Numerical Simulation of Rigid Projectiles Penetration into Concrete Targets with Different Warhead Shapes

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Abstract. When the projectiles with different head shapes impact and penetrate the concrete targets, the resistances of the target plates to the projectiles are significantly different, which is manifested by the time history curve of different accelerations, velocities and the penetration depths of the projectiles, resulting in the obvious differences of the penetration ability of the projectiles to the targets with a same compressive strength. In order to determine the influence degree of projectiles with different head shapes on the penetration ability, ANSYS/LS-DYN is adopted. The finite element numerical simulation software is used to simulate and analyze the three kinds of rigid projectiles: oval (including double oval and oval), conical (including double conical and conical) and cone oval. Among them, the projectiles all penetrated C40 concrete cylindrical targets vertically at an initial velocity of 700m/s. The results show that the penetration ability of the optimal oval, conical and cone oval projectile is gradually reduced, and the highest penetration ability is the oval projectile numbered as dan001, whose final penetration depth is 539cm.

Keywords: Rigid projectiles with different head shapes, Penetration mechanics, C40 concrete, Numerical simulation

1. Introduction

There are many factors affecting the penetration ability of a projectile penetrating into a concrete target, among which the most important factors are the strength and density of concrete material, the material strength and density of the projectile, the head shape of the projectile, the initial velocity and the incident Angle [1,2], etc. In the process of a rigid projectile penetrating into concrete, the most intense interaction area between projectile and target is in the head area of the projectile. The change of the shape of the projectile head will directly affect the stress state of the projectile, and then affect the penetration effect of the projectile. Therefore, it is necessary to make a detailed study on the influencing factor of the head shape of the projectile.

Here, we use the numerical simulation method to study the influence of the head shape on the penetration ability of the projectile. Numerical simulation is not only helpful for us to understand the process of projectile penetrating into the target intuitively, but also can provide us with the specific data required by the time history curve of projectile acceleration, velocity and penetration depth in the process of a projectile penetrating into a target and can calculate the penetration ability of projectile quantificationally. So, it can provide the basis for the optimization of the head shape of a projectile.
2. Numerical Simulation Calculation

2.1. Rigid Projectile Structure

The numerical simulation of three kinds of projectile bodies with oval shape, conical shape and conical oval shape was carried out.

2.1.1. Double Oval and Oval Bombs. The head of the double ovoid warhead has two arcs, while the ovoid warhead has only one arc. The best shape of the warhead is determined by numerical simulation of two kinds of warhead shapes.

To study the rules of the double oval head shape of projectile penetrating concrete, we select double oval head shape parameters L1 and α, the L1 is the axial length of the first period of circular arc of the projectile head, α is the axis Angle of circular arc of the tangent of the second period, the second section of the radius of the circular arc is 316 cm (remaining constant), there are only two variables: L1 and α. These are shown in figure 1.

![Figure 1. Schematic diagram of double ovoid projectile.](image)

When L1 is large enough, the double ovoid warhead becomes an ovoid warhead. When the radius of the arc is 226cm, L1=80cm, as shown in figure 2.

![Figure 2. Oval projectile (dan001).](image)

When the L1 is 11cm, 12cm and 30cm respectively, change the size of α to carry out numerical simulation, that is, use the control variable method to determine the warhead shape variables L1 and α.

2.1.2. Biconical and Conical Projectiles. The head of a biconical warhead has two straight lines, while the conical warhead has only one straight line. The best shape of the warhead is determined by numerical simulation of two kinds of warhead shapes.

To study the rules of projectile with the double conical and conical head shape penetrating concrete target, select double conical head shape parameters L1, α1 and α2. L1 represents the axial length of first line of the projectile head, α1 represents the angle between the first straight line and the axis, α2 represents the angle between the second straight line and the axis, there are only three variables: L1, α1 and α2. These are shown in figure 3.
When $\alpha_1=\alpha_2$, the biconical warhead becomes a conical warhead. In particular, when $\alpha_1=\alpha_2=10^\circ$, $L_1=80\text{cm}$ ($L_{10_{DU}_{10DU}}$), as is shown in figure 4.

Fixing the values of $L_1$ and $\alpha_1$ and changing the size of Angle $\alpha_2$, the warhead shape variables $L_1$, $\alpha_1$ and $\alpha_2$ were determined by the control variable method.

2.1.3. Cone Oval Bomb. The first section of the cone oval warhead is a straight line, and the second section is a circular arc. The radius of the circular arc is $R=316\text{cm}$.

In order to study the penetration into concrete rules of a projectile with a cone oval head shape, the shape parameters $L_1$ and $\alpha$ are selected. $L_1$ is the axial length of the first straight line of projectile head, and $\alpha$ is the Angle variable between the first straight line and the axis. There are only two variables: $L_1$ and $\alpha$. As is shown in figure 5.

Fixing $L_1$ at a specific value and changing the size of Angle $\alpha$ to carry out numerical simulation, that is, using the control variable method to determine the warhead shape variables $L_1$ and $\alpha$.

2.2. Concrete Target
When rigid projectile penetrates concrete target, the diameter of concrete target plate should not be less than 30 times of the diameter of the projectile in order to avoid the influence of lateral boundary of concrete cylindrical target on the penetration capability of the projectile. Therefore, in the numerical simulation, the diameter of the concrete cylindrical target is set as $960\text{ cm}$. According to experience, when the velocity of the projectile with ovoid head is $700\text{m/s}$, the penetration depth is about $500\text{cm}$, so the length of the concrete cylindrical target is set as $600\text{cm}$. In order to improve the calculation efficiency, the central area of the concrete target was refined with a radius of $R = 160\text{cm}$. Specific parameters of concrete cylindrical targets are shown in table 1.
Table 1. Main parameters of concrete target slab.

|                | Diameter (cm) | Density (g/cm³) | Compressive Strength(MPa) |
|----------------|---------------|-----------------|---------------------------|
| Concrete       | φ 960*600     | 2.44            | 40                        |

2.3. Parameter and Setting of Numerical Simulation

In the simulation, the element type of shell case, charge column, bottom screw and target is 3D Solid 163, and the grid is all six sides. Among them, the material model of shell case, cylinder and bottom screw is *MAT_ELASTIC, and the material model of concrete is *MAT_JOHNSON_HOLMQUIST_CONCRETE and *MAT_ADD_EROSION. The contact type of the two is *CONTACT_ERODING_SURFACE_TO_SURFACE [3-6]. In addition, cm-us-g unit system is used in the simulation. The initial velocity of the projectile penetrating into concrete is 0.07cm/us.

3. Numerical Simulation Results and Analysis

3.1. Oval Shell L1=11cm

When L1=11cm, different α values (7°, 8°, 9°) were taken for numerical simulation. The time-history curves of acceleration, velocity, and penetration with different warhead shapes were shown in figures 6(a), 6(b), and 6(c).

![Figure 6a.](image)

In the process of double ovoid and ovoid projectiles penetrating concretes, the target produces resistance to the projectile, so the sign of acceleration is negative, that is, the acceleration value is negative. As shown in figure 6(a), when L1=11cm, the time history curve of the acceleration of the double-ovoid projectile has a similar trend: The absolute value of acceleration increases firstly and lasts for a long time about 10000us (2500us to 12500us) within a certain range of acceleration value (about 5500G), and then the absolute value of acceleration decreases sharply to zero in a short time (2500us). However, the absolute value of acceleration of dan001 (oval-shaped projectile) decreased slowly and lasted for a long time.

In the main stage of penetration, the curve of acceleration moves up as a whole with the increase of α, that is, the absolute value of acceleration gradually decreases at the same time. It shows that with the increase of α, the penetration resistance of double ovoid projectile decreases gradually. It can be seen from figure 6(a) that when L1=11cm and α=9°, the double-ovoid projectile has a better penetration ability into concrete.
In the process of double ovoid and ovoid projectiles penetrating concrete, the target produces resistance to the projectile, and the projectile slows down. As shown in figure 6(b), the initial velocities of double ovoid and ovoid projectile bodies are 0.07cm/μs(700m/s), and the projectile bodies decrease linearly with time. For the double ovoid projectile, the velocity of the double ovoid projectile decreases to zero at about 12500μs. The velocity of the oval-shaped projectile drops to zero at 2000μs.

During the main stage of penetration, the velocity curve moves up as a whole with the increase of α, that is, the velocity increases gradually at the same time. It shows that with the increase of α, the penetration ability of double ovoid projectile into concrete target increases gradually. As can be seen from figure 6(b), when L1=11cm and α=9°, the double-ovoid projectile has a better penetration ability into concrete. When the velocity of the double ovoid projectile becomes zero, the ovoid projectile still has a residual velocity, so the penetration ability of the ovoid projectile is higher.

As shown in figure 6(c), the whole process of penetration can be divided into three stages, namely, the first stage: the penetration depth of double ovoid and ovoid projectiles increases linearly from time to time. At the same time in this stage, the penetration depth of double ovoid and ovoid projectiles is basically the same. The second stage: the penetration depth of double ovoid and ovoid projectile increases with curves at any time. At the same time in this stage, the penetration depth increases with the increase of α. The third stage: the penetration depth of double ovoid and ovoid projectiles tends to be stable with time. In addition, in the later stage of penetration, the penetration depth decreases slightly, because the concrete at the head of the projectile produces elastic rebound. Because the value is small, it is ignored.

According to figure 6(c), with the increase of α, the final penetration depth of the double-ovoid projectile increases, indicating that with the increase of α, the penetration ability of the double-ovoid

![Figure 6(b). Time history curve of double ovoid and ovoid projectile penetration into concrete L1=11cm.](image_url)

![Figure 6(c). L1=11cm double ovoid and ovoid projectile penetration into concrete time history curve.](image_url)
projectile into the concrete target plate gradually increases. According to figure 6(c), when \( L_1 = 11 \text{ cm} \) and \( \alpha = 9^\circ \), the final penetration depth of the double-ovoid projectile is larger, which is about 463 cm. The final penetration of oval projectile dan001 is the largest, about 539 cm.

3.2. Oval Shell \( L_1 = 12 \text{ cm} \)

When \( L_1 = 12 \text{ cm} \), different \( \alpha \) values (6°, 7°, 8°, 9°) were taken for numerical simulation. The time-history curves of acceleration, velocity, and penetration of different warhead shapes were shown in figures 7(a), 7(b), and 7(c).

![Figure 7(a)](image_url)

Figure 7(a). Time history curve of acceleration of double ovoid and ovoid projectile penetration into concrete \( L_1 = 12 \text{ cm} \).

In the process of double ovoid and ovoid projectiles penetrating concrete, the target produces resistance to the projectile, so the sign of acceleration is negative, that is, the acceleration value is negative. As shown in figure 7(a), when \( L_1 = 12 \text{ cm} \), the time history curve of the acceleration of the double-ovoid projectile has a similar trend: The absolute value of acceleration increases first and lasts for a long time about 10000uS (2500uS to 12500uS) within a certain acceleration value (about 6000G), and then the absolute value of acceleration decreases sharply to zero in a short time (2500uS). However, the absolute value of acceleration of dan001 (oval-shaped projectile) decreased slowly and lasted for a long time.

In the main stage of penetration, the curve of acceleration moves up as a whole with the increase of \( \alpha \), that is, the absolute value of acceleration gradually decreases at the same time. It shows that with the increase of \( \alpha \), the penetration resistance of double ovoid projectile decreases gradually. It can be seen from figure 7(a) that when \( L_1 = 12 \text{ cm} \) and \( \alpha = 9^\circ \), the double-ovoid projectile has a better penetration ability into concrete.

![Figure 7(b)](image_url)

Figure 7(b). Time history curves of double ovoid and ovoid projectile penetration into concrete \( L_1 = 12 \text{ cm} \).

In the process of double ovoid and ovoid projectiles penetrating concrete, the target produces
resistance to the projectile, and the projectile slows down. As shown in figure 7(b), the initial velocities of double ovoid and ovoid projectile bodies are 0.07cm/μs (700m/s), and the projectile bodies decrease linearly with time. For the double ovoid projectile, the velocity of the double ovoid projectile decreases to zero at about 12500μs. The velocity of the oval-shaped projectile drops to zero at 20,00μs.

During the main stage of penetration, the velocity curve moves up as a whole with the increase of α, that is, the velocity increases gradually at the same time. It shows that with the increase of α, the penetration ability of double ovoid projectile into concrete target increases gradually. As can be seen from figure 7(b), when L1=12cm and α=9°, the double-ovoid projectile has a better penetration ability into concrete. When the velocity of the double ovoid projectile becomes zero, the ovoid projectile still has residual velocity, so the penetration ability of the ovoid projectile is higher.

![Figure 7(c). L1=12cm double ovoid and ovoid projectile penetration into concrete.](image)

As shown in figure 7(c), the whole process of penetration can be divided into three stages, namely, the first stage: the penetration depth of double-ovoid and ovoid projectiles increases linearly from time to time. At the same time in this stage, the penetration depth of double-ovoid and ovoid projectiles is basically the same. The second stage: the penetration depth of double ovoid and ovoid projectile increases with curves at any time. At the same time in this stage, the penetration depth increases with the increase of α. The third stage: the penetration depth of double ovoid and ovoid projectiles tends to be stable with time. In addition, in the later stage of penetration, the penetration depth decreases slightly, because the concrete at the head of the projectile produces elastic rebound. Because the value is small, it is ignored.

According to figure 7(c), with the increase of α, the final penetration depth of the double-ovoid projectile increases, indicating that with the increase of α, the penetration ability of the double-ovoid projectile into the concrete target plate gradually increases. According to figure 7(c), when L1=12cm and α=9°, the final penetration depth of the double-ovoid projectile is larger, about 473cm. The final penetration of ovoid projectile dan001 is the largest, about 539cm.

### 3.3. Oval Shell L1=30cm

When L1=30cm, different α values (3°, 4°, 5°, and 6°) were taken for numerical simulation. The time-history curves of acceleration, velocity, and penetration of different warhead shapes were shown in figures 8(a), 8(b), and 8(c).
In the process of double ovoid and ovoid projectiles penetrating concrete, the target produces resistance to the projectile, so the sign of acceleration is negative, that is, the acceleration value is negative. As shown in figure 8(a), when L1=30cm, the trend of the time history curve of the acceleration of the double-ovoid projectile is similar: The absolute value of acceleration increases first and lasts for a long time about 10000μS (2500μS to 12500μS) within a certain acceleration value (about 6000G), and then the absolute value of acceleration decreases sharply to zero in a short time (2500μS). However, the absolute value of acceleration of dan001 (oval-shaped projectile) decreased slowly and lasted for a long time.

In the main stage of penetration, the curve of acceleration moves up as a whole with the increase of α, that is, the absolute value of acceleration gradually decreases at the same time. It shows that with the increase of α, the penetration resistance of double ovoid projectile decreases gradually. It can be seen from figure 8(a) that when L1=30cm and α=6°, the double-ovoid projectile has a better penetration ability into concrete.

In the process of double ovoid and ovoid projectiles penetrating concrete, the target produces resistance to the projectile, and the projectile slows down. As shown in Fig. 8b, the initial velocities of the double ovoid and ovoid projectiles are 0.07cm/us(700m/s), and the projectile bodies show approximately linear decreasing changes with time. For the double ovoid projectile, the velocity of the double ovoid projectile decreases to zero at about 12500μS. The velocity of the oval-shaped projectile drops to zero at 20,00μS.

During the main stage of penetration, the velocity curve moves up as a whole with the increase of α,
that is, the velocity increases gradually at the same time. It shows that with the increase of $\alpha$, the penetration ability of double ovoid projectile into concrete target increases gradually. As can be seen from figure 8b, when $L_1=30\text{cm}$ and $\alpha=6^\circ$, the double-ovoid projectile has a better penetration ability into concrete. When the velocity of the double ovoid projectile becomes zero, the ovoid projectile still has residual velocity, so the penetration ability of the ovoid projectile is higher.

**Figure 8(c).** $L_1=30\text{cm}$ double ovoid and ovoid projectile penetration into concrete time history curve

As shown in figure 8c, the whole process of penetration can be divided into three stages, namely, the first stage: the penetration depth of double-ovoid and ovoid projectiles increases linearly from time to time. At the same time in this stage, the penetration depth of double-ovoid and ovoid projectiles is basically the same. The second stage: the penetration depth of double ovoid and ovoid projectile increases with curves at any time. At the same time in this stage, the penetration depth increases with the increase of $\alpha$. The third stage: the penetration depth of double ovoid and ovoid projectiles tends to be stable with time. In addition, in the later stage of penetration, the penetration depth decreases slightly, because the concrete at the head of the projectile produces elastic rebound. Because the value is small, it is ignored.

According to Fig. 8c, with the increase of $\alpha$, the final penetration depth of the double-ovoid projectile increases, indicating that with the increase of $\alpha$, the penetration ability of the double-ovoid projectile into the concrete target plate gradually increases. According to Fig. 8c, when $L_1=30\text{cm}$ and $\alpha=9^\circ$, the final penetration depth of the double-ovoid projectile is larger, about 475cm. The final penetration of ovoid projectile dan001 is the largest, about 539cm.

By using the same steps and changing the relevant parameters, the process of penetration of biconical, conical and conical ovoid projectiles into concrete is simulated and the optimal warhead shape is determined.

### 3.4. Determination of Optimal Warhead Shape

Through the above analysis, the optimal warhead shape in the projectile of double oval, double conical and cone oval warhead shape is determined respectively: Dan001 in double oval shape, L10_10DU_10DU in double cone shape, and L10_46DU in cone oval shape are shown in figure 9(a), 19b and 19c. Time history curves of acceleration, velocity and penetration of the three are now analyzed. To determine the warhead shape with the highest penetration capability of all warhead shapes.
In the process of the optimal double-ovoid, double-conical and ovoid projectile penetration into concrete, the target produces resistance to the projectile, so the sign of acceleration is negative, that is, the acceleration value is negative. As shown in figure 9(a), in the time history curve trend of acceleration of three warhead shaped projectile bodies, the double-oval shape and the double-cone shape are relatively similar: the absolute value of acceleration first increases and lasts for a long time about 7500us (2500us to 10000us) within a certain range of acceleration value (about 5500G), and then the absolute value of acceleration gradually decreases to zero. However, the absolute value of the acceleration of the optimal cone ovoid projectile is much larger than that of the former two in the early stage, about 7000G. In the later stage of penetration, the absolute value of the acceleration decreases to zero in about 2500us.

In the process of penetration of the optimal double-ovoid, double-conical and ovoid projectiles into concrete, the target produces resistance to the projectile and the projectile decelerates. As shown in figure 9(b), the initial velocities of the double-optimal double-ovoid, biconical and ovoid conical projectile bodies are 0.07cm/us(700m/s), and the projectile bodies show approximately linear decreasing changes with time. Among them, the optimal double oval and double cone velocity curves basically coincide in the whole process of penetration. Only in the later stage of penetration, the velocity of the optimal double-ovoid projectile (dan001) is higher than that of the optimal double-cone projectile (L10_10DU_10DU). The velocity curves of cone oval shape were lower than that of dan001 and L10_10DU_10DU during the whole penetration process.
Figure 9(c). The optimal time history curves of double-ovoid, double-conical and double-ovoid projectile penetration into concrete.

As shown in figure 9(c), the whole process of penetration can be divided into three stages, namely, the first stage: penetration depths of projectile bodies of three warhead shapes increase linearly at any time. At the same time in this stage, penetration depths of projectile dan001, L10_10DU_10DU and L10_46DU are the same. In the second stage, the penetration depth of the three projectiles increases by curve at any time. At the same time in this stage, the penetration depth of L10_10DU_10DU and L10_46DU are the same. The penetration depth of L10_46DU is lower than the first two. The third stage: the penetration depth of projectile dan001 and L10_10DU_10DU tends to be stable with time, and the penetration depth of projectile dan001 is slightly higher than the latter. In addition, in the later stage of penetration, the penetration depth decreases slightly, because the concrete at the head of the projectile produces elastic rebound. Because the value is small, it is ignored.

It can be seen from figure 9(c) that the penetration ability of the optimal double-ovoid projectile, double-conical projectile and double-ovoid projectile gradually decreases. Among them, the final penetration depth of the ovoid projectile dan001 is the largest, which is about 539cm; the final penetration depth of the double-conical projectile L10_10DU_10DU is 517cm; and that of the cone-ovoid projectile L10_46DU is 393cm.

The optimal warhead shape is shown in figure 10.

4. Conclusion

Through the numerical simulation research of projectiles with different head shapes penetrating concrete target with a same material strength, we firstly determined the best head shape with highest penetration ability from the oval head shape, conical head shape and oval-conical head shape separately, we can choose out three head shapes. With the further comparison of the projectile penetration ability among them, the best head shape among the oval head shape, conical head shape and oval-conical head shape was determined, which is the optimal shape of the warhead, namely the shape of the projectile numbered dan001, which is an oval projectile, the length of the projectile head L1 is 80cm, and the radius of the circular arc is 226cm.

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