

Research Article

Impounding Experimental Research of Large Span Aqueduct

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Abstract: In this study, we have a research of the impounding experimental research of large span aqueduct. Caohe aqueduct is the mark building of the middle line of the South-to-North Water Diversion Project, of which the span is 30m. For this aqueduct, the structure is relatively complicated with great technical difficulties, what's more there's no engineering experience or theoretical method to provide reference in domestic and abroad. It can be seen clear that whether the actual stressing state, deformation conditions and prestressed tension effect etc. meet the design requirements will directly affect the safe operation of aqueduct, so the impounding experiment of the aqueduct was carried out before formal operation. At the meanwhile, the deformation characteristics and stress characteristics of the aqueduct under various impounding conditions were analyzed in detail. The experiment results analysis shows that, the aqueduct structure is under a good elastic working condition with only 0.98mm maximum deflection deformation at mid-span, which meets the design and specification requirements. At the same time, all of the measure point's stress is in the range of designed material, which means the structure form is safe and reliable and can meet the requirements of the later operation good.

Keywords: Aqueduct, deflection deformation, impounding condition, large span

INTRODUCTION

The longitudinal and horizontal cross-sections of the aqueduct are shown in Fig. 1 (Bian *et al.*, 2008; Wang *et al.*, 2007; Peng *et al.*, 2006; Niu, 2005; Deng *et al.*, 2011). As the structure form is relatively complicated, there is no similar engineering experience or theoretical method to provide reference in domestic and abroad. In order to master the deformation laws and stress characteristic of the aqueduct more deeply and provide important guidance and reference for the later operation, the impounding experiment was carried out before formal operation of the aqueduct.

In this study, we have a research of the impounding experimental research of large span aqueduct. Caohe aqueduct is the mark building of the middle line of the South-to-North Water Diversion Project, of which the span is 30m. For this aqueduct, the structure is relatively complicated with great technical difficulties, what's more there's no engineering experience or theoretical method to provide reference in domestic and abroad. It can be seen clear that whether the actual stressing state, deformation conditions and prestressed tension effect etc. meet the design requirements will directly affect the safe operation of aqueduct, so the impounding experiment of the aqueduct was carried out before formal operation.

LOADING SCHEME

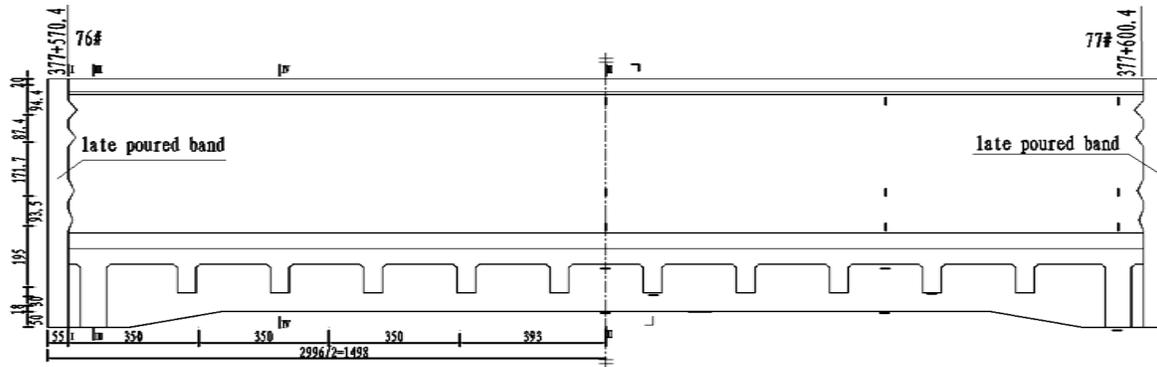
According to the design requirements, the impounding load experiment consists of 3 impounding conditions, which is middle-aqueduct impounding, left and right side-aqueduct impounding and three-aqueduct impounding and considers 3 water levels respectively. The experiment conditions are shown in Table 1. Before the experiment the two ends of aqueduct were plugged and steel tension rods were tied at each side to ensure stability of plugging structure. High-power water pump was adopted to inject water gradually and the photos before or after impounding are shown in Fig. 2.

MEASURING POINTS ARRANGEMENT OF DEFLECTION DEFORMATION

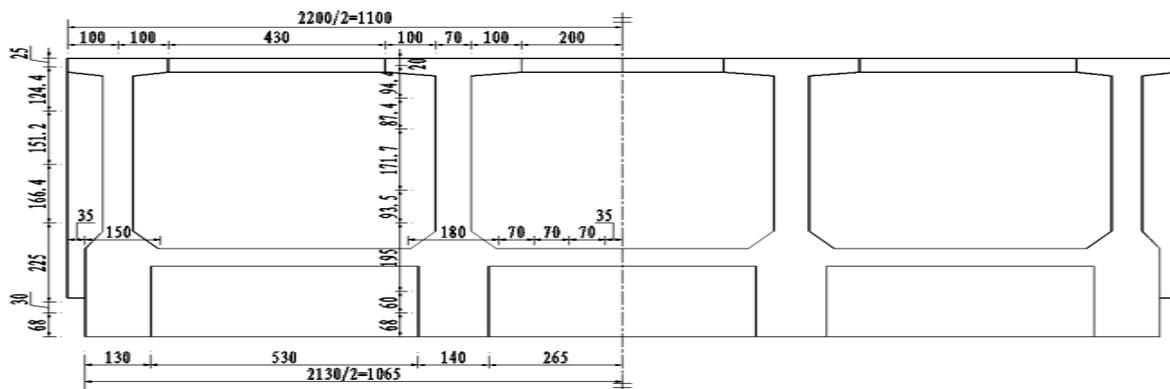
According to the structure symmetry, the measuring points of deflection deformation were laid on the mid-span section, L/4 section, 3L/4 section and two-end supports of longitudinal beam. There were 12 displacement sensors and 12 dial indicators. Measuring points' arrangement diagram of deflection deformation is shown in Fig. 3.

And the photos of typical measuring points are shown in Fig. 4.

During the experiment, 20 observing points were laid on the four sidewalk-boards of the aqueduct to provide verification and comparative analysis and then



(a) Longitudinal section graph



(b) Horizontal cross section graph

Fig. 1: Longitudinal and horizontal cross section graph of the aqueduct

Table 1: Impounding conditions of the aqueduct

Conditions serial number	Water level of (m)		
	Middle-aqueduct	Side-aqueduct	3-aqueduct
1	4.150	×	×
2	4.792	×	×
3	5.400	×	×
4	×	4.150	×
5	×	4.792	×
6	×	5.400	×
7	×	×	4.150
8	×	×	4.792
9	×	×	5.400

the aqueduct. The arrangement diagram of the measuring points is shown in Fig. 5.

For observing the horizontal deformation and vertical deformation of the top measuring points more accurately, six deformation observation reference points were laid in a stable position near the aqueduct, showed in Fig. 6, the reference points' serial number is CJ0 ~ CJ5.

MEASURING POINTS ARRANGEMENT OF STRESS

During impounding experiment, resistance strain gauges were laid at the longitudinal beam, secondary beam, bottom, side wall, top pull rod etc. of the aqueduct to observe the changes of stress and strain on the concrete surface.

According to the symmetry and the structural characteristics of the aqueduct, strain measuring points were mainly laid on the end-section, L/4 section and L/2 section and check tablets were as well laid on corresponding locations and the strain gauges and temperature compensation gauges sum to 124 and 16. In the analysis of results, the experiment data of embedded instruments were considered in the mean time.

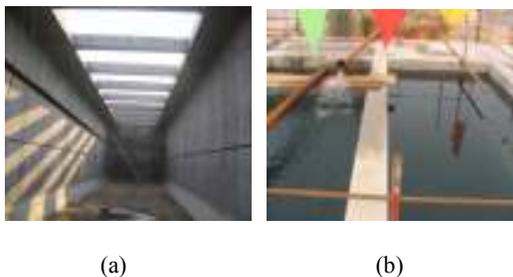


Fig. 2: Photos before and after impounding of the aqueduct

corresponding measurement method was used to monitor the settlement and horizontal displacement of

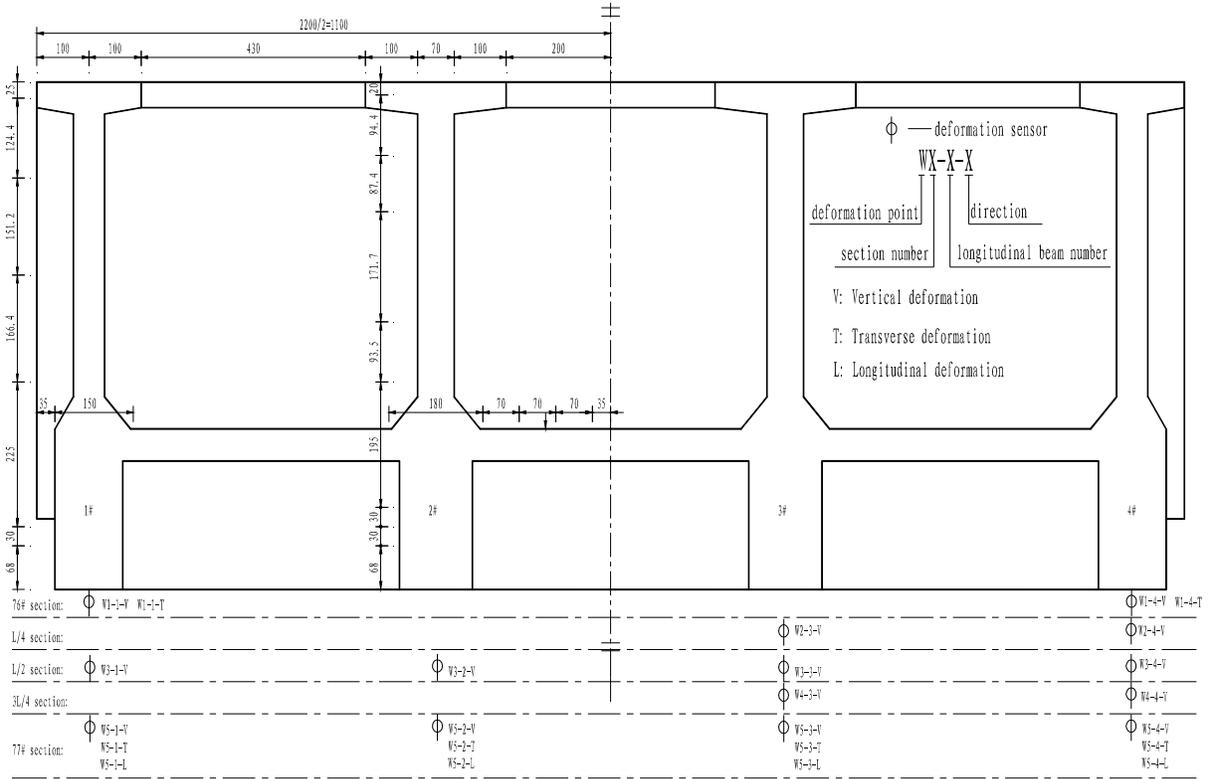


Fig. 3: Measuring points arrangement diagram of deflection deformation

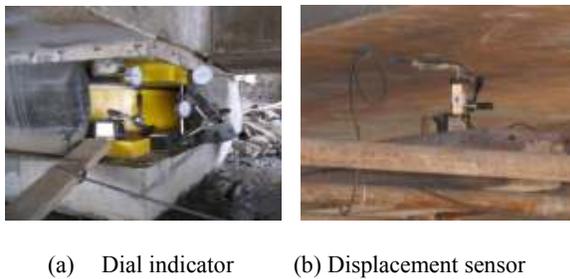


Fig. 4: Photo of typical deflection deformation measuring points; (a) Dial indicator, (b) Displacement sensor

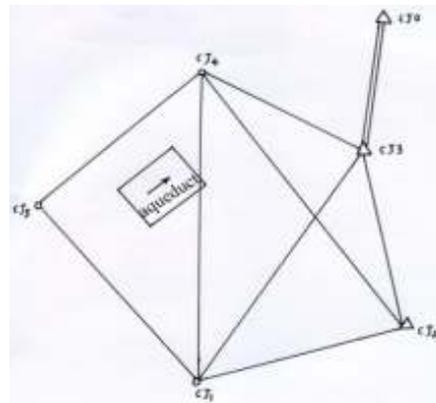


Fig. 6: Layout of reference points

The arrangement diagram of strain measuring points on L/2 section and embedded instruments are shown in Fig. 7.

And the photos of typical strain measuring points are shown in Fig. 8.

EXPERIMENT RESULTS AND ANALYSIS OF DEFLECTION DEFORMATION

In the whole impounding experiment, deflection deformations of longitudinal beams of the aqueduct are shown in Table 2. The deformation-time graphs of

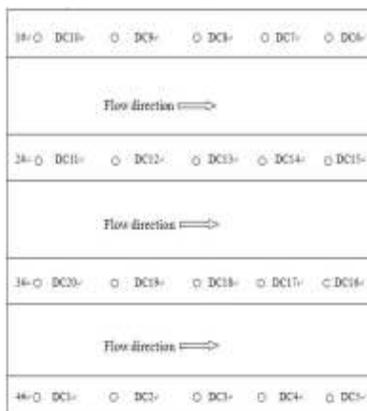


Fig. 5: Observing points arrangement diagram on the sidewalk-boards

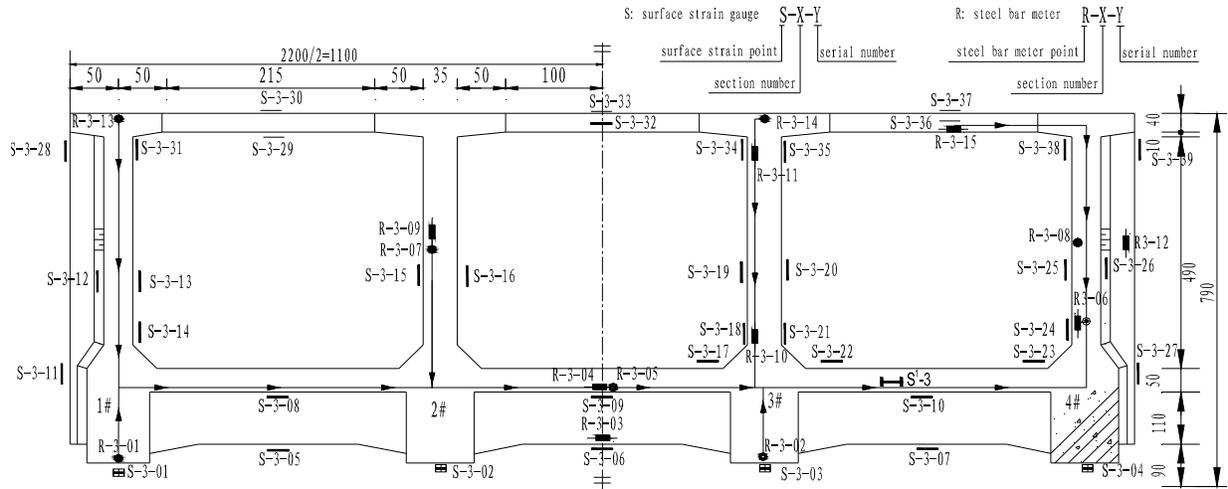


Fig. 7: Arrangement diagram of strain gauges and steel bar meters at L/2 section



(a) Strain gauge on the beam; (b) Strain gauge on the poll rod

Fig. 8: Photos of typical strain measuring points; (a) Strain gauge on the beam, (b) Strain gauge on the poll rod

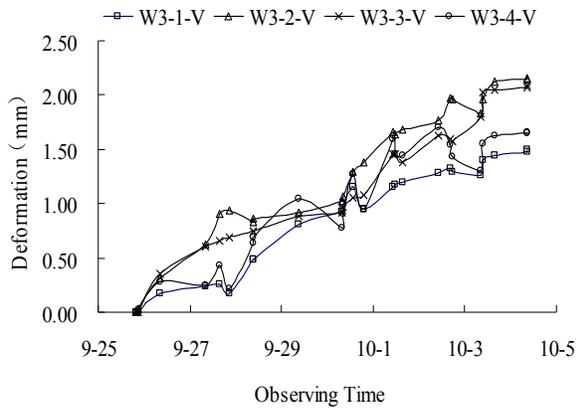


Fig. 9: The vertical deformation-time graphs of measuring points on L/2 section

deformation measuring points on L/2 Section are shown in Fig. 9.

As it can be seen from the Table 2 and Fig. 9, during the impounding experiment, the vertical displacement of supports and the deflection deformations on L/4, L/2 and 3L/4 sections of longitudinal beam increasing with the water level rising

and the overall deformations have the same tendency, while the vertical deformation of mid-longitudinal beam (intermediate-supports) was relatively large, the vertical deformation of side-longitudinal beam (side-supports) is relatively small, which were symmetric basically with small uneven deformation. The maximum deflection deformation at mid-span of longitudinal beam was 0.37 mm when mid-aqueduct impounded to 5.4 m, which was 0.72 mm when left and right-side aqueduct impounded to 5.4 m and it come to 0.98 mm when three aqueducts all impounded to 5.4 m.

All in all, the maximum deflection deformation was in the allowable range of design and specification (DL/T5057, 1996; DL/T5178, 2003) and less than the theory calculation value of 2.49 mm (Luo *et al.*, 2007).

Observing results of settlement are shown in Table 3, when the water level of three aqueducts impounded to 5.4 m, the maximum deformation at mid-span of longitudinal beam is 2.00 mm, which is quite close the deflection deformation measuring result of 1.83 mm (including the settlement of the supports). Therefore, the impounding experiment results of deflection deformation are credible.

STRESS EXPERIMENT RESULTS AND ANALYSIS

The aqueduct had a three-dimensional prestress in December 2005. After tension of the prestressed anchorage cable, each measuring point appeared great compressive stress increment, which indicates the aqueduct structure is under compression state. When the water level of three-aqueduct come to 5.4m, a certain tensile stress increment appeared at the structures of the concrete surface such as longitudinal beam, secondary beam, base plate and poll rod and etc., showing as Table 4, however the whole structure was still under the compression state.

Table 2: Deflection deformation statistical table of longitudinal beam of the aqueduct (unit: mm)

Conditions serial number	Deflection deformation measuring points														Mid-span deflection deformation			
	W1-1-V	W1-4-V	W2-3-V	W2-4-V	W3-1-V	W3-2-V	W3-3-V	W3-4-V	W4-3-V	W4-4-V	W5-1-V	W5-2-V	W5-3-V	W5-4-V	1#	2#	3#	4#
Before impounding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.12	0.11	0.25	0.2	0.34	0.62	0.6	0.33	0.22	0.2	0.11	0.34	0.33	0.07	0.23	0.28	0.27	0.24
2	0.13	0.14	0.3	0.28	0.4	0.71	0.66	0.45	0.24	0.22	0.19	0.35	0.35	0.21	0.24	0.36	0.31	0.28
3	0.14	0.15	0.36	0.3	0.47	0.74	0.69	0.52	0.26	0.25	0.24	0.37	0.36	0.23	0.28	0.37	0.33	0.33
4	0.34	0.33	0.62	0.38	0.81	0.92	0.88	0.84	0.44	0.36	0.36	0.47	0.46	0.32	0.46	0.45	0.42	0.52
5	0.38	0.37	0.7	0.52	0.93	1.02	0.97	0.98	0.51	0.52	0.45	0.55	0.53	0.43	0.52	0.47	0.44	0.58
6	0.41	0.43	0.71	0.59	1.05	1.29	1.06	1.07	0.54	0.53	0.5	0.57	0.55	0.53	0.60	0.72	0.51	0.59
7	0.46	0.48	0.81	0.61	1.15	1.46	1.36	1.13	0.65	0.6	0.51	0.73	0.82	0.55	0.67	0.73	0.54	0.62
8	0.49	0.52	0.85	0.7	1.23	1.57	1.6	1.24	0.77	0.63	0.61	0.74	0.9	0.59	0.68	0.83	0.70	0.69
9	0.52	0.57	0.93	0.83	1.36	1.83	1.79	1.32	0.84	0.7	0.64	0.85	0.96	0.63	0.78	0.98	0.83	0.72

1#, 2#, 3# and 4# stand for the longitudinal beam number

Table 3: Observing results of mid-span settlement at the top of the aqueduct (unit: mm)

Observing points numbers	Water level of mid-aqueduct(m)		Water level of left and right-side aqueduct(m)		Water level of three-aqueduct(m)	
	4.150	5.400	4.150	5.400	4.150	5.400
DC1	0.1	0.2	0.6	0.6	0.8	1.0
DC2	0.0	0.0	0.5	0.6	0.5	0.8
DC3	0.1	0.1	0.5	0.5	0.7	0.9
DC4	0.0	0.3	0.6	0.7	0.7	0.8
DC5	0.1	0.1	0.4	0.5	0.5	0.8
DC6	0.0	0.2	1.0	1.1	1.0	1.3
DC7	0.0	0.0	0.8	0.8	1.5	1.7
DC8	0.1	0.2	0.4	0.6	0.6	0.8
DC9	0.1	0.2	0.5	0.6	0.8	0.9
DC10	0.1	0.1	0.3	0.9	1.1	1.3
DC11	0.2	0.4	0.5	1.0	1.4	1.5
DC12	0.3	0.4	0.8	1.3	1.5	1.5
DC13	0.2	0.5	0.9	1.1	1.3	1.4
DC14	0.4	0.7	0.9	1.0	1.1	1.2
DC15	0.4	0.8	1.2	1.3	1.3	1.5
DC16	0.2	0.3	0.6	0.7	0.7	0.8
DC17	0.3	0.7	1.9	1.9	1.9	2.0
DC18	0.2	0.6	1.8	1.8	1.8	2.0
DC19	0.2	0.5	1.0	1.1	1.1	1.1
DC20	0.3	0.5	0.8	1.0	1.2	1.3

Table 4: Monitoring stress value of observing points on the concrete surface of aqueduct

Observing points position	After tension of prestress		3-aqueduct water level come to 5.4m		
	Stress increment (Mpa)	Deformation tendency	Stress increment (Mpa)	Deformation tendency	Final stress state
Mid-span of longitudinal beam	2.1~4.6	Compression	0.8~2.2	Tension	Compression
Mid-span of secondary beam	2.6~5.2	Compression	1.2~2.8	Tension	Compression
Mid-span of base plate	1.2~1.8	Compression	0.7~1.3	Tension	Compression
Top of the poll rod	2.0~4.5	Compression	1.2~2.8	Tension	Compression

Table 5: Concrete stress measured value of embedded instruments in mid-span section (unit: MPa)

Serial number	Before impounding	Stress state	3-aqueduct water level come to 5.4m	Final stress state
R-3-01	-3.30	Compression	-1.30	Compression
R-3-02	-7.20	Compression	-5.40	Compression
R-3-03	-5.60	Compression	-3.70	Compression
R-3-04	-10.60	Compression	-9.90	Compression
R-3-05	-9.50	Compression	-8.60	Compression
R-3-06	-10.70	Compression	-8.70	Compression
R-3-07	-8.00	Compression	-7.90	Compression
R-3-08	-12.20	Compression	-11.90	Compression
R-3-09	-1.80	Compression	-0.90	Compression
R-3-10	-3.00	Compression	-1.70	Compression
R-3-11	-3.90	Compression	-2.70	Compression
R-3-12	-9.00	Compression	-9.80	Compression
R-3-13	-15.90	Compression	-16.60	Compression
R-3-14	-17.00	Compression	-18.80	Compression
R-3-15	-3.50	Compression	-3.50	Compression
R-3-16	-4.40	Compression	-3.60	Compression

The monitoring data of the embedded instruments in mid-span section is shown in Table 5. Comparing the values in Table 4 and 5, it's clear that the stress change tendency of the concrete surface and concrete interior is basically consistent and the aqueduct structures were still under the compression state after impounding.

CONCLUSION

- During the experiment, the maximum deflection deformation at mid-span of longitudinal beam is only 0.98 mm when three-aqueduct impounded to 5.4m, which meets the requirements of specification and design
- During the experiment, certain increment of tensile stress appears at longitudinal beam, secondary beam, bottom surface of floor and top pull rod of aqueduct, however considering the tension effect of previous three-dimensional prestressed comprehensively, the aqueduct structure was generally under compression state
- During the experiment, there's no new crack appeared and at the same time the old cracks didn't extend
- The experiment results show that, impounding has a little influence on the stress and deformation of the aqueduct structure, which meets the requirements of design and specification, so the aqueduct structure is safe and reliable and can meet the requirement of latter operation good

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