Local behavior of reinforced concrete slabs to aircraft engine projectile impact

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1. Introduction

Structural safety evaluation of nuclear power plant considers two distinct types of structural failure, local failure and global failure. In the local failure evaluation, considered projectiles can be divided as internal and external projectile according to the impact location, and they also can be divided as rigid and soft projectile according to the deformation level after impact. Frequently considered projectiles are aircraft engine, tornado, and turbine projectile. When the speed and weight of the projectiles are considered, the most influential projectile is aircraft engine, which is one of the soft projectiles.

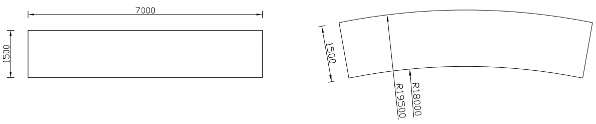
Sugano et al. [1] performed impact test using an engine model projectile, which is derived from GE-J79 engine and concentrated mass-spring model idealization. Kojima [2] and Sugano et al. [1] demonstrated from their experiments that steel liner on the rear side of the concrete wall reduces impact induced damage and suppresses debris scattering. Chung et al. [3] performed comparison study of various formulae suggested for local damage evaluation using previously performed numerous local impact test results. Also, they validated a methodology of numerical analysis for impact simulation using LS-DYNA [4]. Previously suggested formulae and research results do not consider the effect of liner plate or curved shape of the containment building walls on the local damage.

In this research, flat wall and curved wall are individually modeled using the same curvature of nuclear power plants, and the effects of curvature and liner plates on the local damage are analytically investigated.

2. Numerical impact analysis

Figure 1 illustrates the sectional shapes of two distinct types of targets considered in the numerical impact analysis. The curvature-type target model has the same curvature value as containment building of small-medium-type nuclear power plants. The dimensions of the targets are 7m, 7m, and 1.5m in height, width and thickness respectively. The layout of the rebars is shown in the Figure 2, and the diameters and sectional areas of the rebars are listed in the Table 1.

Commercial explicit dynamic analysis code, LS-DYNA is adopted for numerical impact analysis, and aircraft engine is selected as a projectile. Aircraft engine projectile is modeled according to the idealized soft projectile model suggested by Sugano et al. [1].



(a) Flat-type (b) Curvature-type
Fig. 1. Sectional shapes of the concrete targets

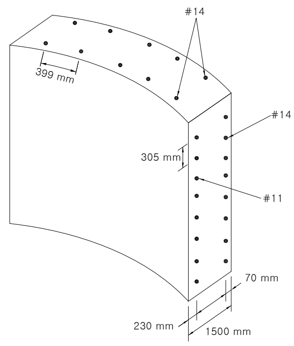


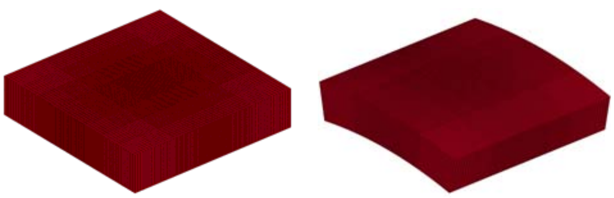
Fig. 2. Reinforcement layout (ref. Korean-type Nuclear Power Plant)

Table I: Rebar diameter and sectional area

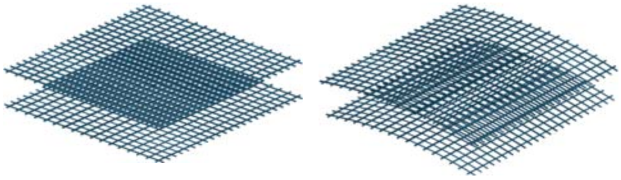
Rebar #	Diameter (mm)	Sectional area (mm^2)
#11	35.8	1006
#14	43.0	1452

2.1 Finite element model

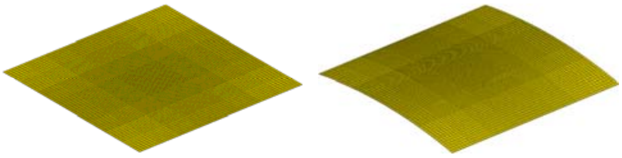
8-node solid element is used for the modeling of the concrete slab and the steel liner plate, and truss element is used for the modeling of rebars. The overall shapes of FE models are shown in the Figure 3 ~ 5. Fixed boundary condition is applied on the four edges of the slabs since these models are a part of wall structures.



(a) Flat type (b) Curvature type
Fig. 3. FE Model of Concrete target



(a) Flat type (b) Curvature type
Fig. 4. FE Model of Rebars



(a) Flat type (b) Curvature type
Fig. 5. FE Model of Steel liner

(a) exterior (b) section
Fig. 6. FE Model of the projectile.

A total of four distinct types of targets are modeled and named as F-NSL, F-SL, CS-NSL, and CS-SL, where the acronym F and CS stands for “flat” and “curved shape”, and the acronym SL and NSL stands for “steel liner” and “no-steel linear”.

Aircraft engine projectile is modeled using 8-node solid element as shown in the Figure 6 based on the previous research of Sugano et al. [1]. The total weight of the projectile is 1470 kgf, and the impact velocity is assumed as 215 m/sec.

2.2 Material model

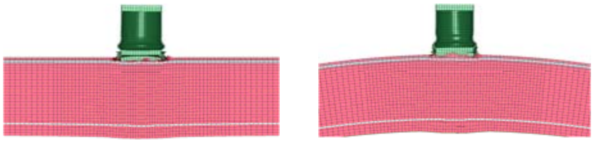
A number of material models are supplied by LS-DYNA for nonlinear concrete, such as CSCM, Winfrith, Concrete damage rel.3, etc. Chung et al. [3] applied the three concrete models for impact simulations and compared the results with experimental test results presented by other researches. As a result, they demonstrated that the CSCM concrete model shows the closest results to the test results. Therefore, CSCM concrete model is adopted in this research, and the strain rate effect is included considering the speed of the projectile (215 m/sec) and the compressive strength of the concrete (41.38 MPa). Plastic_kinematic material model is applied for the modeling of rebars, steel liner plate, and projectile. The material properties of steel parts are listed in the Table II.

Table II: Material properties of steel

	Rebar	Projectile	Liner
E (MPa)	199,075	201,000	210,000
σ_y (MPa)	411.88	349.10	220.63
υ	0.3	0.3	0.3

3. Analysis results

Figure 7 shows sectional views at the impact instants, and the maximum deflections and penetration depths are listed in the Table III. As shown in the figures and the Table, considerable deformations are observed. Among the two parameters of curvature and liner plate, curvature showed more remarkable influence in reducing penetration depth. In contrast, according to the maximum deflection, liner plate affects more than curvature.



(a) F-NSL (b) CS-SL
Fig. 7. Sectional view at the impact instant

Table III: Penetration depth & max. deflection (mm)

Case	Penetration depth (mm)	Max. deflection (mm)
F-NSL	100.08	278.65
F-SL	95.65	79.24
CS-NSL	89.18	268.28
CS-SL	86.13	78.80

4. Conclusion

According to the results of numerical impact analyses, both curvature and liner plate reduce the penetration depth, and curvature shows larger influence. Due to the consideration of the curvature, penetration depth is reduced by 10~11% than the flat slab.

In contrast, reduction of maximum deflection is more affected by existence of liner plate that curvature. Maximum displacement is reduced by 70.6~71.6% due to the consideration of the liner plate.

Consequently, more reliable local damage evaluation is possible by considering the curvature of the wall and the effect of the liner plate.

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