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ESTIMATING THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE MAMMALS IN THE COASTAL AREA OF NORTHWESTERN BLACK SEA

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***Abstract**: To determine the values of distances calculated for threshold values of impact levels were obtained the values within the ranges specified for the threshold of developing impact level and the most important impact level on the three species of dolphins on the Black Sea (Phocena phocena, Dephinus delphis and Tursiops Tursiops) when mines and torpedoes are used. The mortality or injury thresholds appear at distances of 240-250 (m) or 335-350 (m), mammals are disturbed if the two means of combat producing explosions will act at distances of 2200 (m) and the lowest impact is expected to be met when using reactive bombs, depending directly on the amount and nature of explosives.*
***Key-words**: Black Sea, Phocena phocena, Dephinus delphis and Tursiops Tursiops*

1. INTRODUCTION

Determining the parameters of underwater explosion at various immersions, and at the air/water mixture is well documented in the specialty literature. The shock wave is described with precision both theoretically and through computer simulation using different methods such as CTH (McGlaun et al., 1990). Unda de şoc este descrisă cu precizie atât teoretic, cât şi prin simulare pe computer prin diferite metode cum ar fi CTH (McGlaun et al., 1990). Also, a thorough monograph on numerical modeling of explosives detonation can be found in Mader (1979). Studies by Ward et al., (1998) were focused on propagation and sound attenuation, using technics described by Yelverton et al., (1973, 1975) and Swisdak (1978). Yelverton conducted a series of tests in order to determine the correlations between the distance from the explosion field and the effects on mammals and birds using as explosives pentholite and TNT (charges of 3-4 kg) at depths of 3m.

Stuhmiller et al., (1990), Swisdak and Montaro (1992) have compiled a large quantity of experimental informations in order to create similarities between equations that describe the peak pressure, the pulse, time constants and the density of the energy flux depending on a scaled range for a different number of exploding sources.

In turn, Young (1991) conducted a series of experiments that applied pressure of the shock wave front on different fish species, in order to develop predictive models, designed to determine the effects on species for different distances and types of explosive charges. Goertner (1982) conducted studies in order to determine the distances to which marine mammals are injured by underwater explosions.

This brief review of the literature, referring to the parameters that define the underwater explosions and their effects on the coastal marine environment, allows to describe the main characteristics of underwater explosion, namely:

- explosives types and their properties;
- the energy released by the underwater explosion defined by amplitude, duration, frequency, pressure, momentum, energy flux density;;
- mass of the load and configuration;
- evolutionary laws of the explosion;
- the type of propagation mechanism (spherical, cylindrical or flat);
- measuring and calibrating equipment (Dzwilewski şi Fenton, 2003).

To study the impact on hydrobionts, we will focus on the direct effect parameters, namely: the peak pressure and impulse.

Peak pressure (pressure in the shock wave front)

An underwater explosion pressure is decreasing exponentially in time depending mainly on the amount of explosive and the distance from the explosion, the pressure rising to a maximum pressure, P_m, in a very short time frame, usually at several microseconds . There are many relations that describe this parameter in the literature (many of them determined experimentally). We will stop at two of them used in the studies below:

a. Swisdak (1978)

$$P(t) = P_m\, e^{-(t/\theta} \quad (1)$$

where : P_m – maximum pressure;
θ- time constant.
for which

$$P_m = K(W^{1/3}/R)^{\alpha} \ \text{(MPa)} \quad (2)$$

$$\theta K_2 W^{1/3}(W^{1/3}/R)^{\alpha_2} \ \text{(ms)} \quad (3)$$

where: *R* in meters (m); the pressure in megapascals (MPa); the time in miliseconds (ms) and the explosive's mass in kilograms (Kg). The coefficients *K*, *K2*, α şi α_2 are specific to the explosive used.

b. Bărbărie et al., (2011)

$$P_d = 533((\alpha\omega_{ex})^{1/3}/d)^{1,13} \ (\text{daN/cm}^2) \quad (4)$$

where: P_d – the value of dynamic pressure in the shock wave front; α - coefficient effect in TNT equivalent of explosive load (α =1 for TNT; α =1,4 for TGAG-5;);
ω_{ex} – the quantity of explosive in kg; d – the distance to which the impulse value is measured.

The impulse

The importance of the impulse results from the fact that a pressure which acts at a moment will have the same effect as another moment when the pressure value is two times the pressure that previously acted but half the time considered in the previous case. Therefore, this parameter indicates the pressure evolution per unit time obtained by the following formula:

$$I = \int_0^{\infty} P(t)\delta t \quad (5)$$

where: *I* – the impulse in pascals per second (Pa/s); *P(t)* – the pressure in pascals (Pa); *δt* – time interval of interest.

Since the estimated effects on hydrobionts, according to the literature, are reported to impact distances measured in meters, corresponding to the pressure in the shock wave front, we will use as formula for determining the pressure in the shock wave front relation (4).

2. METHOD

The experimental configuration and the proposed method for the theoretical determination of parameters of underwater explosion when combat means are used made in coastal areas (districts) of the North – West Black Sea, in routine situation (training / experimental releases), in order to to estimate their effects on hydrobionts.

In order to obtain the parametres of underwater explosion in routine situations, and to estimate the effects on the main categories of hydrobionts, we developed and applied the following method :

1. The selection of districts in which various combat means in routine situations are used, made in compliance with the rules of the navy, had in view technico - tactical caracteristics and specific exercises, as seen in the layout 1.250.01 of districts, for application activities, in order to determine the potential effects on coastal marine environment (Fig.1). The general purpose of the established districts, as seen on the map, is as follows:

a_1. Anti-submarine Bomb Releases: Mangalia III; Midia III, Constanta III.

a_2. Anti – submarine torpedo releases, or releases of anti-submarine torpedos against surface ships: Mangalia IV-V.

a_3. Rocket launches and artillery firings: Mangalia II, Constanta II; Midia II.

a_4. Dredging exercises: Mangalia II; Midia II; Constanța II.

2. Selecting means for fighting specific for each district, taking into consideration their possible use (anti-submarine bombs, torpedoes, marine mines) (**Table 1**)

3. Setting the distances for measuring the explosion parameters, taking into account the explosion site and its production (m), in compliance with the existing regulations;

4. Calculation of the dynamic pressure value (Pd), in the shock wave (daN/cm2 or bar), as related to the distance measured from the production site of the explosion (m), based on the selected formula;

5. The analysis of estimated effects on the main categories of hydrobionts, if different types of combat means are used, based on quantitative and qualitative evaluation of species and their reporting to the determined values (calculated) of dynamic pressure (Pd) on the shock wave.

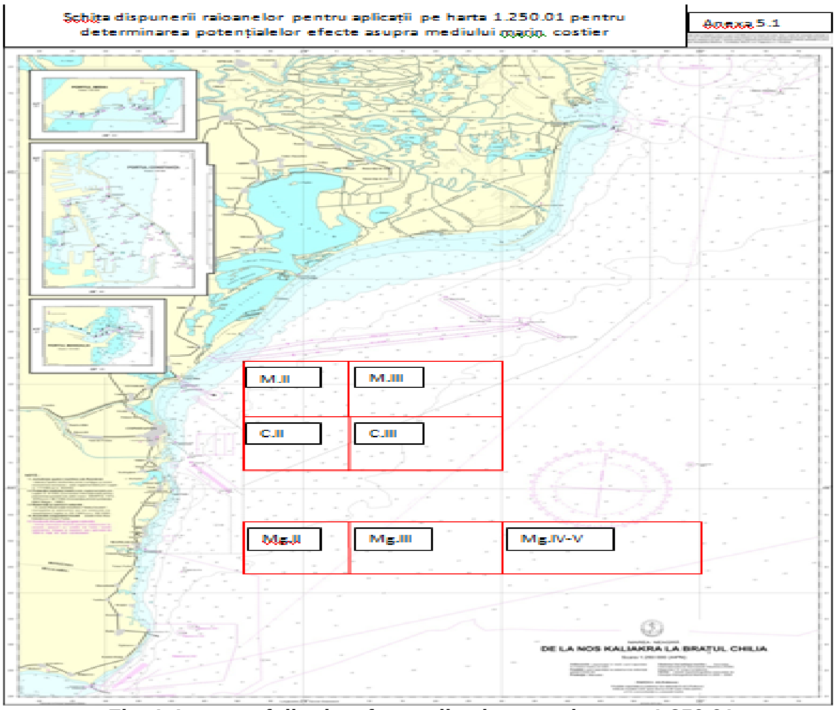


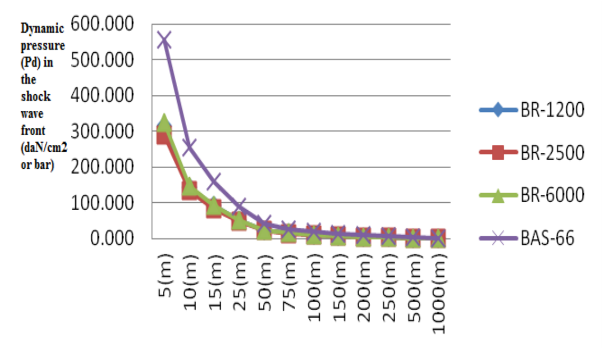
Fig. 1. Layout of districts for applications on the map 1.250.01

Table 1 Selection of underwater combat means on types of districts

Nr crt	Type of district	The selected combat means	Observations- description of combat means
1.	District for anti-submarine bomb releases	BR-1200, BR-2500, BR-6000, BAS-66	Technic – tactical, and constructive characteristics in compliance with cub chapter
2.	District for torpedoes for anti-submarine torpedoes releases against surface ships or T 53-VA, T53-KE, SET 53, SET 53 M	T 53-VA, T53-KE, SET 53, SET 53 M	
3.	District for dredging exercises (destruction of mines) MMCA-1, MMA - 2, MAD - 1, MAD - 2	MMCA-1, MMA – 2, MAD – 1, MAD – 2	

3. RESULTS

Considering the current state of knowledge of the effects of the main parameters of the underwater explosion on the species we determined the **<u>first stage</u>**, i.e. the theoretical values of underwater explosions related to underwater combat means used in coastal areas, based on the calculus relation established, and different of means of combat selected according to the method; thus, we obtained the theoretical values for dynamic pressure (Pd) in the shock wave (daN/cm2 or bars) in relation to the distance measured from the production site of the explosion (m) with different types of weapons.



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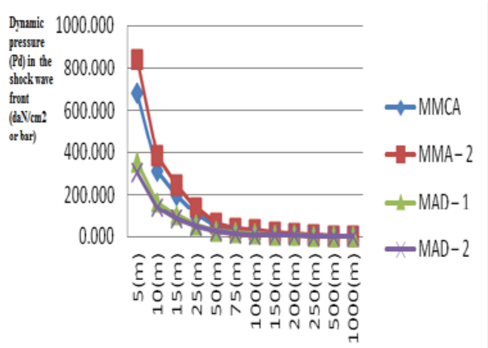

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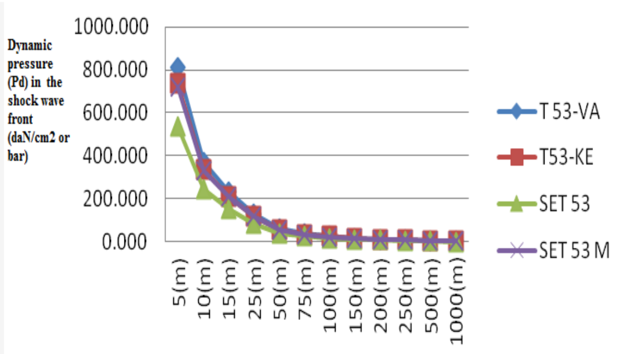
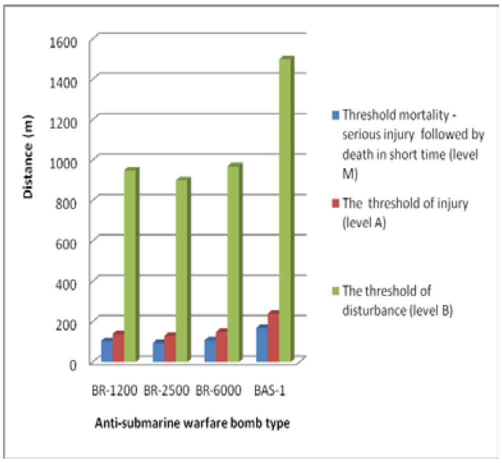


Fig. 2 – Value of dynamic pressure (Pd) in the shock wave front (daN/cm2 or bar) compared to the measured distance (m) in relation to the place of explosion, considering types of: a - anti-submarine bombs, b - marine mine, c – torpedoes

A few conditions must be taken into consideration when establishing the intervals for measuring the pressure of the shock wave front: the amount and nature of explosives used; intended effects on the target species (death, injury, safety threshold, etc.); characteristics of the district. Ranges proposed for theoretical calculations, as well as for the *in situ* experimental validation, according to the model proposed in chapter method are as follow:
5 (m), 10 (m), 15 (m), 25 (m), 50 (m), 75 (m), 100 (m), 150 (m), 200 (m), 250 (m), 500 (m), 1000 (m). (Fig. 2)

The second stage consisted of estimating the effects of underwater explosions when various means of underwater devices were used on marine mammals in the coastal area of northwestern Black Sea for determining the values of distances calculated to determine the threshold values of impact levels, according to literature in the field.

The following results were obtained:
- The values obtained are within the ranges specified for the threshold of developing impact levels confirmed in international literature (MMPA, Parvin et al., 2007);
- The most important impact level on the three species of dolphins (*Phocena phocena, Dephinus delphis and Tursiops Tursiops*) will occur when MMA-2 mine, and T 53-VA torpedo will be used; mortality or injury thresholds appear at distances of 240-250 (m) or 335 to 350 (m); mammals are disturbed if the two means of combat producing explosions will act at distances of 2200 (m) (Fig. 3);
- The lowest impact is expected to be met when using reactive bombs (BR-1200, BR-2500 and –BR 6000, depending directly on the amount and nature of explosives.



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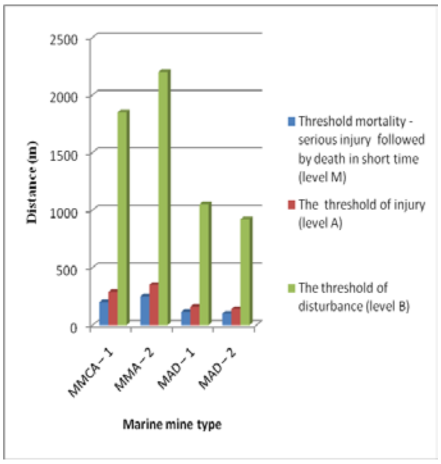

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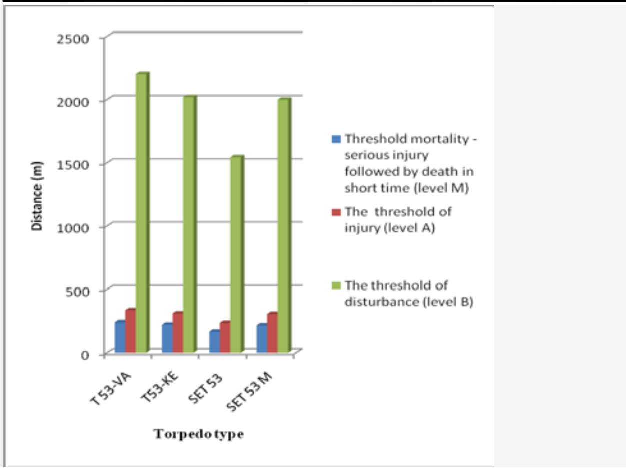

c

Fig. 3 - Estimating the effects of underwater explosions on marine mammals when using: a –anti-submarine bombs; b - sea mines; c-torpedoes

4. CONCLUSIONS

The values were calculated for the case when only one single explosive is used (a single means of combat). In reality when military applications take place more than one explosive is used (especially for reactive bombs), so that distances calculated for threshold levels of impact can "shift" with the successive distances between successive explosions, to which the distance calculated in tables is added .

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