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Limits of elongation variation of tendons in post-tensioning

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Abstract. This paper analyses tensioning data obtained from a variety of projects that have been completed in South Africa in recent years in order to determine the causes of variation in elongation and suggest practical elongation limits. Current limits, prescribed by the South African standards (SANS 2001-CC1 and COLTO), of elongation variation limit of ±6% and an average elongation variation limit of ±3% are causing huge problems to the post-tensioning industry. The scatter of tendon elongation results is often greater than the range prescribed by these standards. This usually requires the contractor to re-tension the tendons at huge financial costs. In most cases the results obtained after re-tensioning are the same.

Keywords. Elongation variation, post-tensioning, tendon, tension, friction, wobble.

Introduction

In South Africa, guidelines for post-tensioning are provided by SANS 2001-CC1 [1] and COLTO [2]. In these standards the specification for high tensile steel wire and strand for the pre-stressing of concrete comply with the requirements of BS 5896 [3] and the mechanical tests for post-tensioning systems (including anchorages and couplers) comply with the requirements of EN 13391 [4]. According to these specifications the measured extension on individual tendons should be within 6% of the theoretical extension and the average of the measured extensions of all the tendons in a unit should not deviate from the theoretical extension by more than 3%. The accomplishment of these limits is causing problems in the South African post-tensioning industry because some elongation variations do not fall within these specifications. Such tendons are normally re-stressed (at the cost of the post-tensioning contractor); however, it has been found that after re-stressing the elongations do not change. This paper seeks to study post-tensioning data on several projects constructed in South Africa in order to solve this puzzle. The data was provided by Freyssinet, South Africa.

1. Presentation and discussion of tendon results

A total of 402 tendons from various projects, done by Freyssinet, were studied. Table 1 summarizes the average, standard deviation, maximum, minimum and range of the

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elongation results for the 402 tendons that were considered. The data was divided into groups, and these groups were split according to the type of project, date of stressing and type of jack. This ensured that tendons in the same group were stressed under similar conditions. Tendons of the same project, but stressed at different dates are numbered differently. For instance, Mthatha 1-10 tendons are from the same project as those of Mthatha 11-20, however these tendons were stressed at different dates. As can be seen from Table 1, the average value of +4.06% for all tendons is high, considering that the expected average elongation variation is ±3% (SANS 2001-CC1 [1] and COLTO [2]. Since only five of the sixteen tendon groups met this requirement, this requirement can be considered to be too stringent. The positive average elongation variation also shows that post-tensioning tendons tend to over-elongate during stressing.

Table 1. Summary of elongation variation results

Project	Tendons	Average (%)	Std. Deviation (%)	Max. Value (%)	Min. Value (%)	Var.range (%)
Coega-Colchester (1-14)	28	+6.07	2.27	+10.18	+1.04	+8.30
Coega-Colchester (15-21)	14	+5.03	2.09	+7.41	+1.39	+8.22
Kwa-Mashu	14	+0.78	5.02	+9.83	-5.94	-3.03
K46 15.24mm (1-9)	18	-8.38	4.10	+0.49	-15.29	+6.85
K46 15.24mm (17-32)	52	-3.87	6.00	+3.70	-22.85	-2.43
Malendela	54	-0.14	3.60	+8.12	-7.69	-2.90
Mthatha 1-10	50	+0.73	5.38	+10.84	-13.21	+7.43
Mthatha 11-20	50	+0.11	5.16	+9.99	-13.21	+7.38
Jean Ave. P76	24	+2.53	8.82	+14.46	-22.81	+4.46
Jean Ave. P77	18	+5.70	5.04	+16.00	-1.10	+4.28
Jean Ave. P78	4	+8.76	4.19	+14.09	+4.12	-
Jean Ave. P80	16	+6.55	3.97	+11.88	-2.08	+5.72
John Vorster P6	18	+10.17	5.40	+19.17	+3.00	+4.43
John Vorster P7	16	+6.50	5.13	+16.75	-1.00	+3.74
John Vorster P8	20	11.00	3.75	+16.70	+4.81	+5.58
John Vorster P10	6	+13.43	2.92	+16.39	+9.33	-
Mean		+4.06%	4.55%	11.63	-5.09	+5.56

The standard deviation from Table 1 of 4.55% indicates a high degree of scatter of elongation variation results. It means that the majority of elongation variation results will occur in the region of 4.55% on either side of the average value. Since this standard deviation is the average value of the standard deviations of a group of tendons, the tolerance range can be taken as two standard deviations combined, from the average value. Hence, a standard deviation of 4.55% would give an elongation variation of ±9.1% (rounded to 9%), which is about 50% greater than the current limit of ±6%. Since none of the tendons considered in this paper failed when subjected to the prescribed tension, an elongation variations of ±9% can be considered to be safe. The limit of elongation variation of ±6% is too stringent, and do not reflect site conditions. All the tendons in Table 1 were stressed to their target tension forces.

To illustrate how the elongation variations of tendons compare with standards, selected elongation variation graphs of tendons are presented and discussed in this section. These graphs help to show the actual scatter of variation data from 0% and how these results relates to the limits provided by SANS 2001-CC1 [1] and COLTO [2]. The results considered in this section includes tendons that predominantly experienced balanced elongation (Mthatha 1-10 and Mthatha 11-20), over-elongation (Coega to Colchester 1-14 and John Vorster P8) and under-elongation (K46 (1-9)). The variation in elongation was calculated as the difference between the theoretical and the real elongation.

1.1. Mthatha 1-10 and Mthatha 11-20 tendons

Mthatha 1-10 and Mthatha 11-20 tendons, in Figures 1 and 2, are examples of projects that experienced balanced elongation variations. This is due to the fact that the corresponding average elongation variations of +0.73% and +0.11% are small (close to 0%) and well below the average elongation variation of ±3% (Table 1). In addition standard deviations of 5.38% and 5.160% are below the limit elongation variation of ±6%, provided by the standards. In both groups of tendons the scatter of elongation results is almost the same about the datum (Figure 1 and 2), which clearly shows that there was a balance between under and over-elongation results. Despite the fact that the length of these two groups of tendons were the same (15.85 m) Mthatha 1-10 tendon elongation results vary from a minimum of -13.21% to a maximum of 10.84%, and Mthatha 11-20 from a minimum of -13.21% to a maximum of 9.99%. According to the SANS 2001-CC1 [1] and COLTO [2] specifications, 13 out of 50 of Mthatha 1-10 tendons (26%), and 14 out of 50 tendons of Mthatha 11-20 (28%) fall outside of the limit of ±6% (Figures 1 and 2).

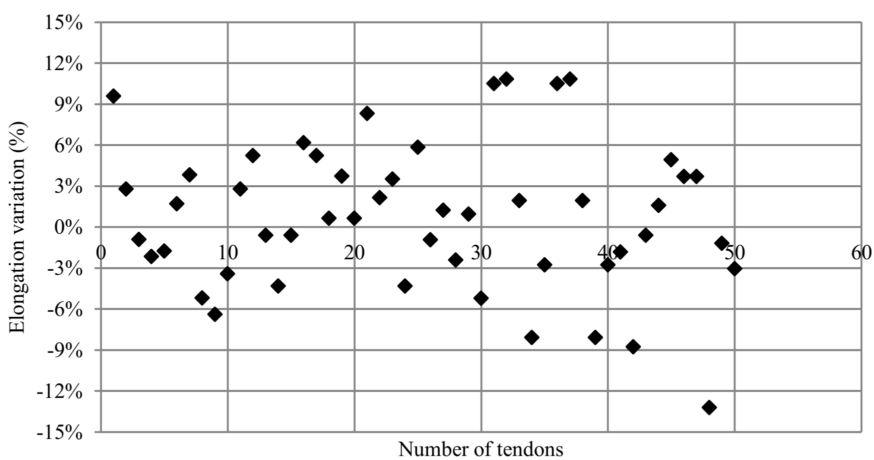

Figure 1. Elongation variations of Mthatha 1-10 tendons

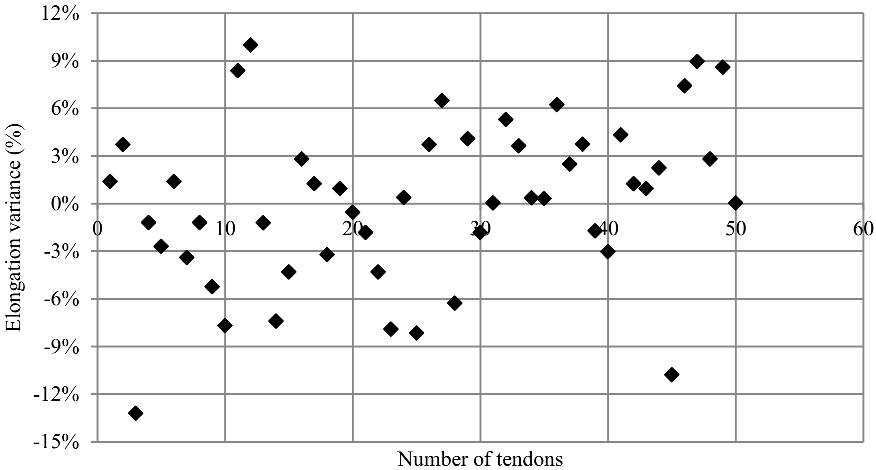

Figure 2. Elongation variations of Mthatha 11-20 tendons

If the recommended elongation variation range of ±9% is applied then only six Mthatha 1-10 and 3 Mthatha 11-20 would fall out of the specification limits. Tendons with significantly higher negative elongations show evidence of higher friction or wobble experienced by the tendons. None of the strand certificates showed an elastic modulus or cross-sectional area that is high enough to cause such a drastic change in gradient. Negative elongation variations imply that more force is required to attain a pre-determined elongation. Friction increases the tensile force and reduces the resultant elongation; this increases the stiffness of the tendon. A lower friction will have the reverse effect, causing greater elongation than theoretically predicted.

1.2. Coega to Colchester 1-14 and John Vorster P8 tendons

The Coega to Colchester 1-14 (Figure 3) and John Vorster P8 (Figure 4) set of tendons produced average elongation variations of 6.07% and 11.00%, respectively, which are completely outside of the limit of 3%. However, their corresponding standard deviation of 2.27% and 3.75% are low, which indicates that there is little deviation from the average values of 6.07% and 11.00%, respectively. The large average elongation variations occurred despite the fact that the prescribed tensile force was achieved in the tendons. The positive maximum and minimum elongation values for the two groups of tendons (+10.18% and +1.04% for Coega to Colchester 1-14, and +16.70% and +4.81% for John Vorster P8) shows that the tendons experienced significant over-elongation. The shift in the elongation results was probably caused by reduced friction in the sheathing or by assuming too high friction and wobble factors. It is interesting to note that if the average value in these graph was taken as the datum, then all the elongation variations for Coega to Colchester 1-14 tendons will fall within the ±6%, specified by SANS 2001-CC1 [1] and COLTO [2]. If such a shift in noticed earlier, re-stressing of the tendons can be avoided. It is also important to note that if the proposed limit of ±9% was applied, then both Coega to Colchester 1-14 and John Vorster P8 tendons will be within the specified limits.

As indicated before, a shift in elongation results could also be caused by the loose "lay" of the strands in the tendons. Loose, outer wires tend to have a greater length than a normal tight strand. When a force is applied to the strand, the outer wires are tightened, causing the strand to lengthen, under a small tensile force from the jack. This elongation shifts the stress-strain plots to the right of the graph. Loose wires can also result in a lower initial elastic modulus in the strand. This situation is caused by the uneven distribution of tension in the 7-wire strand. When the strand is tightened the centre wire immediately resists the tension whilst the outer wires lag behind. Such a tendon would experience over-elongation during the initial tensioning increments.

Loose wires in a strand increase the variability of the elongation results, however, they do not seem to have affected Coega-Colchester (1-14) and John Vorster tendons much, because the elongation standard deviations of 2.27% and 3.75 are small. It should be noted that over-elongation was not caused by the material properties since the actual average elastic moduli and areas of these two groups of tendons did not differ much from the assumed values of 195 GPa and 150 mm².

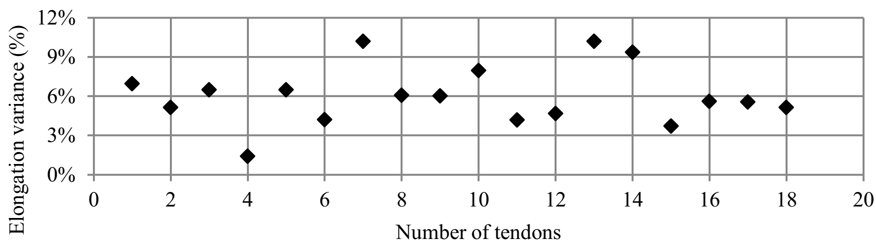

Figure 3. Coega to Colchester 1-14 tendons

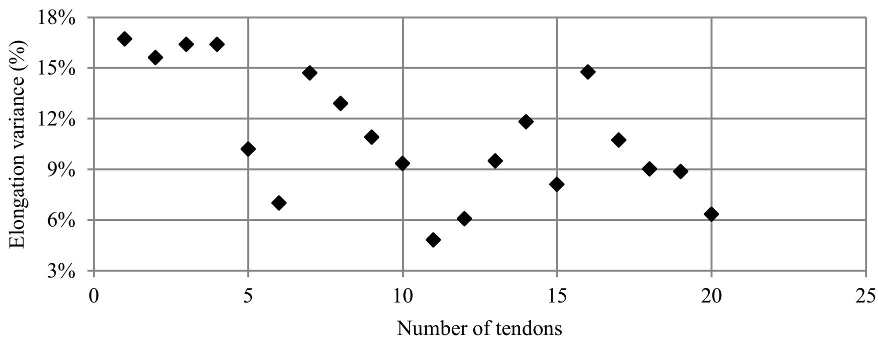

Figure 4. John Vorster P8 tendons

1.3. K46 (1-9) tendons

Except one, all K46 (1-9) tendons (Figure 5) experienced under-elongation. The tendons are 16.22 m long, and can be accommodated by the proposed elongation variation limit of ±9% if the datum is shifted downwards. Since the material properties of each group of tendons are almost the same, it can be assumed that under-elongation was either caused by higher than expected friction, wobble, elastic modulus and cross-sectional area, or any combination of these. A larger than expected friction or wobble might indicate that the tension in the tendon is not distributed evenly. This is a cause for concern since some sections of the tendon might be tensioned more than the others.

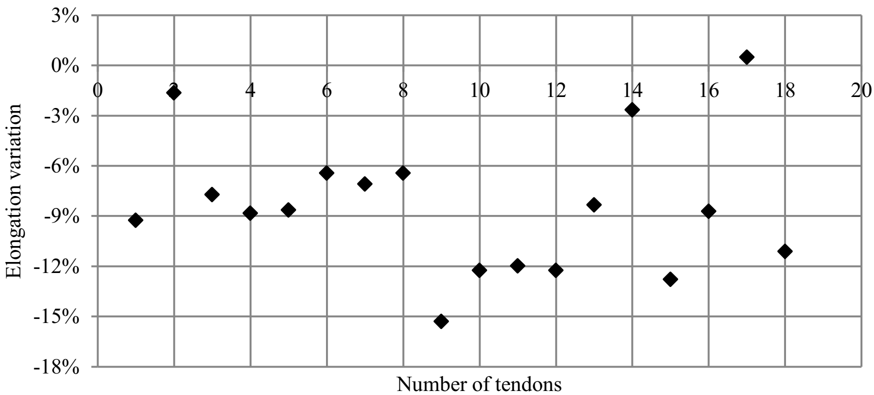

Figure 5. K46 (1-9) tendons

2. Summary and conclusions

The aim of this paper was to determine if the SANS 2001-CC1 [1] and COLTO [2] limits for elongation variation of ±6% are too stringent or not. To achieve this selected elongation variation graphs of tendons are presented and discussed. The following conclusions are deduced from this study:

- Elongation variations are dependent on the assumed friction and wobble coefficients. Over-elongation is caused by less than expected friction, wobble, elastic modulus and cross-sectional area, or any combination of these. When these factors are large they favour negative elongation. A larger than expected friction or wobble might indicate that the tension in the tendon is not distributed evenly. This is a cause for concern since some sections of the tendon might be under-tensioned and others over-tensioned.
- It is also noted that when larger values of friction and wobble are assumed during the calculation of the tendon elongation then there is a positive shift of results. This means that the results would shift in the negative side if the friction and wobble values are small. In interpreting the results, the engineer must consider the shift and judge the elongation results of the tendons accordingly.
- The average elongation variations of the tendons range from a minimum of -8.38% to a maximum of +13.43%. An average elongation variation of 4.06% shows that tendons tend to over-elongate during stressing. Over-elongation reflects a better distribution of tension in the strand due to lower friction encountered by the strand [5]. The average elongation variation also exceeds the average elongation variation limit of ±3%, provided by SANS 2001-CC1 [1] and COLTO [2]. It can be seen from Table 1 that only five out of sixteen tendon groups met this requirement.
- The standard deviation from Table 1 of +4.55% indicates a high degree of scatter of elongation variation results. This scatter occurred despite the fact that the

correct tension was applied to all the tendons considered in this paper. Since this standard deviation is the mean of the average standard deviation for all groups of tendons, the elongation variation of tendons can be expected to extend two standard deviations from the average value. Hence, it is recommended that the limit ±6 be adjusted to ±9%. This gives an average elongation variation of ±4.5%.

References

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