Mechanical Analysis and Structure Health Monitoring of Congruence Beam Cable-stayed Bridge

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Abstract: The Wajiatan Yellow river bridge is a congruence beam cable-stayed bridge, which was analyzed by finite element method to simulate the structure dynamic characteristics and structure response under different loads. By numerical simulations, the structure dangerous points and structure monitoring priorities can be obtained. The analysis results can be used to guide the arrangement of measurement gauges in bridge health monitoring.

Introduction

There are many factors lead to bridge safety problems. It is necessary to identify the hazard factors to design bridge. During the life cycle of the bridge health monitoring system, the factors lead to threat of structural safety[1~3]. While designing a bridge health monitoring system, the structural analysis should be carried out firstly, and then the arrangement of measurement gauges should be determined. The mechanical behavior of the bridge structure should be grasped, and the key components and positions of the structural stress should be clarified to guide the sensor arrangement[4]. This paper analyzes the static, dynamic and seismic response of the Wajiatan Yellow river bridge to grasp the law of the structure force and examine the key parts of the structure stress, it provides scientifically and reasonably detailed information for arranging measuring points [5].

The Wajiatan Yellow river bridge is the largest cable-stayed bridge with double pylons and double cable planes in Qinghai Province. The main bridge is 1000 meters in length (104+116+560+116+104), which is steel-concrete congruence beam cable-stayed bridge with double pylons and double cable planes. The total height of the main towers are 186.2 and 193.6 meters respectively. The inclined cables are arranged in a fan-shaped arrangement and 88 pairs of cables are made of low-relaxation galvanized high-strength steel wires. The cable stays are anchored on the main girder using an anchor plate. The main beams, crossbeams and small longitudinal beams whose shapes are connected by a friction type high-strength bolt into steel girder sections. The main girder is equipped with a longitudinally movable and a vertically rigid spherical[5].

Analysis of the risk of cable-stayed bridges

The structural analysis of damage sensitivity and other aspects is carried out. At the same time, combined with the measured data can be further calculated and analyzed for structural state assessment[6~7]. In this paper, the main calculation contents include: stresses of main beam in operation stage, stresses of cable, displacements of tower and beam, etc.

Numerical simulation model

The stay cable adopts a rod unit, and its elasticity modulus is modified according to the Ernst formula. The main beam and the cable tower adopt linear finite strain beam elements. In the analysis of the self-vibration characteristics of the finished bridge state, the secondary dead load is simulated by the mass unit. The bottom of the cable tower is fixed. The tower girders are all living hinge supports and a single rod unit is used to simulate vertical support. The end of the concrete beam is used as the origin of the coordinate system. The final finite element model is shown in Fig. 1.
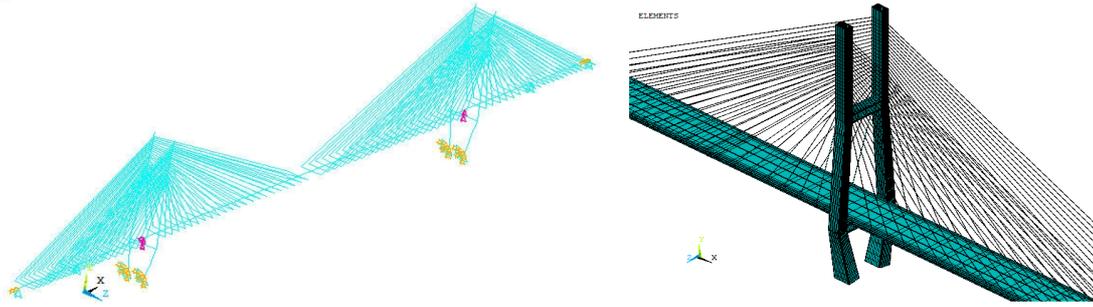
Fig. 1 Finite element model

Static analysis

Considering the structural response under dead load and live load, the static calculation and analysis of the structure is performed. Under the combined effects of dead load and live load, the stress envelope diagrams for cables and towers are shown in Fig. 2 to Fig.4, respectively. Under the action of live load, the displacement envelope diagrams of beams and towers are shown in Fig. 5 to Fig.7, respectively.
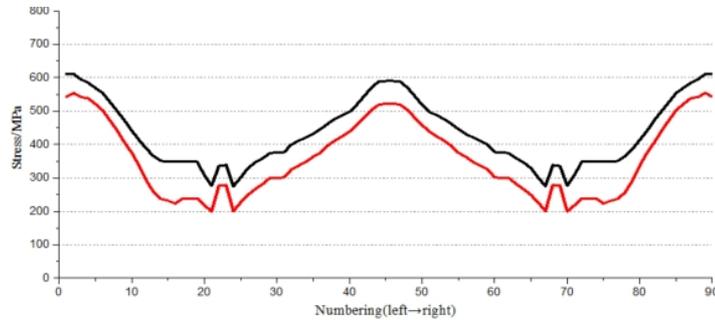

Fig. 2 The stay cable stress envelope
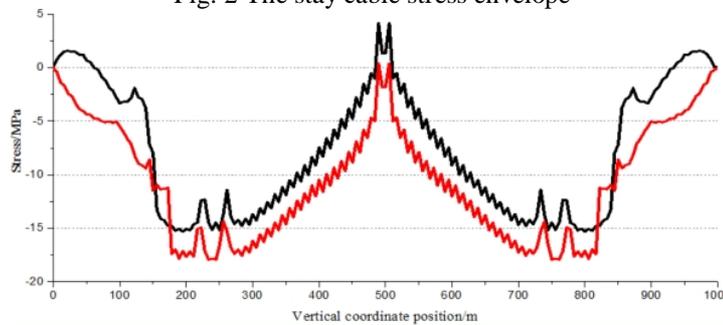
Fig. 3 The stress envelope of upper edge of main girder
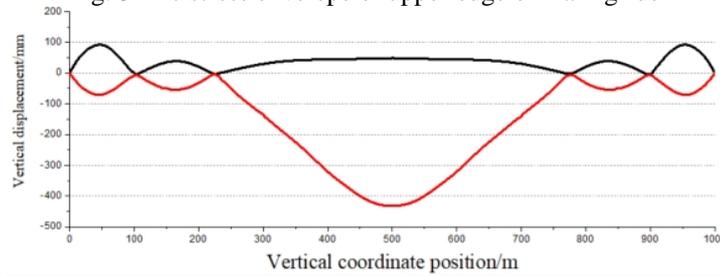
Fig.4The vertical displacement envelope of main girder
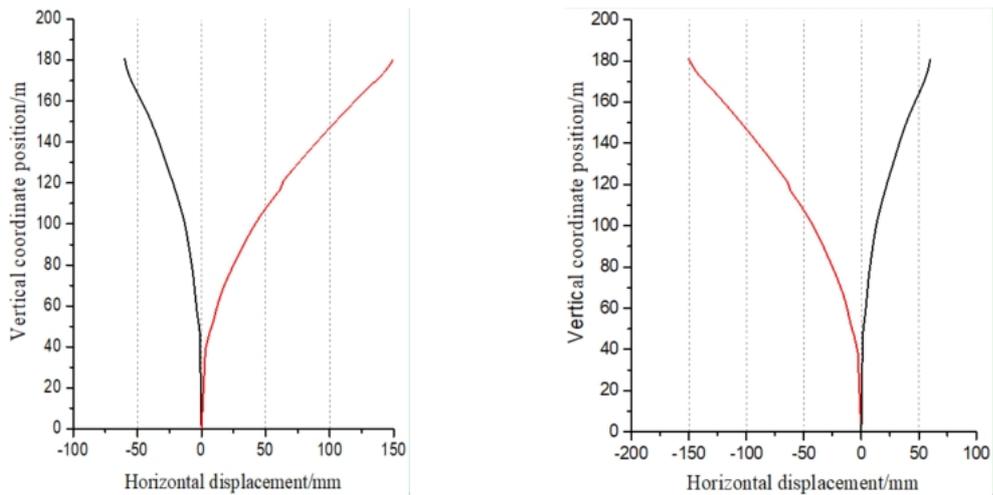
Fig. 5longitudinal displacement envelope of 20# tower   Fig.6ongitudinal displacement envelope of 21# tower

Through calculation and analysis, the maximum vertical deflection occurs at the mid-span position of the main girder. However, the maximum horizontal displacement of the cable tower occurs at the top. These locations are not only the key points of the structure displacement control, but also the control parameter selection of the monitoring instrument. Under the action of load, the distribution of cable force and stress is more uniform, the tail cable and the shortest cable with higher stress levels and large change amplitudes can be selected by monitoring. The stress of the girder is greater at the cable tower and the mid-span of side span. These locations can be preliminarily identified as the critical control points for structural stress.

Dynamic characteristics analysis

The bridge dynamic parameters can reflect the overall characteristics of the bridge structure. The important structural self-vibration characteristics are shown in Table 1.

Table 1. Structural self-vibration characteristics and description

Order	Frequency（Hz）	Period（s）	Mode description
1	0.1132	8.8370	main beams longitudinal drift
2	0.2624	3.8108	Main beam first-order symmetrical lateral bending
3	0.2766	3.6151	Main beam first-order symmetrical vertical bending
4	0.3298	3.0319	Main beam first-order symmetrical twist
5	0.3567	2.8033	number 21 tower column side bend
6	0.3620	2.7622	Main beam first-order anti-scaling
7	0.3824	2.6147	number 20 tower column side bend

As shown in dynamic analysis, the first vibration mode of the structure is a longitudinal drift. It is possible to arrange a forward bridge acceleration measurement point. The second-order vibration mode is symmetrical lateral bending, and a lateral acceleration measuring point can be arranged at the maximum lateral vibration amplitude of the main span. A vertical acceleration measuring point is arranged in upstream and downstream of the mid-span.

Seismic response analysis

While an earthquake occurs, the vibrations reflected on the ground surface may not be exactly the same because the seismic waves received by the ground point may pass through different paths. The two main towers of the Wajiatan Yellow river bridge are far apart, and the seismic waves received by the different source distances are bound to have a phase difference[8~9]. In this paper, the large-mass method is used to analyze the response of the bridge under the excitation of seismic waves, and the influence of the seismic traveling wave effect on the structure is analyzed.

The basic earthquake acceleration in the area is located as 0.1g with the fortification intensity VII. Based on the above features, the adjusted EL-Centro wave is used as the input seismic wave in the

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