Finite element analysis and static load test for guyed form traveller of cable-stayed bridge

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Abstract. To ensure the security of the cantilever construction and elevation template adjustment for cable-stayed bridge, finite element model of guyed form traveller of Gan-zhu-xi cable-stayed bridge was built. At first, two models are considered under actual construction stage, then a static load test was carried out. The theoretic result was in consistent with the results from field test. It also showed that the optimal design was reliable and the operational performance could meet the construction requirements. Elevation template can be determined by the deflection measured results.

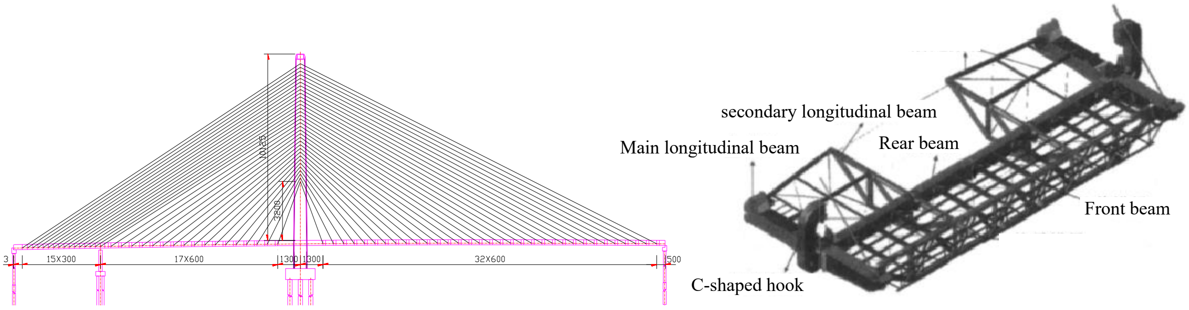
1. Introduction

As the core equipment for prestressed concrete (PC) cable-stayed bridge cantilever cast method with guyed traveler, the carrying capacity and deformability of guyed traveler affect the safety and quality of the bridge directly. Before it is put into use, finite element calculation and load test are required, which aim to check the quality and carrying capacity of the guyed traveler to see whether it meet the design requirements. Also, inelastic deformation of the guyed traveler can be eliminate and elevation template can be calculated through the load test[1-5]. The paper conducts finite element analysis and the load test of guyed traveler for Gan-zhu-xi cable-stayed bridge, aim to check the mechanical property and safety through the theoretic stress result and load test result of the key components[6-8].

2. Description of guyed form traveller of Gan-zhu-xi cable-stayed bridge

Gan-zhu-xi cable-stayed bridge lies on the Guangzhou south ring road of national main highway line. The main bridge is a single tower PC cable-stayed bridge with double cable planes, whose tower and beam are consolidated together. The span combination of the main bridge is (50m + 115m + 210m). The style of main is a single box with triple cells, PC flat box girder with 38.7m wide. Single box includes three rooms. Cable spacing of standard girder section is 6 m, While the standard girder section weights more than 420 tons. The general method of construction the concrete cable-stayed bridges is cast-in-place cantilever by guyed form traveler.

The guyed form traveler applied in Gan-zhu-xi cable-stayed bridge consists of various steel components, including the two main longitudinal beams, two secondary longitudinal beams, one front transverse truss beam and one back transverse truss beam with C-shaped hook. The size of the guyed traveler is 16.3m×39.1m×4m, the weight is 130 tons. The material is Q235 steel, whose allowable stress is 215MPa. The horizontal thrust of the guyed traveler is set on the anchor block of the casted concrete box girder. The horizontal force of the cable is resisted by the bracket set on the horizontal thrust.



(a) Layout of Gan-zhu-xi bridge(unit: mm); (b) Structure diagram of guyed form traveller
Fig. 1 Gan-zhu-xi bridge and guyed form traveller

3. Finite element model

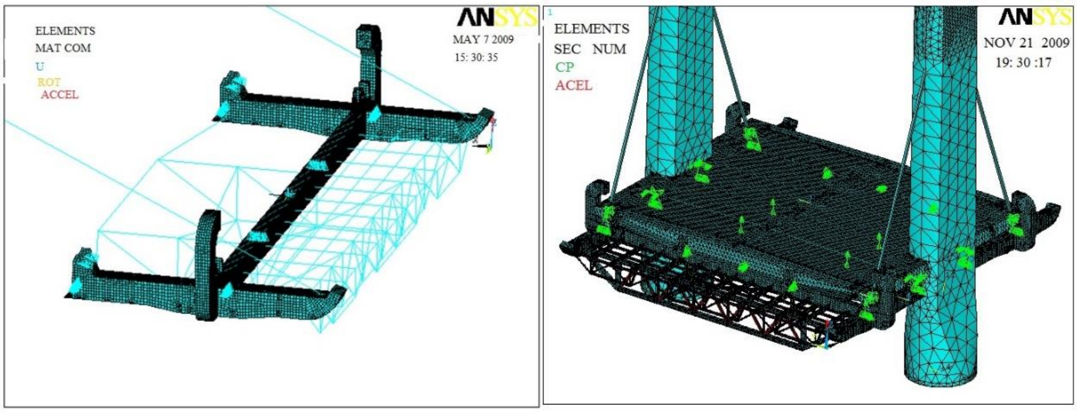
This paper sets up an three-dimensional model by using ANSYS software. In addition, guyed traveler is put on the main girder to simulate the connection between travelling carriage and main girders. Besides, the following two conditions need to be considered, as shown in Fig. 2:

Condition 1: individual model: stress state under dead load (self weight).

The whole model has 25815 elements and 50007 nodes. All the space truss structures apply beam 188 element. Main longitudinal beam adopt shell 63 element.

Condition 2: entire model: stress state under construction load.

The guyed form traveler is connected with 2 # main girder of bridge, who adopts solid 65 element. The bridge tower adopts beam 44 element with equivalent rectangle cross section. Stayed-cable adopts link 8 element. The joint between guyed traveler and back transverse beam adopts the method of master-slave node degrees of freedom. Counter-top of guyed traveler and horizontal thrust thrusting point are respectively connected to the main girder and cable-stayed anchorage connection by link8 element.



(a)Condition 1: individual model ; (b)Condition 2: entire model
Fig. 2 Finite element model

4. Static load test

The aim of this experiment is to evaluate stress value and deflection of main components under static load. According to the construction scheme, the experiment was carried out with the following steps: (1)dead load(self weight); (2) tensioned of stay cables; (3) 50% loading; (4) 100% loading (450t); (5) 50% unloading; (6) 100% unloading.

The stress testing sections of main longitudinal beam ,secondary longitudinal beam, front beam and rear beam are designed as follows:

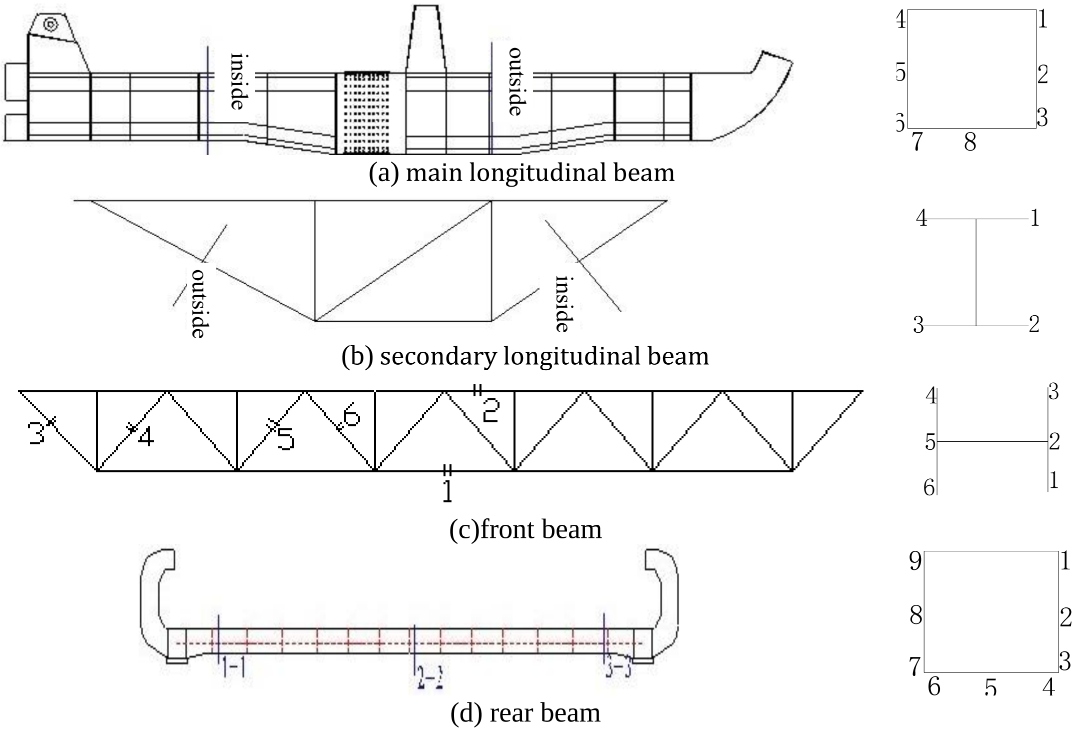


Fig. 3 Location of cross section and sensor distribution of main components

5. The results analysis

5.1. Stress analysis

According to the arrangement of measuring points in test plan, the test extracts the theoretical stress value and the measured values of the three components under three steps: (1)dead load(self weight); (2) tensioned of stay cables; (4) 100% loading (450t).

Tab. 1 Theoretical and measured stress results of main longitudinal beam

Step		dead load			tensioned of stay cables			100% loading		
location	measured point	Theoretical axial stress（MPa）	Measured stress (Mpa)	relative error	Theoretical axial stress（MPa）	Measured stress (Mpa)	relative error	Theoretical axial stress（MPa）	Measured stress (Mpa)	relative error
Outside section	1	-25.6	-26.66	4.13%	-38	-49.1	29.21%	-20.6	-26.5	28.64%
	2	-37.1	-44.82	20.80%	-41.1	-52.2	27.01%	-30.1	-38.2	26.91%
	3	-23	-30.06	30.70%	-9.1	-11.4	25.27%	-10.9	-14.5	33.03%
	4	-22.6	-28.39	25.60%	-51.8	-60.6	16.99%	-45.7	-54.6	19.47%
	5	-15.5	-19.97	28.84%	-21.3	-24.4	14.55%	-23.2	-24.8	6.90%
	6	-32.5	-43.18	32.85%	-0.95	-1.11	16.72%	-5.79	-7.5	29.53%
	7	3.29	3.21	-2.31%	31.8	40.6	27.67%	20.4	25.2	23.53%
Inside section	1	12	15.26	27.19%	-30.5	-25.7	-15.74%	-21.8	-23.5	7.80%
	2	0.25	0.29	15.92%	-1.22	-2.58	111.48%	-1.87	-4.77	155.08%
	3	-2.13	-2.67	25.26%	12.2	15.5	27.05%	19.3	13.2	-31.61%
	4	8.89	10.85	22.07%	-38.9	-46.5	19.54%	-34.9	-42.7	22.35%
	5	-2.74	-3.39	23.81%	-0.96	-2.1	118.52%	-9.66	-8.71	-9.83%
	6	-13.4	-15.93	18.85%	31.8	22.2	-30.19%	17.5	17.2	-1.71%
	7	-14	-15.91	13.65%	31.5	36.2	14.92%	18.7	23.2	24.06%

	8	-7.58	-8.44	11.41%	25.9	33.9	30.89%	23.7	29.2	23.21%

Tab. 2 Theoretical and measured stress of front beam and secondary longitudinal beam

Step		dead load			tensioned of stay cables			100% loading		
location	section	Theoretical axial stress （MPa）	Measured stress (Mpa)	relative error	Theoretical axial stress （MPa）	Measured stress (Mpa)	relative error	Theoretical axial stress （MPa）	Measured stress (Mpa)	relative error
The front beam	1	18.1	23.3	28.72%	38.1	42.2	10.76%	69.5	62.2	-10.50%
	2	-12.9	-15.9	23.56%	-28	-34.5	23.21%	-50.6	-57.8	14.23%
	3	10.3	12.8	24.19%	21.7	21.2	-2.30%	42.5	41.2	-3.06%
	4	-2.97	-3.7	24.85%	-26.2	-25	-4.58%	-38.7	-35	-9.56%
	5	-19.5	-14.6	-25.03%	-17.8	-16.5	-7.30%	-44.1	-46.5	5.44%
	6	14.3	16.4	14.72%	10.9	14.7	34.86%	29.3	37.2	26.96%
secondary longitudinal beam	lateral	-22.4	-26.6	18.70%	-6.93	-5.98	-13.71%	-47	-61.2	30.21%
	interior	-18.2	-16.7	-8.17%	-3.96	-3.03	-23.48%	-40.9	-51.6	26.16%

Tab. 3 Theoretical and measured stress results of rear beam

Step		dead load			tensioned of stay cables			100% loading		
location	measured point	Theoretical axial stress （MPa）	Measured stress (Mpa)	relative error	Theoretical axial stress （MPa）	Measured stress (Mpa)	relative error	Theoretical axial stress （MPa）	Measured stress (Mpa)	relative error
Section 1	1	1.38	1.76	27.38%	-4.3	-3.18	-26.05%	-11.7	-13.6	16.24%
	2	-0.21	-0.22	8.33%	-4.49	-3.25	-27.62%	-8.24	-7.96	-3.40%
	3	-3.7	-5.03	35.82%	-5.17	-3.95	-23.60%	-5.83	-6.15	5.49%
	4	0.75	0.82	10.03%	3.04	4.36	43.42%	3	2.92	-2.67%
	5	0.17	0.19	12.56%	17.1	12.3	-28.07%	1.76	4.23	140.34%
	6	-0.42	-0.47	11.97%	9.91	12.8	29.16%	5.24	2.18	-58.40%
	7	-0.37	-0.42	12.66%	9.59	11.4	18.87%	4.35	4.68	7.59%
	8	-0.41	-0.52	28.32%	4.83	5.52	14.29%	2.96	3.17	7.09%
	9	-0.37	-0.51	37.31%	-0.95	-1.06	11.46%	4.03	9.68	140.20%
Section 2	1	-15.1	-19.14	26.74%	-9.06	-11.9	31.35%	-14.9	-18.6	24.83%
	2	0.14	0.18	24.61%	-2.5	-2.41	-3.64%	12.2	11.3	-7.38%
	3	27	34.84	29.02%	-8.02	-10.5	30.92%	10.8	13.1	21.30%
	4	-18.3	-22.65	23.78%	29.4	36.7	24.83%	-18.1	-23.4	29.28%
	5	-36.7	-46.48	26.65%	-2.33	-3.05	30.90%	-29.8	-33.5	12.42%
	6	7.87	9.66	22.80%	3.8	4.3	13.16%	33.8	40.7	20.41%
	7	12.3	15.7	27.68%	-7.38	-8.85	19.92%	18.6	22.4	20.43%
	8	10.2	11.24	10.16%	4.81	5.88	22.25%	12.2	15.7	28.69%
	9	10.4	13.08	25.72%	4.84	6.12	26.45%	12.6	14.9	18.25%

According to the tables above, the maximum measured stress value 62.2 MPa. appears on 1 # section of front beam. The theoretical stress values mainly appear local stress in thrust, C-shaped hook. But all the stresses have not exceed the allowable stress values. The deviation area of measured value and theoretical value is within 30% (except few fail point). The main factors for that are as follows:

(1)The guyed traveler fulcrum of theoretical calculation model was constrained by rigid constraints. However, the constraint forms of actual structure can not be simulated accurately[9].

(2)The sandbag stack method is adopted in guyed traveler static load test. The sand loads are uniformly distributed on guyed traveler section. Meanwhile, the bevel between secondary longitudinal beam and main longitudinal beam distributed with sand trapezoidal load. The FE modes are mostly simplified to the corresponding line load. They slightly differ from the loading method of actual structure.

(3)Vibrating wire gauges are used to test strain of the main components. The length of vibrating wire strain gauge is 150 mm. The measured stress value for measuring point is in a range around 150 mm of average stress value. And the results of theoretical calculation for the stress value of one certain point, therefore deviation produces[10].

(4)The actual stiffness of the structure is very difficult to accurately simulate in the theoretical calculation. Based on the deviation, the actual stiffness is slightly smaller than the theoretical value.

(5)Due to the smaller absolute value of stress and greatly influenced by the external environment, the deviation of some measuring points is less than 30%. While its absolute deviation value is small without affecting the performance evaluation of the whole structure.

Based the theoretical calculation results and measured values of on the three working conditions, the two kinds of results' general trend is consistent, which proves that calculation and test results are reliable.

5.2. *Deflection analysis.*

When the 33 # main girder is under construction, some points are taken as reference points including the both ends of the beam(a), and the middle part of front beam (c), the middle part of rear beam (c), and front-end of secondary longitudinal beam (d), the joint between secondary longitudinal beam and rear beam (e), the rear of secondary longitudinal (f), when calculating the vertical displacement separately of guyed traveler shows in Tab. 4.

According to Tab. 4, the displacement of guyed traveller under a separate model and the deformation trend of whole model are basically the same. But when guyed traveller inserts into the main girder, the deformation of built main girder is required to remove deformation of guyed traveller since their relative deformations are basically identical.

Tab. 4 the deflection results of key points when 33 # main girder is under construction (unit: mm)

model	condition	a	b	c	d	e	f
individual model	initial tension of cable	12.5	-3.5	-0.3	-0.7	0	-3.7
	pouring	-9.6	-19.3	-1.76	-20.3	-0.8	0
entire model	initial tension of cable	172.7	158.6	156.6	161.2	156.7	148
	pouring	-52.6	-59.6	-35.8	-62.7	-56.4	-16.8

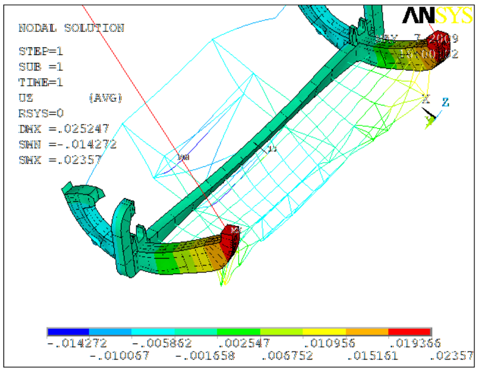


Fig. 4 the deflection of front guyed traveller when 33 # main girder is under construction

6. Conclusion

Based on the finite element analysis and field static load test of Gan-zhu-xi cable-stayed bridge, the following conclusion can be drew out:

(1)Under each test condition, the measured stress value of test section is less than the allowable stress value. The material structure strength meets with the specification requirements with high stress safety reservation.

(2)Compare with the corresponding condition, the theoretical value and the measured values stress of measuring points on the guyed traveler, measured values are close to the theoretical values and their basic deviation is no more than 30%. Under the effect of various environmental factors, the test results are true and correct. However, the measured values of structure is slightly larger than the theoretical value, which proves that the actual stiffness of structure is slightly smaller than the theoretical value.

(3)In the process of static load test, under the full load condition, the stress of pressed rod pieces are smaller without any deformations which proves that stability of structure under pressure is good.

Acknowledgment

This work was supported in part by the National Natural Science Foundation of China under Grant No.51608136 and the New Talent Project of Guangzhou University(No.2608). The authors confirm that this article content has no conflict of interest.

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