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# PENETRATION OF STEEL AND ICE BARRIERS BY A PROJECTILE AT LOW INITIAL SPEEDS (< 325 m/s)

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## ABSTRACT

The process of penetration of the ice block and a thin steel plate by the projectile has been studied experimentally. The ice block was completely destroyed by fragments, and a hole (diameter ~ 9 mm) was fixed in a steel plate. The residual velocity of the projectiles was obtained. The main features of the process of destruction of objects of research are fixed. New research tasks are formulated.

***Keywords:*** ice, projectile, steel, numerical simulation, post-penetration analysis, destruction.

## INTRODUCTION

Constant improvement of the means of kinetic influence on the protected objects forces developers of shockproof protectors to look for new ways to increase their impact resistance. Due to the fact that the possibilities of constructional materials are limited, there is a certain scientific interest in researching the properties of functional graded materials and porous materials, high-strength fabrics, ceramics under dynamic loading. A well-known fact is an attempt is made to use the mentioned materials in the formulations of the newest protective structures: multi-layered plates, laminated-bonded and block-modular and sandwich panels, etc. A review of this topic is given (G. Ben-Dor, 2017). Ballistic performance of some materials conducted in (Tria D, 2017 and Iqbal M A *et al*., 2016).

At the Research Institute of Applied Mathematics and Mechanics (RI AMM), studies are constantly conducted on the impact resistance protective structure penetrated by impactors of various shapes and weight. The team of authors has some experience of theoretical and experimental studies increase the impact resistance of protective structures. The results of numerical simulation of penetration of steel plates by compact impactors and projectiles were presented (Gerasimov, 2007). Various impactors were considered, including compact and elongated impactors as well as single-layered and two-layered steel plates. Two types of bonding of the layers are considered, including the type of bond that imitates a weld. The thickness of the single-layered plate was equal to the thickness of the two-layered plates. Two-layered plates consisted of "base layer" and an "additional layer", the thickness of which was equal to half of the "base layer". The location of the "additional layer" on the front side gave the structure a greater impact resistance than its location on the rear side up to 1500 m/s.

The purpose of current research is impact resistance ice plate and steel plate by penetrated projectile. In future research, it makes sense to consider these plates as additional layers of multi-layered protective structures. Below are only the results of experimental research.

## EXPERIMENTAL SETUP

To carry out these studies, a mobile experimental setup located on the basis of the Tomsk Bullet Society was used, Figure 1. As it was said before, its distinctive feature is mobility. With the help of this experimental setup it is possible to investigate the processes of destruction of single-layer and multilayer structures (the total thickness is up to 20 cm). The tested range of initial velocity is up to 1100 m/s. In this case, it was possible to shoot the process penetrating from different sides. Therefore, the shape of the cloud of fragments after penetration of the plate was founded, including the residual velocity of the projectile. Video shooting allows estimate the number of fragments that have separated from the plates from the front and back sides.

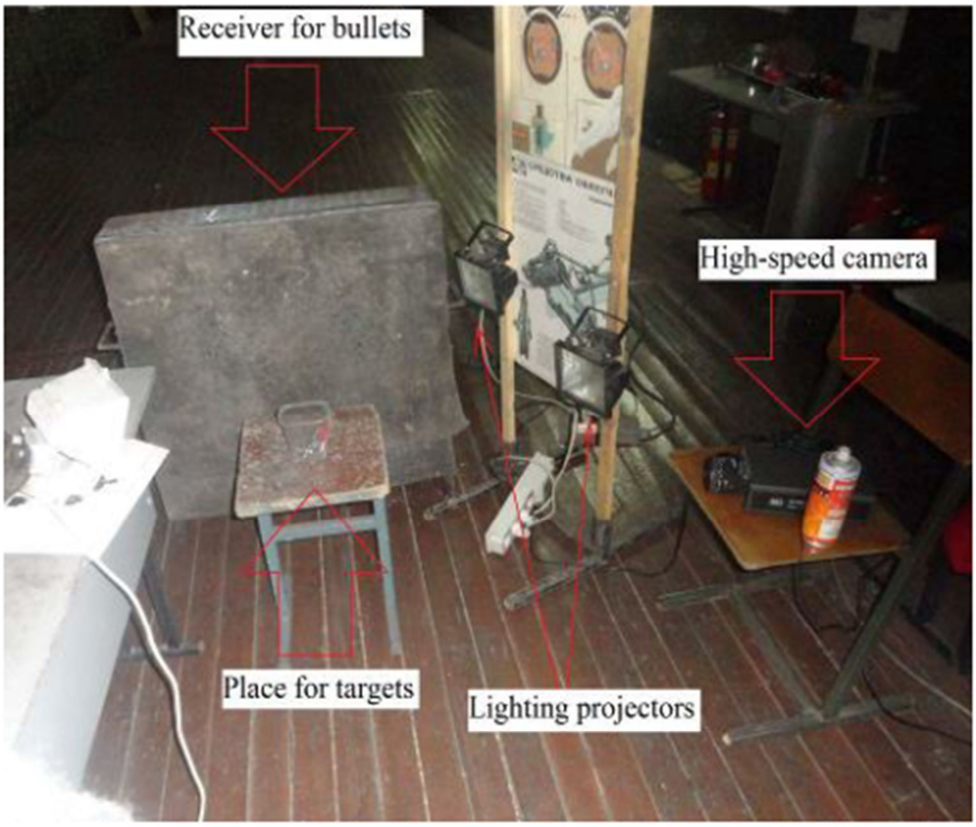
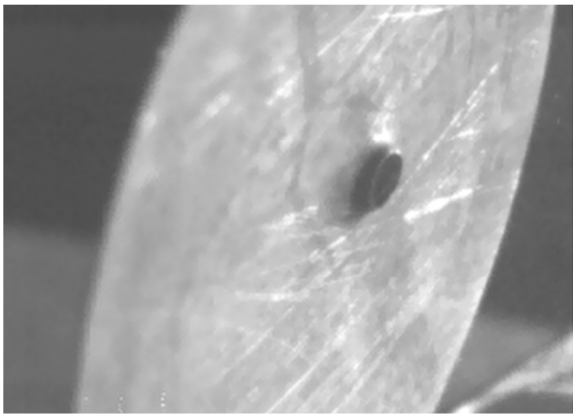



Fig. 1 - Experimental Setup

Figure 1 shows the experimental setup. The main components were a bullet-trap, light projectors, a special place for targets and a high-speed camera (Photron Fastcam APX RS, 10000 frames per second). The bullet-trap can retain the shape of the projectile after penetrating the plates. The video camera was located under a straight and a sideward angle to the plates. For the first time the experimental setup is described in the work (Orlov, 2017).

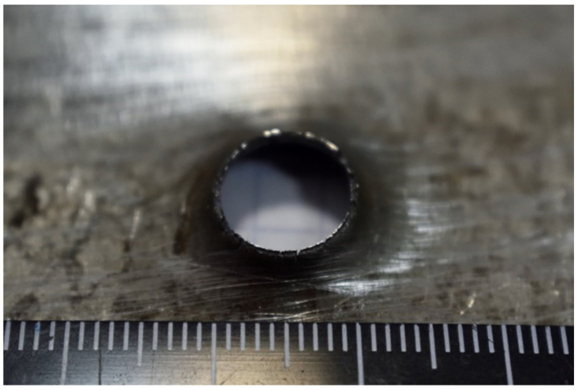
## RESEARCH OF PENETRATING STEEL PLATE BY PROJECTILE

In this section focuses author's experimental research on the penetration steel plate by projectile. The authors excluded the overview on the topic and limited only to the description of the experimental results. This fact can be explained by a large number of works on this topic. The target is a thin steel plate. The material of the plate is Steel 3 (In accordance with GOST of Russian structural steels). Thickness of the steel plate is 1 mm, the diameter is 150 mm. The projectile is a well-known Makarov bullet. Bullet consists of a steel core in a lead "shirt" (weight 6.1 g, diameter 9 mm, height 12.35 mm). The impact was normal up to 325 m/s. The exact velocity was approximate 317 m/s.



(a)

(b)



(c)

Fig. 2 - (a) Results impact tests: high-speed shooting of a steel plate after penetration (photo by V. Pashkov); (b) Left projectile - after penetration ice barriers (single barrier and two-layered barrier), right projectile - after penetration single steel plate (photo by V. Solonenko); (c) Rear side steel barrier (Photo by M. Orlov)

Post penetration analysis showed that there was a through penetration of the steel plate. The penetration was accompanied by knocking out steel "cork" from the plate (cork not shown on photo). The diameter of the "cork" was approximately equal to the projectile diameter. After the penetration, the projectile moved along with the cork. This indicates that the impulse was increased and the impact effect of the projectile increased. An important point is that the pieces of the steel plate had small dimensions and were barely visible on the high-speed video. Figure 2(a) shows a steel barrier after a through penetration by a projectile. The approximate time is 150 μs. After penetration, the projectile had a slight deformation of the head part. This is clearly seen in Figure 2(b). The projectile in the left part of the photo is the projectile before the impact; the projectile on the right side of the photo is the projectile after breaking through the steel barrier.

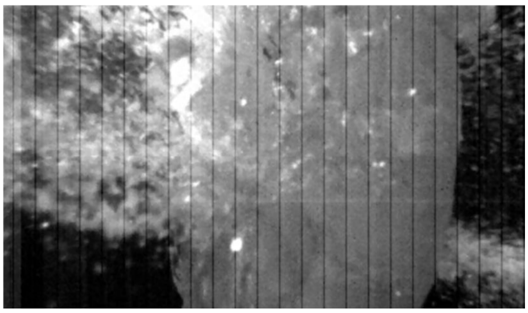
Figure 2(c) illustrates the back side of the steel plate after penetration. The zone of plastic deformation of the plate has a diameter approximately equal to two diameters of the projectile. The edges of the holes are even and curved inwards by 5 mm. Such a picture is typical when perforation of thin metal plates by projectiles. The residual velocity projectile was approximately 20% of the initial its.

## RESEARCH OF PENETRATING ICE BLOCKS BY PROJECTILE

In this section, the process of penetration of ice plate by a projectile is discussed. An overview of this topic was given in (Orlov, 2016), so the authors focus only on the results of experiments.

The projectile and the initial velocity was the same as the previous section. The object of research is an ice cylinder with a diameter of 100 mm and a thickness of 45 mm. The ice was made in a refrigerated chamber by freezing fresh water for 40 hours. The freezing temperature was -18 C (Degrees Celsius). This ice was investigated in (Bogorodsky V, 1980), where its strength characteristics are also given.


(a) (b)



(c)

Fig. 3 - (a) Ice barrier before and (b) after impact. Bar represent 1mm. Photo reprinted from [5]; (c) High-speed shooting of the process of penetration of the ice block, t = 50 μs

Figure 3(a) illustrates the initial configuration of the ice block and the fragments that remained after the impact. Fragments of the size of about 3-5 cm are visible on the figure. Such fragments were formed by separating the ice from the center through the main cracks. There were fragments measuring 1 cm or less. Some of them can be seen on the high-speed video.

Figure 3(b) shows the process of penetration of a single-layered ice barrier by a projectile. In the experiment, there were also multilayered ice blocks, but they are not discussed in the current article. In this figure, the barrier stands at a slight angle to the high-speed camera. The results of penetration are evident due to the difference in the strength characteristics of ice and steel. Therefore, the main interest is the regularity of the ice penetrating process.

Of course, all the regularities of the process of destruction can only be determined numerically. This refers to the time in which the first foci of destruction originated in the ice block, the development of main cracks, the time of through penetration of block, hydrostatic pressure at control points, velocity of the rear surface, etc. In the opinion of the authors, this information will allow us to reproduce the scenario of the destruction of any object of research, including ice block.

Below we consider the morphology of the destruction of ice (the size and shape of the fragments), the numerical value of the residual velocity, the relative shortening of the projectile (if it took place). It can be seen that the destruction of ice has nothing to do with the destruction of steel. The destruction of ice generally has no analogues among other natural materials. This experiment once again confirmed this fact. The projectile was not subjected to plastic deformation during the penetration. The residual velocity of the projectile was almost equal to its initial velocity.

## RESULTS

The penetration of a thin steel plate by the projectile was accompanied by knocking out “cork” and deforming the plate in the contact zone of the "projectile − target". The target was bent in the direction of projectile movement. “Cork” had a round shape and bent edges. The hole had smooth edges, and its diameter was approximately equal to the initial diameter of the projectile. Projectile had plastic deformation only in the region of the nose. Its cylindrical part had only small scratches. On the high-speed video are visible small steel fragments (sizes less than 1 mm). The residual projectile velocity was 20% initial velocity projectile.

The destruction of the ice block under impact had more differences than the general with the previous case. Ice almost did not resist the penetrating of the projectile. The process of destruction was accompanied by the separation of the ice block into fragments of various sizes. Among the fragments were pieces of ice 3-5 cm in size. There was a splash of ice both on the front side of the ice block, and on the back side its. A large number of ice fragments measuring about 1 cm or less were noted. As mentioned in (Gerasimov, 2007), corundum ceramics may have a somewhat similar morphology of destruction. The residual velocity of the projectile was almost equal to its initial velocity.

Research conducted in the current work allowed us to formulate new research tasks. The scientific interest is the increase the thickness of the ice block and the location behind the "additional" steel layer. The possibility of frostbite on the steel plate is also not excluded. A three-layer construction consisting of a steel thin plate, an ice block and a steel thin plate can very well be the object of research.

## CONCLUSION

In the current work, an experimental research was made of the penetration of single-layer ice block and thin steel plates by the projectile at low initial velocities. The penetration of ice by the projectile was not accompanied by a significant decrease its initial velocity. The penetration of a thin steel plate by the projectile was accompanied by knocking out "cork" from it and slightly deforming projectile.

## ACKNOWLEDGMENTS

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