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Analytical Study on the Behavior of Prestressed Concrete Panels Subjected to Blast Load

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ABSTRACT

Blast loads generally have the potential to cause significant damage to structures. Particularly in the case of critical facilities such as nuclear power plants, they can result in immense devastation. This study focuses on examining the blast resistance performance of prestressed concrete structures commonly utilized in containment buildings. Nonlinear finite element analysis method is employed for the investigation. The behavior of panels from four different types of structural systems is analyzed: NC (Normal Concrete), RC (Reinforced Concrete), PSNC (Prestressed Normal Concrete), and PSRC (Prestressed Reinforced Concrete). Performance indicators such as maximum and residual deformations are considered. The results reveal that the prestressed concrete structure with rebars exhibits a notable improvement in blast resistance performance when compared to the other groups. Detailed specimen configurations are referenced from previous research articles (Yi et al., 2013; Wang et al., 2019).

1. INTRODUCTION

Structural safety against extreme loads generated during explosive disasters should be considered during the design of national infrastructure. Blast loads generally have the potential to cause significant damage to structures. Particularly in the case of critical facilities such as nuclear power plants, they can result in immense devastation. While numerous studies have analyzed concrete structures, there has not been sufficient analysis conducted on the behavior and failure mechanism of two-way prestressed concrete structures commonly utilized in containment buildings under blast loads. This study focuses on examining the blast resistance performance of prestressed concrete structure, considering maximum and residual deformations at the center point as performance indicators. Nonlinear finite element analysis method is employed for the investigation.

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2. ANALYSIS SETUP

Four types of specimen panels were designed for each structural system referring to the criteria of the Korean nuclear power plant APR-1400 and previous studies: NC (Normal Concrete), RC (Reinforced Concrete), PSNC (Prestressed Normal Concrete), and PSRC (Prestressed Reinforced Concrete). Fig. 1 shows the PSRC model, representing the containment wall. For this study, the PSNC or PSRC specimen was prestressed by D35 steel tendons of the same cross sectional area with pre-tensioning method, even though the actual structure is an unbonded post-tensioned concrete. To conduct performance evaluations according to different levels of prestress force, two tendon tensioning strengths of 820 kN and 580 kN were set as variables.

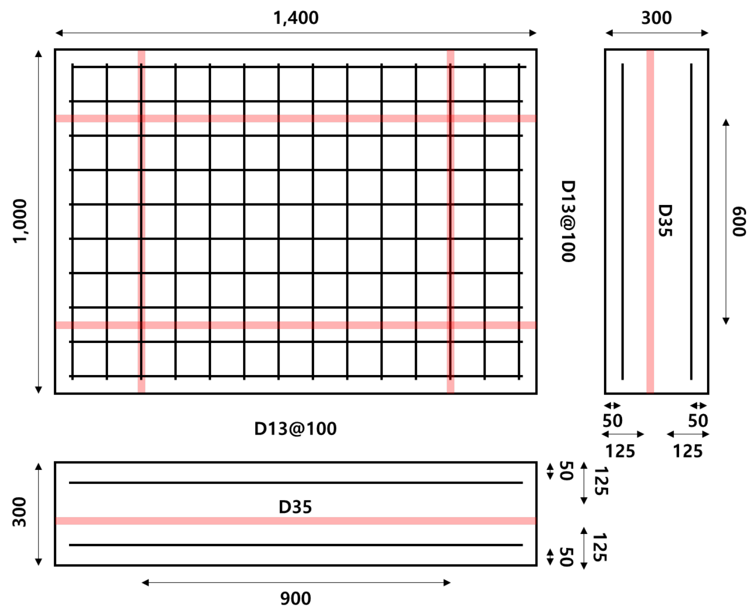


Fig. 1 Analytical model of PSRC specimen

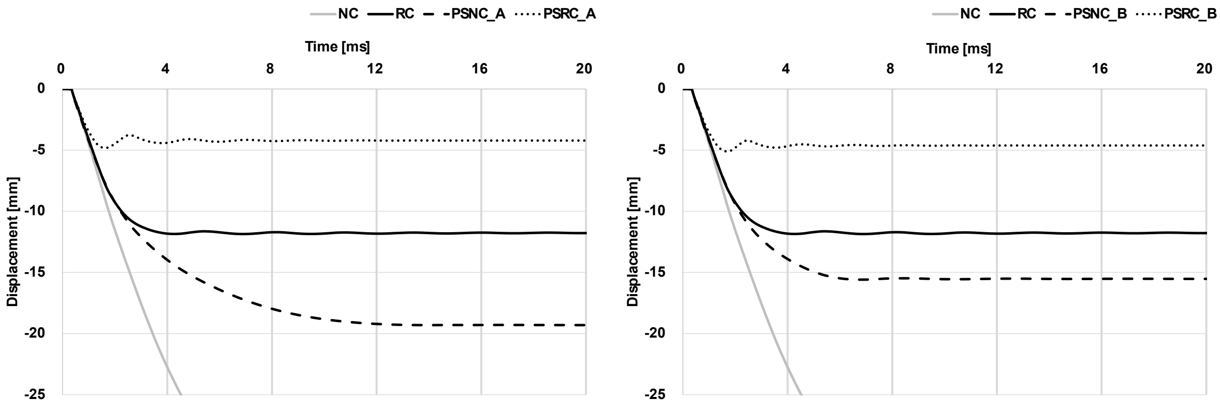
Based on the actual nuclear power plant design and relevant studies, an appropriate blast scenario was selected. It involves 18.52 kg of TNT at a distance of 1 m from the panel, with a scaled distance of 0.378 $\mathrm{m/kg^{1/3}}$. The free-air burst blast environment was applied, considering it to be the scenario closest to the actual blast test conditions, without the amplification of the initial shockwave and the influence of reflected waves. Blast loads were calculated based on the ConWep program, and during this process, the negative pressure that has a minimal impact on the structure was disregarded. The standoff distance was increased to 2 m for additional analysis, for examining the performance variation with respect to magnitude of the blast loads.

Table 1 Analysis variables

Structure type	Standoff distance (m)		Tendon Force (kN)	
NC	1	2	-	
RC			-	
PSNC			A : 820	B : 580
PSRC				

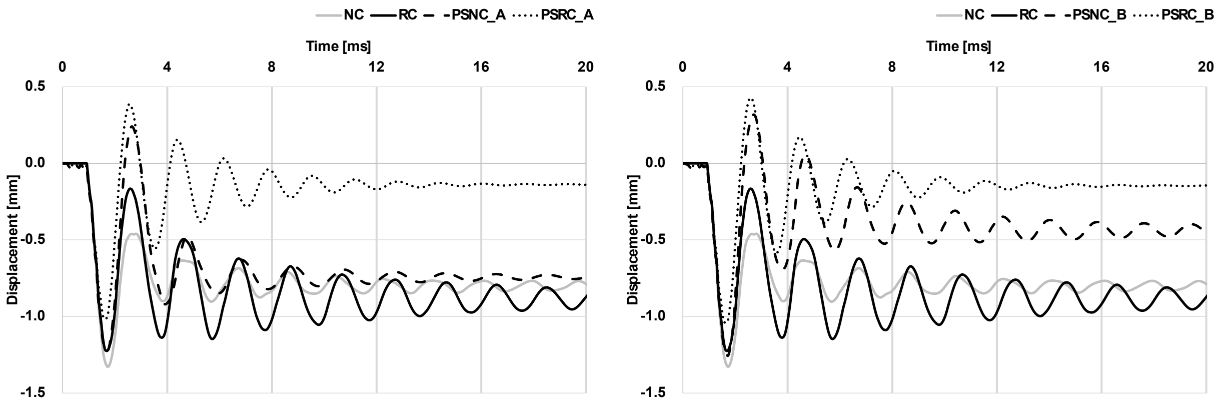
3. ANAYLSIS RESULTS AND DISCUSSION

Figs. 2 and 3 show the analysis results for different variables. The PSRC specimen demonstrates superior performance over the RC and PSNC specimens. The PSNC specimen appears to be influenced by the magnitude of the blast load more sensitively. In the case where the standoff distance is 1 m, PSNC specimen exhibits inferior performance compared to RC. However, as the blast load decreases, PSNC demonstrates better performance than RC. Moreover, unlike PSRC which shows better performance with increasing prestressing force, PSNC exhibited better performance with lower prestressing force when the blast load was significant.



(a) Type A (820 kN) (b) Type B (580 kN)

Fig. 2 Displacement response (Standoff distance = 1 m)



(a) Type A (820 kN) (b) Type B (580 Kn)

Fig. 3 Displacement response (Standoff distance = 2 m)

This can be attributed to the fact that the PSNC specimens have an insufficient amount of steel unevenly distributed compared to RC. As a result, when the blast load is relatively weak, the initial prestressing force plays a more effective role in providing resistance performance. However, under relatively strong blast, tendons can exhibit yielding behavior, leading to degraded overall performance. Furthermore, for the PSNC specimen, it was indeed observed that for some cases larger prestressing force led to poor performance such as increased extent of cracking and reduced ductility, compared to RC.

4. CONCLUSIONS

The results of this study are as follows:

1. The performance of the PSNC specimens without reinforcing bars is influenced by the behavior of the tendons, which varies according to the blast load.
2. PSRC, which is sufficiently reinforced with rebars to provide adequate ductility and tensile strength, exhibits excellent blast resistance performance.
3. Additional analyses are needed to consider aspects such as shear failure due to blast loads and to investigate the variations based on different prestressing methods.

ACKNOWLEDGEMENT

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