EXPERIMENT OF STEEL CABLE-PYLON ANCHORAGE SYSTEM OF LONGCHENG BRIDGE

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ABSTRACT

Based on the numerical analysis, a full-scale model test of the cable-pylon anchorage of Longcheng Bridge was performed and the stress distribution on anchorage was monitored. The experimental and FEM analysis results were compared. The stress distribution and mechanical behavior under cable force were studied. The experimental result shows that: (1) the test data correspond with the FEM result and the specimen can simulate the anchorage zone; (2) the cable-pylon anchorage zone is safe under the 1.4 times maximum design cable force; (3) the anchor box has the mechanical behavior of a deep beam which leads to out-of-plane load-carrying character of plates the anchor box directly welded to.

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INTRODUCTION

Background of the Project

The experiment is based on Longcheng Bridge (shown in Figure 1) across Beijing-Hangzhou canal in Changzhou, China. The bridge is a self-anchored suspension-cable-stay system with single arch pylon and 3 spans steel-concrete composite girder (72.2+113.8+30m). The main span is a suspension structure. The main cable is anchored to the main girder on the auxiliary piers at one end, and splays to 7 cables anchored on pylon at the other end. The side span is cable-stayed structure with 5 pairs of cables. The stayed cable and main cable form a spatial cable system. The stayed cable and inclined arch pylon work together to balance the force of the suspension cable.

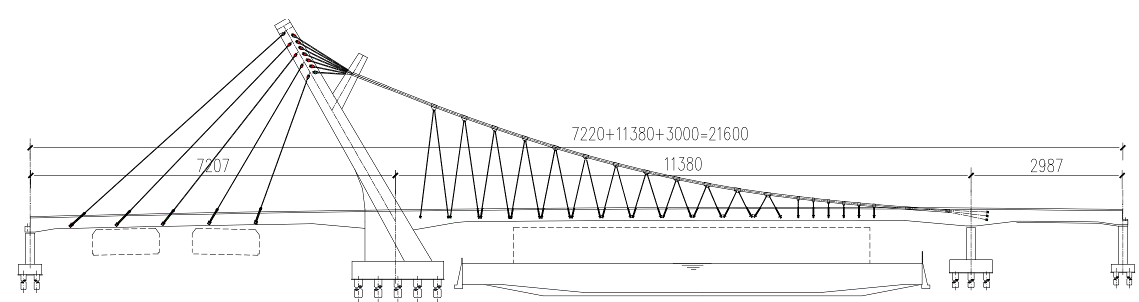

Fig. 1. General layout of Longchen Bridge.

The pylon (shown in Figure 2-a, 2-b) is a varying cross-section arch. This arch pylon has a 30 degree of inclination towards side span. The secondary arch which is attached to the arch pylon with an angle of 60 degree is only for aesthetic use. The cross section (shown in Figure 2-c) of the arch pylon is 4.124m~3m (in bridge axis direction) by 2m (perpendicular to bridge axis direction) box. In anchorage zone, the box section is divided into 2 side cells (0.495 meter wide

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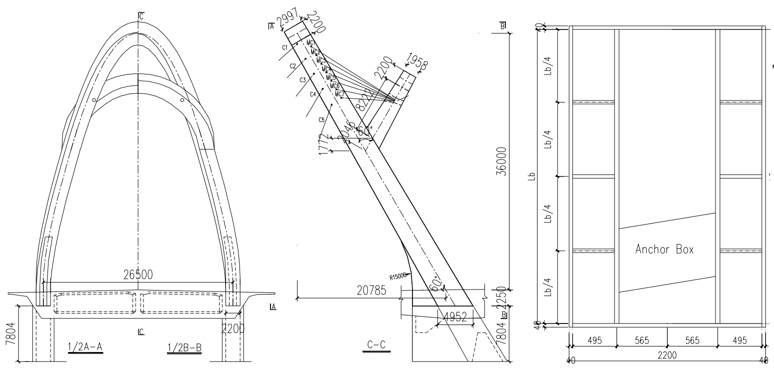
each) and 1 middle cell (1.130 m wide). Each side cell is divided into 4 cells by 3 ribs. The material of the arch pylon is Q420qd.

The arch pylon anchorage (Figure 3 shows the name and number of each plate which will be mentioned below for short.) uses the form of steel anchor box. The steel boxes are welded to middle cell of the pylon section. Because the space in arch pylon is limited, the length of anchor box along the cable is only 700mm, much smaller than the minimum length of the anchor box on Sutong bridge; The maximum design force of the 7 splayed cables is 876t, greater than the maximum design cable force on Sutong bridge; At the same time, the arch pylon consists of 4 spatial curved surface and form a spatial angle with the cable, which make the cable force an out-of-plane load to the steel pylon wall. The limited space and great deal of plates cause great manufacturing problems. The plate thickness in anchorage zone reaches 50mm, the mass of welding work leads to prominent residual stress and deformation. All of which have great influence on failure pattern and ultimate capacity, and make the arch pylon anchorage zone much more complicated than regular cable-stayed bridge pylon anchorage zone. It is necessary to perform a model experiment to confirm the structure safety and study the mechanical behavior and failure mechanism.



(a) (b) (c)

Fig. 2. Arch pylon and cross-section.

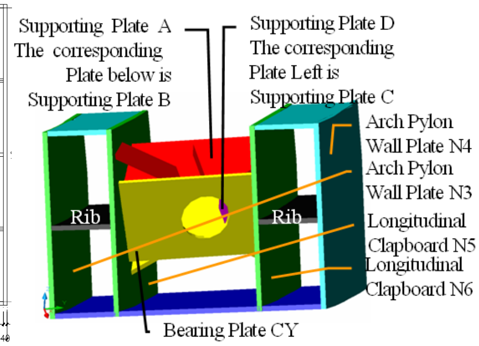


Fig. 3. Anchorage sketch

EXPERIMENTAL STUDY

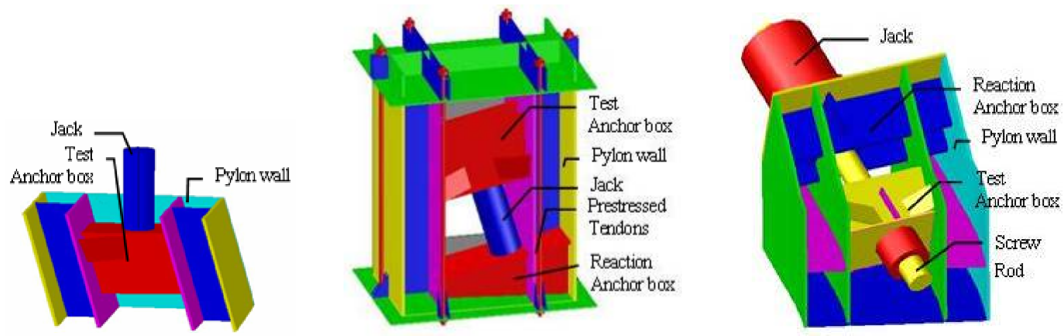
Design of Specimen

A full scale specimen is designed to simulate the anchor box MC1, which is on top of the arch pylon and resists the largest cable force splayed from the main cable. In order to diminish boundary effect, the web plates N5, N6, which are connected with MC1, arch wall plates N1, N3, and N4, and ribs are also included in the specimen. With the model scale of 1.0, all the plates in specimen have the same thickness with the prototype. The experimental set-up was chosen in such a way that for all load cases the model would subject to same stresses and displacements as the prototype of the anchorage. Three models are put forward at first (shown in Figure 4):

Model 1 is the simplest, and the FEM analysis shows it resemble the mechanical behavior of real arch pylon. But this structure needs a reaction with a capacity of over 1000 tons to balance the test load. No suitable reaction wall can be found. Model 2 is a self-balance system. A reaction anchor box is designed to solve the reaction problem. The pre-stressed tendons can simulate the axial force in arch pylon. But according to FEM analysis, the arch wall in front of the anchor box is subjected to great tension which can hardly be balanced by pre-stressed tendon under the test load. This is different from the real arch pylon. Besides, the place inside the pylon is too limited, a jack with a capacity more than 1000tons is impossible to put in. Model 3 is also a self-balance system with a reaction anchor box. Because the place inside the pylon is too limited to contain the jack, a hollow pulling jack is used to pull a screw rod to apply compression on test anchor box; thus the pulling jack can be positioned outside the pylon. Model 3 is finally selected.

In order to figure out the boundary effect and testify the similarity of the model test, a FEM comparison was perform between the selected specimen and real arch pylon. Figure 5 are the stress distribution on N5 and anchor box of both specimen and real arch pylon when MC1 is applied to 876 tons of pressure. The stress distribution on anchor box is almost the same. The maximum stress of anchor box is 355MPa on the specimen and is 343MPa on the real arch pylon; the deviation is only 3%. The stress distribution of specimen and real arch pylon is also similar on N5, N6 except a little bit difference at the position of reaction anchor box due to the structure difference. The FEM comparison shows that: the specimen is well designed and can simulate the stress distribution of anchor box and adjacent plates on real arch pylon.

The specimen used the same manufacture process and material as the real arch pylon (shown in Figure 6). Carbon-dioxide gas shielded arc welding is used and followed by ultrasonic inspection.



Model 1 **Model 2** **Model 3**

Fig. 4. Model comparison.

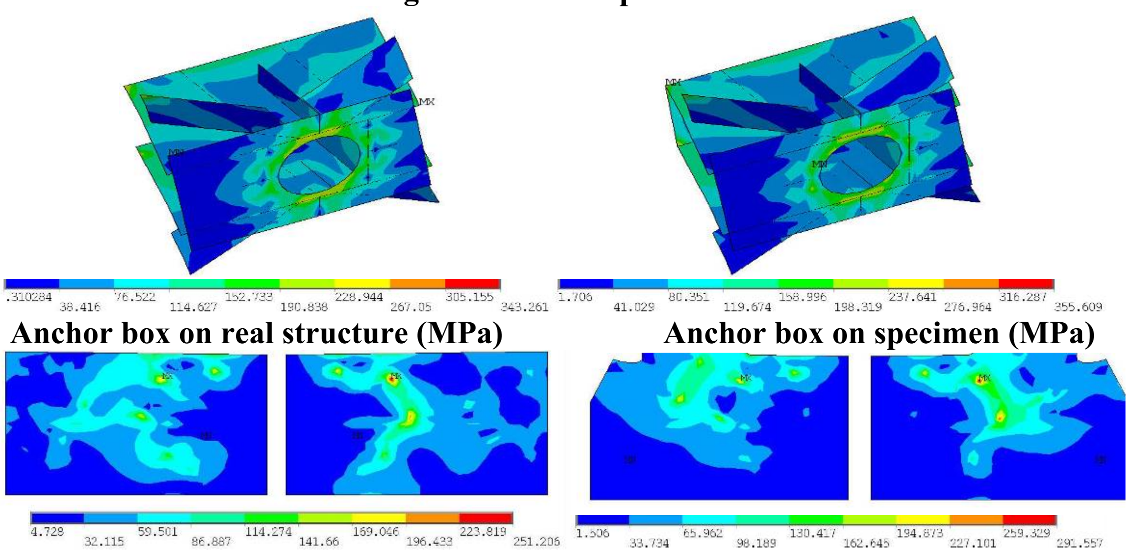


Fig. 5. Comparison of Mises stress distribution between specimen and real structure.

Fig. 6. Specimen.

Loading Equipment and Loading Scheme

The hollow hydraulic pulling jack is shown as figure 7. Nominal capacity is 17100kN. Nominal oil pressure is 54MPa. The diameter of the center hole is 330mm. The stroke of the cylinder is 550mm. The external dimension is Φ300mmx4050mm, and the self weight is 3270kg. The center hole hydraulic pulling jack is equipped with a duplex circuit high pressure oil pump (show as figure 8) which can provide a maximum oil pressure of 63MPa. The dimension of the screw rod is Φ300mmx4050mm, and self weight is about 3000 kg. The screw rod goes through the jack and the test anchor box, and transfers the pulling force from the jack to the anchor box by two big screw caps on both ends of the rod. The center hole hydraulic pulling jack and duplex circuit high pressure oil pump were calibrated before the test with pressure tester (2000t capacity) and pressure sensor. The load step is shown as Table 1.

Table 1. Load step

Load Step	1	2	3	4	5	6	7
Force（kN）	-7.001	85.759	178.519	271.279	364.039	456.799	549.559
Remark	Zero Adjustment	Pre-loading		3MPa Oil Pressure (92.76kN)			
Load Step	8	9	10	11	12	13	14
Force（kN）	642.319	735.079	827.839	874.219	-7.001	874.219	920.599
Remark	per Load Step			$1.0F_d$	Return to Zero	$1.0F_d$	2MPa
Load Step	14	16	17	18	19	20	21
Force（kN）	982.439	1044.279	1106.119	1167.959	1229.799	1291.639	-7.001
Remark	Oil Pressure (61.84kN) per Load Step					$1.4F_d$	Return to Zero

Test Content and Method

The load applied on test anchor box and measured stress is monitored. The test data is acquired by electric measurement and computer collecting system (shown as figure 9). The index of the measure system is: (1) DH3815 DH3816 static strain collecting instruments: sensitivity: 1με;

range: ±20000με; sampling rate: 12 points per second; maximum measure points: 60 points; (2) foil strain gauge and strain rosette (2mm×3mm): Resistance:120Ω; index of sensitivity: 2.0.

In order to get the strain on each plate and study the stress distribution, 134 foil strain rosette and 258 foil strain gauge is placed on anchor box MC1 and both side of N5 N6. Measure points position on N5 and A are shown as figure 10. The total number of test channels is about 660.

Fig. 7. Hydraulic jack

Fig.8. Oil pump

Fig.9. Measure system

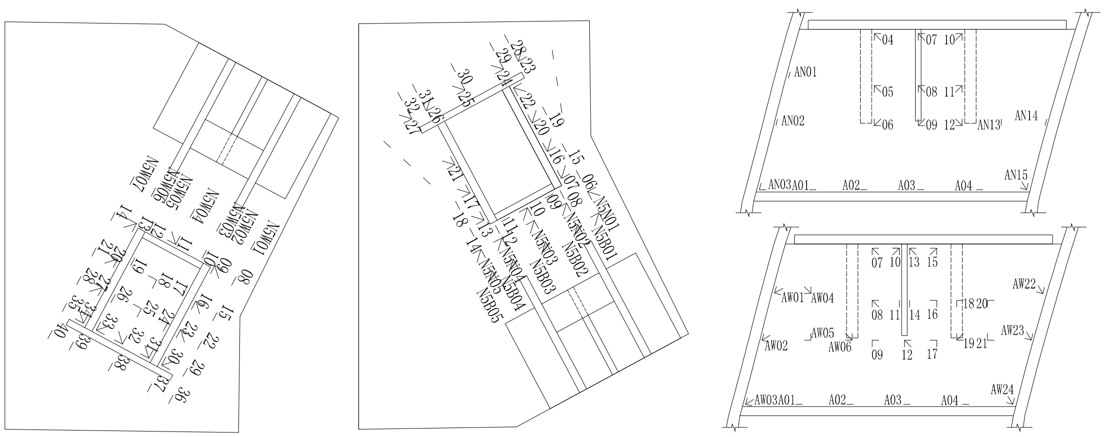
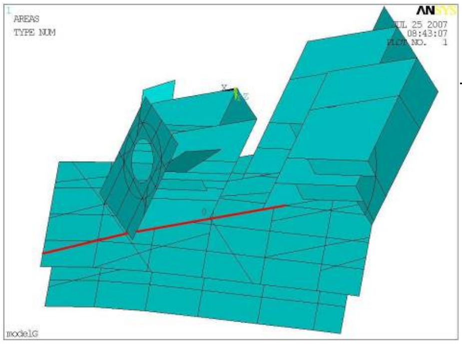


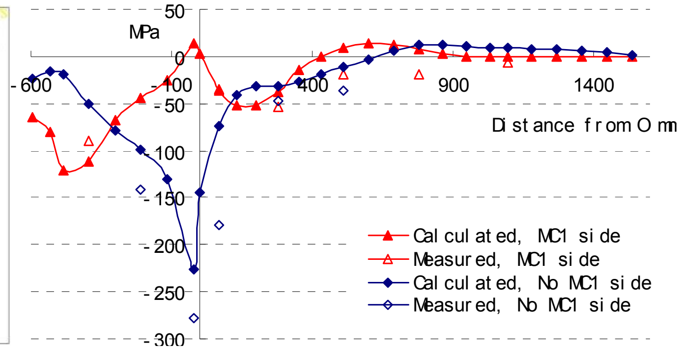
Fig. 10. Measure points number on N5 and A

EXPERIMENT RESULTS

Stress Distribution on N5

The measured and calculated stress distribution of N5 is compared in figure 11. Stress concentration appears on the end of the weld which connects the anchor box and N5 N6, the maximum stress reaches 400MPa. Great out-of-plane moment leads to great differences on the stress distribution of two sides of N5 and N6. The out-of-plane moment is mainly caused by following reasons: The height of the anchor box is relatively low, so the anchor box acts like a beam rather than a column carrying the moment caused by cable force; the cable is not parallel to N5 and N6, so there is an out-of–plane component force acting on N5 and N6; N5 N6 are curved plates, which will also aggravate the out-of-plane moment.





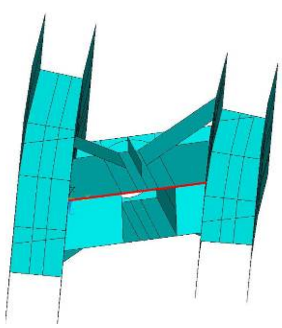
Measure point position and stress direction **Stress distribution on both side of N5**

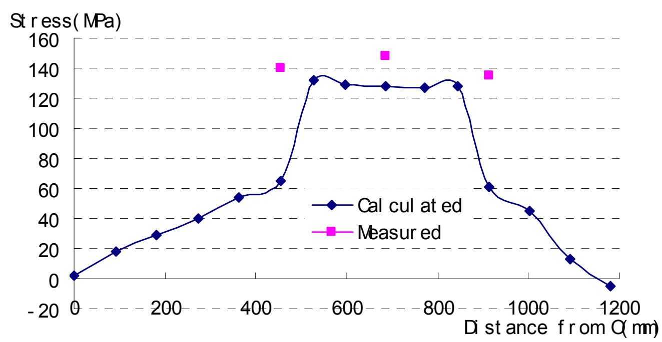
Fig. 11. Comparison of stress distribution on N5

The measured stress distribution on inner side of N5 is well in accord with FEM result, but the correspondence between measured and calculated stress is less good due to the measure point position deviation. N5 N6 are curved thick plate, which cause difficulty in positioning the measure point.

Stress Distribution on Supporting Plates A

The measured and calculated stress distribution of A is compared in figure 12. The measured stress distribution on Plate A is well in accord with FEM result. The compressive stress under the anchorage in cable force direction decreases from top to bottom of anchor box. The stress perpendicular to cable force direction exhibits a linear variation. The stress is compressive at top of the anchor box and tensile at bottom of anchor box. The maximum compressive and tensile stress is -40MPa and 170MPa. The mechanical behavior of the anchor box is similar to a bending beam.





Measure point position and stress direction **Stress distribution on both side of A**

Fig. 12. Comparison of stress distribution on A

CONCLUSIONS

The maximum load in the full-scale model test of Longchen bridge arch pylon anchorage zone is 12900kN. According to the experiment results, conclusions are drawn as follows:

- The measured stress distribution is consistent with FEM result on anchor box and nearby plates. Specimen can simulate the anchorage zone. The model simplification method of complex anchorage zone used in this paper is reasonable.
- Under the load of 12900kN ($1.4F_d$), stress of a few measure points approaches yield stress, with no buckling and failure of plates. No welding crack observed. The safety factor of the specimen is greater than 1.4.
- Coupling effect of bending moment and direct local compression is prominent on the anchor box with small depth. The anchor box has the mechanical behavior of a deep beam, which is different from regular anchorage zone. Due to the end-moment effect of the anchor box, plates N5 N6 exhibit the character of out-of-plane load-carrying.

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