NUMERICAL SIMULATION OF HIGH-VELOCITY PROJECTILE INTERACTIONS WITH GROUPS OF SPACED RODS AND PLATES

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ABSTRACT

The study of the problem of protecting the elements of constructions from impact loadings is very important due to the constant perfection of the means of shock-wave impact on the objects of modern technology. Creating of a reliable way to protect structures from destruction by high-velocity elongated projectiles dictates a need to develop different ways to counter the penetration into target. The interaction of projectiles with plates and rods which are thrown towards projectile by HE is investigated.

Keywords: hypervelocity impact, numerical simulation, probability, fragmentation.

INTRODUCTION

The most common way to protect objects is to use materials with high physical and mechanical properties, such as ceramics and composites based on it. Layered barrier enable prevent damage and destruction of protected structures or stretching of the pressure pulse in the layered system due to multiple reflection of waves from layers with different acoustic impedances, or pressure pulse energy dissipation during plastic deformation of highly porous layers or fragmentation of ceramic materials.

Porous and functionally-gradient materials are the most effective protective layers in the layered systems. Materials with physical and mechanical properties continuously changed in certain directions are the materials consisting of discrete-continuous layers with the increasing or decreasing values of acoustic impedance due to increasing the number of layers. One of the parameters changed in a selected direction can be represented by the porosity of a protective layer. Such materials are known as functionally-gradient materials (Gerasimov, 2016). They are characterized by a continuous change of the composition in a specified direction and represent a mixture, the component concentration of which is changed in the spatial coordinates according to a certain law.

The second possible way to counter high-velocity projectiles is to throw groups of spaced plates and rods from conventional and composite materials towards projectiles. As a result of the dynamic interaction and intense deformation occurs the partial destruction of the projectiles or the deviation projectiles from the line of collision. Consequently, the projectiles can rebound from the surface barrier, or deviate from the object to be protected and do not interact with the barrier. All these factors reduce the penetration of projectiles into the
protected object. In this work numerical simulation of the interaction of high-velocity projectiles with groups of rods and spaced plates is carried out.

BASIC RELATIONS AND SOLUTION METHOD

The 3D computations are conducted considering the natural heterogeneous material structure that influences on the distribution of physical and mechanical characteristics over the volume of structural elements and is one of the factors determining the behavior of fracture. The necessity to account the given factor for equations of deformable solid mechanics dictates the application of probabilistic laws of distribution of physical-mechanical characteristics into the volume of the construction under consideration. The spatial adiabatic motion of a solid compressible medium is described using the equation of mass conservation, the momentum equation and the energy equation. In general case, they are given in the form (Wilkins, 1999). To describe the shear strength of the body, the Prandtl-Reuss equations and the von Mises yield condition are used. The state equation of a solid was chosen in the form of Mi-Grüneisen. The criterion of ultimate equivalent plastic strain (Kreyenhagen, 1970) was used as a shear fracture criterion. To simulate an initial heterogeneous structure, the ultimate equivalent plastic strain is distributed over the cells by a modified random number generator that generates a random value according to the chosen distribution law.

The technique for the calculation of the elastic-plastic flows uses tetrahedral cells and is based on the combination of the Wilkins method for the calculation of internal body points and the Johnson method for calculation of contact interactions (Johnson, 1979). A three-dimensional area is divided into tetrahedrons by using the numerical codes for the automatic construction of a mesh. The ideology and methodology of a probabilistic approach applied to the solid fracture problems is given in detail in the monograph (Gerasimov, 2016).

The natural heterogeneous structure of plates and technogenic fragments, which influences on the distribution of physical and mechanical material characteristics (FMC), is one of the main factors determining the material fracture behavior. This factor can be considered in the equations of deformable solid mechanics by using a random distribution of the initial deviations in the strength properties from the nominal values (simulation of initial defect material structures).

The equations of deformable solid mechanics used in the recent studies concerning the dynamic fracture of constructions and materials do not consider this factor, which can distort the real picture of the impact fracture. The random distribution of the initial deviations in the strength properties from the nominal value of FMC leads to the fact that in these cases, the process of fracture becomes probabilistic, which is more consistent with the experimental data.

RESULTS

Earlier, the work (Gerasimov, 2013) considered the interaction of a rod with two and three spaced plates thrown towards this rod. The interaction of a rod with four plates moving towards and away from this rod was considered in the work (Gerasimov, 2015). This paper, for
the further development of the approach to thrown plates, presents the interaction of a tungsten rod with four tungsten plates. The plates move both towards and away from the rod. The distance between the plates is varied. The radius of the rod is 1.2 cm, the length is 65.4 cm. The thickness of the plates is 1 cm, the thickness of the target is 5 cm, and the oblique angle of the rod relative to the target is $60^0$. The sizes of the plates and target are as follows: the width is 15 cm, the length is 60 cm, and the oblique angle relative to the horizontal surface is $30^0$. The distance between the plates, and the plates and the target $h_1$, $h_2$, $h_3$, $h_4$ are varied for different problems. The rod velocity is $V = -2000$ m/s, the normal velocities of the plates $V_1$, $V_2$, $V_3$, $V_4$, and the distance between the plates are also varied for different problems. Fig. 1 shows the location of the rod and the target with the plates at the initial moment of time.

![Fig. 1](image)

**Fig. 1** - Initial configuration of the «rod-plate-target» system: three-dimensional computation (a); 2D cross-section of a three-dimensional computational area (the velocity of the plates is directed towards the rod) (b); 2D section of a three-dimensional computational area (the velocity of the two plates is directed towards the rod and the velocity of the other plates is directed away from the rod) (c); 2D cross-section of a three-dimensional computational area (the velocity of the plates is directed along the plane) (d)

![Fig. 2](image)

**Fig. 2** - Interaction of a rod with the plates (the velocity of the plates is directed normally to the surface): three-dimensional computation (a); 2D cross-section of a three-dimensional computational area (b)

Fig. 2 shows the computations for the throwing of the four plates (Fig. 1b) at a normal velocity of 1000 m/s. The impact of the bodies led to the insignificant fracture of the rod and the change of the axisymmetric shape.
The velocity vector deviation of the plates from the normal by $30^0$ led to a noticeable change of interaction between the plates and the rod (Fig. 3). There is the significant increase in the fracture of the contact rod surface and the deviation of the rod from the initial direction of impact. The deformed part of the rod is almost parallel to the surface of the target, which can lead to the ricochet of the rod or flying past the target.

Fig. 4 shows the interaction of the rod and plates, when the velocity vector of the plate deviates from the normal by $45^0$, which leads to a noticeable change in the fracture and deviation of the rod as compared to Fig. 3, and to the increase in the probability of the ricochet and deviation of the rod from the target.

Fig. 5 - Initial configuration of the plate-rod system: 2D cross-section of a three-dimensional computational area
Fig. 5 shows the initial configuration of a system that consists of the three plates (targets), as well as a fourth thrown plate and a thrown cylindrical projectile. The velocity of the thrown plate is 1000 m/s, the velocity of the tungsten projectile is -2000 m/s. The sickness of the thrown tungsten plate is 2 cm. The plates (targets) are made of the following materials: the material of the first plate (counting from the impacting plate) is steel, the thickness is 1.5 cm; the material of the second plate is titanium, the thickness is 1 cm; the material of the third plate is aluminum, the thickness is 0.8 cm. The target is made of steel, the thickness is 1 cm. The distance between the target and the plates is 2 cm.

After the impact of the plate with the plates (targets), the plates (targets) start moving and diverging, which leads to the formation of a spaced protection against the projectile (Fig. 6).

The interaction of the plates with the projectile leads to the fracture and deviation of the projectile from the initial flight trajectory. In the following case steel ribbed plate was thrown towards the projectile. Ribbed plate is a combination of two systems - plates and spaced rods (Fig. 8).
The use of a ribbed plate for protection changes its interaction with a rod (Figs. 9-10). The ribs deform the rod to form waves, which leads to the fracture of the rod and the ricochet of fragments produced from the target surface. The fracture of the target in the computations is insignificant and observed only in the surface layer of the material.

An absolutely different picture is observed during the impact of ribbed plate with a projectile. In this case, there is the intensive fragmentation of the plate and the projectile. The remaining parts of the projectile ricochets from the target surface that is slightly fractured (Fig. 9).
CONCLUSION

The goal of this work was the numerical simulation of spatial deformation and fracture of high-velocity projectiles caused by the elements of multilayered composite systems and various combinations of rods thrown towards the projectiles, as well as the investigation concerning the impact of high-velocity projectile fragments with the target protected. The problems were solved using a three-dimensional formulation, since this approach allowed the dynamic loads to be studied by the most appropriate method.

The computations given in the work showed the possibilities of the proposed approaches to reduce the penetration of the projectile. Intensive dynamic interaction leads to the deformation and fracture of the projectiles, as well as the deviation of the projectiles from the impact line with the target. As a result, the projectiles either ricochet from the surface of the target or deviate from the protected object and do not interact with the target. All these factors reduce the penetration of projectiles and reduce the probability of penetration through the body of an object protected.

The computations also have shown that the developed 3D numerical technique allows us to simulate the high-velocity interaction of long projectiles with spaced plates, rods and ribbed constructions, as well as to simulate the interaction between the residues of projectiles and protected objects during the normal and oblique impact in a wide range of velocities and angles of impact, and also to investigate the fragmentation of projectiles and targets, and the behavior of the fragmentation fields formed. The conducted comparison have shown that the theoretical and experimental data are in good agreement, which allows the developed technique to be used for computations of mechanical-engineering constructions under dynamic loading and for the selection of the most effective materials and geometric parameters of thrown elements. The computations showed that a group of plates could reduce the fracture of the protected object. The most effective way is to throw plates with a velocity vector directed at an angle of $45^0$ relative to the surface of plates. The other variants of using plates provide a less protective effect. The dynamic formation of a spaced target allows the protection system to correspond to the specified sizes.

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REFERENCES


