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Numerical analysis on projectile collision to PSC panels

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ABSTRACT

Structural safety of pre-stressed concrete (PSC) infrastructures including nuclear power plants and bridges should be guaranteed under collisions with extreme hazards. While most of prior studies on the impact resistance of panels focused on conventionally reinforced concrete and fiber-reinforced concrete members, only a few studies of PSC structures have been conducted. In this study, a series of finite element analyses using LS-DYNA on projectile collision to PSC panels were carried out to identify the effect of prestressing steel and prestressing force (Ahn and Kang 2021; Kim et al. 2020). The perforation limit velocity for 400 × 400 (*W* × *H*) mm PSC panels having thicknesses of 60, 80, and 100 mm was determined by nonlinear analysis. Two levels of prestressing force of 2.5 and 5 MPa and flat type projectile having a mass of 1 kg and diameter of 20 mm were considered in the analysis. Also, twelve finite element analyses were conducted to estimate the damage mode and energy dissipation performance of PSC panels. The analytical models were verified by baseline experimental results and sensitivity studies. The analytical results show that prestressing force effectively improves penetration and perforation resistance of the concrete panel.

1. RESEARCH METHODOLOGY

Two sizes of prestressed concrete panels were numerically analyzed to verify the effect of prestressing to impact resistance performance: 1) 2,000 × 2,000 × 500 mm (*W* × *H* × *D*) concrete panels with un-deformable and deformable missiles having an impact velocity of 170 m/s (Ahn and Kang 2021); and 2) 400 × 400 mm (*W* × *H*) concrete panels with a depth of 60, 80 and 100 mm applied by an elastic missile (Kim et al. 2020). Numerical analysis was performed using LS-DYNA commonly used for impact and explosion analysis. Each component constituting the prestressed concrete panel was realistically modeled as shown in Fig. 1 and Fig. 2(a). The nonlinear and strain rate effects of materials were considered for accurate analysis. The prestressing force was applied to the concrete panel prior to impact as shown in Fig. 2(b). Table 1 and

Table 2 summarize specimen details.

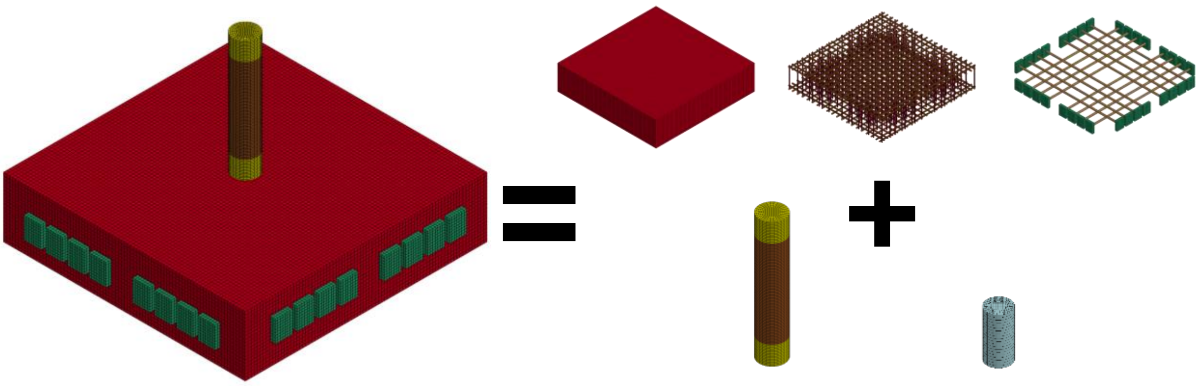
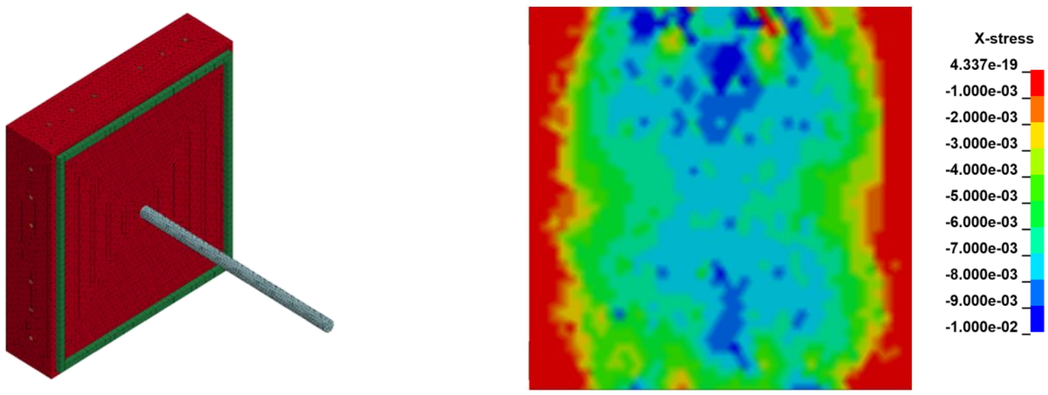


Fig. 1 Finite element model for un-deformable and deformable missile impact



(a) finite element model (b) prestress distribution before impact

Fig. 2 Small-size impact analysis

Table 1 Specimen details and analytical results of large-size impact scenario

Specimen	Projectile	Prestressing bar	Pre-compressive stress in concrete [MPa]	Fracture mode	Peak impact force [kN]
U_RC	Un-deformable missile	X	-	Just perforation	29,605
U_0.0		O	0	Just perforation	28,911
U_1.2		O	1.2	Just perforation	31,680
U_2.4		O	2.4	Just perforation	32,783
U_3.7		O	3.7	Scabbing	33,862
U_4.9		O	4.9	Scabbing	34,550
D_RC	Deformed missile	X	-	Scabbing	27,748
D_0.0		O	0	Scabbing	27,751
D_1.2		O	1.2	Scabbing	28,476
D_2.4		O	2.4	Scabbing	28,880
D_3.7		O	3.7	Scabbing	31,549

D_4.9		O	4.9	Scabbing	33,121

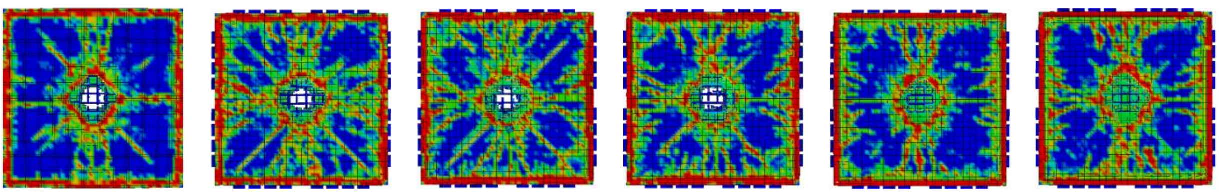
Table 2 Specimen details and analytical results of small-size impact scenario

Specimens	Pre-compressive stress in concrete [MPa]	Ballistic limit [m/s]			Analytical velocity normalized by predicted velocity	
		Analysis	CEA-EDF (Berriaud et al. 1978)	Kim et al. (2020)	CEA-EDF	Kim et al.
60_RC	-	65	57.0	66.2	1.14	0.98
60_2.5	2.5	75	57.0	74.2	1.32	0.98
60_5.0	5.0	85	57.0	77.9	1.49	1.06
80_RC	-	90	83.7	100.9	1.08	0.89
80_2.5	2.5	125	83.7	113.0	1.49	1.08
80_5.0	5.0	150	83.7	118.8	1.79	1.24
100_RC	-	95	112.7	139.9	0.84	0.68
100_2.5	2.5	135	112.7	156.7	1.19	0.85
100_5.0	5.0	155	112.7	164.7	1.38	0.93

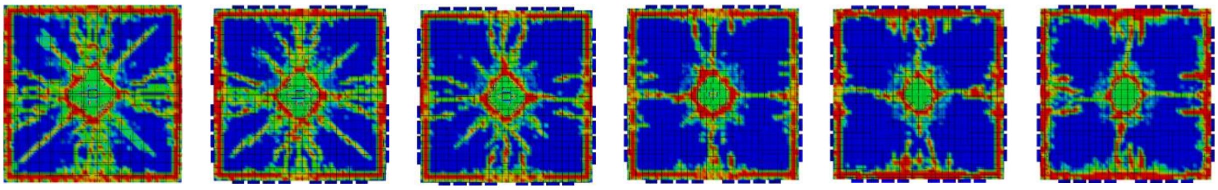
2. ANALYTICAL RESULTS

Analytical results are summarized in Table 1 and Table 2. Fig. 3 shows that perforation did not occur at U_3.7 and U_4.9 having high-level of prestressing force. In the case of un-deformed missile impacts, while the scabbed area was little to none. Affected by increased prestressing force, the number and length of cracks were significantly reduced. Fig. 4(a) shows that the rebar and stressing bar could directly increase the impact resistance performance of concrete panels. Structure-impactor interaction was well simulated as shown in Fig. 4(b).

Table 2 shows a proportional relationship between ballistic limit and prestressing force. It was confirmed that while the CEA-EDF equation predicts the ballistic limit of reinforced concrete panels with an accuracy ratio of 1.02, the ratio for prestressed concrete panels is 1.44. However, Kim et al. equation, which was improved to consider confined concrete, shows a good accuracy ratio of 0.98 for small-size specimens.

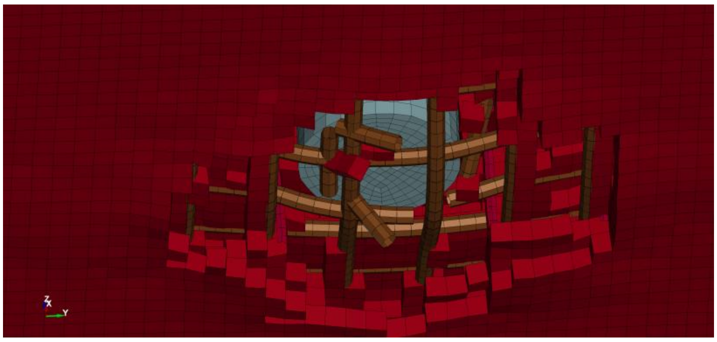


(a) U_RC (b) U_0.0 (c) U_1.2 (d) U_2.4 (e) U_3.7 (f) U_4.9



(g) D_RC (h) D_0.0 (i) D_1.2 (j) D_2.4 (k) D_3.7 (l) D_4.9

Fig. 3 Analytical results of large-size model



(a) prestressed concrete panel

(b) deformable missile

Fig. 4 Fracture shapes

4. CONCLUSIONS

In this study, a series of impact simulations of both small-size and large-size prestressed concrete panels were well performed. It was confirmed that just adding prestressing bar has a little effect on the improvement of the perforation resistance performance, but an increase in prestressing greatly improves the performance. Furthermore, prestressing enhances the overall structural response by suppressing the occurrence of cracks in concrete members against the un-deformable and deformable missile impact. It was verified that Kim et al. equation predicts the ballistic limit of prestressed concrete panels with high accuracy under limited impact conditions. Further experimental and analytical studies are needed to expand to a common range.

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