Stressing & Field Measurements Guidelines

Question:

If the elongation measurements are not within the acceptable limits, what shall we do?

Answer:

When a post – tensioned (PT) tendon is stressed, it tries to become straight between anchorage ends resulting to an upward lifting force. A compression force is applied into the structure through the bearing plates (trump-plates).

Although we perform stressing using hydraulic jacks well maintained and pressure gauges properly calibrated, **the elongation measurement of the strands is a confirmation for the Engineer that the required force has been transferred to the PT tendon.**

According to Hooke's Law the modulus of Elasticity E and the strain ε are inversely proportional considering invariable the stress σ of a linear elastic system:

$$\sigma = E \cdot \varepsilon , \qquad (1.1)$$

For a PT tendon, the elongation ΔL is calculated as follows:

$$\varepsilon = \frac{\Delta L}{L} , \qquad (1.2)$$

$$\varepsilon = \frac{\sigma}{E} \therefore \frac{\Delta L}{L} = \frac{\sigma}{E} \therefore \Delta L = \frac{\sigma}{E} L , \qquad (1.3)$$

The stress σ is not stable through the whole length of the tendon because of the friction losses that are result of the curvature effect and the wobble effect. So, an integration of the stresses is necessary for the estimation of the elongation according to the following formula:

$$\Delta L = \int_0^L \frac{\sigma}{E} dx = \frac{1}{E} \int_0^L \sigma dx , \qquad (1.4)$$

The stress at a random point x of the tendon is:

$$\sigma_x = \sigma_i \cdot e^{-(\mu \alpha + Kx)} , \qquad (1.5)$$

where:

σ_i is the stress at a previous point or the anchorage.

x is the distance from that previous point or the anchorage.

a is the angle of deviation (rad) between the previous point or the anchorage.

μ is the friction coefficient between the strand and the sheath (1/rad).

K is the coefficient of the unintentional angular deviation (rad).

Knowing all above values, the theoretical elongation of the tendon can be calculated.

From theory to practise, there are many factors which must be taken into consideration and several assumptions because we do not have an accurate information about all phenomena occur while installing & stressing a PT tendon.

Although all Int'l PT systems specify values for μ & K, these should not be considered as fixed and solid since are depend on several factors among them to mention properties of materials (concrete, strand & anchorages), especially strand modulus of elasticity (E), roughness, dimensions tolerances, stirrups location and tightening, cement paste and concrete curing, unintentional curvatures, geometry profile deviations, wedge drawn-in and seating losses, in other words commonly known as prestress losses.

Without entering into technicalities, the prestress losses are categorized as:

Short term losses such as friction, concrete elastic deformation and seating losses (wedge drawn-in) and
Long term losses such as creep & shrinkage of concrete and strand relaxation.

The determination of the exact amount of stressing losses is very difficult. In fact, precise determination of the prestress losses is impractical because we do not have an accurate information about all above descibed phenomena.
Prestress losses are combination of many parameters as decribed above not mentioning the human factor due to installation errors and damages.

At the end of the day we have to confirm that the proper stressing force has been applied in a PT tendon and this force is remaining. A way to reassure this is the applied pressure in the stressing jack and as a back-up the field measurements of elongations which have to be compared with the theoretical elongation value.

This is the point where problems start because **theoretical elongation is based on assumptions**.

Basic guidelines during stressing:
Always use a well-maintained stressing equipment and a properly calibrated pressure gauge.

Before placing the anchor head onto bearing plate, check if the tendon close to stressing end is clear and the strands are not blocked with concrete.

Clean the strand overlength from dust and cement paste.

Place properly the anchor head and wedges before stressing. The anchor head must be seated onto bearing plate without gap. Wedges must be seated properly inside the conical holes of anchor head.

Perform an initial stressing (not exceeding 7-10% of the final stressing force) so as to allow the proper seating of anchor head and wedges (especially when you have a PT tendon with two stressing ends).

Mark the strands. We would like to bring into consideration that marking of the strands prior of the initial stressing is not recommended since the final measurements of elongation will include a considerable amount of seating tolerances.

Perform stressing always in phases. Although at the end of the day you are aware about the application of the final stressing force which could be accomplished in one phase depending on the jack's stroke capacity, this process is not recommended since you are not monitoring the behaviour of the PT tendon during stressing. By stressing in phases, you have a controllable way to check the function of PT tendon in steps and avoid unpleasant circumstances.

Some examples:

If a PT tendon is blocked by concrete, its active length is less than the expected. By applying in one phase the final stressing force you jeopardize to break the strands trying to reach the expected elongation (in short active tendons small differences in mm are related with high applied forces).

If a strand inside a PT tendon is not properly anchored in its fixed end, by applying in one phase the final stressing force this strand is moving outwards without being elongated. The whole stressing force is applied in less number of strands (less area) jeopardizing the tendon's failure.

In conclusion, the application of stressing in phases allows you to verify that the tendon is elongated as expected following the linear relation between the force/elongation Law. Any deviation can be easily observed and remedial actions can follow without witnessing circumstances beyond the control.

Basic guidelines for elongation measurements:

By recording the jack's stroke extension, you measure the apparent elongation and not the actual one. This apparent elongation is not considering wedges drawn-in of the anchor head, strand overlength elongation and jack's wedges drawn-in as well. Depending on the PT system you are using, these specific data/parameters must be considered by deducting specific figures from the apparent elongation. This final apparent value has to be compared with the strand measurements took place on the strands after initial stressing.

The apparent elongation based on the jack's stroke extension minus the PT system parameters and the actual elongation based on the strands markings, both have to be compared with the theoretical one (specified by the design).

It is commonly accepted by all Int'l Standards, the field measurements to have a tolerance of:

±5% in comparison with the theoretical values or ±7% (ACI 318) or ±10% (PTI) for short tendons (less than 15m).

For tendons that are shorter than 8m, the tolerance should be ±6mm and not %, as above, because a small discrepancy will exceed the allowable 7% tolerance (PTI).

Low elongation measurements are mostly due to the following reasons:

- Excessive friction (inaccurate placement of PT tendon, improper placement of strands or damaged sheathing).
- Excessive wobble (sloppy placement or excessive tendon deviations).
- Excessive seating losses (poor placement of the anchorage, existence of cement paste) to enter the wedge cavity.
- Modulus of elasticity and/or steel area value that is higher than the theoretical assumed in the design calculations (commonly 195GPa).
- Improper function of stressing equipment.
- Finally, calculation errors in formulas.

High elongation measurements are mostly due to the following:

- Lower friction.
- Lower wobble.
- Modulus of elasticity and/or steel area value that is lower than the theoretical assumed in the design calculations.
- Overstressing the tendon by mistake due to improper calibrated pressure gauge.
- Finally, calculation errors in formulas.

What is important:

Low elongation could conclude to less stressing force applied that the required by the design in the PT tendon.

You may perform a lift-off so as to check the remaining force in the PT tendon. No need to perform this in all tendons.

High elongation could conclude to overstressing, i.e., higher force that the required by the design in the PT tendon.

You may detention and re-stress.

Consider:

If the calculated elongation is reached before the calculated load is obtained, continue stressing till elongation does not exceed 1.05 times (stressing load less than 80% of strands UTS).

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Elongation measurements are not an 100% accurate method of verifying field stressing procedures. Remember that human factors are still involved (errors and wrong measurements etc.). Elongations are subject to the allowable tolerance without any consideration for fluctuations in the material properties or other variables as described above.

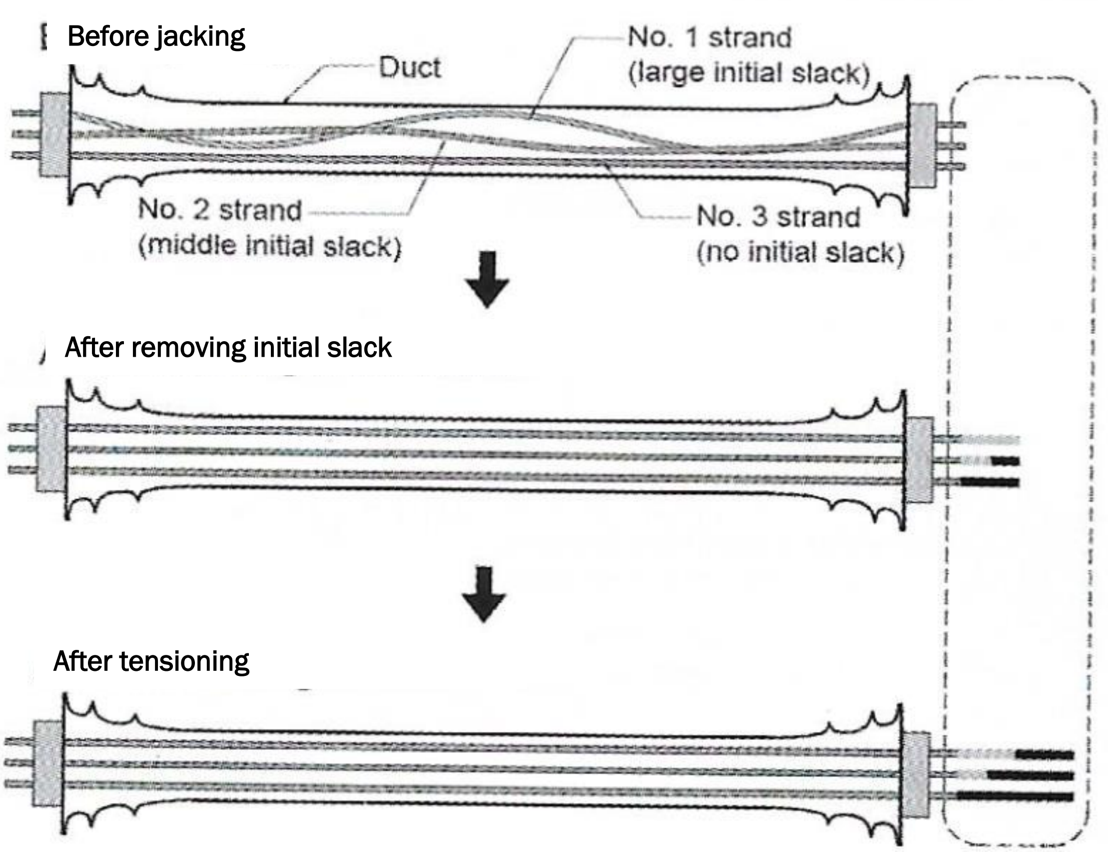
Discuss with the Consultant, re-check calculations, understand the impact of these issues as a whole picture and not concentrate only in one PT tendon.

Question:

Why the marks on the strands are not aligned after stressing?

Answer:

Before jacking in a straight tendon there is always slack phenomena due to the non-straight placement of strands, anchor heads and wedges.



If the marking of strands is taking place before removing the initial slack, then the marks on the strands include the slack and can lead in false actual measurements, thus we always mark the strands after initial stressing.

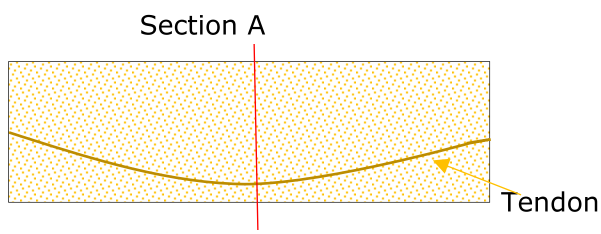
The Int'l standards define that this initial slack is eliminated by stressing initially a tendon about 5% < final stressing force < 25% (AASHTO Bridge Constructions Specifications 10.10.1.4).

As you can realize there no specific percentage number which we could implement in order to zero the slack in a tendon, so we always consider that after initial stressing there is always a slack, even a small one.

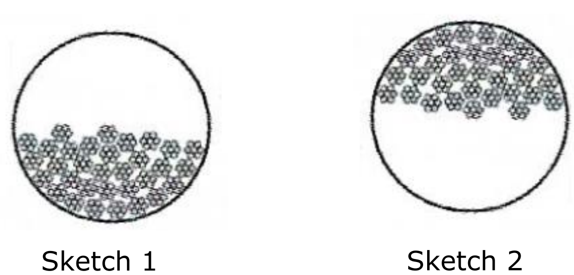
In a straight tendon after stressing and considering that the slack has been totally removed, all marks should be aligned.

However, in a common bridge tendon with a non-straight profile, the combination of slack and friction between strands and duct will always lead to differential locations of initial marks on the strands.

Assuming a typical tendon profile as per below sketch.



The arrangements of strands-before stressing- inside the duct at section A will be as per below sketch 1, while after stressing as per sketch 2.



The configuration 2 imposes different friction in each and every strand, i.e., lower strands have less friction compared with mid and upper strands in contact with the duct.

Different frictions lead to different elongations, therefore the final position of markings on the strands cannot be expected to be aligned. Below some characteristic photos:

The higher the friction the bigger the misalignment of the marks on the tendons. If you combine the slack phenomena, you can achieve differences of several cm.

Conclusion:
Differences in the marking of strands should be expected and are acceptable.

If one or some groups of the strand's marks are not aligned, this does not mean that these specific strands are not properly stressed but higher friction phenomena are applied. By adding the slack phenomena in these specific strands which cannot be eliminated, we may lead to significant misalignments of marks.

At the end of the day what is important is the final force applied to the tendon. The tendon as a bunch of strands acts as one unit in terms of stressing force, however, due to all above, each and every strand can have different elongation.