Force analysis of fabricated box girder bridge based on auxiliary structure

Jun Tian

1Department of Civil Engineering, Ordos Institute of Technology, Ordos, Inner Mongolia, China

First author’s e-mail: lele1008@oit.edu.cn

Abstract: Prefabricated small box girder bridges have been widely used in urban viaducts and highway bridges at home and abroad. Concrete deck paving and guardrails are well bonded to the main girder, which contributes to the rigidity of the main girder structure. Ignoring the influence of the auxiliary structure of the bridge deck will cause a certain deviation between the structure and the actual state. This paper takes the prefabricated box girder bridge as an example, using the finite element method to analyze the variation of the lateral distribution coefficient of the bridge deck and guardrail and the degree of influence on the main girder force. The calculation results show that the bridge deck pavement has little effect on the lateral distribution coefficient of the main girder, the increase in the rigidity of the main girder by the guardrail cannot be ignored, and the difference in the bearing capacity and stress of the side main girder is significant.

1. Introduction

The prefabricated small box girder bridge has reasonable structure, convenient construction, relatively low engineering cost, and significant economic benefits[1]. Compared with traditional T-beams and hollow slabs, it has better cross-sectional form and stress performance. The simple-supported and then-continuous structure with a span of 20-50m greatly reduces bridge joints and improves driving stability and comfort. Therefore, urban viaducts and highway bridges at home and abroad have been widely used. Lanes and six lanes are the main ones.

The prefabricated small box girder bridge generally adopts single-piece prefabrication and then assembled on site. The flanges are made of beam-slab extending steel bars with longitudinal supplementary steel bars and cast-in-place concrete to form a reliable connection. Generally, the cast-in-situ end cross-beam at the support is added with a cross-piece in the middle of the span to increase the lateral rigidity of the structure. The lateral load transfer between the chambers mainly relies on the cast-in-place wet joints of the bridge deck system. The lateral effect of the structure and the spatial force characteristics are outstanding.

The deck of prefabricated box girder bridge is cast-in-situ concrete layer of 8~10cm, and connecting steel bars and steel mesh are laid inside. literature[2-3]It is stipulated that in the theoretical calculation of the internal force and load test of the main girder structure of the highway bridge, the bridge deck pavement is applied as an external load, that is, the second-stage dead load, on the main girder structure, regardless of their participation in the force of the main girder structure. Guardrails are the most basic safety facilities on highway bridges to prevent vehicles from overriding the bridge. SA or SS-grade concrete guardrails are often used in expressways. The bridge deck concrete paving and guardrail can not only participate in the force of the main girder, but also affect the lateral
distribution of the moving load. Barker[4]A three-span continuous beam bridge is used as the object to study the influence of guardrails, curbs and deck paving on the bridge's bearing capacity. Shi Xiongwei[5]Et al. found that the thickness of the concrete bridge deck pavement has a certain influence on the load test calibration coefficient of small and medium-span prestressed concrete continuous box girder and hollow slab girder. Le Jinchao et al.[6-7]Based on the three-dimensional finite element method and anisotropic linear elastic theory, the orthotropic contact model is used to simulate the contact between the layers, the shear stress between the asphalt layer and the concrete layer is analyzed, and the thickness of the paving layer is considered. influence level. Shang Yunfu etc.[8]By considering the joint force of the pavement layer and the precast hollow slab, it is found that for the simply supported hollow slab bridge, considering the participation of the pavement layer, the stress and deflection of the concrete at the bottom of the beam under each loading condition are reduced by 12% to 23%, and the calibration coefficient is increased 15%~30% larger.

A lot of load test practice and research[9-13] shows that the bonding between the concrete bridge deck pavement and the main girder structure is very good, and it participates in the common force of the main girder[14-15]; The protective fence has a certain contribution to improving the bearing capacity of the main beam structure. In the design of highway bridges, for the bridge deck structure (paving layer and anti-collision guardrail), in the calculation of the internal force of the main girder structure, out of structural safety considerations, the auxiliary structures such as bridge deck paving and anti-collision guardrails are often ignored. The overall rigidity of the beam structure is improved. Without considering the contribution of the auxiliary structure to the force of the main girder, there will be excessive misjudgment of the force performance of the main girder, which will cause certain errors in the bridge design and bearing capacity evaluation[16-18].

This paper takes the prefabricated small box girder bridge as the research object. Based on the participation of the pavement and the guardrail, it is divided into different levels, and the law of the lateral distribution coefficient of the pavement and the guardrail and the degree of influence on the force of the main girder are studied separately. Bridge design and inspection provide analysis basis.

2. Analysis principle

2.1 Lateral distribution calculation theory

The single beam shown in Figure 1(a) comes, \( \eta(x) \) Represents the internal force influence line of a certain section on the beam, then the internal force value of the section \( S = P \eta(x) \). Here \( \eta(x) \) It is a single-valued function. The force and deformation of the beam in the xoz plane is a simple plane problem.

A multi-girder bridge shown in Figure 1(b) is a girder bridge composed of bridge decks and transverse beams. When a load \( P \) is applied to the bridge, due to the lateral rigidity of the structure, the load must be transmitted in the x and y directions at the same time. All main beams are involved in the work to varying degrees. If the internal force influence surface at a certain point of the structure uses a
dual function $\eta(x,y)$, The internal force value of the section can be expressed as $S = P \cdot \eta(x,y)$. In order to simplify the calculation, the space problem is reasonably transformed into the plane problem shown in the figure (a) to solve. The aforementioned influence $\eta(x,y)$ separate into the product of two single-valued functions, namely: $\eta_1(x) \cdot \eta_2(x)$, The internal force value of a certain section of a main beam can be expressed as $S = P \cdot \eta_1(x) \cdot \eta_2(x)$ (1)

In the above formula $\eta_1(x)$ It is the internal force influence line of a single beam longitudinal bridge to a certain section, which will $\eta_2(x)$. It is regarded as the influence line of the lateral distribution of the load when the unit load acts at different positions along the transverse direction, then $S = P \cdot \eta_1(x) \cdot \eta_2(x)$ Is when $P$ acts on $\eta_2(x)$ The load distributed to a beam along the transverse direction at the point is simplified to the plane problem shown in Figure 1, and the internal force value of a certain section on a beam is obtained.

Generally, the lateral distribution coefficient of each beam is determined by the deflection of each beam or the lateral distribution law of internal force, and the spatial problem is reasonably simplified into a plane problem. This method is called "load lateral distribution theory", which transforms the spatial structure into a plane. The problem should satisfy:

$$\frac{\omega_1(x)}{\omega_1(x)} = \frac{M_1(x)}{M_1(x)} \frac{Q_1(x)}{Q_1(x)} = \frac{P(x)}{P(x)} = \cos \phi$$

(2)

Where: $\omega_1(x)$, $M_1(x)$, $Q_1(x)$, $P(x)$ They are the deflection, bending moment, shear force of the beam section and the assigned force or load.

According to beam deflection theory:

$$M(x) = -EI\omega'$$

$$Q(x) = -EI\omega''$$

(3)

(4)

Substituting equations (3) and (4) into equation (2), we get:

$$\frac{\omega_1(x)}{\omega_1(x)} = \frac{\omega_1(x)}{\omega_1(x)} = \frac{\omega_1(x)}{\omega_1(x)} = \frac{P(x)}{P(x)} = \cos \phi$$

(5)

Equations (1) and (4) show that under the action of a single concentrated load $P$, the deflection, bending moment, shear force and the assigned force or load of a certain section of the beam are proportional, and the above equation cannot be established.[16] In response to the above problems, Li Guohao[17] The concentrated load or distributed load acting on the bridge is decomposed into a sine series by series expansion, and the lateral load distribution is calculated approximately. However, this traditional theoretical method is an approximate solution of load distribution, and its result has a certain deviation from the actual situation, and it cannot accurately reflect the real situation of the lateral load distribution in space. In order to maximize the elimination of traditional theoretical methods and actual errors, the finite element method is used to calculate and analyze the degree of influence of bridge deck auxiliary structures (paving and guardrail) on the load lateral distribution coefficient.

2.2. Project example

A 4×30m simple-supported-to-continuous small box girder bridge on a certain expressway, with a width of 12m, adopts SA-grade C40 concrete guardrail; the bridge deck is covered by 8cm thick C50 concrete cast-in-place layer and 10cm asphalt pavement. The main beam spacing is 2.9m, and the side beam cantilever is 1.65m. The main beam is C50 concrete.

3. Bridge deck paving layer

3.1. Finite element simulation

In order to study the influence of the pavement thickness on the transverse distribution coefficient of the main girder, midas is used to establish a refined spatial girder grid model based on this project example. The main beam and pavement are simulated by beam elements. Moving load considers the
two working conditions of eccentric load and medium load as shown in Figure 2.

The asphalt layer of the bridge deck pavement is not equipped with steel bars. In the C50 concrete cast-in-situ layer, 10×10cm steel bars are usually laid, and D16 connecting steel bars are buried in the top slab of the main girder at a spacing of 40cm to make the concrete paving layer form the bridge deck and work together. Judging from the working state of the in-service bridge, the pavement layer and the main girder top slab did not have obvious dislocation. Considering that the concrete paving layer is a post-cast belt, it is impossible for the bridge deck to not participate in the force nor fully participate in the force. In order to clarify the contribution of the pavement layer to the lateral distribution, it is divided into five levels (0cm, 2.5cm, 5cm, 7.5cm and 10cm), and the pavement layer is considered to participate in the force of the main beam to study the pavement layer's influence on the lateral distribution of the prefabricated small box girder. The degree of influence of the distribution coefficient.

3.2. Horizontal distribution coefficient

![Figure 3 Comparison of lateral distribution coefficients of eccentric load](image-url)
It can be seen from Figure 3 that under eccentric load, 1# and 2# consider different pavement thickness to participate in the force, the lateral distribution coefficient deviation of each longitudinal bridge position is within 2%. The maximum difference of 3# beam lateral distribution coefficient is 2.4%, and the maximum difference of 4# beam lateral distribution coefficient is 6.5%. Because of the large gap between the internal force and the design limit state, the influence of 3# and 4# beams can be ignored. Under the action of eccentric load, as the thickness of the pavement layer is increased, the lateral distribution coefficients of the longitudinal and bridge positions of the 1# beam have a tendency to increase, and the maximum occurs at the side fulcrum, which is only 1%; The loading layer participates in the increase of the force-bearing thickness, and the lateral distribution coefficient of the 2# beam at all longitudinal bridge positions except for the middle span has a decreasing trend, the L/4 is the most obvious, the maximum difference is 1.9%.

It can be seen from Figure 4 that under medium load, 1# and 2# consider the different pavement thickness to participate in the force, the deviation of the lateral distribution coefficient of each longitudinal bridge position is within 2%. Under the action of medium load, as the thickness of the pavement layer is increased, the lateral distribution coefficient of the 1# beam at all longitudinal bridge positions except for the middle span has a tendency to increase, especially at L/4, with a maximum difference of 2.3%; Because of the large gap between the internal force of 1# beam and the design limit state, the change can be ignored. With the increase in the thickness of the pavement layer involved in the force, the lateral distribution coefficient of the 2# beam at all longitudinal bridge positions except for the middle of the span has a decreasing trend. The maximum difference is 2%, which occurs at L/4.

In general, whether it is eccentric load or medium load, as the pavement layer participates in the increase in the force thickness, the transverse distribution coefficient of the main beam corresponding to the design state increases, and the transverse distribution coefficient of the beam in the non-design state decreases. Trend, aggravate the "uneven" force phenomenon in the lateral distribution; except for the mid-span, as the pavement layer participates in the increase of the force thickness, the force of the beam that originally bears the larger internal force becomes smaller, and the smaller the internal force as it becomes larger, the lateral distribution of the main beams becomes more "even".

Whether it is bridge design or inspection, the influence of the pavement layer on the lateral distribution coefficient is small; in the design of the beam, the influence of the 2% difference on the internal force and deformation of the load is negligible.
### 3.3. Bearing capacity of main beam

![Diagram of main beam bearing capacity](image)

Figure 5 Envelope diagram of main beam bearing capacity

Considering the load effects of dead load, moving load, temperature gradient, system temperature rise and fall, and support settlement, the load combination of the main beam under the ultimate state of bearing capacity is carried out. Figure 5 shows that in the ultimate state of the bearing capacity, the resistance of the 2.5cm, 5cm, 7.5cm, and 10cm pavement layers at the mid-span of the main beam under the force is increased by 1.6%, 3.3%, 4.9% and 6.3%, respectively; The resistance at the fulcrum of the beam was reduced by 2.1%, 4.1%, 6.1% and 8.2% respectively. As the pavement layer increases the eccentricity of the steel beam at the negative bending moment, the load-bearing capacity of the main beam near the center fulcrum is reduced; the side beam and the middle beam have similar changes.

### 4 Guardrail

#### 4.1. Finite element simulation

In order to study the influence of guardrail stiffness on the lateral distribution coefficient, a spatial beam grid model was established using midas. According to the foregoing, the influence of the pavement layer on the lateral distribution coefficient is only 2% at most, ignoring the contribution of the stiffness of the bridge deck paving layer, the main beam and guardrail are simulated by beam elements, considering the difference between the guardrail and the main beam material, and its elastic modulus and area Reduction conversion. Moving load considers eccentric load and medium load, as shown in Figure 2 above:

According to the different contribution of the guardrail participating in the force, it is divided into three numerical analysis conditions:

1. Regardless of the stiffness contribution of the guardrail, it only participates in the force in the form of load (spatial beam element model).
2. Consider the contribution of steel bars in the guardrail and ignore the bonding effect of concrete (spatial superimposed beam element model).
3. Consider the force of the full section of the guardrail, ignore the bond slip and false joints between the two (spatial beam element model).
4.2. Horizontal distribution coefficient

Figure 7 Comparison of lateral distribution coefficients of eccentric load
It can be seen from Figure 7 that under the eccentric load, only considering the effect of the "shear bond" of the steel bar, the maximum difference in the transverse distribution coefficient of each beam is 5.2%, which occurs at the second side span of the 1# beam 4 locations. Considering the joint action of steel bar and concrete, the full stiffness of the guardrail participates in the force, the maximum difference of the lateral distribution coefficient of each beam is 11.1%, which occurs at the 3L/4 of the 4# beam side span. In view of the large gap between the 3# and 4# beams and the design state, the changes of the 1# and 2# beams are emphasized. For 1#beam and 2#beam, regardless of whether the full rigidity of the steel bar or the guardrail is considered, the lateral distribution coefficients of the side fulcrum and the middle of the span have a small change, and the maximum difference is only 1.1%, which affects the middle fulcrum and L/4 Larger, especially at L/4, the biggest difference is 10.6%.

It can be seen from Figure 8 that under the action of medium load, only considering the effect of the "shear bond" of the steel bars, the maximum difference in the transverse distribution coefficient of each beam is 3.4%, which occurs at the second side span of the 1# beam L/4 locations. Considering the joint effect of steel and concrete, the full stiffness of the guardrail participates in the force, the maximum difference of the transverse distribution coefficient of each beam is 8.8%, which occurs at the L/4 of the 1# beam secondary span. There is a big gap between 1# and the design state, so the change of 2# beam is considered. For the 2# beam, regardless of whether the full rigidity of the steel bar or the guardrail is considered, the lateral distribution coefficients at the side fulcrum and the middle of the span have little change, and the maximum difference is only 2.3%, which has a greater impact on the middle fulcrum and L/4. L/4 is particularly obvious, the biggest difference is 7.2%.

On the whole, whether it is eccentric load or medium load, as the guardrail participates in the force stiffness increase, the effect of "redistribution" of the lateral distribution coefficient at the L/4 and middle fulcrum of the beam in the design state is obvious. The influence of mid-position is negligible. The ratio of the increased value of the lateral distribution coefficient of the guardrail considering only the effect of the reinforcement and the lateral distribution factor considering the contribution of the full stiffness of the guardrail, the stiffness contribution of the guardrail steel bars participating in the force action can be obtained. The results show that the contribution of the guardrail steel reinforcement stiffness accounts for the full section stiffness of the guardrail The contribution is about 30%~50%. If there is no obvious "slip" between the bridge guardrail and the side girder, the "redistribution" effect of the guardrail on the lateral distribution coefficient cannot be ignored, and the contribution of the guardrail stiffness should be properly considered.
4.3 Main beam bearing capacity and stress

![Envelope diagram of bearing capacity of side beam](image)

**Figure 9** Envelope diagram of bearing capacity of side beam

![Normal stress diagram of main beam](image)

**Figure 10** Normal stress diagram of main beam
Considering the load effects of dead load, moving load, temperature gradient, system temperature rise and fall, and support settlement, the load combination of the main beam under the ultimate state of bearing capacity is carried out. It can be seen from Figure 11 that in the basic combination, considering the full-section force of the guardrail, compared with not considering the force of the guardrail, the flexural bearing capacity of the side main girder section at the mid-span is increased by 19.2% to 19.4%, and the near-center fulcrum is reduced. This is because the guardrail increases the eccentric distance between the negative bending moment steel beam near the fulcrum and the top plate,
resulting in a decrease in the negative moment bearing capacity near the fulcrum. Because the steel beam and cross-section characteristics have not changed, the load-bearing capacity of the beam has not been improved or reduced.

Figure 10 shows that when considering the full-section force of the guardrail and not considering the force of the guardrail, the normal stress on the upper edge of the cross-section of the side main girder at the middle of the span increases by 3.2~4.2Mpa, and tensile stress appears; the compressive stress on the lower edge decreases. 0.9~1.87Mpa. The normal stress at the upper edge of the cross-section at the middle span of the middle main beam increases by 1.9~3.5Mpa, and only the tensile stress appears at the middle of the middle span; the compressive stress at the lower edge decreases by 0.4~2.2Mpa; consider the full-section force of the guardrail and only consider the guardrail The stress results of the steel bars are close, and the maximum difference between the side beam and the middle beam in the longitudinal direction of the bridge is not more than 0.7Mpa.

Figure 11 shows that the main tensile stress of the oblique section at the middle of each span of the side main girder increases by 0.9~1.49Mpa, which is the tensile stress; the main compressive stress increases by 0.6~1.2Mpa. The main tensile stress at the mid-span section of the main girder increases by 0.2~1.2Mpa, which is all tensile stress; the main compressive stress at the lower edge increases by 0.75~1Mpa; considering the full-section force of the guardrail is close to considering only the force of the guardrail reinforcement. The maximum difference between the main stresses in the longitudinal direction of the side beam and the middle beam does not exceed 0.5Mpa.

5. Conclusion
This paper takes a 4×30m simple-supported-to-continuous small box girder bridge on a certain expressway as an example, considers the contribution of paving and guardrails to the rigidity of the main girder in stages, uses the finite element method to calculate the transverse distribution coefficient of the main girder, and analyzes its change law; And considering the influence of the load combination on the force of the main beam under the most unfavorable state, the following conclusions are obtained:

(1) The influence of the pavement layer on the lateral distribution coefficient is relatively small, and the design state beam has only a 2% difference. Considering the force of the pavement layer, the resistance at the mid-span of the main girder is increased by 1.6% to 6.3%; the resistance at the mid-span of the main girder is reduced by 2.1% to 8.2%.

(2) With the increase of the rigidity of the guardrail participating in the force, the "redistribution" effect of the horizontal distribution coefficients at the L/4 and middle fulcrum of the beam in the design state is more obvious, and the maximum difference in the horizontal distribution coefficient of each beam is 11.1%. The contribution of the steel reinforcement stiffness of the guardrail accounts for about 30%-50% of the total section stiffness of the guardrail. The influence of the guardrail on the lateral distribution coefficient cannot be ignored.

(3) The full-section force of the guardrail increases the flexural bearing capacity of the main girder at the mid-span and decreases at the fulcrum, which is a significant difference. The existence of the guardrail will increase the tensile stress at the upper edge of the main beam mid-span, reduce the compressive stress at the lower edge, and increase the "inverse arch". Considering the full-section force of the guardrail is closer to the result when only considering the effect of the reinforcement of the guardrail.

(4) The contribution of guardrails to the rigidity of the main girder should not be ignored in the design and bridge inspection, otherwise it may cause the main girder to be too large in the middle of the span, cracking at the top edge, and excessively "overestimating" the flexural bearing capacity near the fulcrum.

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