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Researching on penetration process of steel warheads in concrete protectives by using ansys autodyn

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KEYWORDS

Projectile impact
Penetration model
Impact constitutive model

ABSTRACT

The analysis of penetration of warheads in concrete protective structures is an important part of the study of weapon effects on protective structures. This type of complicated analysis requires that the design loading in the form of a warhead is determined. The characteristic and performance of the protective structure have to be known. To resolve it, there are several ways to find it such as experimental equation or using finite element (FE) analyses. However, it requires the combination of several factors, e.g. development of suitable material models for concrete, enhancement of numerical methodology and affordable high capacity computer systems. Furthermore, warhead penetration has primarily been of interest for the armed forces and military industry, with a large part of the conducted research being classified during considerable time. Hence, the paper is focused on simulating the progress of penetration of a steel warhead into the protective plate.

1. Problems

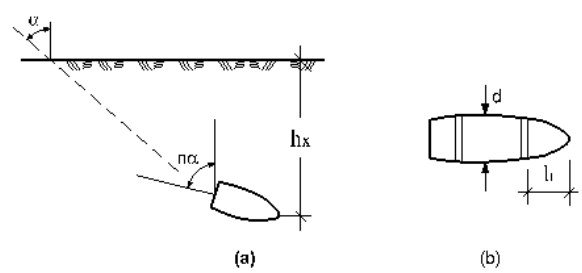
After directly impacting into a protective structure, the bullet having impact velocity V_o can penetrate inside the shield structure. The depths of penetration and trajectories have been depended on the value of velocity, shape, strength and weight of warheads and the impact angle of penetrator as well as derived target resistance.

Whenever the warhead impacts the structure, compressive wave will appear and propagate spread out into the surrounding. In case of compression wave reach the back surface of the reinforced concrete structure, they will reflect and transform into tensile wave. Under affected tensile stress, concrete layers of the rear face can be pulled out if the tensile stress exceeds the tensile limit strength of concrete. This phenomenon is called scabbing. The critical problem is that the scabbing of fragments can occur and damage human and equipment inside the fortifications.

Hence, one of the most important duties of designers is to determine the penetration depth of projectiles into the structure h_x, scabbing limit thickness h_{scab} (the minimum thickness of the target required to prevent the scabbing at the rear face for a given projectile striking velocity) and perforation limit thickness h_{per} (the minimum thickness of the target required to prevent the perforation for given projectile striking velocity).

2. Determine penetration depth of warhead

In order to determine the depth of penetration of warhead, the empirical models have been introduced and use for a long time. In Vietnam, the popular model is the Berezan model. Based on the empirical theory, the depth of penetration depends on factors such as the impact energy of the penetrators, penetration resistance coefficient K_x, penetration time, impact angle, warhead shape and diameter of warheads. The depth of penetration h_x is expressed as Figure 1 [1-4]:



a) the depth of penetration of the warhead;

b) the length of the tapered part of the warhead

Figure 1. Determination of bullet penetration depth.

$$h_x = \lambda_1.\lambda_2.K_x\cdot\frac{P}{d^2}V_0\left(1-e^{-\frac{d^2}{\lambda_1\lambda_2K_xP}t}\right)\cdot\cos\left(\frac{1+n}{2}\right)\alpha \quad \text{(m)} \quad (1);$$

where:

λ_1 is the influence of projectile nose geometry factor;;

λ_2 is the calibre factor;

d is diameter of the projectile (m);

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V_0 is initial impact velocity (m/s);

α is impact angle (degree);

t is delay time (s);

n is the change direction coefficient of the bullet that describes the effect of angle penetration changing ;

K_x is coefficient that characterized by the penetration resistance of materials. Coefficient K_x has been determined experimentally. Currently, K_x can be used based on Russian experiments [1-2].

3. Analysis of penetration process between a projectile into an FRP reinforced concrete B45 (60 MPa) defensive structure.

The concrete defensive plate is usually used to push the centre of the explosive far away from the main defence structure. There is the sacrificial structure that will receive all loading from the warhead such as penetration and blast loading. Due to the complexity of the bomb penetration process in the fortifications and the lack of suitable calculation tools, this problem is often solved based on experimental formulas with many assumptions to simplify the problem. With the new materials, we do not have the necessary experimental data to take into account.

The following section will present the results of using numerical simulation for the penetration problem of 130 mm shells to the bullet shield made of concrete B45 (M600). The one-meter thickness protective slab is reinforced with FRP bar layers. Impact model problems have been simulated with some different impact angles.

3.1.Model problem

a. Geometrical model

The geometry model includes the 3D model of the 130mm-calibre warhead and the FRP reinforced concrete defensive plate. The warhead 130 mm for artillery has been designed by Space Claim in Ansys [3-4]. The basic parameters of the projectile are as following:

+ Warhead weight: 33.4 kg;

+ Warhead trunk diameter: 130 mm;

+ Projectile length: 635 mm;

+ Taper length: 383.5 mm;

+ Delay time: 3.0 ms.

The protective shell of the defence structure is also enormous. To reduce calculation time, it is assumed that only the dimensions of the calculating plate have been selected at least 3 times the radius of the plastic stress impacted region. Assumed that the plate has dimensions as 2 x 2 x 1 m. The FRP reinforced beams have simulated as a bar element of Ansys. The 10mm-radius bar elements have also assembled into the concrete plate into 4 layers.

The contact between the FRP layers and concrete is set up like the bond reinforced concrete contact. The bonds allow describing the interaction between FRP and concrete as the friction bonds. Figure 2 below depicts the defensive structure and the interaction between the warhead and the protective slab.

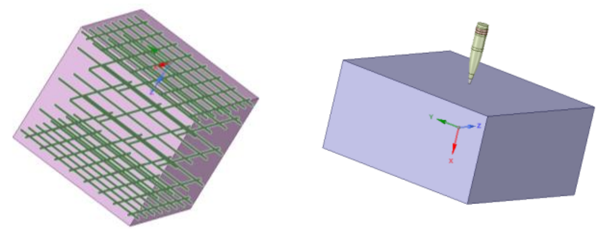


Figure 1. The model of the warhead 130 mm, the 130 mm warhead and the protective shell with FRP layers.

After creating the geometrical model in the Workbench. The elements can be created by using the mesh tool in Dynamic Explicit. Because of the complicated model, Hexa elements were used to describe the warhead and the concrete structure. Besides, the initial conditions, the input parameters also were set up. After that, the total model has been exported and transported into AUTODYN environment [4].

b. Material models

In the simulation problem, the properties of materials are shown in the following parameter table [5-11].

c. Meshing and initial conditions

Assume that the impact velocity of the warhead is 300 m/s in the direction of the bullet axis. Ignore the warhead's rotational motion [1-3], [12-13].

The boundary of the concrete slab is assumed to be the fixed boundary. The 3D impact between the warhead and the defensive slab is the symmetry problem, so it is necessary to simulate with only half of the warhead and the defensive concrete structure.

The concrete slab is meshed using Lagrange mesh. Because of devastate concrete elements, it is necessary to apply the Erosion algorithm to describe material erosion and destruction. The warhead and TNT explosive in the warhead are demonstrated by the SPH method with the 5mm particles. [3-4].

The penetration depths of the 130mm projectile into the concrete B45 slab are shown in Table 3 below, according to different impact angles, respectively:

Table 1.

FRP material parameters [5-7].

Equation of State	Linear	Erosion	Geometric Strain
Reference density	1.65000E+00 (g/cm^3)	Erosion Strain	4.00000E-01 (none)
Bulk Modulus	7.27000E+07 (kPa)	Type of Geometric Strain	Instantaneous
Reference Temperature	2.95150E+02 (K)	**Material Cutoffs**	-
Specific Heat	4.77000E+02 (J/kgK)	Maximum Expansion	1.00000E-01 (none)
Thermal Conductivity	0.00000E+00 (J/mKs)	Minimum Density Factor	1.00000E-04 (none)
Strength	**Elastic**	Minimum Density Factor (SPH)	2.00000E-01 (none)
Shear Modulus	4.83500E+07 (kPa)	Maximum Density Factor (SPH)	3.00000E+00 (none)
Failure	**Principal Stress**	Minimum Soundspeed	1.00000E-06 (m/s)
Principal Tensile Failure Stress	6.20000E+09 (kPa)	Maximum Soundspeed (SPH)	1.01000E+20 (m/s)
Max. Princ. Stress Difference/2	2.80000E+05 (kPa)	Maximum Temperature	1.01000E+20 (K)
Crack Softening	No		
Stochastic failure	No		

Table 2.

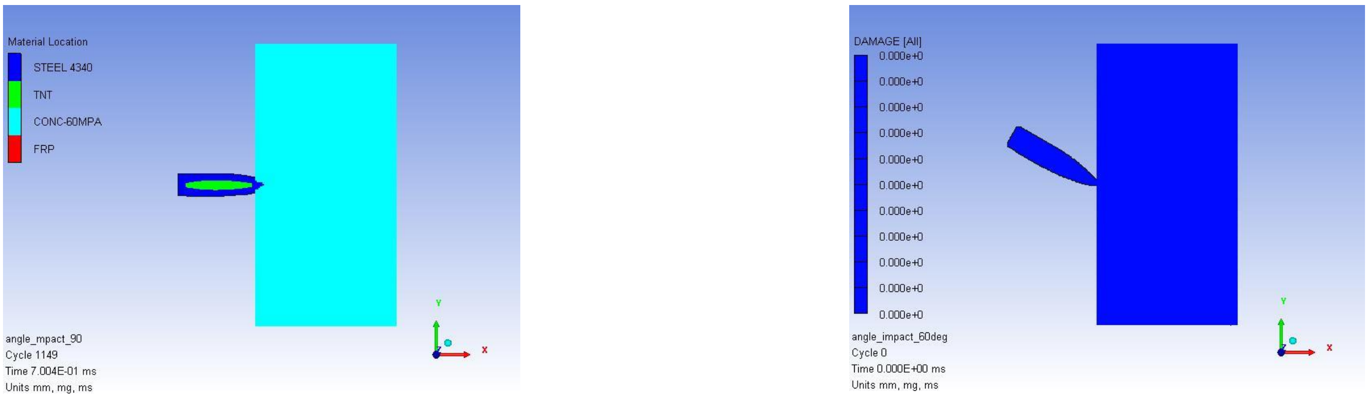
Concrete 60 MPa Material Parameters [5],[10-11].

Equation of State	P alpha	Strength	RHT Concrete
Reference density	2.75000E+00 (g/cm^3)	Shear Modulus	2.20600E+07 (kPa)
Porous density	2.52000E+00 (g/cm^3)	Compressive Strength (fc)	6.00000E+04 (kPa)
Porous soundspeed	3.24200E+03 (m/s)	Tensile Strength (ft/fc)	1.00000E-01 (none)
Initial compaction pressure	9.33000E+04 (kPa)	Shear Strength (fs/fc)	1.80000E-01 (none)
Solid compaction pressure	6.00000E+06 (kPa)	Intact Failure Surface Constant A	1.60000E+00 (none)
Compaction exponent	3.00000E+00 (none)	Intact Failure Surface Exponent N	6.10000E-01 (none)
Solid EOS	Polynomial	Tens./Comp. Meridian Ratio (Q)	6.80500E-01 (none)
Bulk Modulus A1	3.52700E+07 (kPa)	Brittle to Ductile Transition	1.05000E-02 (none)
Parameter A2	3.95800E+07 (kPa)	G (elas.)/ (elas.-plas.)	2.00000E+00 (none)
Parameter A3	9.04000E+06 (kPa)	Elastic Strength / ft	7.00000E-01 (none)
Parameter B0	1.22000E+00 (none)	Elastic Strength / fc	5.30000E-01 (none)
Parameter B1	1.22000E+00 (none)	Fractured Strength Constant B	1.60000E+00 (none)
Parameter T1	3.52700E+07 (kPa)	Fractured Strength Exponent M	6.10000E-01 (none)
Parameter T2	0.00000E+00 (kPa)	Compressive Strain Rate Exp. Alpha	9.09000E-03 (none)
Reference Temperature	2.95150E+02 (K)	Tensile Strain Rate Exp. Delta	1.25000E-02 (none)
Specific Heat	6.54000E+02 (J/kgK)	Max. Fracture Strength Ratio	1.00000E+20 (none)
Thermal Conductivity	0.00000E+00 (J/mKs)	Use CAP on Elastic Surface?	Yes
Compaction Curve	Standard	**Material Cutoffs**	-
Failure	**RHT Concrete**	Maximum Expansion	1.00000E-01 (none)
Damage Constant, D1	4.00000E-02 (none)	Minimum Density Factor	1.00000E-04 (none)
Damage Constant, D2	1.00000E+00 (none)	Minimum Density Factor (SPH)	2.00000E-01 (none)
Minimum Strain to Failure	1.00000E-02 (none)	Maximum Density Factor (SPH)	3.00000E+00 (none)
Residual Shear Modulus Fraction	1.30000E-01 (none)	Minimum Soundspeed	1.00000E-06 (m/s)
Tensile Failure	Hydro (Pmin)	Maximum Soundspeed (SPH)	1.01000E+20 (m/s)
Erosion	**None**	Maximum Temperature	1.01000E+20 (K)

Table 3.

Penetration depths of the 130mm warhead into the concrete B45 slab (cm)

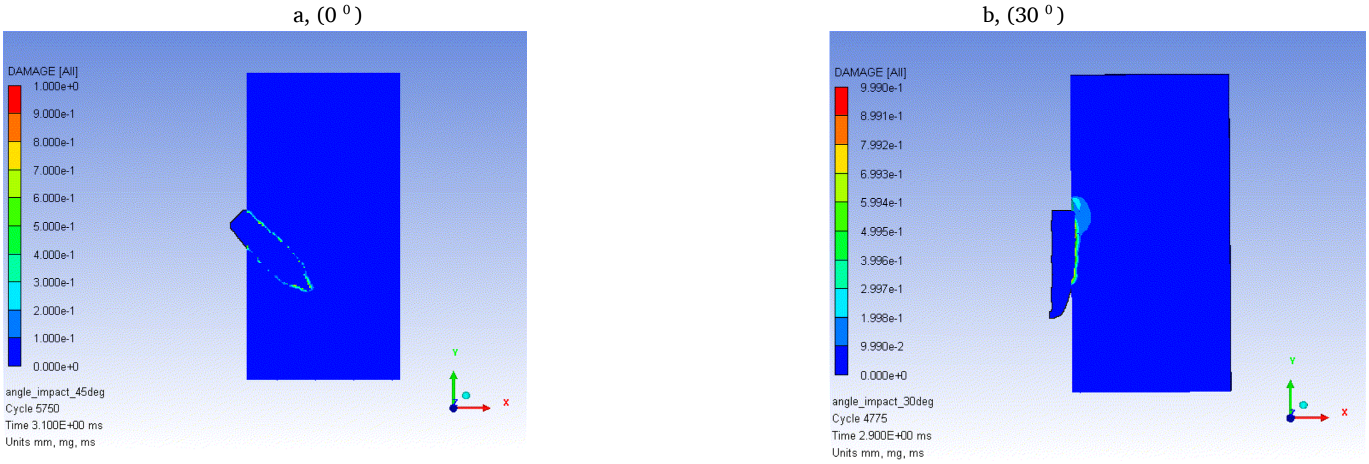
Time / Impact angles	0ms	0.7ms	1.4ms	2.9ms
0^0	0	12	25	53
30^0	0	10	22	46
45^0	0	9	18	41
60^0	0	2	3	3



a, (0^0)   b, (30^0)

Figure 3. Penetration depths of the 130 mm warhead into the concrete B45 at the time 0ms (0^0 và 30^0).

a, (0^0)   b, (30^0)



c, (45^0)   d, (60^0)

Figure 4. Comparison among the penetration depth of warhead into the slab after 2.9 ms (0^0, 30^0, 45^0, 60^0).

*** Comments**

Using the high-strength B45 reinforced concrete stab with 1m thickness is satisfied with the requirement of anti-penetration of the 130 mm projectile. When the warhead is perpendicular to the plane of the protective slab, the projectile can penetrate deepest. Warhead penetration decreases drastically with smaller impact angles. The use of high compressive strength concrete is recommended if we have possible conditions.

4. Comparison among the penetration depth of warhead by using simulating and empirical functions

Table 4.

Penetration depths of the 130 mm warhead into the concrete B45 slab (cm)

No	Impact angles	Expriment al functions	Simulation	Errors	Commen ts
1	0^0	59.4	53	10 %	
2	30^0	51.4	46	10.5 %	
3	45^0	42.1	41	2.6 %	
4	60^0	29.3	3	-	Bounding affect appear!

*** Comments**

The differences between simulated results and experimental formula fluctuate around 20 %. However, in the case of a 60-degree impact angle, there is so exciting phenomenon here. The result is very high difference if we calculate by using the experimental function (Berezan function) while there is the appearance of bounding effect by using simulation. The error results are acceptable due to the complexity of the calculation model, especially lacking correct input material parameters. Besides, the use of simulation not only allows determining the depth of penetration but also describes the interaction of the bullet and the defensive structure and predict the results in the case of complex models. Using simulation can allow computing the complex interactive problems while the experiments can only be performed limitedly because of budget. However, due to the limited budget conditions and difficulties in organizing experiments, the current experiments to determine the parameters of the materials have not been fully performed in our country.

5. Conclusions and recommendations

Researching on the problem of penetration resistance has been conducted for a long time in the world. In Vietnam, the experimental formula is widely used in calculating the fortifications directly under the effect of warhead, cited from Berezan methods. However, there is a big problem in Berezan formula is that using only the penetration resistance coefficients applied to large kinds of materials can lead to significant errors. Besides, the simulation method should be conducted in the case of calculating complicated problems such as outside using range of experiment formula or requiring to calculate the depth of scabbing.

It is necessary to experimentally study the impact between the warhead and protective concrete in the real field. The results are so important to verify experimental functions as well as initial material parameters in simulation. The application of experimental formulas should be considered as a reference and the scope of application of the formulas.

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