



A static load test study for one continuous beam bridge

Wei Liu, Yanjie Xue*

Jilin University of College of Construction Engineering, Changchun 130010, China

Email: xueyanjie2016@163.com

ABSTRACT

In the bridge construction process, the external environment changes and parameter errors might lead to the deviation of finished bridge state from the theoretical value, therefore a static load test should be conducted at the completion of construction. Static load test of bridge is one key part of new bridge completion acceptance and old bridge detection, and the related test results are the important basis to judge whether the bridge load carrying capacity and stiffness satisfy the specified requirements. With the continuous beam bridge (CBB) as one of the widely-used bridge structural forms, it is of great significance to study the static load test of CBB. This paper, by analysing the practical test of one CBB in Baiyun city, mainly elaborates on the content, principle and result analysis of structural static load test, and emphasizes on the study of the loading scheme design and working conditions plan in static load test of this bridge, which could provide experiences and references for the same type of bridge static tests.

Keywords: Continuous Beam Bridge (CBB), Load Distribution Plan, Static Load Test, Strain, Deflection.

1. BRIDGE INTRODUCTION

This bridge adopts the continuous box girder structure, with span arrangement $(26+38+36) + (36+38+26) = 200\text{m}$. The division-framing design is used, 2cm-wide break-joint in the middle, and each segment is constructed with single-box double-cell. Besides, other related parameters include: top surface width of box girder 13.99m, bottom surface width 9m, exterior cantilever 3m, interior cantilever 1.99m, mid-span web thickness 0.45m, support web thickness 0.8m, top slab thickness 0.25m and base slab thickness 0.22m. Refer to Fig. 1 for cross section diagram. Except that in the first and sixth spans, the high beam is 1.4m and mid-beam is 2m, the other are all 2m high. This bridge is located in the urban secondary trunk road at the designed driving speed 40km/s, with the bridge design safety Class I and A-level urban load standard.

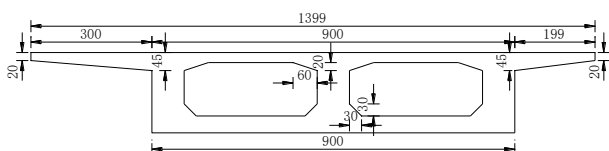


Figure 1. Cross section diagram (mm)

2. TEST CONTENT

The bridge load carrying capacity could be evaluated by applying the static imposed load similar to design load into

the bridge structure, testing the mechanical effects such as deflection, strain, possible cracks, load transverse distribution under the different loads of control positions and sections, and then making comparison with the calculated values and related specified values under the same loads[1-3]; based on the bridge engineering characteristics, the first and second section have the same bridge type structure, and the left and right segment have the symmetrical structure with the same design load and capacity, but the right segment is slightly unfavourably loaded, therefore, the right segment of the first section was selected for static load test, and the results are still equivalent to that of the left segment of the first section and the left and right segments of the second section. In the static test, three principles should be followed: (1) test position highlights the key stress for structural system; (2) test content reflects the structural bearing capacity index; (3) the actual test should be controlled from damaging the structure.

2.1 Loading scheme

Midas civil 2015 finite element program was applied to calculate and analyse the bridge design load and test conditions. In the calculation, take the max sagging moment at mid-span and max hogging moment at support as the control load, and design the test loading scheme according to design load standard values. For this bridge with prestressed concrete continuous box beam structure, based on the structure loading features and theoretical analysis results, select the max cross section for bending moment and every support cross section of the right segment in section 1 as the test object, make test loading at the most unfavourable

loading of influence line, and arrange five loading conditions [4]; refer to Fig 2-6 for loading conditions, and Table 1 for the control cross section bending moment and test load efficiency ratio in five difference conditions:

Table 1. Bending moment and test load-efficiency ratio

Conditions	Design Bending moment(KN·m)	Test bending moment(KN·m)	Test load efficiency ratio η
Condition 1 (max sagging moment at mid-span 1)	7324.7	7152.8	0.98
Condition 2 (max sagging moment at mid-span 2)	9782.9	9892.9	1.01
Condition 3 (max sagging moment at mid-span 3)	11483.1	11516.6	1.00
Condition 4 (max hogging moment at support of pier top 1#)	-9084	-8796.1	0.97
Condition 5 (max hogging moment at support of pier top 2#)	-10866.7	-10388.2	0.96

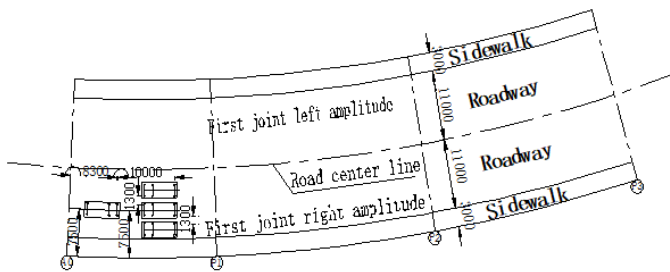


Figure 2. Loading in condition 1 (mm)

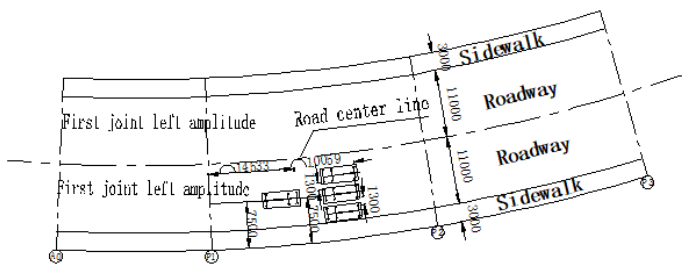


Figure 3. Loading in condition 2 (mm)

According to Load Test Methods for Highway Bridge (JTG/T J21-01-2015), static test load efficiency η_q is the ratio of the computation effect of one certain control cross-section under the test load and the designed control effect corresponding to this cross-section. To ensure full reflection of the structure loading feature in the load test, generally the higher load test efficiency ratio is required; for the load test in acceptance, the load efficiency ratio η_q should be in the range 0.85-1.05 [5]. The finally-selected η_q value in this test satisfied the requirements above, so the mechanical effect

produced by the test load should also be capable of meeting the requirements for bridge usage conditions inspection.

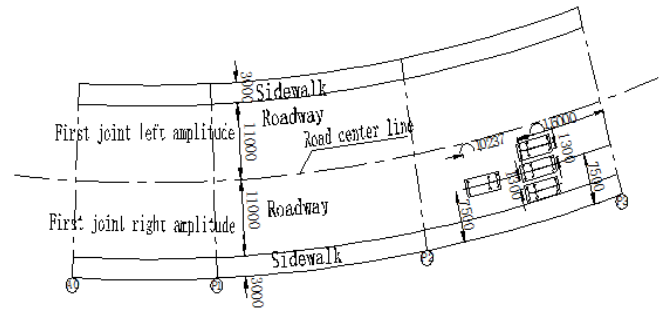


Figure 4. Loading in condition 3 (mm)

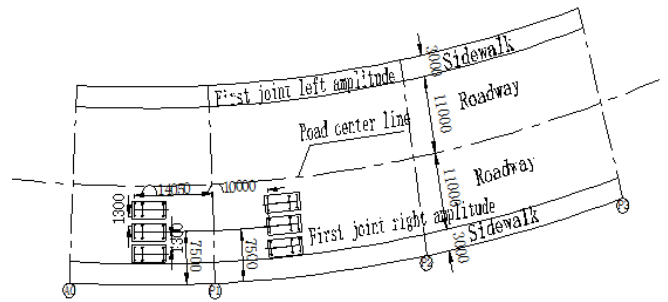


Figure 5. Loading in condition 4 (mm)

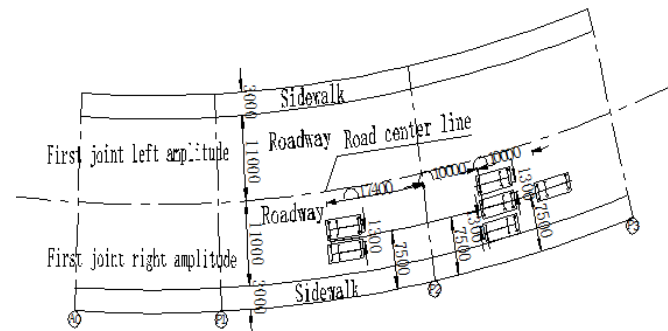


Figure 6. Loading in condition 5 (mm)

2.2 Loading vehicle

In the load test, 6 tri-axial heavy-duty vehicles were adopted for loading: 4 vehicles for working condition 1, 2 and 3; 6 for working condition 4 and 5. Refer to Fig. 7 for vehicle loading, and Table 2-3 for vehicle parameters.

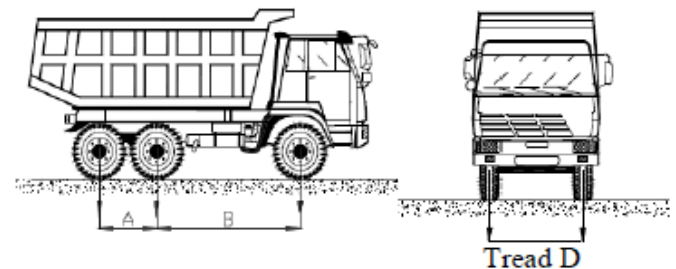


Figure 7. Loading vehicle

Table 2. Wheel parameters of loading vehicle

Vehicle	A (m)	B (m)	D (m)
Vehicle 1	1.4	3.8	1.8
Vehicle 2	1.4	3.8	1.8
Vehicle 3	1.4	3.8	1.8
Vehicle 4	1.4	3.8	1.8
Vehicle 5	1.4	3.8	1.8
Vehicle 6	1.4	3.8	1.8

Table 3. Loading vehicle parameters

Vehicle	Axial load (t)			Total loads
	Front-axial load	Mid-axial load	Back-axial load	
Vehicle 1	8.2	20	20	48.2
Vehicle 2	8.5	20	20	48.5
Vehicle 3	8.5	20	20	48.2
Vehicle 4	8.5	20	20	48.5
Vehicle 5	8.5	20	20	48.2
Vehicle 6	8.5	20	20	48.5

3. TEST ONSITE ORGANIZATION

The following steps should be followed in every specific working condition [6,7]:

- (1) According to the instruction of test centre, every test group takes the initial readings of bridge before loading;
- (2) After taking initial readings, every test group reports back to test centre. With all initial data reading completed, the test centre gives an instruction to start loading (batch-by-batch, and slow loading);
- (3) In the loading process, every test group should make real-time data monitoring; if abnormal data occurs, report to the test centre in time, and stop loading;
- (4) When loading is ready, the dispatcher reports back to test centre; the test centre starts timing, until reaching stable state; then it gives an instruction of test, so every test group shall start to take readings simultaneously;
- (5) After completing the test, every test group reports to the test centre; with all test data collected, the test centre gives unloading instruction to make unloading (batch-by-batch, and slow loading);
- (6) Some key test data is collected; only if the data is judged errorless by test centre, the loading in the next working condition can start.

In addition, if the structural effect is over the allowable value or anything abnormal in the test process, the loading should be terminated.

4. TEST RESULTS ANALYSIS

4.1 Test data collection

In different working conditions, based on the test purpose

and evaluation demands for usage function, the mid-span section deflection, strain and strain at the support section were mainly tested, and also the beam cracks were observed [8-11].

(1) Collect the deflection data with one 0-50mm dial indicator. To make deflection test, 3 dial indicators were placed at every rib slab of midspan beam respectively. Refer to Fig 8 for the dial indicator layout.

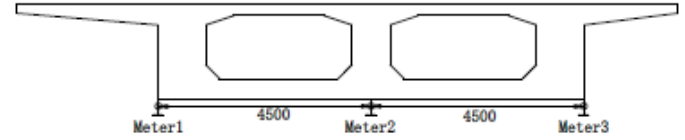


Figure 8. Layout of dial indicators (mm)

(2) Vibrating wire transducer is used to make strain test and data collection. Five transducers were placed on the cross sections of midspan support, where 3 were placed at beam bottom, 2 under the slab with haunched ribs. Refer to Fig. 9 for the layout of vibrating wire transducers.

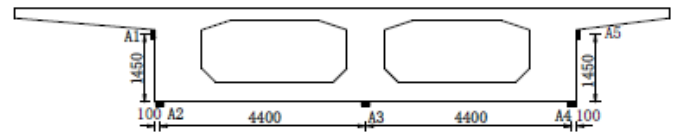


Figure 9. Layout of vibrating wire transducers (mm)

4.2 Calculation of static test results

Under the test load, make tests of the deflection and strain at different measuring points, and then calculate the test data in the methods as follows [13-15]:

1) Calculate the actual deflection of mid-span section by deducting the influence of support settlement. Considering the support settlement influence on test section deflection, the measured section deflection should be corrected when calculating the test data. The corrected value is calculated as:

$$C = \frac{l-x}{l} a + \frac{x}{l} b$$

where, C-is correction influenced by support settlement; l -is the distance between two supports; x the distance between deflection measuring point and starting support; a -is the settlement of starting support; b -is the settlement of end support.

2) Deflection and strain calculation at each measuring point:

$$\text{Total strain: } S_t = S_L - S_i$$

$$\text{Elastic strain: } S_e = S_L - S_u$$

$$\text{Residue strain: } S_p = S_t - S_e = S_u - S_i$$

where, S_i is the initial value of every point before loading (initial loading); S_L is the measured value when the loading in stable state (loading value); S_u is the measured value when unloading in stable state (unloading value).

3) Calculation of verification coefficient. The main measuring points (control measuring point or the point at the position with max loading test efficiency ratio) in the loading test are calculated as [16,17]:

$$\eta_q = \frac{S_e}{S_s}$$

where, S_e is the measured elastic deflection (or strain) value under test load; S_s is the theoretical deflection (or strain) value under the test load.

4) Relative residual deformation is an index to evaluate the elastic working performance of the structural member under loads; the less relative residual deformation of mid-span deflection means the structure elastic operating condition is better. The relative residual deformation S'_p is calculated as:

$$S'_p = (S_p/S_t) \times 100\%$$

where S_p is the residual deformation of midspan deflection; S_t the total deformation of midspan deflection.

According to the specified computation requirements above, the relative residual deformation of the structure should be lower than 20%, and the verification coefficient be below 1, which means that the structure meets the requirement; the less the verification coefficient, the better the structure safety capacity shall be [18-20].

4.3 Deflection test analysis in five conditions

The most unfavourable loading test was made in these five working conditions. Data collection was made at every measuring point when loading step by step in every condition. Refer to Table 4-5 for the deflection test results.

Table 4. Deflection test results in working condition 1, 2, 3, 4 and 5

condition	Measuring point	Initial reading (mm)	50% loading reading (mm)	100% Loading reading (mm)	Unload reading (mm)	Total deformation (mm)
Condition 1	Mid-span 1	0	1.19	2.40	0.08	2.40
Condition 2	Mid-span 2	16.35	18.69	20.86	16.84	4.51
Condition 3	Mid-span 3	38.20	39.33	42.09	38.25	3.89
Condition 4	Mid-span 1	0	0.59	1.17	1.69	0.20
	Mid-span 2	15.19	16.08	17.04	17.94	15.33
Condition 5	Mid-span 2	18.55	19.01	19.73	20.91	18.88
	Mid-span 3	48.01	48.98	49.95	51.52	48.25

Table 5. Deflection test results in working condition 1, 2, 3, 4 and 5

condition	Measuring point	Elastic deformation (mm)	Residual deformation (mm)	Relative residual deformation (%)	Theoretical deflection (mm)	Verification coefficient η_q
Condition 1	Mid-span 1	2.32	0.08	3.4	3.97	0.58
Condition 2	Mid-span 2	4.02	0.49	12.2	6.87	0.58
Condition 3	Mid-span 3	3.84	0.05	1.3	7.60	0.51
Condition 4	Mid-span 1	1.69	1.49	0.20	13.4	1.81
	Mid-span 2	2.75	2.61	0.14	5.4	3.09
Condition 5	Mid-span 2	2.36	2.03	0.33	14.0	2.84
	Mid-span 3	3.51	3.27	0.24	7.3	5.73

4.4 Deflection and strain analysis of midspan and support section

The most unfavourable loading test was made in these five working conditions. Data collection was made at

every measuring point when loading step by step in every working condition. Refer to Table 6-7 for the strain test results.

Table 6. Strain test results in working condition 1, 2, 3, 4 and 5

condition	Point number	Measuring point#	Initial reading ($\mu\epsilon$)	50% loading reading ($\mu\epsilon$)	100% Loading Reading ($\mu\epsilon$)	Unload reading ($\mu\epsilon$)	Total strain ($\mu\epsilon$)
Condition 1	Underarm underarm	2742	2741	2736	2741	-6	-5
	Beam bottom	2706	2730	2759	2709	53	50

Condition 2	Underarm underarm	3306	3300	3299	3305	-7	-6
	Beam bottom	3367	3393	3428	3372	61	56
Condition 3	Underarm underarm	3412	3403	3406	3411	-6	-5
	Beam bottom	3121	3150	3173	3126	52	47
Condition 4	Underarm underarm	3181	3185	3189	3191	3182	10
	Beam bottom	3341	3336	3331	3321	3338	-20
Condition 5	Underarm underarm	3022	3024	3026	3029	3022	7
	Beam bottom	3344	3337	3329	3319	3342	-25

Table 7. Strain test results in working condition 1, 2, 3, 4 and 5

condition	Point number	Measuring point#	Elastic strain ($\mu\epsilon$)	Residual strain ($\mu\epsilon$)	Relative residual strain (%)	Theoretical strain ($\mu\epsilon$)	Verification coefficient ^q
Condition 1	Underarm underarm	2742	-1	16.67	-10	0.5	2742
	Beam bottom	2706	3	5.66	64	0.78	2706
Condition 2	Underarm underarm	3306	-1	14.29	-7	0.86	3306
	Beam bottom	3367	5	8.20	70	0.8	3367
Condition 3	Underarm underarm	3412	-1	16.67	-15	0.33	3412
	Beam bottom	3121	5	9.62	87	0.54	3121
Condition 4	Underarm underarm	3181	9	1	10.00	13	0.69
	Beam bottom	3341	-17	-3	15.00	-36	0.47
Condition 5	Underarm underarm	3022	7	0	0.00	10	0.7
	Beam bottom	3344	-23	-2	8.00	-50	0.46

5. CONCLUSION

(1) The load test mainly includes the control index such as strain and deflection etc, which reflects the safety capacity of bridge structure in the most unfavourable conditions [21]. The carrying capacity index is the physical mechanics index of structural carrying capacity influenced by different factors. In the five working conditions, the calculation for measured deflection values has been made to obtain the verification coefficient between 0.57-0.84, relative residual deformation 1.3%-14%; with the verification coefficient below 1 and relation residual deformation lower than 20%, it means the structural stiffness meets the design requirements. In the calculation of actual measured strain values, the verification coefficient 0.33-0.86 is below 1 and relative residual strain 0-16.67% below 20% [22], which indicates the structural carrying capacity also meets the design requirements.

(2) The bridge load test aims to understand the actual load carrying capacity, ensuring safe passage, therefore, the load test cannot damage the bridge in any way, and the loading tonnage should be designed properly to avoid damaging the bridge. In the loading process, no cracks found in the main beam indicates the good structural stiffness.

6. REFERENCES

- [1] Chen H., Li Z.P. (2008). Study on Load Test of Inclined Beam Bridge. Heilongjiang Transportation Technology Press, Vol. 31, No. 6, pp. 50-51.
- [2] Zhou L., Guan G.D., Xie Y.P. (2007). study on static load test of skew bridge, *Journal of Highway and Transportation*, No. 4, pp. 154-156.
- [3] Wang D.N., Wang L., Li M., Sun Y.L. (2014). Study on the static and dynamic load test of Nicky Bridge, *Applied Mechanics and Materials*, Vol. 2974, No. 501, pp. 501-504, 1194-1198
- [4] Peng J.J., Zhang H., Li X.J. (2014). Study on the loading scheme of bridge static load test, *Chinese and foreign highways*, Vol. 34, No. 06, pp. 188-190.
- [5] Wang L.B., Jiang P.W., Ma Y.P., Zhao Y. (2015). Research on the calibration coefficient and optimization evaluation method of static load test, *Highway traffic science and technology*, Vol. 32, No. 06, pp. 62-68.
- [6] Wu J.J., Chen and Zhang Q.W., Yuan W.C. (2004). Field static load test of bridge evaluation and analysis, *Highway*, No. 12), pp. 62-65.
- [7] Huang J., Zhang Z. (2009). The static load test and analysis of the bridge, *traffic in the North*, No. 08, pp. 69-71.
- [8] Ge J. (2015). Application of static load test in bridge detection, *China Water Transport (the second half of the month)*, Vol. 15, No. 07, pp. 220-221.

- [9] Liu Z.G., Zhang Y.H. (2007). Dynamic and static load analysis of bridge reinforcement effect, *Western Communications Technology*, No. 03, pp. 56-60.
- [10] Wang B., Chen Zh.Zh. (2006). Tsai minimum static load test and analogue analysis of reinforced concrete arch bridge, *Engineering and Construction*, No. 03, pp. 181-182.
- [11] Han H.B., Wang L., Li Z.X., Long H. (2014). Study on the static and dynamic load test of Skew Bridge, *Advanced Materials Research*, Vol. 2920, No. 859, pp. 127-130.
- [12] Chen N., Cai Sh.H., Li N., Liu Sh.K. (2015). Research on static load tests of damaged bridge strengthened with pre-stressed HFRP, *Advanced Materials Research*, Vol. 3716, No. 1079, pp. 258-265.
- [13] Fan L.X., Hong H. (2014). Study on the static load test of bridge inspection, *Advanced Materials Research*, Vol. 2920, No. 859, pp. 149-152.
- [14] Zhang H., Wang S., Zhou T., An Q.P., Bao K.H. (2014). Study on bridge static test based on close-range photogrammetry, *Advanced Materials Research*, Vol. 2837, No. 838, pp. 838-841+1054-1057.
- [15] Fang T., Guang M.X. (2014). Study on the static load test of bridge inspection, *Advanced Materials Research*, Vol. 3255, No. 971, pp. 149-152.
- [16] Wang W., Wang L. (2014). Study on static and dynamic load test of Huaronggou Bridge, *Applied Mechanics and Materials*, Vol. 3308, No. 587, pp. 587-589+1500-1506.
- [17] De C.F., Yu H.W., Wang L. (2014). Static and dynamic testing study on mechanical behavior of Longtan Bridge, *Applied Mechanics and Materials*, Vol. 3615, No. 684, pp. 100-104.
- [18] Huang J., Zhang Z. (2009). Static load test and analysis of bridge, *North Traffic*, No. 08, pp. 69-71.
- [19] Yu Z.F. (2013). Analysis of an example of a bridge static load test, *Anhui Architecture*, No. 05, pp. 127-129.
- [20] Zhang W.H., Liu X.F., Hu T.B., Chen B. (2012). The bridge static load test case analysis, *Journal of Wuhan Polytechnic University*, Vol. 31, No. 01, pp. 80-82+92.
- [21] Wang W., Wang L. (2014). Study on static and dynamic load test of Huaronggou Bridge, *Applied Mechanics & Materials*, pp. 587-589+1500-1506.
- [22] Yu S., Zhang T., Zhao Q. (2013). Study on the static and dynamic load test of continuous girder bridge, *International Conference on Civil*, pp. 405-408+1641-1644.