

# **Site Effects Assessment Using Ambient Excitations**

## **SESAME**

**European Commission – Research General Directorate  
Project No. EVG1-CT-2000-00026 SESAME**

**Final Report**

**WP09**

**FD code to generate noise synthetic**

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## *Summary*

In the following we report the flowchart and the guide user of the Fortran95 Program Package NOISE, a program for numerical generation and simulation of seismic noise in 3D heterogeneous viscoelastic media. This program package consists of two programs: program RANSOURCE and program FDSIM. The whole program is presented in the attached CR ROM.

In the appendix, a set of canonical models for seismic noise simulations is described. The set of the canonical models will serve for extensive parametric study of synthetic seismic noise which will create a basis for deducing systematic features of the noise and decisive factors determining peak H/V and HT (VT) frequencies and corresponding amplitudes.

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## Chapter 1 : Flowcharts of the program package NOISE

During this first year, the Fortran95 Program Package NOISE for numerical generation and simulation of seismic noise in 3D heterogeneous viscoelastic media has been developed. The program package consists of two programs: program RANSOURCE and program FDSIM.

**Program RANSOURCE** is designed for random space-time generation of point sources of seismic noise. The output files serve as input files for the program FDSIM.

The algorithm of random noise generation assumes regular spatial distribution of potential point sources inside of a specified source volume. The spatial distribution is controlled by the prescribed minimum distance between two neighbour point sources, minimum distance between a point source and a receiver, and maximum distance between a point source and a receiver.

The temporal distribution of point sources is controlled by the prescribed minimum and maximum numbers of point sources acting at the same time.

For each generated position of a point source, a direction of acting single body force at the position, time function and maximum amplitude are randomly generated.

The time function is either delta-like signal or pseudo-monochromatic signal (a harmonic carrier with the Gaussian envelope). Spectrum of the delta-like signal is low-pass filtered in order to fit the prescribed frequency range. In the case of the pseudo-monochromatic signal, first its duration, then its predominant frequency are randomly generated.

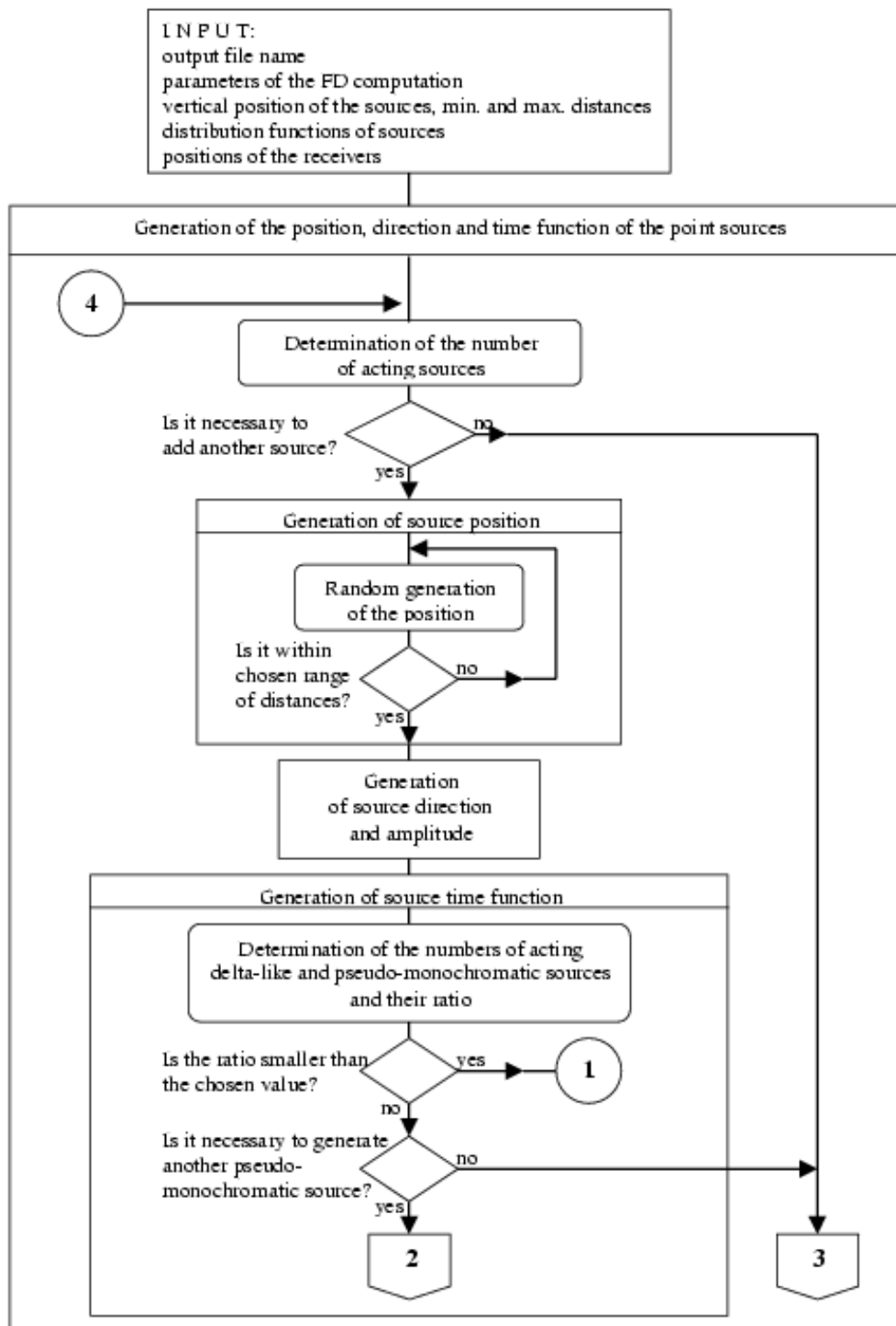
The maximum amplitude of the signal is randomly generated from the interval  $(0,1>$  according to a chosen distribution.

The program has to be run before the finite-difference simulation of the noise itself. The program generates two files for all delta-like sources and as many files as the number of generated pseudo-monochromatic sources. All the files serve as the input data files for the program FDSIM.

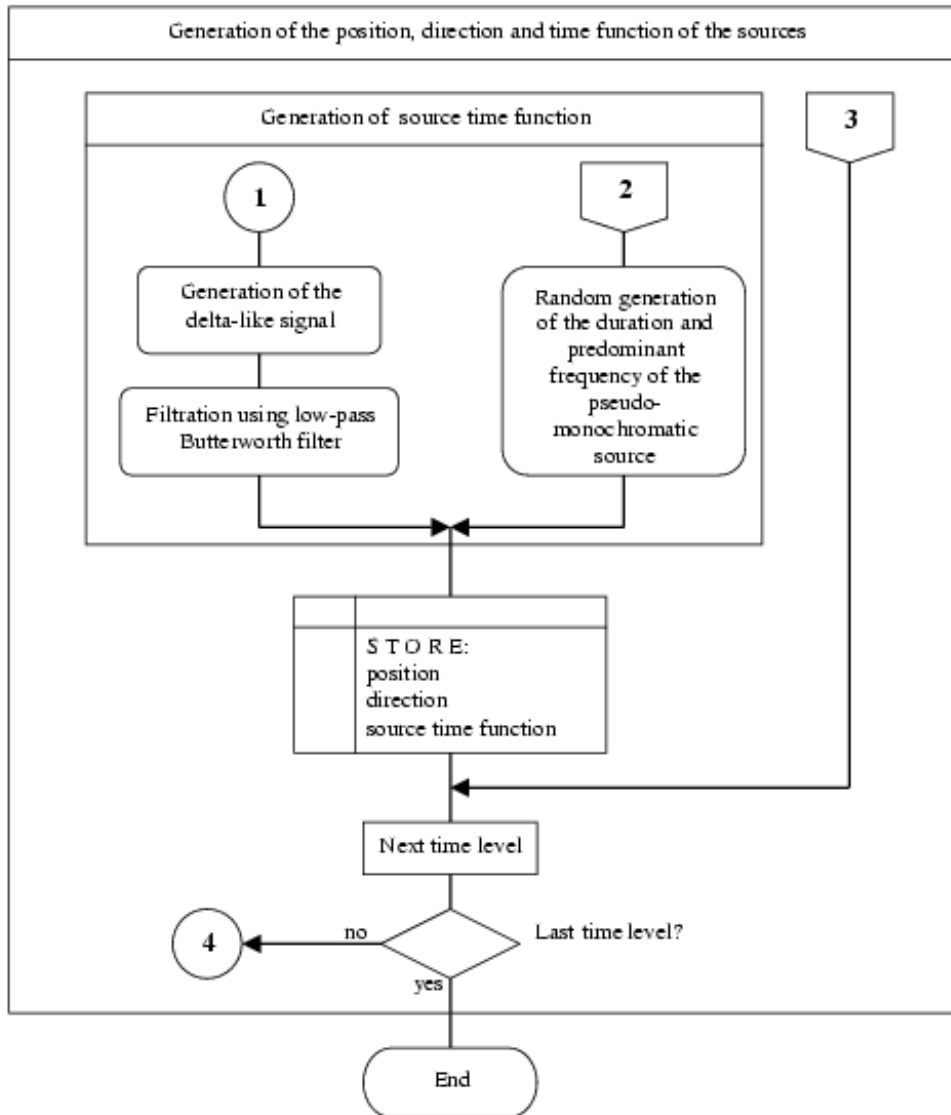
**Pages 4 and 5:** Flowchart of the program RANSOURCE.

**RANSOURCE: Flowchart of the program**

1



**RANSOURCE: Flowchart of the program**



**Program FDSIM** is designed for the finite-difference simulation of seismic wave propagation and seismic ground motion in a 3D surface heterogeneous viscoelastic structure with a planar free surface.

The computational algorithm is based on the explicit heterogeneous finite-difference scheme solving equations of motion in the heterogeneous viscoelastic medium with material discontinuities. The scheme is 4<sup>th</sup>-order accurate in space and 2<sup>nd</sup>-order accurate in time. The displacement-velocity-stress scheme is constructed on a staggered finite-difference grid.

The computational region is represented by a volume of a parallelepiped with the top side representing a planar free surface, and bottom, rear, front, left and right sides representing either non-reflecting boundaries or planes of symmetry. Different types of non-reflecting boundaries can be chosen on different sides of the computational region.

The discontinuous spatial grid is used to cover the computational region. The upper part of the grid has three times smaller grid spacing than the lower part. Each part itself is a uniform rectangular grid.

The rheology of the medium corresponds to the generalised Maxwell body. This makes possible to account both for spatially varying quality factors of the P and S waves and for arbitrary Q-omega law.

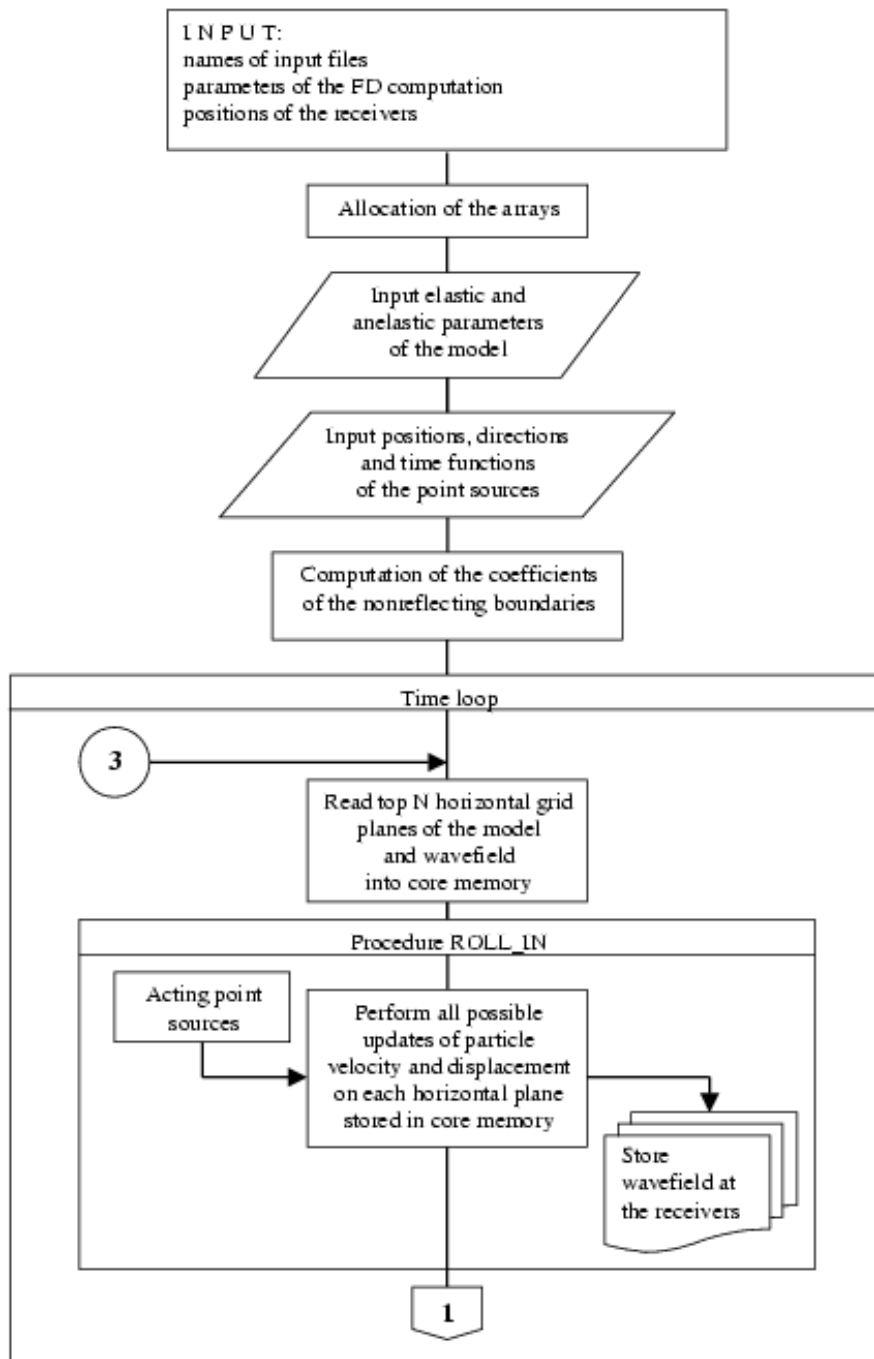
The wavefield is excited by a set of randomly generated point sources, each representing a single force acting in an arbitrary direction.

The core memory optimisation is applied in order to significantly reduce requirements of the computer's core memory.

**Pages 7, 8 and 9:** Flowchart of the program FDSIM.

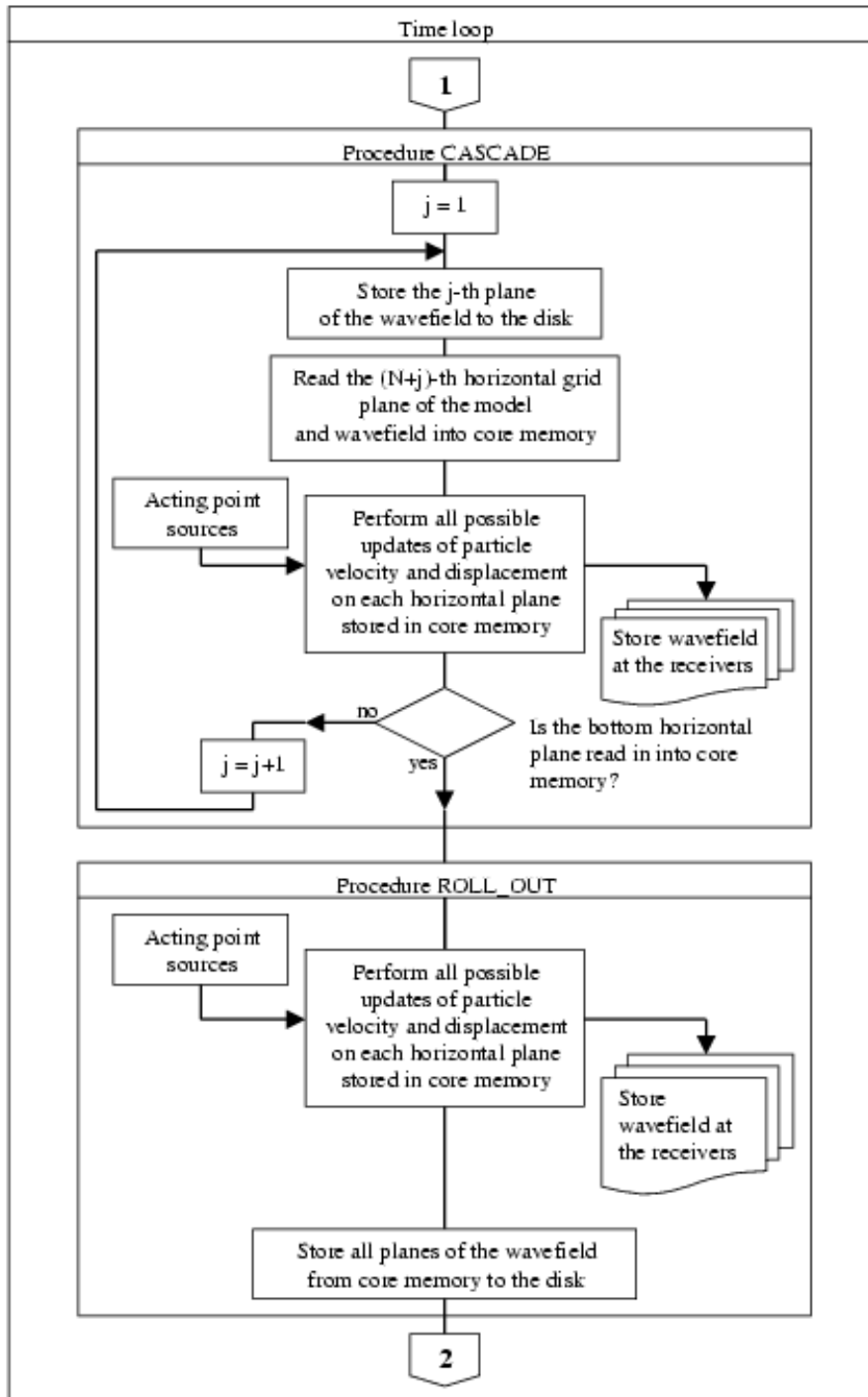
*FDSIM: Flowchart of the program*

1



*FDSIM: Flowchart of the program*

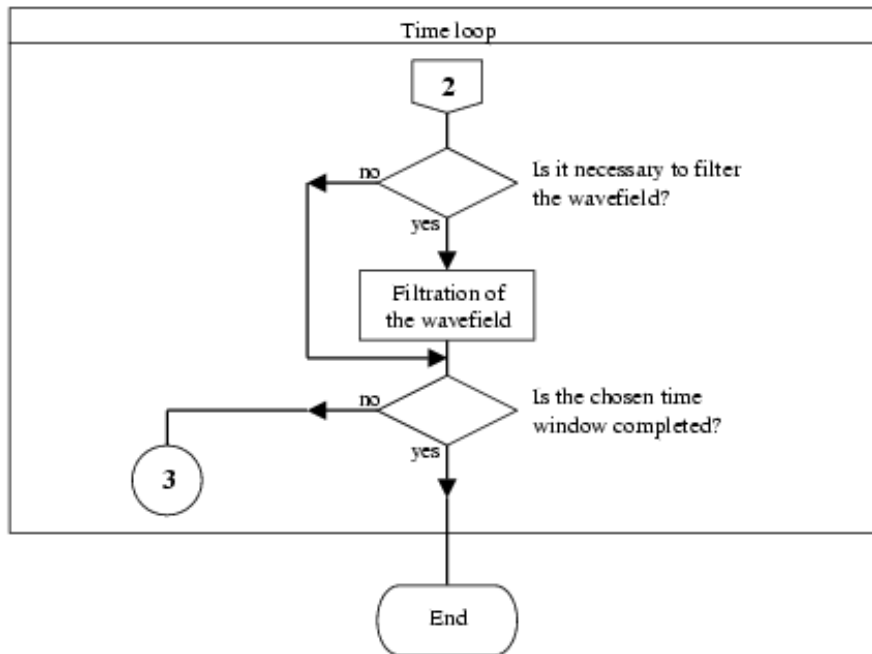
2





*FDSIM: Flowchart of the program*

3



## Chapter 2 : User Guide

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|
|                                     USER'S GUIDE TO
|
|                                     =====
|                                     N O I S E
|                                     =====
|
|                                     The Fortran95 Program Package
|                                     for Numerical Generation and Simulation
|                                     of Seismic Noise
|                                     in 3D Heterogeneous Viscoelastic Media
|
|                                     by
|
|                                     Jozef KRISTEK & Peter MOCZO
|
|                                     Bratislava, April 30, 2002
|
=====
=====

```

Note: This is the first version of the program package. The version is functional but may be a subject of further improvement/modification based on numerical experience with simulating seismic noise in a set of canonical structures and selected models of real sites in the course of work within the SESAME project.

### Introduction

Purpose: The program package NOISE is designed for computation of seismic noise in 3D heterogeneous surface geological structures with planar free surface due to surface and near-surface random sources.

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### Availability and use of the program package:

Upon request from the authors.

The user is asked to make reference to the papers given below in case that he publishes results obtained with the program package since the program package NOISE is not published.

Moczo, P., J. Kristek, V. Vavrycuk, R.J. Archuleta, and L. Halada: 3D Staggered-grid Finite-difference Modeling with Volume Harmonic and Arithmetic Averaging of Elastic Moduli and Densities. Submitted to Bull. Seism. Soc. Am.

Kristek, J., P. Moczo and M. Kristekova: Finite-difference Simulation of Ambient Noise in 3D Surface. Sedimentary Structures: Part 1 - Method. In preparation.

**Short description:**

The program package consists of two programs written in Fortran95:  
     program RANSOURCE and program FDSIM.

**Program RANSOURCE** is designed for random space-time generation of point sources of seismic noise. The output files serve as input files for the program FDSIM. The algorithm of random noise generation assumes regular spatial distribution of potential point sources inside of a specified source volume. The spatial distribution is controlled by the prescribed minimum distance between two neighbour point sources, minimum distance between a point source and a receiver, and maximum distance between a point source and a receiver. The temporal distribution of point sources is controlled by the prescribed minimum and maximum numbers of point sources acting at the same time. For each generated position of a point source, a direction of acting single body force at the position, time function and maximum amplitude are randomly generated. The time function is either delta-like signal or pseudo-monochromatic signal (a harmonic carrier with the Gaussian envelope). Spectrum of the delta-like signal is low-pass filtered in order to fit the prescribed frequency range. In the case of the pseudo-monochromatic signal, first its duration, then its predominant frequency are randomly generated. The maximum amplitude of the signal is randomly generated from the interval (0,1) according to a chosen distribution. The program has to be run before the finite-difference simulation of the noise itself. The program generates two files for all delta-like sources and as many files as the number of generated pseudo-monochromatic sources. All the files serve as the input data files for the program FDSIM.

**Program FDSIM** is designed for the finite-difference simulation of seismic wave propagation and seismic ground motion in a 3D surface heterogeneous viscoelastic structure with a planar free surface. The computational algorithm is based on the explicit heterogeneous finite-difference scheme solving equations of motion in the heterogeneous viscoelastic medium with material discontinuities. The scheme is 4th-order accurate in space and 2nd-order accurate in time. The displacement-velocity-stress scheme is constructed on a staggered finite-difference grid. The computational region is represented by a volume of a parallelepiped with the top side representing a planar free surface, and bottom, rear, front, left and right sides representing either non-reflecting boundaries or planes of symmetry.

Different types of non-reflecting boundaries can be chosen on different sides of the computational region. The discontinuous spatial grid is used to cover the computational region. The upper part of the grid has three times smaller grid spacing than the lower part. Each part itself is a uniform rectangular grid. The rheology of the medium corresponds to the generalized Maxwell body. This makes it possible to account both for spatially varying quality factors of the P and S waves and for arbitrary Q-omega law. The wavefield is excited by a set of randomly generated point sources, each representing a single force acting in an arbitrary direction. The core memory optimization is applied in order to significantly reduce requirements of the computer's core memory.

**Acknowledgements:**

The program package has been developed in the Geophysical Institute of Slovak Academy of Sciences, Bratislava, Slovak Republic, within the 5th Framework Program grant project EVG1-CT-2000-00026 "Site Effect Studies Using Ambient Excitations", SESAME.

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**Program RANSOURCE**

Program RANSOURCE is designed for random space-time generation of point sources of seismic noise. The output files serve as input files for the program FDSIM.



The flowchart of the program is presented in the file F\_RANSOURCE.ps.

**Algorithm**

- point sources (PS) regularly distributed in a 'source volume';  
 PSPSMIN - the minimum distance between two neighbouring point sources,  
 PSRECMIN - the minimum distance between a point source and a receiver,  
 PSRECMAX - the maximum distance between a point source and a receiver,

- minimum and maximum # of acting PS at the same time - MNS and MXS

#### Time function

- PDL % of PS have time function given by a filtered delta-like signal,  
 (100-PDL) % of PS have time function given by a harmonic carrier with the Gaussian envelope;  
 - delta-like signal is given by a Gabor wavelet with the free-parameter values of  $fp=0.45$ ,  $gama=0.1$  and  $psi=0$ ,  
 ORDER is an order of a low-pass Butterworth frequency filter with a corner frequency FMAX applied to delta-like signal;  
 - frequency of a harmonic carrier is randomly picked up from the interval  $\langle FMIN, FMAX \rangle$ ,  
 selected frequencies are uniformly distributed on a logarithmic scale ( KEY\_LOG\_F = .TRUE. ) or a linear scale ( KEY\_LOG\_F = .FALSE. ).

#### Amplitude

- maximum amplitude of each time function is randomly picked up from interval  $(0,1)$ ,  
 distribution of amplitude values in the interval  $(0,1)$  is given by an exponential function EF defined on the interval  $(0,1)$ . The minimum value of the function EF is  $EF(1) = DAMIN$ , the maximum value is  $EF(0) = DAMAX$ .

#### Source volume

Let H1 be some thickness in meters. H1 may represent a thickness of a flat surface layer, maximum depth of the sediment valley or other appropriate thickness.  
 Five different depth intervals define five different positions of a source volume in the vertical direction (variable SPLANE in the code):

```
SPLANE = 1 : < 0, H1/4>
SPLANE = 2 : < H1/4, 3H1/4>
SPLANE = 3 : <3H1/4, 5H1/4>
SPLANE = 4 : <2H1 , 3H1 >
SPLANE = 5 : < 0, 3H1 >
```

## 1. AUXILIARY FILE 'HFRANS'

JOBNAME (A17)

## 2. INPUT DATA FILE 'JOBNAME.IN'

NAMELIST /NAMES/ SR\_FILE\_NAME

SR\_FILE\_NAME= name of the output file containing parameters of the point sources  
 (A20)

NAMELIST /CONTROLDATA/MT1,MT2, DT, MX, MY, LPAS, H, &  
 MXS, FMIN, FMAX, KEY\_LOG\_F, SPLANE, H1, &  
 DAMIN, DAMAX, PSPSMIN, PSRECMAX, PSRECMIN, &  
 ORDER, PDL  
 (REAL)

MT1, MT2 The computations in FDSIM are performed from the time level  
 MT1 until the time level MT2.  
 (INTEGER)

DT = time step in seconds. It has to satisfy the stability  
 condition  $DT \leq 6 / (7 * \sqrt{3}) * R$ , where R is the minimum of the  
 ratios (grid spacing)/(local P-wave velocity).  
 (REAL)

MX, MY Total numbers of the grid cells in the x- and y- directions  
 (both horizontal) in the coarser grid. (The corresponding  
 total numbers of the grid spacings are MX-1 and MY-1.) MX\*MY  
 is the total number of the grid cells in one horizontal grid  
 plane.  
 (INTEGER)

---

LPAS                    The vertical grid index of the last grid plane of the finer grid and, at the same time, the first grid plane of the coarser grid. The first grid plane of the coarser grid shares the values of the z- components of the displacement and particle velocity, and the xz- and yz- stress-tensor components of the last grid plane of the finer grid. LPAS has to be larger than 4.  
If LPAS == 0 then only coarser grid covers whole computational region. (INTEGER)

H                        Grid spacing in the coarser grid (in meters).  
(The grid spacing in the finer grid is then H/3.) (REAL)

MNS, MXS (INTEGER)

FMIN, FMAX            (in Hz) (REAL)

KEY\_LOG\_F (LOGICAL)

SPLANE (INTEGER)

H1                      if LPAS > 0, H1 has to be smaller than (LPAS - 6)\*H/3, (in meters) (REAL)

DAMIN, DAMAX (REAL)

PSPSMIN, PSRECMAX, PSRECMIN  
if LPAS > 0, multiples of H/3  
if LPAS = 0, multiples of H (INTEGER)

ORDER, PDL (INTEGER)

NAMELIST /REC/ MR (INTEGER)

MR = number of receivers (INTEGER)

IREC (J), KREC (J), LREC (J) ; J = 1, MR

IREC (J) = grid index in the x- direction of the J-the receiver. All grid planes in the x- direction (i.e. the yz-planes) including those in the finer grid have to be considered if the receiver is located in the finer grid. (INTEGER)

KREC (J) = grid index in the y- direction of the J-th receiver. All grid planes in the y- direction (i.e. the xz-planes) including those in the finer grid have to be considered if the receiver is located in the finer grid. (INTEGER)

LREC (J) = grid index in the z- direction of the J-th receiver. All grid planes in the z- direction (i.e. the horizontal planes) including those in the finer grid have to be considered.  
If LREC (J) == LPAS, the horizontal grid indices should only refer to the coarser grid. (INTEGER)

### 3. OUTPUT DATA FILE SR\_FILE\_NAME

NAMELIST /SOURCE/ NPS (INTEGER)

NPS = number of point sources (INTEGER)

```
DO I = 1, NPS
  WRITE (10,*) IS(I), KS(I), LS(I), ITSB(I), ITSE(I)
  WRITE (10,*) CUS(I), CVS(I), CWS(I)
END DO
```

IS (I) = grid index in the x- direction of the I-th source. All grid planes in the x- direction (i.e. the yz-planes) including those in the finer grid have to be considered if the source is located in the finer grid. (INTEGER)

KS (I) = grid index in the y- direction of the I-th source. All grid planes in the y- direction (i.e. the xz-planes) including those in the finer grid have to be considered if the source is located in the finer grid. (INTEGER)

LS (I) = grid index in the z- direction of the I-th source. All grid planes in the z- direction (i.e. the horizontal planes) including those in the finer grid have to be considered. If LS (I) == LPAS, the horizontal grid indices should only refer to the coarser grid. (INTEGER)

ITSB (I) = time level corresponding to the initial time of the I-th source's time function. (INTEGER)

ITSE (I) = time level corresponding to the end of the I-th source's time function. (INTEGER)

CUS (I) = amplitude of the I-th source in the x- direction  
 CVS (I) = amplitude of the I-th source in the y- direction  
 CWS (I) = amplitude of the I-th source in the z- direction  
 ALL (REAL)

**4. OUTPUT DATA FILE(S) SRCxxxx.DAT**

SRCxxxx.DAT = SRC0001.DAT, SRC0002.DAT, ..., SRCvalu.DAT, where val is the value of NPS  
 SRCDELI.DAT

File SRC0001.DAT contains the source time function for the first source, SRC0002.dat for the second source, ... .  
 File SRCDELI.DAT contains the source time function of the delta-like signal.  
 The files are direct-access files and are open in the code as follows:

```
OPEN ( 10, FILE = 'SRC0001.DAT', FORM = 'UNFORMATTED', &
      ACCESS = 'DIRECT', RECL = PP, STATUS='NEW' )
      where
      PP = 4 for single precision (default)
          = 8 for double precision
```

```
DO I = ITSB(1), ITSE(1)
  WRITE ( 10, REC=I-ITSB(1)+1 ) SOURTF(I)
END DO
```

SOURTF(I) = source time function at time level I (REAL(PP))

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## Program FDSIM

Program FDSIM is designed for the finite-difference simulation of seismic wave propagation and seismic ground motion in a 3D surface heterogeneous viscoelastic structure with a planar free surface.

⇒ The flowchart of the program is presented in the file F\_FDSIM.ps

### 1. AUXILIARY FILE 'HFFDSIM'

JOBNAME (A17)

### 2. INPUT DATA FILE 'JOBNAME.IN'

NAMELIST /NAMES/	MO_FILE_NAME, Q_FILE_NAME, & JMH_FILE_NAME, JMH3_FILE_NAME, & SR_FILE_NAME	
MO_FILE_NAME	= name of the file containing elastic parameters and densities describing types of material cells	(A20)
Q_FILE_NAME	= name of the file containing anelastic parameters describing types of material cells	(A20)
JMH_FILE_NAME	= name of the file containing spatial distribution of material cell types in the coarser (i.e. lower) spatial grid whose grid spacing is H	(A20)
JMH3_FILE_NAME	= name of the file containing spatial distribution of material cell types in the finer (i.e. upper) spatial grid whose grid spacing is H/3	(A20)
SR_FILE_NAME	= name of the file containing parameters of the point sources	(A20)
NAMELIST /KEYS/	KEY_TLV, KEY_TLD, KEY_SNV, KEY_SND, & KEY_DISK	
KEY_TLV	= .TRUE.: Output file containing time levels of the particle velocities at specified receivers. = .FALSE.: Output file is not generated.	(LOGICAL)
KEY_TLD	= .TRUE.: Output file containing time levels of the displacements at specified receivers. = .FALSE.: Output file is not generated.	(LOGICAL)
KEY_SNV	= .TRUE.: Output file containing snapshots of the particle velocities at the free surface. = .FALSE.: Output file is not generated.	(LOGICAL)
KEY_SND	= .TRUE.: Output file containing snapshots of the displacements at the free surface. = .FALSE.: Output file is not generated.	(LOGICAL)
KEY_DISK	= .TRUE.: Field values are stored in disk memory. = .FALSE.: Field values are stored in core memory.	(LOGICAL)

```

NAMELIST /CONTROLDATA/ MT1 , MT2 , DT , IPAS1 ,      &
MX , MY , MZ , LPAS , H ,      &
STRIP, IFILT, HWFILT

```

MT1, MT2            The computations are performed from the time level MT1 until the time level MT2. If MT1 >2, the displacement and particle velocity values for the previous time levels have to be read in from the files. MT2 has to be equal to  $n*(STRIP-4)/3$ , where n is an integer number.

(INTEGER)

DT                = time step in seconds. It has to satisfy the stability condition  $DT \leq 6/(7*\sqrt{3})*R$ , where R is the minimum of the ratios (grid spacing)/(local P-wave velocity).

(REAL)

IPAS1            = 1: The displacement and/or particle velocity values at each time level are stored.  
= 2 (3,...): The displacement and/or particle velocity values at each second (third,...) time level are stored.

(INTEGER)

MX, MY            Total numbers of the grid cells in the x- and y- directions (both horizontal) in the coarser grid. (The corresponding total numbers of the grid spacing are MX-1 and MY-1.) MX\*MY is the total number of the grid cells in one horizontal grid plane.

(INTEGER)

MZ                Total number of the horizontal grid planes including all grid planes of the finer grid

(INTEGER)

LPAS            The vertical grid index of the last grid plane of the finer grid and, at the same time, the first grid plane of the coarser grid. The first grid plane of the coarser grid shares the values of the z- components of the displacement and particle velocity, and the xz- and yz- stress-tensor components of the last grid plane of the finer grid. LPAS has to be larger than 4 and smaller than MZ-2.  
If LPAS == 0 then only coarser grid covers whole computational region.

(INTEGER)

H                Grid spacing in the coarser grid. (The grid spacing in the finer grid is then H/3.)

(REAL)

STRIP            Number of the horizontal grid planes in a moving subset of grid planes. STRIP has to be equal to  $3*k + 4$ , where k is an integer number

(INTEGER)

IFILT            A symmetric FIR filter (specified in the input file FC.DAT) is applied to displacement and particle velocity fields at each IFILT-th time level.  
If IFILT is not specified, no filtering is applied.

(INTEGER)

HWFILT           # of filter coefficients in FC.DAT  
HWFILT has to be equal to  $k*(STRIP-4)/3-1$ , where k is an integer number.

(INTEGER)





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THPPLE	Angle theta [rad] for the P/P incidence/reflection at the left-hand side boundary for which the artificial reflection should be suppressed more than for other angles in the Peng & Toksoz boundary.	(REAL)
THPPRI	The same as THPPLE but for the right-hand side boundary.	(REAL)
THPPRE	The same as THPPLE but for the rear boundary.	(REAL)
THPPFR	The same as THPPLE but for the front boundary.	(REAL)
THPPBO	The same as THPPLE but for the bottom boundary.	(REAL)
THSSLE	Angle theta [rad] for the S/S incidence/reflection at the left-hand side boundary for which the artificial reflection should be suppressed more than for other angles in the Peng & Toksoz boundary.	(REAL)
THSSRI	The same as THSSLE but for the right-hand side boundary	(REAL)
THSSRE	The same as THSSLE but for the rear boundary.	(REAL)
THSSFR	The same as THSSLE but for the front boundary.	(REAL)
THSSBO	The same as THSSLE but for the front boundary.	(REAL)
NAMELIST /TXT	TEXT	
TEXT	Arbitrary alphanumeric text (e.g. describing the computation).	(A20)
NAMELIST /SNAP/	IPAS2	
	Included only if KEY_SNV or KEY_SND == .TRUE.	
IPAS2	= 1: The displacement and/or particle velocity snapshots at each time level are stored. = 2 (3,...): The displacement and/or particle velocity snapshots at each second (third,...) time level are stored.	(INTEGER)
NAMELIST /REC/	MR	
MR	= number of receivers	(INTEGER)
IREC (J), KREC (J), LREC (J) ; J = 1, MR		
IREC (J)	= grid index in the x- direction of the J-th receiver. All grid planes in the x- direction (i.e. the yz-planes) including those in the finer grid have to be considered if the receiver is located in the finer grid.	(INTEGER)
KREC (J)	= grid index in the y- direction of the J-th receiver. All grid planes in the y- direction (i.e. the xz-planes) including	

those in the finer grid have to be considered if the receiver is located in the finer grid.

(INTEGER)

LREC (J) = grid index in the z- direction of the J-th receiver. All grid planes in the z- direction (i.e. the horizontal planes) including those in the finer grid have to be considered. If LREC (J) == LPAS, the horizontal grid indices should only refer to the coarser grid.

(INTEGER)

### 3. INPUT DATA FILE SR\_FILE\_NAME

NAMELIST /SOURCE/ NPS

NPS = number of point sources

(INTEGER)

```
DO I = 1, NPS
  READ (10,*) IS(I), KS(I), LS(I), ITSB(I), ITSE(I)
  READ (10,*) CUS(I), CVS(I), CWS(I)
END DO
```

IS (I) = grid index in the x- direction of the I-th source. All grid planes in the x- direction (i.e. the yz-planes) including those in the finer grid have to be considered if the source is located in the finer grid.

(INTEGER)

KS (I) = grid index in the y- direction of the I-th source. All grid planes in the y- direction (i.e. the xz-planes) including those in the finer grid have to be considered if the source is located in the finer grid.

(INTEGER)

LS (I) = grid index in the z- direction of the I-th source. All grid planes in the z- direction (i.e. the horizontal planes) including those in the finer grid have to be considered. If LS (I) == LPAS, the horizontal grid indices should only refer to the coarser grid.

(INTEGER)

ITSB (I) = time level corresponding to the initial time of the I-th source time function.

(INTEGER)

ITSE (I) = time level corresponding to the end of the I-th source time function.

(INTEGER)

CUS (I) = amplitude of the I-th source in the x- direction  
 CVS (I) = amplitude of the I-th source in the y- direction  
 CWS (I) = amplitude of the I-th source in the z- direction

ALL (REAL)

### 4. INPUT DATA FILE MO\_FILE\_NAME

READ ( 14 ) JMNUM

(INTEGER)

JMNUM = number of material cell types.

```
READ ( 14 ) ( DENU(JM1), DENV(JM1), DENW(JM1), &
  LAM (JM1), MU (JM1), &
  MUXY(JM1), MUXZ(JM1), MUYZ(JM1), JM1 = 1, JMNUM)
```

DENU (I) = volume arithmetic average of the density [kg/m<sup>3</sup>] in the grid position of the x- component of the displacement in the I-th type. (REAL(PP))

DENV (I) = volume arithmetic average of the density [kg/m<sup>3</sup>] in the grid position of the y- component of the displacement in the I-th type. (REAL(PP))

DENW (I) = volume arithmetic average of the density [kg/m<sup>3</sup>] in the grid position of the z- component of the displacement in the I-th type. (REAL(PP))

MU (I) = Volume harmonic average of the torsion modulus in the grid position of the diagonal stress-tensor components in the I-th type. [Pa] (REAL(PP))

LAM (I) = Lamé's elastic coefficient 'lambda' in the grid position of the diagonal stress-tensor components in the I-th type. Value of this parameter is obtained as  $KAPA(I) - (2/3)MU(I)$ , where KAPA is volume harmonic average of the bulk modulus in. [Pa] (REAL(PP))

MUXY (I) = Volume harmonic average of the torsion modulus in the grid position of the xy- stress-tensor component in the I-th type. [Pa] (REAL(PP))

MUXZ (I) = Volume harmonic average of the torsion modulus in the grid position of the xz- stress-tensor component in the I-th type.. [Pa] (REAL(PP))

MUYZ (I) = Volume harmonic average of the torsion modulus in the grid position of the yz- stress-tensor component in the I-th type. [Pa] (REAL(PP))

PP = 4 for single precision (default)  
 = 8 for double precision

**5. INPUT DATA FILE Q\_FILE\_NAME**

```

READ ( 15 ) ( YLAM (JM1,1:8), YMU (JM1,1:8),           &
              YMUXY(JM1,1:8), YMUXZ(JM1,1:8), YMUYZ(JM1,1:8), &
              JM1 = 1, JMNUM)
    
```

YLAM (I,IFREQ) = value of the anelastic material parameter at the IFREQ-th relaxation frequency corresponding to  $YKAPA(I) * KAPA(I) - (2/3)YMU(I) * MU(I)$ . (REAL(PP))

YMU (I,IFREQ) = value of the anelastic material parameter at the IFREQ-th relaxation frequency corresponding to MU(I). (REAL(PP))

YMUXY(I,IFREQ) = value of the anelastic material parameter at the IFREQ-th relaxation frequency corresponding to MUXY (I). (REAL(PP))

YMUXZ(I,IFREQ) = value of the anelastic material parameter at the IFREQ-th relaxation frequency corresponding to MUXZ (I). (REAL(PP))

YMUYZ(I,IFREQ) = value of the anelastic material parameter at the IFREQ-th relaxation frequency corresponding to MUYZ (I). (REAL (PP))

PP = 4 for single precision (default)  
= 8 for double precision

## 6. INPUT DATA FILE JMH\_FILE\_NAME

The file is a direct-access file and is open in the code as follows:

```
INQUIRE ( IOLENGTH = IOLENINT ) JM (1:MX,1:MY,1:1)
```

```
OPEN ( 13, FILE = JMH_FILE_NAME, FORM = 'UNFORMATTED', &
      ACCESS = 'DIRECT', RECL = IOLENINT, STATUS='OLD' )
```

```
DO L = LPAS, MZ
  READ (13, REC = L+1-LPAS) JM( 1:MX,1:MY, L)
END DO
```

JM (I,K,L) = integer number specifying a type of block in the (I,K,L)-th grid cell. (INTEGER\*2)

## 7. INPUT DATA FILE JMH3\_FILE\_NAME

The file is a direct-access file and is open only if LPAS>0 in the code as follows:

```
INQUIRE ( IOLENGTH = IOLENINT ) JMF (1:MXF,1:MYF,1:1)
where
  MXF = (MX-1)*3 + 1, MYF = (MY-1)*3 + 1
```

```
OPEN ( 33, FILE = JMH3_FILE_NAME, FORM = 'UNFORMATTED', &
      ACCESS = 'DIRECT', RECL = IOLENINT, STATUS='OLD' )
```

```
DO L = 0, LPAS
  READ (33, REC = L+1) JMF( 1:MXF,1:MYF, L)
END DO
```

JMF (I,K,L) = integer number specifying a type of block in the (I,K,L)-th grid cell. (INTEGER\*2)

## 8. INPUT DATA FILE(S) SRCxxxx.DAT - generated by the RANSOURCE program

SRCxxxx.DAT = SRC0001.DAT, SRC0002.DAT, ..., SRCvalu.DAT, where val is the value of NPS  
SRCDELI.DAT

File SRC0001.DAT contains the source time function for the first source, SRC0002.dat for the second source, ... .

The files are direct-access files and are open in the code as follows:

```
OPEN ( 10, FILE = 'SRC0001.DAT', FORM = 'UNFORMATTED', &
      ACCESS = 'DIRECT', RECL = PP, STATUS='OLD' )
where
  PP = 4 for single precision (default)
     = 8 for double precision
```

```
DO I = ITSB(1), ITSE(1)
  READ ( 10, REC=I-ITSB(1)+1 ) SOURTF(I)
END DO
```

SOURTF(I) = source time function at time level I  
(REAL (PP))

## 9. INPUT DATA FILE FC.DAT

Each line of the file contains a value of one filter coefficient.

1st line : Zero-th coefficient,

2nd line : 1st coefficient,

...

HWFILT + 1 line: HWFILT-th coefficient

OUTPUT FILES:

=====

If KEY\_TLD == .TRUE.

SEISU.DAT - ascii file containing values of the x-component of displacement  
at specified receivers at each IPAS1 time level, e.g.

1st column - time

2nd column - displacement values at receiver 1

3rd column - displacement values at receiver 2

.

.

.

(MR+1)th column - displacement values at receiver MR

SEISV.DAT - the same as SEISU.DAT but for y-component

SEISW.DAT - the same as SEISU.DAT but for z-component

NOTE! The order of receiver has to be read from JOBNAME.LOG file!

SEISU0.DAT - the x-component of displacement interpolated at the grid position  
of the z-component at the free surface

SEISV0.DAT - the same as SEISU0.DAT but for the y-component

SEISW0.DAT - the same as SEISW.DAT

-

If KEY\_TLV == .TRUE.

VELOU.DAT - ascii file containing values of the x-component of particle  
velocity at specified receivers at each IPAS1 time level, e.g.

1st column - time

2nd column - particle velocity values at receiver 1

3rd column - particle velocity values at receiver 2

.

.

.

(MR+1)th column - particle velocity values at receiver MR

VELOV.DAT - the same as VELOU.DAT but for y-component of particle velocity

VELOW.DAT - the same as VELOU.DAT but for z-component of particle velocity

NOTE! The order of receiver has to be read from JOBNAME.LOG file!

VELOU0.DAT - the x-component of particle velocity interpolated  
at the grid position of the z-component at the free surface

VELOV0.DAT - the same as VELOU0.DAT but for the y-component

VELOW0.DAT - the same as VELOW.DAT

If KEY\_SND == .TRUE.

If KEY\_WC == .FALSE.

SNAP.Dxxxxx - unformatted file containing displacement values at the  
free surface at time level xxxxx (,e.g. SNAP.D00010, for  
10-th time level)

WRITE ( 18 ) UFM(1:MXF,1:MYF,1), &  
VFM(1:MXF,1:MYF,1), &

```

                WFM(1:MXF,1:MYF,1)
else
  SNAP.Dxxxxxx - unformatted file containing wavelet compressed
                 displacement values at the free surface
                 at time level xxxxxx (,e.g. SNAP.D00010, for
                 10-th time level)

If KEY_SNV == .TRUE.

  If KEY_WC == .FALSE.
    SNAP.Vxxxxxx - unformatted file containing particle velocity values at the
                   free surface at time level xxxxxx (,e.g. SNAP.V00010, for
                   10-th time level)
    WRITE ( 18 ) UF (1:MXF,1:MYF,1),           &
                 VF (1:MXF,1:MYF,1),         &
                 WF (1:MXF,1:MYF,1)
  else
    SNAP.Vxxxxxx - unformatted file containing wavelet compressed
                   particle velocity values at the free surface
                   at time level xxxxxx (,e.g. SNAP.D00010, for
                   10-th time level)

```

Note about stop and continue computations:

=====

If it is necessary to stop the computation before reaching MT2 time level:

- create an empty file with name 'STOP' in the directory where the computation is running
- if it will be desirable to continue the computation after stopping and KYE\_DISK was set to .FALSE. then create an empty file with name 'DISK' in th directory where computation is running.
- after while the computation will be stopped and in the file 'STOP' it will be written number of the following first time level

to continue the computation:

- delete the temporary files JOBNAME.BOU, JOBNAME.BOF, JOBNAME.REC, JOBNAME.SRC
- KEEP the files WAVE.CF\* and WAVE.CO\*, SEIS.TL\*, VELO.TL\*
- set MT1 equal to the number stored in the file 'STOP'
- run the computation

---

## Acknowledgements

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## List of Appendices

**Appendix 1: Canonical models**

**Appendix 2: CD ROM with the program NOISE**

## Appendix 1 : Canonical models

A set of canonical models for seismic noise simulations has been defined. The set of the canonical models will serve for extensive parametric study of synthetic seismic noise which will create a basis for deducing systematic features of the noise and decisive factors determining peak H/V and HT (VT) frequencies and corresponding amplitudes.

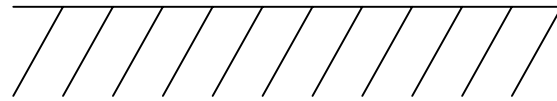
The set consists of the following models (each being described in the following pages):

- M1 : homogeneous halfspace,
- M2 : single layer over halfspace
  - ▶ parameter study with several mechanical parameters
  - ▶ single layer over halfspace – Grenoble,
  - ▶ single layer over halfspace – Liege,
- M3 : dipping layer, semiinfinite layer over halfspace,
- M4 : semi-infinite layer over halfspace,
- M5 : single layer with a rough layer-halfspace interface,
- M6 : deep sediment valley
  - ▶ A – 2D case
  - ▶ B – 3D, axisymmetric case
- M7 : shallow sediment valley
  - ▶ A – 2D case
  - ▶ B – 3D, axisymmetric case
- M8 : single layer with a trough at the bottom
  - ▶ A – 2D case
  - ▶ B – 3D, axisymmetric case
- M9 : buried fault
- M10 : two-layer models
  - ▶ A – thick and shallow layers
  - ▶ B – two shallow layers, with and without velocity inversion
- M11 : shallow layer, gradient model
  - ▶ A – with increasing velocity
  - ▶ B – with decreasing velocity

The set of the canonical models will serve for extensive parametric study of synthetic seismic noise which will create a basis for deducing systematic features of the noise and decisive factors determining peak H/V and HT (VT) frequencies and corresponding amplitudes.



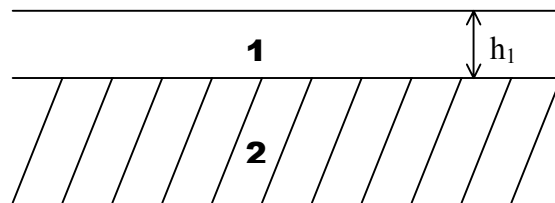
• **M1: Homogenous halfspace**



$\alpha = 2000 \text{ m/s}$	$\beta = 1000 \text{ m/s}$	$\rho = 2500 \text{ kg/m}^3$	$Q_s = 50$
			$Q_p = 100$

• **M2: Single layer over halfspace**

➤ **Parameter study with several mechanical parameters**



$\alpha_1 \text{ (m/s)}$	$\beta_1 \text{ (m/s)}$	$h_1 \text{ (m)}$	$\rho_1 = 1900 \text{ kg/m}^3$
400 – 1350	200	25	$Q_{s1} = 25$
500 – 1350	250	31.25	$Q_{p1} = 50$
667 – 1350	333	41.6	
1000 – 1350	500	62.5	$f_0 = 2 \text{ Hz}$
1350	667	83	$f_{max} = 10 \text{ Hz}$

$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ kg/m}^3$	$Q_{s2} = 50$			
			$Q_{p2} = 100$			
$\alpha_1/\beta_1$	$\beta_2/\beta_1$	1.5	2.0	3.0	4.0	5.0
2		YES	YES	YES	YES	YES
3			MAYBE	MAYBE	MAYBE	MAYBE
4				YES	YES	YES
5					MAYBE	MAYBE
10						YES

➤ **Single layer over halfspace - Grenoble**

Thickness of the layer:  $h_1 = 500 \text{ m}$

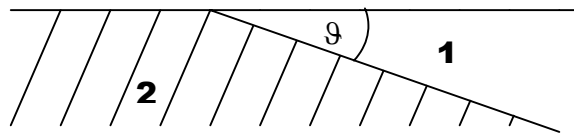
$\alpha_1 = 1800 \text{ m/s}$	$\beta_1 = 600 \text{ m/s}$	$\rho_1 = 2000 \text{ kg/m}^3$
$\alpha_2 = 5000 \text{ m/s}$	$\beta_2 = 3000 \text{ m/s}$	$\rho_2 = 2500 \text{ kg/m}^3$

➤ **Single layer over halfspace - Liège**

Thickness of the layer:  $h_1 = 10 \text{ m}$

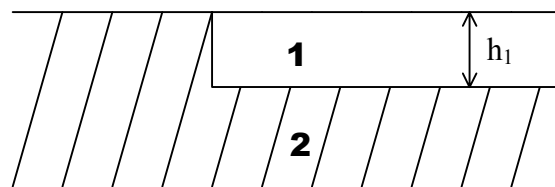
$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 200 \text{ m/s}$	$\rho_1 = 1900 \text{ kg/m}^3$
$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ kg/m}^3$

• **M3: Dipping layer**



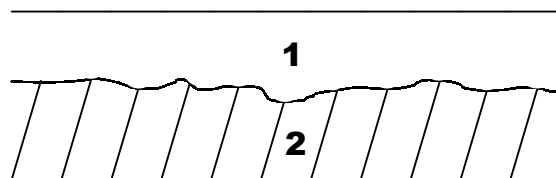
$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 250 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$	9
	$\beta_1 = 500 \text{ m/s}$		$Q_{P1} = 50$	
$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ m/s}$	$Q_{S2} = 50$	10°
			$Q_{P2} = 100$	20°

• **M4: Semiinfinite layer over halfspace**



$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 250 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$	$h_1 \text{ (m)}$
	$\beta_1 = 500 \text{ m/s}$		$Q_{P1} = 50$	
$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ m/s}$	$Q_{S2} = 50$	31,25
			$Q_{P2} = 100$	62,5

• **M5: Single layer with a rough layer halfspace interface**



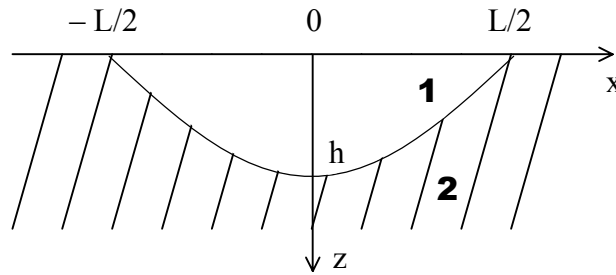
$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 250 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$
			$Q_{P1} = 50$
$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ m/s}$	$Q_{S2} = 50$
			$Q_{P2} = 100$

Average thickness of the layer:  $\bar{h} = 31,25 \text{ m}$

Amplitude of the roughness: 15 % of the layer thickness  
30 % of the layer thickness

Correlation length:  $\frac{1}{2} \frac{\beta_1}{f_0}$ ,  $\frac{\beta_1}{f_0}$ ,  $2 \frac{\beta_1}{f_0}$

• **M6: Deep sediment valley**



➤ **A – 2D case**

Interface between sediments and bedrock is defined by

$$z = h \cdot \cos\left(\frac{\pi}{L} x\right), \quad x \in \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

$$z = 0, \quad x \notin \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

Width of the valley:  $L = 2500$  m  
 Depth of the valley:  $h = 500$  m

$\alpha_1 = 1800$ m/s	$\beta_1 = 667$ m/s	$\rho_1 = 2000$ m/s	$Q_{S1} = 50$
			$Q_{P1} = 100$
$\alpha_2 = 3500$ m/s	$\beta_2 = 2000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 100$
			$Q_{P2} = 200$

➤ **B – 3D, axisymmetric case**

Interface between sediments and bedrock in the xz-plane is defined by

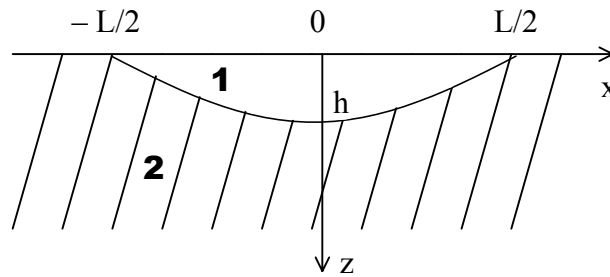
$$z = h \cdot \cos\left(\frac{\pi}{L} x\right), \quad x \in \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

$$z = 0, \quad x \notin \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

Width of the valley:  $L = 2500$  m  
 Depth of the valley:  $h = 500$  m

$\alpha_1 = 1800$ m/s	$\beta_1 = 667$ m/s	$\rho_1 = 2000$ m/s	$Q_{S1} = 50$
			$Q_{P1} = 100$
$\alpha_2 = 3500$ m/s	$\beta_2 = 2000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 100$
			$Q_{P2} = 200$

• **M7: Shallow sediment valley**



➤ **A – 2D case**

Interface between sediments and bedrock is defined by

$$z = h \cdot \cos\left(\frac{\pi}{L} x\right), \quad x \in \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

$$z = 0, \quad x \notin \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

**1<sup>st</sup> model:**  $L_1 = 5000$  m  
 $h_1 = 500$  m

$\alpha_1 = 1800$ m/s	$\beta_1 = 667$ m/s	$\rho_1 = 2000$ m/s	$Q_{S1} = 50$ $Q_{P1} = 100$
$\alpha_2 = 3500$ m/s	$\beta_2 = 2000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 100$ $Q_{P2} = 200$

**2<sup>nd</sup> model:**  $L_2 = 312,5$  m  
 $h_2 = 31,25$  m

$\alpha_1 = 1350$ m/s	$\beta_1 = 250$ m/s	$\rho_1 = 1900$ m/s	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 2000$ m/s	$\beta_2 = 1000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 50$ $Q_{P2} = 100$

➤ **B – 3D, axisymmetric case**

Interface between sediments and bedrock in the xz-plane is defined by

$$z = h \cdot \cos\left(\frac{\pi}{L} x\right), \quad x \in \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

$$z = 0, \quad x \notin \left\langle -\frac{L}{2}, \frac{L}{2} \right\rangle$$

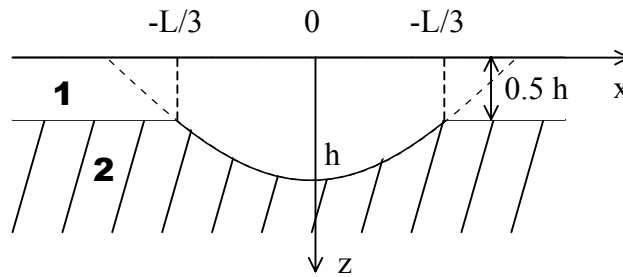
**1<sup>st</sup> model:**  $L_1 = 5000$  m  
 $h_1 = 500$  m

$\alpha_1 = 1800$ m/s	$\beta_1 = 667$ m/s	$\rho_1 = 2000$ m/s	$Q_{S1} = 50$ $Q_{P1} = 100$
$\alpha_2 = 3500$ m/s	$\beta_2 = 2000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 100$ $Q_{P2} = 200$

**2<sup>nd</sup> model:**  $L_2 = 312,5$  m  
 $h_2 = 31,25$  m

$\alpha_1 = 1350$ m/s	$\beta_1 = 250$ m/s	$\rho_1 = 1900$ m/s	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 2000$ m/s	$\beta_2 = 1000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 50$ $Q_{P2} = 100$

• **M8: Single layer with a through at the bottom**



➤ **A – 2D case**

Interface between sediments and bedrock is defined by

$$z = h \cdot \cos\left(\frac{\pi}{L} x\right), \quad x \in \left\langle -\frac{L}{3}, \frac{L}{3} \right\rangle$$

$$z = \frac{h}{2}, \quad x \notin \left\langle -\frac{L}{3}, \frac{L}{3} \right\rangle$$

**1<sup>st</sup> model:**  $L_1 = 2500$  m  
 $h_1 = 500$  m

$\alpha_1 = 1800$ m/s	$\beta_1 = 667$ m/s	$\rho_1 = 2000$ m/s	$Q_{S1} = 50$
			$Q_{P1} = 100$
$\alpha_2 = 3500$ m/s	$\beta_2 = 2000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 100$
			$Q_{P2} = 200$

**2<sup>nd</sup> model:**  $L_2 = 312,5$  m  
 $h_2 = 31,25$  m

$\alpha_1 = 1350$ m/s	$\beta_1 = 250$ m/s	$\rho_1 = 1900$ m/s	$Q_{S1} = 25$
			$Q_{P1} = 50$
$\alpha_2 = 2000$ m/s	$\beta_2 = 1000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 50$
			$Q_{P2} = 100$

➤ **B – 3D, axisymmetric case**

Interface between sediments and bedrock in the xz-plane is defined by

$$z = h \cdot \cos\left(\frac{\pi}{L} x\right), \quad x \in \left\langle -\frac{L}{3}, \frac{L}{3} \right\rangle$$

$$z = \frac{h}{2}, \quad x \notin \left\langle -\frac{L}{3}, \frac{L}{3} \right\rangle$$

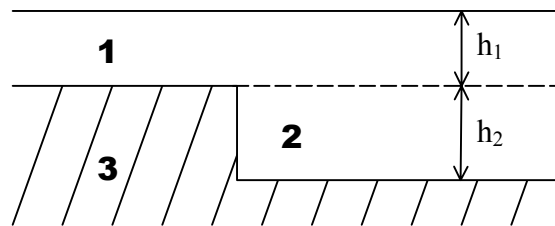
**1<sup>st</sup> model:**  $L_1 = 2500$  m  
 $h_1 = 500$  m

$\alpha_1 = 1800$ m/s	$\beta_1 = 667$ m/s	$\rho_1 = 2000$ m/s	$Q_{S1} = 50$
			$Q_{P1} = 100$
$\alpha_2 = 3500$ m/s	$\beta_2 = 2000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 100$
			$Q_{P2} = 200$

**2<sup>nd</sup> model:**  $L_2 = 312,5$  m  
 $h_2 = 31,25$  m

$\alpha_1 = 1350$ m/s	$\beta_1 = 250$ m/s	$\rho_1 = 1900$ m/s	$Q_{S1} = 25$
			$Q_{P1} = 50$
$\alpha_2 = 2000$ m/s	$\beta_2 = 1000$ m/s	$\rho_2 = 2500$ m/s	$Q_{S2} = 50$
			$Q_{P2} = 100$

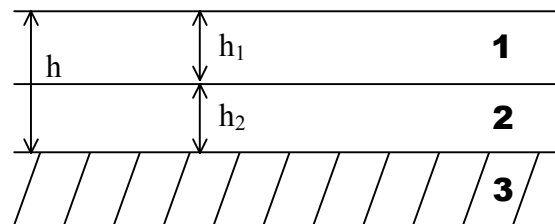
• **M9: Burried fault**



$h_1 = 31,25 \text{ m}$   
 $h_2 = 375 \text{ m}$

$\alpha_1 = 500 \text{ m/s}$	$\beta_1 = 250 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 1800 \text{ m/s}$	$\beta_2 = 750 \text{ m/s}$	$\rho_2 = 2100 \text{ m/s}$	$Q_{S2} = 50$ $Q_{P2} = 100$
$\alpha_3 = 3900 \text{ m/s}$	$\beta_3 = 2250 \text{ m/s}$	$\rho_3 = 2500 \text{ m/s}$	$Q_{S3} = 100$ $Q_{P3} = 200$

• **M10: Two layer models**



➤ **A – thick and shallow layers**

$h_1 = 31,25 \text{ m}$   
 $h_2 = 375 \text{ m}$

$\alpha_1 = 500 \text{ m/s}$	$\beta_1 = 250 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 1800 \text{ m/s}$	$\beta_2 = 750 \text{ m/s}$	$\rho_2 = 2100 \text{ m/s}$	$Q_{S2} = 50$ $Q_{P2} = 100$
$\alpha_3 = 3900 \text{ m/s}$	$\beta_3 = 2250 \text{ m/s}$	$\rho_3 = 2500 \text{ m/s}$	$Q_{S3} = 100$ $Q_{P3} = 200$

➤ **B – thick and shallow layers, with and without velocity inversion**

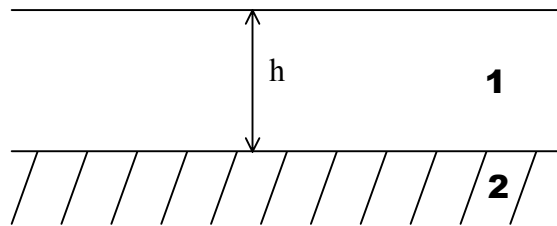
**1<sup>st</sup> model:**  $h_1 = 18 \text{ m}$   
 $h_2 = 18 \text{ m}$

$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 250 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 1350 \text{ m/s}$	$\beta_2 = 333 \text{ m/s}$	$\rho_2 = 1900 \text{ m/s}$	$Q_{S2} = 25$ $Q_{P2} = 50$
$\alpha_3 = 2000 \text{ m/s}$	$\beta_3 = 1000 \text{ m/s}$	$\rho_3 = 2500 \text{ m/s}$	$Q_{S3} = 50$ $Q_{P3} = 100$

**2<sup>nd</sup> model:**  $h_1 = 18 \text{ m}$   
 $h_2 = 18 \text{ m}$

$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 333 \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 1350 \text{ m/s}$	$\beta_2 = 250 \text{ m/s}$	$\rho_2 = 1900 \text{ m/s}$	$Q_{S2} = 25$ $Q_{P2} = 50$
$\alpha_3 = 2000 \text{ m/s}$	$\beta_3 = 1000 \text{ m/s}$	$\rho_3 = 2500 \text{ m/s}$	$Q_{S3} = 50$ $Q_{P3} = 100$

• **M11: Shallow layer, gradient model**



➤ **A – with increasing velocity**

$h = 36 \text{ m}$

$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 200 + 5z \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ m/s}$	$Q_{S2} = 50$ $Q_{P2} = 100$

➤ **B – with decreasing velocity**

$h = 36 \text{ m}$

$\alpha_1 = 1350 \text{ m/s}$	$\beta_1 = 380 - 5z \text{ m/s}$	$\rho_1 = 1900 \text{ m/s}$	$Q_{S1} = 25$ $Q_{P1} = 50$
$\alpha_2 = 2000 \text{ m/s}$	$\beta_2 = 1000 \text{ m/s}$	$\rho_2 = 2500 \text{ m/s}$	$Q_{S2} = 50$ $Q_{P2} = 100$

## Appendix 2: Program NOISE

see the CD ROM attached to this report.