

# Adaptability analysis of load limit standard for prestressed hollow slab bridge

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**Abstract.** In recent years, with the rapid development of social economy and highway transportation, the phenomenon of overweight transportation is increasingly serious, which is the main reason for the frequent occurrence of bridge collapse accidents in our country, causing heavy economic losses and casualties to the society. Due to the lack of unified bridge load limit management standards at the national level, it is difficult to fundamentally improve the adverse situation of bridge overload operation by relying on the existing over-limit management measures. Based on this background, we made the following work: (1) load carrying capacity check and calculation of prestressed hollow slab bridge: check whether the bridge used meets the requirements of the specification, so as to provide a reliable engineering basis for the analysis of load limit value in the following paper. According to the 04 specification, the load carrying capacity of the car is checked and calculated to verify whether the bridge meets the design requirements of the load carrying capacity. Then, the mid-span deflection of the bridge and the crack resistance of the main beam are checked to determine whether the bridge meets the design requirements in the normal limit state of use. (2) prestressed hollow slab bridge limit load values adaptability analysis first, calculates the design safety grade level on the limit load of prestressed cored slab jointless security levels of primary, secondary and tertiary limit load vehicle load effect, on this basis, from bearing capacity limit state and serviceability limit state analysis of the bridge limit load values of adaptation.

## 1 Introduction

With the development of society and economy, highway bridge transport vehicles in the trailer, the development of large-scale and containerization, large monomer type truck, semi-trailer train, car, vehicles, such as train using the vehicle type is increasing, has brought the serious harm to bridge, and overload limit load has become a pair of principal contradiction of our country's highway Bridges safety operation. As the load of the overweight vehicle is much higher than the design load of the bridge, it not only seriously affects the durability of the bridge structure, increases the maintenance cost of the bridge, but also poses a major safety hazard to the normal operation of the bridge, which is the main reason leading to the increasing trend of bridge damage events in China year by year.

## 2 Load calculation

### 2.1. Permanent action calculation

The gravity of sidewalks and railings shall be calculated by 12.0kN/m on one side according to the design data of ordinary Bridges. For the asphalt concrete with a thickness of 10cm, the gravity of the entire bridge's width pavement is  $0.1 \times 11.5 \times 24 = 27.6$  (kN/m). For the

convenience of calculation, it is considered that the weight of each hollow slab is approximately equal to that of each slab, and the weight of each hollow slab is  $g_2 = (12 \times 1 + 27.6) / 9 = 4.4$  kn/m. Thus, the total gravity  $g$  of the hollow plate per meter is:

$$g_1 = A \cdot \gamma = 11.4192 \text{ kN/m}$$

(The first stage is structural dead weight) (1)

$$g_2 = 4.4 \text{ kN/m}$$

(The second stage is structural dead weight) (2)

$$g = \sum g_i = g_1 + g_2 = 15.8192 \text{ kN/m} \quad (3)$$

The permanent effect (dead weight) of the hollow plate can be calculated. The calculation results are shown in Table 1

### 2.2 Variable effect calculation

This bridge load level using road- I load vehicles, vehicle - super load level 20 and standard five-axis limit load. According to the bridge regulations, the overall calculation of the bridge structure adopts the lane load. Level road - I lane load by the  $q_k = 10.5$  (kN/m) of uniformly distributed load and  $P_k = 180 + (360 - 180) \times (12.60 - 5) / (50 - 5) = 210.4$  (kN) concentrated load of two parts. In the calculation of shear effect, the concentrated load standard value  $P_k$  should be multiplied by the

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coefficient of 1.2. In the calculation of shear force, the uniformly distributed load of the lane load according to the "bridge regulation" should be fully distributed on the same line of influence that causes the most adverse effect on the structure, and the concentrated load standard value only ACTS on the peak value of the maximum impact line in the corresponding impact line. Multi lane bridge on multiple lanes should also be considered reduction, reduction factor factor = 0.78 three lanes, but shall not be less than two lanes load effect.

### 2.3 Combination of effects

According to "bridge regulations", the design of highway bridge and culvert structure should combine the effects according to the ultimate state of bearing capacity and the limit state of normal use, and be used for different

calculation projects. According to the basic combination expression of the ultimate state of bearing capacity design, as described in equation (4), when the section stress of structural members in elastic stage needs to be calculated, the effect combination of standard value should be adopted. In other words, the expression of the effect combination is:

$$S = S_{Gk} + S_{Q1k} + S_{Qjk} \quad (4)$$

Where: S-combined design value of standard value effect;  $S_{Gk}$ ,  $S_{Q1k}$ ,  $S_{Qjk}$  -standard values of permanent effect, automobile load effect (included in automobile impact force), crowd load effect. According to the calculated effects, the combined design values of different effects can be calculated according to various combined expressions in "bridge rules". The load effects of side plate and middle plate are summarized in Table 2-4.

**Table 1.** Dead load effects

Function type	Function $g_i$ (kN/m)	calculated span $l$ (m)	Effect $M$ (kN/m)		Effect $V$ (kN)	
			Middle span	$l/4$	fulcrum	$l/4$
$g_1$	11.4192	12.60	226.21	169.96	71.94	35.97
$g_2$	4.4	12.60	87.32	65.49	27.72	13.86
$g$	15.8192	12.60	313.93	235.45	99.66	49.83

**Table 2.** Effect combinations of carrying capacity limit state

Position of slabs	Function type	Bending moment $M(kN \cdot m)$		Shear $V(kN)$		
		Middle span	$l/4$	Middle span	$l/4$	fulcrum
Side slabs	$S_{ud}$	866.75	650.07	80.32	187.26	343.81
Middle slabs	$S_{ud}$	862.30	646.72	79.59	187.76	343.53

**Table 3.** Effect combinations of normal using limit state

Position of slabs	Function type	Bending moment $M(kN \cdot m)$		Shear $V(kN)$		
		Middle span	$l/4$	Middle span	$l/4$	fulcrum
Side slabs	$S_{sd}$	497.05	372.79	30.02	97.46	183.44
	$S_{ld}$	418.57	313.93	17.15	77.05	147.54
Middle slabs	$S_{sd}$	495.38	371.54	29.74	97.02	183.33
	$S_{ld}$	417.62	313.22	17.00	76.80	147.47

**Table 4.** Effect combinations of elastic stage section stress standard value

Position of slabs	Function type	Bending moment $M(kN \cdot m)$		Shear $V(kN)$		
		Middle span	$l/4$	Middle span	$l/4$	fulcrum
Side slabs	S	663.95	497.97	57.37	140.87	159.82
Middle slabs	S	660.77	495.58	56.85	141.23	259.62

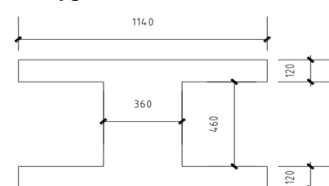
## 3 The ultimate state of bridge bearing capacity is checked

### 3.1 The flexural capacity of the mid-section of the main beam span is checked

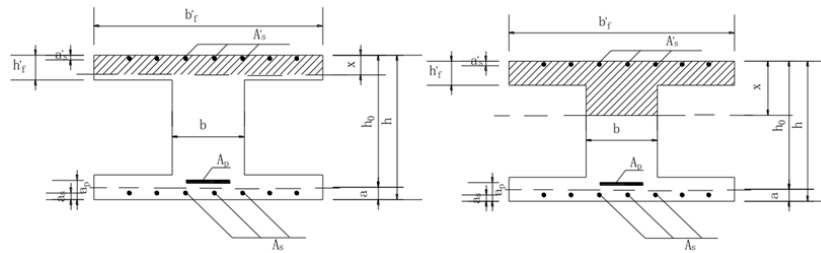
The section of the hollow plate is converted to the equivalent i-shaped section for consideration. The size of the equivalent i-shaped section is shown in Figure 1.

When the amount of prestressed reinforcement is appropriate, the calculation of flexural bearing capacity of normal section should first judge which kind of

section it belongs to for the i-section members with prestressed and non-prestressed reinforcement in the tension zone and only non-prestressed reinforcement in the compression zone. Figure 2 shows i-type and i-type cross sections of type I and II.



**Fig.1.** Hollow plate equivalent I-shaped cross-section(dimensions in mm)



**Fig. 2.** The position of prestressed concrete beam of I-shaped cross-section flexural members Neutralaxis

The height of compression zone  $x$  is calculated by formula (5) :

$$f_{sd}A_s + f_{pd}A_p = f_{cd} [b \bullet x + (b_f' - b) \bullet h_f'] + f_{sd}'A_s' \quad (5)$$

Where,  $A_s$  and  $f_{sd}$  are respectively the design values of sectional area and tensile strength of longitudinal non-prestressed reinforcement in the tensile zone;  $A_p$  and  $f_{pd}$  are the design values of sectional area and tensile strength of prestressed reinforcement in the tensile zone respectively;  $A_s'$  and  $f_{sd}'$  are respectively the design values of sectional area and tensile strength of longitudinal prestressed reinforcement in the tensile zone;  $f_{cd}$  are design value of axial compressive strength of concrete;  $b$ ,  $b_f'$  are web and flange width.

After the  $x$  value of the height of the section compression zone is obtained, the bending capacity of the normal section is checked according to equation (6) :

$$\gamma_0 M_d \leq M_u = f_{cd} b x \left( h_0 - \frac{x}{2} \right) + f_{sd}' A_s' (h_0 - a_s') \quad (6)$$

The calculation results are used to verify whether the shear bearing capacity of the inclined section of the side plate and the middle plate at different positions of the bridge under the action of the design vehicle meets the design requirements of the formula.

### 3.2 Shear capacity of inclined section of main beam is checked

For prestressed concrete members with rectangular sections of stirrup and bent prestressed reinforcement, the basic expression of shear bearing capacity of inclined section is:

$$\gamma_0 V_d \leq V_{cs} + V_{pd} \quad (7)$$

Where,  $V_d$  are the maximum combined design value of shear force generated by action (or load) on the normal section under compression of inclined section (kN);  $V_{cs}$  are the design value of shear bearing capacity (kN) for both concrete and stirrup in inclined section;  $V_{pd}$  are the design value of shear strength (kN) of prestressed bent steel bar intersecting inclined section.

#### 3.2.1 Design value of shear bearing capacity of concrete and stirrup in inclined section ( $V_{cs}$ )

The prestress of components can effectively prevent the occurrence and development of inclined section cracks, increase the height of concrete shear zone, and thus improve the shear resistance of concrete. Based on the

above factors, the calculation formula of shear bearing capacity ( $V_{cs}$ ) of concrete and stirrup in inclined section adopted in highway bridge regulations is as follows

$$V_{cs} = \alpha_1 \alpha_2 \alpha_3 0.45 \times 10^{-3} b h_0 \sqrt{(2 + 0.6 p)} \sqrt{f_{cu,k} \rho_{sv} f_{sv}} \quad (8)$$

In the formula:  $\alpha_1$  are influence coefficient of different bending moment, when calculating shear bearing capacity of simply supported beam,  $\alpha_1=1.0$ ;  $\alpha_2$  are improvement factor of prestress. For prestressed concrete bending members,  $\alpha_2=1.25$ ;  $\alpha_3$  are influence factor of compression flange. For section with compression flange, take  $\alpha_3=1.1$ ;  $b$  are width of rectangular section (mm) at the top section of the compression zone of oblique section;  $h_0$  are effective height on the normal section of the compression zone of inclined section, distance from the resultant point of longitudinal tensile reinforcement to the compression flange (mm);  $p$  are reinforcement ratio of longitudinal tension reinforcement in oblique section,  $p=100 p$ ,  $p = (A_s + A_p + A_{pb}) / b h_0$ , when  $p > 2.5$ ,  $p=2.5$ ;  $f_{cu,k}$  are standard compressive strength of concrete cube (MPa);  $\rho_{sv}$  are stirrup reinforcement ratio;  $f_{sv}$  are design value of stirrup tensile strength (MPa);

#### 3.2.2 Design value of shear bearing capacity of prestressed bent reinforcement ( $V_{pb}$ )

The shear capacity of the inclined section of prestressed bent reinforcement is calculated according to the following formula:

$$V_{pb} = 0.75 \times 10^{-3} f_{pd} \sum A_{pd} \sin \theta_p \quad (9)$$

Where,  $p$  - the Angle between the tangent line of the prestressed steel bar and the horizontal line;  $A_{pb}$  -- area of section (mm<sup>2</sup>) of prestressed bent reinforcement with the same curved plane in the inclined section;  $f_{pd}$  - design value of tensile strength of prestressed reinforcement. According to equation (7)-(9), it is calculated whether the shear capacity of the inclined section of the side plate and the middle plate at different positions of the bridge meets the design requirements under the action of the designed automobile load.

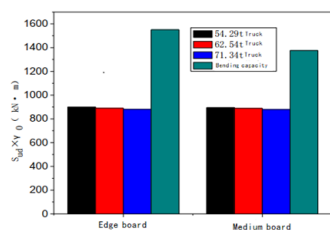
## 4 Analysis of ultimate state adaptability of prestressed hollow slab bridge

### 4.1 Analysis of ultimate bending state adaptability of prestressed hollow slab bridge

In order to analyze the limit load adaptability, values can be calculated through Table 2-4 restricted carrying

vehicles cross bending effect in combination with flexural bearing capacity, as shown in Figure 3, you can compare plate, medium plate in three typical limit load vehicles across under the action of bending moment combination effect and flexural bearing capacity, are analyzed from the aspects of bearing capacity limit state limit load values of adaptation.

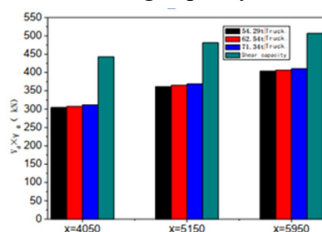
The results show that the bridge in the first, second and tertiary safety limit load levels, respectively, 54.29 t, 62.54 t and 71.34 t five-axis truck as typical limit load vehicle load mode, 54.29 t, 62.54 t and 71.34 t truck side plate across five axis of bending moment is flexural bearing capacity of 58%, 57% and 57% respectively, across the plate bending moment in the flexural bearing capacity is 65%, 65% and 64% respectively, were significantly less than the bending bearing capacity, satisfies the requirement of counsels bending.



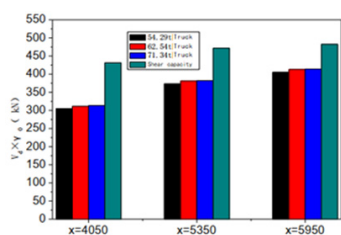
**Fig. 3.** Comparison Chart of blending moment combinations by typical truck of weight limits and capacity of resisting bending moment

#### 4.2 Analysis of ultimate shear state adaptability of prestressed hollow slab bridge

In order to analyze the adaptability of load limit value, Figure 4.4 and 4.5 respectively compare the combined effect of shear force on fulcrum and shear bearing capacity of side plate and middle plate under the action of three typical load limit vehicles, and analyze the adaptability of load limit value from the perspective of ultimate state of bearing capacity.



**Fig. 4.** Comparison Chart of shear force combinations by typical truck of weight limits and capacity of resisting shear force in side beam



**Fig.5.** Comparison Chart of shear force combinations by typical truck of weight limits and capacity of resisting shear force in middle beam

The shear effect combination of 54.29t, 62.54t and 71.34t five-axle truck side plate at  $x=5950m$ , 5350m and 4050m is respectively 86%, 81% and 72% of the flexural bearing capacity, which is obviously less than the shear bearing capacity of each section and meets the design requirements. To sum up, the prestressed hollow slab bridge reaches the safe level of design under three typical load limiting vehicle loads. Meet the requirement of shear gauge.

## 5 Conclusion

In view of the increasingly serious situation of overweight transportation in our country, the highway management department urgently needs to clarify the value of load limit of Bridges of different grades, which can be used as the basis for making load limit signs.

This paper analyzes the adaptability of the value of load limit from the limit state of bearing capacity and the limit state of normal use, and verifies the engineering applicability of the value of load limit for this kind of bridge. The research conclusions of this paper are mainly as follows:

(1) based on the theory of structural reliability, the simplified analysis model of bridge load limit is applied to determine the value of ideal resistance bridge load limit corresponding to the given allowable failure probability of the structure and the effect ratio of  $\rho$  of the standard value of live constant load, and then the typical load limit vehicles corresponding to Bridges with different safety levels of load limit are determined.

(2) the load effect of prestressed hollow slab bridge designed according to the design safety level I is calculated under the action of load limiting vehicles corresponding to the load limiting safety level I, ii and iii; On this basis, the flexural bearing capacity of the normal section and shear bearing capacity of the inclined section of the girder under the action of load limited vehicles are analyzed. Verify whether it can meet the safety design requirements of the project.

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