Numerical simulations of normal penetration of tandem charge weapons into concrete targets

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1. Introduction

As military and industrial facilities have been buried for its protection, penetrator warhead has been also developed to enhance the performance of penetration against HDBTs. A tandem weapon that has an explosive device and penetrator has been designed for deep penetration and enhancement of effectiveness weapon by exploding inside the targets. The first stage of the weapon, which is typically a weak shaped charge, pierces the targets without detonating it leaving a channel through the target so that the penetration power of the second warhead may increase due to the reduction of resistance on the projectile. The related problems of penetration into concrete targets are emphasized to improve the penetration effect and the corresponding capability of the penetration warheads. In defense applications, concrete has been widely utilized for HDBTs because it is known for cost-effective materials. Although concrete shows inherently brittle and very weak in tensile stress, its high compressive strength leads to versatile applications for construction and military field. Thus, it is necessary to understand the physical phenomena of penetration into concrete targets and analyze the penetration process of tandem warheads.

In this paper, we considered penetration into concrete targets with a finite length cavity induced by a shaped charge of tandem warheads. We developed a semi-empirical model which is based on spherical cavity expansion theory [1] for penetration analysis of tandem warheads. The damaged target is assumed as a cylinder cavity of finite length with a uniform radius. For the verification of our proposed model, we compared it with experimental data of undamaged [2, 3] and damaged targets.

2. Semi-empirical model for damaged concrete targets

An analytical model for penetration into undamaged concrete targets was developed by Forrestal et al. [2]. They considered a normal impact of a rigid projectile on concrete targets. The normal stress acting on the projectile, which was derived from the spherical cavity-expansion theory [1, 3], can be expressed as

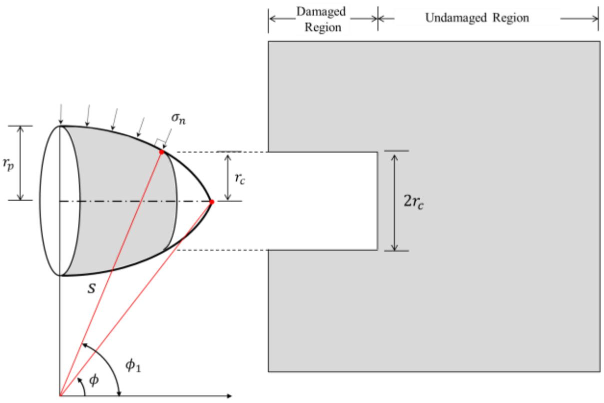

Fig.1 Schematic description of penetration of a projectile into a damaged concrete target containing a pre-drilled cavity.

$$\sigma_n = D_c + \rho v_n^2 \tag{1}$$

where D_c is the strength parameter of undamaged concrete, ρ is the density of concrete targets, and v_n is the rigid-body velocity of the projectile that is equal to the cavity expansion velocity. To estimate the axial force of the projectile, which is the resistance by the damaged concrete target, the normal stress is integrated over part of the projectile surface area in contact with the target as shown in Fig. 1. As a result, the axial force of the projectile into the pre-drilled concrete target is expressed as

$$F_x = \alpha + \beta v_n^2$$

with $\alpha = \pi r_p^2 D_h \left(1 - R^2\right)$

and $\beta = \frac{\pi r_p^2 \rho}{24\psi^2}\left\langle (8\psi - 1) - R^2\left\{6(4\psi - 1) + 8R(1 - 2\psi) - 3R^2\right\}\right\rangle$

where r_p is the projectile radius, $R = r_c / r_p$ indicates the normalized cavity radius, and ψ is the caliber-radius-head of the ogive-nosed projectile. The empirical constant, termed strength parameter D_h for the damaged region in the current study, can be obtained from the experiment results of the penetration depth with respect to the striking velocity. In this paper, the penetration depth, velocity, and acceleration of a projectile are numerically evaluated by solving the equations of motion by means of the fourth-order Runge-Kutta algorithm.

3. Results and Discussion

For validation of our proposed method, we analyzed a normal impact of an ogive-nosed projectile on the undamaged concrete target and compared the obtained results to the experimental data [3]. The projectile was machined by 4340 Rc45 steel with a diameter of 80 mm, length of 530 mm, CRH of 3.0, and mass of 13 kg. The concrete target had an average compressive strength of 39 MPa and a density of 2250 kg/m^3. The final penetration depth, time histories of displacement, velocity, and acceleration obtained using the semi-empirical model were compared to the experimental data [3] and Autodyn results at impact velocity of 238 m/s. Fig. 2 shows time profiles of the velocity and acceleration of the projectile, which were evaluated using the semi-empirical model, numerical method, and experimental method. Overall, the results from the semi-empirical model were consistent with those from the numerical method.

We performed a penetration analysis of damaged concrete targets with a certain length of a pre-drilled cavity that ranged from 0 to 700 mm. The radius of the pre-drilled cavity was fixed to 0.015 m, which is corresponding relative cavity radius (*R*) of 0.375. For the lack of experimental data, we conducted a penetration analysis with the aid of explicit FEM. Fig. 3 presents penetration depth versus cavity length. We found that penetration depth increases obviously in proportion to the cavity length because the resistance on the projectile decreases in the damaged region. The slope varies by three factors such as initial contact distance, crater region assumed as $4r_p$, and maximum penetration depth, which is identical to that of the damaged concrete target with cavity of the infinite length, as shown in Fig. 3. With a given cavity radius, maximum penetration depth is limited by the concrete target with the cavity of infinite length. For comparison, the explicit FEM results were obtained and plotted together in Fig. 3. It shows that the results from the semi-empirical model were in good agreement with the numerical results.

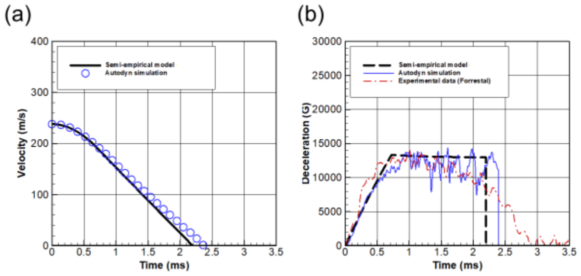

Fig.2 Comparison of semi-empirical with, numerical, and experimental results [3] at an impact velocity of 238 m/s: (a) velocity and (b) acceleration.

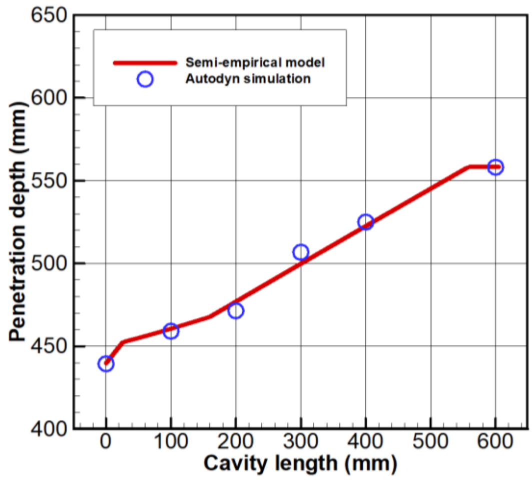

Fig.3 Comparison of penetration depth obtained by the semi-empirical model and the explicit FEM.

From the results of explicit FEM, we demonstrated that our proposed model is a simple and accurate method for estimating the performance of tandem warhead. The present study deepens the understanding of penetration analysis of tandem warhead. We believe that our findings will provide a useful tool for designing tandem warhead and enhance the efficiency of the design of a tandem warhead.

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