Vibration Remote Monitoring System of Continuous Steel Truss girder for the Wuhu Yangtze River Bridge

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ABSTRACT :

Important significance of vibration monitoring in bridge structure health monitoring is briefly introduced first in this paper. The software of ANSYS is adopted to establish the finite model of the Wuhu Yangtze River Bridge, and the detailed structure analysis and sensor optimization layout are proposed. The vibration monitoring ideas and practical plans for the Wuhu Yangtze River Bridge are proposed. The vibration monitoring subsystem which includes monitoring contents, layout of measuring points, transducers, amplifiers and methods of signal analysis and processing etc is significantly investigated. The vibration monitoring mode is designed and it divides into two types, one is real-time trigger acquisition, the other is cyclical acquisition. A set of software, which can realize the remote data acquisition, reception, analysis, real-time display, alarm and data save, is developed with the use of the advanced software platform LabVIEW. And a set of perfect vibration remote monitoring and state evaluation system is established. The structural safety monitoring and state evaluation system can realize the monitoring of the structural responses and working conditions in real time, and it can analyze the structural working state and assess the structural reliability using the information obtained from the monitoring system for the Wuhu Yangtze River Bridge. It would be able to provide the scientific decision-making bases for the bridge management and maintenance.

KEYWORDS: The Wuhu Yangtze River Bridge, continuous steel truss girder, vibration remote monitoring, system

1. Introduction

Accompany with the development and advancement of science technique, bridge structure is developing into the large-span, light-flexibility, complexity and multi-function. So the safety and durability monitoring of bridge structure become very important. How to assure the operation safety of large-span bridge structure is not only a very grave technical problem, but also a very grave economic and social problem which need to be solved quickly all over the world [ ]. The test and analysis of bridge dynamic character is the important evidence of bridge structure safety evaluation. During the course of actual operation of bridge structure, the main damage element is the bridge vibration which accused by each load [ ].

The old bridge test method is manual method, with which the work condition of bridge structure can not be acquired in time. So that it is very difficult to make an objective appraisal for the integral safety of the bridge structure. If we want to know the operation state of bridge correctly, the real-time monitoring of each work factors (includes dynamic character, distribution condition of temperature, stress of main truss, deflection of main truss, distribution condition of vehicle load) must be realized first, and the operation performance of bridge should be evaluated by using of bridge evaluation expert system. The natural vibration character of bridge structure is an important factor which can reflect the whole safety state of bridge. The vibration message of bridge structure makes an important action in amending theoretical analysis model, evaluating damage, appraising the whole performance of bridge (includes safety, durability and stability) and perfecting design standard.

In order to realize the long-term health monitoring and evaluation of load-bearing ability, operation state and fatigue state of the continuous steel truss girder for the Wuhu Yangtze River Bridge, a long-term health monitoring system is established. The goal of vibration monitoring is to establish an on-line monitoring and analysis system which has the feature of safety, credibility and flexibility. The vibration monitoring system can monitor the vibration responses (include vibration frequency, vibration mode, ratio of damping, amplitude of vibration, and so on) of the bridge under the vehicle load, wind load, seismic load and other external load change. It can also realize the real-time monitoring, the real-time anglicizing, the real-time alarming and the data network share. The characteristic parameter extracted from the vibration response is an important evidence for evaluating the integral performance of bridge structure.

2 Project background

The Wuhu Yangtze River Bridge is a highway and railway bridge, the span layout from west to east is 120m＋2×144m＋2×(3×144m)+(180m＋312m＋180m)＋2×120m, the part of (180m＋312m＋180m) is continuous steel truss structure with low-tower and stiffening inclined cable, the other is continuous steel truss structure with concrete deck slab. The high of the continuous steel truss girder is 14m, the width is 12.5m, the panel length is 12m, the low-story is double-line railway and the upper deck is four-line highway.

The Wuhu Yangtze River Bridge is an important bridge of highway web and railway web in China, and it also is a mark structure in construction history. It represents the modern highest level of bridge design and construction in China. Figure 1 is the Wuhu Yangtze River Bridge, and figure 2 is the front view of the continuous steel truss girder of the Wuhu Yangtze River Bridge.

Figure.1 The Wuhu Yangtze River Bridge

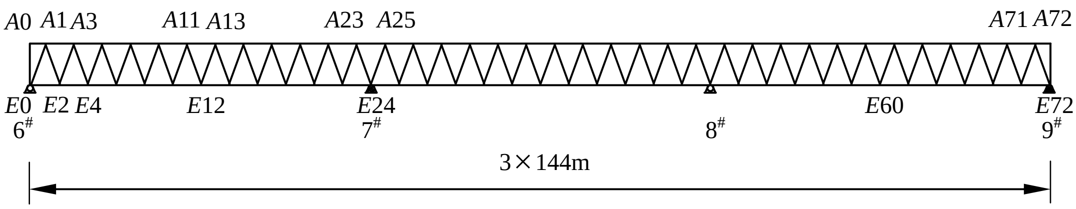

Figure.2 The continuous steel truss girder of the Wuhu Yangtze River Bridge

3 vibration remote monitoring system

3.1 Monitoring contents

In the health monitoring system of bridge structure, the contents and the number of measuring point of vibration monitoring are always limited. But it was expected that the more information of structure parameter would be obtained with a few sensors. And the corresponding relationship between the measured data and the theoretical analysis mode should be established. Therefore, the significance of the different monitoring contents should be distinguished during the course of determining how to choose the monitoring contents and how to lay out the measuring point.

According to the theoretical analysis results and the measured results, the monitoring contents of vibration of the bridge were determined. The contents include the lateral and vertical vibration displacement and acceleration of main bridge, and the horizontal vibration displacement of piers, and so on. The purpose of establishing a vibration monitoring system is to obtain the vibration response of the bridge structure in the course of running process, to get the change of the dynamic character which includes natural vibration frequency, damping and vibration mode, and to provide evidences for the safety evaluation of the bridge structure.

3.2 Measuring point layout

In order to establish vibration remote monitoring system of the bridge structure, a efficient and reasonable sensor layout project needs to be designed in the light of the monitoring propose firstly. The special model of the bridge (figure 3) is established by the use of finite element software ANSYS, and the natural vibration character results (as figure 4 and table 3.1) of the continuous steel truss bridge of the Wuhu Yangtze River Bridge are obtained.

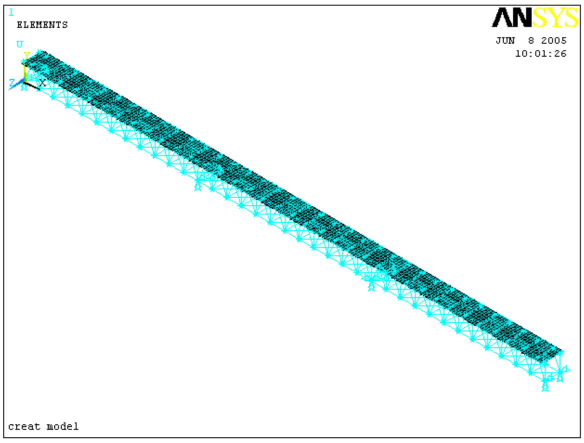

Figure.3 Finite element model of the continuous steel truss girder

Table3.1 Calculate value of natural vibration frequency of the continuous steel truss girder

Frequency order	1	2	3	4	5	6
Natural vibration frequency /Hz	0.927	0.946	1.133	1.161	1.391	1.654

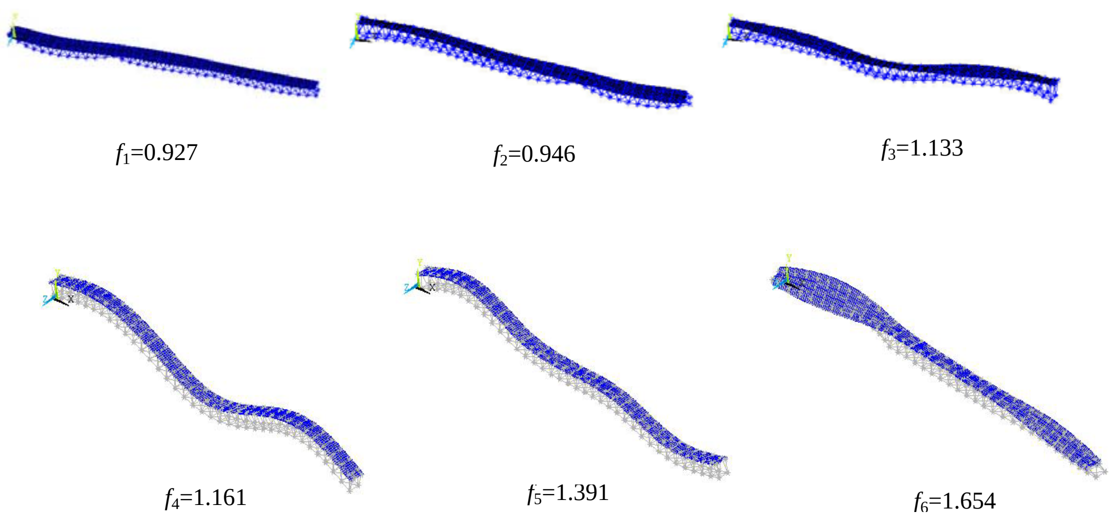

Figure.4 Vibration mode of the continuous steel truss girder

According to the theoretical analysis result and the actual condition, the 891-4 type vibration sensors were adopted to monitor the vibration displacement; the MEMS acceleration sensors were adopted to monitor the acceleration. Eight vertical vibration measuring points are arranged at the lower chord nodal point which located in the each middle-span. Four lateral vibration measuring points are arranged at the railway deck which located in the middle-span of the up-stream side. Seven lateral vibration measuring points are arranged at the highway deck which located in the middle-span and the overhead of support of the up-stream side. Five lateral vibration measuring points are arranged at the top of piers. One longitudinal vibration measuring point is arranged at the top of 8th pier. Three lateral acceleration sensors are arranged at the railway deck which located in the middle-span of the up-stream side, and three vertical acceleration sensors are arranged at the same location with the lateral acceleration sensors. There are thirty one sensors arranged at the bridge. Figure 5 is the sensors layout plan.

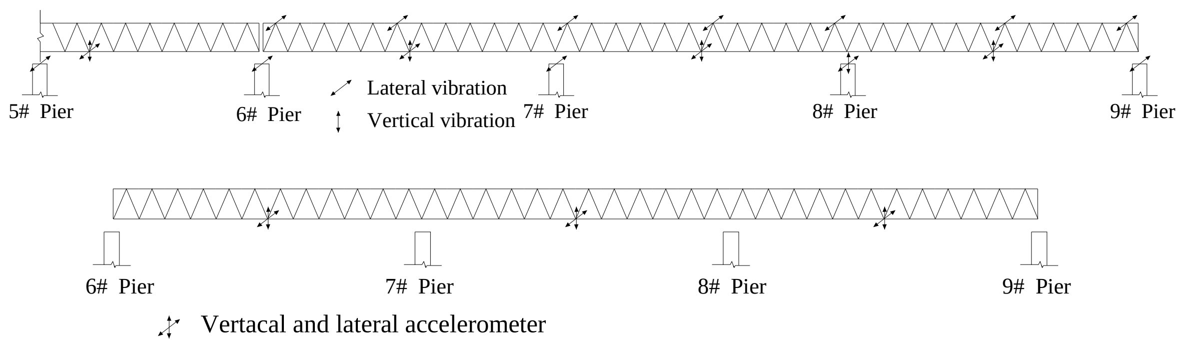

Figure.5 layout plan of different sensors

3.3 Signal acquisition

The acquisition device of vibration signal is the 1601 network data acquisition processor which is autonomously developed. Various analog signals which were Transmitted by sensor system were collected, and then the analog to digital conversion was completed by the network data acquisition processor. The modified digital signal was transferred to the network processor according to the

TCP/IP Corporation through the fiber optic cable. The network processor locates in the monitoring control room, it can real-time display the vibration monitored data which can reflect the structure health state. The network processor can complete the work of data analyzing, transacting, storing and inquiring.

The vibration monitoring mode is divided into two types: one is the real-time trigger acquisition, another is the cyclical acquisition. The real-time trigger is a live-load trigger. It means that the acquisition system is triggered by the train information when a train is passing the monitoring region, and then the signals of the vibration and acceleration sensors are collected. And the collection will be finished when the train lefts. When the signal of monitoring train arriving in the test region exceeds the normal value, the system will be triggered to begin collecting. The cyclical acquisition mode will begin collecting the dynamic information of the bridge under dead-load at the preset time according to the requirements of the system. It means that the signals of the vibration and acceleration sensors are collected during the preset time interval. All of the collected data is transferred by network to the data acquisition computer after signal pre-processing and stored into the data-base.

3.4 Software design of monitoring system

The vibration monitoring system of the continuous steel truss girder of the Wuhu Yangtze River Bridge has many merits: huge data size, data real-time display and overrun alarm. A set of software is developed by the use of LABVIEW in order to resolve these problems which include the data-base backup, the data safety scheme, the real-time display of monitoring data and the data invoking and so on. The software has the merits of high real-time and high rapidity. It has many functions, for instance, it can realize the remote data acquisition, reception, analysis and the real-time data display, alarm functions. According to the operating requirement of user, the system is divided into four functional modules: real-time monitoring module, data inquiry module, data analysis module and report output module. Figure 6 is the real-time displayed interface of vibration monitoring data.

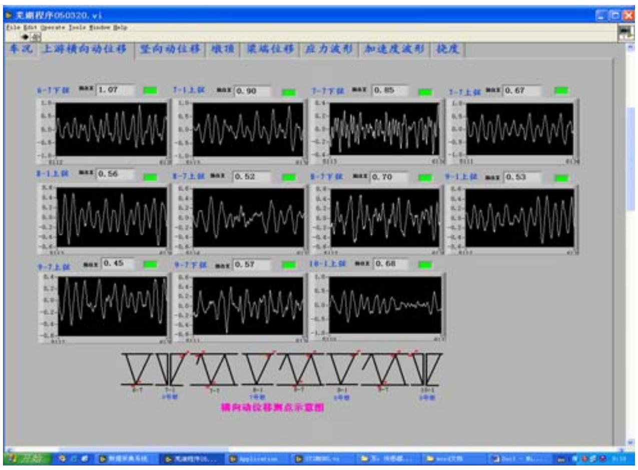

Figure.6 real-time displayed interface of vibration monitoring data

4 Monitoring result

The installation and debugging work of the whole monitoring system is completed in March 2005. The system can monitor the vibration response of the bridge structure when trains pass through it. The vibration system has monitored about 160,000 trains which pass through the bridge after the system is completed. Figure 7 and 8 are the vibration history time curves measured by the system.

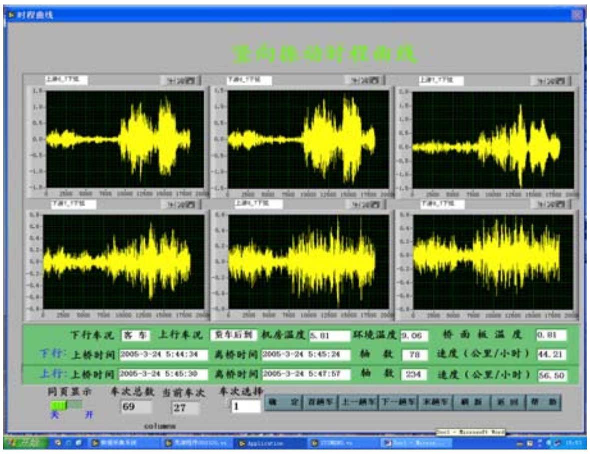

Figure 7 Vertical vibration displacement temporal curves of girder

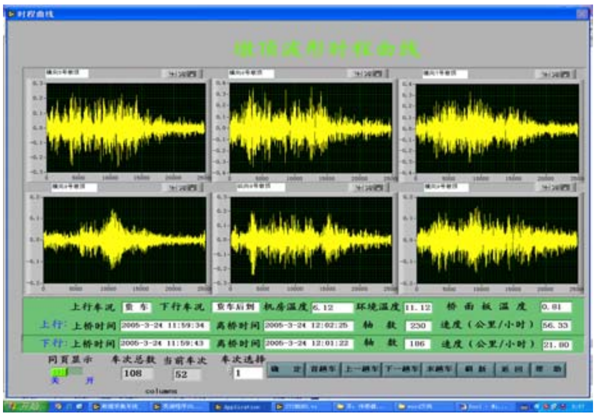

Figure 8 Lateral vibration displacement temporal curves of pier

The results obtained from the monitored data is following:

1. When a train passes through the bridge, the vertical vibration amplitude of mid-span node is small. And the normal maximal vertical amplitude is less-than 2.0mm. The vertical amplitude of nodes located in the up-stream side is similar to that in the down-stream side when a train passes through the bridge. The vertical amplitude of mid-span node will increase with the increase of train speed. The vertical vibration of mid-span express as three modes: vertical first-order mode, vertical high-order mode and torsion.

2. The lateral vibration amplitude is small when a train passes through the bridge. The maximal lateral amplitude of lower chord node in up-stream side is less-than 3.5mm, the maximal lateral amplitude of upper chord node in upstream side is less-than 2.0mm.

3. The vertical lateral amplitude of the top of pier is small. The maximal value is less-than 0.5mm.

4. The vertical first order natural vibration frequency is 1.4672Hz. The lateral first-order natural vibration frequency is 0.9803Hz.

According to above results, it can be concluded that the dynamic character of the continuous steel truss girder of the Wuhu Yangtze River Bridge can meet the requirement of the design standard.

5 Conclusions

Accompanying with the development of test technology and the continuous complement of analysis theory, it could be realized that the structure damage of the bridge could be diagnosed, the location and degree of the damage could be identified, the structure collapse accident could be prevented by the use of the bridge structure health monitoring system.

In this paper, the vibration monitoring system of continuous steel truss girder of the Wuhu Yangtze River Bridge is introduced. The real-time monitoring, the real-time displaying, the real-time analyzing and the real-time alarming function are realized in this system. It could provide technical support for discovering the abnormality and damage of the bridge, avoiding the occurrence of bridge collapse accident, ensuring the running safety of bridge structure.

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