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Penetration analysis of projectile with inclined concrete target

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Abstract. This paper presents numerical analysis result of projectile penetration with concrete target. We applied dynamic material properties of 4340 steels, aluminium and explosive for projectile body. Dynamic material properties were measured with static tensile testing machine and Hopkinson pressure bar tests. Moreover, we used three concrete damage models included in LS-DYNA 3D, such as SOIL_CONCRETE, CSCM (cap model with smooth interaction) and CONCRETE_DAMAGE (K&C concrete) models. Strain rate effect for concrete material is important to predict the fracture deformation and shape of concrete, and penetration depth for projectiles. CONCRETE_DAMAGE model with strain rate effect also applied to penetration analysis. Analysis result with CSCM model shows good agreement with penetration experimental data. The projectile trace and fracture shapes of concrete target were compared with experimental data.

1. Introduction

Generally, the concrete penetration experiment evaluates survivability, deceleration, penetration depth and residual stress of projectile [1–5]. In this study, we performed a penetration test and analysis of warhead with concrete target. The main purpose of test is to evaluate the survivability of warhead against to inclined concrete target.

Analysis results were compared with the test result of sled equipment. Concrete damage models that were provided by the LS-DYNA commercial codes [6] were applied for penetration analysis of concrete target.

2. Penetration analysis

2.1. Modelling and analysis condition

Projectile and concrete target were modelled as a half shapes in consideration of symmetry, as shown in Fig. 1. Steel supporters were modelled as a rigid body (rigid wall) to support the concrete target. Supporters were located at front and rear side and a lower part of two concrete targets.

Figure 2 shows the detailed projectile shapes. Projectile is composed of 4340 steel warhead case, explosive and fuze and aluminium shroud head and body. Figure 3 shows concrete target with strength of 5000 psi. Two layers of concrete are inclined with 30 degrees. Initial impact conditions are the same with the sled experimental conditions. Projectile of 232 kg impacts with initial velocity of 333 m/s.

Target shape after sled test is shown in Fig. 4. Warhead penetrated the first layer of concrete, but did not pass through the second layer of concrete. Finally, the warhead has been fractured at the middle region of body.

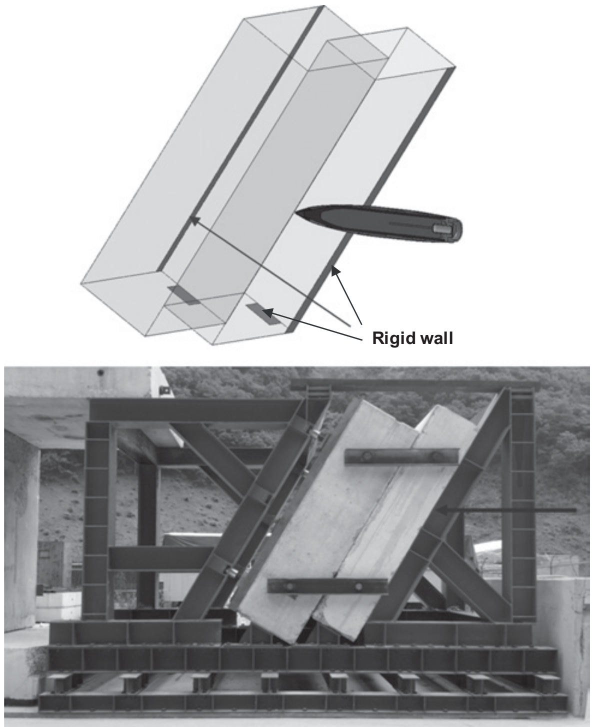

Figure 1. Concrete target.

2.2. Mechanical properties

Material of warhead body is 4340 steel with heat treatment. Simplified Johnson-Cook model for steel is utilized for penetration analysis. Figure 5 shows the yield stress distribution with strain rate obtained from the static tensile testing machine and Hopkinson pressure bar testing machine. Table 1 show the coefficients for J-C model of 4340 steel. Figure 6 shows concrete strength distribution with respect to the test age. Sled test was performed after

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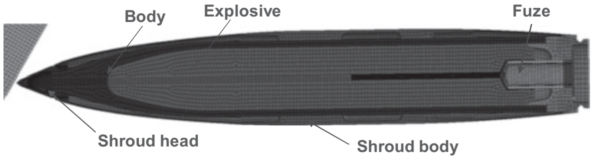

Figure 2. Projectile modelling.

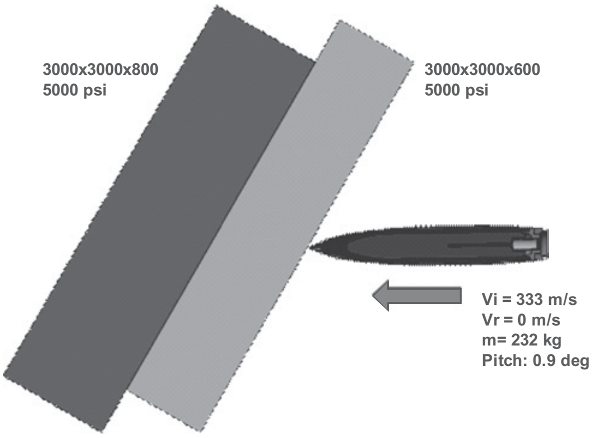

Figure 3. Projectile and target modelling.

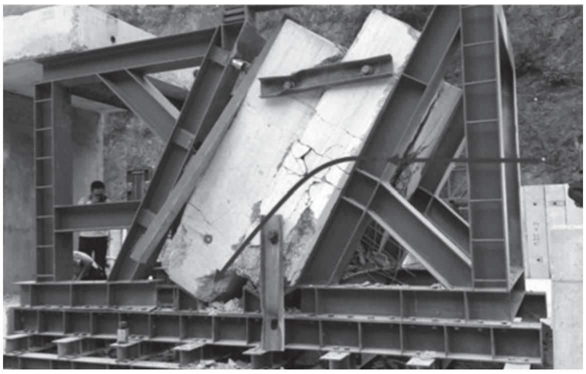

Figure 4. Concrete shape after sled penetration test.

Table 1. Coefficients of J-C model.

Coefficients of J-C model, $\sigma = (A+B\varepsilon^n)(1+C\ln(\dot{\varepsilon}/\dot{\varepsilon}_0))$	
A	1330 MPa
B	1004 MPa
n	0.5
C	0.021

4 weeks. The average concrete strength is about 5000 psi based on cube test.

2.3. Analysis result

Commercial F.E. code, LS-DYNA 3D v.971 was used with several included concrete models. Three concrete material models such as SOIL_CONCRETE, CSCM and CONCRETE_DAMAGE were utilized.

Analysis result with SOIL_CONCRETE model shows that the warhead has been failed to penetrate the target, as shown in Fig. 7. Aluminium shroud was fractured and remained at the tail part of warhead. Generally, shroud of projectile should be designed to be well fractured during the target penetration. Warhead trajectory with inclined target is different from the experimental result. Warhead was stopped with a little degree of descent direction compared with initial impact direction. Therefore, this model may be suitable to evaluate the penetration depth and residual velocity with normal direction target. However it may not be appropriate to estimate the exact

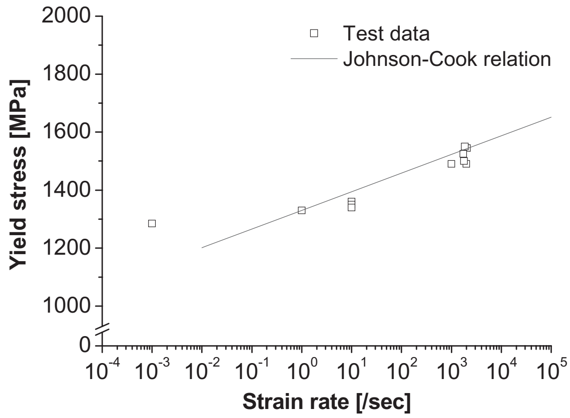

Figure 5. Yield stress distribution with strain rate for 4340 steel.

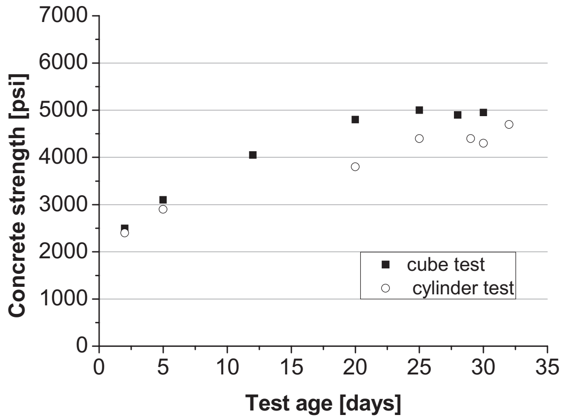

Figure 6. Concrete strength with test age.

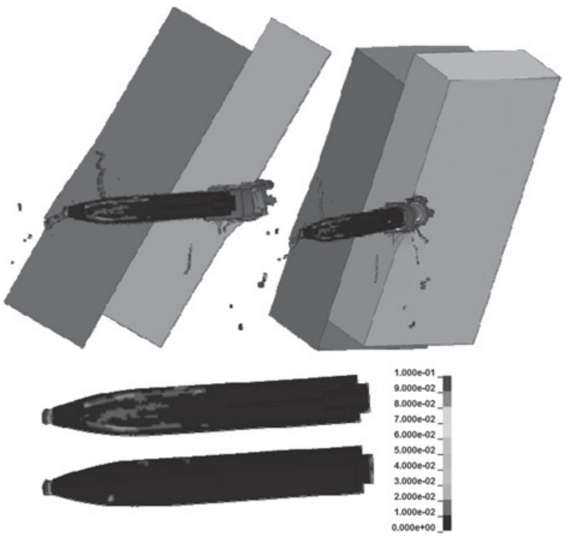

Figure 7. SOIL_CONCRETE model.

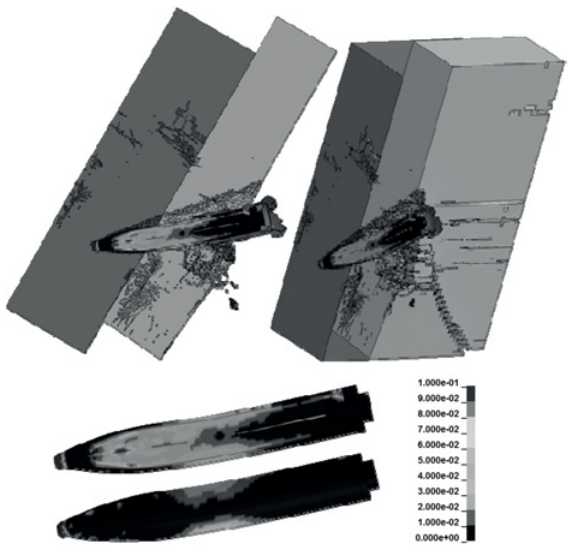

Figure 8. CSCM model.

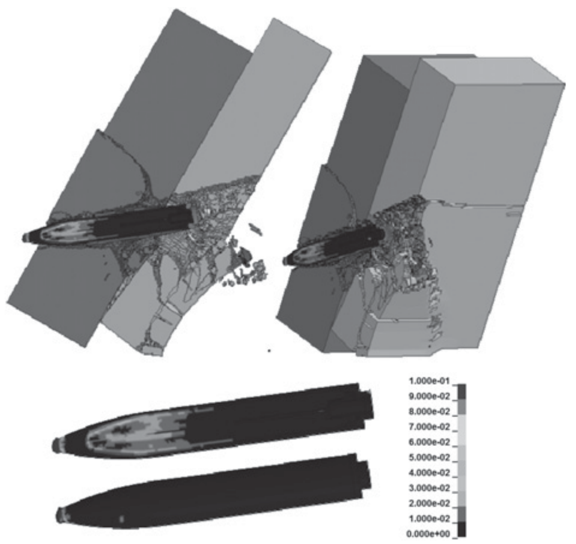

Figure 9. CONCRETE_DAMAGE model.

projectile trajectory or concrete target fracture shapes, especially for inclined target.

Figure 8 shows the analysis result with the CSCM model. Lower part of the first layer concrete cracked down toward to the edge. And warhead has stopped toward the bottom of the concrete target. In particular, the plastic deformation amount of warhead is higher than 7% at final state. This plastic strain concentrates in the central portion of the warhead, and it is likely to be fractured at this part. For 4340 steel, the fracture elongation for 4340 steel is about 7 ∼ 8% in static tensile test. During the dynamic impact penetration, fracture elongation could be decrease compared to static state.

CONCRETE_DAMAGE model shows the most severe concrete fracture, as shown in Fig. 9. This means that the concrete strength is smaller than the other concrete models. The trajectory of the warhead side down similar to the test results, but the penetration depth of the warhead in this model is the larger than the other two models. The other two models did not consider the strain rate effect of concrete. Standard CONCRETE_DAMAGE model in LS-DYNA does not use the strain rate effect of concrete. However, dynamic properties of concrete was applied to this analysis for the consideration of strain rate effect [7,8]. Generally, as strain rate increases, the strength of concrete also increases. Though considering the strain rate effect with this model, concrete strength is weak in comparison to other two models.

Thus, three analysis results with different concrete models show obviously different penetration depth, trajectory and fracture shapes in spite of the same strength for concrete (5000 psi) and the same eroding values for numerical element deletion. Compared to the penetration depth, the concrete is considered weakly in the order of CSCM, SOIL_CONCRETE and CONCRETE_DAMAGE model.

3. Conclusions

This paper presents the numerical analysis with various concrete models compared with the experimental results. Analysis result with CSCM model shows good agreement with penetration experimental data. The traces of projectile and failure shapes of concrete target were compared with experimental data.

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