The Study on Bridge Damage Identification Based on Vibration Mode Analysis and Hadoop Platform

Zongjun Sun *, Guanghui Wang, Lunbin Li and Chongchong Li
Shandong University of Science and Technology, Qingdao 266590, China.
* Corresponding author email: 913637035@qq.com

Abstract. The methods of damage identification of bridge structures are developing rapidly and various. With the development of science and technology, especially the development of cloud computing technology in recent years, which has brought great convenience to human life, at the same time, it may also provide a new technical way to solve the problem of bridge damage identification. As an open source and distributed system architecture, the Hadoop is the most extensive research and applied data processing platform at home and abroad. Hadoop platform processes the data collected by tests aisles objectively and properly, makes the bridge damage identification more accurate and credible.

Keywords: bridge; Damage identification; ANSYS; Modal analysis; Hadoop.

1. Introduction
Previous bridge structure damage identification has more or less certain limitations, which depends on the knowledge and experience of analysts to a certain degree, and there are inevitable errors. Moreover, the bridge has been affected by external factors such as weather and temperature, which results in the incompleteness of the bridge information and we can not have a comprehensive grasp of the state of the bridge. As a distributed system architecture of open source[1-3], Hadoop is the most widely researched and applied data processing platform at home and abroad. From the aspects of the bridge structure itself and the foundation of science and technology development[4], we can see that it is very necessary to carry out the research on bridge damage identification based on Hadoop. In this paper, finite element analysis software ANSYS is used to establish a simple steel truss bridge model[5] and it is analyzed. Damage identification indexes of the dynamic characteristics such as natural frequency, strain mode and modal mode[6] are used to be as input variables of cloud computing identification method, and data are analyzed by Hadoop platform. The finite element analysis software ANSYS is combined with the big data Hadoop platform for the study of bridge damage identification based on Hadoop platform.

2. Model establishment
In this paper, the low-bearing simply supported steel truss bridge is adopted as the research object. It is known that the length of the bridge is 60 meters, each segment is 10 meters long, the width of the bridge is 8 meters, and the height is 12 meters, and the concrete slab with a thickness of 0.3 meters is used in the bridge panel. The diagram is shown in Figure 1, the elastic modulus of steel is 2.1x1011Pa, the elastic modulus of concrete is 3.5x1010Pa, the poisson ratio of steel is 0.3, the poisson ratio of concrete
is 0.1667, the density of steel is 7800kg/m³, and the density of concrete is 2500kg/m³. The specifications of truss bars are shown in Table 1.

**Tab.1** Steel truss bridge member specifications

| member bar    | Section number | shape   | specification |
|---------------|----------------|---------|---------------|
| End slant     | 1              | I-shaped| $400 \times 400 \times 12 \times 12$ |
| Lateral beam  | 2              | I-shaped| $400 \times 400 \times 10 \times 10$ |
| string        | 3              | I-shaped| $400 \times 400 \times 10 \times 10$ |
| Other webs    | 4              | I-shaped| $400 \times 300 \times 10 \times 10$ |

**Fig.1** Well-integrated truss bridge model schematic
Against the specific problems of simply supported steel truss bridge, First, generate the node of half span bridge, then generate the unit, choose the first unit properties, establish the diagonal beam element, select the second unit attributes to set up top and bottom chord and beam girder unit, choose the third unit attributes, build top the bottom chord and beam girder unit, choose the fourth unit properties, set up bridge panel unit, finally, produce the finite element model of whole bridge and merge overlapping nodes to get the finite element model of the simply supported steel truss bridge. The model has a total of 64 units, 24 nodes. As shown in Figure 1.

Through the finite element analysis for mode of the simply supported girder bridge model, it can be known that the middle part of the bridge has the maximum displacement. And it can be used as the main research object of damage.

Afterward, element analysis software ANSYS is used to simulate the dynamic[7] index of simply supported steel truss bridge. By reducing the stiffness of the 8 units, the damage of the 8 units is simulated. By reducing the stiffness of 4 units and 12 units, multi-position damage was simulated in this simple beam model. Then, the modal analysis of the simply supported steel truss bridge model[8] is carried out under the damage condition of 8 units, 4 units and 12 units at the same time.

3. HADOOP algorithm analysis
The flow chart of the simulation identification algorithm is shown in figure.2

![Fig. 2 Hadoop-based damage identification method flow chart](image)

After building Hadoop platform, the compilation of Map module and Reduce module will be followed. When the two modules are compiled, there is no need to compile too many program structures, only targeted programming for the functions to be implemented is good. Generally, the compilation of Map and Reduce functions[9] is as follows. In this process, Map function and Reduce function play different conversion roles respectively.
\textit{map} : (\textit{key}1, \textit{value}1) \rightarrow \textit{list} (\textit{key}2, \textit{value}2) \\
\textit{reduce} : (\textit{key}, \textit{list} (\textit{value}2) \rightarrow \textit{list} (\textit{key}3, \textit{value}3)

In the above formula, \textit{key}1 and \textit{value}1 represent the initial input information of the Map module. After mapping transformation of the Map module, new values are outputted. Among them, \textit{key} represents the key, \textit{value} represents the value corresponding to different keys. Two these are together to be called Key-value pair. First, the data are classified, then these classified data are inputted to Reduce, which is processed through parallel calculation of Reduce and output the final result. The final results of these outputs are the each \textit{key} value and corresponding total values.

After completing the Hadoop platform model, the key is to write the Map function module and Reduce function module. In this paper, Hadoop is introduced into the field of bridge damage identification[10], which is to write the corresponding Map function module and Reduce function module that can identify the damage of bridge structure so as to realize its goal.

In view of the Map function module, the total stiffness matrix and mass matrix under the various states extracted by the finite element analysis software ANSYS is as the Map function module. We select the pieces of data and have model process for the data in the first place, after the standardization of data and model order, data are fitted, then calculate the fit and standard deviation of the fitted data and the intact state[11]. The key value pairs of the Map function module are as follows:

\begin{align*}
< \text{data position, data length} > & \rightarrow < \text{detection point aisle, residual and standard deviation} > \\
< \text{detection point aisle, residual and standard deviation} > & \rightarrow < \text{detection point aisle, damage characteristic index} > \\
\end{align*}

After the calculation and analysis of Map Reduce[13], the damage characteristic index of each aisle in different states can be obtained for damage identification.

4. Case simulation analysis

24 measuring point aisles are arranged on the simply supported steel truss bridge model, a aisle of measuring points corresponds to a node including the aisle 1 to 24, respectively. Because the middle part of the displacement is most obvious in bridge across, so the main simulation is unit in beam span damage.

Suppose the dynamic characteristic equations of \textit{n} freedom system[14] are shown in (1) and (2).

\begin{align*}
K\phi_j &= \lambda_j M_0 \phi_j \\
\lambda_j &= (2\pi f_j)^2, j = 1,2,3,\cdots, N_m
\end{align*}

Therefore, the stiffness matrix can be expressed as shown in equation (3).

\begin{equation}
K = K_0 - \sum_{i=1}^{N_e} \alpha_i K_i
\end{equation}

Where:

\begin{align*}
K_0 & \quad \text{the stiffness matrix in the non-damaged state;} \\
K_i & \quad \text{the element stiffness matrix of the} \ i \ \text{element;} \\
M_0 & \quad \text{the mass matrix in the non-damaged state;} \\
\lambda_j & \quad \text{The} \ j \ \text{order eigenvalue of the characteristic equation;} \\
\phi_j & \quad \text{The} \ j \ \text{eigenvector of the characteristic equation;}
\end{align*}
$f_j$ --- the natural frequency of the $j$ order;

$N_e$ --- the total number of units in the structural model;

Introduce the coefficient $a_n(n = 1,2,\cdots,n)$ to represent the damage degree of a unit respectively. The damage degree judgment is mainly completed by the reduction of stiffness.

Suppose $\alpha = 0$ when the bridge structure is in the state of no damage, and then different values are set to simulate different degrees of damage as the state to be recognized.

Modeling using finite element analysis software ANSYS [15], the total stiffness matrix $K$ and the total mass matrix $M$ under various conditions of the bridge structure model can be extracted by the HBMAT command method. Run the HBMAT commands on the finite element analysis software ANSYS, total stiffness matrix and mass matrix extracted are stored as Harwell - Boeing format file, which are used to be index storage, display non-zero elements of the matrix. The format of the generated file records is large sparse matrix standard exchange format, the basic format of the file is to show the basic content first, and then list the elements of matrix.

This model has 64 units and 24 nodes, each nodes constraints two freedom degrees. The simply supported steel truss bridge model has a total of 48 freedom degrees. It means that the total stiffness matrix and the total mass matrix of the simply supported steel truss bridge are all $48 \times 48$ order real symmetric matrices. Taking the extraction of total stiffness matrix as an example, the harwell-boeing file of total stiffness matrix extracted by ANSYS is shown in Table 2.

| Tab.2 The first five columns of the Harwell-Boeing file for the total stiffness matrix |
|--------------------------------------|-------|-------|-------|-------|
| Stiffness matrix from ANSYS FULL file dumped into Harwell-Boeing format |       |       |       |       |
| RSA (I14)                         | 353   | 49    | 128   | 128   |
| F (I14)                           | 48    | 48    | 128   | 0     |
|                                   | (d25.15) | (d25.15) |       |       |
|                                   | 1     | 48    |       |       |

Among them, the first line represents literal interpretation of the file, which represents the harwell-boeing file, the second line represents the total stiffness matrix. The second line indicates that the file has 353 rows of data, the total number of rows in the matrix column pointer is 49, the total number of rows in the matrix row index is 128, the total number of rows in the matrix element value is 128, and the total number of rows on the right side is 48. The third row indicates that the stiffness matrix is a real symmetric matrix with 48 rows and 48 columns, in which there are 128 non-zero elements. The fourth line represents the output format of the relevant corresponding data. The fifth line represents all data are stored on the right-hand side, which have 48 rows and 1 column.

Using ANSYS to extract the total stiffness matrix and mass matrix to be as the test data, by setting different $\alpha$ value, the data in all cases are as input parameters of the Hadoop platform. According to the different measuring point aisle in the platform and different damage, the data are divided to be fragments. First, the residual and standard deviation in the Map are output in different aisles corresponding to the different damage cases, then use the Reduce to process data, and the structural damage characteristic index corresponding to each unit is obtained by comparing and analyzing the state of recognition and the undamaged state. Finally, the unit damage characteristic index under different damage conditions is output. In the whole process of Hadoop analysis, only raw data need to be input on the main architecture distributed file system of Hadoop platform, the $\alpha$ value is set, then the Hadoop platform will automatically calculate the result.

At first, suppose that the unit 8 position damages, and set up different damage degrees for 8 unit ranging from 5% to 50%. The selected measuring point aisle is the aisle related to the 8 unit position, the aisle 13, and the aisle unrelated to the 8 unit position that aisle 5 and aisle 10, by studying the unit 8 position damage and the relationship between the dynamic response of the measuring point aisles, calculate the structural damage characteristic index and extract the damage information. The damage condition is shown in Table 3.
Tab.3 8-unit location damage conditions

| Working condition | degree of damage | Working condition | degree of damage |
|-------------------|------------------|-------------------|------------------|
| 1                 | 5%               | 6                 | 30%              |
| 2                 | 10%              | 7                 | 35%              |
| 3                 | 15%              | 8                 | 40%              |
| 4                 | 20%              | 9                 | 45%              |
| 5                 | 25%              | 10                | 50%              |

The selected structural damage characteristic value bar chart of each aisle is shown in Figure 3.

Fig. 3 8-unit damage conditions

Fig. 4 8-unit damage
In Figure 3, the horizontal axis represents the damage condition and the vertical axis represents the structural damage characteristic index value. For 8 units location, choose the related test aisle 9 and 13, besides, choose the unrelated aisle 5 and 10. From the Figure 3 (a) and (b) it can be seen when the single damage of 8 unit position occurs, the structural damage characteristic index values of aisle 5 and aisle 10 are basically above and below the value 1, the determinate units have not damage. It can be seen from Figure 3 (c) and (d) that the structural damage characteristic index of aisle 9 and aisle 13 are both greater than 1, by which we can determine the damage of the unit. Moreover, with the increase of damage degree, the structural damage characteristic index also tends to increase.

In Figure 4, the abscissa represents the degree of damage, and the ordinate represents the structural damage characteristic index, which respectively represents the relationship between the four aisles and the damage degree of the 8 units. Figure 4 can be seen very intuitively that the aisle damage characteristic index associated with the damage unit increases as the damage level increases. While the damage characteristic index of other aisles is around 1 without significant change, which provides a good reference for the quantitative judgment of damage degree of the unit.

Next, analyze the damage identification under multiple damage conditions, Simulate 8 unit position and 12 unit position damage, set up different damage degrees ranging of 5% to 50% in response to 8 unit and 12 unit, The selected measuring point aisle is aisle 9, aisle 13 associated with the 8 unit position, aisle 11 and aisle 15 associated with the 12 unit position, and aisle 5 and aisle 10 which are not related to the two positions. By studying the relationship between the damage unit and the dynamic response of each measuring point aisle, the structural damage characteristic index is calculated and the damage information is extracted, the damage identification situation is shown in Figure 5.

![Fig. 5 8- and 12-unit damage](image_url)
Fig. 6 8- and 12-unit damage

In Figure 5, the abscissa represents the damage condition and the ordinate represents the structural damage characteristic index value. For the case of multiple damage in the 8 unit and 12 unit positions, the structural damage characteristic index values of the aisle 5 and the aisle 10 which are not related to the damaged unit are basically above and below the value 1, and we can determinate that the units are not damaged. The structural damage characteristic indexes of aisle 9, aisle 13, aisle 11, and aisle 15 associated with the damage units are greater than 1, and we can determinate that the units are damaged. Moreover, as the degree of damage increases, the structural damage characteristic index also increases.

In FIG. 6, the abscissa represents the degree of damage and the ordinate represents the structural damage characteristic index, respectively indicates the relationship between the six aisles and the degree of damage in multiple damage conditions. Figure 6 shows that the aisle damage characteristic index associated with the damage unit increases with the degree increase of damage, while the damage characteristic indexes of other aisles are around 1 without significant changes, which provides a good reference for the quantitative judgment of damage degree of the unit.

Researching on the damage identification method of bridge structure based on Hadoop, we found that the method can well identify the unit of structural damage, based on the structural damage characteristic index, the quantitative determination of the degree of damage can be made. The above research results prove that the Hadoop-based bridge damage identification analysis method is effective for the location and estimation of bridge structure damage.

References

[1] Tan Jingjing. Research on isolated point mining of bridge monitoring data based on Hadoop [D], Chongqing Jiaotong University, 2016
[2] Sohn H, Farrar CR, Hemez FM, Czarnecki JJ, Shunk DD, Stinemates DW, et al. A review of structural health monitoring literature:1996-2001, Los Alamos National Laboratory Report LA-13976-MS, 2003
[3] Teng Liang. Study on comparison and selection of damage identification indicators for bridge structures and damage degree identification methods [D], Jilin University, 2014
[4] Lu Xiaoyun. Research on the application of bridge health monitoring IoT based on Hadoop [D], Wuhan University of Technology, 2015
[5] Fu Pengtao. Finite element analysis and damage identification of large bridges based on ANSYS [D], Chang’an University, 2011
[6] Zeng Chun. Research on finite element dynamic analysis of bridge crane bridge structure based on ANSYS [D], Wuhan University of Technology, 2006
[7] Zheng Fei, Xu Jinyu. Structural damage identification based on strain energy and frequency of polycondensation mode[J], Engineering Mechanics, 2012, 29(7): 117-123
[8] Li Jun, Yu Dedong, Bai Huiren. Structural damage location method based on strain mode[J], World Earthquake Engineering, 2007(01): 104-109
[9] Hu Ning. Damage identification using the flexibility matrix obtained from test data [A]. Modern Vibration and Noise Technology, Beijing: Aerospace Industry Press, 2000: 35-39
[10] Lin Jingwei. Structural damage detection based on cloud computing [D], Jinan University, 2014
[11] Salawu O S, Williams C. Damage location using vibration mode shapes. Proceedings of the 12th International Modal Analysis Conference, 1994: 933-939
[12] Wang Tianqi. Construction monitoring method and problem analysis of long-span steel-mixed composite girder bridge [D], Chongqing Jiaotong University, 2015
[13] Fan Jianyong. Research on several key technologies of cloud GIS based on Hadoop [D], PLA Information Engineering University, 2013
[14] Lin Jingwei. Structural damage detection based on cloud computing [D], Jinan University, 2014
[15] Chen Yong. Design and implementation of distributed query algorithm for communication data based on Hadoop platform [D], Beijing Jiaotong University, 2009