Simulation on Penetration of Image Homing Rocket Projectiles in Steel Plate- Concrete Targets

Shidong Fang, Dong Chen*, Yong Li, Pan Wu and Bin’an Jiang
Artillery and Air Defense Academy, Hefei Anhui 230031, China
*Corresponding author’s e-mail 181593881@qq.com; 283644775@qq.com

Abstract. In order to study the penetration performance of image homing rocket projectile in steel plate-concrete targets, firstly, according to the characteristics of projectile and target, the material constitutive models and state equation were constructed, numerical models were built and the penetration was simulated with the software of LS- DYNA. Then, on the basis of verifying the accuracy of penetration simulation models, penetrations in two typical steel plate-concrete targets were simulated under the conditions of different slant angles. The simulation results show that the rockets can penetrate through the steel plate-concrete targets. Meanwhile, the force, velocity and penetration performance of the projectile were greatly affected by the steel plate in the process of penetration, and the impact, collapse and pit opening effect on the concrete covered by the steel plate were not obvious. In a word, the image homing rocket projectile has good penetration performance in steel plate- concrete targets, which can meet the tactical and technical requirements.

1. Introduction
Penetration performance is an important technical index for image homing rocket projectiles, which are equipped with penetrating warhead, and mainly used to hit the solid targets such as enemy bunkers and underground command posts. Generally, concrete [1] or reinforced concrete [2] targets are taken as penetrated objects for the research on the penetration performance. In recent years, with the improvement of protection requirements, more and more fortifications adopt steel plate-concrete structures with high initial stiffness, strong deformation capacity and good plastic energy dissipation for protection [3]. However, there is little research on the penetration in such targets. So it is particularly important to strengthen the research on the penetration performance of image-homing rockets in the steel plate-concrete targets.

According to the deformation characteristics of penetration object and projectile body during penetration, the Smooth Particle Hydrodynamic (SPH) method [4] and the standard Lagrangian finite element mesh method [5] were selected respectively to construct the geometric model and material constitutive model of targets and projectiles, and conduct penetration simulation. At the same time, due to the lack of test data, the theoretical calculation, literature comparison and other methods will be used to verify the simulation results, and determine the reliability of the simulation results. Then, based on the simulation results, the penetration performance of the rocket projectiles to the steel plate-concrete targets will be analyzed, which provides a reference for its effect evaluation and operational use.
2. Geometric equivalent model of projectiles and targets

2.1. Geometric equivalent model of projectile
The image homing rocket projectile's body is made of A24302 high strength alloy steel with a sharp V shape warhead, length to diameter ratio of 7.4 and projectile type coefficient $\lambda$ value of 1.5. There is high explosive in the projectile body. The equivalent model of the penetrating warhead is shown in figure 1.

![Figure 1. Geometric equivalent model of warhead](image)

2.2. Geometric equivalent models of targets
According to the penetration performance of rocket projectiles and common fortifications protection at present, the equivalent models of the steel plate-concrete composite targets will be built with concrete material of C35, steel material of Q235, and a thickness of 310cm. According to the common targets of steel plate-concrete composite board structure, two kinds of composite board targets models will be built, as shown in figure 2. Figure 2 (a) is made of single steel plate, located on the concrete bottom surface (recorded as target I), Figure 2 (b) is made of double steel plate, on the concrete top surface and bottom surface (recorded as target II).

![Figure 2. Schematic diagram of targets](image)

3. The simulation and verification
According to the characteristics of projectile body and target material, different material constitutive models will be selected, and joint modeling method will be adopted to conduct numerical modeling of projectile body and different types of targets. LS-DYNA-Solver will be used for simulation calculation, and theoretical calculation and literature comparison will be used to verify the simulation model and results. The units of the model are cm-μs-g.

3.1. Material constitutive model

3.1.1. Constitutive model of projectile body. According to projectile penetration process characteristics and material properties, the Plastic Following Material Model is selected. Parameters of the projectile body constitutive model are shown in table 1.

| Parameters | $R_{0}/g.cm^{-3}$ | $E$(GPa) | $PR$ | $\beta$ | $\varepsilon_{p}^{0}$ | $E_{inw}$(GPa) | $\sigma_{v}$(GPa) | $C$ | $P$ |
|------------|-----------------|-----------|------|-------|----------------|--------------|--------------|------|------|
| Value      | 7.85            | 210       | 0.28 | 1.8   | 2.1           | 1.6          | 1            | 100  |      |
3.1.2. **constitutive model of steel plate.** Johnson/Cook strain and temperature sensitive plastic model (J-C model for short) is adopted for steel plate, which is mainly used for large strain rate and high temperature softening problem, and can meet with simulation analysis of penetration problem of projectile to steel plate. The parameters of the steel plate constitutive model are shown in table 2 [7] (unit g-cm-gpa).

| Parameters | Value | Parameters | Value | Parameters | Value |
|------------|-------|------------|-------|------------|-------|
| $\rho$     | 7.8   | $T_r$      | 300   | $D_2$      | 0     |
| $G$        | 79    | $\dot{e}_0$| 1E-4  | $D_1$      | 0     |
| $A$        | 0.3   | $e_{min}$  | 0.1   | $D_3$      | 0     |
| $B$        | 0.426 | $CP$       | 4.77E-6| $D_2$      | 0     |
| $C$        | 0.015 | $PC$       | -9.0  | $C2/P$     | 0     |
| $n$        | 0.34  | $SPALL$    | 3.0   | $EROD$     | 0     |
| $m$        | 1.0   | $IT$       | 0.0   |            |       |
| $T_m$      | 1793  | $D_1$      | 0.4   |            |       |

In table 2, part of the symbolic meaning is as follows: $G$-shear modulus; $CP$-specific heat; $PC$-tensile failure stress or shear stress; $SPALL$-debris type, for the solid unit, 3.0 means that, the pressure is reset to 0 when $p < PC$; $IT$-plastic strain iteration option, default value is 0, no iteration; $EROD$-erosion option, default value is 0, that is to allow cell erosion; $C2/P$-optional strain rate parameter.

3.1.3. **constitutive model of Concrete.** JOHNSON_HOLMQUIST_CONCRETE model (JHC model for short) is adopted for concrete material. The main parameters of the concrete JHC material model are shown in table 3 [8] (unit g-cm-gpa).

| Parameters | Value | Parameters | Value | Parameters | Value |
|------------|-------|------------|-------|------------|-------|
| $\rho$     | 2.4   | $T$        | 0.004 | $\mu_{lock}$| 0.1   |
| $G$        | 14.86 | $\dot{e}_0$| 1E-6  | $D_1$      | 0.04  |
| $A$        | 0.79  | $e_{min}$  | 0.01  | $D_2$      | 1.0   |
| $B$        | 1.60  | $S_{max}$  | 7.0   | $K_l$      | 85    |
| $C$        | 0.007 | $P_c$      | 0.016 | $K_2$      | -171  |
| $N$        | 0.61  | $\mu_{crush}$| 0.001| $K_i$      | 208   |
| $f_t$      | 0.048 | $P_{lock}$ | 0.8   |            |       |

3.2. **Equation of state**

Gruneisen equation of state is adopted for simulation of steel plate penetration. According to the properties of steel plates, the parameters of the gruneisen equation of state are shown in table 4.

| Parameters | Value | Parameters | Value | Parameters | Value |
|------------|-------|------------|-------|------------|-------|
| $C$        | 0.4578| $S1$       | 1.33  | 0          |       |
| $S2$       | 0     | $S3$       | 1.67  | 0.43       | 1     |
| $\gamma_0$ | 0     | $\alpha$  | 0.43  |            |       |
| $E_0$      | 0     | $V_0$      | 1     |            |       |

3.3. **The numerical model**

Firstly, according to the simulation requirements of forward penetration and oblique penetration, 1/4 and 1/2 mesh models of projectile body are established in LS-DYNA, SOLID 164 is adopted for solid unit, and is exported as a K file.

Then, the K file is imported into the LS-Prepost software, and the SPH numerical models of steel plate target, concrete target and steel plate - concrete composite target are construct respectively with the SphGen tool in the software. After the contact type, penetration velocity, simulation time and other parameters are set up, the file is exported as a K file again.

Finally, simulation calculation is implemented with LS-DYNA-Solver. After the solution is completed, the "d3plot" file can be read with the LS-Prepost processing software to view and analyze the simulation results.
3.4. The simulation verification

3.4.1. The simulation verification of penetration to concrete. Firstly, the penetration depth (Record as D_e) will be estimated by empirical formula and target velocity (Record as v_0), due to the penetration depth of concrete can be affected by the thickness of target plate. Then the 3D model of concrete target will be established according to D_e, and penetration is simulated. Finally, the accuracy of penetration simulation model will be compared and analyzed.

(1) Penetration depth estimation
The D_e value of penetration depth is estimated with empirical equation by the 3th research institution of the former General Staff. \[9\]. According to the known conditions, the parameter values are calculated: \(N_1=1.328\), \(K_2=2.1\), \(\rho_c=2400\text{kg.m}^{-3}\), \(f'_c=48\text{MPa}\). Under condition of \(v_0=0.03, 0.04, 0.05, 0.06\text{ cm.us}^{-1}\), the estimated penetration depth is 245cm, 327cm, 409cm and 490cm, respectively.

(2) Simulation of penetration
The 1/4 models of targets are estimated with the thickness of 245cm, 327cm, 409cm and 490cm. Under condition of that the slant angle is 90 °, the projectile velocity \(v_0\) is 0.03, 0.04, 0.05, 0.06 cm.us\(^{-1}\), the penetration simulation effects are shown as in figure 3.

(3) The comparison analysis
The comparison results between simulation calculation of penetration depth to plain concrete and the estimated depth are shown in table 5.

| \(v_0/\text{cm.us}^{-1}\) | Thickness/cm | Penetration depth/cm | Residual velocity \(v_\nu/\text{cm.us}^{-1}\) | Differential ratio |
|-----------------|-------------|---------------------|-----------------|-----------------|
| 0.03            | 245         | 243                 | 0.000           | 0.8%            |
| 0.04            | 327         | through             | 0.0032          | 8.0%            |
| 0.05            | 409         | through             | 0.0046          | 8.1%            |
| 0.06            | 490         | through             | 0.0055          | 9.0%            |

It can be seen from the data in the table 5 that the difference between the simulation result and the empirical calculation value is no more than 10%. It indicates that the models are accuracy.

In addition, compared with the simulation and experimental results in literature [2], the simulation effect of concrete failure morphology is more realistic.

3.4.2. The simulation verification of penetration to steel plate.
(1) Simulation of penetration to steel plate
Assuming that \(v_0=0.04\text{ cm.us}^{-1}, \theta=80\ °\), the simulation effect is shown in figure 4.
As shown in Figure 4, the residual velocity $v_s$ of the projectile is 0.0386 cm.us$^{-1}$. According to the law of conservation of kinetic energy, the penetrating ultimate velocity $v_c = 0.01049 \text{ cm.us}^{-1} = 104.9 \text{ m.s}^{-1}$.

(2) theoretical calculation of penetrating ultimate velocity

The accuracy of steel plate penetration model is verified by comparing theoretical calculation with simulation calculation. K.A. Belking formula is adopted to calculate the penetrating ultimate velocity of the warhead through the steel plate$^{[10]}$. It is known that the yield limit of Q235 steel plate is 400 ~ 490 MPa, and 450 MPa is taken here. According to the relevant parameters of penetrating projectile, the penetrating ultimate velocity is calculated as $v_c = 110.9 \text{ m.s}^{-1}$.

(3) The comparison analysis

It can be seen from figure 4 (a) that in the process of penetration, the projectile mainly damages the steel plate in a petal mode, and the failure morphology is consistent with the simulation and experimental results of projectile penetration steel plate in relevant literature $^{[11]}$. The penetrating ultimate velocity obtained from the simulation calculation of velocity curve in figure 4 (b) is consistent with the theoretical calculation value, and the difference ratio is only 5.7%. It is indicated that the penetration simulation model to steel plate is credibly.

4. Analysis of simulation results

4.1. Simulation analysis of general penetration process

Assuming that the slant angle $\theta$ is 80°, the projectile velocity $v_0 = 0.045 \text{ cm.us}^{-1}$, the penetration simulation effect is shown in figure 5.

Simulation results show that the rocket can penetrate through the two types of composite targets effectively. However, its failure morphology is slightly different from the simulation effect as shown in Figure 3 and Figure 4. On the one hand, the steel plate effectively inhibits the effect of opening pit and seismic collapse in the process of penetration, and on the other hand, the concrete has a certain inhibitory effect on the petal damage of the steel plate on the upper surface.

The acceleration curve in the X direction of the projectile penetrating the two composite board targets is shown in Figure 6.
It can be seen that the projectile acceleration in the process of penetration at steel plate is significantly greater than at the concrete. The maximum acceleration reached \(-5.5 \times 10^6 \text{cm.us}^{-2}\) when penetrating at target II surface of steel plate. According to the quality of the projectile to estimate its biggest resistance is about \(2.75 \times 10^6 \text{N}\), increasing by about 44.7% than the penetrating at the concrete.

The velocity curve of projectile penetrating two composite board targets is shown in Figure 7.

![Velocity curve](image)

(a) to target I  (b) to target II

Figure 6. The acceleration curve of projectile

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![Velocity curve](image)

(a) to target I  (b) to target II

Figure 7. The velocity curve of projectile

It can be seen that the residual velocity of projectile is \(0.0158 \text{ cm.us}^{-1}\) and \(0.0145 \text{ cm.us}^{-1}\) respectively, and it can be calculated that the penetrating ultimate velocity across the two composite targets is \(0.0421 \text{ cm.us}^{-1}\) and \(0.0426 \text{ cm.us}^{-1}\) respectively.

However, Under the same conditions, the penetrating ultimate velocity across concrete targets with the same thickness is \(0.0398 \text{ cm.us}^{-1}\). In contrast, the ultimate velocity across the two composite plates is higher than 5.7% and 7.0% respectively, that is, when the rocket penetrates the steel-concrete composite plates, the velocity attenuation is greater than that of the ordinary concrete plates.

4.2. Simulation analysis on influence of slant angle

In order to study the penetration ability of projectile to the composite panels under the condition of the small slant angles, take the slant angles of \(20^\circ\), \(40^\circ\), \(30^\circ\) as examples, the simulation results are shown in figure 8.

![Simulation results](image)

(a) \(\theta = 20^\circ\)  (b) \(\theta = 30^\circ\)  (c) \(\theta = 40^\circ\)

Figure 8. Penetration effect to targets with smaller slant angles

It can be seen from the simulation effect in Figure 8, the rocket projectile also has better penetration ability when it penetrates the composite targets slantly. Meanwhile, the projectile deforms is more severely when the slant angle is smaller.

5. Conclusions

From the penetration simulation results, it is shown that image homing rocket projectiles has good performance in penetrating across steel plate-concrete targets, which can meet the requirements of
technical and tactical indexes. However, rocket projectiles need larger slant angle and falling velocity to penetrate across the steel plate-concrete targets than the ordinary concrete targets.

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