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Study for Real-time Monitoring of Large-Span Bridge Using GPS

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Abstract: In order to know the safeties of large-span bridges, monitoring their real-time displacement and recording their fatigue history are very important. With the development of Global Position System (GPS) and computer science, the GPS of navigation satellites now can be used for the real-time monitoring of large-span bridge. The GPS monitoring system, which is developed by Tsinghua University, is introduced in this paper. It can be divided into two parts. One is the real-time displacement monitoring system. The other is the real-time displacement display system. This paper describes the principle, survey method and equipment needed for such system. Then, the test results of this system, which were carried on Tsing-ma Bridge of Hong Kong and Humen Bridge of Guangdong, are presented, too. The practical application shows that this system has such advantages as real-time, distinctness, and on influence to the traffic.

Key words: GPS; large-span bridge; monitoring system

1 Introduction

In order to know the safeties of large-span bridges, monitoring their real-time displacement and recording their fatigue history are very important. The methods, which are often used for such survey, are acceleration integration method, laser distance gauge method and total station method [1, 2]. The acceleration integration method integrates the acceleration, which is measured by acceleration gauge, to obtain the displacement. But its error is relatively large. The laser distance gauge method is often influenced by the weather, so does the total station method. Furthermore, the later two methods often need to stop the traffic, which brings a lot of costs. So these methods are suitable for some structures whose survey distance is relatively short and the displacement is relatively small. But to such structures like large-span bridges, these methods are difficult to use. With the development of Global Positioning System (GPS), the sampling frequency of GPS receiver can reach about 20 times per second, while the location precision can approach 5~10 mm. So the GPS can be used in the displacement monitoring of large structure. This paper describes the principle, survey method and equipment of such system. And the test results of this system, which was carried on Tsing-ma Bridge of Hong Kong and Humen Bridge of Guangdong, are presented, too.

2 The Principle of GPS in Surveying Displacement of Bridge

The carrier phase double difference mathematic model is adopted to survey the structures with GPS. This model can remove the error between the clocks in the satellite and the receiver. The errors of satellite orbit and atmosphere can be reduced by kinematic GPS positioning with instantaneous cycle ambiguity resolution of On-the-Fly. Because the errors of orbit and atmosphere are connected with the distance between the datum point and monitoring point, a GPS receiver antenna should be placed near to the target bridge as a datum station. This point should be stable, and there are no buildings above 5^0 to envelop or reflect signals. Another GPS receiver antenna should be placed on the monitoring point, which is often at the mid-span, quarter span or the top of towers [3]. And there had better be no structures to envelop the signal, either. At lease 5 satellites signal should be received at the same time, and the data will be stored in the computer real-time. The datum point and monitoring point record 15~20 min data synchronously, which is call a monitoring stage. In data processing, data of the former 200s, just about 3 minutes, are used to obtain the instantaneous cycle ambiguity resolution. When the ambiguity resolution is determined, the displacement of each time point can be obtained. The results are provided in

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WGS-84 geodetic coordination. And the horizontal and vertical displacement of bridges can be computed by coordinate projection and translation. The main vibration frequencies and vibration amplitudes can be determined by spectrum analysis with fast fourier transform algorithm method (FFT), too.

3 Real-Time Bridge Displacement-Monitoring System

The bridge displacement monitoring system is made up with 3 parts. They are: ① GPS receiver; ② data transmit system; ③ data manage and monitoring system. The relationships of the 3 parts are shown in Fig. 1.

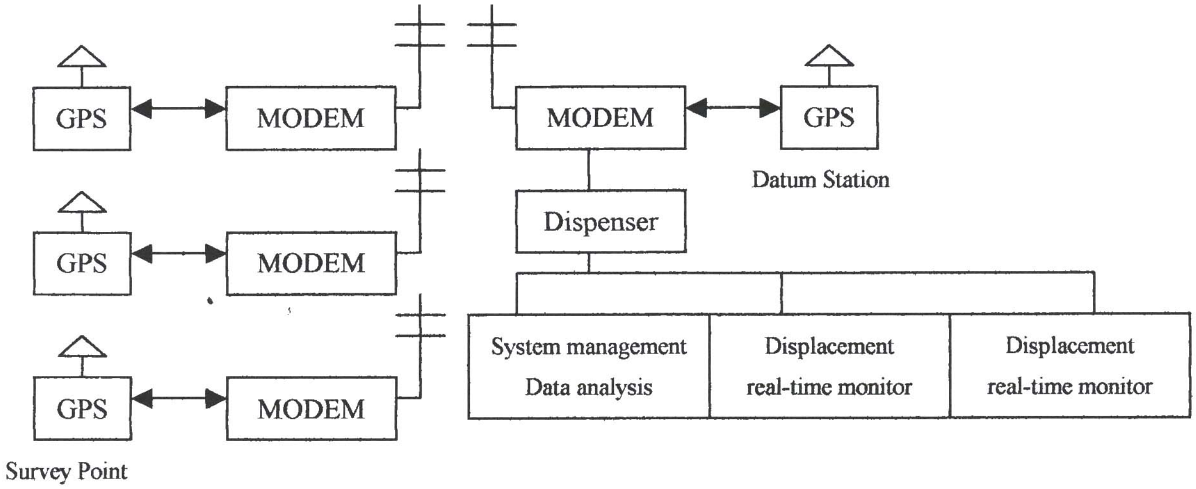


Fig. 1 Displacement real-time monitoring system

Here the monitoring system, which is used on Tsing-ma Bridge, is introduced as an example to explain the components of such system

3.1 The requirement to the monitoring system

(1) The basic vibration period of Tsing-ma Bridge is 8~14s, while the basic vibration period of the towers is about 4s. So the sampling frequency should be larger than 1 Hz under typhoon, while the sampling frequency should be larger than 4 Hz in the later analysis after typhoon. Thus, the sampling frequency should be larger than 4 Hz and can be modified artificially.
(2) The time lag to apply the displacement of bridge under wind load should be less than 10~15s.
(3) The accuracy of displacement should be 1~2 cm.
(4) The data are processed in the central control room.
(5) Data should be transmitted wirelessly.
(6) The data needed including: ① displacement real-time record; ② time-displacement curve (t-x, t-y, t-z); ③ 2 dimension deformation figure; ④ rotation of the tower; ⑤ dynamic vibration simulation animation; ⑥ frequency spectrum analysis;

3.2 Hardware and software components in GPS automatic monitoring system

3.2.1 GPS monitoring station

(1) Hardware: Using NOVATEL RT-12 12-channel GPS receiver, which can process double frequency kinematic monitoring. The difference accuracy is 1~2 cm, the data output frequency is 4 Hz, and the antenna can avoid multi-path effects.
(2) Monitoring software: It is developed by Tsinghua University, which can accomplish the parameter setup of GPS real-time carrier phase difference; datum station difference signal transmit monitoring and satellite situation monitoring.

3.2.2 Data transmitting system

Wireless multi-to-one communication method is adopted. The difference signal sent from the datum station is 279BYT; the sampling frequency of flowing station is 0.25 Hz. The signal sent back is 35BYT per group.

3.2.3 Data management and monitoring system

Data processing and control system is set up in the control room. 4 microcomputers are needed for data processing.

Software system including: ① database management software; ② bridge displacement real-time monitoring software; ③ bridge safety analysis software; ④ general control software;

3.3 Results for GPS monitoring system

The time-displacement curves, which were determined in the Tsing-ma Bridge of Hong Kong [1], are shown in Fig. 2. And the time-displacement curves in one day of Humen Bridge in Guangdong [3] are shown in Fig. 3. The temperature-displacement relationship is shown in Fig. 4 [3]. Especially, the displacement of Humen Bridge under typhoon is shown in Fig. 5 [3]. It is clear that this system is very sensitive and can be applied for multi-function of safety monitoring.

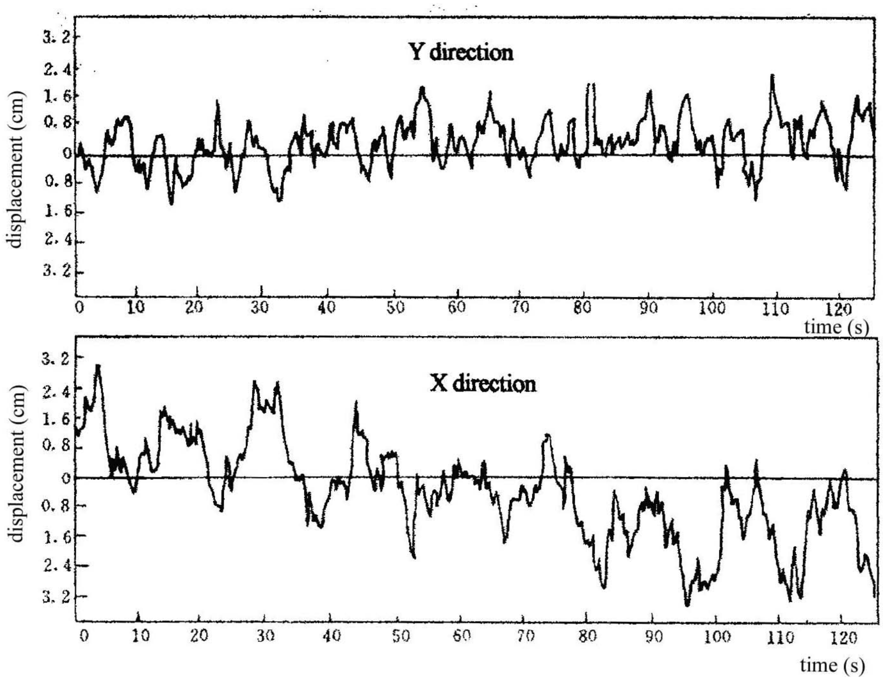


Fig. 2 Time-Displacement Curve of Tsing-ma Bridge

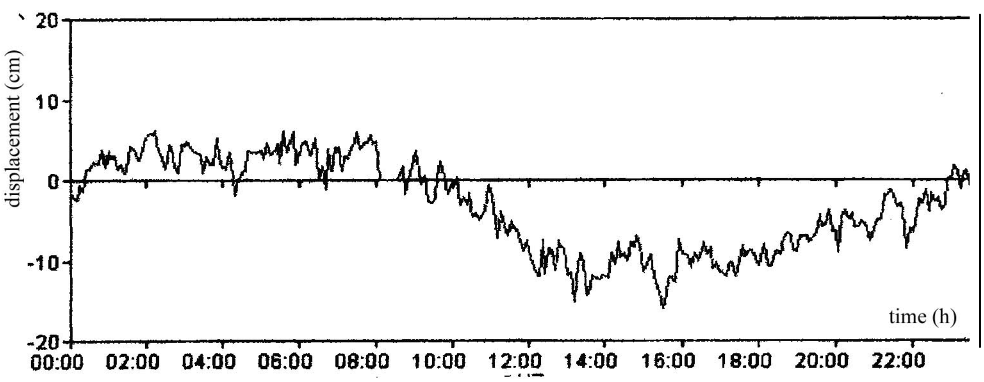


Fig. 3 Time-Displacement Curve of Humen Bridge

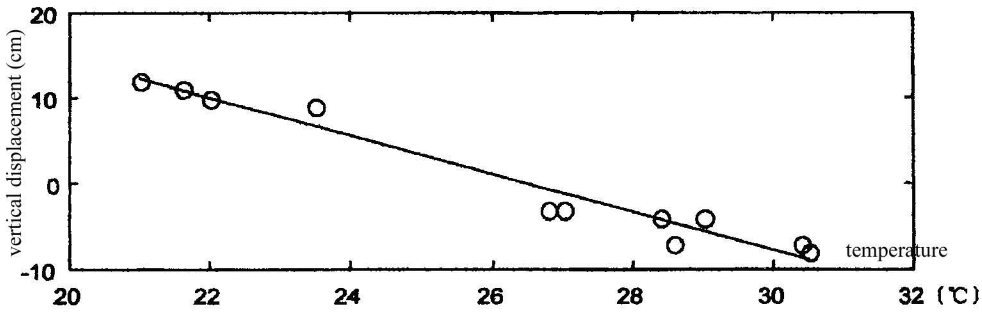
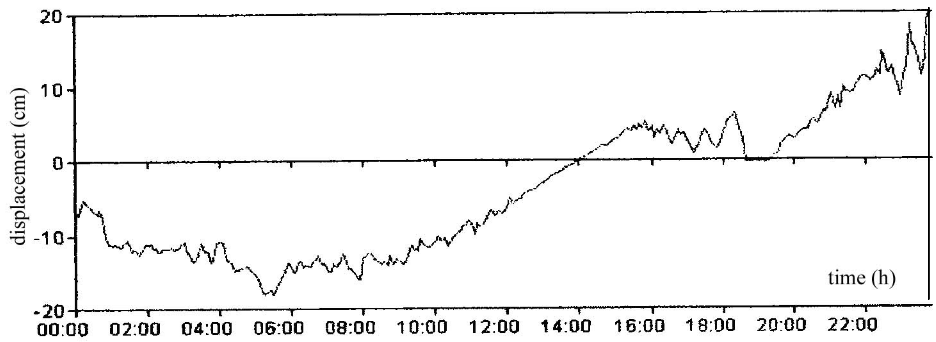
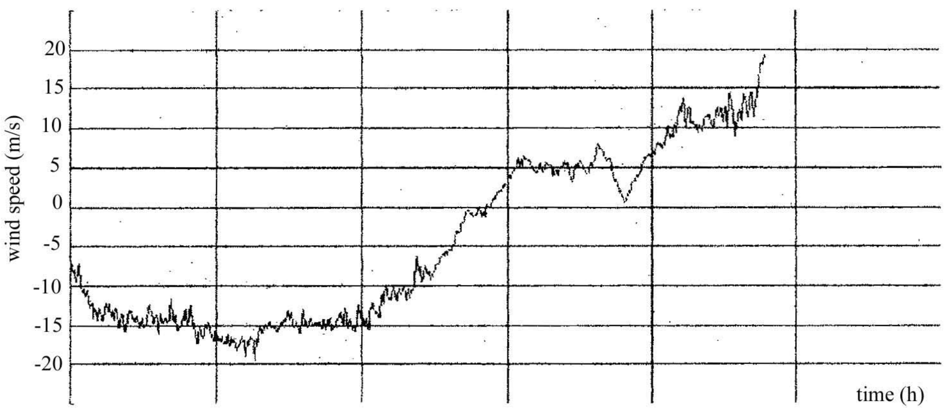


Fig. 4 Temperature-displacement relationship of Humen Bridge



(a)



(b)

Fig. 5 Displacement of Humen Bridge under typhoon

(a) Time Displacement curve at mid-span (b) Wind speed-time curve

4 Displacement Real-Time Display System of Bridge

In order to give the user a clear and direct conception to understand the deformation of the bridge, three dimensional displacement real-time display system is add into the bridge monitoring system.

4.1 Technical requirement

(1) It should be able to communicated with the monitoring system and analyze the data in the monitoring system directly.
(2) It should be able to share data with other software used on the bridge.
(3) It should be able to obtain the deformation of total bridge with the survey point displacement.
(4) It should be able to display the deformation real-time.

(5) The deformation can be displayed in 2-dimension or 3-dimension, respectively. The display scale can be modified by the user.
(6) It can display the time-displacement curves of survey points.

4.2 Technical details and display examples

With Object-Oriented programming technology and ODBC open database interface, the display system is connected to the total monitoring system smoothly, while it also can execute independently as an external function. With the displacements of survey points which are placed on the different span position, fast fourier transform algorithm method (FFT) is adopted to do the frequency spectrum analysis to obtain the amplitudes of former 3 vibration models. Thus, the horizontal and vertical displacement of each point on the bridge are computed by interpolation, and displayed on the screen. With advanced graphic engine, the display of 2-D and 3-D deformation graph is processed parallel with the data processing and spectrum analysis. The deformation can be displayed real-time, and the users can "wondering" on the bridge to see the deformation details. The displacements of survey curves are shown together with the 2-D and 3-D graph. The working interface of this system is shown in Fig. 6.

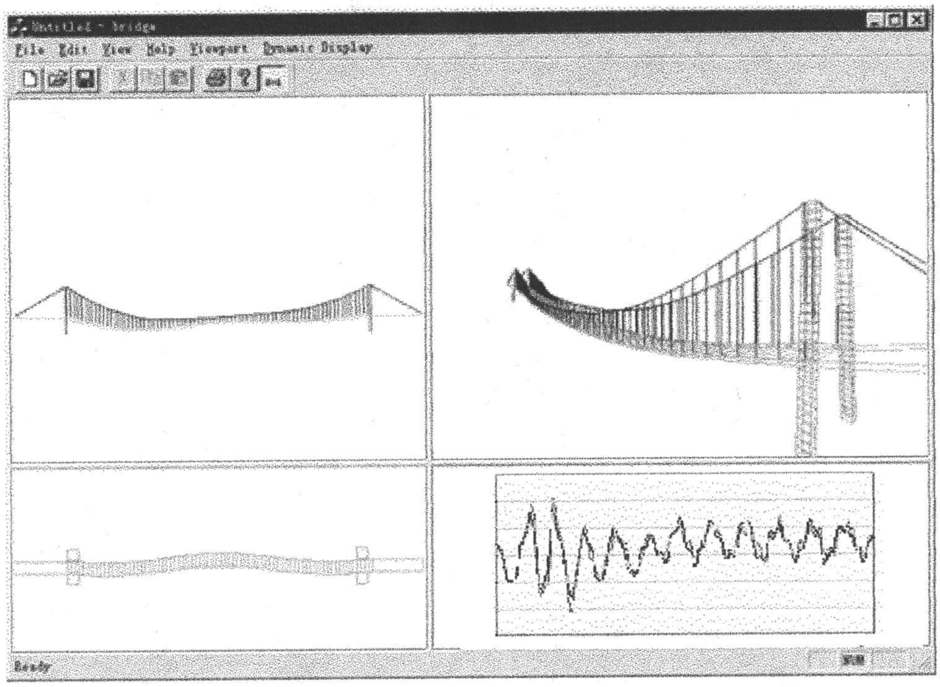


Fig. 6 The working interface of display system

5 Compare of Cost between GPS System and Traditional System

Using the data obtained on Humen Bridge as example, the cost compare of GPS method and total station method in the first two years seen in table 1 [3]. We can see that though the GPS costs more in the installation period, it need not to stop the traffic and will not influence the usage of the bridge. So it has more long-term benefit. After all, the GPS method will not be influenced by the weather and it can work under any weather condition including fog, rain, typhoon and so on. This is very important to the safety of bridges.

Table 1 Compare of cost in the first two years between GPS system and total station method

Item cost	GPS system method	Total station method
Equipment ($\times 10^4$ CNY)	220	25
Labor ($\times 10^4$ CNY)	2	6
Traffic stop ($\times 10^4$ CNY)	0	400 (8 nights)

Total (×10^4 CNY)	222	431

6 Conclusions

GPS is an effective method in the safety monitoring fields of large span bridge. It can be used in any weather conditions and will not bring any influence to the traffic on the bridge. Above all, GPS can record the displacement history at any moment and this is very important to the fatigue safety of the bridge. And it can also be applied on some other structures such as tall buildings, large stadiums and so on.

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