FDwave 1.0

Simulate seismic wave in earth and materials

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Contents

Chapter 1

Introduction

FDwave is a a set of MATLAB functions which can simulate the wave propagation in a different rheologies (acoustic/elastic/viscoelastic/anisotropic). In the present version FDwave1.0 only elastic rheology is included. This code is intended for the use by students and researchers.

Code characteristics

- Based upon finite difference time domain modeling over- staggered grid in 2-dimension.
- Vectorized code for faster execution.
- Temporal and spatial accuracy of $(\Delta t^2, \Delta x^4)$
- Free surface and damping absorbing boundary condition can be applied.

Utilities

- Various rheologies available (e.g. acoustic, elastic, viscoelastic, anisotropic).
- Readily define the layered model, create used defined geometry, or read model from SEGY file.
- Various source wavelet are available
- Various geometries for source and receiver layout are available, e.g. straight line along surface, VSP, user defined.

Contents in the package The package contains two directories

- FDwave: This directory contains all the programs & functions related to seismic modelling.
- scripts: This directory contains all the file containing commands used for the modelling.

Installation :
This package has been tested on windows environment and currently being under test on Linux/unix environment. This package is provided in "ready to use" form. The MATLAB-scripts-files from the script-folder can be run directly. Which utilize the `FDwave_initialization` function and its details are provided in the next chapter.

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Disclaimer :
The code comes without any guarantee and author will not be responsible for any kind of loss.

References :
This work has resulted in following articles. Kindly consider citing these if this code was useful in your work.

- Malkoti, A., Vedanti, N., & Tiwari, R. K. (2018). An algorithm for fast elastic wave simulation using a vectorized finite difference operator. Computers & Geosciences, 116, 23-31.

- Malkoti, A., Vedanti, N., & Tiwari, R. K. (2019). A highly efficient implicit finite difference scheme for acoustic wave propagation. Journal of Applied Geophysics, 161, 204-215.

- Malkoti, A., Vedanti, N., Kunagu, P., & Tiwari, R. K., 2015, Modeling viscoelastic seismic wave propagation in Deccan flood basalt, western India, SEG Expanded Abstracts presented at New Orleans, USA.

The FDwave package has also resulted in development of following 3D wave simulation package.

- Lei Li, Jingqiang Tan, Dazhou Zhang, Ajay Malkoti, Ivan Abakumov & Yujiang Xie (2021). FD-wave3D: a MATLAB solver for the 3D anisotropic wave equation using the finite-difference method. Computational Geosciences, doi.org/10.1007/s10596-021-10060-3

Chapter 2

Setup and running code

The program can be run either in two modes

- GUI mode, with limited functionality and
- COMMAND mode, which offers more options.

A quick outline/steps used in modelling is given below:

1. Initialization
2. Model building and plot it [1]
3. Source selection and plot it [1].
4. Analyse the parameters for various conditions
5. Derive the additional parameters.
6. Select the parameters for boundaries and plot it [1].
7. Generate the source and the receiver geometry and plot it [1].
8. Run the FD calculation for given shot and plot it [1].

Initialization and setting up the path :
For initialization we require two pats:

1. It is necessary to provide the path to directory were the code files can be located. It can be done as following:

```
code_path='F:\My_M_Codes\FDwave'; % path
addpath(code_path);              % Add the code folder to the current command space
```

2. Path to the working directory where data should be provided. In case when it is not provided then it is the automatically set to the current working directory. Following command shows how to setup a folder as the working directory for the first time.

```
code_path='F:\My_NVPAIR\FDwave';          % path
initialize('cp',code_path,'wfp',wf_path); % initialization of code
```

You may want to start with a fresh, clean installation by removing earlier output files/folders of previous simulations, run following.

```
code_path='F:\My_NVPAIR\FDwave';                                % path
initialize('cp',code_path,'wfp',wf_path,'clean','y'); % initialization (clean) of code
```

[1] Plotting is optional

Sample Program :

A sample program can be written as following:

```
--------------------------------------------------------------------------------
% Add the code folder to the current command space
code_path='F:\My_NVPAIR\FDwave';
addpath(code_path);

% Do necessary steps for initialization
wf_path='F:\My_Test';
initialize('cp',code_path,'wfp',wf_path);

% Initialize the model
model_n_layers('wave_type','Elastic','dx',10,'dz',10,'Thickness',[2000 2000],...
        'HV_ratio',1,'Vp',[1700 2000],'Vs',[1500 1800],'Rho',[1600 1800],'PlotON','y');

% Generate the source wavelet
source_ricker('wfp',wf_path,'T',3,'dt',.001,'f0',15,'plotON','y');

% Analyse the parameters
analyse_elastic('wfp',wf_path)

% Derive additional parameters
model_derived_elastic_g1('wfp',wf_path)

% Select the Absorbing boundaries
bc_select('wfp',wf_path,'BCname','ABL','BCtype','topFS','nAB',50,'PlotON','y') ;

% Place a single source
geometry_src_single('wfp',wf_path,'PlotON','y')

% Place an array of receivers
geometry_rec_st_line_surf('wfp',wf_path);

% Run the simulations
calculation_elastic_g1('plotON','y');
--------------------------------------------------------------------------------
```

Each of the above command will be described later in respective chapters

Chapter 3

Model building

This package comes with many pre defined models. There is also a way to customize a model according to your preferences. For each model there are different model parameters and all of them are described below one by one.

3.1 N-Layered model

Complete description of command :

```
--------------------------------------------------------------------------------
 MODEL_N_LAYERS
  This function can create a model consisting of 'n' horizontal layers.
  Complete Syntax:
      model_N_layers('WFP',path,'WAVE_TYPE',options,'DX',value,'DZ',value,'THICKNESS',value,...
          'HV_RATIO',value,'VP',value,'VS',value,'RHO',value,'QP',value,'QS',value,'PlotON',
              option )

        Description of parameters:
        WFP          :  Path to working folder
        WAVE_TYPE    :  'acoustic1', 'acoustic2', 'elastic', 'viscoelastic'
        DX, DZ       :  Grid size in horizontal and vertical direction in meters
        THICKNESS    :  Thickness of each layer in form of vector
        HV_RATIO     :  Total size of the model in respect to
        VP, VS       :  Velocity of P and S wave in form of vector
        RHO          :  Density of medium in form of vector
        QP, QS       :  Attenutation of P and S value in form of vector
        PlotON       :  'y'/'n' for plotting
  Note:
        acoustic1 - requires VP
        acoustic2 - requires VP, RHO
        Elastic   - requires VP, VS, RHO
        viscoelastic - require VP, VS, RHO, QP, QS
        The vector is in the form of e.g. [600,700,800,1000]
  Example:
      model_n_layers('WFP',wf_path,'WAVE_TYPE','Elastic','DX',4,'DZ',4,'THICKNESS'
          ,[250,500,300,450,600],'HV_RATIO',1,'Vp',2000:250:3000,'VS',1700:250:2700,'RHO'
          ,2300:100:2700,'PlotON','y')
--------------------------------------------------------------------------------
```

Demonstration/Example :

To create a N-stacked layer model we issue following command at MATLAB command prompt

```
>> model_n_layers('WFP',wf_path,'Wave_Type','Elastic','DX',4,'DZ',4,'Thickness'
     ,[250,500,300,450,600],'HV_Ratio',1,'Vp',2000:250:3000,'VS',1700:250:2700,'RHO'
     ,2300:100:2700,'PlotON','y')
```

Ouptut :
It causes some info to appear at the command screen, as shown below:

```
--------------------------------------------------------------------------------
FUNC: Model Building
   Model Selected: N-Layers
          Provided parameters
   Type of wave       : Elastic
   Grid spacing along x : 4
   Grid spacing along x : 4
   X/Y dimension Ratio : 1      (Default)
   Thickness of layer(s): 250 500 300 450 600
   Vp of layer(s)     : 2000  2250  2500  2750  3000
   Vs of layer(s)     : 1700  1950  2200  2450  2700
   Density of layer(s) : 2300 2400 2500 2600  2700
   dh =  4
   dv =  4
   nh =  527
   nv =  527
   Model saved inF:\My_Test\Data_IP\model
--------------------------------------------------------------------------------
```

Following command can also be used to plot the model. However the plot will be same as before.

```
>> model_plot()
```

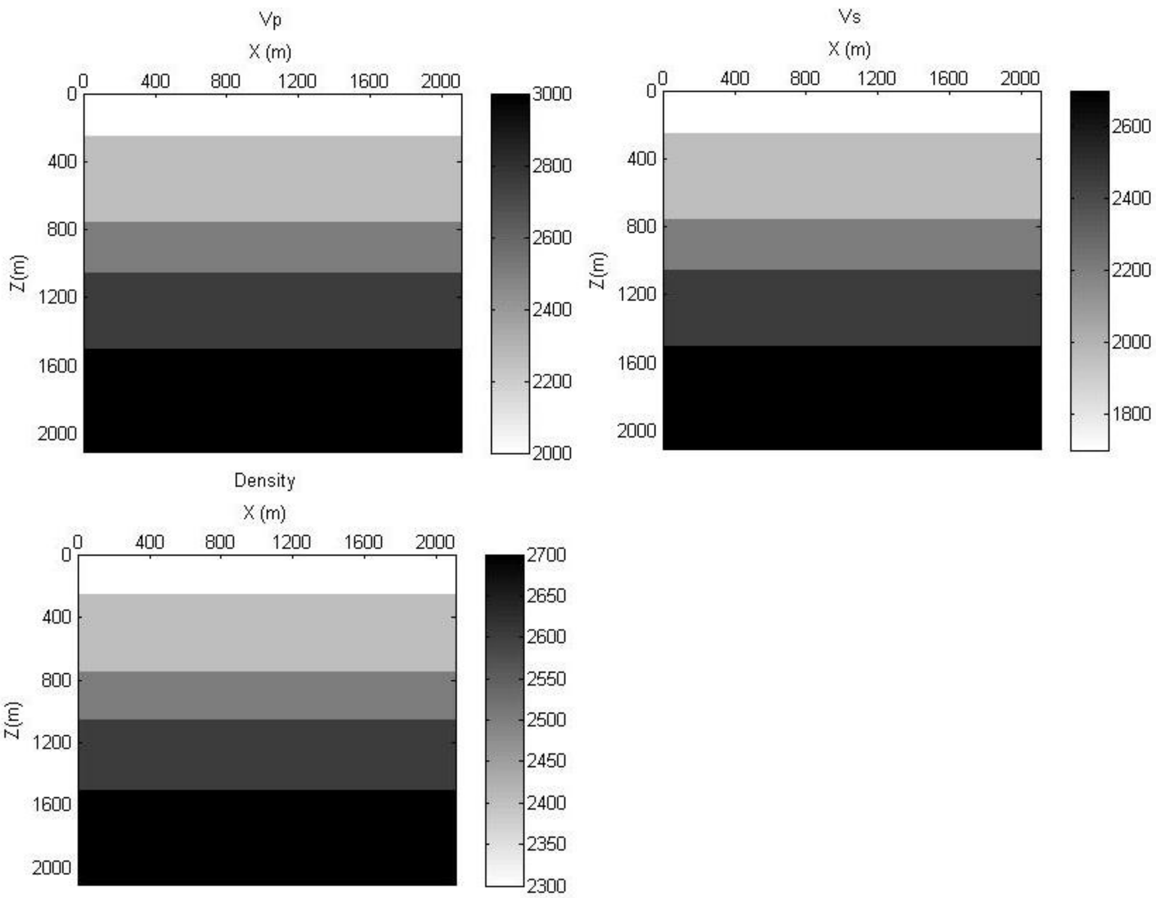


Figure 3.1: A N-Layerd model generated using `N-Layered model` command

3.2 Marmousi model

This is one of the very famous model which was generated by Institut Français du Pétrole (IFP) in 1988. To use this model you many need to unzip the files first (provided in model folder). The model has a dimension of the model is 13601x2801 in grid point. Separation between the grid points is 1.5m.

Complete description of command :

```
-------------------------------------------------------------------------------
MODEL_READ_SEGY
  This function can load the segy file of marmousi model which is
  originally a fine scaled model with dx=dz=1.5m.
  This func can CROP as well as INTERPOLATE the model to form a coarse/finer model
Complete Syntax:
        model_read_segy('WFP',path,'M_NAME',name,'WAVE_TYPE',options,'CROP_MODEL',option, 'X1',
             value, 'Z1',value, 'X2',value, 'Z2',value,'INTERPOLATE',option, 'DX_NEW',value,'
             DZ_NEW',value,PAD,option,PADN,value,PADSIDE,option,'PlotON',option )
Description of parameters:
        WFP          :  Path of the folder where model should be saved.
        M_NAME       :  Name of the model (string)
        WAVE_TYPE    :  'acoustic1', 'acoustic2', 'elastic', 'viscoelastic'

        CROP_MODEL   :  'y/n'   ( If selected yes then following parameters must be provided:
                        X1, Z1 represent the left upper corner of selected model
                        X2, Z2 represent the right lower corner of selected model

        INTERPOLATE : 'y'/'n'  ( If selected yes then following parameters must be provided:
                        DX_NEW, DZ_NEW: new grid spacing(in meters) along x and z direction

        PAD          :  'y'/'n' ( If selected yes then following parameters must be provided:
                        PADN    : No of layers to be placed outside extra
                        PADSIDE : 'tblr'/'blr'
        PlotON       :  'y'/'n'
Example:
        model_read_segy('WAVE_TYPE','elastic',...
          'CROP_MODEL','y', 'X1',7000, 'Z1',600, 'X2',15000, 'Z2',4200,...
          'INTERPOLATE','Y', 'DX_NEW',12.5,'DZ_NEW',12.5)

Note: Initialization must have been performed.
        acoustic1 - requires VP
        acoustic2 - requires VP, RHO
        elastic  - requires VP, VS, RHO
        viscoelastic - require VP, VS, RHO, QP, QS
        The vector is in the form of e.g. [600,700,800,1000]
-------------------------------------------------------------------------------
```

Demonstration/Example :

To create marmousi model for a **Elastic wave** with **grid spacing** of 4m, while using only portion of $7000m < x < 12000m$ and $700m < z < 4200m$ issue following command:

```
>> model_read_segy('WFP',wf_path,'M_NAME','marmousi','WAVE_TYPE','Elastic','CROP_MODEL','y','X1'
    ,7000,'Z1',700,'X2',12000,'Z2',4200,'INTERPOLATE','y','DX_NEW',4,'DZ_NEW',4,'PlotON','y')
```

Output of command :

It causes some information to apper on the command screen as shown below:

```
-------------------------------------------------------------------------------
>>FUNC: Model Building
   Model Selected: MARMOUSI
   Note: This function require the SegyMAT package installed
          Provided parameters
```

```
    Type of wave   : Elastic
    Cropped        : Yes
    Interpolated   : Yes
            Final model properties
    dh =  4
    dv =  4
    nh =  1250
    nv =  875
    Model saved in "F:\My_Test\Data_IP\model
--------------------------------------------------------------------------------
```

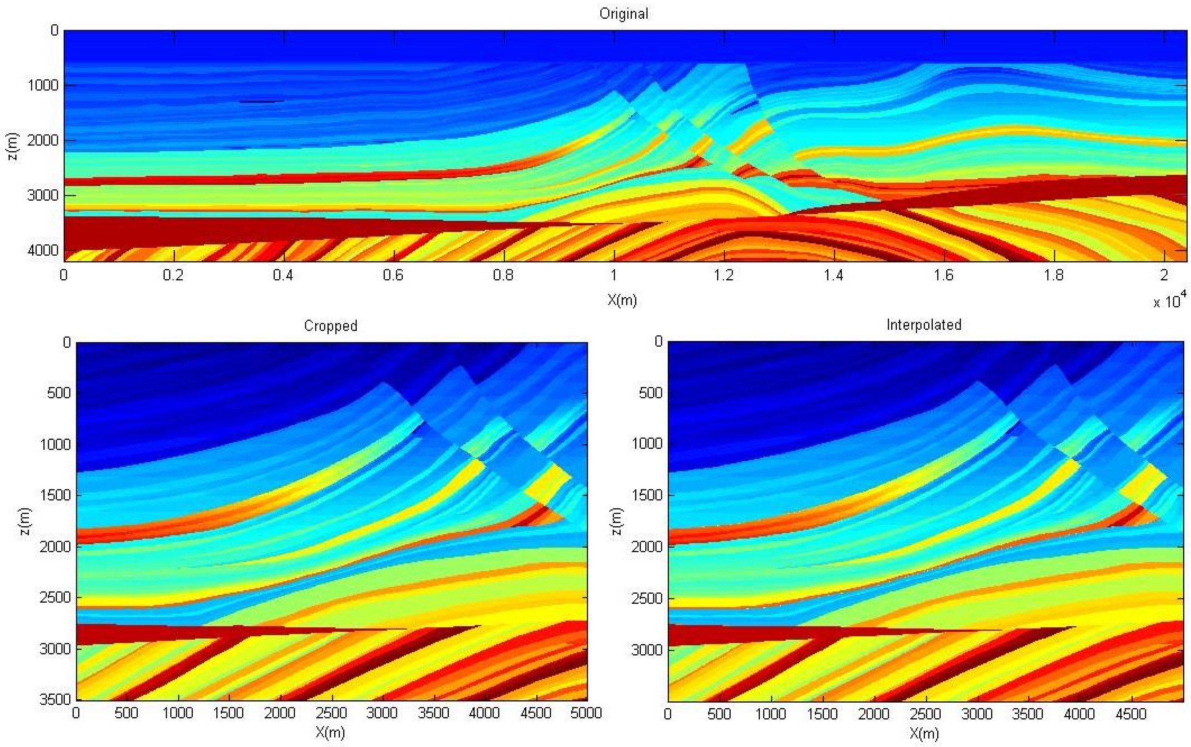


Figure 3.2: Above figure shows the original, cropped and interpolated stages/versions of Marmousi model which are generated using `model_read_segy` function.

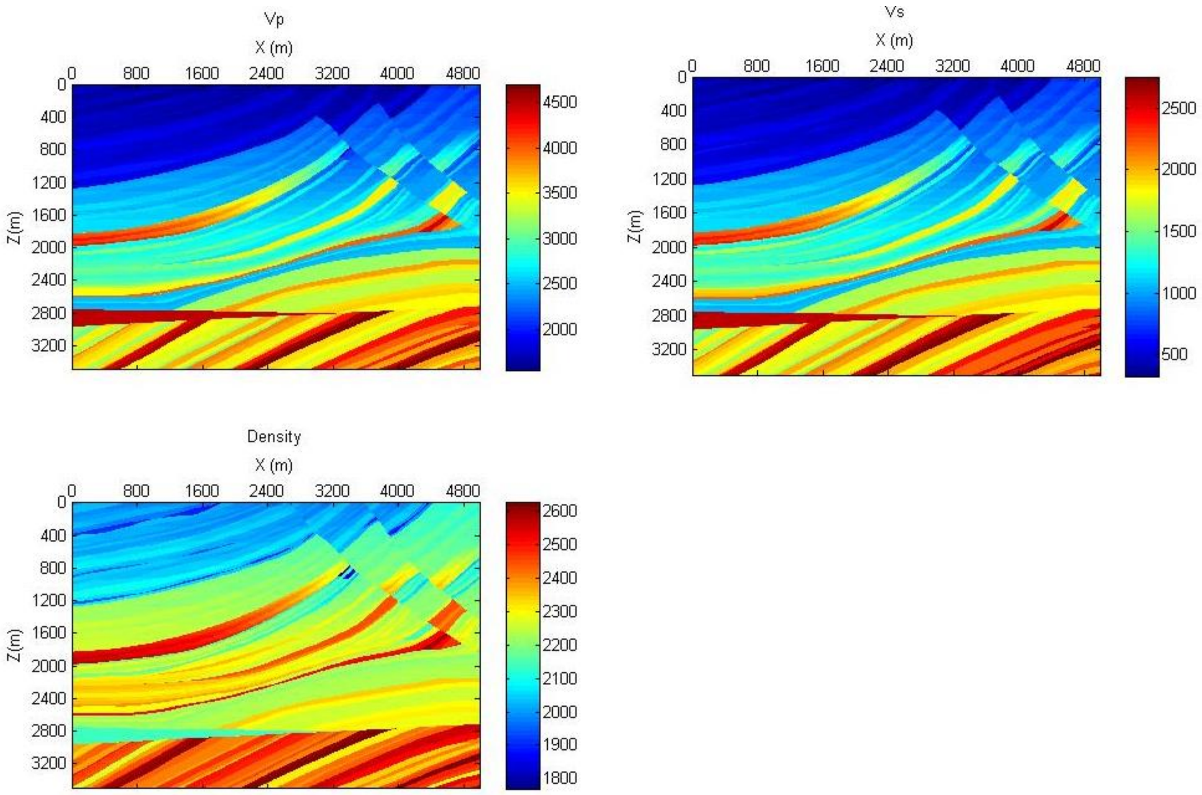


Figure 3.3: A cropped and interpolated Marmousi model generated using `model_read_segy` function. The positions are modifies for better visibility and understanding.

3.3 Build a NEW MODEL yourself

This program helps you to build a model in a layer-by-layer (or object-by-object) manner. It uses coordinates to define a layer/objects. Model building is achieved primarily through two steps.

1. Initialize the model: It creats the initial background model and saves it. The command name to initialize the model is **model_build_init**. The complete syntax for the model initialization command is

```
model_build_start('WFP',path,'WAVE_TYPE','elastic','NX',value,'NZ',value,'DX',value,'DZ',
    value,'VP',value,'VS',value,'RHO',value,'QP',value,'QS',value, 'PlotON',option)
```

2. Create layer(s): A single layer properties of the existing model are changed using the object/shape building function **model_build_shape_arbitrary**. In fact, if you want to change 'n' layers value then you may require to call this function n times. The syntax of the command is following

```
model_build_shape('WFP',path,'COORD',struc,'VP',value,'VS',value,'RHO',value,'QP',value,'QS
    ',value,'PlotON',option)
```

3.3.1 Command: MODEL_BUILD_INIT

Complete description of command (model_build_init) :

```
-----------------------------------------------------------------------------
MODEL_BUILD_INIT
  This function can be used to create a single layer of arbitrary shape.
  The shape is defined by a set of points connected linearly.
  It doesn't create a new model but modifies the existing and then saves
  new one.
```

```
 Complete Syntax:
      model_build_start('WFP',path,'WAVE_TYPE','elastic','NX',value,'NZ',value,'DX',value,'DZ',
          value,'VP',value,'VS',value,'RHO',value,'QP',value,'QS',value, 'PlotON',option)

Description of parametes
      WFP         :  Path to working directory
      WAVE_TYPE   : 'acoustic1', 'acoustic2', 'elastic', 'viscoelastic'
      NX,NZ       : No of grid points along x and z directions
      DX,DZ       : Grid spacing along x and z
      VP, VS      : Velocities of P and S wave
      RHO         : Density of the material
      QP, QS      : Attenuation values of the material.
      PlotON      : 'y'/'n'
 Note:
      acoustic1 requires Vp
      acoustic2 requires Vp, Rho
      elastic requires Vp, Vs, Rho
      viscoelastic require Vp, Vs, Rho, Qp, Qs
      The structure for coordinats can be defined as {[x1,z1],[x2,z2],...}
 Example:
      model_build_start('WFP',pwd,'WAVE_TYPE','elastic','NX',200,'NZ',200,'DX',5,'DZ',5,'VP'
          ,2200,'VS',1800,'RHO',1800,'PlotON','y')
--------------------------------------------------------------------------------
```

Demonstration/Example :
Following command makes/initialize an homogeneous Elastic model of dimension (nx,nz), of specified grid spacing (dx,dz) and assigns the respective values for material parameters (vp, vs, etc.)

```
>> model_build_init('WFP',wf_path,'Wave_Type','elastic','NX',500,'NZ',400,'DX',5,'DZ',5,'Vp'
    ,2200, 'VS',1800,'RHO',1600,'PlotON','y')
```

Output of command :
Above first command makes some information, about the created model, to appear at command window

```
--------------------------------------------------------------------------------
FUNC: Model Building
    Model Selected      : Build
        Provided parameters
    Type of wave        : Elastic
    No of grids along x : 500
    No of grids along x : 400
    Grid spacing x (m)  : 5
    Grid spacing z (m)  : 5
    Vp (m/s)            : 2200
    Vs (m/s)            : 1800
    Density (g/cc)      : 1600
        Final model properties
    dh =  5
    dv =  5
    nh =  500
    nv =  400
    Model saved inF:\My_Test\Data_IP\model
--------------------------------------------------------------------------------
```

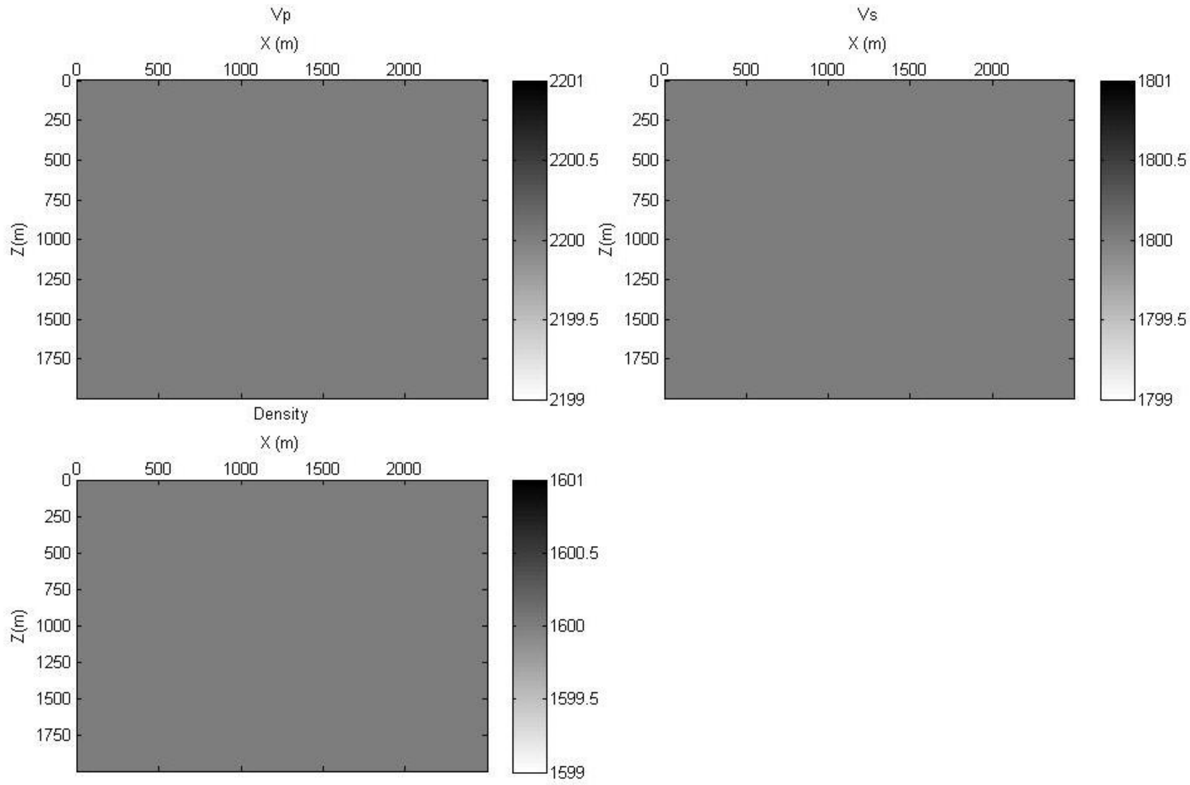


Figure 3.4: A model generated/initialized using `model_build_init` funtion.

3.3.2 Command MODEL_BUILD_SHAPE_ARBITRARY

Complete description of command (model_build_shape_arbitrary) :

```
--------------------------------------------------------------------------------
MODEL_BUILD_SHAPE_ARBITRARY
  This function can be used to create a shape/object of arbitrary shape.
  The shape is defined by a set of points connected linearly.
  It doesn't create a new model but modifies the existing and then saves
  new one.
  Complete Syntax:
        model_build_shape('WFP',path,'COORD',struc,'VP',value,'VS',value,'RHO',value,'QP',value,'QS',value,'PlotON',option)
  Description of the parameters:
        WFP             :  Path to working directory
        COORD           :  A structure of coordinates of shape vertices
        VP,VS           :  P and S Velocities of the structure/object
        RHO             :  Density of the structure/object
        QP, QS          :  P and S Attenuations of the structure/object
        PlotON          :  'y'/'n'
  Note:
        acoustic1 requires Vp
        acoustic2 requires Vp, Rho
        elastic requires Vp, Vs, Rho
        viscoelastic require Vp, Vs, Rho, Qp, Qs
        The structure for coordinats can be defined as {[x1,z1],[x2,z2],...}
  Example:
     model_build_shape_arbitrary('coordinates',CVec,'Vp',2800,'Vs',2200,'Rho',1800,'PlotON','y');
--------------------------------------------------------------------------------
```

Demonstration/Example :

Following are commands to create a corner model (to study diffractions). The rectangle shape/object is superimposed over the existing model.

```
>> CVec={[250,200],[500,200],[500,400],[250,400],[250,200]};
>> model_build_shape_arbitrary('WFP',wf_path,'Coord',CVec,'Vp',2800,'VS',2200,'RHO',1800,'PlotON
    ','y');
>> model_plot('WFP',wf_path)
```

Output of command There are two outputs-

- Intermediate output:
  It shows the current layer only (plotted by plotON option in command). such output for above command is shown below. The rectangle shown is created by above command only.

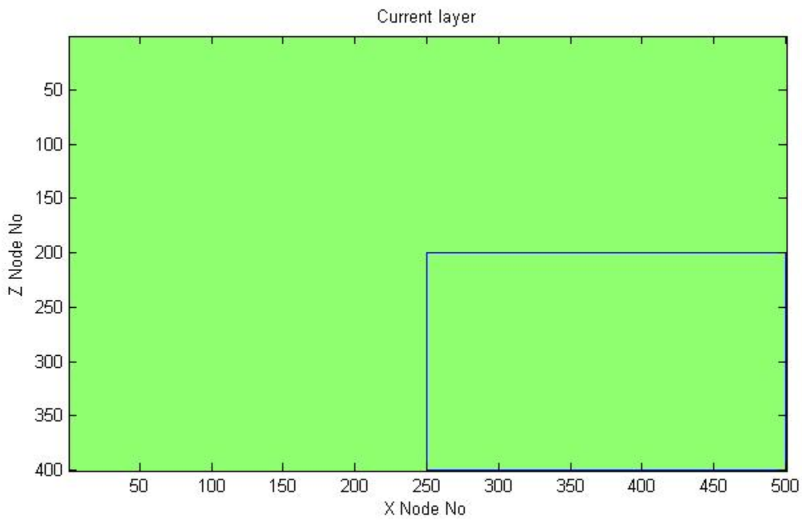


Figure 3.5: A homogeneous model is modified using `model_build_shape_arbitrary` funtion to include a wedge type structure.

- Final output: It shows the final model (plotted by model_plot command)

  It shows the final modified model achieve after initialization, previous and current operation of this command.

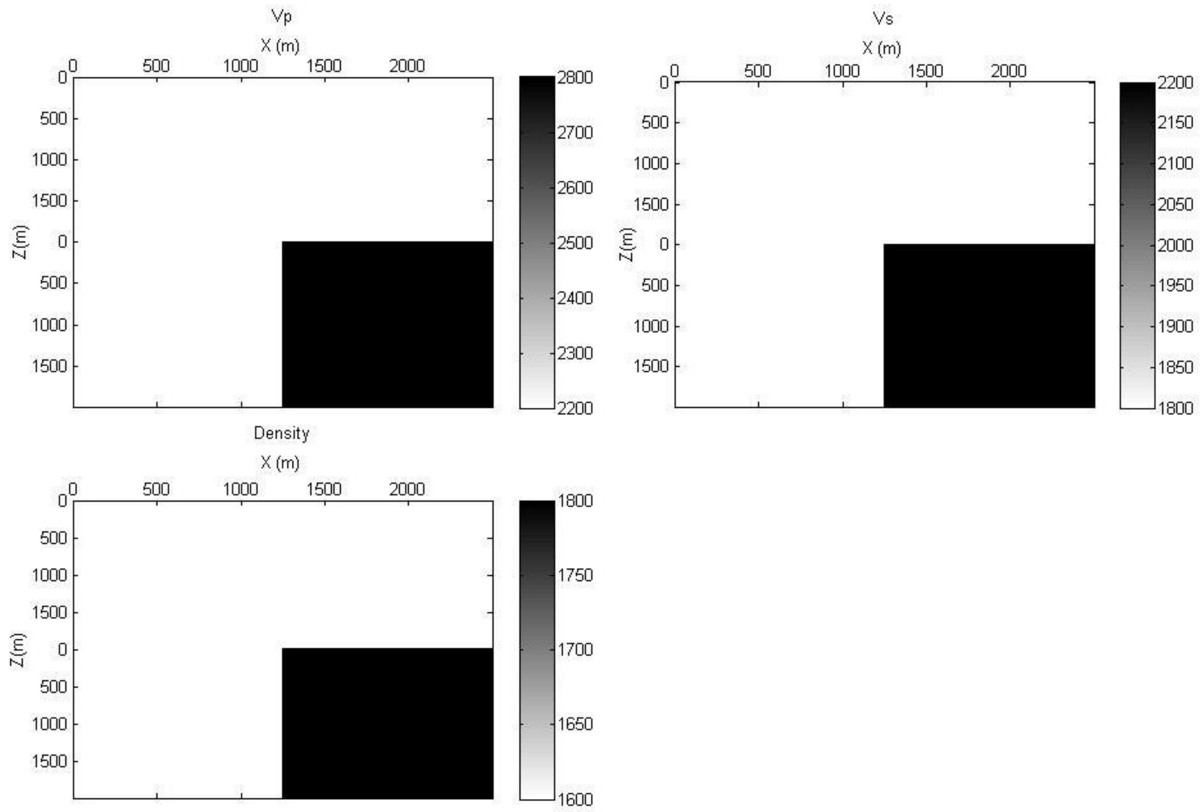


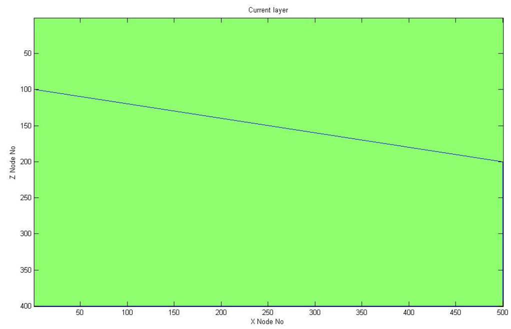
Figure 3.6: The final model produced after modifying the homogeneous model using `model_build_shape_arbitrary` funtion to include a wedge type structure.

3.4 Two working examples

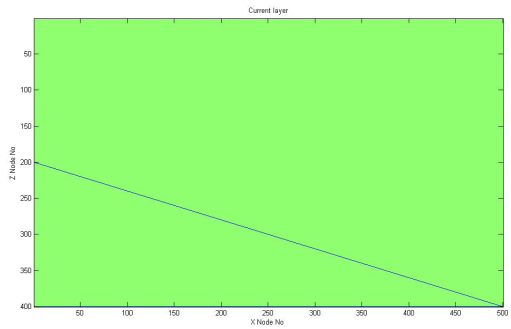
Example 1 : Building a simple dipping layer model consists of 2 layers.

```
---------------------------------------------------------------------------
% A dipping-layer model

% Initialize a model with a homogeneous background.
model_build_init('WFP',wf_path,'Wave_Type','Elastic','NX',500,'NZ',400,'DX',5,'DZ',5,'vp',2200,'VS',1800,'RHO',1600,'plotON','y')

% Create first dipping layer (at shallow depth).
CVec={[1,100],[500,200],[500,400],[1,400],[1,200]};
model_build_shape_arbitrary('WFP',wf_path,'coord',CVec,'VP',2500,'VS',2000,'RHO',1800,'plotON','y');

% Create second dipping layer (at greater depth).
CVec={[1,200],[500,400],[500,400],[1,400],[1,200]};
model_build_shape_arbitrary('WFP',wf_path,'coord',CVec,'VP',2800,'VS',2200,'RHO',2000,'plotON','y');

% Plot the final model.
model_plot('WFP',wf_path)
---------------------------------------------------------------------------
```

The starting/initialized homogeneous model is same as fig ?? shown earlier hence not shown again. The intermediate and final output of above command are following respectively.



(a) Dipping Layer with gentle slope)



(b) Dipping Layer with steep slope)

Figure 3.7: Intermediate results for the 2 dipping layers model generated using recursive use of `model_build_shape_arbitrary` function.

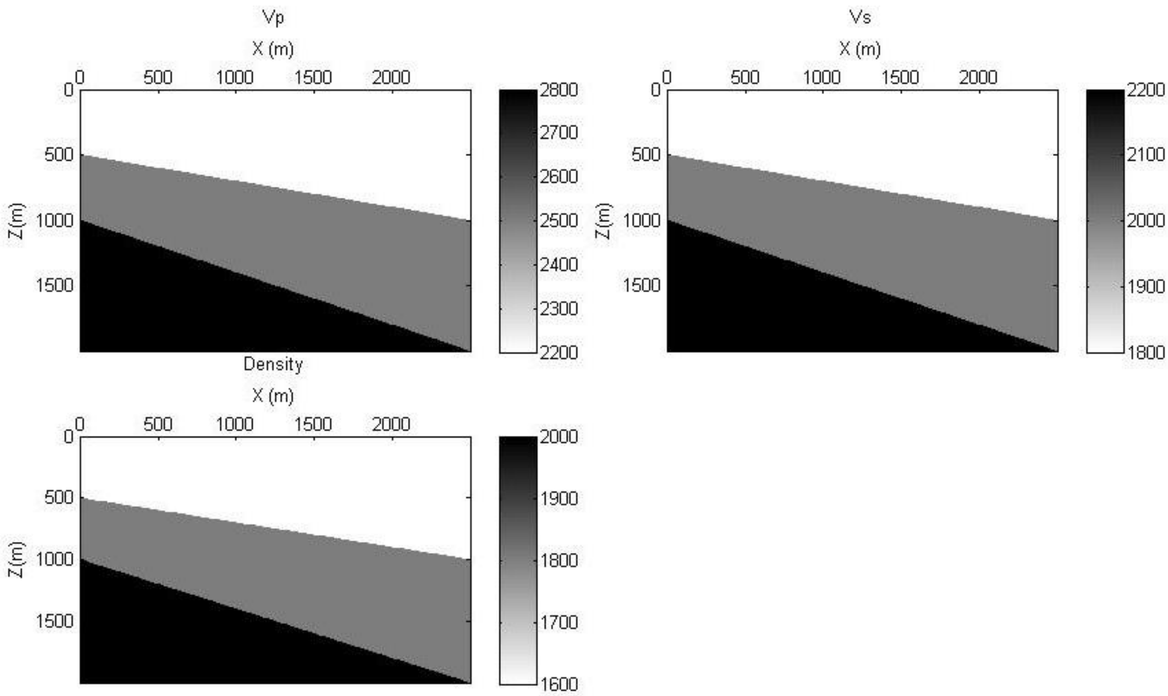
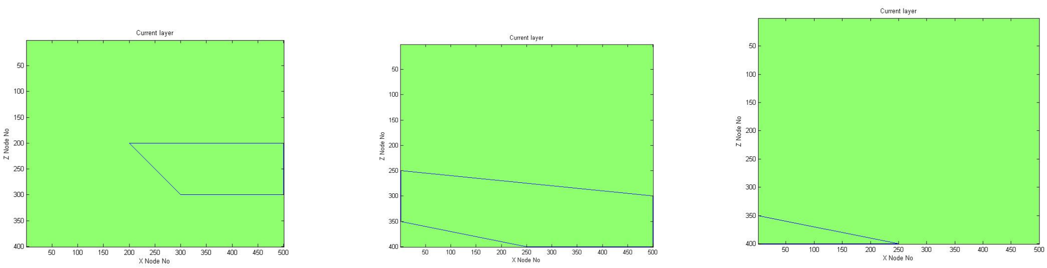


Figure 3.8: Final output for a 2-layers model, created using the `model_build_shape_arbitrary` function

Example 2: A wedge model with dipping layers

```
-------------------------------------------------------------------------------
% Building a complex model (wedge with dipping layers)

% Initialize a model with a homogeneous background
model_build_init('WFP',wf_path,'Wave_Type','Elastic','NX',500,'NZ',400,'DX',5,'DZ',5,'VP',2200,'VS',1800,'RHO',1600,'plotON','y')
model_plot2

% insert: a wedge
CVec={[200,200],[500,200],[500,300],[300,300],[200,200]};
model_build_shape_arbitrary('WFP',wf_path,'coord',CVec,'VP',2800,'VS',2200,'RHO',1800,'plotON','y');
model_plot('WFP',wf_path)

% insert: a dipping layer
CVec={[1,250],[500,300],[500,400],[250,400],[1,350],[1,250]};
model_build_shape_arbitrary('WFP',wf_path,'coord',CVec,'VP',3000,'VS',2400,'RHO',2000,'plotON','y');
model_plot('WFP',wf_path)

% insert: a triangle to fill rest of part,
CVec={[1,350],[250,400],[1,400],[1,350]};
model_build_shape_arbitrary('WFP',wf_path,'coord',CVec,'VP',3100,'VS',2500,'RHO',2100,'plotON','y');
model_plot('WFP',wf_path)
-------------------------------------------------------------------------------
```

Here we will be showing only the figures generated at intermediate steps and the final mode.



(a) Layer 1: Wedge (b) Layer 2: Dipping layer (c) Layer 3: dipping layer

Figure 3.9: Intermediate results for the complex model generated using recursive use of `model_build_shape_arbitrary` function.

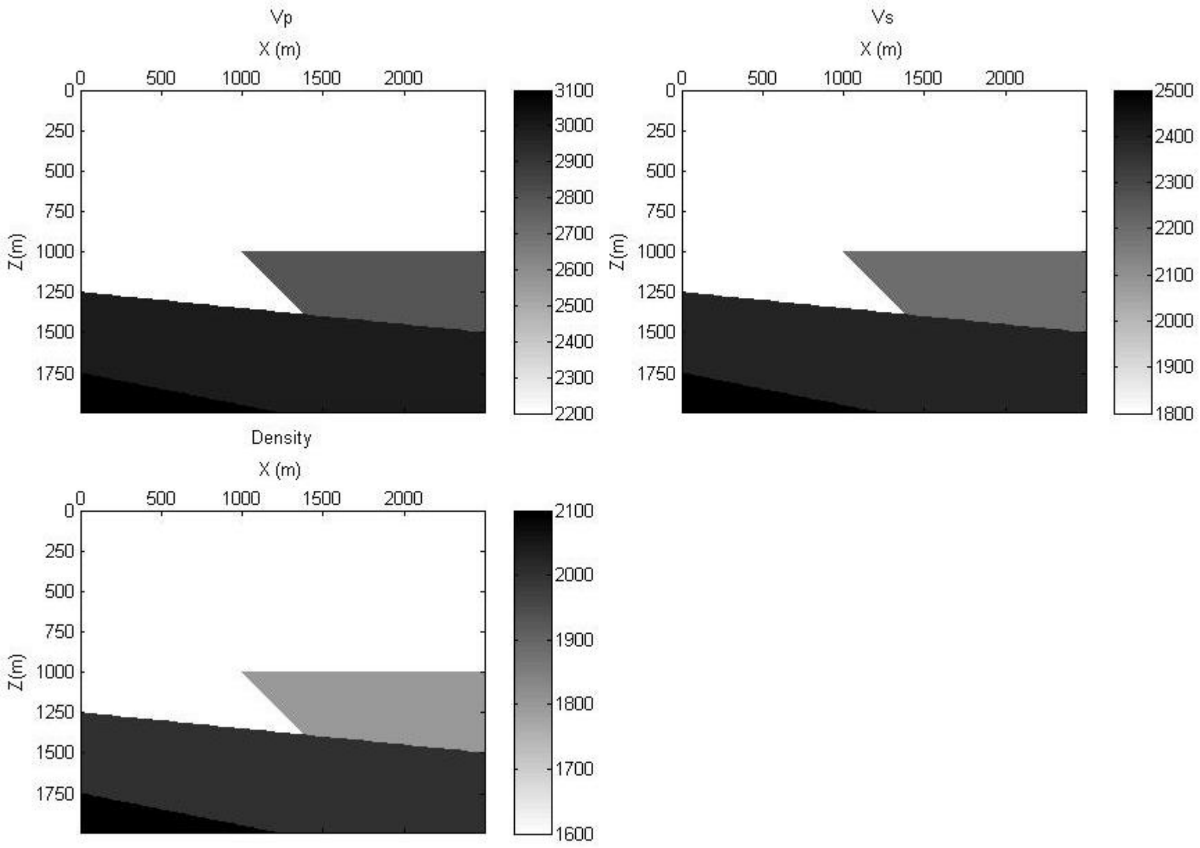


Figure 3.10: Final output for the complex-model, created using the `model_build_shape_arbitrary` function

Chapter 4

Source

FD wave provides various types of the sources as listed below

4.1 Sine source

Complete description of the command :

```
--------------------------------------------------------------------------------
 SOURCE_SINE
  This function generates the Sine wavelet signature.
  Complete Syntax:
        source_sine('WFP',path,'T',value, 'DT',value, 'F0',value, 'T0',value, 'SRC_SCALE',value,'
            PlotON',option)
  Description of parameters:
        WFP        :  Path to working directory
        T          :  Total time duration for simulation.
        DT         :  Time step
        F0         :  Central frequency of source
        T0         :  Zero offset time aka Lag time (optional)
        SRC_SCALE  :  Scaling of amplitude (optional)
        PlotON     :  'y'/'n'
  Example:
        source_sine('WFP',pwd,'T',2,'DT',.0004,'F0',10)
        source_sine('T',2,'DT',.0004,'F0',10,'T0',.03,'SRC_SCALE',1,'PlotON','y');
--------------------------------------------------------------------------------
```

Demonstration/Example :

```
>> nvpair_source_sine('WFP',wf_path,'T',1,'DT',.001,'F0',20,'PlotON','y');
```

Output of the command :

```
--------------------------------------------------------------------------------
  FUNC: Source parameters
        Source type              :    Sine Wavelet
        Source Frequency,      f0 =  20
        Time step size,        dt =  0.001
        Total time duration,    T =  1
        Time shift,            t0 =  0        (Default)
        Source amplitude scaling = 1        (Default)
--------------------------------------------------------------------------------
```

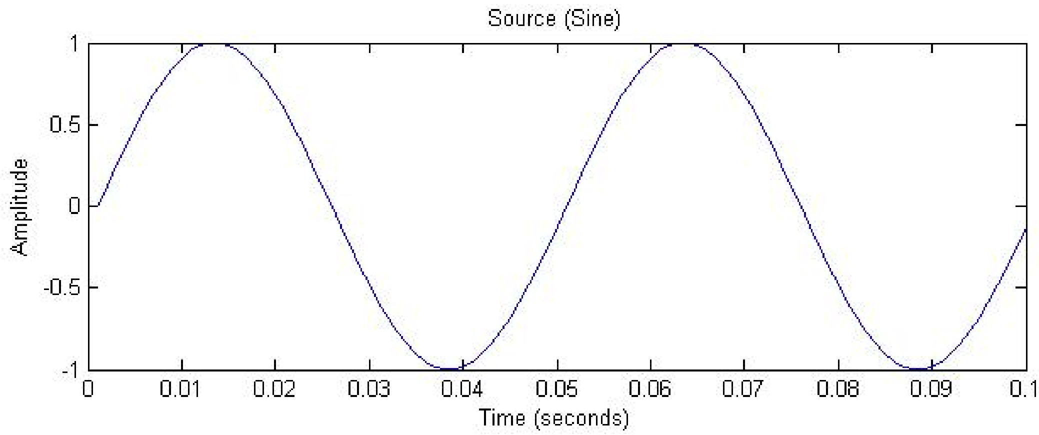


Figure 4.1: A sine function source signature generated using the command nvpair_source_sine

4.2 Gaussian Family wavelets

:
The Gaussian family wavelets include the

1. Gaussian wavelet
2. First derivative of Gaussian wavelet a.k.a. Maxican-Hat wavelet
3. Second derivative of Gaussian wavelet a.k.a. Ricker wavelet

The arguments for each of above are almost same (assuming alpha f0).

4.2.1 Gaussian wavelet

Complete description of the command :

```
--------------------------------------------------------------------------------
 SOURCE_GAUSSIAN
 This function generates the gaussian wavelet signature.
 Complete Syntax:
       source_gaussian('WFP',path,'T',value,'DT',value,'F0',value,'T0',value,'SRC_SCALE',value,'
            PlotON',option)
 Description of parameters:
       WFP        :  Path to working directory
       T          : Total time duration for simulation.
       DT         : Time step
       ALPHA      : Related to central frequency of source
       T0         : Zero offset time a.k.a. Lag time (optional)
       SRC_SCLAE  : Scaling of amplitude (optional)
       PlotON     : 'y' for plotting
                    'n' for not plotting (default)
 Example:
       source_gaussian('WFP',pwd,'T',2,'DT',.0004,'F0',10)
       source_gaussian('T',2,'DT',.0004,'F0',10,'T0',.03,'SRC_SCLAE',1,'PlotON','y');
--------------------------------------------------------------------------------
```

Demonstration/Example :

```
>> nvpair_source_gaussian('WFP',wf_path,'T',1,'DT',.001,'ALPHA',20,'PlotON','y');
```

Output of the command :

```
--------------------------------------------------------------------------------
 FUNC: Source parameters
      Source type              :    Gaussian Wavelet
      Source parameter,  alpha = 20
      Time step size,       dt =  0.001
      Total time duration,   T =  1
      Time shift,           t0 = 0.3        (Default)
      Source amplitude scaling = 1        (Default)
--------------------------------------------------------------------------------
```

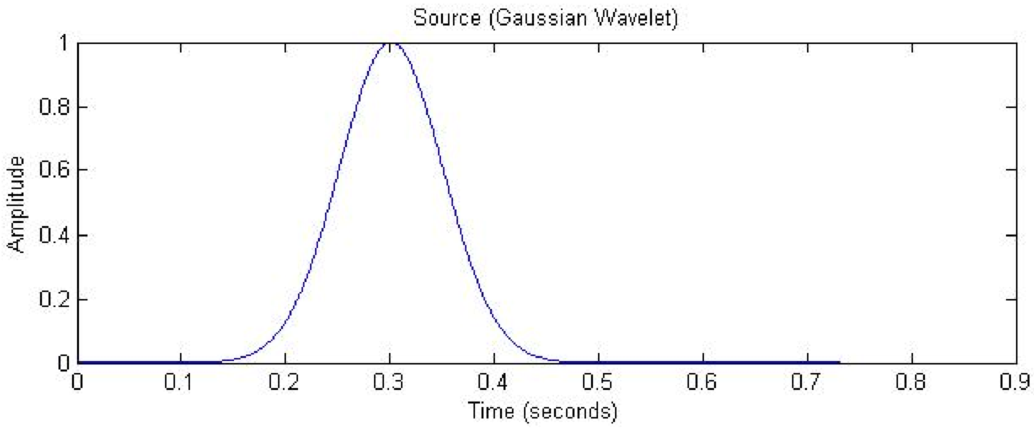


Figure 4.2: A sine function source signature generated using the command `sources_gaussian`

4.2.2 Maxican-Hat wavelet

Complete description of the command :

```
--------------------------------------------------------------------------------
 SOURCE_GAUSSIAN1
 This function generates the gaussian1 wavelet signature.
 Complete Syntax:
      source_gaussian1('WFP',path,'T',value, 'DT',value, 'F0',value, 'T0',value, 'SRC_SCALE',
          value,'PlotON',option)
 Description of parameters:
      WFP        :  Path to working directory
      T          : Total time duration for simulation.
      DT         : Time step
      ALPHA      : Related to central frequency of source
      T0         : Zero offset time aka Lag time (optional)
      SRC_SCALE  : Scaling of amplitude (optional)
      PlotON     : 'y' for plotting
                   'n' for not plotting (default)
 Example:
      source_gaussian1('WFP',pwd,'T',2,'DT',.0004,'T0',10)
      source_gaussian1('T',2,'DT',.0004,'F0',10,'T0',.03,'SRC_SCALE',1,'PlotON','y');
--------------------------------------------------------------------------------
```

Demonstration/Example :

```
>> nvpair_source_gaussian1('WFP',wf_path,'T',1,'DT',.001,'ALPHA',20,'PlotON','y');
```

Output of the command :

```
--------------------------------------------------------------------------------
FUNC: Source parameters
       Source type              :    gaussian1 Wavelet
       Source parameter,  alpha = 20
       Time step size,       dt =  0.001
       Total time duration,   T =  1
       Time shift,           t0 =  0.3       (Default)
       Source amplitude scaling = 1        (Default)
--------------------------------------------------------------------------------
```

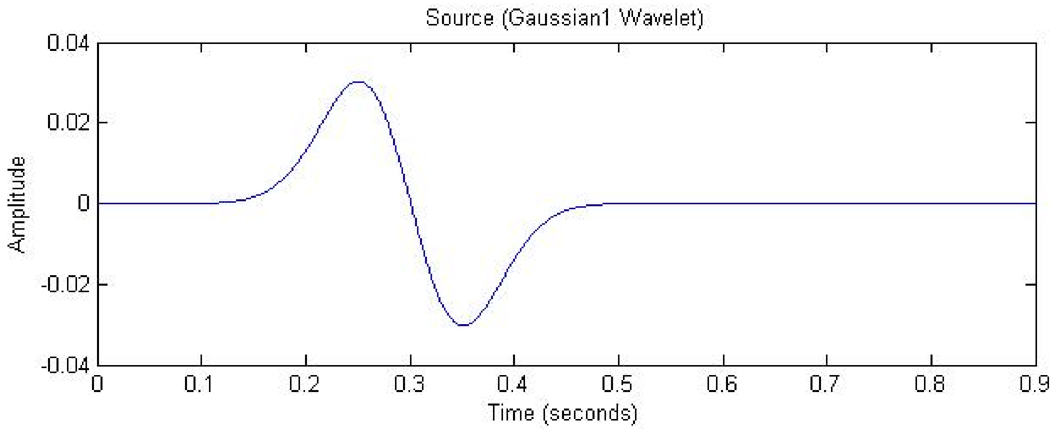


Figure 4.3: A sine function source signature generated using the command `sources_gaussian1`

4.2.3 Ricker wavelet

Complete description of the command :

```
--------------------------------------------------------------------------------
 SOURCE_RICKER
  This function generates the ricker wavelet signature.
  Complete Syntax:
       source_ricker('WFP',path,'T',value,'DT',value,'F0',value,'T0',value,'SRC_SCALE',value,'
           PlotON','y');
  Description of parameters:
       WFP         :  Path to working directory
       T           : Total time duration for simulation.
       DT          : Time step
       F0          : Central frequency of source
       T0          : Zero offset time aka Lag time (optional)
       SRC_SCALE   : Scaling of amplitude (optional)
       PlotON      : 'y'/'n'
  Example:
       source_ricker('WFP',pwd,'T',2,'DT',.0004,'F0',10)
       source_ricker('T',2,'DT',.0004,'F0',10,'T0',.03,'SRC_SCALE',1,'PlotON','y');
--------------------------------------------------------------------------------
```

Demonstration/Example :

```
>> nvpair_source_ricker('WFP',wf_path,'T',2,'DT',.0003,'F0',15,'T0',0.07,'PlotON','y');
```

Output of the command :

```
--------------------------------------------------------------------------------
    FUNC: Source parameters
       Source type              :    Ricker Wavelet
       Source Frequency,      f0 =  15
```

```
        Time step size,       dt =  0.0003
        Total time duration,   T =  2
        Time shift,           t0 =  0.07
        Source amplitude scaling = 1       (Default)
-------------------------------------------------------------------------------
```

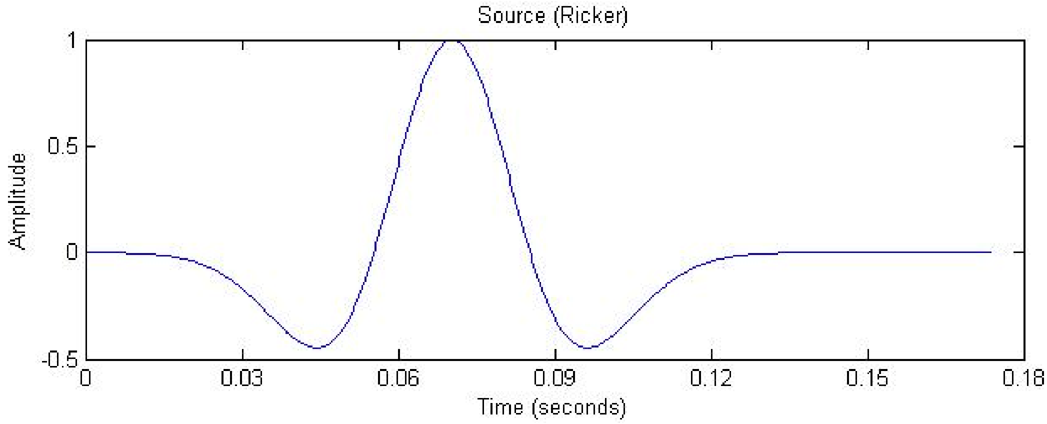


Figure 4.4: A sine function source signature generated using the command `sources_ricker`

4.3 Plotting function

The plotting function is very useful if you want to modify the plotting pattern. It takes the stored wavelet and plot it according to given parameters.

```
-------------------------------------------------------------------------------
SOURCE_PLOT
  This function generates the Sine wavelet signature.
  Complete Syntax:
        source_plot('WFP',path,'Wave_Type',option,'FigNO',value,'I1',value,'I2',value,'I3',value)
  Description of parameters:
        WFP          : Path to working directory
        Wave_Type    : Type of wave  e.g. Elastic
        FigNO        : Figure number
        I1,I2,I3     : subfigure index
  Example:
        source_plot('WFP',pwd,'FigNO',1,'I1',1,'I2',1,'I3',1)
-------------------------------------------------------------------------------
```

Chapter 5

Set-up Boundaries

There are many types of boundaries used in seismic modelling depending upon the type of wave used. For now we will use non-reflecting boundary condition [1].

In this method a damping layer consisting of some nodes is wrapped around the model so that the reflection from edges can be suppressed.

To set up boundaries it is necessary to define the model first. We will be using a N-Layer model which can be created using following command.

```
>> nvpair_model_n_layers('WFP',wf_path,'WAVE_TYPE','Elastic','DX',4,'DZ',4,'THICKNESS'
    ,[250,500,300,450,600],'HV_RATIO',1,'Vp',2000:250:3000,'VS',1700:250:2700,'RHO'
    ,2300:100:2700,'PlotON','y')
```

Description of command :

```
--------------------------------------------------------------------------------
  SELECT_BC
  It generate the necessary data for different BC
  Complete Syntax:
        select_bc('WFP',path,'BCNAME',value,'BCTYPE',value,'NAB',value,'PlotON',option)
  Description of parameters:
        WFP    :  Path to working directory
        BCNAME =  'ABC1'  for Englist & Clayton EnglistClayton (acoustic wave eqn) (future
            implementation)
                  'ABC2'   for Raynold EnglistClayton (acoustic wave eqn)(future implementation)
                  'ABL'    for Damping EnglistClayton, after Cerjan
        BCTYPE =  'topFS'   for free surface at top
               =  'topABC'  for absorbing type boundary at surface
        NAB    =  no of layers to be used (for damping BC only)
        PlotON =  'y', To plot the boundaries
  Example:
        select_bc('WFP',pwd,'BCNAME','ABL','BCTYPE','topABC','NAB',40)
--------------------------------------------------------------------------------
```

Note: Only damping type of boundaries will not work with elastic wave equation. Other boundaries are retained for future implementations.

Demonstration/Example: Top Free, others as absorbing surfaces :
For the free surface following command can be used

```
>> nvpair_bc_select('WFP',wf_path,'BCTYPE','topFS','NAB',50,'PlotON','y') ;
```

Output of the command :

```
--------------------------------------------------------------------------------
    FUNC: Select the boundary types
        BC Method    :  Damping Layer (Cerjan)
```

[1] Cerjan C. Kosloff D. Kosloff R. Reshef M., 1985. A non-reflecting boundary condition for discrete acoustic and elastic wave equation, Geophysics , 50, 705–708.

```
        No of Layers : 50
        BC type      :  topFS
        BC name      :  ABL
--------------------------------------------------------------------------------
```

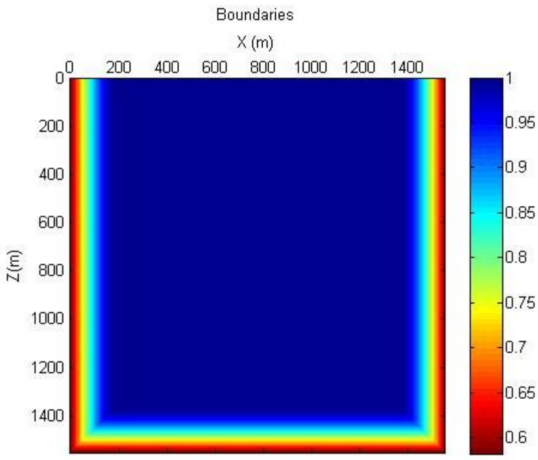


Figure 5.1: Absorbing boundaries generated using the `select_bc` function.

Demonstration/Example: All side absorbing layer :
To place absorbing boundaries all around the model following command can be used.

```
>> nvpair_bc_select('WFP',wf_path,'BCTYPE','topABC','NAB',50,'PlotON','y') ;
```

Output of the command :

```
--------------------------------------------------------------------------------
    FUNC: Select the boundary types
        BC Method    :  Damping Layer (Cerjan)
        No of Layers : 50
        BC type      :  topABC
        BC name      :  ABL
--------------------------------------------------------------------------------
```

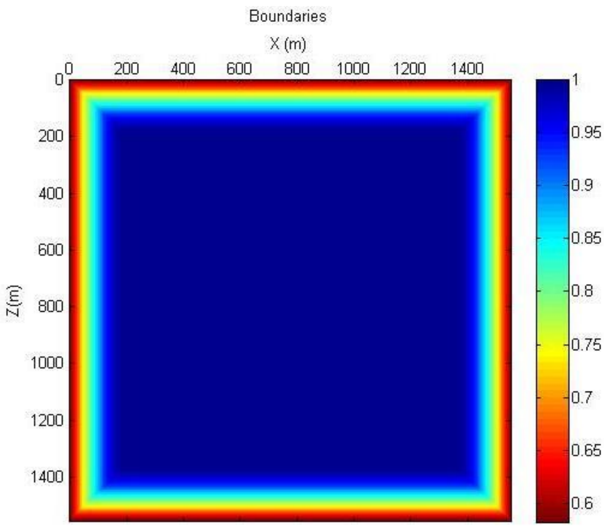


Figure 5.2: Absorbing boundaries generated using the `select_bc` function.

Chapter 6

Setup acquisition geometry

6.1 Introduction

Source and receivers can be laid out in various configurations. In FDwave there are primarily three ways to create geometry.

1. Along surface (conventional reflection/refraction surveys)
2. Along vertical (similar to VSP)
3. User defined position

In following sections we have explained these geometries one by one for source and receivers respectively. This modules assume model and boundaries has been created. Hence we will be assuming following model for creating different geometries.

```
>> % Create Model
>> nvpair_model_n_layers('wave_type','Elastic','DX',4,'DZ',4,'Thickness',[200,300,150,400,500],
    'HV_ratio',1,'VP',2000:250:3000,'VS',1700:250:2700,'RHO',2300:100:2700);

>> % Create boundaries
>> nvpair_bc_select('BCname','ABL','BCtype','topFS','nAB',50,'plotON','y' ) ;
```

Note 1: Boundary creation is not necessary but important for plotting part. It helps you to avoid you to place any source or receiver in absorbing layer.

Note 2: Later in this chapter, we will explain three plotting functions which are handy for visualizing the position of source and receiver with/without model and will be used frequently.

6.2 Source geometry

6.2.1 Single source

```
GEOMETRY_SRC_SINGLE
It places a single source at the given location
Check is applied so that no reciever is placed in absorbing boundary.
Complete Syntax:
        geometry_src_Single('WFP',path,'SX',value, 'SZ',value,'DX',value,'DZ',value,'NX',value,
            'NZ',value,'BCTYPE',value, 'NAB',value)
Description of parameters:
        WFP   :  Path to working directory
        SX    :  Node Location of source (x-position)
        SZ    :  Node Location of source (z-position)
        DX    :  Grid size in x direction
        DZ    :  Grid size in y direction
        NX    :  No of nodes in model along X axis
        NZ    :  No of nodes in model along Z axis
        BCTYPE:  Type of boundary used
        NAB   :  Number of grid nodes used for boundaries.
```

```
        PlotON: 'y'      to plot the source positions
Note:
1) Do not place source very close to surface.
2) Give all the position after adding/subtracting the ABC layer thickness
   according to side where they are added.
   e.g. if you want to place source at some depth then grid location for
        topABC is then, Sz = nAB + dept/dz
3) All parameters are mandatory.
       In case any parameter is not provided the program will try to use
       the values stored in input folder.
       If it cannot find any stored value then it shows error.
Example:
       geometry_src_Single('WFP',pwd,'Sx',2000,'Sz',300,'dx',5,'dz',5,'BCtype','topABC','nAB'
            ,50,'PlotON','Y');
       geometry_src_Single('Sx',2000,'Sz',300)
       geometry_src_Single()
```

Demonstration/Example :

```
>> nvpair_geometry_src_single('WFP',wf_path,'SX',200,'SZ',200,'PlotON','y');
```

Output of command :

```
FUNC: Source geometry (Single at surface)
      Source location along x(m)     :  800
      Source location along z(m)     :  800
      Source node location along x : 200
      Source node location along z : 200
      Note: the program take care of absorbing boundary nodes (if present).
```

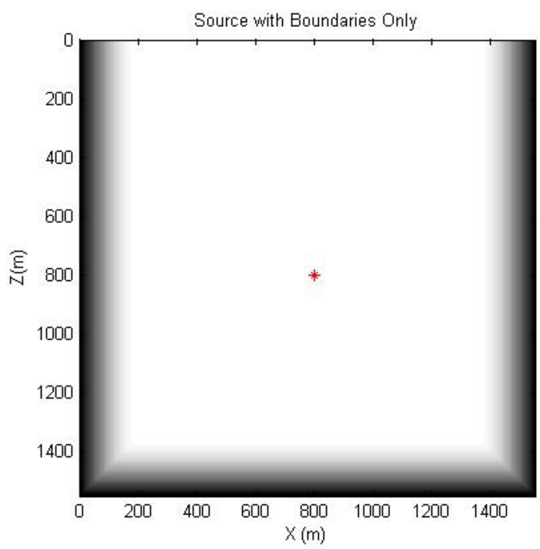


Figure 6.1: Source placed at center with the help of function `nvpair_geometry_src_single`

6.2.2 Array of sources at surface

Description of command :

```
-----------------------------------------------------------------------------------------------

GEOMETRY_SRC_ST_LINE_SURF
```

```
It places sources along the surface at a given depth.
Complete Syntax:
      geometry_src_StLine_Surf('WFP',path,'Depth',value,'FIRST',value,'LAST',value,...
      'DIFF',value,'DX',value,'DZ',value,'BCTYPE',value,'NAB',value,'PlotON',option)
Description of parameters:
      WFP   :  Path to working directory
      DEPTH : Depth in terms of nodes
      FIRST : Location of first Source along x in terms of nodes
      LAST  : Location of last Source along x in terms of nodes
      DIFF  :  Difference in consecutive Source along x in terms of nodes
      DX    :  Grid size in x direction
      DZ    :  Grid size in y direction
      BCTYPE: Type of boundary used
      NAB   :  Number of grid nodes used for boundaries.
      PlotON: 'y'     to plot the source positions
Note:
1) Give all the position after adding/subtracting the ABC layer thickness according to side where they are added.
2) All parameters are mandatory.
      In case any parameter is not provided the program will try to use the values stored in input folder.
      If it cannot find any stored value then it shows error.
Example:
      geometry_src_StLine_Surf('DEPTH',300,'FIRST',260,'LAST',4400,'DIFF',20,'DX',5,'DZ',5,'BCTYPE','topABC','NAB',50);
      geometry_src_StLine_Surf('WFP',path,'DEPTH',300,'FIRST',260,'LAST',4400,'DIFF',20)
      geometry_src_StLine_Surf()
-----------------------------------------------------------------------------------------------
```

Demonstration/Example :

```
>> nvpair_geometry_src_st_line_surf('WFP',wf_path,'DEPTH',10,'FIRST',55,'LAST',330,'DIFF',5,'PlotON','y');
```

Output of command :

```
FUNC: Source geometry (Along surface)
   First source location (m) : 220     (Default, stored)
   Last source location (m) : 1320      (Default, stored)
   Distance between two consecutive source : 100    (Default, stored)
Position of source on grid
   Depth of all source (in terms of node) : 10      (Default, stored)
   First source location (in terms of node) : 55    (Default, stored)
   Last source location (in terms of node) : 330     (Default, stored)
   Distance between two consecutive source (in terms of node): 25  (Default, stored)
Note:
   Node position in grid(N) & distances(X) related by (N= nAB + X/h), due to ABC layer.
```

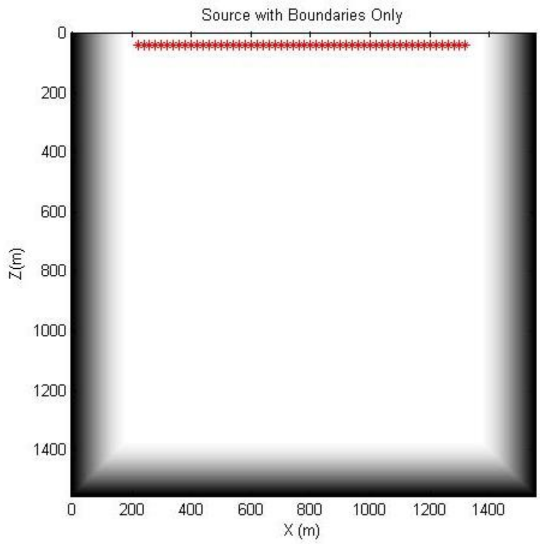


Figure 6.2: Placing an array of sources at the surface with the help of function `nvpair_geometry_src_StLine_Surf`

6.2.3 User defined array of sources

Description of command :

Demonstration/Example :

Output of command :

6.3 Receiver Geometry

6.3.1 Array of receivers at surface

Description of command :

```
GEOMETRY_REC_ST_LINE_SURF
It places recievers along the surface at a given depth.
Check is applied so that no reciever is placed in absorbing boundary.
Complete Syntax:
      geometry_rec_st_line_surf('WFP',path,'DEPTH',value, 'FIRST',value, 'LAST',value,...
      'DIFF',value, 'DX',value, 'DZ',value, 'BCTYPE',value, 'NAB',value,'PlotON',option)
Description of parameters:
       WFP   :  Path to working directory
       DEPTH : Depth in terms of nodes
       FIRST : Location of first Receiver along x in terms of nodes
       LAST  :  Location of last Receiver along x in terms of nodes
       DIFF  :  Difference in consecutive Receiver along x in terms of nodes
       DX    :  Grid size in x direction
       DZ    :  Grid size in y direction
       BCTYPE: Type of boundary used
       NAB   :  Number of grid nodes used for boundaries.
       PlotON: 'y'/'n'
Note:
1) Give all the position after adding/subtracting the ABC layer thickness according to side
    where they are added.
2) All parameters are mandatory.
     In case any parameter is not provided the program will try to use the values stored in
        input folder.
     If it cannot find any stored value then it shows error.
Example:
     geometry_rec_st_line_surf('WFP',pwd,'DEPTH',300,'FIRST',260,'LAST',4400,'DIFF',20,'DX',5,
        'DZ',5,'BCTYPE','topABC','NAB',50);
     geometry_rec_st_line_surf('DEPTH',300,'FIRST',260,'LAST',4400,'DIFF',20)
     geometry_rec_st_line_surf()
```

Demonstration/Example :

For the model defined in introduction part we can define the

```
>> nvpair_geometry_rec_st_line_surf('WFP',wf_path,'DEPTH',10,'FIRST',55,'LAST',330,'DIFF',5);
```

Output of command :

```
FUNC: Reciever geometry (Along surface)
     First receiver location (m) : 220     (Default, stored)
     Last receiver location (m) : 1320      (Default, stored)
     Distance between two consecutive Receiver : 8    (Default, stored)
Position of receiver on grid
     Depth of all receiver (in terms of node) : 10      (Default, stored)
     First receiver location (in terms of node) : 55    (Default, stored)
     Last receiver location (in terms of node) : 330     (Default, stored)
     Distance between two consecutive Receiver (in terms of node): 2  (Default, stored)
Note:
     Node position in grid(N) & distances(X) related by (N= nAB + X/h), due to ABC layer.
```

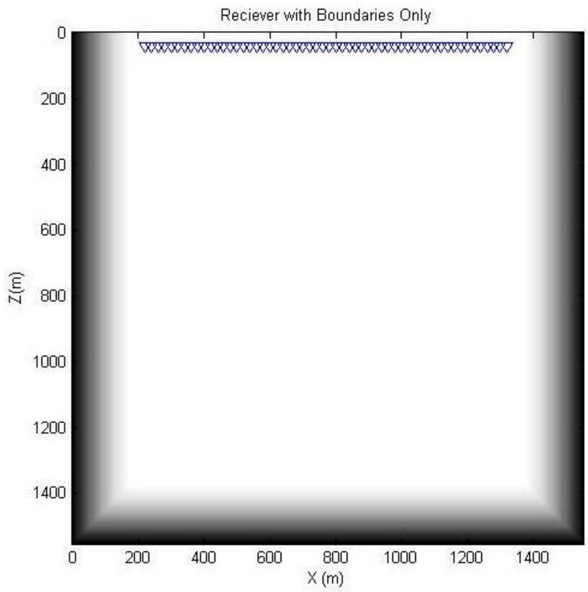


Figure 6.3: An arry of receiver placed at surface using function `nvpair_geometry_rec_StLine_Surf`.

6.3.2 Array of receivers along borehole/depth aka VSP

Description of command :

```
GEOMETRY_REC_STLINE_VSP
 It places recievers vertically along the depth at some given x.
 The configration is similar to the VSP configration of receivers.
   Complete Syntax:
       geometry_rec_StLine_VSP('HLOC',value,'FIRST',value,'LAST',value,'DIFF',value...
               'DX',value,'DZ',value,'BCTYPE',option,'NAB',value,'PlotON',option)
 Description of parameters:
              HLOC   :  Horizontal location in terms of nodes
              FIRST  :  Location of first Receiver along x in terms of nodes
              LAST   :  Location of last Receiver along x in terms of nodes
              DIFF   :  Difference in consecutive Receiver along x in terms of nodes
              DX     :  Grid size in x direction
              DZ     :  Grid size in y direction
              BCTYPE :  Type of boundary used
              NAB    :  Number of grid nodes used for boundaries.
              PlotON :  'y'/'n'
 Note:
 1) Give all the position after adding/subtracting the ABC layer thickness according to side
     where they are added.
    Node position in grid(N) & distances(X) related by (N= nAB + X/h), due to ABC layer.'
 2) In case of free surface two topmost node layers are ignored (imaging technique for Free
     surface)
    Hence a node vertical position is given by N= (X/h)-2;

 3) All parameters are mandatory.
       In case any parameter is not provided the program will try to use the values stored in
           input folder.
       If it cannot find any stored value then it shows error.
 Example:
       geometry_rec_StLine_VSP('HLOC',500,'FIRST',5,'LAST',1000,'Diff',5,'DX',5,'DZ',5,'BCTYPE',
           'topABC','NAB',50,'PlotON','y')
       geometry_rec_StLine_VSP('HLOC',500,'FIRST',5,'LAST',1000,'DIFF',5,'PlotON','y')
       geometry_rec_StLine_VSP()
```

Demonstration/Example :

```
>> nvpair_geometry_rec_st_line_vsp('HLOC',250,'FIRST',5,'LAST',350,'DIFF',10,'PlotON','y');
```

Output of command :

```
FUNC: Receiver geometry Along Depth (or VSP type)
      Horizontal position of receiver (m)    :  1000      (Default, stored)
      First receiver depth (m)               :  12       (Default, stored)
      Last receiver depth (m)                :  1392      (Default, stored)
      Distance between two consecutive receivers : 40    (Default, stored)

      Position of source on grid
      Horizontal position of all receivers (in terms of node) : 250      (Default, stored)
      First receiver location (in terms of node)              :  5       (Default, stored)
      Last receiver location (in terms of node)               :  350      (Default, stored)
      Distance between two consecutive receiver (in terms of node): 10  (Default, stored)
```

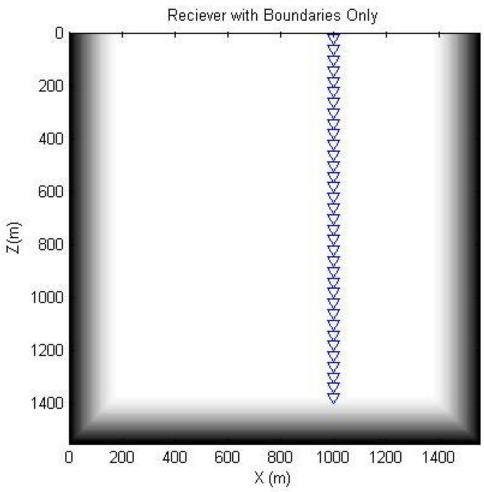


Figure 6.4: An array of receivers is placed along depth using function `geometry_rec_st_line_vsp`

6.3.3 User defined array of receivers

Description of command :

Demonstration/Example :

Output of command :

6.4 Plotting functions

In case of very dense arrays the plotting all objects (source and receivers) can obscure each other. For this reason separate functions are provided.

6.4.1 Source plotting function

Description of command :

```
GEOMETRY_PLOT_SRC
    This function can be used to plot the source over the with/without model.
Complete syntax:
       geometry_plot_src('figno',value,'hop',value,'snh_vec',vector,'snv_vec',vector)
Description of parameters:
       FIGNO    :  Figure no in which to be plotted.
```

```
                If blank then plotted in new figure.
     HOP      :  No of object (sources) to be skipped
     snx_vec :  A vector containing X location of all sources
     snz_vec :  A vector containing Z location of all sources
     BCPLOT   :  To plot the source with boundries
     MODELPLOT: To plot the source with boundaries and model
Example:
          nvpair_geometry_plot_src('figno',3,'hop',5)
```

Demonstration/Example :

```
>> nvpair_geometry_src_st_line_surf('WFP',wf_path,'DEPTH',10,'FIRST',55,'LAST',330,'DIFF',5,'
    PlotON','y');
>> geometry_plot_src('WFP',wf_path,'HOP',5,'BCPLOT','y','MODELPLOT','y')
```

Output of command :

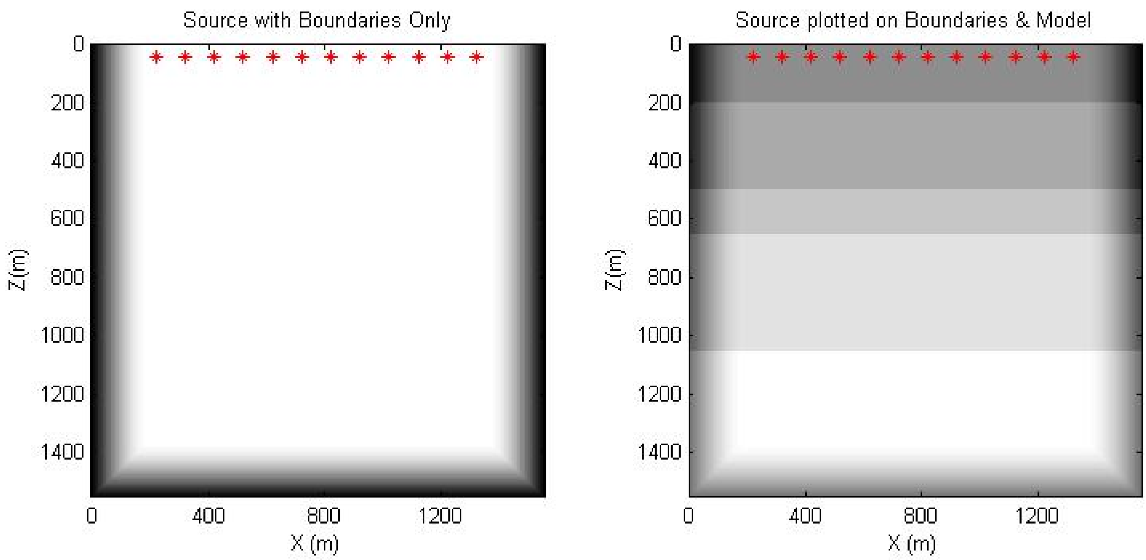


Figure 6.5: An array of receiver is plotted such that it doen't show all sources by plotting every 5th only.

6.4.2 Receiver plotting function

Description of command :

```
GEOMETRY_PLOT_REC
      This function can be used to plot the recievers over the with/without model.
Complete syntax:
       geometry_plot_rec('WFP',path,'FIGNO',value,'HOP',value,'RNX_VEC',vector,'RNZ_VEC',vector)
Description of parameters:
              WFP      :  Path to working directory
              FIGNO    :  Figure no in which to be plotted.
                          If blank then plotted in new figure.
              HOP      :  No of object (receivers) to be skipped
              RNX_VEC :  A vector containing X location of all sources
              RNZ_VEC :  A vector containing Z location of all sources
Example:
              nvpair_geometry_plot_rec('WFP',pwd,'figno',3,'hop',5)
```

Demonstration/Example :

```
>> nvpair_geometry_rec_st_line_surf('WFP',wf_path,'DEPTH',10,'FIRST',55,'LAST',330,'DIFF',5);
>> geometry_plot_rec('WFP',wf_path,'BCPLOT','y','MODELPLOT','y');
```

Output of command :

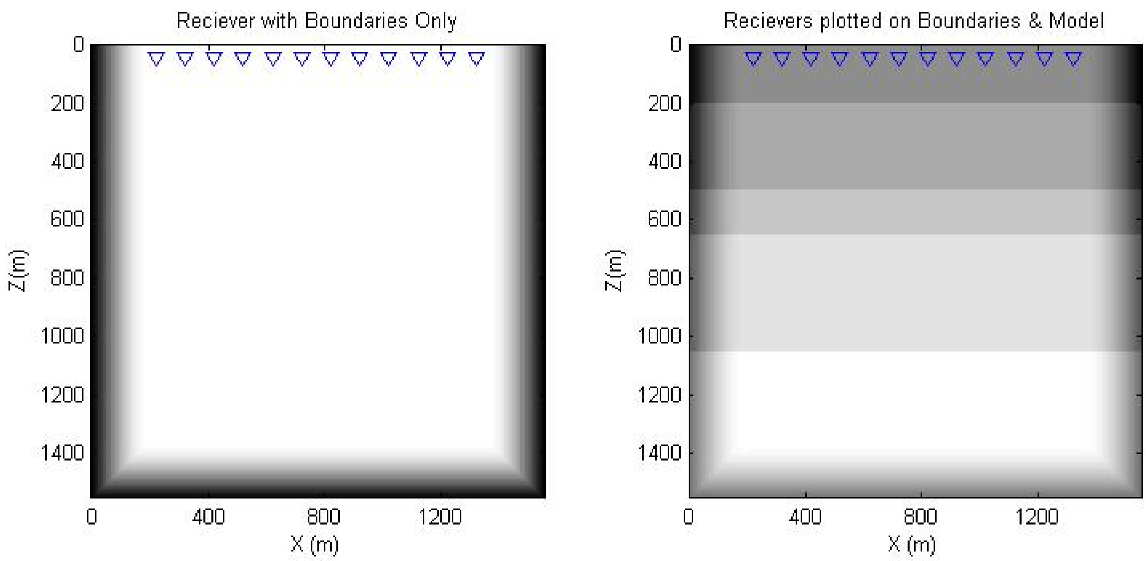


Figure 6.6: An array of receiver is plotted such that it doen't show all sources by plotting every 5th only.

6.4.3 Plotting source and receiver in same figure

Description of command :

```
GEOMETRY_PLOT
The program to plot the source and reciever with and without model.
Complete Syntax:
        geometry_plot('FIGNO',value,'HOP_S',value,'HOP_R',value)
Description of parameters:
             FIGNO   :  Plot in figure number given by.
             HOP_S   :  No of receiver to be skipped
             HOP_R   :  No of receiver to be skipped
Note:
1) Don't place source very close to surface.
2) Give all the position after adding/subtracting the ABC layer thickness according to side
    where they are added.
3) All parameters are mandatory.
     In case any parameter is not provided the program will try to use the values stored in
         input folder.
     If it cannot find any stored value then it shows error.
Example:
     geometry_plot('FIGNO',3,'HOP_S',1,'HOP_R',5);
     geometry_plot()
```

Demonstration/Example :

```
>> nvpair_geometry_src_st_line_surf('WFP',wf_path,'DEPTH',10,'FIRST',55,'LAST',330,'DIFF',5,'
    PlotON','y');
>> nvpair_geometry_rec_st_line_vsp('HLOC',250,'FIRST',5,'LAST',350,'DIFF',10,'PlotON','y');
>> nvpair_geometry_plot('FIGNO',3, 'HOP_S',5, 'HOP_R',4)
```

Output of command :

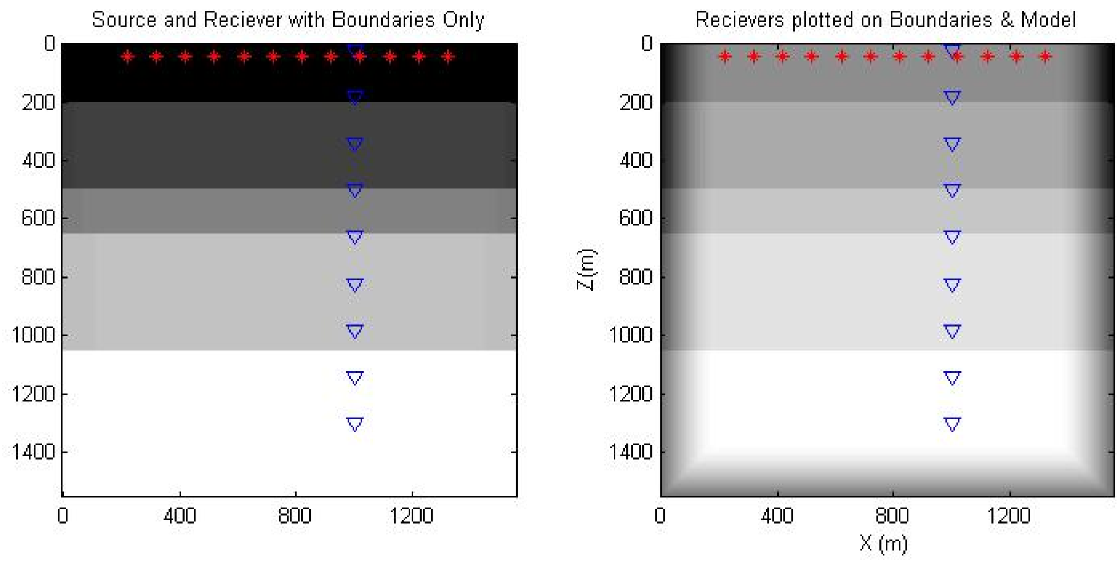


Figure 6.7: An array of receiver is plotted such that it doen't show all sources by plotting every 5th only.

Chapter 7

Other functions

7.1 Analaysis

This is function is essential to find out the stability of the current simulation for the given parameters. The stability is checked using the CFL conditions [1].

The dispersion condition is also analysed by this code. This condition is important to keep dispersion below 5% level, however, it is not necessary for simulation to run [2].

This can be simply checked by running following function

```
>> analyse_elastic('WFP',wf_path)
```

If everything is ok it will produce following type of output:

```
FUNC: Analysis for Elastic wave
      Time step size,       dt =  0.0003       (Default, stored)
      Source Frequency,     f0 =  15       (Default, stored)
      Grid spacing Taken,   dx =  3       (Default, stored)
      Total time duration,  dz =  3       (Default, stored)
      Vp model supplied      (Default, stored)
      Vs model supplied      (Default, stored)
              Analysis Results:
      Given time step: ok;     "dt" Present value( 0.000300) < Required( 0.000387).
      Given grid spacing: ok;    "dh" Present value( 3.000000) < Required( <3.624569).
      CFL and Grid size requirement analysis done.
```

In case time step is higher then a *error* message will come up as following

```
FUNC: Analysis for Elastic wave
      Time step size,       dt =  0.0008       (Default, stored)
      Source Frequency,     f0 =  15       (Default, stored)
      Grid spacing Taken,   dx =  5       (Default, stored)
      Total time duration,  dz =  5       (Default, stored)
      Vp model supplied      (Default, stored)
      Vs model supplied      (Default, stored)
              Analysis Results:
Error using nvpair_analyse_elastic (line 61)
      Revise time step...!!!    "dt" Present value( 0.000800) > Required( 0.000645).
```

In case of grid spacing is not satisfying the dispersion condition then a *warning* message will come up as following

```
FUNC: Analysis for Elastic wave
      Time step size,       dt =  0.0003       (Default, stored)
      Source Frequency,     f0 =  15       (Default, stored)
      Grid spacing Taken,   dx =  5       (Default, stored)
      Total time duration,  dz =  5       (Default, stored)
      Vp model supplied      (Default, stored)
```

[1] Courant, R.; Friedrichs, K.; Lewy, H. (March 1967) [1928], "On the partial difference equations of mathematical physics", IBM Journal of Research and Development, 11 (2): 215–234,

[2] Levander, A., 1988, Fourth-order finite-difference P-SV seismograms, Geophysics, 53, 1425-1436.

```
     Vs model supplied     (Default, stored)
             Analysis Results:
     Given time step: ok;     "dt" Present value( 0.000300) < Required( 0.000645).
Warning:       Revise grid spacing...!!!!   "dh" Present value( 5.000000) > Required( <3.624569)
       .

> In nvpair_analyse_elastic at 78
     CFL and Grid size requirement analysis done.
```

7.2 Derive Material parameters

The material parameters has to calculated according to the grid position of the material parameters [3]. It is an essential step hence this function has to be called before running the simulation.

The parameters for staggered grid can be derived using following function

```
>> model_derived_elastic_g1('WFP',wf_path)
```

It shows following output

```
FUNC: Deriving Elastic Parameter for grid type g1
      Vp model supplied        (Default, stored)
      Vs model supplied        (Default, stored)
      Density model supplied        (Default, stored)
      Derived parameters generated successfully
```

Which shows the parameter generation for the staggered nodes was successful.

7.3 Simulation

The last part of it is to carry out the simulation which can be done using following function.

Complete syntax of code :

```
CALCULATION_ELASTIC
The solution of wave equation is done here using follownig grid.
Complete Syntax:
      calculation_elastic_g1('SRC_I',value, 'DN_W',value, 'DN_SS',value, 'PlotON',value)
Description of parameters:
      SRC_I   :  Source No for which the simulation will be carried out.
      DN_W    :  No time steps of wavefield to skip
      DN_SS   :  No time steps of synthetic seismogram to skip
      PlotON  :  Show wave propagation while simulation
      DN_P    :  No of time steps to skip plotting.
Example:
      calculation_elastic_g1('SRC_I',1, 'DN_W',1, 'dN_SS',1, 'PlotON','y','dN_P',10)
      calculation_elastic_g1('SRC_I',1, 'DN_W',10000, 'dN_SS',4, 'PlotON','y')
      calculation_elastic_g1()
Note:
1) It is advised to keep dN_W to very large value if you don't want to save entire wavefield
2) Plotting itself takes much time so it is advisable to skip few steps in case of very fine
    steps.
3) All other parameters are taken from the input folder.
4) The grid arrangement used in calculation is given following
%%%%%%%%%%%%%%%%%%%% Grid arrangement%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                 txx,tzz----------vx---------txx,tzz------>
                lbd,mu |        bh           |
                       |         .           |
                       |         .           |
```

[3] Ajay Malkoti*, Nimisha Vedanti, Praveen Kunagu, and R.K. Tiwari (2015) Modeling viscoelastic seismic wave propagation in Deccan flood basalt, western India. SEG Technical Program Expanded Abstracts 2015: pp. 3764-3768.doi: 10.1190/segam2015-5898555.1

```
                         |         .           |
                      vz |..........txz        |
                      bv |         muvh        |
                         |                     |
                         |                     |
                         |                     |
                 txx,tzz |---------------------|
                         |
                        \|/
```

Demonstration/Example :
If an array of source is provides and we want to carry out simulation with following considerations:

1. Carry out simulation only for given source (say no 5).
2. Do not save wave field (set dN_W to very high value).
3. Skip a few samples in synthetic seismogram to save space (set dN_SS to some value).
4. Visualize the wave propagation (set plotON to 'y')

```
>> nvpair_calculation_elastic_g1('src_i',5,'dN_W',100000,'dN_SS',4,'plotON','y');
```

Plotting of Results :

```
CALCULATION_PLOT
   This function is used for plotting the synthetic seimogram with scaling
   and clipping the amplitudes.
   Complete syntax:
       calculation_plot('Wave_Type',option,'ShotGather',matrix,'FigNo',value,...
           'ShotNo',value,'clip',value,'Scale')
   Description of Parameters
       ShotGather  :  The synthetic seimogram (Optional)
       Wave_Type   :  'Acoustic', 'Elastic', etc.
       FigNo       :  Figure No on which you want to plot
       ShotNo      :  Source No, if there are more than one (e.g. for an array)
       Clip        :  To remove very high amplitudes
       Scale       :  To enhance deeper/later reflections.
   Example
       calculation_plot('wave_type','elastic','shotno',5)
       calculation_plot('wave_type','elastic','shotno',5, 'clip',.95,'scale',6)
```

Chapter 8

Acknowledgemets

The MARMOUSI model used for the synthetic modelling can be downloaded from UoH website [1]
The SEGYMAT MATLAB package [2] was used in this pack to read the segy file.

[1] http://www.agl.uh.edu/downloads/downloads.htm
[2] http://segymat.sourceforge.net/