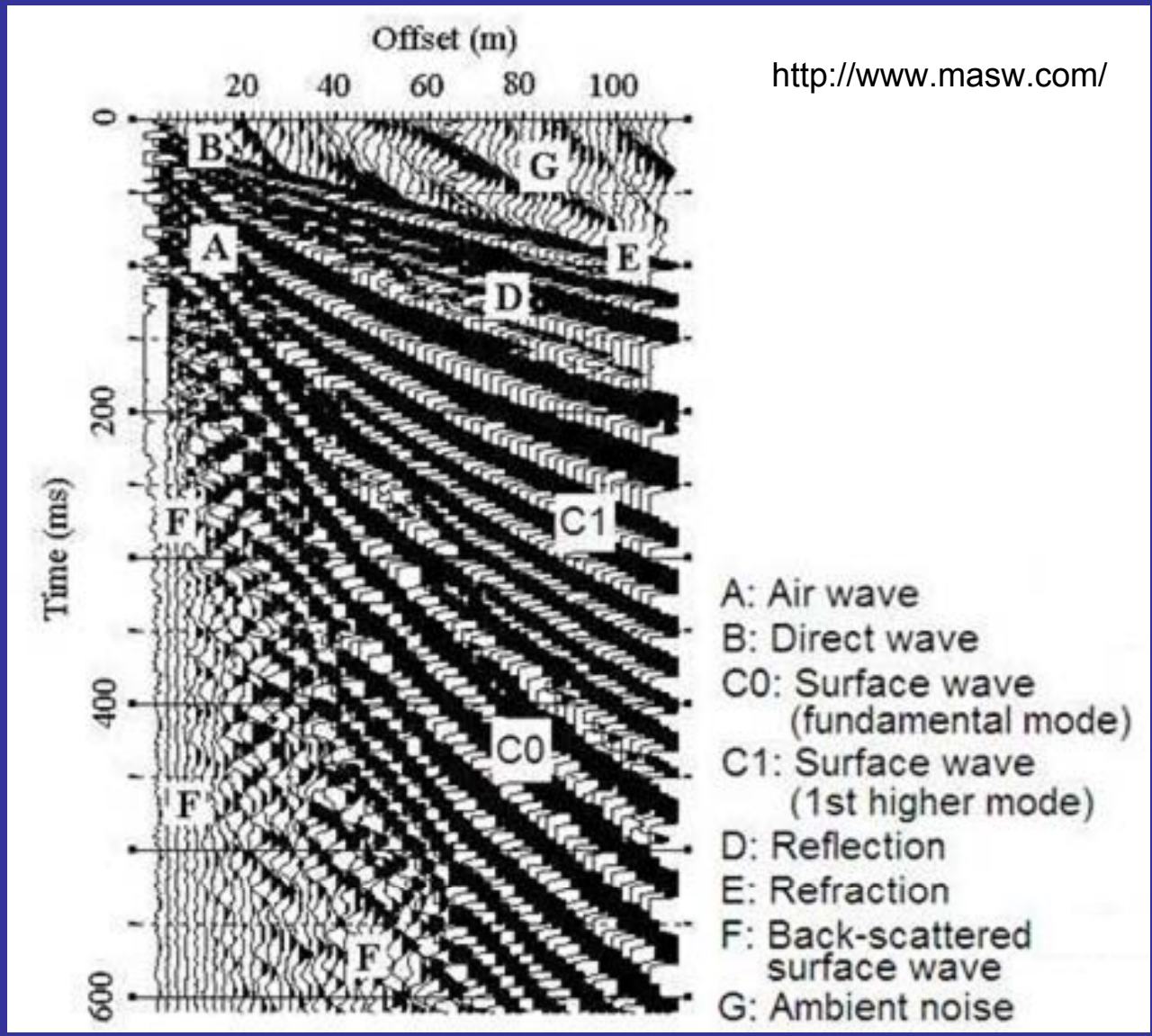
Active surface waves analysis

December 6-12th 2008, Thessaloniki, Greece



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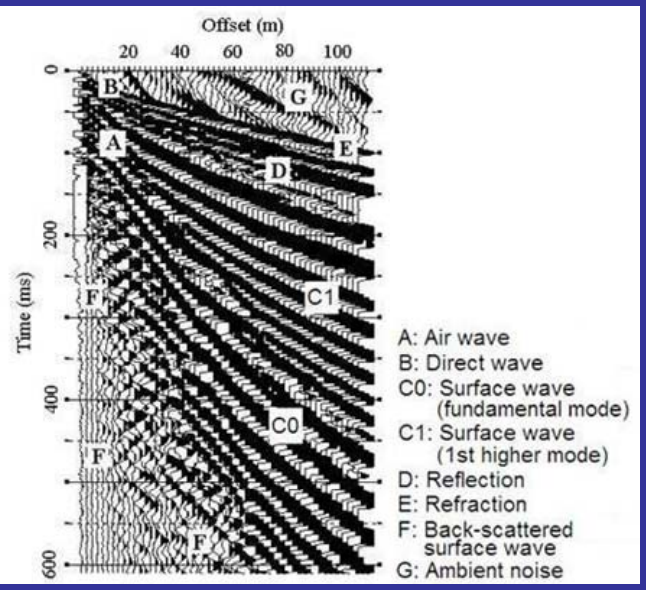
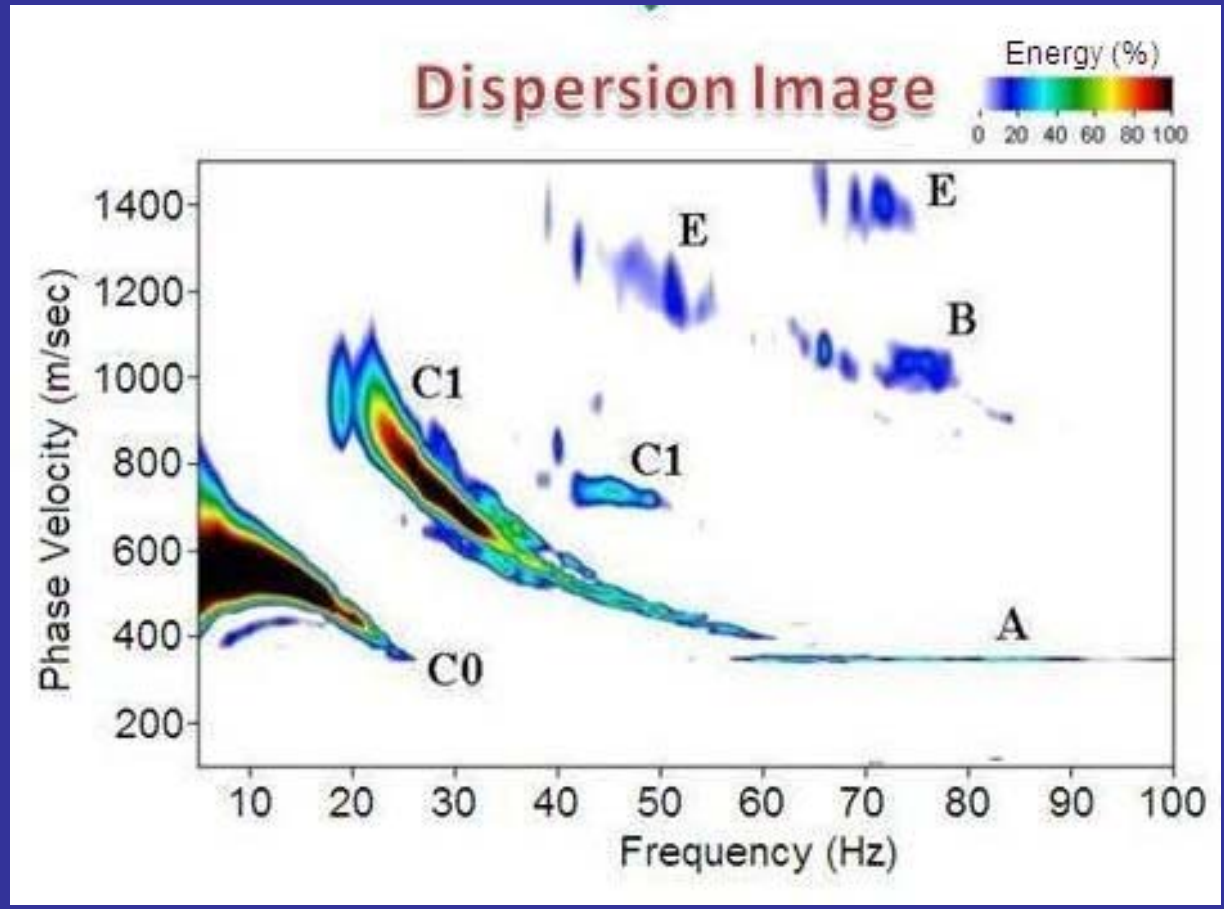
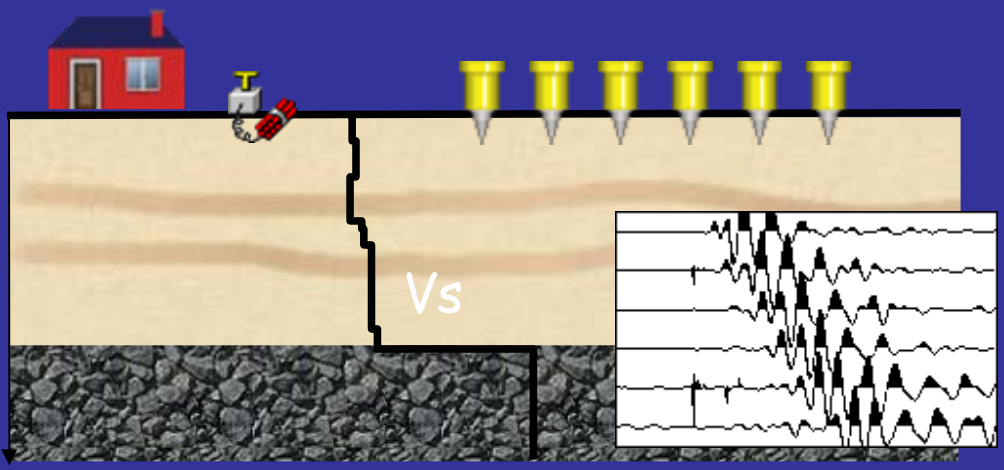
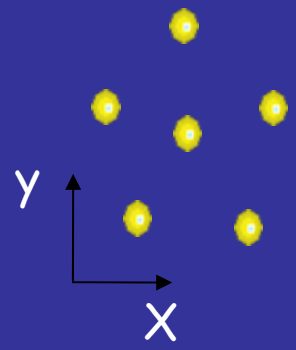
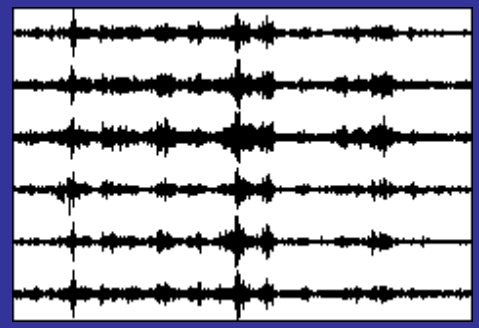
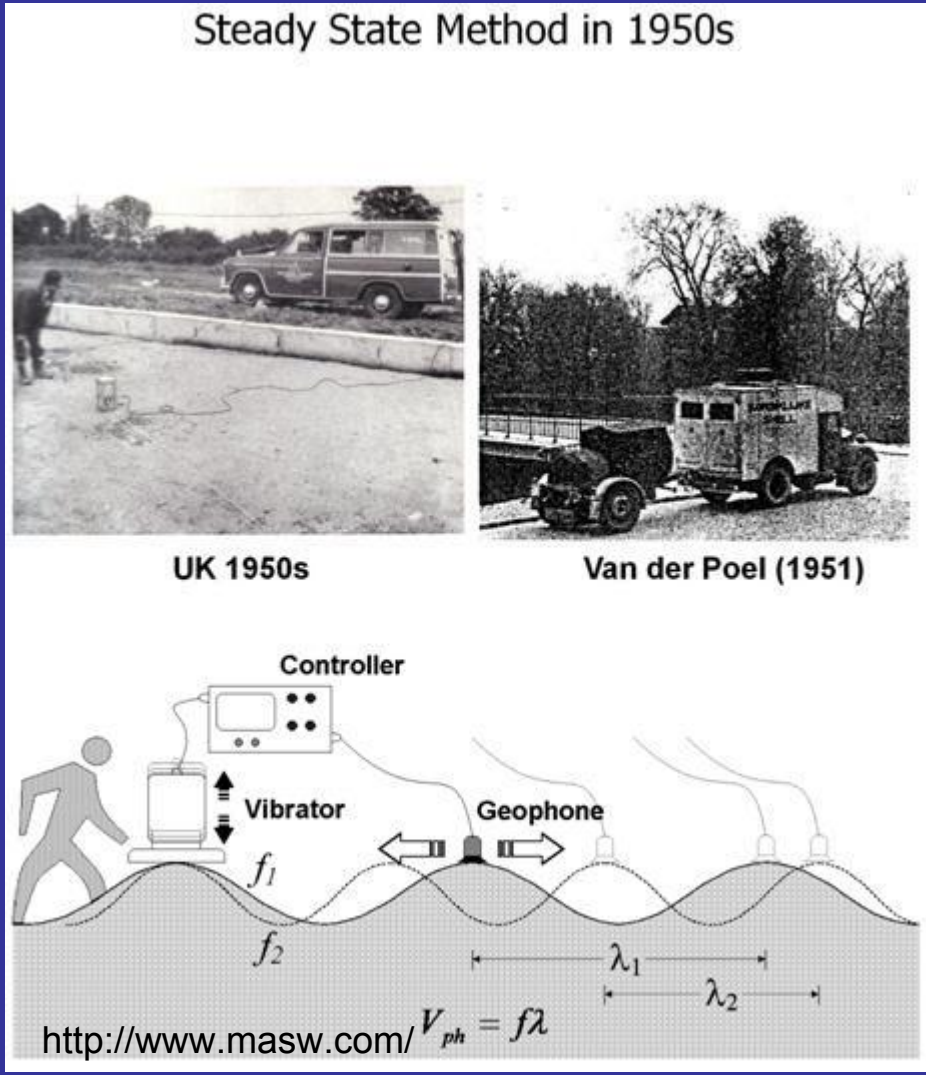

Offset (m)
20
40
60
80
100
Time (ms)
0
200
400
600
B
G
A
E
D
C1
F
C0
F
F
A: Air wave
B: Direct wave
C0: Surface wave (fundamental mode)
C1: Surface wave (1st higher mode)
D: Reflection
E: Refraction
F: Back-scattered surface wave
G: Ambient noise


Dispersion Image
Energy (%)
0 20 40 60 80 100
Phase Velocity (m/sec)
1400
1200
1000
800
600
400
200
E
E
B
C1
C1
A
C0
10
20
30
40
50
60
70
80
90
100
Frequency (Hz)

	Artificial source	Ambient noise
	 Depth	 
Frequency range	High frequency	Low frequency
Penetration depth	Few tens of metres	Few hundreds of metres
Propagation	Only one direction	Multiple arrivals
Source localization	Yes	Unlocalized
Source function	Monitored	Unknown

Pioneer work



Vibrator exciting a single frequency f_i

Scan of the ground surface with a sensor

Evaluation of the distance x_i between 2 consecutive amplitude maxima

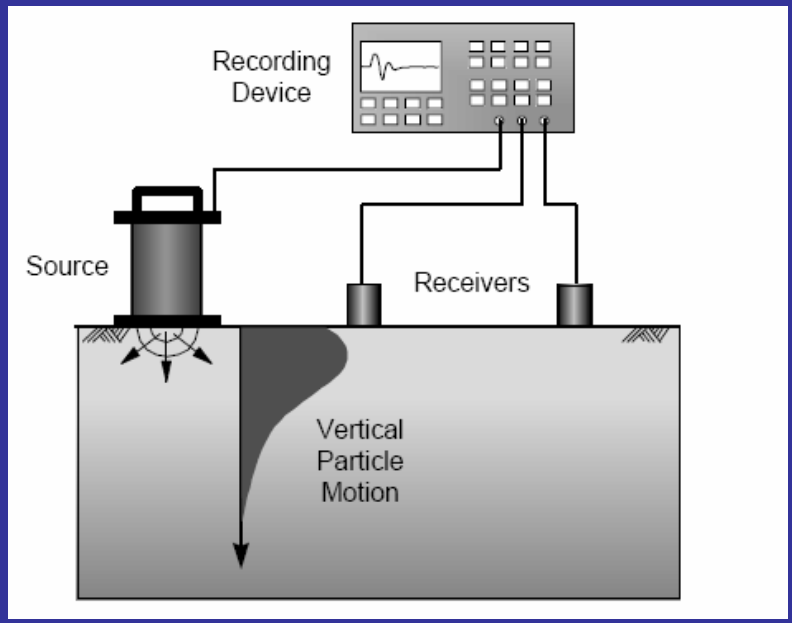
Estimation of phase velocity
$c = x_i * f_i$

Repeat measurement for different frequencies to construct a dispersion curve.

<u>Implicit assumption:</u>
<u>one single surface wave mode</u>

SASW (Spectral Analysis of Surface Waves)

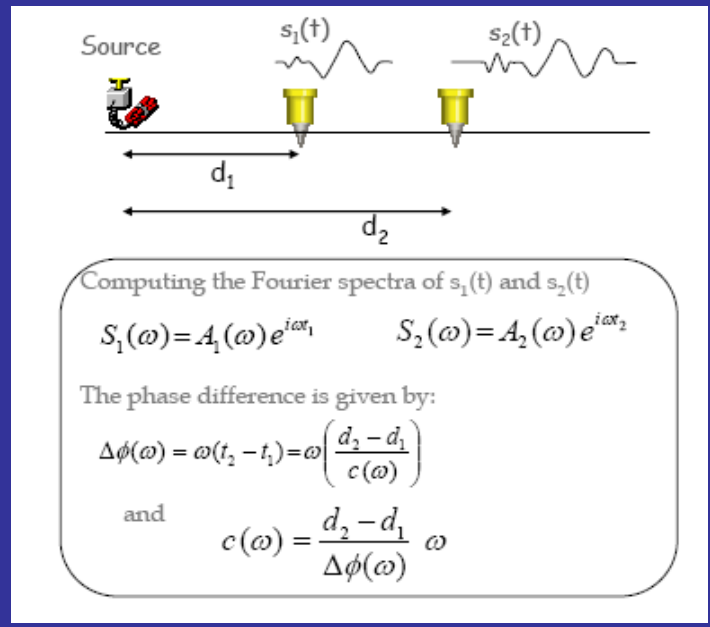
Introduced by Heisey et al., 1982; Nazarian et al., 1983



Rix, 1997

Nazarian and Stokoe 1984, 1986; Stokoe and Nazarian 1985; Stokoe *et al.* 1988, 1994; Roesset *et al*. 1991; Gucunski and Woods 1991; Tokimatsu *et al*. 1992; Rix et al., 1991

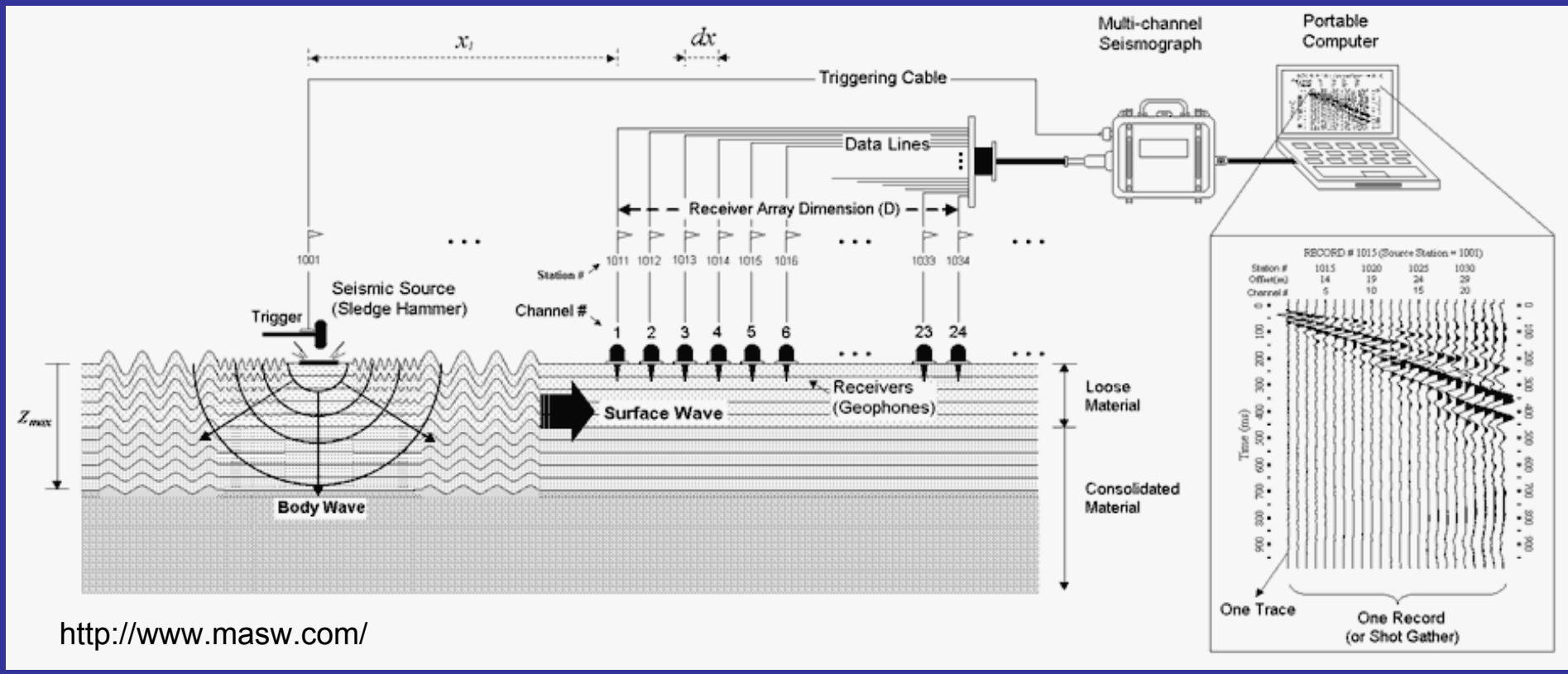
Pair of receivers
Multi-frequency source (sledge-hammer, vibroseis, etc)
Inter-sensor distances is varying in order to sample different wavelengths



Implicit assumption: one single surface wave mode

Multichannel analysis of surface waves (MASW)

First studies: Al-Husseini et al., 1981; Mari, 1984; Gabriels et al., 1987
Park et al. (1999) widespread MASW technique



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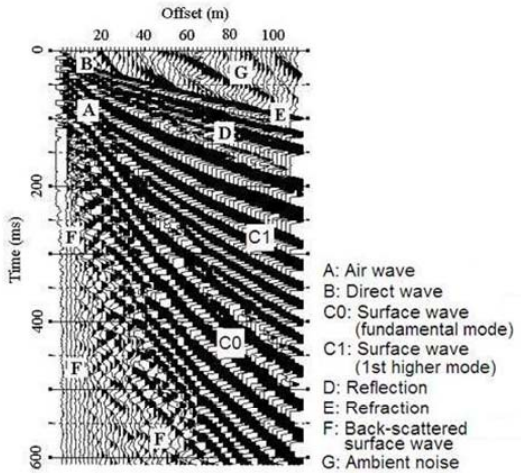
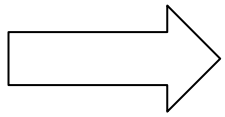
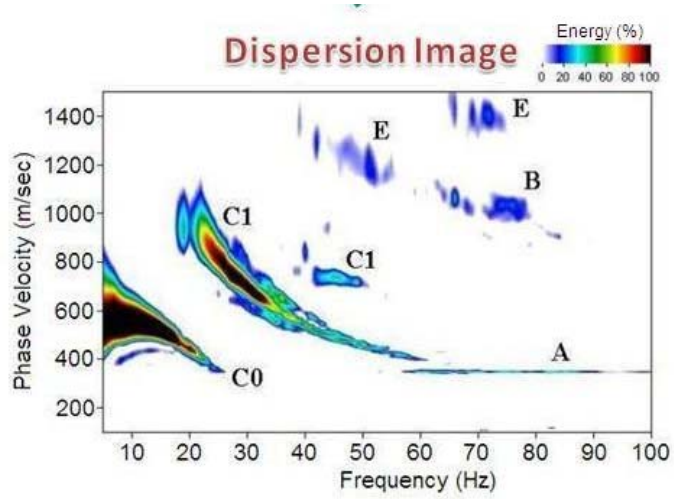
Multichannel analysis of surface waves (MASW)

Different processing technique: slant-stack, F-K,
Allows extraction of different modes







F-k method or Slant stack method

Signals (t, x) → *transform method* → E(c,f) or E(c,T)

$c(f) = \max(E(c,f))$

MASW : main limitations

Source energy content and physical space available

Near field effects

Far field effects (attenuation of high frequencies at long distances ⇔ source energy content; body waves effects)

Spectral aliasing: space sampling (similar than for 2D arrays)

Source energy content

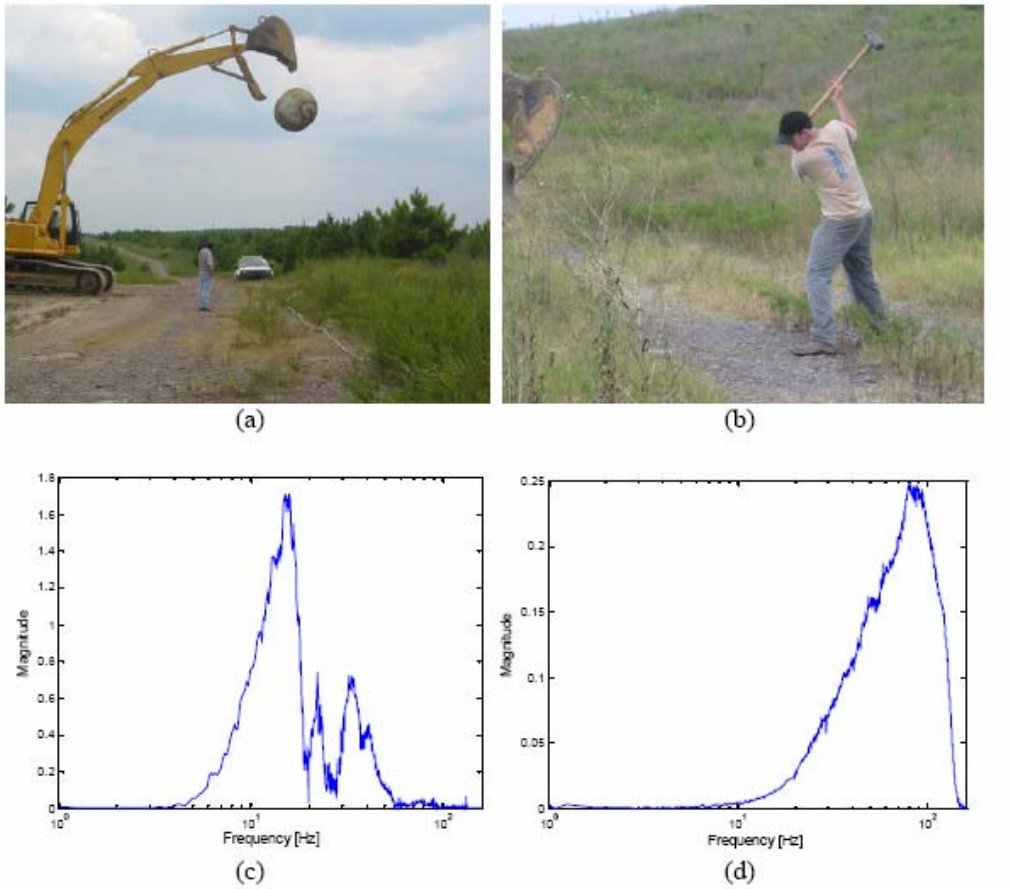


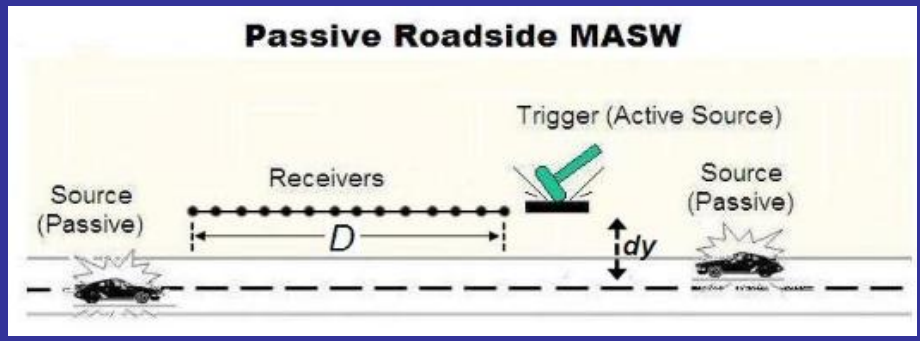
Figure 3.2 Examples of two different transient sources and their frequency contents: (a) dropped heavy weight, (b) sledge hammer, (c) frequency content for the dropped heavy weight, and (d) frequency content for the sledge hammer.

Sungsoo, 2005

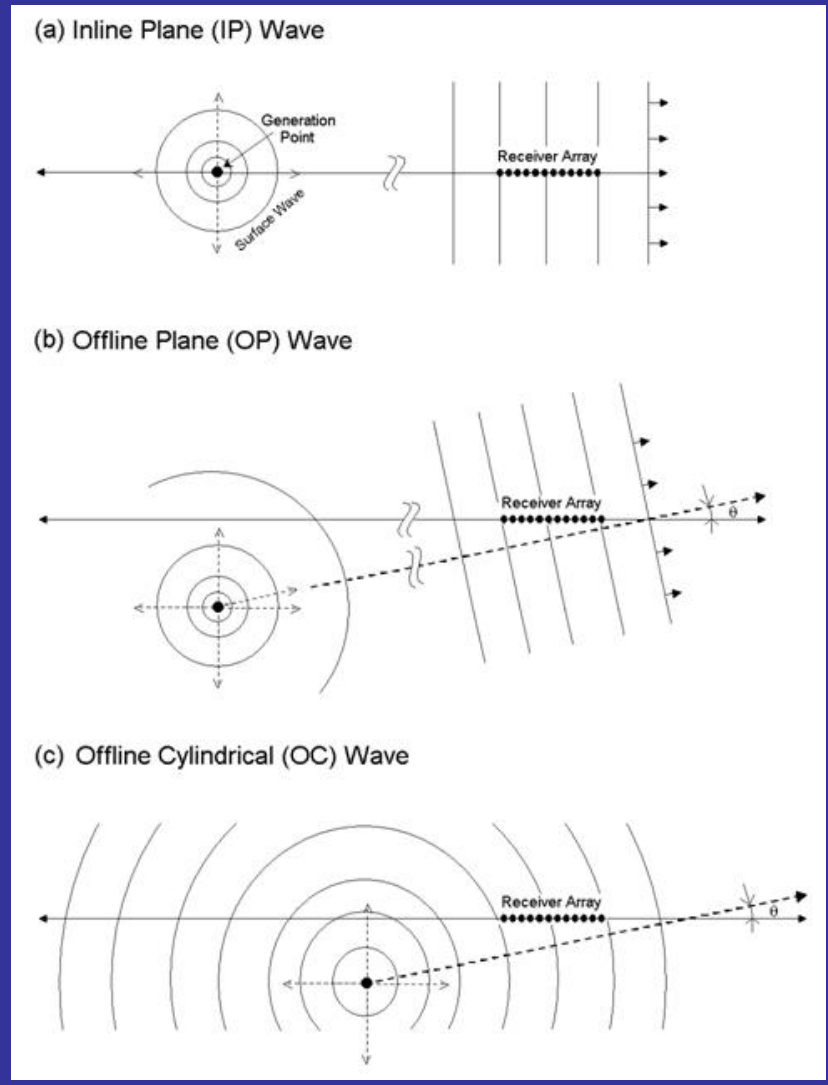
Depends on the source type (hammer shot, explosion, vibroseis, ...)

Depends on the site characteristics (velocity structure, attenuation)

Roadside MASW



Park and Miller, 2008

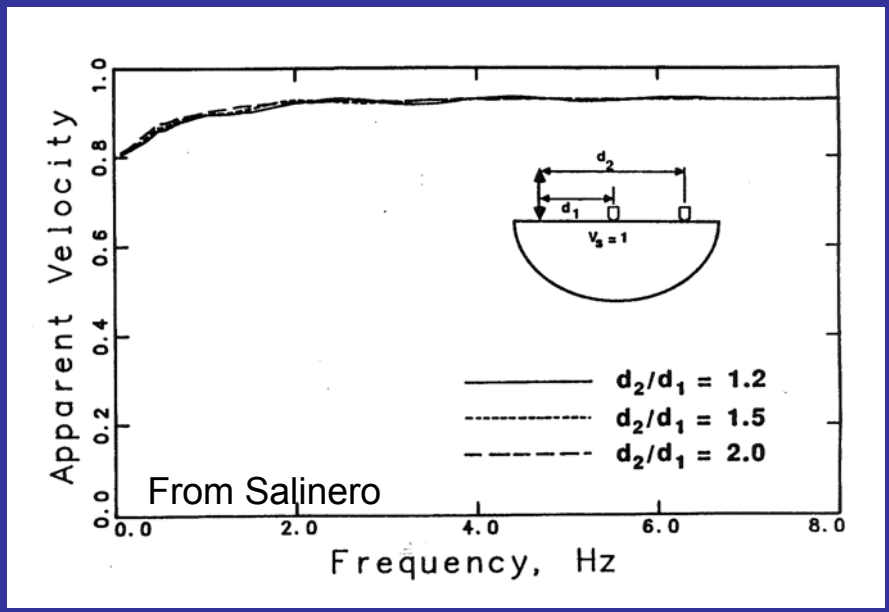


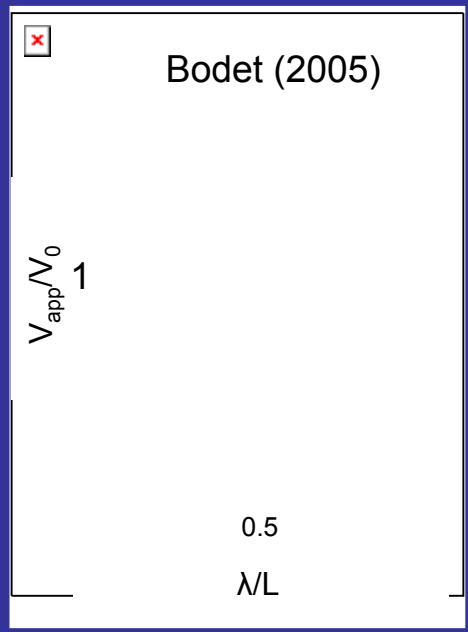
Near field effects

Cylindrical propagation near the source (Zywicki, 1999)

Distance from which surface waves can exist (Xu et al., 2006)

- Interference between direct S and P reflected in depth
- Interference between S reflected at surface and P converted wave





Near field effects

Park, 1999; Stockoe et al., 1994

In order to avoid near-field effects, source offset $\geq 0.5\lambda_{max}$

source offset $\geq z_{max}$

λ_{max} : Maximum desired wavelength z_{max} : Maximum "achievable" depth

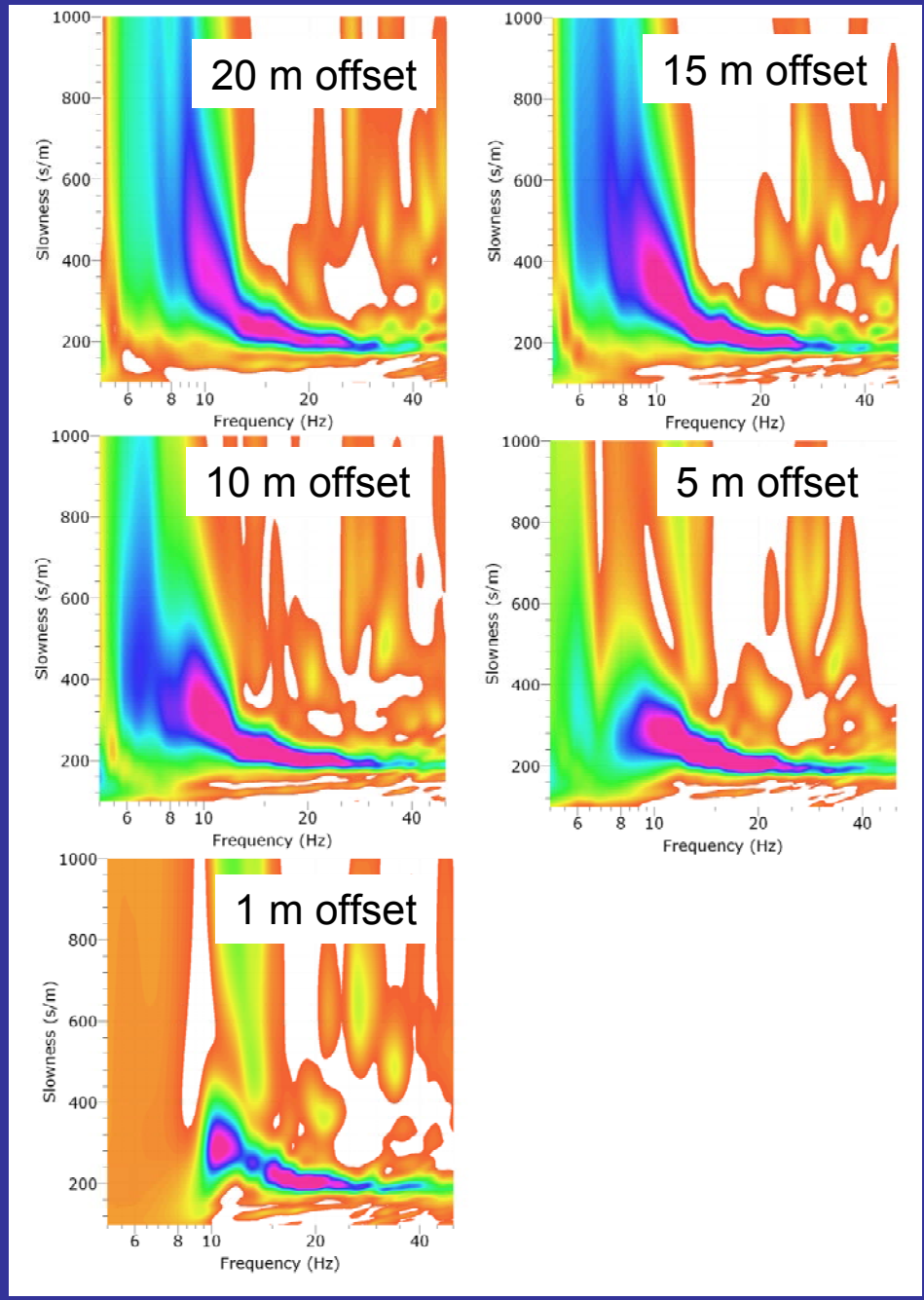
Depth (Z_{max})[1] (m)	Source (S)[2] (lb)	Receiver (R)[3] (Hz)	Receiver Spread (RS) (m)			
			Length[4] (D)	Source Offset[5] (X_1)	Receiver Spacing (dx)	
					24-ch*	48-ch
≤ 1.0	≤ 1	4.5–100	1–3	0.2–3.0	0.05–0.1	0.02–0.05
	(1)**	**(40)**	**(2.0)**	**(0.4)**	**(0.1)**	**(0.05)**
1–5	1–5	4.5–40	1–15	0.2–15	0.05–0.6	0.02–0.3
	(5)	**(10)**	**(10)**	**(2)**	**(0.5)**	**(0.25)**
5–10	5–10	≤ 10	5–30	1–30	0.2–1.2	0.1–0.6
	(10)	**(4.5)**	**(20)**	**(4)**	**(1.0)**	**(0.5)**
10–20	≥ 10	≤ 10	10–60	2–60	0.4–2.5	0.2–1.2

http://www.masw.com/

Near field effects

Socco and Strobbia, 2004

band. These two phenomena are strongly dependent on the site and the experimental conditions, and in general cannot be predicted to determine the best source-offset. Possible solutions are the acquisition with different source-offsets to recognize the near-field, or the use of a small offset and the filtering of the near-field during processing. On the other hand, some rule of thumb has


20 m offset
15 m offset
10 m offset
5 m offset
1 m offset
Slowness (s/m)
Frequency (Hz)
1000
800
600
400
200
6
8
10
20
40

From litterature, main use of MASW measurements

1) To complete the high frequency part of the dispersion curve obtained through ambient noise array technique

2) Mapping of Vs30