Letter

Underwater explosion measurement of multi-ton charges in the Dead Sea

Lippe Sadwin

Sadwin Engineering Consultancy, Kefar Pines, ISRAEL
e-mail: ldsadwin@netvision.net.il

Received: May 27, 2005 Accepted: July 22, 2005

Abstract

Measurements were made from the underwater explosions of two (2) ton and five (5) ton explosive charges detonated separately at a depth of seventy (70) meters in the Dead Sea. The overall purpose of the tests was to efficiently generate long range detectable seismic waves which emanate from these explosions.

The measurements were made with piezoelectric gages suspended in the high density water of the Dead Sea. The high barometric pressure and water density both strongly influence the underwater shock wave and bubble period. The paper describes the methods of recording the data, the pressure versus time recordings and the handling of the effects of water density and barometric pressure.

Keywords: Underwater explosions, Commercial explosives, TNT equivalency, Shock energy, Bubble energy, Dead Sea

1. Introduction

A series of underwater explosion tests was conducted in the Dead Sea by the Geophysical Institute of Israel. The purpose of the tests was to generate controlled seismic waves for calibrating local seismographic systems and those in neighboring countries and at long range.

The Sadwin Engineering Consultancy, having extensive experience in measuring underwater explosions[1], was contracted to make pressure measurements of the two largest explosions. The data analysis gives an indication of the energies released by each detonation of the locally manufactured slurry type, blasting agent Chen-Ammon in terms of a corresponding weight of TNT.

2. Experimental

The two tests of the series for which underwater explosion measurements were made were:

Two tons of Chen-Ammon fired at a depth of 70 m.

Five tons of Chen-Ammon fired at a depth of 70 m.

The distances at which measurements of the underwater shock waves were made were determined by means of the LOCATE program developed by NSWC*. The program utilizes timing data from the primary shock wave and the corresponding surface reflection. The measurement gages were located at 791 m and 816 m from the 2 ton test and 636 m from the 5 ton explosion. The pressure gages were placed at a depth of 30 m. The gage at 816 m on the 2 ton test was actually located at a depth of 25 m.

The pressures were measured using type 138A01 piezoelectric, underwater, blast sensors manufactured by PCB Piezotronics. The pressure versus time (P-t) signals were recorded by a data acquisition system with a 500 kHz sampling rate for eight channels (62.5 kHz per channel).

Time zero for triggering the computer recordings was obtained by a using a switch attached to the case an electric detonator wired parallel to the main detonator. The switch closure was fed to an SEC developed single-pulse circuit. The time values shown on each of the P-t records are from the time of detonation of the main detonator attached to the detonating chord at the surface. The detonation of the main charge was about 7 ms later. The true times from the actual detonation are 7 ms less than those shown on the graphs of the P-t records.

* The LOCATE program was developed and is used by Ronald Tussing of the Carderock Division of the NSWC in Bethesda, Maryland. It uses data on times of arrival of the primary shock wave and its reflection as well as the characteristics of the water to determine the range of a measurement point from the explosion source. The results are considerably more accurate than location data from GPS equipment.

The pressure, density and velocity conditions influence the underwater explosion shock wave propagation and bubble oscillation and energy characteristics[2]. The barometric pressure measured at the Dead Sea was 79.2 cm Hg. The water density was 1,236 kg m^{-3} and the in-situ acoustic velocity was 1,770 m s^{-1}. The shock waves generated were considerably stronger than those from similar explosions in ocean water. The bubble periods recorded were likewise shorter than those from similar explosions in regular ocean water. These parameters were taken into account in the TNT equivalence determinations.

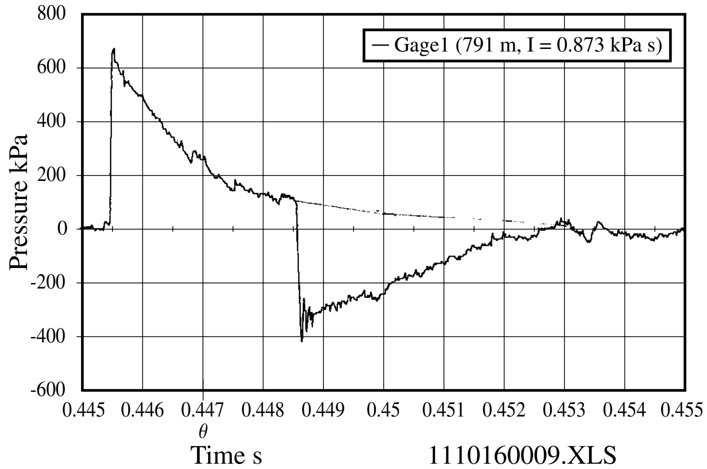

Fig. 1 Pressure versus time curve at 791 m from 2,000 kg of Chen-Ammon.

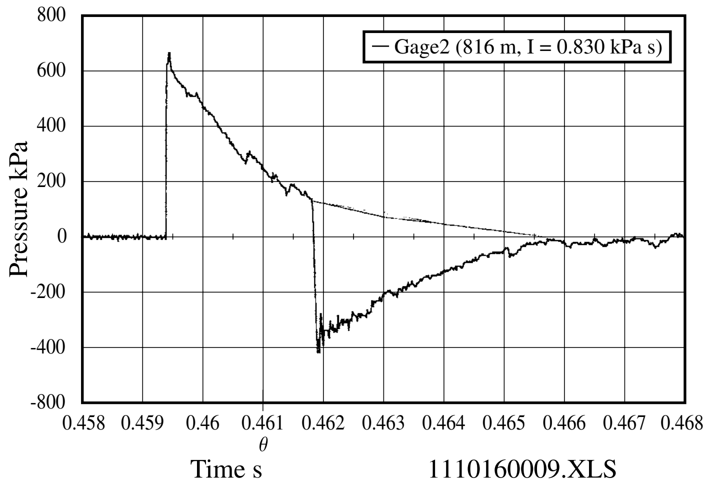

Fig. 2 Pressure versus time curve at 816 m from 2,000 kg of Chen-Ammon.

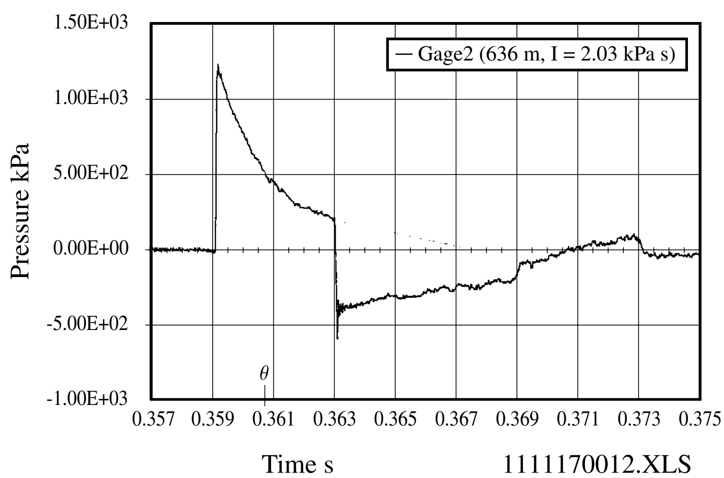

Fig. 3 Pressure versus time curve at 636 m from 5,000 kg of Chen-Ammon.

Table 1 Underwater explosion data (as measured).

Explosive weight, kg	Distance, m	Peak pressure, kPa	(θ), Time constant, ms	Impulse, kPa ms
2,000	791	668	1.55	>873
2,000	816	654	1.6	>830
5,000	636	1,205	1.67	>2,030

3. Results and discussion

The two P-t recordings for the 2 ton test are presented in Figs. 1 and 2. The P-t data for the 5 ton test is given in Fig. 3. The data are in kPa for pressure and the time from detonator functioning is in s.

All of the P-t signals have typical shapes characteristic of underwater explosions from conventional explosives. The signal starts as a shock wave and has an exponential decay of pressure with time. The negative going "shock" wave signal seen on all recordings (after about three ms on the 2 ton shot and about two ms on the 5 ton test) is that of the shock wave reflected from the surface.

The maximum negative pressure possible corresponds to the hydrostatic pressure at the depth of the gage. There is evidence of cavitation at the minimum pressure level (small oscillations) since the pressure reflected from the surface is larger than the hydrostatic pressure at a depth of 30 m.

The peak pressures and impulses (until the reflected wave cut-off) measured from the P-t curves in Figs. 1-3 are presented in Table 1:

The unique characteristics of the Dead Sea water (paragraph 2.5) must be considered in determining the TNT yield of the two underwater explosions. With the aid of factors that take into account water density and acoustic velocity[2], a comparison was made with TNT detonated under standard ocean conditions. This analysis was done with the assistance of the author's colleagues at the NSWC, Carderock Division in Bethesda, Maryland.

The yield analysis based on our actual measurements is summarized in Table 2. For this table, the weights of TNT, which would provide the same peak shock pressures as those measured from Chen-Ammon were determined by iterative calculations.

Values of the first bubble period obtained from seismographic data of the Geophysical Institute of Israel were as follows:

For 2,000 kg Chen-Ammon, 70 m deep: 0.55 s,

For 5,000 kg Chen-Ammon, 70 m deep: 0.77 s.

The bubble energy developed is a function of the cube of the bubble period[3].

The bubble energies generated by the Chen-Ammon explosions were considerably weaker than those from an equivalent TNT explosion.

For the 2,000 kg explosion the bubble energy was 41 % of that for a TNT yield of ~1,900 kg. Similarly, the explosion of 5,000 kg of Chen-Ammon generated a bubble energy 46 % of that for 4,773 kg of TNT.

Table 2 Summarized results of the yield analysis.

Explosive weight, kg	Range, m	TNT yield (calculated), kg	Bubble period (for TNT yield), s
2,000	791	1,864	0.734
2,000	816	1,986	0.750
5,000	636	4,773	1.005

4. Conclusions

The Chen-Ammon explosions gave underwater peak pressures relatively close to those of TNT having the same weight.

The peak pressure yields were between 93 % and 99 % of TNT.

The bubble energies were found to be between 41 % and 46 % of those for the above yields of TNT.

The time constants of the pressure decay were about 50 % of those for the TNT yields (based on peak pressure). This indicates that the underwater total impulses of Chen-Ammon would be much less than those expected from TNT.

The Dead Sea is a good location for underwater explosion tests in light of the negligible effects on the environment.

Acknowledgements

To the Geophysical Institute of Israel, as sponsors of this work and for the bubble period data.

Special thanks are due to Ronald Tussing and associates at the Carderock Division of NSWC for valuable assistance in analyzing the data.

The assistance during the test phase at the Dead Sea of BenZion Yonaev and Gaby Gabrilov is gratefully acknowledged.

References

1) L. D. Sadwin, *et al*., "Underwater Evaluation of the Performance of Explosives", International Symposium on Mining Research, Pergamon Press, 1962.
2) J. F. Goertner, "Scaling Underwater Explosion Shock Waves for Differences in Ambient Sound Speed and Density", NSWC-TR 80-491, U.S. Naval Surface Weapons Center, 18 December 1980.
3) R. H. Cole, "Underwater Explosions", Princeton University Press, 1948.