Mobile laboratory “Explosive destruction of natural materials”: Investigation of the behavior of ice and limestone under explosive loading

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Abstract. In the paper, the behavior of ice and natural limestone under explosion condition was investigated. The objects of study were the river ice and natural limestone quarry on Siberia. The practical significance of research due to the need to increase production of oil and gas in permafrost regions, the fight against ice jams, etc. We organized a mobile laboratory “Explosive destruction of the natural materials” at the National Research Tomsk State University. The main purpose of the laboratory is express analyzing of explosive destruction of natural materials. The diameters and depths of explosive craters in the limestone and explosive lane in the ice were obtained. The results can be used to test new models and numerical methods for calculating shock and explosive loading of different materials, including ice.

1. Introduction

Nowadays, researches of the behavior of certain natural materials are relevant. This is due to the development of the northern territories, the extraction of natural resources in the Far North, etc. In the Far North, under a layer of ice may be a natural limestone, granite and various rocks. Currently, many scientists are studying the behavior of geological materials under dynamic loads [1–3]. It is known that many natural materials under certain conditions have a common mechanism of failure. However, ice is the oldest little known natural material. The modern concept of failure the ice is just beginning to develop. This is due to the complex structure of the ice, the presence of phase transitions during deformation, unique plastic properties. There are over 16 types of ice; the latter type of ice has an extraterrestrial origin. In the United States resumed the program “SCICEX” within which there is a collection of scientific data using the ships of the Navy. The existing experimental data on dynamic loading of ice is not consistent with each other due to the complex structure of ice. Experimental data on explosive loading of ice were not found. In the Research Institute of Applied Mathematics and Mechanics at Tomsk State University has developed a new physical mathematical model of ice behavior under the shock and explosive loads [4]. Numerical method for calculating shock and explosive loading of various natural materials was modified. Innovation consists of the improved algorithm for calculating the contact surfaces by blasting explosives of different masses. For the development of a numerical method requires reliable experimental data on the processes of destruction the
ice with explosive conditions. The scientific data on the behavior of ice and natural materials under shock and explosion have been summarized [5,6].

2. Full-scale tests
The paper summarizes the experimental results of the process of explosive loading of limestone and river ice. Undermining these natural materials was carried out by means of emulsion explosives.

2.1. Experiment on explosive loading natural limestone
The results experiment on the explosive loading limestone is presented. The results were an experiment on the explosive loading limestone. Experiments were carried out in March along with “KuzbasSpetsVzryv” company. The object of study is a monolithic array of limestone area of over 100 m$^2$. The limestone surface was smooth. It has been established that the depth of the array of limestone was approximately 10 meters. Below is the water in the liquid phase. The diameters holes for laying explosive were 11 cm. The depth of the well is 560 cm. The number of experiments was 7. The wells were made by mechanical means, as limestone has a hard rock. Due to weather conditions in the wells was freshwater. The water level was 200–350 cm. Explosive consists of nitrate and Emulast 90-FP (figure 1). The weight nitrate was 50 kg. Emulast weight varied from 4 to 12 kg depending on the water level in the well. Only one well Emulast weight was 12 kg. Undermining explosives carried out simultaneously in 7 wells.

![Figure 1. Preparations for the explosion. Two pieces of emulsion explosives Emulast-90FP: 4 kg + 4 kg, Nitrate 25 kg.](image)

| Well  | Average diameter | Mass of HE Emulast + Nitrate | Level of water |
|-------|------------------|------------------------------|---------------|
| Well 1| 1.2 m            | 8 + 50                       | 2.5 m         |
| Well 2| 1.7 m            | 12 + 50                      | 2.8 m         |
| Well 3| 1.6 m            | 12 + 50                      | 2.8 m         |
| Well 4| —                | 16 + 50                      | 3.2 m         |
| Well 5| 1.3 m            | 8 + 50                       | 2.5 m         |
| Well 6| 1.3 m            | 8 + 50                       | 2.5 m         |
| Well 7| 1.4 m            | 8 + 50                       | 2.5 m         |
The first photos were obtained 10 minutes after the explosion. The photo illustrates the different types of experimental platform after the explosion (50 photos). Photos obtained from a distance of 10 and 5 meters, respectively. There were large fragments of a diameter of about 90 cm or more. However, most of the fragments were small (diameter below 30 cm). Height of debris cloud reached about 30 meters. The diameter of debris cloud was about 100 meters. After the explosion, it was very difficult to determine the depth of the explosive crater. Apparently, explosive crater depth was equal to the original depth of the well. In table 1 results explosive loading limestone process are presented. The table illustrates the number of wells, the average diameter of the explosive crater, the mass of explosives (Emulast + Nitrate) and the water level in the well. In the fourth case, calculate the diameter of the crater failed.

A detailed examination of the surface of the limestone found diameters explosive craters that were about 120–170 cm. Qualitative assessment of the depth and diameter of the crater in the limestone were obtained. Depth of explosive crater was 5.60 m. The diameter of the crater was 1.2–1.7 m.

2.2. Experiments on the explosive loading freshwater river ice
Full-scale experiments were held on the explosive loading of annual river ice. Experiments were carried out in the spring of 2013 and 2014 years. Venue was a suburb of the city of Tomsk. The objects of study chosen snow ice cover and bare ice cover on the Tom. The explosive pawned under the ice in the water. Such an explosion called UNDEX (Under Explosive). The wells were done manually.

Figure 2 shows the snow and bare ice after explosive. Ice thickness was equal to 80 and 70 cm, respectively. Snow thickness was 20 cm. It is evident that lane had a circular shape with a diameter of 200 and 430 cm. Figure 2 shows the lane in the snow ice after the explosion. Weight of explosives was 4 kg (TNT equivalent about 3 kg). Three days before the experiment was warm weather, so the ice is more porous. Figure 2b illustrates the lane in the bare ice after the explosion. Weight of explosives was 8 kg (TNT equivalent about 6 kg). Breakaway fragment of ice on the left is due to defects in the ice cover. As can be seen from the figure 2, the state of the ice edge was different. In the second case was more ice fragments of different sizes. The fragments of ice had dimensions of 20 cm. The diameter debris cloud was about 25 m. Modified Lagrangian method was modeled first experiment [7]. The time of interaction, the volume of destruction, speed of the free surface ice and the diameter of the lane were
obtained numerically. Ice modeled elastic-plastic medium with averaged physical and mechanical characteristics without phase transitions. Calculations were carried out in a two-dimensional axisymmetric formulation. The difference between numerical simulation and experiment data was 7%.

Experimentally found that the porosity of the ice affects the pattern of destruction of ice under explosive loading. The results are preliminary and may be used for testing the physical and mathematical model of deformation and fracture of ice in the explosion. It is planned to measure the porosity of the ice with the help of ultrasonic devices.

3. Conclusion
Organized in Tomsk State University mobile laboratory “Explosive destruction of the natural materials” is capable of conducting express analysis process of explosive loading of materials. All done are 5 expeditions. Unfortunately, it was not possible to quantify the diameter and depth of the explosion crater in the limestone. Under explosive loading, limestone formed fragments of different sizes. Diameters lanes in the ice under explosion the snow and bare ice were obtained. Lane in the ice had a circular shape with a diameter of 200 to 430 cm. The results can be used to verify the means of mathematical modeling.

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