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EVALUATION OF BEARING CAPACITY OF LARGE-SPAN CONCRETE ARCH BRIDGES BASED ON DYNAMIC AND STATIC LOAD TESTS

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Анотація

Як незамінна структура в нашому щоденному транспорті, мости продовжують зменшуватися з часом. В данній роботі розглядається приклад з великим прогином бетонної арки і використовується MIDAS для встановлення аналізу теорії кінцевих елементів та моделі розрахунку. За допомогою динамічних та статичних випробувань навантаження ми отримуємо динамічні характеристики, такі як структурний штам та зміни відхилення мостової структури під статичним навантаженням, частоту самовібрації структури під час динамічного навантаження для визначення фактичної вантажепідйомності мосту.

Ключові слова：Динамічний та статичний тест навантаження；бетонна арка -міст；оцінка потужності

Abstract

As an indispensable structure in our daily transportation, bridges have continued to decline as time goes by. This paper takes a large-span concrete arch bridge as an example, and uses Midas to establish a finite element theory analysis and calculation model. Through dynamic and static load tests, we obtain dynamic characteristics such as the structural strain and deflection changes of the bridge structure under the static load test, the structure's self-vibration frequency and impact coefficient under the dynamic load test, so as to determine whether the actual load carrying capacity of the bridge meets the normal use requirements, ensure the safety of the structure, and establish a bridge "fingerprint" file.

Keywords：Dynamic and static load test；Large span concrete arch bridge；carrying capacity assessment

Introduction

As the world's largest bridge power, China has more than 961,100 highway bridges as of the end of 2021. However, the problem of bridge aging is gradually becoming prominent, and costs for dangerous and old bridge renovation and reinforcement are also increasing due to structural (component) damage and material aging. Therefore, improving the bridge management system, accurately understanding the actual status of the bridge, scientifically and accurately judging the bridge bearing capacity and safety performance, providing economic and reasonable design solutions for subsequent bridge reinforcement and transformation, and continuously improving the bearing capacity and service life of the bridge has become an urgent engineering problem to be solved at present.

Purpose and significance of bridge static load test

Therefore, this paper takes a large-span concrete arch bridge as an example, uses Midas to establish a finite element theory analysis and calculation model, and conducts dynamic and static load tests based on its current use, analyzes the current structural stress status, evaluates its bearing capacity and safety performance, and provides reference for subsequent large-span concrete arch bridge bearing capacity evaluation.

The bridge is a middle-bearing steel box tied arch bridge with a total length of 655.4m. The main bridge is 230m long and the span is 46m+138m+46m. The south approach bridge is a 90m cast-in-place continuous beam, the north approach bridge is a 120m cast-in-place continuous beam, the guide lane is 215.4m. The bridge deck is a two-way four-lane, the total width of the bridge deck is 28m. Both sides are pedestrian and non-motor vehicle lanes. The bridge is designed to have a city-A magnitude, an earthquake intensity of 8 degrees, a main beam concrete C50, and a main arch ring steel: Q345.

and reinforcement data and on-site inspection data, Midas is used to establish a finite element theory analysis and calculation model. The whole bridge uses beam units to build a model. The main bridge is connected in an elastic connection mode. The constraints at both ends of the main bridge are in the form of sliding constraints, and the arch bridge is in the form of fixed constraints. Loading mainly detects the main arch ring, and the loading method considers symmetric loading and asymmetric loading. Vehicle loads are mainly loaded in the form of concentrated loads.

and determination of control loads are the top priority. In this static load test, the control load is based on the principle of loading the internal force influence line of the control section, and the load value corresponding to the calculated internal force value of the control section is taken. Theoretically, the control load should be the same as the test load, but during the test, the test load and the control load are often slightly different. Therefore, in order to ensure the smooth implementation of the test and the authenticity of the test results, the static load test efficiency is used to control the magnitude and loading position of the test load. Arrange the load according to the most unfavorable working conditions calculated or detected by theoretical calculations to achieve maximum test efficiency of the control section[1].

Load efficiency is expressed by definition：

$$\eta_q = \frac{S_t}{S_d(1+\mu)} \tag{1}$$

Where：

S_t ——Calculated value of detection site deformation or internal force under the action of test load；

S_d ——Calculated values of detection site deformation or internal force under the action of design standard loads (considering spatial action and impact coefficient)：

μ ——Designed impact coefficient.

According to the regulations， η_q Should be satisfied：

$$0.85 \le \eta_q \le 1.05$$

This experiment determines the test operating conditions based on the impact line calculated by the finite element static analysis, and then determines the vehicle counterweight, wheel position layout, etc. according to the vehicle loading requirements of each test operating condition. The vehicle information loaded in this test is shown in Table 1.

Table1— Loading the vehicle reference table

Vehicle number	Total weight/KN	Axis weight/KN			Wheelbase/m		Wheel range/m
		Front axis	Central axis	Rear shaft	Front middle	After the time	
1	351.4	71.5	140.4	140.4	3.8	1.4	1.8
2	349.8	71.8	139.6	139.8	3.8	1.4	1.8
3	352.3	72.2	140.2	140.1	3.8	1.4	1.8
4	351.2	73.5	139.8	139.5	3.8	1.4	1.8

The test section and loading conditions of this test are shown in Figure 1 and Table 2 respectively:

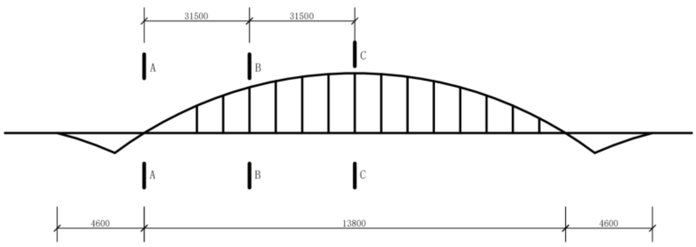

Figure 1— Schematic diagram of the load test control section

Table 2 — Bridge test section and test content

Working conditions	Vehicle loading location	Test content
1	Vault cross-section symmetric loading	C-CCross-section strain, deflection
2	Eccentric loading of vault section	C-CCross-section strain, deflection
3	Symmetric loading of arch feet	A-ACross-section strain
4	Eccentric loading of arch feet	A-ACross-section strain
5	Quarter arch symmetrical loading	B-BCross-section strain
6	Quarter arch eccentric loading	B-BCross-section strain

The specific test sections are shown in Figures 2 and 3:

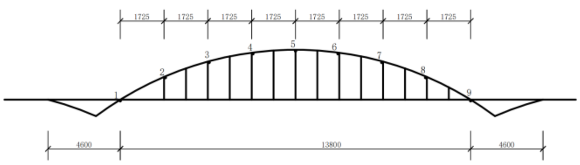

Figure 2— Strain measurement point diagram

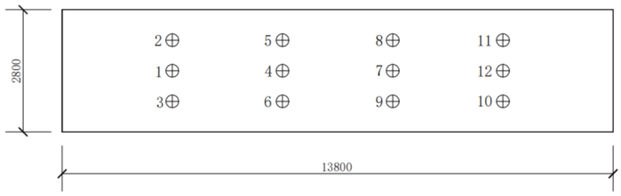

Figure 3 — Deflection measurement point layout plan

The test load efficiency is shown in Table 3.

Table 3— Test load efficiency

Working conditions	Design load effect	Test load efficiency	Loading efficiency
1	1400.3KN	1260.3KN	0.95
2	1391.8KN	1266.5KN	0.97
3	1365.8KN	1270.2KN	0.98
4	1354.6KN	1273.3KN	0.98
5	1378.5KN	1268.2KN	0.99
6	1347.7KN	1280.3KN	0.95

In the test, in order to eliminate the interference of temperature difference on the test results, the test should choose a time period with a small change in temperature difference for testing, and adopt a test method of rapid unloading of vehicles, etc., so this load test is arranged to be conducted at night, so the impact of temperature changes on the test has been minimized.

Structural verification coefficient ζ It expresses the similarity between the theoretical values of stress (internal force) and strain (displacement) of each measured point and the actual measured value， Used $\zeta = S_e / S_S$ to represent.If ζ <1， This means that the actual strength or stiffness of the bridge structure has a safe reserve，If ζ >1， It indicates insufficient strength or stiffness[2]。

The residual strain reflects the elastic working state of the structure. The smaller the value, the closer the structure is to the elastic working state. The residual strain calculation is shown in the following formula.

$$S_P^{'} = \frac{S_P}{S_t} \times 100\% \quad (2)$$

Where：

S_P —The measured residual strain or displacement of the main measurement points；

S_t —The measured total displacement or total strain of the main measurement points under the test load。

（1）Under the test load conditions, the maximum vertical displacement of the actual measured cross-section of the bridge main beam is 12.8mm, and the trend of the measured deformation value is basically consistent with the theoretical calculated value.

（2）Under loading conditions, the strain verification coefficient and deformation verification coefficient both meet the provisions of "Technical Specifications for Inspection and Assessment of Urban Bridges" (CJJ /T 233-2015) less than 1, indicating that the bridge's bearing capacity and vertical stiffness meet the current usage requirements.

（3）The relative residual displacement of the structural measurement points is less than 20%, indicating that the elastic recovery performance after the structure is unloaded and the structure is in an elastic working state.

The simulation model was established using Midas software. Through eigenvalue calculation and finite element analysis, the first-order frequency of the bridge was f1=4.659Hz, the second-order frequency of f2=5.841Hz, and the third-order frequency of f3=6.943Hz.

The measurement of the self-vibration characteristics of the bridge is performed by the pulsation method. The pulsation method is a method to determine the dynamic characteristics of the structural using the tiny and irregular vibrations of the environment in which the bridge structure is located [3]. This test mainly uses nearby vehicles and machinery to measure the frequency of the bridge's various orders.

The sports car speed is positioned at several levels at the designed speed. The load-loaded cars in this test drove across the bridge deck at a constant speed of 5km/h, 10km/h and 20km/h respectively. The dynamic displacement time curve can be measured when the test vehicle is on the bridge deck, and the impact coefficient can be calculated and analyzed according to the following formula based on the recorded dynamic displacement time curve:

$$1+\mu=\frac{S_{\max}}{S_{mean}} \tag{3}$$

Where：

$S_{\max}$ —Maximum strain (or deflection) value of the measured point under dynamic load；

S_{mean} —The maximum strain (or deflection) value of the corresponding static load measurement point

The bridge has nine measurement points, and the specific measurement points are arranged as follows.

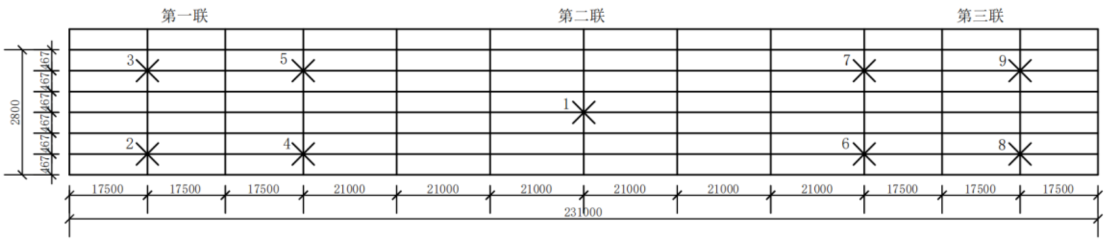

Figure 4 —Acceleration sensor measurement point layout diagram

The first order frequency obtained by analyzing the actual measurement results of the bridge through DASP software is f1=6.467Hz, the second order frequency is: f2=7.751Hz, and the third order frequency is: f3=8.752Hz.

The theoretical and measured self-vibration frequency of the bridge is shown in Table 4.

Table 4 — Statistics of theoretical calculation frequency and actual measured frequency

Modal	Theoretical calculation frequency f_d (Hz)	Actual amplitude frequency f_{me} (Hz)	f_{me}/f_d	Assessment scaling
1	4.659	6.467	1.38	1
2	5.841	7.751	1.33	1
3	6.943	8.752	1.26	1

According to the actual measured data, it can be found that the measured frequency is greater than the theoretical calculation frequency. According to the bridge self-vibration frequency evaluation standard in Article 5.9.2 of the "Regulations on the Testing and Assessment of the Load Capacity of Highway Bridges", the comprehensive evaluation scale is 1.

3.4.2Impact coefficient

According to the bridge design specifications, the impact coefficient is calculated according to the following formula：

$$f_{me} < 1.5Hz \qquad \mu = 0.05$$

$$1.5Hz < f_{me} < 14Hz \qquad \mu = 0.05$$

$$f_{me} > 14Hz \qquad \mu = 0.45$$

Where：f——The fundamental frequency of the structure(Hz)。

The theoretical value of the impact coefficient is calculated from the above formula: 0.3.

Table 5— Impact coefficients at different speeds

Speed（Km/h）	Impact coefficient	
	Actual measured value	Theoretical value
5	0.09	0.30
10	0.14	
20	0.17	

By comparing and analyzing the test data of the dynamic load test of the bridge and the corresponding theoretical calculation data, the following main conclusions can be obtained:

(1) The actual measured vertical fundamental frequency of this bridge is 6.467Hz, the theoretical calculated fundamental frequency is 4.659Hz, and the measured structure's self-vibration frequency is greater than the theoretical calculated value, which shows that the actual stiffness of the bridge is greater than the theoretical stiffness, and the quality of the bridge is good.

(2) The actual measured value of the impact coefficient of the bridge is less than the theoretical value, indicating that the impact of vehicle traffic on the bridge is small and the bridge is in a stable state.

To sum up, bridge load test is the most direct and effective method to truly and fully grasp the stress performance and working state of the span structure of the bridge in service. This project uses MIDAS software to establish a reliable finite element simulation model based on the bridge design characteristics and stress performance, conduct theoretical analysis before the experiment, and then formulate a thorough implementation plan. The static load test determines the test operating conditions through theoretical analysis, and measures static strain, displacement, deflection and other indicators. The strain and deformation verification coefficients can be used to determine whether the bearing capacity and stiffness of the bridge meet the usage needs; based on the finite element theoretical calculation and analysis, the dynamic load test is measured through the sports car test to determine whether the dynamic stiffness and quality of the bridge meet the operating needs.

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