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Inspection Mechanism and Experimental Study of Prestressed Reverse Tension Method under PC Beam Bridge Anchorage

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Abstract: the prestress under anchorage is directly related to the structural security and performance of PC beam bridge. The reverse tension method is a kind of inspection which confirms the prestress by exerting reversed tension load on the exposed prestressing tendon of beam bridge anchoring system. The thesis elaborately expounds the inspection mechanism and mechanical effect of reverse tension method, theoretically analyzes the influential elements of inspection like tool anchorage deformation, compression of conjuncture, device glide, friction of anchorage loop mouth and elastic compression of concrete, and then presents the following formula to calculate prestress under anchorage. On the basis of model experiment, the thesis systematically studies some key issues during the reverse tension process of PC beam bridge anchorage system like the formation of stress-elongation curve, influential factors, judgment method of prestress under anchorage, variation trend and compensation scale, verifies the accuracy of mechanism analysis and demonstrates: the prestress under anchorage is less than or equal to 75% of the ultimate strength of prestressing tendon, the error of inspect result is less than 1%, which can meet with the demands of construction. The research result has provided theoretical basis and technical foundation for the promotion and application of reverse tension in bridge construction.

1. Introduction

In the past five years, there are over 20 thousand bridges being constructed, and it's expected to break the record of a million in 2015[1]. As its proficient technology and economic cost, PC beam bridge has become the preferred choice of medium-scale and large-scale bridge types in domestic high-end highway construction, it's estimated that its occupancy has exceeded 75%[2-4]. The structural rigidity, bearing capacity, security and durability of PC beam bridge greatly depend on the exertion of prestress under anchorage[5-6]; as a result, the most concerned problem in the current bridge is whether the size of PC beam bridge can meet with the designing or constructional requirements or not, which has also become the hot issue in experimental and inspectional industry.

At present, there are mainly the following measurement methods of beam bridge prestress under anchorage: effective rigidity method, stress releasing method, static method, elastic wave method, strain method, reverse tension method and so on[7-11]. Based on Newton's third law and twice tension principle, the reverse tension confirms the prestress by exerting reversed reverse tension load on the exposed prestressing tendon of beam bridge anchoring system in a way of simple principle, convenient operation and high accuracy, the similar method has been earliest adopted in the inspection of geotechnical engineering prestress anchor cable[12-16], in recent years, many scholars and universities have gradually applied it in PC beam bridge inspection through repeated practices[17-19]. So far, the inspection mechanism of PC beam bridge has not been clearly expounded yet, so there exist discrepancies and even total differences and disorders in inspection data, inspection error, application scope, accuracy and judgment standard. Hence, it's necessary to further expound and analyze its inspection mechanism.

2. Reverse Tension Method

2.1. Ideal Condition

The anchorage system of PC beam bridge is a kind of double-ended anchored and bearing linear or curved component, which consists of anchorage section, free section and exposed section as shown in figure 1. Under ideal condition, the concrete structure and anchorage system will mutually affect to provide anchorage force, the working stress of stress tendon free section inside the anchorage system is the pre-stress under anchorage σ_0 (tension f_0), which is less than or equal to 75% of the stress tendon's ultimate strength f_{pk} and at the stage of elastic deformation; the anchor bearing plate in concrete structure provides supporting stress σ_1 (bearing f_1) to support working anchorage, $f_1 = f_0 = S\sigma_0 = S_1\sigma_1$, S is the sectional area of stress tendon, S_1 is the sectional area of working anchorage.

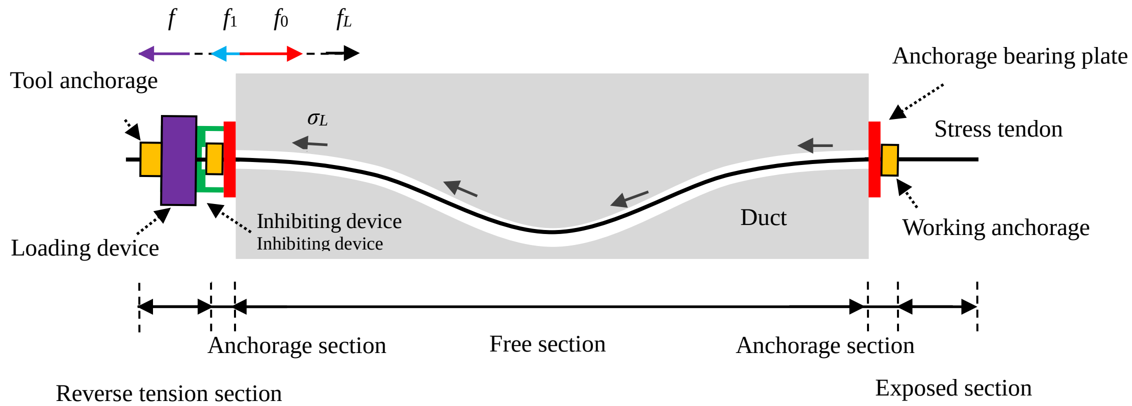


Fig 1 Schematic diagram of reverse tension method in PC bridge anchorage structure

Before reverse tension, it's necessary to install the inhibiting device, loading device and working anchorage on the exposed section of stress tendon, coincide the resultant force line of reverse tendon with the axis of stress tendon, and then rely on inhibiting device to be delivered to bearing plate of anchorage section or concrete structure. During the process of reverse tension, the loading device clamps the exposed section of stress tendon to exert reversion tension f, the reverse tension σ grows from 0, $f = S\sigma$, whereas the stress of anchorage bearing plate on supporting working anchorage is σ_1 and then gradually decreases, $f + f_1 = f_0$, the free section stress increment of stress tendon $\sigma_L = 0$. As the reverse tension is equal to the pre-stress under anchorage, $f = f_0 = S\sigma_0 = S\sigma$, the force of anchorage bearing plate on supporting working anchorage f_1 decreases to 0(as shown in figure 2). Meanwhile, the exposed section of stress tendon is stressed to extend, and the calculation of its displacement is as follows:

$$\Delta l = \Delta l_l = \frac{\sigma l}{nSE} \quad \cdots\cdots 1\text{-}1$$

In this formula, σ refers to the reverse stress, Δl is the elongation, l is the length of reverse tension section, n is the amount of steel strand, S is the sectional area of a single strand, E is the elasticity modulus. Keep on the action of reverse tension $\sigma > \sigma_0$, $f_{\max} \le 0.75 f_{pk}$, as $\sigma_L > 0$, the free section and exposed section of stress tendon will be stressed to extend together, and the displacement is calculated as below:

$$\Delta l = \Delta l_l + \Delta l_L \quad \cdots\cdots 1\text{-}2$$

$$\Delta l_L = \frac{\sigma_L L}{nSE}\frac{1-e^{-(kL+\mu\theta)}}{kL+\mu\theta} \quad \cdots\cdots 1\text{-}3$$

In formula, σ_0 refers to the prestress under anchorage, L is the length of free section, Δl_L is the displacement of stress tendon free section extension, θ is the sum of included angles formed by the tangent line of prestress tendon from tension end to the duct part of calculated sectional curve, k is the influence coefficient of local deviation per meter on friction, μ is the frictional coefficient between prestressing tendon and duct wall, suppose $\lambda = \left[1 - e^{-(kL+\mu\theta)}\right] / (kL + \mu\theta)$, then formula 2-2 will be altered to:

$$\Delta l = \frac{l + \gamma L}{nSE}\sigma - \frac{\gamma \sigma_0 L}{nSE} \quad \cdots\cdots 1\text{-}4$$

From formula 2-1 and 2-4, it can be found that the curve of reverse tension σ and elongation Δl is formed by two lines with different gradients, the gradient catastrophe point or linear crosspoint is the value of prestress under anchorage, refer to figure 2.

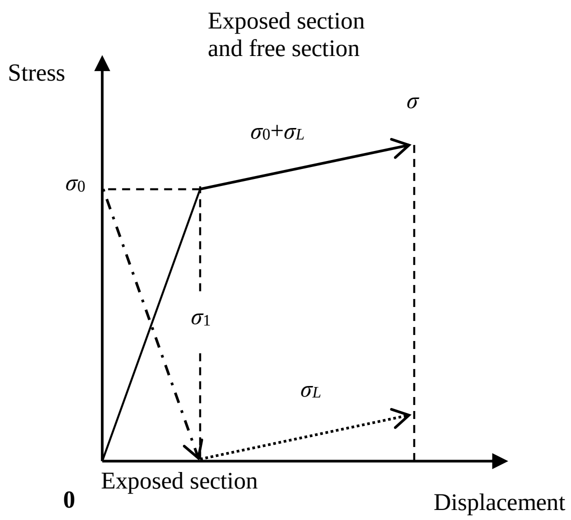


Fig 2 The tension stress-elongation curve and stress-time curve under ideal conditions

2.2. Actual conditions and calculation of prestress under anchorage

Under ideal conditions, it has been measured that the elongation Δl of stress tendon reverse section and free section means reverse stress σ is loss-free or be totally applied to stress tendon. In fact, at the preliminary stage of loading, in the reverse section, the stress loss $\Delta\sigma_{l1}$ and displacement Δl_{l1} produced by tool anchorage deformation and conjuncture compression, the gliding loss $\Delta\sigma_{l2}$ and displacement Δl_{l2} generated by loading device and inhibiting device; as σ grows, the stress tendon and clip, anchor loop mouth create frictional loss $\Delta\sigma_{l3}$ and displacement Δl_{l3}; meanwhile, when $\sigma > \sigma_0$, the elastic compression loss $\Delta\sigma_{L1}$ and displacement Δl_{L1} caused in the concrete structure. As a result, under actual conditions, the force and elongation of stress tendon is somewhat different under ideal conditions, and an explicit analysis will be implemented.

2.2.1. Loss and elongation of stress tendon reverse section. The reverse section of stress tendon is linear, at the preliminary stage, $\sigma < \sigma_0$, the reverse stress is σ, the stress of stress tendon reverse section is σ_l, losses $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$ and related elongations Δl, Δl_l, $\Delta\sigma_{l1}$ and Δl_{l2}:

$$\sigma_l = \sigma - \Delta\sigma_{l1} - \Delta\sigma_{l2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{1-5}$$

$$\Delta l = \Delta l_l + \Delta l_{l1} + \Delta l_{l2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{1-6}$$

In the formula, $\Delta\sigma_{l1}$ and Δl_{l1} of reverse section are generally obtained through experiments, as there is no reliable data, it's necessary to refer to the normal ultimate status to calculate the theoretical values of different anchorages and conjuncture types[20], and then simplify the calculation of loss through $\Delta\sigma_{l1} = E_p\left(\sum \Delta l_{l1}/l\right)$; $\Delta\sigma_{l2}$ and Δl_{l2} are mainly influenced by the instrument installation and somewhat uncertain; then with the growth of $\sigma\,(\sigma < \sigma_0)$, the stress will be gradually exerted on the reverse section of stress tendon σ_l, and its elongation can be calculated according to formula 1-1. As a result, when $\sigma < \sigma_0$, $\sigma - \Delta l$ curve consists of two parts as in figure 3, the preliminary stage of loading is affected by $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$ and their elongations $\Delta\sigma_{l1}$, Δl_{l2} to be nonlinearly related(ab section), subsequently, by overcoming the tool anchorage deformation, conjuncture compression, slides of loading equipment and inhibiting device, it becomes linear related(bc section)l through σ_l - Δl curve extension line, Δl_{l1} and Δl_{l2} can be acquired.

2.2.2. Frictional loss and elongation at the anchorage loop mouth. As the stress tendon reverse section σ_l approaches the prestress under anchorage σ_0, the containment stress at the anchorage loop mouth gradually decreases to be 0, when $\sigma_0 = \sigma_l$, the stress tendon under anchorage and reverse section should establish balance. But in the actual reverse tension, anchorage loop mouth, clip and steel strand will rub and maintain on changing, eventually, $\Delta\sigma_{l3} \neq 0$, so the equivalent balance relation between σ_l and σ_0 is:

$$\sigma_0 = \sigma_l - \Delta\sigma_{l3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{1-7}$$

In the formula, $\Delta\sigma_{l3}$ is related to the friction containment coefficient at the anchorage loop mouth, and its scale and elongation Δl_{l3} are generally confirmed through experiments[21], the $\sigma - \Delta l$ curve under this condition presents nonlinear, as shown in cd section of figure 3.

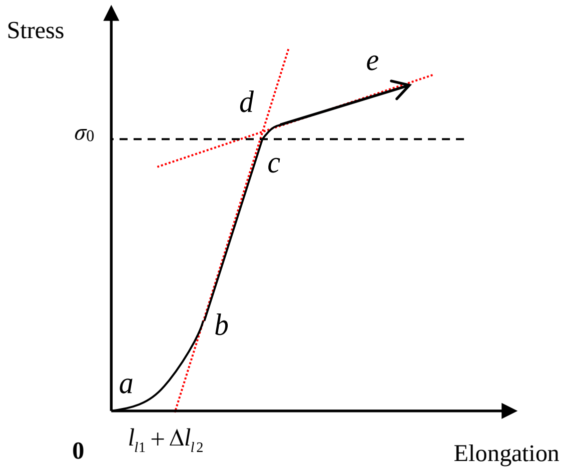


Fig 3 The tension stress-elongation curve under actual situation

2.2.3. Compression loss and elongation produced in concrete structure. As the prestress under anchorage σ_0 generated by reverse stress σ grows($\sigma_L=\sigma-\sigma_0-\sigma_{l1}-\sigma_{l2}-\sigma_{l3},\sigma_L>0$), the supporting force or stress σ_{pc} of concrete structure will relatively increase and then produce stress ε_{pc} or decrement Δl_{pc}, so the stress loses of prestress tendon $\Delta\sigma_L$, Δl_{pc} and $\Delta\sigma_L$ are calculated:

$$\Delta l_{pc}=\varepsilon_{pc}\cdot L=\sigma_L\cdot\frac{nSL}{S_jE_c} \quad \text{...... ....} \; 1\text{-}8$$

$$\Delta\sigma_L=\alpha_{EP}\cdot\sigma_{pc}=\alpha_{EP}\cdot\sigma_L\left(\frac{1}{S_j}+\frac{x^2}{I_j}\right) \quad \text{........... ......} \; 1\text{-}9$$

In formula, σ_L stands for the increment of prestress under anchorage, α_{EP} refers to the ratio between stress tendon and concrete elastic modulus E/E_c, $\Delta\sigma_{pc}$ t is the concrete method stress increment generated by σ_L when calculating the section stress tendon centroid, S_j is the net sectional area of concrete structure, I_j is the inertia moment of net section, x refers to the distance between stress tendon centroid and concrete gravity axis[22-23]. By considering that the structure is generally reinforced concrete structure which owns a certain rigidity and elasticity, during the process of reverse tension, the bridge deformation can be viewed as axial compression, and the formula 2-8 can be further simplified as:

$$\Delta\sigma_L=\alpha_{EP}\cdot\frac{\sigma_L}{S_j} \quad \text{...... ....} \; 1\text{-}10$$

Therefore, it can be seen that the concrete structural compression Δl_{pc} and stress tendon loss $\Delta\sigma_L$ are mainly related to the increment of prestress under anchorage, elastic modulus of concrete structure and net sectional area of concrete structure, Δl_{pc}, $\Delta\sigma_L$ and σ_L are similarly linear. So, as $\sigma_L>0$, $\sigma-\Delta l$ curve is approximately linear with only a change in gradient, as shown in *de* section of figure 3.

2.2.4. Calculation of prestress under anchorage. In conclusion, under the influence of losses like $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$, $\Delta\sigma_{l3}$ and $\Delta\sigma_L$ during the process of reverse tension, the formula to calculate prestress under anchorage is:

$$\sigma_0 = \sigma - \sigma_L - \Delta\sigma \text{ .... 1-11}$$

In the formula, $\Delta\sigma$ is the total loss of stress generated by stress tendon free section when it is elongated under the reverse stress, σ_L is the stress increment generated by stress tendon free section elongation Δl_L, according to the formula 2-3, $\Delta l_L = \Delta l - \Delta l_{l1} - \Delta l_{l2} - \Delta l_{l3} + \Delta l_{pc}$. As there exists a certain objective error between the theoretical vale and actual value in σ_L calculation, generally, by measuring the linear relation between stress tendon reverse section and $\sigma - \Delta l$ curve under the impact of free section stress, and fitting a straight-line intersection to acquire σ_0' - the prestress tendon under anchorage at the preliminary moment of elongation, as shown in figure 3, the formula can be simplified as:

$$\sigma_0 = \sigma_0' - \Delta\sigma \text{ .... 2-12}$$

At this moment, $\Delta\sigma$ is only related to $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$ and $\Delta\sigma_{L1}$, and has nothing to do with $\Delta\sigma_{l3}$, Δl_{l1}, Δl_{l2}, Δl_{l3} and Δl_L, which has diminished σ_L calculation error.

3. Model Experiment

3.1. Experimental model and testing system

The experiment adopts a T-beam experimental model with an abutment strength of C50(15cm long, 0.7 wide and 1.2 m high), which is embedded with a casing pipe of 19cm diameter. The experimental model and inspection device is shown in figure 4, the stress tendon reverse section (exposed section) has installed the inhibiting device, loading device (DS-10 tension system) and tool anchorage; the anchorage section A consists of working anchorage, dynamometer, base plate and abutment; free end is in the structural internal casing pipe, the anchorage end *B* is fixed by loading device (DS-10 tension system) and working anchorage. The stress tendon consists of four steel strands, the diameter of a single strand is 15.2mm, the length is 17m, the valid sectional area is 140 mm^2, the stretching resistance f_{pk} is around 269.7kN, the non-proportional extension force is 247.4kN, the extension rate is 5.5%, the elastic modulus 190.37GPa; the working anchorage, tool anchorage and clip are OVM15-4, in accordance with the result of HRC, the rigidity of anchorage ≥20, the clip ≥57; the inhibiting device adopts customization; DS-10 tension system can collect and record tension bearing and elongation, the bearing range is 0-1300kN, its resolution ratio is 0.01kN, the elongation range is 0-200mm, and its resolution ratio is 0.01mm; the dynamometer range is 0-1300kN, and the resolution ratio is 0.01kN.

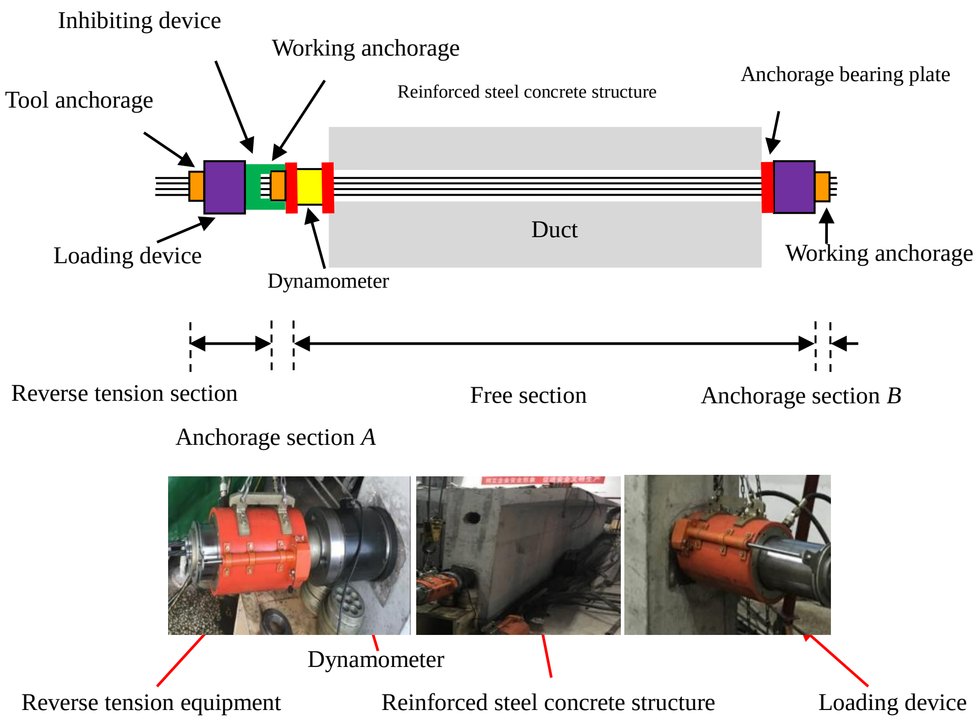


Fig 4 Experiment Model and Test Equipment

3.2. Experimental Process

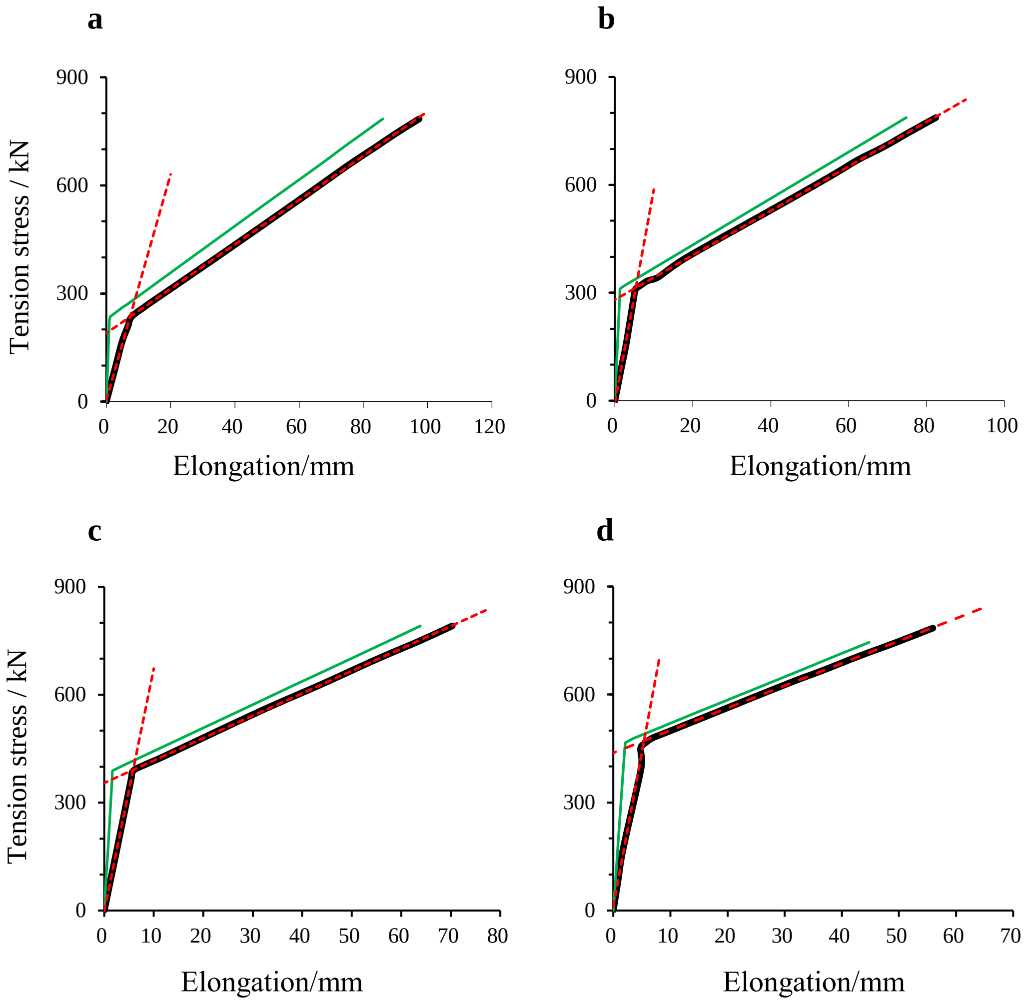
Before experiment, it's necessary to demarcate DS-10 tension system and dynamometer, the error ≤1‰; the prestress of anchorage section A $\sigma_0 = f_0/A$ (be simplified as f_0) will be exerted through B-end DS-10 tension system, which can be measured by dynamometer; $f_0 = \eta \cdot f_{max}$, $\eta = 0.3 \sim 1.0$, f_{max} is the maximum reverse tension which equals to 72% of the steel strand ultimate tension f_{pk} (4 strands*195.3kN/strand), refer to table 1. When the prestress under anchorage stabilizes as the set value f_0, a reverse tension loading will be exerted on the loading device-DS-10 tension system of stress tendon exposed section, the initial stress is 0.05 times of f_{max}, and then the tension bearing and elongation shall be recorded every 10kN, after the ending of reverse tension, the loading device at the reserve tension end will unload the bearing, and the dynamometer will always record the change of prestress under anchorage at the anchorage end; as the stress stabilizes, the prestress under anchorage will be unloaded through DS-10 tension system at the internal anchorage B end. The above is an experimental testing cycle, after the end of experiment, the next group of reverse tension experiments on prestress under anchorage will be implemented. There are altogether 8 groups of experiment, the values of each group of prestresses under anchorage should be set as in table 1.

Table 1- Prestressed in anchorage structure experimental set values (kN)

Serial No.	1#	2#	3#	4#	5#	6#	7#	8#
f_0	234.65	312.43	389.39	469.36	546.70	625.47	703.30	781.19
f_{max}	782.42	784.8	789.1	782.42	783.37	780.51	783.37	786.28
η	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

4. Experimental Result and Analysis

Figure 5 demonstrates the experimental curve $f-\Delta l$ of experimental model under different anchorages of prestress f_0; according to formula 1-1 and formula 1-4, the ideal curve(green) can be drawn; it can be seen that the experimental curve conforms to the ideal curve, which all consists of two similar lines; two fitting straight-lines $b'c'$ and $d'e'$ in the experimental curve $f-\Delta l$ are created, it can be found that the related gradients k_l and k_L are smaller than the ideal gradients k_l' and k_L', as shown in table 2, when reverse tension f approaches f_0 and reaches the range of $f > f_0$, the ideal curve inflexion is angular, and the experimental curve inflexion inclines to be round; it can explain the feasibility of reverse tension inspection and verify the rationality of theoretical analysis. Then it's going to explicitly analyzes the experimental results.



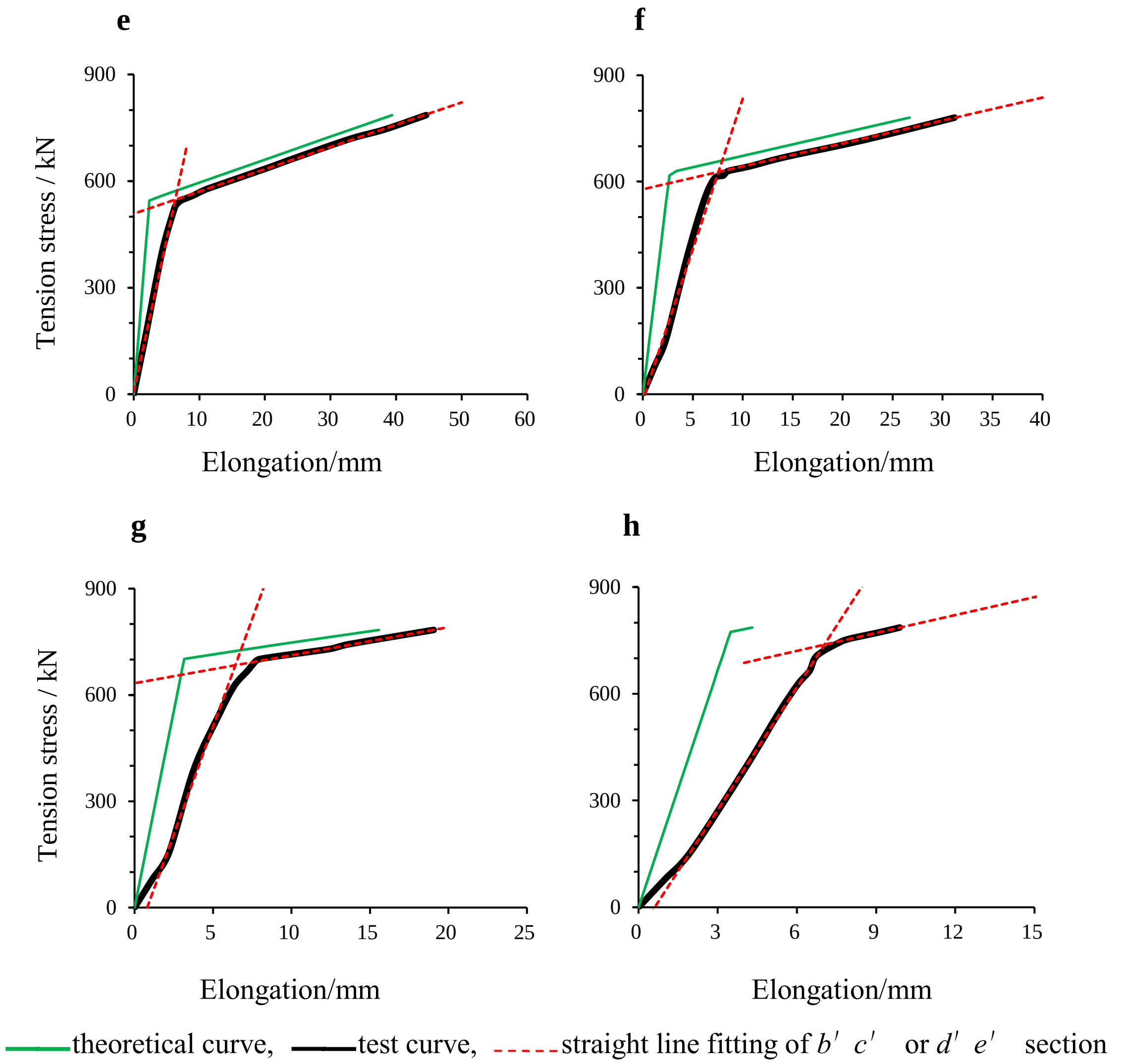


Fig 5 Theoretical and test curve of tension stress-elongation under the different prestressed in anchorage structure experimental

When $f < f_0$, the experimental curve gradient k_l is far less than the ideal curve gradient k_l' (k_l' =222.1) in table 2, which expounds that the total stress loss $\left(\Delta\sigma_{l1}+\Delta\sigma_{l2}\right)$ and elongation $\left(\Delta l_{l1}+\Delta l_{l2}\right)$ caused by tool anchorage deformation, conjuncture compression and loading device and inhibiting device sliding at the preliminary stage of reverse tension can't be ignored. Meanwhile, as f_0 decreased, the deviation between k_l and k_l' grows or the ratio k_1'/k_1 grows, which can explain that $\left(\Delta\sigma_{l1}+\Delta\sigma_{l2}\right)$ is larger than the stress σ_l and elongation l_l of stress tendon reverse tension section, $\left(\Delta\sigma_{l1}+\Delta\sigma_{l2}\right)$ and σ_l overlap in stress range without a clear distinction, refer to experiment 1# to experiment 5#; with the growth of f_0, k_l grows and its deviation or ratio with k_l' decreases($k_l'/k_l \le 3$), which can expound that $\left(\Delta\sigma_{l1}+\Delta\sigma_{l2}\right)$ is smaller than the stress σ_l and elongation l_l of stress tendon reverse tension section, from the experimental curve $f-\Delta l$, the main range of $\left(\Delta\sigma_{l1}+\Delta\sigma_{l2}\right)$ and σ_l can be clearly distinguished, refer to experiment 6# to 8#. From the intersection of the fitting line $b'c'$ and Δl axis of reverse tension curve of $f-\Delta l$. It can be found that the elongation $(\Delta l_{l1}+\Delta l_{l2})$ caused by $(\Delta\sigma_{l1}+\Delta\sigma_{l2})$ is somewhat discrete, and related to the installation effect of inspection instruments(tool anchorage, clip, jack and inhibiting plate; when f_0 is relatively smaller, $(\Delta l_{l1}+\Delta l_{l2})<0$, which tells that $(\Delta\sigma_{l1}+\Delta\sigma_{l2})$ is in a dominant position.

Table 2- The anchorage structure experimental test results

Serial No.	1#	2#	3#	4#	5#	6#	7#	8#
f_0/kN	234.65	312.43	389.39	469.36	546.70	625.47	703.30	781.19
k_l	30.24	60.21	66.4	85.47	79.21	84.961	121.72	114.87
k_L	6.01	6.16	6.28	6.31	6.41	6.60	7.91	16.79
$(\Delta l_{l1}+\Delta l_{l2})$/mm	-0.22	-0.09	-0.03	-0.15	0.11	0.19	0.61	0.80
η	0.99	0.99	0.98	0.98	0.98	0.96	\	\
f_L'/kN	287.89	340.86	419.13	493.92	576.76	659.38	726.58	807.89
$\Delta\bar{f}_l$/kN	53.24	28.43	29.74	24.56	30.06	33.91	23.28	26.7
Δl_{l3}/mm	\	\	0.30	0.11	0.12	0.33	0.49	\
f_0'/kN	235.23	313.97	390.97	471.49	547.74	621.01	683.87	751.81
κ	0.25%	0.49%	0.41%	0.45%	0.19%	1.37%	1.37%	3.76%
κ_l'	\	\	\	\	\	0.88%	0.73%	0.22%
f_{lk}/kN	729.30	728.7	732.04	730.5	731.9	726.9	728.08	778.09

Figure 6 shows the relation curve between reverse tension f and prestress under anchorage f_0, when $f<f_0$, f_0 basically remains and is similar to a horizontal line, which can tell that the stress has not pulled or be delivered to the stress tendon under anchorage as influenced by $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$ and $\Delta\sigma_{l3}$ at this stage; as f approaches f_0, with the growth of f, f_0 starts to slowly and nonlinearly ascend, $f-f_0$ curve is an arc, which says that stress is gradually delivered to the prestress tendon under anchorage, and mainly affected by $\Delta\sigma_{l3}$; as $f>f_0$, $f-f_0$ curve will gradually become linear, which expounds that the stress can totally overcome the losses of $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$ and $\Delta\sigma_{l3}$, and the reserve section and prestress tendon under anchorage establish an equivalent force balance. A fitting curve is made for $f>f_0$ of $f-f_0$ curve, the gradients of experiments $1^{\#}$ to $6^{\#}$ are 0.99, 0.99, 0.98, 0.98, 0.96, which may say that the average friction loss coefficient η of anchorage loop mouth, clip and steel strand is 0.98; according to the theoretical stress value f_L' obtained at the elongation moment in the experimental curve $f-\Delta l$, it can be found that the stress losses $\Delta\sigma_{l1}$, $\Delta\sigma_{l2}$ and $\Delta\sigma_{l3}$ of $\Delta f_l=f_L'-f_0$ ranges from 23.28kN to 33.91 kN, and the average value is around $\Delta\bar{f}_l$=28kN; in accordance with l_{f_0}, $l_{f_L'}$ and the theoretical elongation $\Delta l_L'$ of stress tendon free section under the effect of Δf_{l3}, the elongation of Δl_{l3}($\Delta l_{l3}=l_{f_0}-l_{f_L'}-\Delta l_L'$) under $\Delta\sigma_{l3}$ impact can be calculated, namely the mobility displacement of working anchorage clip, the result is that Δl_{l3} is less than 0.5mm, and the average value $\Delta\bar{l}_{l3}$= 0.27mm.

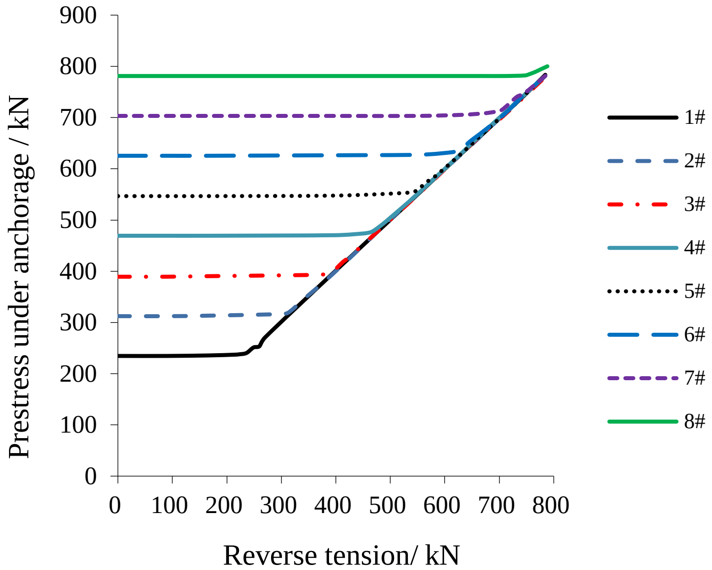


Fig 6 Correlation between reverse tension and prestress under anchorage

As $f > f_0$, when the stress leads the prestress tendon under anchorage to elongate, the concrete generates elastic compression loss $\Delta\sigma_L$ as in experiment 1# to 5#, $f_0 \le 0.7 f_{\max}$, k_L is less than the theoretical gradient k_L' (k_L'=6.46), the ratio k_L'/k_L inclines to 1 in table 2, which shows that $\Delta\sigma_L$ and its displacement Δl_{pc} is a continuous process under the impact of reverse stress, and smaller than the stress σ_L' ($\sigma_L' = \sigma_L - \Delta\sigma_L$) and elongation Δl_L of free section stress tendon, according to σ_L, α_{EP} and S_j and formula 1-10, Δl_{pc} and $\Delta\sigma_L$ can be almost ignored. When $0.7 f_{\max} < f_0 \le f_{\max}$, refer to experiment 6# to experiment 8#, k_L is more than the gradient k_L', $k_L'/k_L < 1$, especially the gradient of experiment 8#, k_L is 2.6 times of k_L', $\Delta\bar{f}_l/(f_{\max} - f_0) = 5.5$, which explains that the total loss $\Delta\sigma$ and displacement $\Delta l'$ are relatively larger than σ_L' and Δl_L, $\Delta\sigma_{l3}$ and Δl_{l3} take the lead.

4.4. Calculation of prestress under anchorage. On the basis of formula 2-12, the deviation between f_0' and f_0 ($\sigma_0 = f_0/S$) can be acquired from experiment 1# to 5#- $\kappa = |f_0' - f_0|/f_0 < 0.5\%$ between $\kappa = |f_0' - f_0|/f_0 < 0.5\%$, as in table 2, which states that the adoption of linear-fitting intersection method is workable to acquire the prestress under anchorage; κ is somewhat discrete, which can be mutually verified with $(\Delta\sigma_{l1} + \Delta\sigma_{l2})$ and $(\Delta l_{l1} + \Delta l_{l2})$, but also effectively controlled through the initial stress setting at the preliminary loading stage. When $k_L'/k_L < 1$, refer to experiment 6# to 8#, as the difference between $f_{\max}$ and f_0 is small and $\Delta\sigma_{l3}$ is dominant, it's proper to adopt linear-fitting intersection method; at this time, the calculation of formula 2-11 can be simplified to $f_0 = f_L' - \Delta\bar{f}_l$ or $f_0 = f - \Delta f_l$, the deviation $\kappa' < 0.88\%$, f is the reverse tension stress caused by the mobility displacement Δl_{l3} of working anchorage clip, Δf_l is the stress generated by the theoretical elongation Δl_{l3} of stress tendon free section.

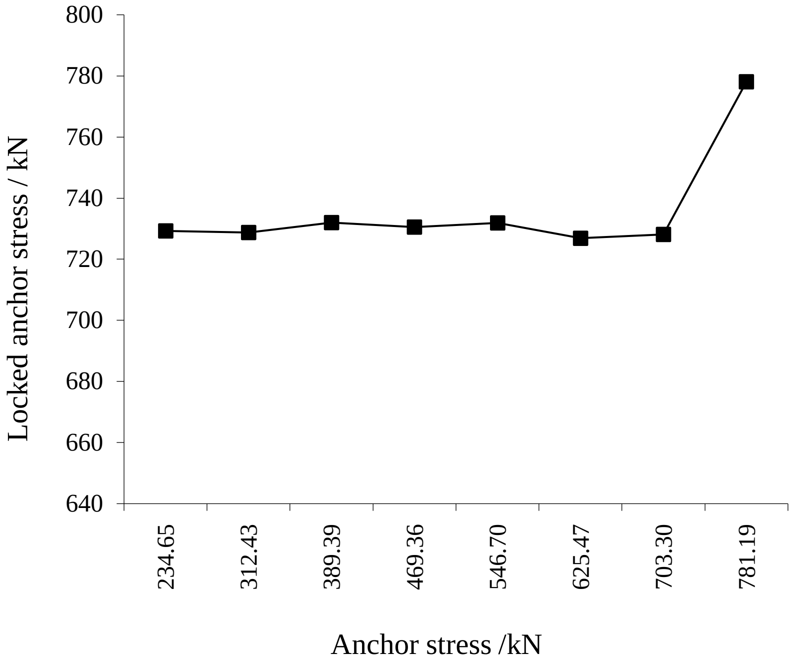


Fig 7 Correlation curve of set value of anchor stress and locked anchor stress after reverse tension

4.5. After reverse tension, the scale of prestress under anchorage shall be locked. Figure 7 shows the scale of locked prestress f_{lk} after reverse tension under different f_0 conditions. As f_0<703kN, refer to experiment 1$^{\#}$ to 7$^{\#}$, after the reverse tension method inspection, f_{lk} ranges between 720kN and 730kN, which says that the adoption of reverse tension method can somewhat complement the stress tendon with insufficient prestress under anchorage, whereas the scale of stress compensation is influenced by f_0, $f_{\max}$ and anchorage clip deformation after reverse tension and reinforcing steel bar f_0=781.19kN, there exists no change in f_{lk}, $f_{\max}$ - f_0=5.09kN, the stress increment is far less than $\Delta\sigma$, which can be mutually verified with the above content.

5. Conclusion

Reverse tension method is a kind of efficient method for PC beam bridge to inspect the prestress under anchorage. Under ideal conditions, the reverse tension f and elongation Δl curve(or $\sigma - \Delta l$) are two linear and elastic deformation stages, which consists of two different lines of various gradients, and the intersection stands for the stress under anchorage.

Under actual conditions, $\sigma - \Delta l$ curve is measured to consist of four non-linear stages, the inflexion is smooth and round, and the linear-fitting gradients of stress tendon reverse tension section and free section of curve are less than those under ideal conditions; generally, the linear-fitting intersection method is applied to judge the prestress under anchorage.

Experimental research has proved the inspection mechanism of reverse tension method, analyzed the composition form of f - Δl curve and related influential factors, and then showed: the working anchorage deformation, conjuncture compression, sliding of loading device and inhibiting device are related to the effect of inspection instrument installation, which can be effectively controlled through the setting of initial stress at preliminary stage; concrete structure compression is related to elastic modulus, net sectional are, cross sectional moment of inertia and rigidity, generally, its scale and stress loss are smaller and can even be ignored; the friction among anchorage loop mouth, steel strand and clip is continuous, when the loss and displacement are greater than the actuating quantity of prestress tendon under anchorage, the calculation of prestress under anchorage is suggested to apply reverse stress and elongation as the working anchorage clip looses, and the error is less than 1%; similarly, the reverse tension method can complement the stress tendon with insufficient prestress under anchorage. Then, the next research will concentrate on the standardization of inspection method and the corrected value under normal conditions.

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