Benchmark model correction of monitoring system based on Dynamic Load Test of Bridge

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Abstract. Structural health monitoring (SHM) is a field of research in the area, and it's designed to achieve bridge safety and reliability assessment, which needs to be carried out on the basis of the accurate simulation of the finite element model. Bridge finite element model is simplified of the structural section form, support conditions, material properties and boundary condition, which is based on the design and construction drawings, and it gets the calculation models and the results.But according to the design and specification requirements established finite element model due to its cannot fully reflect the true state of the bridge, so need to modify the finite element model to obtain the more accurate finite element model. Based on Da-guan river crossing of Ma - Zhao highway in Yunnan province as the background to do the dynamic load test test, we find that the impact coefficient of the theoretical model of the bridge is very different from the coefficient of the actual test, and the change is different; according to the actual situation, the calculation model is adjusted to get the correct frequency of the bridge, the revised impact coefficient found that the modified finite element model is closer to the real state, and provides the basis for the correction of the finite model.

1. Introduction

Structural health monitoring is a hot research field at home and abroad, is the basis for accurate simulation in finite element model, utilizing the signal and data collected by the sensor is installed on the bridge, and the damage identification and evaluation methods to realize the bridge safety and reliability assessment[1-5].
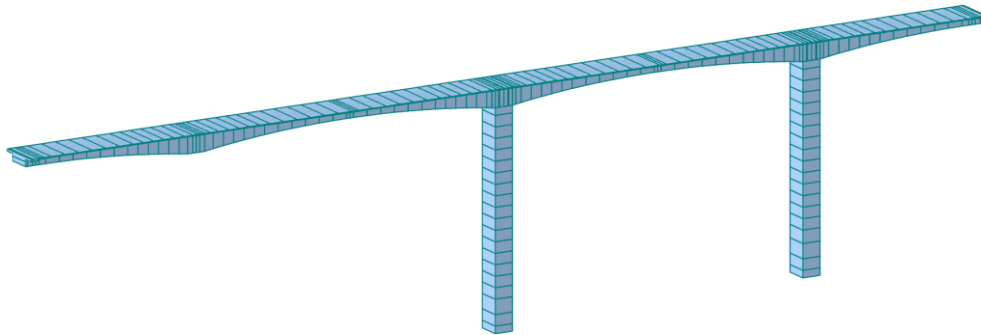
The finite element model of the bridge is based on the design of the construction drawing, and the structure section, supporting conditions, material properties and boundary conditions are simplified and established. The model built according to the design and specification can not reflect the real state of the bridge completely, so we need to modify it to get a more accurate finite element calculation model.

There are many methods to modify the model, but relatively, the structural dynamic test information is easier to get. The method of dynamic information has always been a hot topic in the field of damage identification. Dynamic testing information can be used as an incentive to use the load （e.g. wind、microtremors、random vehicles and crowds）in the natural environment, and the dynamic information of the structure is obtained by the acceleration sensor, selecting appropriate revised target as state variable for model correction, such as frequency, vibration, modal flexibility etc[8].   According to the difference of the modified reference base, the dynamic FEMU can be divided into two types: model correction based on modal parameters and model correction based on frequency response function[7].
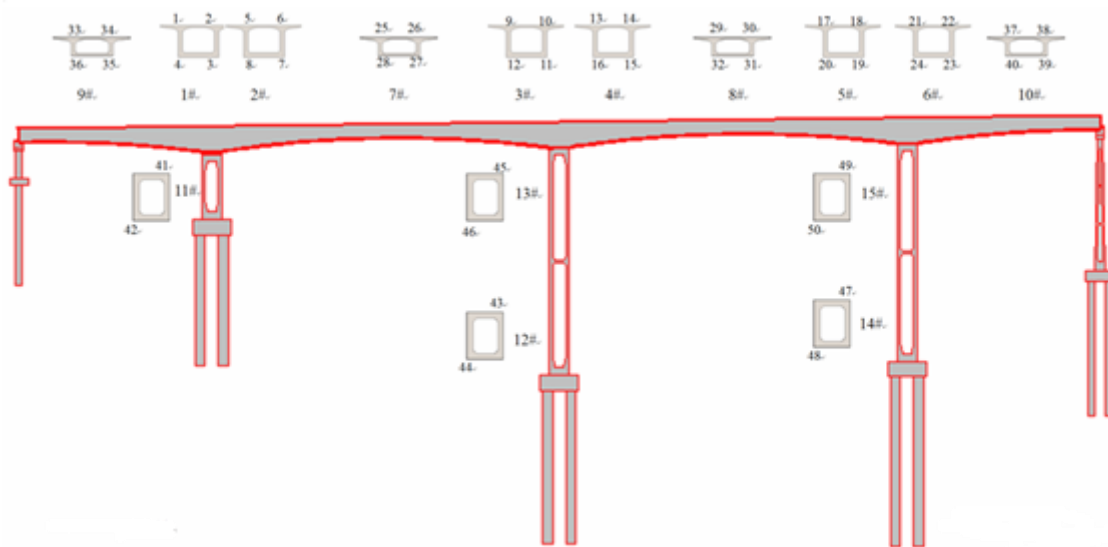
2. Background of the project

Ma Liu Wan - Zhaotong section expressway is an important section of the national expressway network G85 Chongqing-Kunming Expressway and the main line is about 105km. There are high mountains and lofty hills，complex terrain and geological conditions along the line. The entire tunnel ratio reached 50.2% and there are 45 kilometers in Da-guan area, which is the most significant control project in the whole line. The research object is one of the eight double bridge (16 bridgess in total). Its finite element calculation model is shown in Figure 1.

Figure 1. model of dynamic load test for Da-guan bridge

Figure 2. The health monitoring system of Da-guan bridge layout.

It is difficult to find and track bridge problems in time and there are always errors in the analysis and judgement of the problems because of the large number of bridges, heavy workload and limited maintenance personnel in the future. The health monitoring system is established for the bridge is a technical guarantee for the long term health monitoring of the bridge, which plays a key role in the operation and maintenance of the bridge. Figure 2 is the layout of the monitoring system.

3. Data analysis of dynamic load experiment

The dynamic characteristic of the bridge structure is the basic characteristics of the structure and the necessary parameters for the structural analysis. The natural frequencies, damping coefficients and mode shapes of structures are only related to the inherent properties of the structure, such as the form, stiffness, mass distribution, supporting conditions and material properties of the structure, which are independent of load and other properties. The dynamic response of each part of the structure:

amplitude, stress, displacement, acceleration and response structure dynamic interaction impact coefficient based on the actual dynamic load, it not only reflects the stress state of the bridge structure under the dynamic load, but also reacts the influence of the dynamic action on the comfort of the driver and passenger.

In the current bridge detection, it is often used to evaluate the overall performance and technical status of the bridge structures by the proportion of the measured natural frequencies and the calculated natural frequencies.Specific criteria for evaluation are shown in Table1.

Table.1 assessment of technical state standards for bridge structures based on natural frequency of vibration

Bridge Component	Bridge superstructure		Bridge substructure	
Evaluation scale	fdi /fni	Technical statu	fdi /fni	Technical statu
1	≥1.10	good	≥1.20	good
2	1.00~1.10	preferably	1.00~1.20	preferably
3	0.90~1.0	Poor	0.95~1.0	Poor
4	0.75~0.90	bad	0.80~0.95	bad
5	below0.75	danger	below0.80	danger

The small damping of the bridge structure is often not included in the calculation and analysis of the dynamic characteristics of the bridge. Therefore, the undamped vibration mode and natural frequency are obtained. The natural frequency of the structure with damping is obtained in the dynamic load test of the bridge structure, in theory:

$$f_{di} = f_{ni}\sqrt{1 - \zeta^2}$$

(Formula 1)

Where：f_{di} is actual measurement value；f_{ni} is theoretical arithmetic of frequency value；ζ is structural damping ratio.

Using the Da-guan Bridge as an example to analyze the modal data shown in table2 and 3.

Table.2 Left amplitude mode of Da-guan Bridge

Vibration type	Modality stage	fni（Hz）	fdi（Hz）	relative error（%）	fdi /fni	$\sqrt{1 - \zeta^2}$
Transverse vibration	First stage	0.568	0.641	3.57	1.128521	0.998726
	Second stage	1.168	1.099	1.98	0.940925	0.999608
	Third stage	2.213	1.740	1.24	0.786263	0.999846
Vertical vibration	First stage	1.299	1.648	1.56	1.268668	0.999757
	Second stage	1.715	2.289	1.44	1.334694	0.999793
	Third stage	2.729	3.662	0.71	1.341883	0.99995

Table.3 Right amplitude mode of Da-guan Bridge

Vibration type	Modality stage	fni（Hz）	fdi（Hz）	relative error（%）	fdi /fni	$\sqrt{1 - \zeta^2}$
Transverse vibration	First stage	0.568	0.671	4.73	1.181338	0.997763
	Second stage	1.168	1.099	2.77	0.940925	0.999233

	Third stage	2.213	1.740	2.40	0.786263	0.999424
	First stage	1.300	1.648	1.48	1.267692	0.999781
Vertical vibration	Second stage	1.715	2.319	1.41	1.352187	0.999801
	Third stage	2.730	3.662	1.02	1.341392	0.999896

It is known from the technical state standard of bridge structure：It can be shown that the actual situation of the bridge is better than the design requirement, and the actual stiffness of the bridge is better than the design when $\frac{f_{di}}{f_{ni}} > 1$. It can be seen from Formula 1 that when the damping value is less than the theoretical value, the theoretical value has an error compared with the measured value.

4. Simplified analysis of impact effect

The structure will be impacted when the vehicle running on the bridge, the magnifying coefficient is used to simulate the structure. However, due to vehicle bridge coupled vibration and Bridge irregularities, the impact analysis of vehicles is very complex. Based on a simplified assumption, the vehicle bridge coupling can be simplified.

Hypothesis: ① The vehicle is simplified to mass, spring and damping, the vibration excitation only considers the unevenness of the bridge deck and the effect of the vehicle on the bridge. ② The load of the vehicle to the bridge is applied on the bridge deck node in the form of triangular function, and it is carried forward by the speed of the vehicle on the bridge surface.

The time domain simulation of bridge surface irregularity is described according to the 《Mechanical vibration-Road surface Profiles-reporting of measured data》, and the power spectrum is used to describe the road unevenness. The fitting formula is :

$$G(d_n) = G(d_0)\left(\frac{n}{G(d_n)}\right)^{-\omega}$$

（Formular 2）

where：ω is frequency index；$G(d_n)$ is pavement flatness coefficient；

According to the above calculation method, simplified calculation of vehicle impact effect in MIDAS CIVIL, and process dynamic load experiment of the Da-guan Bridge. Measured results of impact coefficient and simplified calculation results under driving condition are shown in Table4..

Table.4 Traffic impact coefficient in the Da-guan Bridge

speed（Km/h）	The left line of the Da-Guan Bridge			The right line of the Da-guan Bridge		
	20	30	40	20	30	40
Actual measured impact coefficient	0.1	0.128	0.16	0.1	0.13	0.12
Calculation of impact coefficient	0.17	0.11	0.08	0.02	0.2	0.05

It can be seen from the above table that the impact coefficient of the simplified calculation is quite different from the measured impact coefficient, and the variation of the impact coefficient is also different from the measured ones. The materials physical parameters specified in the code are usually different from the actual ones, which leads to the fact that the finite element model used in theoretical calculation can not reflect the actual state of the bridge exactly.

5. Model modification

Parameterization is the key of the finite element model modification. The correction of the model in this paper is mainly based on two aspects of the mass density and the modulus of elasticity of concrete: the mass density of concrete is less influenced by environmental factors, Considering other factors such as construction, the density of the concrete is within $0.95{\sim}1.1{\times}2550$kg/m^3; The elastic modulus

of the bridge pier concrete is 32.5GPa~42GPa based on the experimental data and the relevant literature. The elastic modulus of concrete of box girder is 35GPa ~39GPa.

In formula 1 as the objective function, the finite element model of the Da-guan Bridge was modified, the results in Table 5.

Table.5 The Left line mode of Da-guan Bridge

Location	Mode of vibration	Stage of mode	fni（Hz）	fdi（Hz）	Corrected frequency
Left line	Vertical vibration	First stage	1.299	1.648	1.508
		Second stage	1.715	2.289	2.004
		Third stage	2.729	3.662	3.536
Right line	Vertical vibration	First stage	1.300	1.648	1.508
		Second stage	1.715	2.319	2.004
		Third stage	2.730	3.662	3.536

The impact factor is calculated by the simplified method of impact effect after the model is corrected and the result is shown in Table 6.

Table.6 Driving impact coefficient in the left line of Da-guan Bridge after the model corrected

Location	speed（Km/h）	20	30	40
Left line	Actual measured impact coefficient	0.1	0.128	0.16
	Modified impact coefficient	0.11	0.13	0.15
Right line	Actual measured impact coefficient	0.1	0.13	0.12
	Modified impact coefficient	0.11	0.16	0.104

It can be seen that the impact coefficient calculated by the modified model is closer to the measured value, and the variation of the impact with the velocity also conforms to the law of the measured data.

In the case of static load test of the Da-guan Bridge, the calculated deflection before and after the correction are shown in Table 7 and 8.

Table.7 Static load test deflection in left line of the Da-guan Bridge

Section	Test deflection value（mm）	The calculation value of the deflection of the model before the correction（mm）	The calculation value of the deflection of the model after the correction（mm）	Calibration coefficient	
				Uncorrected	Corrected
1#	-7.0	-7.4	-5.6	0.946	1.25
4#	-10.0	-20.4	-15.4	0.490	0.650
7#	-10.2	-14.4	-11.0	0.708	0.927
10#	-1.7	-5.2	-3.4	0.327	0.5

Table.8 Static load test deflection in right line of the Da-guan Bridge

Section	Test deflection value/mm	The calculation value of the deflection of the model before the correction/mm	The calculation value of the deflection of the model after the correction/mm	Calibration coefficient	
				Uncorrected	Corrected
1#	-3.9	-7.4	-5.6	0.527	0.696

4#	-12.7	-20.4	-15.4	0.6233	0.825
7#	-7.0	-14.4	-11.0	0.486	0.636
10#	-2.0	-5.2	-3.4	0.385	0.588

6. Conclusion

This paper obtains the following conclusions through the analysis of the theoretical calculation load test of the Da-guan Bridge:

1) The impact coefficient of simplified calculation in the theoretical calculation model of the bridge is quite different from the measured impact coefficient, and the change law of impact coefficient is also different from the measured ones.

2) According to the actual situation, based on the analysis of the load test data of the Da-guan Bridge, the correction frequency of the bridge is obtained, which provides the basis for the correction of the finite model.

3) After adjusting the calculation model, The calibration coefficients of most of the sections increase in varying degrees, indicating that the modified finite element model is more close to the real state.

In order to improve the accuracy of finite element model updating technology and ensure that the model can simulate the real bridge to a greater extent, we should combine theoretical analysis, numerical simulation, model test and engineering application for further model updating.

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