Manual of Multi-Channel Analysis of Surface Waves (MASW)

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Toshiaki Yokoi

IISEE, BRI, Japan

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- 2. Field Data Acquisition
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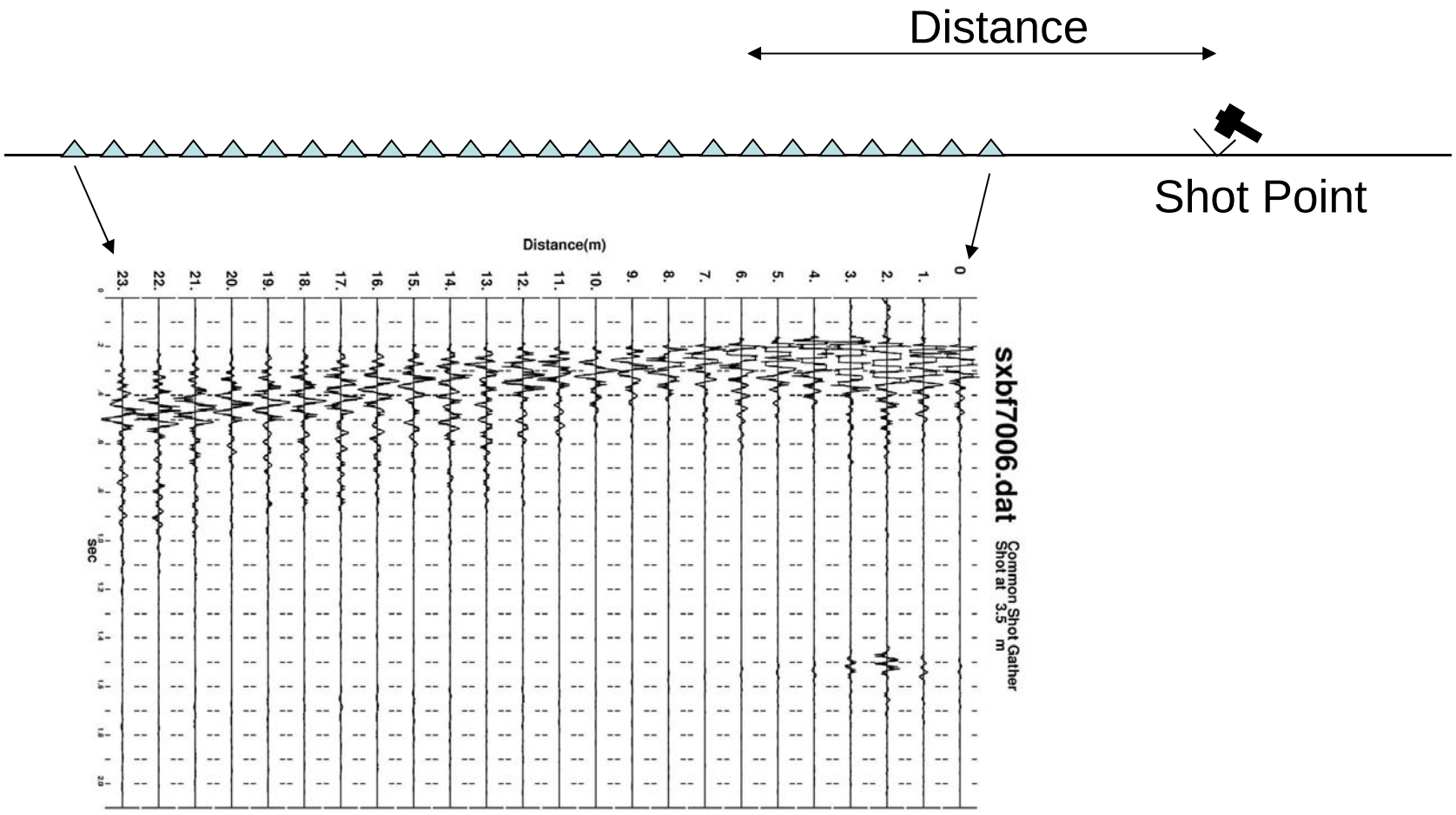
Note: This program package was developed on Linux: Ubuntu 12.04.1 LTS on 64 bit PC using gfortran compiler.
It has been tested also on Cygwin on Windows 8.1 (64bit) with re-compilation of the executable files.
Operation on other OS may require additional revision or correction by users themselves.

1. Instruction Manual of Programs for Analysis

Glossary: Common Shot Gather

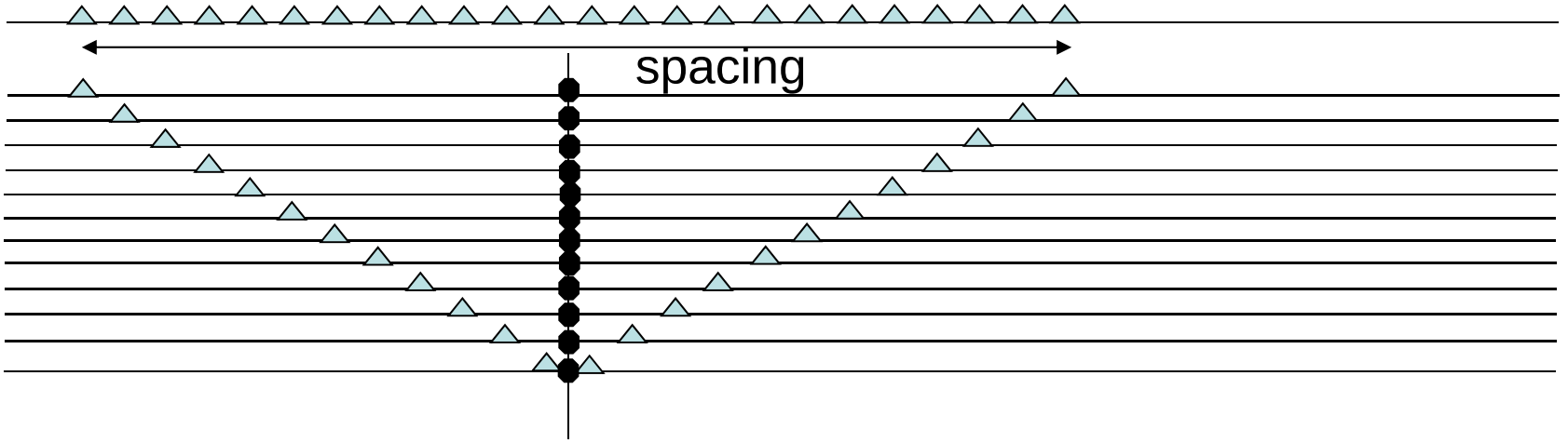
A group of seismic traces having the same shot point



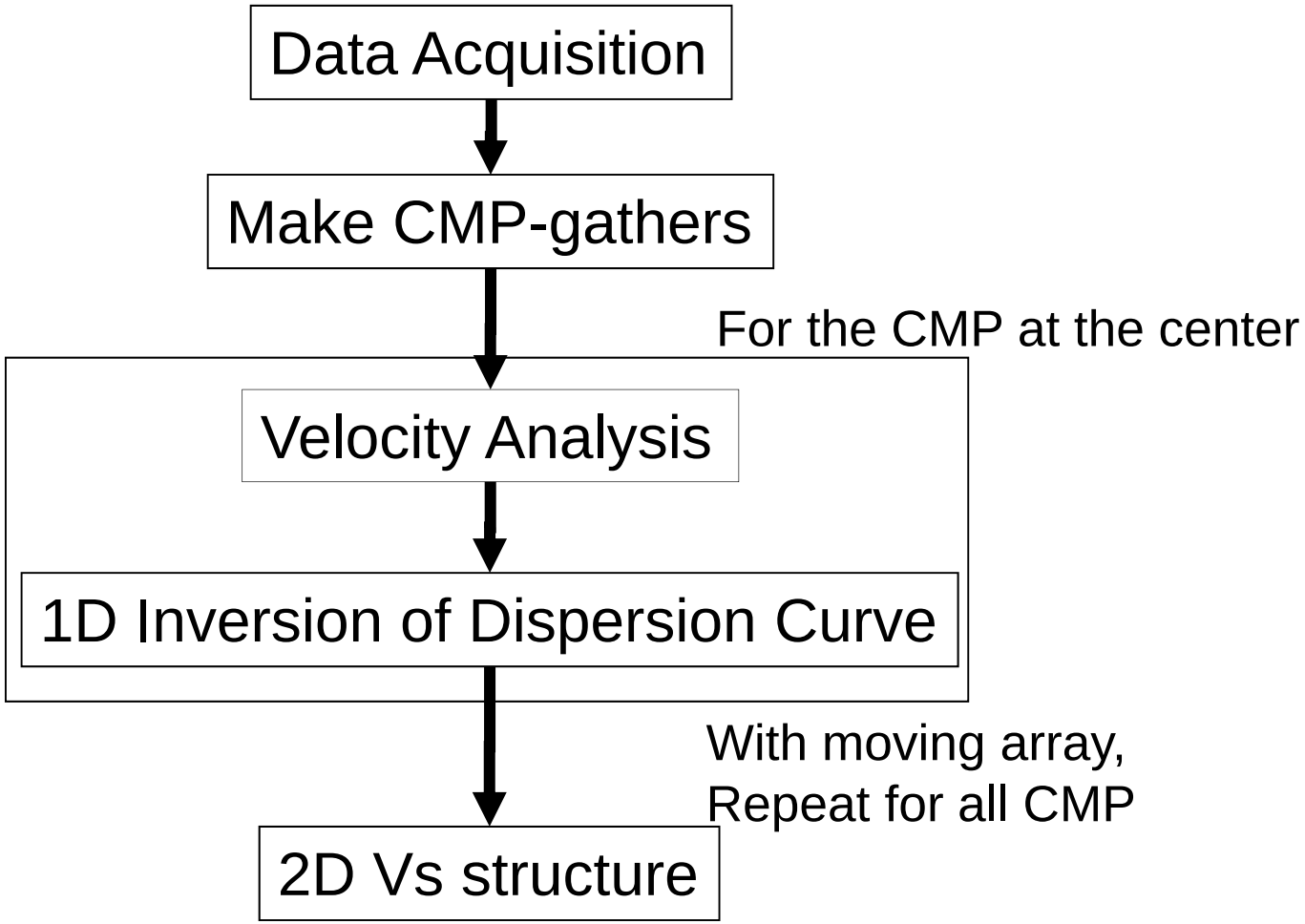
Glossary: Common Mid Point Gather

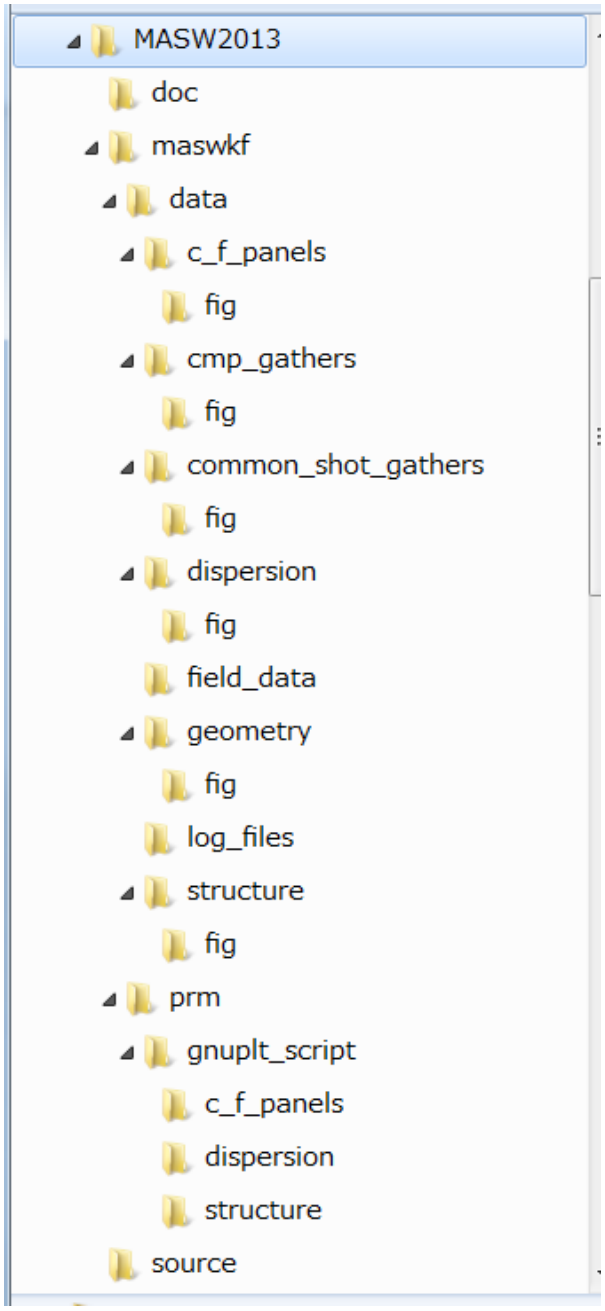
Usual definition: A group of seismic traces having the same mid point between shot and detector (geophone)

For MASW: A group of correlograms having the same mid point between a pair of detectors (geophone). A CMP gather includes correlograms of various spacing.



Task Flow of MASW





Folder Structure

Every necessary programs and files are stored under the folder “MASW2013”. The command operation is conducted in the same folder.

The source codes of the programs are stored in the subfolder “source”, whereas the subfolder “doc” includes document files including the instruction manual.

The subfolder “maswkf” contains the subfolder “prm” for parameter files including script files of GNUPLOT and the subfolder “data” for data files including graphic ones.

Note: GNUPLOT scripts files

The folder “MASW2013” includes the following files of GNUPLOT scripts.
disp_all
disp_cal_all
draw2d_plt
geometry
multi_cf
vel_cal_all
and others under the subfolder ./maswkf/prm/gnuplt_scripts
These can be loaded on GNUPLOT as load ‘????’

Some programs create the command strings of GNUPLOT in that the command
‘set terminal wxt’ ,
that works on the GNUPLOT on Windows. However, the GNUPLOT started from Cygwin X-terminal does not accept this command. This should be written as
‘set terminal X11’. Replace it and recompile the programs.

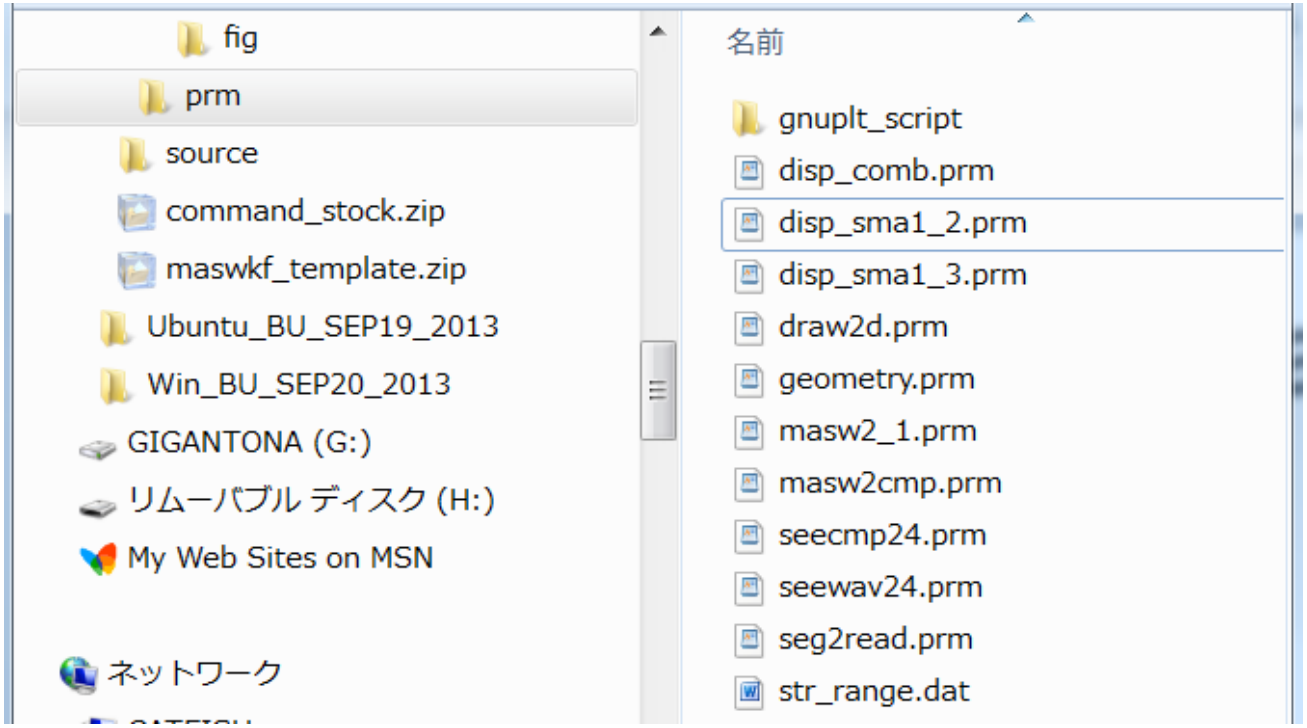
Note:

The folder “MASW2013” includes the special files: disp_comb & connect_all, that include a series of Linux commands. “execution” is permitted for these files.
This permission, however, can be broken when copied or unzipped on a different OS.
Then, it may be required to change the permission mode after coping.

chmod 777 disp_comb
chmod 777 connect_all

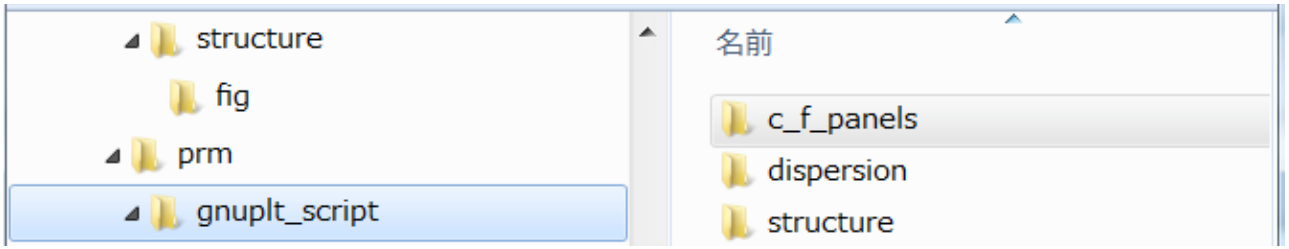
Note: Parameter files

All parameter files are stored in the subfolder “./maswkf/prm” and have their extension “.prm” except “str_range.dat”.
It is often required to modify these parameter files in the analysis explained in the following slides. Any text editor can be used, e.g., “gedit” on Ubuntu and/or “nedit” on Cygwin, notepad.exe on Windows XP etc..



Note: Script files of GNUPLOT

The subfolder “./maswkf/prm/gnuplt_script” includes the script files of GNUPLOT that are created during the analysis and used for the graphic outputs.These can be loaded on GNUPLOT as load ‘????’
Hereafter GNUPLOT scripts are written in red, whereas Linux(Ubuntu or Cygwin) commands are in blue.



There are some ways to use GNUPLOT with Linux (Ubuntu or Cygwin).

+ Working on Ubuntu using only one console window. GNUPLOT is started by gnuplot on the same console. Linux command can be executed on the GNUPLOT mode by putting “!” at the head of the command. For example, typing
  gnuplot> !pwd
  results the same as pwd on Linux command line.
+ Working on Ubuntu using two consoles: one for GNUPLOT scripts and another for Linux command line operation.
+ Working on Cygwin on Windows & GNUPLOT for Windows. Use them independently similar as above.

Note: Source Code Files

- All source code files are stored in the subfolder ./source .
- Type in
  gfortran ./source/XXX.for –o XXX.exe
  in the folder “MASW2013” for re-compilation, where XXX denotes Fortran source code file name.

1. Instruction Manual of Programs for Analysis

1.1 Data Format Conversion

The data acquisition equipment/software usually provides binary format files. It is necessary to convert them in ASCII text format. In this package, the format converter from seg2 standard is prepared. Note: this program can not process the data that includes AUX channel and/or more than 24 channels. Don’t use AUX channel in the field, or exclude it when the binary data files are converted to seg2 format.

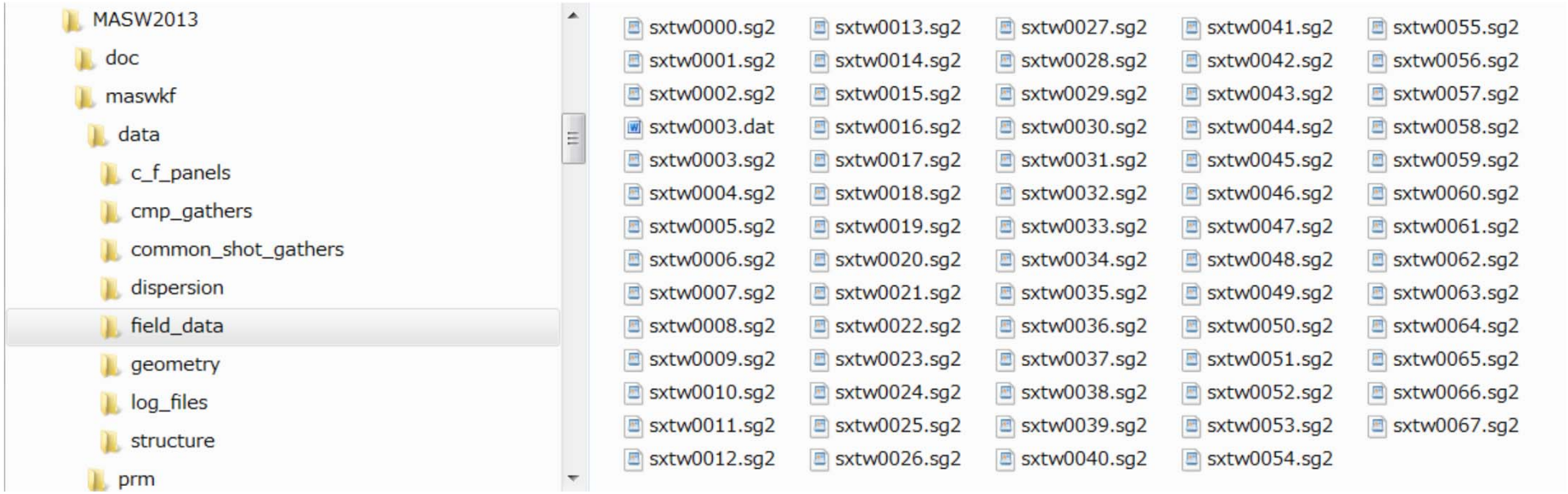
seg2read.for + seg2read.prm

If you need the re-mapping of channel configuration,

seg2readr1.for + seg2read.prm

However, it is necessary to modify the program depending of the pattern of re-mapping.

Copy the field data files in seg2 format into the subfolder ./maswkf/data/field_data



File name must consist of 4 alphabetic character, 4 integers with the extension ".sg2". These integers are used to represent the numbering of the shots applied in the field. Consecutive numbers are required for the convenience of the latter processing.

In the example above, the data set consists of 68 shot gathers (0000-0067)

Parameter file: seg2read.prm

```
sxtw00   :cname, '.sg2' is added for input seg2 format file.
 00  67  :measurement numbering for starts and ends
 0.E0  0 :scale factor, Gain of sensor V/(m/s)
24       :Channel number
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.

Explanation:
1st line : input file name (e.g., 'sxbg80'), '.sg2' is added for input file.
2nd line : measurement numbering for starts and ends
           e.g.,  (00 03)==>from sxbg0000.sg2 to sxbg0003.sg2 for input
3rd line : Scale factor (=0.,descaling factor in seg2 file is used),
           Gain of sensor V/(m/s) (=0. results in voltage output)
4th line :mch=number of channel in use. Channels from 1 to mch are processed
5th line :Comment(A80)
```

This example means that the seg2 format files from sxtw0000.sg2 to sxtw0067.sg2 that have 24 channels are converted to ASCII text format.

seg2readr1.for

This program works with “seg2read.prm” .
Channel configuration re-mapping is conducted using “data” statetment:

```
      data ncanal/1,2,3,4,5,6,7,8,9,10,11,12,
     *           24,23,22,21,20,19,18,17,16,15,14,13/
```

For this example,
Data of ch1 of the input file is re-mapped to ch1 itself for output,
…

ch12	is re-mapped to	ch12 itself for output,
ch13		ch24
ch14		ch23
…		
ch23		ch14
ch24		ch13 .

Change this statement & recompile the program when a different way of re-mapping is necessary from this example.

Run in the folder “MASW2013”

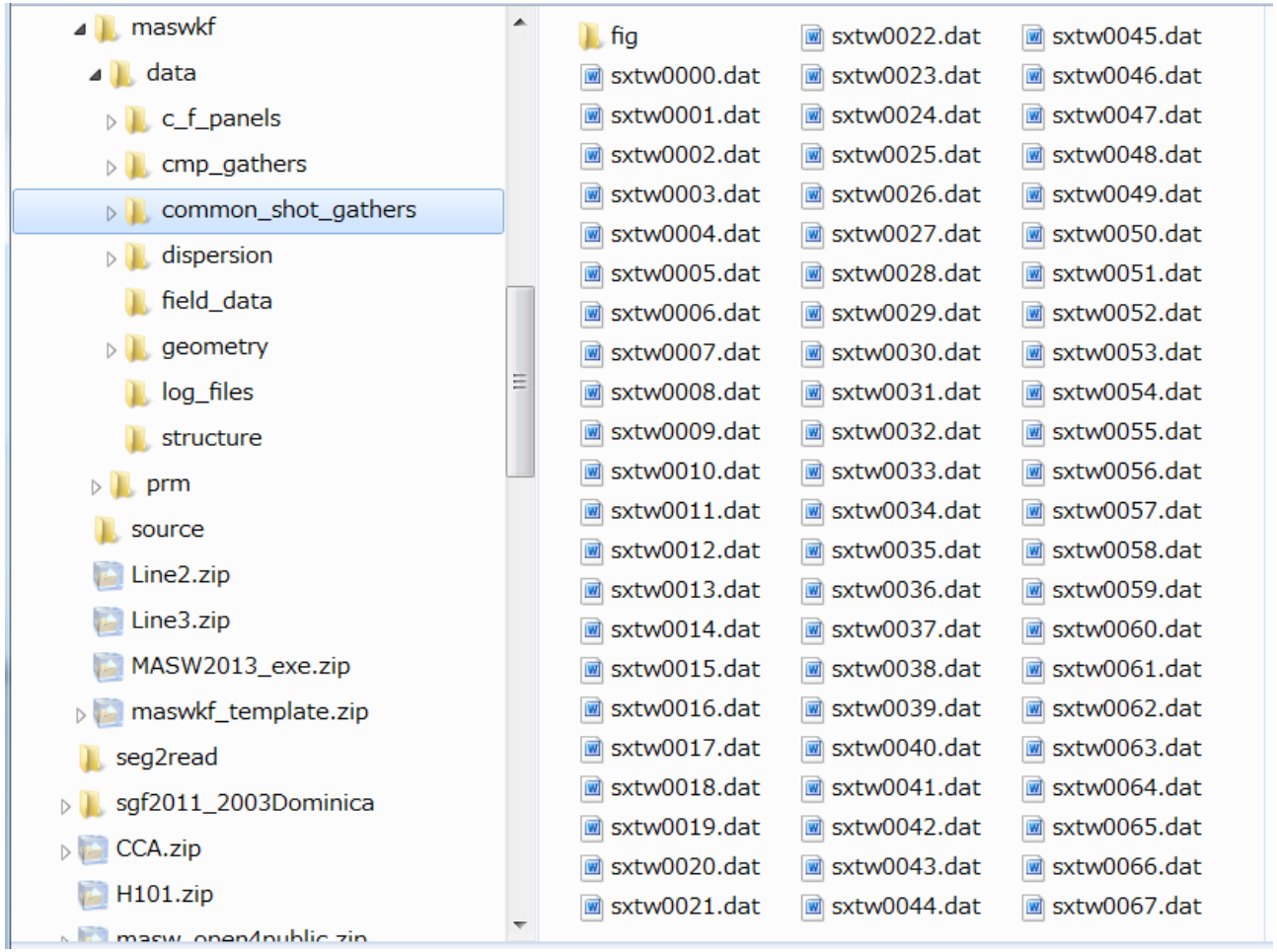
./seg2read.exe

Example of the output to the display.

```
sxtw00
Read Input file:sxtw0000.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
 Descaling factor=  0.(V/digit) is used.
Output to :sxtw0000.dat
Read Input file:sxtw0001.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0001.dat
Read Input file:sxtw0002.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0002.dat
Read Input file:sxtw0003.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0003.dat
Read Input file:sxtw0004.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0004.dat
Read Input file:sxtw0005.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0005.dat
Read Input file:sxtw0006.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0006.dat
Read Input file:sxtw0007.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0007.dat
Read Input file:sxtw0008.sg2:
 nch= 24 kch= 1 mch= 24 dt=  0.00100000005 nn= 1024
Output to :sxtw0008.dat
```

ヘルプを表示するには、F1 キーを押してください。

The converted files are stored in the subfolder ./maswkf/data/common_shot_gathers



Fortran statements used to write the output multi-channel files:

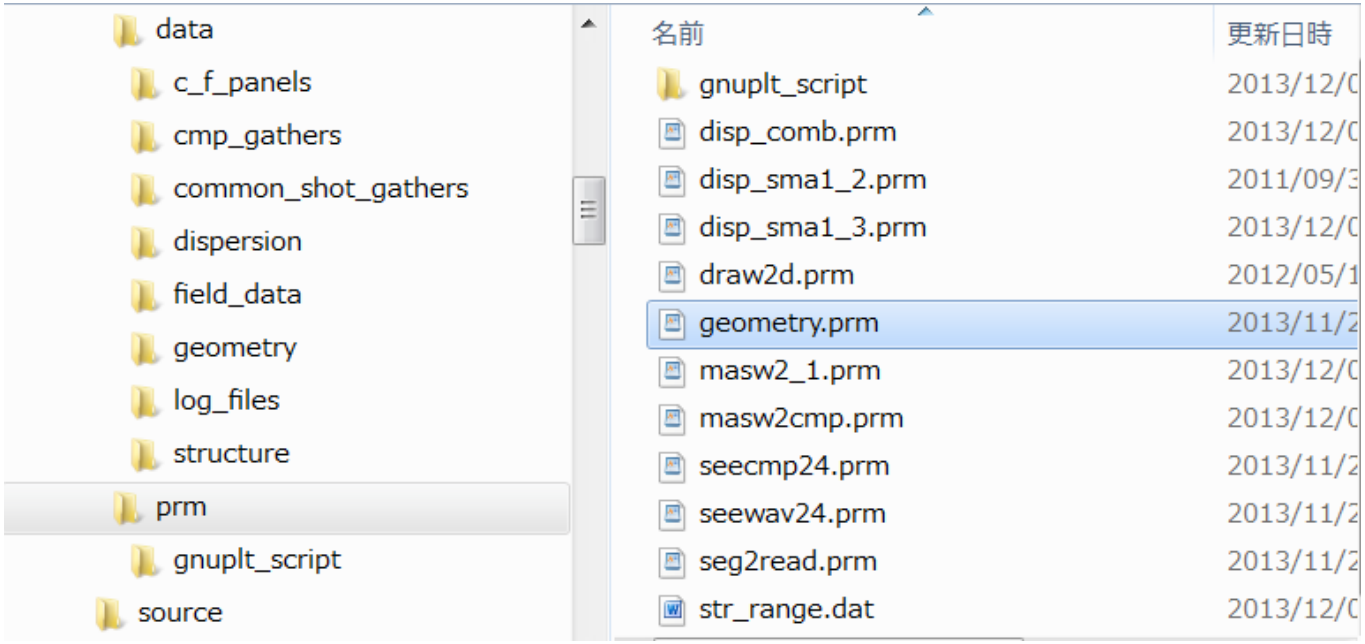
```
write(2,'(i8,f8.5,i8,e16.3)')nch,dt,nn,scale
do ich=kch,mch
   write(2,'(i12)')ich
   write(2,'(6e13.6)')(xx(i,ich)/scale,i=1,nn)
Enddo
```

```
 24 0.00100    1024       0.100E+01
           1
 0.300884E-03 0.334449E-03 0.351585E-03 0.357248E-03 0.357285E-03 0.355795E-03
 0.354305E-03 0.352852E-03 0.349760E-03 0.345215E-03 0.339180E-03 0.331730E-03
 0.322863E-03 0.312544E-03 0.300996E-03 0.288330E-03 0.274733E-03 0.260390E-03
 0.245340E-03 0.168659E-03 0.152491E-03 0.135988E-03 0.888929E-04 0.725389E-04
 0.413358E-04 0.183210E-04-0.791252E-05-0.335127E-04-0.622943E-04-0.751093E-04
-0.869930E-04-0.128351E-03-0.137925E-03-0.146195E-03-0.153236E-03-0.159122E-03
-0.164002E-03-0.167988E-03-0.171080E-03-0.173204E-03-0.174247E-03-0.174209E-03
-0.173092E-03-0.170968E-03-0.168025E-03-0.164375E-03-0.160202E-03-0.155509E-03
-0.150405E-03-0.144929E-03-0.139192E-03-0.133269E-03-0.127234E-03-0.905693E-04
-0.844598E-04-0.784248E-04-0.725016E-04-0.667647E-04-0.612140E-04-0.405163E-04
...
```

1. Instruction Manual of Programs for Analysis

1.2 Input manually the information of Field Geometry

Edit ./maswkf/prm/geometry.prm using any text editor, e.g., “gedit” on Ubuntu.



geometry.prm

```
MASW,LINE1,Iwaki City Office, Dec. 22, 2012.
68    1.                      :Number of files,dx(geophone interval)
sxtw0000.dat   -0.5   0.     :Input File Name (Common Shot Gather),shot position, position of 1ch
sxtw0001.dat    1.5   2.
sxtw0002.dat    3.5   4.
sxtw0003.dat    5.5   6.
sxtw0004.dat    7.5   8.
sxtw0005.dat    9.5  10.
sxtw0006.dat   11.5  12.
sxtw0007.dat   13.5  14.
sxtw0008.dat   15.5  16.
sxtw0009.dat   17.5  18.
sxtw0010.dat   19.5  20.
....
```

Explanation:

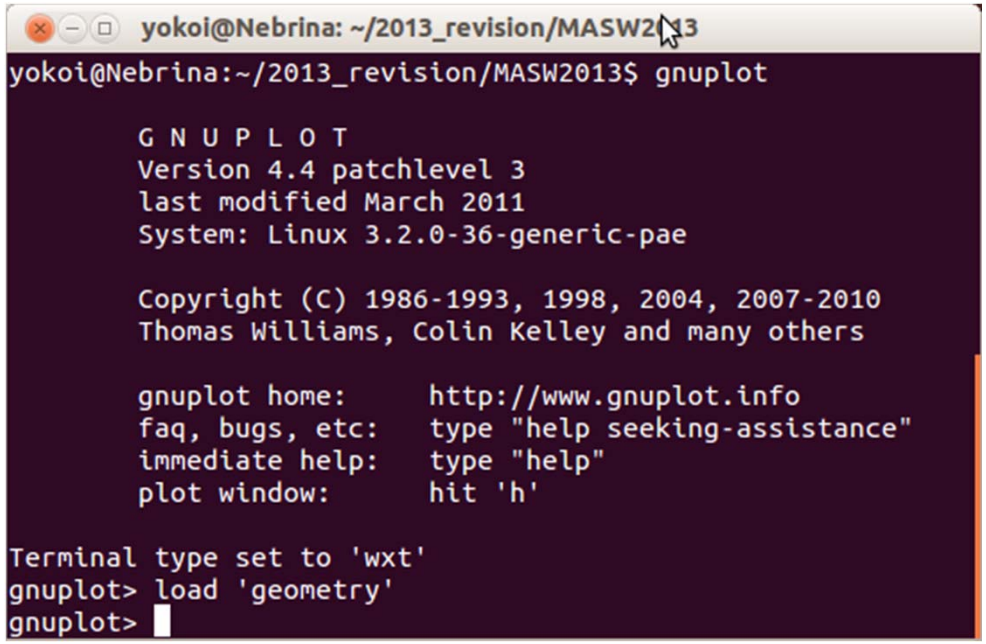
1st line: Comment (a80) that appears in all graphic outputs in the following procedures.
2nd line: Number of seg2 format files, geophone interval in meter
following lines: Input File Name (Common Shot Gather),shot position,
position of 1st channel

Drawing geometry in PostScript file by ./geometry_plt.exe and then by GNUPLOT

Run by
./geometry_plt.exe
On Linux (Ubuntu or Cygwin).
This creates three interim output files:
./maswkf/data/geometry/x_shot.dat:
./maswkf/data/geometry/x_cmp.dat:
./maswkf/data/geometry/x_sta.dat:

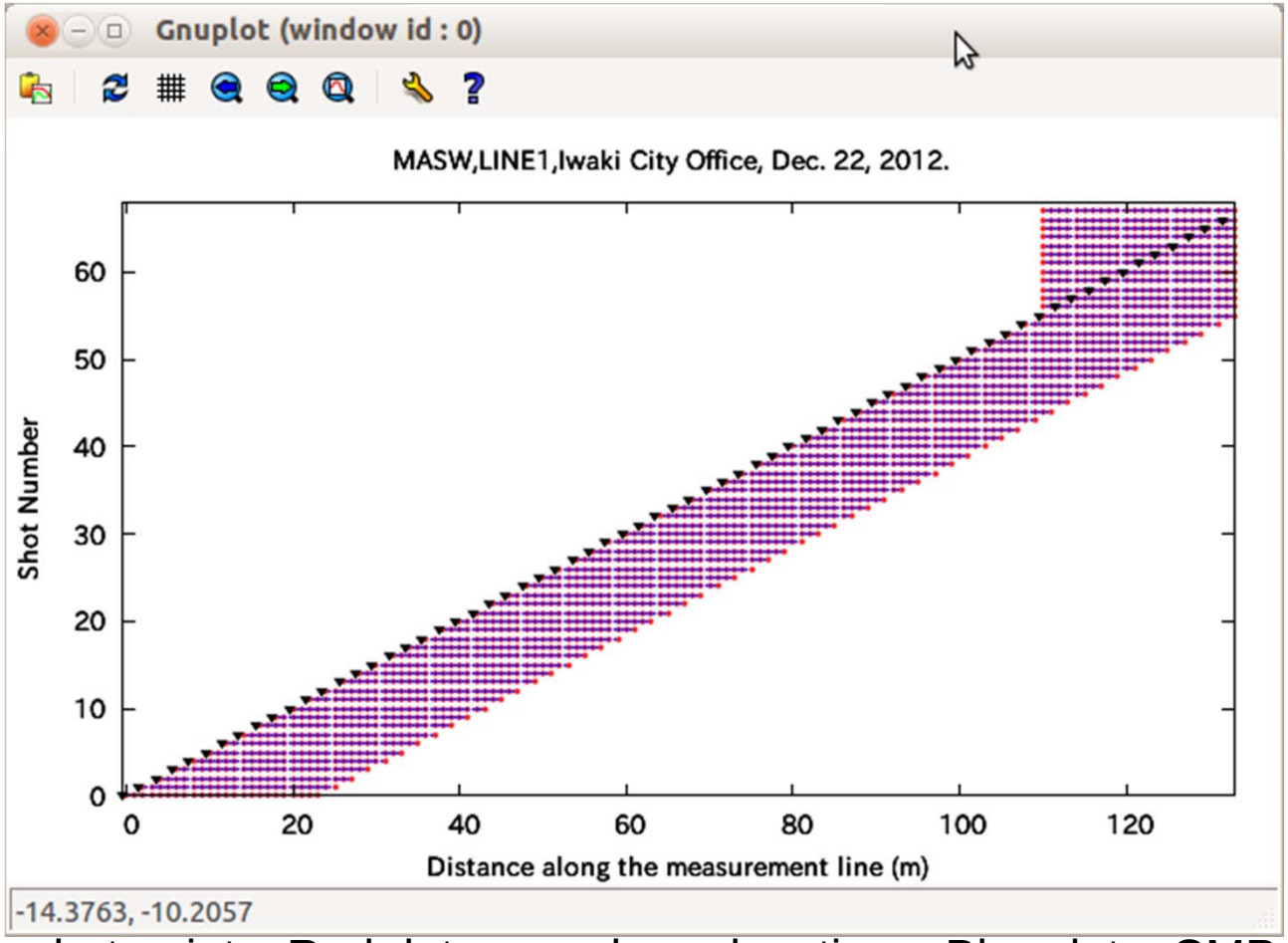
and a GNUPLOT script
./maswkf/prm/gnuplt_script/geometry.plt

Start GNUPLOT by “gnuplot”
and type in
load ‘geometry’



Then, a postscript file is created
./maswkf/data/geometry/fig/geometry.ps
Use Ghostview to open this PostScript file: “gv &” from Ubuntu command line
after quitting from GNUPLOT, or “!gv &” from GNUPLOT command line.

When the program is run, the drawing of geometry appears in a X-windows as shown below. Simultaneously, the same image is stored in the Postscript file ./maswkf/data/geometry/fig/geometry.ps



Triangles: shot points, Red dots: geophone locations, Blue dots: CMP location. Modify ./maswkf/prm/gnuplt_script/geometry.plt and load it again to change marks, titles, fonts sizes etc..

./maswkf/prm/gnuplt_script/geometry.plt: a script file of GNUPLOT

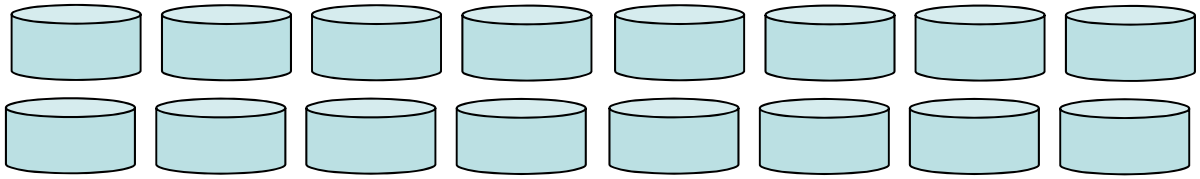
```
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012.  "
# Horizontal axis: label & range
set xlabel "Distance along the measurement line (m)"
set xrange [ -0.5:  133.]
# Verical axis: label & range
set ylabel "Shot Number"
set yrange [0:  68.]
set multiplot
plot "./maswkf/data/geometry/x_sta.dat" with points pt  6 ps .3 lc rgb "red"
plot "./maswkf/data/geometry/x_cmp.dat" with points pt  6 ps .1 lc rgb "blue"
plot "./maswkf/data/geometry/x_shot.dat" with points pt 11 ps .7 lc rgb "black"
unset multiplot
set terminal postscript color enhanced
set output "./maswkf/data/geometry/fig/geometry.ps"
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012.  "
# Horizontal axis: label & range
set xlabel "Distance along the measurement line (m)"
set xrange [ -0.5:  133.]
# Verical axis: label & range
set ylabel "Shot Number"
set yrange [0:  68.]
set multiplot
plot "./maswkf/data/geometry/x_sta.dat" with points pt  6 ps .3 lc rgb "red"
plot "./maswkf/data/geometry/x_cmp.dat" with points pt  6 ps .1 lc rgb "blue"
plot "./maswkf/data/geometry/x_shot.dat" with points pt 11 ps .7 lc rgb "black"
unset multiplot
set output
set terminal wxt
```

1. Instruction Manual of Programs for Analysis

1.3 Plotting Common Shot Gathers

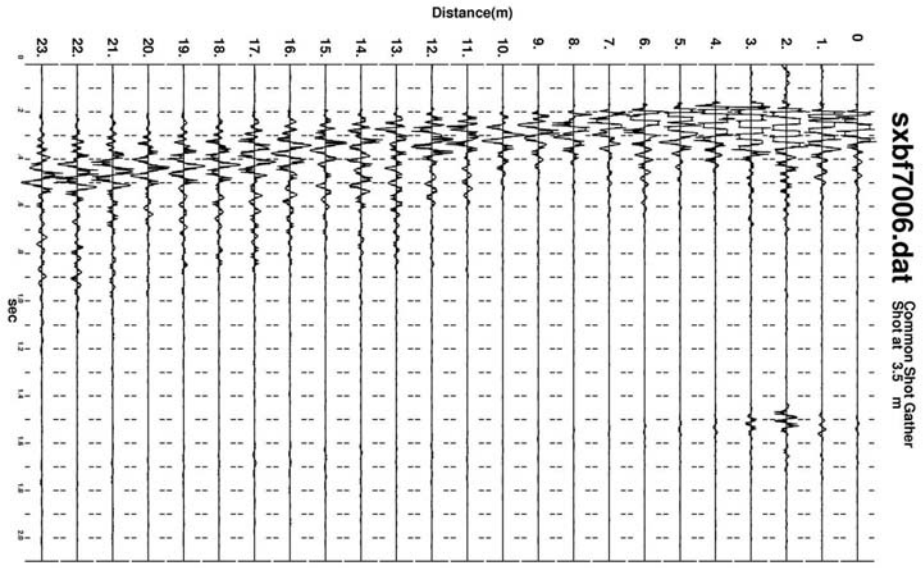
seewav24.for + seewav24.prm

Field Data = Common Shot Gathers



seewav24.for

+ seewav24.prm



Plot the paste-up of 24 Channel traces

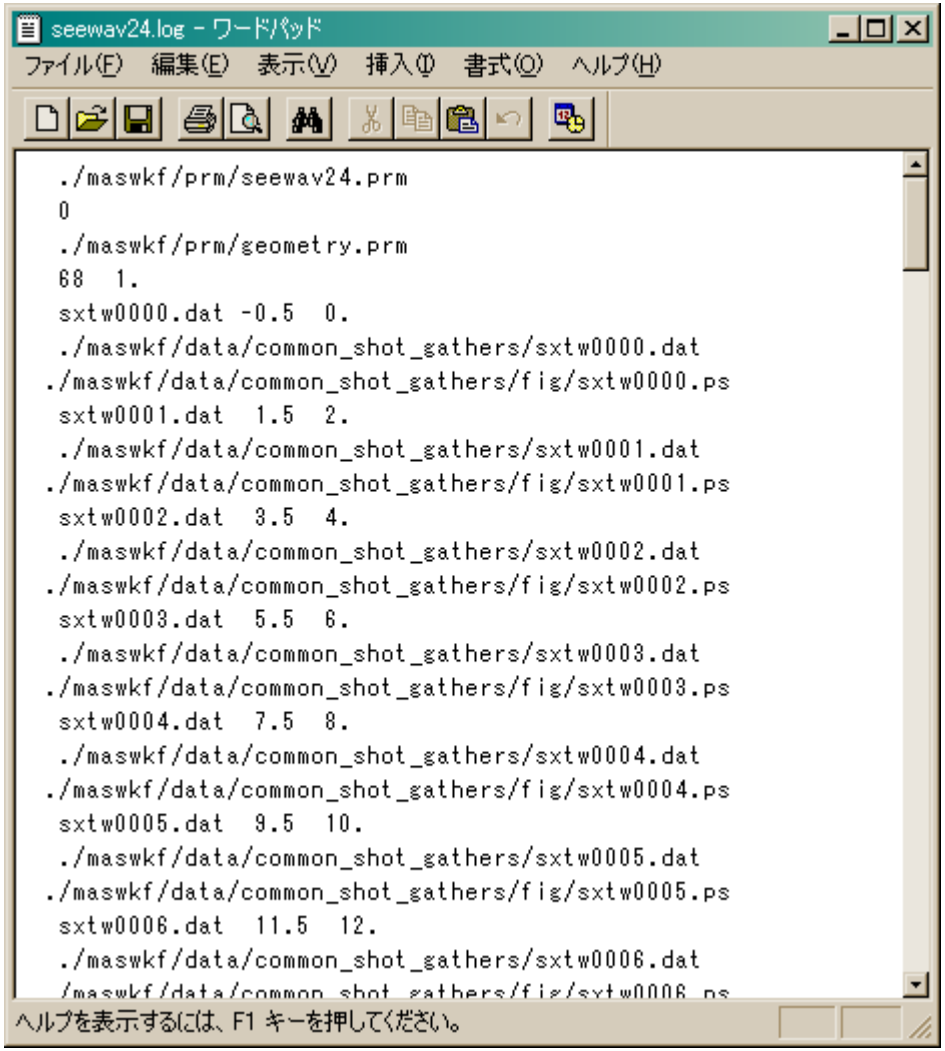
Draw paste-up of common shot gathers by
./seewav24.exe

This program uses the parameter file
./maswkf/prm/seewav24.prm
and the geometry information
./maswkf/prm/geometry.prm
to draw the paste-up of all common shot gathers
in the PostScript files stored in the subfolder
./maswkf/data/common_shot_gathers/fig

Use Ghostview to plot these PostScript files: gv &.

Parameter File: seewav24.prm

0 :Flag for normalizing(=0; by max. of each ch,=1: by max. of all ch)



Example of the output to CRT.

Input File Format

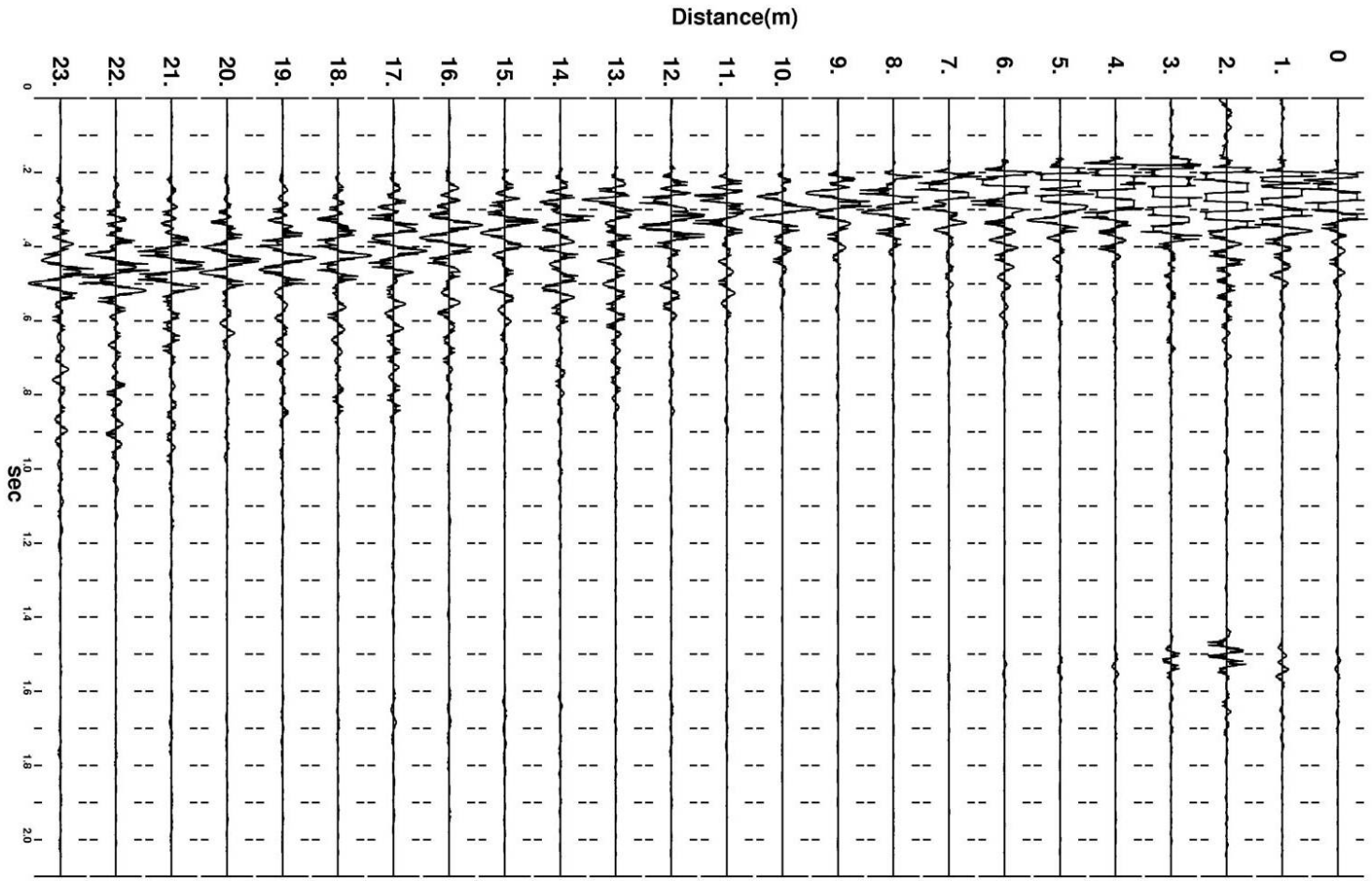
```
 24 0.00100    1024       0.100E+01
         1
0.300884E-03 0.334449E-03 0.351585E-03 0.357248E-03 0.357285E-03 0.355795E-03
0.354305E-03 0.352852E-03 0.349760E-03 0.345215E-03 0.339180E-03 0.331730E-03
0.322863E-03 0.312544E-03 0.300996E-03 0.288330E-03 0.274733E-03 0.260390E-03
…
```

1st line: Number of channels, dt, number of samples, scale factor
2nd line: channel number
3rd line: data
Below:

Writing sentences in the program (seg2read.for) used when these files were created.

```
write(2,'(i8,f8.5,i8,e16.3)')nch,dt,nn,scale
      do ich=1,mch
       write(2,'(i12)')ich
       write(2,'(6e13.6)')(xx(i,ich)/scale,i=1,nn)
      enddo
```

Example of Common Shot Gather Plot

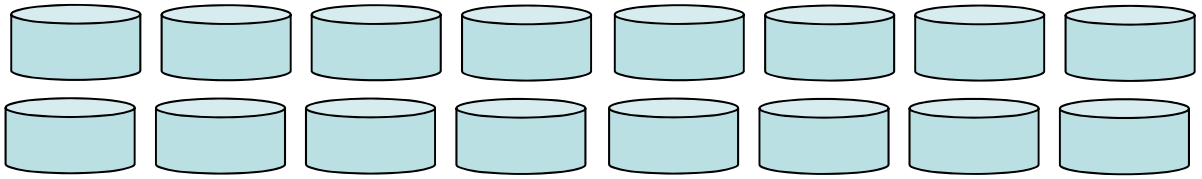


1. Instruction Manual of Programs for Analysis

1.4 Making Common Mid Point Gather of correlograms

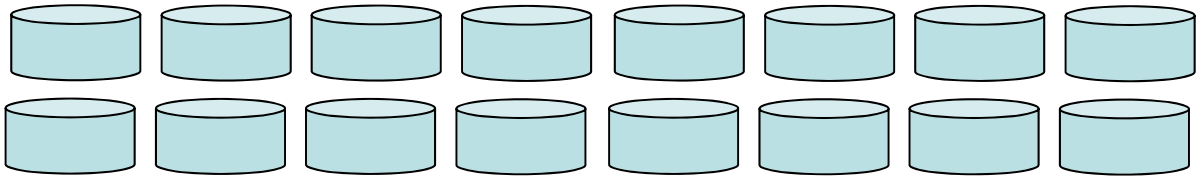
masw2_1.for + masw2_1.prm

Field Data = Common Shot Gathers



Masw2_1.for + masw2_1.prm

Common Mid Point Gathers for various mid points



Run by
./masw2_1.exe
This program uses the parameter file
./maswkf/prm/masw2_1.prm
and
./maswkf/prm/geometry.prm
to create the files of CMP gathers in the subfolder
./maswkf/data/cmp_gathers
with file name
cmp???.dat
, where ??? denotes the numbering of CMPs.

Have a coffee break during the processing, as it takes time.

Parameter File: masw2_1.prm

```
 1.0 20.0 0.001      :fmin,fmax,dt
 5. 23.              :rrmin,rrmax
24 133. 1.0 1024     :# of channel for a Common Shot Gather,length of
                      measurement line,dx,nn
```

Explanation:

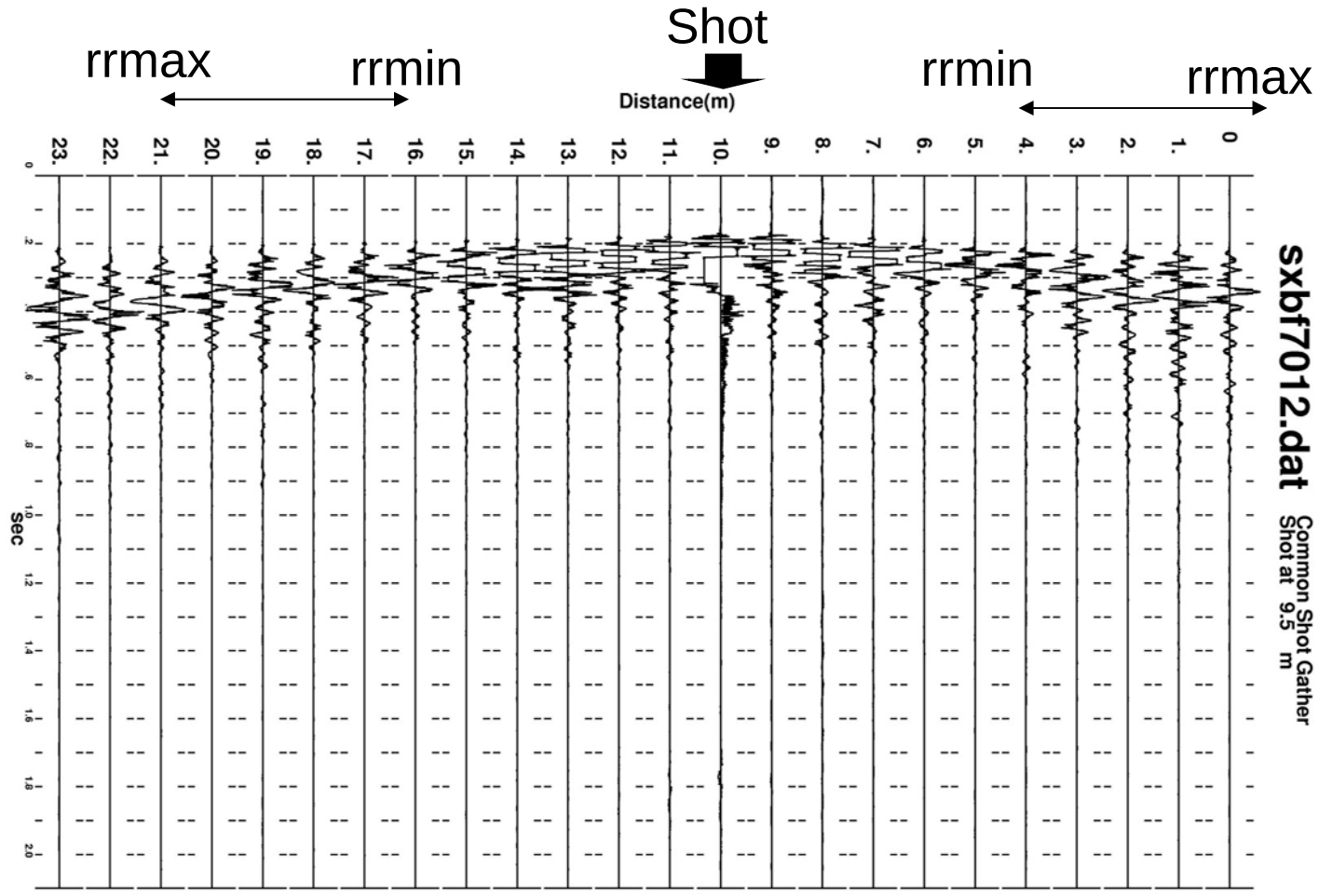
1st line: (fmin, fmax) the minimum and maximum frequencies for analysis and the sampling interval(dt)

2nd line: (rrmin, rrmax) the minimum and the maximum distance from shot point to geophones. See next slide.

3rd line: Number of channels for a Common Shot Gather, length of measurement line, interval between geophones, number of samples in a file

2nd line: (rrmin, rrmax) minimum and maximum distance from shot point to geophones

The traces nearby the shot point are clipped and those far from have the problem of low signal to noise ratio. Then CMP gather is made from the traces of which distance from the shot point is between rrmin and rrmax.



Input Files

- Common Shot Gather Files of the same measurement line that are stored in the subfolder ./maswkf/data/common_shot_gathers
- Their file name is cmp???.dat, where ??? denotes the numbering of CMP.

Input File Format

```
 24 0.00100    1024       0.100E+01
         1
0.300884E-03 0.334449E-03 0.351585E-03 0.357248E-03 0.357285E-03 0.355795E-03
0.354305E-03 0.352852E-03 0.349760E-03 0.345215E-03 0.339180E-03 0.331730E-03
0.322863E-03 0.312544E-03 0.300996E-03 0.288330E-03 0.274733E-03 0.260390E-03
…
```

1st line: Number of channels, dt, number of samples, scale factor
2nd line: channel number
3rd line: data
Below:

Writing sentences in the program (seg2read.for) used when these files were created.

```
write(2,'(i8,f8.5,i8,e16.3)')nch,dt,nn,scale
      do ich=kch,mch
       write(2,'(i12)')ich
       write(2,'(6e13.6)')(xx(i,ich)/scale,i=1,nn)
      enddo
```

Output File: Correlograms of Common Mid Point Gather

File names are automatically given as “cmp??ds.dat” , where ?? Is sorted from “01” to the maximum numbering of CMP.

```
  27  13.500   0.001    1024       9
      1   1.000  13.000  13.500  14.000       5
 0.146614E-06 0.226895E-06 0.304618E-06 0.372445E-06 0.424314E-06
 0.456951E-06 0.466428E-06 0.453546E-06 0.421210E-06 0.373336E-06
 0.315429E-06 0.250940E-06 0.186377E-06 0.124637E-06 0.683129E-07
....
```

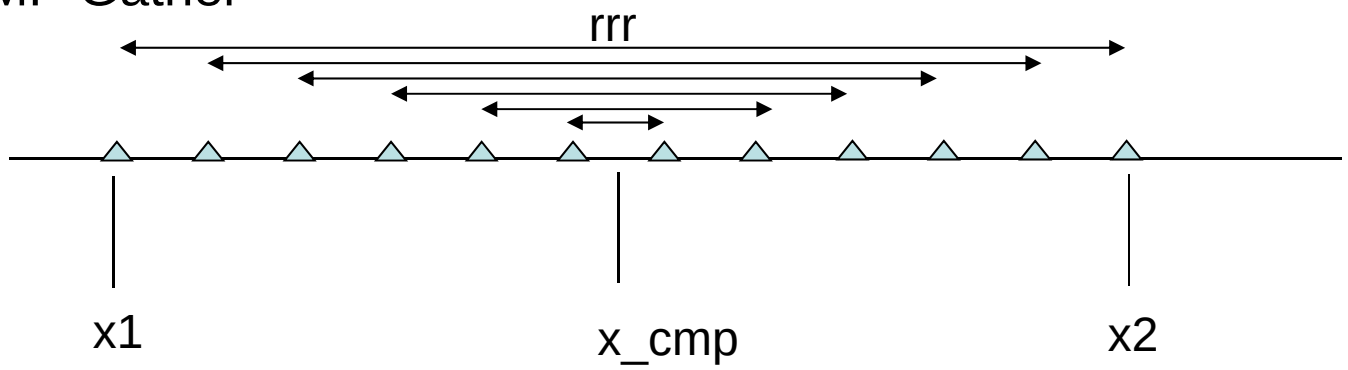
Writing sentences of the program:

```
open(13,file=filen,status='unknown')
write(13,'(i8,2f8.3,2i8)')icmp,x_cmp,dt,nn,n_trace
do irr=1,nch
 write(13,'(i8,4f8.3,i8)')irr,rrr,x1,x_cmp,x2,nstack(irr)
 write(13,'(5e13.6)')(cr(i,irr),i=1,nn)
enddo
close(13)
```

Output File: Correlograms of Common Mid Point Gather

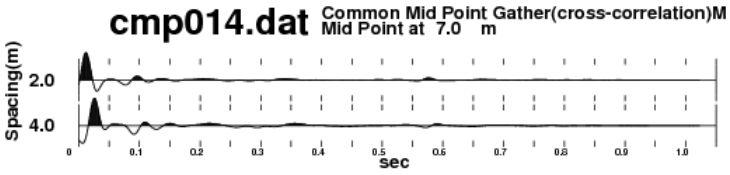
icmp,x_cmp: Numbering and position of Common Mid Point
dt,nn,n_trace: sampling interval, number of sampling, number of correlograms
irr,rrr: Numbering of trace, spacing of CMP gather
x1,x_cmp,x2,nstack(irr): x1, Position of CMP,x2, number of stack
(cr(i,irr),i=1,nn): samples of the correlograms

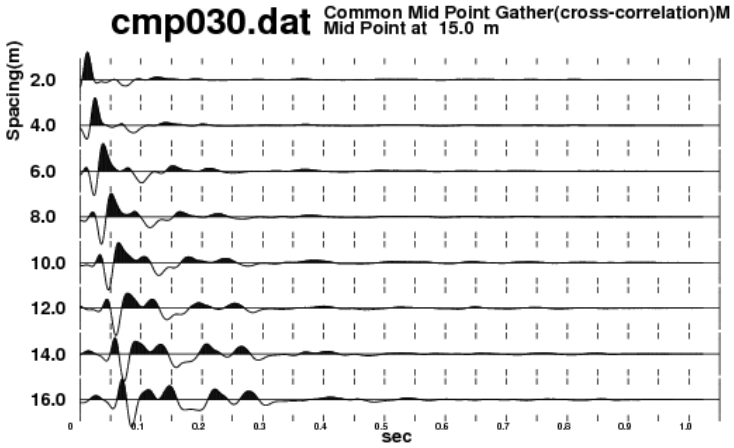
CMP Gather



The correlograms having the same mid point and the same spacing are stacked together.

Note: Sufficient number of correlograms can not be obtained at close to the ends of measurement line.





These figures are drawn using seecmp24.exe that is explained in the next.

If the number of shots is small, for example, only at two ends of a fixed measurement line, CMPCC technique can not show a good performance.
The program “masw2_0.for” is prepared for the conventional MASW method. It provide more stacks at each points on the measurement line in comparison with CMPCC.

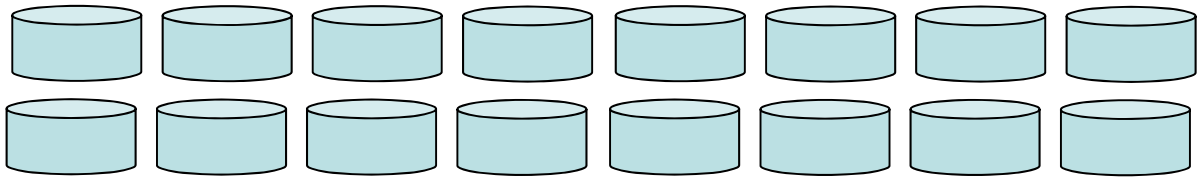
Use
./masw2_0.exe
instead of “masw2_1.exe” for the conventional MASW analysis. This program refers its own parameter file “masw2_0.prm” in the subfolder “./maswkf/prm”.
The latter procedure is common for both of them.

1. Instruction Manual of Programs for Analysis

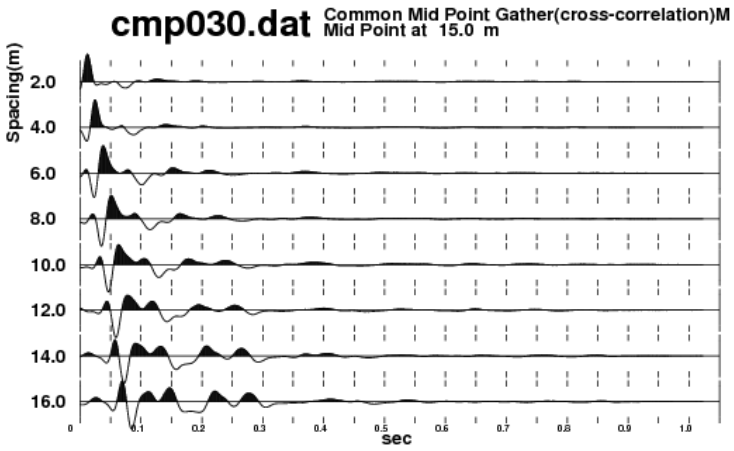
1.5 Plotting Common Mid Point Gathers

seecmp24.for + seecmp24.prm

Common Mid Point Gathers cmp???.dat



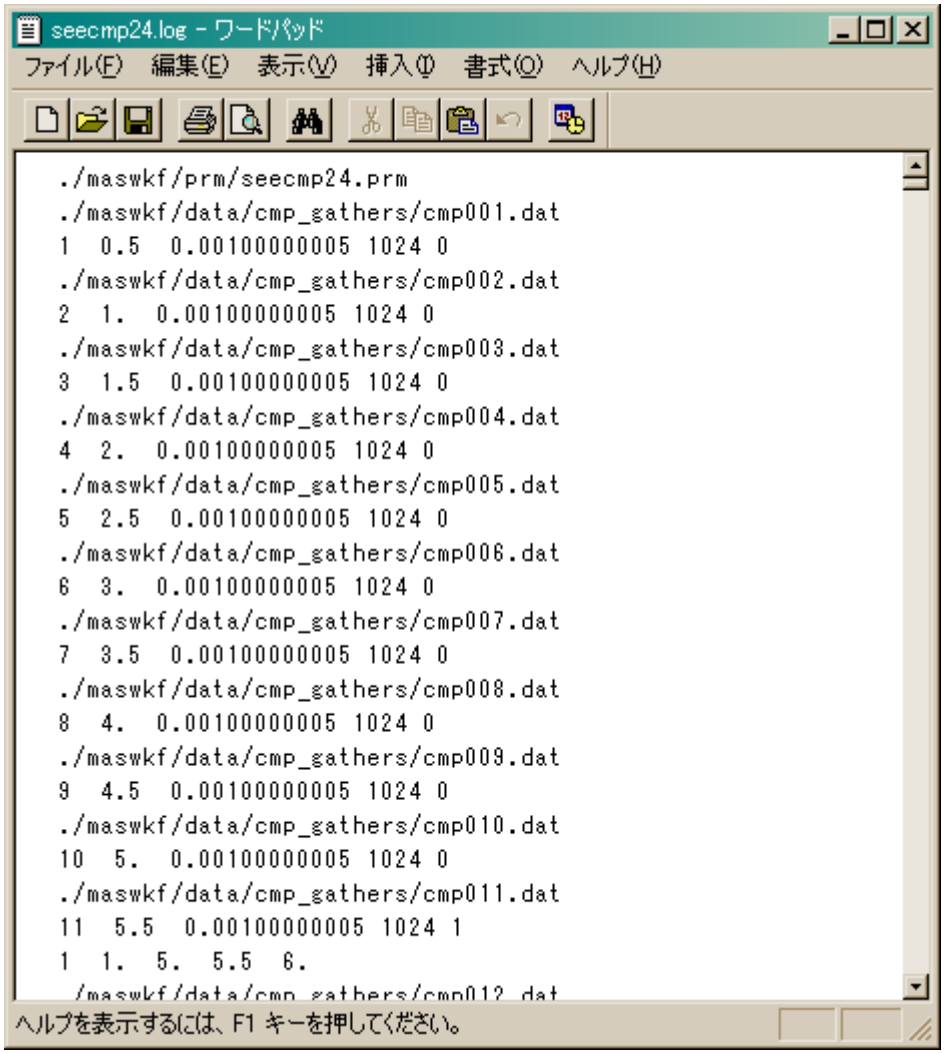
seecmp24.for
+ see2cmp24.prm



Plot CMP traces
cmp???.ps

Parameter File

1 23 1 0 :ncmps, ncmpe, ncmpd, Flag for normalize(=0; by max. of each ch,=1: by max. of all channels)



The program searches cmp-gather files from ncmps-th cmp to ncmpe-th one with increment ncmpd.

Run by
./seecmp24.exe
Input files: the output files of masw2_1.exe, that are Common Mid Point Gathers. These are stored in ./maswkf/data/cmp_gathers

The program looks for the CMP gather files from cmp001.dat to cmpmax.dat, where “max” denotes the number of files (1st parameter of the 1st line of seecmp24.prm).

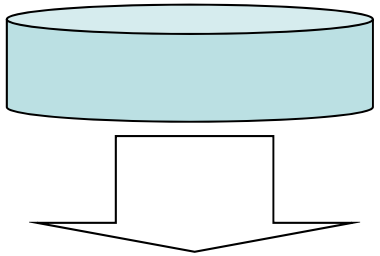
Output files:
in Post Script (PS) format
A file is created for each Common Mid Point Gather and stored in ./maswkf/data/cmp_gathers/fig
These files can be opened, for example, using Ghostview: gv &

1. Instruction Manual of Programs for Analysis

1.6 Velocity Analysis using CMP Gathers

masw2cmp.for + masw2cmp.prm

Common Mid Point Gathers
cmp???.dat



masw2cmp.for
+ masw2cmp.prm
+ geometry.prm

Output: dispersion Curve Files for each CMP gather

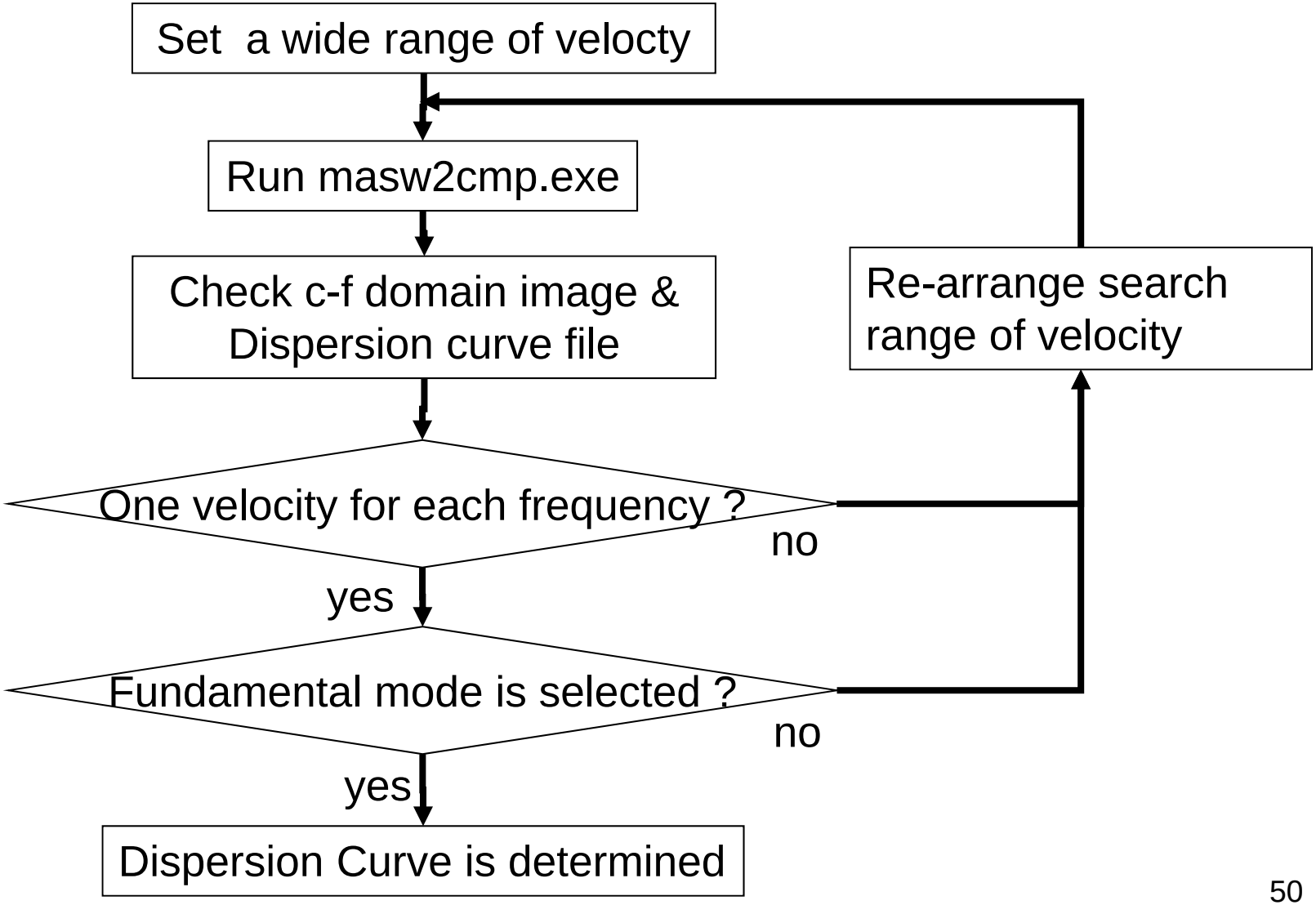
GNUPLOT script files for drawings

Interim output files for the c-f domain image and peaks

PostScript files for images in the c-f domain

Interactive Task between man (the operator) and machine (the programs) is required, because it is necessary to change the values of the control parameters due to the gradual changes of the dispersion curve CMP by CMP.

Task Flow of Velocity Analysis



Parameter File: masw2cmp.prm in ./maswkf/prm

```
5.5 20.0 0.001  1      :fmin,fmax,dt,n_parzen(=0, No, =1, Yes)
 1   0                 :n_cf_domain,normalize(=0 all, =1 each freq.)
 50.  400. 1.0         :vmin,vmax,dv
  15  250   1          :ncmps,ncmpe,ncmpd
                       cmp numbering ==>'cmp???.dat'(File name of
                       CMP gather), 'cmp???ds.dat'(file name for
                       dispersion)
 2.  80  10.  80. 15.  80. :(f1,v1),(f2,v2),(f3,v3) for lower limit
 2. 600   7. 150. 18. 100. :(f1,v1),(f2,v2),(f3,v3) for upper limit
```

(f1,v1),(f2,v2),(f3,v3) for lower and upper limits are explained in the slide of output file. They control the search range for peaks on the result of the velocity analysis.

cmp files are handled by the following do loop.

“do icmp=ncmps,ncmpe,ncmpd

…

enddo”

(fmin,fmax,dt) must be the same as those used in “masw2_1.prm”.

./maswkf/prm/geometry.prm is also read.

Input File: cmp???.dat

Input files: the output files of masw2_1.exe, that are Common Mid Point Gathers. These are stored in the subfolder ./maswkf/data/cmp_gathers

Output File

Interim output files:
./maswkf/data/c_f_panels/coh_pk???.dat
(data files for the peak locations in the c-f domain image)

Dispersion curve files:
./maswkf/data/dispersion/cmp???ds.dat

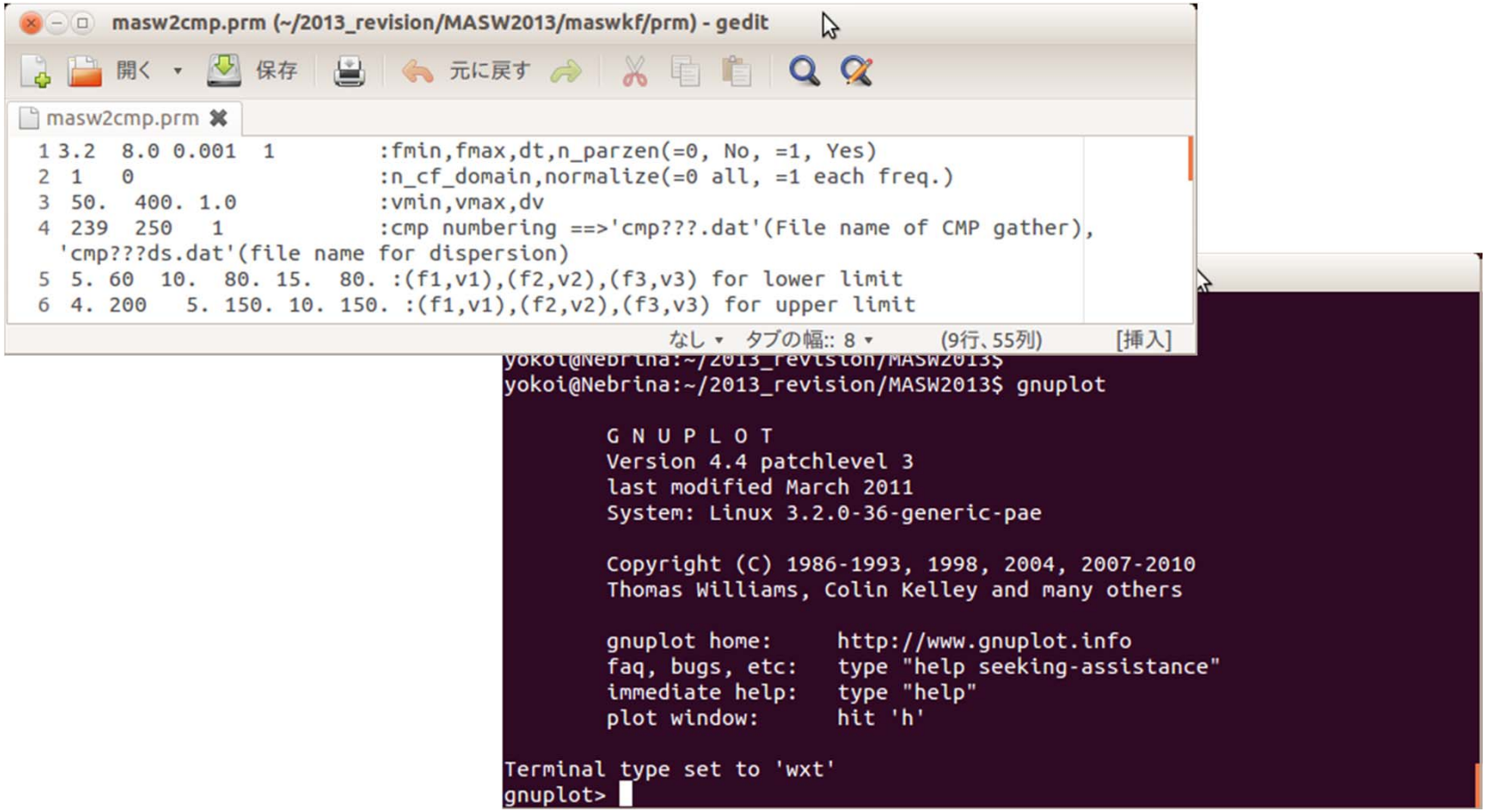
GNUPLOT script files:
./maswkf/prm/gnuplt_script/c_f_panels/masw???.plt

, where ??? denotes the numbering of CMP.

Example

Preparation

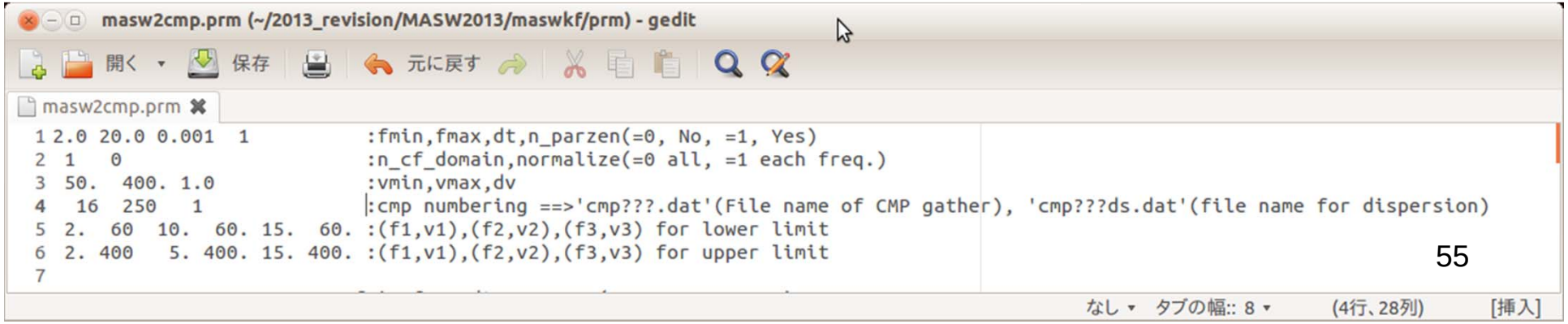
1. Open the parameter file using “gedit” :
   ./maswkf/prm/masw2cmp.prm
   Start GNUPLOT by “gnuplot” on the console window.



Example (cont.)

Draw c-f panels preliminary

1. Set the parameter file: ./maswkf/prm/masw2cmp.prm
   using a text editor. In the 4th line, (16 250 1) is set. This means CMPs numbered from 16 to 250 are processed with increment 1.
   Run by
   !./masw2cmp.exe or ./masw2cmp.exe after quitting from GNUPLOT using "quit".
   Processing starts from cmp016.dat. It takes time.
   Note: Exclamation mark ("!") at the head allows to use Linux command in GNUPLOT mode.
   In this step, only c-f panels are drawn preliminary. Then, a wide frequency range fmin=2. fmax=20. is set.
   The 5th and 6th lines are used to control the search for the dispersion curves and not used in this step. A wide range is set as shown below.

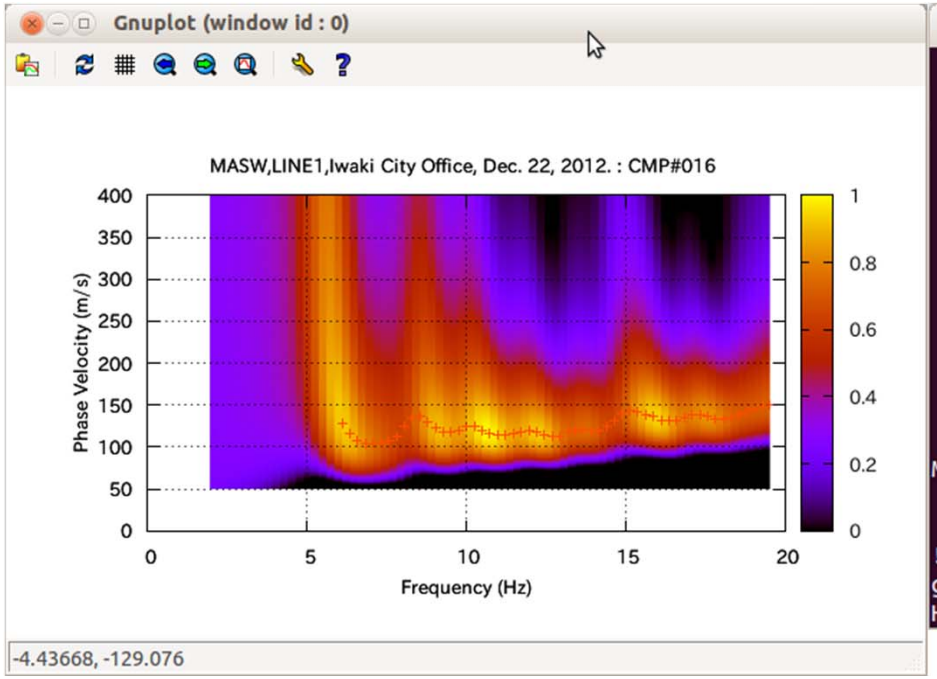


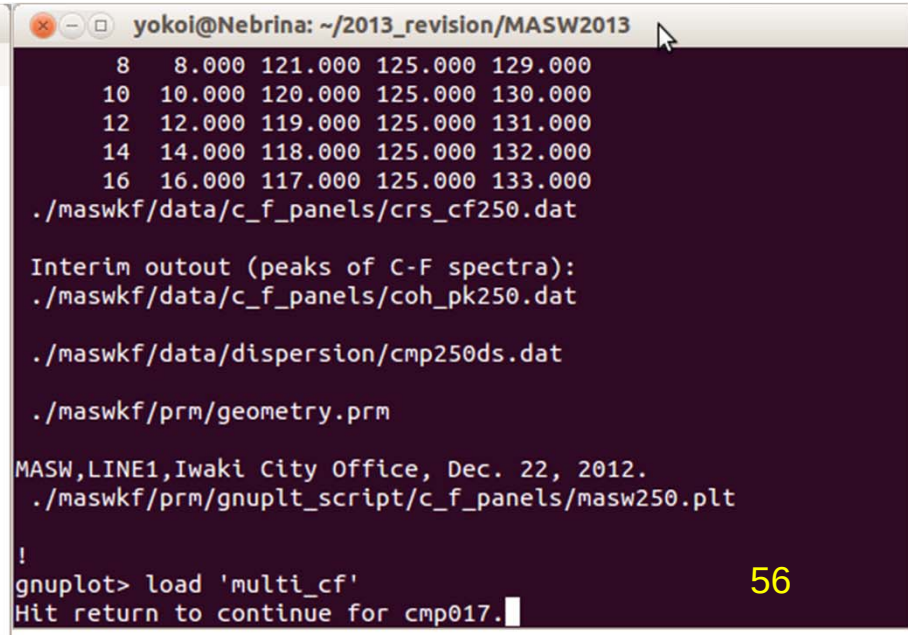
Example (cont.)

Starting from cmp016.dat, finally cmp250.dat is processed.
Type in: load ‘multi_cf’

Note, “load” is a command of GNUPLOT. The single quotation mark is required.

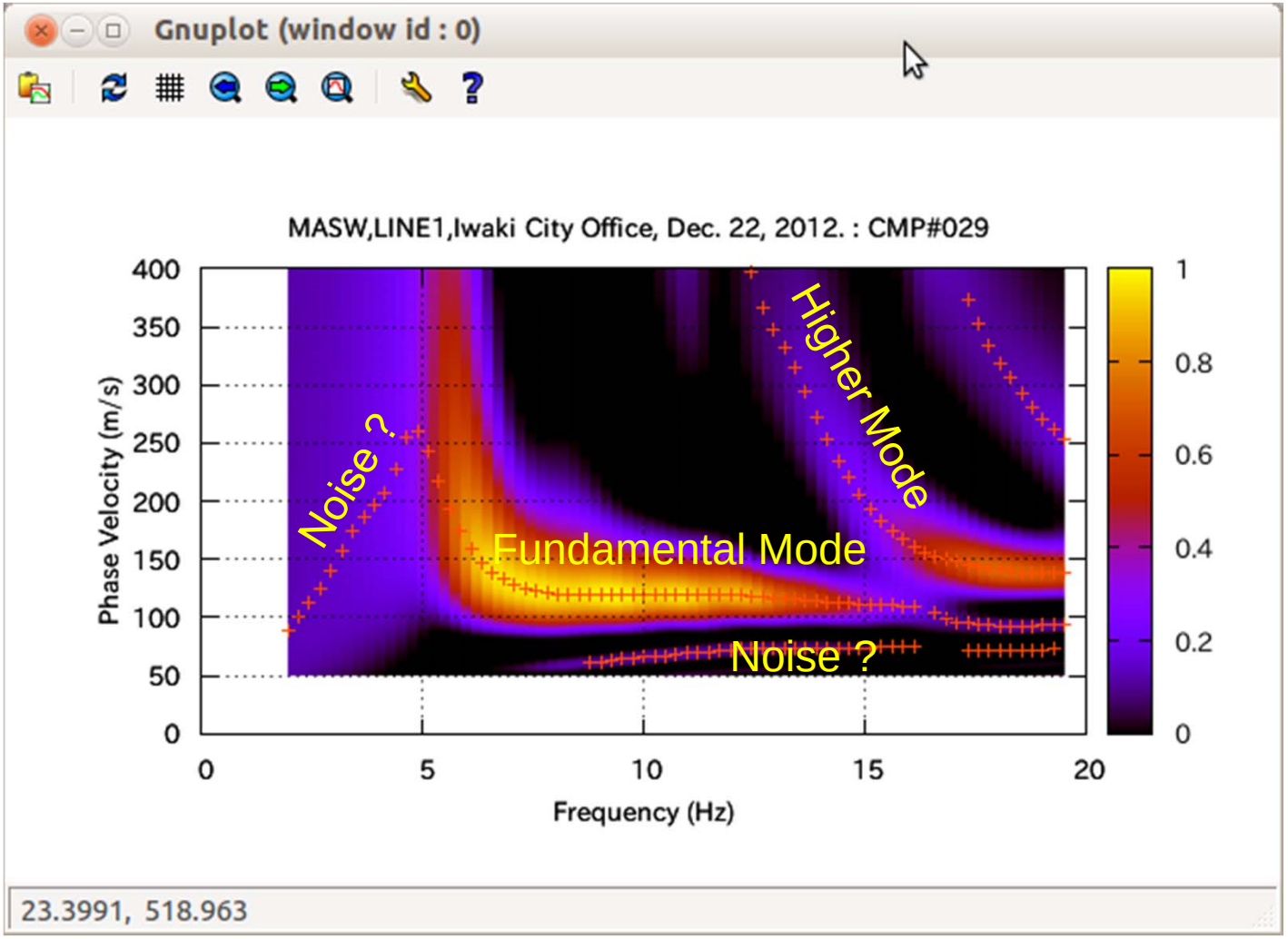
Then, c-f panel image for CMP016 appears on a X-window.
Simultaneously, the same image is stored in the Postscript file ./maswkf/data/c_f_panels/fig/cmp016.ps.
The title of this c-f panel is taken from the 1st line of ./maswkf/prm/geometry.prm .
Hit return key (Enter key) to advance to the next CMP as shown in the command line.
Advance to CMP250, but check the c-f panel images.



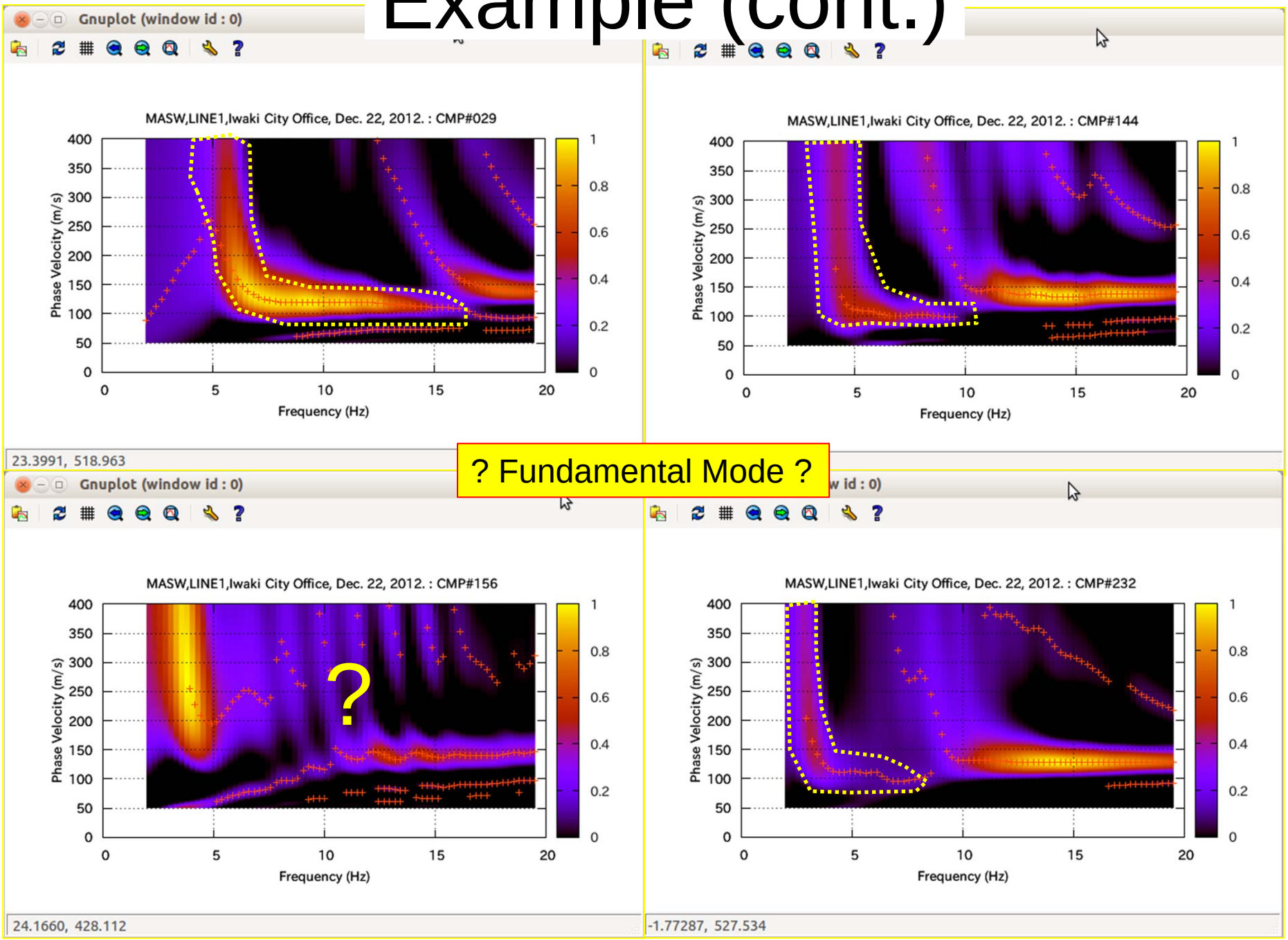


Example (cont.)

Red “+” marks on c-f panel images indicate the candidates of the phase velocity c(f).
It is necessary to extract the c(f) of the fundamental mode of Rayleigh waves, because “+” mark appears by the higher modes and by noises.



Example (cont.)



Example (cont.)

Determination of dispersion curve for a CMP

1. Set the parameter file: ./maswkf/prm/masw2cmp.prm
   using a text editor. In the 4th line, (30 16 -1) is set. This means only CMP030 is processed with decrement 1. Run the program again by !./masw2cmp.exe

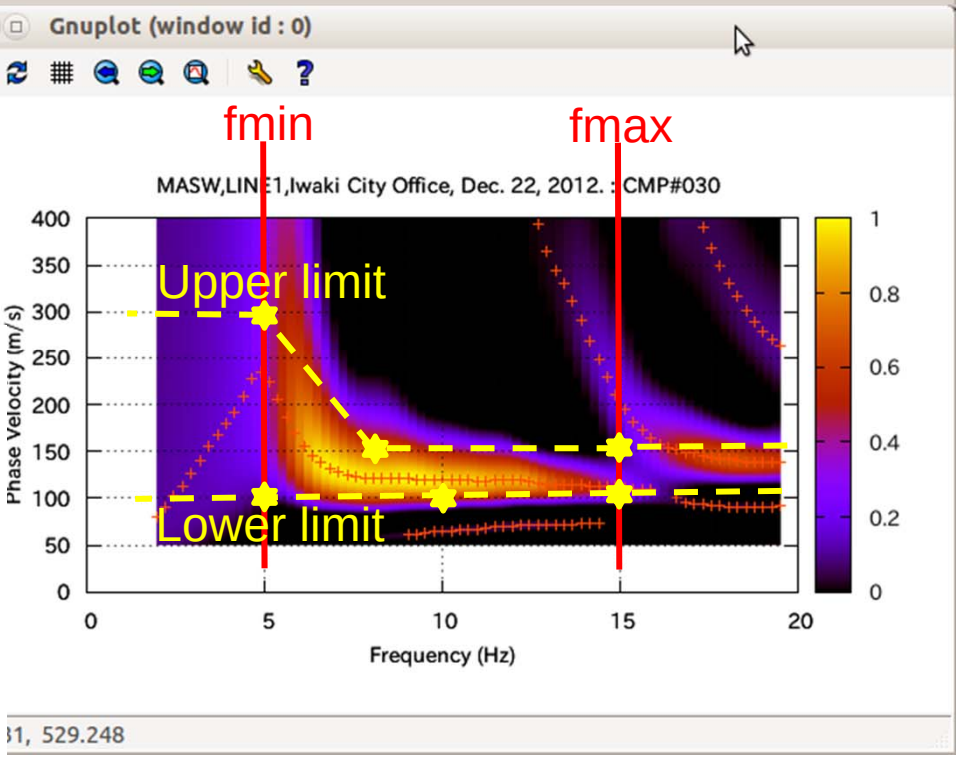
masw2cmp.prm (~/2013_revision/MASW2013/maswkf/prm) - gedit

開く 保存 元に戻す

masw2cmp.prm

```
1 5.0 15.0 0.001  1        :fmin,fmax,dt,n_parzen(=0, No, =1
2  1   0                   :n_cf_domain,normalize(=0 all, =1
3  50.  400. 1.0           :vmin,vmax,dv
4   30   16   -1           :cmp numbering ==>'cmp???.dat'(F
5  5. 100  10. 100. 15. 100. :(f1,v1),(f2,v2),(f3,v3) for lo
6  5. 300   8. 150. 15. 150. :(f1,v1),(f2,v2),(f3,v3) for up
7
```

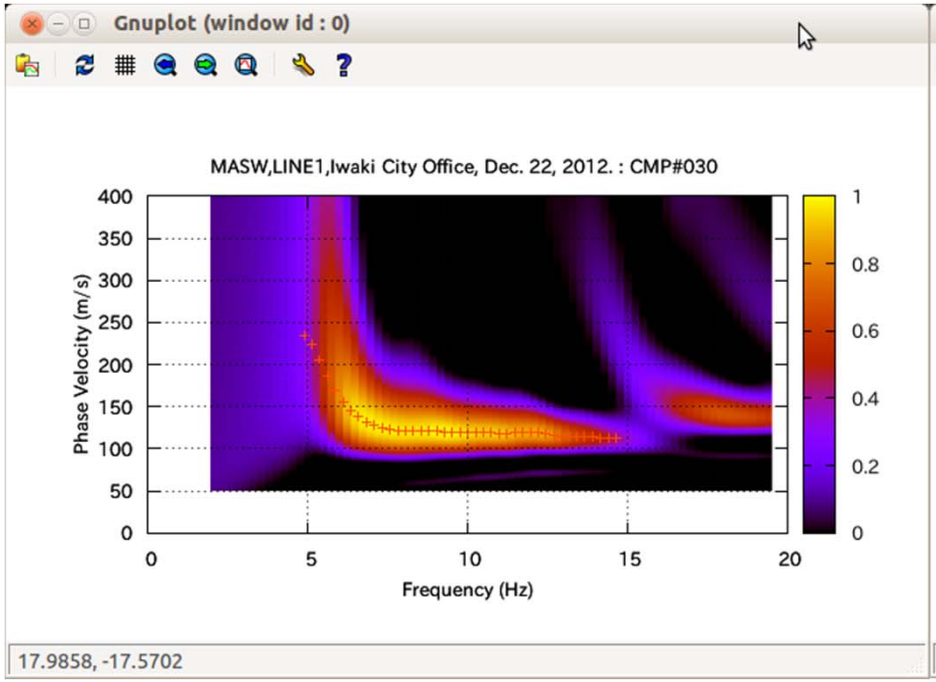
Set the search range for c(f) of the fundamental mode using (fmin fmax) and lower and upper limits controled by the values listed in the 5th and 6th lines of the parameter file. It may be necessary to change the setting of the parameter file, because the dispersion relation gradually changes due to the velocity structure.

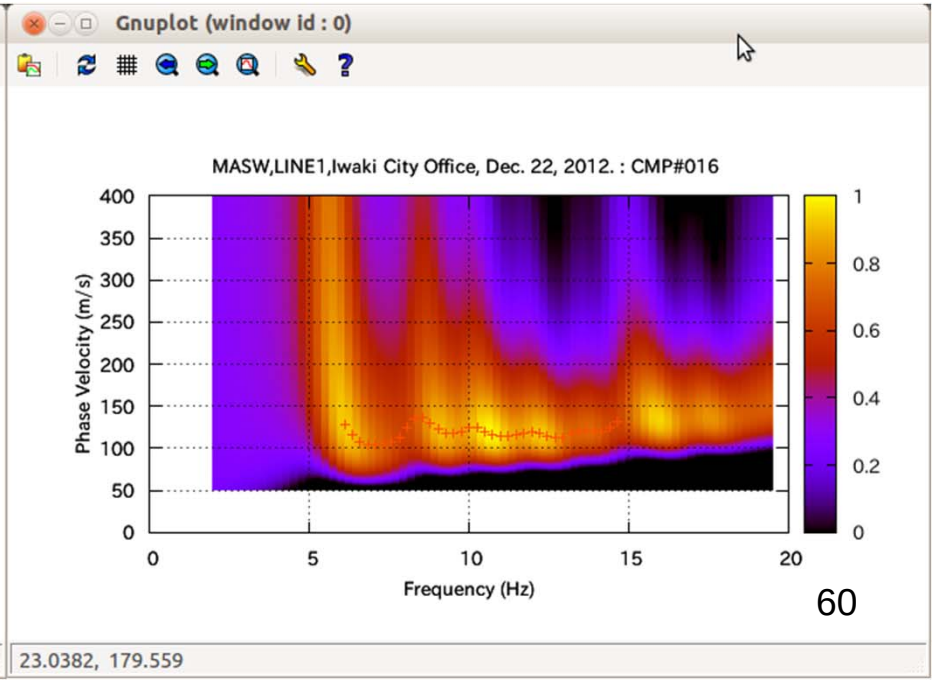


Example (cont.)

From cmp030.dat to cmp016.dat are processed.
Type in: load ‘multi_cf’
Check c-f panels and red “+” marks by hitting Return(Enter) key one by one.
+ Only one “+” at a frequency is shown.
+ Shape of the series of “+” on each c-f panel.

2. Similar procedure is repeated for other CMPs. Check the preliminary c-f panels explained in the previous slides to set groups of CMPs. In this example, fmin is set 5.0Hz considering on the natural frequency of the used geophones (4.5Hz), although “+” can be traced in lower frequency range in some c-f panels. Setting of fmax is changed gradually, because the border between the fundamental mode and the higher order’s one gradually moves toward lower frequency.





Example (cont.)

3. After loading ‘multi_cf’ and running it, the images of c-f panel with “+” marks are stored in the postscript file

./maswkf/data/c_f_panels/fig/cmp???.ps

; the GNUPLOT script file is

./maswkf/prm/gnuplt_script/c_f_panels/masw???.plt

; the data to plot this image are stored in

./maswkf/data/c_f_panels/crs_cd???.dat

; the data of c(f) are stored in

./maswkf/data/c_f_panels/crs_cd???.dat

, where ??? denotes the numbering of CMPs.

Beside the data for the determined dispersion curves are stored in

./maswkf/data/dispersion/cmp???ds.dat .

Their format is

```
#  Freq.  V.m/s
  5.371  221.000
  5.615  193.000
  5.859  172.000
  6.104  156.000
  6.836  129.000
  7.080  125.000
….
```

masw030.plt: a script file of GNUPLOT

```
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. : CMP#030 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [0:20]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [0:400]
# C-F spectra
set zrange [0:1]
#
set pm3d map
set multiplot
splot "./maswkf/data/c_f_panels/crs_cf030.dat"
splot "./maswkf/data/c_f_panels/coh_pk030.dat" with points pt 1 lt 8
unset multiplot
set terminal postscript color enhanced
set output "./maswkf/data/c_f_panels/fig/cmp030.ps"
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. : CMP#030 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [0:20]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [0:400]
# C-F spectra
set zrange [0:1]
#
set pm3d map
set multiplot
splot "./maswkf/data/c_f_panels/crs_cf030.dat"
splot "./maswkf/data/c_f_panels/coh_pk030.dat" with points pt 1 lt 8
unset multiplot
set output
set terminal wxt
```

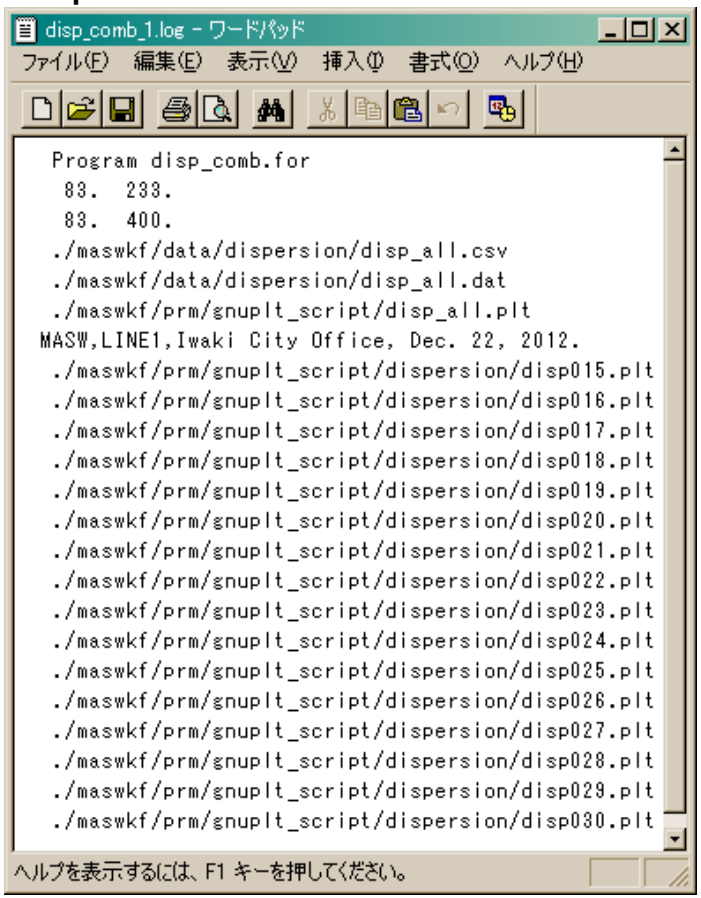
multi_cf.plt: a script file of GNUPLOT

```
...
 load './maswkf/prm/gnuplt_script/c_f_panels/masw032.plt'
 pause -1 "Hit return to continue for cmp033.
 load './maswkf/prm/gnuplt_script/c_f_panels/masw033.plt'
 pause -1 "Hit return to continue for cmp034.
 load './maswkf/prm/gnuplt_script/c_f_panels/masw034.plt'
 pause -1 "Hit return to continue for cmp035.
 load './maswkf/prm/gnuplt_script/c_f_panels/masw035.plt'
 pause -1 "Hit return to continue for cmp036.
…
```

Example (cont.)

4. After determined all necessary dispersion curves:
   Execute the batch file “./disp_comb” by typing in !./disp_comb
   or ./disp_comb after quitting from GNUPLOT.
   to creates the parameter file ./maswkf/prm/disp_comb.prm
   and then run !./disp_comb.exe.
   This program creates the following files.
   ./maswkf/data/dispersion/disp_all.csv
   ./maswkf/data/dispersion/disp_all.dat
   ./maswkf/prm/gnuplt_script/disp_all.plt
   ./maswkf/prm/gnuplt_script/dispersion/disp???.plt
   , where ??? denotes the numbering of CMPs.

   Note: these ./disp_comb is different from
   ./disp_comb.exe .

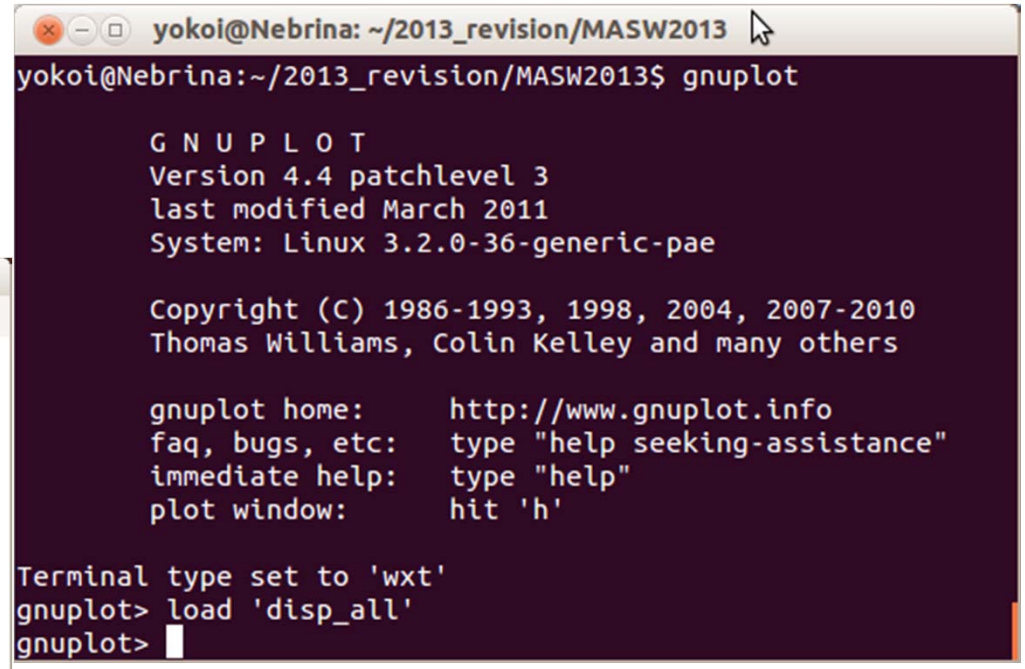


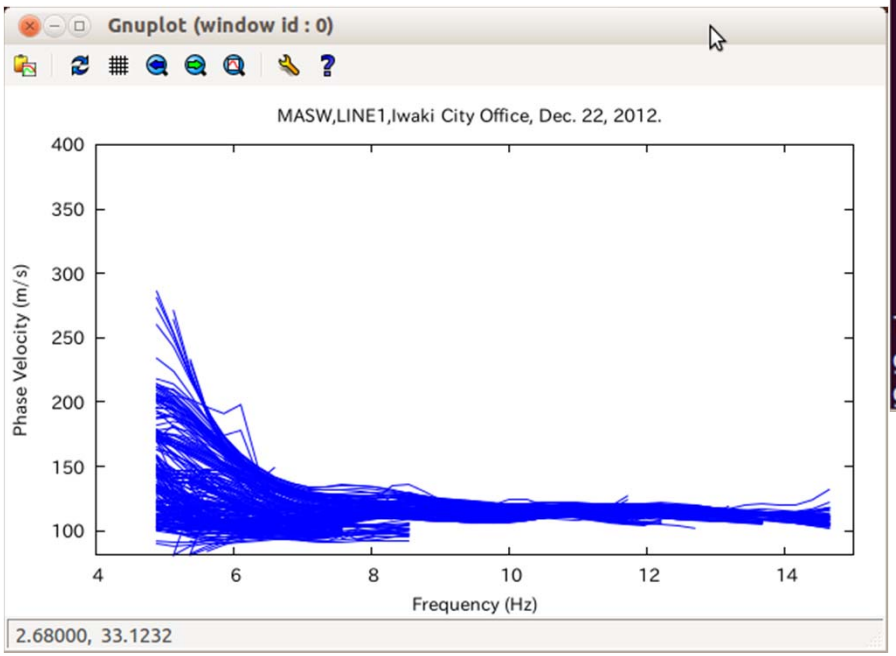
Example cont.

5. Type in load ‘disp_all’

This script file of GNUPLOT draws the dispersion curves of all CMPs together on a X-window and simultaneously creates a postscript files ./maswkf/data/dispersion/fig/disp_all.ps , that has the same image.

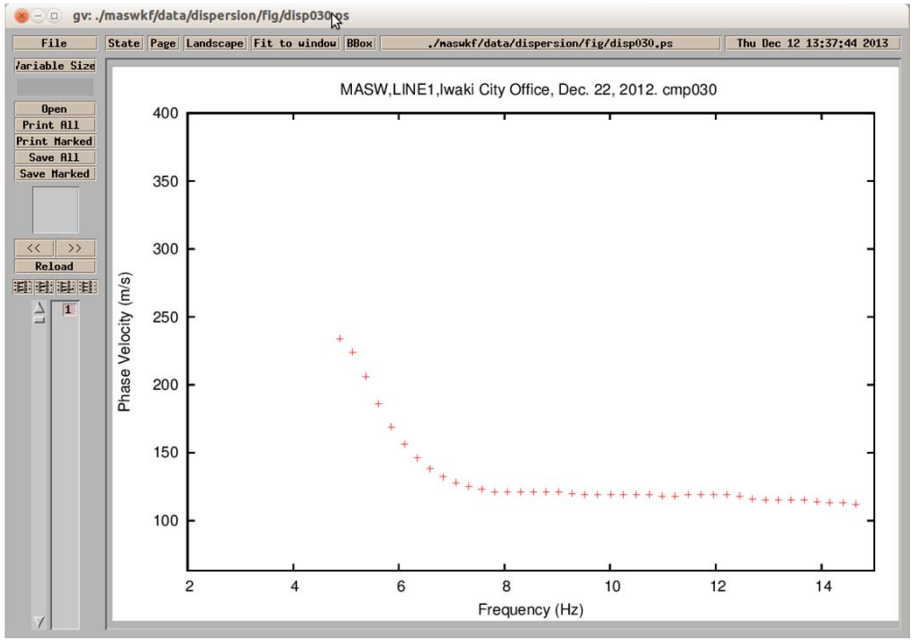
Quit from GNUPLOT using “quit”.





load ‘./maswkf/prm/gnuplt_script/dispersion/disp???.pl’

This script of GNUPLOT draws the dispersion curve of processed CMP into the individual postscript files
./maswkf/data/dispersion/fig/disp???.ps



The data for the determined dispersion curves are stored in
./maswkf/data/dispersion/cmp???ds.dat
and used in the next processing.
A csv format file
./maswkf/data/dispersion/disp_all.csv
is created for drawing using Excel.

disp030.plt: a script file of GNUPLOT

```
set terminal postscript color enhanced
set output "./maswkf/data/dispersion/fig/disp030.ps"
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012. cmp030 "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [  5.:  20.]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [  81.:  400.]
plot "./maswkf/data/dispersion/cmp030ds.dat" with points lc rgb "red"
set output
set terminal wxt
```

disp_all.plt: a script file of GNUPLOT

```
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012.  "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [  5.:  20.]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [  81.:  400.]
set multiplot
plot "./maswkf/data/dispersion/disp_all.dat" with lines lc rgb "blue"
unset multiplot
set terminal postscript color enhanced
set output "./maswkf/data/dispersion/fig/disp_all.ps"
reset
unset key
# Graph title
set title "MASW,LINE1,Iwaki City Office, Dec. 22, 2012.  "
# Horizontal axis: label & range
set xlabel "Frequency (Hz)"
set xrange [  5.:  20.]
# Verical axis: label & range
set ylabel "Phase Velocity (m/s)"
set yrange [  81.:  400.]
set multiplot
plot "./maswkf/data/dispersion/disp_all.dat" with lines lc rgb "blue"
unset multiplot
set output
set terminal wxt
load './maswkf/prm/gnuplt_script/dispersion/disp015.plt‘
...
load './maswkf/prm/gnuplt_script/dispersion/disp250.plt'
```

Note: A way to combine many c-f panels

An executable file ./connect.exe is prepared to combine many postscript files of c-f panels in one. This refers to a parameter file ./maswwkf/prm/connect.prm.

This can be executed from ./MASW2013 by typing in ./connect.exe
or in GNUPLOT mode !./connect.exe
Then, type in the following in GNUPLOT mode !./connect_all

A postscript file 'cmp_all.ps' is created in ./maswkf/data/c_f_panels/fig

Example of 'connect.prm'

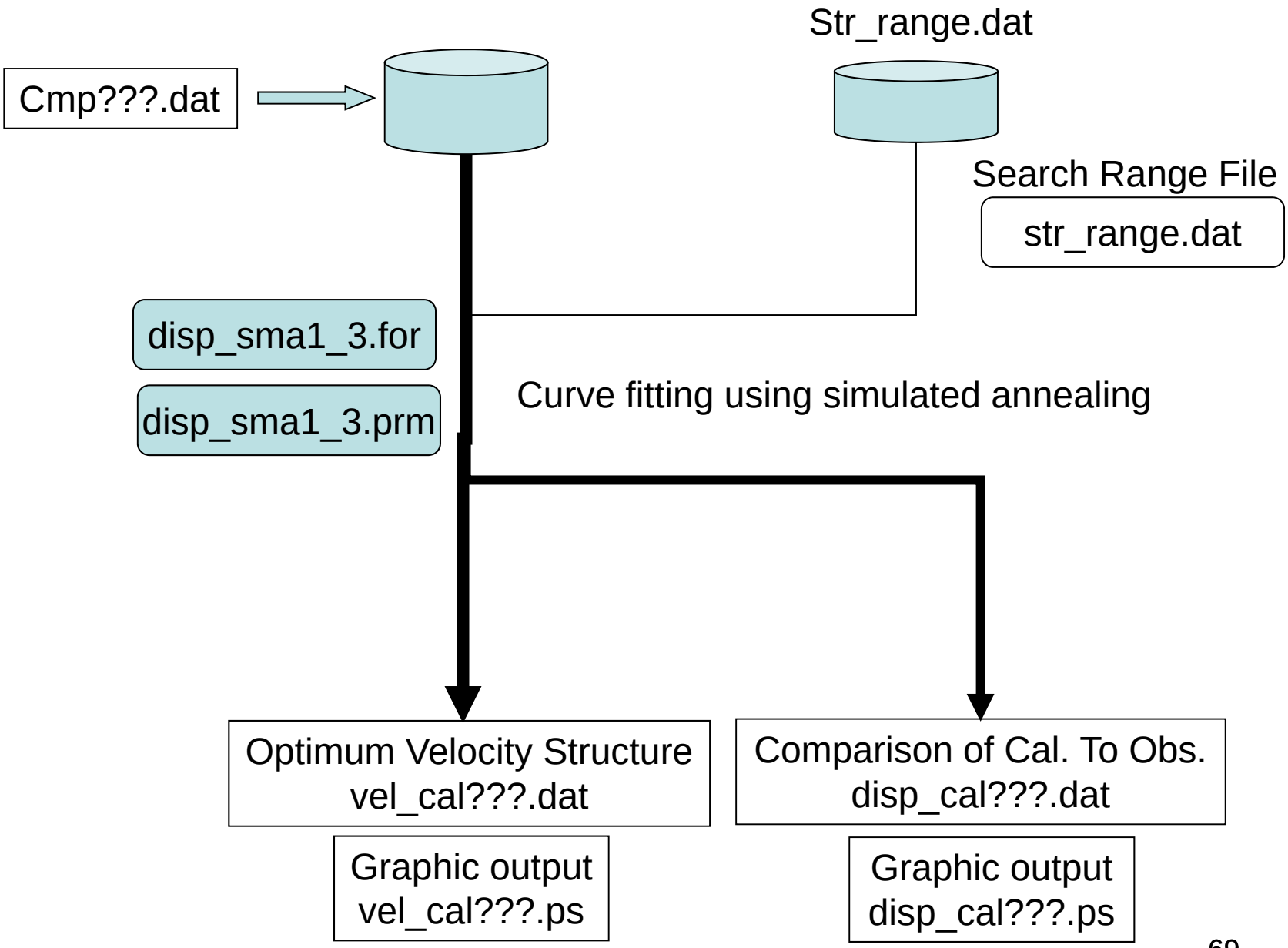
```
'maswkf/data/c_f_panels/fig'   26  :folder name ('./' is added), number of letters
'cmp'   3                          :top part of file name, number of letters
'.ps'   3                          :tail part of file name, number of letters
18 250 1                           :ncmps, ncmpe, ncmpd
```

This means that the postscript files from cmp018.ps (ncmps=18) to cmp250.ps (ncmpe=250) with increment 1 (ncmpd=1) are searched in ./maswkf/data/c_f_panels/fig and combined into a multi page postscript file cmp_all.ps in the same folder.
It is sometimes useful to check the gradual change of c-f panels using this combined postscript file as a flip book.
It is possible to combine other series of postscript files by re-writing 'connect.prm', e.g., disp???.ps in ./maswkf/data/dispersion/fig .

1. Instruction Manual of Programs for Analysis

1.7 Inversion of dispersion curves

disp_sma1_3.for + disp_sma1_3.prm


Str_range.dat
Cmp???.dat
Search Range File
str_range.dat
disp_sma1_3.for
disp_sma1_3.prm
Curve fitting using simulated annealing
Optimum Velocity Structure
vel_cal???.dat
Comparison of Cal. To Obs.
disp_cal???.dat
Graphic output
vel_cal???.ps
Graphic output
disp_cal???.ps

Parameter File: disp_sma1_3.prm

```
  1 1. 0.6 1.3 5000  5 :idum,t0,a,c,ntemp,j0
  0.005                :eps0
     1    1    1       :n_roh,n_vp,n_initial
     1    0    1       :ini_flg,ndsp_flg,n_err
     0    1            :kflg,jflg
     0    0            :n_vs,n_th
 str_range.dat         :File name for the initial velocity model (a25).
  30 15 1              :ncmps,ncmpe,ncmpd
```

```
Control parameter for the simulated annealing method
idum      :Random seed (integer). As the result may
          depend on the initial velocity model given by
          random number, it is strongly recommended for
          users to apply this program several times with
          various values of random seed and tograsp the
          scatter of result.
t0        :Initial Temperature
a,c       :Coefficients for T=T0*exp(-c*k**a), where k is
          iteration number
ntemp     :Maximum number of temparature change
j0        :Number of iteration for each temperature

Threshold for conversion
 eps0     : averaged deviation

CMP numbers
ncmps,ncmpe,ncmpd: start, end, interval
          ncmpd>0 if ncmps<ncmpe,ascending  cmp number
          ncmpd<0 if ncmps>ncmpe,descending cmp number
```

```
flags of empirical relations for roh and vp
 n_vp     : 1=by Ludwig et al(1970),
            vp=1.11*vs+1.29
            0=fixed to the initial values
 n_roh    : 1=by Kitzunezaki et al(1990),
            roh=1.2475+0.399*vp-0.026*vp**2
            0=fixed to the initial values
 n_initial: 1=Initial model is set to the given value
            0=Initial model is set using random seed
flags for output to Display
 ini_flg  : Initial Velocity Structure Model 1=yes
 ndsp_flg : Observed Dispersion Relation     1=yes
 n_err    : Error at each iteration          1=yes
 kflg     : Missfit at each temp. change     1=yes
 jflg     : Missfit at each itration with the same temp.
                                             1=yes
 n_vs     : Vs value  (n_vs=layer number, 0=no output)
 n_th     : Thickness (n_th=layer number, 0=no output)
 n_err    : errors
```

Input File

- “str_range.dat” is the name of the file that includes the initial structure model and the search range.
- “cmp??ds.dat” that includes the observed dispersion curve.

Format of “str_range.dat”

```
Iwaki City, SS-1,22/12/2012                                          :Comment(a30)
    5                                                                :IL(I5),Layer Number
1.9   1.5    0.001  0.010  0.06 0.12  0.0032  0.10 :density,Vp,hmin,hmax,vmin,vmax,hini,vini
1.9   1.5    0.001  0.010  0.10 0.15  0.0035  0.15
1.9   1.5    0.001  0.020  0.06 0.12  0.0014  0.08
1.9   1.5    0.001  0.020  0.10 0.18  0.0045  0.16
2.0   1.70   998.0  999.0  0.18 0.35  998.0   0.34
```

(hmin, hmax): the minimum and maximum of the serach range of layers thickness. For the deepest layer they must be (998.0, 999.0).

(vmin, vmax): the minimum and maximum of the search range of shear wave velocity Vs.

(hini,vini):given initial values of the thickness and Vs of each layer.

Format of the file for Dispersion curve

```
 #  Freq.  V.m/s
   5.371  206.000
   5.615  186.000
   5.859  169.000
   6.104  156.000
   6.348  146.000
   6.592  138.000
   6.836  132.000
   7.080  128.000
   7.324  125.000
   7.568  123.000
   7.812  121.000
   8.057  121.000
....
```

It’s the same as the output file “cmp??ds.dat” of “masw2cmp.exe”

Output file

- “vel_cal???.dat” of the example of the parameter file shown above. File for the estimated velocity structure by the heuristic search.
- “disp_cal???.dat” of the example of the parameter file shown above. File that includes the observed and calculated dispersion curve together.
- Both can be read by Excel.

Format of output file “vel_cal???.dat”

#	depth (m)	Density(Kg/m^3)	Vp (m/sec)	Vs (m/sec)
1	0.0	1755.5	1401.0	100.0
2	3.3	1773.5	1456.5	150.0
3	6.8	1748.2	1378.8	80.0
4	8.2	1777.3	1468.3	160.6
5	12.7	1847.1	1688.6	359.1
6	14.0	1847.1	1688.6	359.1

Format of output file “disp_cal???.dat”

# Frequency(Hz)	Observed Vel(m/	Calculated Vel(m/s)
5.371	206.000	196.983
5.615	186.000	179.416
5.859	169.000	165.158
6.104	156.000	154.711
6.348	146.000	147.245
6.592	138.000	141.766
6.836	132.000	137.630
7.080	128.000	134.424
7.324	125.000	131.881
7.568	123.000	129.825
7.812	121.000	128.135
8.057	121.000	126.719
8.301	121.000	125.526

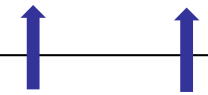
…

Example

1. 1st trial for a representative CMP:

Select a representative CMP that is not located close to the ends of measurement line where an accurate dispersion curve can not be expected due to a shortage of stacking. In this example, CMP030 is selected, however it is case by case in reality.
Set the search range of thickness and Vs in the file “str_range.dat” together with the values of density (Roh) and Vp. It is better to refer the borehole data nearby if available. Leave (hini,vini) with arbitrary values, because they are not used in the 1st trial.

```
Iwaki City, SS-1,22/12/2012   :Model(a30)
         5                      :IL(I5),Layer Number
1.9   1.5    0.001  0.010  0.06 0.12  0.0032  0.10 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.010  0.10 0.15  0.0035  0.15 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.020  0.06 0.12  0.0014  0.08 :density,Vp,hmin,hmax,vmin,vmax
1.9   1.5    0.001  0.020  0.10 0.18  0.0045  0.16 :density,Vp,hmin,hmax,vmin,vmax
2.0   1.70   998.0  999.0  0.18 0.35  998.0   0.34
```



hini vini

Example cont.

Set the parameter file “disp_sma1_3.prm”. Especially set n_initial=0, then (hini,vini) are given randomly among the search range.
Set ncmps=ncmpe (=30) equal to the above selected CMP. This means that the inversion is applied only to the selected CMP030.
Run ./disp_sma1_3.exe.
The structure of the converged solution is shown in the console.
This solution (estimated velocity structure) is simultaneously stored in ./maswkf/data/structure/vel_cal???.dat.
The observed and theoretical dispersion curves are simultaneously stored in ./maswkf/data/dispersion/disp/cal???.dat.

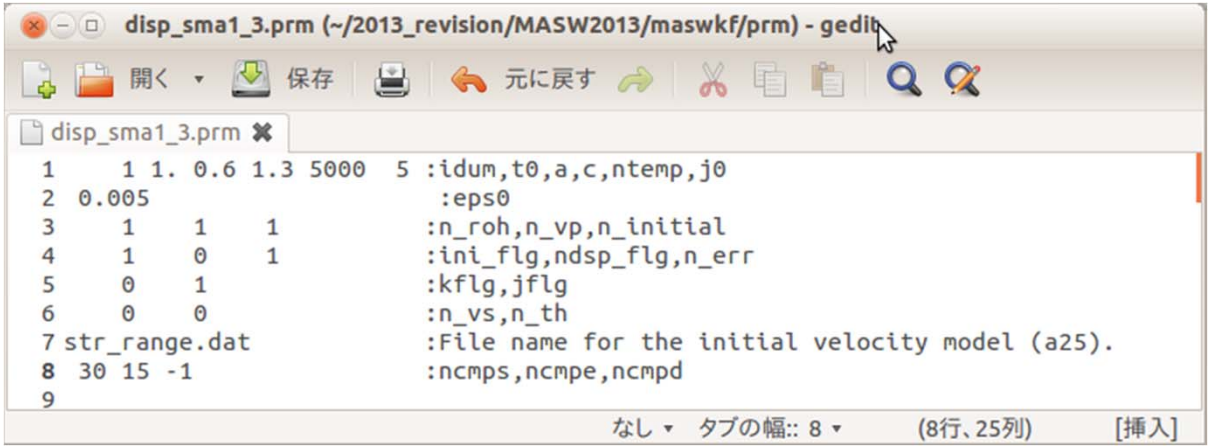
```
 1 1. 0.6 1.3 5000  5     :idum,t0,a,c,ntemp,j0
 0.006                    :eps0
    1    1    0          :n_roh,n_vp,n_initial
    1    0    1          :ini_flg,ndsp_flg,n_err
    0    1               :kflg,jflg
    0    0               :n_vs,n_th
str_range.dat            :File name for the initial velocity model (a25).
 30 30   1                :ncmps,ncmpe,ncmpd
```

Example cont.

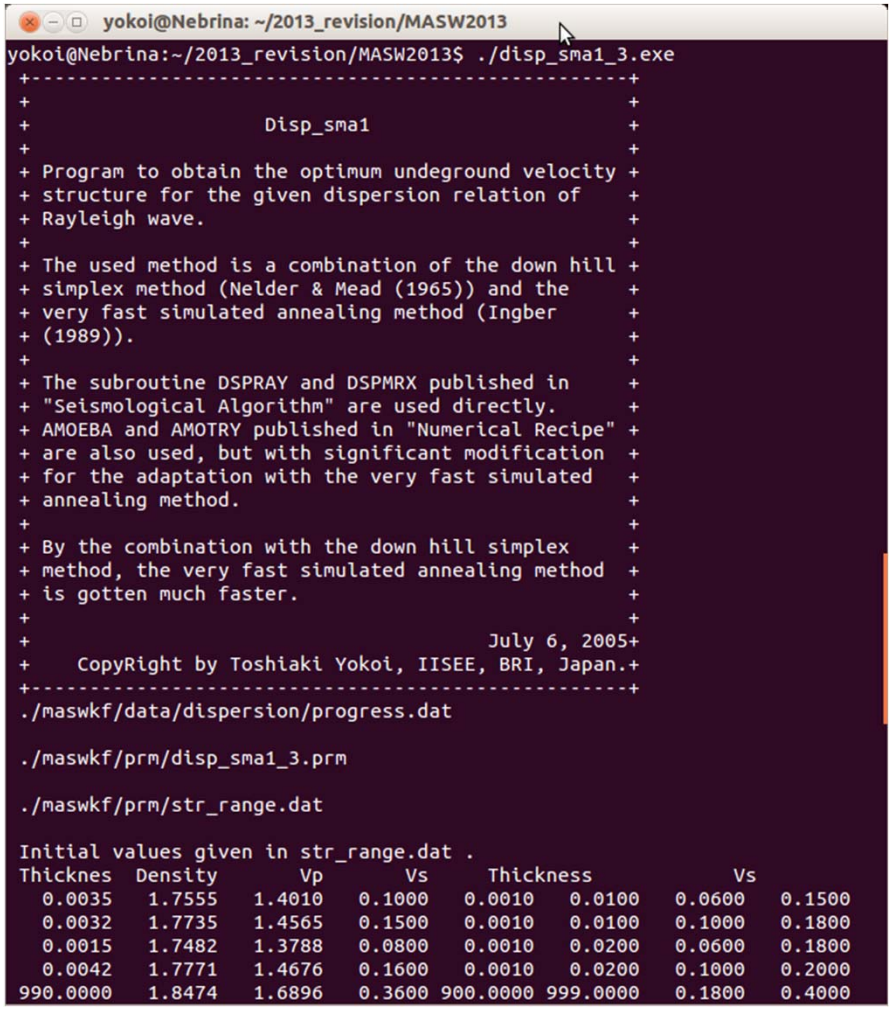
2. Inversion for a group of CMPs:

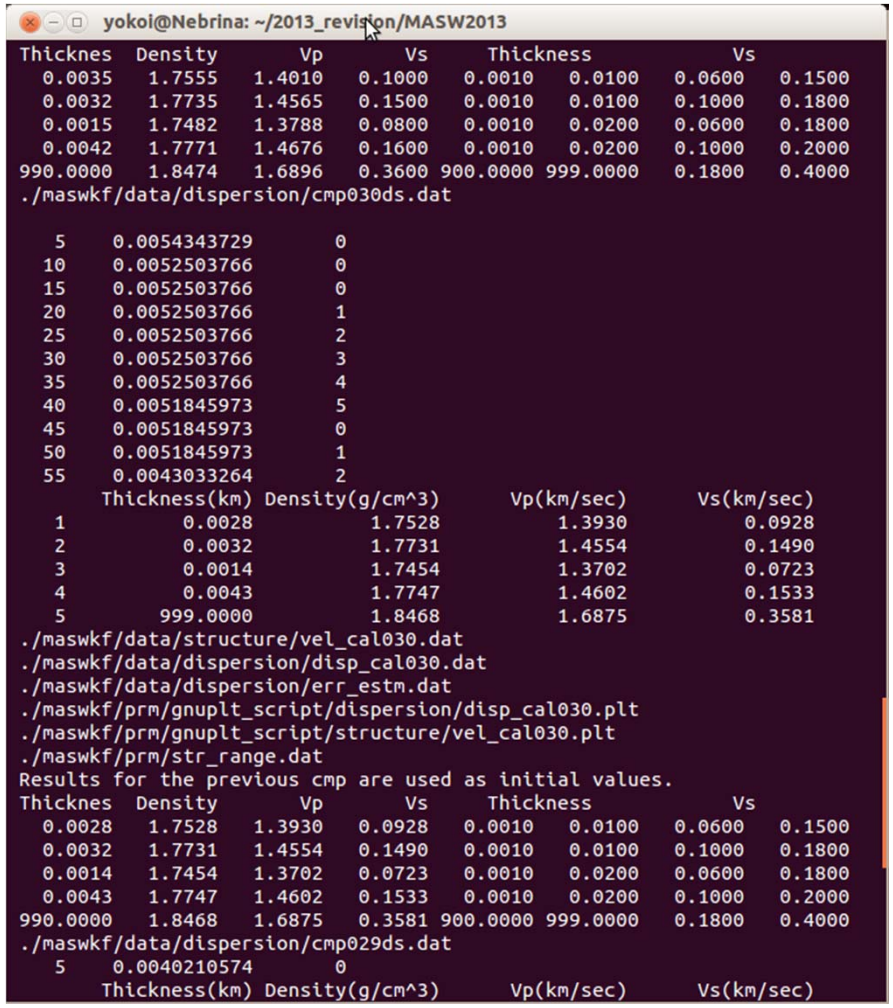
Type the values of thickness and Vs of the converged solution for CMP030 in (hini,vini) of each layer in the file “str_range.dat”.
Set n_initial=1 and (ncmps, ncmpe,ncmpd) to the CMPs that will be analyzed. For example, (30 16 -1).
Run again ./disp_sma1_3.exe.
From CMP030 to CMP016 are processed with decreasing numbering with -1.
The converged solution of the previously processed CMP is used as (hini vini) sequentially.

Have a coffee break, it really takes time.



Example cont.





Example cont.

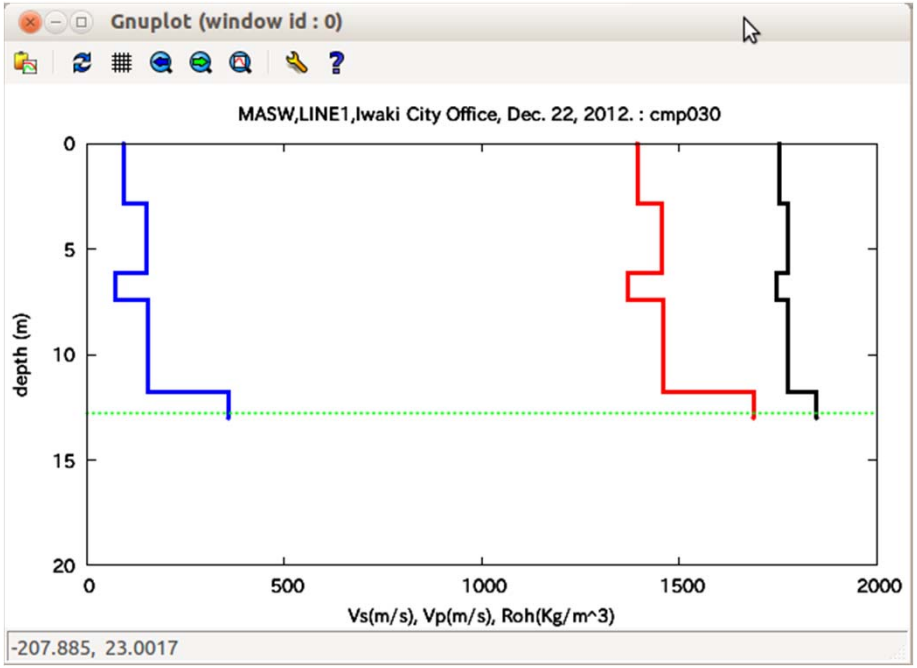
Start GNUPLOT and type in

load ‘vel_cal_all’

The image of velocity structure of CMP030 is shown in a X-window. The same image is stored simultaneously in

./maswkf/data/structure/fig/vel_cal030.ps

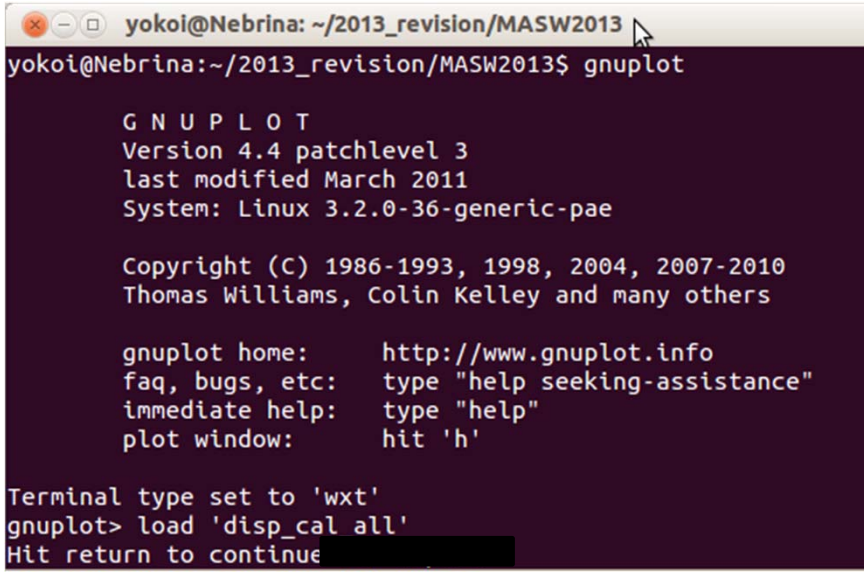
The consecutive images of velocity structure are shown and stored by hitting Return (Enter) key.

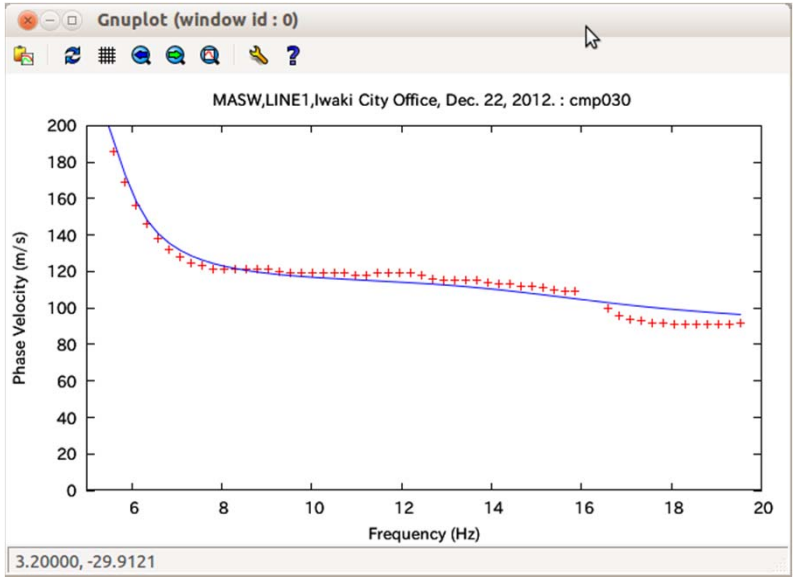


Example cont.

Type in
load ‘disp_cal_all’
The image of observed and theoretical dispersion curves is shown in a X-window. The same image is stored simultaneously in
./maswkf/data/dispersion/fig/disp_cal030.ps
The consecutive images of dispersion curves are shown and stored by hitting Return (Enter) key.

The above mentioned procedure “Inversion for a group of CMPs” is repeated until all CMPs are processed.
Quit from GNUPLOT using ‘quit’.



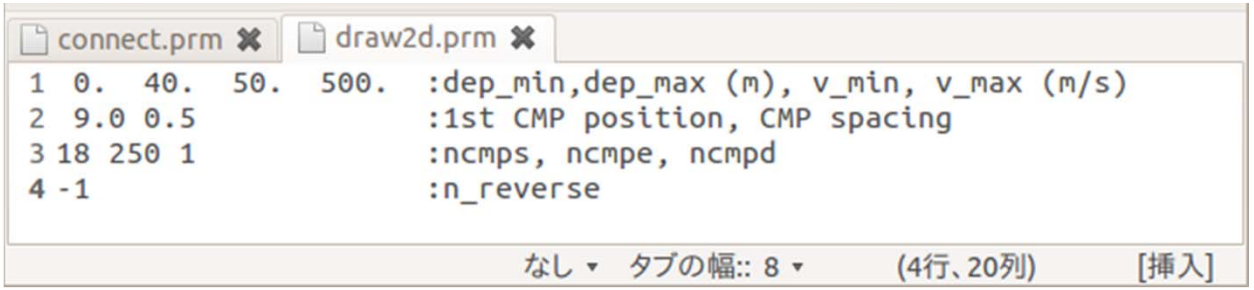


1. Instruction Manual of Programs for Analysis

1.8 Plotting 2D velocity structures

draw2d.for + draw2d.prm

Parameter File: draw2d.prm



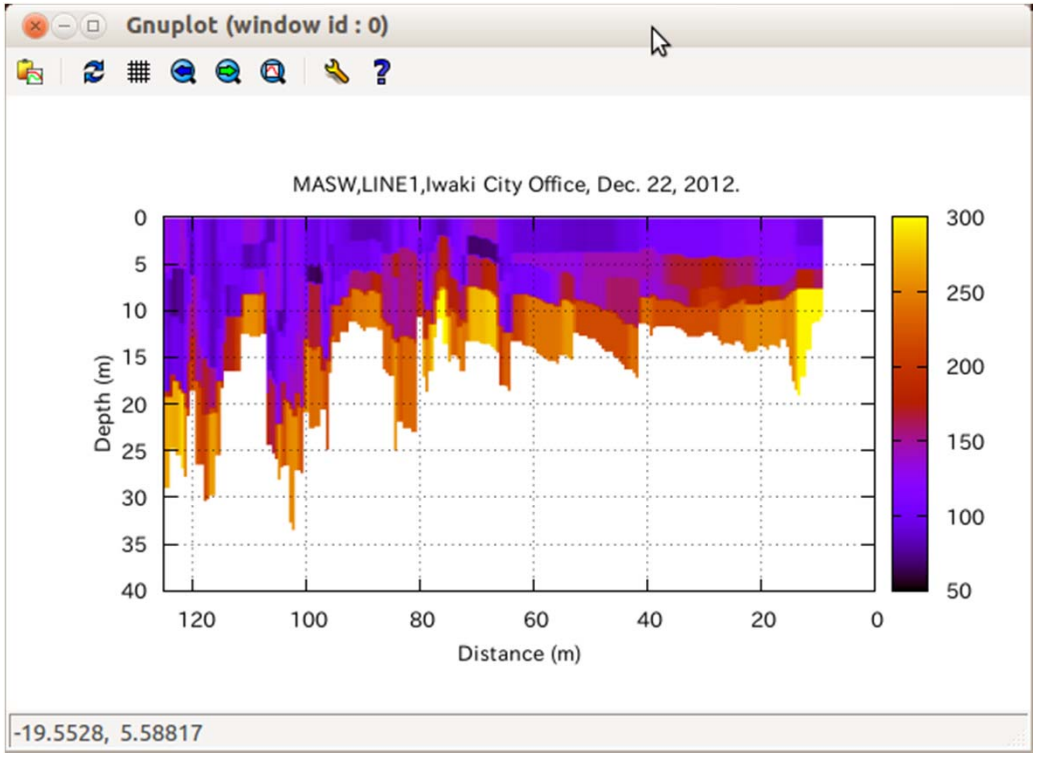
Input File

- The file of the estimated Vs structure “vel_cal???.dat” stored in ./maswkf/data/structure .

Output File

- Interim data file: ./maswkf/data/structure/draw2d.dat
- Interim script file of GNUPLOT:
  ./maswkf/prm/gnuplt_script/draw2d.plt

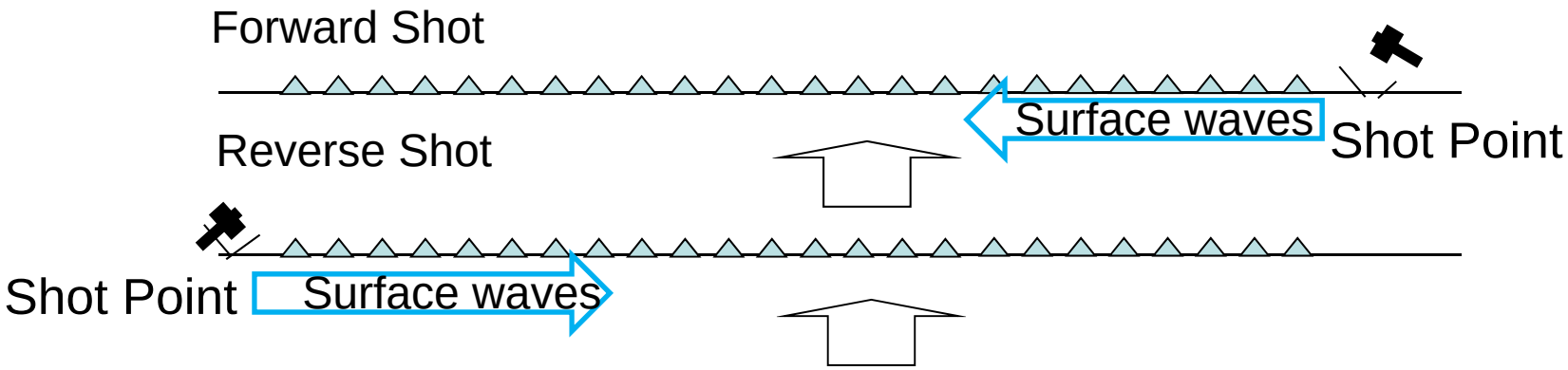
Type in !./draw2d.exe in GNUPLOT mode or ./draw2d.exe on the Linux command line.
Then, load ‘draw2d_plt’
2D plot of velocity structure is drawn in a X-window. Simultaneously, the same image is stored in ./maswkf/data/structure/fig/draw2d.ps .



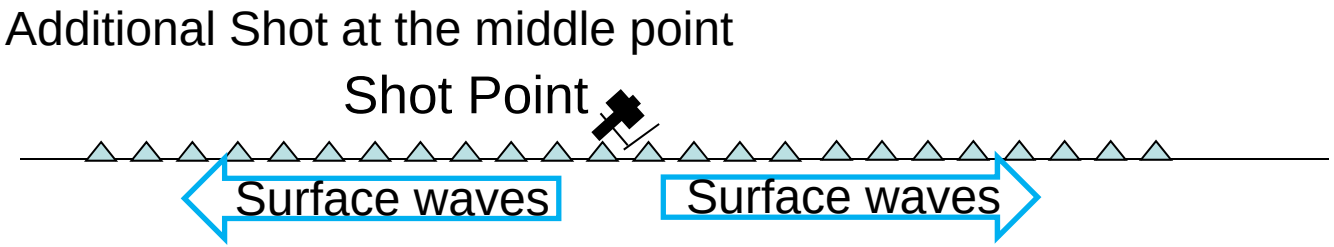
2. Memo: Field Data Acquisition

1D exploration

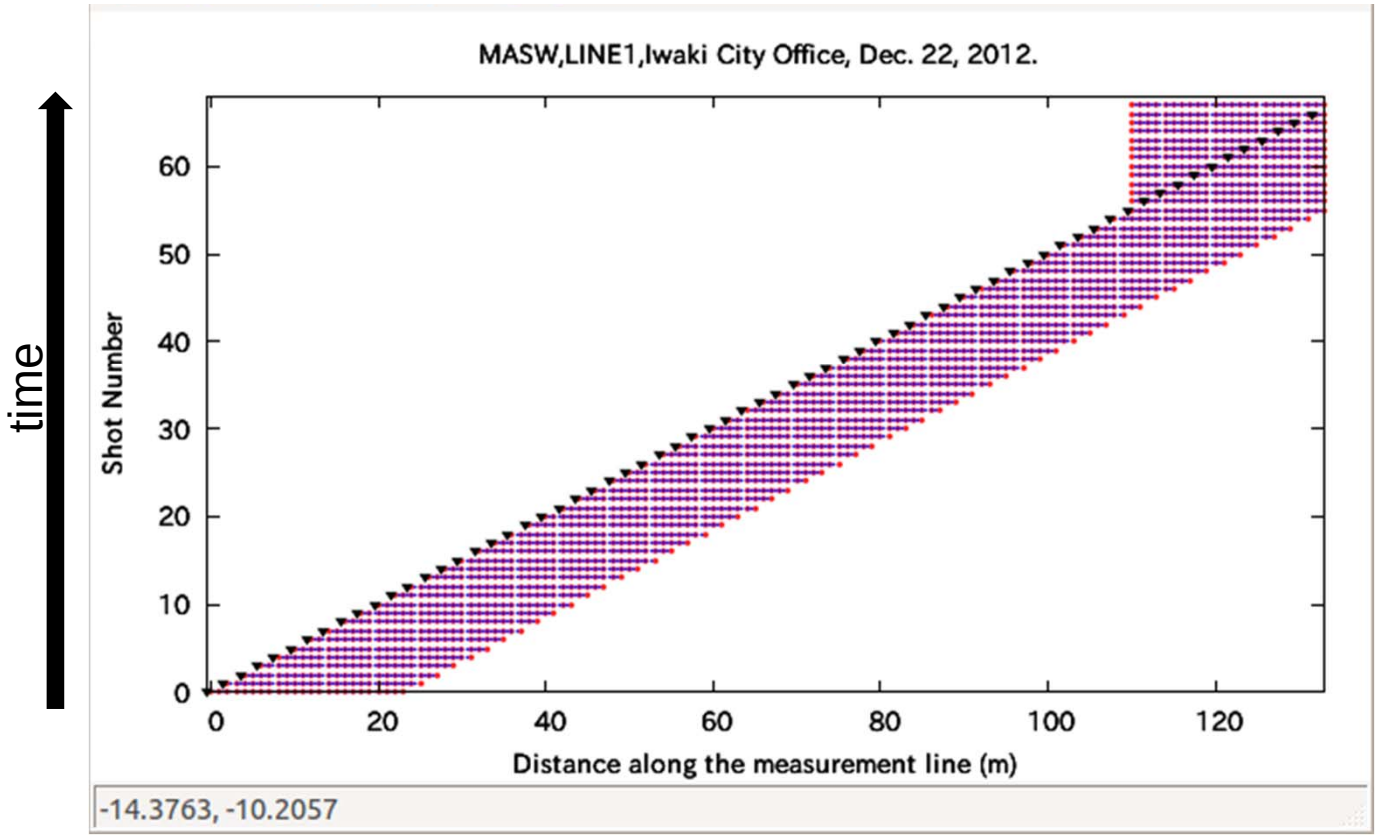
A pair of measurements is conducted in the field changing the shot position as shown below.



Then, the velocity analysis is conducted for all the geophone pairs on the measurement line.
Shots, e.g., at the middle of the measurement line, are added in order to enhance the signal to noise ratio.



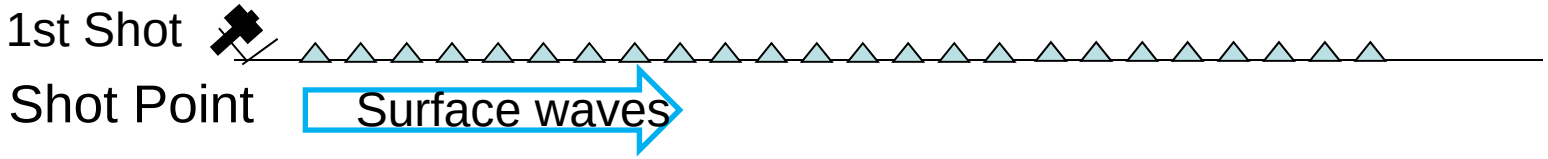
2D Exploration
(configuration)



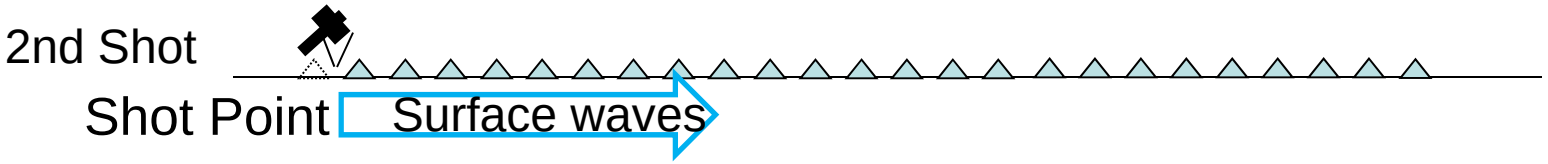
Triangles: shot points, Red dots: geophone locations,
Blue dots: CMP location.

2D Exploration (cont.)

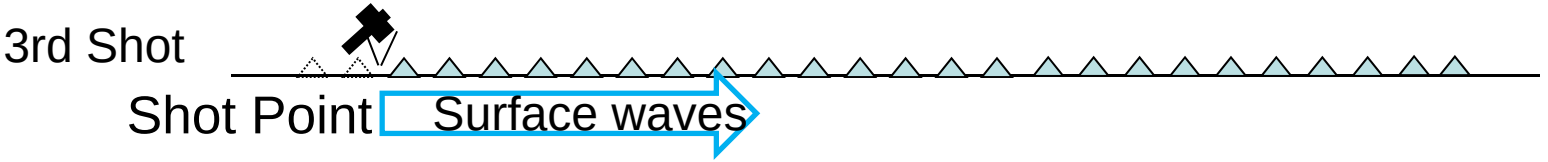
+ 1st shot is applied at an end of the measurement line.



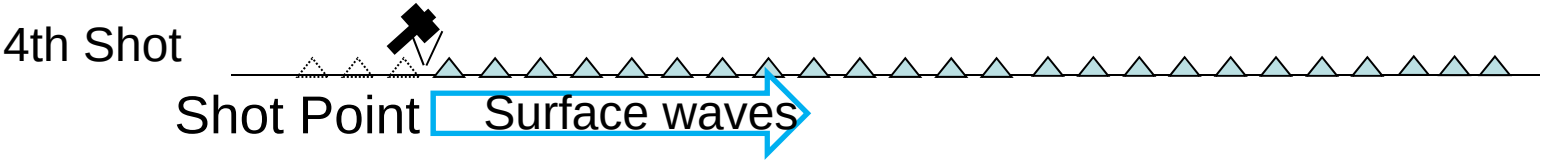
+ Geophone array is moved with dx (geophone interval). 2nd shot is applied.



+ Geophone array is moved with dx (geophone interval). 3rd shot is applied.



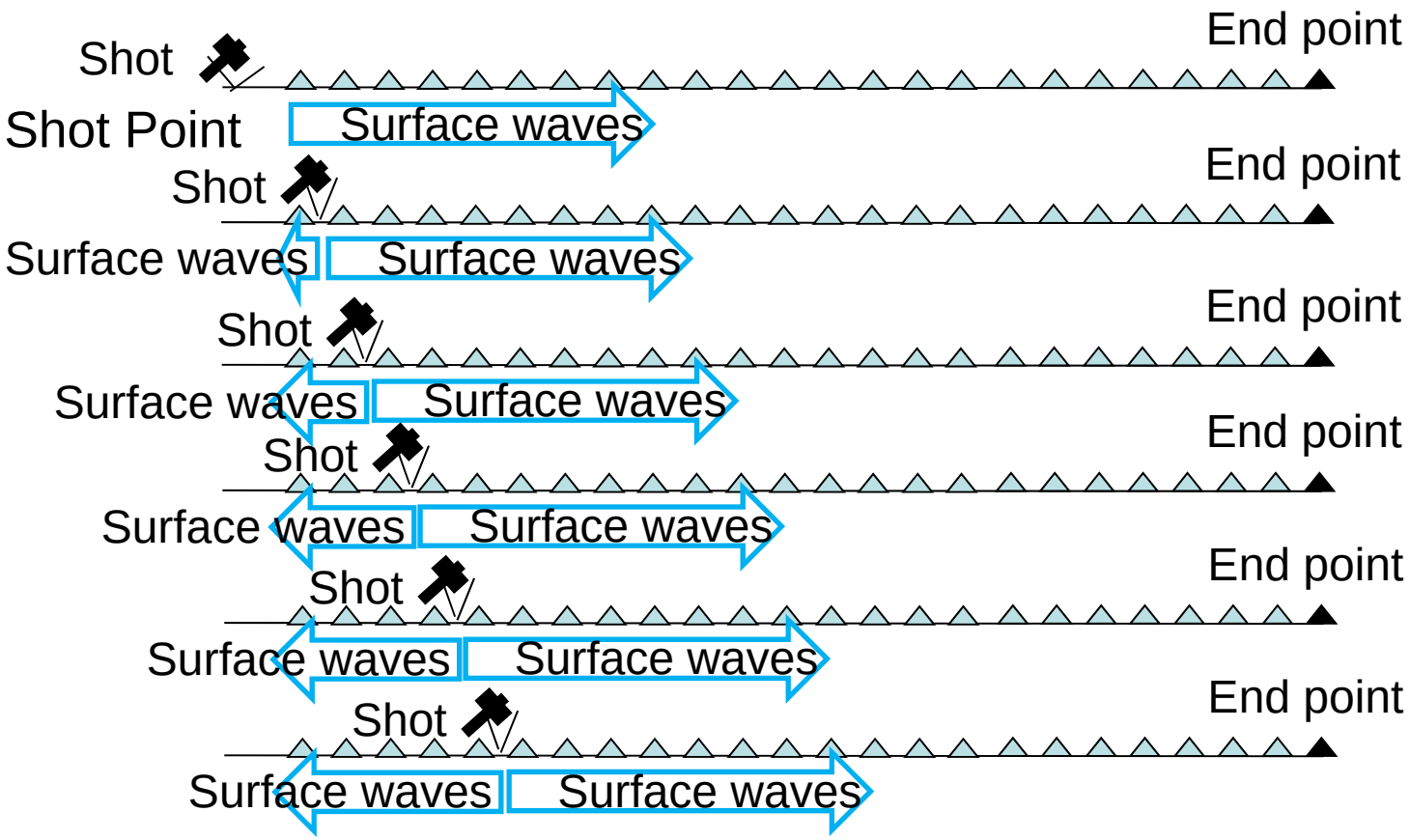
+ Geophone array is moved with dx (geophone interval). 4th shot is applied.



+ Continue the same procedure until the final channel's geophone reaches at another end of the measurement line.

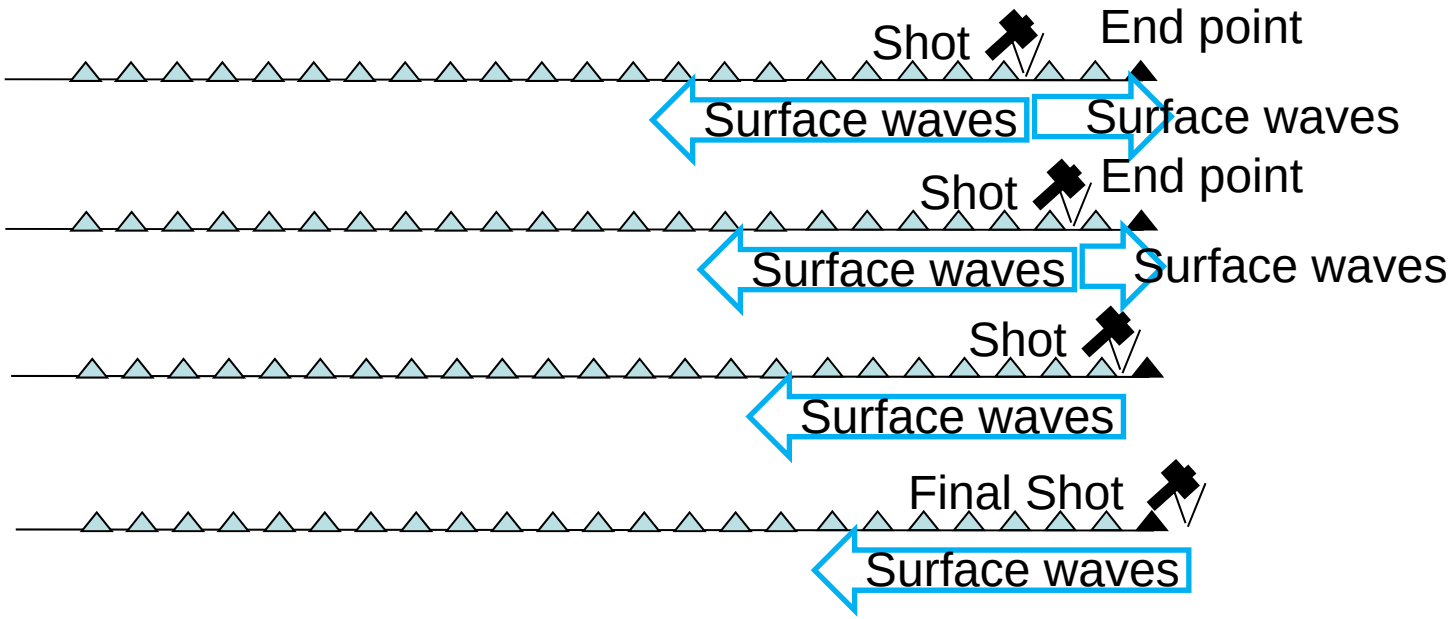
2D Exploration (cont.)

+ When the final channel's geophone reaches at another end of the measurement line, Geophone array stops and shot point goes on moving toward the end point



2D Exploration (cont.)

+ The final shot is applied at outside of the end.



3. References

Hayashi, K. and H. Suzuki, 2004, CMP cross-correlation analysis of multi-channel surface-wave data, Exploration Geophysics, **35**, Butsuri-Tansa, 57, Mulli-Tamsa, 7, 7–13 (one issue published jointly in English)..