

Study of Analysis System for Bridge Test

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Summary

Analysis System for Bridge Test (Chinese name abbr.: QLJC) is an application software specially designed for bridge test to analyze the static and dynamic character of bridge structures, calculate efficiency ratio of load test, pick up the results of observation points and so on. In this paper, research content, system design, calculation theory, characteristics and practical application of QLJC is introduced in detail.

1 Introduction

At present, China is coming into the period of high-speed development of highway construction. And the bridges that play important roles in communication system have also come into advanced level in the world. Bridge test is significant to ensure bridges use safely.

The kernel of load test of bridge structures is analysis and evaluation of test results data. It is essential to analyze static and dynamic characteristics of bridge structures and then compare the calculated values with the measured values. Before QLJC, there is still not a set of software special for bridge test analysis in China. Without special software, bridge diagnoses engineers usually use some structure design software or general finite element program to analyze the mechanical character of bridge structures under test loads. Generally speaking, design software pays more attention to construction stage analysis and design function, at the same time the workload of modeling and post-processing of general finite element program is very heavy. It usually cost engineers much time and energy to get perfect results and affect the efficiency of the bridge test seriously. These kinds of software are unsuitable for practical requirements of bridge test analysis, so a set of software with specialty, facility and powerful function is needed urgently. For this reason, Analysis System of Bridge Test, Chinese name abbr. QLJC, is developed by RIOH (Research Institute of Highway) of MOC (Ministry of Communications) of China.

2 Integrated Concept

QLJC is designed on the base of GQJS (Chinese name abbr.)---Structure Design System of Highway Bridge, and JFDJ (Chinese name abbr.) ----Static and Dynamic Analysis system of Spatial Nonlinear Bridge Structure, which were also developed by RIOH. GQJS has been popularized in china because of friendly interface and convenient use, and JFDJ is used in spatial nonlinear and dynamic analysis. QLJC succeeded to use the style of GQJS interface, supplemented some spatial data for bridge test and adopted the calculation kernel of JFDJ.

With the use of QLJC, the data not only can be written at the interface directly but also can be imported by GQJS data file. After added some essential information, spatial element model is

erected. Test load information and observation points distribution should be input and then the loading plan is determined. Through meshing into beam elements or solid elements, calculation data of structure are formed to analyze.

QLJC inherits the virtue of friendly interface and convenient use of GQJS as well as extended the strongpoint of JDFJ on analysis function. According to test load information, the efficiency of load test can be calculated to optimize the test plan, and the distribution of concentrated and vehicle loads such as number, position and direction can be viewed for checking up the accuracy of data input easily. When calculation finished, structure distortion or modal shapes can be displayed in spatial diagram and calculated results of every observation point can be list in table. It is helpful for engineers to release them from heavy work of picking up needed results from plenty of results data.

The diagram of QLJC system composition is list as fig1.

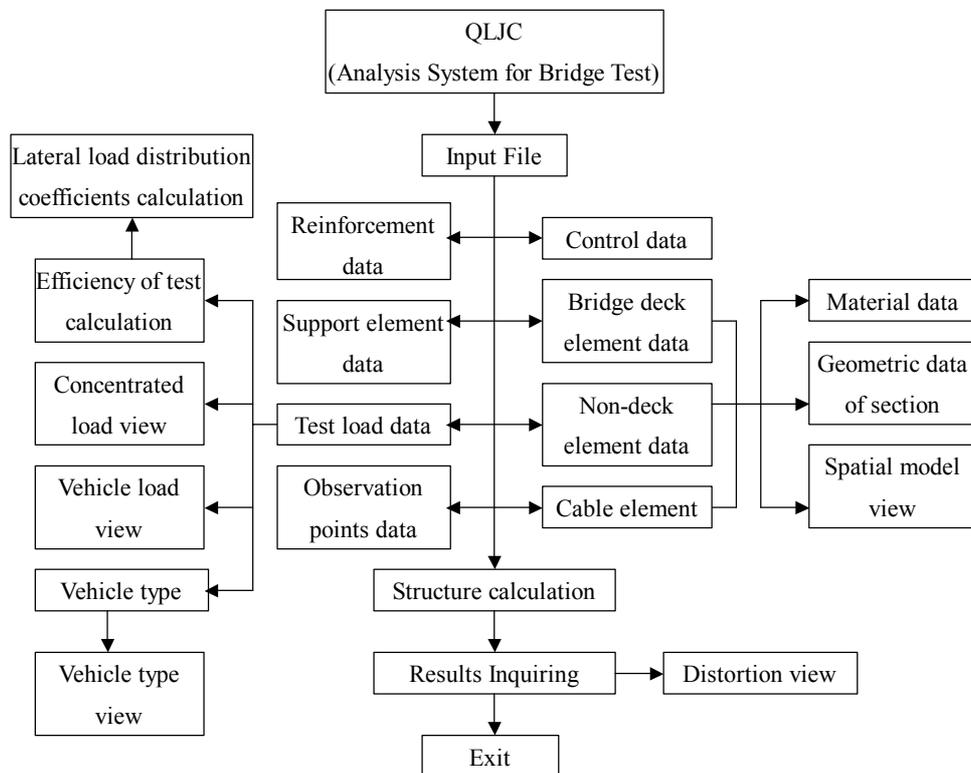


Fig.1 Diagram of system composition

3 Characteristics of QLJC

The characteristics of QLJC are listed as followed.

- a) QLJC is applied for bridge structures, which can be analyzed as spatial beam element or solid element, such as continuous beam, continuous arch, truss element, T shape rigid frame, cable-stayed bridge and etc.
- b) The original data of QLJC can be imported by GQJS data file. With added some essential information and meshed into beam or solid elements, finite element analysis model is erected.

- c) According to the parameter of plane and vertical curve of route line, coordinates are auto-calculated and the data of curved, skew and slope bridge can be formed easily.
- d) Based on plane support information and spatial structure data, spatial support element data is auto-formed.
- e) The vehicle loads are defined with position, wheelbase, tread and axle weight. The loading plan can be recorded and the layout drawing of loads can be created.
- f) With picking the points from elevation and section drawing with mouse, the data of observation points at those positions will be recorded and general layout of all the observations of bridge can be viewed.
- g) The position of load and observation points are described with stake, the vertical distance from it to deck and the offset distance from it to center line of road. The general x, y, z coordinates will be auto-calculated. This method is easier to use and closer to the habits of engineering.
- h) The efficiency of load test can be calculated. Based on the results and though adjusting the data input properly, the best plan of load test will be acquired.
- j) The results of displacement, stress and strain of every loading stage are calculated and compared with practical measured results.
- k) Natural frequency can be calculated, as well as displacement of each natural mode of vibration.
- l) The graphs of structure distortion of loading and modal type can be viewed as projection drawing at random direction and coefficient of amplification.
- m) The structural meshed model, construction drawing of main girder and loading efficiency calculation can be output as *.DXF file, which can be edit, input or printed in other drawing software.

4 Principle of QLJC

4.1 Model Erection

To erect spatial model conveniently, bridge structure are divided into five parts according to position and function, such as bridge deck elements, non-deck elements, cable elements, reinforcement elements and support elements etc. Bridge deck elements mean the elements of superstructure touched with vehicle wheels. Non-deck elements mean the elements of piles, piers, pylons, arch ring and etc, which are not touched with vehicle wheels. Cable elements describe the cable or suspender of cable-stayed bridge, suspend bridge and tied arch. Support elements simulate support and boundary condition of structure. Reinforcement elements mean the reinforcement steel bar or prestressed steel bar. The position of elements is as fig.2.

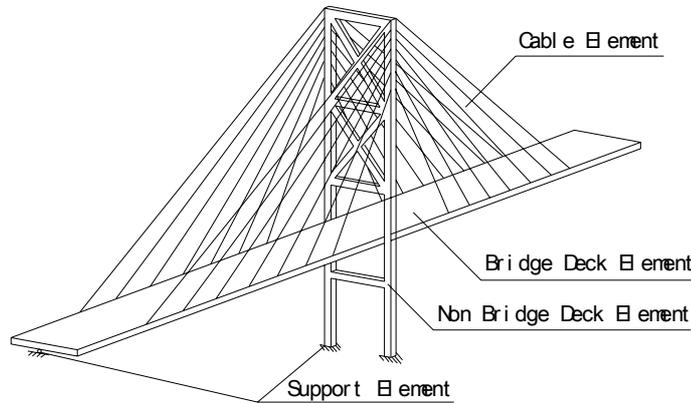


Fig.2. Diagram of position of elements

The interface of data input is designed based on the character of different groups of elements in order to input, check up and modify data such as coordinates, materials, geometric dimension and other essential information. The coordinates of bridge deck element are described with length of element and parameter of route line (fig.3). According to the parameter of plane and vertical curve of route line, coordinates of structural nodes are auto-calculated. Support constrain condition is described with longitudinal constrain, vertical constrain and bending angle constrain as habit of two-dimensional system. And the position of constrain points is described with stake and vertical distance from it to deck. With it and some transverse information, three-dimensional support element data is auto-arranged. Element information is divided into two relatively independence parts of transverse and longitude direction. The geometric information is described with the information of points of width change, which is written by hands as well as input drawing from *.DXF file to form information of change of width (fig.4). From it, the geometric characteristic, such as area, inertia moment and etc, can be calculated.



Fig.3 Interface of bridge deck element data



Fig.4 Interface of geometric dimension data of section

4.2 Finite Element Meshing

There are two methods of meshing supplied in this software: three-dimensional beam element and solid element.

4.2.1 2-Nodes Three-dimensional Beam Element

If the meshing method of three-dimensional beam element is chosen, deck element and non-deck element are meshed into 2 nodes and 12 degrees of freedom beam elements, and cable element and support element are meshed into 2 nodes and 6 degrees of freedom link elements. The beam element is as fig.5.

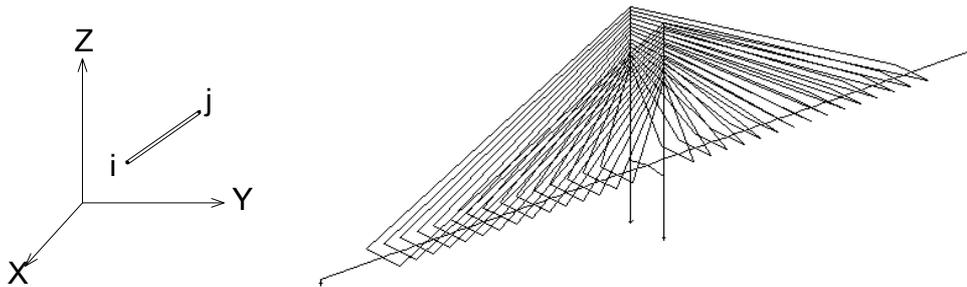


Fig.5 2-nodes three-dimensional beam element Fig.6 three-dimensional beam element model of cable-stayed bridge

System judges conjunction state by the distance between nodes. When the distance is close to zero, the two nodes are deemed as common node. Rigid beam is adapted when the distance between two neighboring nodes is large or structural elements connect with support element to simulate practical structure better.

4.2.2 12-Nodes Solid Element

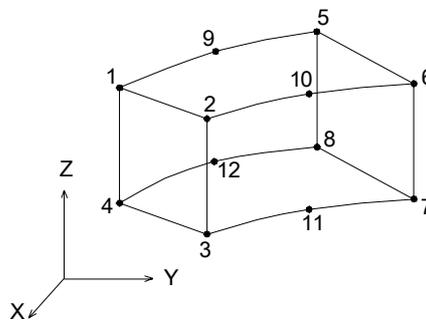


Fig.7 12-nodes solid element

When the solid element method is chosen, support element, cable element and reinforcement element are meshed to link element, similar to it of beam element method. And bridge deck element and non-deck element are meshed into 12-nodes solid elements (fig.7). 12-nodes solid element is evolved from 8-20-nodes solid element, and more suitable for slim structure. In fig.7, 1-2-3-4 side and 5-6-7-8 side are two end transverse sides of beam element. 9-10-11-12 side is mid transverse side of beam element. 1-2-10-6-5-9 side, 1-9-5-8-12-4 side, 4-3-11-7-8-12 side and 2-3-11-7-6-10 side are longitudinal side. Because there are three nodes on longitudinal length, curve can be described with second order parabola so curved beam can be described. Therefore, 12-nodes solid element is very suitable for bridge structure since more and more curved beam bridge appeared.

12-nodes solid element is adopted in order to enhance calculated precision. Traditional 8-nodes solid element is applied to element with similar length of all of sides. However, general bridge

structures are slim structure, with small side on cross section and large side on longitudinal section. The amount of elements will be large number, if structure is meshed into similar hexahedral elements with enough precision. So 12-nodes element is a good meshing method with fewer elements, higher calculated efficiency and enough precision.

Deck elements and non-deck elements are divided into some element groups according to length of longitudinal segment. Every element group is fractionized into some 12-nodes solid elements according to the cross section mesh. At first, cross section is divided into initial mesh based on character of section, as fig.8. And then, according to the biggest dimension of elements limited at control information interface, every quadrangle is divided into subdivision mesh, as fig.9.

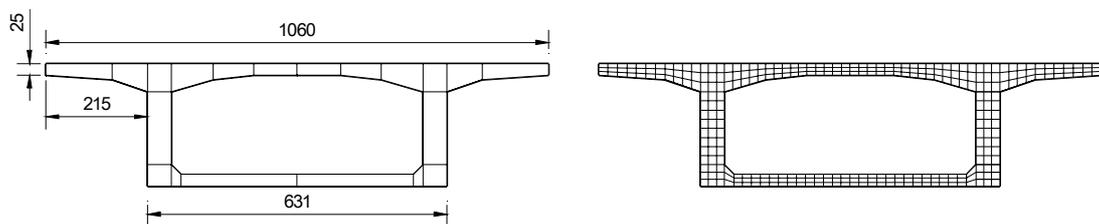


Fig.8 Initial mesh of section of box girder Fig.9 Subdivision mesh of section of box girder

Through meshing of longitudinal length and transverse section, bridge structure is divided into many 12-nodes solid elements. The displacement relationship of nodes of neighboring groups is restricted by equation of compatibility of displacement. It is available to resolve the problem of variable cross-section meshing.

4.3 Test Load

The engineering practice is taken into account in this system design. We are concerned about the change of structure before and after loading, and some measures are taken to avoid influence leading by other factors, such as temperature. Therefore, in order to simplify the data structure, the test load includes concentrated and vehicle loads only, as fig.10.

The concentrated loads are described with position, value and direction. And position are described not with x, y, z coordinates, but with stake, the vertical distance from it to deck and the offset distance from it to center line of road, more suitable for practice. From these information and parameter of plane and vertical curve of route line, coordinates are calculated by software and load forces are distributed to relative nodes. It is very convenient special for skew and curved bridge.



Fig.10 Interface of test load data input



Fig.11 Interface of defining vehicle type

The vehicle loads are defined with type, direction, stake of axle ahead and offset distance. The vehicle type is described with tread, wheelbase and axle weight, and the data can be input by hands or input standard vehicle type, such as Auto-20, Trailer-80 on Code (see 1) (fig. 11). The loads of axle weight of vehicles are exchanged to vertical concentrated forces at relative nodes.

The method of exchange concentrated loads to concentrated force at nodes is as followed. The first step is judging position of concentrated loads. If the force is on a 2-nodes element, exchange it to two forces at the two ends of element, according to the distance between the point of application and each end. If the 2-nodes element is beam element, bend moment produced by force arm of distance between point of application and nodes will be considered. If the force is on a solid element, exchange it to forces at all of the nodes of element. The force value is prorated according to the distance between the point of application and each node.

4.4 Loading Efficiency

The calculation of efficiency of test loading is formulated as followed.

$$\eta_q = \frac{S_s}{S \cdot (1 + \mu)}$$

Note: S_s ---- The maximum of calculated effect value of internal force or displacement of control section under a certain static test loads.

S ---- The maximum of calculated effect value of internal force or displacement of same section under control design loads.

μ ---- The impact coefficient from the Code (see 1).

η_q ---- The efficiency of static test load.

According to the Codes (see 2) of bridge load test, the efficiency of static test load should be between 0.95 and 1.05. The main basis of determining test plan is calculation of efficiency. But, the calculating process is quite troubled. So the module of efficiency calculation is supplied in this system to calculate the efficiency of test load according to the information of test load and designing standard load. Users can input data of test load distribution design standard load, lateral load distribution coefficients and etc. The dynamic programming method is adopted for effect calculation of design load. And loading on the influent line is to calculate effect value of test load. Users can adjust the parameter of test load based on initial calculated results. Through pilot calculation with many times, the best test plan will be determined, at the same time the diagram of analysis results of test load efficiency can be output for writing test report (fig.12).

For the convenience of design load effect calculation, the module of lateral load distribution coefficients calculation is supplied, as fig.13. It includes four method of calculation: Rigid Transverse Beam Method, Rigid Connection Slab Method, Hinged Slab Method and Lever Method.

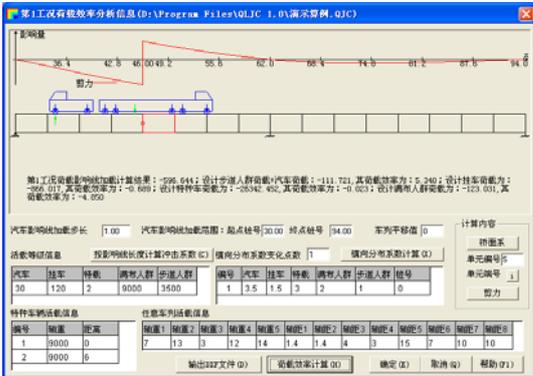


Fig.12 Interface of test load efficiency calculation

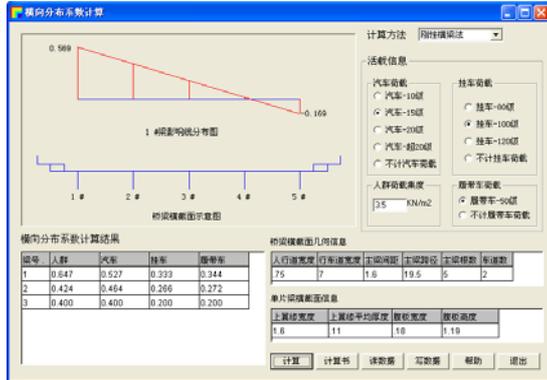


Fig.13 Interface of lateral load distribution coefficients

4.5 Observation Points

The information of observation points is described with type and position. The type of observation point means the content of observation including stress, strain and displacement at transverse, vertical and longitudinal direction etc. The position of observation points is described with stake, vertical distance and offset distance like it of concentrated loads, as fig.14.

After calculating, the needed results of observation points can be picked up from plenty of results based on the information of type and position. For 2-nodes element, the result of observation points is interpolated by the result of two nodes of element. For solid element, the result is prorated of the results of all the nodes of element according to the distance between the observation point and each node, and the result of each node is averaged by it of all the elements shared that node. The results of all of observation points are list in a table including calculated results, measured results and ratio of them, and the section graph with initial shape and distortion shape, as shown in fig.15.

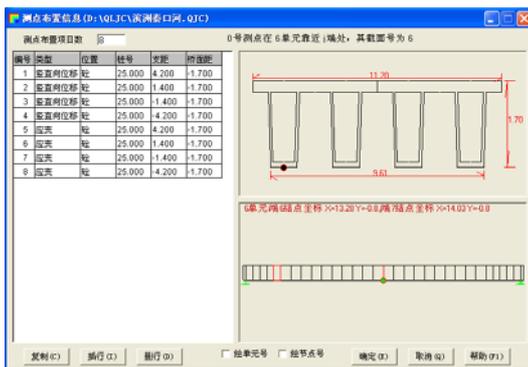


Fig.14 Interface of distribution of observation points



Fig.15 Interface of results display

4.6 Graphic Display

The results are displayed not only as numeric mode but also as graphic mode and the latter is more direct. In the interface of graphic display, the graphics of structure distortion of loading and modal type can be viewed on any direction and ratio of amplification, as shown in fig.16 and fig.17.

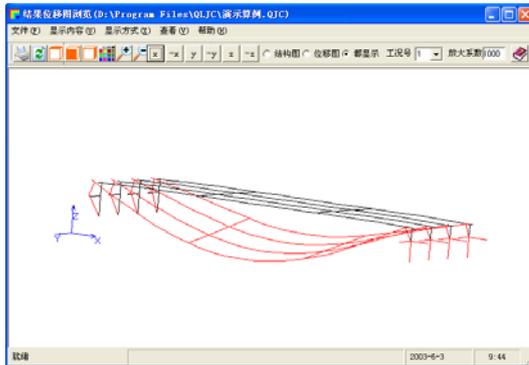


Fig.16 Structural distortion of static loading

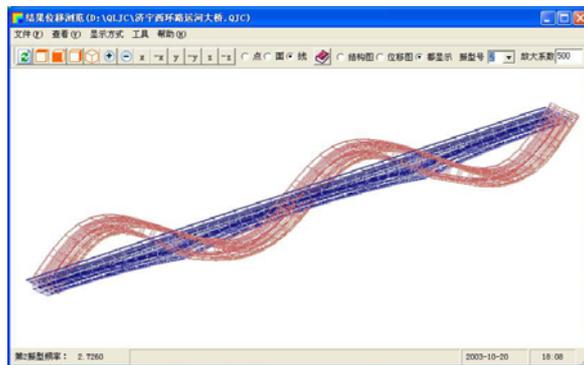


Fig.17 Natural mode of vibration

5 Practical Example

5.1 Static Load Test Analysis of the Qinkou Bridge

The Qinkou Bridge is located above the Qinkou River in ShanDong province in china. Overall length of bridge is 305.2m and width is 10.0m(carriageway)+2x0.5m(crash barrier). The superstructure is 10 spans of 30m P.C box beam with variable cross-section. The box beam is composed of 4 girders at transverse section. The design load is auto-20 and trailer-100 of Code (see 1). The bridge was open to traffic at 1995, Oct and was tested with static load at 2002, Oct.

There are three trucks with 360kN weight adopted as test load. The distribution of observation points of displacement and strain is as fig.18.

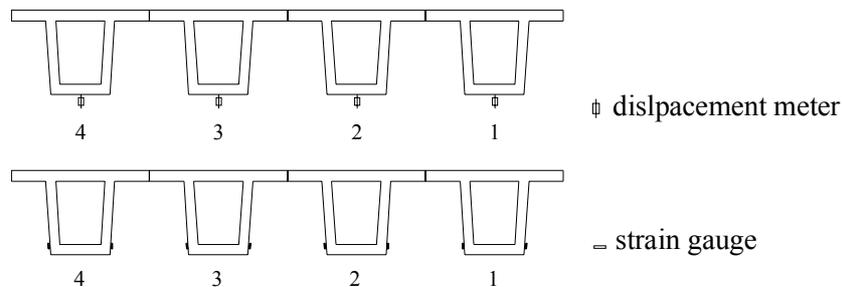


Fig. 18 Distribution of observation points

The finite element model of the Qinkou bridge structure is as fig.19.

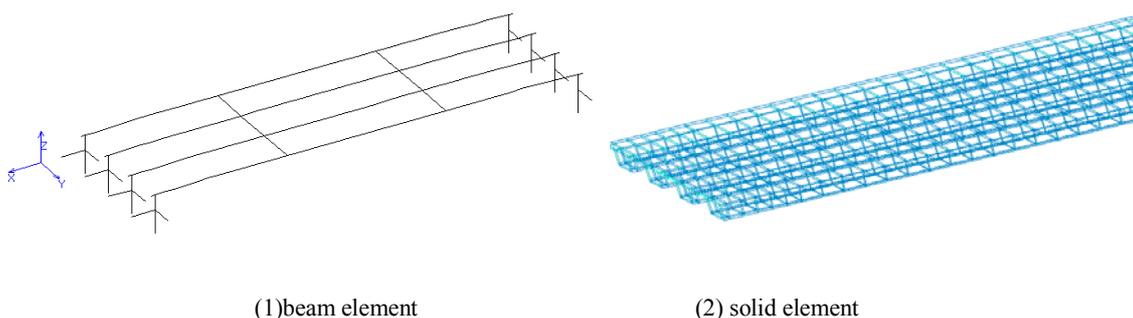


Fig.19 Finite element model of structure

The results of efficiency calculation are list as fig.20.

Content	Auto-20	Trailer-100	Test Load
Bend moment at center of span (kN.m)	7467.7	6704.1	7274.8
Load efficiency (η)	Auto-20: 0.974	Trailer-100: 1.085	

Fig.20 Efficiency of static load test

From the table, we know that the efficiency of this test satisfy the demand of the Code (see 2) of judging bearing capacity of highway bridge. That is to say, when control load is auto, the load efficiency (η) is between 0.95 and 1.05, and when control load is trailer, η is enhanced a little.

Beam No. Loading stage	1			2			3			4		
	Measured value	Calculated value		Measured value	Calculated value		Measured value	Calculated value		Measured value	Calculated value	
		①	②		①	②		①	②		②	②
I-1	4.08	4.77	5.15	3.41	4.06	3.97	0.88	3.27	3.08	0.266	2.55	2.40
I-2	7.578	8.81	9.33	6.859	7.98	8.05	3.808	6.75	6.61	2.757	5.76	5.47
I-3	12.177	12.2	12.6	11.237	11.6	11.9	9.170	10.5	10.7	7.446	9.62	9.42
I-4	10.419	10.9	11.2	10.580	11.0	11.5	10.565	11.0	11.5	10.343	11.0	11.2

Fig.21 Displacement of beam bottom of center span (cm) (see3)

Beam No. Loading stage	1			2			3			4		
	Measured value	Calculated value		Measured value	Calculated value		Measured value	Calculated value		Measured value	Calculated value	
		①	②		①	②		①	②		①	②
I-1	50.32	57.2	74.6	47.24	59.4	58.7	14.14	48.0	42.7	3.95	48.6	34.9
I-2	90.69	104	129	77.09	131	121	48.43	95.8	92.7	30.82	96.1	75.4
I-3	146.55	151	171	130.39	191	165	110.89	156	152	78.00	143	128
I-4	117.91	153	151	128.96	167	159	128.96	168	159	117.91	153	151

Fig.22 Strain of beam bottom of center span (1×10^{-6})(see 3,4)

From the above tables, we know that the ratio of measured value and calculated value is less than 1.0 and displacement values are less than $L/600$. It means that the bearing capacity of this bridge is enough for the demand of the Code (see 2).

5.2 Dynamic Analysis of the Jinghang Canal Bridge

The Overall length of Jinghang Canal Bridge is 1267.66m and overall width is 28.0m. The superstructure is continuous rigid frame with variable cross-section. The contrast of calculated results and measured results is list as fig.23.

The measured natural frequency of first stage is 1.9533 Hz, larger than calculated value 1.014(0.995). It explains that general practical rigidity of structure is larger than design rigidity and with good capacity.

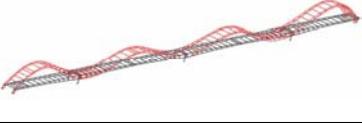
	Natural frequency			Modal type
	Measured value	Calculated value①	Calculated value②	
First	1.9533	1.014	0.995	
Second	2.0509	1.724	1.680	
Third	3.1252	2.638	2.537	
Four	3.2717	3.238	3.082	

Fig.23 Contrast of natural frequency (see 3)

6 Conclusions

QLJC is developed to spatial beam element system and solid element system from traditional plane beam element system, with friendly interface and power function and credible results. QLJC is studied special for bridge test, easy to use, and with it the efficiency and veracity will be enhanced. So we believe that QLJC will be a good helper of diagnoses engineers and have popularizing value.

7 Endnotes

- 1) The Design Code of Highway Bridge, Ministry of Communications of PRC, 1989
- 2) The Rules of Judging Bearing Capacity of Highway Bridge, Highway Research Institute of MOC of PRC, 2002
- 3) The Calculated value(1) is the results of beam element method, and calculated value(2) is the results of solid element method.
- 4) The strain values in the table are stretching strain.

8 Reference

The Design Code of Highway Bridge (JTJ021-89), MOC of PRC, 1989

The Design Code of P.C and R.C. Highway Bridge, MOC of PRC, 1985

The Method of judging Bearing Capacity of Old Bridge, 1988

The Rules of Judging Bearing Capacity of Highway Bridge, Highway Research Institute of MOC of PRC, 2002