Proceedings of the 3rd International Conference on Green Energy, Environment and Sustainable Development (GEESD2022), X. Zhang et al. (Eds.)

doi:10.3233/ATDE220374

Bridge Deflection Measuring Device with Suspension Cable and Data Collection Method

Yixuan YANG[1]
Chang'an Dublin International Collage of Transportation at Chang'an University, Chang'an University, Xi'an 710064, Shannxi, China

Abstract. Deflection is a key index to reflect the bearing capacity and the operation situation of bridges. As the existing measurements methods have their limitations, this paper tries to introduce a new method using suspension cable to measure the deflection of bridges. This method sets the supports for dial meters by erecting main cables and sets up longitudinal measuring points on the bridge deck. The existing of counterweights and limit bars avoids the horizontal disturbance of the structure and keeps the stability. The tools used in this method are light and convenient to adapt the complex conditions. This method has been successfully used in the bridge inspection and has obtained the precise data that reflects the change of deflection of the bridge.

Keywords. Bridge detection, deflection, dial gauge, displacement

1. Introduction

There are more and more bridges in the world and the lifespan of some bridges is also increasing. There are many problems in the process of bridge use because of natural factors, overload problems, and other bridge structures, which affect the use of bridges [1]. It is important to inspect the performance of bridges precisely and conveniently to ensure the safety and stability of the transportation system [2]. Among the many properties of bridges, the deflection of the bridge is a very important performance parameter of the structure [3]. It can reflect the stiffness of the entire bridge structure and judge the weak parts and damaged components of the bridge. It is necessary to accurately measure deflection of the bridge as the basis of evaluating the bridge.

2. Analysis of Existing Deflection Measurement Methods

At present, there are many bridge deflection measurement methods in China and abroad, which are mainly divided into two categories, namely, full artificial measurement method and automatic measurement method. The total manual measurement method includes mechanical measurement method and optical instrument measurement method, mechanical measurement and percentage measurement method and suspension method,

[1] Corresponding Author, Yixuan Yang, Chang'an Dublin International Collage of Transportation at Chang'an University, Chang'an University, Xi'an 710064, Shannxi, China; Email: 1455127452@qq.com.

optical instrument measurement method includes leveling method and total station measurement method; automatic measurement methods include inclinometer measurement method, accelerometer method, Charge-coupled Device (CCD) image method, position sensitive sensor (PSD) laser measurement method, GPS method.

2.1. Methods Introduction

- Level measurement method

The principle of level measurement method is simple, and it only needs to subtract the values before and after loading. This method has high measurement accuracy and reliable results. The disadvantage is that the dynamic continuous observation cannot be realized, and a good vision is needed. The deflection measurement of long-span bridges needs multiple turning points, and the measurement is time-consuming [4].

- Total station measurement method

The basic principle of total station deflection measurement is trigonometric leveling. The preparation of total station measurement method is simple and easy to operate. The disadvantage is that the continuous observation of each measuring point cannot be realized, and the requirements for observation conditions such as topography and weather are high [5].

- Inclination measurement method

This method measures the inclination of each node, and the deflection curve of the bridge beam structure can be obtained by integral. At present, it is not a problem to use inclinometer to measure the deflection under static load. To use inclinometer for dynamic deflection test, the requirements for the phase difference between inclinometers, the transient response of inclinometers, and the zero drift of inclinometers are high [6]. This method is rarely used in China.

- Accelerometer method

Although the acceleration observations measured by the high-precision accelerometer can obtain the lateral and vertical displacement vectors after secondary integration [7], the displacement obtained by this method is incomplete and discontinuous because the accelerometer is not sensitive to the low-frequency oscillation of the bridge. The acceleration sensor has poor identification effect for low-frequency static displacement. In order to obtain the displacement, it must be integrated twice. The accuracy is not high, and it cannot be real-time. The frequency of large suspension bridges is generally low.

- CCD image method

CCD image method is a long-distance non-contact measurement method that uses CCD photoelectric coupling device to measure bridge deflection, which combines long-distance imaging technology [8]. But the equipment is expensive and vulnerable to environmental conditions.

- PSD laser measurement method

Position sensitive sensor (PSD) is a photoelectric device that uses transverse photoelectric effect to realize light point position detection [9]. This method requires the installation of laser emission device, and the cost is high.

2.2. Inclusion of Methods

In general, the artificial measurement method has obvious advantages in cost and accuracy, and the advantages of automatic measurement method are reflected in the convenience and rapid data output, and there is no measurement method to meet the requirements of accuracy, efficiency, convenience and adaptability. Through the research and analysis of the existing technology, equipment and measurement system, this paper developed a method for measuring bridge deflection by hanging cables. This method has the advantages of simple operation, convenient layout, high accuracy of measurement results and low cost, and is successfully applied to the deflection measurement of a prestressed hollow slab structure.

3. Introduction of a Kind of Suspension Cable Measuring Bridge Deflection Device and Method

3.1. The Composition of the Measuring Device for Suspension Cables

The deflection measurement device shown in Figures 1 and 2 is mainly composed of columns, cables, fixed pulleys, wire ropes, counterweight blocks, limit plates, beams, splints and dial gauges. During the deflection measurement, several inverted dial gauge probes hanging on the cable contact with the bridge guardrail within the bridge span to test the deflection change of the bridge surface.

Before measuring the deflection of the bridge, the expansion bolt is inserted on the pre-set position of the anti-collision wall and the sliding track is installed outside the span of the bridge. The nut and the sliding track of the column are locked to avoid relative sliding, and the fixed pulley used for the rotation cable is placed at the top of the column. The cable adopts wire rope and turns from side span to main span by fixed pulley. The cable is locked with a steel wire tensioner at the side span and an expansion bolt embedded in the crash barrier. The stainless steel chuck is placed on the upper cable at the predetermined measuring point of the bridge, which is connected with the limit plate through the wire rope (Figure 3). The counterweight is placed above the limit plate, and the watch frame is installed below it. The watch frame is fixed with a dial indicator that faces down and contacts with the bridge collision barrier. In order to obtain accurate and complete data, the beam suspended in the device can be set below the main girder of the bridge at 1 / 4 span, midspan and 3 / 4 span. In order to make the cable have effective gravity stiffness and prevent the lateral displacement of the cable, there are also counterweight blocks and limit plates at the cable suspension gage.

3.2. Principle of Measuring Device for Suspension Cable

After the flexible suspension cable is subjected to load, the suspension cable is in a tensile state and has the ability to resist bending. The ability of this suspension cable is called gravity stiffness. The larger the section stiffness of the device is, the smaller the deformation of the device when resisting the deflection of the test beam is, so that the movement of the dial indicator itself can be ignored to accurately calculate the deflection of the main beam. The precise degree of the dial gauge and the stable vertical configuration of the device can ensure the accuracy of the data, which is also one of the highlights of the device.

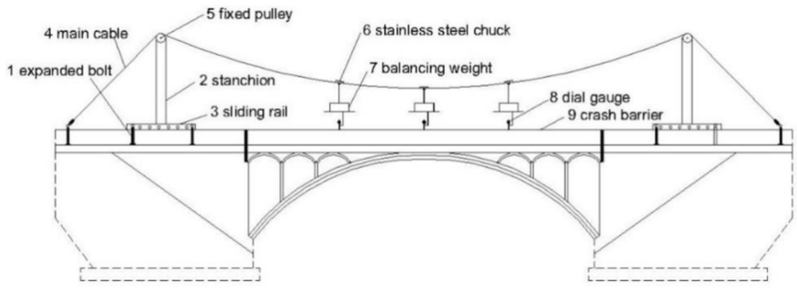


Figure 1. Facade after installation of deflection measuring device.

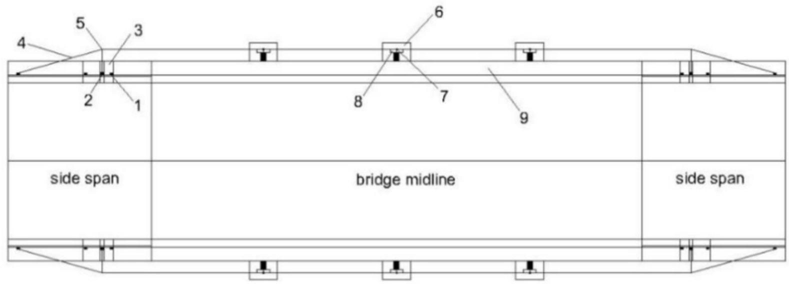


Figure 2. Overlooking after installation of deflection measuring device.

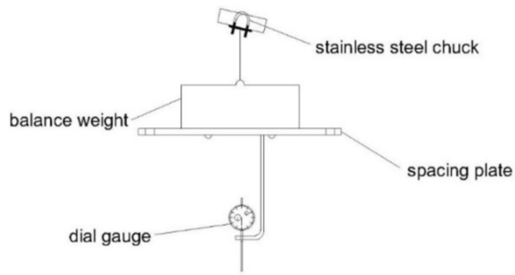


Figure 3. Local structure of cable with chuck.

3.3. Main Parameters of the Device

(1) Measurement accuracy: 0.001 mm;
(2) Applicable bridge types: small and medium-sized bridges;
(3) Measurement range of dial indicator: 0-100 mm;
(4) Weight: 5 kg.

3.4. Performance Characteristics of the Device

The bridge deflection measurement device and method mentioned in this paper is measured by the digital micrometer hanging under the cable. The measurement accuracy of the digital micrometer is very high (0.001 mm), and the volume is small and easy to carry and install. The micrometer is transmitted to the PC terminal through the single chip microcomputer to realize the digital collection of measurement data [10]. It can be used for short-term load test. Because this method does not affect the traffic on and under the bridge, it can also be applied to long-term health monitoring. The setting of limit plate and counterweight block can effectively avoid the horizontal interference in the transverse and longitudinal directions, ensure the stability and reliability of the dial gauge results in the measurement process, and make the device overcome the influence of adverse weather.

4. Engineering Example and Analysis

4.1. Bridge Information

No. 4 Lanhe Bridge on Line $K105 + 400$ of $S207$ is a 60 m reinforced concrete rigid frame arch, with $L_0 = 60$ m, $f_0 = 7.5$ m and $f_0 / L_0 = 1/8$. The superstructure is composed of three rectangular arch ribs. The rib spacing is 3.2 m. The mid-span section is 60 cm$\times$ 35 cm. The main arch leg section is 90 cm$\times$ 35 cm, and the secondary arch leg section is 60 cm$\times$ 35 cm. There are 16 transverse diaphragms in the whole bridge. The lower structure is gravity abutment. In 2013, the superstructure of the bridge was reinforced, and the design load level after reinforcement was highway-II; the width of bridge deck is arranged as net 8.3 m$+2 \times 0.5$ m (guardrail).

4.2. Engineering Verification

According to the purpose of the load test and the influence line of the test bridge, in order to make the bridge span structure load detection under the most unfavorable load condition and ensure the validity and rationality of the test, the test holes are carried out according to the following two working conditions.

(1) Condition I

The loads are distributed along the bridge direction according to the most unfavorable position of the positive bending moment of the mid-span section, and the loads are distributed along the transverse bridge direction according to the double trains.

(2) Condition II

The load is distributed along the bridge direction according to the most unfavorable position of the positive bending moment of the mid-span section, and the lateral load is the partial load of the double trains.

4.3. Solution Analysis

The measured values of the deflection measuring points of the mid-span section of the bridge span structure under the test load conditions I and II are compared with the theoretical values obtained by theoretical calculation, and the calibration coefficient can be obtained. The measured and theoretical values of the control section are shown in Table 1.

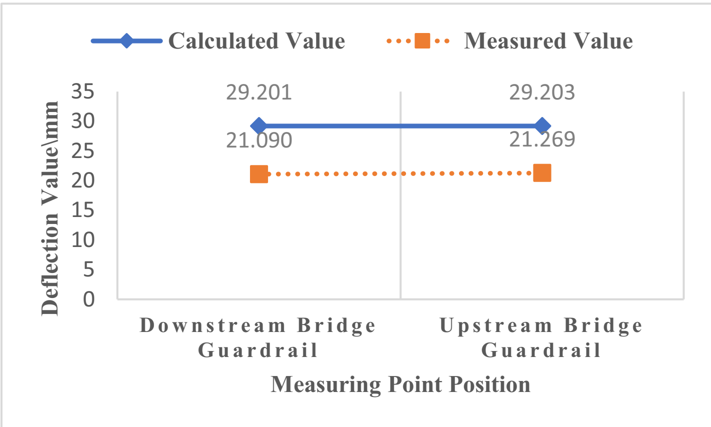
(1) There is a good coordination between the measured deflection and the theoretical value of the bridge span structure (Figure 4). The working performance of the bridge span structure can be evaluated by using the calibration coefficient of deflection.

(2) Under the load of test Condition I, the calibration coefficient of the measuring point of the control section is 0.72~0.73, with an average of 0.73 less than 1.0 ; under

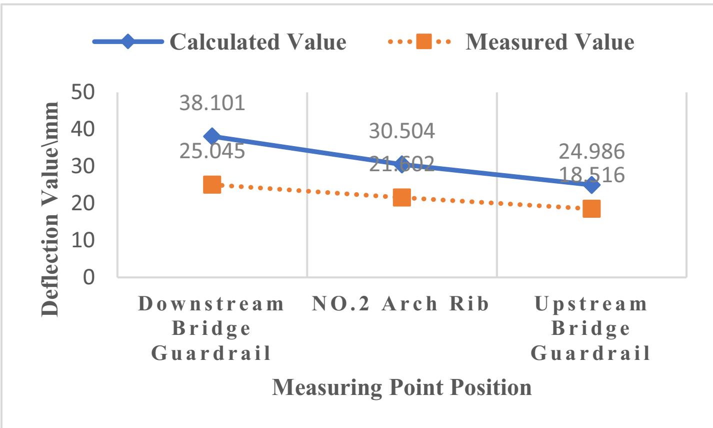
the test condition II load, the calibration coefficient of the control section measuring point is 0.66~0.74, with an average of 0.70, less than 1.0.

Table 1. Calibration Coefficient in Test Load.

Working condition	Section location	Measuring point position	Measuring points number	Calculated value/mm (1)	Measured value /mm First (2)	Second (3)	Average (4)	Calibration coefficient (4)/(1)
I	Midspan	Downstream Bridge Guardrail	00	29.201	21.154	21.026	21.090	0.72
		Upstream Bridge Guardrail	01	29.203	21.449	21.089	21.269	0.73
II	Midspan	Downstream Bridge Guardrail	00	38.101	25.051	25.039	25.045	0.66
		No.2 Arch Rib	02	30.504	21.461	21.743	21.602	0.71
		Upstream Bridge Guardrail	01	24.986	18.690	18.342	18.516	0.74



(a) Condition I: Comparison between theoretical value and measured value



(b) Condition II: Comparison between theoretical value and measured value

Figure 4. Deformation characteristics of main arch ring under load.

5. Conclusion

The device and method described in this paper can efficiently and accurately measure the deflection of the bridge. Compared with the existing deflection measurement technology, it has the following technical effects.

(1) The design and measuring point arrangement of the device is reasonable, the operation is simple, the demolition is convenient, and the investment cost is low, which effectively solves the shortcomings of time-consuming and laborious manual measurement and does not apply to high altitude measurement.

(2) The deflection measurement is read by the digital display dial gauge. The digital display dial gauge is not only small in size but also has high measurement accuracy. The dial gauge installed on the beam can measure all the main girders. The bridge deck guardrail measuring points form a network measuring point distribution, which has the ability to measure the overall bridge. The data transmission between digital display dial gauge and PC is realized by single chip microcomputer, which improves the convenience of measurement.

(3) This method does not affect the normal traffic operation, and can be used for both short-term load test and long-term health monitoring.

(4) The device has simple structure, light weight and easy operation, and the presence of limit plate and limit guide rod avoids the horizontal interference of the device, making the measurement system stable and reliable. This makes this measurement method not only overcome the adverse weather effects such as wind and rain, but also adapt to the measurement of large and medium-sized bridges.

References

[1] Sihai H. A review of highway bridge detection and evaluation Technology. Jiangxi Building Materials, 2019: p. 32-34.

[2] Wang YF. Detection technology and application analysis of highway bridge. Sichuan Building Materials, 2020. **46**: p. 28-29.

[3] Lan Z, Zhang H, Zhou J. A new bridge deflection measurement system based on laser and video. Chinese Journal of Scientific Instrument. 2009. **30**(11): p. 2405-2410.

[4] Wang A, Chen X, Zhang Q. Application of deflection measurement method in bridge load test. Engineering & Test, 2012. **52**(01): p. 31-33+39.

[5] Zhu X, Hu W. Total station method deflection deformation observation of runyang suspension bridge. Journal of Highway and Transportation Research and Development. 2006(07): p. 104-107.

[6] Ma Z, et al. Application of wireless inclination sensor in long-term monitoring of bridge deflection. Journal of Highway and Transportation Research and Development, 2016. **12**(04): p. 7-9.

[7] Zhu J. Design and research of MEMS acceleration angle sensor in bridge deformation monitoring. 2020, South China University of Technology.

[8] Hu M, et al. Application research of bridge dynamic displacement measurement based on digital image technology. Journal of Hefei University of Technology. 2015. **38**(12): p. 1661-1667.

[9] Wang L, et al. Bridge Dynamic Deflection Test Based on Hanging Hammer. Science Technology and Engineering. 2021. **21**(21): p. 9108-9115.

[10] Wang S, Peng X, Yan J. Data acquisition system of digital display micrometer based on single chip microcomputer. Electronic Measurement Technology. 2019. **42**(24): p. 120-124.