

DETERMINATION OF THE BUBBLE ENERGY AT
UNDERWATER EXPLOSIONS WHERE THE WALLS
CONTRIBUTE TO THE RESULTS.

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Summary

In this report the relevance of the "bubble test" is discussed and different kinds of energies are estimated, e:g the shock wave energy, energy of the gas, and the kinetic and potential energy of the water. An approximate formula for evaluation of the bubble energy from the oscillation period of the bubble is derived and some test blastings are performed. The results show that the bubble energy transferred to the water is between 38 and 60% of the explosive energy while the mortar energy for the same explosives is between 25 and 35%.

Translated from Swedish by Ann-Marie Mårtensson. DS 1969:37.

Introduction.

The strength or capacity of explosives was earlier determined with the mortar test where a little quantity (5-20 g) of an explosive was fired in a chamber closed with a projectile.

For some new insensitive explosives a strong primer is necessary and to reduce its influence a great amount (about 10 kg) must be used. A further additional reason for the use of bigger quantities is that these explosives do not detonate at all in smaller dimensions.

As the mortar test can't be used here we have tried to find new test methods. One of these is the bubble test, where a charge is fired at a certain depth and the size or the oscillation period of the gas bubble is measured and from that the energy is evaluated.

As an explosive detonates a shock wave goes out into the water and its energy disappears. After that the water can be considered incompressible and energy is transferred to the water as kinetic and potential energy. When the gas bubble rebounds the kinetic energy is zero and the water contains only potential energy which is

$$E_{v2} = p_o V_2 \quad (1)$$

where V_2 is the maximum volume of the bubble and p_o is the total overburden pressure.

Then the energy of the gas is

$$E_{g2} = \int_{V_2}^{\infty} p dV \quad (2)$$

If we put

$$pV^{\gamma} = p_o V_o^{\gamma} \quad (3)$$

where V_o is the volume of the bubble at pressure p_o and $\gamma = C_p/C_v$ (2) gives

$$E_{g2} = \frac{p_o V_2}{\gamma - 1} \left(\frac{p_2}{p_o} \right) \quad (4)$$

Estimation of different energies.

As mentioned above a part of the energy in the shock wave disappears. The amount of this energy depends on many factors and may vary from a few unto 50% of the explosive energy.

From /2/ (fig. 4) we find that Nitroglycerine at $p_0 = 2$ bar,
 $R_2 = 2,55 R_0$ and $p_0 = 33,3 p_2$. From the same figure and (3) is
 found that $\lambda = 1.25$.

Then eq. (4) gives

$$E_{g2} = 0.12 E_{v2} \quad (5)$$

If we determine how much energy there is in the gas at pressure p_0 we
 in the same way get

$$E_{g0} = 0.24 E_{v2} \quad (6)$$

By measuring the maximum size of the bubble it is according to (1)
 possible to calculate the energy E_{v2} transferred to the water while
 the shock wave energy E_s and the energy of the gas E_{g2} can not be
 determined. This may seem to be a limitation. Some results indicate,
 however, that these energies do not appreciably contribute to the result
 in rock blasting and therefore the measurement of the bubble energy E_{v2}
 ought to be a good measure of the energy or strength of an explosive.

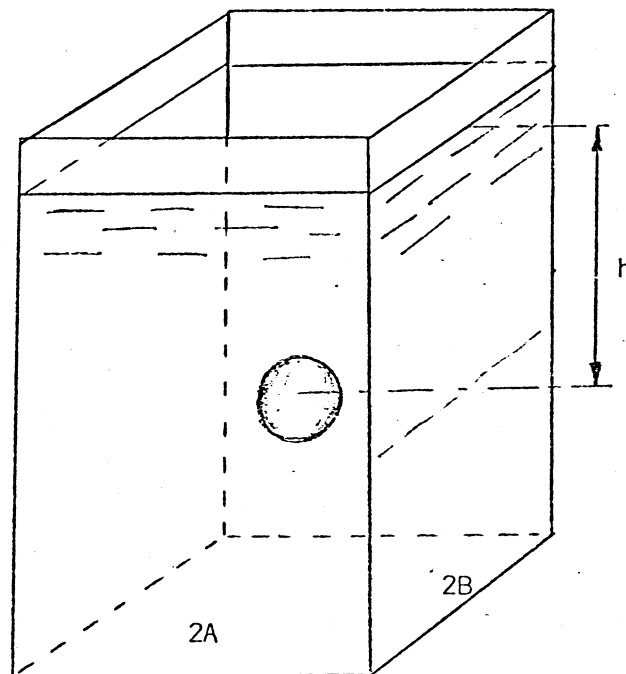


Fig. 1. Watercontainer with an expanding gasbubble.

Determination of the bubble energy from the oscillation period.

Generally it is not possible to measure the volume of the gas bubble and therefore we instead measure the oscillation period and from this period calculate the energy.

If the container is very large compared with the gas bubble the water flows radially and its kinetic energy is

$$E_k = 2\pi \rho R^3 \left(\frac{dR}{dt}\right)^2 \quad (7)$$

where R is the radius of the bubble. On the other hand if the container is small it can be considered as a vertical tube and the kinetic energy becomes

$$E_k = 2AB\rho h \left(\frac{dh}{dt}\right)^2 \quad (8)$$

where the energy near the bubble is neglected.

From the change of volume we get

$$dV = 4\pi R^2 dR = 4ABdh \quad (9)$$

which in (8) gives

$$E_k = 2AB\rho h \left(\frac{\pi R^2}{AB}\right)^2 \left(\frac{dR}{dt}\right)^2 \quad (10)$$

A combination of (7) and (10) gives

$$E_k = 2\pi \rho R^3 \left(1 + \frac{\pi hR}{AB}\right) \left(\frac{dR}{dt}\right)^2 \quad (11)$$

Eqn. (11) is valid in the two limits $AB \rightarrow \infty$ and $AB \rightarrow 0$ but may certainly diverge for other values.

When the bubble has turned we get

$$\frac{4\pi}{3} p_0 (R_2^3 - R_1^3) = 2\pi \rho R^3 \left(1 + \frac{\pi hR}{AB}\right) \left(\frac{dR}{dt}\right)^2 + \int_V^{V_2} p dV \quad (12)$$

which yields the time till the collapse of the bubble

$$t = \left(\frac{3\rho}{2p_0}\right)^{1/2} \int_{R_1}^{R_2} \frac{\left(\frac{R}{R_2}\right)^{3/2} \sqrt{1 + \frac{\pi hR}{AB}} dR}{\sqrt{1 - \left(\frac{R}{R_2}\right)^3 - \frac{1}{E_{V2}} \int_V^{V_2} p dV}} \quad (13)$$

An analysis of the contribution of the detonation gas on the time shows an increase of it with about 2%. Therefore we can neglect the integral under the square root sign in (13). With the substitution

$$R^3 = R_2^3 \sin^2 \alpha \quad (14)$$

(13) becomes

$$t = \left(\frac{2\rho}{3p_0}\right)^{1/2} R_2 \int_0^{\pi/2} \sin^{2/3} \alpha \sqrt{1 + \frac{\pi h R_2}{AB} \sin^{2/3} \alpha} d\alpha \quad (15)$$

if we set the period $T = 2t$ after a series expansion of (15) we become

$$T = 2 \left(\frac{2\rho}{3p_0}\right)^{1/2} R_2 \int_0^{\pi/2} \sin^{2/3} \alpha \left[1 + \frac{\pi h R_2}{2AB} \sin^{2/3} \alpha - \frac{1}{8} \left(\frac{\pi h R_2}{AB}\right)^2 \sin^{4/3} \alpha + \frac{1}{16} \left(\frac{\pi h R_2}{AB}\right)^3 \sin^2 \alpha \right] d\alpha \quad (16)$$

This series converges for $\pi h R_2 < AB$, and as the series is alternating the upper and lower limits can be determined.

Integration of (16) yields

$$T = 1.633 \left(\frac{\rho}{p_0}\right)^{1/2} R_2 \left[1.12 + 1.43 \frac{h R_2}{AB} - 0.96 \left(\frac{h R_2}{AB}\right)^2 + 1.34 \left(\frac{h R_2}{AB}\right)^3 \right] \quad (17)$$

Inserting the density of water $\rho = 1.000 \text{ kg/m}^3$ and according to (1)

$$R_2 = \left(\frac{3E}{4\pi p_0}\right)^{1/3} \quad (18)$$

we get

$$T = \frac{35.9}{p_0^{5/6}} E^{1/3} \left[1 + 0.792 \frac{h}{AB} \left(\frac{E}{p_0}\right)^{1/3} - 0.330 \left(\frac{h}{AB}\right)^2 \left(\frac{E}{p_0}\right)^{2/3} + 0.286 \left(\frac{h}{AB}\right)^3 \frac{E}{p_0} \right] \quad (19)$$

Setting $h = 10 \text{ m}$ we get $p_0 = 2 \cdot 10^5 \text{ N/m}^2$ and then (19) yields

$$T = \frac{E^{1/3}}{7.28} + \frac{E^{2/3}}{5.37} \left(\frac{h}{AB}\right) - \frac{E}{7.54} \left(\frac{h}{AB}\right)^2 + \frac{E^{4/3}}{5.09} \left(\frac{h}{AB}\right)^3 \quad (20)$$

where T is given in sec. and E in MWs.

Fig. 2 shows T as a function of E for different values of $\frac{h}{AB}$. A. Persson and L.Å. Almgren /5/ have performed blastings in a waterfilled mine-cavity at a depth of 10 m and with the approximate dimensions $A = 10 \text{ m}$, $B = 20 \text{ m}$ and distance charge - bottom 10 m.

Table I gives the result where the bubble energy has been determined by the aid of the diagram in fig. 2 for $\frac{h}{AB} = 1/20$. The values are between 38 and 60% of the calculated explosion energy. As a comparison the mortar value according to /1/ is given. Blasting gelatine and dynamex show a large divergence. We may assume that the blasting gelatine which has given the highest value and dynamex without a primer partially have detonated with low velocity at which a smaller part of the energy is lost in the shock wave.

T (sec.)

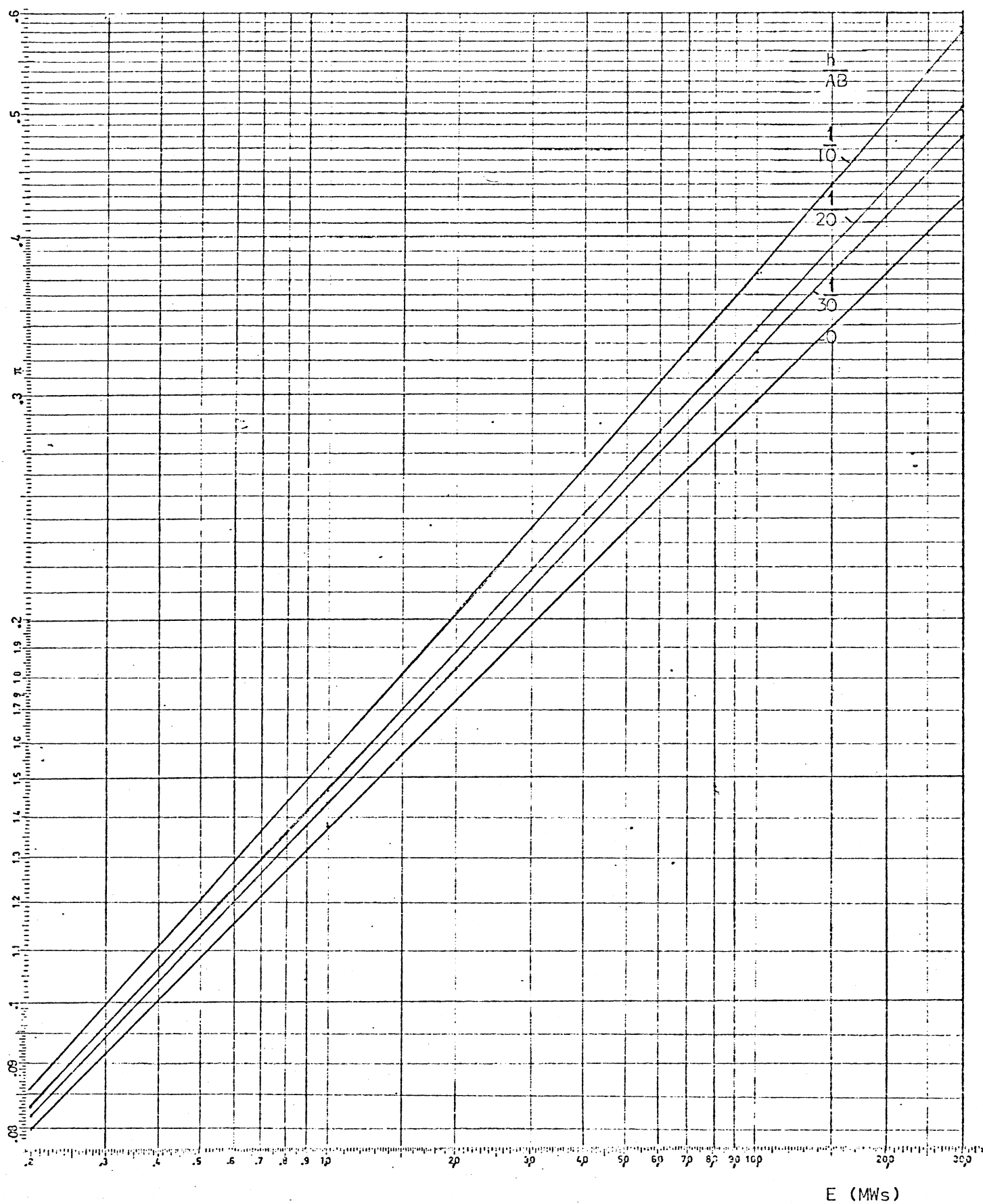


Fig. 2. The oscillation period as a function of the bubble energy with $\frac{h}{AB}$ as a parameter.

Explosive	Charge weight Q kg	Bubble period ms	Bubble energy (E_b) MWs/kg	Explosive energy (E_e) MWs/kg	E_b/E_e %	Mortar energy %
TNT pressed	0.1	84.0	2.00	4.10	48.4	26.0
" "	0.1	82.5	1.90	4.10	46.3	26.0
" "	0.1	83.0	1.95	4.10	47.5	26.0
" "	0.1	83.0	1.95	4.10	47.5	26.0
TNT-sphere, cast	7.5	372.0	1.70	4.10	41.5	26.0
TNT-cyl., cast	7.75	372.0	1.65	4.10	40.2	26.0
Blasting gelatine without primer	7.75	435.0	2.58	6.70	38.5	25.6
" "	7.5	510.0	4.00	6.70	59.7	25.6
Dynamex with primer	7.2	384.0	1.97	4.44	44.3	34.8
without primer	7.0	410.0	2.42	4.44	55.5	34.8

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