Flexural behavior analysis on RC simply supported girder strengthened by adding diagonal brace

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Abstract: Adding the diagonal bracing to strengthen RC simply supported beam bridge has certain engineering application space. In order to study the flexural performance of the strengthened members, the finite element model was established by Midas/Civil to calculate and analyze the load effect of 20m span RC simply-supported T beam under 12 flexural strengthening conditions. The results showed that the connection form of diagonal brace has little influence on the deformation behavior of the strengthened beam. After reinforcement, the positive moment and deflection of mid-span of the main beam can be reduced by more than 50%. At the same time, the main beam appears negative moment, horizontal reaction force, and vertical negative reaction force may occur. The reasonable arrangement of the brace position can ensure that the main beam does not have vertical negative reaction force, and the main beam negative moment and horizontal reaction force, the horizontal and vertical reaction force of the diagonal brace are controlled to obtain ideal load effect results.

1. Introduction
Changing the structural system reinforcement method refers to a method of improving or adjusting the force of the original structure by changing the structural system. In reinforcement of RC simply supported girder bridge. There are usually two reinforcement techniques for changing the structural system of the reinforcement method: simply supporting variable continuous and adding supporting structure [1]. The commonly used bridge reinforcement methods are increasing section method, pasting steel plate method, pasting fiber composite material method, external prestressing method and changing structure system method. Each method has its own characteristics [1]. At present, relevant personnel carry out more research and application on the method of increasing section, pasting steel plate, pasting fiber composite and external prestressing, and the results are also rich [2-7]. Although the research and application of the method of changing structural system has been carried out, for example, the literature [8] studies the mechanical behavior, negative moment section structure improvement technology and rubber bearing replacement technology of RC simply supported beam bridge strengthened by the method of changing simply supported to continuous, but the number of relevant results is obviously less, and mainly focuses on the reinforcement of simply supported to continuous, and the research on adding supporting structure reinforcement is relatively rare rarely. This paper analyzes the technical feasibility
and the flexural performance of reinforced members of RC simply supported beam bridge by adding diagonal brace (which belongs to the strengthening technology of additional supporting structure). The results can provide reference for the reinforcement design of RC simply supported beam bridge.

2. Technical feasibility analysis

The schematic diagram of adding diagonal bracing to strengthen RC simply supported beam bridge is shown in Figure 1. The reinforcement mechanism of this technology is: reducing the calculated span of main beam, reducing the effect of internal force and deformation, so as to improve the ultimate bearing capacity [9]. The following analyzes the feasibility of this technology from three aspects.

![Figure 1. Schematic diagram of strengthening](image)

(1) Applicability and diagonal bracing arrangement. The technology needs to set diagonal braces under the bridge to affect the clearance under the bridge, so it is necessary to evaluate the impact on the bridge with traffic, navigation and flood discharge demand, but this impact can be controlled by the layout position design of diagonal braces, and not all bridges have traffic, navigation and flood discharge demand, such as a large number of mountain bridges, the height of such bridges is small, and the sensitivity to the change of clearance under the bridge is also small smaller. This technology puts forward additional requirements for the bearing capacity of bridge piers, abutments and foundations. Generally, bridge piers, abutments and foundations have a certain bearing capacity safety reserve, so the additional requirements for bearing capacity should not exceed the safety reserve.

(2) The diagonal brace material, supporting form, connection form and mode. The diagonal braces can be made of reinforced concrete and section steel, and the support forms can be divided into rigid support and elastic support according to the stiffness of diagonal braces. There are two kinds of connection forms between diagonal bracing and strengthened components and bridge piers and abutments: Consolidation and hinged support. As for the connection mode, when the diagonal brace is made of section steel, the dry connection can be used, and when the diagonal brace is made of reinforced concrete, the wet connection or dry wet mixed connection can be used.

(3) Reinforcement construction. Reinforcement construction needs to be carried out under the bridge. If reinforced concrete is used for diagonal bracing, the construction difficulty is equivalent to that of increasing section method. There are a lot of engineering practice experience for reference. If section steel is used, corresponding hoisting equipment is needed during construction. With the popularization and application of light and high strength materials in the field of engineering construction in the future, the difficulty of hoisting under the bridge will be greatly reduced [10].

According to the above analysis, the reinforcement technology can be used for the reinforcement of RC simply supported beam bridges with small height and few spans without considering the requirements of traffic, navigation and flood discharge. Some data show that there are a considerable number of such bridges, which provides a certain engineering application space for the reinforcement technology.

3. Analysis of bending resistance

3.1. Analysis of bending moment and deformation

The test specimen NT of a 20 m span RC simply supported T-beam of an old bridge in reference [11] is taken as the analysis object. Midas/Civil is used to establish the finite element model of the bar system, and the model is shown in Figure 1 above. Considering the dead weight load, the positive bending
moment \( M \) and deflection \( u \) of the main girder in the middle span under the test loading condition are obtained. Keeping the loading condition unchanged, 12 kinds of diagonal brace strengthening conditions are calculated respectively. The diagonal brace is made of the same material as the T-beam, and its section is a square whose side length is equal to the thickness of the T-beam web. The reinforcement conditions and calculation results are shown in Table 1. In Table 1, \( h \) is set as the distance from the intersection of diagonal brace and bridge pier to the bottom of beam, \( d \) is set as the distance from the intersection of diagonal brace and main beam to the near end of beam, and \( M_f \) is the maximum negative bending moment of main beam.

| Reinforcement working conditions | \( h \)/m | \( d \)/m | \( M/\) kN\( \cdot \)m | \( u/\)mm | \( M_f/\) kN\( \cdot \)m | \( u/\)mm |
|-------------------------------|------|------|----------------|-----|----------------|-----|
| unreinforced                  |     |     | 3217.9        | -45 | 3217.9        | -45 |
| 1                             | 1    | 2    | 1573.0        | -15 | 1573.7        | -15 |
| 2                             | 1    | 3    | 1547.0        | -15 | 1548.0        | -15 |
| 3                             | 1    | 4    | 1559.8        | -17 | 1561.3        | -17 |
| 4                             | 1    | 5    | 1603.1        | -19 | 1605.3        | -19 |
| 5                             | 2    | 2    | 1513.7        | -14 | 1522.6        | -14 |
| 6                             | 2    | 3    | 1383.9        | -12 | 1384.4        | -12 |
| 7                             | 2    | 4    | 1301.6        | -12 | 1302.1        | -12 |
| 8                             | 2    | 5    | 1251.6        | -12 | 1252.4        | -12 |
| 9                             | 3    | 2    | 1563.1        | -14 | 1564.2        | -14 |
| 10                            | 3    | 3    | 1355.4        | -11 | 1356.0        | -11 |
| 11                            | 3    | 4    | 1217.1        | -10 | 1217.7        | -10 |
| 12                            | 3    | 5    | 1111.2        | -10 | 1111.9        | -10 |

According to Table 1, under the same reinforcement condition, the bending moment difference between consolidation and hinged support is very small, and the deflection is exactly the same, which indicates that the connection form of diagonal brace has little influence on the bending moment and deflection deformation effect of main girder. The midspan positive bending moment \( M \) of the main girder under various reinforcement conditions is significantly reduced compared with that without reinforcement, the maximum reduction is about 65% (working condition 12), and the minimum reduction is about 50% (working condition 4). The mid span deflection \( U \) of the main beam under various reinforcement conditions is also significantly reduced compared with that without reinforcement, the maximum reduction is about 78% (working condition 11 and 12), and the minimum reduction is about 58% (working condition 4). It shows that the diagonal brace reinforcement has obvious effect on reducing the \( M \) and \( u \) of the strengthened beam, and the reduction effect of \( M \) and \( u \) is different under different reinforcement conditions, because the diagonal brace position is different rather than its self-weight change. After strengthening, the main beam has a negative bending moment, and the maximum negative bending moment \( M_f \) is different for different strengthening conditions. For example, the \( M_f \) of working condition 5 is larger, which is -1048.9 kN\( \cdot \)m, while the \( M_f \) of working condition 8 is small, which is -275.6 kN\( \cdot \)m. In actual engineering, the main girder of the RC simply supported girder bridge must be a double-reinforced cross-section, and the diagonal bracing position is reasonably arranged. If the \( M_f \) can be controlled within the level that can be borne by the existing longitudinal steel bars on the same side, the main girder can be prevented from damage caused by negative bending moments without additional reinforcement.

### 3.2. Reaction analysis

The calculation and analysis carried out in Section 3.1 above can get the reaction results. The reaction effect of diagonal brace is mainly shown as concentrated force no matter it is consolidated or hinged. The reaction distribution diagram of reinforced beam is shown in Figure 2, and the reaction calculation
results are shown in Table 2 to 3.

![Figure 2. Schematic diagram of reaction distribution](image)

### Table 2. Reaction calculation results 1

| Reinforcement working conditions | Conservation / kN | F1x | F1z | F2x | F2z | F3x | F3z | F4x | F4z |
|----------------------------------|------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| unreinforce                      |                  | 0   | 393.7 | 393.7 | — | — | — | — | — |
| 1                                |                  | 321.2 | 54.8 | -71.8 | 642.0 | 324.8 | -963.2 | 483.2 |
| 2                                |                  | 405.5 | 173.5 | 79.4 | 596.0 | 202.5 | -1001.5 | 337.0 |
| 3                                |                  | 483.4 | 235.4 | 163.0 | 534.6 | 137.4 | -1018.0 | 258.1 |
| 4                                |                  | 544.7 | 272.8 | 218.3 | 469.4 | 97.7 | -1041.4 | 206.7 |
| 5                                |                  | 142.1 | -117.8 | -229.7 | 499.3 | 499.7 | -641.4 | 639.8 |
| 6                                |                  | 164.4 | 22.7 | -53.4 | 533.2 | 357.5 | -697.6 | 466.4 |
| 7                                |                  | 215.7 | 108.0 | 43.5 | 530.2 | 267.8 | -746.0 | 375.3 |
| 8                                |                  | 277.0 | 163.2 | 107.9 | 510.2 | 207.1 | -787.1 | 317.8 |
| 9                                |                  | 87.8 | -179.0 | -282.9 | 375.3 | 562.6 | -463.1 | 695.2 |
| 10                               |                  | 89.2 | -45.8 | -107.7 | 428.1 | 429.5 | -517.3 | 518.1 |
| 11                               |                  | 111.8 | 40.5 | -9.5 | 451.0 | 340.5 | -562.7 | 424.0 |
| 12                               |                  | 150.9 | 99.3 | 54.2 | 456.1 | 276.4 | -607.0 | 366.8 |

It can be seen from Table 2 and Table 3 that the difference between the reaction results of consolidation and hinged support under the same reinforcement condition is very small, which indicates that the influence of diagonal brace connection form on the reaction distribution of strengthened beam is very small. The distribution of the reaction force after the reinforcement of the component changes significantly. For the main beam, the horizontal reaction force appears after the reinforcement, and the vertical reaction force is significantly reduced and may become negative value, for diagonal braces, the horizontal and vertical reaction forces are relatively large. Under partial reinforcement conditions, the absolute value of the horizontal reaction force of diagonal braces is much greater than that of the main beam (such as working condition 3). It is still large when it is not reinforced (such as working condition 5). It should be pointed out that the bending moment effect of the diagonal brace is small under any
reinforced working condition. The results of different reinforcement conditions are quite different because of the different position of the diagonal brace rather than the change of its own weight. On the whole, the reaction force result of working condition 8 is relatively ideal, showing that the horizontal reaction force of the main beam is moderate, the vertical reaction force is positive, and the horizontal and vertical reaction force of the diagonal brace is relatively balanced. Together with the bending moment and deformation results of section 3.1, it can be seen that among the 12 brace reinforcement conditions, the result effect of condition 8 is ideal. In the reinforcement design, a more ideal bending moment, deformation and reaction force effect can be obtained through the reasonable arrangement of the diagonal brace position.

4. Conclusions
(1) The additional diagonal bracing reinforcement can be used for the reinforcement of RC simply supported beam bridge with smaller height and fewer spans without considering the requirements of traffic, navigation and flood discharge. The number of such bridge in bridge engineering is considerable, which provides a certain space for the application of the reinforcement technology.

(2) After reinforcement, the positive bending moment and deflection of the main beam can be reduced by more than 50%. At the same time, the main beam appears negative bending moment, horizontal reaction and vertical negative reaction. Through the reasonable arrangement of diagonal bracing position, it can ensure that there is no vertical negative reaction on the main beam, and control the negative bending moment and horizontal reaction of the main beam and the horizontal and vertical reaction of diagonal bracing.

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