Simulation on projectiles penetrating multi-layered concrete target with attack angle

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Abstract. In order to explore the variation rule of the projectile's flying state in the process of projectile penetrating into multi-target, the numerical simulation of 60mm calibre projectile penetrating multi-layer C40 concrete target is carried out. The effect of the initial velocity and initial angle of attack on the ballistic deflection is studied. The variation trend of the posture of the projectile with time and the changing trend of the velocity with time are obtained by numerical simulation, and then the changing law of the angle of attack is obtained. From the result, we can get that the attack angle of projectile can be divided into several stages when penetrating into a single target, and the bigger the initial attack angle is, the more obvious the change is.

1. Introduction
As the most widely used constructional materials in the world, concrete has attracted much attention from civil and military engineers [1,2]. For a long time, scholars have done a great deal of research on penetrating concrete target [3,4]. The main research direction is the limit penetration depth of semi-infinite target plate, but the research on the penetration of thin target is less. However, most modern civil and military buildings can be equivalent to multi-layer thin concrete targets, so it is of high engineering significance to study the penetration of multi-layer targets.

2. Simulation
2.1. Selection of working conditions
This paper uses LS-DYNA software to carry out numerical simulation. The penetration body is an oval solid projectile with a diameter of 60 mm, with a CRH of 4 and an aspect ratio of 5, and a target plate with a diameter of 1200 mm and a thickness of 180 mm. In order to improve the efficiency of calculation, a 1/2 model is established for simulation. In order to ensure the accuracy of calculation, there are 12 grids in the direction of the projectile, the mesh of the target is divided into 2.5mm×2.5mm×2.5mm. The effect is shown in Figure 1.
In order to study the impact of the angle of attack on the penetration results, we have a numerical simulation of the different angle of attack at the same velocity. Defined angle of attack was \( \theta \), initial angle of attack was \( \theta_0 \). The detailed parameters of the numerical simulation are shown in Table 1.

**Table 1. Initial parameters of simulation**

| No. | 1 | 2 | 3 | 4 |
|-----|---|---|---|---|
| velocity (m/s) | 750 | 750 | 750 | 750 |
| \( \theta_0 \) (deg.) | 5 | 10 | 15 | 20 |

**2.2. Selection of constitutive models**

The material of penetration body is defined as MAT_RIGID because it does not have the effect of erosion when it penetrates the concrete target at low velocity. It has a density of 3.8g/cm^3. In view of the high compression state of concrete, the constitutive model of HJC concrete proposed by Holmquist and Johnson is considered to be a better model [5], and it can be used to calculate various kinds of concrete penetration problems [6]. The constitutive parameters in this paper were derived from the reference [5], and the effective plastic strain at the time of failure was changed from 3 to 2. Add keywords MAT_ADD_EROSION to define failure, the maximum volume strain of failure is 0.2, the maximum principal strain is 1.1. The minimum pressure before failure is -4 MPa.

**3. Results and analysis**

**3.1. Single-layer target penetration**

In the case of velocity 750m/s, the situation of leaving the target at different initial angle of attack is shown in Figure 2. The angle between the projectile axis and the horizontal axis (\( \alpha \))
changes with time, as in Figure 3. The changing trend of $\theta$ with time was shown in Figure 4. The changing trend of velocity with time was shown in Figure 5. The changing trend of angle velocity ($\omega_z$) with time was shown in Figure 6.

![Figure 2. The situation of leaving the target at different initial angle of attack](image1)

![Figure 3. $\alpha$ changes with time](image2)

![Figure 4. $\theta$ changes with time](image3)

![Figure 5. Velocity changes with time](image4)

![Figure 6. $\omega_z$ changes with time](image5)

Defined the angle between the projectile axis and the horizontal axis was $\alpha$ when the projectile was leaving target, and the initial angle was $\alpha_0$, $\zeta=\alpha^*-\alpha_0$. The relationship between $\zeta$ and $\theta_0$ was shown in Figure 7. Similarly, the angle of attack was $\theta^*$ when the projectile was leaving target, $\beta=\theta^*-\theta_0$. The relationship between $\beta$ and $\theta_0$ was shown in Figure 8.
According Figure 4~6, we can saw that with the increase of $\theta_0$, $\alpha$, $\theta$, $\omega$ also increase, and velocity decrease. When the time was about 0.3ms, $\theta$ began to decrease, and caving occurred behind the target, $\omega$ reached maximum.

According Figure 7 and Figure 8, $\zeta$ and $\theta_0$ were basically linear, so was $\beta$ and $\theta_0$.

### 3.2. multi-layer target penetration

In multi-layer target simulation, the distance between target and target was 1000mm, and the diameter of target was infinite. Simulation calculation of the next layer target with the state of the projectile after penetrating previous target as input parameters. The result of penetrating a multi-layer concrete targets at initial angle of attack of 5 degrees and a velocity of 750 m/s was shown in Figure 9. Figure 10 was the result with the same velocity and angle of attack of 10 degrees.
According Figure 9 and Figure 10, we can saw that when $\theta_0$ was $5^\circ$, it can penetrate 3 layers of target, but $\theta_0$ at $10^\circ$ can only penetrate 2 layers of target. The reason was that when the projectile has large angle of attack and angle velocity, it is easy to deflect in the target, thus reducing the penetration ability.

4. Conclusion
In this paper, the HJC constitutive model was used to simulate the penetration of rigid projectile into multi-layer concrete target, and the influence of the initial angle of attack on the penetration ability was explored. It was concluded that the increment of attack angle before and after penetration and the increment of angle between projectile axis and horizontal axis has a linear relationship with initial angle of attack.

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