

# *Application of construction monitoring for three-span pre-stressed concrete continuous rigid frame bridge*

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**Abstract:** Pre-stressed concrete continuous rigid frame bridges are widely used in valley and river crossings, and the issues of alignment, stress and safety control during their construction are receiving increasing attention. Taking a continuous steel structure with a main span of 96m+180m+96m as an example, this paper discusses the monitoring scheme, alignment and stress measuring point arrangement; establishes a construction monitoring model and calculates the stress and deformation of all construction stages; conducts construction monitoring of the whole process. The results show that in the bridge construction process, through reasonable construction supervision to ensure that the bridge is smoothly united and the bridge structure alignment meets the design requirements, effectively controlling the construction quality of the bridge.

## 1. Introduction

Construction monitoring plays the role of safety warning in the bridge construction process, with the important function of guiding construction and optimizing the construction plan. It is an important task to ensure the quality of bridge construction, and its purpose is to provide effective control of the completed bridge goals.

In this paper, combined with engineering examples, from the perspective of continuous rigid bridge construction, it follows this process in a continuous cycle until completion: model calculation and prediction → guidance construction → data testing and analysis → error identification and correction → improvement construction → effect prediction → inspection and acceptance. During the construction process to ensure the safety of the structure, we should correct the error of various parameters during the construction process to ensure that the internal force and alignment of the structure meet the design requirements after the bridge is completed.

## 2. Project Overview

In this paper, a concrete bridge crossing a river with a width of about 40 m is taken as an example. The bridge is located at the border between Yunnan and Guizhou provinces in China, and the bridge is in a straight line in plan and in a vertical curve of  $R=60,000$  m in longitudinal section.

The main bridge is a prestressed concrete variable section continuous rigid structure (Its elevation diagram is shown in Figure 1) with a hole span arrangement of 96m+180m+96m. The main bridge is a double span bridge with a deck width of 12.65m and a single box single chamber section with a box width of 7.0m and a flange cantilever width of 2.825m on both sides. The main girder is made of C55 concrete, the bridge deck pavement is made of C50 (waterproof) concrete, the bridge pier is made of C50 concrete, and it is constructed by hanging basket suspension method.

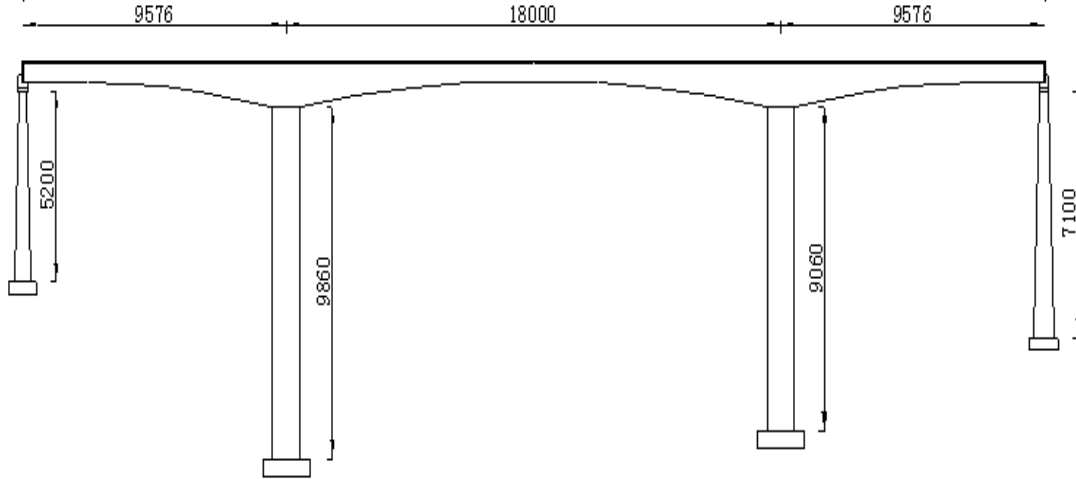


Figure 1: Elevation of the bridge (unit: cm)

### 3. Construction monitoring calculation

Finite element analysis of the bridge construction process is used to determine the theoretical deformations and internal forces at each stage of the construction process, which are used as a basis for controlling and guiding the construction process so that the alignment and internal forces of the completed bridge meet the design requirements.

The structural analysis is carried out according to a realistic construction plan, taking into account the effects of the structure's own weight, pre-stressing, temperature and concrete shrinkage and creep. The analysis model is shown in Figure 2. There are 157 units and 160 nodes in the bridge.

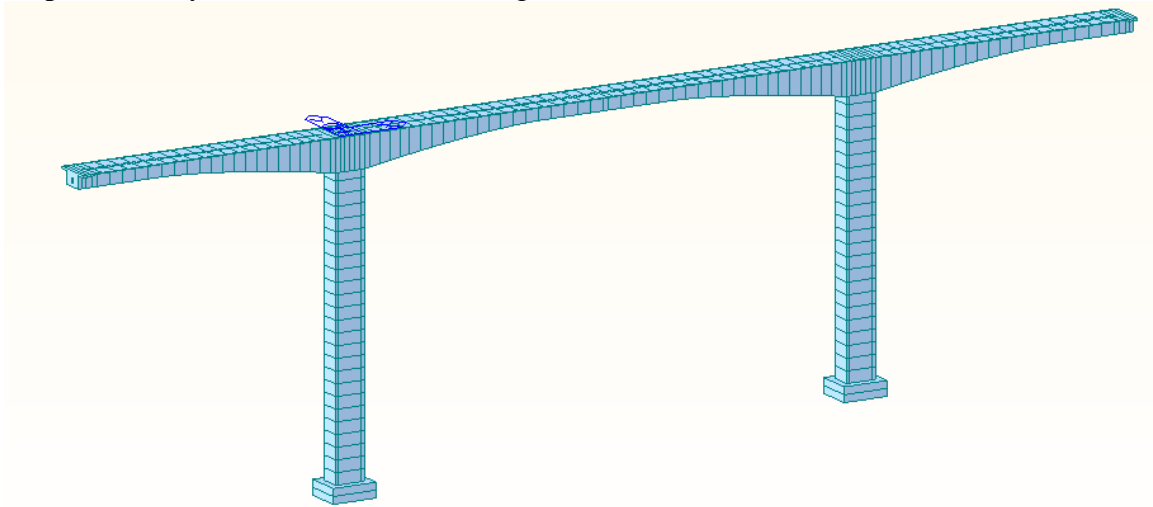


Figure 2: Finite element model of the bridge

The construction of the main bridge was divided into 78 calculated stages for the simulation, with a total construction period of 621 days, according to the design drawings and the construction

organisation design for the division of the construction stages. A detailed description is given in Table 1.

Table 1: Division of construction phases in the calculation model

Construction Phase	Duration /day	Start time /day	End time /days	Description of working conditions
1	15	1	16	Pouring concrete for the plinth
2	240	16	256	pouring concrete for bridge pier
3	20	256	276	Pouring concrete for No. 0 beam section
4	2	276	278	Prestressed steel tendons for beam section No. 0
5	4	278	282	Hanging basket installed on the No. 1 beam section
6	10	282	292	Pouring concrete for No. 1 beam section
7	1	292	293	Tensile prestress for the No. 1 beam section
8	1	293	294	Move the hanging basket to the No. 2 beam section
9	10	294	304	Pouring concrete for the No. 2 beam section
10	1	304	305	Tensile prestress for the No.2 beam section
13-64	$12 \cdot 17d = 204$	305	521	Beam section No. 3-No. 20: moving the hanging basket forward, pouring concrete, tensioning and pre-stressing 12 days for each beam segment
65	2	521	523	Remove the hanging basket
66	5	523	528	Erection of guide beams and application of cantilever end counterweight
67	15	528	543	Pouring concrete for side span cast-in-place sections
68	7	543	550	Pouring concrete for side span closing sections
69	2	550	552	Unloading the counterweight at the cantilever end of the side span
70	2	552	554	Prestress in tensioned side spans
71	2	554	556	Remove the guide beam of the side span closing section
72	2	556	558	Install hangers for mid-span closure
73	7	558	565	Pouring concrete for the mid-span closing section
74	2	565	567	Unloading the mid-span cantilever end counterweight
75	2	567	569	Prestress of tensioned mid-span
76	2	569	571	Remove the hanger of the mid-span closing section
77	20	571	591	Bridge pavement
78	30	591	621	into a bridge

#### 4. Monitoring point layout and results

Construction monitoring is a real-time measurement system set up on site to track the stresses and displacements of the structure during construction. The inspection system provides actual measurement data for monitoring works to ensure the safety of the structure during bridge construction, as well as providing parameters and calibration of the measured structure for monitoring calculations.

After simulation and analysis of the entire bridge construction process and theoretical calculations, and after extensive consideration, the alignment of the main girders and the stresses in the main girders were monitored during the construction of this bridge, with the following three main tasks.

(1) Before forming each beam section, the height of the formwork shall be calculated. After the formwork height has been adjusted by the construction unit in accordance with the surveillance

work instructions, the surveillance team shall check that the formwork height meets the requirements of  $\pm 3$  mm;

(2) After concreting and pre-stressing of each beam section, the height is measured and the results are compared with the theoretically calculated values to ensure that the changes in height at each stage of construction are within a controllable range;

(3) After each beam segment has been prestressed and stretched, the strain is measured and the results compared with the theoretically calculated values. If the actual measured value deviates significantly from the theoretical value, the cause of the deviation should be analysed and dealt with.

#### 4.1 Stress measurement point layout

Stress monitoring measurement is to carry out actual on-site measurement of the stress test section at each stage of construction to obtain the measured increase in stress under the working condition, so as to judge and check the changes in construction load under each working condition during the construction process.

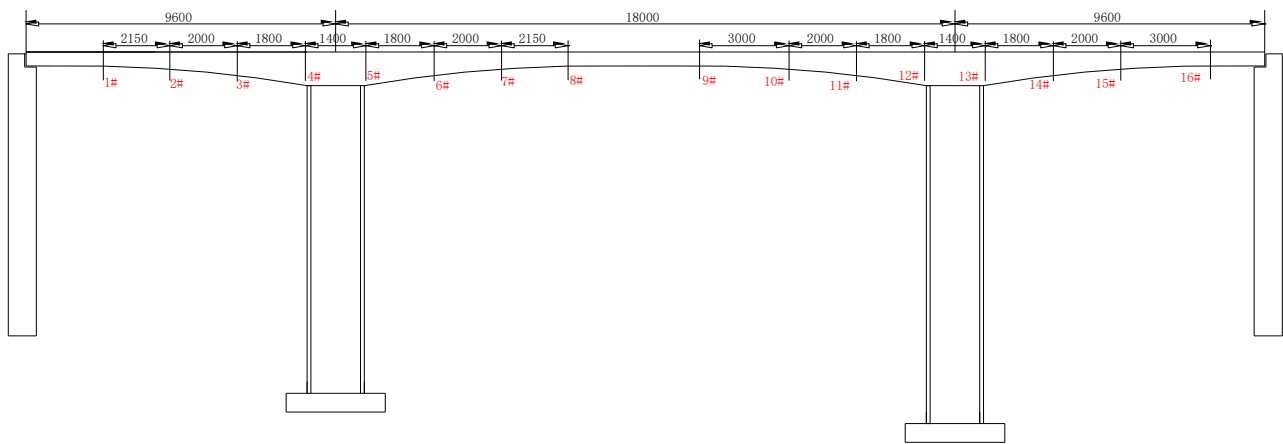


Figure 3: Schematic diagram of main bridge stress (strain) test section (unit: cm)

The layout of the stress (strain) monitoring section is shown in Figure 3, and the arrangement of the stress measurement points is shown in Figure 4.

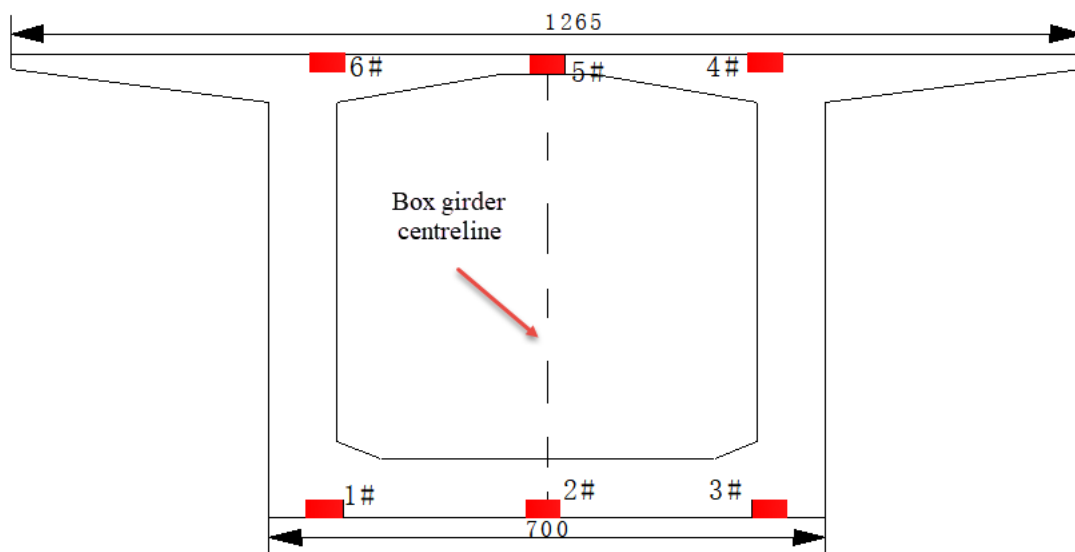


Figure 4: Positioning of strain measuring points in sections 1 to 16 of the main bridge /cm

## 4.2. Deformation testing point layout

The main purpose of linear monitoring is to monitor the changes in elevation at the centre line of the left and right webs at the base of the box girder under each construction condition.

The observation points are first marked, and then by comparing the measurement data between the observation points and the reference points, the height changes of the measurement points under each construction process can be reflected. The layout of the height observation points is shown in Figure 5.

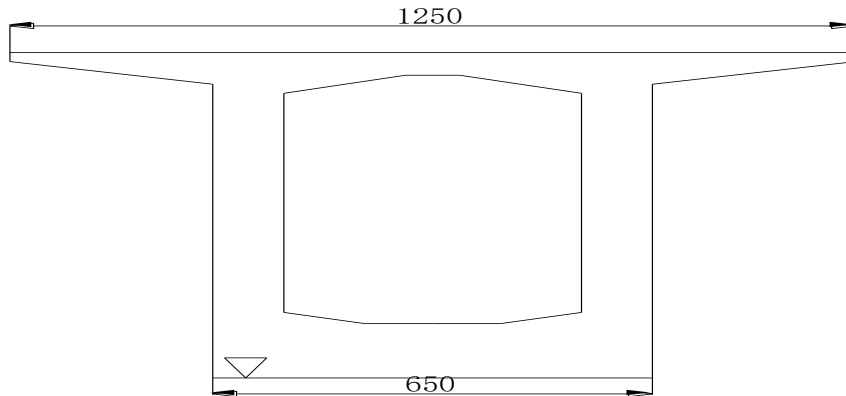


Figure 5: Location of the box girder deformation testing points /cm

## 4.3. Results of stress monitoring

Table 2: Results of stress monitoring-1

section	Measuring point	After No. 1 beam section is stretched			After No. 2 beam section is stretched		
		measured value/MPa	theoretical value/MPa	Relative deviation	measured value/MPa	theoretical value/MPa	Relative deviation
Section 4	4#	-1.24	-1.46	15.07%	-2.81	-3.1	9.35%
	5#	-1.49	-1.46	2.05%	-3.01	-3.1	2.90%
	6#	-1.27	-1.46	13.01%	-2.76	-3.1	10.97%
Section 5	4#	-1.35	-1.46	7.53%	-2.88	-3.1	7.10%
	5#	-1.37	-1.46	6.16%	-2.91	-3.1	6.13%
	6#	-1.42	-1.46	2.74%	-2.81	-3.1	9.35%

Table 3: Results of stress monitoring-2

section	Measuring point	After No. 13 beam section is stretched			After No. 14 beam section is stretched		
		measured value/MPa	theoretical value/MPa	Relative deviation	measured value/MPa	theoretical value/MPa	Relative deviation
Section 10	1#	-0.86	-0.85	1.18%	-1.45	-1.37	5.84%
	2#	-0.81	-0.85	4.71%	-1.32	-1.37	3.65%
	4#	-7.04	-6.84	2.92%	-8.45	-8.25	2.42%
	5#	-6.76	-6.84	1.17%	-8.17	-8.25	0.97%
	6#	-7.13	-6.84	4.24%	-8.01	-8.25	2.91%
Section 15	1#	-0.81	-0.85	4.71%	-1.42	-1.37	3.65%
	2#	-0.89	-0.85	4.71%	-1.33	-1.37	2.92%
	3#	-0.83	-0.85	2.35%	-1.31	-1.37	4.38%
	5#	-7.13	-6.84	4.24%	-8.34	-8.25	1.09%
	6#	-7.01	-6.84	2.49%	-7.91	-8.25	4.12%

Stress monitoring and measurement is to conduct on-site measurement of the stress test section at each construction process stage to obtain the measured stress increment under this working condition, so as to judge and check the construction load change of each working condition during the construction process. The stress monitoring results for this bridge section are shown in Table2-4.

The stress monitoring results of sections No. 4 and 5 after pre-stressing of beam sections No. 1 and No. 2 are described in detail in Table 1 and the stress monitoring results of sections No. 10 and No. 15 after pre-stressing of beam section No. 20 are described in Table 2 and the stress monitoring results of sections No. 1, No. 8, No. 9 and No. 16 after pre-stressing of beam section No. 20 are described in Table 3.

Table 4: Results of stress monitoring-3

Cross-section	Test point 1	1#	2#	3#	4#	5#	6#
Section 1	Measured value	-5.81	-5.9	-5.34	-5.24	-5.2	-5.16
	Theoretical value	-5.52	-5.52	-5.52	-5.76	-5.76	-5.76
	Relative Deviation	5.25%	6.88%	3.26%	9.03%	9.72%	10.42%
Section 8	Measured value	-5.34	-5.28	-5.14	-6.04	-6.12	-5.22
	Theoretical value	-5.52	-5.52	-5.52	-5.76	-5.76	-5.76
	Relative Deviation	3.26%	4.35%	6.88%	4.86%	6.25%	9.38%
Section 9	Measured value	-3.97	-3.54	-3.21	-3.08	-3.18	-3.22
	Theoretical value	-3.7	-3.7	-3.7	-3.52	-3.52	-3.52
	Relative Deviation	7.30%	4.32%	13.24%	12.50%	9.66%	8.52%
Section 16	Measured value	-3.98	-3.79	-3.64	-3.28	-3.11	-3.64
	Theoretical value	-3.7	-3.7	-3.7	-3.52	-3.52	-3.52
	Relative Deviation	7.57%	2.43%	1.62%	6.82%	11.65%	3.41%

#### 4.4. Results of deformation monitoring

The details of the monitoring results of the height observation points of each test section at different stages of the construction process are shown in Table 5.

Table 5: Results of deformation monitoring

construction stage	Measuring point	elevation/m	Settlement values/mm	
			Measured values	Calculated values
After pouring the concrete for beam section 1	1-1	1717.528	-25.1	-26
After tensioning the pre-stressed reinforcement of beam section 1	1-1	1717.529	2	0.4
After pouring the concrete for beam section 4	4-1	1719.360	-15	-22
After tensioning the pre-stressed reinforcement of beam section 4	4-1	1719.362	1.7	1.5
After pouring the concrete for beam section 9	9-1	1722.337	-24.5	-22
After tensioning the pre-stressed reinforcement of beam section 9	9-1	1722.340	3	3.9
After pouring the concrete for beam section 13	13-1	1724.146	-25	-29
After tensioning the pre-stressed reinforcement of beam section 13	13-1	1724.154	7.6	12.1
After pouring the concrete for beam section 18	18-1	1724.975	-37.9	-40
After tensioning the pre-stressed reinforcement of beam section 18	18-1	1724.984	8.5	18.5
After pouring the concrete for beam section 20	20-1	1725.125	-28.6	-50
After tensioning the pre-stressed reinforcement of beam section 20	20-1	1725.138	12.9	15.6

## 5. Conclusions

By monitoring the construction of this continuous rigid bridge, appropriate control of multiple objectives such as alignment and tension was achieved and the relevant provisions of the specification were met.

(1) The relative error between the measured and theoretically calculated values of the stresses in the concrete structure at each stage of construction shall not exceed  $\pm 20\%$  of the value required by the Code;

(2) The differences between the measured and calculated heights of the cantilevered sections meet the specified requirements;

(3) The deformation values of each section after concreting and the arching values after tensioning the pre-stressing bars are similar to the theoretically calculated values and meet the objectives of the monitoring.

The construction of a bridge is a system project. The construction process is also the operation of this system. During the construction process, the safe construction of the bridge was ensured by a large amount of actual measurement data and analysis. Monitoring the entire bridge construction process is not only a technical method and a means of correction to control the quality of bridge construction, but also a strong guarantee of safe bridge construction.

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