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# Experimental Verification of the Effectiveness of a Water Charge in Engineer Support Tasks

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**Abstract**

The study evaluates the effectiveness of water charges for engineer support and EOD operations. These charges combine a small explosive with water to achieve controlled disruption of objects while minimizing collateral damage. The experiments focused on opening wooden crates using detonating cord and 550 ml of water. At least three segments of NP V detonating cord were required to successfully release the closures. The method enables safe inspection of the contents without their complete destruction. Although the results are promising, the procedures are not yet incorporated into the regulations of the Czech Armed Forces and require further research on different configurations.

**KEY WORDS:** *detonating cord; engineer support; explosive ordnance disposal; PETN; survivability; water charge.*

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## 1. Introduction: The Physics and Application of Water-Backed Charges in EOD and Engineering Support

In explosive ordnance disposal (EOD) and combat engineering, the ability to disrupt or open objects in a controlled manner is essential, particularly when there is a risk of triggering sensitive mechanisms. Traditional explosive charges often produce a strong fragmentation effect and significant overpressure [1,2], which may lead to undesirable collateral damage or unintended activation of internal components. Therefore, alternative approaches that enable more controlled energy transfer are of considerable interest.

One such approach is the use of water-backed charges, where a relatively small amount of explosive is combined with a volume of water acting as a nearly incompressible medium. [3,4] In this configuration, the detonation energy is not only released into the surrounding air but is partially transformed into a directed mechanical impulse. This effect is often described as a "water hammer" phenomenon, where the accelerated mass of water transfers momentum to the target surface, enabling localized structural failure. [5,6]

While numerous studies have addressed underwater explosions or water as a tamping medium, significantly fewer sources focus on the application of water charges operating freely in the air, particularly in the context of engineer support tasks. In such cases, the effectiveness of the charge is influenced by several key parameters, including the amount of explosive, the volume of water, the geometry of the charge, and the configuration relative to the target. [7]

The present study focuses on the experimental verification of the effectiveness of water charges in specific engineer support scenarios, namely the controlled opening of wooden crates. The aim is not only to determine whether the desired effect can be achieved, but also to compare the performance of water-backed charges with standard explosive charges without a water medium. Particular attention is paid to the nature of the resulting damage, the degree of fragmentation, and the suitability of the method for practical EOD applications.

By analyzing these factors, the study seeks tontribute to a better understanding of the mechanisms governing the interaction between explosive energy and water as a transfer medium, and to assess the practical applicability of water charges in minimizing collateral effects while maintaining sufficient effectiveness.

Summary of the most important factor variables in this study:

• $m_{TNT}$ (explosive mass): 2.3 – 13.7 g
• $m_{H2O}$ (amount of water): 550 ml per charge
• Charge geometry: "bag"; water positioned between the target element and the explosive
• Stand-off distance: 0 cm (contact)
• Attachment: loosely applied (double-sided adhesive tape)

Main objective: To quantify the effectiveness of a water charge for a selected engineer support task (structural disruption) and to compare it with a reference solution (standard explosive without water).

The research questions addressed in this study are:
• What is the relationship between the explosive mass, the amount of water, and the resulting effect?
• How does water influence the shock wave parameters (peak overpressure, impulse) and the dispersion of secondary fragments?

The primary effect on the target is assessed based on the following attributes:
• Whether the desired result was achieved (binary: achieved/not achieved)
• Dimensions of the effect: depth of damage or area and volume of removed material
• Energy indicator: work performed on the obstacle (estimated based on the mass of removed material and displacement/height) in Discussion I section.

## 2. The Theoretical Background

### Shock Wave Propagation: Air vs. Water

The fundamental difference between a standard air blast and a water-backed charge lies in the medium's density and compressibility. In the atmosphere, an explosion almost instantaneously compresses the surrounding air into a shock wave that propagates supersonically. Air, however, is highly compressible, which leads to a rapid decay of peak overpressure as the wave expands.

In contrast, water has a much higher density and lower compressibility. When an explosive detonates against a water container, the resulting underwater shock wave travels at a significantly higher velocity—approximately 1,500 m/s (5,000 fps). Because water is essentially incompressible, it serves as a highly efficient medium for energy transfer. Instead of the energy being lost to the "cushioning" effect of air, the mass of the water is accelerated as a single, high-energy slug. [8]

### The Role of Impulse and the "Water Hammer" Effect

While air blast damage is often calculated based on peak overpressure using the Hopkinson-Cranz scaling law ($Z=R/W^{1/3}$), (R = Range (m); Z = Constant of Proportionally (dependent on acceptable blast overpressure)); W = Explosive Weight (kg)), the effectiveness of water charges is primarily driven by impulse. [9]

• Peak Overpressure: The initial, near-instantaneous rise in pressure.

• Impulse: The integral of pressure over time (the area under the pressure-time curve).

In the case of a water-backed charge, the detonation accelerates the water mass, creating a focused dynamic pressure (the force associated with the net motion of the medium). This mass of water acts as a mechanical "piston" or water hammer. When this slug hits a target, such as a wooden box or a door, it delivers a high-duration impulse that exceeds the structural integrity of the target's locks or hinges. For certain EOD tasks, such as opening wooden crates, the focused mechanical impulse of the water is far more effective at "prying" open fasteners than the shattering effect of a bare explosive.

### Impedance and Energy Transfer

The efficiency of this "pusher" effect can be explained by acoustic impedance (the product of a medium's density and the speed of sound within it). Energy transfer is most efficient when the impedance of the explosive medium matches the impedance of the target. [10]

• Air has very low impedance, leading to poor coupling with solid targets.

• Water has an impedance much closer to that of organic materials (like wood) or thin metal, allowing a greater portion of the detonation's energy to be transmitted directly into the target rather than reflecting away.

### Mitigation of Secondary Effects

One of the primary advantages of using water containers is the reduction of collateral damage:

• Fragmentation Mitigation: The water volume acts as a buffer that can decelerate primary fragments (from the explosive's own casing or nearby debris). The drag forces in water are significantly higher than in air, rapidly depleting the kinetic energy of small projectiles. [3]

• Thermal Suppression: Explosions produce a fireball and intense thermal radiation. The high heat capacity of water allows it to absorb a substantial portion of this thermal energy, reducing the risk of secondary fires or the activation of heat-sensitive sensors within a suspicious package.

• Blast Attenuation: Outside the direct line of the water "slug," the water mass can actually help shield the surroundings by absorbing energy that would otherwise contribute to a wider air blast wave.

**Practical Experimental Observations**

Practical experiments (such as those conducted at defense universities) emphasize that the configuration and quantity of the explosive are critical. [11] For instance, using segments of detonating cord (like Np V) attached to a 550 ml water source requires a specific minimum "charge weight" to overcome the inertia of the water and the target's resistance. If the charge is too small, the water mass is not sufficiently accelerated; if it is too large, the "tamper" effect is lost to excessive fragmentation of the container and air blast leakage.

**Parameters of the blast wave in an unconfined atmosphere**

The maximum overpressure at the front of the shock wave $\Delta p_{\Phi}$ can be expressed as follows [9,12]:

$$\Delta p_{\varphi} = \frac{6{,}7}{\bar{R}^3} + 1\frac{kp}{cm^2} \;\; , \;\; \Delta p_{\varphi} \geq 10\ kp/cm^2$$

$$\Delta p_{\varphi} = \frac{0{,}975}{\bar{R}} + \frac{1{,}455}{\bar{R}^2} + \frac{5{,}85}{\bar{R}^3} - 0{,}019\ kp/cm^2\ , 0{,}1 \leqq \Delta p_{\varphi} \leqq 10\ kp/cm^2$$

$$\bar{R} = \frac{R}{\sqrt[3]{W}} \quad m/kg^{1/3}$$

$$\Delta p_{\varphi} = p_{\varphi} - p_0 \tag{1}$$

where $\bar{R}$ is the scaled distance [m/kg$^{1/3}$], $R$ is the distance of the considered point from the center of the charge [m], $W$ is the explosive mass [kg], $p_{\varphi}$ is the pressure at the front of the shock wave, and $p_0$ is the atmospheric pressure. The equations are formulated for the standard explosive TNT, and all variables must be substituted in the specified units to obtain results in consistent units.

According to [9] and the research conducted therein, additional equations were derived:

$$\Delta p_{\varphi} = \frac{0.662}{\bar{R}} + \frac{4{,}05}{\bar{R}^2} + \frac{3{,}288}{\bar{R}^3}\ kp/cm^2\ , 1 \ \leqq \bar{R} \leqq 10 \tag{2}$$

which are valid for TNT within the specified range of scaled distance $\bar{R} = [m/kg^{1/3}]$.

Another important parameter of the shock wave is the variation of overpressure over time. According to Brode, the shape of this relationship depends solely on the peak overpressure at the wave front, $\Delta p_{\varphi}$. The corresponding curve can be expressed by the following equation:

$$\Delta \mathrm{p}(t) = \Delta p_{\varphi}(1 - t/\tau)e^{-at/\tau} \tag{3}$$

This shock wave overpressure, together with the presence of water, acts on objects in its immediate vicinity. In this study, the assessment of this effect is treated in a simplified binary manner with respect to field conditions and the specific target.

## 3. The Experimental verification No. 1

In Experiment No. 1, water charges were used, consisting of:

1. Water bags (volume 550 ml) with dimensions of 18 × 12 cm.
2. Detonating cord Np V containing 90% PETN and 10% TNT in the total explosive content. This detonating cord contains 12 g of explosive per 1 m length.
3. Additional equipment such as double-sided adhesive tape, crimping pliers, detonator Ž, and UNICORD safety fuse.

The experiment was conducted at the Březina military training area, specifically at the Pulkava blasting pit. The weather conditions during Experiment No. 1 were overcast, without rain, temperature 13°C, and wind speed 13 km/h.

Within Experiment No. 1, a total of six water charges were prepared and attached to the upper side of the wooden crates using double-sided adhesive tape. The orientation of the charges was selected above the crate latches, assuming a post-detonation pushing effect of the water directed against the latches. This means that the detonating cord segments were attached on the upper side of the charges. The charges were connected into a series detonating cord network and initiated simultaneously.

The explosive content for individual charges is presented in Table 1. Conversion to 100% TNT equivalent was performed using the relative effectiveness (RE) factor.

Table 1.

Explosive mass for individual water charges

| Length of detonating cord segments (cm) | Explosive mass (90% PETN, 10% TNT) | Conversion to 100% TNT* |
|---|---|---|
| 15 | 1.8 | 2.3 |
| 2x 15 | 3.6 | 4.6 |
| 3x 15 | 5.4 | 6.9 |
| 4x 15 | 7.2 | 9.1 |
| 5x 15 | 9 | 11.4 |
| 6x 15 | 10.8 | 13.7 |
| * The results are rounded to one decimal place | | |

The charges were placed on a total of three military crates, each equipped with two latches for closure. The initiation of the charges was carried out simultaneously to ensure that the result was not influenced by the adjacent latch (Figure 1). The crates were spaced 4 m apart and were completely filled with excavated soil (heavy clay).

**Fig. 1** Assembly of water charges consisting of three and four detonating cord segments, including the arrangement of the detonating cord initiation network (left) and effect of detonation (right)

**Limitations:** The crates used in the experiment were not identical in shape or wood thickness; however, all latches were of the same type. The side thickness at the latch location was 14.24 mm for crate No. 1 (charges No. 1 and 2), 20.43 mm for crate No. 2 (charges No. 3 and 4), and 22.72 mm for crate No. 3 (charges No. 5 and 6). These differences may have influenced the resulting structural response to the applied loads.

**Evaluation:** The primary objective was to release the latches and enable safe inspection of the crate contents, considering the potential presence of an IED initiation sensor. The results indicate that effective and reliable latch release was achieved from a configuration of three detonating cord segments. This threshold is specific to the tested latch type and material properties, which were also affected by the explosive loading. Configurations using one or two segments resulted in latch release; however, they did not produce sufficient structural disruption to allow partial opening of the crate, and therefore the potential activation of internal sensors could not be assessed. It should also be noted that the experiment was not instrumented with high-speed imaging or pressure sensors, limiting the depth of quantitative analysis.

Based on these findings, Experimental Verification No. 2 was conducted to more precisely define the threshold values of the required explosive mass for the water charge to achieve reliable effectiveness in releasing the crate latches.

**Discussion I:** For the two wooden fragments detached from the upper part of the crate lid, it is possible to estimate the work associated with fracture formation. In the case of wood, three approaches can be considered: fracture work, bending work, and work associated with displacement. Among these, fracture energy represents the most accurate and relevant indicator:

$$Wlom = Gc \cdot Alom$$

where $A_{lom}$ is the area of the newly created fracture surface ($m^2$), and $G_c$ is the critical fracture energy ($J/m^2$), which depends on the type of wood, grain orientation, moisture content, and other material properties.

If the failure mechanism were governed by bending, the minimum work could be estimated based on the bending moment at failure:

$$Wohyb \sim \int M(\kappa)\, d\theta$$

In practice, however, the minimum work is difficult to determine without force–deflection measurements. Therefore, a simplified approach is often used, based on conversion to an equivalent static test (three-point bending), where the work is estimated as the area under the force–displacement ($F - u$) curve. This approach was not applied in the present study due to the absence of high-speed imaging and the inability to accurately determine the fracture surface.

A third approach considers kinetic energy and gravitational effects; however, for the same reason—the lack of high-speed recording—this method could not be applied either.

$$Wg = mg\,\Delta h$$

$$Wk = ½\,m \cdot v2$$

The failure mode followed the wood grain (longitudinal direction), with additional tearing observed in the front section near the latches. The results indicate a short-duration impulse combined with localized pressure loading. Fracture initiation occurred along the edges of the boards.

The dimensions of the detached fragments were as follows: both pieces had a length of 600 mm; the average width of the first fragment was 40 mm, while the second (rear) fragment had an average width of 90 mm. The thickness of the lid was identical to that of the side boards, i.e., 20.43 mm. The material was dried spruce wood; however, its actual moisture content was not measured.

Based on these parameters, further calculations can be expressed as follows:

$$A = L \cdot \bar{b}$$

for which the total value for both detached fragments is $A_{\Sigma} = 0{,}078\ m^2$. The volume of the detached fragments can then be expressed as follows:

$$V = L \cdot \bar{b} \cdot t$$

for which the total value for both detached fragments is $V_{\Sigma} = 1{,}5935 \cdot 10^{-3}\ m^3$. The mass was estimated on the basis of wood density. However, since density depends on moisture content, which was not measured in this case, a reference value for dry wood of 450 kg/m³ was used. Thus:

$$m = \rho \cdot V$$

for which $m_{\Sigma} = 0{,}72$ kg (without correction for moisture content). These parameters—the delaminated area, volume, and estimated mass—make it possible to compare the extent of damage among individual tests independently of the loading method.

The critical fracture energy $G_c$ is determined experimentally as a material parameter, or more precisely as a parameter for a specific failure mode and grain orientation. In wood, this value is strongly anisotropic and highly sensitive to the orientation of the grain relative to the crack path (L-R-T directions), as well as to moisture content, density, knots, growth defects, and loading rate.

Regardless of the loading source, the work (W) supplied up to the point of crack propagation can be determined using the Single Edge Notched Bending (SENB) method. This is a standardized fracture mechanics test:

$$W = \int_0^{u_c} F(u)\,du$$

Moisture content affects not only the strength and stiffness of the material, but also its fracture behavior and dynamic response. [13]

## 4. The Experimental verification No. 2

In Experiment No. 2, water charges were used with the following configuration:

1. The same water bags as in Experiment No. 1.
2. The same Np V detonating cord with identical segment lengths.
3. Additional equipment including double-sided adhesive tape, crimping pliers, detonator Ž, and UNICORD safety fuse.

In addition, charges containing the same explosive (Np V detonating cord) but without water bags were also used. The objective was to compare the effect and efficiency of charges with and without the pushing medium (water) on identical crates equipped with the same type of latch.

The experiment was conducted at the Březina military training area, at the Pulkava blasting pit. Weather conditions during Experiment No. 2 were clear, without precipitation, with temperatures ranging from 10 to 16°C and wind speeds up to 10 km/h.

Within Experiment No. 2, two water charges were prepared and attached to the upper side of the crate using double-sided adhesive tape. The orientation of the charges was identical to that in Experiment No. 1, with the detonating cord segments positioned on the upper side of the charge. The charges were connected in a series detonating cord network and initiated simultaneously. In addition, a reference configuration consisting of detonating cord segments without water was prepared and applied directly to the crate, allowing for a direct comparison with the primary objective of the experiments.

The charges were placed on a total of three military crates. Two crates were equipped with a single latch each, while one larger crate had two latches. The charges were initiated simultaneously to prevent interaction effects between adjacent latches (Figure 2). The crates were spaced 4 m apart and were completely filled with excavated soil (heavy clay). The experiment was conducted at the same blasting pit as Experiment No. 1.

The selection of two and three detonating cord segments for the water charges was based on the results of Experiment No. 1, where the configuration with two segments produced inconclusive results, while three segments provided reliable performance.

**Fig. 2** Assembly of water charges consisting of two and three detonating cord segments, including the arrangement of the detonating cord initiation network (left and middle) and standard charge without water (right)

**Limitations:** In this experiment, the crates used for the water charges were of identical shape and wood thickness, with dimensions of 35 (L) × 31 (W) × 18.5 (H) cm. The third crate, used for the reference configuration (standard charge without water), differed in both shape and wood thickness. All crates were equipped with identical latches. The side thickness at the latch location for crates No. 1 and 2 (water charges No. 1 and 2) was 14.60 mm, and the lid thickness was also 14.60 mm. For crate No. 3, the side thickness was 19.70 mm and the lid thickness was 19.25 mm. All measurements were taken at the latch locations.

**Evaluation:** In addition to the same partial objective as in Experiment No. 1 (i.e., to release the latches and enable inspection of the internal contents while considering the possible presence of an IED initiation sensor), the main objective was to repeat the experiment and define the threshold conditions for water charges with respect to the selected crate configuration, as well as to compare the results with a standard reference charge.

In this experiment, the latches of both crates equipped with water charges were successfully released by the detonation effect (Figure 3), and the results can be considered conclusive, with the objective fully achieved.

**Fig. 3** Effect of detonation of water charges consisting of two (left) and three (right) detonating cord segments

The standard reference charges (two and three detonating cord segments) also provided sufficient energy to release the latches. However, based on the resulting fragments (Figure 4), a pronounced fragmentation effect can be observed, which is not always desirable for precise EOD operations. [1]

Similarly to the previous experiment, this test was not recorded using a high-speed camera, and no pressure measurement sensors were employed.

**Fig. 4** Comparison of detonation effects: water-backed charge with a pushing effect (left) and standard fragmentation effect (right)

**Discussion II:** In the case of the first crate with two detonating cord segments, the explosion produced a single significant fragment detached from the crate lid. The width of this fragment ranged from 40.20 to 48.95 mm (see Figure 3, left), while its length remained unchanged compared to the original lid dimension.

In contrast, the crate subjected to the standard charge (fragmentation effect) produced numerous small wooden fragments, and the structure of both the lid and the side walls was considerably less homogeneous compared to the effect of the water-backed charge. The largest fragment in this case had a width of 29.44 mm at the edge, gradually narrowing toward the center, with a total length of 360 mm.

Wooden crates with latches represent only one of many objects that EOD specialists must approach with caution due to the potential presence of IED threats. [14] Such containers were commonly encountered during coalition operations in Afghanistan and remain relevant in the current conflict in Ukraine, as they are widely used for storing various types of ammunition of both Eastern and Western origin. [15]

The use of water-backed charges offers a significant advantage in that the water jet acts as the primary pushing medium, allowing for a generally lower explosive mass to be used. Although the overall charge becomes heavier due to the inclusion of water, this approach is desirable from a safety perspective for EOD teams. Additionally, the directionality of the water jet can be adjusted through the configuration of the charge, making it suitable even for less accessible locations.

Water-backed charges are also commonly employed in breaching operations [4], particularly for doors in structural environments, which represents another important task within engineer support. This is primarily due to the need to protect the assault team and, where applicable, any hostages located behind the barrier.

## 5. Conclusions

The experimental results confirm that water-backed charges represent an effective solution for selected engineer support and EOD tasks requiring controlled structural disruption. [8] By using water as a nearly incompressible medium, part of the detonation energy is transformed into a directed mechanical impulse, enabling localized failure while reducing secondary effects.

The effectiveness of the charge is strongly dependent on the ratio between the explosive mass, water volume, and target resistance. The experiments showed that a minimum of three 15 cm detonating cord segments is required to reliably release the latches of the tested wooden crates. Lower configurations produced only partial or insufficient effects.

A key finding is the qualitative difference between water-backed and standard charges. While both achieved the primary objective, standard charges caused significant fragmentation and irregular damage, whereas water-backed charges resulted in more localized and homogeneous disruption. This makes them more suitable for applications requiring controlled access and reduced collateral damage.

From a practical perspective, water charges offer advantages in terms of safety and control; however, factors such as preparation time, repeatability, and environmental conditions must be considered. Future applications may also involve the integration of water-backed charges with unmanned ground vehicles (UGVs), enhancing operational safety and efficiency in EOD scenarios. [16] Further research should focus on optimizing charge configuration and improving measurement capabilities to better quantify the underlying processes.

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