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A study on individual strand elongation tolerance and post-tensioning tendon installation method

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ABSTRACT

Inevitable deviation of individual strand elongations occurs in multi-strand post-tensioning tendons due to the construction errors and initial slack effect. Because the deviation may affect the member strength and long-term behavior, standards and specifications such as AASHTO (2017), ASME (2019), and PTI/ASBI (2012) restrict the strand installation methods to minimize the deviation of individual strand elongations. In this study, the effect of individual strand elongation difference on the strength of multi-strand post-tensioned concrete members is analyzed through a series of numerical analysis. Based on the numerical analysis and thorough review on current standards and specifications, adequacy of the current requirements on tendon installation and elongation tolerance is discussed.

1. INTRODUCTION

Due to the characteristics of multi-strand tensioning jack, which simultaneously tensions multiple strands in a tendon, there is a deviation in the tensile forces applied to the individual strands. The deviation of individual strand tensile forces can be caused by an initial slack effect. The initial slack is associated with the phenomenon that multiple strands in a post-tensioning duct are irregularly arranged with different local curvatures, as shown in Fig. 1. At the tensioning operation, initial slack is removed. During this process, a large difference typically exists in the tensile stress applied to the individual strands. The initial slack is one of the influential parameters on the force deviation. For that reason, some standards and specifications require specific strand installation methods, where the allowable limits are not theoretically given but empirically determined.

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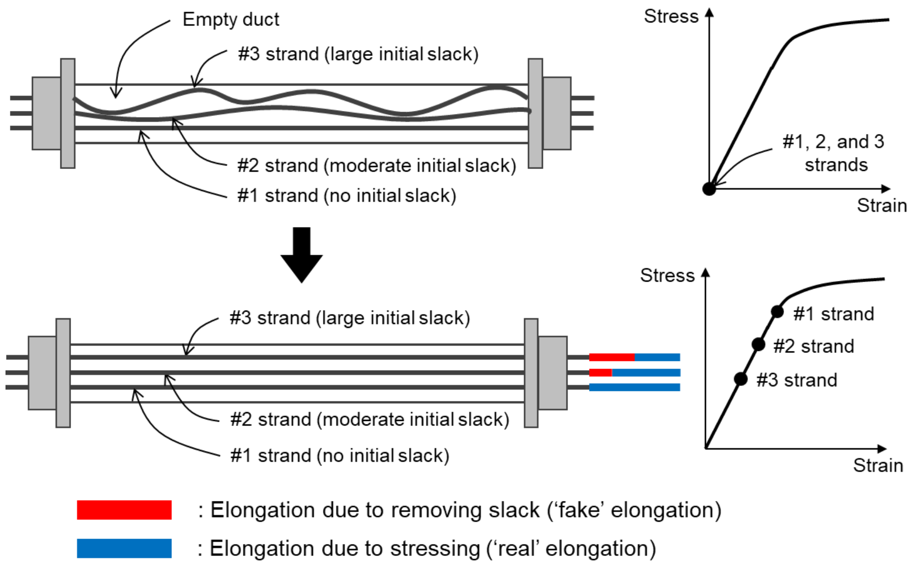

Fig. 1 Differential individual strand forces due to initial slack effect

2. NUMERICAL ANALYSIS ON THE EFFECT OF STRAND FORCE DEVIATION

A series of numerical analysis are conducted with the main analysis parameter of individual strand force deviation. For the analysis, previous experimental research by Mattock et al. (1971) is used, which includes two flexural tests of a bonded PT beam (RB1 specimen) and an unbonded PT beam (RU1 specimen). All geometrical or material properties of analysis models are the same as the original experiments, except for the individual strand force deviations modeled by equivalent tendon stress-strain relationship proposed by authors.

Table 1 Effect on flexural strengths of PT beam

RB- series (Bonded)	**C.O.V.*, %**	0	5.0	10.0	15.0	20.0	25.0
	$M_{u,FEA}$, kN	90.37	90.98	90.88	90.21	89.94	89.70
	Strength reduction, %	0	-0.67	-0.56	0.17	0.48	0.74
RU- series (Unbonded)	**C.O.V.*, %**	0	5.0	10.0	15.0	20.0	30.0
	$M_{u,FEA}$, kN	79.38	79.32	78.78	78.52	78.31	77.14
	Strength reduction, %	0	0.08	0.76	1.09	1.36	2.82

* C.O.V. is the coefficient of variation of individual strand tensile forces applied in the analysis model.

Table 1 shows analytical results of ultimate loads ($P_{u,FEA}$), ultimate flexural strengths ($M_{u,FEA}$), and percentages of strength reduction with respect to those of the bonded and unbonded models with 0% coefficient of variation (C.O.V.) of tensile forces.

As shown in Table 1, the flexural strength of PT beam tended to slightly decrease, as the force deviation (C.O.V.) increased. Overall, both the bonded and unbonded PT beams experienced negligible strength reduction at the realistic level of force deviations (0 ~ 10% C.O.V.). Flexural capacity of PT beam highly depends on the tensile stress at ultimate flexural strength (f_{ps}), while the force deviation has a limited effect on the f_{ps}.

Thus, it can be noticed that the force deviation does not affect the ultimate capacity of PT members and their design. Nonetheless, because this is a risk of steel yielding or fracture with the large individual strand force deviation, there is a needs for a specification for controlling the deviation.

3. REQUIREMENTS ON THE TENDON ELONGATION AND INSTALLATION

Current standards and specifications specify the tendon elongation tolerances and tendon installation methods. The requirements for elongation tolerance are intended to verify whether the tensile force and elongation is properly matched to the design values. Most standards and specifications only provide allowable limits for the difference between the theoretical and measured elongations of the entire tendon. Although MOLIT (2016) only provides tolerances for individual strands (Table 2), there are no specific guidelines on the level of individual strand force deviations (e.g. standard deviation and C.O.V.) in other current standards and specifications.

Table 2 Tendon elongation tolerances in standards and specifications (summary)

Standards/Specification	**Entire tendon**	**Individual strand**
ASME (2019)	7%	-
AFCEN (2012)	+8%, -5%	-
PTI/ASBI (2012)	$\pm$(7% + 6.35 mm) for $L \leq 12$ m $\pm$7% for $L > 12$ m	-
AASHTO (2017)	$\pm$7% for $L \leq 15$ m $\pm$5% for $L > 15$ m	-
MOLIT (2016)	$\pm$7% for $L \leq 15$ m $\pm$5% for $L > 15$ m	$\pm$15% for $L \leq 15$ m $\pm$10% for $L > 15$ m

Note: '-' is 'not mentioned'; and L is the length of tendon.

Table 3 Tendon installation and preliminary tensioning requirements in standards and specifications (summary)

Standards/Specification		**Tendon installation (threading) method**				**Preliminary tensioning (Use of initial arrangement jack)**
		Twisting	**Pulling bundled strands**	**Pushing individual strands**	**Pulling individual strands**	
ASME (2019)	Horizontal circumferential tendon	Specified	Specified	Not permitted	Not permitted	-
	Vertical tendon	-	-	-	-	-
AFCEN (2012)		-	-	Specified	-	Required
PTI/ASBI (2012)		-	Specified	Specified	Specified	-
AASHTO (2017)		-	-	Specified	Specified	Required

Note: '-' is 'not mentioned'.

In order to reduce the strand force deviation (not requiring measuring the deviation), the current standards and specifications provide the requirements for strand installation and preliminary tensioning operation. In the case of ASME (2019), the code requires to install all horizontal tendons by twisting each strand or by pulling the bundled strands, which are unnecessarily complicated and difficult to be applied in actual construction fields. Whereas, AFCEN (2012) and AASHTO (2017) require performing preliminary tensioning using an initial arrangement jack before the main tensioning operation.

4. CONCLUSIONS

Although the individual strand force deviation has a limited effect on the ultimate strength of PT members, there may be a need to separately set the allowable limits for the standard deviation or C.O.V. of strand force deviation (or elongation deviation). For long-term durability and performance in terms of relaxation loss, fatigue, and stress corrosion of strands, it is considered necessary to limit the initial tensioning stress lower than the upper limit, which is smaller than the yield strength of the strand.

For the tendon installation requirements, there is a proper alternative method using an initial arrangement jack to reduce the strand force deviation as per AFCEN (2012) and AASHTO (2017). With the use of the initial jack, the selection of strand installation method is in the best interest of contractors, PT suppliers and relevant personnel.

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