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IMPULSE ACTION OF UNDERWATER SHOCK WAVE AS A CAUSE OF DISABLING THE SHIP POWER PLANT

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Abstract

This paper presents action of shock wave resulting from an underwater non-contact explosion, exerted on ship hull plating. The impulse load was considered in the range of wave regular reflection and refraction at the boundary of two media: water and steel. In most cases the impulse action leads to failures or damages of elements of ship power plant as well as shipboard equipment, however without endangering ship's floatability. Typical kinds of failures which recurred on ships of various tonnage, are presented, a.o., on the example of ships sailing in Red Sea waters during Iraq-Iran war.

Keywords*: explosion, pressure, shock wave, destruction*

1. Introductory remarks

Underwater non-contact explosion does not cause usually ship's sinking but only complete loss of its maneouvrability due to many failures in the ship's power plant and shipboard equipment. And, ship's hull plating which takes up the first impulse of load may sustain local plastic deformations; the loss of ship's maneouvrability does not constitute itself a danger in the case of ships not engaged in warfare as it took place e.g. during Iraq-Iran war where a dozen or so ships flying various flags sustained failures. A good example describing consequences of explosion is a general cargo ship, m/s „Józef Wybicki"[1]. In the case of ships taking part in warfare (e.g. convoys to Murmansk) such situation became extremely dangerous and usually led to ship's loss.

On all the ships such failures due to impact load were similar. The most endangered were elements made of fragile materials, e.g.: cracks in shaftline casings, lugs of foundations of combustion engines and electric motors, tearing off electric driving motors of compressors, pumps and hoisting winches (fig. 1, 2, 3).

Another type of failures are plastic deformations of screw joints, bending deformations of main engine crankshafts and propeller shaft segments. Radiocommunication and navigation equipment sustains failures of another type [1, 5].

This way, i.e. as a result of non-contact explosion of mines, 17 ships in total have been damaged during one month in Red Sea waters.

Depending on magnitude of experienced impulse load the ships had to be subjected to various repairs: beginning from minute repairs performed by crew personnel itself to serious repairs in shipyards, lasting many months.

Fig. 1. A crack in upper casing of shaftline bearing

Fig. 2. Foundation bolts torn off the seating of main engine's turbocharger

Fig. 3. Electric driving motor torn off the hoisting winch body

2. Reflection and refraction of two-dimensional acoustic wave

Value of impulse load resulting from shock wave action to ship's hull plating decides on acceleration to which ship equipment elements are subjected.

In [2] is presented the load resulting from shock wave reflection from non-deformable plane, both in the regular and irregular range.

In this paper the load applied to a flat wall is considered in regular range, with taking into account wave refraction at its passing into the other medium.

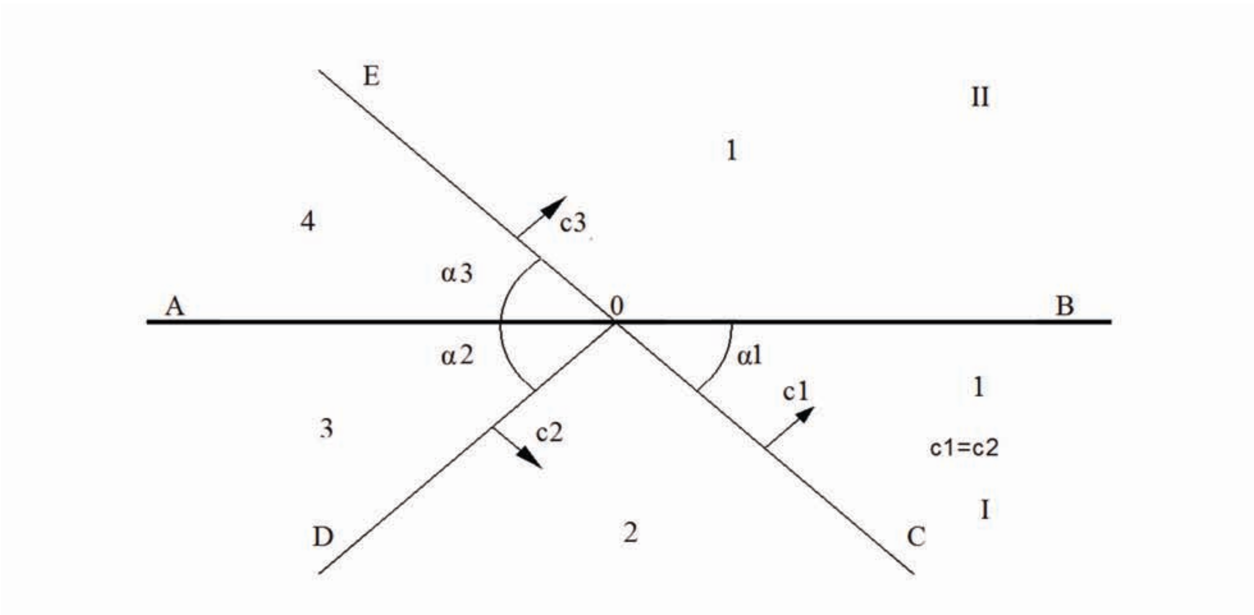

Fig. 4. Acoustic wave reflection from and refraction at a flat wall

Fronts of incident wave and reflected one propagate in the medium I (water). The refracted wave penetrates the medium II (steel). In the zone 1 limited by the front of the waves OC and OE the both media, I and II, are undisturbed. In the zone 2 between the incident wave and reflected one, OC and OD, the medium is disturbed at the parameters of the incident wave. In the zone 3 between the dividing boundary AB and the reflected wave front OD, the medium I is disturbed by the reflected wave parameters. In the zone contained between the refracted wave front OE and the dividing boundary AB, the medium II is disturbed by the refracted wave parameters (fig. 4).

Where:
AB – boundary between two media: I and II,
OC – incident wave front,
OD – reflected wave front,
OE – refracted wave front,
α_1 – incidence angle,
α_2 – reflection angle,
α_3 – refraction angle,
c_1, c_2, c_3 – wave propagation velociti*es* in the media: I and II, respectively,
ρ_1, ρ_2 – density of the media: I and II,
p_1, p_2, p_3 – pressure of incident, reflected and refracted wave, respectively.

By making use of: the regular reflection condition, the crossing point of wave fronts on the boundary of media, Snellius principle, as well as the continuity conditions [4] it yields:

from the reflection condition: $\alpha_1 = \alpha_2$ i $c_1 = c_3$

and, from the Snellius principle:

$$\frac{c_1}{\sin\alpha_1} = \frac{c_3}{\sin\alpha_3} \Rightarrow \frac{\sin\alpha_1}{\sin\alpha_3} = \frac{c_1}{c_3} \tag{1}$$

From the continuity condition of velocity of normal displacements and pressures on the dividing boundary of the media it results that:

$$\begin{aligned} & c_1 \cos\alpha_1 - c_2 \cos\alpha_2 = c_3 \cos\alpha_3 \\ & p_1 + p_2 = p_3 \end{aligned} \tag{2}$$

The formulas for pressure of reflected wave and refracted one have the form:

$$\frac{p_2}{p_1} = \frac{\rho_2 c_3 \cos\alpha_1 - \rho_1 c_1 \sqrt{1 - \frac{c_3^2}{c_1^2}\sin^2\alpha_1}}{\rho_2 c_3 \cos\alpha_1 + \rho_1 c_1 \sqrt{1 - \frac{c_3^2}{c_1^2}\sin^2\alpha_1}} \tag{3}$$

$$\frac{p_3}{p_1} = \frac{2\rho_2 c_3 \cos\alpha_1}{\rho_2 c_3 \cos\alpha_1 + \rho_1 c_1 \sqrt{1 - \frac{c_3^2}{c_1^2}\sin^2\alpha_1}} \tag{4}$$

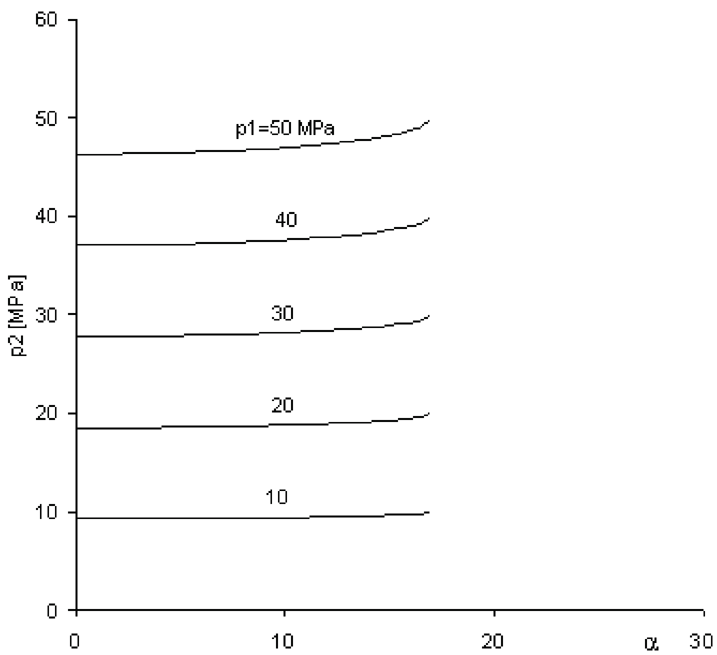

Fig. 5. The pressure p_2 on the reflected wave front in function of the incidence angle α_1 and the shock wave pressure p_1

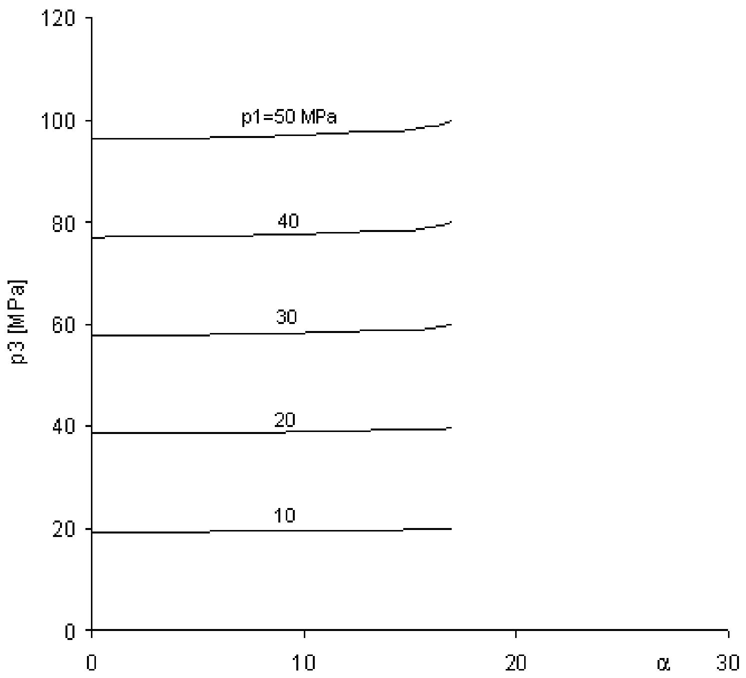

Fig.6. The pressure p_3 on the refracted wave front in function of the incident angle α_1 and the shock wave pressure p_1

The shock wave pressure at cross-section of a perfectly stiff wall was considered in [2]. Formulating the equation of mass conservation, equation of momentum, and equation of the state Teta, one has calculated the pressure acting on ship's hull plating (i.e. the pressure due to reflected wave), hence also the impact load.

The pressure p_2 applied to the wall in function of the incidence angle α_1 and the shock wave pressure p_1 is presented in fig. 7:

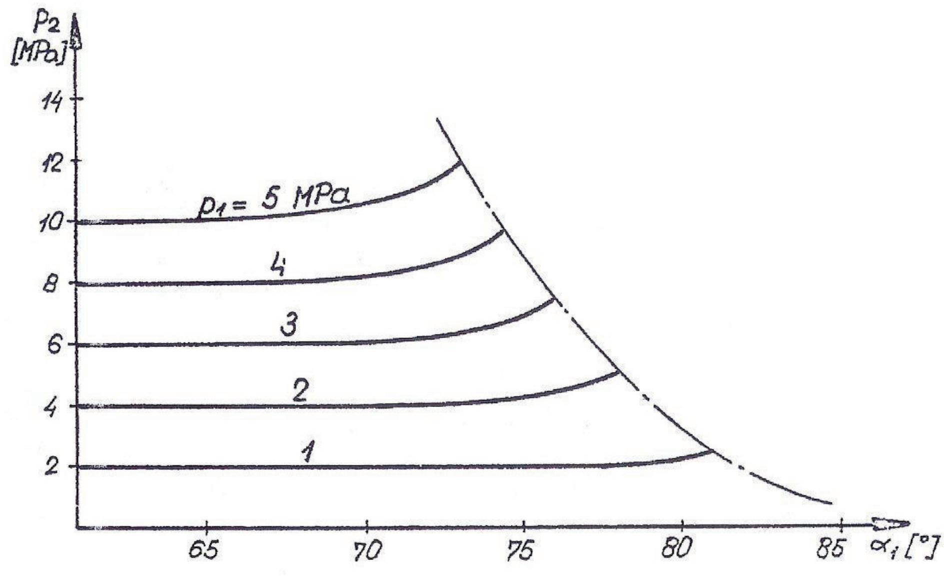

Fig. 7. The pressure p_2 applied to the wall in function of the incidence angle α_1 and the shock wave pressure p_1

3. Remarks and conclusions

As results from the above given formulas, the ratio of the reflected wave pressure and the refracted wave pressure to the incident wave pressure depends on the acoustic wave resistance of the media and the incidence angle α_1. In the case when the medium II is more stiff than the medium I, i.e. $c_2 > c_1$, real values of reflection coefficient are obtained at the angle values $\alpha_1 \le \alpha_{kr} = arc\sin\frac{c_1}{c_3}$. In the considered case: $c_1 \approx 1500\frac{m}{s}$ (water), $c_3 \approx 5000\frac{m}{s}$ (steel), $\alpha_{kr} = arc\sin 0,3 = 17°30'$. At a high value of wall stiffness the pressure p_3 (fig. 6) and pressure p_2 (fig. 5) differs only a little to each other in this range, hence the assumption on perfectly stiff wall results in loads greater than real ones.

As a result of explosion a part energy is transferred into stiff hull structure and propagated inside the ship through particular structural elements which serve as a kind of waveguides. Difraction, refraction and interference of waves takes place. In consequence apart from damages of elements made of fragile materials, also failures of joints of steel elements occur.

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