Study on the implementation of reinforced concrete target in PELE with hood

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Abstract-In order to analyze the influence of the material and shape of the hood of the medium-caliber PELE warhead on the damage effect of the reinforced concrete wall with PELE projectile, the three-dimensional nonlinear dynamic finite element program LS-DYNA was used to numerically simulate the penetration of the PELE projectile with the hood of different shapes and materials into the 0.25 thick thin reinforced concrete wall target at various velocities. The results show that under the same conditions, the hollow cone shaped phenolic resin hood can achieve better damage effect of reinforced concrete wall.

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1. Introduction
In the urban area, because the concrete material has the advantages of convenient production, highly cost performance, strong compressive performance and so on, it can be applied to various urban construction or defense structure. Reinforced concrete organically combines the tensile and compressive properties of steel with concrete, which makes the two can coordinate deformation under the action of load and work together. Thus, reinforced concrete is most widely used in military and civilian fields. In urban warfare, the use of ordinary ammunition against urban defensive positions is not obvious; while Armor-piercing projectiles can penetrate walls of high thickness, but the hole is small cut through the wall and it has no damage ability against targets behind the target[1].

Penetrator with enhanced lateral effect [2-5] (PELE) is a new type of ammunition which can break through walls, penetrate armor and produce a large number of fragments after the target without loading explosive and fuze. The ammunition for the urban ordinary reinforced concrete using the transverse effect of the principle of action, to achieve the formation of a large opening and target after the killing effect, which can provide a new type of multifunctional ammunition for urban operations.

In the process of using Pele to hole through the wall, the hope is to make the largest hole possible and to cut the steel in the concrete, therefore, it is necessary to strengthen the research on the structure and material of PELE projectile. In the actual combat application and experiment process, the head of PELE projectile is equipped with a hood in addition to the body, while the shape and material of the hood have certain influence on the penetration process, therefore, it is also necessary to study the hood of the PELE warhead. In this paper, three - dimensional nonlinear dynamical finite element program LS-DYNA is used for calculating the impact of PELE projectiles with different shapes and different materials on reinforced concrete targets at different velocities, in order to calculate the PELE projectile access hole diameter, residual velocity and the cutting of steel bar[6].
2. Numerical simulation

2.1 Simulation model

2.1.1 Geometric model
The large diameter PELE vertical penetration test of high strength reinforced concrete is used as reference for the geometrical model of missile target action. The geometry of the projectile body is shown in Figure 1. Several types of hoods designed are shown in Figure 2[7].

![Schematic diagram of PELE projectile](image1)

Fig. 1 Schematic diagram of PELE projectile

![Fig. 2 The basic shape and hood of the projectile body](image2)

To consider the material properties of reinforced concrete, when the finite element model of the target plate is established, the separate model is adopted. As shown in Figure 3, the shape of the target plate is rectangular, with dimensions 2.0m×2.0m×0.25m, two layers of reinforcement and layer spacing is 200 mm, reinforced mesh is 0.12m×0.12m and reinforcement ratio is 0.72%. The diameter of steel bar is 12 mm and the reinforcement material is Q235. The protective layer thickness of front and back concrete is 0.05m concrete with the design compressive strength 35MPa.

![Schematic diagram of reinforced concrete target](image3)

Fig. 3 Schematic diagram of reinforced concrete target

2.1.2 Finite Element Model
Reinforced concrete is modeled by separated finite element model, which can truly reflect the nonlinear effect of some details. The concrete target in the model adopts eight-node hexahedral solid element (SOLID164) and the reinforcement is made of BEAM element, the steel and concrete units are modeled separately by the way of node sharing, as shown in Figure 4 and Figure 5, the surface of symmetry and the fixed boundary conditions are also applied. When the deformation of concrete material element meets the failure criterion, the element is deleted and the mass is redistributed, so as to simulate the opening phenomenon of projectile body. When the plastic strain of reinforcement reaches the failure strain, the element is deleted to describe the phenomenon of extrusion deformation and impact fracture of reinforcement.
The PELE shell body, shell core and hood are all made of an eight-node hexahedral solid unit (SOLID164). Due to the symmetry of the projectile's vertical penetration into the concrete target, all the calculation models adopt the 1/4 structure of the original physical model to improve the running speed of the program.

All mesh cells adopt Lagrange algorithm, in which the mesh of the cells is attached to the material and the deformation of the cells is generated as the material flows. This algorithm can fully describe the dynamic mechanical behavior of the reinforced concrete wall destroyed by PELE and the calculation is stable. The contact mode of ERODING_SURFACT_TO_SURFACE is adopted between PELE projectile and target plate, while the contact mode of AUTOMATIC_SURFACT_TO_SURFACE is used between the shell and the shell core loading material.

2.1.3 Material Model
In the calculation, the shell material model is used as a follow-up/isotropic hardening elastoplastic material, the ideal elastoplastic material model is selected to describe the stress state and deformation of reinforcement, SOIL_CONCRETE model is used as concrete material, which can simulate the phenomenon of concrete crushing and caving to a certain extent. Parameters of each material are shown in Table 1, \( \rho \) is the density, \( E \) is the elastic modulus, \( \nu \) is the Poisson's ratio, \( G \) is the shear modulus and \( K \) is the volume modulus.

| Material  | \( \rho/(g.cm^{-3}) \) | \( E/GPa \) | \( \nu \) | \( G/GPa \) | \( K/GPa \) |
|-----------|------------------------|-------------|----------|------------|------------|
| jacket    | 7.85                   | 210         | 0.29     | /          | /          |
| inner     | 1.09                   | /           | /        | /          | 0.472      |
| Rebar     | 7.89                   | 210         | 0.284    | /          | /          |
| Concrete  | 2.50                   | /           | /        | 0.125      | 0.1667     |

3. Simulation Results

3.1 General Situation
The numerical simulation of PELE vertical impact on reinforced concrete target plate is carried out by using three-dimensional nonlinear dynamical finite element program LS-DYNA3D. The calculated object is the projectile core loaded with inert material of steel shell penetrating into the reinforced concrete target and the target velocity is 800m/s.

3.2 Influence of different shapes
In order to compare the influence of different hood structures on the wall breaking effect, four kinds of hollow straight hood, hollow arc hood, hollow arc cone and solid arc cone hood were designed.
respectively (as shown in Figure 2). Hit the reinforced concrete target at a speed of 800 m/s.

| Shape                        | Damage condition of concrete (diameter /cm) | Fracture condition of reinforcement |
|------------------------------|---------------------------------------------|-------------------------------------|
|                              | Facing projectile’s side | Back projectile’s side | Facing projectile’s side | Back projectile’s side |
| Hollow straight round table  | 48                           | 75                       | not broken                | broken                 |
| Hollow arc round table       | 48                           | 66                       | not broken                | not broken             |
| Hollow arc cone              | 54                           | 90                       | broken                    | broken                 |
| Solid arc cone               | 60                           | 63                       | broken                    | broken                 |

![Fig. 10 Shell velocity variation diagram with different shapes of hoods](image)

It can be seen from the damage of reinforced concrete: When Pele projectiles of various structural hoods penetrate into the reinforced concrete target, the concrete caving zone on the facing projectile surface is even smaller than that on the back projectile surface. The damage of Pele projectile with conical hood to steel bar is stronger than that of round hood. As can be seen from Figure 10: After penetrating the target, the residual velocity of PELE projectile with round hood is larger than that of Pele projectile with conical hood, the main reason is that: After penetrating the target, the residual velocity of Pele projectile with round hood is larger than that of PELE projectile with conical hood, which shows that the PELE projectile with round hood loses less energy during the penetration process and the energy of the cone-shaped PELE projectile is more lost in the process of crushing concrete and breaking steel bars. PELE projectile with conical hood has better effect than Pele projectile with round hood.

### 3.3 Influence of different materials

In order to compare the influence of hood of different materials on the effect of wall breaking, in this paper, for the hood with circular arc outer surface, four materials, aluminum, nylon, phenolic resin and rubber, were used for analysis. The results are shown in Table 3 and Figure 11.

| Material | Damage condition of concrete (diameter /cm) | Fracture condition of reinforcement |
|----------|---------------------------------------------|-------------------------------------|
|          | Facing projectile's side | Back projectile's side | Facing projectile's side | Back projectile's side |
| Al       | 48                           | 69                       | not broken                | broken                 |
| Nylon    | 60                           | 45                       | not broken                | broken                 |
Resin  54  90  broken  broken  
Rubber  66  78  not broken  broken

| Resin  | 54 | 90 | broken | broken |
|--------|----|----|--------|--------|
| Rubber | 66 | 78 | not broken | broken |

As can be seen from Table 3: After penetrating the reinforced concrete target, the concrete caving zone on the facing projectile surface is even smaller than that on the back projectile surface. At the same time, the steel bars on the back projectile face are broken due to the large area of concrete caving, but the steel bars on the opposite projectile face are also broken when the phenolic resin hood is penetrated. From Fig. 11, we see that after the hood penetrated the reinforced concrete target, the residual velocity of the shell was in the order of aluminum, phenolic resin, rubber and nylon.

The reasons are as follows: (1) The hardness of aluminum is higher, which is conducive to penetration, so the concrete falls less than the other three materials in the face and back of the elastic surface; (2) The elastic modulus or Poisson's ratio of nylon, phenolic resin and rubber increased successively and the positive and negative concrete collapse also increased successively, which was consistent with the conclusion in literature [1]. (3) Under the current velocity of the four materials, the steel bars on the back projectile surface break, while most of the steel bars on the face projectile surface do not break. It is because the projectile body does not contact the reinforcement bar (the projectile body penetration network center is set during calculation) under the penetration condition, the bond between the steel bar and the concrete results in the extrusion and shearing of the concrete during the penetration process. Under the pressure of the projectile, the concrete expands in all directions, resulting in a variety of complex pressures, tensile and shear forces on the rebar, the failure of steel bar results from the force between concrete and steel bar. The frontal damage area is small, the compression damage is obvious and there are radial cracks near the surface. There is a large damage area on the back side, resulting in radial crack and annular crack, and the tensile damage is more serious. Therefore, the steel bar on the back projectile surface is broken, and most of the steel bars on the face projectile surface are not broken.

As for phenolic resin hood, the steel bars on the facing projectile surface and the back projectile surface are all broken and the collapse area of concrete on the facing projectile surface and the back projectile surface is basically the same as that of other materials. Therefore, the material analysis of the hood: phenolic resin material hood is better than other materials.

3.4 Influence of different speeds

In order to compare the influence of the hood on the wall breaking effect at different speeds, using the hollow curving conical hood that material is phenolic resin to hit the reinforced concrete target at a speed of 600-1200 m/s respectively.

As can be seen from Table 4, the speed ranges from 600 m/s to 1000 m/s. As the speed increases, the concrete caving area gradually increase. However, when the velocity increases to 1200 m/s, the caving area decreases somewhat, which illustrates that there is an optimal velocity range for the damage effect of PELE projectile on reinforced concrete, which is consistent with the conclusion in literature [2].
Table 4. Damage of reinforced concrete targets at different impact velocities

| Velocity (m·s⁻¹) | Damage condition of concrete (diameter /cm) | Fracture condition of reinforcement |
|------------------|------------------------------------------|-------------------------------------|
|                  | Facing projectile's side | Back projectile's side | Facing projectile's side | Back projectile's side |
| 600              | 53                        | 33                      | broken                  | not broken             |
| 700              | 56                        | 45                      | broken                  | not broken             |
| 800              | 54                        | 90                      | broken                  | broken                 |
| 900              | 64                        | 87                      | broken                  | not broken             |
| 1000             | 66                        | 96                      | broken                  | not broken             |
| 1100             | 60                        | 75                      | broken                  | not broken             |
| 1200             | 63                        | 72                      | broken                  | broken                 |

4. Conclusion
Pele penetration into reinforced concrete is simulated in this paper, the simulation results show that the front surface pits, the middle perforation, the back layer cracks and the initiation and propagation of radial and circumferential cracks of concrete material are well reflected. The failure characteristics of reinforced concrete under impact penetration are simulated accurately.

In addition, the numerical simulation of PELE projectile penetrating 0.25 m thick thin reinforced concrete wall target with different shapes and materials of hood at various velocities is carried out. The results showed that: Under the same conditions, the use of hollow cone shaped phenolic resin hood can achieve better damage effect of reinforced concrete wall.

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