Small Scale Tests on Mitigation Effects of Water in a Model of the KLOTZ Club Tunnel in Älvdalen.

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Abstract

The effects of water in close contact with detonating high explosives have been studied in several test series and it has been determined that water has a mitigation effect on the blast wave from an explosion. Both maximum overpressure and impulse density will be reduced. The effective charge size can be reduced with more than 50 %, possibly as much as 80 %. This means that possible equivalence factor is 0.2 (amount of high explosive with/without water giving the same effects).

It has been suggested as a very interesting concept to store ammunition or high explosive together with containers of water to reduce the effects of accidental explosions.

A full scale test with real ammunition and water used for mitigation is planned to take place in The KLOTZ Club tunnel in Älvdalen in fall 1996. For planning and preparation purpose of the full scale test a comprehensive test series in a small scale model of the tunnel has been performed.

Different locations of water and charge to water ratio have been studied. Pressure time histories have been recorded inside and outside the tunnel. Some simple experiments were also made to compare the effects of debris throw, with and without water mitigation.

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Introduction

The effects of water in close contact with detonating high explosives have been studied in several test series in Sweden for instance by Eriksson as early as 1974 (Eriksson, 1974) and recently in a test series reported by Keenan and Wager (1992) and by Vretblad and Eriksson (1994) and Eriksson (1994). From those test series it has been determined that both maximum overpressure and impulse density was reduced when water containers were stored close to the high explosive. In test series with Carbon tetrachloride and with ice - reported to KLOTZ CLUB (1994, 1995) - it was shown that the mitigation effect is dependent of the heat capacity of the additive.

It has been suggested as a very interesting concept to store ammunition or high explosive together with containers of water to reduce the effects of accidental explosions. Of course it is a problem to store water in a ammunition magazine.

The test series mentioned above can be considered as small scale compared to real ammunition magazines. The weight of high explosive has been in the range of 0,5-100 kg. Loading density (weight of high explosive divided by the volume of the confinement) has not been in the range that is common in many ammunition magazines. In the experiments only bare charges without casing have been used.

It is therefore important in order to verify the usefulness of water as a mitigation agent in ammunition magazines to perform experiments with real ammunition (cased charges) and in full scale (realistic loading density and realistic total weight of high explosive).

A full scale test with real ammunition and water used for mitigation is planned to take place in The KLOTZ Club tunnel in Älvdalen in fall 1996. The test will be a repetition of previous experiments made with 180 artillery shells (m/36) each with a weight of 45 kg and with 5,5 kg charge weight of TNT (Vretblad, 1987 and Vretblad, 1990). Thus the total weight of high explosive will be 1000 kg. All shells will be initiated simultaneously.

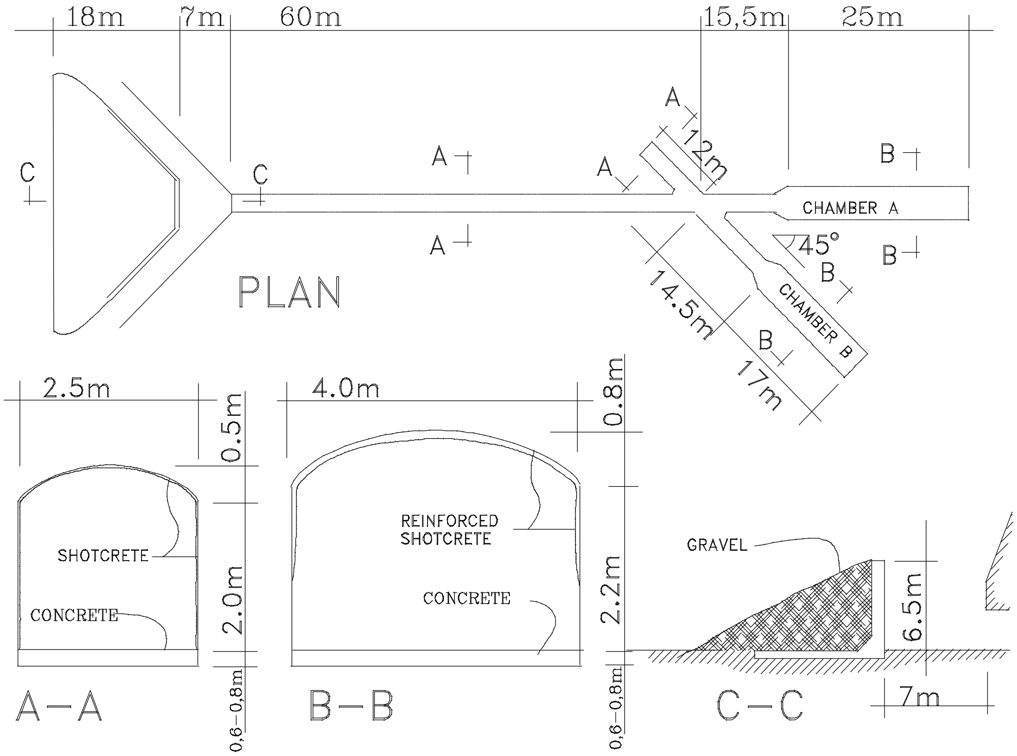
In contrast to previous experiments in the tunnel in Älvdalen were no water mitigation was used, this time a number of water barrels will be placed around the shells. In contacts with Swedish and Norwegian personnel responsible for ammunition storage it has been declared that it would be practical to use as small water containers as possible. 25 litre plastic barrels will be used stored on loading pallets on all four sides of the shells. The reason to use small barrels is to minimize the consequences of an accidental leakage. For practical reasons it is a wish to keep the amount of water to a minimum and, furthermore, it is practical not to store the water in absolute contact with the shells.

In order to study the influence of the location of water and amount of water as a preparation to the full scale test, a small scale test series has been performed in a 1/20 model of the KLOTZ Club tunnel.

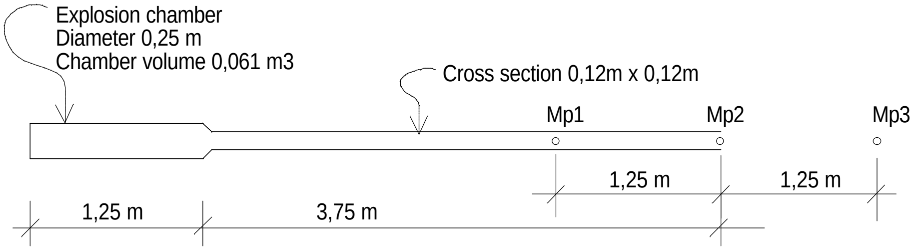
Test set up

The experiments were made in a 1/20 scale model of the KLOTZ-Club tunnel in Älvdalen (Figure 1).

The small scale tunnel used in the experiments is not a true model but simplified in the matter that the chamber B is lacking, as is the berm in front of the tunnel entrance. The model consists of steel pipes with circular and quadratic cross sections.



The KLOTZ Club tunnel in Älvdalen



The small scale model

Figure 1. The KLOTZ Club tunnel in Älvdalen and the small scale model.

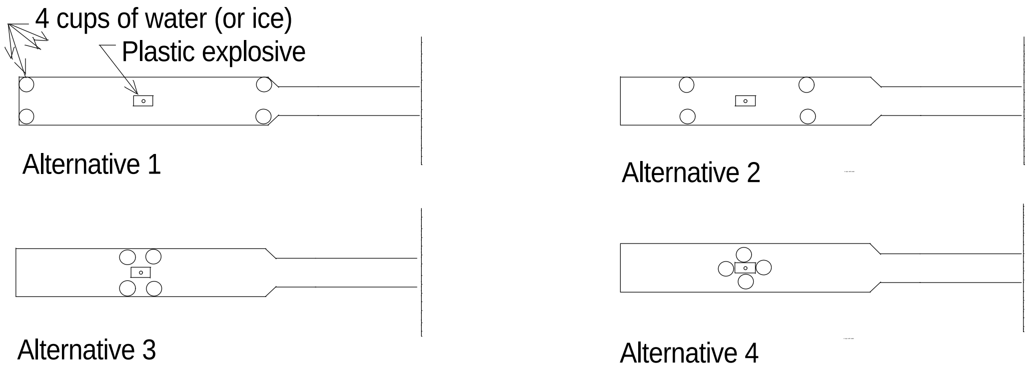
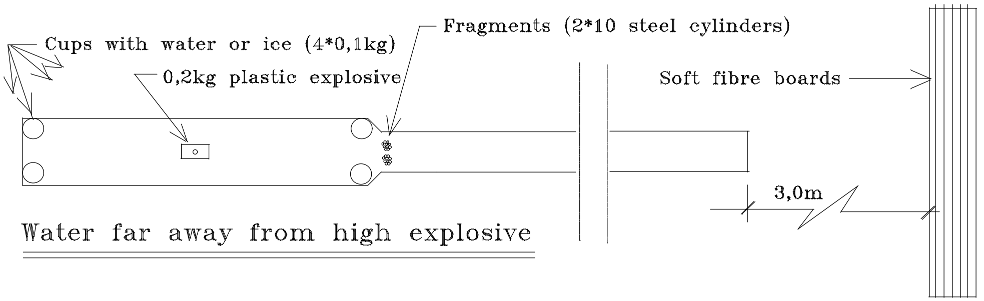
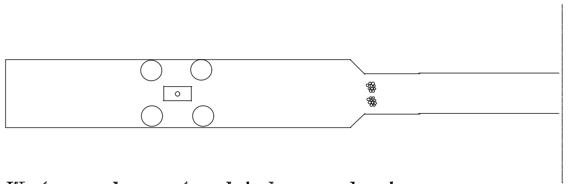


Figure 2. Location of water cups in the experiments. In most tests Alternative 1 or Alternative 3 was used.

In total 25 experiments were made in the model and the pressures were recorded at three locations, Mp1, Mp2 in the ceiling of the ”tunnel” and Mp3 in the ground outside the entrance, See Figure 1. Plastic explosive charges were used with a composition close to that of C4 and the charges were placed on a 5 cm thick corrugated cardboard layer in order to reduce the crater. Usually, the charge weight was 200 g. In some tests water or solid ice was placed in cups at different locations in the explosion chamber, See Figure 2. Normally, we used 4 x 100 g water / ice.



Water far away from high explosive



Water close to high explosive

Figure 3. Set up in experiments with fragments.

In a few experiments steel fragments were placed at the intersection of the explosion chamber and the tunnel, See Figure 3. Outside the tunnel, 3 m from the entrance, a package of soft fibre boards were placed to give a rough idea of the velocity of the fragments. The number of marks and holes in the fibre boards were counted. The different set ups in the experiments with fragments were:

- water cups were placed far away from the high explosive charge (alternative 1 in Figure 2)
- water cups were placed close to the high explosive charge (alternative 3)

- cups with ice were placed far away from the high explosive charge (alternative 1)
- cups with ice were placed close to the high explosive charge (alternative 3)
- the explosion chamber was filled with aqueous foam
- no mitigation

Results

Pressure

Variation of the distance between the charge and the water.

The distance between charge and water had a significant influence on the mitigation, See Figures 4 and 5, especially when it comes to the pressure. With a water to charge ratio W/Q = 3 the pressure was reduced with approx. 50 % if the water cups were in contact to the charge (alternative 4) but only with approx. 10 % when the cups were placed in the corners (alternative 1). Since there is no reason to the unordered variation from one gage point to another in Figure 4 the deviation from the mean value can be seen as an illustration of the reproducibility in these tests.

Because of gauge problems some of the evaluated values of the impulse given in Figure 5 are known to be too low, See Mp1 and Mp3 alternative 2. This makes it more difficult to draw conclusions but it seems as the reduction of the impulse is more dependent of the distance to the gauge (that is to the time of influence) than to the distance between the charge and the water.

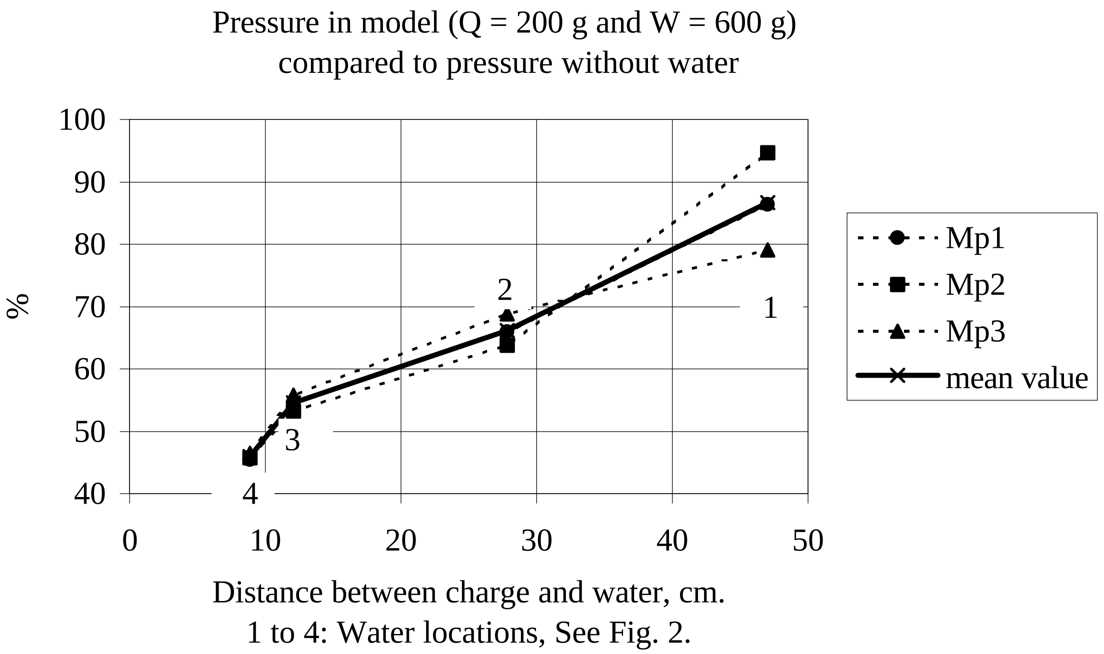


Figure 4

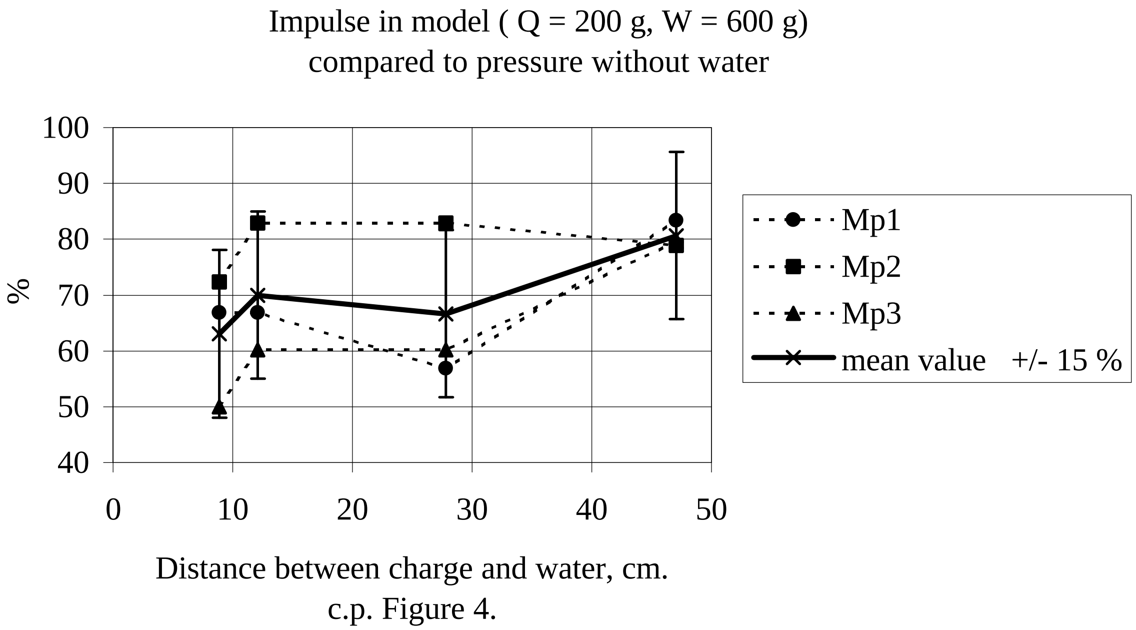


Figure 5.

Water and solid ice.

In earlier test, (KLOTZ CLUB, 1995) it was shown that ice had a slight better mitigation effect than water. This is thought to be due to the heat of the extra phase transition, that from the solid state to the liquid state. In those tests we used crushed ice. Now when the tests were repeated (in a different geometry) with solid ice it looks as the ice had less influence on the blast than water. At Mp1, See Figure 6, the results with ice - close or far away - is within the variation in the outcome from tests with no water. At Mp3 outside the tunnel the difference between ”no water” and ”ice” is, however, noticeable, See Figure 7.

Charge size

In the tests series reported here we used only two charge sizes. Most tests were performed with Q = 200 g and only two with Q = 100 g.

Simplified relations can be used to estimate the pressure in- and outside a tunnel in which an explosion occurs. According to such relations, See e.g. Abrahamsson (1978), the pressure inside the tunnel is $p = c_1 Q^{\alpha}$, where the constant c_1 is depending on the geometry and the pressure outside the tunnel p_R at the distance R is related to the pressure at the muzzle, p_M, by $p_R = p_M c_2 (D/R)^{\beta}$. We thus have $p = c Q^{\alpha}$ if only Q is changed. The ”constants” c_i , α, β have of course constant values only over a limit pressure interval and different values are used in different handbooks. But if we use $\alpha = 0.61$ a change of the charge size with a factor 0.5 will change the pressure with a factor $0.5^{0.61} = 0.65$, or 65 %, at any location in the tunnel. This is in good agreement with the results, Se Figures 6 and 7.

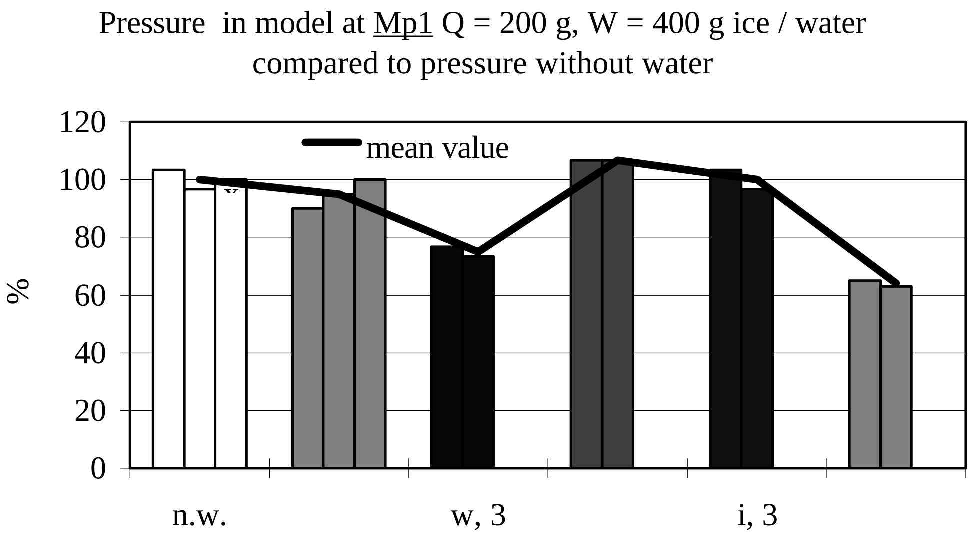


Figure 6. The effect of ice not significant at Mp1. From left to right: no water (n.w.), water alternative 1, water alternative 3 (w, 3), ice alternative 1, ice alternative 3 (i, 3) and, finally, as a comparison Q = 100 g no water. The mean value for ”no water” is taken from more than the three results given in figure.

The pressure signature.

It was noticed that the pressure-time signature was changed by the water. This is illustrated in Figure 8. As can be seen from the figure a second peak after approx. 2 ms is almost cancelled by the water but instead a ”plateau” is formed with an almost constant pressure approx. 10 to 20 ms after the front.

The explanations to this can be that the reflected front from the back-wall (0.625 m from the charge) meet with *distributed* water which can work more efficiently. But the boiling process doesn’t not only take energy, it increases the gas volume. (The transition from water to steam means an increase of the volume with a factor of, approx., 1000.)

Foam

In a previous test series, KLOTZ CLUB (1994), it was shown that foam has a significant influence on the pressure in a closed room. When a charge was detonated inside a cubicle with 5 strong walls and a weaker test wall, the test wall was

completely destroyed	if there was ”no water” or ”water far away”
almost intact	if there was ”water close”
unaffected	if the room was filled with foam

In this test series we could not control the distribution of the foam into the chamber and the registrations from this part of the tests are not evaluated.

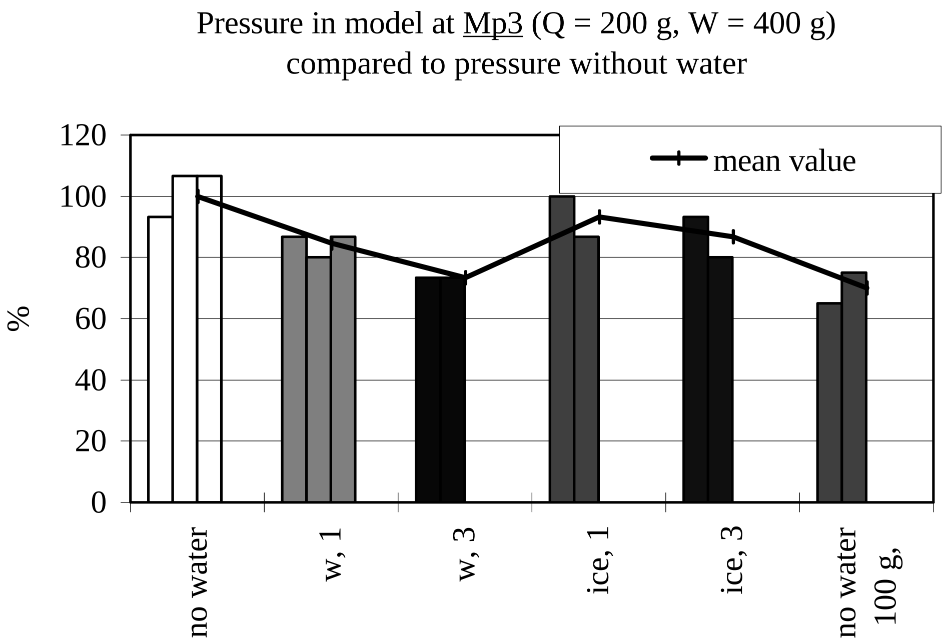


Figure 7. At Mp3 the effect of ice is visible.: The same order as in Figure 6.

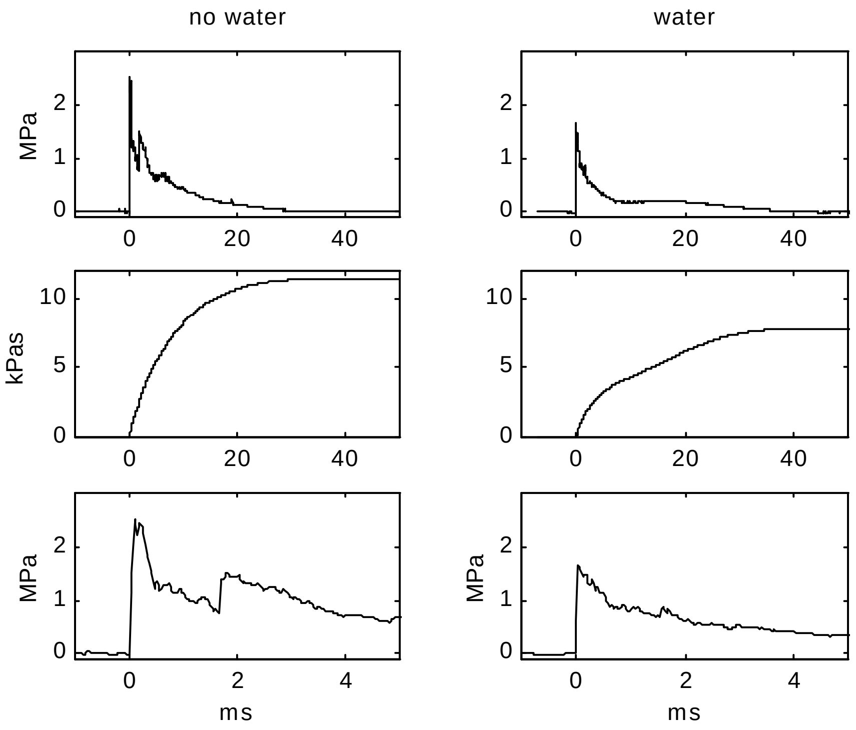


Figure 8. Registrations from Mp2, Q = 200 g, W = 0 and 400 g (alternative 3).

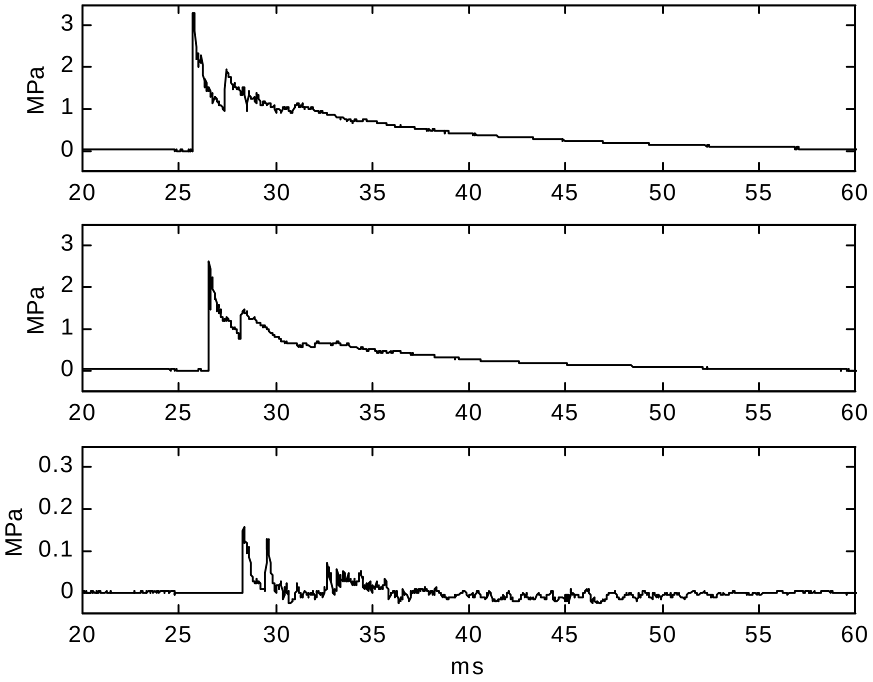


Figure 9. Registrations from Mp1, MP2 and MP3. (Q = 200 g no water)

Fragments

The number of perforations and the number of marks in the fibre boards were counted at the six different experiments (Figure 10).

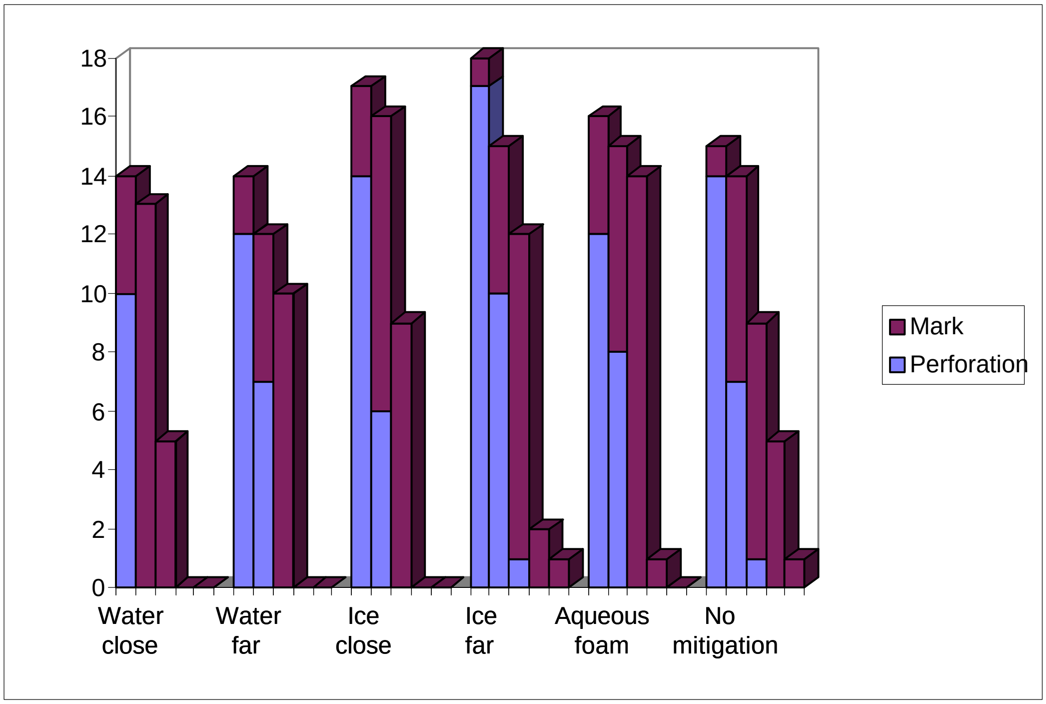


Figure 10. Number of perforation or marks in the five fibre boards.

In three of the experiments with fragments, water close, water far, and ice close, only three fibre boards were affected with holes or marks. In the experiment with water close there were only holes in the first fibre board.

In two of the experiments with fragments, ice far and no mitigation, five fibre boards were affected with holes or marks.

The experiments with ice gave even more marks or holes in the first fibre board than in the experiment with no mitigation. A reason could be that not only the steel fragment hits affect the fibre boards but also ice particles.

The mitigation effect with aqueous foam is surprisingly low. It was not verified however that the explosion chamber was filled all up with foam in this experiment.

Within an approximately circular area with 0,35m diameter the fibre boards are hit by the fragments. This means that the angle between most deviated fragments and the axis of the tunnel is approximately 3 degrees.

Discussion

It has been determined before that the blast effects are reduced when water containers are store close to a high explosive charge. To use this concept in a real ammunition magazine involves some difficulties.

- The water must of course be stored in a safe way so that the risk for and the consequences of a water leakage are small. To meet this 25 litre plastic barrels piled up in standard racks is a solution proposed by experts and it makes possible both manual handling and handling by use of fork-lift trucks.
- In many magazines there is no room for any water barrels. In other magazines there may be possible to bring in racks with water barrels but these must be stored in such a way that the handling of the ammunition is not affected. (Reachable in a safety way.) Since it has been shown that the mitigation effect of water is decreased when the distance water to ammunition is increases there is a conflict. Perhaps the concept only can be applied to magazines for long-time storage.

The boiling of water in a closed room leads to a pressure built-up. It has been shown, however, that the overall effect of water close to a detonating charge is a reduction of the pressure.

The tests performed so far indicates that W = 2Q kg water placed close to a Q kg charge will reduced the blast effects to those from a 0.5Q kg charge. More water will give a higher reduction but W/Q = 2 seems to be a realistic approach. A simplified approach gives that a this reduction of the effective charge will reduce the pressure inside and outside the tunnel with a factor 0.65 compared to a ”no water” case.

No attempts have been reported to simulate the mitigation effect by use of some hydrocode.

No tests have been reported with cased charges. It is known that a thin water ”barrier” of the kind proposed for the Älvdalen test has very little effect on the fragments from the casing but it is no reason to believe that the mitigation effect on the blast leaving the chamber will not be the same as for an uncased charge.

The experiments with fragments placed in the tunnel clearly indicate that water close to the high explosive charge also reduces the effects of debris throw.

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