Seismic Sources

- Seismic sources
  - Requirements;
  - Principles;
  - Onshore, offshore.
- Reading:
  - Telford et al., Section 4.5
  - Sheriff and Geldart, Chapter 7

Seismic Source

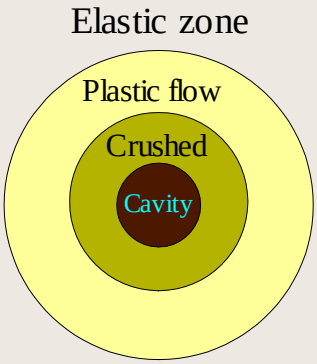
- Localized region within which a sudden increase in elastic energy leads to rapid stressing of the surrounding medium.
- Most seismic sources preferentially generate *P*-waves
  - Easier to generate (pressure pulse);
  - Easier to record and process (earlier, more impulsive arrivals).
- Requirements
  - Broadest possible frequency spectrum;
  - Sufficient energy;
  - Repeatability;
  - Safety - environmental and personnel;
  - Minimal cost;
  - Minimal coherent (source-induced) noise.

Land Source

- Explosives – chemical base
  - Steep pressure pulse.
  - Shotguns, rifles, blasting caps;
  - …bombs, nuclear blasts…
- Surface (mechanical)
  - Weight drop, hammer;
  - Piezoelectric borehole sources (ultrasound);
- Continuous signal
  - Vibroseis (continuously varying frequency, 10-300 Hz)
  - Mini-Sosie (multiple impact);
    - Combination with Vibroseis (Swept Impact Seismic Technique, SIST)
  - Drill bit ('Seismic While Drilling');
  - sparkers, ...truck spark plugs.

Mechanism of generation of seismic waves by explosion

- **Stage 1**: Detonation.
  - Start of explosion - electric pulse ignites the *blasting cap* placed inside the charge. The pulse is also transmitted to recorder to set $t = 0$;
  - Disturbance propagates at ~ 6-7 km/s (supersonic velocity); surrounding medium is unaffected;
  - The explosive becomes hot gas of the same density as the solid - hence its pressure is very high (several GPa)
- **Stage 2**: Pressure pulse spreads out spherically as an *inelastic shock wave*
  - Stresses >> material strength;
  - Extensive cracking in the vicinity of the charge.
- **Stage 3**: At some distance, the stress equals the elastic limit
  - Pressure pulse keeps spreading out spherically as an *elastic wave*.



Important parameters of an explosion

- Radius of the Explosion Cavity:

$$R[\,ft] = BW^{\frac{1}{3}}$$

Weight in lbs

Rock type	*Granite*	*Chalk*	*Limestone*	*Soft Sandstone*	*Clay*
B	0.46	0.6	0.3-1.0	1.3	1.3

- Pulse width: $T[ms] = 2.8 \cdot W^{\frac{1}{3}}$
  - Frequency *decreases* for larger charges.
- Energy:
  - Only 4 % (soft sandstone), 9% (clay) to 10-20 % (granite) of chemical energy is radiated as seismic waves;
  - Absorption and scattering cause energy loss:
    - At 3 m from the source, there remains 2.5 % of available energy;
    - At 30 m - 0.5 %.
- Effects of shot depth:
  - If water table is shallow - place shots below it;
  - Seismic amplitude increases as the shot depth decreases
    - However, ground roll becomes broadband and hard to attenuate.

Criteria for selection of explosives

- **Density**
  - Higher density means the explosive column length is shortened, resulting in an energy pulse of higher frequency. Higher frequency means better data quality. Typical values are 1.2-1.8 g/cc.
- **Velocity**
  - Higher velocity means a higher frequency energy pulse will be generated because the explosive column detonates more quickly. Typical values are 6-8 km/sec.
  - Ground velocities < 5 cm/s are considered safe for structures;
- **Detonation pressure**
  - Detonation pressure is an indication of energy released by the detonation. High detonation pressure is beneficial in seismic blasting. Typical range - 2-4 GPa (70-250 kBar).
- **Self-disarming**
  - Unexploded charges left in the ground could be hazardous to future drilling or excavation. Seismic explosives that self-disarm are the best choice.

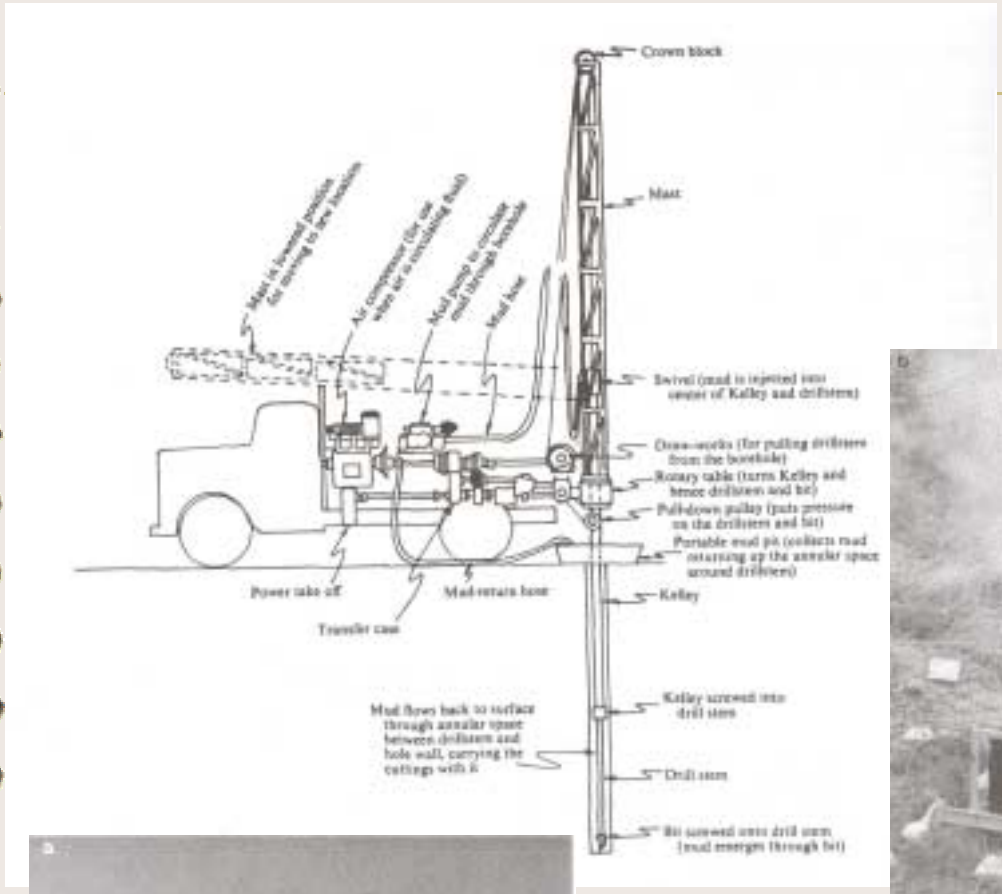
Standard for minimum distances

- International Association of Geophysical Contractors:
  - Pipelines - 60 m;
  - Telephone lines - 12 m;
  - Railroad tracks - 30 m;
  - Electric lines - 24 m;
  - Oil wells - 60 m;
  - Water wells, cisterns, masonry buildings - 90 m.
- Ground velocity of 5 cm/s is concidered 'safe' for structures
  - For seismic explosives, achieved at distances $x = 23m^{1/3}$ m, where m is the charge in kg.

Explosives

- Gelatin dynamite, ammonium nitrate, pentolite (SEIS-X).
- Packaged in tins, cardboard or plastic tubes ~5 cm in diameter (0.5-5 kg each).
- Connected to make desired charges.

Charge emplacement



Surface Energy Sources
(less powerful, easier access)

- Thumper/weight dropper

Bison Accelerated Weight Dropper

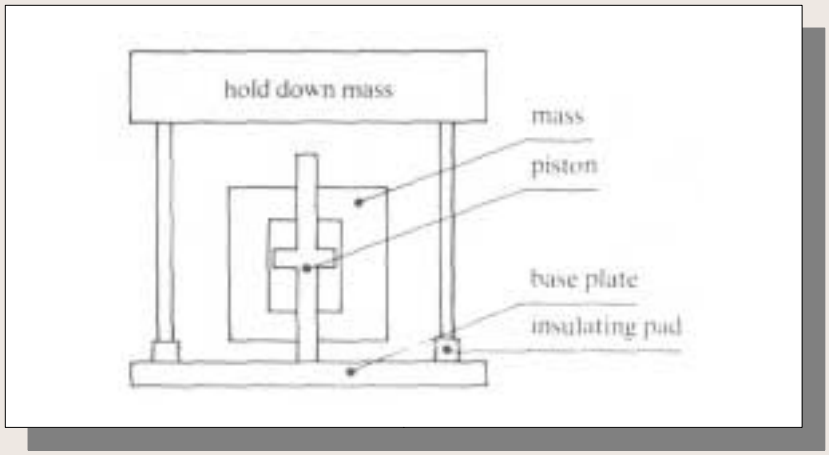
DIGPULSE 1180

- Dynoseis
  - Mixture of O_2 and propane exploded in an expandable chamber with a metal plate as the bottom
    - Mounted on a truck or used as a buried explosive charge
    - Self-disarming (the metal plate rusts through and the gas dissolves)

Vibroseis

Used in > ½ of land seismic exploration

- Vibroseis
  - Energy introduced into the Earth in the form of a *sweep* of varying frequency for several seconds
    - Typical sweep time - 7-35 s;
      - ~45 minutes in recent mantle investigations
    - Typical frequencies - 12 -> 60 Hz (upsweep) or 60 -> 12 Hz (downsweep);
    - Low energy density - environmentally friendly;
    - Time-Distributed signal - lower noise requirements.
  - A control signal causes a vibrator to exert variable pressure on a steel plate pressed against the Earth.
    - Radio-controlled hydraulics allows *syn-phase* vibration of a *group* of vibrators;
    - Shear-wave vibrators also shake the ground in horizontal directions

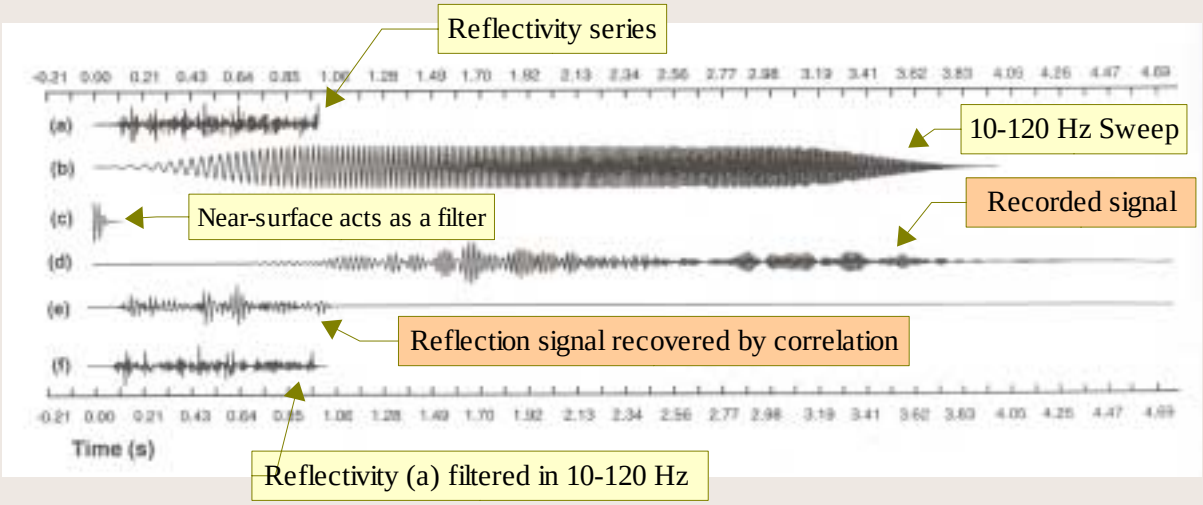


Vibroseis

Mini-Vibroseis

Vibroseis Correlation

- Recorded signal is *cross-correlated* with the *sweep* sent into the ground
  - As a result, matching waveform patterns (caused by reflections) are identified;
  - The signal is compressed in time - the energy of the entire sweep is condensed into a single pulse.



Other Land Sources

(for shallow or mine investigations)

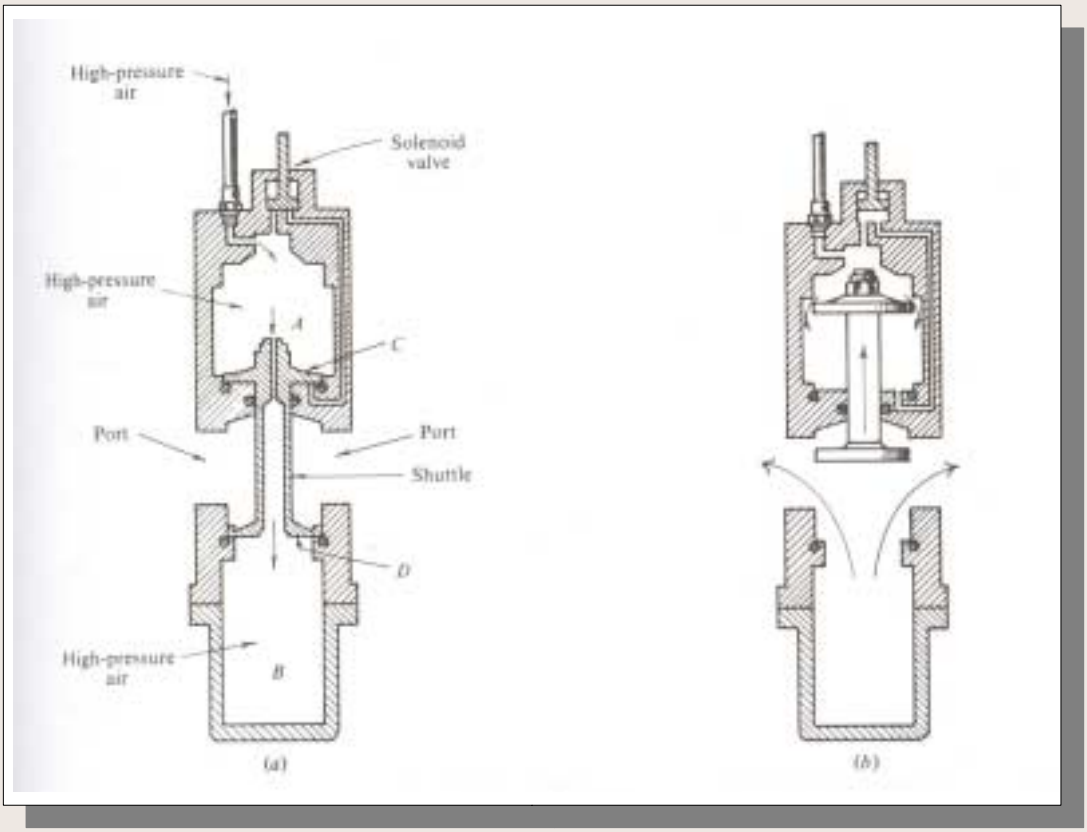
- Sosie, Mini-Sosie, SIST
  - Impactor hits ground 5-15 times per second, in ~3-min long, *pseudo-random* series.

- Sparkers

Air Gun

Primary marine source

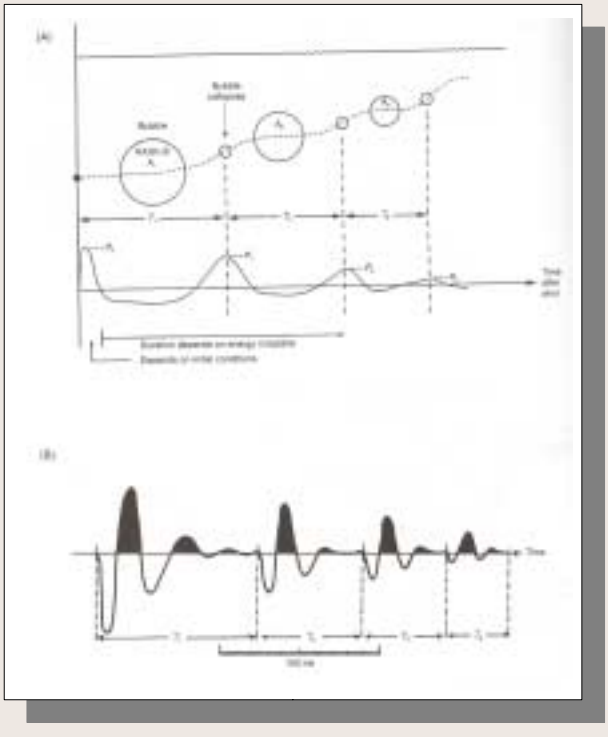
- High pressure bubble of air is released into the water
  - Operating pressure 10-15 MPa, in 1-4 ms;
  - Size (volume of the lower chamber) 10-2000 in^3 (0.16-33 liters)
  - Primary pulse is followed by a *surface ghost* and a train of *bubble pulses*



Air Gun

Bubble oscillations

- Over-pressured bubble expands expelling water radially
  - ... and becomes.. under-pressured;
- Under-pressured bubble collapses under water pressure
  - ... and becomes over-pressured again.
- This cycle is repeated until the energy dissipates and/or bubble vents into through the surface.

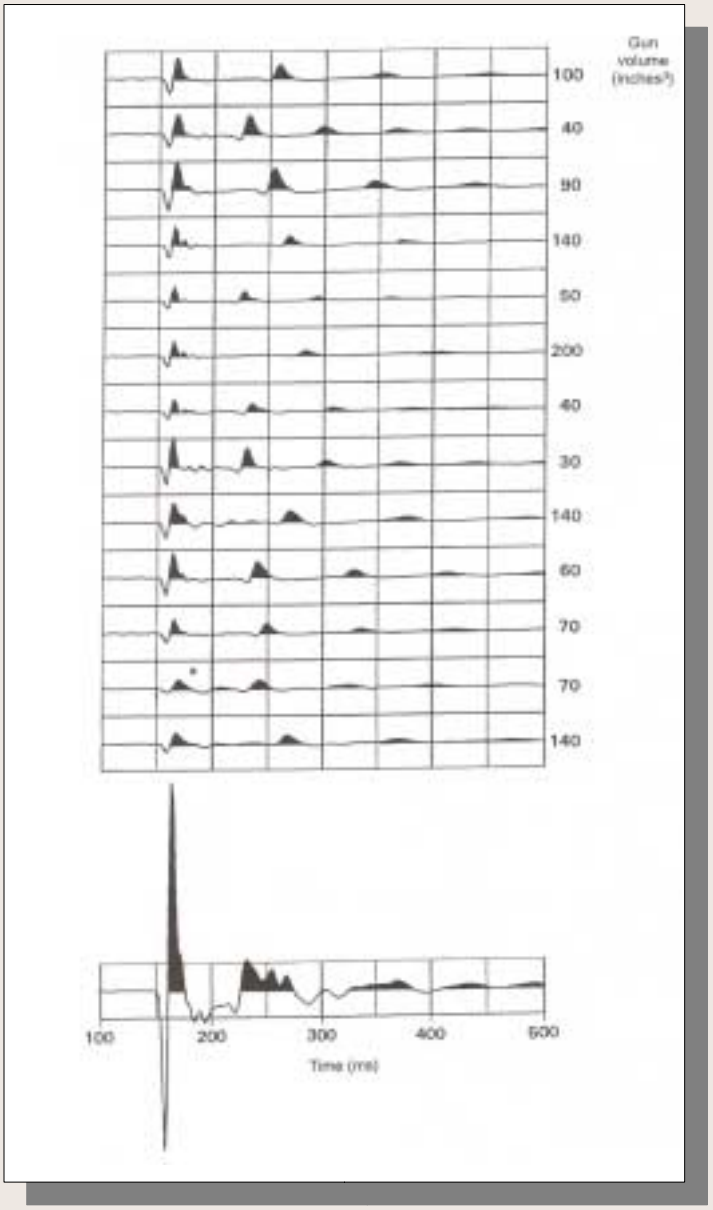


Suppression of bubble pulses

Bubble pulses can be suppressed in two ways:

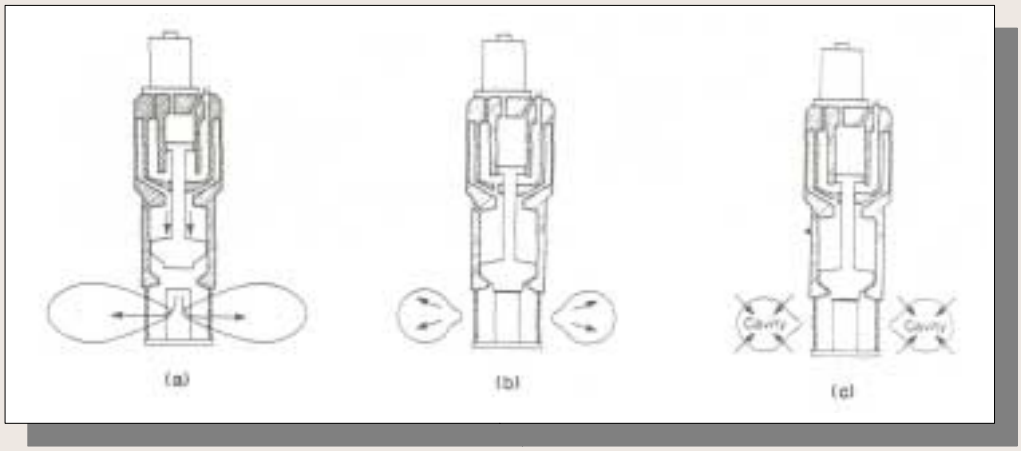
- Use array of air guns with different dimensions;
- Shallow firing (~2 m) - bubble vents to the surface.

During digital processing, the wavelet is further compressed by using *deconvolution*.



Other Marine Sources

- Water gun
  - Compressed air drives a piston that ejects a jet into the surrounding water;
  - Vacuum cavity created behind the jet causes an implosion generating a strong pulse.
  - No bubble pulse.



- Piezoelectric transducers
  - e.g., barium titanate - change their volume when subjected to electric field;
  - Up to 2-10 kHz frequency for shallow water work.

Q-Marine

- More then double improvement in resolution by:
  - Calibrated sources;
  - Single-sensor recording;
  - Steerable streamers;
  - An order of magnitude increase in sensor density;
  - Enhanced positioning systems.
  - Accurate processing.