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Investigation of the Mechanical Features of Steel–Concrete Composite Girder Rigid Frame Bridges with V-Shaped Piers during Construction Stages

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Abstract: Steel–concrete composite girder rigid frame bridges with V-shaped piers are a new type of bridge structure. Based on the traditional composite continuous beam bridge, part or all of the vertical piers are changed into V-shaped piers. This special structure makes them have the mechanical characteristics of both composite continuous beams and V-shaped piers. In this paper, the finite element model of the first steel–concrete composite continuous beam V-pier rigid frame bridge in China is established by simulation software, the construction process of the bridge is simulated, and the stress and deflection of the bridge in each construction stage are studied. At the same time, the stress of the completed bridge model considering the construction stage is compared with that of the completed bridge model without considering the construction stage. It is found that the stress difference between the two concrete slabs is as high as 2.7 MPa. The results show that the stress state of the bridge is greatly affected by the construction process. This study can provide guidance for the design and construction of such bridges, which is of great significance.

Keywords: steel–concrete composite girder; continuous beam rigid frame bridge; V-shaped pier; composite system; construction stage; mechanical performance

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Citation: Zeng, Y.; Yu, T.; Xiao, Y.; Li, W. Investigation of the Mechanical Features of Steel–Concrete Composite Girder Rigid Frame Bridges with V-Shaped Piers during Construction Stages. *Appl. Sci.* **2024**, *14*, 3343. https://doi.org/10.3390/app14083343

Academic Editor: Carmelo Gentile

Received: 26 February 2024
Revised: 30 March 2024
Accepted: 1 April 2024
Published: 16 April 2024

1. Introduction

V-pier steel–concrete composite girder rigid frame bridges are a new structure composed of V-piers, continuous girder piers, and solidified girders. In the longitudinal direction of a bridge, the vertical pier is one pier with one support, while the V-shaped pier is one pier with two supports. This structure makes the V-shaped pier bridge shorten the span of the main beam, has a higher capacity in the same case, and increases the ornamental [1] and carrying capacity [2], which is more in line with the development needs of future bridges. Previous studies have shown that the bridge structural system with V-shaped piers has good seismic performance [3].

The Hollandsch Diep Bridge in the Netherlands is the longest railway bridge on the Schipho–Antwerp high-speed line. The bridge is 2 km long, of which the water is about 1100 m, the main span is supported by 11 piers of composite beams, and the bridge span is 105 m. The main river bridge in Germany is 299 m long and the approach bridges on both sides are 184 m and 330.5 m, respectively. The superstructure adopts the form of a box girder with variable sections. The angle between the V-shaped pier and the vertical line is about 30°. In addition, the United States, France, and Japan have also built a number of V-shaped pier bridges. In recent years, prestressed concrete is rarely used in bridges with V-shaped piers. V-pier bridges built with steel structures are more common because they can effectively increase the span of the bridge and reduce the weight of the structure [4].

Based on the fact that V-shaped pier and steel main beams are consolidated, Zeng Yong and Li Yongqi et al. [5], through finite element simulation software [6], regarded the rigid main beam and concrete bridge panel of V-shaped pier steel–concrete composite beam bridges as a composite section and the rigid main beams and bridge panels as different parts of the same section. On this basis, the influences of removal time, angle of V-shaped pier, and counterweight on the mechanical performance of the bridge are analyzed. The research shows that the mechanical performance of the bridge is greatly affected by the structure.

By combining test and numerical analysis, Zhang Fei and Wang Yan [7] studied the rigid spatial stress distribution of bidirectional V-shaped continuous steel structure bridge piers: beams. The research shows that tensile stress will occur in the consolidation area between the support base of the V-shaped pier and the vertical pier, which is a dangerous area, and measures can be taken to strengthen the anti-crack reinforcement in this area. In addition, some suggestions are put forward to enhance the mechanical properties of the bridge by raising the height of the vertical pier.

Zheng Yuanxun and Cao Zhanlin et al. [8]. established a spatial model of a two-way four-lane reinforced concrete composite continuous beam bridge with finite element software. Combined with the vehicle information recorded at the toll station in the past 10 years, the fatigue performance [9] of the steel–concrete composite continuous box girder bridge deck was studied. The results showed that when the load position was 7.0 m away from the bridge center line, the fatigue stress of the bridge deck was most unfavorable.

Guo-an Yin [10] et al. studied the connection performance of the rectangular joint plate, π-shaped joint plate, and J-shaped joint plate of steel–concrete composite truss for the bridge by combining test and numerical simulation. The results showed that the three connection forms all had excellent mechanical properties and large safety residuals, which met the safety requirements.

Based on the reinforcement case of a solid bridge in Beijing, Zhang et al. [11] introduced the application of a steel–concrete composite structure in the reinforcement project of a T-beam bridge. By comparing the mechanical characteristics of the bridge before and after reinforcement, it was found that the dynamic characteristics and load-bearing capacity of the bridge were significantly improved after reinforcement with this method, which provided an important basis for such work.

Antonio Bilotta et al. [12]. adopted the convolutional neural network method to identify the damage in the connection of steel–concrete composite beams, demonstrated how to train simple convolutional neural networks to identify the damage, studied the applicability of the data and the influencing factors, and discussed the errors existing in the modeling and the cancellation methods.

2. Engineering Background

A steel–concrete composite girder rigid frame bridge with (20 + 24 + 34 + 56 + 34) m span was constructed in Chongqing, China. The main beam section is a typical π(double main beam) steel–concrete composite section. The bridge is the world's first steel–concrete composite beam continuous beam V-pier rigid frame bridge. The elevation view of the bridge is shown in Figure 1.

The bridge deck is made of precast reinforced concrete slab, the longitudinal bridge length of a single precast slab is 3 m, the transverse bridge width is 8.9 m, and the midline thickness of the slab is about 0.3 m. A single precast slab has four shear nail group holes and the precast slab and steel main beam form a composite system through shear nails. The bridge section is shown in Figure 2.

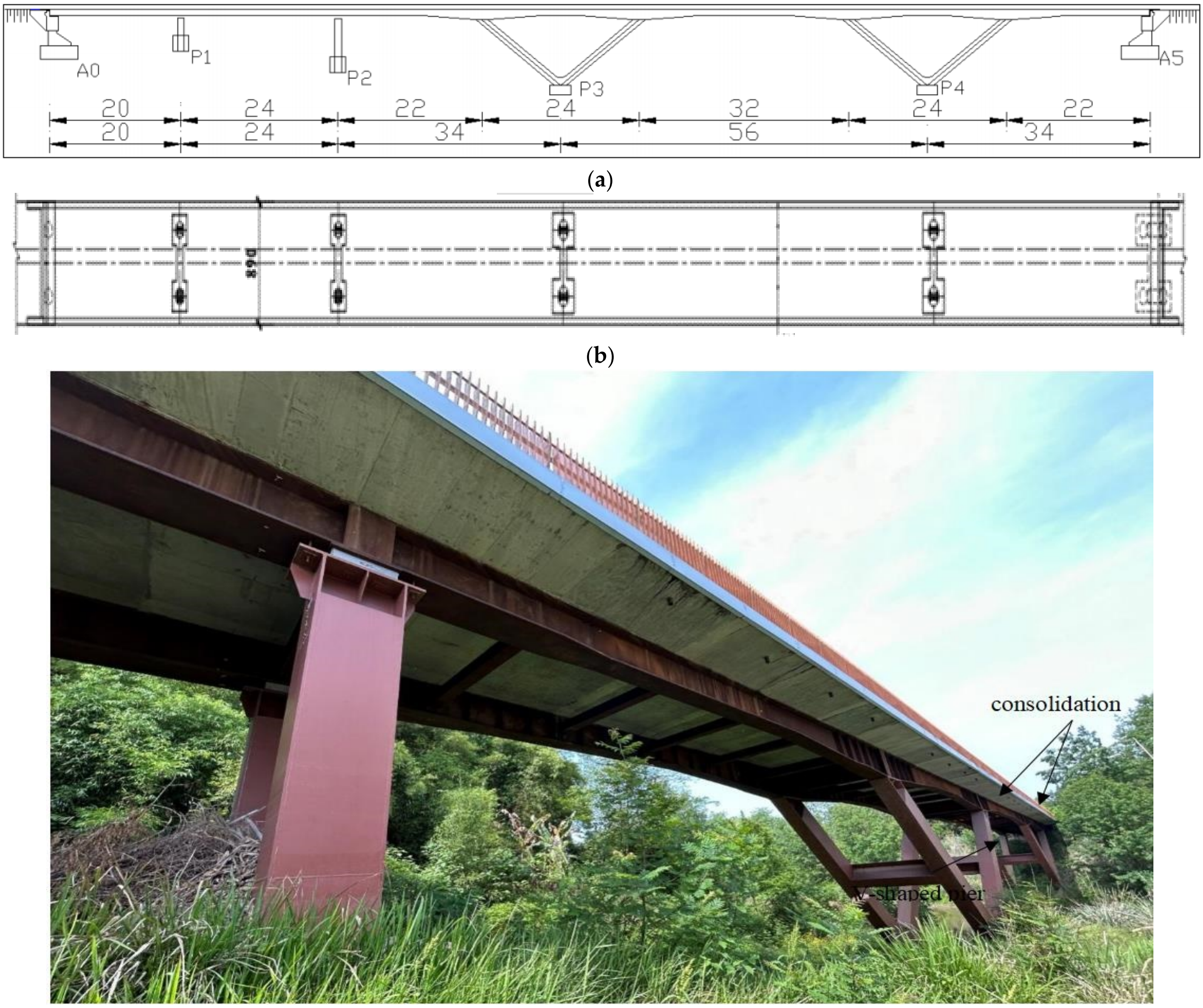
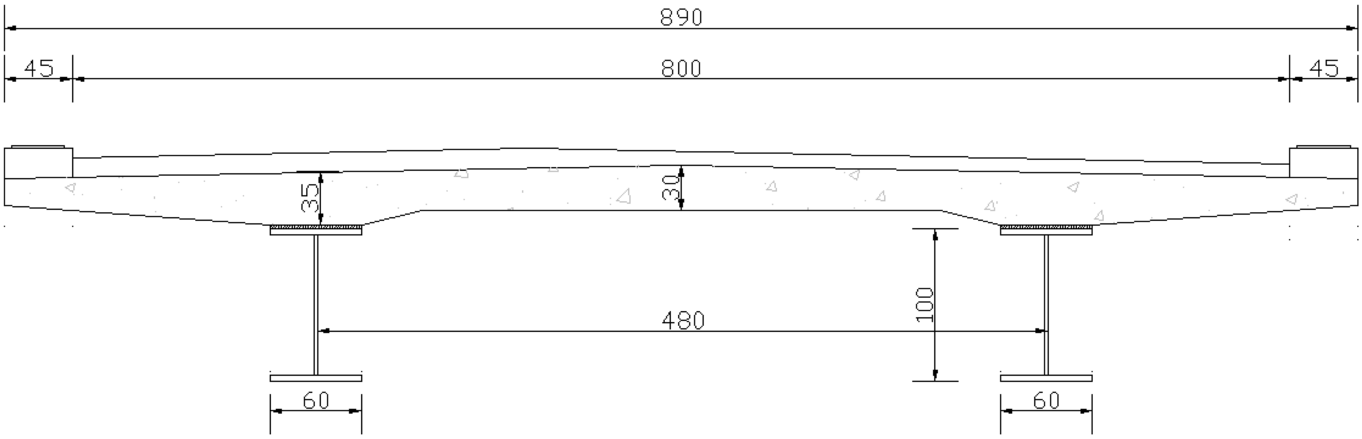


Figure 1. Elevation of the bridge: (**a**) elevation of the bridge; (**b**) bridge layout; (**c**) in situ bridge.

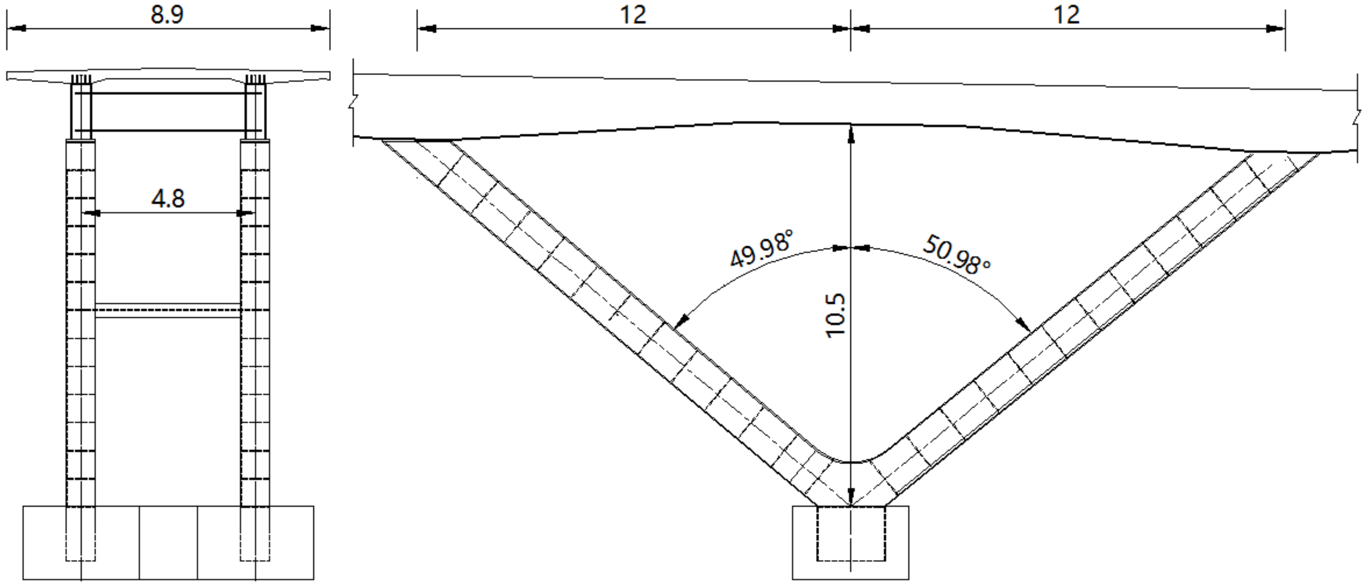
Piers P1 and P2 are vertical piers and piers P3 and P4 are V-shaped piers. A hinge support is set between piers P1 and P2 and the main beam. Piers P3 and P4 are connected to the main beam by high-strength bolts [13] and the transverse wet joint rebar and the main beam are welded [14] together to support the bridge panel. The structural diagram of the V-shaped pier is shown in Figure 3.



(**a**)

(**b**)

Figure 2. Bridge section (cm): (**a**) section of the bridge; (**b**) in situ section of the bridge.



(a)

(b)

Figure 3. V-shaped piers of the bridge: (**a**) V-leg dimensions; (**b**) in situ V-shaped piers.

3. Finite Element Model

3.1. Division of Construction Stages

For the convenience of description, the structure is numbered. From the A0 abutments, along the longitudinal direction of the bridge, the section of the beam that forms a combined section with the concrete deck before preloading is denoted as k1 to k7 and the section of the beam that is poured concrete after the negative bending moment is named as d1 to d6. Since the bridge is not structurally continuous at the abutment location, it is not necessary to consider the pre-compression of concrete near the abutment. Modeling calculations are appropriately simplified. The beam segment division is shown in Figure 4.

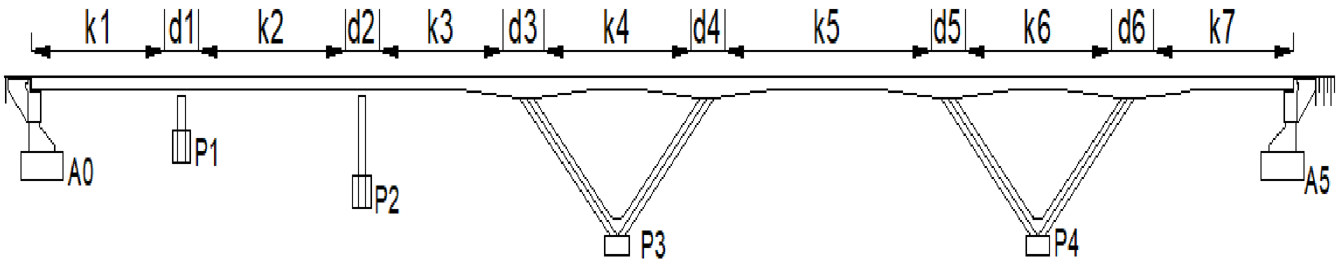


Figure 4. Beam segmental division with a number.

The simplification and division of each construction stage are shown in Table 1.

Table 1. Divisions of construction stages.

Construction Stage	Construction Contents
CS1	Construction of substructures and steel beams
CS2	Installation of precast bridge decks from k1 to k7 and pouring of wet joints
CS3	Preloading the mid-span of k1 and k2 beam sections and cast-in-place d1 beam section concrete
CS4	Unloading the preload of k1, preloading the mid-span of k2 and k3 then cast the concrete of d2 beam section in situ
CS5	Unloading the preload of k2, preloading the mid-span of k3 and k4 then cast the concrete of d3 beam section in situ
CS6	Unloading the preload of k3, preloading the mid-span of k4 and k5 then cast the concrete of d4 beam section in situ
CS7	Unloading the preload of k4, preloading the mid-span of k5 and k6 then cast the concrete of d5 beam section in situ
CS8	Unloading the preload of k5, preloading the mid-span of k6 and k7 then cast the concrete of d6 beam section in situ
CS9	Unloading the preload of k6 and k7 preloading and applying secondary loads

3.2. Parameter Selection

According to the design drawings, the unit weight of concrete is 25 kN/m^3, the unit weight of the main beam is 76.98 kN/m^3, and the secondary load is 22.8 kN/m. Considering the influence of shrinkage, creep edge, and concrete age, the construction period of the in situ cast construction section is 14 days and the foundation is well selected without considering the displacement of the foundation. The top of the vertical pier is constrained according to the actual bearing capacity of the bridge, as shown in Figure 5. The rigid connection is used to simulate the high-strength bolts at the joint of the V-pier and steel beam.

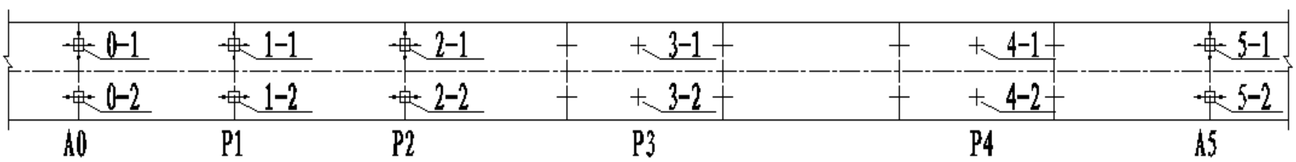


Figure 5. Bridge support.

Using the method of the joint section in construction stages, the effective width of the bridge deck, ignoring the influence of the cross slope, and the longitudinal slope of the bridge deck are considered and a simplified FEM model is established. The simplified model is shown in Figure 6.

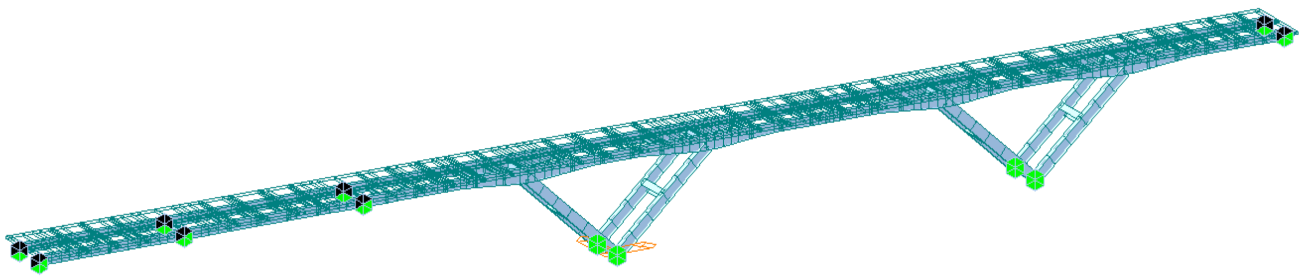


Figure 6. FEM model of the bridge with V-shaped piers.

4. Calculation Results of the Phased Construction Process

The construction method has an obvious influence on the negative bending moment section of composite beams and the construction of a steel–concrete composite girder rigid frame bridge with a V-shaped pier is also carried out in stages. In order to study the stress characteristics of such bridges in the construction process, the stress analysis of key construction stages of the whole bridge is carried out based on the finite element method.

4.1. Results of the Steel Beam Structure Construction Completion Stage (CS1)

After the steel beam construction is completed, the bending moment peak appears at the V-shaped pier and the bending moment of the main beam continues to exist on the whole bridge. The sudden change in bending moment occurs only at the position of consolidation between the top of the V-shaped pier and the main beam. The main reason is that the bending moment in the V-shaped pier has a certain influence on the bending of the main beam. At this time, the bending moment control section of the whole bridge's main beam is near d5.

Under the action of self-weight, the internal stress of the steel beam is very small. As can be seen from Figure 7, the stress on the upper flange of the steel beam is basically continuous along the longitudinal direction of the bridge, while the stress at the lower flange consolidation position (d3, d4, d5, and d6) of the steel beam with the V-pier changes suddenly. The reason is that the top of the V-shaped pier and the lower flange of the steel beam are consolidated into a whole by high-strength bolts. The bending moment of the V-shaped pier causes the bending moment of the lower flange of the steel beam at the consolidated position of the pier beam to change abruptly and the bending moment of the steel beam causes the local stress of the steel beam to change abruptly. At this stage, the maximum tensile stress of the steel beam is 13.1 MPa and the maximum compressive stress is 12.6 MPa.

When the span is asymmetrical, the forces acting on the V-shaped pier are also asymmetrical. At present, the maximum stress cross-section of the V-shaped pier roof (main beam side) is 1/2 above the single pier and the maximum stress cross-section of the V-shaped pier bottom (ground side) is at the foot of the V-shaped pier. From the perspective of the whole V-shaped pier, the most unfavorable force is at the bottom of the V-shaped pier near the side span.

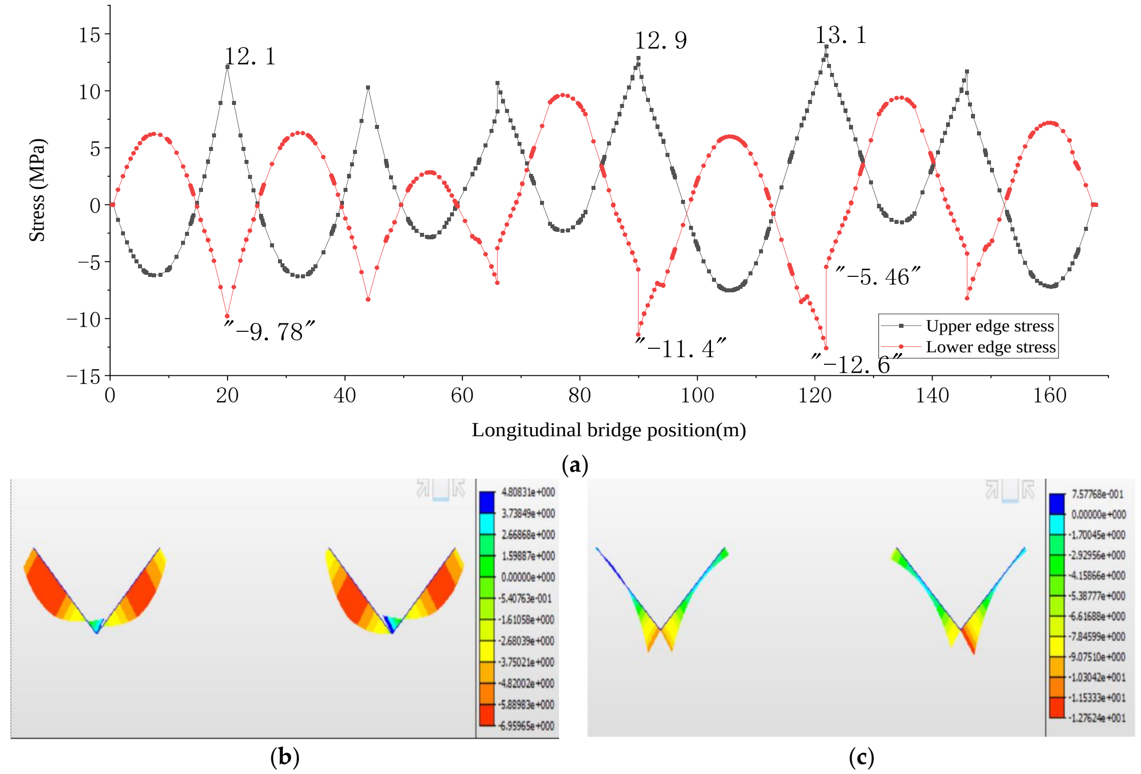


Figure 7. CS1 stage steel main beam and V-shaped pier stress: (**a**) rigid main beam stress; (**b**) stress on the upper flange of the V-leg; (**c**) lower flange stress of the leg. (Instructions: in the picture, e + 000 means 10,000, e + 001 means 10,001, and so on).

4.2. Analysis of Precast Slab Pavement Completion Stage (CS2)

At this stage, the characteristics of internal forces acting on the steel girders are consistent with those of the previous stage and the maximum section of bending moment is still at position d5 of the longitudinal bridge. The weight of the deck has a great influence on the bending moment of the steel girder.

The stress curve characteristics of the upper and lower flange of the steel beam at this stage are basically consistent with those of the previous stage. The bridge panel is directly connected to the steel main beam and the load is transferred to the steel main beam, which increases the stress of the steel main beam and the maximum compressive stress is 72.7 MPa. As shown in Figure 8, the maximum tensile stress of the steel main beam is 77.6 MPa and the maximum compressive stress is 72.7 MPa.

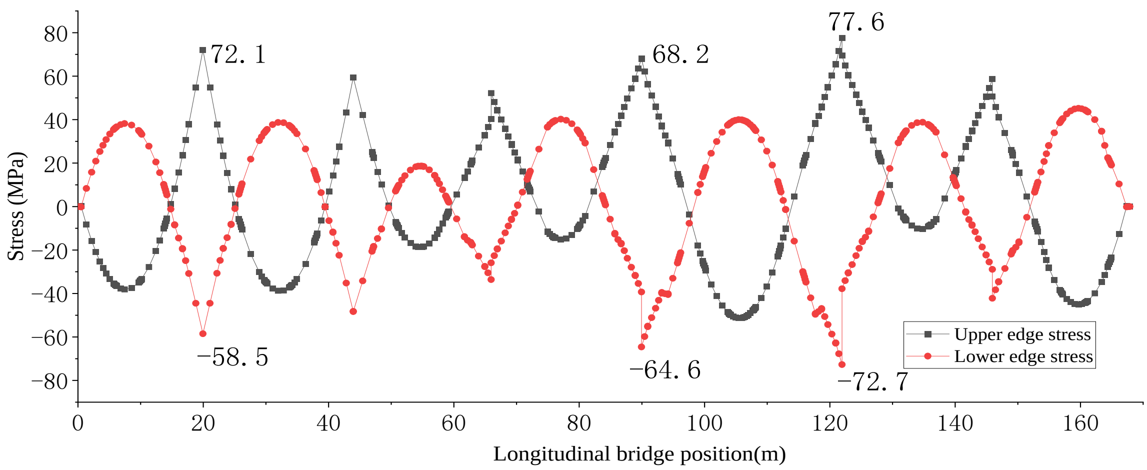


Figure 8. Stress of steel girder in the CS2 stage (MPa).

At the completion stage of the precast slab pavement, the maximum tensile stress and maximum compressive stress in the concrete slab are not more than 0.1 MPa, so it can be considered that the concrete bridge deck is not stressed at this time. The stress of the bridge deck is shown in Figure 9. When the weight method is used to lay the prefabricated bridge deck in the span, the longitudinal stress of the bridge deck does not occur due to the longitudinal support of steel beams and the use of post-cast concrete for the shear nail group holes. The concrete slab is not integrated with the steel beam until the elastic deflection of the main beam is caused by bearing the weight of the concrete slab. From the stress state of the concrete slab at this stage, the simulation of the change process of the section stiffness is correct, which reduces the calculation error.

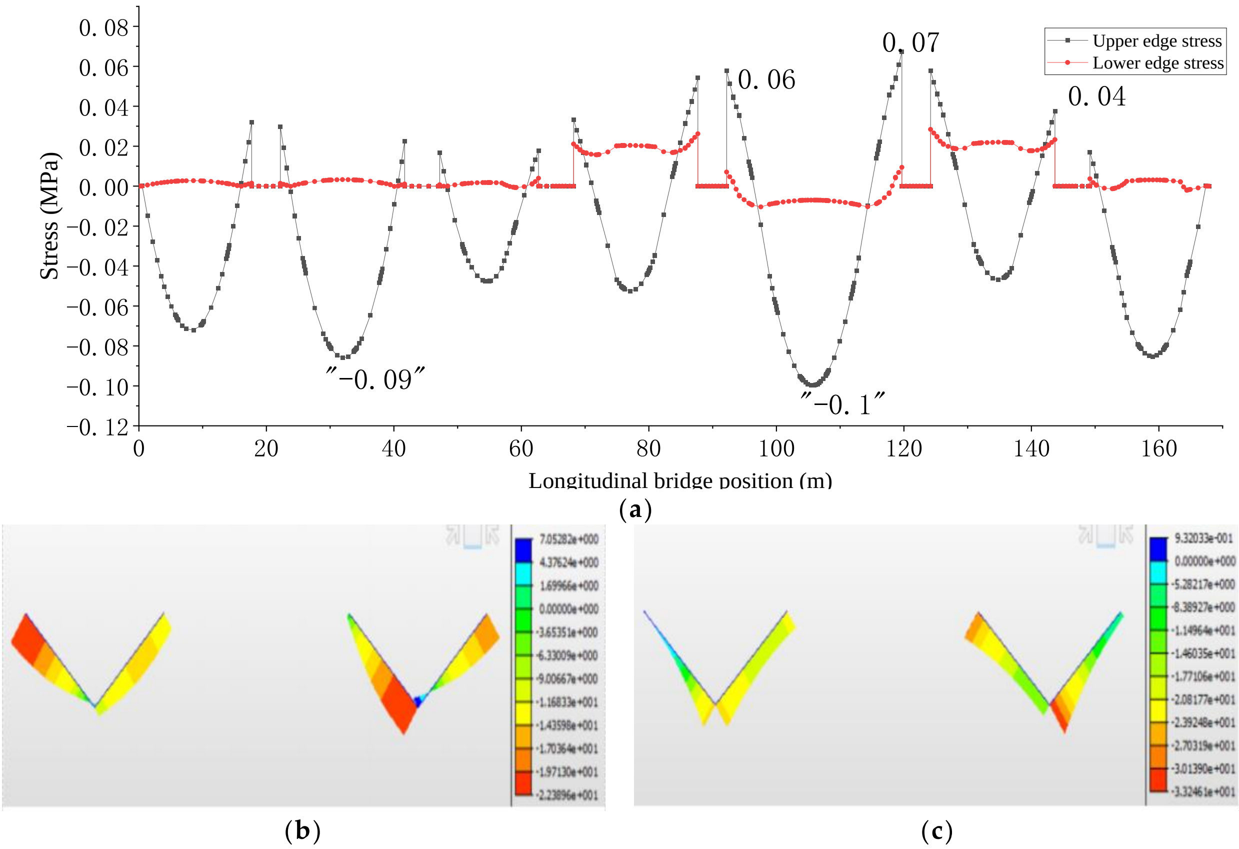


Figure 9. CS2 bridge floor and V-shaped pier stress: (**a**) bridge floor stress; (**b**) stress on the upper flange of the V-leg; (**c**) lower flange stress of the leg. (Instructions: in the picture, e + 000 means 10,000, e + 001 means 10,001, and so on).

The maximum stress section is still at the bottom of the V-shaped bridge plate near the side span and the maximum compressive stress is 33.2 MPa. At this time, the most unfavorable position of flange plate stress on the V-shaped pier becomes the root of the V-shaped pier and the internal stress of the V-shaped pier shows a very obvious asymmetry. The stress of the V-shaped pier is shown in Figure 9b,c. At this stage, the effect of the bridge on the steel beam is only equivalent to applying a constant load and does not participate in the structural force. The section formed at the end of this stage is the initial state of the combined section of the positive moment region.

4.3. Analysis of the Bridge Completion Stage

This stage is the bridge completion stage of the main beam and the secondary loads have been included. By analyzing the bending moment of the steel girder, it can be found that the negative bending moment of the steel girder in sections d4 and d5 has been significantly improved.

The stress curve of the upper flange of the steel girder is no longer as continuous as that of CS1 and CS2 and a sudden increase in stress occurs in each negative bending moment section. The reason is that the construction of the negative moment section has been completed and the medium weight of the span has been unloaded. However, due to the restraint of the studs by concrete, the elastic deformation of the flange plate on the steel beam is difficult to recover and the tensile stress level in the steel beam is maintained to a certain extent. By analyzing the stress curve of the lower flange of the steel beam, it is found that the linear characteristics of the curves have not changed and there is no sudden change in the stress curves. This shows that the method of gravity has little effect on the stress characteristics of the lower flange of the main girder. At this time, the maximum tensile stress and compressive stress of steel girder under dead load are 110.0 MPa and 95.1 MPa, respectively. The stress of the steel girder during the completion stage is shown in Figure 10.

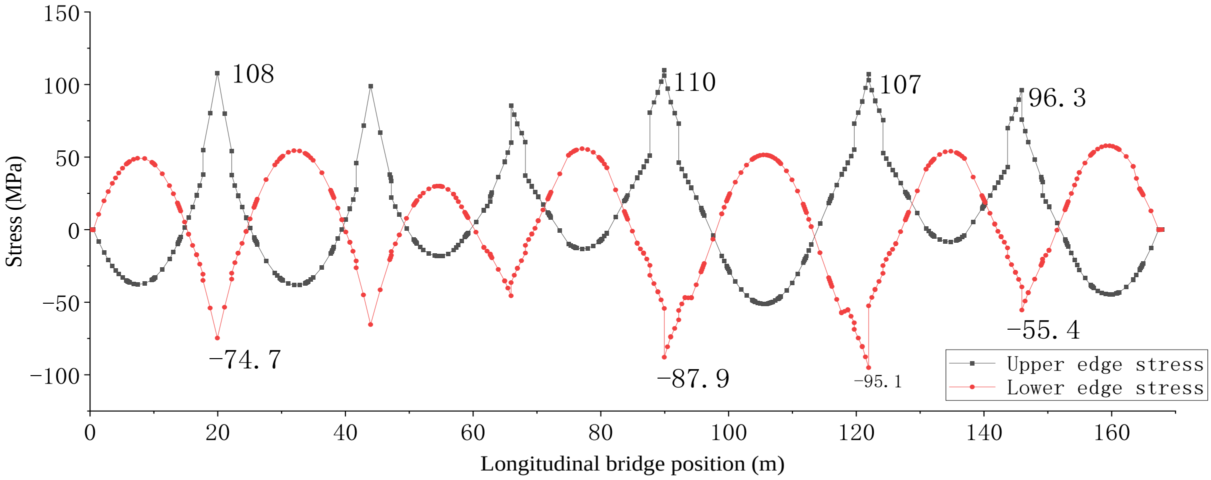
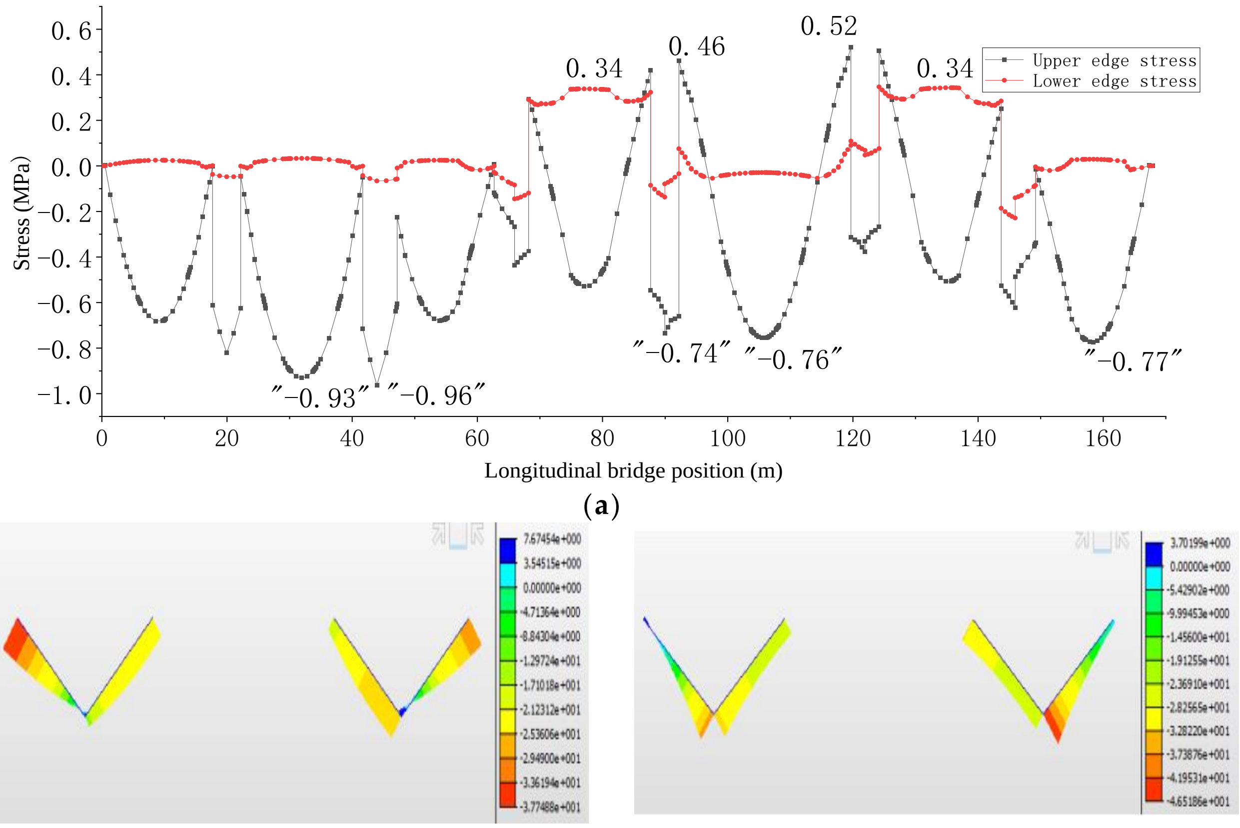


Figure 10. Stresses of the steel main girder in the bridge completion stage (MPa).

When the bridge is completed, the upper edge of the concrete deck in the negative moment area of P1 and P2 piers' top is in the compression state, as shown in Figure 11. The upper edge of the concrete bridge deck in the negative bending moment area of the pier top of the P3 and P4 V-shaped pier has certain tensile stress, up to 0.52 MPa. The main girder span has little difference and, according to the construction plan, the weight of different spans has been adjusted accordingly. The pressure of the large span is slightly heavier than that of the small span. It can be seen by calculation that the pier crest of a vertical pier is obviously better than that of V-shaped piers by the weight method.

The V-shaped pier control section is still close to the V-shaped pier bottom plate on the side span side and the maximum compressive stress at this stage is 46.5 MPa. At this time, the stress of the V-shaped pier continues to maintain obvious asymmetry. In the finished state, the stress level at the root of the V-shaped pier caused by the self-weight of the structure is not significant compared with the strength of the materials used.

The FEM model can accurately simulate the process of phased construction of the bridge and the change in section stiffness during the construction. In the finished state, the bridge is always in the stage of elastic change and the concrete is only subjected to very small tensile stress at the top of the V-shaped pier. Because the influence of reinforcement in concrete on the stiffness of the concrete slab is not taken into account, the actual calculated tensile stress is still too large.



(**b**) (**c**)

Figure 11. Stress of bridge floor and V-shaped pier in the completion stage: (**a**) bridge floor stress; (**b**) stress on the upper flange of the v leg; (**c**) lower flange stress of the v leg. (Instructions: in the picture, e + 000 means 10,000, e + 001 means 10,001, and so on).

4.4. Comparative Analysis of Each Stage

The performance of the steel beam upper flange, steel beam lower flange, upper edge of concrete slab, lower edge of concrete slab, and deflection of the whole bridge in different construction stages are compared and analyzed in the following.

(1) Flange stress on the steel beam

The calculation results of the construction process of the upper flange of the steel beam are shown in Figure 12.

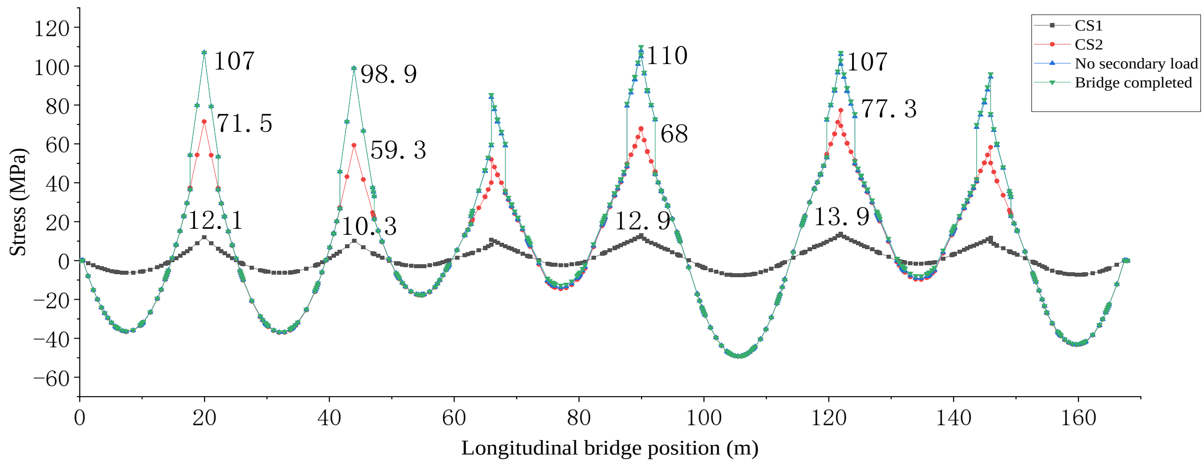


Figure 12. Stress of the upper flange of the steel beam in each construction stage (MPa).

Before the construction of the negative bending moment zone is completed, the tension stress curve of the upper flange of the steel beam is continuous and has no sudden change in the longitudinal direction of the bridge. The stress increases evenly with increasing mid-span constant load. After the construction of the negative bending moment zone, the stress curve of the upper flange of the steel beam has an obvious catastrophe. After the unloading under medium pressure and heavy load, the elastic deformation of the flange plate on the steel beam is difficult to recover due to the restraint of studs by concrete. The tension stress level of the steel beam is maintained to a certain extent. The effect of secondary loads on the upper flange of the steel beam is not obvious and the stress curves of the upper flange of the steel beam are almost identical before and after the addition of the secondary loads.

(2) Stress of lower flange of steel beam

As shown in Figure 13.The asymmetric structure of the bridge also causes the force to be asymmetrical. Under the condition of the bridge, the control section of the lower flange of the steel beam is at the top of P4 pier near the main span and the maximum compressive stress is 94.8 MPa; the control section of tensile stress is at the position of side span k7 near the middle span and the maximum tensile stress is 57.4 MPa. It can be found that the stress at the joint between the top of the V-shaped pier and the lower flange of the main beam changes abruptly, indicating that the V-shaped pier exerts additional stress on the steel main beam compared with the vertical pier.

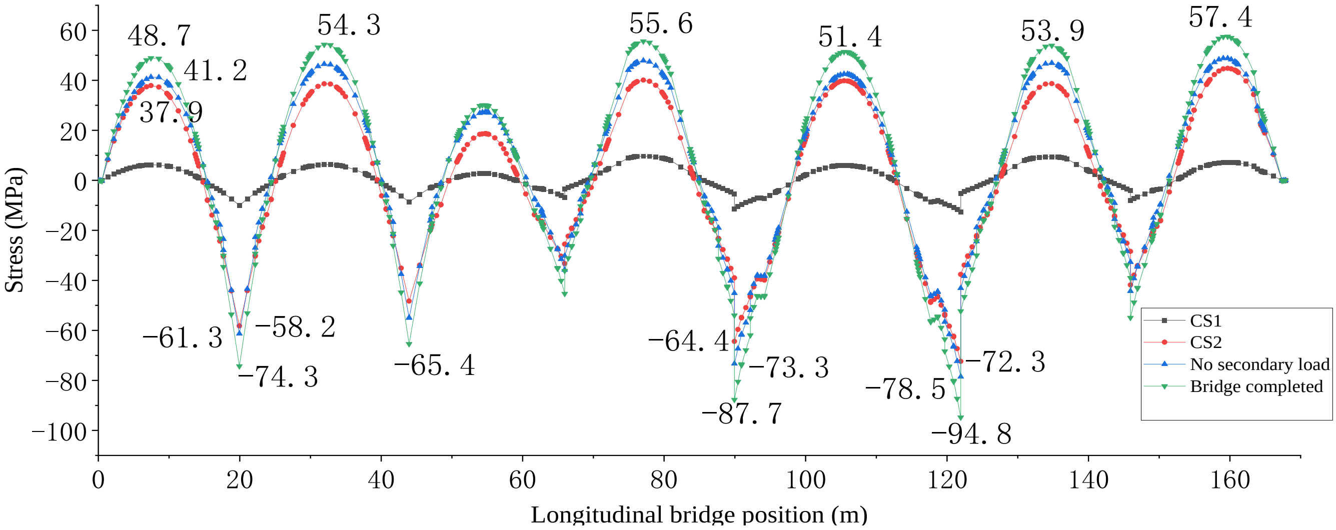


Figure 13. Stress of the lower flange of the steel beam in each construction stage (MPa).

(3) Stress of the upper edge of the concrete slab

The calculation results of the construction process of the upper edge of the bridge deck are shown in Figure 14. It can be seen that when the mid-span bridge deck is just laid, the longitudinal force of the bridge deck is not stressed. At the end of the construction of in situ cast concrete slabs in all negative bending moment zones, the reserve of compressive stress in the negative bending moment zone reaches the maximum value. At this time, the longitudinal edge of the full bridge concrete slab is under pressure. After secondary loading, the top tensile stress of the V-shaped pier is small, the top compressive stress reserve of the vertical pier is reduced, and the upper edge of the concrete is still under free pressure. It can be seen that the effect of applying pressure stress reserve to the negative bending moment area of a vertical pier top is better than that of the negative bending moment area of a V-shaped pier top when the same construction method is used. It is considered temporarily to be caused by the vertical rigidity of the V-shaped pier.

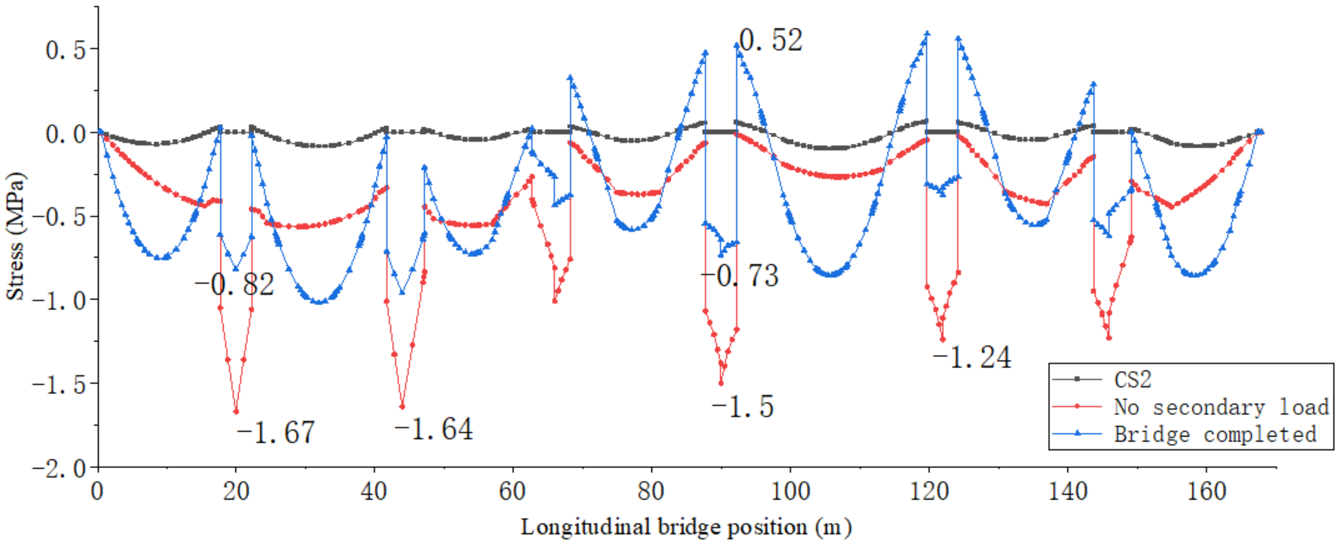


Figure 14. Stress of the upper edge of the concrete slab in each construction stage (MPa).

(4) Stress of the lower edge of the concrete slab

The calculation results of the construction process of the lower edge of the bridge deck are shown in Figure 15. From the longitudinal direction of the whole bridge, the lower edge of the concrete slab maintains a low-stress level after the construction with the compaction method. The maximum tensile stress of the lower flange of the main beam on the top of the V-shaped pier is 0.15 MPa before the secondary load and 0.36 MPa. After the secondary load is applied, the compressive stress of the vertical pier is reduced but it is still under pressure and the reduction in the compressive stress of the vertical pier is obviously not as large as the increase in the tensile stress of the V-shaped pier. Similar to the upper flange of the concrete slab, the precompression reserve effect of the lower flange of the concrete slab in the negative bending moment area of the top of the vertical pier is higher than that of the vertical pier when the compaction method is adopted.

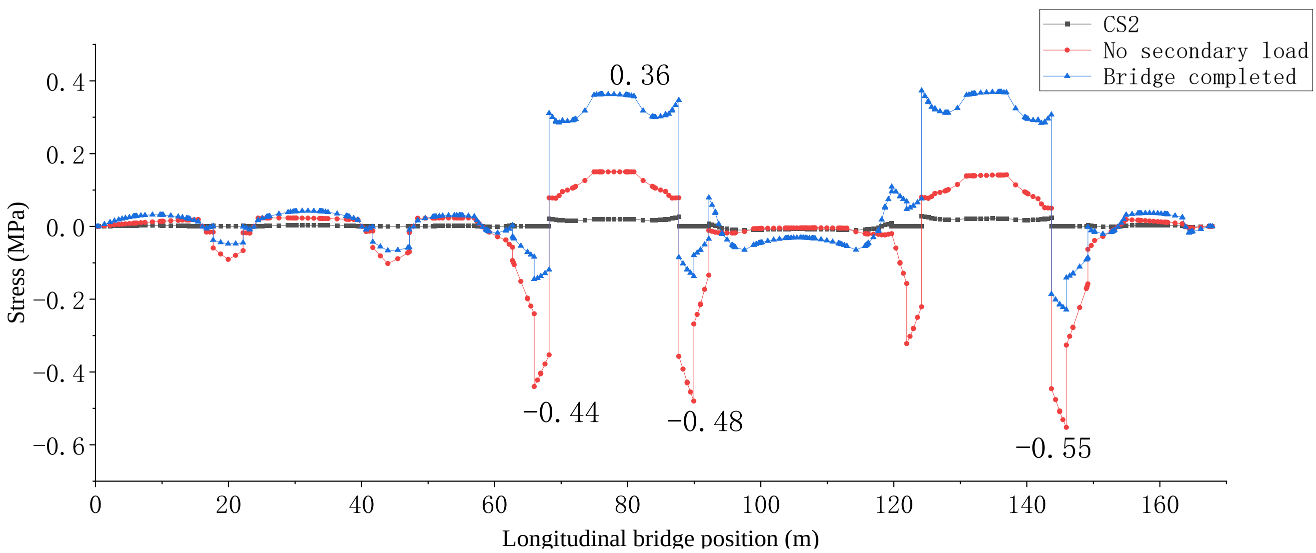


Figure 15. Stress of the lower edge of the concrete slab in each construction stage (MPa).

(5) Deflection variation of the whole bridge during construction

The deflection variation of the whole bridge during the construction stage is shown in Figure 16. In the negative bending moment area of the V-shaped pier top, the main girder will show a small downward deflection along with the construction stages until the completion stage. The maximum downward deflection is up to 8.5 mm at the location of d6. There are obvious differences in the deflection of the main girders in the negative moment area between d5 and d6 in the longitudinal bridge upward direction. There is almost no downward deflection in d5 and the largest downward deflection of pier crest occurs in d6. The main reason is that the girders are continuous along the longitudinal bridge and the span arrangement is asymmetric. The deflections of the main span and side span are inconsistent, resulting in uneven deflection of the pier at two places of the same V-shaped pier.

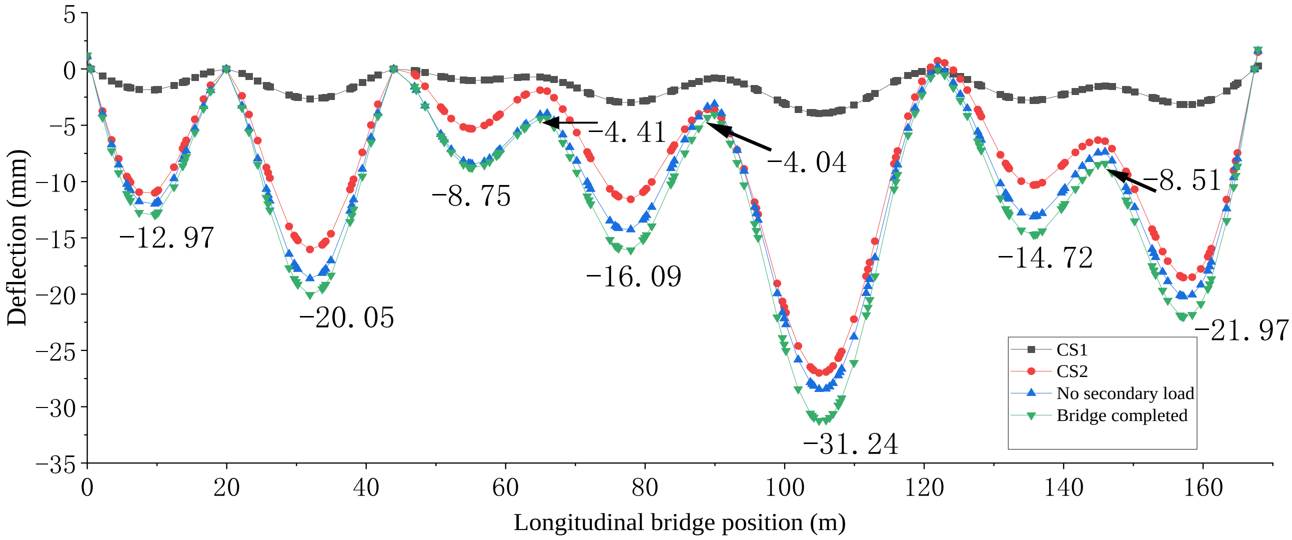


Figure 16. Deflection in different construction stages (MPa).

5. Comparisons between One-Time and Staged Formation of Combined Sections

The finite element model of the one-time formation of the composite section is established with an age of 180 days, which is compared with the calculation results of the bridge formed by stages of the composite section. This model does not exist in the actual continuous beam bridge construction. It is only used to analyze the differences between the final completed bridge state and the accurate simulation of the construction process of the composite girder bridge.

5.1. Deflection Difference in the Completed Bridge

Staged construction has a great influence on the deflection of the completed bridge. When the staged construction is not considered, the combined section of the main beam is formed at one time and the maximum mid-span vertical deflection of the main beam is only 15.9 mm under the dead load. If phased construction is considered, the weight of the paved or cast-in-place deck is borne only by the steel beams when the longitudinal section of the bridge is not formed. When these deflections occur, the steel beam and concrete form a combined section. The cumulative difference in deflections of steel beams in several stages will eventually lead to a huge difference between the two analysis methods. The final deflection of the bridge under different calculation methods is shown in Figure 17.

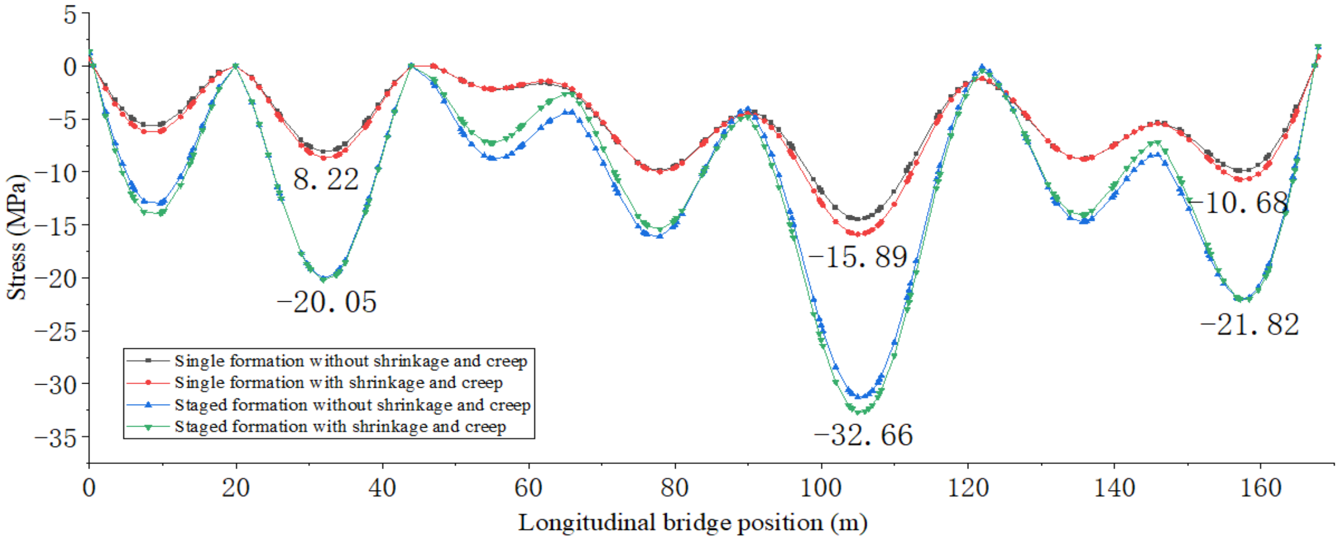


Figure 17. Bridge deflection under different calculation methods (MPa).

5.2. Stress Difference in the Completed Bridge

In a model of one-time formation of a composite section, the main girders have formed a composite section before they are subjected to dead loads. At this point, the upper flange of the steel beam is in the position of the neutral axis of the combined section. When a bridge is completed, the upper flange of a steel beam that forms a composite section at one time is subjected to very little tensile and compressive stresses. The upper flange stresses of steel girders that form a composite section at one time differ greatly from those of staged bridges. Compared with the calculation data of the composite section model formed at one time, the maximum tensile stress of the d5 section increases by 84.0 MPa and the maximum compressive stress of the k5 section increases by 46.2 MPa during the calculation of phased construction. Therefore, it will be seriously distorted if the flange stress on the steel beam is calculated by using a one-time completed bridge model. The upper flange stress of steel beams under different calculation methods is shown in Figure 18. The meaning of the line segment is the same as in Figure 17.

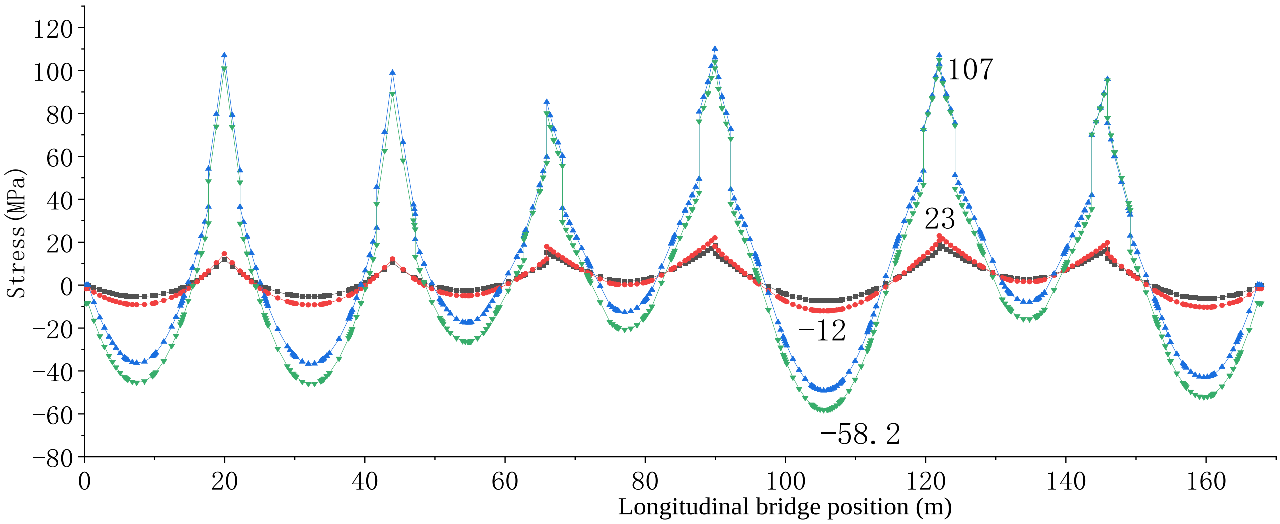


Figure 18. Upper flange stress of steel beam under different calculation methods (MPa).

By using the single forming method of the combined section, the mid-span tensile stress of the lower flange of the main beam and the compressive stress near the pier top can be studied clearly under different working conditions. The lower flange stress of steel beams under different calculation methods is shown in Figure 19. The meaning of the line segment is the same as in Figure 17.

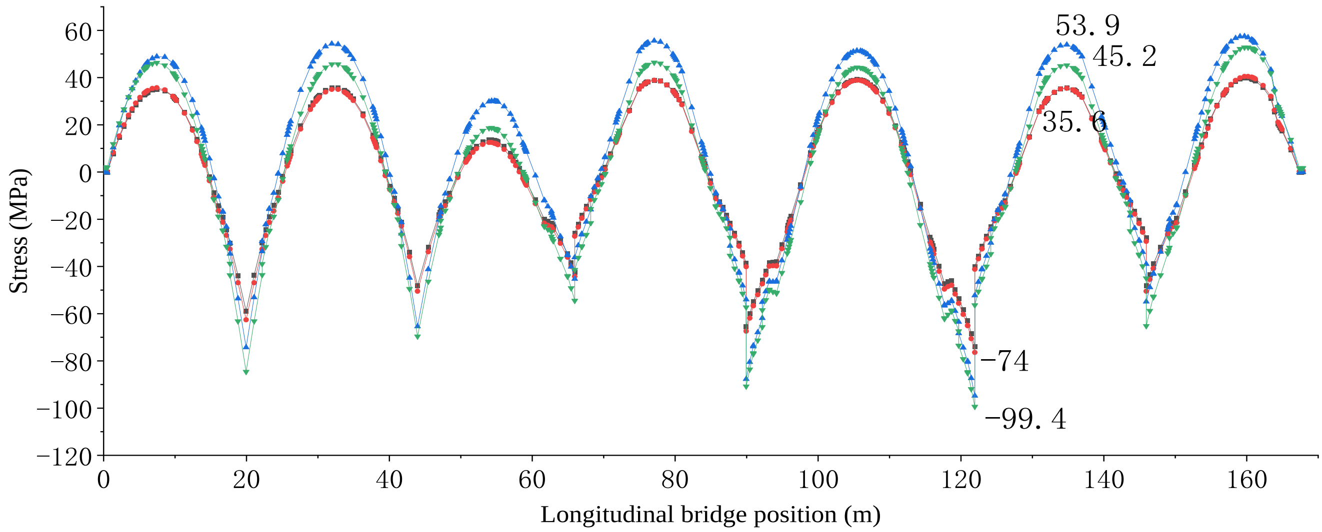


Figure 19. Lower flange stress of steel beam under different calculation methods (MPa).

The maximum tensile stress of the upper flange of concrete is 3.3 MPa when the combined section is formed at one time and the maximum compressive stress of the main span is 0.35 MPa. The calculation results show that the concrete has already cracked, which is seriously inconsistent with the actual situation. Stresses of the upper and lower edges of concrete slabs under different calculation methods are shown in Figures 20 and 21. The meaning of the line segment is the same as in Figure 17.

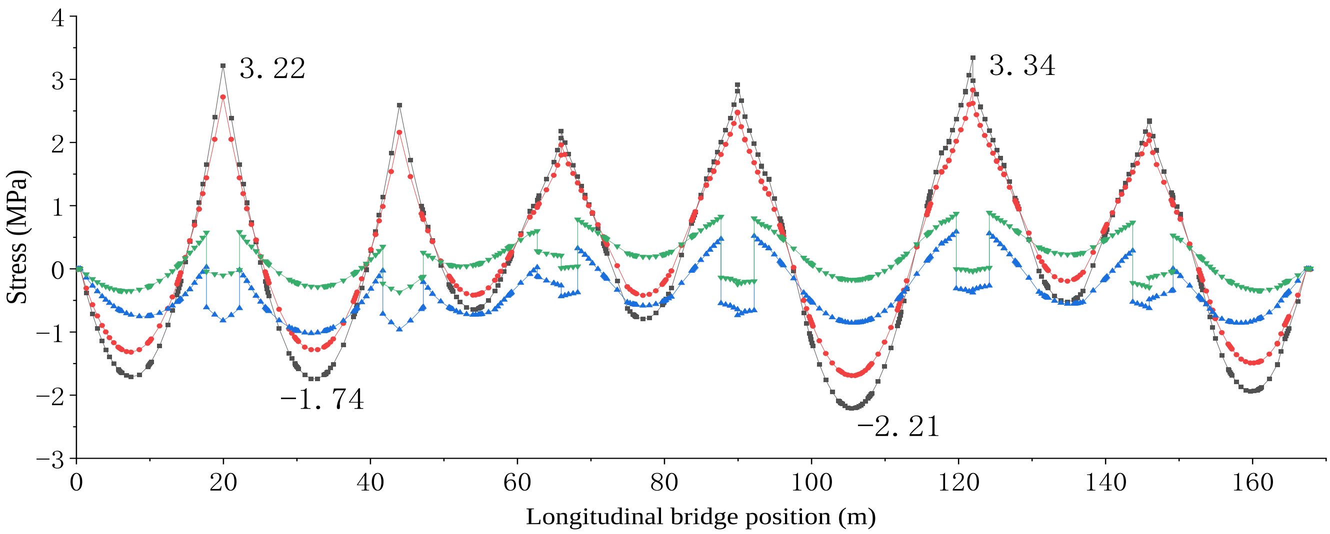


Figure 20. Upper edges of concrete slabs under different calculation methods (MPa).

In general, when carrying out simulation analysis for composite structure bridges, in order to consider the completed state of the composite bridge, it is necessary to carry out accurate simulation for its construction stage.

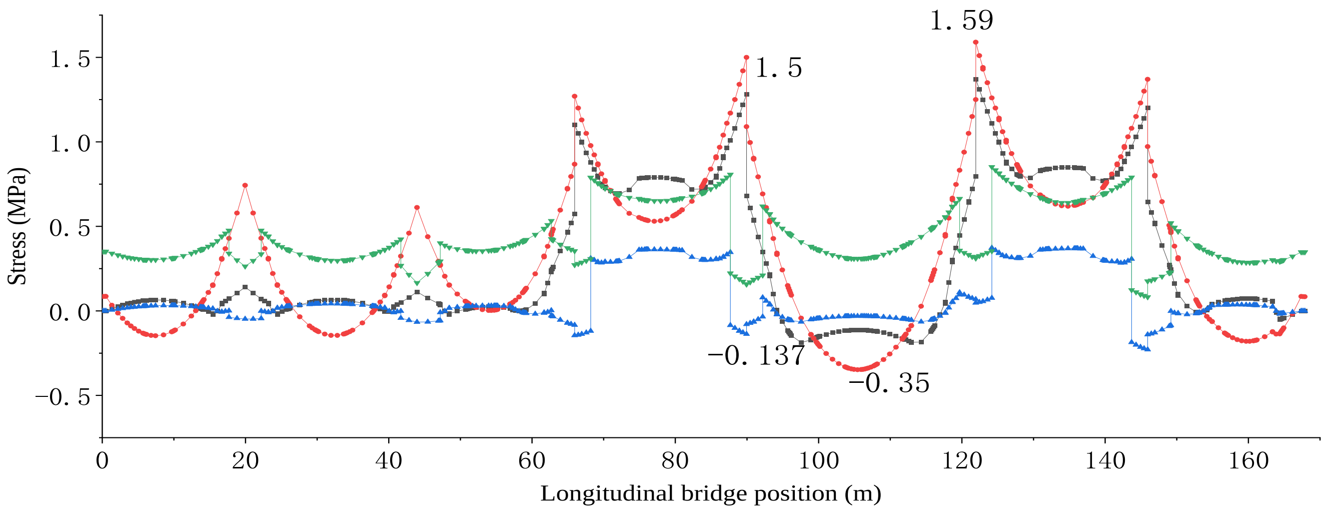


Figure 21. Lower edges of concrete slabs under different calculation methods (MPa).

6. Conclusions

This paper centers on the first continuous beam and V-shaped pier rigid frame bridge with a steel–concrete composite girder in China. Based on the elasticity theory, a finite element analysis model of the whole bridge considering the construction stages was established by combining the structural characteristics and the construction process. Then, the initial stress state of the girders in each main construction stage is analyzed and the following conclusions are obtained.

(1) The stress of the upper flange of the steel beam in a cast-in-place section of the pier top is basically stable after the completion of cast-in-place concrete construction. Thereafter, the secondary load has no obvious effect on the stress of the upper flange of the steel beam. The substructure of the V-shaped pier results in additional tensile stress on the lower flange of the steel girder at the top of the V-shaped pier;
(2) When the tensile stresses in the upper flange of the steel main girders at the top of the vertical and V-shaped piers are equal in magnitude, in the upper and lower edges of bridge slabs, the compressive stress reserve of the vertical pier is higher than that of the top cast-in-place section of V-shaped pier;
(3) The bridge formation model without considering the construction process was compared with the finite element calculation results considering the construction process. The difference in stresses in the concrete slab between the two cases is found to be up to 2.7 MPa, indicating that the stress state in the bridge formation of the continuous beam and V-shaped pier rigid frame bridge with a steel–concrete composite girder is strongly influenced by the construction process;
(4) There is a certain tensile stress on the upper edge of the concrete bridge floor in the negative bending moment area at the top of the V-shaped pier under the condition of bridge formation, up to 0.5 MPa, and the tensile stress may increase under the action of load, temperature difference, shrinkage, creep, etc., which is unfavorable to the stress of the concrete structure. During construction, prestressed steel bundles can be considered to make the fulcrum attachment bridge panel have a certain compressive stress when the bridge is formed.

Author Contributions: Conceptualization, Y.Z.; Resources, Y.X.; Data curation, T.Y. and W.L.; Writing—original draft, T.Y.; Writing—review & editing, Y.Z. All authors have read and agreed to the published version of the manuscript.

Funding: The support of the Natural Science Foundation of China (Grant No. 51908093), Chongqing Returned Overseas Scholars' Entrepreneurship and Innovation Support Funds (Grant No. cx2018113, cx2020117), the Science and Technology Research Program of Chongqing Municipal Education

Commission (Grant No. KJZD-K202300702), and National Key R&D Program Fund (Grant No. 2022YFB2302501−3) are greatly appreciated.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in this article. All data included in this study are available upon request by contact with the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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