

**Research Article**

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The Influence of Auxiliary Piers on the Mechanical Properties of Single Tower Cable-Stayed Bridge

Faqing Wang¹ and Kongliang Chen^{1*}¹Institute of Civil Engineering of Wuyi University, Jiangmen, China***Corresponding authors:** Kongliang Chen, Institute of Civil Engineering of Wuyi University, Jiangmen, 529020, China.**Received Date:** February 03, 2026**Published Date:** March 12, 2026**Abstract**

Taking a single-cable-plane steel-concrete composite beam cable-stayed bridge as the research object, the Midas/Civil software was adopted to establish finite element models for two structural systems with and without auxiliary piers respectively. The mechanical performance of the two structural systems was calculated, and their bending moments, displacements, natural frequencies and modal characteristics were compared and analyzed. The results show that the arrangement of auxiliary piers in the side spans has a relatively minor effect on the internal forces and displacements of the single-tower cable-stayed bridge. In terms of dynamic characteristics, the addition of auxiliary piers exerts a certain influence on the vibration modes and frequencies of the bridge, which thus requires a balanced consideration in accordance with the design requirements during the design process.

Keywords: Cable-stayed bridge; Auxiliary pier; Main span; Natural frequency**Introduction**

Cable-stayed bridges feature excellent structural load-bearing performance, clear force transmission paths, large spanning capacity and aesthetic structural forms, thus being widely applied in bridge engineering. Long-span cable-stayed bridges are typical flexible structures and generally present flexible mechanical characteristics [1-6]. The installation of auxiliary piers on the side spans of cable-stayed bridges offers multiple benefits, it not only enhances the overall structural rigidity and stability but also optimizes the structural mechanical performance in general. For instance, it can significantly reduce the horizontal displacement at the tower top, the bending moment at the tower base and the internal forces of the main girder; additionally, it improves the stability of the main girder during construction and effectively mitigates the adverse double-cantilever state of the main girder in

the construction stage. At present, auxiliary piers are installed on the side spans of nearly all long-span cable-stayed bridges that have been completed or are under construction.

Project Overview

This single-pylon cable-stayed bridge has a total length of 320 meters, configured with two-way four motor lanes, two slow traffic lanes and two sidewalks. The main structure of the bridge is supported by a single large-scale pylon with two cable planes for span bearing, adopting a steel-concrete composite structure. Its side spans are constructed with fish-bellied prestressed concrete girders. The bridge pylon features a straight design with a total height of 90 meters, where the vertical height from the deck to the pylon top is 68 meters. Stay cables are densely arranged in a fan pattern on the pylon at a standard spacing of 3.0 meters; on the

girders, the standard spacing of stay cables is 6 meters for the side spans and 12 meters for the main span, respectively.

In summary, this bridge project adopts an advanced design and structural system, which not only satisfies the traffic service requirements but also ensures the overall safety and structural stability of the bridge.

Establishment of Finite Element Model

For the calculation of the overall structural stress of the main bridge, the Midas/Civil software was adopted based on the spatial beam finite element method. This method enables the establishment of a full-bridge finite element model encompassing the main girder, pylon, stay cables and foundation, for the purpose of analyzing the structural stress state of the bridge.

The main girder and pylon were modeled with spatial beam elements, while the stay cables were simulated with tension-only

truss elements that automatically incorporate the material elastic modulus correction. A spine beam model was applied to the main girder, which is connected to the stay cable nodes via transverse rigid arms.

The side piers of the bridge are connected to the main girder, with their vertical degrees of freedom constrained by special measures. Bearing supports are arranged at the actual bearing positions of the main girder and guided by steel arms, which constrain the transverse translational degree of freedom of one bearing point. The pylon is rigidly connected to the corresponding nodes of the main girder, and the bottom of the main pylon is treated as a fixed support in the model. The aforementioned calculation method and finite element model were employed to conduct the structural stress analysis of the main bridge, facilitating an in-depth understanding of its stress state and structural performance. The finite element calculation model without auxiliary piers is shown in Figure 1, and that with auxiliary piers is shown in Figure 2.

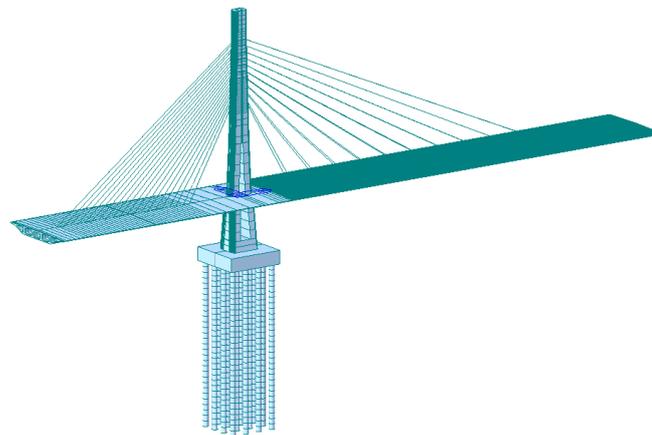


Figure 1

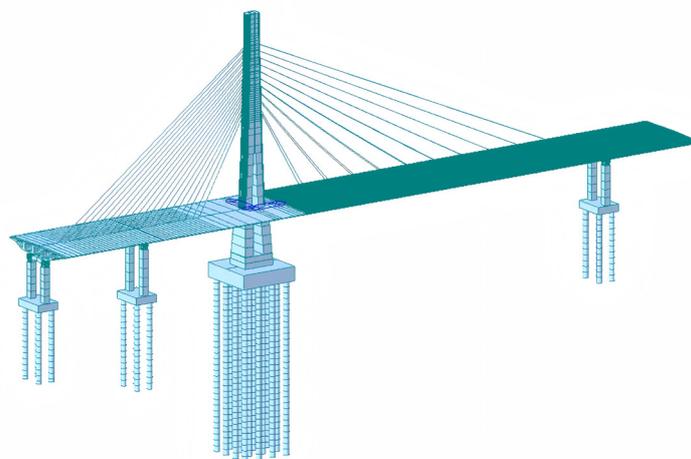


Figure 2

Setting of Auxiliary Piers

The auxiliary pier can play a limiting role in the stress system of long-span cable-stayed bridges, so its setting method will have a significant impact on the static and dynamic characteristics of the structure. That is to say, it will also have a significant impact on the seismic response of the structure. From a static perspective, the

installation of auxiliary piers can make the structure of long-span cable-stayed bridges more robust, reduce internal forces at the bottom of the tower under live loads, and minimize displacement of the main beam structure. From a power perspective, the installation of auxiliary piers can have a strong restraining effect on the vibration of the main beam (Table 1).

Table 1: Material Property Parameters.

Strength grade	Elastic modulus E_c	Standard value of axial compressive strength f_{ck} (MPa)	Standard value of axial tensile strength f_{tk} (MPa)	Corresponding components
C55	3.55×10^{10}	35.5	2.74	Main beam, cable tower
Q345	2.06×10^{11}	345	345	Main beam

Calculation of the Impact of Auxiliary Pier Settings on the Structure

The setting of auxiliary piers will have multiple impacts on the structure. It can reduce the bending moment and deflection of the main beam and improve the overall stiffness of the structure.

At the same time, it can also improve the stressful performance

of the structure, making it more stable.

The influence of auxiliary piers on the internal forces of the main beam and tower

Primary Dead Load mainly comprises the self-weight of the main beam, crossbeams, bridge towers, and stay cables, with the density of concrete taken as 26 kN/m^3 and that of steel as 76.98 kN/m^3 .

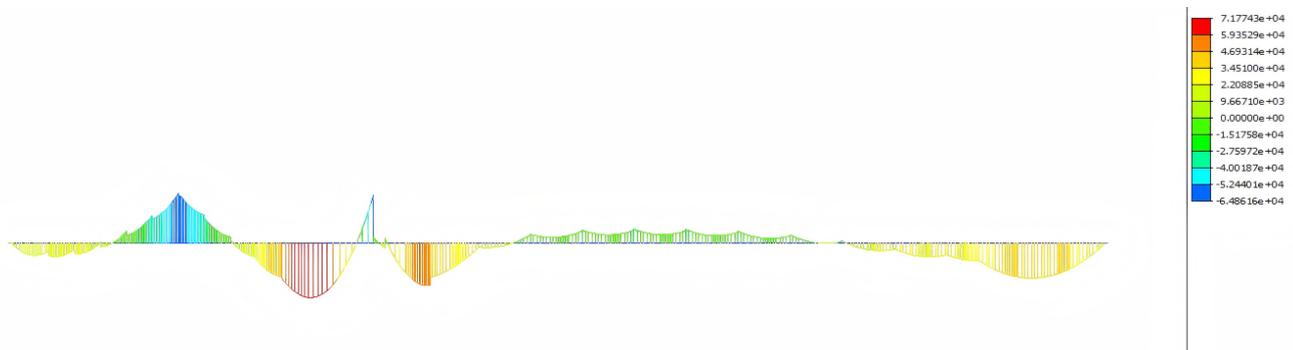


Figure 3

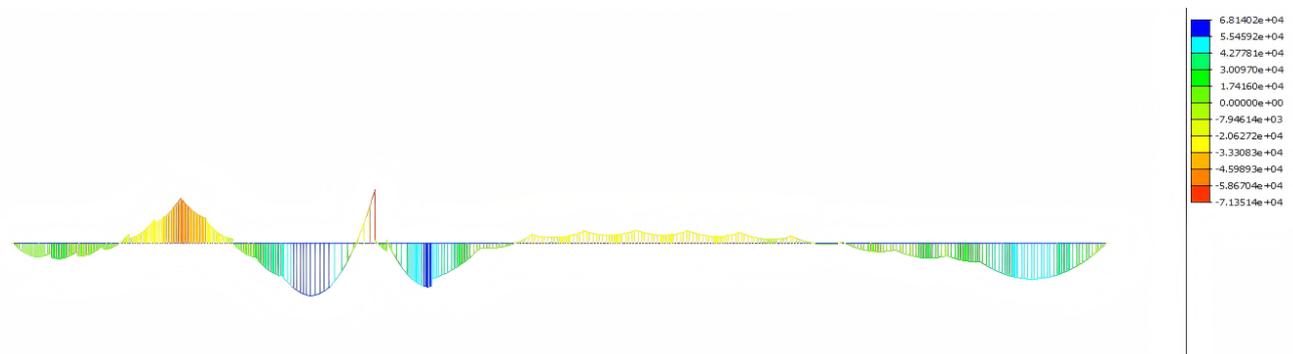


Figure 4: Bending moments with auxiliary piers.

Secondary Dead Load is primarily composed of anti-collision guardrails, sidewalk slabs, bridge deck paving, and water supply pipes. A comparative analysis of the main beam bending moments under constant load conditions without and with auxiliary piers are presented in Figures 3 and 4.

As shown in the figure, under constant load:

- (1) The main beam bending moment and main tower bending moment of the two structural systems have the same trend of change.
- (2) The maximum positive bending moment of beams with and without auxiliary piers occurs at a distance of 15m from the main tower, and bridges with auxiliary piers reduce it by

5.1% compared to bridges without auxiliary piers.

- (3) The maximum negative bending moment of the main beam with auxiliary piers occurs at a distance of 47m from the main tower, while the maximum negative bending moment of the main beam without auxiliary piers occurs at a distance of 4m from the main tower. Bridges with auxiliary piers have an increase of 10% compared to bridges without auxiliary piers.

The influence of auxiliary piers on the displacement

Under constant load, the comparative analysis of displacement between the main beam without and with auxiliary piers are shown in Figures 5 and 6. The comparative analysis of lateral displacement of the main tower is shown in Figures 7 and 8.

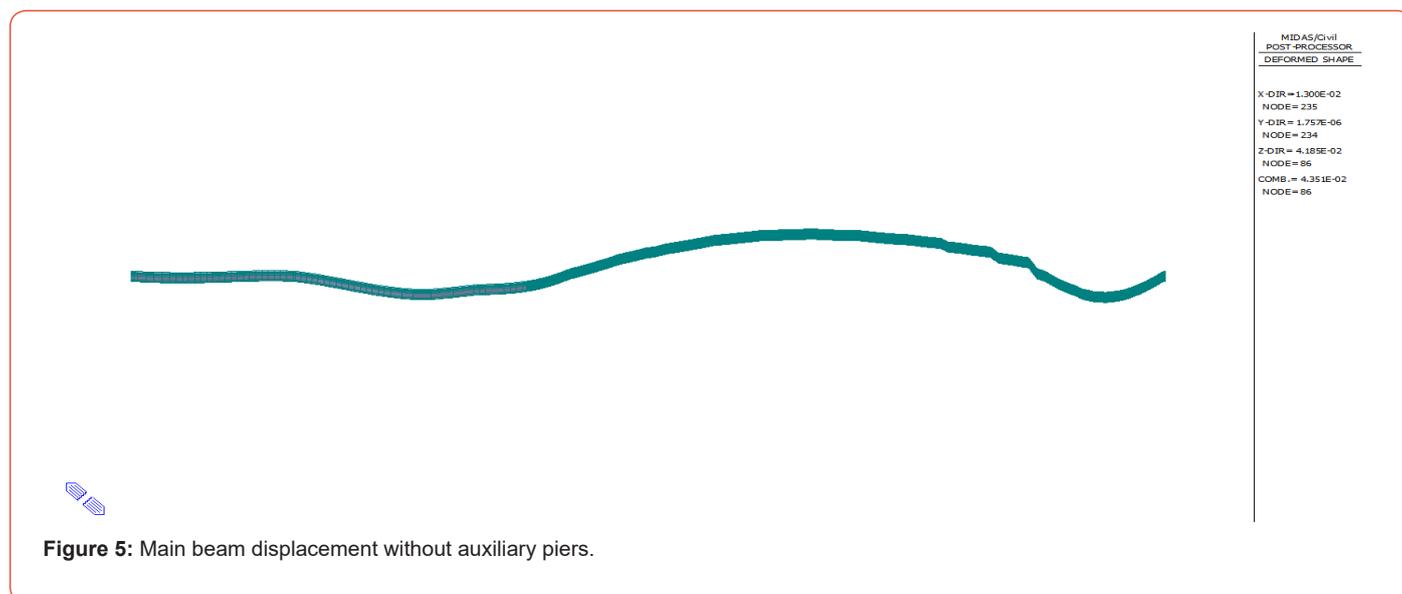


Figure 5: Main beam displacement without auxiliary piers.

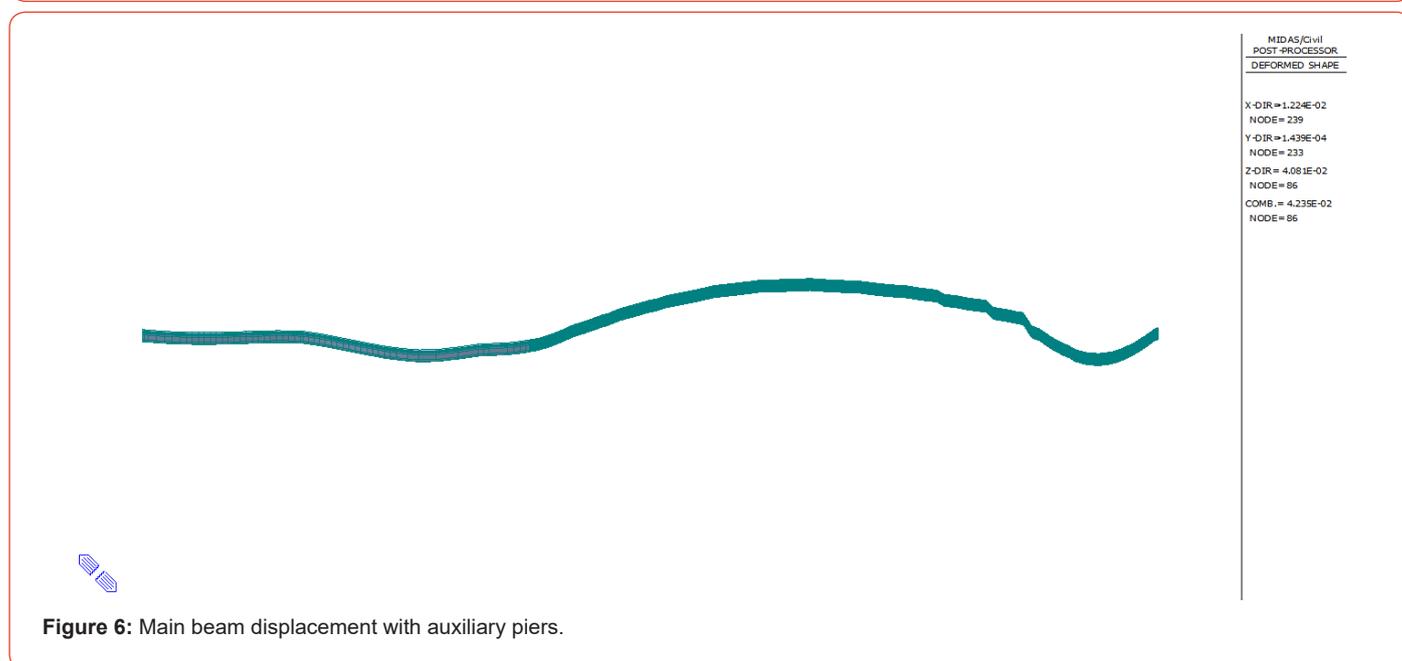


Figure 6: Main beam displacement with auxiliary piers.

As shown in the figure under constant load:

- (1) The displacement trend of the main beam under constant load is consistent for the two structural systems.
- (2) The maximum of both structural systems occurs at a

distance of 114.5m from the main tower.

- (3) The minimum horizontal and vertical displacement of the main tower in both structural systems occurs at the top of the tower.

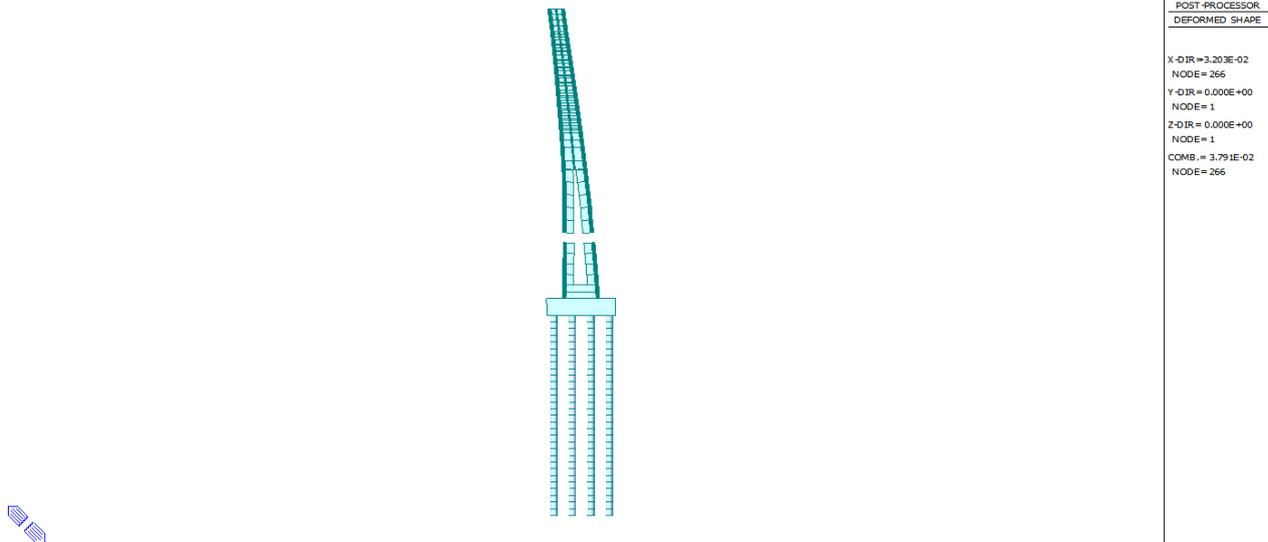


Figure 7: Tower displacement without auxiliary piers.

Table 2: Data Comparison.

Model number	With auxiliary piers		Without auxiliary pier	
	f/Hz	Vibration mode description	f/Hz	Vibration mode description
1	1.20	First-order vertical bending of the main span beam; longitudinal bending of the main tower	1.20	First-order vertical bending of the main span beam; longitudinal bending of the main tower
2	1.97	Second-order vertical bending of main-span girder; longitudinal Bending of main tower	1.78	First-order transverse bending of side-span and main-span Girders ;transverse bending of main towers
3	2.58	Third-order vertical bending of main-span girder; longitudinal bending of main towers	2.09	Second-order vertical bending of main-span girder; transverse Bending of Main Tower
4	3.27	First-order Transverse Bending of side-span and main-span girders, transverse bending of main tower	2.17	Secondary-order Transverse Bending of Main-span Girder; transverse Bending of Main Tower
5	4.36	Fourth-order vertical bending of main-span girder; longitudinal bending of main tower	2.60	Third-stage vertical bending of main-span girder; longitudinal Bending of Main Towers

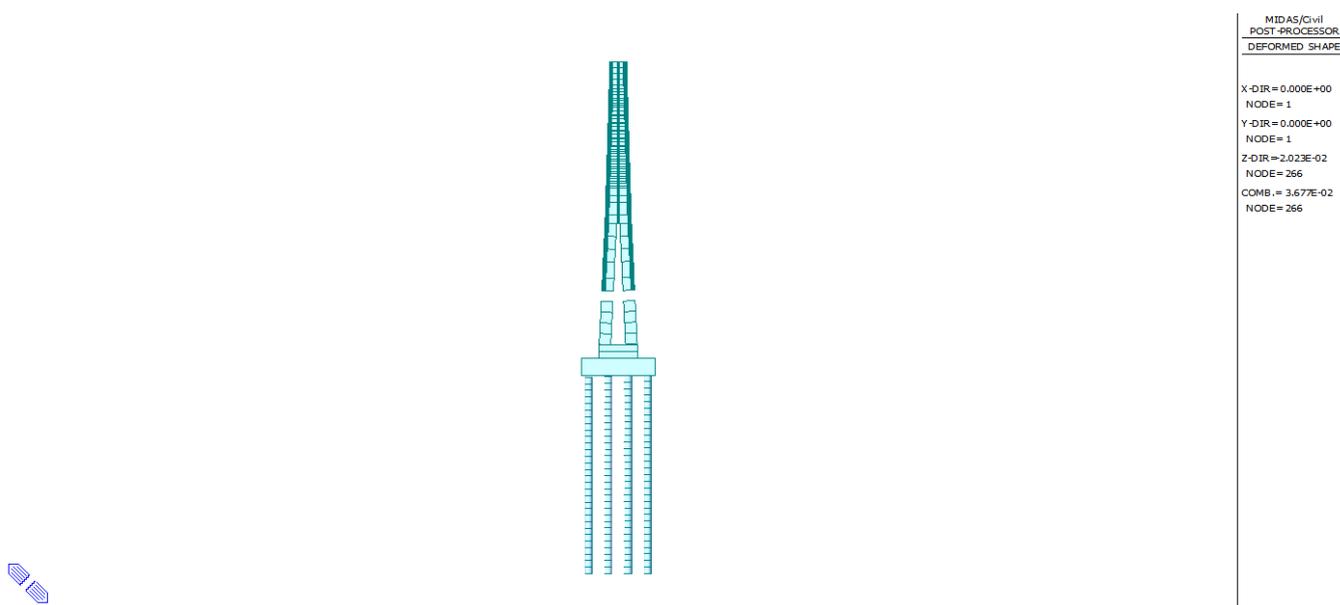


Figure 8: Tower displacement with auxiliary piers.

Analysis of the Natural Frequency and Mode Characteristics of Auxiliary Piers

Through dynamic analysis of two structural systems of a single-tower cable-stayed bridge based on table 2, the following conclusions are drawn:

(1) The installation of auxiliary piers exerts no influence on the first-order vibration mode of the cable-stayed bridge (natural frequency: 1.2 Hz), where the main span girder undergoes first-order vertical bending and the main tower experiences longitudinal bending in both systems.

(2) For the cable-stayed bridge with auxiliary piers, Second-order vertical bending of main-span girder appears as the second-order mode (natural frequency: 1.97 Hz), and this mode is the third-order one (natural frequency: 2.09 Hz) in the system without auxiliary piers. The presence or absence of auxiliary piers has a negligible effect on the vertical bending frequency of the main-span girder.

(3) In the system with auxiliary piers, the transverse bending mode of the main tower is the fourth-order mode (natural frequency: 3.27 Hz), while in the system without auxiliary piers, it is the second-order mode (natural frequency: 1.78 Hz). The transverse bending mode of the main tower in the system with auxiliary piers is delayed by two orders relative to those without auxiliary piers, with a higher corresponding natural frequency. This indicates that the installation of auxiliary piers significantly improves the overall stiffness of the bridge.

Conclusion

From the analysis outcomes of the cable-stayed bridge considering the presence and absence of auxiliary piers, the conclusions below are summarized.

(1) The bending moment variation trends of the girders and main towers are consistent in the two structural systems, and the installation of auxiliary piers can effectively reduce the bending moments of the girders and main towers of the single-tower cable-stayed bridge.

(2) Under dead load, the displacement variation laws of the girders and main towers are identical in the two systems. Adding auxiliary piers is conducive to restraining the displacement and deformation of the girders and main towers of the single-tower cable-stayed bridge.

(3) The installation of auxiliary piers has a notable effect on the vibration mode and natural frequency of the main tower, which is beneficial for enhancing the stiffness of the main tower. It exerts a negligible influence on the vertical bending vibration modes and natural frequencies of the main span girders, yet exerts a significant impact on their transverse bending performance. Specifically, this measure elevates the fundamental natural frequency of the structure and effectively enhances its overall stiffness.

Acknowledgement

None.

Conflict of Interest

No conflict of interest.

References

1. Ma Ning (2014) Analysis of the influence of auxiliary pier settings on the internal forces of cable-stayed bridges . Northern Transportation 6: 32-35.
2. Fan Xiaobo (2016) Research on Optimization Setting of Auxiliary Piers for High low Tower Cable stayed Bridges. Chang'an University.
3. Liu Hongyan (2018) Analysis of the influence of auxiliary piers on the dynamic and static mechanical properties of long-span composite beam cable-stayed bridges. Chang'an University.
4. Zhou Qiong (2013) The influence of auxiliary pier tension compression bearings on the dynamic characteristics and seismic response of a high and low tower cable-stayed bridge. Changsha University of Science and Technology.
5. Li Jianglong (2009) The influence of auxiliary piers on the static and dynamic response of cable-stayed bridges. Harbin Institute of Technology.
6. Bu YJ (2014) Study on dynamic behavior and seismic performance of cable stayed bridge with different auxiliary pier positions. Applied Mechanics and Materials 587-589:1655-1658.