the test points in the compression zone of the test beam are shown in Figure 5, respectively.

![Figure 5. Strain curve of the first test beam](image3)

It can be seen from the strain-load change curve of the test point in the compression zone of the test beam that during the first loading process, there are obvious changes in the compressive stress of the T-beam roof across the mid-span section. Two are 0 ~ 44t and 44 ~ 73t. The broken line segment indicates that there is a new cracking of the concrete at the mid-span section at 44t.

The highest measuring points of 1/8 section, 3/4 section, and 5/8 section are arranged at 1.9m from the bottom edge of the T beam. The thickness of the T beam strengthened roof is increased by 20cm, which causes the neutral axial movement of these sections Therefore, relative to the same measuring
point position before reinforcement, the values of these measuring points are relatively small, and there is also tension.

5. Analysis of experimental phenomena
The development of cracks in the test beam during test loading is given.

5.1. Observation of crack development
The change of the number of cracks at each loading level is shown in Figures 6 to 7.

![Figure 6. Curves of the number of cracks of 2 # beams with different lengths](image1)

![Figure 7. Curves of the number of cracks in 2 # beams in different ranges](image2)

During the entire loading process, the vertical crack spacing at the horseshoe showed a regular change. Before 52.5t, the crack spacing changed rapidly, the spacing change between 52.5t ~ 75t slowed down, and the crack spacing between 75t ~ 135t became the slowest; By the end of the loading, the vertical crack spacing at the horseshoe of the T beam is about 7cm.

It can be seen from Figure 2. that the number of cracks with a length less than 1 / 2h before the loading level is 105t is far greater than the number of cracks with a length greater than 1 / 2h. During this loading stage, the increase in the number of cracks is obviously related to the length of the cracks; After the level is 105t, the number of newly added cracks and the number of crack extensions remain basically the same.

It can be seen from Figure 3. that when the load is less than 67.5t, the number of crack growth between 1 / 3L and 2 / 3L is significantly greater than the number of crack growth outside its range; after more than 67.5t, the number of crack growth in each range is roughly the same.

5.2. Crack width change curve
Typical fracture width changes and crack width data during loading
From the typical crack width change curve, it can be seen that there are several stages of crack width change. The first stage is 0 ~ 30t. The small change in fracture width has a linear relationship with the tonnage. As the rate increases, the growth rate of the slit width becomes larger.

The test beam was loaded to the final stage. The maximum slit width of diagonal cracks reached 1.438mm, and the maximum slit width of vertical cracks reached 1.126mm.

6. Conclusion

(1) During the loading of levels 1 ~ 4 (0 ~ 36t), the fractures did not develop, and the original fractures were in the "inactive" state; During the loading stage of 4 ~ 8 (36 ~ 60t), vertical cracks at the horseshoe and a small number of diagonal cracks at the 1/3 and 2/3 spans mainly appear.

According to the above test phenomenon, it can be concluded that after the T beam is strengthened, its mechanical performance is greatly improved, the crack load of the T beam is increased, the crack development is slowed, and the durability under heavy load traffic is improved.

(2) The deflection of the test beam is divided into three stages: 0 ~ 30t, 30 ~ 66t, and 66 ~ 134t. The deflection change value gradually increases, and the turning point of deflection change basically corresponds to the crack development; The stiffness and ultimate bearing capacity of the T beam are greatly improved, which greatly improves the safety of the T beam.

(3) Due to insufficient space at the bottom of the test beam after reinforcement, the loading did not reach the final failure, but the maximum crack width has reached the end of loading condition. Compared with the failure of the beam before reinforcement, this indicates that the elastic stress stage of the T beam is increased after reinforcement, T beam has a strong ability to recover from deformation.

Acknowledgments

Technical service project for residual service life evaluation and reinforcement of old bridge slab in reconstruction and expansion project of Laiwu Linyi (Lu Su Jie) section of Beijing Shanghai Expressway

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