# Performance Evaluation of Continuous Box-girder Bridge Structural Properties Based on the Static Finite Element Model Updating

Shengzhen Kang[1]; Miaoyi Deng[1]; Fuming Wang[2]

[1]Doctor, School of Conservancy and Environment Engineering, Zhengzhou University, Zhengzhou, 450002; Lijia@zzu.edu.cn

[2]Professor, School of Conservancy and Environment Engineering, Zhengzhou University, Zhengzhou, 450002; Lijia@zzu.edu.cn

**ABSTRACT:** This paper represents performance evaluation of the structural properties of five-span continuous box girder bridge of a variable cross-section highway, by using static load test results, based on static structural finite element model updating methods. This report expatiates the application procedure, namely, bridge static load test, structural finite element modeling, finite element model parameter updating, performance evolutions. Updated finite element model (parameters) of the bridge structure and the structural properties performance evolution results could be used for damage identification of bridge structures, maintenance, reinforcement and some further structure analytical work.

## INTRODUCTION

Performance Evaluation of Bridge Structure is the basic work of reinforcement, maintenance to ensure bridge security operations. Compare to structural dynamic test of bridge, static load test has some advantages, such as, intuitive, high-precision test results. The use of static load test results to make performance evolution of bridge structures is higher reliability to be widely used. This report uses static load test results, adopts structural finite element model of static updating methods, makes some performance evaluation and research of a damaged pre-stressed reinforced concrete variable cross-sections five-span continuous box-girder bridge of a highway.

## 1.BRIDGE OVERVIEW

One pre-stressed reinforced concrete variable cross-section continuous box-girder bridges of a highway, which has five spans, spans combination is 31.5+35.5+50.5+30.0+36.5m, as shown in Figure 1, the total length is 183.5m.It opened to traffic in December 1996. The original design load rating is motorcars over level 20, trailers under level 120. The upper part of structure is a single box and single chamber box-girder. As shown in Figure 2, the main girder is GB50# concrete. The below edge of bottom plate in middle span of box-girder part follows B-type pre-stressed concrete component design. The lower structure part is bored pile foundation.

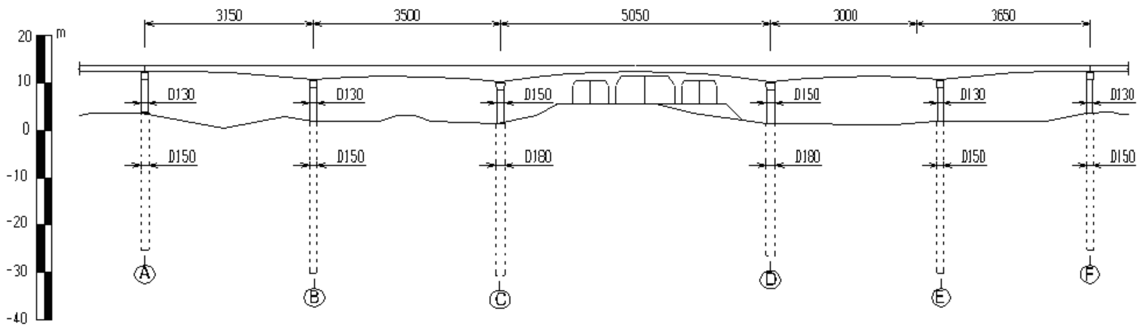


**FIG. 1. Layout of continuous box-girder bridge spans. (Element of bridge span is cm)**

In July 2004, it is discovered that there were some damages, horizontal cracks in the bottom of this box-girder bridge, some diagonal and vertical cracks in web plate. A majority of cracks width was less than 0.15mm. In May 2007, the existing cracks damage developed than that was in 2004. The maximum cracks width has reached 0.3mm, vertical cracks in some of the web plate and horizontal cracks in the bottom connected as "U" shape.

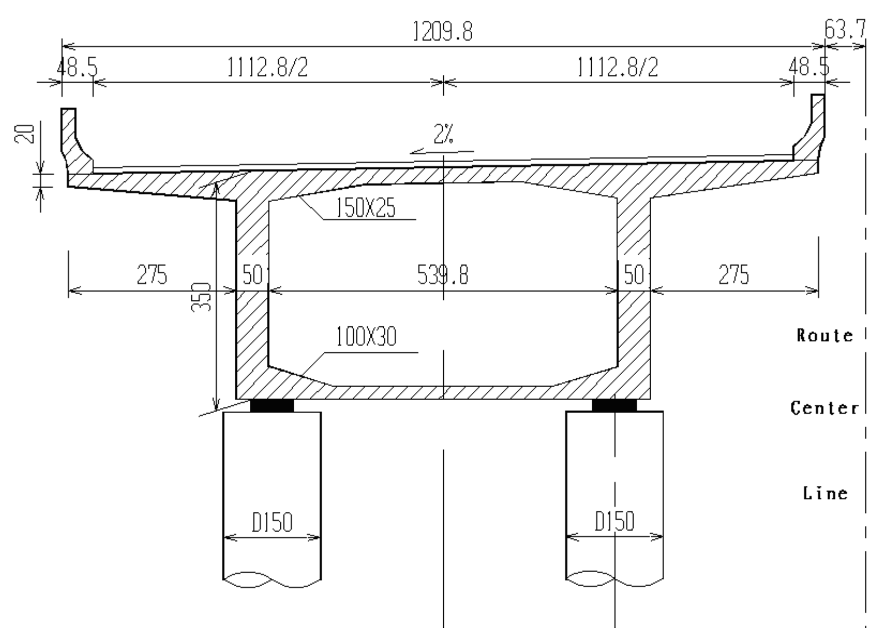


**FIG. 2.Schematic diagram of box girder cross-section (Element is cm)**

## 2. STATIC LOAD TEST OF CONTINUOUS BOX-GIRDER BYIDGE

### *Test Load*

In the mid-span (between C,D piers), loaded a single vehicle of three-axis camion with total weight of 300-400kN, after summary, the axial load as shown in Figure 3, the corresponding load point (finite element model elements) node no. and load values shown in Table 1.

**Table 1. Static load node strength**

| Load No. | Load Node Strength No. | Load Value（kN） |
|---|---|---|
| 1 | 19 | 56.0 |
| 2 | 21 | 167.5 |
| 3 | 22 | 167.5 |
| 4 | 24 | 143.2 |
| 5 | 26 | 257.9 |
| 6 | 27 | 257.9 |
| 7 | 29 | 295.6 |
| 8 | 30 | 295.6 |
| 9 | 31 | 130.4 |

### *Deflection Observation*

Set up deflection (displacement) testment point in the following position: the middle of the two side spans (between pier A and pier B, and between pier E and pier F ), two hypo-side spans (between pier B and pier C, and between pier D and pier E), in mid-span (between pier C and pier D ) L/4 、L/2、 3L/4. The above all is 11 testment points. At the same time, set deflection testment point on the top of every pier for the elimination of the effects of support piers subsidence.

Under the effect of all test loads, at each measuring point after deducted the settlement buttress deflection (displacement), the test results presented in Table 2.

**Table 2. The results of deflection testing**

| Testing Point No. | Node Points No | Deflection Test Value（m） |
|---|---|---|
| 1 | 5 | -0.00178 |
| 2 | 11 | 0.00217 |
| 3 | 13 | 0.00481 |
| 4 | 15 | 0.00383 |
| 5 | 20 | -0.00850 |
| 6 | 25 | -0.01332 |
| 7 | 32 | -0.00706 |
| 8 | 36 | 0.00263 |
| 9 | 38 | 0.00296 |
| 10 | 40 | 0.00173 |
| 11 | 46 | -0.00163 |

Note: Downward direction negative deflection is.

## 3. FINITE ELEMENT MODEL UPDATING AND EVALUATION OF BRIDGE STRUCTURE BASED ON THE TEST RESULTS

*Principles of structural static finite element model updating*

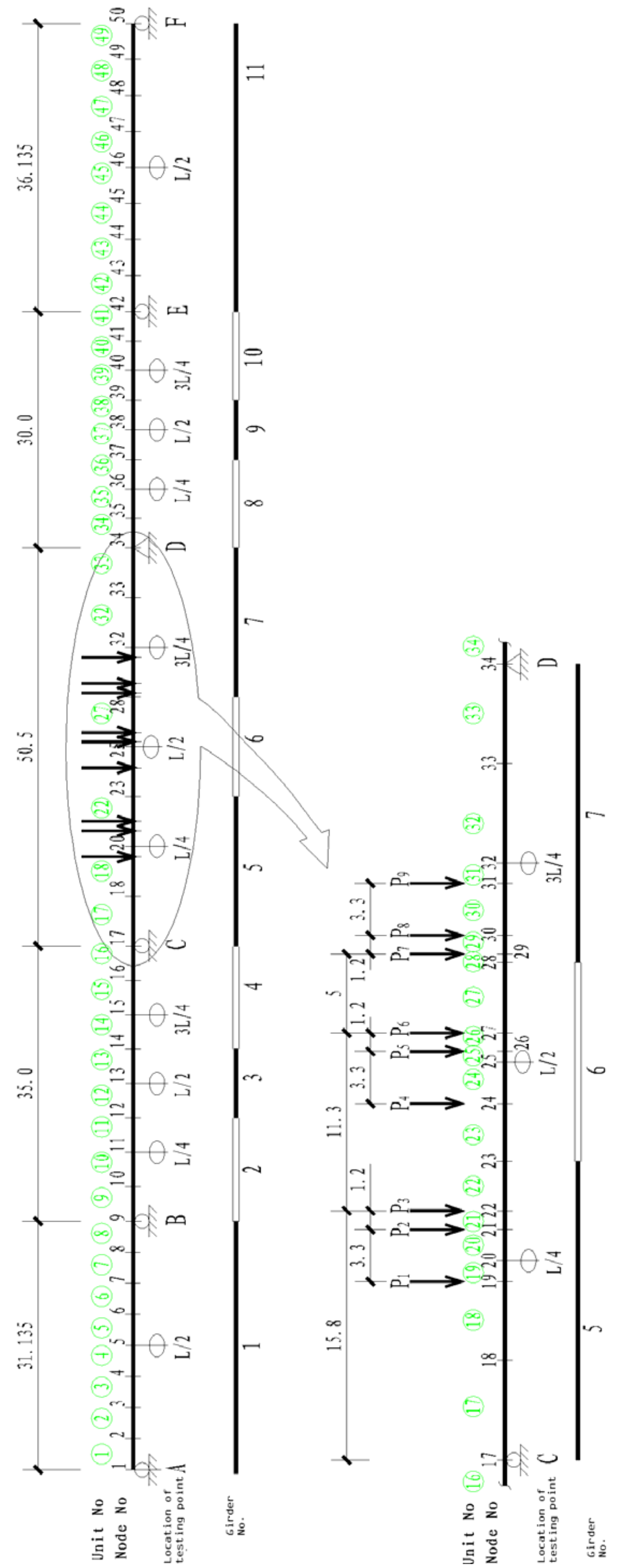


FIG. 3. Bridge load, analysis diagram

Based on the concept of mathematical optimization, finite element model updating of structural static can be expressed as: to find suitable structural finite element model parameters in a certain (reasonable) scope, in order to make the difference between the calculated structures finite element model static response and the actual structure of the static test response is minimum. Static structural finite element model updating could be transformed into a mathematical optimization problem to solve:

$$\begin{cases} \min \quad F(X) \\ \text{s.t.} \quad X_l \le X \le X_u \end{cases} \qquad (1)$$

In the above formula: $X$ is parameters set of the structural finite element model to be updated, $X_u$、$X_l$ are upper and lower limits of the parameters set of structural finite element model (a reasonable range of structural parameters), which is the boundary conditions of the optimization problems. $F(X)$ is the objective function vector reflecting the difference between structural finite element model test response and actual test structural response, which is objective function of the optimization problem.

According to the structural form、testing load operation conditions and different response information, there is a wide range of structural forms of the objective function $F(X)$, a general form can be expressed as:

$$F(X) = F(FEM(P, X) - T) \qquad (2)$$

In the above formula: $T$ is testing response (deflection, strain, curvature, etc.) of the structural static load test, $FEM(P, X)$ is the calculated corresponding structural finite element model despondence of $T$, $P$ is structural static test load.

*Elements division and elements parameters changes mode (parameters updating girder) packet of finite element model of five-span continuous box-girder bridge*

According to the original bridge design, structural characteristics and status of bridge structures, as well as, taking into account of the location of load test and implementation of finite element model updating method, the engineering examples of bridge is divided into 49 girder elements (showed by Figure 3). Finite element model updating did parameters updating of these 49 girder elements cross-section flexural stiffness $B_i$ ( $i = 1, 2, \cdots, 49$ ).

Based on the original design, structural concrete strength, calculation of every element cross-section flexural rigidity original value $B_i^0$. Updating of $B_i$ will be transformed to the updating of cross-section flexural stiffness coefficient $\alpha_i$ ( $B_i = \alpha_i \cdot B_i^0$ ).

According to structural characteristics of the bridge, load test condition and implementation process of finite element model updating, the engineering examples of bridge finite element model updating element parameters change model (parameters updating girder) division is as shown in Figure 3. Each group contained elements and parameters change mode (level) factor of the initial value, the lower limit, upper limit showed in Table 3.

After the above element division, 49 elements of cross-section flexural stiffness co-efficient $\alpha_i$ updating into 11 parameters change model (level) factors updating $\beta_i$ ( $\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_{49} \end{bmatrix} = \left[Q^x\right] \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_{11} \end{bmatrix}$ , $0.2 \le \beta_i \le 5.0$ , initial value $\beta_i^0 = 1.0$ , $\left[Q^x\right]$ is the 49 lines of 11transformation matrix coefficients ) .

**Table 3 Element parameters change model (parameters updating girder) division**

| ( Girder ) Division No. | Element No. included | Parameters change model ( level )factors initial value $\beta_i^0$ | Parameters change model ( level ) factors lower limit | Parameters change model ( level ) factors upper limit |
|---|---|---|---|---|
| 1 | 1、2、3、4、5、6、7、8 | 1.0 | 0.2 | 5.0 |
| 2 | 9、10、11 | 1.0 | 0.2 | 5.0 |
| 3 | 12、13 | 1.0 | 0.2 | 5.0 |
| 4 | 14、15、16 | 1.0 | 0.2 | 5.0 |
| 5 | 17、18、19、20、21、22 | 1.0 | 0.2 | 5.0 |
| 6 | 23、24、25、26、27 | 1.0 | 0.2 | 5.0 |
| 7 | 28、29、30、31、32、33 | 1.0 | 0.2 | 5.0 |
| 8 | 34、35、36 | 1.0 | 0.2 | 5.0 |
| 9 | 37、38 | 1.0 | 0.2 | 5.0 |
| 10 | 39、40、41 | 1.0 | 0.2 | 5.0 |
| 11 | 42、43、44、45、46、47、48、49 | 1.0 | 0.2 | 5.0 |

***Model updating result***

Comparison to bridge static load test deflection in response to the tested value and finite element model for calculating the value of the deflection response, according to type (2) structural optimization of the objective function, establish form-type (1) finite element model of the structure updating optimization problem. Adopt linear weighted and multi-objective optimization method into single-objective optimization problems, make the application of sequential quadratic programming (SQP), solving constrained optimization problems.

As updated, 11(girder) cross-section flexural rigidity parameters change mode (level) factor $\beta_i$ updated values presented in Table 4.

**Table 4 Every ( Girder ) element group cross-section flexural rigidity parameters change mode factors $\beta_i$ updating value**

| ( Girder ) element No. | Element No. included | Parameters change mode ( level ) factors $\beta_i$ updated value |
|---|---|---|
| 1 | 1、2、3、4、5、6、7、8 | 1.7980 |
| 2 | 9、10、11 | 2.1250 |
| 3 | 12、13 | 0.2142 |
| 4 | 14、15、16 | 0.9486 |
| 5 | 17、18、19、20、21、22 | 0.6055 |
| 6 | 23、24、25、26、27 | 0.7958 |
| 7 | 28、29、30、31、32、33 | 2.1790 |
| 8 | 34、35、36 | 1.3450 |
| 9 | 37、38 | 2.8910 |
| 10 | 39、40、41 | 0.5614 |
| 11 | 42、43、44、45、46、47、48、49 | 1.9340 |

*Performance evaluation of bridge structures based on model updating results*

Updated finite element model of the bridge structure (parameters) is consistent with the result of bridge static load test, which reflecting the current structural condition of the bridge model (parameters). Element group cross-section flexural stiffness model parameters (Level) factors $\beta_i$, whose updated value is based on box-girder cross-section flexural rigidity from static load test, based on the calculation of the original design ratio of stiffness, directly reflects the change in the performance of bridge structures. In Table 4, No.3, No.5, No.6, No.10th girder cross-section flexural rigidity of the box-girder is lower than the calculated values, it is means that there are some structural damages of these girders, which lead to reduction of cross-section flexural rigidity. It is consistent with the crack location and distribution of box-girder web and bottom.

Updated finite element model of the bridge structure (parameters) reflected quantificational impact level of the cracks on the structural properties (cross-section flexural rigidity). Updated structural cross-section flexural rigidity of the bridge structure is useful for the calculation of reinforcement maintenance analysis, which will be more objective reflect of the true status of bridge damage.

## 4. CONCLUSION

(1) The use of static load test results and structural finite element model of static updating method is successfully achieve the performance evolution of bridge structures.
(2) Bridge structure finite element model updating (parameters) reflects the structural prosperities of the structural damages (cross-section flexural rigidity), which is the extent of structural reinforcement for maintenance and further calculation and analysis of bridge, it is more objective reflect the current status of real bridge damage.
(3) This report uses 11 deflection response information of bridge load test, which can achieved only 11 finite element model of the structure parameters updating, it is not able to get more sophisticated finite element model updating. Research on the expansion of 11 structures of the effective methods of test data and technical tests are based on static structural finite element model updating method of performance evaluation of the structure is an important subject.

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# The development and application of analysis system of wind characteristics observation for bridge In the west inland

Zhang Yue [1], Zhou Mi[2].

[1] Lecturer, School of Construction and Civil Engineering Xi'an University of Science and Technology , Middle Yanta Road 45#, Xi'an, Shanxi P.R. China 710054. E-mail: zhangyue7810@163.com
[2] Lecturer, Key Laboratory for Bridge and Tunnel Engineering of Shanxi, Shanxi 710064, China. E-mail: zhoumi@yahoo.cn

**ABSTRACT:** Now in the west inland of China construction of large-span bridges become more and more, but in the existing anti-wind specification there is not the explicit values of strong wind characteristic parameters for inland area influenced by complex mountainous region. Considering the phenomenon that the study on Field measurement of turbulence characteristics has not yet been developed and combining the cable-stayed bridge with span 352m in the western gap of valley areas, a data processing system of wind speed observation based on Borland C++ Builder is compiled. The system can quickly and intelligently realize the statistical analysis of wind field monitoring data by the integration with standard template library (STL) which is defined as vector in C++. The paper presents program function, structure and development thoughts. Through the analysis for one-year field measured data, strong wind characteristics such as, the mean wind velocity, direction, turbulence intensity, gust factor and turbulence integral length are obtained. The results of analysis provide the bases for wind tunnel test, flutter and buffeting analysis and wind load calculation and the results are compared with those of numerical simulation by FLUENT. The reliability and efficiency are confirmed.

## INTRODUCTION

Since the late 19th century because of several accidents of bridges destroyed by wind such as the Telford straits bridge on Telford, Brighton continuous pier on Brown, the structural engineer began to aware of the importance of the wind-resistant design of bridges. After the accident of Tacoma bridge ruin in 1940, the wind engineering research has experienced more than half a century of prosperity. The reference of wind-resistant design to bridge is basic speed and wind characteristics, such as, turbulence intensity and integral scale, etc. If the subject is believed to be the input of bridge structure system, the internal of wind load and response of aerodynamic stability is the output of structure system. The basis of computing out put of system is the correct input model, so accurate and fast processing field observation data and getting natural characteristic parameters is the basis of wind-resistance design for bridge [1].

Taking a span of cable-stayed bridge for 352m lied on the western mountainous area as engineering background; the wind environment on bridge site has been monitored for 13 months by using the observation tower established on the field and the ultrasonic anemometer. A data processing system of wind speed observation based on Borland C++ Builder is compiled to analysis the mass monitoring velocity data .The wind field characteristics on bridge site and wind parameters were got, which was used to provide the correct basis for wind tunnel test of bridge , the analysis of chatter and buffeting and wind load calculation of structural analysis

## WIND ANALYSIS SYSTEM OF BRIDGE

### Development purposes

The ultrasonic anemometer of wind environment monitoring generally recorded data once every 0.1s. A wind speed measuring point in a month is up to tens of millions of lines record. On such a vast and complex parameters of the original wind data statistics and analysis, general mathematical tools (such as excel, matlab) in the calculation of both the speed and processing power can not meet the requirements. Therefore, it is necessary to develop a kind of special wind characteristics analysis processing system that can intelligent and fast calculate the characteristic parameters of wind [4].

### Programming language introduction

According to the basic idea of wind data analysis and processing on bridge, the wind characteristics of the bridge system version V1.0 was developed. Program development use c + + Builder6.0 platform, it is a widely used the object-oriented programming language. Object-oriented method to represent the event through an object and to show the links of incidents by message passing between objects. Through the "inheritance" reflects the similarities between subjects, through "multi-state" expression of individuality in different subjects. C + + Builder6.0 covers the C language, key concepts and features, while introducing some new concepts, leading to some new properties, such as classes, inheritance, overloading, polymorphism. C + + Builder6.0 have the most consistent with ANSI C / C + + standard development tools, more than 200 components, and efficient 32-bit ANSI / ISO C + + compiler, for programmers to create highly effective visual development environment. This development of system mainly includes two parts of design and coding [2-3].

### Program function and structure

Program using procedures for wind observation data analysis methods can automatically and rapidly calculate the wind parameters. Process has been completed features that are as follows:

(1) Pre-processing of three-dimensional and two-dimensional wind speed data. ①The monthly data file split into daily paper (daily from 0:00:00-23:59:59 for the day), the independent parameters (check code, temperature) are deleted and time recording format will rewrite as hours, minutes, seconds, automatically save a month&day. dat file. ②More time for the bad points, continuous record of more than 10 minutes, then removes the dead pixel directly, and note the dead pixel time. The bad points of not