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Effects of Strand Force Deviation on Ultimate Inner Pressure Capacity of PT Silos

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ABSTRACT

Multi-strand tendons have inevitable deviation of individual strand tensile forces due to the construction field management such as initial slack effect. In this study, the effect of individual strand force deviation on the ultimate inner pressure capacity of post-tensioned silo structures is investigated through a series of nonlinear finite element analyses. With application of equivalent tendon stress-strain relationship proposed by the authors, the force deviation is accounted for in the numerical model. The ultimate inner pressure capacity degradation with increasing deviation is investigated.

1. INTRODUCTION

Inevitable deviation of individual strand tensile forces occurs in multi-strand post-tensioning tendons, due to the construction errors and initial slack effect. However, the effect of individual strand force deviation on the structural behavior of post-tensioned structures has not been studied thoroughly. To investigate such phenomena and structural effect, in this study, the influence of individual strand force deviation on the ultimate inner pressure capacity of post-tensioned silo structures is analyzed through a series of numerical analyses.

The nonlinear analysis is carried out, with a primary parameter of deviation of individual strand forces in each tendon. To describe the force deviation in multiple strands in the numerical analysis procedure, an equivalent tendon stress-strain relationship is proposed by the authors and utilized in the study. From the analysis results, the strength degradation with increasing standard deviation of individual strand forces is studied in depth.

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2. EQUIVALENT TENDON STRESS-STRAIN RELATIONSHIP

Modeling all of the strands to consider the deviation requires a lot of computational cost. As an alternative way to consider the force deviation, an equivalent tendon material model is proposed. The purpose of the model is to create a single stress-strain curve by averaging the individual stress-strain curves of the strands. By initial slack effect, the strands are tensioned with different stresses and have different remaining strength to reach ultimate strength of strand.

When averaging the tensile stress of the individual strands, tensile stress follows the average of remaining stress-strain curves of the individual strands. Until the average tensile stress of the tendon, stress follows the original constitutive law of individual strand. After the average tensile stress of the tendon, stress follows remaining stress-strain relationship to reach the ultimate strength of individual strand. As shown in Fig. 1, the equivalent stress-strain relationship has a little lower yield strength and a much lower ultimate strength than individual strands.

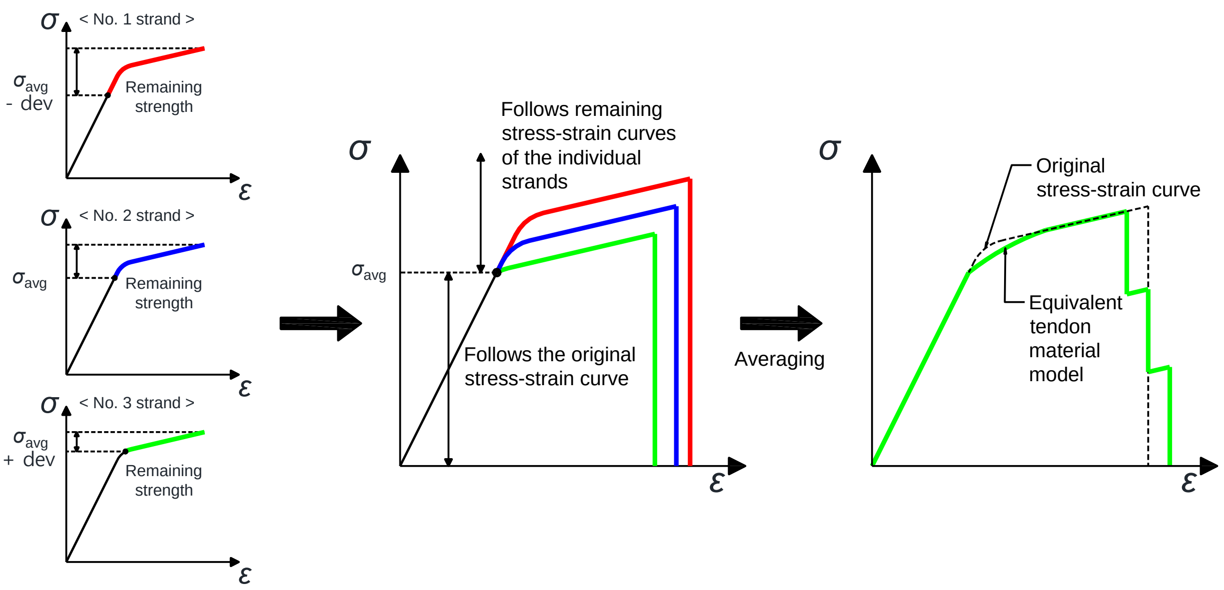


Fig. 1 Concept of equivalent tendon stress-strain relationship

3. NUMERICAL MODELING

The geometry and material properties of post-tensioned silos are modeled based on the experimental research conducted by Hessheimer et al. (2003). The original test specimen and numerical models are shown in Fig. 2. The post-tensioned silo model has 10 tendons, with 48 strands per tendon. The strands in one tendon are modeled as an equivalent strand using the equivalent tendon stress-strain relationship. To analyze the effects of bonded and unbonded conditions, both of the analysis models with unbonded tendons and bonded tendons are modeled. Total 6 numerical models are created with a main analysis parameter of Coefficient of Variation (C.O.V.) of individual strand tensile forces. The analysis parameters are summarized in Table 1.

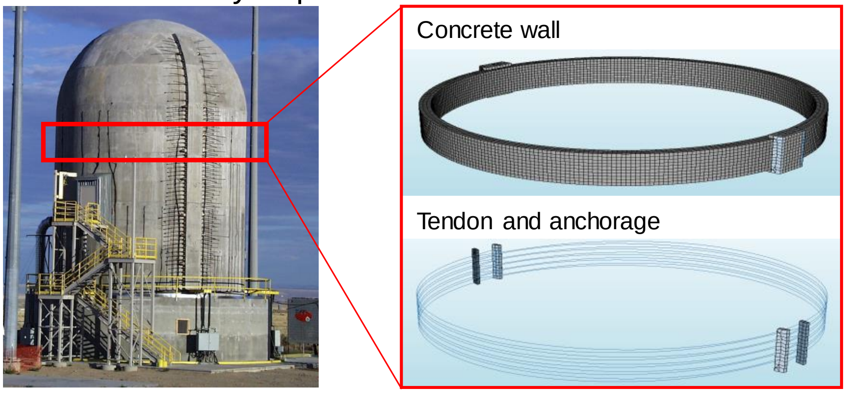


Fig. 2 Original experiment specimen (Hessheimer et al., 2003) and numerical model

Table 1. Analysis parameters

Numerical model	Type of the tendons	Average tensile stress of tendon	C.O.V. (%)	Standard deviation (MPa)	Equivalent tendon model's materials		
					f_{py} (MPa)	f_{pu} (MPa)	ε_{pu} (%)
SB-0%	Bonded tendon	0.65f_{pu} (=1,210 MPa)	0	0	1,680	1,857	4.50
SB-10%			10	121.0	1,675	1,852	4.35
SB-25%			25	302.5	1,625	1,800	3.43
SU-0%	Unbonded tendon	0.65f_{pu} (=1,210 MPa)	0	0	1,680	1,857	4.50
SU-10%			10	121.0	1,675	1,852	4.35
SU-25%			25	302.5	1,625	1,800	3.43

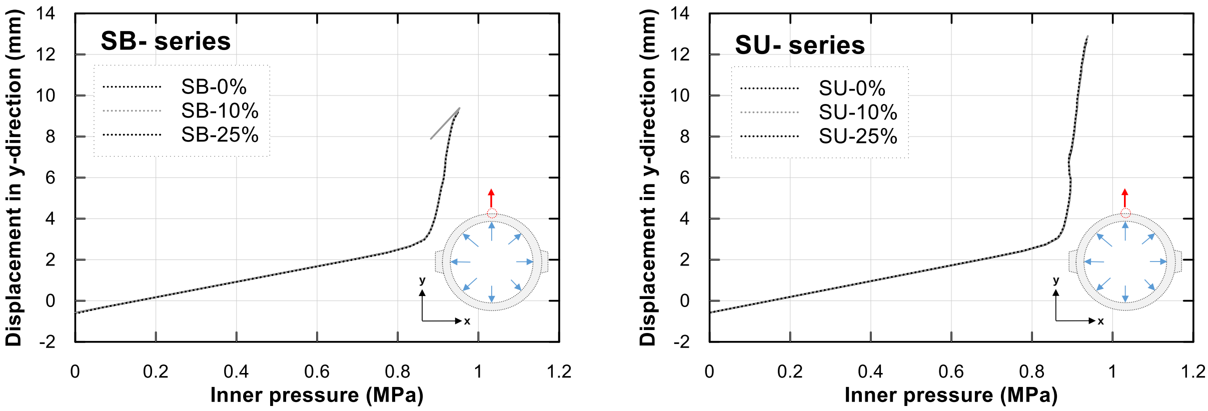
Note: f_{py} is yield strength of equivalent tendon, which is defined as stress at 1% elongation; f_{pu} is ultimate tensile strength of equivalent tendon; and ε_{pu} is elongation at ultimate tensile strength (f_{pu})

4. ANALYSIS RESULTS

The inner pressure-displacement curves obtained from each analysis are shown in Fig. 3, and the ultimate inner pressure, inner pressure at cracking, and percentage of inner pressure capacity reduction in reference to the analysis models with no tensile force deviations (SB-0% and SU-0%) are summarized in Table 2.

The analysis results show that the individual tensile stress deviation has negligible effect on the ultimate inner pressure capacity of post-tensioned silo structures. In the realistic level of tensile force deviation (10% C.O.V.), the ultimate pressure slightly increased. Considering the error due to the analysis load step size and/or convergence criteria, it can be concluded that there is negligible strength reduction effect due to the tensile force deviation. Even though there is large tensile force deviation around 25% C.O.V., the decrease of ultimate pressure is less than 0.6%.

As shown in Table 2, the tensile stresses at ultimate state (f_{ps}) are much lower than the equivalent yield stress (f_{py}) of the tendon, which are still in the elastic region. Because the strength reduction of tendon is perceptible near yield stress, there is no significant change in material properties of tendons. Thus, the strength of structure is not affected by tensile force deviation.



(a) SB- series (bonded tendon) (b) SU- series (unbonded tendon)

Fig. 3 Original experiment specimen (Hessheimer et al., 2003) and numerical model

Table 2. Analysis results

Numerical model	Ultimate inner pressure (MPa)	Pressure at cracking (Mpa)	Strength reduction (%)	Initial stress of tendon (MPa)			Tensile stress of tendon at ultimate pressure (f_{ps}) (MPa)		
				At jacking end	At 1/4 length	At 1/2 length	At jacking end	At 1/4 length	At 1/2 length
SB-0%	0.9496	0.8665	0	1,195	868	679	1,260	1,017	759
SB-10%	0.9534	0.8664	-0.40				1,259	1,013	759
SB-25%	0.9445	0.8646	0.54				1,253	1,013	758
SU-0%	0.9353	0.8648	0				1,310	986	795
SU-10%	0.9386	0.8647	-0.35				1,312	987	797
SU-25%	0.9378	0.8643	-0.27				1,311	986	796

5. CONCLUSION

In this study, the effect of individual strand force deviation on the ultimate inner pressure capacity of post-tensioned silos is analysed. The difference among the analysis results is not perceptible and the influence on the ultimate inner pressure capacity is close to be zero. It can be concluded that the negligible effect is due to the combined effect of the relatively low average tensile stress associated with large friction loss and the relatively small tensile stress at ultimate state (f_{ps}).

REFERENCES

Hessheimer, M. F., Klamerus, E. W., Lambert, L. D., Rightley, G. S., and Dameron, R. A. (2003), “Overpressurization Test of a 1:4-Scale Prestressed Concrete Containment Vessel Model,” Sandia National Laboratories, NUREG/CR-6810, SAND2003-0840P, Albuquerque, NM.