The behavior limestone under explosive load

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Abstract. Limestone behavior under explosive loading was investigated. The behavior of the limestone by the action of the three types of explosives, including granular, ammonite and emulsion explosives was studied in detail. The shape and diameter of the explosion craters were obtained. The observed fragments after the blast have been classified as large, medium and small fragments. Three full-scale experiments were carried out. The research results can be used as a qualitative test for the approbation of numerical methods.

1. Introduction

Impact and blast threats exist in a wide range of engineering, security and defense sector. Therefore, investigations of the behavior of materials under dynamic loads are relevant. Recent investigations are carried out in many of the world's scientific centers [?, 1–3]. Reliable experimental data are needed to create mathematical models of the behavior of materials under dynamic loads. For example, one reason for the lack of an adequate model of the behavior of ice under dynamic loads is the lack of experimental data [?]. Full-scale experiments on explosive loading of natural materials are laborious and costly. In Tomsk State University has developed a software package for modeling multicontact dynamic problems of solid mechanics. Modern multicontact dynamic problems are tasks of deep penetration homogeneous and multilayer structures by impactors [2].

In 2013, at the initiative of authors was organized mobile laboratory "Explosive destruction of natural materials". The leading idea of the laboratory is snap analysis the objects of study under dynamic load [4]. Mobile laboratory partners are "KuzbasSpetsVzryv" Ltd and the Ministry of Emergency Situations of the Russian Federation. It was carried out the expedition in two regions of the Siberian Federal District. As a result, it was detail studied of river ice and limestone under explosion. At the moment, the database on the behavior of natural materials under explosive loads was developing. The database is needed to improve the mathematical model and numerical method of simulation [5].

2. Mobile laboratory "Explosive destruction of natural materials"

The first expedition a mobile laboratory was in 2013. In the spring, KuzbasSpetsVzryv Ltd in the Siberian was carried out flood protection events on the Tom River. It was then the laboratory was founded. The porous snow medium thick ice was selected as the first object of study. Under these conditions, the experiment was carried out on the underwater explosion (UNDEX) of emulsion explosive. In the future, the experiment has been successfully modeled in two-dimensional axisymmetric statement. The discrepancy between the experimental and numerical data was approximately 10%. Subsequent expeditions, objects of the research are bar ice cover and ice cover sandwich structure (snow–shuga–ice) [5, 6].

The mobile laboratory extends research team opportunities. In addition, to laboratory experiments and computational experiment it became possible to carry out full-scale tests. This is a very important moment for the determination of basic mechanisms and regularities of dynamic fracture process of materials. Arsenal mobile laboratory are a certified modern measuring tools, including ultrasonic range finder and other measures of length and others accessories. State research facilities after the explosion is fixed by means of a digital camera with a high resolution matrix. The first photos of the objects of research are obtained within 2 minutes after the explosion. Each full scale test was filmed. The main results should be considered as measured by the diameter of the craters of explosion and lanes, the crater depth, the diameter of the debris cloud. It is sufficient for the qualitative and quantitative tests. Thus an effective research tool are developing that can be used to multiplication the scientific knowledge of the destruction of the materials, and to verify the new mathematical models and numerical methods.

3. Investigation of explosive destruction of limestone

The results of experimental research on the explosive loading of natural limestone are presented. There were two stages of research. This article describes the first stage of the comprehensive research of the dynamic load of limestone. At this stage, there were only full-scale experiments. Three experiments were considered. The experimental scheme was not changed, but type explosive and depth of the set explosives were different. It was blown up about 1000 kg of trinitrotoluol (henceforth TNT). Limestone is a solid rock and has well known properties. The subject of research is the state of limestone after the explosion, including the shape of the crater and so on.

3.1. Preparing for the blast experiment

The experimental scheme was the same in all cases. The area of the experimental site was about 1000 m^2. Limestone surface was smooth. Previously it found that at a depth of 10 meters of water. Well depth was varied from 200 to 600 cm. The diameter was 11 cm only. Before the detonation, explosives completely fill the space well. Subject of research is a state of the limestone after the blast of explosives, including the diameter and depth of the crater and morphology destruction (size of the fragments). Expansion of the limestone fragments under detonation products (henceforth DP) also studied. There were three types explosion, including granular explosive (GE), ammonite explosive (AE) and emulsion explosive (EE). Serial number of the experiment corresponded to the number of explosives. The initiation point of explosion was at the top of the sample charge. In next paragraphs shows the results of experiments in chronological order. All experiments were successful.

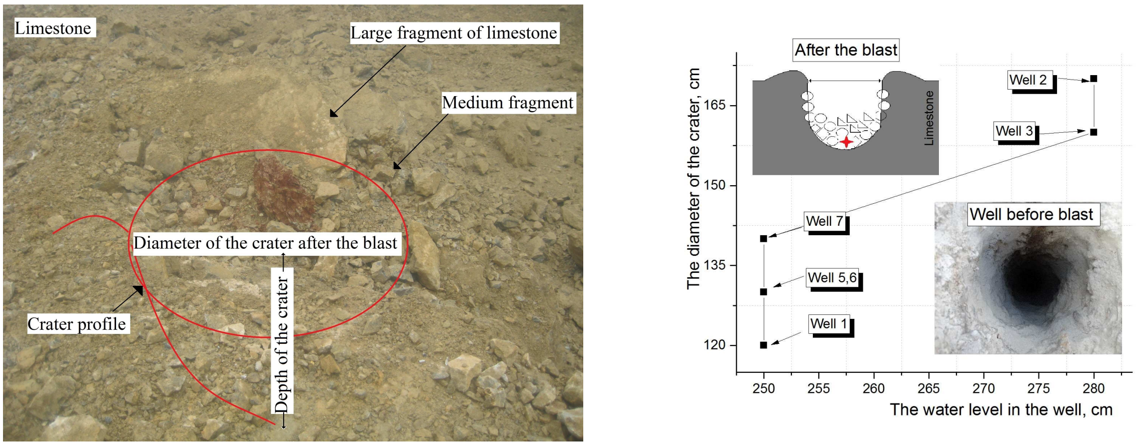
3.1.1. Full-scale test 1 For the first time explosive was mixture from GE, AE and EE. This type of explosive was called explosive mixture (henceforth EM). Explosives mass varied depending on the water level in the well. Mass EE ranged from 8 to 12 kg, the mass AE from 0.3 to 0.6 kg. Mass of GE remained constant at 50 kg. In the wellbore component positioned upward. Blast experiments preceded by warm weather, so in all wells was water.

Initial data full-scale test 1 is as follows: the number of wells—7; well depth—560 cm; the diameter of the well—11 cm; EM explosives (TNT equivalent—53.89–60.11 kg); level of the water in the well—2.5–3.2 m.

Figure 1 shows the results of the full-scale test 1. The components of the explosive mixture consists of two pieces EE, one piece AE and one piece GE. Figure 1a shows the experimental

Table 1. Properties of explosives.

Type of explosive	Initial density g/cm^3	The velocity of detonation m/s	TNT equivalent Size free
EE	1.40	4500	0.75
AE	1.20	4000	1.03
GE	0.95	2600	1.08



(a) (b)

Figure 1. Full-scale test 1: limestone after the blast (a) and the diameter of crater versus the water level in the well (b).

site after the explosion. Graphic dependence of crater diameter on the water level in the well is represented in figure 1b. Properties of the explosive are summarized in table 1.

State of experimental area is shown in figure 1a. The photo was taken from the hill by V Golubyatnikov. Initial examination showed that the area was fully covered with small fragments and dust. Detailed examination showed that there were large pieces of limestone (piece is over 50 cm) and the remains of the DP. It was difficult to determine the shape of the crater of the explosion. Figure 1a shows the outline of the crater of the explosion, which was formed after the blast of the well. In the center of the photo is the author of this article. The crater from above was shaped like a circle. Near large fragment of limestone (piece is over 100 cm) is discovered. The height and the diameter of the fragments emission were more than 25 meters. This assessment was qualitative. It was found that some of the limestone turned into sand, but has retained its original color.

The experimental results are presented in the table 2. The main results were measured diameters of the craters. The error of measurements is not more than 1 cm. The depth of the crater could not be measured, but most likely, it was no more than 560 cm. In four variants AE mass was equal to 0.3 kg. This is due to the water level in the well of 250 cm. In three variants AE mass was equal to 0.6 kg. Two variants EE mass was 12 kg and only one variant (well 4) mass EE was equal 16 kg. Diameter crater could not be measured in the latest variant. Thus crater diameter was changed from 120 cm to 170 cm.

Table 2. Results of explosive loading limestone.

Number of well	Average diameter, m	Mass of HE Emulast + Nitrate	Level of water, m
1	1.2	8 + 50	2.5
2	1.7	12 + 50	2.8
3	1.6	12 + 50	2.8
4	—	16 + 50	3.2
5	1.3	8 + 50	2.5
5	1.3	8 + 50	2.5
1	1.4	8 + 50	2.5

3.1.2. Full-scale test 2 The results of the full-scale test 2 are presented. Experiments were carried out in autumn 2015 in the same place. The distance from the experimental site of the full scale test 1 to experimental site of the full-scale test 2 was around 200 meters. After 10 meters was a ravine. The distance from the well to the ravine was around 25 meters. On the day of the experiment was zero temperature. The well was water. Only one blast was produced. In that experiment AE was selected as explosives (I.e. was homogeneous). This is a significant difference from the previous experiment.

The initial data full-scale test 2: Well depth was 600 cm. The number of wells is 1. The diameter of the well is 11 cm. The water level was no more than 100 cm. Mass of AE was 42 kg (equivalent of 34 kg of TNT).

The results of the full-scale test 2 are shown in figure 2. Before the blast 140 pieces of AE was placed in the well. AE is also shown in figure 2 in the upper right. As in the previous case, the explosive fills the space well. In figure 2, assistant A Orlov examines the bottom and sides of the crater.

The experiment was successful, explosives exploded completely. After inspecting the most important issue was the question of the difference picture limestone destruction. Differences and common features in the morphology of limestone fracture were observed. The common features were fragments of various sizes, slide near the edge of the crater, the dust and the remains of the DP. As in the previous case, from above the crater had the shape a circle. The diameter of the fragment emission was more than 25 m. It can be a coincidence, but a near crater the large limestone fragment was found. A fragment is for the assistant back in figure 2.

Also, differences in the morphology of limestone destruction were found. One difference was that the number of the fragments (pieces are 50 cm and more) was observed much greater. The second difference is that the height of debris near slides of the edge of the crater was about one meter. The third difference was that the layer of fine dust was under the debris layer. This is clearly evident on photo and was not in the full-scale test 1. The main result should be considered that the diameter of the crater was equal to 450 cm, and the depth of the crater was ~ 230 cm.

3.1.3. Full-scale test 3 Finally a full-scale test 3 was carried out. Blast limestone was produced in winter 2016. The experimental site was the smallest. As in the previous case, the explosive was homogeneous. Emulsion explosives were used. Blast up explosives manufactured at the same time. All the blasts carried out successfully.

Initial data full-scale test 3: the depth of the well is 200 cm; the number of wells is 6; water is not detected in the wellbore; EE in the well was 16 kg (13.4 kg of TNT equivalent); the number of charges in the well was 4; the total mass of explosives was 96 kg (80.4 kg of TNT equivalent).

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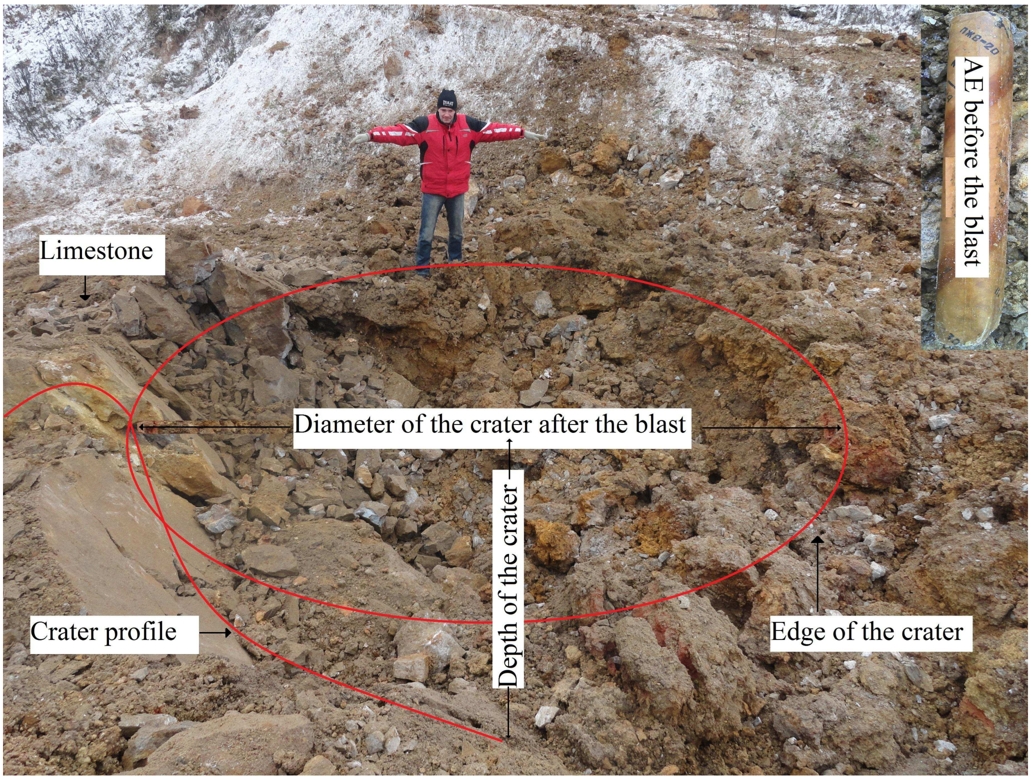

Figure 2. Full-scale test 2: the crater into limestone after the blast up.

The experimental results are shown in figure 3. The construction the explosive consisted of four charges EE. It is seen that the well depth is almost equal to the height EE structure. Figure 3 shows well after blast up.

It can be seen in the crater and around the crater were fragments limestone of various sizes. The size of fragments was different. The diameter of the fragment emission was about 10 meters. And at such a distance came the very small pieces. Many of the mechanisms of destruction of limestone were found in full-scale tests 1 and 2. Deepening of the crater led to a narrowing of the crater. Thus the diameter of the crater after the blast EE changed in the range from 150 to 170 cm. Moreover, the crater depth without removing debris from the bottom was 120 cm.

4. Discussion of the results of experiments

After the blast up of different types of explosives, one could observe general features limestone destruction. In all cases, fragments of various sizes of limestone, dust and residues DP were detected. Under the action DP in the vicinity of the experimental area has been formed a cloud of debris. This cloud of debris had different sizes. Maximum dimensions of the cloud debris reached in the full-scale test 1, but minimum dimensions of the cloud were in the full-scale test 3. Fragments of limestone after the explosion were classified as large (pieces are 50 cm or more), medium and small fragments (pieces are less than 15 cm). The largest number of small fragments found in full-scale test 1. After the explosion of AE most of the fragments were large. After blasting EE, a number of medium and small fragments were approximately the same. Profiles of all the craters are shown in figure 4. The crater from above was shaped like a circle. It was revealed that the full-scale test 1 had the “glassful” shape crater. The crater had “cup-shaped” and “V” shaped forms is the full-scale tests 2 and 3.

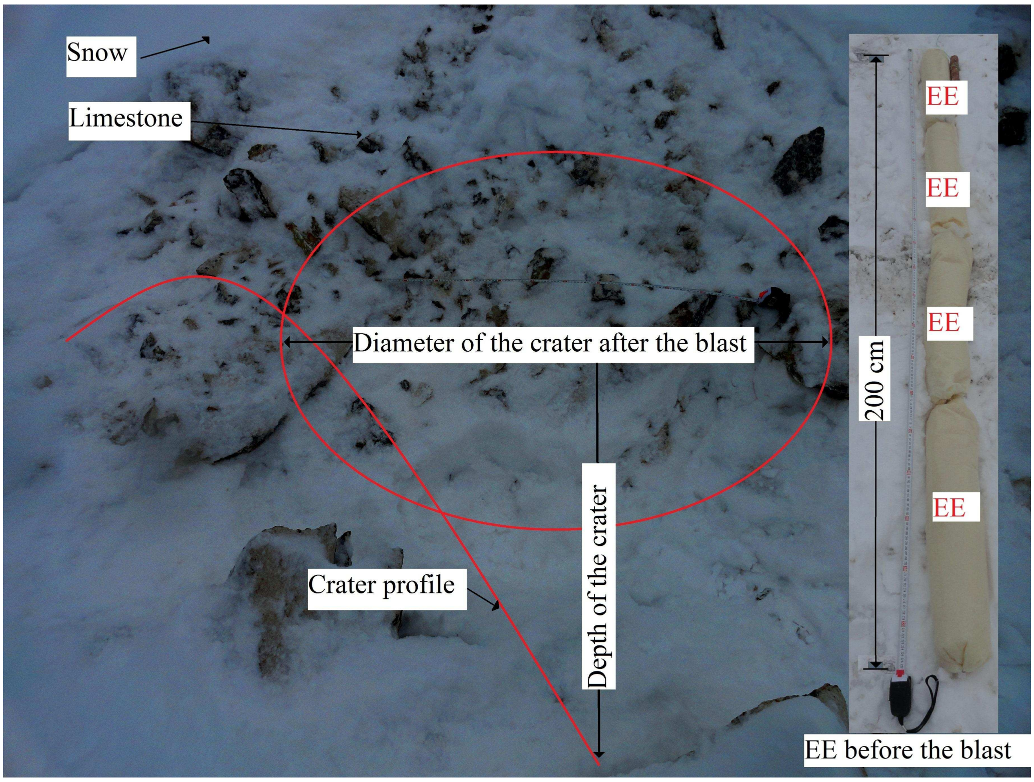

Figure 3. The well in 1 day after the blast.

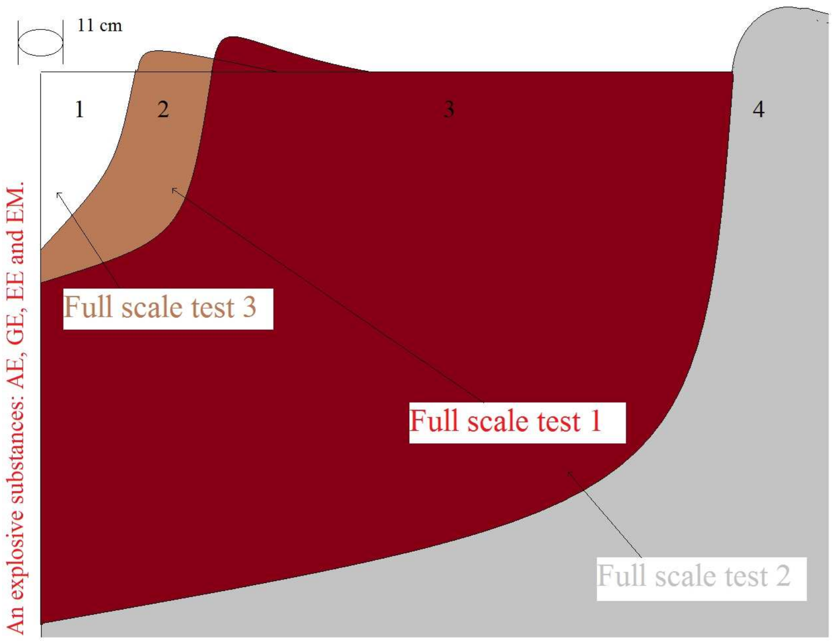

Figure 4. Profiles of the craters: 1—EM, 2—AE, 3—EE, 4—limestone.

5. Conclusion

Thus, the organized mobile laboratory is able to carry out express analysis of the explosive destruction of natural limestone. The size of the cloud fragments after the blast of explosives, the depth and the diameter of the crater were recorded. Fragments of limestone were classified as large, medium and small. Unfortunately, the quantitative assessment the depth of the crater was not obtained. The main results were identified forms of the crater after blast. The results can only be used as a qualitative tests when validation of numerical methods.

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