Measurements of the Peak Pressure and Sound Exposure Levels of Underwater Explosions

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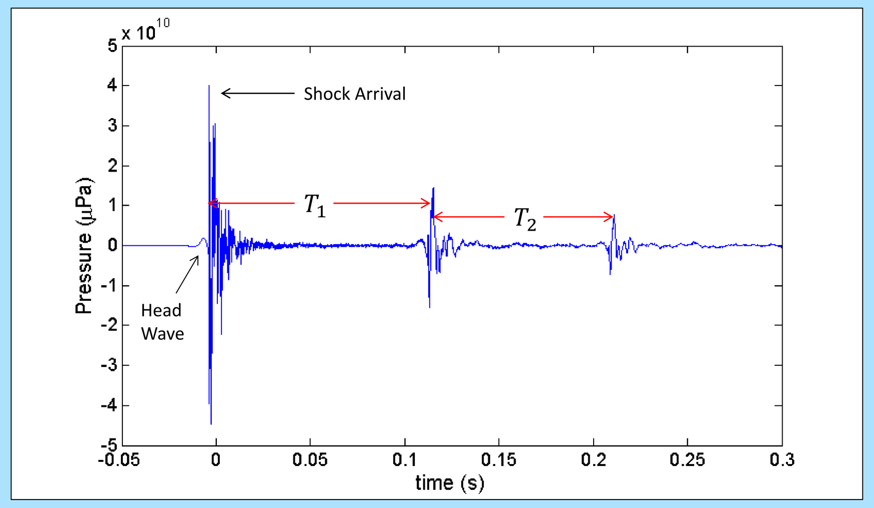
Abstract

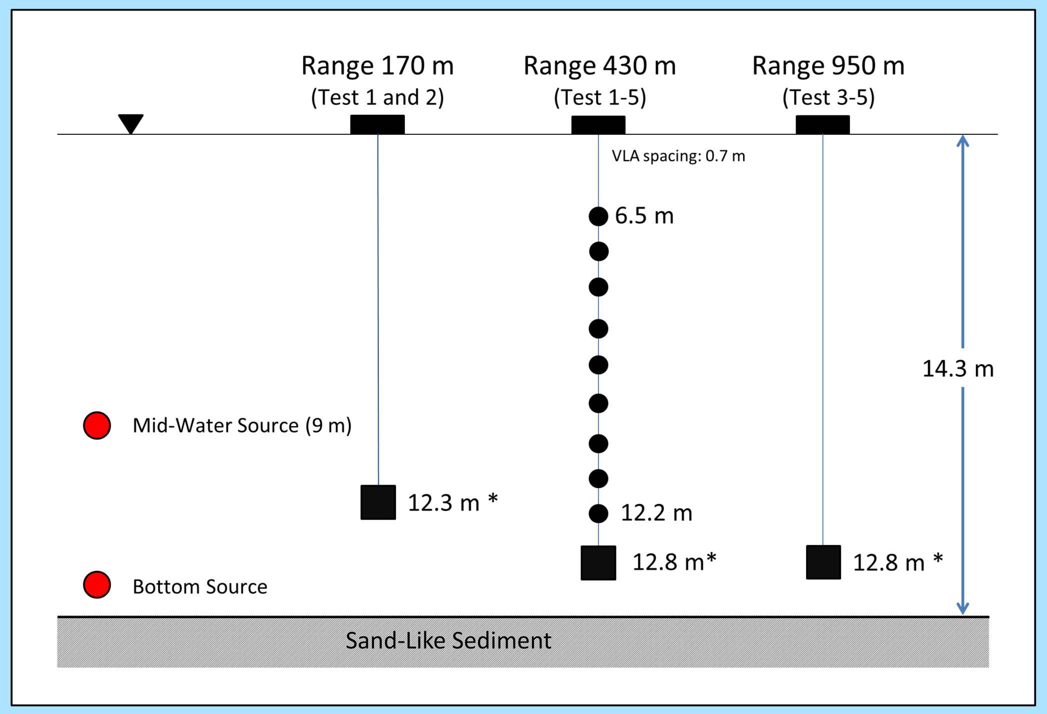
Naval activities such as ordinance disposal, demolition, and requisite training, can involve detonation of small explosive charges in shallow water. This work presents measurements of underwater sound from explosions in shallow water (depth order 10 m) during a naval training exercise with focus on peak pressures, sound exposure levels, and time series analysis. The peak pressures are compared to semi-empirical equations of scaled range, and the influence of elastic properties in the seabed are investigated. The ultimate goal of this work is to provide both accurate ground truth data, and improved modeling of such sound, to minimize impact on marine life.



Sample time series of an underwater explosion. The main shock arrival can be seen at 0 s (relative time) with the first (T_1) and second (T_2) bubble pulses arriving at 0.1 s and 0.2s (relative time) respectively. Additionally, there is a head wave that arrives just before the main shock.

Field Measurements

- Underwater explosion measurements were collected 7 km off Virginia Beach, Virginia in September 2012 during a training exercise for Navy Ordinance Disposal divers.
- Shallow water with constant depth 14 m.
- Iso-speed water velocity profile of 1528 m/s and sand-like sediments.
- Five charges deployed (see table below) corresponding to scaled range of order (100 – 1000) $m\ kg^{-1/3}$.



*single element Loggerhead system

Test	Explosive	Depth	Charge Weight (Kg)	TNT Equivalent	TNT Equivalent Weight (Kg)
1	C-4	Mid-water	0.2	1.34	0.3
2	C-4	Bottom	0.5	1.34	0.6
3	C-4	Mid-water	2.3	1.34	3
4	C-4	Bottom	4.5	1.34	6
5	CH-6	Mid-water	0.07	1.5	0.1

Summary of test charges including TNT equivalent weight and detonation depth.

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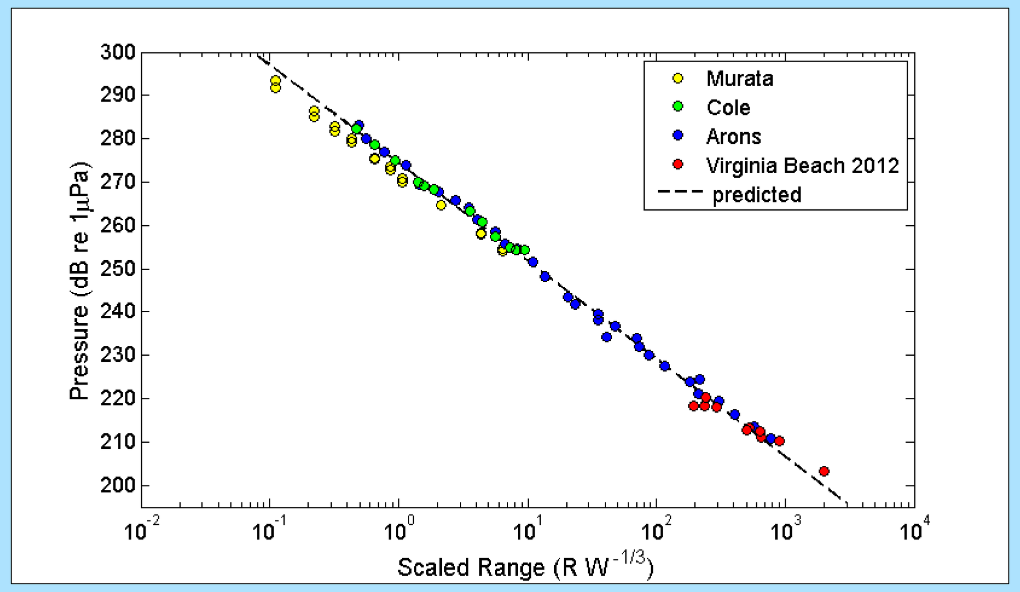
Peak Pressure

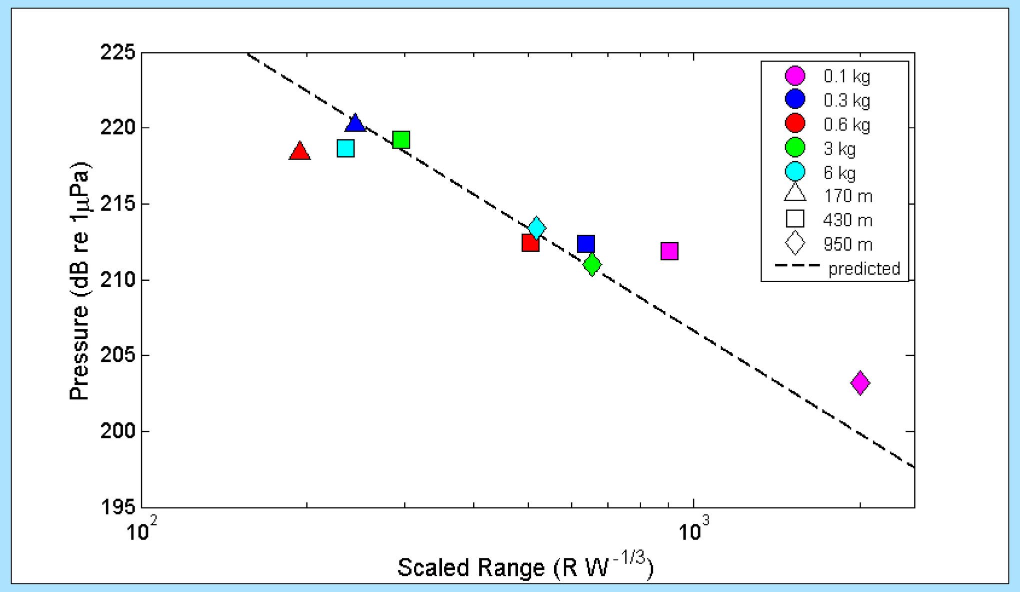
Measurements of underwater explosions have been used to develop semi-empirical equations for peak pressure in terms of scaled range, $R\,W^{-1/3}$, for example [1][2],

$$P_{peak} = 52.4 \times 10^6 \left(\frac{R}{W^{1/3}}\right)^{-1.13}$$

where P_{peak} is predicted peak pressure (Pa) , R is measurement range (m) and W is the weight of the charge in TNT equivalent weight (kg TNT).



Peak pressure from the Virginia Beach 2012 measurements are plotted against predicted levels along with previous measurements from Arons [2], Murata [3], and Cole [4].



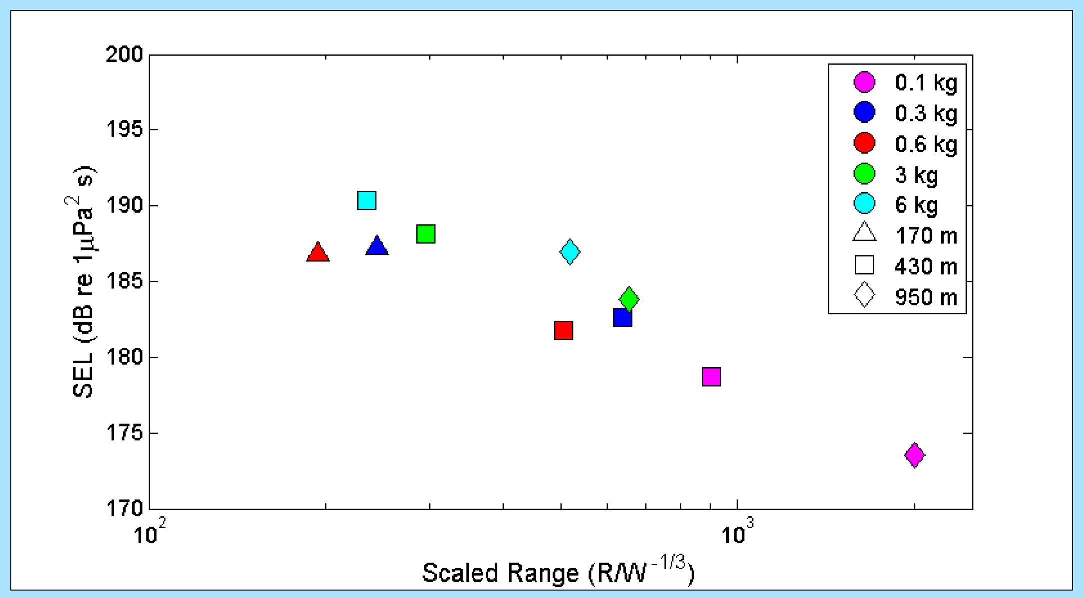
The peak pressures from the Virginia Beach 2012 measurements are shown with the corresponding measurement range identified by marker color, and the range given by the marker size.

Sound Exposure Levels

The 90 % Sound exposure levels (SEL_{90}) from the explosions were calculated from

$$SEL_{90} = 10\log_{10}\left(\frac{1}{p^2{}_{ref}}\int_0^T p^2(t)\,dt\right)$$

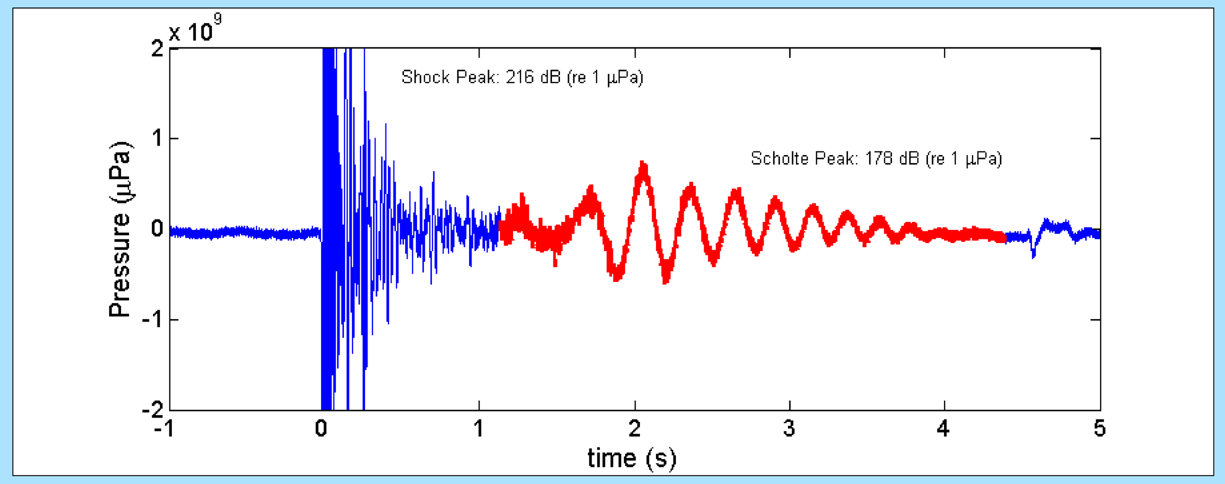
Where $p(t)$ is the instantaneous pressure (Pa), and T is the pulse duration (s)



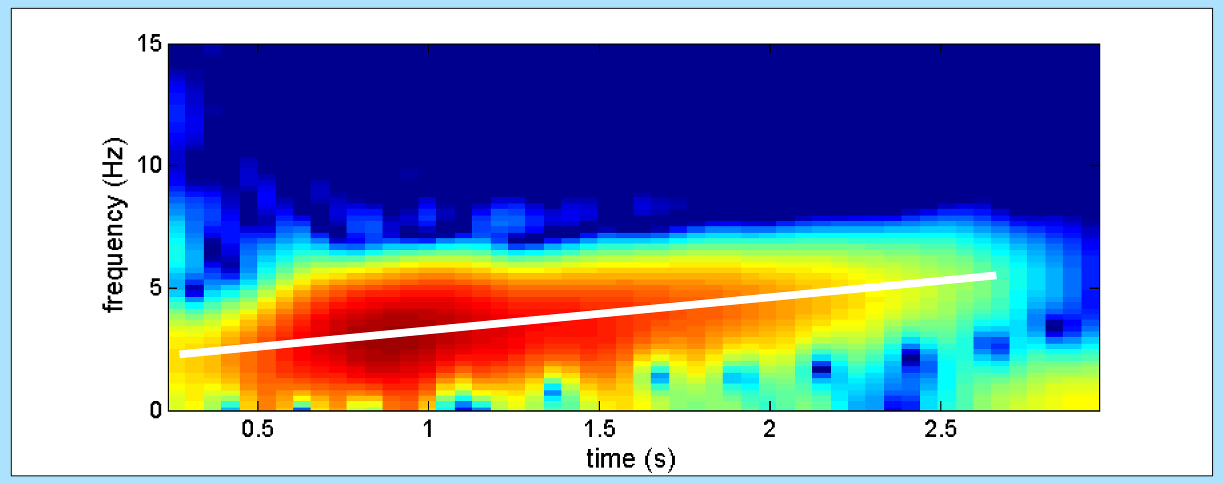
SEL_{90} calculated from the Virginia Beach measurements plotted against scaled range. Marker color and shape identify the charge weight and measurement range respectively.

Elastic Properties of Seabed

- Scholte waves (interface waves) were recorded for Test 3 (3 kg TNT) and Test 4 (6 kg TNT).
- The dispersive properties of the Scholte wave are typical for layered bottoms with sound speed increasing with depth. [5]



Time history for the 6 kg explosion shown with the Scholte wave identified in red.



Time frequency analysis of Scholte wave shown in red above. Dispersion trend shown by white line.

Conclusions

- The **peak pressure** measurements are in agreement with the scaled range equations.
- The **sound exposure levels** of the measurements have a clear dependence on weight, with larger charges producing higher levels. Values tend to collapse with scaled range.
- Measurements of dispersive **Scholte waves** point towards a layered, elastic bottom with shear speed increasing with depth.

Future Work

- Develop simple scaled range equation to predict sound exposure levels from explosions.
- Use the Scholte wave measurements to invert for the shear properties in the sediment to develop site-specific geo-acoustic model.
- Simulation of propagation of explosive pulse using elastic model

References

[1] A. B. Arons, "Underwater Explosion Shock Wave Parameters at Large Distances from the Charge," *J. Acoust. Soc. Am.*, vol. 26, no. 3, pp. 343–346, 1954.

[2] N. R. Chapman, "Measurement of the waveform parameters of shallow explosive charges," *J. Acoust. Soc. Am.*, vol. 78, no. 2, pp. 672–681, Aug. 1985.

[3] K. Murata, K. Takahashi, and Y. Kato, "Measurements of Underwater Explosion Performances by Pressure Guage Using Fluoropolymer," *J. Mater. Process. Technol.*, vol. 85, no. 1–3, pp. 0924–0136, 2002.

[4] S. Temkin, "A Review of the Propagation of Pressure Pulses Produced by Small Underwater Explosive Charges.," Rutgers University, New Brunswick, NJ, Memorandum NRL-MR-6181, 1988.

[5] D. Rauch, "Seismic Interface Waves in Coastal Waters: A Review," SACLANTCEN, La-Spezia, Italy, SR-42, Nov. 1980.