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# The Analysis of the Internal Forces in Strengthened Old Concrete Bridge Subject to Vehicular Load by Transforming Simply Supported into Continuous System

Huanan He and Lijuan Xin
School of Civil Engineering, Dalian University of Technology

## ABSTRACT

In the past half century, large numbers of simply supported bridges were constructed in China; however, with the passing of years and the increase in the volume of transport, many of the bridges are out of normal service level and even gradually lose their bearing capacity due to overload or environmental influence. Therefore, some strengthening works have to be carried out in order for these old bridges to work well. Among the common strengthening methods, an efficient way to transform a simply supported into a continuous system is widely used in simply supported bridges with small or medium span. After the transformation of the system, the internal forces in the bridge are redistributed. This paper investigated, using the FEM software ANSYS, both the endogen forces of an old T-type bridge transformed from a simply supported to a continuous system under vehicular load. The result of the analysis indicates that the flexural moments in mid-span of all lateral T beams are significantly decreased and negative moments at supports are formed, while the shear forces in controlling sections are increased that are required to be reinforced based on the computation. In addition, after transformation, both longitudinal and lateral stiffnesses of T beams are improved that provides beneficial effects on the deflections of the bridge.

## 1. INTRODUCTION

Due to the rapid growth of the Chinese economy, the transportation sector has developed significantly, and thus the bearing capacity of many old simply supported concrete bridges constructed several decades ago cannot meet the load effect as a result of overload or aging of their concrete structures. However, it is impractical to rebuild all these old bridges. Therefore, it is necessary to improve the bearing capacity and durability of the bridges with appropriate strengthening technology to make such bridges still work and serve the present transportation needs. For the old simply supported concrete bridges, among the common strengthening methods, transforming a simply supported to a continuous system is effective for the upper structure of the bridge. In this study, we made an analysis of such a transformation in the endogen force of old bridges based on an actual project, by contrasting the vehicular load effects of the models before and after strengthening. Some strengthening suggestions are given, and analytical results showed the advantage of this transforming system.

## 2. ENGINEERING BACKGROUD OVERVIEW

A bridge which was built in 1967 in Liaoning Province in China was taken as an analytical model. It includes 10 uniform spans, and the single-span length is 22.2 m. Clear width of the bridge is 7 m with 0.5 m of protection walls on both sides. The upper structure of the bridge is prefabricated reinforced concrete T beams with only end diaphragm between kingposts. Five T beams were allocated in the lateral direction, and each T beam was 22.16 m long, with a clear span of 21.6 m. The support of the bridge is steel plate-fixed bearing and expansion bearing. The designed load level is autocar-13, full trailer-60, which are the original design vehicle loads of highway bridges in China (Chen, 2007).

Nowadays, a new level of highway bridge design vehicle load is applied which is divided into road–I and road–II. For the vehicular load, road–I and road–II levels use the same vehicular standard load values. The vehicular load arrangement from Load Code for a Chinese highway is shown in Figure 1. The main technical statements are shown in Table 1 (CCCC Highway Communication Construction Co., Ltd).

## 3. STRUCTURAL MODEL

### 3.1 Material parameters

The actually measured strength of the concrete of the old bridge is about C30, the modulus of elasticity is $E_c$ = 3.0 x $10^4$ MPa, Poisson's ratio $\mu_c$ is 0.167, the temperature coefficient of linear expansion $\alpha$ is 1.0 × $10^{-5}$, and the gravity density of reinforced concrete $\gamma$ is 26 kN/m$^3$. Design value of steel tensile strength $f_y$ = 280 MPa.

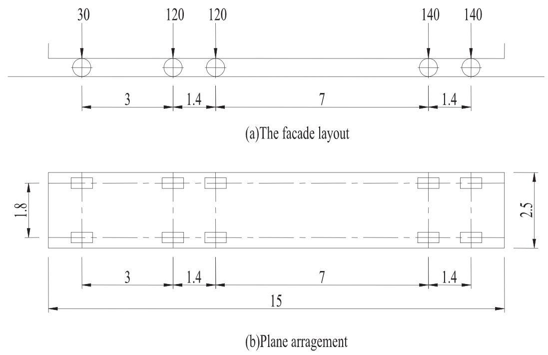


**Figure 1.** The arrangement of the vehicle load (units: gross rail load on axle, kN; length, m).

**Table 1.** The main technical parameters of vehicle load.

| Item | Value | Item | Value |
|---|---|---|---|
| Standard gravity of vehicle | 550 kN | Wheel span | 1.8 m |
| Standard gravity of front axles | 30 kN | Landing width and length of front wheel | 0.3 × 0.2 m |
| Standard gravity of middle axles | 2 × 120 kN | Landing width and length of middle and rear wheel | 0.6 × 0.2 m |
| Standard gravity of rear axles | 2 × 140 kN | Overall dimension of wheel (length × width) | 15 × 2.5 m |
| Spread of axles | (3 + 1.4 + 7 + 1.4) m | | |

The newly cast concrete used in the reinforcing process is also C30 concrete and is of approximately the same strength value as that of the old bridge. The other properties of the concrete material are elastic modulus $E_c$ = 3.0 x $10^4$ MPa, Poisson's ratio $m_c$ = 0.2, temperature coefficient of linear expansion $\alpha$ = 1.0 × $10^{-5}$, and gravity density $\gamma$ = 26 kN/m$^3$. The newly cast concrete C30 is used in the beam end, wet joint between lateral T beams, cross beam, cast-in-site segment of pier top, and the connection between the old and new coping; concrete C40 is used for the structure layer of the bridge deck. Steel fiber concrete CF40 is used for contiguous blocks of pier top.

### 3.2 A simply supported structure model

A simply supported model with five T beams hinged in the transverse direction and single span in the lengthways direction was built. The total length of the T beam is 22.2 m, and the clear span is 21.6 m. The thicknesses of the surfacing layer and the asphalt concrete layer are 100 mm and 50 mm, respectively. The detail of the cross-section of the single span is shown in Figure 2, and the corresponding finite element model is used in the SOLID45 block unit in ANSYS as shown in Figure 3. The longitudinal, lateral, and vertical element sizes are 0.2 m, 0.1 m, and 0.1–0.2 m, respectively. The total number of units is 42,320, and the total number of nodes is 64,067.

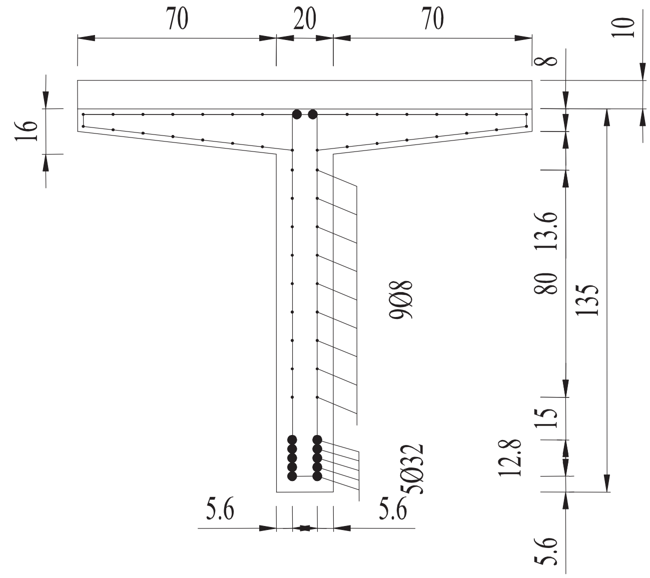


**Figure 2.** The cross-section of the original bridge.

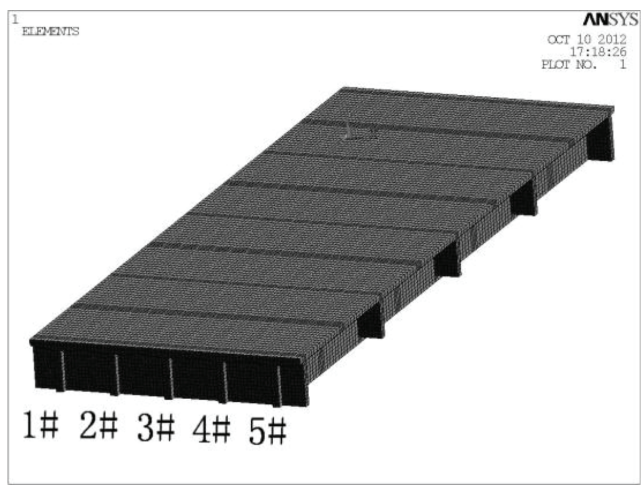


**Figure 3.** Finite element model of simply supported bridge.

### 3.3 A model for continuous beam

Also, a continuous beam model with five T beams hinged in the transverse and five spans in the lengthways direction is built. The total length of continuous beam is 111 m. The thickness of later cast structural layer is 120 mm, and the thickness of asphalt concrete layer is 50 mm. The cross-section of the continuous beam is shown in Figure 4, the finite element model of SOLID45 unit is also used for analysis. The size of the longitudinal element, lateral element, and vertical element are 0.2 m, 0.1 m, and 0.1–0.2 m, respectively. The total number of units is 118,924 and total node number is 82826.

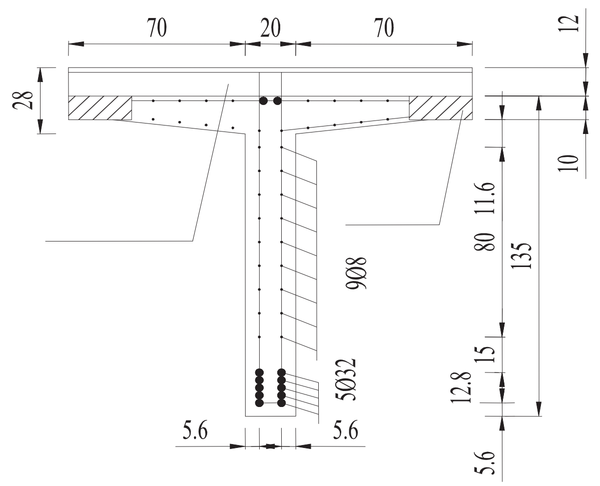


**Figure 4.** Sectional view of the continuous beam.

## 4. COMPARISION OF ENDOGEN FORCE UNDER VEHICULAR LOAD BEFORE AND AFTER STRENGTHENING

### 4.1 Endogen force calculation

Based on the influence line of endogen force of the sections under vehicular load, the most unfavorable is determined as well as endogen force of the section. Before strengthening, the influence line of the sections of a simply supported bridge is determined in accordance with structural mechanics knowledge; while after strengthening, the influence line of the continuous bridge is obtained with the method in ANSYS (Wang, 2004). The details of the calculation are presented as follows.

Step 1: Apply unit load $P$ = 1 in all positions of the structure needed to draw the influence line. Step 2: Set up $N$ load steps. Step 3: Solve all step loads. Step 4: Extract a degree of freedom at a position at each load on the response value, and draw the corresponding influence line. Step 5: Repeat the step 4 extraction process of response values, complete the influence line of all the degrees of freedom. The mid-span moment influence line of the first span is shown in Figure 5, the second bearing bending moment influence line is shown in Figure 6, and the shear influence line of $Z$ = 1.0 m section is shown in Figure 7.

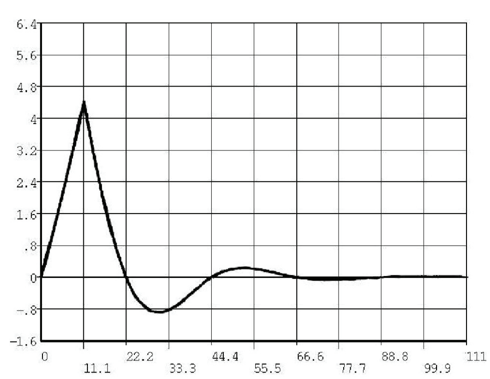


**Figure 5.** The mid-span moment influence line of the first span.

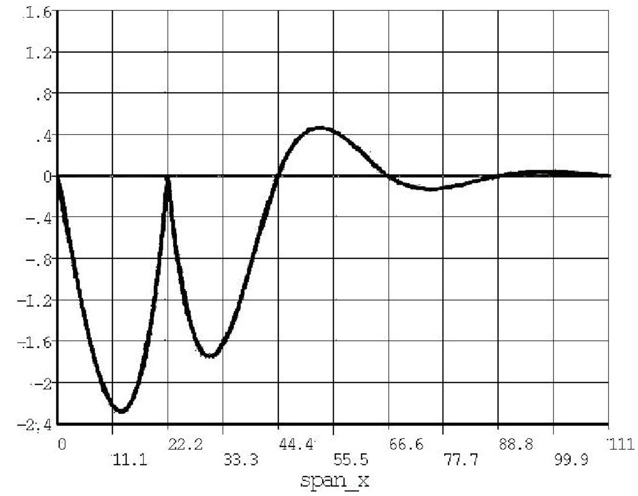


**Figure 6.** The second bearing bending moment influence line.

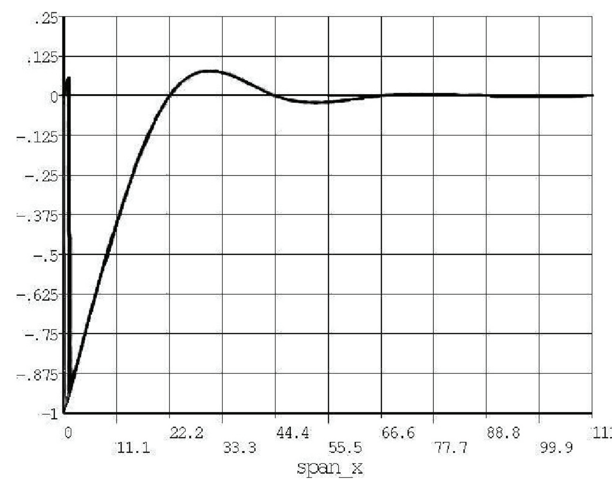


**Figure 7.** The shear influence line of $Z$ = 1.0 m section.

### 4.2 Comparison analysis of bending moment

Contrastive analysis of mid-span moment design value of T beam before and after strengthening under vehicular load is shown in Table 2.

**Table 2.** The values of mid-span moment under vehicular load.

| Structure type | | Moment of mid-span (kN·m) | Moment decrease ratio (%) |
|---|---|---|---|
| **Simply supported bridge** | | **851** | |
| Continuous beam | First span | 640 | 24.7 |
| | Second span | 532 | 37.5 |
| | Third span | 523 | 38.5 |

Table 2 indicates the following. (1) Structural transformation from simply supported beam into continuous beam for strengthening old bridges causes the redistribution of endogen force in the whole bridge. At the supports, negative moments occur and the moment in mid-span decreases significantly. (2) No matter whether in a simply supported or a continuous system, the lateral constraint to boundary T beam is less than that to middle T beam; therefore, the flexural moment of control section of the first T beam is always maximal, that of the second T beam is intermediate, and that of the third T beam is minimal.

### 4.3 Comparison analysis of shear force

Contrastive analysis for the shear force in the control section of T beam before and after strengthening under vehicular load is shown in Table 3.

**Table 3.** The shear force in control section under vehicular load.

| Structure type | Cross-section position, *Z* (m) | Shear force (kN) | Shear increasing ratio (%) |
|---|---|---|---|
| **Simply supported bridge** | **1.0** | **169** | |
| | 1.0 | 178 | 5.3 |
| Continuous beam | 21.4 | 177 | 4.7 |
| | 23.0 | 200 | 18.3 |

Table 3 shows that the shear force of the control section is higher than that under the simply supported condition; as a result, it is necessary to strengthen the shear capacity of the web of the beam in the meantime to improve the flexural capacity of the bridge.

## 5. CONCLUSIONS

(1) The mid-span moment of the first T beam is always maximal before and after strengthening.

(2) The shear of the first T beam under vehicular load is maximal before strengthening; however, the shear of the third T beam under vehicular load becomes maximal after strengthening.

(3) The mid-span moment is decreased significantly after the transforming of the structural system, and, as a result, the level of the reinforcement required is achieved.

(4) The shear force of a T beam is increased after the structural system is transformed, so it is necessary to strengthen the shear capacity of the web of the T beam.

## ACKNOWLEDGMENTS

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