Use of Rayleigh Waves as Reference for Determining Setback Distances for Explosions near Shorelines

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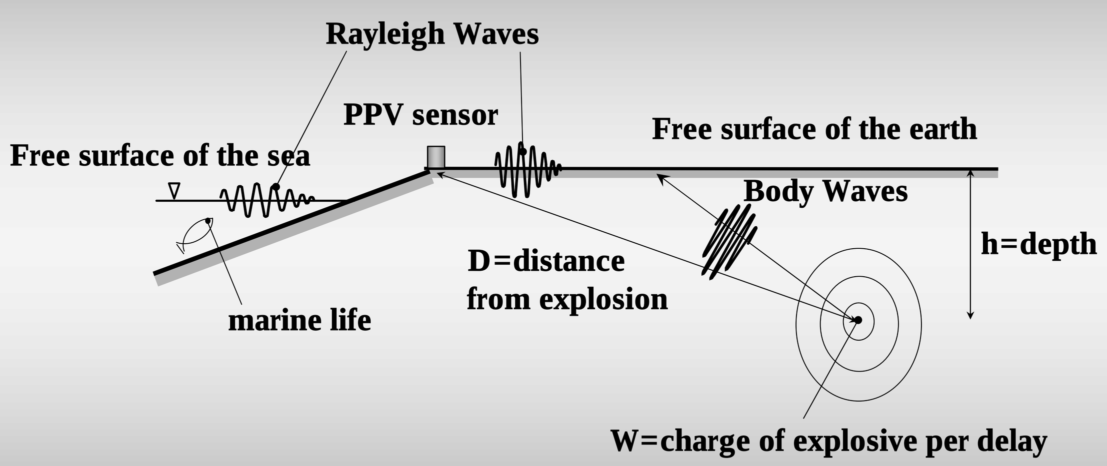
ABSTRACT: The use of explosives in engineering works, such as stone quarries, may produce negative effects not only on structures and people, but also on the environment. Usually only the direct compression waves are considered in assessing the damage to fish and marine mammals in the vicinity of the explosion. Rayleigh waves can be transmitted from solid to liquid and, consequently, affect the marine environment. Rayleigh waves (the surface waves) travel on the free surface of the earth or water to a depth of about 1.5 times the wavelength. However, they attenuate more slowly than the compression and shear waves (the body waves). The key parameters from a quarry blast are the peak particle velocity (PPV) and the dominant frequency. The low frequencies are characterised by wavelengths which may involve the upper 100m of the sea. The relationship among the several factors which influence the attenuation phenomenon (i.e., distance and depth of explosion, weight of the charge, ground conditions, shape of excavation) is analysed and the results are compared with other laws proposed in the literature. The difference in the geometrical attenuation laws of body waves and Rayleigh waves implies that, at a certain distance from the explosion, the peak particle velocity (or, equivalently, the overpressure) is higher for Rayleigh waves than for body waves. In order to respect the upper limit of PPV and overpressure imposed by the prevailing guidelines (for example, 1.3cm/s and 100kPa, respectively, in the Fisheries and Ocean Canada guidelines), the required setback distance from the centre of the explosive to fish habitat will be greater for Rayleigh waves than for body waves.

Description of the key aspects of explosions near shorelines



1) Rayleigh waves can transmit vibrations caused by blasting to marine life

Body waves versus Rayleigh waves

Body waves

- Include both compression and shear waves travelling in the interior of the ground with spherical wave fronts
- Shear waves do not transfer from solid to water
- The amplitude of the vibrations is inversely proportional to the distance

Rayleigh waves

- Propagate on the free surface of both earth and sea with cylindrical wave fronts
- They do transfer from solid to water
- The amplitude of the vibrations is inversely proportional to the square root of the distance; therefore, Rayleigh waves attenuate more slowly than body waves
- Depth reached by Rayleigh waves is about 1.5 times the wavelengths

2) Rayleigh waves travel farther than Body waves (ref. 2)

Basic Attenuation law

$$PPV\left(D,W\right)=k\frac{W^b}{D^a}$$

K, α & β are constants that depend on: type of wave, geometry of the problem, ground characteristics & units

Using the units of cm/s for PPV, m for D, kg for W the values of the constants derived from the references (see slide 9) are:

K=100, α=1.6 & β=0.8 for body waves (ref. 1)

Keeping constant the values of K & β, the value of α is:

α=0.5 from theory for Rayleigh waves (ref. 4)

α=1.1 from experimental data for Rayleigh waves (ref. 3)

3) Attenuation law of peak particle velocity PPV with distance D and weight, W, of explosive

Setback distance of explosion from fish habitat

$$D=\left[\frac{K}{PPV}\cdot W^b\right]^{\frac{1}{a}}$$ setback distance from limit 1

$$D=\left[\frac{\frac{z_w}{z_g}}{1+\frac{z_w}{z_g}}\, r_g V_g \cdot K \cdot \frac{W^b}{P_w}\right]^{\frac{1}{a}}$$ setback distance from limit 2

z_w, z_g are acoustic impedences of water and ground, respectively

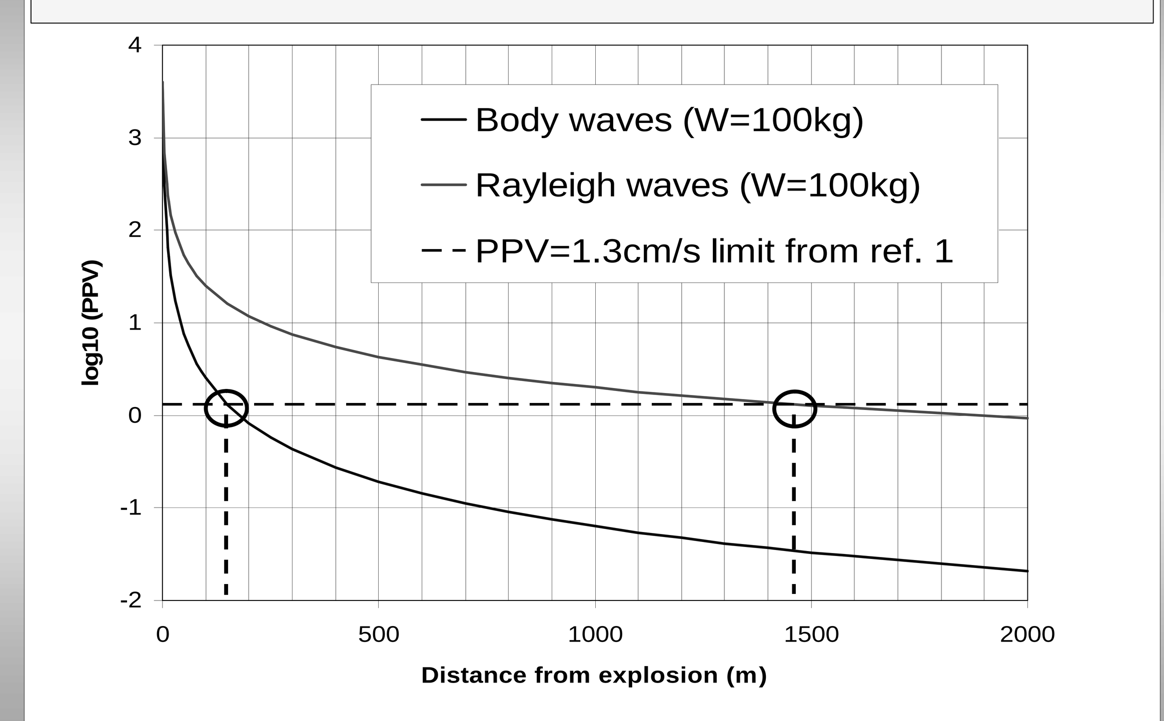
ρ_g, V_g are density and compression wave velocity of the ground

Limit imposed by DFO (ref. 1 in slide 9):

1. PPV=1.3cm/s for spawning habitat
2. Pw=100kPa for fish habitat

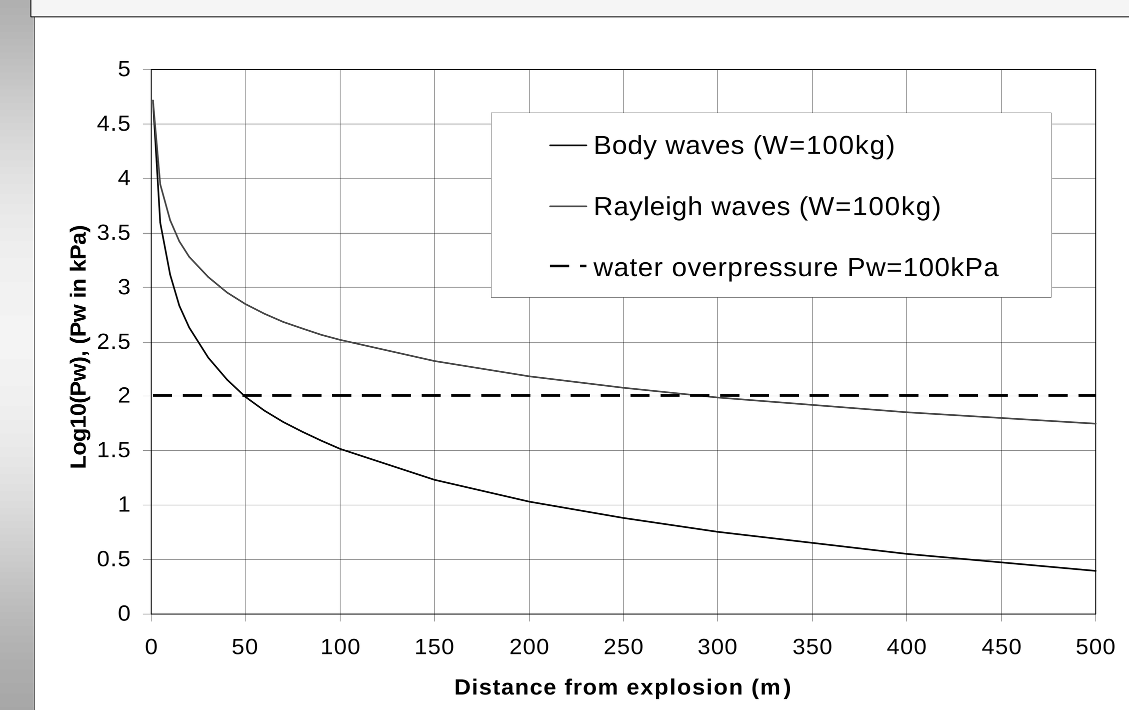
4) The formulas for determining the setback distance of explosion from fish habitat

Setback distance using limit 1 for Body and Rayleigh waves



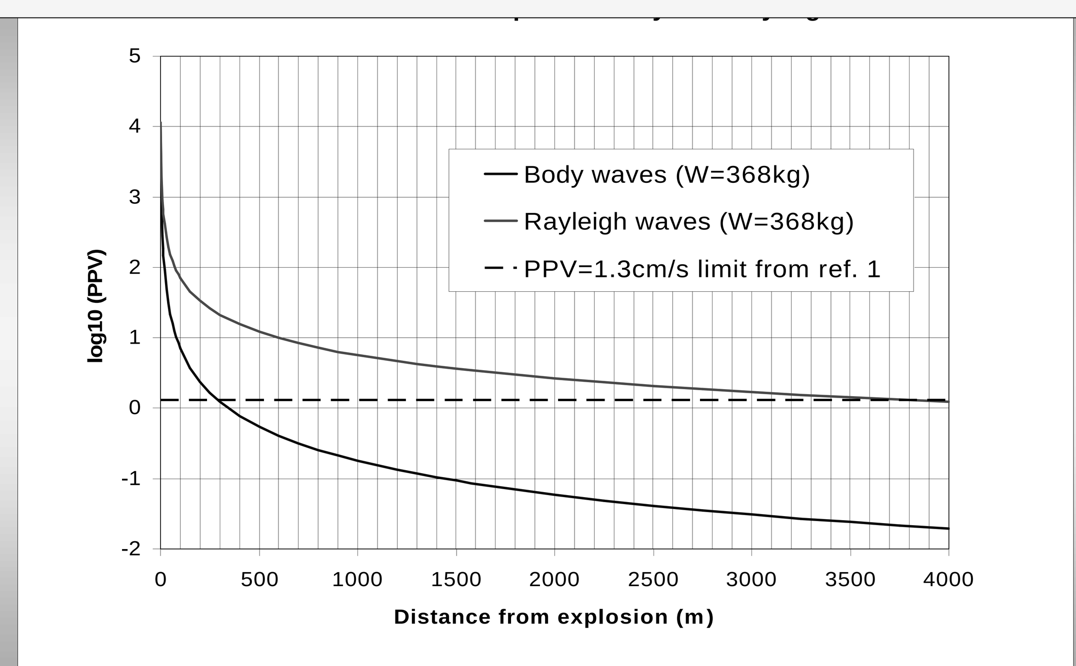
5) The setback distance is significantly greater for Rayleigh waves than for Body waves

Setback distance using limit 2 for Body and Rayleigh waves



6) The setback distance is smaller using limit 2 than for limit 1

Setback distance for the example for Body and Rayleigh waves



7) The example refers to a proposed rock quarry near the Bay of Fundy shoreline. For Rayleigh waves the setback distance for the example is about 4km compared to 300m for Body waves

Conclusions and Recommendations

- The above analyses indicate that the setback distance from an explosion, using pre-assigned limits for PPV or overpressure, is significantly greater for Rayleigh waves than for Body waves. Therefore, for assuring a safe marine environment, the use of Rayleigh waves should be more appropriate for establishing the setback distance from explosions.
- Since explosions involve a wide range of frequencies, the low frequency components of the Rayleigh wave motion on the surface of water can reach depths of about 100m.
- Depending on the mechanical characteristics of the ground, dissipation of the energy released by blasting varies considerably. Vibrations traveling through rock masses experience very low dissipation compared to vibrations through soils. The Bay of Fundy shore consists of hard rocks like basalt; therefore, low dissipation of vibrations is expected and the impact of blasting will be felt at large distances from the explosions

8) The importance of Rayleigh waves in environmental impact of explosions near shorelines has been demonstrated.

References

(1) Wright, D.G. and Hopky G.E. (1998): "Guidelines for the use of explosives in or near Canadian fisheries waters", Can. Tech. Rep. Fish. Aquat. Sci. 2107: iv +34p

(2) McLaughlin, K.L., Jessie, L.B. & Barker, T. (2004): "Seismic source mechanisms for quarry blasts: modelling observed Rayleigh and Love wave radiation patterns from a Texas quarry", Geophysical Journal International, vol. 156, Issue 1, pp.79-93.

(3) Tangchawal, S. (2004): "Vibration prediction and optimization: the case history of quarry blasts in Thailand", Proceedings of Fifth Int. Conference on Case Histories in Geotechnical Engineering, New York, NY, April 13-17

(4) Roma, V. (2001): "Soil properties and site characterization by means of Rayleigh waves", Ph.D Dissertation, Structural and Geotechnical Engineering Department, Technical University of Turin (Italy)

9) The principal References used for the study.