Numerical simulation analysis of construction of steel truss arch bridge with in-situ reconstruction of continuous girder bridge

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Abstract: In order to carry out the stability analysis of the in-situ reconstructed steel truss bridge with continuous girder bridge, this study understood the basic overview of the project and the construction scheme, which carried out the construction analysis by numerical simulation method. It is easy to find that the maximum stress of bracket is 75N/mm^2 which is less than 110N/mm^2.The maximum deformation is 9.2mm, and column height/500=40mm.Stability is calculated as 10.2, which is in accordance with the code. Setting the reinforcement ring at the node part, the local stress is reduced from 285 N/mm^2 to 145 N/mm^2, which avoids the Z-direction tearing of the steel plate. During the construction stage, the tensile stresses at the top edge of block and bottom edge were 1.4 MPa and 1.5 MPa respectively, and the normal stress meets the construction requirements. The flexural bearing capacity can be satisfied without the temperature T-degree effect in consideration. The study can provide reference for the stability analysis of related cases.s

1. Introduction

With the improvement of bridge load levels and the increase of operating years in China, some bridges built in the early stages of construction can no longer meet the needs of modern transportation development due to their lower design load levels and smaller traffic capacity. Thus, a considerable number of bridges, even large-span prestressed bridges, have no potential for load level improvement. It faces the reality of renovating old bridges[1-5].

The construction safety of bridge reconstruction has been a hot research topic, and many scholars have studied it. Pan et al. proposed an in situ replacement scheme of bridge piers and caps, which can maintain the existing stress state of the bridge without changing the bearing position. Fu et al. (2022) adopted the Analytic Hierarchy Process (AHP) method to analyze the multisource data and set the early warning threshold for bridge safety in construction based on the multi-source data of nearby construction and demolition construction of a large-span RC arch bridge in China [6]. Han et al. (2021) considered a new type of corrosion-resistant steel, A709-50CR, for girder replacement. The reliability- and risk-based bi-objective optimizations were conducted on a multi-girder carbon steel bridge to determine when and which carbon steel girders should be replaced under different target performance indicators [7]. Seyed et al. (2020) investigated the effects of different alternatives for superstructure and substructure systems on the progressive collapse procedure after verifying the bridge collapse procedure [8]. In addition, the application of restrainers at the connection of the deck to the abutment was studied as an effective solution in order to prevent collapse propagation and minimize associated damages. Based on the deformation coordination principle and suspension cable theory, Huang et al. (2022) proposed a practical calculation method that can calculate the load of the tower acting by a cable system in the cable lifting construction of arch bridges, to calculate and analyze cable lifting construction more quickly and accurately [9]. Moreover, a large-span arch bridge under construction was used as a case study, and the correctness of the calculation method was verified by measuring the displacements of the tower top. Li et al. (2022) proposed using the Copula function to calculate the reliability index of the bridge structure construction process system [10]. The basic theory of the Copula function was introduced in detail, and the formula was improved according to the actual situation of bridge construction.

Although there are currently many cases of bridge reconstruction, there are relatively few studies on the in-situ demolition and renovation of continuous beam bridges and the construction of new steel truss arch bridges. This study is based on the 07 Provincial Road Yanpingtang Bridge and proposes a construction plan for the reconstruction of a steel truss arch bridge on an old continuous beam bridge. In order to solve the problems of bearing capacity and stability of old bridges under the construction conditions of new and new bridges, numerical simulation method is used to determine the safety of the entire construction process.

2. Project overview

The Yanpingtang Bridge is located on Provincial Road 07 in Pinghu City, Zhejiang Province. The maximum designed navigable water level is 1.96m. The navigation

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clearance scale of the original bridge is 5.5m, and the net height is less than 7m, which cannot meet the current requirements. Therefore, the existing old bridge will be demolished and a new bridge will be built. The demolished part includes a 40+70+40m cast-in-place box girder main bridge and a 20m approach bridge on both sides. The new main bridge will be a 41+90+41 steel truss arch bridge. In order to reduce construction costs and save time, the construction plan of "using old bridges to build new bridges and demolishing old bridges based on new bridges" is adopted in this project.

The original 40+70+40m cast-in-place box girder was constructed using a suspended casting method, divided into 8 sections. The mid span beam is 2m high, and the support point beam is 4.2m high. The bridge is 16.5m wide and adopts a single box and single chamber section. The width of the beam bottom is 8.75m, and the length of the cantilever plates on both sides is 3.875m. The thickness of the top plate is 28cm, and the bottom plate gradually changes from 25cm to 60cm according to a quadratic parabola. The continuous beam concrete adopts C50 concrete. The vertical view of the bridge can be shown in Fig.1.

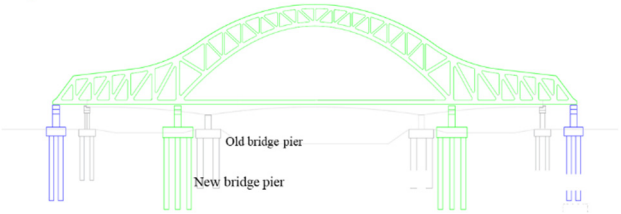


Fig. 1 Vertical view of the bridge

3. Construction programme

This project considered using the existing old bridge as the construction platform, erecting supports in the span of the old bridge for the construction of the new bridge (truss arch), and installing steel truss arch segments by using the supports on the bridge and the car crane. The specific process was as follows: erecting bracket→installing side span→installing tie rod→installing lower chord of arch rib→installing upper chord of arch rib→installing wind brace. The specific installation process should control the self-weight, configuration, working radius and lifting weight of the crane to ensure the safety of the crane itself and avoid collision during lifting. The bracket construction site can be shown in Fig. 2.

Fig.2 Layout of the bracing system on the old bridge

4. Numerical simulation calculation of the new bridge

4.1 Structural analysis model

For the main bridge of Yanpingtang Bridge, the calculation software used MIDAS/CIVIL to establish a plane truss model for calculation. The modeling used beam elements to simulate arch ribs (upper and lower chord members), tie beams, web members, transverse and longitudinal beams, horizontal and transverse connections. Truss elements (only subjected to tension) to simulate suspension cables were adopted. Due to the influence of geometric nonlinearity during calculation, the division of construction stages was carried out according to the construction steps predetermined in the construction plan. There were a total of 1018 elements used in the calculation, including 992 beam elements and 26 truss elements, with a total of 518 nodes. The new bridge model can be shown in Fig. 3. The bracket model and site plan can be shown in Fig. 4.

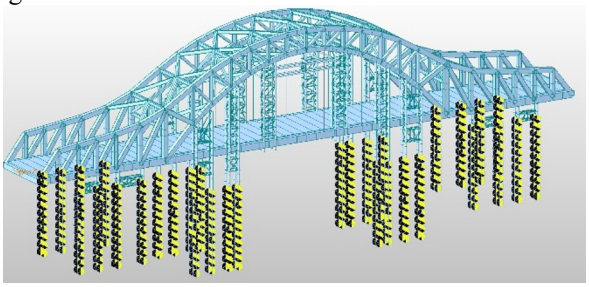


Fig. 3 Discrete schematic diagram of the main bridge structure

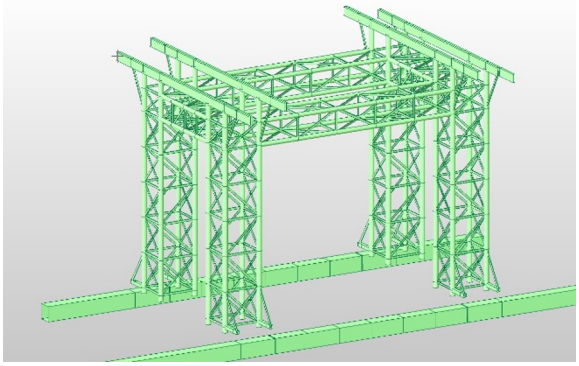


Fig. 4 Discrete schematic diagram of bracket structure

4.2 Parameter selection

The main material parameters used in the analytical calculations can be shown in Table 1.

Table 1 Table of material properties

Material	Used part	Unit weight (kN/m^3)	Elastic modulus (MPa)	Linear expansion coefficient	Standard compressive strength (MPa)	Standard tensile strength (MPa)
Q235	Column, flat joint and X-brace	78.5	2.06×10^5	1.2E-5	—	190

Q345Q	Steel truss arch bridge	78.5	2.06×10^5	1.2E-5	—	275
Steel strand	Hanger rod	78.5	1.95×10^5	1.2E-5	—	1860

4.3 Calculation results of bracing forces during the construction phase

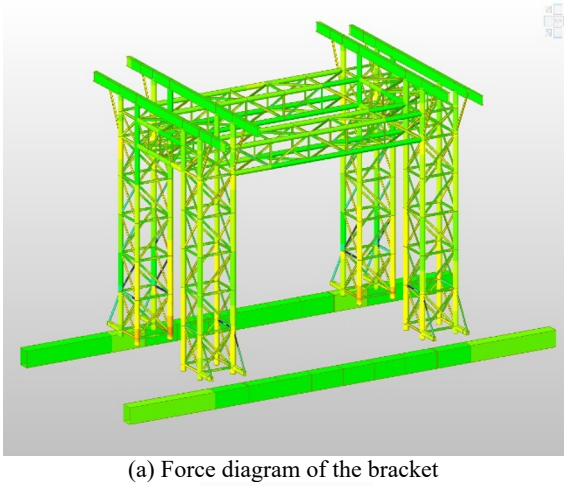
4.3.1Overall calculation of the support

According to the overall calculation model, the bracket is subjected to the pressure as shown in the Table 2.

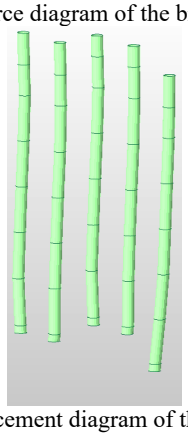
Table 2 Pressure calculation table for the bracket

Bracket number	Erection of bracket 3	Erection of arch rib 1	Closure of tie beam	Lower chord of the closing arch rib	Upper chord of the closing arch rib	Disengage the jack
1-1	4.5	4.5	12.9	14.5	18.5	9
1-2	4.3	4.3	12.2	14.9	19.2	10.2
2-1	5.2	5.2	13.1	15.9	19.1	11.2
2-2	5	5	153	16.4	19.8	12.3

Extract the most unfavourable force of the support according to the overall calculation structure. The strength, stiffness and stability of the structure were checked by combining the local wind load of one in 10 years.



(a) Force diagram of the bracket



(b) Displacement diagram of the bracket

Fig.5 Force and displacement diagrams of the bracket

According to Fig. 5, The maximum stress is 75N/mm^2 which is less than 110N/mm^2.The maximum deformation is 9.2mm, and column height/500=40mm.Stability is calculated as 10.2, which is in accordance with the code. The wind load of one in 10 years plus construction load is the most unfavourable reaction force.

4.3.2 Local calculation results of the bracket

The calculation diagram of the bracket nodes can be presented in Fig. 6. For the weak point of the bracket where the stress is especially concentrated, the plate unit is used to analyze it locally. Setting the reinforcement ring at the node part, the local stress is reduced from 285 N/mm^2 to 145 N/mm^2, which avoids the Z-direction tearing of the steel plate.

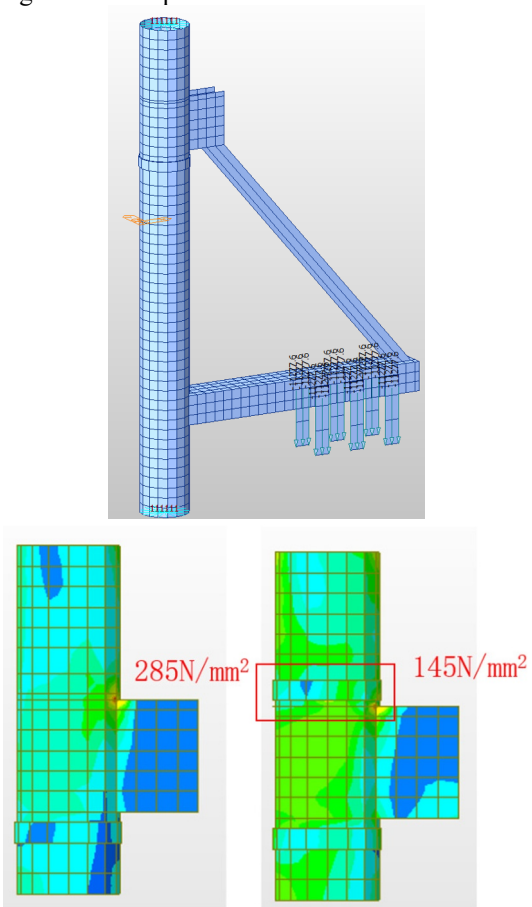


Fig.6 Simulation and computational modelling of nodes

5. Numerical simulation analysis of old bridge demolition

The whole bridge adopted Midas civil for overall modelling calculation. Each component was established as a beam unit, and only compression elastic connection was used between the temporary support and the beam body. The rest of the components were used between the general elastic connection. The equivalent simplification of the car crane, transporter and 20T steel crossbeam was added in the form of nodal loads.

The bridge main span 1-9 section was cut by cutting process. The cut segments were lifted onto the transporter by a car crane and transported away, and the transverse beams and secondary longitudinal beams were installed simultaneously. block 0 and side span 1-10 are crushed in situ by a gun head machine. The schematic diagram of the whole bridge can be shown in Fig. 7.

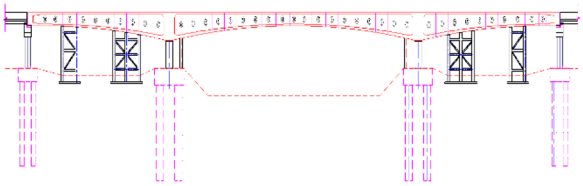


Fig. 7 Schematic diagram of full bridge

Table 3 Table of section parameters of Yapingtang Bridge

	Parameter value										
Beam section	10	9	8	7	6	5	4	3	2	1	0
Section length	4.0	2.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.5	5.0
C50 concrete（m^3）	56.5	20.7	41.7	42.4	38.3	40.6	42.9	45.2	48.0	51.2	100.3
Pavement（m^3）	10.6	5.3	10.6	10.6	9.2	9.2	9.2	9.2	9.2	9.2	13.2
Girder section weight	174.4	67.5	135.9	137.7	123.6	129.6	135.6	141.5	148.8	157.1	295.1

The specific material parameters can be shown in Table 3. The unit weight of concrete is 26kN/m^3, and the unit weight of steel is 78.5kN/m^3. The tensile, compressive and bending strength of Q235 steel is 215MPa, and the shear strength is 125MPa. The allowable value for describing the bending deformation of the structure is L/400. The calculation working conditions are as follows. The demolition of the old bridge includes one 70T truck crane, one transport vehicle, and ten tons of concrete blocks. The installation of the new bridge includes one 70T truck crane, one transport vehicle, and a 20T steel crossbeam.

The calculation model of the whole bridge can be shown in the Fig.8.

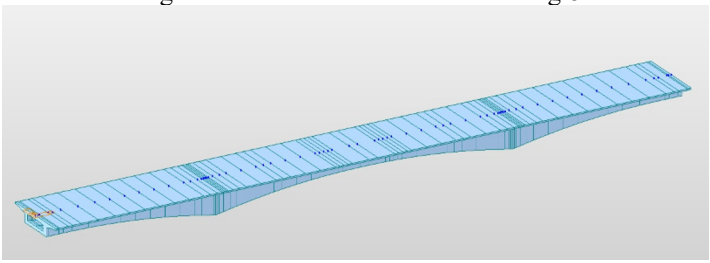
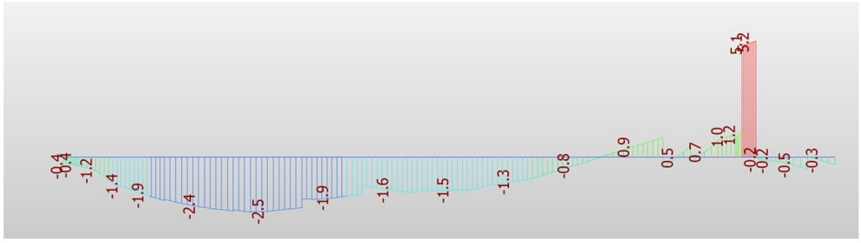
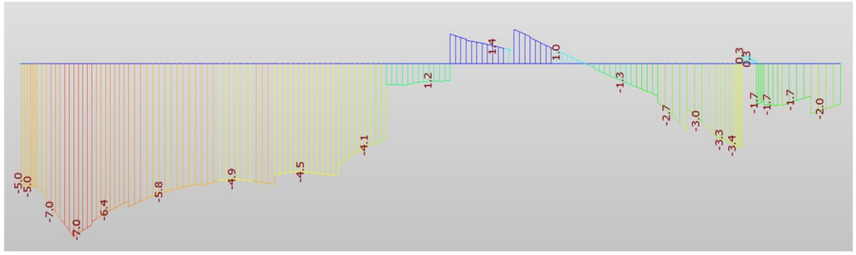


Fig. 8 Calculation model of the whole bridge



(a) Normal stress at top edge of box girder



(b) Normal stress on bottom edge of box girder

Fig. 9 Normal stress diagram of box girder

During this construction phase, the shear bearing capacity meets the requirements which can be seen in Fig.9. During the construction phase, if the tensile stress at the top edge of block 1 is 1.4MPa and the tensile stress at the bottom edge is 1.5MPa, then the normal stress meets the construction requirements. The temperature T degree effect should be considered, the maximum bending moment of block 2 is 1440T·m, which is greater than the bending bearing capacity of 1280T·m, which exceeds 12.5%. According to the specifications, the bending bearing capacity can be met without considering the temperature T degree effect.

6. Conclusions

In this study, the following important conclusions were obtained from the numerical simulation of a continuous girder bridge retrofitted with a steel frame bridge.

(1) It is easy to find that the maximum stress of bracket is 75N/mm^2 which is less than 110N/mm^2.The maximum deformation is 9.2mm, and column height/500=40mm.Stability is calculated as 10.2, which is in accordance with the code. The wind load of one in 10 years plus construction load is the most unfavourable reaction force.

(2) Setting the reinforcement ring at the node part, the local stress is reduced from 285 N/mm2 to 145 N/mm2, which avoids the Z-direction tearing of the steel plate.

(3) During the construction phase, if the tensile stress at the top edge of block 1 is 1.4MPa and the tensile stress at the bottom edge is 1.5MPa, then the normal stress meets the construction requirements. The temperature T degree effect should be considered, the maximum bending moment of block 2 is 1440T·m, which is greater than the bending bearing capacity of 1280T·m, which exceeds 12.5%. According to the specifications, the bending bearing capacity can be met without considering the temperature T degree effect.

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