

Basic study on promotion of thawing frozen soil by shock loading

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ABSTRACT

The aim of study is to confirm a new technique that can crush the frozen soil and/or ice block using underwater shock wave generated by the underwater explosion of explosive. This technique can lead to the earlier sowing, which can have the larger harvest because the duration of sunshine increases. Especially, in Hokkaido prefecture, Japan, if the sowing is carried out in April, we can expect to have 150% of harvest in the ordinary season. In the case of small processing area such as road repairing, frozen soil is thawed by using the heat of gas burner and/or the electric heater. It is not a suitable plan to apply these heating methods to agriculture, from the point of view enormous amount of processing area. Thawing technique for frozen soil is effective against the cold regions, for example, Russia, Norway, and Sweden, etc. At first, we carried out experiments using a detonating fuse and ice block. The propagation process of shock wave into the ice block was observed by means of a high-speed camera. In order to check about that influence we tried to give an actual frozen soil a shock wave. We could get a result that existence of water layer serves an important role in promotion of thawing by the shock loading to the frozen soil.

INTRODUCTION

In the cold region like Hokkaido, there are very few snowfalls but the ambience remains considerably colder. Therefore, planting in the early spring that decides the harvest of that year is delayed by farm's freeze. If the frozen soil thawing is suggested, we can have great expectation as 1.5 times of harvest in comparison with conventional harvest process. In the case of small processing area such as road repairing, frozen soil is thawed by using the heat of gas burner and/or the electric heater. It is not a suitable plan to apply these heating methods to agriculture, from the point of view enormous amount of processing area. Therefore, we are planning to break frozen soil and promote thawing by the underwater

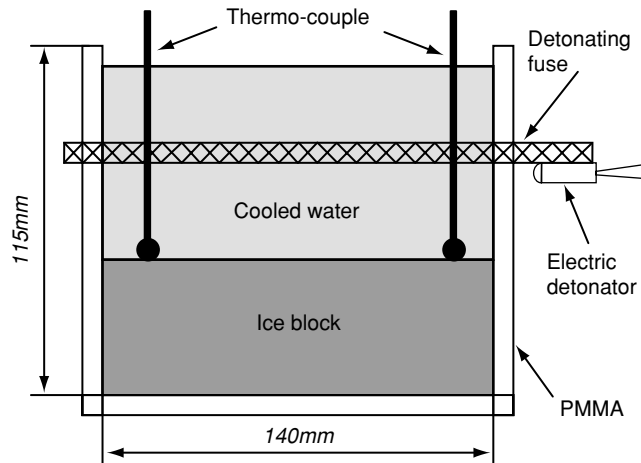


Figure 1 The outline of the experimental device for visualization in the ice solid.

shock wave regarding those problems. The frozen soil is composed of various soil elements, water and air gap. These are distributed complicatedly [1], their thermo-physical properties are needed to discuss the thawing. The magnitude of thermal conductivities for each element is as follows; $\lambda_{ice} > \lambda_{water} > \lambda_{soil} > \lambda_{air}$ (λ : thermal conductivity). Air gaps obstruct thawing of frozen soil and a heat conductive route. Water is drawn in the field, and the detonating fuse is traced and is exploded on the field. The aim in this study is to promote the infiltrating of sunlight and increase of the heat conduction by infiltrating water in a crack on the frozen soil. We carried out experiments about the spreading of shock wave in the ice solid and the water, and the crushing of the ice block by the underwater shock wave. We performed the experiments using shock wave for the actual frozen soil and tried to verify the effect.

EXPERIMENT ABOUT THE SHOCK WAVE SPREAD IN THE ICE SOLID

EXPERIMENTAL APPARATUS AND METHOD

The outline of experimental device is shown in Fig. 1. A container made of PMMA has $140\text{mm} \times 115\text{mm} \times 140\text{mm}$ in inner size, and a block-shaped ice was fixed on the bottom part of this container for the visualization photography. The detonating fuse (Japan Carlit Co. Ltd., The 2nd kind detonating fuse, principal ingredient: PENET, loading density: 1200kg/m^3 , outer diameter: 5.4mm, detonation velocity: 6308m/s) was installed on that (Fig. 2). It is filled with cold water so that water makes detonating fuse set completely, and it completes the preparation for an experiment. The initiation is made by the No.6 electric detonator (Asahi Chemical Industry Co. Ltd., Japan). An image-converter-camera (IMACON486, HADLANDPHOTO-NICS, maximum framing speed of 10 million frames per second, and a maximum streak speed 10 millimeter per nanosecond) was used for the visualization photography. The streak slit is along the perpendicular direction to the detonation progress in the fuse. The illuminative light comes from a Xenon-flash-light source (HL20/50 type Flash-light, HADLANDPHOTONICS, output 500J) with duration time of 50 microseconds. Moreover, the thermo-couples (type K) were used for the temperature measurement. The temperature of ice surface and water in the neighborhood of detonating fuse were monitored before the explosion and temperature measurement were made.

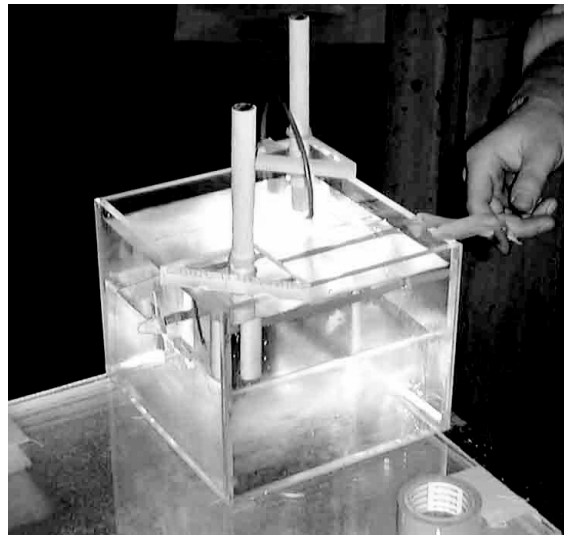


Figure 2 Photograph of the experimental device.

RESULTS AND DISCUSSIONS

The visualization results of the shock wave spreading into the ice solid are shown in Fig. 3(a)-(f). Figure 3(a) is photograph before the explosion. Figure 3(b)-(e) is framing photograph obtained from the initiating 10, 15, 20 and 25 microsecond, respectively. Figure 3(f) is photograph in streak mode [2-4]. The position of streak slit is shown as dotted line in Fig. 3(a). The initial temperature of the ice block is 0.5 degrees Celsius, the initial temperature of the water is 1.7 degrees Celsius in the central part of the water area. In Fig. 3(b)-(e), we can know that the shock wave occurred in the water region and a reflected wave generated on the surface of the ice. In Figure 3(d), it is considered that the front of the light region which has a bigger angle than a shock wave in the water. It is thought the thing that appears by fine crack's going into the ice by the shock wave. By seeing streak photograph of Figure 3(f), incident angle with the shock wave of the ice is bigger than incident angle with the shock wave of the water. When shock wave propagates in the ice region, the shock velocity, which declined during the water for a while, raises from the difference in impedance. Moreover, the value of incident velocity in the ice solid is higher than the incident velocity in the water. It is expected that a pressure is very high due to the high velocity, too. The velocity of shock wave in the photograph downward distance was calculated by an image's analyzing in this photograph [5-6]. The result is shown in Fig. 4. As above-mentioned the difference in the value of the shock wave velocity in the water and the ice are distinct. It was shown that decline in the distance is smaller than one inside the ice than the inside the water. It is found that a decline of the energy of the shock wave is big, which is used for the collapse of the ice inside the ice. However, as the spreading of the shock wave actually faster than the progress of the collapse, it is found that it didn't have an influence against the change in physics and phase, for the progress of the shock wave. It is guessed that shock wave doesn't decline very much inside the ice from the character that scatters, and loss of received shock energy is poor. The received binding force of the molecule in the ice is bigger than that in water. There are a few unnecessary movements in the molecule of the ice. Therefore, it is assumed that arrangement by impedance about the shock wave decline inside the ice is necessary.

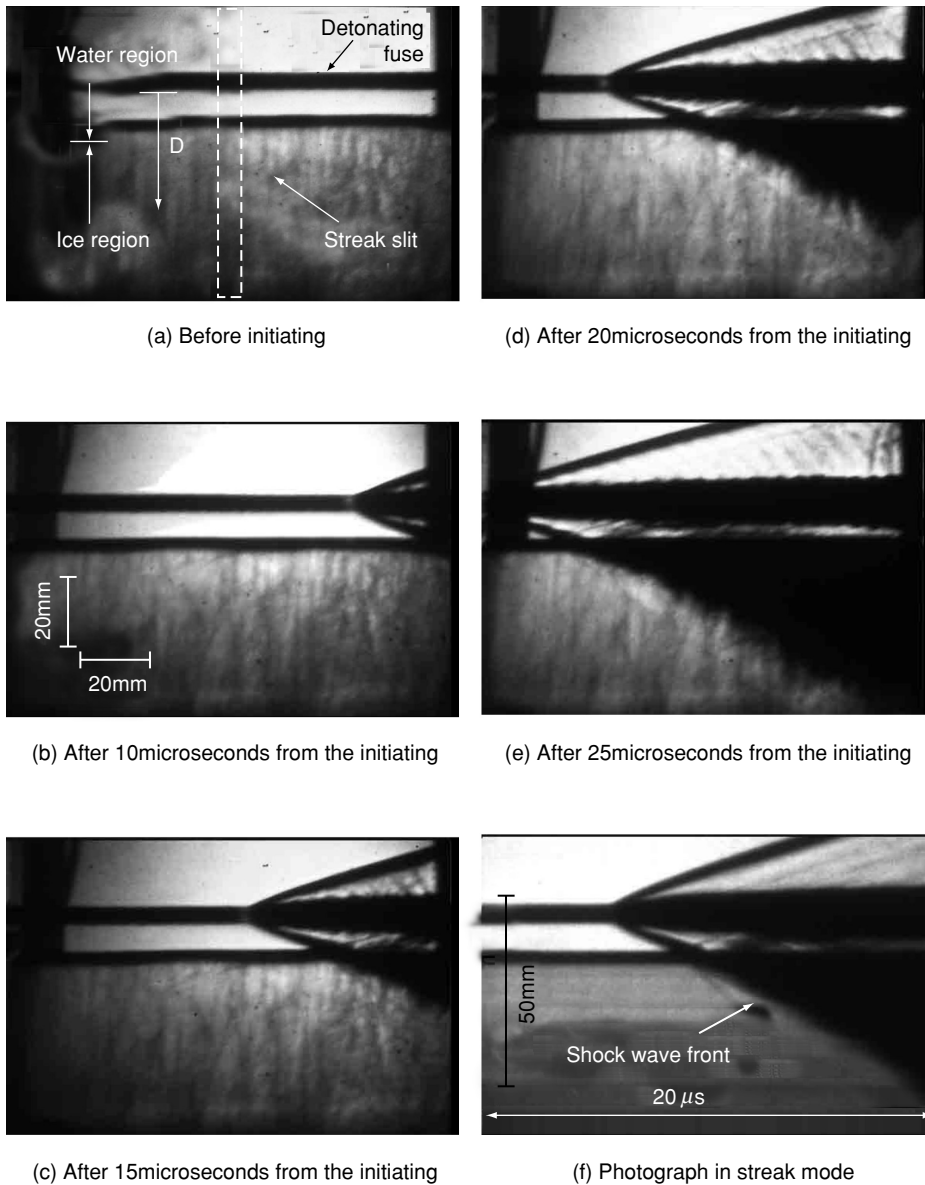


Figure 3 Visualization results using an image-converter-camera.

SHOCK LOADING EXPERIMENT WITH FROZEN SOIL BLOCK

We carried out experiment, which loads the shock wave into actual frozen soil and attempted to verify the effect.

EXPERIMENTAL APPARATUS AND METHOD

The frozen soil was made by filling with liquid nitrogen the soil into the wooden box. The size of a wooden box is 300mm × 300mm × 300mm. Soil was filled up to a height of 200mm. The mass of the soil samples is about 43kg. The shock loading experiment was performed when the temperature on the surface of frozen soil turned into −20 degrees Celsius by

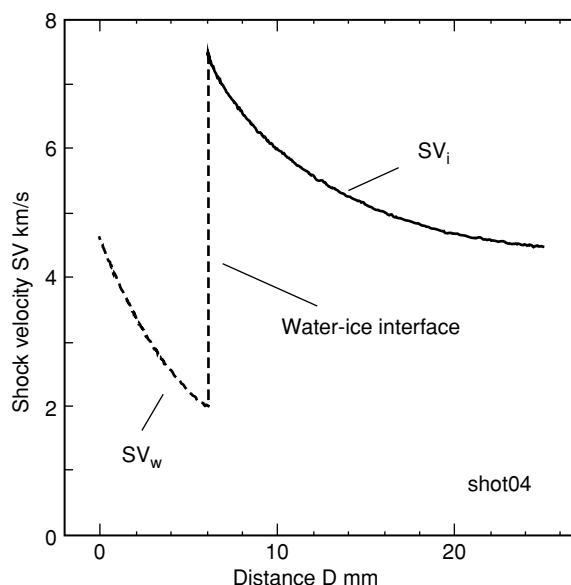
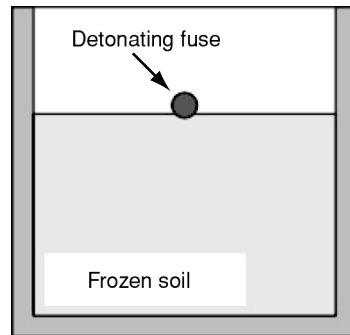


Figure 4 Relationship between shock velocity and distance from the detonating fuse to bottom of the container.

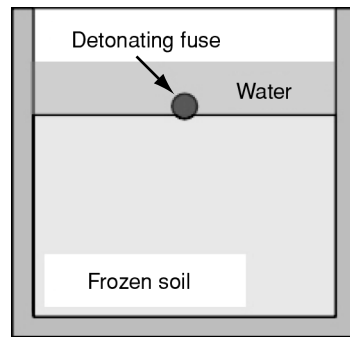


Figure 5 Photograph of the experimental set up for shock loading to frozen soil.

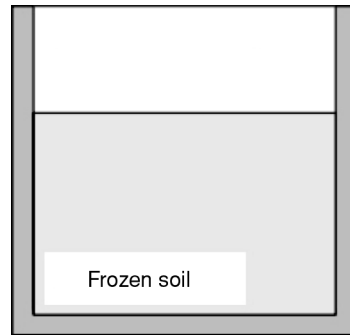
passage of time. The situation photograph when setting detonating fuse to a frozen soil box is shown in Fig. 5. Six frozen soil boxes were prepared in total. These boxes were divided into three groups as follows; the case of only detonating fuse (see in Fig. 6(a), Lot. A, B), the case of detonating fuse and water (see in Fig. 6(b), Lot. C, D), and the case of un-shock loading for control (see in Fig. 6(c), Lot. E, F). In the case of detonating fuse and water, the part of frozen soil where water directly contacts is thawed, when frozen soil box is filled with water. Therefore, the frozen soil was covered by vinyl sheeting, detonating fuse was set on the sheeting. The thickness of water layer formed on the sheet is 20mm.



(a) Experimental condition for Lot. A, B



(b) Experimental condition for Lot. C, D



(c) Experimental condition for Lot. E, F

Figure 6 Outline of experimental condition.

RESULTS AND DISCUSSIONS

In the case of Lot.A, photograph of the frozen soil box is shown in Fig. 7 after shock loading. Although the influence of a shock wave takes effect in the area about 40mm of neighborhoods where detonating fuse was set, in other area, change is not seen at all. In the case of Lot. C, photograph of the frozen soil box is shown in Fig. 8 after shock loading. In this case, the frozen soil was destroyed over the whole and damage has extended to the wooden box. In order to check subsequent progress, we left the all frozen soil boxes (Lot. A-F)



Figure 7 Photograph of the frozen soil box immediately after shock loading in the case of Lot. A.



Figure 8 Photograph of the frozen soil box immediately after shock loading in the case of Lot. C.

to the outdoor. These wooden boxes were exposed to outdoor air without heat insulation materials. The temperature of the outdoor is 18 degrees Celsius, and the weather is fine.

After 3 hours, there was no conspicuously change on the surface of frozen soil in three groups, comparing with immediately after shock wave loading. In the case of Lot. A, frozen soil was soft only near detonating fuse. In the case of Lot. C soil was soft on the whole. In the case of Lot. E, surface of soil was maintaining the state of the hard frozen soil. Then, we broke a part of wooden box, and checked the situation of a frozen soil layer. In the case of Lot. A, the frozen soil layer with a thickness of 60~70mm remained (see in Fig.9). In another case of Lot. C, the frozen soil did not remain at all, but as for the case of the case of Lot. E,



Figure 9 Photograph of the remaining frozen layer 3 hours after shock loading in the case of Lot. A.



Figure 10 Photograph of the remaining frozen layer 3 hours after shock loading in the case of Lot. E.

the 50~60mm frozen soil layer remained (see in Fig. 10). The result of the remaining thickness of all frozen soil layers is shown in Table 1. In the case of only detonating fuse Lot. A, B, the frozen soil of the same quantity remained in comparison with the case of unshocked Lot. E, F. In the case of Lot. C, D that were added water, the frozen soil layer did not remain at all. These results show that existence of water layer serves an important role in the shock loading to the frozen soil.

Table 1 Thickness of remaining frozen soil layer 3 hours after shock loading.

Lot.	A	B	C	D	E	F
Condition	Detonating fuse only	Detonating fuse + water	Detonating fuse + water	Control (Un-shock)		
Thickness of remaining frozen layer	6~7cm	5~6cm	0cm (none)	0cm (none)	5~6cm	5~6cm
Effect	none	none	good	good	—	—

CONCLUSIONS

In order to promote thawing the frozen soil, we carried out the experiments for spreading of shock wave in the ice block and shock loading to frozen soil and attempted to verify the effect. The conclusions can be summarized as follows.

- (1) A shock wave velocity inside the ice is much larger than inside the water. Therefore, it is guessed that pressure is very high, too.
- (2) Existence of water layer serves an important role in promotion of thawing by the shock loading to the frozen soil.

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