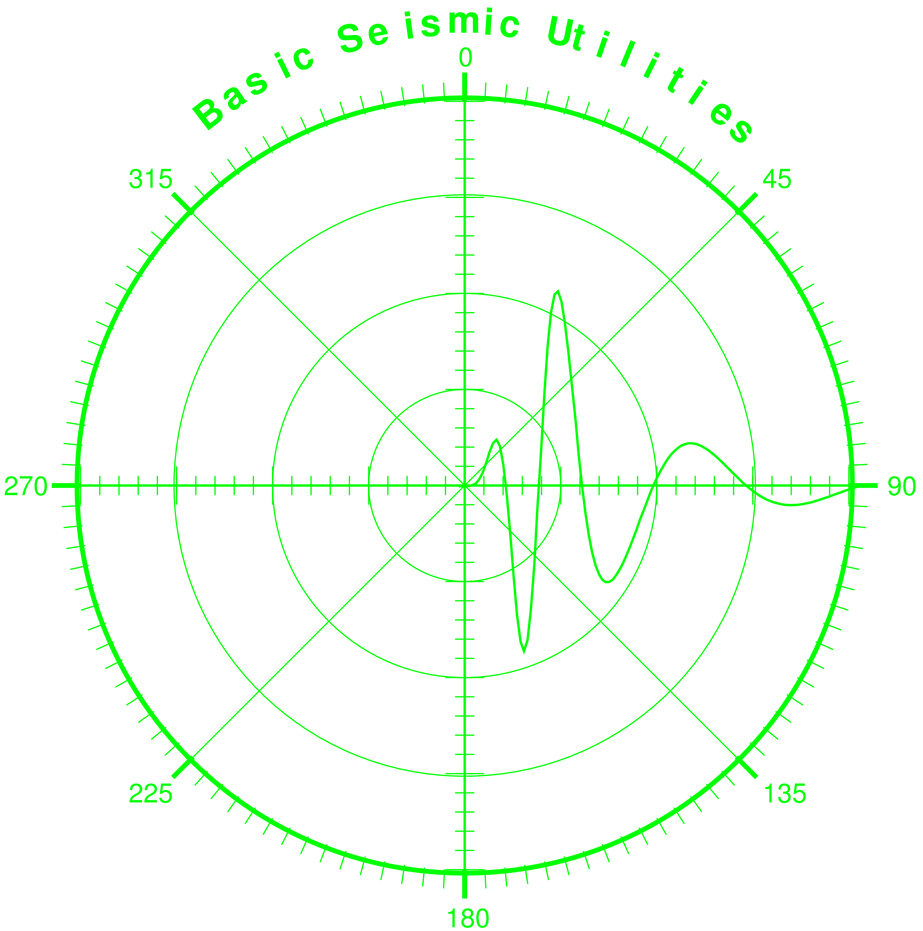
$4fmin$

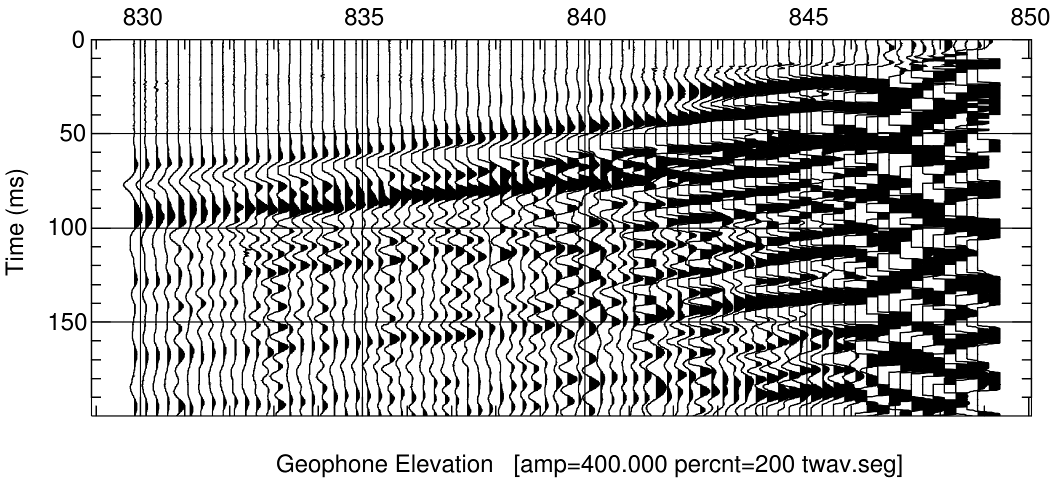
$fmax/2$

C_1

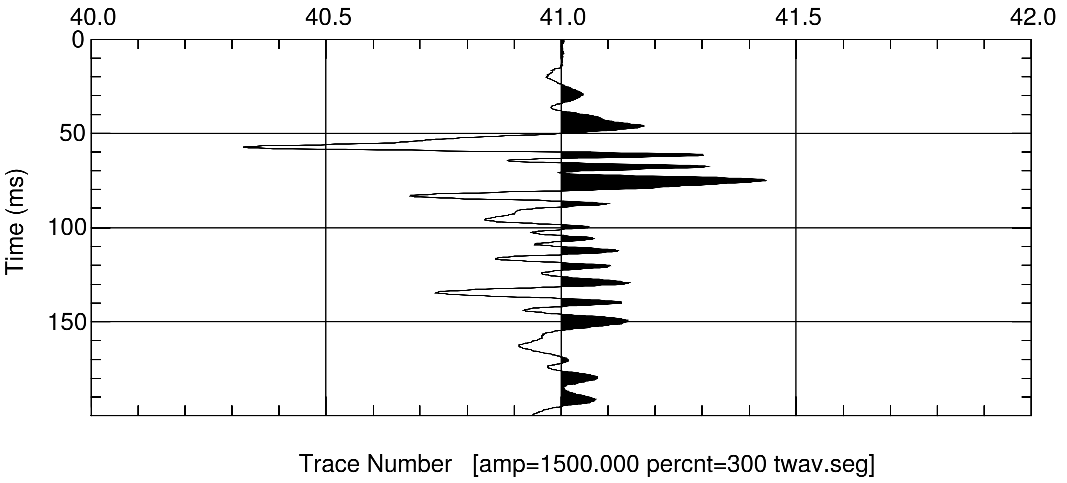
C_2

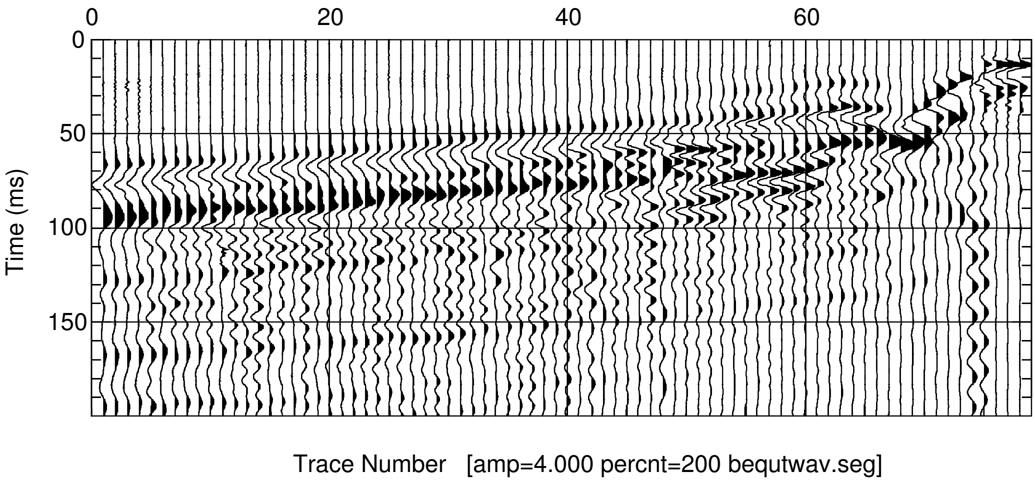


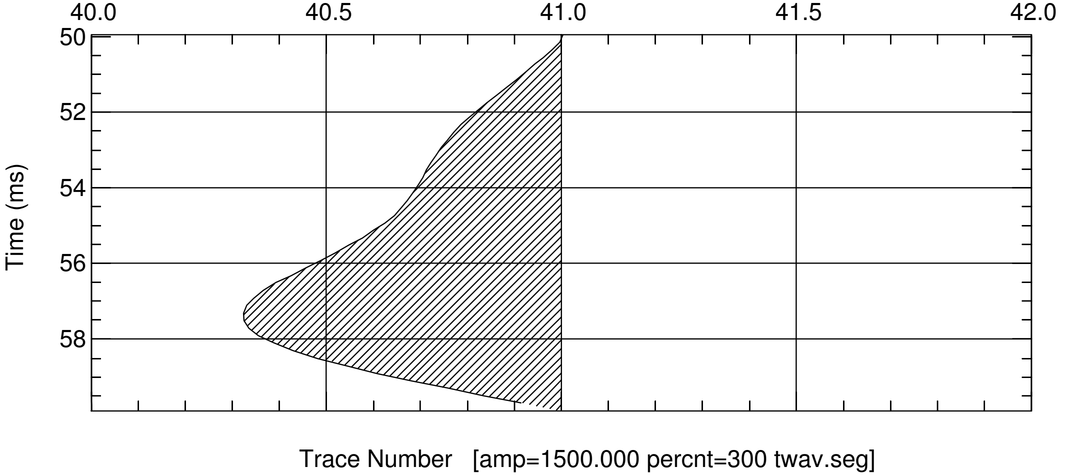
Basic Seismic Utilities
0
45
90
135
180
225
270
315



830
835
840
845
850
0
50
100
150
Time (ms)
Geophone Elevation [amp=400.000 percnt=200 twav.seg]


40.0
40.5
41.0
41.5
42.0
0
50
100
150
Time (ms)
Trace Number [amp=1500.000 percnt=300 twav.seg]

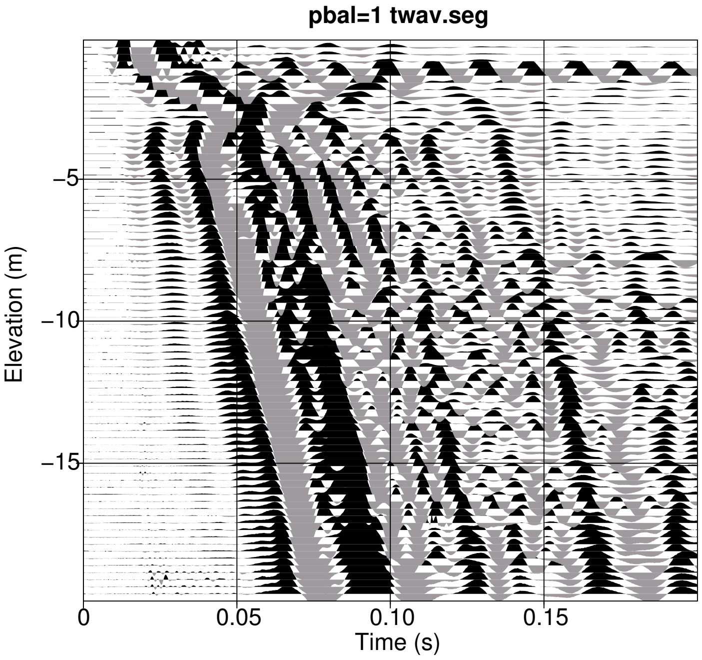

0
20
40
60
0
50
100
150
Time (ms)
Trace Number [amp=4.000 percnt=200 bequtwav.seg]


40.0
40.5
41.0
41.5
42.0
50
52
54
56
58
Time (ms)
Trace Number [amp=1500.000 percnt=300 twav.seg]

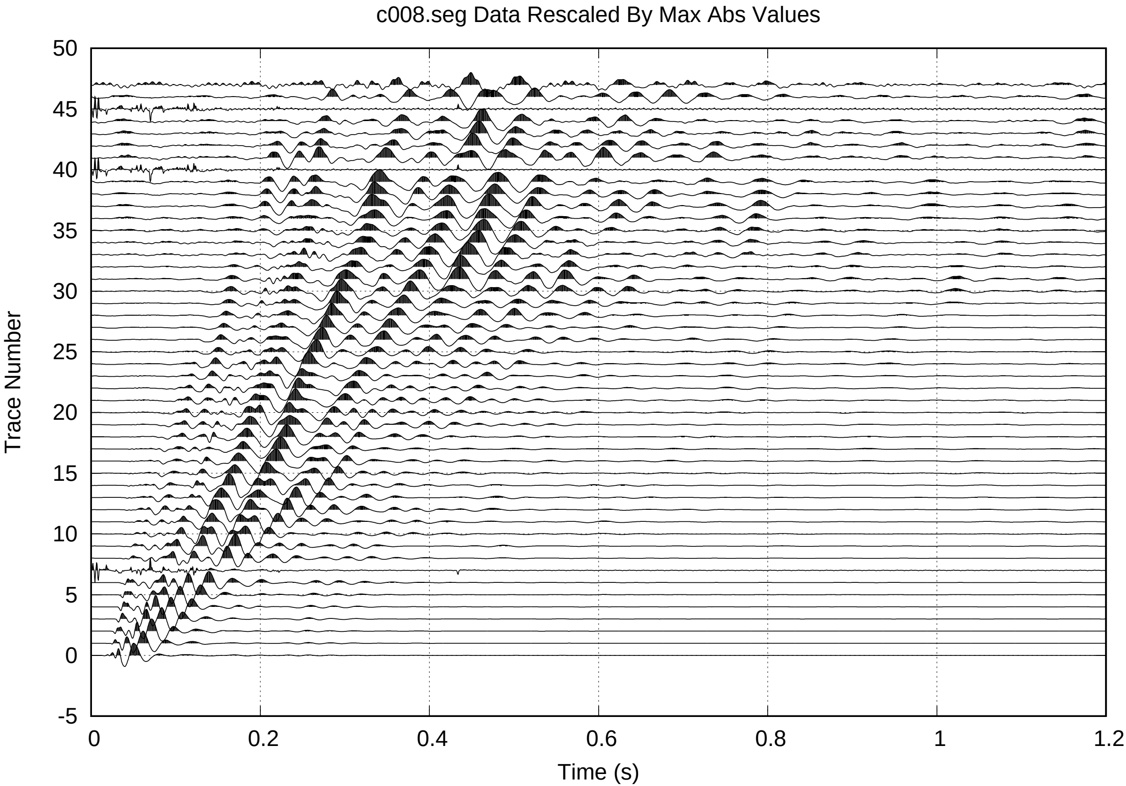
μ

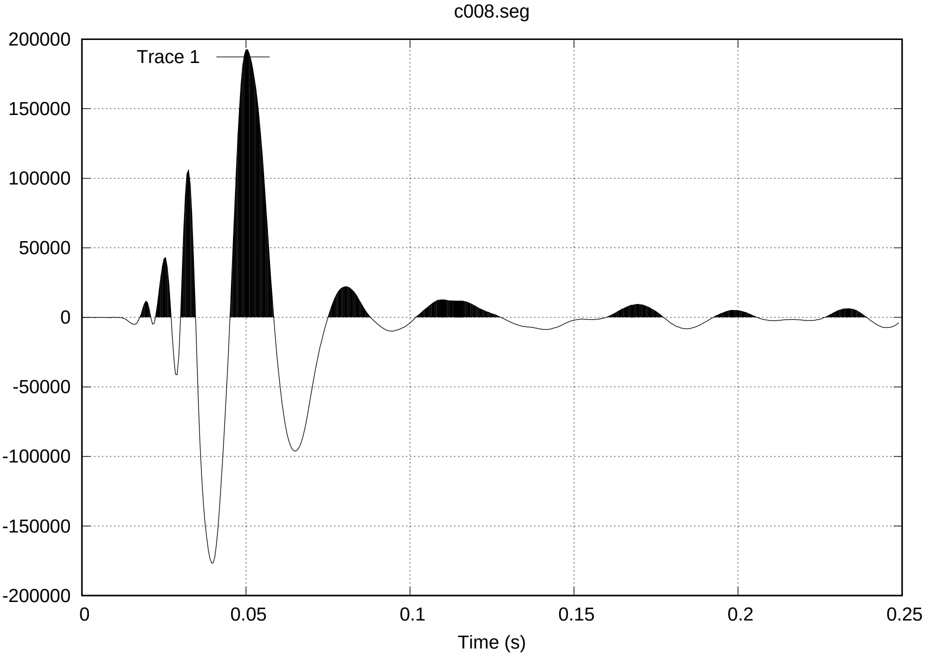
-19.6

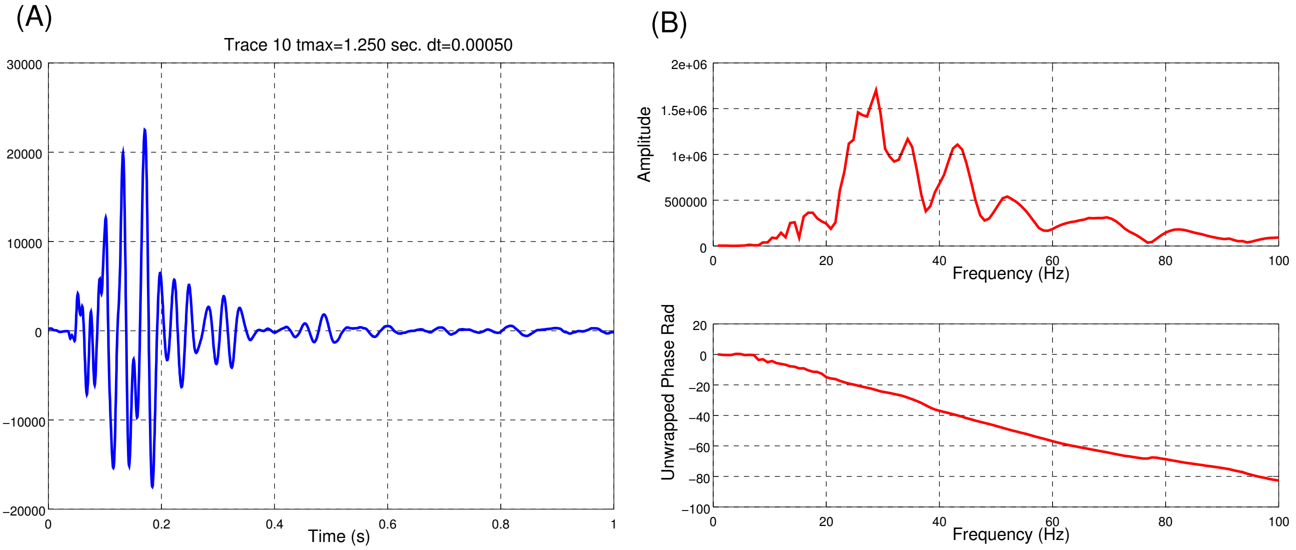
0.25



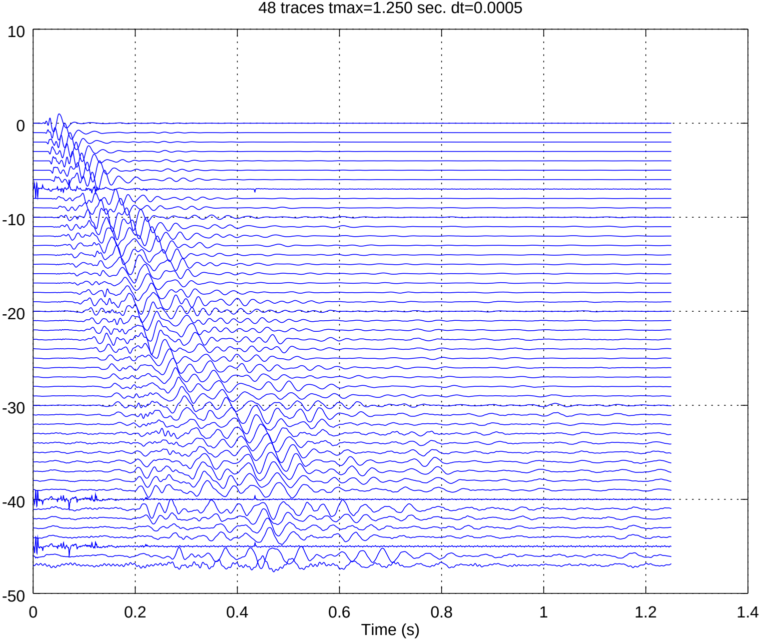
pbal=1 twav.seg
Elevation (m)
−5
−10
−15
0
0.05
0.10
0.15
Time (s)


c008.seg Data Rescaled By Max Abs Values
Trace Number
Time (s)
50
45
40
35
30
25
20
15
10
5
0
-5
0
0.2
0.4
0.6
0.8
1
1.2

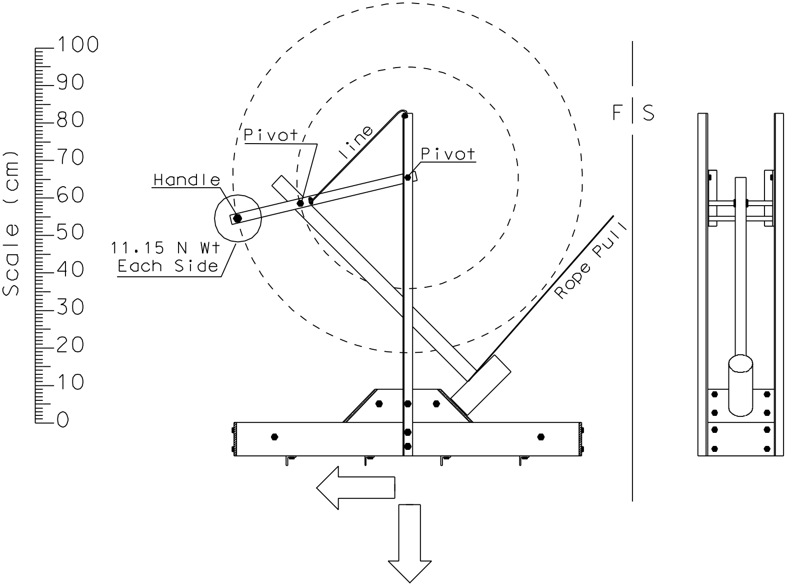

c008.seg
Trace 1
200000
150000
100000
50000
0
-50000
-100000
-150000
-200000
0
0.05
0.1
0.15
0.2
0.25
Time (s)

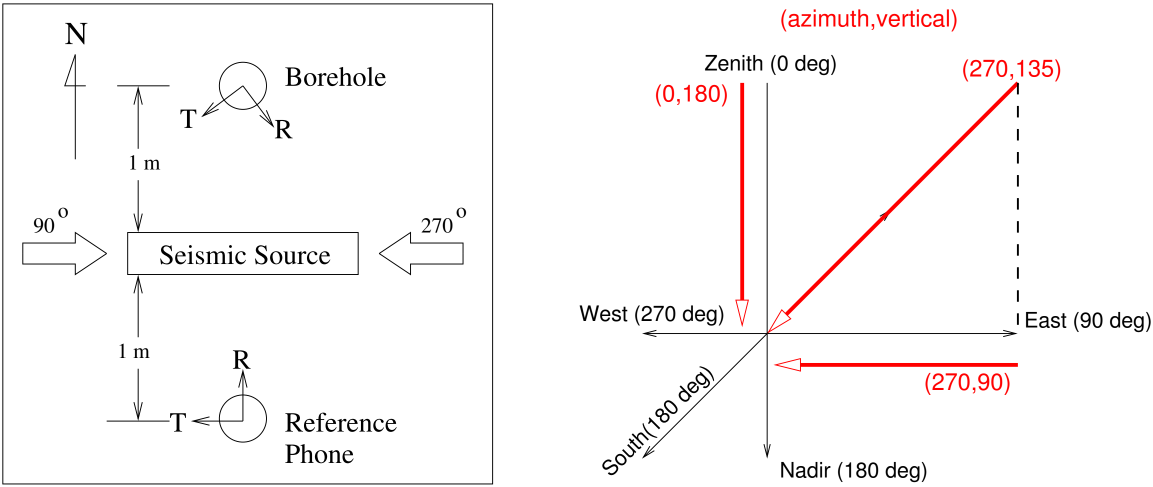


(A)
Trace 10 tmax=1.250 sec. dt=0.00050
30000
20000
10000
0
−10000
−20000
0
0.2
0.4
0.6
0.8
1
Time (s)
(B)
Amplitude
2e+06
1.5e+06
1e+06
500000
0
0
20
40
60
80
100
Frequency (Hz)
Unwrapped Phase Rad
20
0
−20
−40
−60
−80
−100
0
20
40
60
80
100
Frequency (Hz)



48 traces tmax=1.250 sec. dt=0.0005
10
0
-10
-20
-30
-40
-50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (s)

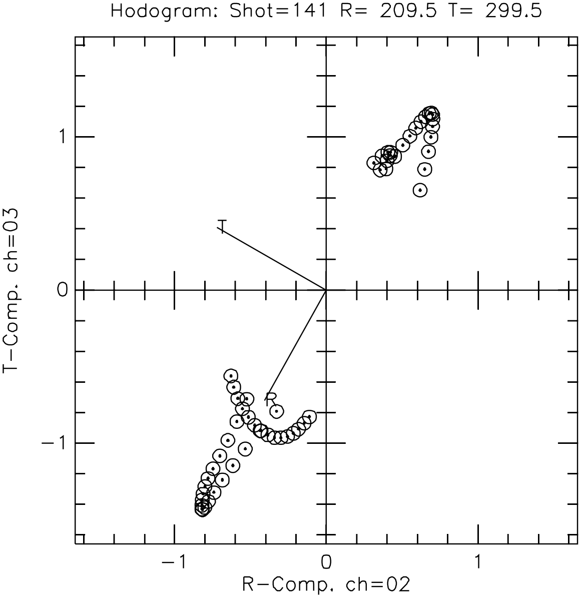

Scale (cm)
0
10
20
30
40
50
60
70
80
90
100
Pivot
line
Pivot
Handle
11.15 N Wt
Each Side
Rope Pull
F
S

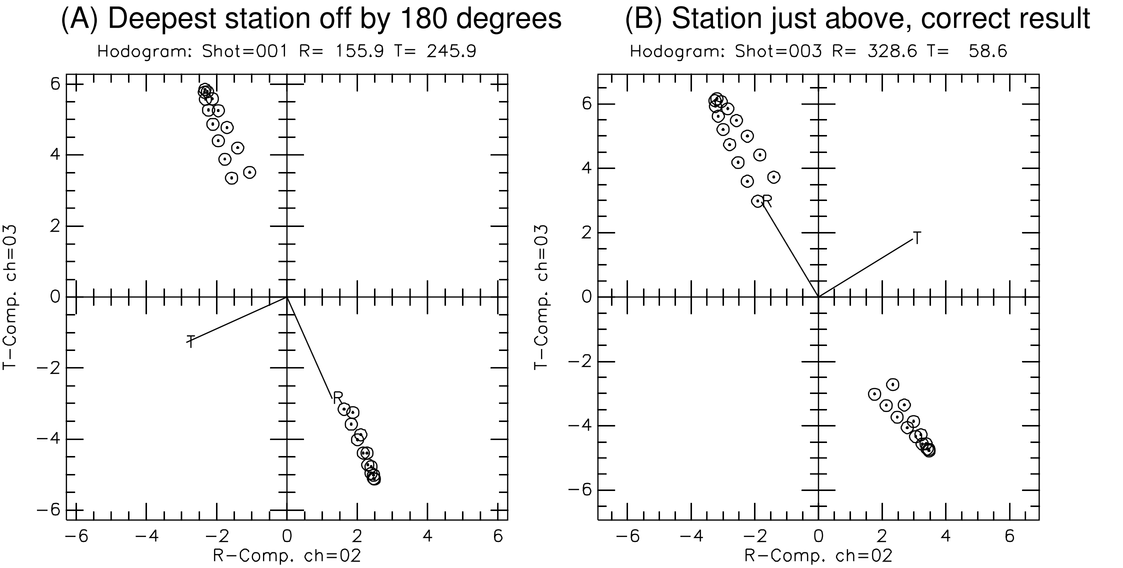

N
Borehole
T
R
1 m
90 o
270 o
Seismic Source
1 m
R
T
Reference
Phone
(azimuth,vertical)
Zenith (0 deg)
(270,135)
(0,180)
West (270 deg)
East (90 deg)
(270,90)
South(180 deg)
Nadir (180 deg)

220^o

240^o

180^o


Hodogram: Shot=141 R= 209.5 T= 299.5
T–Comp. ch=03
R–Comp. ch=02
1
0
−1
T
R


(A) Deepest station off by 180 degrees
Hodogram: Shot=001 R= 155.9 T= 245.9
T−Comp. ch=03
R−Comp. ch=02
R
T
(B) Station just above, correct result
Hodogram: Shot=003 R= 328.6 T= 58.6
T−Comp. ch=03
R−Comp. ch=02
R
T

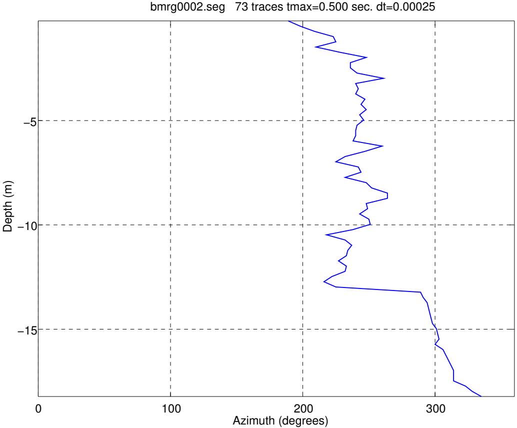
209o

299º

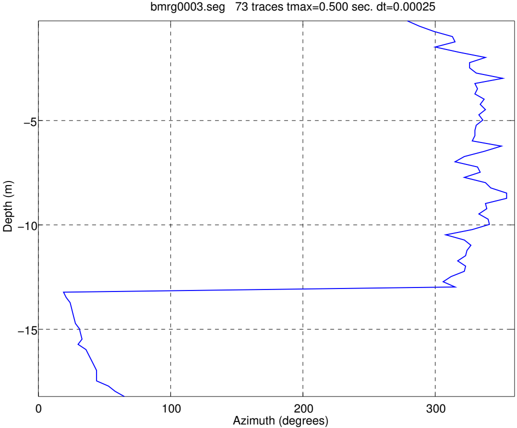
270^o

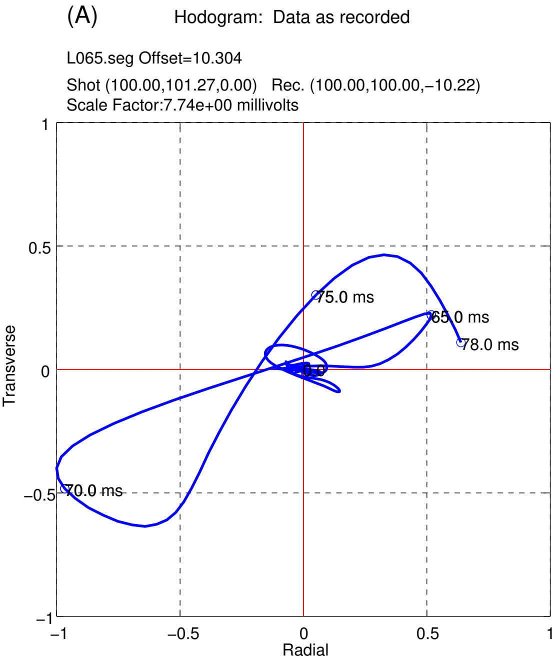
90^o

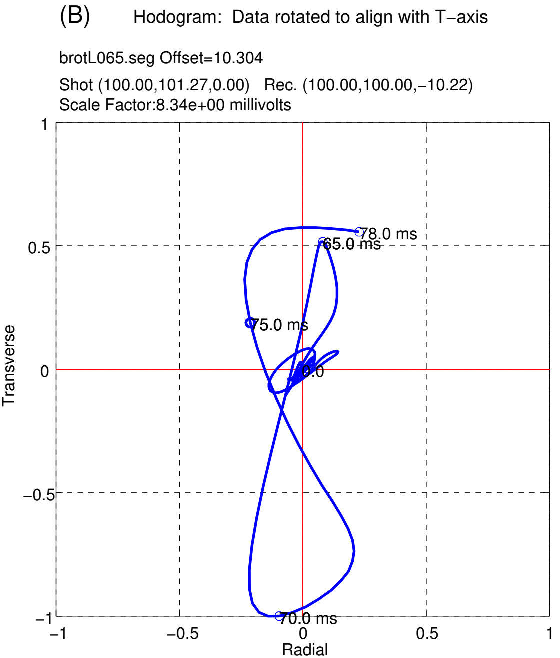
(A) Channel 2



(B) Channel 3




(A)
Hodogram: Data as recorded
L065.seg Offset=10.304
Shot (100.00,101.27,0.00) Rec. (100.00,100.00,−10.22)
Scale Factor:7.74e+00 millivolts
Transverse
Radial
75.0 ms
65.0 ms
78.0 ms
70.0 ms
0.0
1
0.5
0
−0.5
−1


(B)
Hodogram: Data rotated to align with T−axis
brotL065.seg Offset=10.304
Shot (100.00,101.27,0.00) Rec. (100.00,100.00,−10.22)
Scale Factor:8.34e+00 millivolts
Transverse
Radial
78.0 ms
65.0 ms
75.0 ms
70.0 ms
0.0
1
0.5
0
−0.5
−1

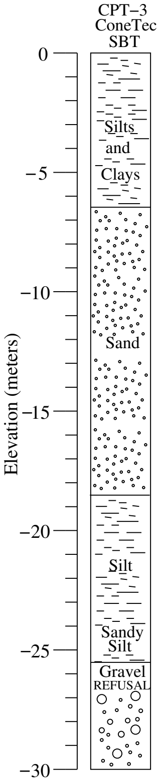
odmax=163

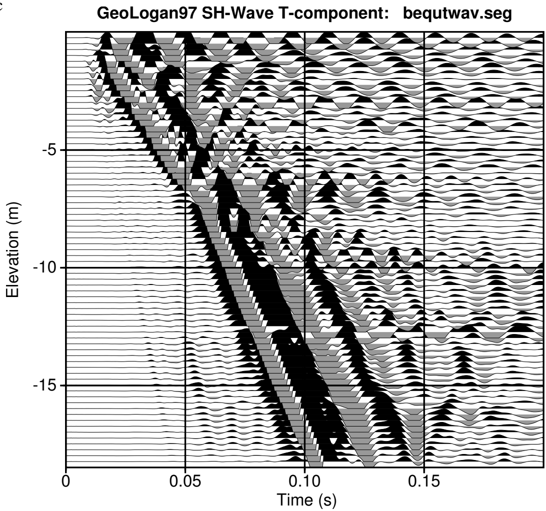
evmax=164

PRFX=w

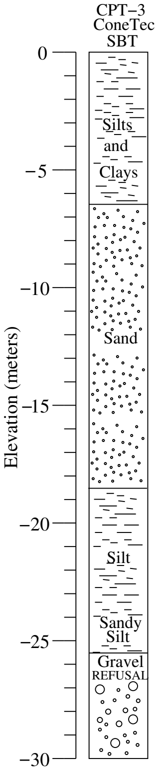
az90=2

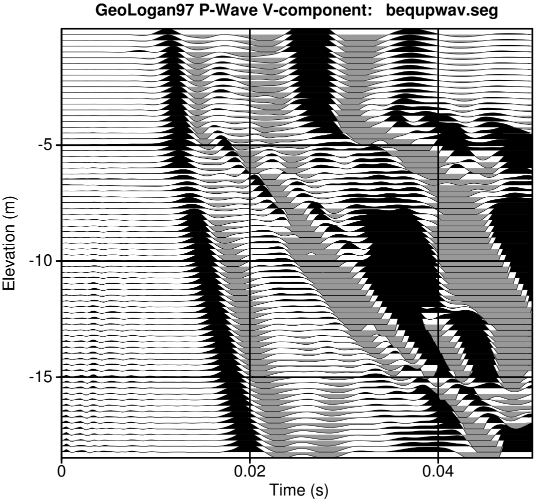
az270=1



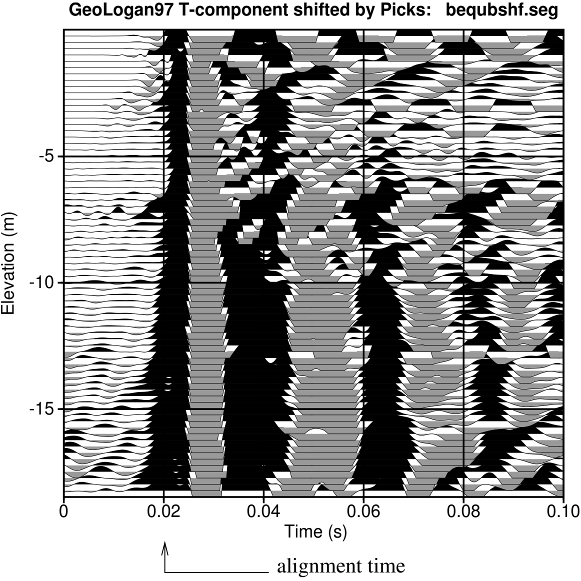


Seismic Survey 15 July 1997, short distance from CPT−3
CPT−3 Survey by ConeTec GeoLogan97 Field Day
Water table not known (borehole sealed at bottom)

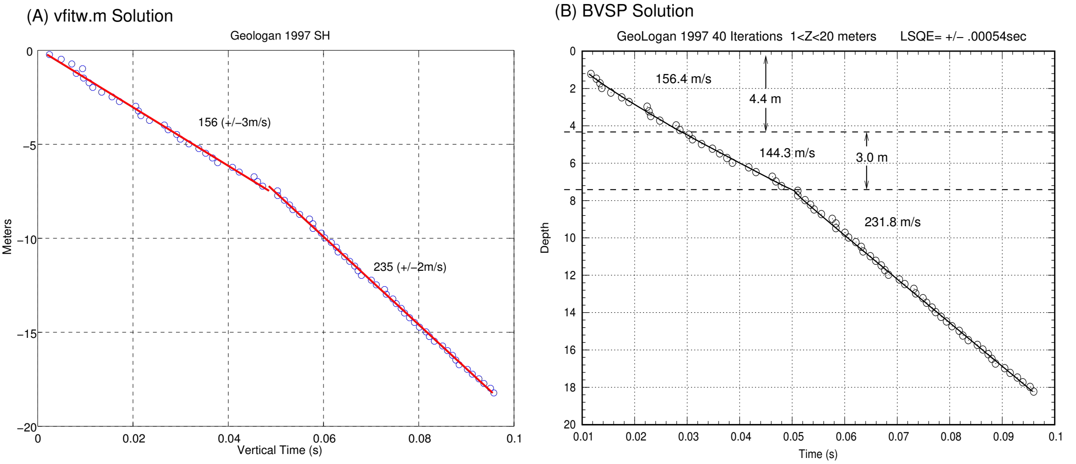




Seismic Survey 15 July 1997, short distance from CPT−3
CPT−3 Survey by ConeTec GeoLogan97 Field Day
Water table not known (borehole sealed at bottom)



GeoLogan97 T-component shifted by Picks: bequbshf.seg
Elevation (m)
-5
-10
-15
0
0.02
0.04
0.06
0.08
0.10
Time (s)
alignment time



(A) vfitw.m Solution
Geologan 1997 SH
156 (+/−3m/s)
235 (+/−2m/s)
Meters
Vertical Time (s)
0
−5
−10
−15
−20
0
0.02
0.04
0.06
0.08
0.1
(B) BVSP Solution
GeoLogan 1997 40 Iterations 1<Z<20 meters LSQE= +/− .00054sec
156.4 m/s
4.4 m
144.3 m/s
3.0 m
231.8 m/s
Depth
Time (s)
0
2
4
6
8
10
12
14
16
18
20
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

$$\frac{\partial^2 u}{\partial t^2} = C_1 \frac{\partial^2 u}{\partial x^2} + C_2 \frac{\partial^3 u}{\partial t \partial x^2}$$

C_1

$$\left(\frac{m^2}{s^2}\right)$$

C_2

$$\left(\frac{m^2}{s} \right)$$

$$C_2 = 0$$

$$\sqrt{C_1}$$

$$C_2 \neq 0$$

$$u(x,t) = \exp(-\alpha x) \cdot \cos(\beta x - \omega t),$$

$$\beta + i\alpha$$

$$\alpha = \frac{4\sqrt{D}\omega^2 C_2}{(2\omega C_2)^2 + D^2}$$

$\boldsymbol{\omega}$

$$D = 2\left(C_1 + \sqrt{C_1^2 + \omega^2 C_2^2}\right).$$

$$c = \frac{2\omega^2 C_2}{D\alpha}.$$

$$C_1 = \frac{\left(\beta^2 - \alpha^2\right)\omega^2}{\left(\beta^2 + \alpha^2\right)^2},$$

$$C_2 = \frac{2\alpha\beta\omega}{(\beta^2+\alpha^2)^2}.$$

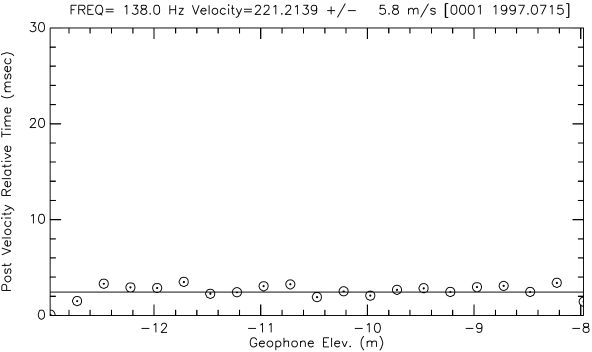
α

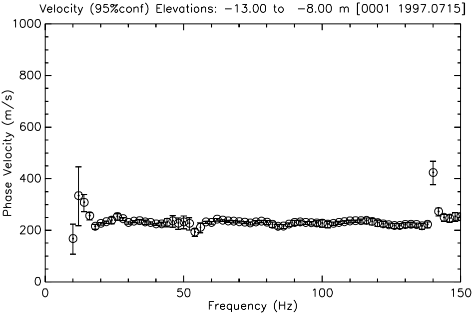
$$\beta = \frac{\omega}{c}$$

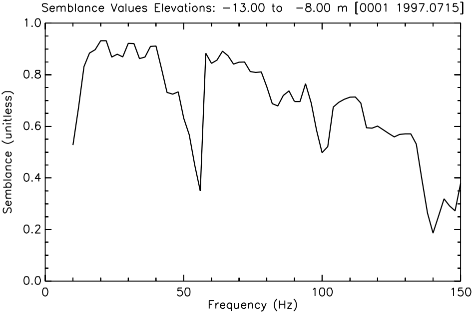
$$\theta = \arccos\left(\frac{\sum(U_i S_i)}{\sqrt{\sum U_i^2}\sqrt{\sum S_i^2}}\right),$$

$$t_s = \frac{\theta}{\omega}.$$

t_s


FREQ= 138.0 Hz Velocity=221.2139 +/- 5.8 m/s [0001 1997.0715]
Post Velocity Relative Time (msec)
30
20
10
0
−12
−11
−10
−9
−8
Geophone Elev. (m)


Velocity (95%conf) Elevations: −13.00 to −8.00 m [0001 1997.0715]
Phase Velocity (m/s)
Frequency (Hz)
0
200
400
600
800
1000
0
50
100
150


Semblance Values Elevations: −13.00 to −8.00 m [0001 1997.0715]
Semblance (unitless)
Frequency (Hz)
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150

z_i

$\overline{t}$

$$y_i = \frac{z_i}{V} + (t_s - \bar{t}).$$

y_i

$$y = mx + b$$

$$\sigma^2_{1/m}$$

$$V = \frac{1}{m} = \frac{\left[\left(\sum x_i\right)^2 - N \sum \left(x_i^2\right)\right]}{\left[\left(\sum x_i\right)\left(\sum y_i\right) - N \sum \left(x_i y_i\right)\right]}.$$

$$\sigma_V^2 = \sigma_{\frac{1}{m}}^2$$

$$\sigma_V^2 = \sigma_{\frac{1}{m}}^2 = \sum \left(\frac{\partial V}{\partial y_i} \right)^2 \sigma_{y_i}^2,$$

σ_y^2

$$\sigma_y^2 = \sigma_{t_s}^2 = \frac{\sum (t_s - \bar{t})^2}{N-1}.$$

$$\sigma_V^2 = \sigma_{\frac{1}{m}}^2 = \sigma_{t_s}^2 \cdot \frac{N\left[N\sum\left(x_i^2\right) - \left(\sum x_i\right)^2\right]^3}{\left[\left(\sum x_i\right)\left(\sum y_i\right) - N\sum\left(x_i y_i\right)\right]^4}.$$

$$\sigma_V^2$$

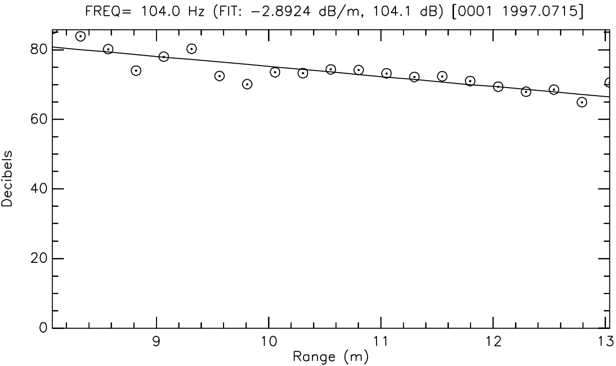
$$A = \left(\frac{A_o r_o}{r} \right) \cdot \exp\left(-\alpha \left(r - r_o \right) \right),$$

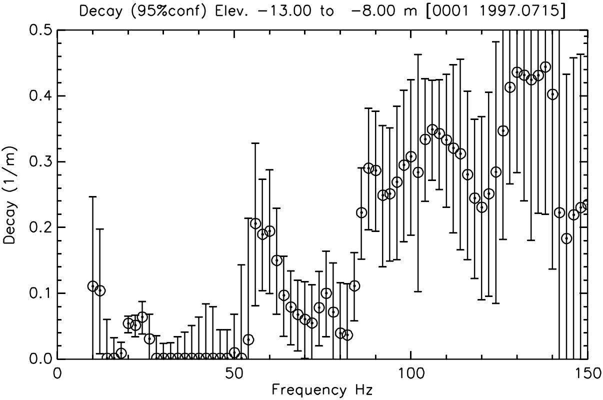
A_o

r_o

$$dB = 20\log_{10}\left(\frac{Ar}{A_o r_o}\right) = -20\left(\log_{10} e\right)\alpha(r - r_o).$$

$$(r - r_o)$$


FREQ= 104.0 Hz (FIT: -2.8924 dB/m, 104.1 dB) [0001 1997.0715]
Decibels
0
20
40
60
80
Range (m)
9
10
11
12
13



Decay (95%conf) Elev. −13.00 to −8.00 m [0001 1997.0715]
0.5
0.4
0.3
0.2
0.1
0.0
Decay (1/m)
0
50
100
150
Frequency Hz

$$m = \frac{\left(\sum x_i\right)\left(\sum y_i\right) - N\sum\left(x_i y_i\right)}{\left(\sum x_i\right)^2 - N\sum\left(x_i^2\right)}.$$

$$\sigma_y^2 = \frac{\sum \left(y_i - (mx_i + b)\right)^2}{N - 1}.$$

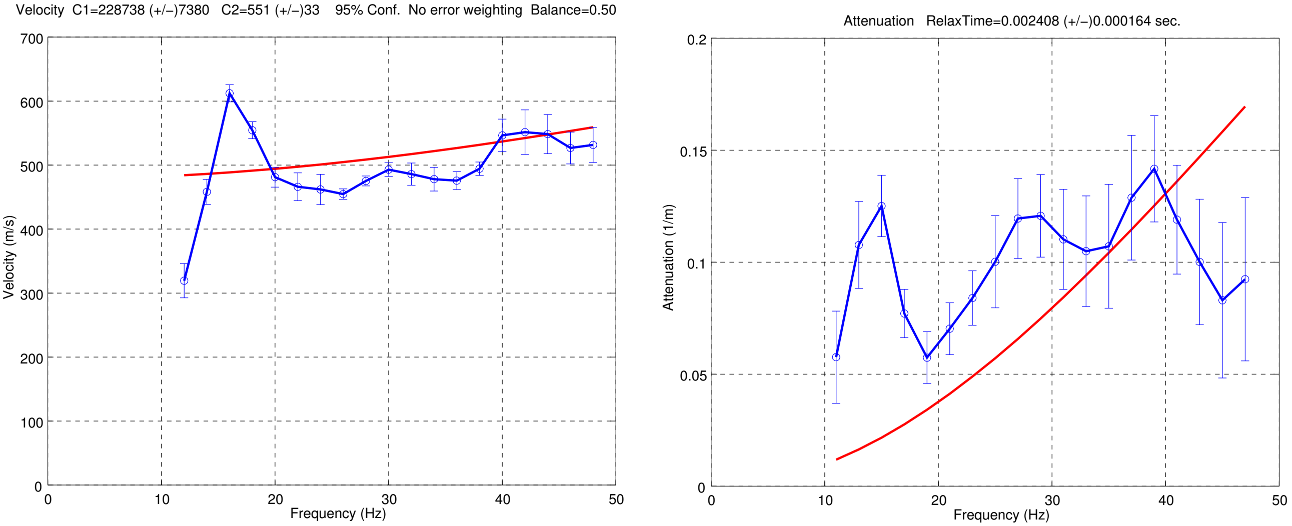
$$\sigma_m^2 = \sum \left(\frac{\partial m}{\partial y_i} \right)^2 \sigma_{y_i}^2,$$

$$\sigma_m^2 = \frac{N\sigma_y^2}{\left[N\sum\left(x_i^2\right) - \left(\sum x_i\right)^2\right]}.$$

Δt

$$\frac{1}{N\Delta t}$$

$$T_r = \frac{C_2}{C_1}$$



Velocity C1=228738 (+/−)7380 C2=551 (+/−)33 95% Conf. No error weighting Balance=0.50
Velocity (m/s)
Frequency (Hz)
0
100
200
300
400
500
600
700
0
10
20
30
40
50
Attenuation RelaxTime=0.002408 (+/−)0.000164 sec.
Attenuation (1/m)
Frequency (Hz)
0
0.05
0.1
0.15
0.2
0
10
20
30
40
50

m^2/s^2

m^2/s

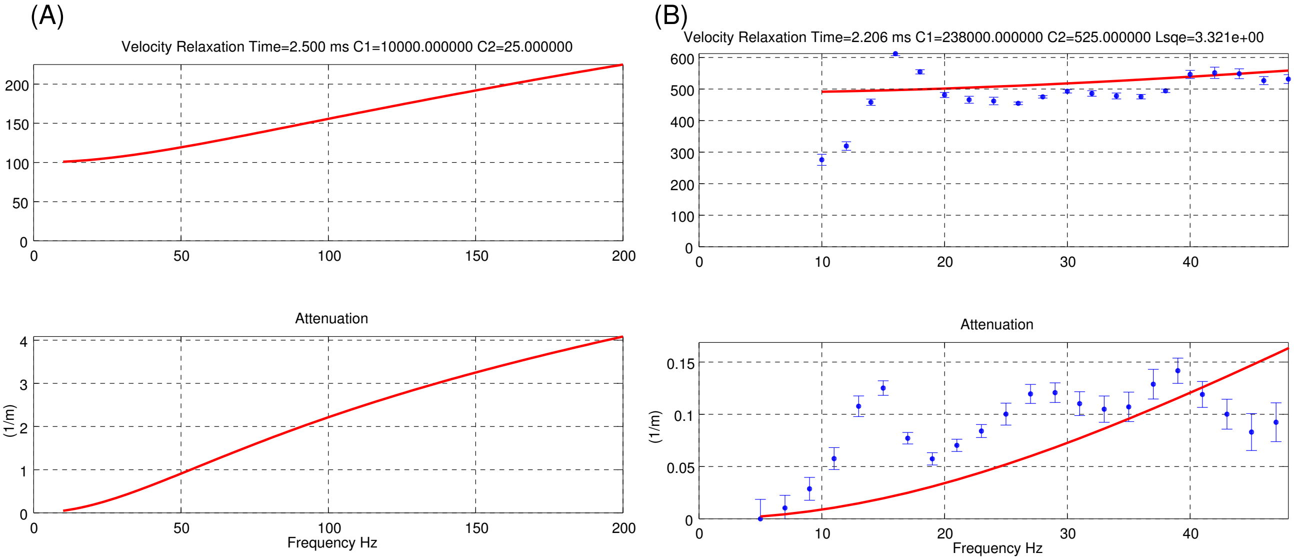
m/s

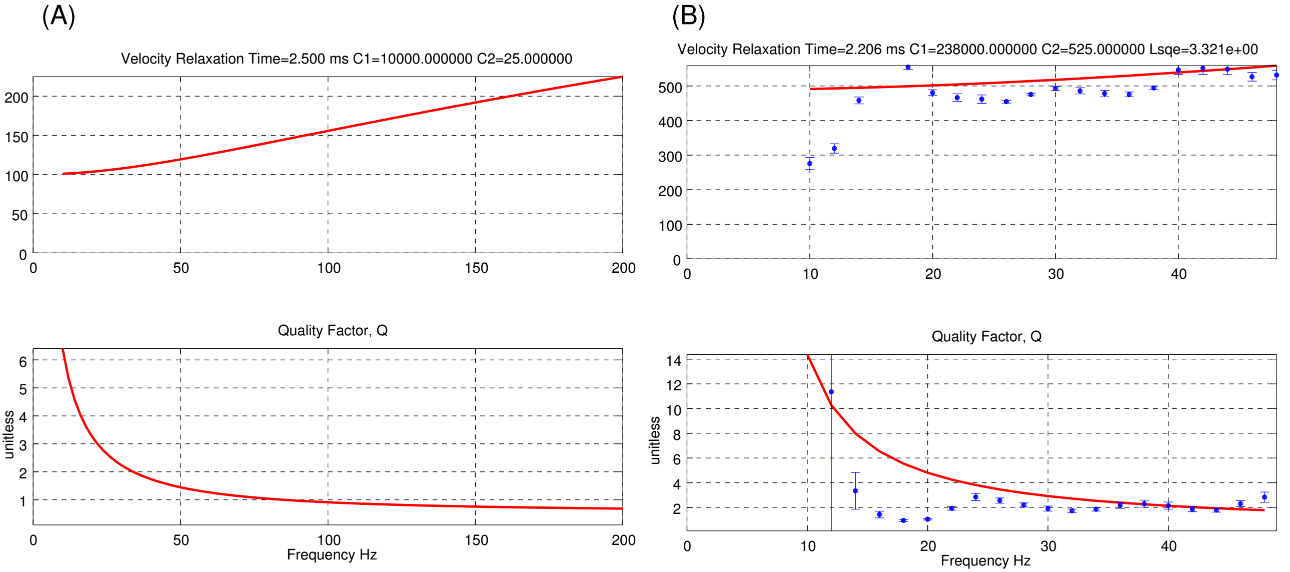
$1/m$

$$Q = \frac{\pi f}{\alpha V}$$

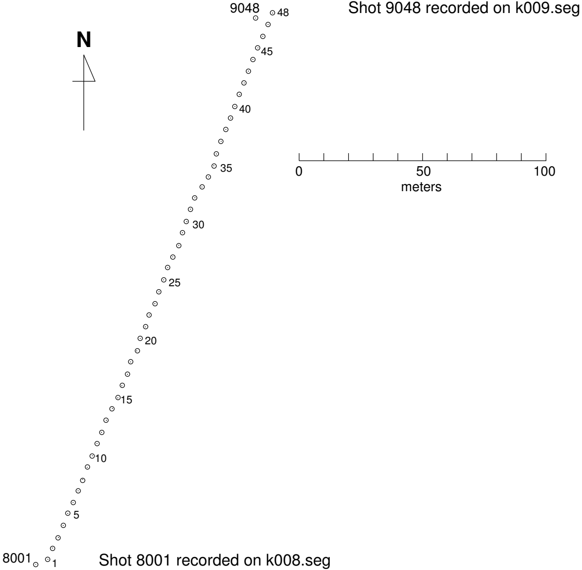
f

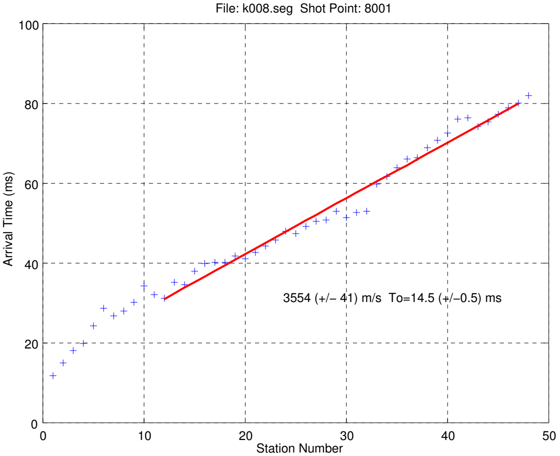
V

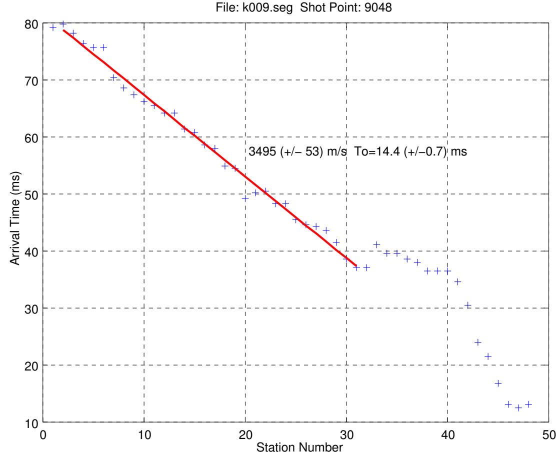

(A)
Velocity Relaxation Time=2.500 ms C1=10000.000000 C2=25.000000
Attenuation
(1/m)
Frequency Hz
(B)
Velocity Relaxation Time=2.206 ms C1=238000.000000 C2=525.000000 Lsqe=3.321e+00
Attenuation
(1/m)
Frequency Hz

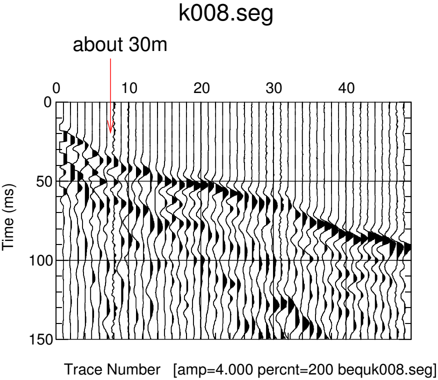


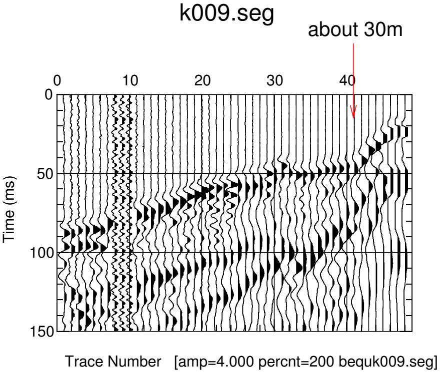
(A)
Velocity Relaxation Time=2.500 ms C1=10000.000000 C2=25.000000
Quality Factor, Q
unitless
Frequency Hz
(B)
Velocity Relaxation Time=2.206 ms C1=238000.000000 C2=525.000000 Lsqe=3.321e+00
Quality Factor, Q
unitless
Frequency Hz

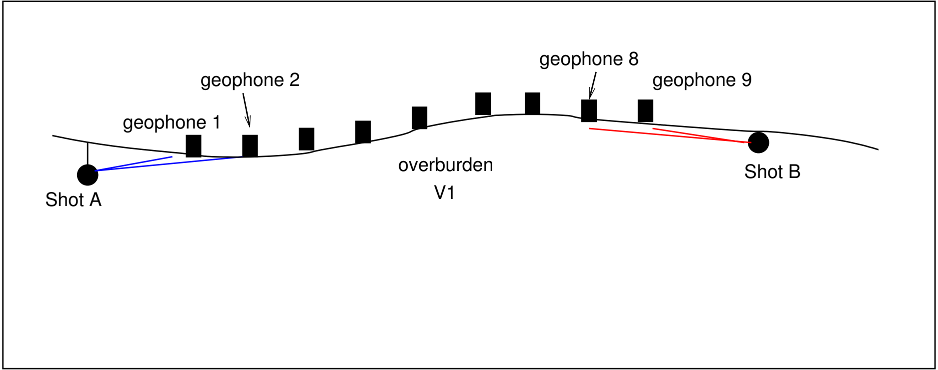

Shot 9048 recorded on k009.seg
N
9048
48
45
40
35
30
25
20
15
10
5
0
50
100
meters
8001
1
Shot 8001 recorded on k008.seg


File: k008.seg Shot Point: 8001
Arrival Time (ms)
Station Number
3554 (+/− 41) m/s To=14.5 (+/−0.5) ms
0
20
40
60
80
100
0
10
20
30
40
50


File: k009.seg Shot Point: 9048
Arrival Time (ms)
Station Number
3495 (+/− 53) m/s To=14.4 (+/−0.7) ms
10
20
30
40
50
60
70
80
0
10
20
30
40
50


k008.seg
about 30m
0
10
20
30
40
0
50
100
150
Time (ms)
Trace Number [amp=4.000 percnt=200 bequk008.seg]


k009.seg
about 30m
0
10
20
30
40
0
50
100
150
Time (ms)
Trace Number [amp=4.000 percnt=200 bequk009.seg]


geophone 8
geophone 2
geophone 9
geophone 1
overburden
V1
Shot A
Shot B

$$X_{a1} \cdot \frac{1}{V_1} = t_{a1}$$

X_{a1}

V_1

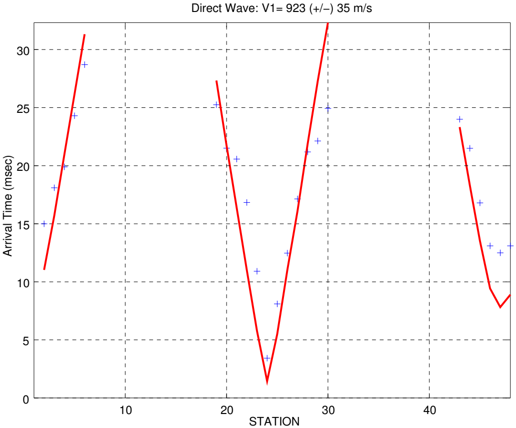
t_{a1}

$$G \cdot m = d$$

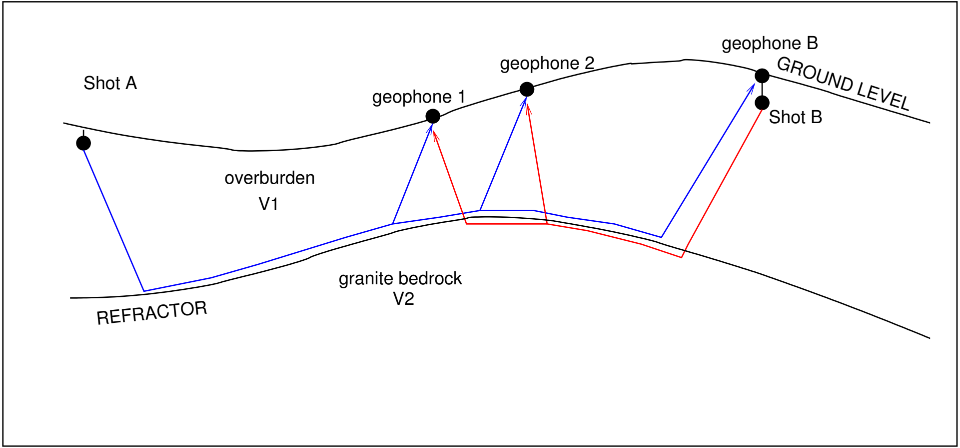
$$\begin{bmatrix} X_{a1} \\ X_{a2} \\ X_{b8} \\ X_{b9} \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{V_1} \end{bmatrix} = \begin{bmatrix} t_{a1} \\ t_{a2} \\ t_{b8} \\ t_{b9} \end{bmatrix}$$

$$m = \left[G^T G\right]^{-1} G^T \cdot d$$

$$V_1 = \frac{1}{m}$$



Direct Wave: V1= 923 (+/−) 35 m/s
Arrival Time (msec)
STATION
0
5
10
15
20
25
30
10
20
30
40



Shot A
geophone 1
geophone 2
geophone B
GROUND LEVEL
Shot B
overburden
V1
granite bedrock
V2
REFRACTOR

$$T_a + T_1 + \frac{X_{a1}}{V_2} = t_{a1}$$

T_a

T_1

V_2

$$\begin{bmatrix} 1 & 0 & 1 & 0 & X_{a1} \\ 1 & 0 & 0 & 1 & X_{a2} \\ 1 & 1 & 0 & 0 & X_{ab} \\ 0 & 1 & 1 & 0 & X_{b1} \\ 0 & 1 & 0 & 1 & X_{b2} \end{bmatrix} \cdot \begin{bmatrix} T_a \\ T_b \\ T_1 \\ T_2 \\ \frac{1}{V_2} \end{bmatrix} = \begin{bmatrix} t_{a1} \\ t_{a2} \\ t_{ab} \\ t_{b1} \\ t_{b2} \end{bmatrix}$$

G

$$T_1 \simeq T_2$$

$$\begin{bmatrix} 1 & 0 & 1 & 0 & X_{a1} \\ 1 & 1 & 0 & 0 & X_{ab} \\ 0 & 1 & 1 & 0 & X_{b1} \\ 0 & 1 & 0 & 1 & X_{b2} \\ 0 & 0 & 9 & -9 & 0 \end{bmatrix} \cdot \begin{bmatrix} T_a \\ T_b \\ T_1 \\ T_2 \\ \frac{1}{V_2} \end{bmatrix} = \begin{bmatrix} t_{a1} \\ t_{ab} \\ t_{b1} \\ t_{b2} \\ 0.0 \end{bmatrix}$$

T_2

$$T_1 - T_2 = 0$$

m

$$\text{m}= \begin{bmatrix} T_a \\ T_b \\ T_1 \\ T_2 \\ \frac{1}{V_2} \end{bmatrix}$$

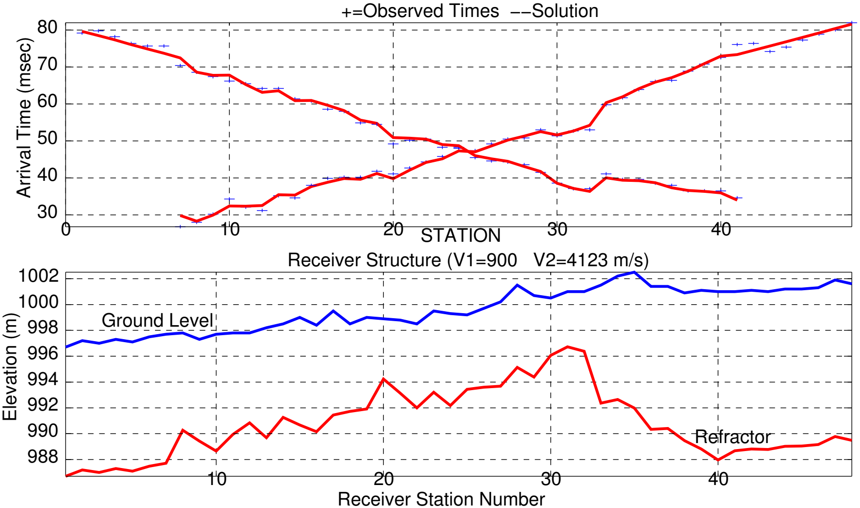
T_a

$$\begin{bmatrix} 1 & 1 & 0 & X_{a1} \\ 1 & 0 & 1 & X_{a2} \\ 0 & 0 & 0 & 4000 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} T_a \\ T_1 \\ T_2 \\ \frac{1}{V_2} \end{bmatrix} = \begin{bmatrix} t_{a1} \\ t_{ab} \\ 1.0 \\ .005 \end{bmatrix}$$

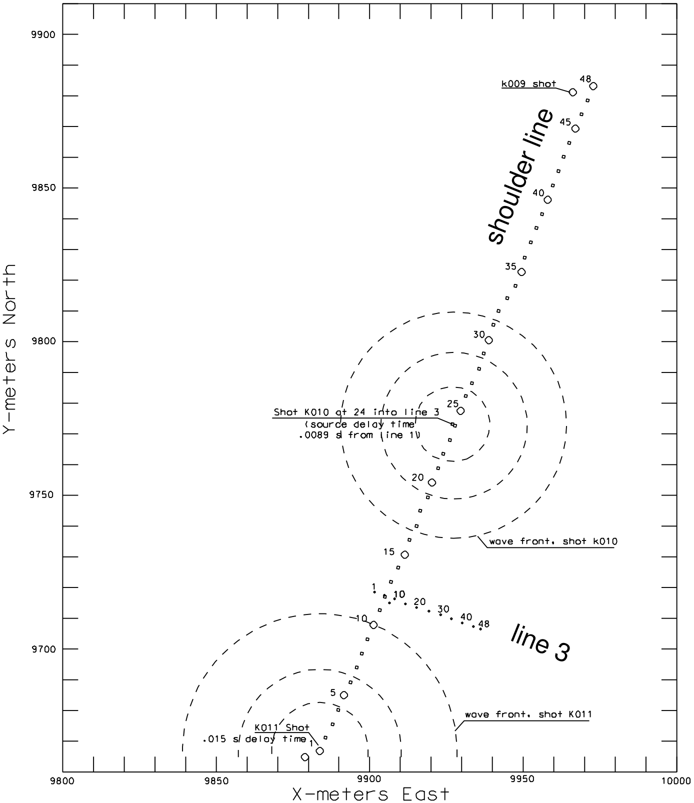
4000

.005

$2x48$



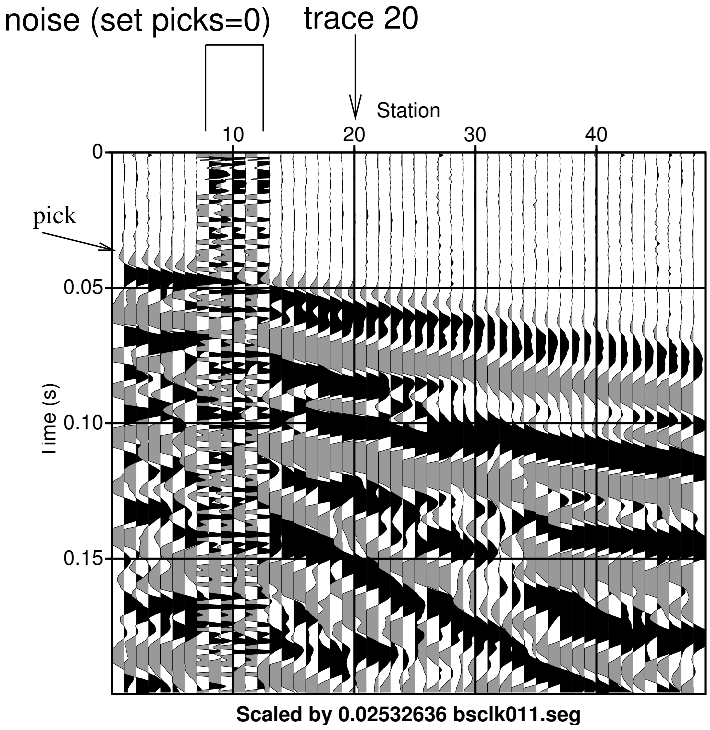
+=Observed Times --Solution
Arrival Time (msec)
80
70
60
50
40
30
0
10
20
30
40
STATION
Receiver Structure (V1=900 V2=4123 m/s)
Elevation (m)
1002
1000
998
996
994
992
990
988
Ground Level
Refractor
10
20
30
40
Receiver Station Number



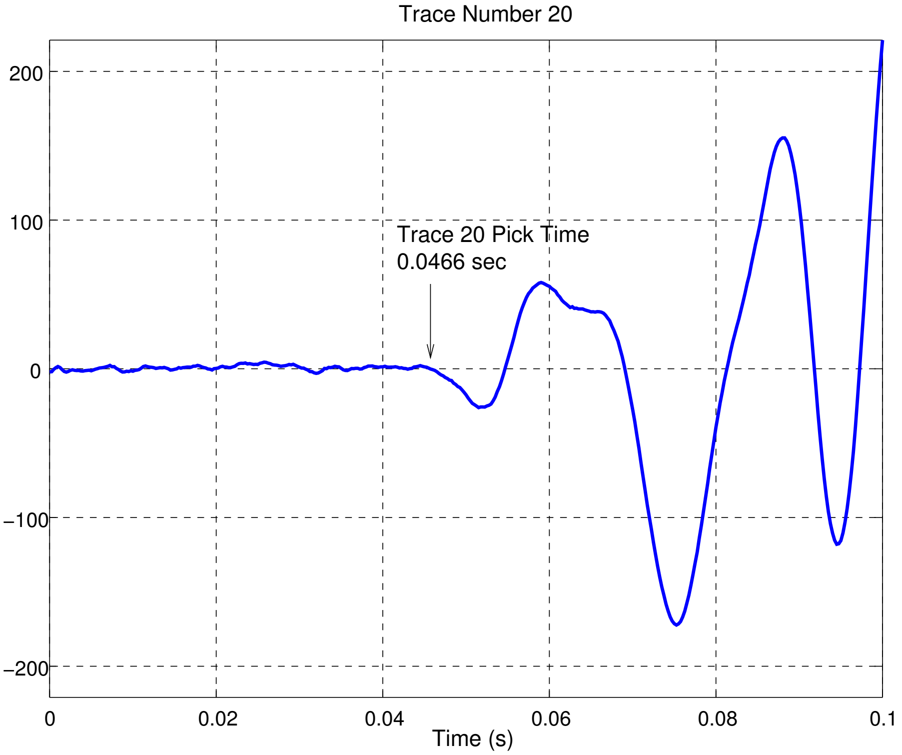
Y-meters North
X-meters East
9900
9850
9800
9750
9700
9800
9850
9900
9950
10000
shoulder line
line 3
k009 shot
48
45
40
35
30
25
20
15
10
5
1
Shot K010 at 24 into line 3
(source delay time
.0089 s from line 1)
wave front, shot k010
1
10
20
30
40
48
wave front, shot K011
K011 Shot
.015 s delay time

31.5^o

30^o



Plotted with Seismic Unix (SU)


Trace Number 20
200
100
0
−100
−200
0
0.02
0.04
0.06
0.08
0.1
Time (s)
Trace 20 Pick Time
0.0466 sec

$$Gm = d,$$

$$T_s + T_g + \frac{x}{V_2} = t_p \,,$$

T_s

T_g

$$\frac{x}{V_2}$$

t_p

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 & x_{11} \\ 1 & 0 & 0 & 1 & 0 & x_{12} \\ 1 & 0 & 0 & 0 & 1 & x_{13} \\ 0 & 1 & 1 & 0 & 0 & x_{21} \\ 0 & 1 & 0 & 1 & 0 & x_{22} \\ 0 & 1 & 0 & 0 & 1 & x_{23} \end{bmatrix} \cdot \begin{bmatrix} T_{s_1} \\ T_{s_2} \\ T_{g_1} \\ T_{g_2} \\ T_{g_3} \\ \frac{1}{V_2} \end{bmatrix} = \begin{bmatrix} t_{11} \\ t_{12} \\ t_{13} \\ t_{21} \\ t_{22} \\ t_{23} \end{bmatrix},$$

T_{s_j}

Tg_j

t_{sr}

x_{sr}

$$-9T_{g_7} + 9T_{g_8} = 0.$$

T_{g7}

T_{g8}

$$10T_{s_1} = .0890$$
$$10T_{s_2} = 0.150 \text{ ,}$$

T_{s_1}

T_{s_2}

$$\frac{4187}{V_2} = 1.000$$

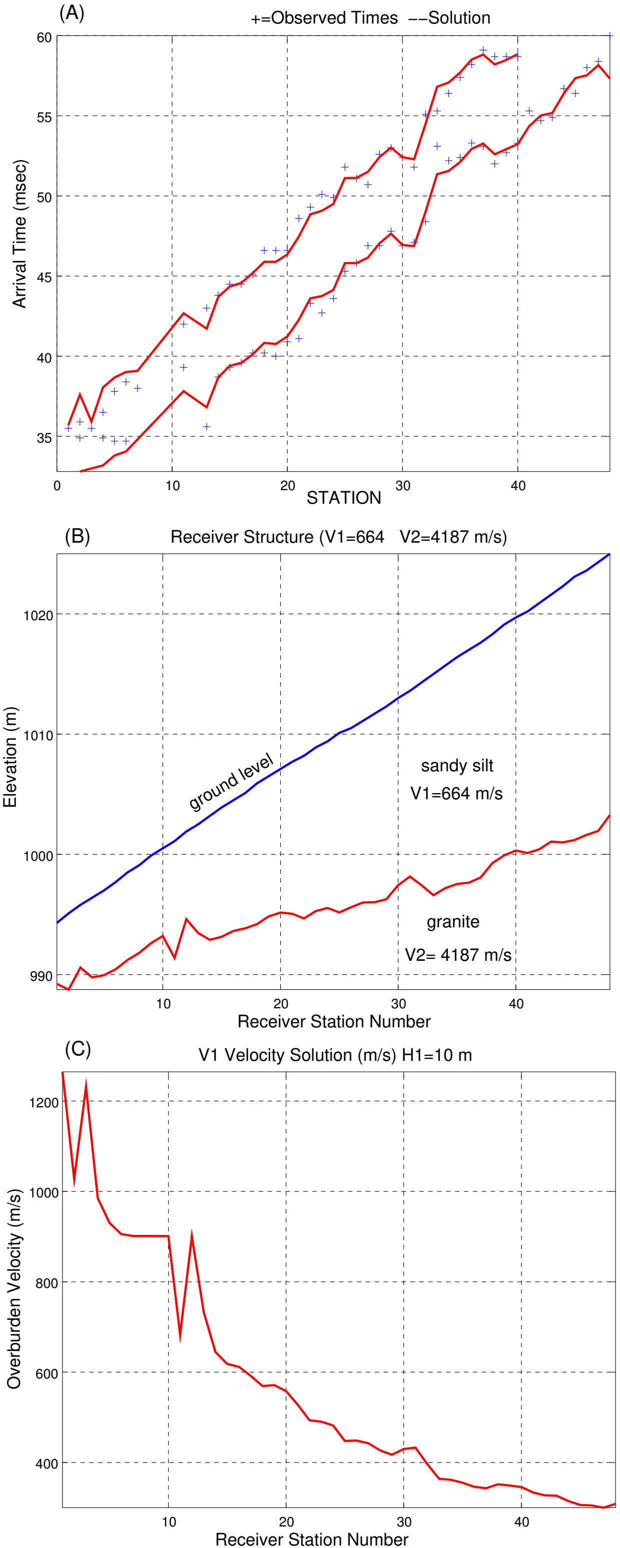
$$h = \frac{V_1}{\cos(\theta)} \cdot T_j$$
$$\theta = \arcsin\left(\frac{V_1}{V_2}\right),$$

T_j

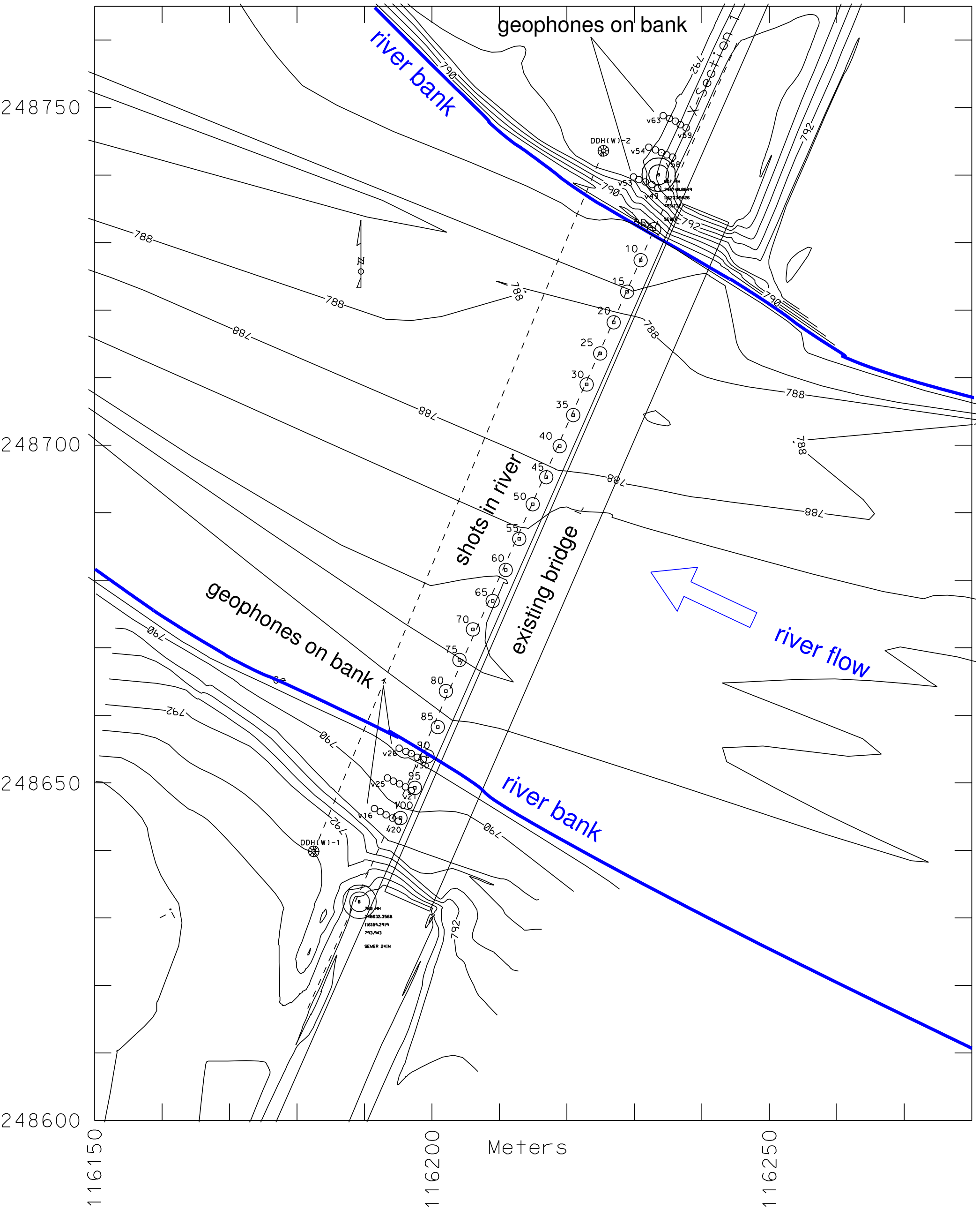
$$V_1 = \frac{V_2}{\sqrt{1 + \left(\frac{T_j V_2}{h}\right)^2}},$$

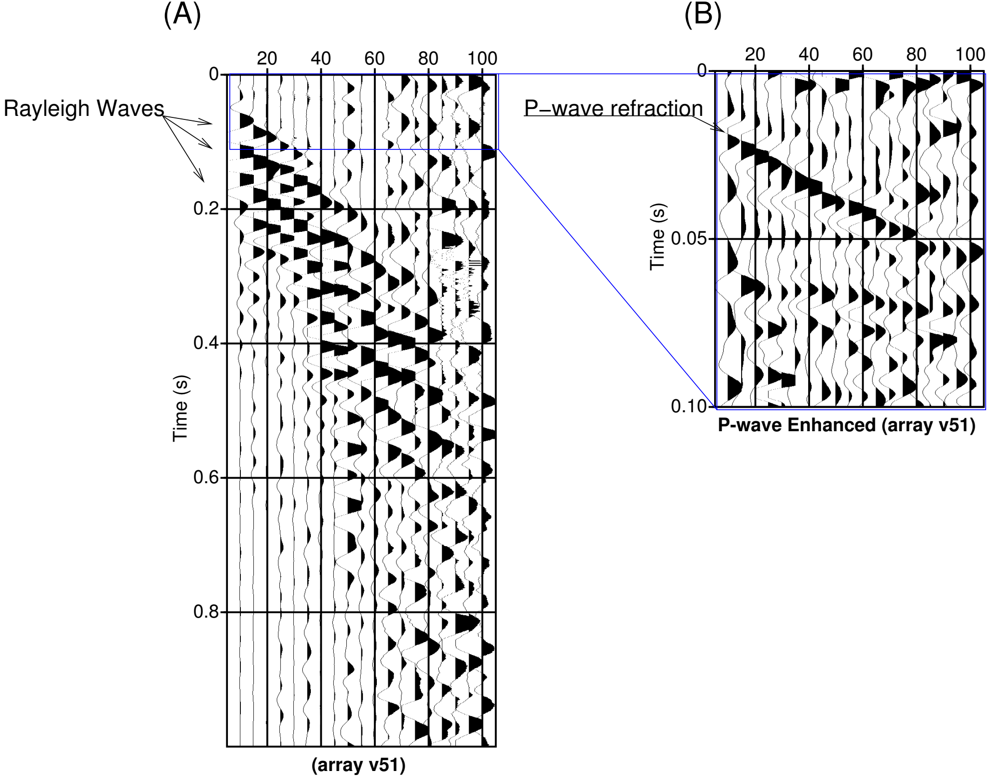
V_2

V_1

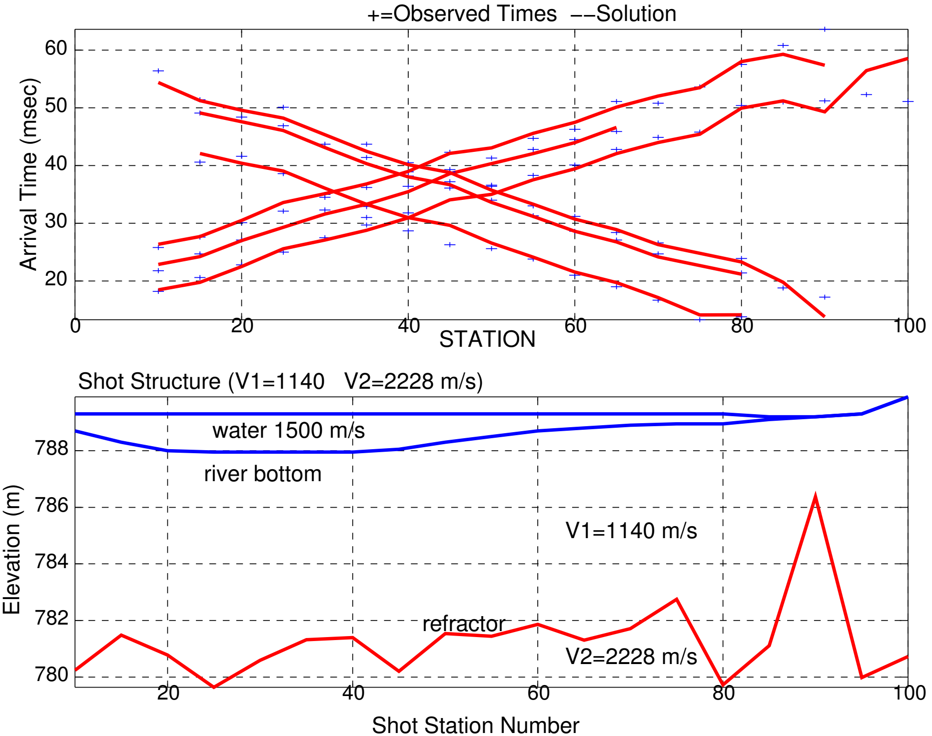


(A)
+=Observed Times --Solution
Arrival Time (msec)
STATION
60
55
50
45
40
35
0
10
20
30
40
(B)
Receiver Structure (V1=664 V2=4187 m/s)
Elevation (m)
ground level
sandy silt
V1=664 m/s
granite
V2= 4187 m/s
1020
1010
1000
990
10
20
30
40
Receiver Station Number
(C)
V1 Velocity Solution (m/s) H1=10 m
Overburden Velocity (m/s)
1200
1000
800
600
400
10
20
30
40
Receiver Station Number


geophones on bank
river bank
X-Section 1
DDH(W)-2
v63
v59
v54
v58
v53
v49
790
792
788
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
120
v26
v30
v25
v21
v16
DDH(W)-1
shots in river
existing bridge
geophones on bank
river bank
river flow
248750
248700
248650
248600
116150
116200
116250
Meters



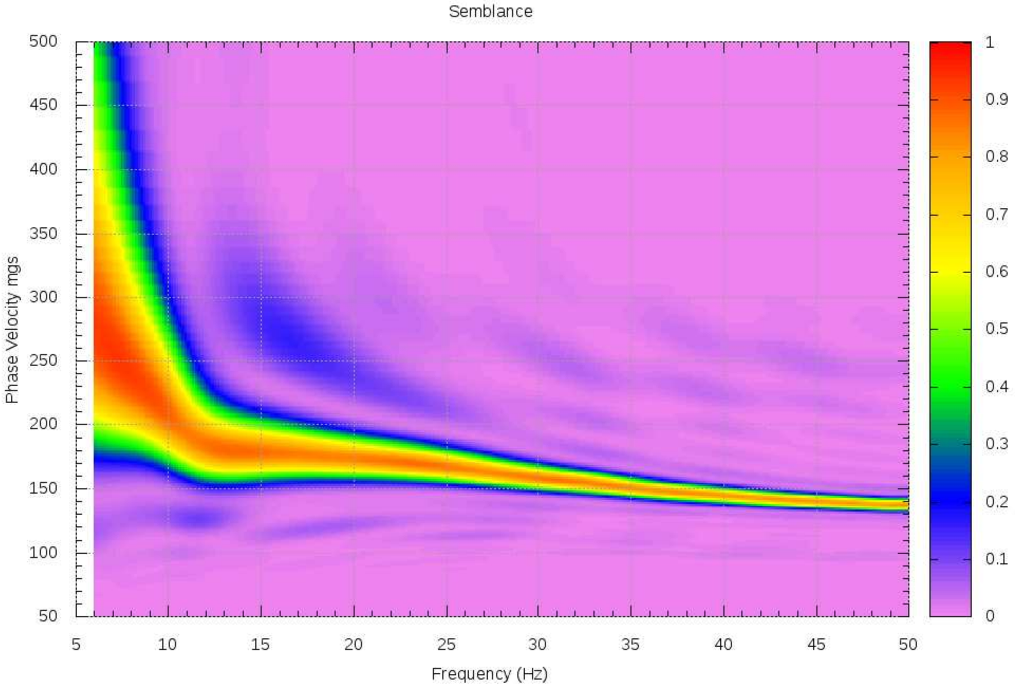
(A)
(B)
Rayleigh Waves
P−wave refraction
Time (s)
(array v51)
P-wave Enhanced (array v51)
20
40
60
80
100
0
0.2
0.4
0.6
0.8
0.05
0.10



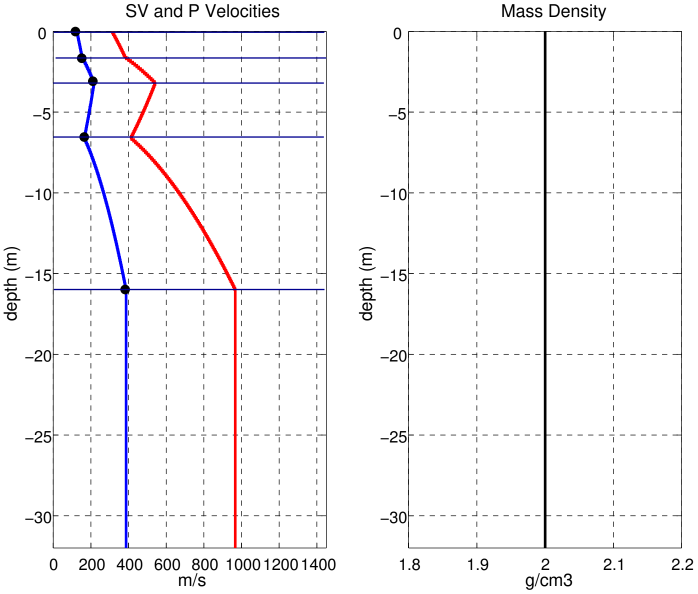
+=Observed Times --Solution
Arrival Time (msec)
STATION
Shot Structure (V1=1140 V2=2228 m/s)
water 1500 m/s
river bottom
V1=1140 m/s
refractor
V2=2228 m/s
Elevation (m)
Shot Station Number

$$delf = 2$$

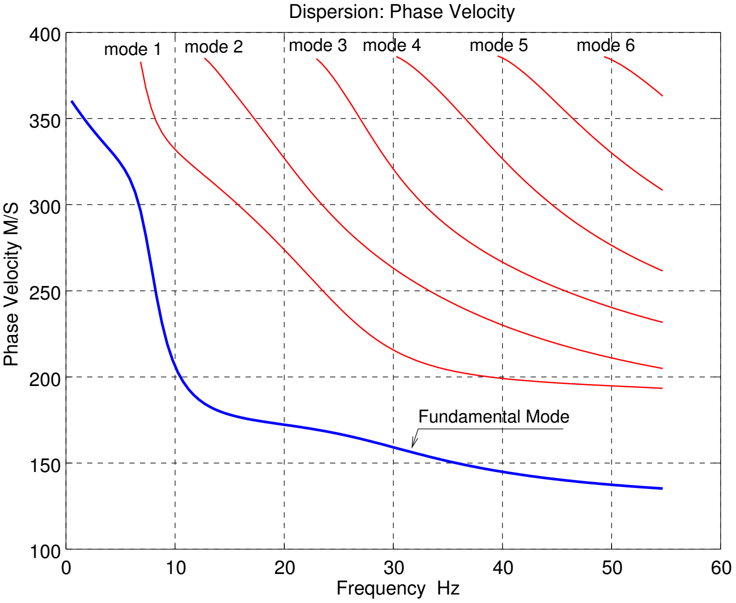
$$delf = 0.5$$

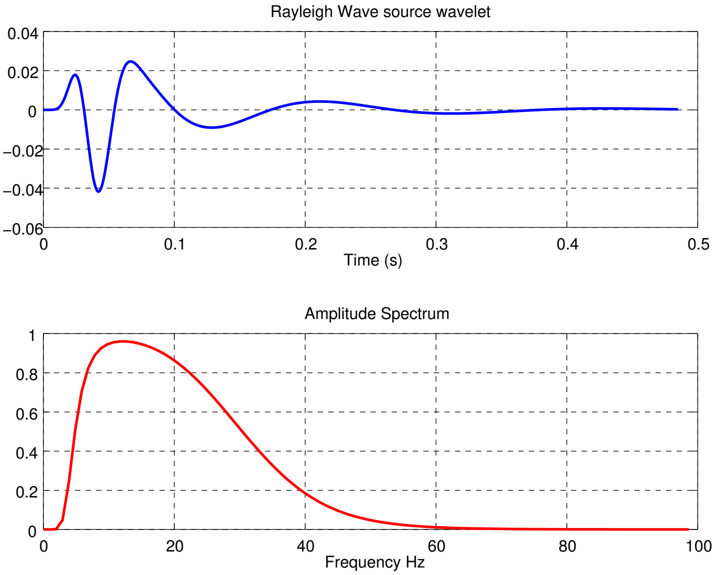


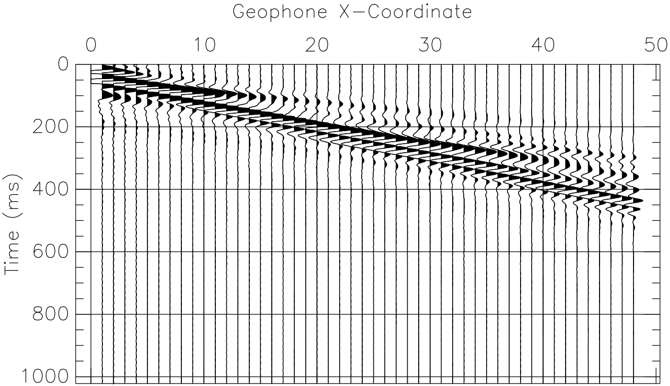
Semblance
Phase Velocity mgs
Frequency (Hz)
500
450
400
350
300
250
200
150
100
50
5
10
15
20
25
30
35
40
45
50
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

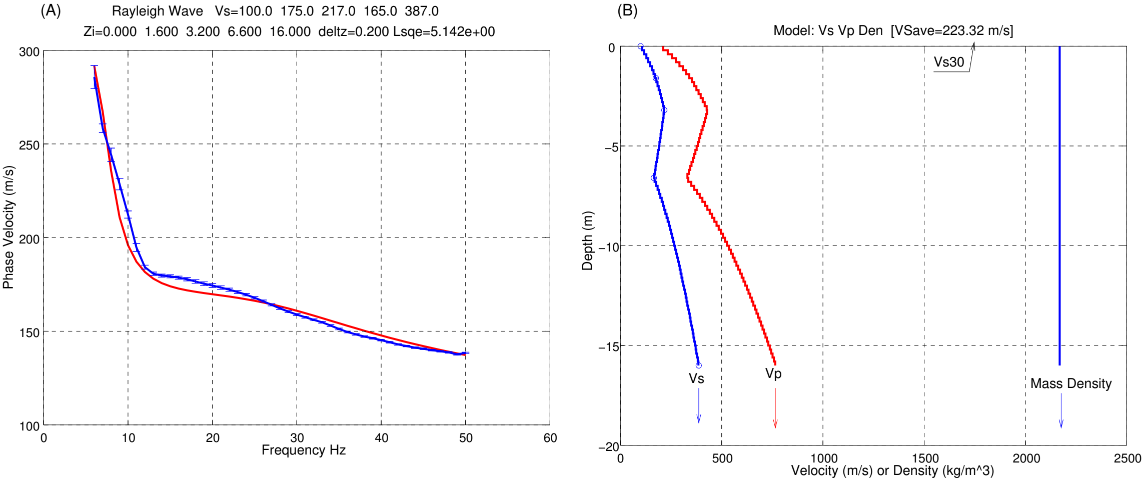


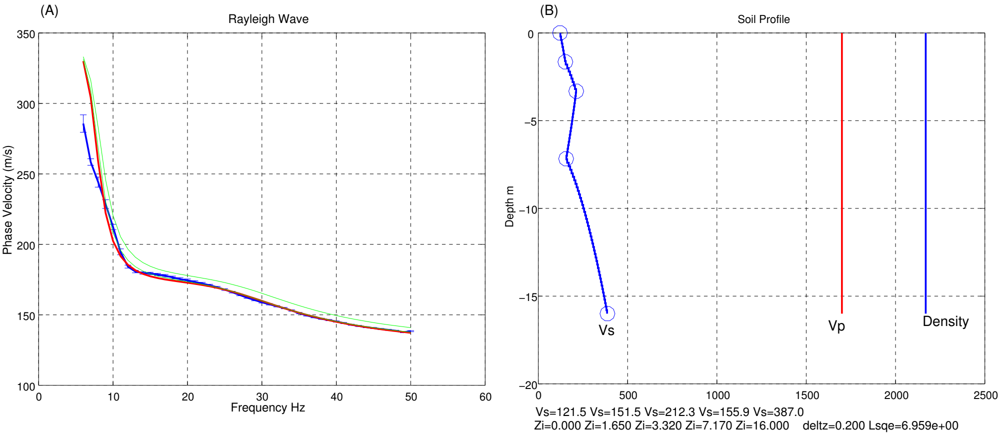
SV and P Velocities
depth (m)
0
−5
−10
−15
−20
−25
−30
0
200
400
600
800
1000
1200
1400
m/s
Mass Density
depth (m)
0
−5
−10
−15
−20
−25
−30
1.8
1.9
2
2.1
2.2
g/cm3

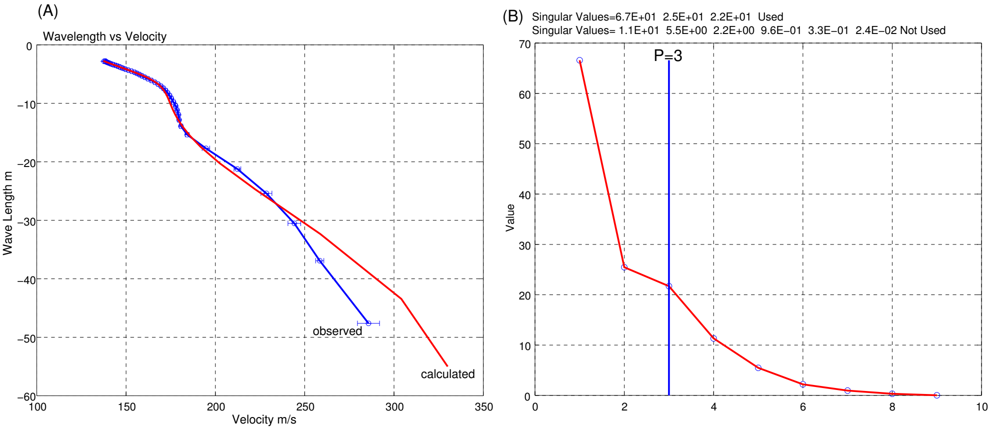

Dispersion: Phase Velocity
mode 1
mode 2
mode 3
mode 4
mode 5
mode 6
Fundamental Mode
Phase Velocity M/S
Frequency Hz
400
350
300
250
200
150
100
0
10
20
30
40
50
60

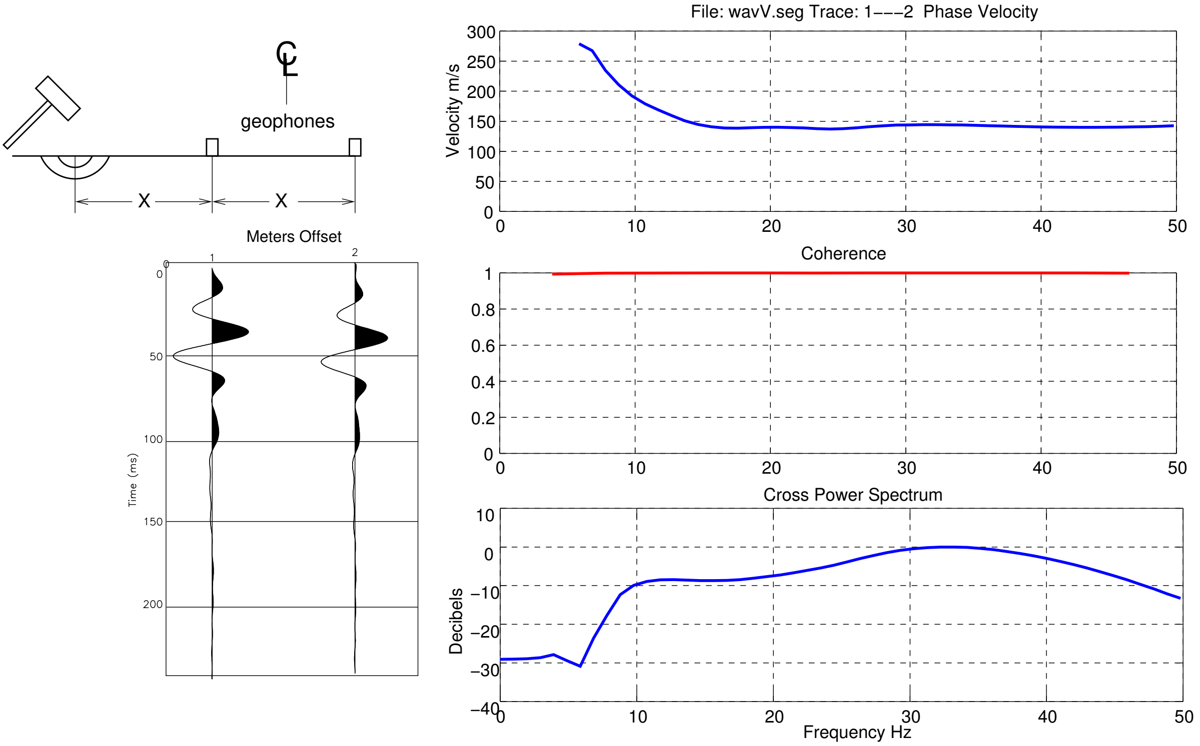

Rayleigh Wave source wavelet
0.04
0.02
0
−0.02
−0.04
−0.06
0
0.1
0.2
0.3
0.4
0.5
Time (s)
Amplitude Spectrum
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Frequency Hz


Geophone X−Coordinate
0
10
20
30
40
50
Time (ms)
0
200
400
600
800
1000


(A)
Rayleigh Wave Vs=100.0 175.0 217.0 165.0 387.0
Zi=0.000 1.600 3.200 6.600 16.000 deltz=0.200 Lsqe=5.142e+00
Phase Velocity (m/s)
Frequency Hz
300
250
200
150
100
0
10
20
30
40
50
60
(B)
Model: Vs Vp Den [VSave=223.32 m/s]
Vs30
Depth (m)
Vs
Vp
Mass Density
Velocity (m/s) or Density (kg/m^3)
0
−5
−10
−15
−20
0
500
1000
1500
2000
2500


(A)
Rayleigh Wave
Phase Velocity (m/s)
Frequency Hz
350
300
250
200
150
100
0
10
20
30
40
50
60
(B)
Soil Profile
Depth m
0
−5
−10
−15
−20
0
500
1000
1500
2000
2500
Vs
Vp
Density
Vs=121.5 Vs=151.5 Vs=212.3 Vs=155.9 Vs=387.0
Zi=0.000 Zi=1.650 Zi=3.320 Zi=7.170 Zi=16.000 deltz=0.200 Lsqe=6.959e+00


(A)
Wavelength vs Velocity
Wave Length m
Velocity m/s
observed
calculated
0
−10
−20
−30
−40
−50
−60
100
150
200
250
300
350
(B)
Singular Values=6.7E+01 2.5E+01 2.2E+01 Used
Singular Values= 1.1E+01 5.5E+00 2.2E+00 9.6E−01 3.3E−01 2.4E−02 Not Used
P=3
Value
70
60
50
40
30
20
10
0
0
2
4
6
8
10



File: wavV.seg Trace: 1---2 Phase Velocity
Velocity m/s
Coherence
Cross Power Spectrum
Decibels
Frequency Hz
geophones
X
X
Meters Offset
Time (ms)

$S_j(f)$

$S_k(f)$

$$G_{jk}(f) = S_j(f) \cdot \tilde{S}_k(f) \quad .$$

$G_{jk}(f)$

$$\phi(f)$$

$$t = T \cdot \phi(f)/2\pi \quad ,$$

T

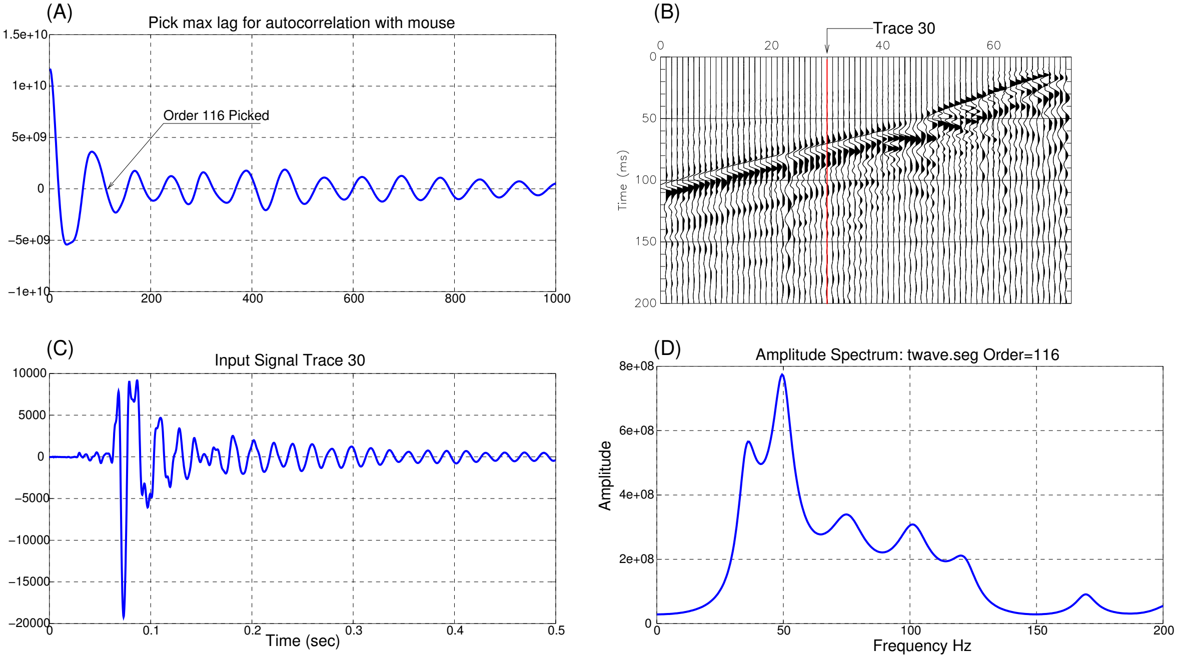
$$T = 1/f$$

$$V = \frac{X}{t} \quad ,$$

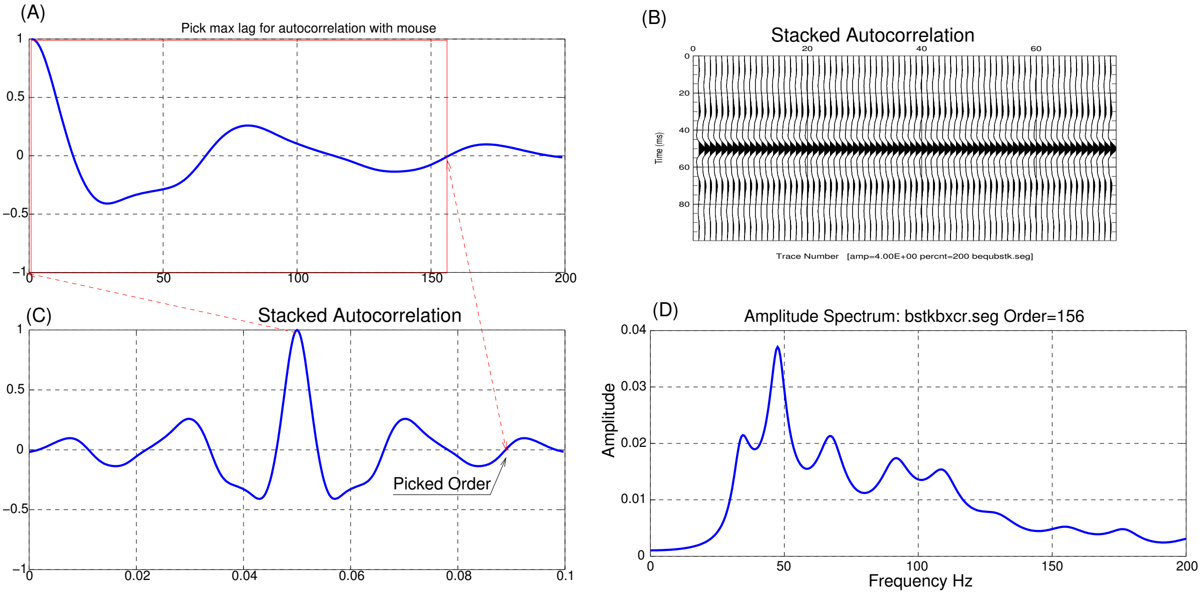
X

C

$$C = \frac{|G_{jk}(f)|^2}{G_{jj}(f) \cdot G_{kk}(f)} \quad .$$



(A)
Pick max lag for autocorrelation with mouse
Order 116 Picked
(B)
Trace 30
Time (ms)
(C)
Input Signal Trace 30
Time (sec)
(D)
Amplitude Spectrum: twave.seg Order=116
Amplitude
Frequency Hz


(A)
Pick max lag for autocorrelation with mouse
(B)
Stacked Autocorrelation
Time (ms)
Trace Number [amp=4.00E+00 percnt=200 bequbstk.seg]
(C)
Stacked Autocorrelation
Picked Order
(D)
Amplitude Spectrum: bstkbxcr.seg Order=156
Amplitude
Frequency Hz

$$\frac{1}{4}$$

$$\tau = \frac{V_s \cdot t}{R},$$

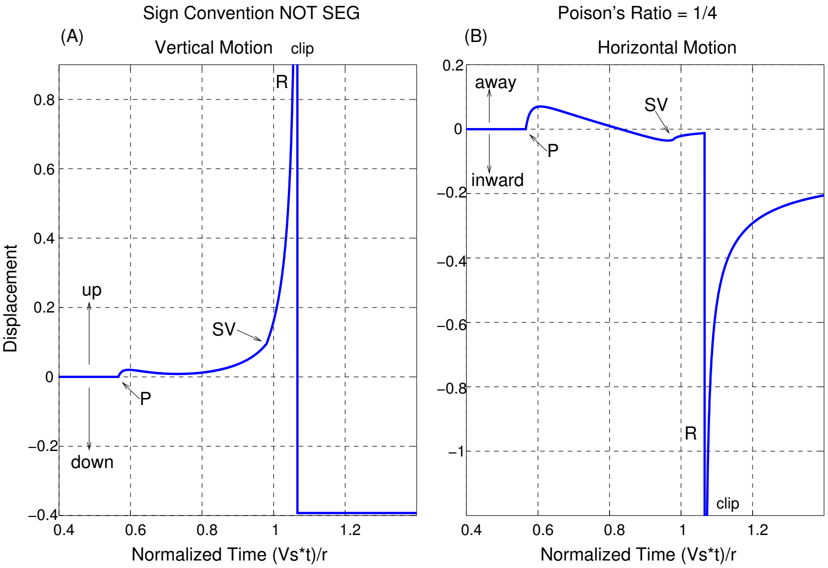
V_s

I_3

I_4

Solution to Lamb's Problem

(After Mooney, 1974)



$$\frac{V_p}{V_s} = \sqrt{3}$$

$$Y(z) = \frac{2}{\Delta t} \cdot \frac{(1-z)}{((1+stab)+z)} \cdot X(z),$$

$$y_j = \frac{\frac{2}{\Delta t}\left(x_j - x_{j-1}\right) - y_{j-1}}{(1 + stab)},$$

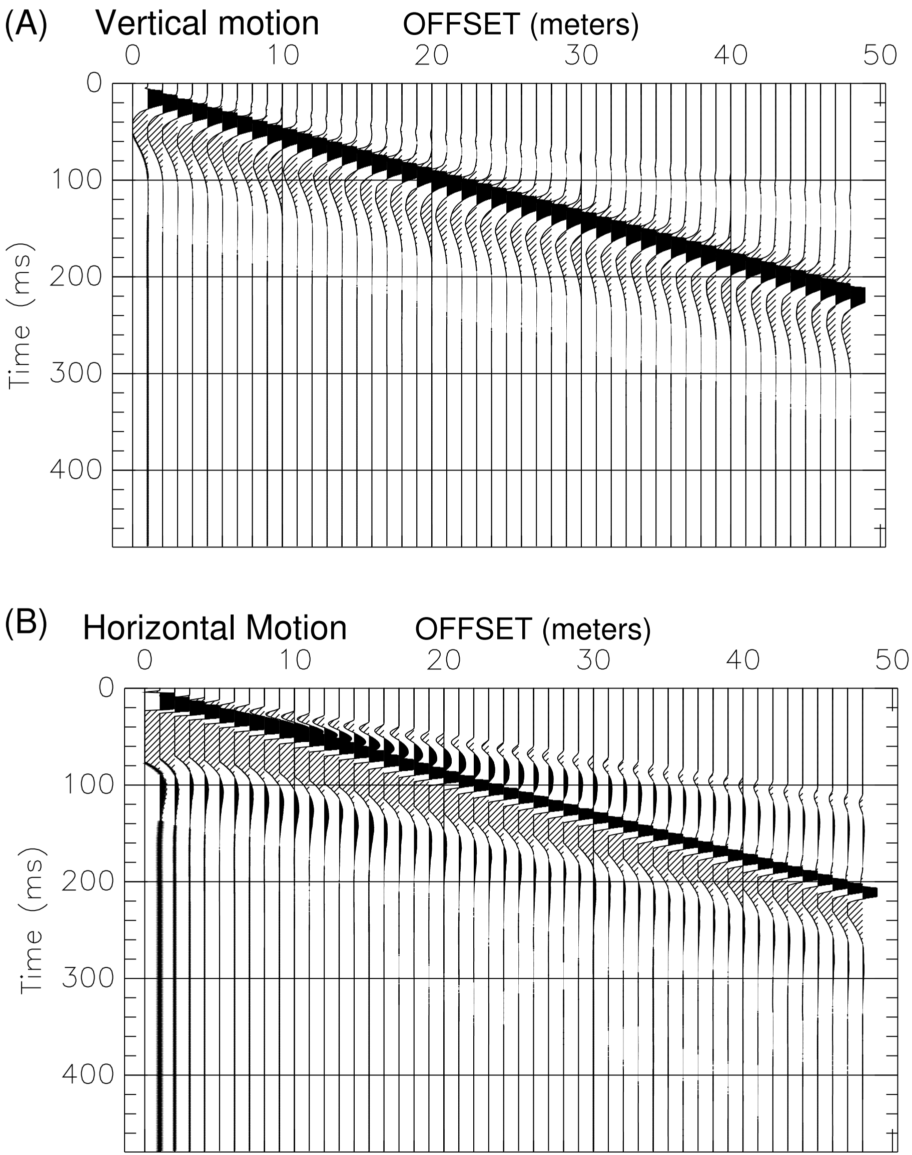
y_j

x_j

$$\frac{kg}{m^3}$$

$$V_s = 250$$

$$V_p = 433$$



(A)
Vertical motion
OFFSET (meters)
0
10
20
30
40
50
0
100
200
300
400
Time (ms)
(B)
Horizontal Motion
OFFSET (meters)
0
10
20
30
40
50
0
100
200
300
400
Time (ms)

$$X_o(t) = \exp(-\alpha t) \cdot \sin(2\pi f_c),$$

f_c

$$
\mathrm{u}_i(x,t) = \begin{array}{c} \frac{1}{4\pi\rho}\left(3\gamma_i\gamma_j - \delta_{ij}\right)\frac{1}{r^3}\int_{\frac{r}{\alpha}}^{\frac{r}{\beta}} \tau X_o(t-\tau)\,d\tau \\ +\frac{1}{4\pi\rho\alpha^2}\gamma_i\gamma_j\frac{1}{r}X_o\left(t-\frac{r}{\alpha}\right) \\ -\frac{1}{4\pi\beta^2}\left(\gamma_i\gamma_j - \delta_{ij}\right)\frac{1}{r}X_o\left(t-\frac{r}{\beta}\right) \end{array},
$$

β

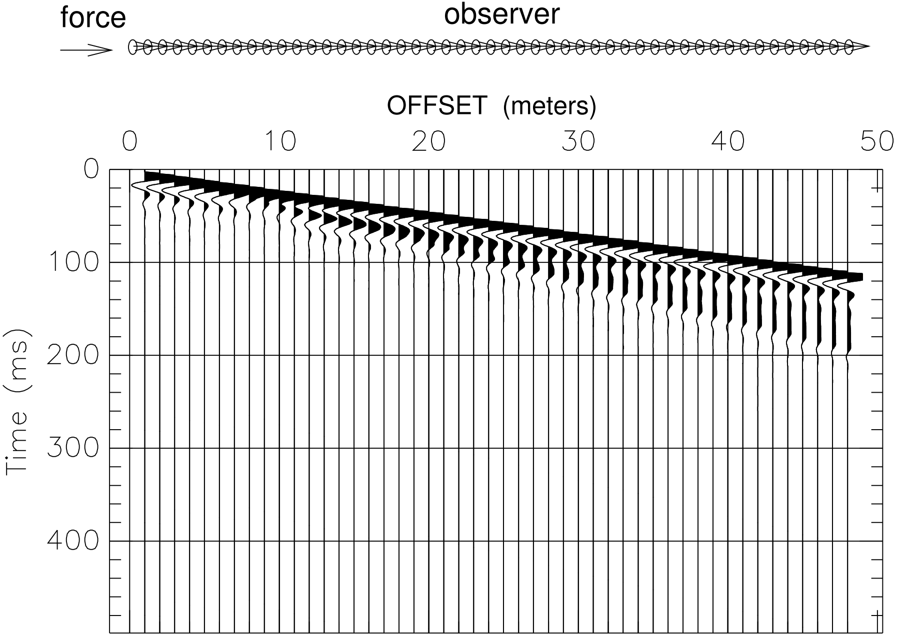
$$\gamma_i = \frac{x_i}{r}$$

ρ

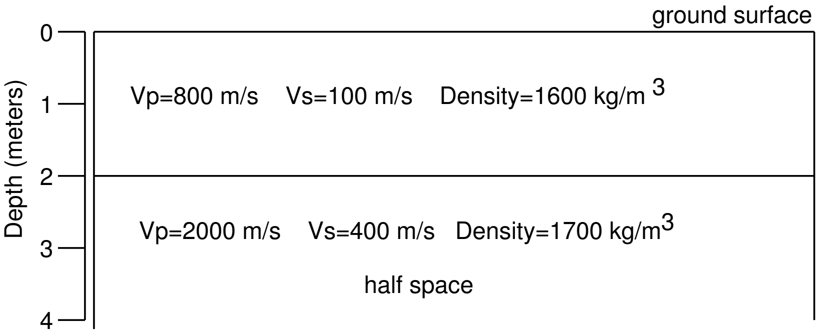
u_i

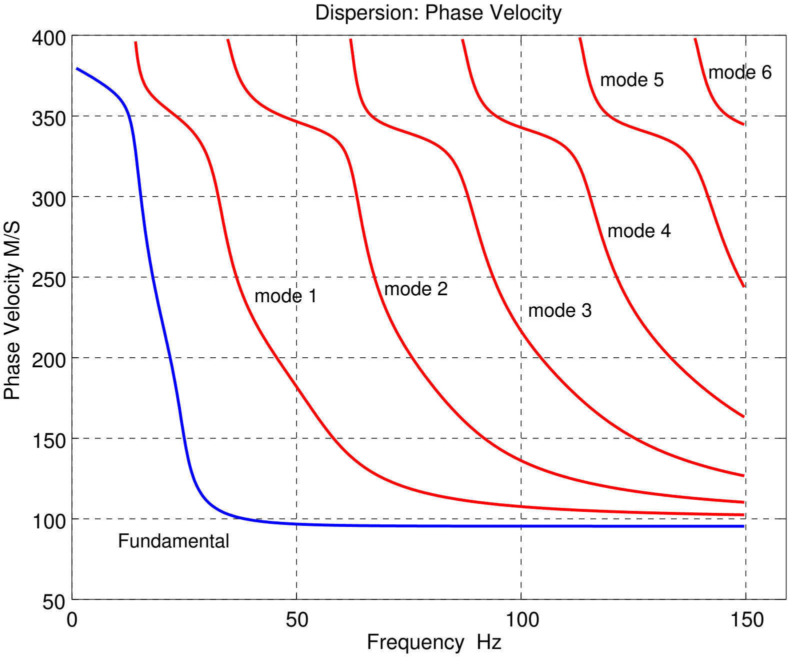
δ_{ij}

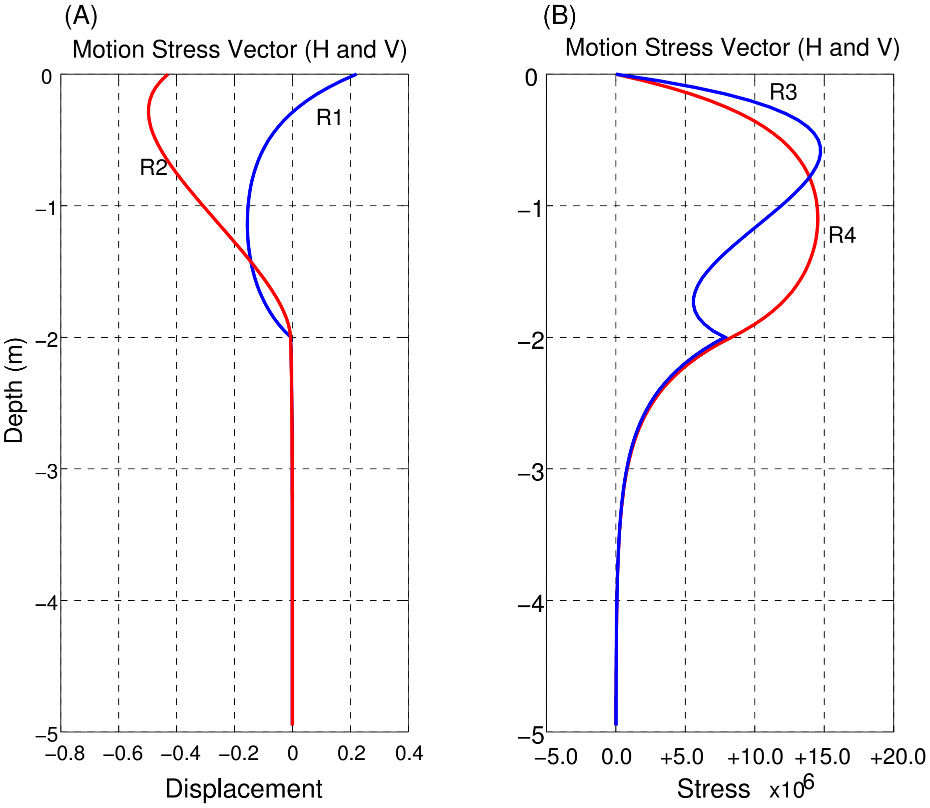
x_1


force
observer
OFFSET (meters)
0
10
20
30
40
50
0
100
200
300
400
Time (ms)

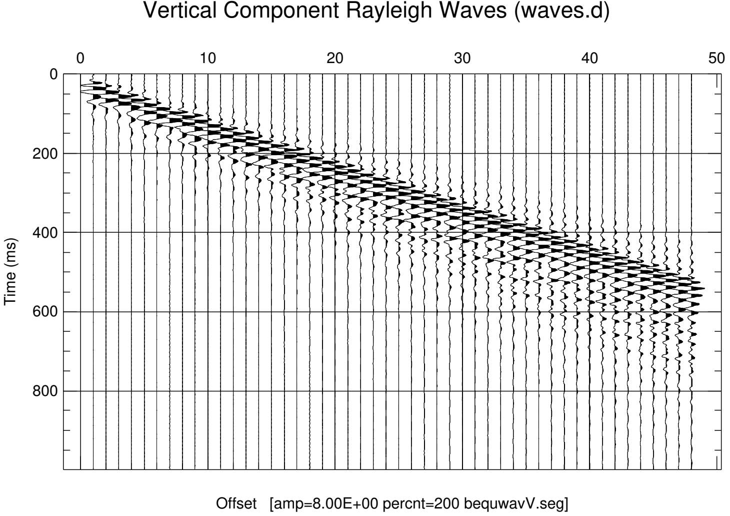
$$\Delta f = \frac{1}{N \Delta t}$$


ground surface
0
1
2
3
4
Depth (meters)
Vp=800 m/s Vs=100 m/s Density=1600 kg/m 3
Vp=2000 m/s Vs=400 m/s Density=1700 kg/m3
half space

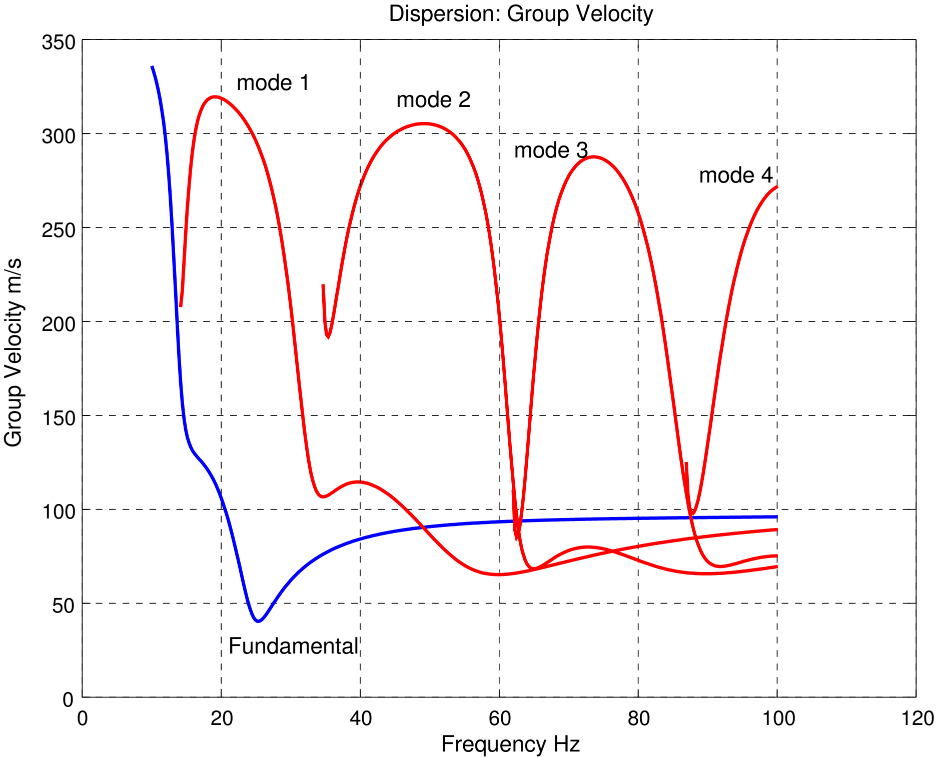

Dispersion: Phase Velocity
Phase Velocity M/S
400
350
300
250
200
150
100
50
0
50
100
150
Frequency Hz
Fundamental
mode 1
mode 2
mode 3
mode 4
mode 5
mode 6

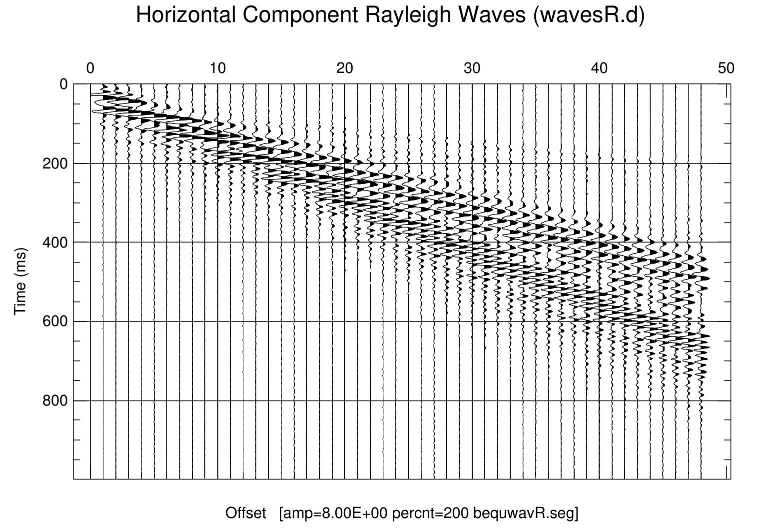


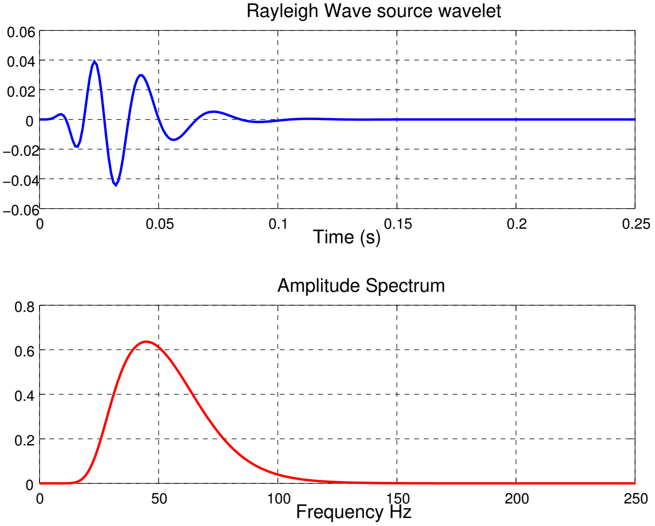
(A)
Motion Stress Vector (H and V)
R1
R2
Depth (m)
Displacement
0
−1
−2
−3
−4
−5
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
(B)
Motion Stress Vector (H and V)
R3
R4
0
−1
−2
−3
−4
−5
−5.0
0.0
+5.0
+10.0
+15.0
+20.0
Stress x10^6



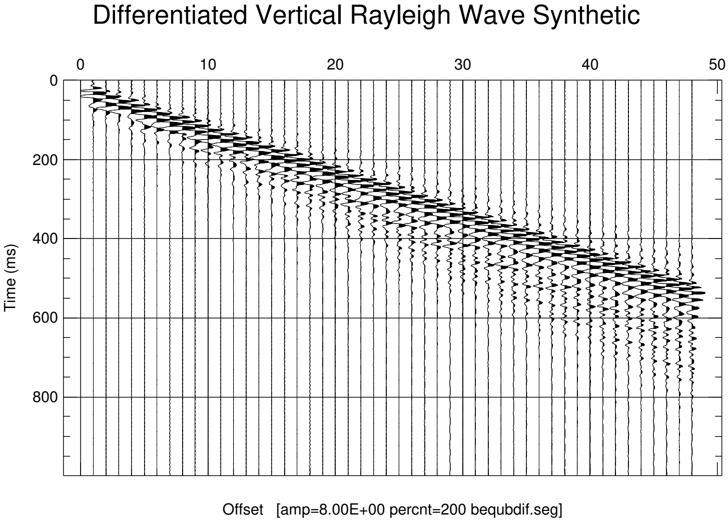
Vertical Component Rayleigh Waves (waves.d)
0
10
20
30
40
50
0
200
400
600
800
Time (ms)
Offset [amp=8.00E+00 percnt=200 bequwavV.seg]


Dispersion: Group Velocity
Group Velocity m/s
Frequency Hz
mode 1
mode 2
mode 3
mode 4
Fundamental
0
50
100
150
200
250
300
350
0
20
40
60
80
100
120


Horizontal Component Rayleigh Waves (wavesR.d)
0
10
20
30
40
50
0
200
400
600
800
Time (ms)
Offset [amp=8.00E+00 percnt=200 bequwavR.seg]



Rayleigh Wave source wavelet
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
0
0.05
0.1
0.15
0.2
0.25
Time (s)
Amplitude Spectrum
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
Frequency Hz



Differentiated Vertical Rayleigh Wave Synthetic
0
10
20
30
40
50
0
200
400
600
800
Time (ms)
Offset [amp=8.00E+00 percnt=200 bequbdif.seg]

$$Z = -1$$

$$Z = -(1 + stab)$$

stab

$$stab = 0.1$$

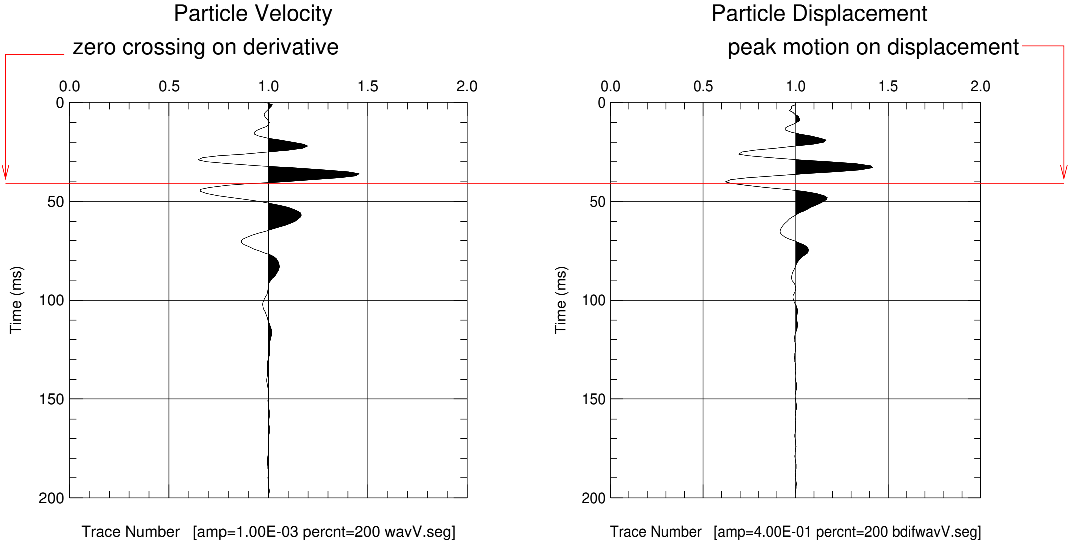
$$0.1 < stab < .5$$

$$Y(Z) = \frac{2}{\Delta t} \cdot \frac{(1-Z)}{((1+stab)+Z)} \cdot X(Z)$$

$$X(Z)$$

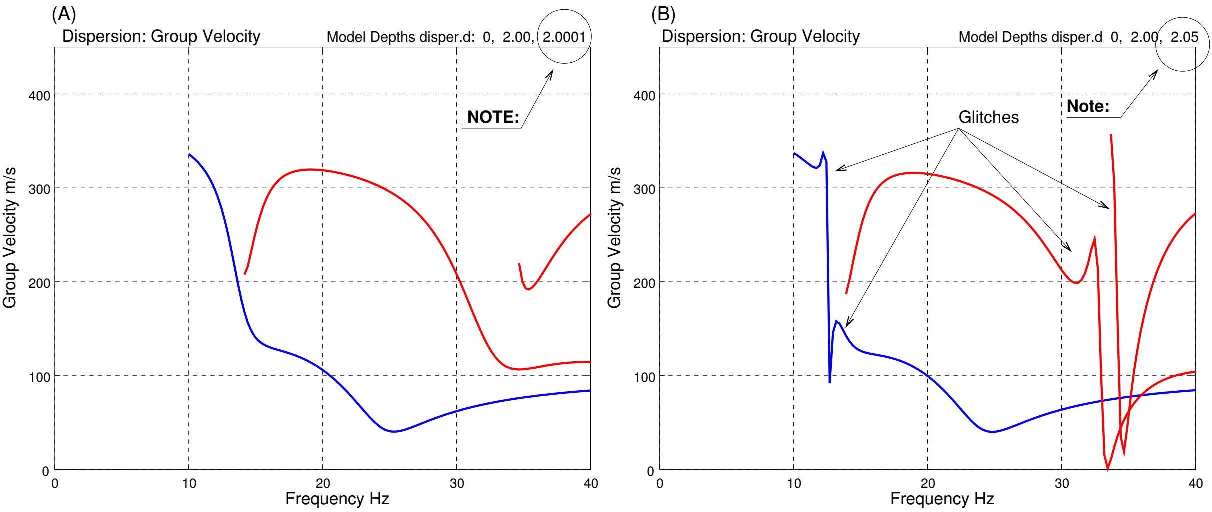
$Y(Z)$

$$y_j = \left(\frac{2}{\Delta t} \cdot \left(x_j - x_{j-1} \right) - y_{j-1} \right) / \left(1 + stab \right) \quad .$$

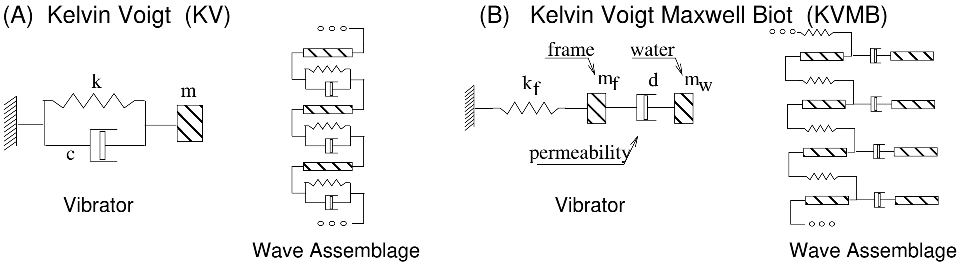

Particle Velocity
zero crossing on derivative
Particle Displacement
peak motion on displacement
0.0
0.5
1.0
1.5
2.0
0
50
100
150
200
Time (ms)
Trace Number [amp=1.00E-03 percnt=200 wavV.seg]
Trace Number [amp=4.00E-01 percnt=200 bdifwavV.seg]

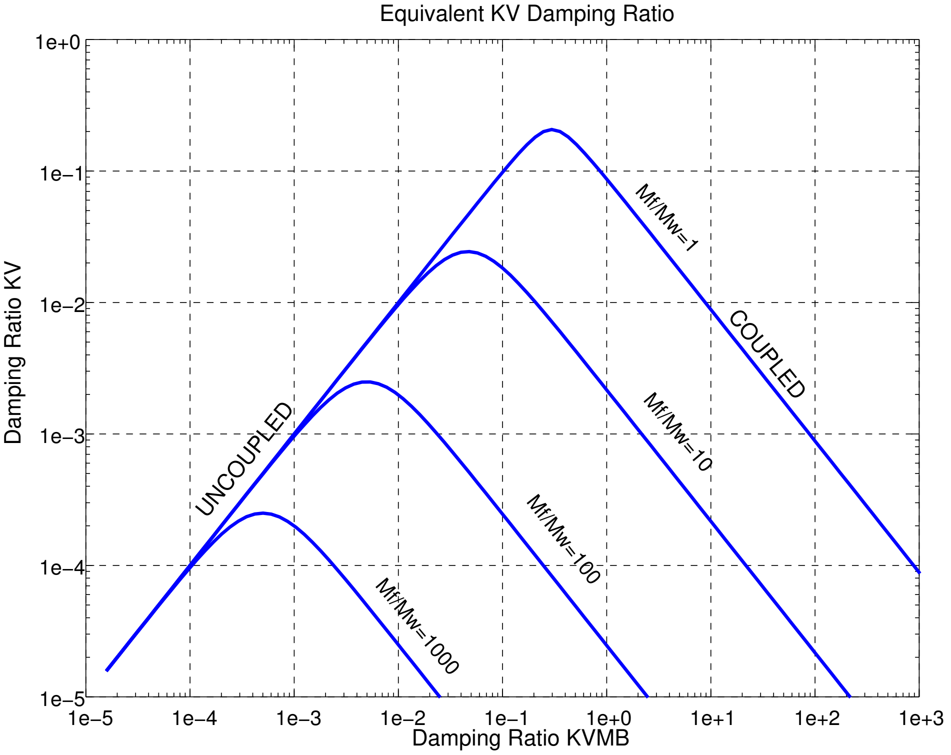
$$\Delta f = 1/(N\Delta t) = 1/tmax$$

$$\lambda = \frac{\beta_{minimum}}{f_{max}}$$



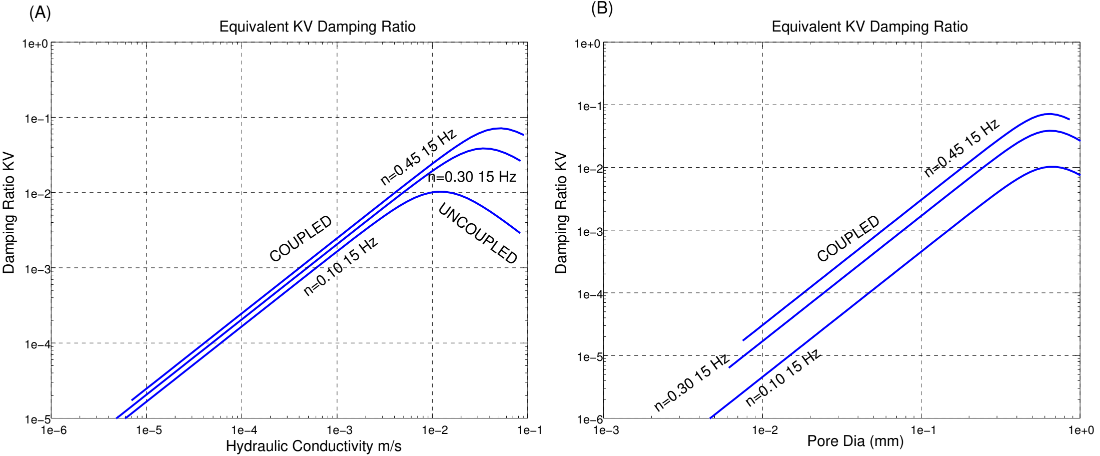
(A)
Dispersion: Group Velocity
Model Depths disper.d: 0, 2.00, 2.0001
NOTE:
Group Velocity m/s
Frequency Hz
0
100
200
300
400
0
10
20
30
40
(B)
Dispersion: Group Velocity
Model Depths disper.d 0, 2.00, 2.05
Glitches
Note:
Group Velocity m/s
Frequency Hz
0
100
200
300
400
0
10
20
30
40

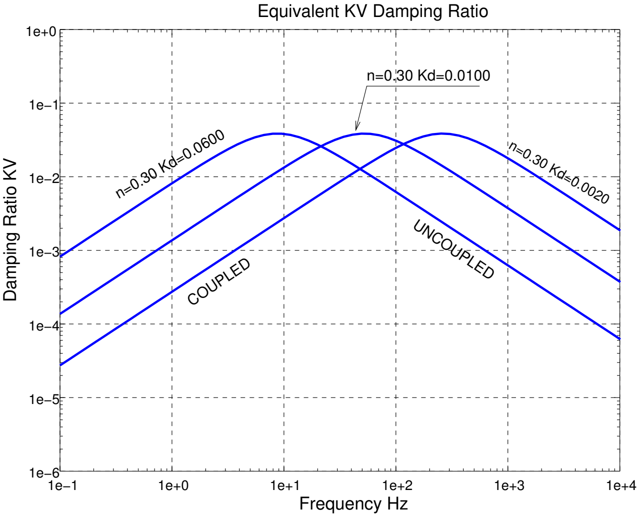

(A) Kelvin Voigt (KV)
k
m
c
Vibrator
Wave Assemblage
(B) Kelvin Voigt Maxwell Biot (KVMB)
frame
water
k_f
m_f
d
m_w
permeability
Vibrator
Wave Assemblage


Equivalent KV Damping Ratio
Damping Ratio KV
Damping Ratio KVMB
1e+0
1e−1
1e−2
1e−3
1e−4
1e−5
1e−5
1e−4
1e−3
1e−2
1e−1
1e+0
1e+1
1e+2
1e+3
UNCOUPLED
COUPLED
Mf/Mw=1
Mf/Mw=10
Mf/Mw=100
Mf/Mw=1000

$$\delta = \frac{D}{2\sqrt{K \cdot M}}$$

m^2


(A)
Equivalent KV Damping Ratio
Damping Ratio KV
Hydraulic Conductivity m/s
1e+0
1e−1
1e−2
1e−3
1e−4
1e−5
1e−6
1e−5
1e−4
1e−3
1e−2
1e−1
n=0.45 15 Hz
n=0.30 15 Hz
n=0.10 15 Hz
COUPLED
UNCOUPLED
(B)
Equivalent KV Damping Ratio
Damping Ratio KV
Pore Dia (mm)
1e+0
1e−1
1e−2
1e−3
1e−4
1e−5
1e−6
1e−3
1e−2
1e−1
1e+0
n=0.45 15 Hz
n=0.30 15 Hz
n=0.10 15 Hz
COUPLED



Equivalent KV Damping Ratio
Damping Ratio KV
Frequency Hz
1e+0
1e−1
1e−2
1e−3
1e−4
1e−5
1e−6
1e−1
1e+0
1e+1
1e+2
1e+3
1e+4
n=0.30 Kd=0.0100
n=0.30 Kd=0.0600
n=0.30 Kd=0.0020
COUPLED
UNCOUPLED

$$\frac{\partial^2 u}{\partial t^2} = C_1 \frac{\partial^2 u}{\partial z^2} + C_2 \frac{\partial^3 u}{\partial t \partial z^2}$$

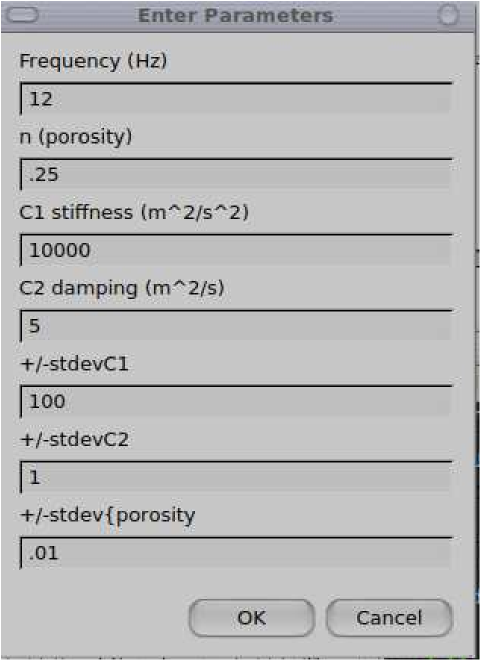
C_2/C_1

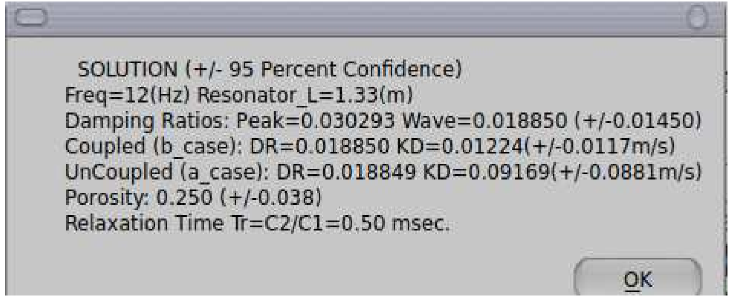
t

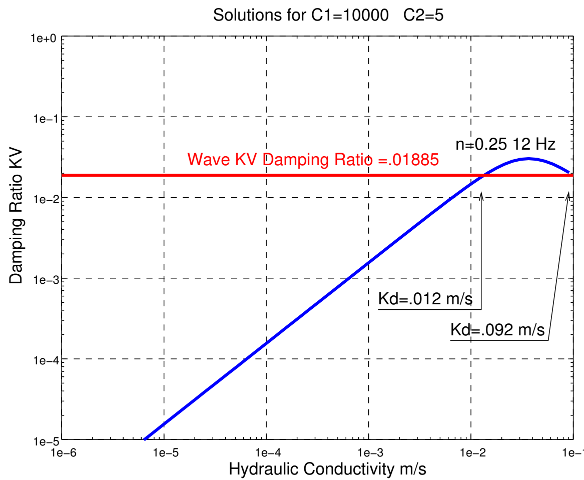
u

Z

$$K_d = .0122 m/s$$


Enter Parameters
Frequency (Hz)
12
n (porosity)
.25
C1 stiffness (m^2/s^2)
10000
C2 damping (m^2/s)
5
+/-stdevC1
100
+/-stdevC2
1
+/-stdev{porosity
.01
OK
Cancel


SOLUTION (+/- 95 Percent Confidence)
Freq=12(Hz) Resonator_L=1.33(m)
Damping Ratios: Peak=0.030293 Wave=0.018850 (+/-0.01450)
Coupled (b_case): DR=0.018850 KD=0.01224(+/-0.0117m/s)
UnCoupled (a_case): DR=0.018849 KD=0.09169(+/-0.0881m/s)
Porosity: 0.250 (+/-0.038)
Relaxation Time Tr=C2/C1=0.50 msec.
OK


Solutions for C1=10000 C2=5
Damping Ratio KV
1e+0
1e−1
1e−2
1e−3
1e−4
1e−5
n=0.25 12 Hz
Wave KV Damping Ratio =.01885
Kd=.012 m/s
Kd=.092 m/s
1e−6
1e−5
1e−4
1e−3
1e−2
1e−1
Hydraulic Conductivity m/s