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A preliminary study on the local impact behavior of Steel-plate Concrete walls

Kap-sun Kim [a,*], Il-hwan Moon [b], Hyung-jin Choi [c], Deok-woo Nam [a]

[a] Korea Hydro & Nuclear Power Co., LTD Central Research Institute, South Korea
[b] KEPCO Engineering & Construction Company, Inc., South Korea
[c] Karagozian & Case, USA

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ABSTRACT

International regulations for nuclear power plants strictly prescribe the design requirements for local impact loads, such as aircraft engine impact, and internal and external missile impact. However, the local impact characteristics of Steel-plate Concrete (SC) walls are not easy to evaluate precisely because the dynamic impact behavior of SC walls which include external steel plate, internal concrete, tie-bars, and studs, is so complex.

In this study, dynamic impact characteristics of SC walls subjected to local missile impact load are investigated via actual high-speed impact test and numerical simulation. Three velocity checkout tests and four SC wall tests were performed at the Energetic Materials Research and Testing Center (EMRTC) site in the USA. Initial and residual velocity of the missile, strain and acceleration of the back plate, local failure mode (penetration, bulging, splitting and perforation) and deformation size, etc. were measured to study the local behavior of the specimen using high speed cameras and various other instrumentation devices. In addition, a more advanced and applicable numerical simulation method using the finite element (FE) method is proposed and verified by the experimental results.

Finally, the experimental results are compared with the local failure evaluation formula for SC walls recently proposed, and future research directions for the development of a refined design method for SC walls are reviewed.

1. INTRODUCTION

According to the International and Korean regulations for nuclear power plants, a nuclear power plant must be able to withstand local impact loads, such as aircraft engine impact, and internal and external missile impact.

These days, SC structure is widely used internationally for nuclear power plant design because of its efficiency of fabrication, erection, and construction. Although extensive studies on the local impact behavior of the conventional RC (reinforced concrete) wall have been performed, and the design methodologies to prevent local failure are already established and included in NEI 07-13 (NEI, 2011) and DOE-STD-3014 (U.S. DOE, 2006), there is no such design methodology available for SC walls except for the one recently suggested by Bruhl et al. (2015).

In general, two types of methods have been applied to evaluate the local impact behavior of the wall. The first involves a numerical simulation using the FE method, and the second is an actual test using a prototype or scale model. Although actual testing is an accurate means of confirming the performance of the wall and verifying the numerical tools and modeling methodology used in the analysis, actual tests are often very expensive. Therefore, they can be performed only in limited cases and only as a Supplementary Method.

In this study, a series of actual high-speed impact tests are performed to confirm the local impact behavior of SC walls and verify the proposed numerical simulation method. In addition, an improved numerical simulation technique using the FE method via the commercial FE code LS-DYNA is introduced, and the detailed local impact characteristics of SC walls subjected to local missile impact load are investigated using the suggested numerical simulation method. Finally, the results are compared with the design methodology for SC walls recently proposed, and future research directions for the development of a refined design method for SC walls are reviewed (Kim et al., 2015)

* Corresponding author.
E-mail address: kapskim11@khnp.co.kr (K.-s. Kim).

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2. Actual impact test

2.1. Test aim

The objectives of the actual impact test are to confirm the dynamic impact characteristics of SC wall models and to verify the proposed numerical simulation method used in the analyses. These objectives are achieved by comparing the numerical and physical test results. Total four SC wall models with four sets of projectile are used in impact tests. The initial impact velocity is designed as 150 m/s for all cases.

2.2. Projectile design

The selection of a suitable scale for the testing program is critically important and must consider both the relevance and validity of the test results as well as practicability and cost-effectiveness. The existing testing facilities (gas-gun) in the EMRTC cater for projectiles of up to approx. 6″ diameter, with reference to Table 1, this result in a test scale of around 1/10.

The proposed solution is to consider the effectiveness of the penetrator in terms of Kinetic Areal Density (the magnitude of kinetic energy imparted by the projectile, per unit area). This approach will consider the engine simulant as a comparable penetrator and model its penetration capacity or effectiveness. A comparison of Kinetic Areal Density for the full-scale engine impact and the test article is shown in the Fig. 1, and the projectile design is shown in the Fig. 2. Projectile diameter will be 150 mm with an overall length of 300 mm. The front end of the projectile will have a slight ogive, but will be aerodynamically unstable. The weight of the projectile and sabot parts will be approximately 40kgf.

2.3. Specimen design

A several preliminary analyses are carried out using commercial FE program LS-DYNA in order to determine the design data for test panel. The SC panels which consist of the concrete having 150–250 mm thickness and steel plate having 4 mm and 6 mm thickness are considered. Based on the results of preliminary analysis, the four types SC panels are set to the final test panels. Table 2 shows the design parameters of the final test panel. The detailed designs of the final test panel are shown in Fig. 3. The SC panel specimens consist of external steel plate, internal concrete, and studs. Basically, this SC panel model has the same design as a real SC wall of the nuclear power plant, except for the absence of tie-bars and H-beam ribs. The overall size of the SC wall model is 2000 mm × 2000 mm, and the thickness of the wall is 175 mm and 250 mm, and the thickness of the steel plate is 4 mm and 6 mm. There is no tie-bar in this test panel, and the studs having 13 mm diameter and 80 mm length are installed in 150 mm intervals.

Table 1
Scaling of the Engine Simulant.

Test Scale	Engine Simulant Dimensions	
	Diameter(mm)	Length(mm)
Full Scale	1400	2130
Tenth Scale	140	213

2.4. Test facility and instrumentation

All tests were conducted using the EMRTC custom 6.4 in. smooth bore gas-gun. The gun tube was mounted on an M174 sled mount. M30 propellant with a 073 web size was used as the main charge. The charge weight was need to be dialed into achieve a projectile velocity of 150 m/s. Velocity checkout tests were conducted prior to testing of customers penetrators in order to ensure a velocity of 150 m/s.

Fig. 4 illustrates the location of the instrumentation and the overall views of the test setup. Five Strain gauges and two accelerometers were applied to the back of all SC panel targets before testing starts, and two high speed cameras were used to record the penetrator both before and after entering the concrete target. In addition, 8 foot long zebra boards were positioned behind the target to record velocity.

3. Outline of numerical analysis

3.1. Numerical analysis method

Numerous alternative methods are available for the SC panel's local impact analysis, ranging from the quasi-static methods that use a static implicit FE code to the detailed dynamic analyses that use a nonlinear explicit FE code. In this study, the dynamic impact characteristics of the model are investigated using an explicit nonlinear dynamic FE simulation with a three-dimensional detailed

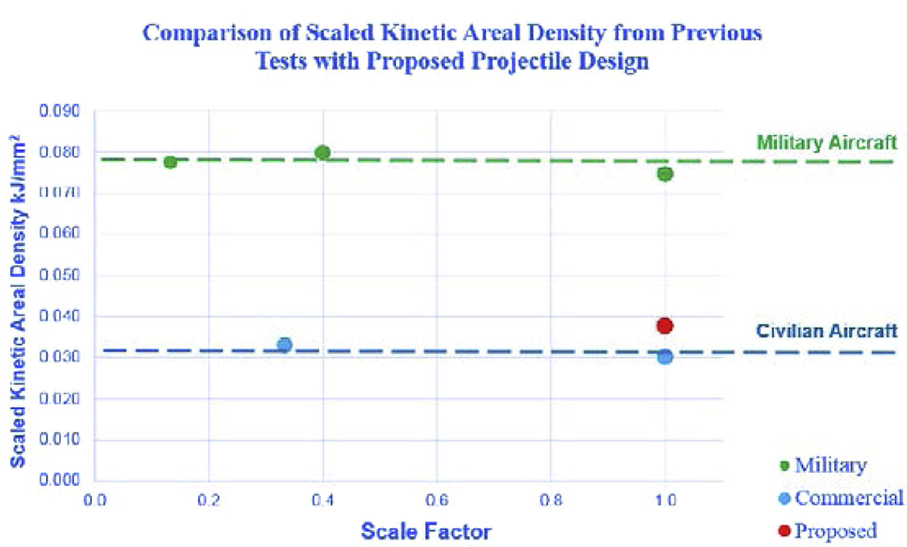

Fig. 1. Comparison of Scaled Kinetic Areal Density.