

# Full-scale Model Test for Anchorage Zone of Pylon: Error Analysis on Elongation of Annular Pre-Stressing Steel Strand

Xijun Ye<sup>1</sup>, Zhuo Sun<sup>1</sup>, and Weifeng Wang<sup>2</sup>

<sup>1</sup> School of civil engineering, Guangzhou University, Guangzhou, China, 510006

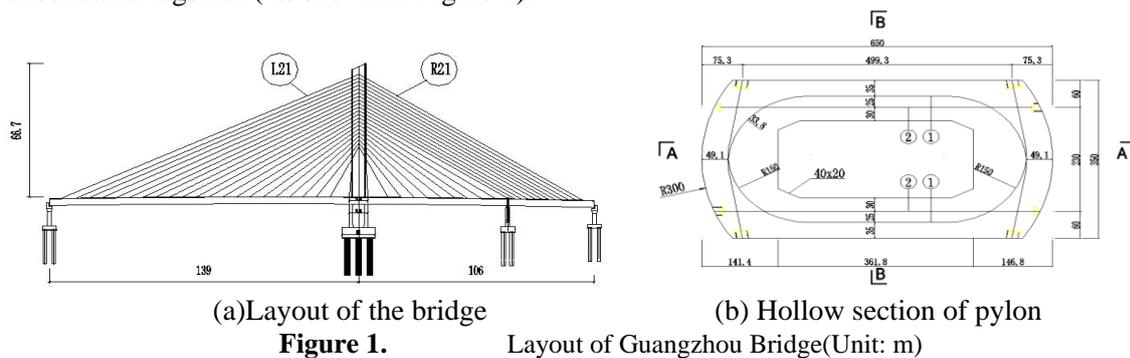
<sup>2</sup> School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, China, 510507.

Email: xijun\_ye@gzhu.edu.cn

**Abstract.** In order to study the mechanism of the annular Pre-stressing steel strands applied to cable-pylon anchorage zone, a full-scale model test and finite element analysis were conducted. Through the research on the full-scale model test of the U-shaped annular Pre-stressing steel strands for the Anchorage Zone of Guangzhou Bridge, the prestressing technique for the U-shaped annular Pre-stressing steel strands was investigated, and the stress distribution in the model were measured and analyzed. It can be found that the elongation of the U-shaped pre-stressing steel strands is greater than the actual theoretical limit, and the results of some project cases also showed that it is a common phenomenon. Finally, the reasons for thus problems and relative suggestions are proposed, they can be used as a reference to engineering practice.

## 1. Introduction

Guangzhou Bridge, with span length of (139m+106m), is an asymmetric concrete cable-stayed bridge with single pylon and single cable plane of 42 pair of stay-cables, whose pier, pylon and beam are consolidated together ( as shown in Figure 1).



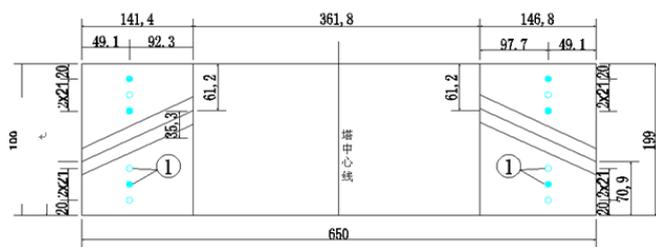
Anchorage zone of the cable-stayed bridge uses approximate rectangular hollow section. Cable anchorage zone on the tower is stiffened by U-shaped annular pre-stressing steel strands (1#) and straight steel strands (2#) ( as shown in Figure 2). 1# steel cable includes 17 steel strands with diameter of 15.24mm; 2# steel cable embraces 9 steel strands with diameter of 15.24mm. Tension control stress is 1395MPa and standard value of tensile strength ( $f_{pk}$ ) is 1860MPa and elasticity modulus ( $E_p$ ) is  $1.95 \times 10^5$ MPa. Pre-stressed duct utilizes plastic corrugated pipes with inner diameter of  $15 \times 19$ mm.



**2. Field test of the full-scale model of anchorage zone**

Normal pitch of cable tower anchorage zone of Guangzhou Bridge is 1.8m. So the standard height of the full-scale model is 1.8m and the anchorage zone of L21 and R21 cables is selected, who has the maximum cable force. Each anchorage zone is equipped with 6 U-shaped annular pre-stressing steel strands and 6 straight steel strands. (As shown in Figure 2).

In order to mitigate the loss of pre-stressing, firstly, U-shaped steel strand is used in the form of two-end tension and then straight steel strand is used in the form of one-end tension. For purpose of synchronizing tension when both ends of a jack are tensioned, the bridge adopts grading tension, and loading rate is strictly controlled, which maintains 30s after loading. In strict accordance with tension procedures of post-tensioned pre-stressing regulated in 12.10.3 section of "Technical Specifications for Construction of Highway Bridges and Culverts(JTJ041—2000)"(hereafter referred to as JTJ041—2000)[1]: installation of steel strands, anchorage device and jacks, initial stress, double initial stress, triple initial stress, quadruple stress and  $\sigma_{con}$  (sustaining load in 2 min and anchoring).  $\sigma_{con}$  refers to tensile control stress, and the stress of this project is 1395MPa and the initial control stress is 15%  $\sigma_{con}$ . The full-scale model can be seen in Figure 2.



Notice: 1. "①"denotes the annular U-prestressing tendon, "②"denotes the one way prestressing tendon, there are in total 6 layers respectively;  
2. □ indicates stretching end  
● indicates anchoring end.

(a) Section A



(b) Full-scale model

**Figure 2.** Field test (Unit: cm)

**2.1. Calibration test.**

Before the model test, a calibration test was conducted to verify the mechanical property of steel strands. A steel strand with diameter of 15.24mm was randomly selected, whose standard value of tensile strength ( $f_{pk}$ ) is 1860MPa and elasticity modulus ( $E_p$ ) is  $1.95 \times 10^5$ MPa. The 1# steel cable includes 17 steel strands with diameter of 15.24mm, tension control stress is 3320MPa, the 2# steel cable embraces 9 steel strands with diameter of 15.24mm, tension control stress is 1750MPa. So the average tension control stress of each steel strand is 195kN.

**Table 1.** Test Result of calibration test

Loaing grade	load (kN)	Theoretical strain ( $\mu\epsilon$ )	Practical strain ( $\mu\epsilon$ )	Relative Error (%)	Theoretical elongation (mm)	Practical elongation (mm)	Relative Error (%)
1	29.7	1087.9	1047.4	-3.7	4.188	4.236	1.3
2	58.7	2151.3	2060.1	-4.2	8.283	8.632	4.2
3	88.2	3231.5	3110.5	-3.7	12.441	12.786	2.8
4	117.3	4295.4	4150.8	-3.4	16.537	16.883	2.1
5	147.2	5392.5	5255.7	-2.5	20.761	21.113	1.7
6	178.3	6531.1	6368.6	-2.5	25.145	25.492	1.4

In the calibration test, 6 loading grades are applied: 1:30kN -260kN- 3:90kN- 4:120kN- 5:150kN- 6:180kN. The calibration results are shown in Table 1. It can be seen that the Theoretical values agree

well with practical ones, the relative error between the two values is less than 5%. The steel strands selected meet the requirements of the full-scale model test.

## 2.2. Theory and Test Result.

According to 12.8.3 section of JTJ041—2000, as pre-stressed tendon is tensioned in the method of stress control method, proofreading shall be based on elongation. Meanwhile, the difference between actual elongation and theoretical elongation shall meet the requirements of design[1]. In the case of no design requirements, the difference shall be controlled within 6%, otherwise tension shall be suspended and can return to normal until problems have been found and solved. Meanwhile, corresponding design formulas of elongation ( $\Delta L$ ) of pre-stressing tension can be seen in JTJ041—2000:

$$\Delta L = \frac{P_p \cdot L}{A_p \cdot E_p} \quad (1)$$

$$P_p = \frac{P(1 - e^{-(kL + \mu\theta)})}{(kL + \mu\theta)} \quad (2)$$

Where  $P_p$  - average tension of pre-stressing tension (N)

$L$  - the length of pre-stressing tension (mm)

$A_p$  - sectional area of pre-stressing tension (mm<sup>2</sup>)

$E_p$  - elasticity modulus of pre-stressing (N/mm<sup>2</sup>)

$P$  - stress under the anchorage of tensioned-end pre-stressing steel strands

$\mu$  - friction coefficient of the wall of pore passage

$k$  - coefficient of influence of local deviation of pore passage in every meter on friction

$\theta$  - the sum of included angle of curves and tangent lines from tensioned-end anchor to calculation section.

**Table 2.** Test Result of elongation of U-shaped pre-stressing steel strands of Guangzhou Bridge

No. of steel strands	Theoretical elongation value (mm)	Elongation value (mm)	loss of due to draw in of clip (mm)	Practical elongation value (mm)	Relative Error (%)
C3-1	75	110	12	98	30.7
C3-2	75	106	12	94	25.3
C3-3	75	100	12	88	17.3
C3-4	75	102	12	90	20.0
C3-5	75	106	12	94	25.3
C3-6	75	112	12	100	33.3
C4-1	75	111	12	99	32.0
C4-2	75	105	12	93	24.0
C4-3	75	113	12	101	34.7
C4-4	75	109	12	97	29.3
C 4-5	75	106	12	94	25.3
C4-6	75	108	12	96	28.0

Actual elongation of steel strand begins at initial stress. Actual pre-stressing strand shall include estimated elongation based on initial value besides measured elongation. Actual elongation of pre-stressing tension ( $\Delta L$  (mm)) can be calculated according to a formula:

$$\Delta L = \Delta L_1 + \Delta L_2 \quad (3)$$

Where  $\Delta L_1$  - actual elongation ranging from initial stress to maximized stress. (mm)

$\Delta L_2$  - estimated elongation based on initial stress.  $\Delta L_2$  adopts grading tension from 15%  $\sigma_{con}$  to 60%  $\sigma_{con}$  and average elongation of steel strands while in grade 3 loading to this bridge. Formula (3) embraces withdrawal value of anchorage clip in the both ends of steel strands. Elongation value can be obtained from deducting withdrawal value. In accordance with given value in JTJ041—2000, deduction value of setback amount of each clip is 6mm. two-end tension method is applied to this bridge, deducting setback amount of 12mm from both ends of clips. Test results are shown in Table 2.

### 2.3. Error analysis.

It can be seen from Table 1 that actual elongation of U-shaped pre-stressing steel strands of Guangzhou Bridge are all greater than its theoretical values. And values of each steel strands exceed the standards regulated in JTJ041—2000, namely, deviation of actual elongation and theoretical elongation shall be controlled within 6%. The author has conducted an investigation in China of the comparison of actual elongation of U-shaped pre-stressing steel strands and its theoretical value (Table 3). And the results reveal that all the actual elongation test results are greater than its theoretical values which are within 6%. Deviation values with obvious discreteness range from 20% to 30%, sometimes reach to 50%.

**Table 3.** Error Comparison of Elongation of Steel Strands in China

Project cases	Average error	Maximum error
Guangzhou Bridge	27.0%	34.7%
Shenzhen bay bridge [2]	25.0%	35.9%
North channel of Hangzhou Bay sea crossing bridge [3]	16.2%	25.3%
A highway interchanges [4]	15.1%	25.9%
Bridge 4[5]	26.0%	37.5%
Tie Luo Ping Bridge 5[6]	25.7%	39.0%
Wuhan Junshan Yangtze River Highway Bridge [7]	26.0%	53.0%
Bridge 8[8]	33.3%	54.3%

By comparison and analysis on above data and combined with actual conditions, the author concludes following reasons that may lead to actual elongation of U-shaped pre-stressing steel strands are greater than its theoretical values:

(1) U-shaped pre-stressing steel strands with minor radius will generate huge radial pressure under the circumstance of huge tensile load so that steel strands will be stiffened, as well as, steel strands in corners sticks close to wall of plastic corrugated pipe. In this case, actual arc length is reduced and steel strands in pipes have extra length, which is transformed into piston stroke under the action of tension, thus making actual piston stroke greater than its theoretical elongation value.

(2) Considering that steel strands are loose before tension, according to calculation method of JTJ041—2000, generally, initial stress is 10-15%  $\sigma_{con}$ . Then elongation under initial stress can be back calculation through grading loading so that actual elongation can be calculated. However, when initial stress is 10-15%  $\sigma_{con}$ , U-shaped steel strands may be loose due to minor radius, twist of steel strands, friction loss, deviation of pipes and the like. Hence, partial unstressed extra elongation is calculated, which leads to a bigger actual value.

(3) Generally, sectional area ( $A_p$ ) and elasticity modulus ( $E_p$ ) of steel strands are given through design in engineering to calculate theoretical elongation of steel strands in the course of tension, rather than actual sectional area ( $A_p$ ) and elasticity modulus ( $E_p$ ) obtained from field measurement. In fact, during the process of tension, diameter of finished steel thread is not a constant value, but a variate that varies as tension proceeds. Meanwhile, correspondent  $A_p$  and  $E_p$  also change, thus having an impact on accurate value of theoretical elongation of steel strands.

### 3. Conclusions

- (1) Comparatively accurate  $\mu$  and  $k$  can be obtained from friction drag experiment which conducts through duct on site. In this paper,  $\mu$  is 0.1929 and  $k$  is 0.0069. Precise  $A_p$  and  $E_p$  of steel strands can be obtained from calibration test so as to ensure the accuracy of theoretical elongation.
- (2) Initial stress shall be increased so that the greater initial stress will slash extra elongation produced in the process of tension pre-stressed steel strands. The paper proposes initial stress shall range from 25% to 30% at best.
- (3) The control of elongation plays an important role in describing overall tension state of pre-stressed steel bars and tension safety. It's essential to calibrate elongation, but it shall not be confined to  $\pm 6\%$ . During construction, it would be better not to regard elongation as the main element of pre-stressed steel bar tension, otherwise pre-stressing may be inadequate.

### 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.

### References

- [1] Industry standard of the People's Republic of China 2000 *Technical Specifications for Construction of Highway Bridges and Culverts (JTJ041-2000)*.
- [2] Wuhan Bridge Science Research Institute of China Railway Bridge Bureau Group Co., Ltd., 2005 *Test report of Shenzhen bay bridge*.
- [3] Wuhan Bridge Science Research Institute of China Railway Bridge Bureau Group Co., Ltd., 2004 *Model test report of the navigable span bridge about the north channel of Hangzhou Bay sea crossing bridge*.
- [4] Xiaogang Chen, Wenqing Wu 2008 Experiment Research on the Friction Resistance of the Ring Prestressed Steel Bundle in the Anchorage Zone of Cable-stayed Bridge Tower *Modern Transportation Technology* vol.5 no.5 pp. 50-52,.
- [5] Dongping Bu 2010 Experiment Research on Prestressed U-shaped Pipe Friction of 190 m Cable-stayed Bridge Main Tower Anchorage Zone *Modern Transportation Technology* vol.7 no.5 pp. 47-50.
- [6] Huaifu Ruan, Binxuan Wu 2009 Experiment Research on the tension of the Ring Prestressed Steel Bundle in the Anchorage Zone of Cable-stayed Bridge Tower *Urban Roads Bridges & Flood Control*, no.11, pp.105-107.
- [7] Weijian Yi, Wangxi Zhang 2001 Experiment Research on the full-scale anchor block segment model of the anchorage zone of the Wuhan Junshan Yangtze River Highway Bridge *Central South Highway Engineering*, vol.26, no.4, pp. 33-35.
- [8] Wei Shan 2005 Study on structural behavior for Anchorage Zone Segment of Cable-stayed Bridge Tower *Ph.D. dissertation*, Northeast Forestry Univ., Harbin, China.