EVALUATION OF LOAD DEFORMATION BEHAVIOR OF UNBONDED POST-TENSIONED PRECAST WALLS

Analytical method　Backbone curve
Rocking wall　Unbonded post tensioning

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1. Introduction

Unbonded post-tensioned precast concrete walls (hereafter rocking walls) is a low-damage structural system in which post-tensioning (PT) provides the restoring self-centering and damage normally concentrates at the rocking toes. The 2015 AIJ guidelines[1)] doesn't include an explicit method for determining the load-deformation relationship (backbone curve) for rocking walls. One possible approach to obtain the backbone curve of rocking walls using AIJ guidelines (hereafter, AIJ method) is to use the equations for bonded post tensioned columns and beams with suggested modification to account for unbonded tendons.

This paper compares the load-deformation relationships of two rocking wall specimens obtained from the analytical method of Aaleti and Sritharan[2)] (hereafter, AS method) and that from AIJ method with experimental test results[3)]. The wall specimens were loaded cyclically in double curvature. Their properties are listed in Table 1.

Table 1 Properties of the rocking wall specimens

	NSW6A	NSW7A
No. of piers	1	2
X-section (mm x mm)	1100(900)* x 200	450 x 200
Shear span ratio	1	2
Axial force ratio	0.1	0.1
PT Tendon	2-φ17mm	1-φ19mm
PT Force ratio	0.70	0.58

* Due to presence of two 100mm long triangular pockets in the stubs

2. Methodology

2.1 AIJ method

In the AIJ method, the load-deformation relationship is calculated at four different performance points, viz., cracking, yielding, peak capacity point (ultimate moment) and failure (ultimate drift). The yielding and failure point are taken as 90% and 80% of the peak moment capacity respectively. The peak moment capacity, M_u, and the neutral axis depth, x_n, are given by the following equations

$$M_u = \sum P_i d_{pi} - \left(\sum P_i + N\right).k_2 x_n + ND/2 \qquad (1)$$

$$x_n = \frac{\sum P_i + N}{k_1 k_3 b \sigma_b} \qquad (2)$$

where, P_i is the ultimate PT force, N is external load, d_{pi} is the position of i^{th} PT tendon from extreme compression edge, D is wall length, σ_b is concrete compressive strength, k_1 k_2 k_3 are equivalent stress block parameters and b is the wall thickness.

AIJ suggests the following equation by Takemoto[4)] to calculate stress increment ($\Delta\sigma_p$) in unbonded PT tendons.

$$\Delta\sigma_p = 98 - \frac{4.9*10^5}{\sigma_c} p_p \quad (N/mm^2) \qquad (3)$$

$$p_p = \frac{A_p * n_{pt}}{b * d_p} \qquad (4)$$

Where, A_p is th area of PT tendon and n_{pt} is the number of PT tendons. The drift values corresponding to the performance points are computed from the equations provided in the AIJ guidelines.

2.2 AS method

In AS method, the calculation of the backbone involves force equilibrium and geometric compatibility conditions. Unlike AIJ, performance states are not distinct and entire backbone curve should be generated to get the maximum point. The original AS method is derived for cantilever walls, but it can be used in double curvature condition by modifying the elongation of PT tendons to also incorporate the gap opening at the top as shown in fig.1. This method uses idealized tri-linear variation of the neutral axis (NA) depth as shown in fig 2. The NA depth is approximated to remain constant from 0.5% drift to 3% drift at x_n. At 0.1% drift, the NA depth is approximated as $2x_n$.

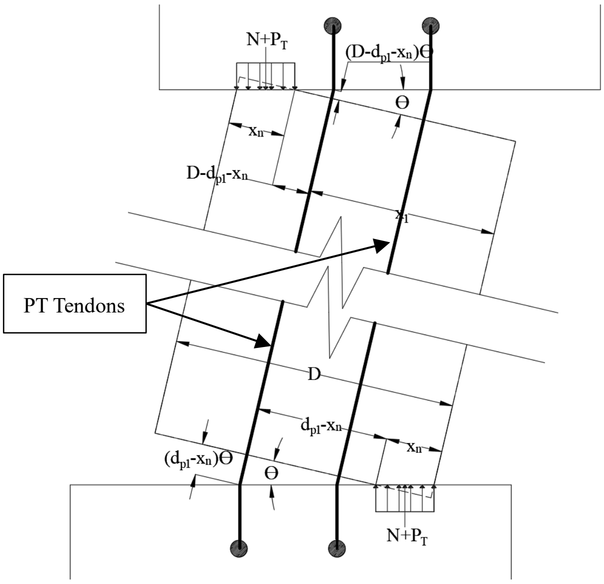

Fig.1　Gap opening and elongation of PT tendons at both top and bottom ends of rocking wall

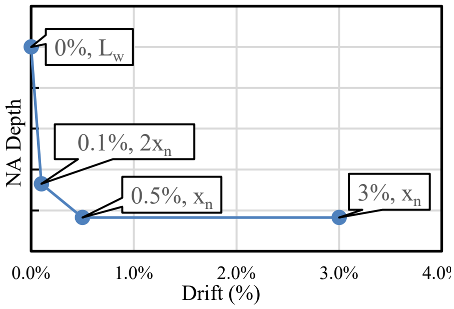

Fig.2 Trilinear idealization of NA depth by Aaleti and Sritharan

The trilinear relationship of NA depth is established by calculating the NA depth (x_n) at $\theta = 2\%$. This is done by assuming an initial value of NA, calculating the strain from the elongation of the tendons as per fig.1, determining the corresponding stress from stress-strain of PT steel, applying equation (5) to get the new estimate of NA depth and reiterating until convergence.

$$x_n = \frac{N + \sum_1^{npt} \sigma_{p,i} A_{p,i}}{\alpha \beta \sigma'_{cc} b} \tag{5}$$

where, α & β are equivalent confined concrete stress block parameters (0.92 and 0.96 respectively for $\theta = 2\%$) and σ'_{cc} is the confined concrete strength calculated using Mander's model$^{5)}$.

Then, moment capacity at various drifts are obtained by taking corresponding NA depth, calculating the elongation and stress in PT tendon at that drift and using equation (6).

$$M_\theta = \sum \sigma_{p\theta,i} A_{p,i}\, d_{pi} - \left(\sum \sigma_{p\theta,i} A_{p,i} + N\right).\beta_\theta x_{n\theta}/2 + ND/2 \tag{6}$$

3. Results and discussion

AS method and AIJ method were used to evaluate the lateral load capacity at different drift of the 2 rocking wall specimens. Comparison of backbone curves with the test are plotted in fig.3 and the maximum shear and PT stress are listed in Table 2.

Table 2. Comparison of maximum shear and PT stress

		NSW6A	NSW7A
1	$Q_{u,\,(exp)}$ (kN)	465	226
2	$Q_{u,\,(AIJ)}$ (kN)	390	193
3	$Q_{u,\,(AS)}$ (kN)	449	243
4	$\sigma_{pu,\,(exp)}$ (N/mm^2)	1008	973
5	$\sigma_{pu,\,(AIJ)}$ (N/mm^2)	740	607
6	$\sigma_{pu,\,(AS)}$ (N/mm^2)	1022	1026
7	$Q_{u,\,(AIJ\ with\ \sigma pu,\,exp)}$ (kN)	431	229
8	$Q_{u,\,(exp)}/\ Q_{u,\,(AIJ)}$	1.19	1.17
9	$Q_{u,\,(exp)}/\ Q_{u,\,(AS)}$	1.04	0.93
10	$\sigma_{u,\,(exp)}/\ \sigma_{u,\,(AIJ)}$	1.36	1.60
11	$\sigma_{u,\,(exp)}/\ \sigma_{u,\,(AS)}$	0.99	0.95
12	$Q_{u,\,(exp)}/\ Q_{u,\,(AIJ\ with\ \sigma pu,\,exp)}$	1.08	0.98

* Row 7 was calculated by taking $\sigma_{pu,\,exp}$ to calculate the PT force in eqn (1)

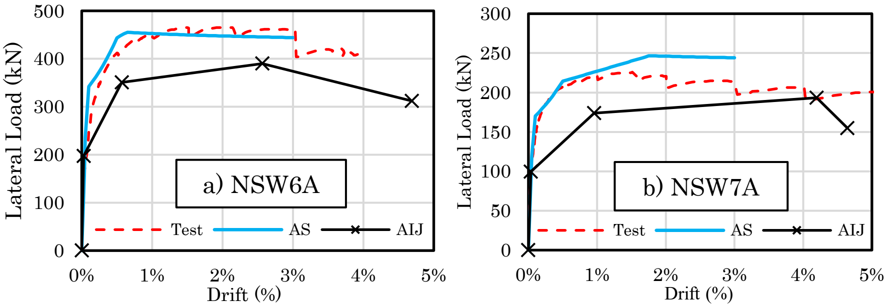

Fig.3 Backbone curves for a) NSW6A and b) NSWS7A

The AIJ method underestimates the maximum moment (and subsequently yield and ultimate moments) and this is attributed to the underestimation of the force in the PT tendons (Table 2, row 10). The scope of equation (3) covers PRC beams with long spans and hence it is unsuitable to adapt it to walls. Taking the PT stress value from experiment, AIJ estimates improve dramatically (Table 2, row 8 and 12). AS method also incorporates confined concrete properties and thus provides better accuracy.

The drift values corresponding to different performance states in AIJ are based on empirical relationship for tests on prestressed beams and columns. It predicts that the lateral stiffness drops significantly after cracking although it is not observed in the test results. In contrast, since the AS method utilizes more realistic NA depth and PT force based on drift, the backbone curve is captured better, although the load capacity beyond 3% drift is out of scope.

4. Conclusion

The AS method modified for confined rocking walls estimated the backbone curve more accurately than the current AIJ guidelines. The procedure to evaluate the tensile force of unbonded PT tendons in rocking walls should be introduced in the AIJ guidelines.

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References

1) AIJ (2015), Guidelines for Structural Design and Construction of Prestressed Concrete Buildings Based on Performance Evaluation Concept
2) Aaleti, S. & Sritharan, S. (2009), A simplified analysis method for characterizing unbonded post-tensioned precast wall systems, *Engineering Structures*
3) Obara, T., Watanabe, H, Kuwabara T, & Kono, S. (2018), Damage Controlling Performance of Unbonded Post-Tensioned Precast Concrete Walls (Japanese), *Journal of Structural and Construction Engineering, AIJ*
4) Takemoto, Y. (1984), Ultimate Tendon Stresses in Unbonded Partially Prestressed Concrete Members (Japanese), *Oyabashi Technical Research Institute Report*
5) Mander, J.B., Priestley, M.J.N, & Park, R. (1983). Theoretical Stress-Strain Model for Confined Concrete, *Journal of Structural Engineering, ASCE*

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