Nonlinear Finite Element Analysis of Prestressed Concrete Shell Element under In-Plane Shear Force

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1. Introduction

A nuclear containment is a last barrel to protect the spread of radiation materials to the environment. It is important to evaluate the performance of a containment during its service life. From this point of view, analytical research to develop nonlinear FE analysis program NUCAS[1] with the sole purpose of evaluating the ultimate pressure capacity of the prestressed concrete containment building has been carried out. In this study, nonlinear FE analysis of prestressed concrete shell element under in-plane shear force to verify the performance of the program NUCAS is employed.

2. Material models for prestressed concrete

2.1 Concrete

The yield criterion for concrete under a triaxial stress state is generally assumed to be dependent on three invariants[2]. However a dependency of the yield function on the mean normal stress I_1 and the shear stress invariant J_2 has proved to be adequate for most situations. This criterion in compression -compression region is formulated in terms of the first two stress invariants and only two material parameters are involved in its definition.

$$f(I_1, J_2) = [\beta(3J_2) + \alpha I_1]^{1/2} = \sigma_0 \tag{1}$$

where and are the material parameters and $_0$ is the equivalent effective stress taken as the compressive stress from a uniaxial test.

The response of concrete under tensile stress is assumed to be linear elastic until the cracking surface is reached. For the cracking surface we used the Niwa[3] model derived for the compression-tension region and Aoyagi-Yamada[4] model for the tension-tension region.

2.2 Reinforcement and Tendon

The material model for reinforcement and tendon are generally assumed to be identical for the tension and compression. For simplicity in a numerical analysis, the reinforcement and tendon are idealized by the one-dimensional stress-strain relationship such as an elasto plastic material model with an isotropic hardening rule.

2.3 Material Matrix

Prestressed concrete structures consist of composit materials with concrete, steel and tendon as shown in Figure 1. The total stress for the element is to be defined with respect to the stress resultants of the individual element (i.e. concrete, steel and tendon). Thus, a constitutive equation of the prestressed concrete element $\{\sigma\}$ is evaluated as

$$\begin{aligned}\{\sigma\} &= \{\sigma_c\} + \{\sigma_s\} + \{\sigma_p\} \\ &= ([\mathbf{D}_c] + [\mathbf{D}_s] + [\mathbf{D}_p])\{\varepsilon\}\end{aligned} \tag{2}$$

where, $\{\sigma_c\},\{\sigma_s\},\{\sigma_p\}$ and $[D_c],[D_s],[D_p]$ are element stress and material stiffness matrix of the concrete, steel and tendon, respectively.

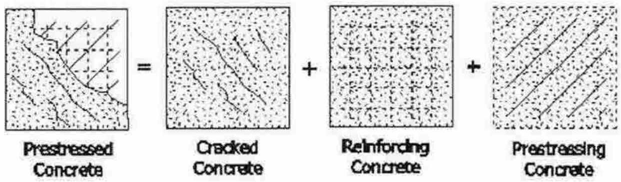

Figure 1. Layout of prestressed concrete element

3. Numerical example

The response of prestressed concrete shell panel subjected to in-plane shear stress has been extensively investigated by Marti and Meyboom. Three specimens had identical dimensions of 1,626 x 1,626 x 287mm. All three specimens were reinforced and partially Prestressed: Specimen PP1 was not prestressed, Specimen PP2 was prestressed to 2.07MPa and Specimen PP3 was prestressed to 4.40MPa.

Table 1 summarizes the main specimen properties and test results of cracking stress and ultimate load of concrete. Figure 1 shows details of the geometrical shape of the three specimens. Figure 3 shows the results of the FE analysis for all three specimens PP1, PP2 and pp3 compared to the experimental data.

Table 1. Material properties and results for the test

Specimen		PP1	PP2	PP3
Prestress, MPa		0	2.07	4.40
Concrete: f'_c, MPa		27.0	28.1	27.7
$_{0,}$		2.12	2.38	1.92
Reinforcement:	$_{px}$,% f_{yp}, MPa	- -	0.293 910	0.586 910
	$_{x}$,% f_{yx}, MPa	1.942 479	1.295 486	0.647 480
	$_{z}$,% f_{yz}, MPa	0.647 480	0.647 480	0.647 480
Crack	Test, MPa	1.71	2.54	3.15
	Analysis, MPa	1.76	2.51	3.11
Ultimate	Test, MPa	4.95	5.50	5.50
	Analysis, MPa	4.91	5.58	5.55

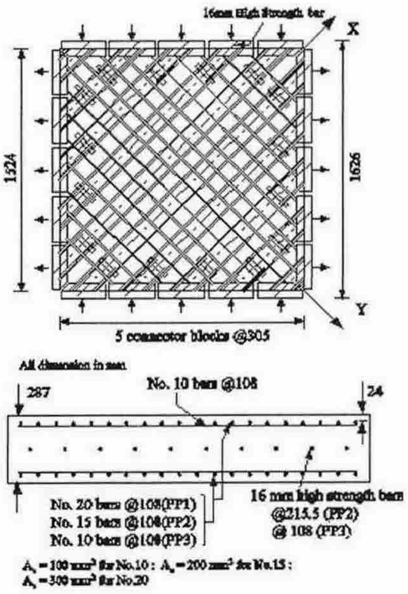

Figure 2. Geometry of the PSC test panel

From the experiment results, stress of the crack occurrence showed at a shear stress of 1.71MPa (PP1), 2.54MPa (PP2) and 3.15MPa (PP3), respectively. Nonlinear FE analysis of specimens PP1, PP2 and PP3 an predicted initial crack point of the concrete to occur at a shear stress of 1.76MPa, 2.51MPa and 3.11MPa, respectively. Form the FE analysis results, a yielding of the reinforcement were predicted to PP1=3.35, PP2=4.15 and PP3=4.43MPa, respectively. As shown in Figure 3, a very satisfactory agreement between the nonlinear FE analysis results and the experimental results is observed up to the failure stress.

As a result, the prestressing force resulted in higher cracking loads and higher ultimate loads.

4. Conclusion

The objective of the present study was to develop FE analysis program to take into account the prestressing force of reinforced concrete and prestressed concrete structures subject to in-plane shear forces. Prestressing force resulted in higher cracking load and higher ultimate load. Finally, the numerical results by this study agree very well with the experimental data.

Acknowledgement

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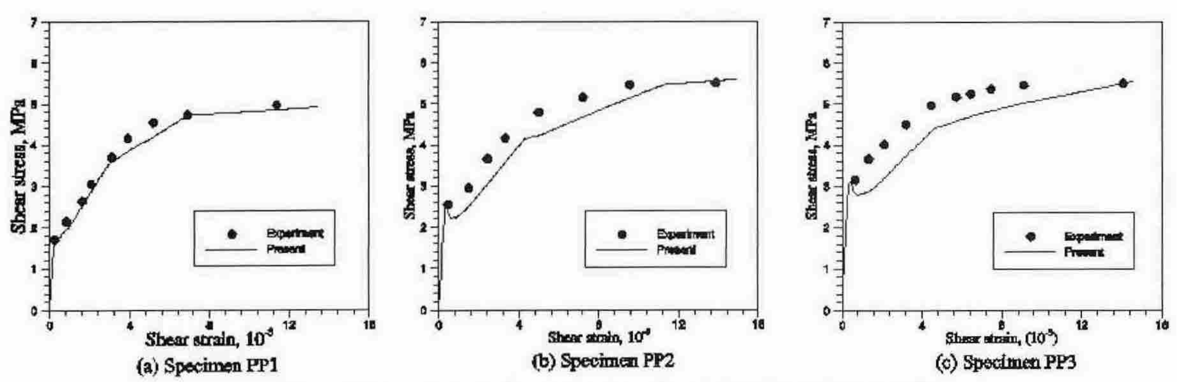

Figure 3. Shear stress-strain relation ship of analysis and experiment results