Research on Oblique Penetration of Projectiles into Targets of Different Materials

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Abstract. In order to study the trajectory deflection of projectile penetrating obliquely into different materials, the Lagrange algorithm of LS-DYNA was used to simulate the three-dimensional model. The impact angle of projectile is 70°, the concrete target and the soil target are penetrated respectively. The state of the target, the strain nephogram and the stress nephogram of the target under the maximum overload are obtained. The curves of penetration depth, penetration velocity, overload and energy are analyzed. The results show that: in oblique penetration, the projectile's trajectory deflects more in the process of entering the concrete target, and then deflects less; the trajectory deflection of the projectile is small in the process of entering the soil target and a certain distance after it, but it becomes larger when it is fast out of the target.

Keywords: Oblique target, Penetration, Trajectory deflection, Numerical simulation

1. Introduction

In modern war, in order to attack underground targets, the research on ground penetrating weapons is particularly important [1-3]. Some underground fortifications are built inside the mountain with thick soil and rock layers as natural barriers, while others are built under reinforced concrete fortifications [4-6]. No matter what kind of field fortifications are, there will be soil layers on the main concrete bunkers, which can improve the concealment on the one hand, and affect the penetration speed and penetration path on the other. Therefore, it is necessary to study the penetration of projectile into soil and concrete [7-10].

Many researchers at home and abroad have carried out theoretical analysis and Experimental Research on Soil and concrete in many aspects in recent ten years. Q.Q. Xiao et al. [11] carried out theoretical calculation and experiment on the penetration effect of jet on soil concrete composite target, and studied the effect of jet on the interface between soil and concrete in the process of penetration; Mehdi omidvar et al. [12] used transparent soil for non-invasive visualization of in-situ particle kinematics at a speed of about 20 m / s, and analyzed various characteristics of interaction between soil and projectile in the process of penetration on a mesoscale. Abdelazziz ads et al. [13] discussed the influence of torpedo shape on penetration depth and pull-out ability of marine soft clay, and concluded that the anti penetration and pull-out resistance of torpedo anchor is greatly affected by its tail design. Y. Peng et al. [14] proposed two models: first, assuming that the drag acting on the projectile during penetration is constant, a new average drag method based on expansion approximation of dynamic cavity is proposed; the second is the first mock exam to predict the penetration depth of different targets, such as concrete, metal and rock.

In this paper, the oblique penetration process of projectile into soil and concrete is studied, and the state of projectile and target, the strain nephogram of target, and the stress nephogram of target under maximum overload, the depth curve of penetration, the velocity curve of penetration, overload curve and projectile energy curve are analyzed.
2. Modeling

The diameter of the projectile is 30 mm, the length is 190 mm, the ratio of curvature to diameter is 1.5, the head of the projectile has a 2 mm fillet, the projectile is a solid projectile, and the distance between the center of mass and the tail of the projectile is 85.6 mm; The target plate is 900 mm×900 mm, and the target length is 1 m. In order to reduce the computation period, the target plate is processed in two steps. The 1/2 model is used to model, and the 150 mm×150 mm of the projectile is used to encrypt the target to enhance the contact accuracy of the target. The remaining part adopts the grid gradual processing method, and the gradual change rate is less than 1.1 times. Ensure that the stress wave propagates correctly inside the target plate. The three-dimensional modeling of the target plate and the projectile is shown in figure 1.

![a) Projectile](image1)

b) Cross section of target plate.

c) 1/2 Model of impact surface.

Figure 1. 3-D model establishment.

In the model, the projectile is made of 4340 steel, and the target plate is made of soil and C40 concrete. Because the velocity of the projectile studied in this paper is 600 m/s, which belongs to the range of medium and low speed, and the penetration process has little effect on the shape of the projectile, the rigid body is used for the simulation of the projectile, and * mat is used for the projectile. Rigid material model [15], as shown in table 1, soil adopts * mat_SOIL_AND_Foam material model [15], as shown in table 2, concrete adopts * mat_ The RHT material model [15] is shown in table 3.

| Name         | Density /(g·cm⁻³) | Young's modulus /GPa | Poisson's ratio |
|--------------|-------------------|----------------------|----------------|
| Projectile   | 7.85              | 210                  | 0.3            |

| Name         | Density /(g·cm⁻³) | Shear modulus /GPa | Bulk unloading modulus /GPa |
|--------------|-------------------|--------------------|----------------------------|
| Soil         | 1.40              | 0.016              | 0.13                       |

| Name         | Density /(g·cm⁻³) | Compressive strength /GPa | Shear modulus /GPa |
|--------------|-------------------|---------------------------|-------------------|
3. Analysis of Simulation Results

In order to study the oblique penetration process of projectile into soil and concrete, the impact angle of projectile is set at 70°. Soil and C40 concrete targets are penetrated respectively. The state of projectile target, the strain nephogram of the target and the stress nephogram of the target under the maximum overload after the projectile penetrates the target are shown in figure 2. The depth and velocity curves of penetration, overload and projectile energy curves of the projectile are shown in figure 3.

| C40 Concrete | 7.85 | 0.027 | 16.29 |

Figure 2. Target state after penetration.
a) Curve of penetration depth of projectile in X direction with time.

b) Time varying curve of projectile penetration depth in Y direction.

c) Velocity curve of projectile in X direction with time.

d) Velocity curve of projectile in Y direction with time.

e) Curve of X-direction overload of projectile with time.

f) Time varying curve of projectile overload in Y direction.
g) Projectile energy versus time curve.

Figure 3. Data changes of the penetration process of projectile.

It can be found from figure 2a) that when the projectile penetrates into the inclined concrete target, the force on the projectile is uneven due to the inclined penetration, which makes the projectile deflect upward, causing the upper part of the concrete target to break and fall more seriously than the lower part of the crater, and the projectile will not deflect after it completely enters the target plate; When the projectile penetrates into the inclined soil target, the front half of the trajectory has a slight upward deflection. After the penetration depth is more than half, the upward deflection of the projectile increases gradually, making the aperture of the rear half larger. After the projectile flies out of the target plate, the upward deflection is more serious. It can be seen from figure 2b) that after the penetration, the strain of concrete is only in a small area near the trajectory, and the deformation at the entrance is serious; the strain range of soil target is large. It can be seen from figure 2c) that when the projectile penetrates into the concrete target, the maximum overload occurs at the head of the projectile when it just penetrates into the target plate; When the projectile penetrates into the soil target, the maximum overload appears around the projectile when it is about to leave the target.

It can be found from figure 3a) that in the x-axis direction, the penetration depth of the projectile to the soil target increases linearly with time; with the increase of time, the penetration depth of the projectile to the concrete target first increases rapidly from zero, then changes gradually, and finally stops. It can be found from figure 3b) that in the y-axis direction, the penetration depth of the projectile to the soil target increases slowly from zero to uniform with the increase of time, which also verifies the description of figure 2a); With the increase of time, the penetration depth of the projectile to the concrete target first accelerates, then slows down, and finally stops.

It can be found from figure 3c) that in the x-axis direction, the penetration velocity of the projectile to the soil target decreases slowly with the increase of time, and the sound velocity after the penetration is slightly greater than 400 m / s; The penetration velocity of the projectile to the concrete target also decreases with the increase of time, but the decreasing velocity is faster, the final velocity is 0, then gradually changes, and finally stops. It can be seen from figure 3d) that in the y-axis direction, the penetration speed of the projectile to the soil target increases slowly at first, then increases at a constant speed, and finally slows down with the increase of time, at this time, the projectile exits the target; With the increase of time, the penetration depth of the projectile to the concrete target first increases rapidly from zero, then turns suddenly, drops sharply, and finally becomes zero.

It can be seen from figure 3e) that in the x-axis direction, the penetration overload of the projectile to the soil target first increases rapidly in the reverse direction with the increase of time, then basically remains unchanged, and then increases slowly in the reverse direction. After reaching the maximum value of 16000g, it sharply decreases to 0; with the increase of time, the penetration overload of the projectile to the concrete target first increases sharply, reaches the maximum value of 48000g, then decreases slowly, and finally decreases sharply to 0. It can be seen from figure 3f) that in the y-axis
direction, the penetration overload of the projectile to the soil target first increases at a very slow speed with the increase of time, then slowly increases to the highest point, and then slowly decreases to 0; With the increase of time, the penetration overload of projectile to concrete target first increases sharply, then decreases sharply to 0, then increases reversely, and finally decreases slowly to 0.

It can be found from figure 3g) that when the projectile penetrates into the soil target, the energy decreases slowly. When the projectile penetrates into the concrete target, the energy decreases rapidly at first and then slowly to zero.

4. Conclusion
During oblique penetration, the projectile’s trajectory deflection is greater when it enters the concrete target, and then the deflection is smaller; the projectile’s trajectory deflection is smaller during and after entering the soil target, and it deviates when it exits the target. Great changes.

References
[1] Yin J P, Wang Zh J 2012 *Ammunition* Beijing: Beijing Institute of Technology Press: 208-222.
[2] Zhou Y 2009 *The Numerical Simulation of Effects of Trajectory in Soil for Earth Penetrating Shell* Nanjing University of Science and Technology.
[3] Chen X W 2019 *Modeling on the Perforation and Penetration* Science Press.
[4] Wang Sh Sh 2019 *Terminal Effects* Science Press.
[5] Tham C Y 2004 Reinforced concrete perforation and penetration simulation using AUTODYN-3D *Finite Elements in Analysis & Design* 41(14).
[6] Shen F, Zhang Q, Huang D, Zhao J J 2012 Peridynamic modeling of failure process of concert structure subjected to impact loading *Engineering Mechanics* 29(S1): 12-15.
[7] Xiao Q Q 2012 *Shaped Charge Jet Penetrating into Soil / Concrete Target* Nanjing University of Science and Technology.
[8] Lin J X, Jiang H Zh, Jiang J W, Wang X L 1999 An analytical model for projectile normally into layered target of soil /concert *Acta Ballistics* (01): 5-14.
[9] Zhang R P 1997 A study on the penetration mechanism and trajectory of projectile and rocket penetrators into soil and rock *Acta Armamentarii* (03): 212-216.
[10] Jiang J W, Men J B, Wan L Zh, Lu Y G 2001 Experimental study on a kinetic energy penetrator penetrating a soil-and-concrete multi-layer target *Journal of Beijing Institute of Technology* (04): 420-423.
[11] Xiao Q Q, Huang Z X, Jia X, Zu X D, Zhu Q F 2017 Shaped charge penetrator into soil–concrete double-layered target *International Journal of Impact Engineering* 109.
[12] Omidvar Mehdi, Iskander Magued, Bless Stephan 2016 Soil–projectile interactions during low velocity penetration *International Journal of Impact Engineering* 93.
[13] Abdelaziz Ads, Magued Iskander, Stephan Bless, Mehdi Omidvar 2020 Visualizing the effect of Fin length on torpedo anchor penetration and pull out using a transparent soil *Ocean Engineering* 216.
[14] Peng Y, Wu H, Fang Q, Gong Z M, Kong X Z 2015 A note on the deep penetration and perforation of hard projectiles into thick targets *International Journal of Impact Engineering* 85.
[15] ANSYS Inc. 2009 *ANSYS AUTODYN User Manual: Release 12.1.*