Experimental study on bridge vibration test

B Jin1*, D Liu1 and CK Zhu1
1. Key Laboratory of Earthquake Engineering and Engineering Vibration of CEA, Institute of Engineering Mechanics, China Earthquake Administration (CEA) Harbin, Heilongjiang, 150080, China
*corresponding author’s email: junpeng@36haojie.com

Abstract. Taking Chaihe bridge in Tieling City and Songhuajiang railway bridge on Binbei line as examples, the vibration test is carried out by using the environmental excitation method. By testing and comparing the first three typical vibration modes of the two bridges, and the experimental research shows that: A. compared with Concrete-Filled Steel Tubular Bridge, truss bridge has higher stiffness. B. The span and height of truss bridge can be higher and farther than that of Concrete-Filled Steel Tubular Bridge; C. Truss bridge is more convenient in testing, maintenance and health monitoring, and has good performance and stability.

Keywords. Model test; Truss Bridge; Concrete Filled Steel Tube Bridge; Environment Excitation; Mode of Vibration

1. Introduction
For large-scale bridges, due to the large size and complex structure, it is difficult to carry out artificial excitation with known input excitation, so the environmental vibration is often used as the input excitation in the relevant test. The time-domain method based on environmental excitation uses the time history function of the response signal data of the structure under random excitation (such as random decrement function, correlation function, etc.) to identify the modal parameters of the structure. Among them, LSCE, ITD and STD are based on ARMA model[1]. However, SSI and ERA are state space models. The identification method based on the autoregressive moving average model (ARMA) has high resolution, but it has high sensitivity to noise and sampling frequency, and poor robustness (also known as anti variability), so it is not suitable for processing large amount of data. However, stochastic subspace recognition (SSI) and eigensystem realization algorithm (ERA) are belong to the state space models methods[2]. The method based on state space model uses SVD decomposition to eliminate the influence of part of the noise in the calculation process and to determine the order of the model. The calculation process is stable and the result accuracy is high. Overall, the frequency-domain method is more mature than the time-domain method in modal parameter identification because of the earlier development of fast spectral calculation[3]. But the frequency domain modal parameter identification method needs to transform the time domain signal into the frequency domain signal through the Fourier transform. In the process of the conversion, many data need to take the average value in the middle, which causes the problems of spectrum loss, overlapping and mixing, and low resolution. The transformation of time-domain signal into frequency-domain signal data will inevitably affect the accuracy of identification methods. Therefore, this kind of method is suitable for systems with small damping and scattered distribution of natural frequency. With the rapid development of related technology and operation ability, time-domain modal parameter identification method has also been developed. Because the time-domain modal analysis method can directly identify the modal parameters of...
the structure from the time-domain signal data, compared with the frequency-domain modal parameter identification method, it has a higher accuracy and is widely used in civil engineering. In the time domain modal parameter identification method, the application effect based on state space model is better than that based on ARMA model. Then, the time-domain modal parameter identification method which is eigensystem realization algorithm (ERA) is used in the analysis of Chaihe bridge in TieLing and Songhuajiang highway and railway dual-purpose bridge on Binbei line in Harbin.

2. Model test of Chaihe bridge in TieLing and Songhuajiang railway bridge on Binbei line

2.1 Chaihe bridge in TieLing
The main bridge of ChaiHe Bridge at the north exit of Tieling city is a three-hole CFST (concrete filled steel tube) truss arch structure with a span of 36+48+36m. The center line of the arch rib is a quadratic parabola and the section is dumbbell shaped. The diameter of the middle-span steel pipe is 0.63m, the thickness of the steel pipe is 12mm, the calculated span is 45.6m, the rise of arch is 12.8m, and three wind bracing connections (dumbbell shape) are set between the two arch ribs. The diameter of the side-span steel pipe is 0.529m, the thickness of the steel pipe is 12mm, the calculated span is 33.8m, the rise of arch is 9.8m, and two wind bracing joints are set between the two arch ribs. The main bridge size is shown in Figure 1. The design load of the bridge is steam super-20, and the check load is suspension -120. This bridge is Completed in 1998.

![Figure 1. General layout diagram of main bridge of Chaihe Bridge. Tieling](image)

2.2 Songhuajiang railway bridge on Binbei line
Songhuajiang railway bridge on Binbei line is the earliest reconstruction project of the steel truss bridge crossing the river in China[4]. Songhuajiang highway and railway bridge of Binbei line is located on Songhuajiang River, which is located in extremely cold area. The design minimum temperature is -43.1 °C. It is the first large-scale steel truss bridge with orthotropic deck in Northeast China[5]. The span of the bridge from south to north is: \(2 \times 96m + (96 + 2 \times 144 + 96)m + 6 \times 96m\), in which the total width of the upper highway deck is 30m, and the width of the lower railway deck is 14m.

![Figure 2. Layout diagram of Songhuajiang railway bridge on Binbei line](image)
3. In-situ test of vibration

3.1 Instruments
The instruments used in the environmental vibration test are: 941b vibration pickup (produced by Institute of Engineering Mechanics, CEA), 941b signal amplifier and DASP data collector. The graph data and text data are obtained by corresponding software.

3.2 Methods of test
The vibration test of the two Bridges adopts the method of environment excitation. We obtained the modal of the bridge by processing the measured data.

3.3 numerical simulation
3.3.1 Chaihe Bridge
Chaihe bridge is a parallel CFST (concrete filled steel tube) arch bridge, its vibration mode mainly includes vertical vibration of arch rib and lateral vibration of transverse bridge. Because the vibration within the arch rib surface causes the vibration of the bridge deck system, the vibration resistance of the arch rib surface is usually larger than that of the external surface, so the frequency of the external vibration of the bridge deck is often lower than that of the internal surface.

In terms of the first few modes we are concerned with, there are usually the following types of in-plane modes. (Figure 4, Figure 5)
3.3.2 Songhuajiang railway bridge on Binbei line

The main materials this bridge use is rolled steel, and concrete is laid on the road and railway lanes. The first 2 modes of the bridge model are shown in Figure 6.

4. Analysis and comparison of the results of vibration test

The ERA method is used for data processing in this test and compared. After the environmental vibration data is input into the calculation method, the spectrum diagram and stability diagram of the signal are obtained. Firstly, the approximate order of the bridge structure that should be extracted and the distribution of the natural vibration frequency of the structure can be determined according to the spectrum diagram and stability diagram, and then the above extracted frequency can be selected by MAC criterion Frequency with relatively high reliability. According to the definition of MAC criterion, the closer the MAC value is to 100%, the closer the corresponding frequency value is to the actual frequency of the building structure.
Table 1. Comparison between two bridges

| Order number | Chaihe Bridge (Hz) | Highway-railway bridge (Hz) | Difference (%) |
|--------------|--------------------|----------------------------|----------------|
| 1            | 1.90               | 3.1114                     | 0.3893         |
| 2            | 2.50               | 3.3364                     | 0.2507         |
| 3            | 3.70               | 3.9216                     | 0.0565         |

From the above results, we can learn that the frequency of the Songhuajiang railway Bridge is higher than that of the Chaihe concrete-filled steel tube bridge, which leads to higher stiffness and can withstand heavier loads. Meanwhile, the span and height of the Songhuajiang railway Bridge deck are also longer than that of the Chaihe concrete-filled steel tube bridge. The difference between the first and the second frequencies is large, and the difference between the third frequencies is small.

5. Conclusion
Now, with the changing of different bridge structure, the form of truss bridge is probably faded out of the vision of designers, but through the practical test and analysis, truss bridge still has many irreplaceable advantages although the appearance is not so beautiful and trendy.
A. The rigidity of truss bridge is not worse than that of concrete-filled steel tube bridge, and easier to construct.
B. The span and height of the truss bridge can be higher and longer than that of the concrete-filled steel tube bridge, meanwhile, the cost is not very high.
C. Truss bridge are more advantageous and feasible in maintenance and health monitoring in the late period, and the cost is lower.

Acknowledgements
This work is partially supported by the Scientific Research Fund of Institute of Engineering Mechanics, China Earthquake Administration (Grant No. 2020B06, 2019C08) and the Natural Science Foundation of Heilongjiang Province (No. LH2019E096).

6. References
[1] Wang SK 2014 Construction design of Binbei Songhuajiang River high-speed railway bridge[J] Haixia Science 4 pp 13-15
[2] Lin YQ and Ren WX 2007 Stochastic state space model-based damage detection of engineering structures[J] Journal of Vibration Engineering 20(6) pp 599-605
[3] Zhang GW 2012 Modal Parameter Automatic Identification for Structures Under Ambient Excitation and Algorithm Optimization[D] Chongqing Unveristy
[4] Liu GH 2015 Quality Standard for Steel Plate and Welded Joints of Bin-Bei Bridge[J] Railway Standard Design 7 pp 108-111
[5] Xu ZB 2016 Main Bridge Design of Key Technology for Songhua River Highway-railway Bridge on Bin Bei line[J] Railway Construction Technology 4 pp 5-9