Study of Intelligent Analysis Technology on Bridge Load Test

An Zhao¹, Na Zhang², Qiang Xu³ and Jia Yu⁴

¹Research Institute of Highway Ministry of Transport, BeiJing,100088, China
²Beijing Urban Construction Design & Development Group Co., BeiJing,100037, China
³Research Institute of Highway Ministry of Transport, BeiJing,100088, China
⁴Beijing Wisdom Bridge Technology CO.,LTD, BeiJing,100012, China
*Corresponding author’s e-mail: 279101052@qq.com

Abstract. The bridge load test analysis system BLT is a special software for the bridge load testing developed by the Highway Research Institute of the Ministry of Transport. It can quickly and easily establish the finite element model of the bridge structure space, and use the solid element and space beam method for static and dynamic test analysis. According to the load test procedure, it can automatically recommend test conditions and layout points, automatically calculate the test load layout, conveniently extract the theoretical calculation values of stress and displacement at the position of the measurement point, and quickly browse the stress and displacement cloud maps. The system is highly intelligent, greatly improving the efficiency of bridge load detection and bringing good news to bridge load test engineering. This paper introduces in detail the characteristics of the intelligent analysis technology, calculation principle and real bridge application examples of the system.

1. Introduction
The purpose of the bridge load test is to measure the response (strain, static displacement and crack, etc.) of the bridge structure under the test load, according to which, can evaluate the bridge technical status, and record the basic characteristics of the bridge and bear the bearing capacity of the bridge, providing scientific evidence and support for assessment and decision making for future maintenance, repair and reinforcement [1].

The bridge load test can be used to: (1) inspect the bridge structure design and construction quality; (2) verify the bridge structure design theory and calculation method; (3) obtain the bridge structure bearing condition directly to judge the actual bearing capacity of the bridge structure; (4) accumulate scientific and technical data, enrich and develop bridge calculation theory and construction technology.

The main contents of the bridge load test include: the purpose specifying of the load test, the test work preparation, the loading plan design, the test point setting, the test loading control, the test safety measure, the test result analysis, the bearing capacity evaluate and the test report writing.

2. The problems of past common software in load test analysis
The basis of the bridge load test analysis is the dynamic and static analysis of the bridge structure [2, 3], which needs to be completed by means of structural analysis software. In the past, there was no dedicated software for bridge load test analysis. Engineers usually used general finite element programs or bridge structure design software for analysis[4]. The general finite element program unit is rich in types and
powerful in calculation, but the speciality for bridge analysis is poor, such as the modelling is cumbersome, the load simulation for road design is difficult, and the post-processing workload is heavy. When doing bridge load test analysis by using bridge structure analysis design software, some design parameters are unnecessary, such as concrete shrinkage and creep, construction stage, etc. Furthermore, bridge load test analysis concerns the local stress[5], transverse deformation, etc., however, the space design software of beam grid cannot act well[6]. In addition, the bridge structure design software and the general finite element software have never provide special modules for the characteristics of the load test[7], such as load efficiency calculation, vehicle load selection and arrangement, measuring point arrangement and point extraction result, etc., making the operation more troublesome. Using those software often costs a lot of time and effort from engineers[8], and the work efficiency is difficult to improve. With the large-scale construction of bridges in recent decades, more and more new bridges have been built and accepted, and the load bearing capacity assessment of in-service bridges is required for load testing. It is an urgent problem that how to improve work efficiency and accuracy.

3. Analytical techniques for intelligent load testing

3.1. Development purpose of BLT software

In view of the above problems, the Highway Science Research Institute of the Ministry of Transport has developed the "Bridge Load Test Analysis Software BLT" for the intelligent and automated research of bridge load test analysis. The software can automatically design the load test method for the bridge structure according to the current specifications, and quickly find the theoretical value of the survey point under the designed load, which is convenient to compare with the measured value, and finally automatically output the load test report to realize the intelligence of the load test analysis. In the end, the work efficiency of testing engineers will be improved by using the convenient and fast calculation tools, and then they can provide better serve for the development of transportation construction.

3.2. Intelligent load test plan determination

3.2.1. Automatically recommend test sections and test conditions

The system automatically recommends the test information such as bridge span, test conditions, etc., according to the “Code for the Evaluation of Load Capacity of Highway Bridges (JTG/T J21-2011)”, “Code for Load Test of Highway Bridges”, the form of bridge structure (including beam bridges, arch bridges, cable-stayed bridges, etc.) and test purposes. The position of the test section is determined according to the principle of the most unfavorable force by calculating the internal force influence line of the bridge structure. The test includes bending moment, shear force, axial force and deflection. The loading method is divided into vehicle load and other loads (concentrated load and uniform load). Users can also modify or add control sections and test conditions as needed.

3.2.2. Automatic design load test plan

To design the load test plan, users should determine the design load effect of the test section first. The program will automatically calculate the impact coefficient according to the structural parameters and the input design load level, and it will give out the design load effect of the control section under each working condition by using the dynamic programming method with transverse distribution coefficient.

Then, according to the weight and length of the test vehicle (default several common standard models, such as steam-20 standard car, steam-20 heavy-duty car, etc.), BLT software will obtain the load arrangement that meets the load efficiency interval value through internal calculation program. The calculation principle is to dynamically load the influence line of the control section of each working condition, and then compare the calculated test load effect with the design load effect. By moving the load position and changing the number of loads, the load within the target range will be reached in the end, with the condition ensure that the load efficiency of other sections does not exceed the upper limit. The "automatic load test program" function module effectively avoids the cumbersome calculation
the process of manually adjusting the vehicle layout trial and error when users use the general finite element software or the bridge structure design software, and it can also conveniently and quickly give out the ideal load arrangement scheme, as shown in figure 1. For the acceptance load test, the load efficiency defaults to between 0.85 and 1.05. For the identification load test, the load efficiency defaults to between 0.95 and 1.05. Users can also modify the load efficiency target range according to the actual test requirements.

![Figure 1 Load test plan by BLT](image)

### 3.2.3. automatic placement of measuring points

The program can automatically determine the number and position of the test points, such as the position of the strain or displacement test, according to the test purpose, test conditions, test sections and other information. The theoretical values of the test points will be listed in a table after the structural calculation. It will reflect the stress and deformation characteristics of the bridge structure intuitively, which is convenient for the test personnel to compare with the measured values. The system automatically arranges the measuring points of each control section according to the bridge load test procedure, which can meet the requirements for general users, and users can also manually modify or add the measuring points as needed.

![Figure 2 Measuring point layout by BLT](image)

### 3.3. Intelligent 3D solid element modeling

Besides providing traditional beam-grid units, providing 3D solid (board) units is also an outstanding feature of BLT software. Because load test concerns the local stress changes and deformation of the structure, the solid element is undoubtedly more suitable for load test analysis than the beam element. In order to solve the complex drawbacks of solid element modeling, the modeling method of BLT software is converting a planar model to a spatial model automatically. In the end, users only need to input simple parameters as the traditional beam modeling method, and then the program automatically generates a three-dimensional entity according to information such as cross section. To a specific structure, whether choosing the beam cell unit calculation or the entity (plate and shell) unit calculation, users just need to input same parameters, so it is convenient for users to select the calculation method according to their needs.

![Figure 3 Three-dimensional finite element model](image)
The calculation accuracy of the solid element model is proportional to the calculation scale, and the increase in accuracy means an increase in calculation time and capacity. In order to solve this problem, the software adopt the method of local-encryption calculation method, and the unit division near the test section is finer, so that the test section (the part concerned by the user) obtains higher precision when the number of full-bridge structural units is limited.

4. Application examples

4.1. Continuous rigid bridge with changing height
A new bridge is located in Hualong County, Qinghai Province, across the Yellow River, with a load rating of Class I, and a 75m+2×120m+75m variable-section continuous rigid frame beam. The variable section modeling is obtained by the program based on the end critical section information through the linear difference of the power function. The whole bridge adopts the solid element model, with 15710 solid units and 10 support units, all of which are automatically modeled by the program according to parameters such as section and member length. Such a model is very large if it is manually modeled according to the traditional method.

The BLT program recommends the control section and test contents (bending moment, shear force, axial force and deflection) of each working condition according to the test procedure, and automatically calculates the test layout scheme that meets the required load efficiency according to the design load and the parameters of the test vehicle. Figure 5 shows the most unfavorable position of the mid-span cross-section bending moment and deflection. The cross-bridge is symmetrically loaded. A single-axle truck with a weight of about 300kN is used as the test vehicle. According to the control section position and shape parameters, the program automatically recommends the measuring point layout scheme that meets the requirements of the specification, as shown in Figure 6.
After the structural calculation, the theoretical value of the position of the measuring point can be automatically extracted. The comparison between calculated value and theoretical value on the measured stress and vertical deflection of the mid-span mid-section of the bridge is shown in Table 1 (the measuring point numbers are numbered from left to right).

| Num | unit | Theoretical value | Measured value | verification coefficient | Relative residual |
|-----|------|------------------|----------------|--------------------------|------------------|
| S-1 | MPa  | 3.67             | 2.45           | 0.67                     | 1.87%            |
| S-2 | MPa  | 3.57             | 3.02           | 0.85                     | 12.32%           |
| S-3 | MPa  | 3.58             | 1.78           | 0.50                     | 9.45%            |
| S-4 | MPa  | 3.58             | 1.90           | 0.53                     | 0.56%            |
| S-5 | MPa  | 3.57             | 2.43           | 0.68                     | 5.32%            |
| S-5 | MPa  | 3.67             | 1.80           | 0.50                     | 1.56%            |
| D-1 | mm   | -0.09            | -0.06          | 0.66                     | 0.00%            |
| D-2 | mm   | -0.09            | -0.09          | 0.99                     | 0.00%            |

4.2. Variable width continuous bridge

The analysis and calculation of a monitoring project of a highway junction overpass adopts the BLT. The bridge is a wide-open single-box multi-chamber continuous box girder with a span of 3*30m and C50-concrete box girder. In the process of model building, the bridge deck is divided into several units. The cross sections at each end of the unit are different with the width. The diaphragm is simulated by the non-bridge deck unit, and the full bridge adopts the solid element model. The model contains 13981 solid units and 16 rod units as shown in Figure 7.

The working load is arranged to arrange four steam-to-weight vehicles at equal intervals in the lateral direction, and the front wheelbase is 8m at the end. In order to accurately reflect the stress of the bridge structure under this working condition, the measuring points for monitoring the bridge cross-stress and vertical deflection are arranged in the mid-span position, as shown in Figure 8.
The theoretical results of the stress and vertical deflection of the mid-span section of the bridge are shown in Table 2 and Table 3.

### Table 2 Theoretical stress results of cross-span mid-span

| Num | C1   | C2   | C3   | C4   | C5   | C6   | C7   | C8   | C9   | Unit  |
|-----|------|------|------|------|------|------|------|------|------|-------|
|     | -0.452 | 1.266 | 1.764 | 1.425 | 1.457 | 1.444 | 1.753 | 1.250 | -0.455 | MPa   |

### Table 3 Theoretical displacement results of cross-span mid-span

| Num | C10  | C11  | C12  | C13  | C14  |
|-----|------|------|------|------|------|
|     | -0.452 | 1.266 | 1.764 | 1.425 | 1.457 |

It can be seen from Table 2 and Table 3 that the stress and displacement calculated values are symmetrically and continuously distributed under the action of the symmetrical load, which is in accordance with the mechanical law. Due to the shear lag effect, the calculated values of stress and displacement at different positions on the bottom surface of the section are different.

5. Conclusion

The analysis of bridge load test is of great significance for recording the basic characteristics of bridges, evaluating the technical status of bridges, and making decisions on bridge maintenance, repair and reinforcement. Improving the efficiency and accuracy of bridge load test analysis is the direction and goal of related software. The “Bridge Load Test Analysis System BLT” software developed by the Highway Science Research Institute of the Ministry of Transport is highly targeted and easy to use. It realizes the intelligence and automation of load test analysis, which can effectively improve computational efficiency and accuracy and provide better serve for the development of traffic construction.

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