Course summary (Dr. Tan)

Explosion
Explosion is a violent event that creates:

- shock wave
- gases
- high pressure

Shock wave
(1) Rankine-Hugoniot equations
Abrupt change pressure *P*, mass density *ρ*, internal energy density *e*. A shock can propagate through solids, liquids or gases.

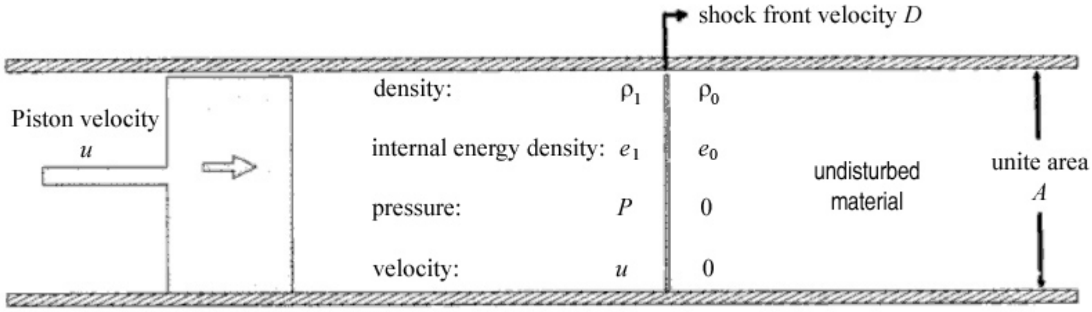

Figure 1. Shock transition from state 0 to state 1

Density ratio across the shock wave

$$\frac{\rho_1}{\rho_0} = \frac{D}{D-u}$$

Pressure applied to the shock

$$P = \rho_0 D u$$

Change of the specific energy

$$e_1 = e_0 + \frac{1}{2}u^2$$

(2) Rapid, continuous push
Shock waves are made by a rapid, continuous push.

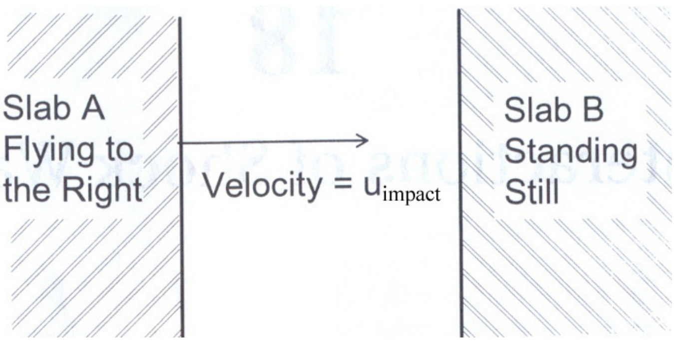

Figure 2. Impact of slab A on B.

Impact velocity: u_{imp}

Particle velocity at interface: u

Pressure at interface: P

<u>In B:</u>

Shock velocity in B: D_B

$$P = \rho_{0B} D_B u \,. \tag{1}$$

$$D_B = c_{0B} + s_B u \,, \tag{2}$$

<u>In A:</u> (reference system is with A flying at the speed of u_{imp})

In this reference system, shock velocity and particle velocity in A are denoted as D_A and u_A, respectively. One has the following relations:

$$P = \rho_{0A} D_A u_A \,. \tag{3}$$

$$u_{imp} - u_A = u \,. \tag{4}$$

$$D_A = c_{0A} + s_A u_A \,, \tag{5}$$

(3) Shockwave interactions create spalling and fragmentation

- The compressive pulse is reflected from the free end of the bar as a tensile pulse.
- When the tensile pulse reaches the ultimate tensile strength of the material a spall is formed, and the end of the bar breaks off.
- A new free end is formed and the remained original pulse is reflected from this new free end.
- Once again the bar breaks when the reflected tensile pulse exceeds the ultimate tensile strength of the material, and a new free end is formed.
- In this way multiple spalling is generated.

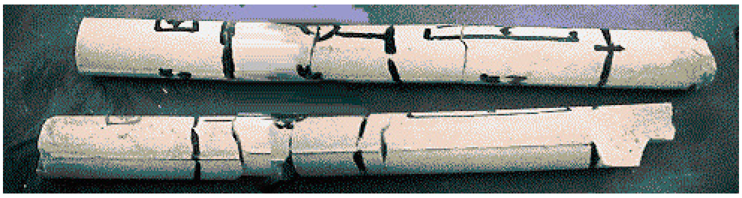

Figure 3. Spalling and fragmentation of a bar

(4) Wave speed

A shock wave travels through most media at a higher speed than an ordinary wave.

Sound speed in a bar $C_{bar} = \sqrt{\dfrac{E}{\rho}}$, E is the Young's modulus, ρ is the density.

Sound speed in water $C_{water} = \sqrt{\dfrac{K}{\rho}}$, K is the bulk modulus, ρ is the density.

Gas released: bubble dynamics

As in Figure 4, upon arrival of the shock wave, the pressure in the bubble rises instantaneously to the peak value and decreases at nearly exponential rate. Subsequent to the shock wave, other pressure pulses occur. These pulses arise from a much slower phenomenon, namely the pulsating of the gas bubble, which contains the gaseous products of the explosion.

If the explosion is deep enough, these bubbles will grow in size. The internal pressure drops rapidly, to a maximum diameter determined by the explosion energy and the burst depth, and then collapse to a minimum size, re-expand, and continue to oscillate with decreasing amplitude and period.

Maximum bubble radius $$R_{\max} = J\left(\frac{E}{P}\right)^{1/3}$$

Oscillation period $$T = K\frac{E^{1/3}}{P^{5/6}}\sqrt{\rho}$$

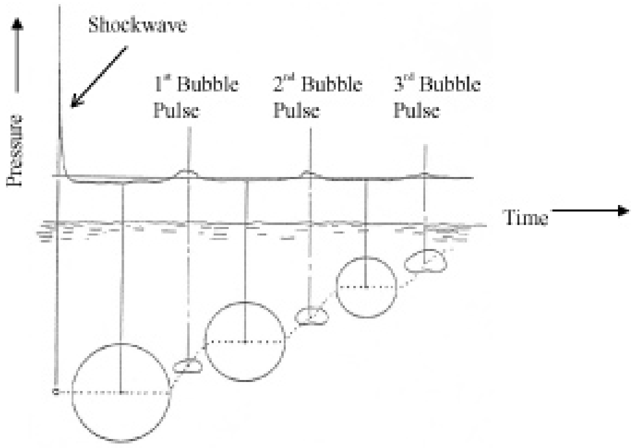

Figure 4. Pressure waves and bubble phenomena.

Applications

(1) Penetration and spalling

During the development of steel armour plating, it was found that an impact on the outer surface which was not powerful enough to cause penetration, nevertheless, could cause the formation of spalls at the inner surface.

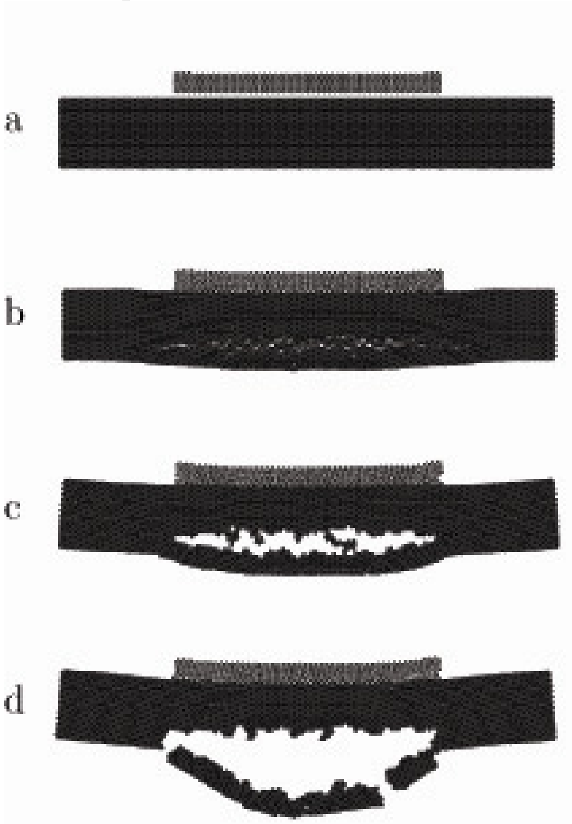

Figure 5. A simulation result shows the sequences of spalling.

(2) Explosive demolition
Shock wave can generate fragmentation. This is used in the demolition stage of the nuclear decommissioning engineering. The most efficient way is to use explosives.

(a) Explosive charges are placed under the towers.

(b) Controlled collapse of each tower.
Figure 6. Explosive demolition for nuclear decommissioning.

(3) Underwater damages

An explosion close to a ship generates a shock wave that can impart sudden vertical motions to a ship's hull and internal systems.

The explosion also generates a gas bubble that undergoes expansion and contraction cycles. These cycles can introduce violent vibrations into a hull, generating structural damage, even to the point of breaking the ship's keel. Many of the internal mechanical systems (e.g. engine coupling to prop) require precise alignment in order to operate. These vibrations upset these critical alignments and render these systems inoperative. The vibrations can also destroy lighting and electrical components, such as relays.

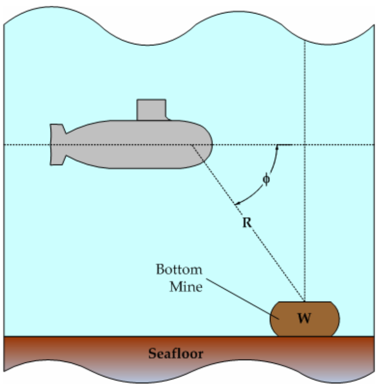

Figure 7. Underwater explosion scenario.

(4) Explosive welding

When an explosive is detonated on the surface of the flyer plate, a high pressure pulse is generated. This pulse propels the flyer plate at a very high rate of speed. If this piece of metal plate collides at an angle with the parent metal plate, welding may occur.

For welding to occur, a jetting action is required at the collision interface. This jet is the product of the collision of two metals surfaces. This jet cleans the metals and allows two pure metallic surfaces to join under extremely high pressure.

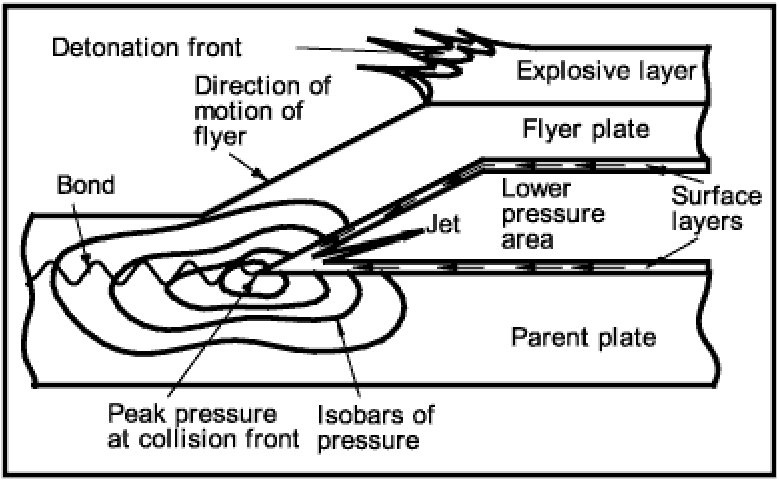

Figure 8, Jetting at the collision front.