

Safety of Transport and Disposal for Explosive Ordnance in Ports, Roadsteads and at Open Sea

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ABSTRACT: In the article principles, pertaining to the safety of transport for explosives and unexploded ordnance of military origin and procedures that guarantee maximal effectiveness of the process of their neutralization, are presented. Since the end of the 2nd World War operations of neutralizing unexploded ordnance (UXO) of that era that still lie in ports, roadsteads and coastal areas are continuously conducted. During that war the Polish coast was one of the major battlegrounds and till now unexploded ordnance are found either on the sea bed or along the coast. Various analyses state that searching the sea and the coastline for unexploded ordnance is a task still to be carried out in the foreseeable future.

1 INTRODUCTION

During the Second World War the Polish coast was one of major battlegrounds. To this day various unexploded ordnance (UXO) is found either in sea or along the coast. In result of the war, the territory of Poland was left replete with great amount of unexploded ordnance. Dozens of millions of such ordnance were found and neutralized after the war, but almost entire territory of the country needed to be thoroughly searched in order to localize devices that could potentially endanger human lives. More than 70 years after the end of the war, operations aimed at neutralizing underwater unexploded ordnance (UUXO) lying on the seabed, roadsteads, and ports or along the coastline are still conducted. The remnants of the war are still a cause of accidents that threaten lives or health of the citizens and human activity on sea.

Many of such devices are unexploded ordnance of large calibers or sizes such as artillery shells, mines, bombs, torpedoes, rockets or grenades. Due to a long

exposure to changing meteorological conditions, they are considered unpredictable. Various factors, such as movement, high temperature, physical contact with another object or attempts of transporting them, may cause they sudden explosion. For this reason, under no circumstances should they be approached by any person, which has not been properly trained and thus does not possess the required qualifications and equipment.

To ensure appropriate execution of the task of cleansing the country's territory of aforementioned remnants, 39 Demining Patrols (DP) in the whole Polish Armed Forces and 2 Explosive Ordnance Disposal Divers Groups (EOD DG) specifically in the Polish Navy, have been created. Among them we distinguish:

- in the Land Forces- 35 x DP
- in the Navy- 2 x DP and 2 x CDG
- in the Air Forces- 2 x DP

The Navy patrols are responsible for areas of sea beaches, the Hel Peninsula, naval ports, the Navy's airports and other areas where the Navy's units are

stationed. The CDG's are responsible for sea areas allocated to the 3rd Ships Flotilla and the 8th Coastal Defense Flotilla, as well as neutralizing UXO's in sea areas where, due to the depth, land patrols cannot operate.

The Air Force patrols only operate on the Air Force proving grounds in Nadarzyce and Ustka. The size of the assigned region corresponds to the amount of interventions usually conducted in it. On average, up to 4 patrols can be located in one voivodship.

2 UNEXPLODED ORDNANCE CHARACTERISTICS

As explosive ordnance we define any devices of military origin, that could pose a threat if handled improperly, such as bombs, shells, wide array of mines, projectiles, rocket-propelled grenades, grenades, fuses or other metallic scrap that could contain explosive materials remnants [3].

Dangerous ordnance are various other devices (of military, industrial or other origin) that have inflammable, toxic, or corrosive properties and pose a threat when mishandled or when in contact with air or high temperature. The definition contains for example flammable liquids, contents of fire extinguishers, steel bottles, or substances stored and used in laboratories.

Explosive ordnance of military origin that lay in the ground can be divided into:

- unexploded ordnance – bombs and projectiles that did not explode after making contact with earth;
- duds – projectiles that, due to their faulty design, failed to fire on command;
- artillery shells and bombs left unattended after cessation of hostilities;
- anti-personnel and anti-tank mines;
- remnants of post-war operations aimed at destroying artillery shells;
- underwater unexploded ordnance and ammunition left on seabeds (sea mines, torpedoes, depth charges, artillery shells, rockets).

Operations concerning neutralizing unexploded ordnance are regulated by the Polish Military Standard - *Detecting, demining and mine clearance operations*, on the basis of which internal documents, that regulate Polish Armed Force's operations pertaining to neutralizing explosives and dangerous devices, are created [6].

The number of leftovers of military origin is proportional to the number of ammunition fired and bombs dropped down on the particular area, which number relies on:

- the duration and intensity of fights conducted in the given area;
- the nature of conducted fights (pursuit fights, sieges);
- the number of equipment available at the disposal of the fighting sides;
- the number of defensive fortifications (shelters, bunkers, trenches, minefields).

If the region had been actively used as a proving ground before fighting occurred (or after it), the

danger of encountering explosive devices in that area rises multiple times. Especially dangerous are the places which were used as ammunition magazines or dangerous military objects disposal grounds, shortly after the war.

The burial depth on which explosive devices may lie depends on their caliber, composition of ground and various other factors. On average, we could assume that 75 mm caliber shells lie up to 1,0 meter, 105 mm caliber shells - 1,2-1,4 meters and 155 mm caliber shells up to 1,6 meters below the ground.

Bombs penetrate the ground to the depth of 1,0 ÷ 6,0 m - depending on their mass and size. Leftover ammunition, anti-tank and anti-infantry mines are most frequently found in layers of humus at 0,3 m. Some kinds of soils are much more susceptible to penetration by bombs and projectiles [8]. Research conducted by Polish sappers indicates that 90-95% of the unexploded ordnance found, are the remnants of the Second World War, the remaining 5-10% are either remains of the First World War or were utilized for training purposes after the World War II.

After the war was over, it was estimated, that the territory of Poland could still contain the following number of unexploded ordnance:

- 1 up to 15 million anti-tank or anti-infantry mines;
- 2 up to 70 million unexploded projectiles, bombs, armor-piercing shells;
- 3 the size of the area that needed clearance was estimated to be around 220 000-250 000 square kilometers – which constitutes about 70-80% of the entire Polish territory.

These analyzes proved to be underestimated, since from 1945 to 1994 sapper patrols neutralized 94,1 million mines and unexploded ordnance of other sorts [10].

Unexploded ordnance is an explosive device in which, despite proper conditions created in order to ensure detonation, potential chemical energy of the material was not transformed into chemical energy [8].

Unexploded ordnance in general- projectile, grenade or bomb- in which, despite proper conditions created in order to ensure detonation (hitting an obstacle, armed fuse) the potential chemical energy of the material was not converted into mechanical energy (due to chemical transformations in the material or faulty mechanisms).

A dud is ammunition that failed to fire due to technical defects or was left behind or lost on a battlefield [7]. A dud is a projectile that was not fired due to the weapon jamming (too short or badly positioned striker, weak striker spring, bullet pressed too deep into the chamber) or ammunition defects (igniter or primer pressed too deep, damaged ignition mass in either the igniter or the primer, wet gunpowder etc.). Immediate recognition of such occurrence is difficult and therefore high level of caution should be taken when dealing with such case.

The dud should be disposed of carefully, not earlier than 3 minutes after the attempt of firing (hang fire possibility).

3 MINE PATROLS TASK CHARACTERISTICS

To ensure appropriate execution of the task of cleansing the country's territory of aforementioned remnants, 39 Demining Patrols (DP) in the Polish Armed Forces (26 in the Land Forces, 9 in the Inspectorate for Armed Forces Support, 2 in the Air Force, and 2 EOD divers group in the Navy) have been created. The way they are located ensures that the entire territory of Poland is covered.

In the Navy two units, specialized in mine clearance operations, were created – the 43rd Sapper Battalion (assigned to the 3rd Ship Flotilla) stationed in Rozewie, and the 8th Sapper Battalion (assigned to the 8th Coastal Defense Flotilla) stationed in Dziwnów.

In each flotilla, EOD Diving Groups was established, tasked with neutralizing explosive ordnance, often found in rivers and lakes and in the seabed in the area of the Polish littoral zone. The littoral zone is the part of a sea, lake or river that is close to the shore and includes the shoreline and adjacent sea and land areas, where bilateral influences between these environments can be observed.

Minehunter vessels and minesweepers from the 12th and 13th MCM Ship Squadron are also charged with the task of neutralizing explosive remnants of both World Wars [8].

Appropriate number and proper localization of the mine clearance patrols is crucial to establishing quick and effective response to various threats (Fig. 1 and Fig. 2). Relevant regulations determine that the response time should be no longer than 72 hours (24 in the case of an imminent and sudden danger).



Figure 1. The Polish Navy sappers during anti-mine operations Source: The Polish Navy's archives

EOD divers groups are responsible for the sea areas assigned to respectively the 3rd and the 8th Flotillas as well as neutralizing dangerous and explosive devices in inland waters, where the depth, on which such devices lie, makes it impossible for land mine clearance patrols to intervene.

The mine clearance patrols under the Air Force only operate on the Air Force Bases proving grounds located in Nadarzyce and Ustka.

The size of the region assigned to a particular patrol corresponds to the amount of interventions conducted in it. On average up to 4 patrols can be located in one voivodship.

The EOD divers and sappers of the Polish Navy, as well as the crews of the specialized minehunters and minesweepers vessels, take part in a couple hundred interventions annually. They operate mainly on the sea areas stretching as far as to the border of the Polish Exclusive Economic Zone [15], but also along the Polish coast [16] and in the inland waters of various Polish regions.



Figure 2. The Polish Navy sappers during anti-mine operations Source: The Polish Navy's archives

CDGs are responsible for the sea areas assigned to respectively the 3rd and the 8th Fleets as well as neutralizing dangerous and explosive devices in inland waters, where the depth, on which such devices lie, makes it impossible for land mine patrols to intervene.

The sapper patrols under the Air Force only operate on the Air Force proving grounds located in Nadarzyce and Ustka.

The size of the region assigned to a particular patrol corresponds to the amount of interventions conducted in it. On average up to 4 patrols can be located in one voivodship.

Most frequently, their task is to dispose of the Second World War remnants such as mines, torpedoes, bombs or artillery shells. In the recent year, the Navy's forces intervened, among others, in Świnoujście (on the construction site of the LNG terminal) [17], cleared the beaches near Kołobrzeg (Fig. 3 and Fig. 4).



Figure 3. The Polish Navy divers during anti-mine operations Source: The Polish Navy's archives.



Figure 4. The Polish Navy divers during anti-mine operations Source: The Polish Navy's archives

Every year, the Navy's mine clearance patrols, EOD Diving Groups, minehunters and minesweepers conduct c.a. 300 interventions either on land or on the Baltic Sea, neutralizing miscellaneous threats including (but not limited to) bombs, artillery shells, torpedoes, mines or other objects of military origin that could pose threat to lives or well-being of the country's and sea's inhabitants.

The divers and sappers of the Polish Navy, as well as the crews of the specialized anti-mine warfare ships, take part in a couple hundred interventions annually.

Being a member of mine clearance patrol is especially demanding for the soldiers. They are required to display professional attitude, appropriate skills, calm and controlled behavior, common sense and the ability to overcome stress. The soldiers are well aware, that their job is very dangerous even during peacetime, but at the same time take pride from being able to save others from deadly menace. Every unexploded ordnance needs to be disposed of not later than 72 hours from detecting (in public places, where such a device could pose an especially great danger, that time is shortened to 24 hours).

According to the mine clearance operations algorithm, after receiving the report of newly found ordnance, the following process begins:

- firstly, an analysis and classification of the report (either as urgent or regular) is conducted;
- secondly, the officer in charge assesses the situation, assigns specific tasks to the members of the patrol and organizes backup means of action;
- thirdly, the mine clearance patrol moves on to the afflicted region, contacts local administration or persons that issued the report, in order to directly localize the explosive device. If necessary, an evacuation of endangered people or property is carried out, and the area is marked off limits;
- the patrol identifies the device and disposes it (or, as they often address the issue - pick up, transport, neutralize);
- after successful actions the patrol returns to its headquarters and reports to superior officers.

According to existing regulations, unqualified people are strictly forbidden to touch the dangerous devices or move them in any way. By qualified, we define properly trained and equipped soldiers.

The patrol consists of soldiers that are specialists in explosive materials. They are carefully selected, experienced, disciplined and well educated. Moreover, they are also prepared to lecture both adults and children on how to properly behave after spotting a dangerous device. Every anti-mine patrol is equipped with specialized detecting tools, means of transport and neutralizing unexploded ordnance, as well as protective gear (Fig. 5 and Fig. 6). The nature of their action is strictly interventional and focuses mainly on neutralizing explosive ordnance of military origin previously reported by the state or local institutions. All ordnance must be disposed of not later than 72 hours after being reported (regular intervention). If the object is particularly dangerous due to its localization (public places, schools, roads, construction sites), the time is shortened to 24 hours (urgent intervention). Responsible for securing the area until the patrol's arrival are the police.



Figure 5. Mine clearance vehicle TOPOLA and other cars and trailers used as means of transporting unexploded. Source: The Polish Navy's archives.

After being picked up by the patrol, the object is then moved to the destruction site (usually military proving ground) [7]. During early spring, due to various factors (snow melting, beginning of construction works) the biggest amount of unexploded ordnance is found.

The Navy's anti-mine patrols are responsible for seashore areas, the Hel Peninsula, the Polish naval ports and other military areas assigned to the Navy.



Figure 6. Mine clearance vehicle TOPOLA and other cars and trailers used as means of transporting unexploded. Source: The Polish Navy's archive

The Clearance Diving Groups are in charge of the sea areas assigned to the 3rd Ships Feet and the 8th

Coastal Defense Fleet as well as the inland waters, where, due to the depth on which the ordnance is located, the land patrol intervention is impossible.

The Air Force's patrols only operate on the Air Force's proving grounds in Nadarzyce and Ustka.

The size of the assigned region depends on the number of interventions usually conducted in it. On average, up to 4 patrols can operate in one voivodships.

Single projectiles with fuses, and other explosive devices should be placed on an anti-shock surface, its longitudinal axis in the middle of the transporting vehicle, parallel to the axis of the wheels. The objects should be secured from shocks, turmoil, friction and other disturbances.

It is forbidden to reside in the close proximity of the explosive ordnance loading/de-loading sites. The explosive remnants of war should be transported and moved mindfully and safely, without rapid or excessive movement. Failing to comply with these safety procedures may cause detonation.

4 UNEXPLODED ORDNANCE DISPOSAL IN ROADSTEDS AND FROM SEABEDS (FROM DETECTION TO DESTRUCTION)

Detection of a dangerous object residing on seabed is usually carried out using means of acoustic location (sonar, multibeam echo sounder), which allow users to localize, classify and identify underwater objects (Fig. 7 and Fig. 8). The procedure is in accordance with the "mine hunting" mine disposal method and generally contains the following four steps:

- detection and determining position of the object (MILCO detection - Mine Like Contact the object is tested for mine-like resemblance)



Figure 7. Clearance diver during mine identification and a mine as seen in the underwater vehicle's camera ROV t. „Ukwiał”.

Procedure's is consistent with the mine methods "minehuntingu" and, in general process involves sequential steps Four:

- detection and specify the location (MILEC Mine Like Echo (the detection of the echo on the sonar screen);
- contact classification (MILCO analysis);
- object identification (determining whether the object is a NOMBO - Non Mine Like Bottom Object

(in the process of identification was determined that there is no object Mina), mine or UUXO – Underwater Unexploded Ordnance (unexploded underwater

- threat (object) neutralization- either by detonation or transporting the object to a safe location.

Within the limits of identifying mine-like objects (images 8 and 9), a thorough inspection, using unmanned underwater vehicles or clearance divers, is conducted, in order to assess the danger and specify terms and means of the disposal.

In 2015 the Polish Navy conducted an operation of neutralizing the Second World War unidentified, unexploded underwater ordnance (naval mines), found in the Gdansk Bay.

In the direct proximity of the port of Gdynia (about 200 meters from the breakwater) as well as in the port (by the Silesian Waterfront) an English MK-VI mine and four German mines were detected (identified later as the GC-1 and GC-2 mines).



Figure 8. Clearance diver during mine identification and a mine as seen in the underwater vehicle's camera ROV t. „Ukwiał”.



Figure 9. Mk VI, II World War mine extraction, conducted by a mine destroyer (March 2015), GC type mine found in The Gdansk detonation Source: author's own resources.

The methods of disposing of underwater unexploded ordnance detected on seabed, classified and identified are as follows:

- object extraction - if no threat of detonation has been determined (or if the object is not explosive), but it could still pose a navigational threat or an

obstacle, it is extracted from the seabed (Fig. 9 and Fig. 10);

Bottom mines type GC-1 (Fot.5) were aerial mines, discarded using parachutes integrated with the mine's construction. The second version of the GC mine, very similar to the previous one, bore the name LMB/s (from the German Luft Minen Model "B") and was launched using surface vessels (for example E-boat class warships) and did not include parachutes.

- object neutralization - it usually means detonating the object on the site (without extracting it), if during the identification process a direct threat to human lives or activity at sea was concluded.

According to available information concerning German underwater armament, in the GC-type mines, the explosive material consisted of hexanite- the mixture of 63% TNT and 23% aluminium.

These mines are considered especially dangerous, due to their size and the amount of explosive material they contain. For that reason a decision was made to dispose of them via the detonation method.



Figure 10. Mk VI, II World War mine extraction, conducted by a mine destroyer (March 2015), GC type mine found in The Gdansk detonation Source: author's own resources

To ensure security of the operation, safety zones had to be established, to protect people, animals, and other objects from being negatively influence by the action.

In the pyrotechnics, it is most common to calculate the pressure of the underwater of the shock wave in the distance scope:

$$5R_0 < D < 1000R_0$$

where: R_0 –the radius of the shaped charge [m],

The maximum pressure of underwater shock wave is determined using the Robert Cole's equation:

$$P_{max} = 533 \cdot 9.869 \cdot 10^4 \left(\frac{\sqrt[3]{G}}{R} \right)^\alpha \quad [\text{Pa}]$$

where: G – the equivalent mass of the explosive material [kg] R – distance [m] α - empirically found index (1,13 for TNT)

The graph below pictures the changes of acoustic (Fig. 11) wave pressure as function of the distance from the detonation zone (in the case of detonating

either GC-type mines or Mk VI mine on the depth of 12 meters).

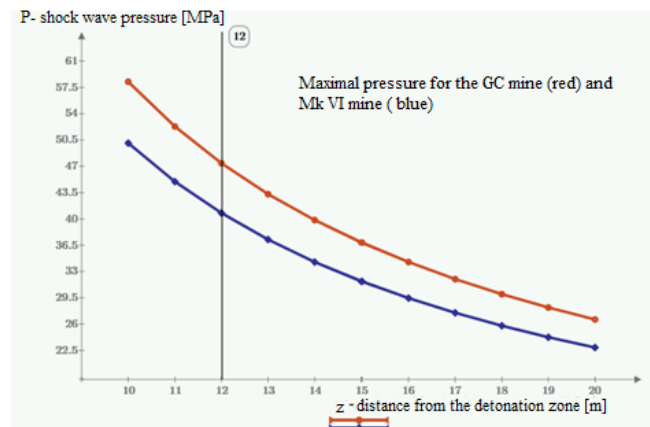


Figure 11. The graph pictures the changes of acoustic Source: author's own resources.

To apply the aforementioned dependency to explosive materials different than trinitrotoluen (for example hexanite, amatol, minol), a TNT equivalent must be calculated and depth factor (which defines the how the force of detonation is affected after reflecting from different types of sea bottom).

The value of the depth factor (k_d) should, in theory, be in the range from 0 to 2. The values from 0 to 1 are applied to charges buried in sea bottom. If the k_d is equal to 2, the bottom is rock solid, in this case half of the detonation energy is reflected. For the analysed case, due to the bottom characteristics, a k_d equal to 1,6 was applied.

Table 1. The depth factor values. [5]

Type of bottom	Value of k_d
Rocky	1,8
Medium density (gravel, clay)	1,6
Light (loam, sand)	1,4

After considering both the TNT equivalent and the depth factor, a "corrected value of explosive material mass" was calculated, marked as q_e .

To properly establish zones where ships are safe from the underwater detonation (underwater shock wave) impact, the following empirical formula [8] is used:

$$R_b = 76 \div 100 \sqrt[3]{q_e'} \quad [\text{m}]$$

To establish the same zone, this time for concrete buildings, the formula is changed:

$$R_b = 18 \sqrt[3]{q_e'} \quad [\text{m}]$$

Table 2. Underwater unexploded ordnance detonation dangerous areas

Mine type	Explosive material mass [kg]	q_e' [kg]	R_b [m] for ships	R_b [m] for buildings
GC (LMB)	696	1336	836 ÷ 1100	198

The explosive objects resided 200-250 meters from the port of Gdynia breakwater and 150 m from the center of the route leading to the Naval Port and the main entrance to the commercial port. There were both ships and elements of local infrastructure inside the established danger zone. The area considered as dangerous for humans or animals was estimated to be about 10 km. (Fig. 12).

Due to the closeness of the port's infrastructure and ships, it was not possible to dispose of the mines using the detonation method. The key element of the operation was hauling the mines to the detonation area, about 5 nautical miles from the detection site. There, they were neutralized with the use of various sapper and remote detonation methods.

The disposal of the threat, conducted by the Polish Navy's forces, was the most fragile and dangerous element. It was crucial to ensure safety of the action during the extraction of the ordnance and later, during its destruction.



Figure 12. The GC-type mines (marked red) and the Mk VI mine (yellow) detected in the port pictured alongside the safety zones. Source: author's own resources

That particular stage was preceded by a reconnaissance procedure, during which a thorough classification and identification of the object was conducted, the results of which determined further actions. To properly organize these two processes allows appropriate forces to be used in the process of neutralization, which in part ensures the maximal security of the people engaged in the operation.

5 CONCLUSIONS

The examples of various dangerous, explosive ordnance (including objects from the Second World War era), presented in the article, are proof to the fact, that there still exists a threat to naval transport, port infrastructure and human activities in these areas.

In the Polish territory, a system of unexploded ordnance clearance has been established, which, despite utilizing restricted forces, ensures the safety of Polish citizens. Vital parts of that system are the Clearance Diving Groups and Anti-Mine Patrols.

In the Polish Military Standards, the anti-mine patrols are called explosive ordnance clearance patrol [6]. On one hand, they partake in anti-crisis management tasks, on the other they make effective functioning of the entire system possible. To alleviate the danger of untoward incidents, especially those connected with dangerous remnants of war, it is mandatory to dispose of them as quickly as possible. In order to do so, a proper reorganization of the system, so that its maximum effectiveness and swiftness may be achieved, is necessary. The most important goal is to make mine disposal operations as unburden some to the local population as possible [5].

The disposal of mines, conducted by the Polish Navy's forces, is the most fragile and dangerous element of the operation, due to exposure to various threats inevitably connected to extracting and neutralizing explosive materials.

In the Polish Responsibility Zone alone, the mine clearance operations were continuously conducted from the end of the Second World War to the middle of the 70s. It is also worth noting that contemporary technology did not make the complete eradication of the threat possible. Due to that fact, there is still unexploded ordnance found in the previously searched areas. Bottom non-contact mines were considered harmless, since the fuse became inactive after their energy sources depleted. There are, therefore, still these types of objects lying on the sea bed.

Transport and neutralization of the explosive underwater ordnance and other, similar threats, described in the dissertation, will be the subject of next researches and analyses, which will be described in publications to come.

In conclusion, transport of unexploded ordnance is a complicated process, which requires specialized knowledge. To organize this process in compliance with various safety regulations is not only crucial to decrease the threat of dangerous incidents, but also ensures its maximal effectiveness. It is worth knowing how to properly select means of transport and proper safety equipment, which would vary depending on the type of the material, its individual properties and dangers it creates.

On the basis of experiences gathered so far, a national plan of creating a Central Center for Unexploded Ordnance Management based in the Engineering and Chemical Forces Training Center was set afoot.

The growing interest in exploiting the Baltic's natural resources will intensify the demining operations in this area. As statistical data proves, these operations are both lengthy and expensive. Lack of thorough analyses concerning possible unexploded ordnance threats could endanger lives of research or construction teams working in the area. The detection of this kind of objects in close proximity of a LNG terminal clearly shows, how important demining operations are to proper investment preparation. The Polish Navy only employs three mine hunters (ORP "Flaming", ORP "Mewa" and OPR "Czajka") with enough equipment to conduct mine detection, identification, classification and neutralization.

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