

# Study on economic design and construction program of steel-hybrid combined girder bridge

Weidong Zhao<sup>1, a \*</sup>, Bing Yang<sup>1, b</sup>, and Yuze Nian<sup>2, c \*</sup>

<sup>1</sup>Yunling construction Co, Ltd of YCIC group, Kunming, Yunnan Province 6500041, PR China;

<sup>2</sup> School of Civil Engineering and Architecture, Jiangsu University of Science and Technology, Zhenjiang, Jiangsu Province 212100, PR China.

<sup>a</sup>562598783@qq.com, <sup>b</sup>262096347@qq.com, <sup>c</sup>954088437@qq.com

**Abstract.** In order to make full use of steel tensile and concrete compressive properties, combined beam cross-section stress-strain distribution characteristics and cross-section characteristics and loading procedures are closely related. At present, the cross-section form of I-beam combined with concrete panel is widely used, and the strength of the upper flange of the steel beam of the supported combined beam and the strength of the concrete panel of the unsupported combined beam have not been fully utilized. Through the theoretical analysis of different loading methods of combined beam strain stress distribution, so as to optimize the cross-section form, the proposed supported combined beam using the lower inverted T-shaped cross-section combined with the form of concrete panels, in the given actual engineering cases can obtain a higher elastic ultimate bearing capacity and can save 9.5% of the amount of steel. The unsupported loading method of I-beam combination beams can use lower grade concrete for better economy. Making full use of the neutral axis position change to design the combined beam cross-section is operable, inverted T-shaped steel beams combined with concrete panel combined beams is a way to save steel and reduce the construction of welded joints, with significant economic benefits.

**Keywords:** Steel composite beams; Economic efficiency; Loading process; Cross-section optimization; Strength exertion rate

## 1. Introduction

The design of steel-hybrid combined girder bridge is to give full play to the material strength of steel and concrete, combined girder force process is closely related to the construction method and process, the same bearing capacity of different design and construction methods have significant differences in material, reflecting the different economy. There are two conventional design and construction methods for combined girder bridge, one of which is the steel-hybrid combined girder is shaped in the prefabrication yard as a whole and transported to the bridge position for installation, featuring that the combined girder is supported in the lower part of the upper part of the concrete pouring, and the combined girder can only be loaded after the removal of the lower part of the support, and the self-weight of the combined girder and the later bridge deck loading are all borne by the combined girder. The second is the first production or erection of steel beams, and then poured concrete on the steel beams to form a combination of beams, characterized by the pouring of concrete under the steel beams without support, the weight of the concrete and steel beams from the weight of the steel beams, the concrete to reach the design strength of the bridge deck load by the combination of beams together to bear. Before and after the formation of steel beams before and after the formation of combined beams cross-section modulus changes dramatically, the concrete solidification process of combined beams stiffness dramatically increased cross-section neutral axis upward, the two design and construction methods of combined beams cross-section stress secondary distribution of a significant difference, which leads to the strength of the material to play with the design and construction methods are closely related. Whether the material strength is given full play to is an important reflection of the economy of the design and construction program.

## 2. Design and Construction of Combined Bridges

Combined beam bridge is characterized by the lower part of the use of closed steel box girder or I-beam, the upper flange using shear nails and concrete to form a combination of girder, such beam bridges across the high-speed road and other low headroom under the bridge is usually used to set up a temporary support subsection lifting construction, after the subsequent pouring of concrete to remove the support, and then the construction of the bridge. The support is removed after subsequent pouring of concrete, and this construction method is defined as a supported combined girder. There is also the inability to set up the support and the use of jacking and other techniques to set up the steel girder, the lower part of the concrete pouring without support, this kind of definition for the unsupported combination of girders. The large-scale construction of combined beams is mostly in the form of lower I-beams and upper concrete panels.

At present, our country specification[1,2] and related research[3,4] give the combination of beam cross-section form is still relatively single, can be summarized as the I-beam cross-section and box cross-section two kinds. Steel-concrete combination bridge design code[5], highway steel-concrete combination bridge design and construction specification [6] adopted the cross-section form are I-shaped cross-section steel girder combined with a concrete plate. In order to facilitate the analysis of simply supported combined girder bridge cross-section Fig. 1b as the object of analysis, China's specification[5,6] in the combined girder bridge load carrying capacity limit state is according to the elastic method for the design and acceptance. In line with the flat cross-section assumption, the formation process of the combined girder directly determines the stress distribution in the beam cross-section. The first type of supported combined girder bridge, the formation of which is in the lower part of the supported conditions of pouring concrete, after reaching the design strength to dismantle the lower part of the support or directly lifting the bridge position combined girder overall stress, the neutral axis and strain state is shown in Fig 1, the tensile strain is negative compressive strain is positive. In the self-weight load Fig. 1a to the design load (self-weight and lane load together) Fig. 1b in the section neutral axis did not change.

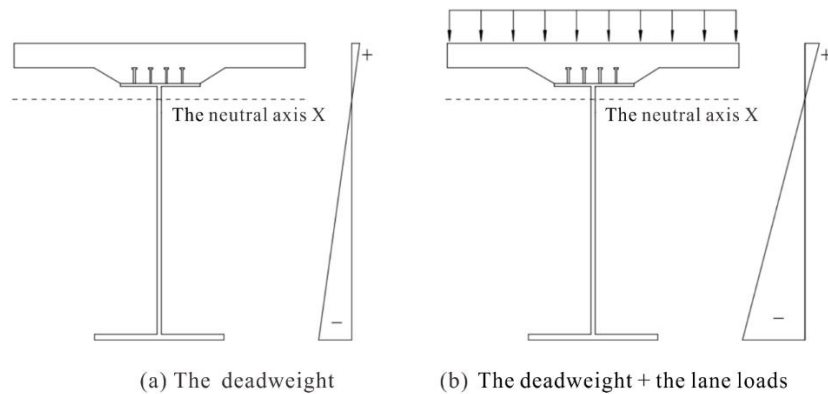


Fig. 1. Neutral axis and strain distribution of supported composite beam sections

Obviously I-beam in the span under the action of bending moment on the flange strain is very small, according to the specification [6] combination of beam neutral axis should be in the cross-section of the steel beam, combination of beams thicker concrete neutral axis may be located in the upper flange, then the steel beam on the edge of the flange stress is zero, and its bending capacity did not play a role in the role of shear nails just play a role in supporting the link between shear nails and the concrete.

Unsupported combined beam design, the first stage of steel beam erection after pouring concrete are steel beam force, concrete design strength to form a combination of beams together to bear the late load. Its neutral axis changes and strain distribution see Fig. 2. self-weight only by the steel beam to bear the load then the neutral axis in the center of the cross-section form, at this time the span section of the upper and lower flanges have a larger strain, the concrete reaches the design strength

of the cross-section form the center of the axis shifted upward, at this time to increase the lane load strain according to the combination of beam cross-section distribution, superimposed on Fig. 2b.

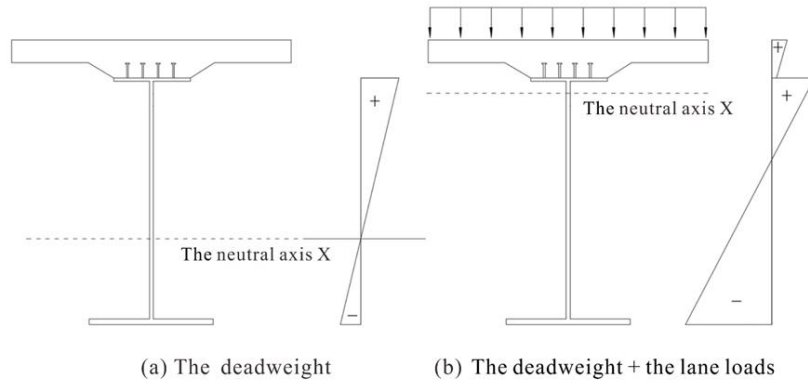


Fig. 2. Neutral axis and strain distribution in unsupported composite beam sections

Combined beam bridge construction, especially the loading sequence should be clearly specified in the design, in recent years, Yunnan has been built highway design cross-section of the vast majority of the above work-shaped cross-section form, spanning bridges or large-span bridges are closed steel box girder covered with concrete to form a combination of beams. However, the construction method is unsupported and supported in two forms. Hua Cheng et al[7] studied the relationship between the economic beam height, span diameter, transverse spacing and steel consumption of the combined beam, the economy of a single combined beam cross-section form did not form a consensus among the parties involved in the construction of the bridge, and the research in this area is also relatively small. The stress distribution of the combined girder bridge corresponds directly to the above strains, and giving full play to the strength of the material should be the initial intention of the economic design of the combined girder.

### 3. Combined beam bridge cross-section optimization

To fully utilize the material strength characteristics of the combined girder, different optimization methods are proposed for the two design and construction schemes. For the unsupported combined beam, steel beams that bear all the loads of the first stage (self-weight), at this time the section of the neutral axis of elasticity is close to the lower flange, then the lower flange of the tensile stress is small, the upper flange of the larger compressive stress, the design of the cross-section form should be close to the upper flange of the stresses in the design of the strength of the steel material. The second stage of the concrete to reach the design strength of the neutral axis upward, the neutral axis of the section should be designed close to the upper flange, the upper flange in the second stage of the load (self-weight + lane load) only a small increase in stress, the lower flange is due to a larger force arm in the tensile stress can be increased to obtain a larger bearing capacity. Therefore, the design principle is that the stress on the upper flange is close to the material strength in the first stage, and the neutral axis is close to the lower flange. The second stage is to fully consider the equivalent cross-sectional area of the concrete and make the neutral axis upward near the upper flange. The more ideal stress process is shown in Fig. 3 a and b, the specific operation should be fully combined with the neutral axis position change to determine the reasonable cross-section form.

For the supported combination of beams due to the neutral axis near the upper flange, the upper flange steel force arm is too small to play the role of bending, see Fig. 3c, this design is supported combination beam, generally can be made in the prefabrication yard tire frame, the same height of the section cancel the upper flange, the guard plate to the upward extension of the length of the upper flange is generally less than 50% of the amount of steel, and in the process of reducing the upper flange and the web weld connection, increase the thickness of the concrete joist can be

increased shear nails welding range. The top protective layer of the web should be reserved for the installation of the upper deck plate reinforcement position, into the bridge after the bridge deck plate in the transverse direction for the continuous beam or cantilever beam, in the web and concrete connection surface, the panel of the negative moment so that the concrete has a tendency to clamp the web, then the steel plate and the concrete can transfer a larger shear force, shear nails and the concrete connection is in a bidirectional state of compression, the form of force is better than the upper flange and the concrete panel connection.

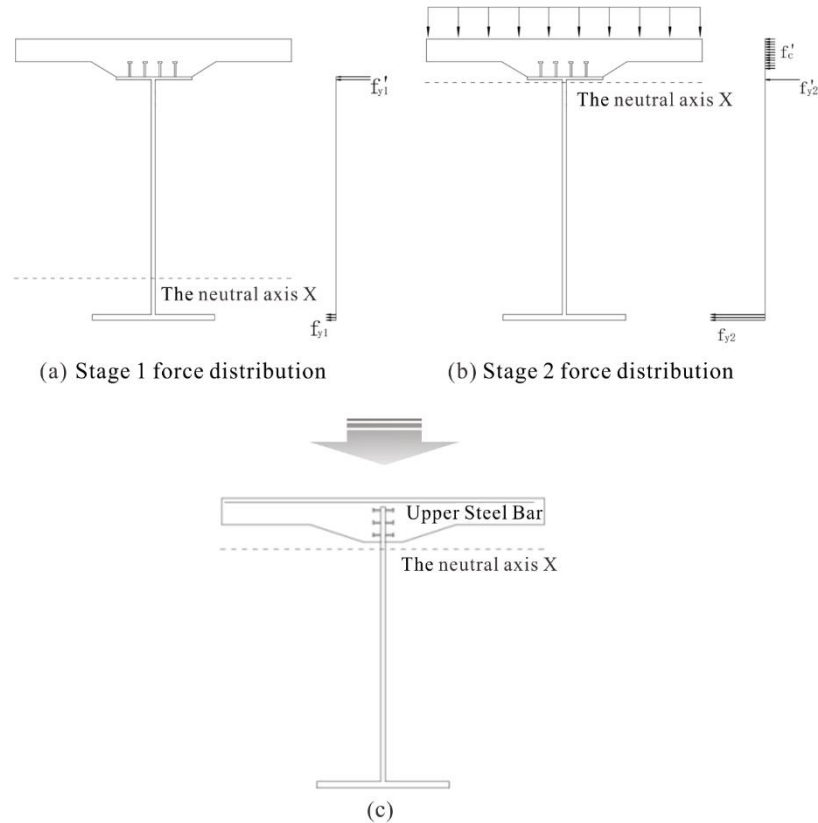


Fig. 3. Stress distribution of a two-stage stressed combined beam and Optimized cross-section of a supported combined beam.

#### 4. Engineering case analysis

Project description for wuding to ifadian to xundian expressway referred to as wu if seek high speed, the total project mileage of about 107km. two-way six-lane, design speed 100km/h, roadbed width 33.5m. wu if seek two standard (total mileage of about 55.456km) within the scope of a total of seven steel-hybrid combination of girder bridges 2021 completed and open to traffic, the combination of girder bridges with a total investment of 810 million yuan, the combination of the girder part of the cost of 430 million yuan, mainly in 30m span and 40m span mainly, including tiansheng bridge special bridge for 40m span total length of more than 2km. The total investment is 810 million yuan, and the cost of combined girder part accounts for 430 million yuan, and the amount of steel used is more than 30,000 tons, mainly 30m span and 40m span, of which Tianshengqiao Bridge is 40m span with a total length of more than 2km. In addition, there are this kind of I-beam combined girder in the under-construction of the Huichiao Expressway and Xuanhui Expressway of Yunnan Province. To 40m span as an example to calculate and analyze the stress distribution, cross-section and structure see Fig. 4, in order to ensure the stability of two pieces of combined beams prefabricated together, a single span of six pieces of combined beams in three lifting, combined beams in the span of the cross-section of the I-beam on the edge of the 500 \* 20, the web 1752 \* 16, under the edge of the 750 \* 36, the steel for the Q390, concrete panels for the C50. All girders are simply supported girders, and the design and construction program is a

supported combined girder, corresponding to the loading method of assembling steel girders in the prefabrication yard, installing the formwork and tying the reinforcement and pouring the concrete after full support, and arranging four rows of the upper flange horizontally through the shear nails connected with the concrete. This construction program in the prefabrication stage of the steel beam is not stressed, the concrete reaches the design strength after

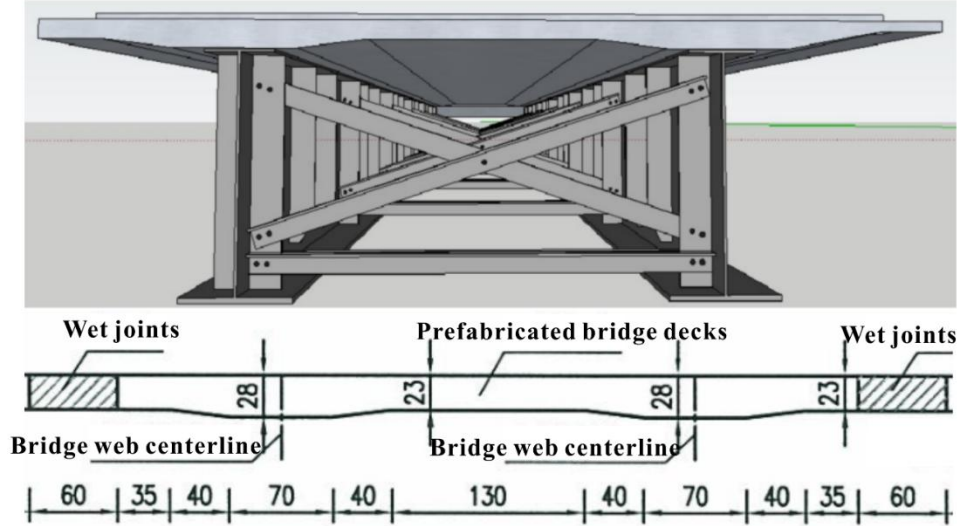


Fig. 4. Schematic diagram of the combined girder bridge model and dimensions of the concrete panels in the span.

transportation and installation to the bridge. The stress form is in line with the characteristics of supported combined girder bridges. According to the relevant technical specifications for combined girder bridges[5,6], the effective section width of the cross-section can be used for the full area of the concrete, according to the modulus of elasticity ratio[6,8] will be equivalent to C50 concrete panels for the steel, the parameters of the cross-section are shown in Table 1.

Table 1 Calculation of cross-section parameters of modular beams and I-beams

Section type	Equivalent area (A/mm <sup>2</sup> )	Horizontal Moment of Inertia (I/mm <sup>4</sup> )	Height of shaped mandrel (from lower edge) (y/mm)	Total height of cross-section (h/mm)
Combined beams	182117	$8.44 \times 10^{10}$	1503	2088
I-beam	65032	$3.30 \times 10^{10}$	677	1808

Original design using supported combination beam loading mode, in order to analyze the comprehensive, analyze the supported and unsupported combination beam of the two kind of load mode combination beam stress distribution. Combined beam weight including super asphalt layer 37.5KN/m, calculated span 39.2m, under the action of the weight of the span bending moment 7203KNm. According to the general design specification for highway bridges and culverts[9] the overall calculation of highway class I lane load  $q = 10.5\text{KN/m}$ ,  $p = 340\text{KN}$  calculations, due to a single piece of combination of beams loaded width of only 2.8m is less than 3.75m, take a lane not to consider the transversal The loading coefficient is still on the safe side. The bending moment under lane load is 5348.84KNm, and the maximum bending moment in the span under design load is 12551.84KNm, which is the sum of the above, and the stresses in each part of the combined beam within the elasticity range are calculated according to the formula of material mechanics (1):

$$\sigma_i = \frac{M}{I} y \quad (1)$$

Where: M is the corresponding stress stage of the mid-span bending moment, I is a combination of beams or pure steel beams strong axial polar moment of inertia, y is the calculated position to the neutral axis distance, of which the concrete panel is taken for the upper panel of the shape of the center of the position of the elastic modulus ratio of the conversion, steel beams to take the upper and lower flanges of the outermost edge.

Table 2 Calculation of stresses in various parts of combined beams and I-beams

Option	Location	Deadweight stress /MPa	Design load stresses (effects) /MPa	Carrying capacity (resisting force) /MPa	Effect/resistance	Overloadable mid-span moment /KN m,	Overloading ratio/%	Control section
Supported combination beams	Concrete panels	6.72	11.71	22.4	52.27%	5979	47.6%	Lower flange
	Steel beam upper flange	26	45.36	330	13.7%			
	Steel beam lower flange	128.3	223.52	330	67.7%			
Unsupported combination beams	Concrete panels	0	4.99	22.4	22.3%	4888	38.9%	Lower flange
	Steel beam upper flange	246.76	266.1	330	80.63%			
	Steel beam lower flange	147.71	242.96	330	73.62%			

The ultimate capacity in the case study is controlled by the lower flange, and the unsupported ultimate capacity in the elastic phase is slightly lower than the supported ultimate capacity, which is not more than 10% in the case study, but the concrete panels in the unsupported loading mode can be cast with a lower concrete strength to save cost.

Cancel the upper flange of steel beams using inverted T-shaped steel beams and upper concrete panels to form a combination of beams in Figure 5. At this time, the upper edge of the web plate is 4cm from the top surface of the concrete panel, you can install the negative moment reinforcement of the plate, the section parameters are shown in Table 3.

Table 3 Calculation of cross-section parameters of combined beams and inverted T-shaped steel beams

Section type	Equivalent area (A/mm <sup>2</sup> )	Horizontal Moment of Inertia (I/mm <sup>4</sup> )	Height of shaped mandrel (from lower edge) (y/mm)	Total height of cross-section (h/mm)
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Combined beams	176853	$8.45 \times 10^{10}$	1498	2088
Inverted T-beams	53640	$2.80 \times 10^{10}$	589	2048

The amount of steel used in the cross-section of the inverted T-shaped combined beam is reduced from the original design by  $500 \times 20 - 240 \times 16 = 6160 \text{ mm}^2$ , and the weight is reduced by 48.4kg/m. Neglecting the influence of load changes, the stresses in each part of the combined beam are still calculated according to the two loading modes, as shown in Table 4.

Table 4 Combined beams, inverted T-shaped steel beams stress calculation table of each part

Option	Location	Deadweight stress /MPa	Design load stresses (effects) /MPa	Carrying capacity (resisting force) /MPa	Effect/resistance	Overloadable mid-span moment /KNm,	Overloading ratio/%	Control section
Supported combination beams	Concrete panels	6.79	11.82	22.4	52.78%	6048	48.2%	Lower flange
	Steel beam upper flange	46.9	81.73	330	24.77%			
	Steel beam lower flange	127.77	222.65	330	67.47%			
Unsupported combination beams	Concrete panels	0	5.04	22.4	18.3%	Exceeds elasticity range	0	Unfeasible
	Steel beam upper flange	375.4	410.23	330	>1			
	Steel beam lower flange	151.65	246.53	330	76.89%			

After optimization of the combination of beam cross-section shaped axis height is slightly shifted downward, under the same loading conditions of the concrete panel stress slightly increased and the lower flange stress slightly reduced, the ultimate bearing capacity is controlled by the lower flange, so the cancellation of the upper flange of the steel beam to reduce the amount of steel after the distribution of the stress tends to be more reasonable, the combination of the beam load carrying capacity instead of improving which is in line with the theoretical analysis.

## 5. Analysis of economic benefits and practical applications

The ultimate load capacity difference between the two types of bridges in the elastic phase is not more than 10% in the given case. At the same time unsupported combination of beams concrete panel stress is only 22.3%, the case can be reduced from C50 concrete panels to a minimum of C25

can also meet the strength index. Therefore, from the theory and case study show that the use of I-beam steel-hybrid combination beams can be canceled when the upper flange using inverted T-shaped steel beams combined with concrete panels in the form of cross-section when supported loading. The optimization result in the case study is to use less steel to obtain greater load carrying capacity. According to the cross-section steel consumption reduction amount is 48.4kg/m, saving steel consumption 9.5%. The single piece of 40m combined beam saves 1936KG, and a span of 40m beam with 3 lanes adopts 6 pieces of I-beams, which can save 11.6t of steel, and the 180 spans can save 2091t of steel if this scheme is adopted in WuXiXuan project. in addition, this optimized scheme reduces the K-shape butt joints between the web and the upper flange, which saves the construction cost and ensures the quality more easily at the same time. From the force on the conventional I-beam through the web to the upper flange and then through the shear nails to the concrete, while the inverted T-beam can be directly through the shear nails to the concrete. The supported loading method using inverted T-shaped steel beams combined with concrete panel combination beams has more superior economic and mechanical properties, in the program comparison stage should be this form of combination beams into the alternative.

## 6. Summary

Commonly used steel-hybrid combined beam bridge cross-section form is too single, I-beam combined with concrete panel combined beam cross-section with supported loading steel beam on the flange strength has not been played, can be used in inverted T-shaped steel beams combined with the cross-section of the concrete panel form, in this paper, case study can save 9.5% of the amount of steel and can be obtained a greater ultimate bearing capacity. I-beam combined with concrete panel combination beam unsupported loading mode can be used thinner concrete panel thickness, or low-grade concrete to obtain better affordability.

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