

# A comparative study of the long-span steel-concrete composite bridge with prestressed concrete bridge based on Midas

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**Abstract.** The bridges mainly include concrete, steel, and steel-concrete composite forms. Due to the lack of steel in China in the 1950s, steel bridges were rarely used in highway bridge construction, which also limited the development and application of steel-concrete combinations in China. In the past few decades, the steel-concrete combination mechanism gradually in China's bridges continues to develop, because of its overall force economy, steel and concrete material characteristics of both play advantages of rationality, ease of construction, and other advantages to be promoted [1]. Two bridge types, a prestressed concrete bridge, and a steel-concrete composite bridge, both with a span of 290 m and a single deck width of 14.75 m, were designed with the background of the original data from a certain location. Afterward, finite element models of the two bridge types were established with Midas, followed by comparative analyses of the flexural, shear, and crack resistance, construction cycle, and investment cost of the two bridge types. The results showed that the steel-concrete composite bridge exhibited better performance in most aspects.

**Keywords:** Prestressed concrete bridge; Long-span steel-concrete composite bridge; Mechanical performance.

## 1. Introduction

### 1.1 General situation

This paper refers to a local bridge type as the engineering background, this bridge crosses a river channel and the provincial road S100 successively. The bridge site is situated in a straight river, with a width of about 300m. The riverbank is relatively narrow and the boundary of the shoal is obvious. The mainstream direction of the river bed intersects the route vertically, and the riverbank on both banks is a complete Bridge span layout not controlled by the flood.

The bridge site is located in the intermontane depression area, and the change in topography is relatively small. According to the lithology revealed by drilling, the basement of the bridge site is composed of sandstone and its weathering layer. The overburden layer at the bridge site is complex. The bottom layer of the bridge site is composed of fine silt, coarse sand, and clayey soil.

Both sides of the bridge are natural slopes, in the west direction across the provincial road S100, there is a village nearby, the bridge line outside the landscape requirements are higher, the scheme comparison should be given special consideration. The topographic cross-section of the bridge is shown in Figure 1.

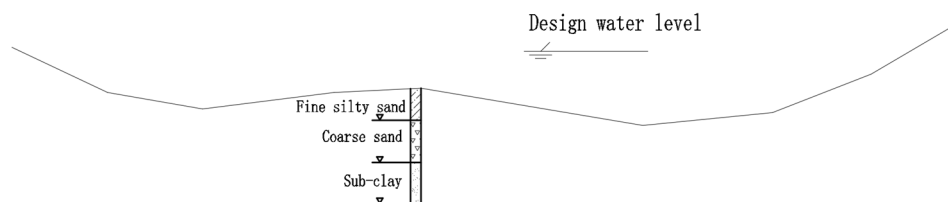


Fig. 1 Topographic map

### 1.2 Technical Standard

- (1) Road class: Expressway;
- (2) Design speed: 80km/h;

- (3) Number of lanes: two-way 6 lanes;
- (4) Design load: Highway-grade I;
- (5) Design flood frequency: 1/200;
- (6) Navigation standards: Grade V of inland waterways;
- (7) Design water level: 684m;

## 2. Scheme design

### 2.1 Prestressed concrete beam bridge (77.5m + 135m + 77.5m)

#### 2.1.1 290m span prestressed concrete bridge design introduction

The main beam section adopts an integral box bridge. The material of the main beam is C50 concrete, and the steel bars used in this project are mainly HRB400 and HPB300. In the analysis of the selection of  $(1 \times 7) \phi 15.2$  mm prestressed strand, the characteristic value of tensile strength value is 1860MPa. The anchor used for tensioning prestressing force shall be a clip anchor and shall also be equipped with a corresponding backing plate and spiral reinforcement.

Roof thickness is not less than 20 cm, choosing 25 cm. The top plate width is 14.5 m and the bottom plate width is 8.75 m. The web width of the bearing support section is 0.6 m, and the web width of the midspan section is 0.4 m. The bottom plate thickness in the support section is 0.7 m, and the thickness of the bottom plate in the mid-span section is 0.2 m. The cantilevered end is 0.15 m thick and 3.5 m long. The longitudinal slope of the bridge deck is 1.5%, and the longitudinal slope of the pedestrian lane is 2%. The support section and cross-section are shown in Figure 2[2,3].

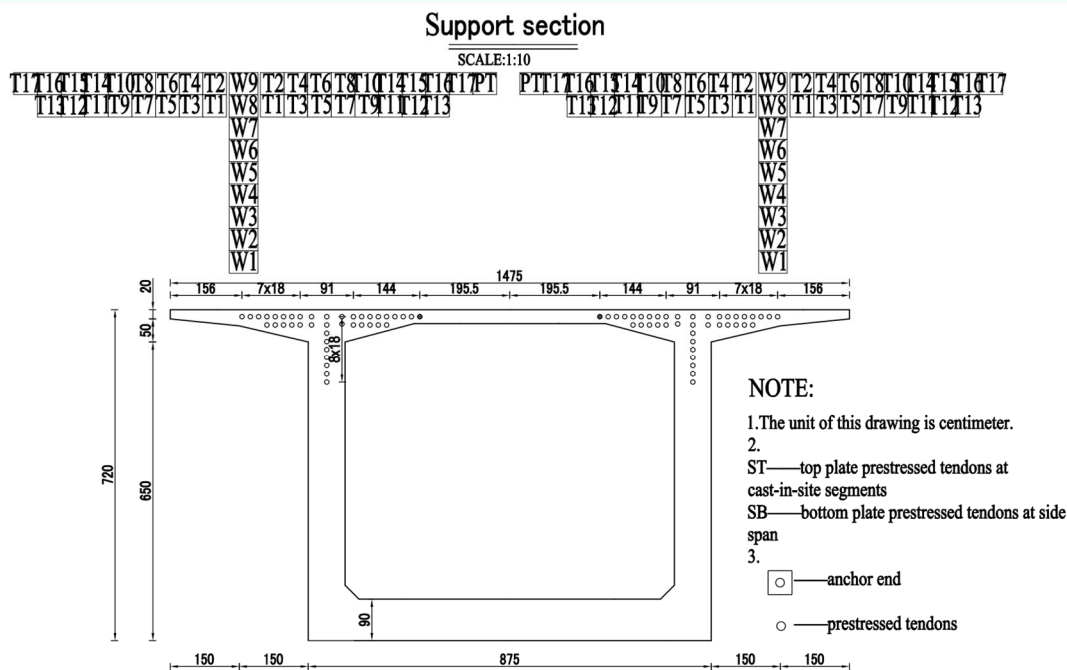
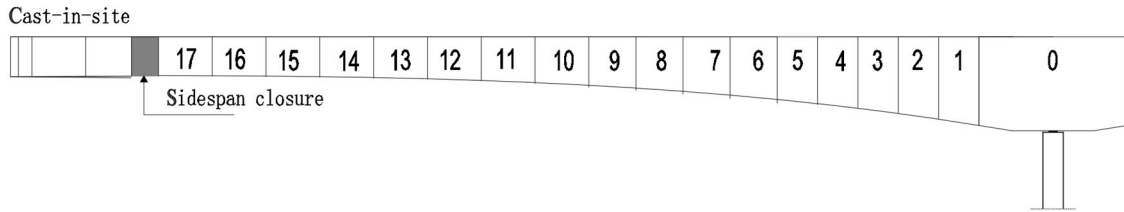


Fig. 2 Cross section of 290m span prestressed concrete bridge (unit: cm)

#### 2.1.2 Bridge construction plan and finite element modeling

The bridge was analyzed for internal forces using Midas software. The length of the main bridge was designed to be 290 meters, divided into 172 units and 193 nodes. The length of the main bridge unit is one meter at the bridge end supports and pier end supports, and two meters at the other units. Each unit is a construction unit and the subdivision of the units makes it easier to carry out section tests.

Figure 3 shows the 17 blocks of the prestressed concrete bridge during the construction phase, and the side span cast-in-place section and side span closure section, divided by CAD.



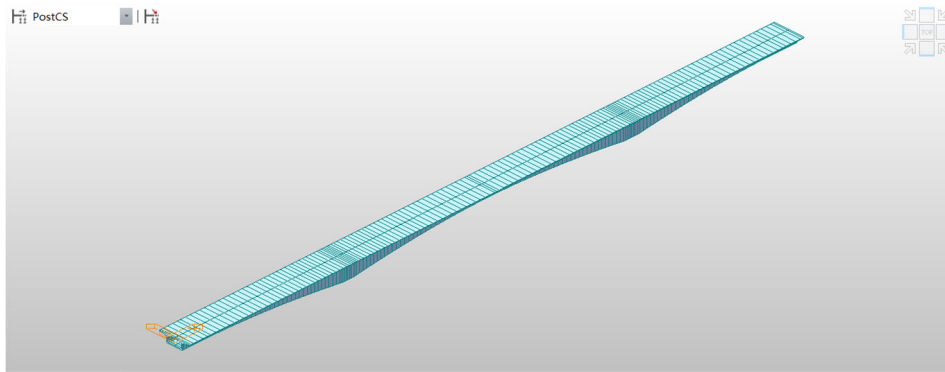
**Fig.1** Blocks of the model (unit: cm)

The following table1 shows the size of each block:

**Table 1.** Detailed dimensions of the prestressed concrete bridge

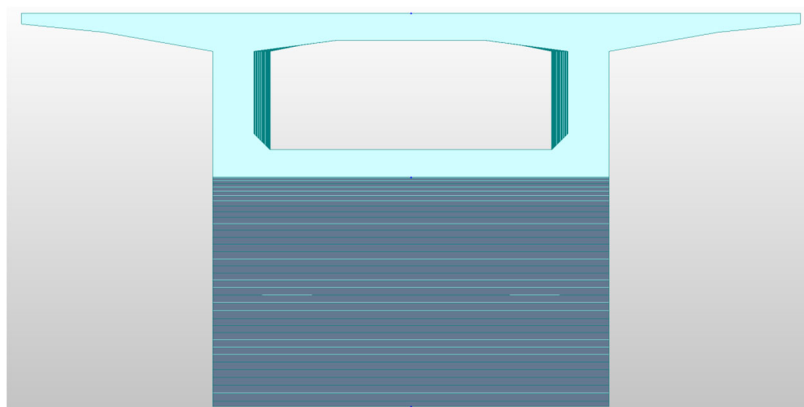
Element	0	1-5	6-9	10-17	Cast-in-site	Closure
Length(m)	11	3	3.5	4	2	9

The cross-sectional data was then input into Midas to obtain the finite element model of the prestressed concrete bridge shown in Figure 4.



**Fig.2** Finite element model of the prestressed concrete bridge

In Midas software, the cross-section of a prestressed concrete bridge takes numerical input, while using a variable section group to make the model consistent with the cross-section in CAD, where the cross-section changes to 1.8 times parabolic, and the Midas cross-section view is shown in Figure 5.



**Fig.3** Cross-section of finite element model of prestressed concrete bridge

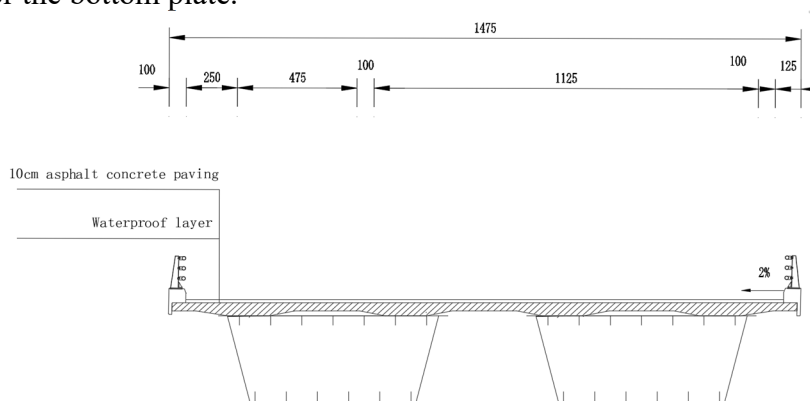
## 2.2 Steel-concrete composite bridge (77.5m + 135m + 77.5m)

### 2.2.1 290m span steel-concrete composite bridge design introduction

In the design of this 290m spans steel-concrete composite box bridge, the single span bridge adopts 2 steel box bridge structures with a combination bridge height of 3m and a height-to-span ratio of 1/20-1/25[4]. The steel main bridge adopts the form of an inclined web, with the outer edge spacing of 4m and the center spacing of 8.0m. The longitudinal and transverse site connections between the

main bridge sections are designed with high-strength bolts. The deck slab is 14.5m wide and 0.3m thick, while the precast concrete slab is 2.3m wide and 0.1m thick. Reinforced rib type is plate rib, height is 0.3m, thickness is 0.03m[5]. One thing worth noting is that since the steel box beam and plate ribs are filled with lines when imported later in Midas, their thickness is not shown in CAD, while the concrete slab is filled using faces and the thickness is shown in CAD. The design cross-section of the steel-concrete composite box bridge is shown in Figure 6.

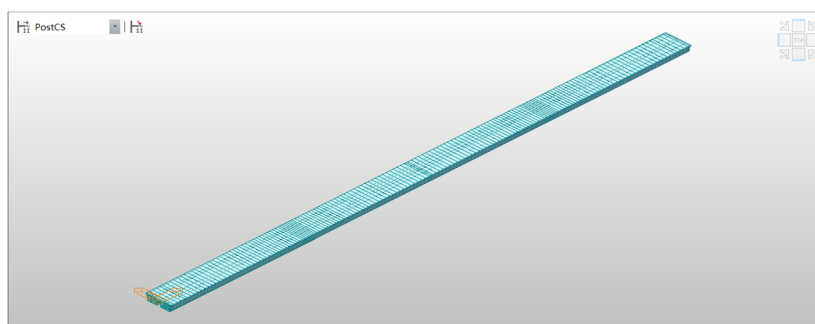
To prevent cracking in the negative moment zone, the web, top plate, and bottom plate were thickened to 200mm near the bearing, from 30mm to 50mm for the top plate and web, and from 40mm to 55mm for the bottom plate.



**Fig.4** Cross section of the 290m span steel-concrete composite bridge

### 2.2.2 Bridge construction plan and finite element modeling

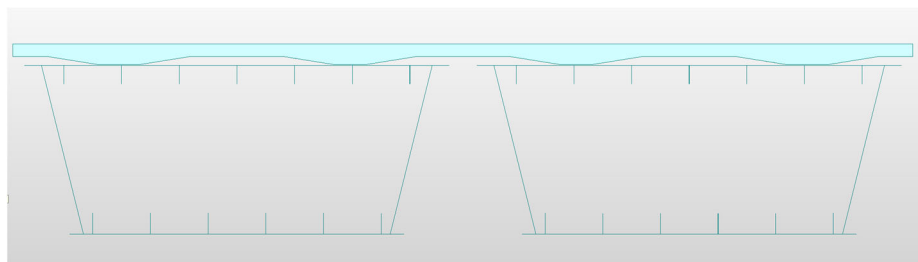
This model adopts the way of bracket segmental lifting, and the bridge deck slab adopts the construction of prefabricated installation first and then the whole cast-in-place, meanwhile, to reduce the welding workload on site, the site connection between each section of main bridges and cross bridges are connected by high strength bolts. MIDAS/Civil2020 was used to carry out finite element simulation after the design of the bridge, the single span bridge calculation model consists of 172 units, and the calculation model of the material parameters are: the material of the bridge deck slab is C50 concrete, elastic modulus  $E_c=3.45 \times 10^4 \text{N/mm}^2$ . The material of the steel box girder is Q345 steel and the modulus of elasticity  $E_s=2.06 \times 10^5 \text{N/mm}^2$ [3], and the finite element model is shown in figure 7.



**Fig.7** Finite element model of steel-concrete composite bridge

In the cross-section design, the cross-section was firstly drawn in CAD, and then the cross-sectional feature values were calculated by importing the dxf file using the cross-sectional feature calculator in Midas software, and the cross-section was obtained as shown in figure 8.

To understand the force performance and deformation of the steel-concrete bridge, the theoretically calculated internal force and deformation values under each loading condition were compared with the design limits, and it can be seen that the theoretically calculated values are less than the design limits. The results show that the bridge span structure has a certain reserve of strength and stiffness. The design strength of Q345 steel with a thickness of 16-40mm is 270MPa[4]. Deflection limit is  $l/500 = 290/500 = 0.58\text{m} = 580\text{mm}$ [4].



**Fig. 8** Cross-section of finite element model of steel-concrete composite bridge

**Table 2.** Force results of steel-concrete composite bridge

Load condition	Mechanical index	Calculation results	Design limits
Basic combination	Maximum tensile stress (MPa)	201	270
Basic combination	Maximum compressive stress (MPa)	155	270
Standard combination	Maximum tensile stress (MPa)	183	270
Standard combination	Maximum compressive stress (MPa)	121	270
Live load	Vertical deformation (mm)	46.6	580

### 3. Comparison of structural analysis

To understand the performance differences between prestressed concrete bridges and steel-concrete composite bridge bridges, the results of various calculations of flexural, shear, cracking, construction period, and investment cost of the two bridge types are compared in the context of this project.

#### 3.1 Durable condition flexural test

As the crack resistance of the two bridges is judged by different standards, the prestressed concrete bridge takes the tensile strength of C50 concrete as the limit, and the steel-cement combination bridge takes the yield strength of Q345 as the limit, to compare, the safety factor is used as the comparison index, for prestressed concrete bridges, the safety factor = maximum section stress/concrete tensile strength, and for steel and concrete bridges, the safety factor = maximum section stress/steel tensile strength. The tensile strength of Q345 steel is 245MPa, tensile strength of C50 concrete  $f_{td}=1.89\text{MPa}$  [3].

**Table 3.** Comparison of flexural properties

Bridge type	$f_{max}(\text{MPa})$	$f_d(\text{MPa})/f_{td}(\text{MPa})$	safety factor
Prestressed concrete beam bridge	1.55	1.89	1.18
Steel mixed combination bridge	201	245	1.22

#### 3.2 Durable condition shear test

In terms of shear resistance, both bridge types rely mainly on the web to resist the shear force, so a safety factor is used to judge, where the safety factor = maximum shear force / allowable shear force.  $V_n$  is the vertical shear capacity of the steel-concrete composite bridge and prestressed concrete bridge. The values of  $V_n$  and  $\gamma_0 V_d$  are derived from the Midas internal force results table.

**Table 4.** Comparison of shear resistance

Bridge type	$\gamma_0 V_d$	$V_n$ (KN)	Safety factor
Prestressed concrete beam bridge	35457	54205	1.53
Steel mixed combination bridge	28223	104996	3.72

**Prestressed concrete bridge:**  $\gamma_0 V_d \leq V_{cs} + V_{sb} + V_{pb} + V_{p.ex} = V_n$  [3]

$V_d$  - design value of shear force (kN);

$V_{cs}$  - design value of shear bearing capacity of concrete and hoop common in oblique section (kN);

$V_{sb}$  - design value of shear bearing capacity of common bending up reinforcement intersecting with oblique section (kN);

$V_{pb}$  - design value of shear bearing capacity of in-body prestressed bending up reinforcement intersecting with oblique section (kN);

$V_{pb,ex}$  - design value of shear bearing capacity of in-body prestressed bending up reinforcement intersecting with oblique section (kN).

**Steel-concrete composite bridge:**  $\gamma_0 V_{vd} \leq V_{vu}; V_{vu} = f_{vd} A_w = V_n$  [5]

$V_{vd}$  - design value of the firm directional shear force of the combined beam

$V_{vu}$  - firm shear load capacity of the combined beam

$A_w$  - cross-sectional area of the steel beam web

$f_{vd}$  - design value of shear strength of steel beam web

### 3.3 Normal section cracking test

Because the single-span span of the bridge exceeds 100m, the design standard adopts the standard of fully prestressed concrete. Since both bridge types crack because of concrete cracking, the ultimate strength value is C50 concrete tensile strength. The safety factor is used as the comparison index:

**Table 4.** Comparison of anti-cracking performance

Bridge type	$\sigma_{max}$ (MPa)	$\sigma_{alw}$ (MPa)	Safety factor
Prestressed concrete bridge	1.448	1.89	1.26
Steel-concrete composite bridge	1.09	1.89	1.68

$\sigma_{max}$  (MPa) : Maximum stress in cross – section

$\sigma_{alw}$  (MPa) : Equal to tensile strength of C50 concrete  $f_{td} = 1.89$ MPa [3]

### 3.4 Construction period

The construction period is also crucial for judging the bridge type. Table 6 shows the construction time for each step and the total construction period of the prestressed concrete beam bridge, and Table 7 shows the construction time for each step and the total construction period of the steel-concrete composite bridge. The construction time of each step of the bridge refers to the average time of the actual construction cases.

**Table 5.** The construction period of the prestressed concrete bridge [3]

Construction steps	Duration(day)
Cantilever 0-17	224
Removal of hanging baskets	5
Application of counterweights	10
Side span closing	10
Dismantling the side span hanger and unloading the side span counterweight, system conversion	10
Middle span closing	10
Dismantling the hanger of the center span closing section and unloading the counterweight of the center span closing section	5
Total construction period	264

**Table 6.** The construction period of the steel-concrete composite bridge [5]

Construction steps	Duration(day)
Erection of steel box	21
Splicing steel box	7
Pouring the bridge deck slab	14
Forming stiffness of bridge deck slab	14
Total construction period	56

### 3.5 Investment cost results and analysis

To compare the economic benefits of the two bridge types, the investment costs of the two bridge types need to be roughly estimated. For this purpose, the current market prices are estimated concerning the current market prices, where the price of a 15.2mm steel strand is 4800 yuan/t, Q345 steel is 5300 yuan/t and C50 concrete is 180 yuan/m<sup>3</sup>. The estimated investment cost of the prestressed concrete bridge is shown in Table 8, and the investment cost of the steel-cement combination bridge is shown in Table 9. In the estimation, the production and installation costs include labor and machinery usage for scaffolding hanging baskets, arranging reinforcement, pouring concrete, and other items.

**Table 7.** Investment cost of prestressed concrete bridge

Prestressed concrete beam bridge	Design quantity	Note
C50 concrete /m <sup>3</sup>	12960	Prefab and cast-in-place
Steel strand/t	1319	Pre-stressed steel bars
Steel/t	1490	Reinforcement
Production and installation costs/(ten thousand yuan)	1104	Labor and machinery usage
Investment cost/(ten thousand yuan)	233.2(concrete)+789.7(steel)+633.34(steel strand)+1104(Production and installation costs) =2760.52	

**Table 8.** Investment cost of steel-cement combination bridge

Steel mixed combination bridge	Design quantity	Note
Steel/t	474	Bridge slab reinforcement
C50 concrete /m <sup>3</sup>	2566	Prefab and cast-in-place
Steel box bridge/t	2918	Welds and high-strength bolt weights are not included
Production and installation costs/ (ten thousand yuan)	790.2	Labor and machinery usage
Investment cost/ (ten thousand yuan)	251.2(steel)+46.1(concrete)+1546.5(Steel box bridge)+790.2(Production and installation costs) =2634	

## 4. Conclusion

In the context of this case, the following conclusions were drawn after comparing the two options, including flexural and shear resistance, positive section crack resistance, and investment costs, for the prestressed concrete bridge and the steel-concrete composite bridge:

In terms of flexural performance, the difference in performance between the two is not significant.

In terms of shear resistance, steel-composite bridge exhibit superior performance.

In terms of positive section crack resistance, the steel-concrete composite bridge also shows certain advantages.

In terms of the construction cycle, since the concrete construction needs to be cast in place by blocks, while the steel box girders are prefabricated and then spliced, it can be seen that the construction cycle of the steel-concrete composite bridge is much smaller than that of the prestressed concrete bridge.

In terms of investment cost, although the steel-concrete composite bridge does not require prestressed steel bars, the raw materials for steel box girders are much more expensive compared to concrete, so the difference between the two total price estimates is not significant.

## References

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