USER'S GUIDE FOR FINDIF AT SACLANTCEN

Ralph A.Stephen

Department of Geology and Geophysics
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

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Index

FIGURES

1. Introduction

FINDIF solves the elastic wave equation for a line source in two dimensions by the finite difference method (Virieux,1986; Stephen,1988b). The solution is carried out in the time domain for either pulse or CW sources. Arbitrary distributions of compressional velocity, shear velocity and density (including fluids and solids) can be defined on the finite difference grid. All compressional waves, shear waves, interface waves and evanescent waves are included as are all conversions between wave types. Multiple forward and backward scattering is automatically treated. **FINDIF** was developed at Woods Hole Oceanographic Institution.

FINDIF has been applied to a wide variety of problems in ocean seismo-acoustics. Early work verified the agreement between finite difference and reflectivity results for laterally homogeneous seafloor models with gradients in elastic properties (Stephen,1983; Hunt and Stephen, 1986). (The reflectivity method is a wavenumber integral approach like **SAFARI**.) The code has been used to study the effects of range dependent environment on deep sea borehole seismic data in the Gulf of California (Stephen,1984) and the equatorial, East Pacific (Stephen,1988a). A modified version of the code has been applied to acoustic well logging problems in horizontally stratified media (Stephen et al, 1985). The code was also used for a series of benchmark wedge models defined by the Acoustical Society of America and the results compared quite favourably with other techniques (Stephen,1990).

Stephen (1988b) summmarizes the evolution of finite difference methods as applied to seafloor interaction problems. The template used in the **FINDIF** code is based on a formulation by Virieux (1986); the source is introduced using a method described by Nicoletis (1981); and the absorbing boundaries are treated using the 'telegraph equation' approach described by Levander(1985).

There are a number of versions of **FINDIF** which are specifically tailored to address particular problems. The version of **FINDIF** which is running at SACLANTCEN is called **SCNTDIF** and it is tailored to study shallow water propagation problems over range dependent, elastic bottoms (ie. bottoms with two-dimensionally varying compressional and shear velocity and density, but without attenuation). In this version the source is always a compressional point source in the water column and the problem is symmetrical in range about the source.

SCNTDIF is run in three stages. The first stage is a preprocessor, **SCNTPREP**, which creates 'COMMON' blocks with the correct dimensions for a given problem. These 'COMMON' blocks are then introduced into subsequent programs by 'INCLUDE' statements. Input is specified through a parameter file, ***MDLID***.PAR. (***MDLID*** is any user specified model identifier.) The second stage requires defining the compressional and shear wave speeds and density on the finite difference grid. This is usually done by a user written FORTRAN program. Some examples, called **CAI01BNY.FOR, CAI02BNY.FOR, AKA01BNY.FOR**, etc are discussed below. The third stage is to actually compute the wave field using **FINDIF**. Results are output as snapshots (the complete two dimensional wavefield at an instant of time) and as time series (time histories of pressure or displacement) at particular locations in the model. (There is a post-processor, **CONVEL**, to convert displacement time series to velocity.)

At SACLANTCEN, **SCNTDIF** is currently configured to run on the **FPS260** with the **VAX8600/VAX9000** host or on the **VAX8600/9000** itself. This user's guide describes the code installed on all three computers at SACLANTCEN and describes some examples.

FIGURE 1: Layout of the Finite Difference Grid

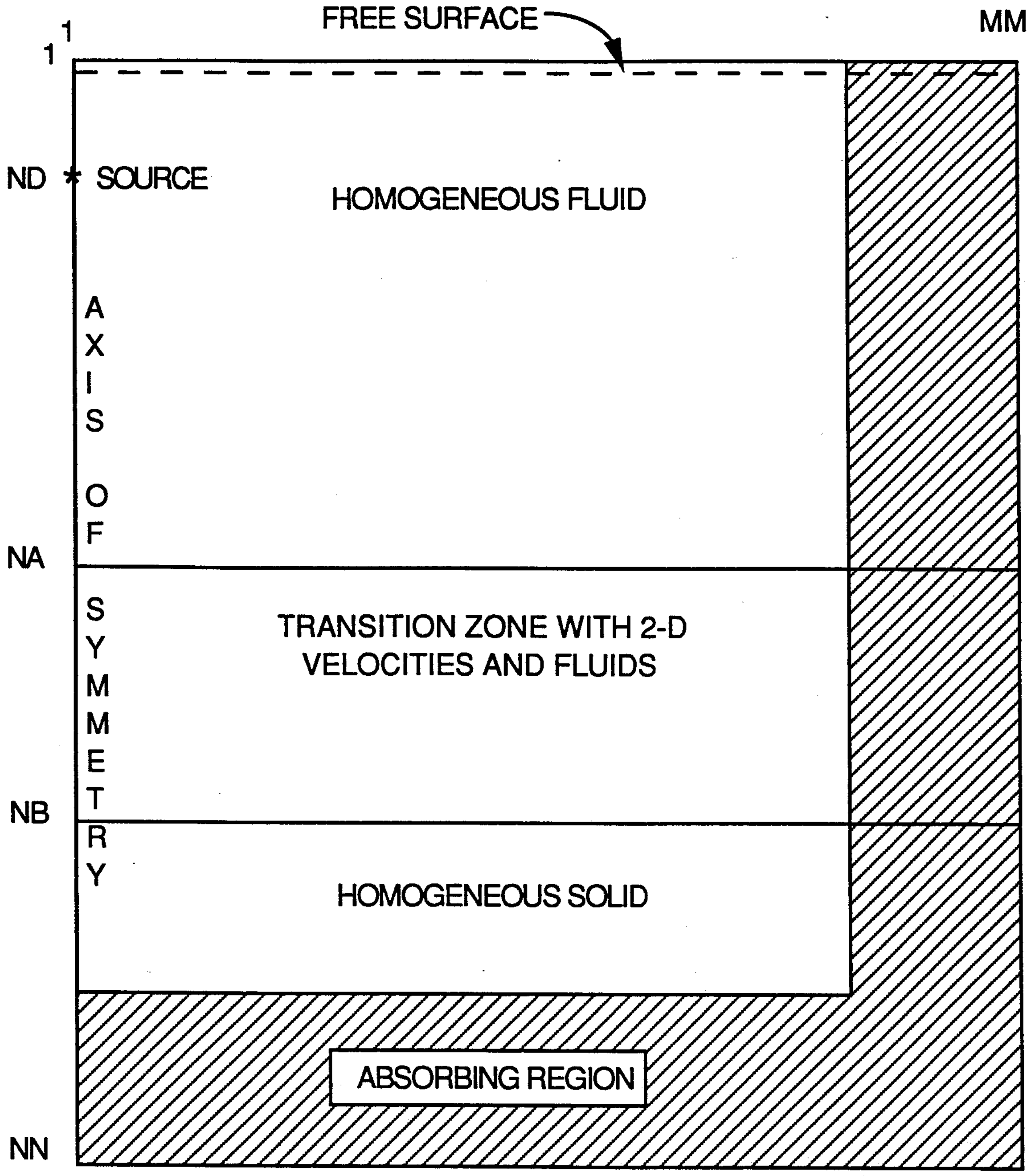
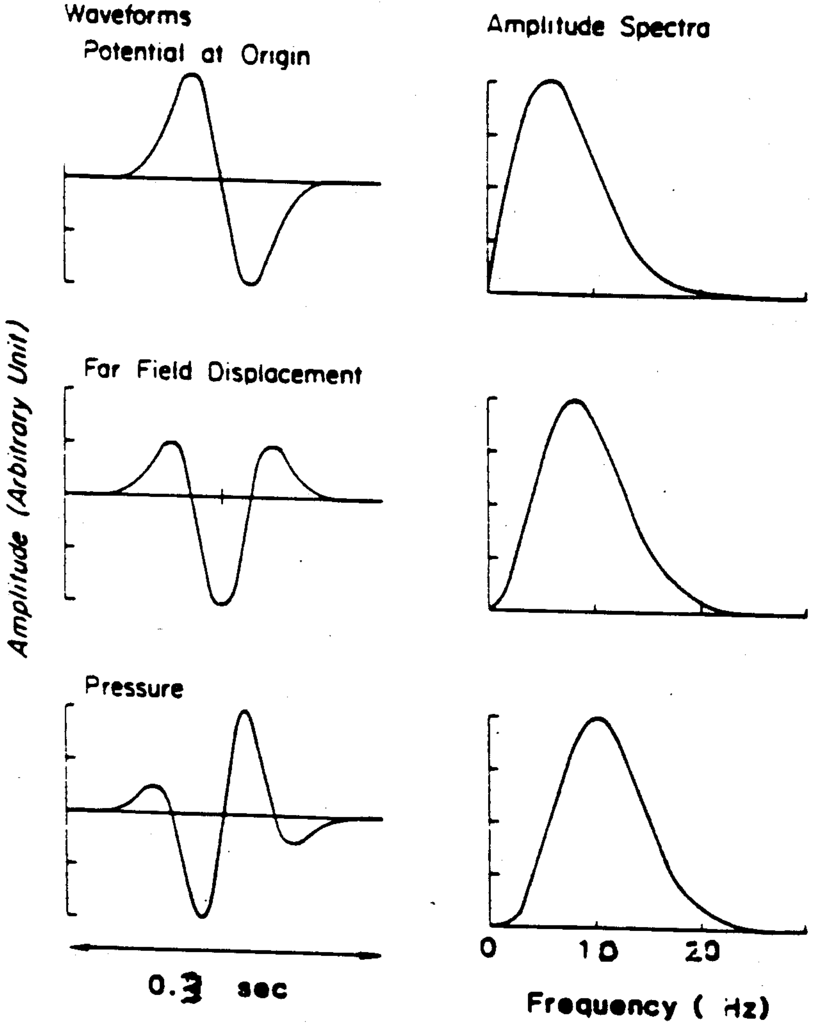


FIGURE 2: Source Waveforms and Amplitude Spectra for Pulse Sources



2. Model Description and the Parameter File

Figure 1 represents a cross section vertically through the ocean and seafloor as used in **SCNTDIF**. The model assumes a Cartesian coordinate system so that features on the grid extend into and out of the page. The top edge is a free surface, the left edge is an axis of symmetry, and the right and bottom edges are absorbing regions. The (line) source is located on the axis of symmetry. In order to improve computational performance the grid is divided into three regions. The top region represents a homogeneous water column. In the middle region, or transition zone, an arbitrary distribution of liquids and solids in two dimensions is treated. This typically represents the seafloor with either surface roughness or volume heterogeneities. If desired the top region can have zero thickness, so that two dimensional variability can go up to the free surface. In this case vertical velocity gradients and/or two dimensional variability in the water column can be treated. The bottom region represents a homogeneous solid and serves to carry energy away from the scattering region where it can be attenuated without contaminating the desired solution.

The time dependence of the source can either be a pulse (in pressure, the third derivative of a Gaussian profile) or a continuous wave, single frequency (CW) signal. The pulse waveforms are shown in Figure 2 and are described in Appendix E of Stephen et al (1985). For a given peak frequency the bandwidth is automatically prescribed. For example, for a 10Hz pulse in pressure, the lower and upper half power points are 6.82Hz and 13.56Hz, respectively.

The absorbing boundaries are treated by applying the telegraph equation in a region adjacent to the boundary. The attenuation coefficient profile and the thickness of the absorbing region have been chosen by trial and error to ensure that reflections from the absorbing region will be negligible for typical seafloor models. In **SCNTDIF** the width of the absorbing boundary is fixed at 90 grid points.

Wave propagation is scale independent. For example, a 10Hz problem for a 5sec duration in a model 10km long with a grid interval of 10m is equivalent to a 1KHz problem for a duration of 50msec in a model 100m long with a grid interval of 100cm. Models are equivalent provided that all range, depth and time parameters are multiplied (or divided) by the same factor. However, for convenient use of the program in shallow water acoustics studies, **SCNTDIF** assumes that all distances are in kilometers and that all times are in seconds (frequencies in Hertz).

FIGURE 3: An example of a parameter file, **CAI04.PAR**

```
CAI04   -   TEST MODEL FOR ANDREA - WITH 3 LAYERS
CAI04
1,   1,      0,      -2,     1,      0,       0,      1
601, 401,    20001, 1,      0.0001, 0.0005, 0.0005
1,   20001, 1,      601,    132,     132
8,   10,     10,     20005, 200
1.5, 0.0,    1.0,    1.7,    0.18,    1.2,131,153,1.7, 0.18,1.2
121, 1,      11,      2
11,  65746.0,        0.0
```

An example of a parameter file is shown in Figure 3. It is a free formatted ASCII file. A description of the lines follows.

Line 1 - LABEL

Label up to 80 characters long describing the model.

Line 2 - FILEID

This is a five character model identifier used to identify all outputs from **SCNTDIF.**

Line 3 - IRECT, IDENS, IFLAT, IKELLY,IEXPL, IVERT, ITRAN, ISORB

IRECT = 1 for Cartesian coordinates.
IDENS = 1 for density variations.
IFLAT = 0 for a water layer beneath a free surface and over an elastic halfspace;
= 1 for the water layer beneath a plane of symmetry;
= -2 for intrinsic attenuation (not yet implemented).
IKELLY = -1 for Gaussian source function applied as a point force on the seafloor (ND=NA+1) (implemented on the FPS version only);
= -2 for Gaussian source function applied as a point source in the water column;
= 0 or -3 for the Schmitt broadband source function applied as a point source in the water column (implemented on the FPS version only).
IEXPL = 1 for explicit finite difference formulation.
IVERT = 0 for timeseries output of pressure, verticaldisplacement, and horizontal displacement;
= 1 for time series output of vertical displacement only;
= 2 for time series output of horizontal displacement only;
= 3 for time series output of pressure only.
ITRAN = 0 for heterogeneous formulation in transition region.
ISORB = 1 for absorbing boundaries.

Line 4 - MM,NN,KK,KSTRT,DELT,DELR,DELZ
MM - Number of points in range;
NN - Number of points in depth;
KK - Number of points in time;
KSTRT = 1 is the starting increment in time
DELT - Time increment (sec);
DELR - Range increment (km)
DELZ - Depth increment (km) (DELZ=DELR).

Line 5 - KOUTST,KOUTEN,MOUTST,MOUTEN,NOUTST,NOUTEN
KOUTST - Initial output time index for time series;
KOUTEN - Final output time index for time series;
MOUTST - Initial output range index for time series;
MOUTEN - Final output range index for time series;
NOUTST - Initial output depth index for time series;
NOUTEN - Final output depth index for time series.

Line 6 - KINC,MINC,NINC,KMARK,KMINC
KINC - Time index increment for time series.
MINC - Range index increment for time series.
NINC - Depth index increment for time series.
KMARK - Time index of first snapshot (If KMARK is greater than KK, no snapshots are output);
KMINC - Time index increment for snapshots.

Line 7 - VP1,VS1,RO1,VP2,VS2,RO2,NA,NB,VPT,VST,ROT
VP1 - P-wave velocity in upper homogeneous layer (forNA.GT.2);
- P-wave velocity at the surface (for NA.LE.2)(km/sec);
VS1 - S-wave velocity in upper homogeneous layer (for NA.GT.2);
RO1 - Density in upper homogeneous layer (for NA.GT.2);
- Density at the surface (for NA.LE.2)(gm/cc);
VP2 - P-wave velocity in lower homogeneous layer (km/sec);
VS2 - S-wave velocity in lower homogeneous layer (km/sec);
RO2 - Density in lower homogeneous layer (gm/cc).
NA - Depth index for the top of the 'transition zone', the region of full elastic two-dimensional variability;
NB - Depth index for the bottom of the 'transition zone'.
VPT - Dummy P-wave velocity (km/sec);
VST - Dummy S-wave velocity (km/sec);
ROT - Dummy density (gm/cc).

Line 8 - ND,MD,NSW, MSW
ND - Depth index of source
MD = 1 Range index of source
NSW - Dummy value
MSW = 2 Gives source resolution.

Line 9 - NSORCE,PLSWID,TSWAVE
NSORCE - Dummy value
PLSWID - Duration parameter for Gaussian source pulse. (PLSWID is 6.574 times the square of the peak frequency in pressure in Hertz)
TSWAVE - Time shift parameter (seconds) for the source. (If TSWAVE equals zero, the code automatically chooses an appropriate value for the source type and frequency.)

3. The Programs

(Sections a-c describe the code implemented using the **FPS264**. Section d describes the code using the **VAX9000.**)

3a) The Preprocessor - SCNTPREP

The source code for **SCNTPREP** resides in PR19_DISK:[STEPHEN.BENCH.VAX.PRP]. **SCNTPREP** reads the ***MDLID*.PAR** file and creates a file,**SCOMFD8.FOR**, which contains 'COMMON' blocks of the arrays necessary to run the other two stages. A **command** file for creating an executable of **SCNTPREP** is shown in Figure 4. **SCNTPREP** requires the 'INCLUDE' file, **SMODPAR.FOR**. It uses subroutines **SRDMPAR, SOPNCOM, DATIM** and **SLOGOUT** which are described in the subroutine section below. A log file, ***MDLID*.LG1**, is also created which lists the parameters and relevant output from **SCNTPREP**.

Figure 4: The **command** file for creating an executable of **SCNTPREP** on the **VAX8600/9000**

```
$!
$!    Link command file for scntprep          10 May 1990
$!
$  SET VERIFY
$  FOR  SCNTPREP.FOR
$  FOR  DATIM.FOR
$  FOR  SLOGOUT.FOR
$  FOR  SOPNCOM.FOR
$  FOR  SRDMPAR.FOR
$  LINK  SCNTPREP,DATIM,SLOGOUT,SOPNCOM,SRDMPAR
$  SET NOVERIFY
```

3b) Generating the Parameter Matrices - *BNY

In all cases, between depth increments NA and NB and for all ranges it is necessary to specify values of compressional velocity, shear velocity and density. Fluids can be represented by setting the shear velocity to zero. This stage requires the most user intervention and can be the most fun because the user can define his own media. The code is commonly referred to as the transition zone code because it defines the grid values in the transition zone between NA and NB.

The code resides in PR19_DISK:[STEPHEN.BENCH.FPS.BNY]. ***BNY** reads the ***MDLID*.PAR** file. It then computes Lame's parameters and density for each grid point, extrapolating and interpolating if necessary and outputs the values to a ***MDLID*.BNY** file for use by **SCNTDIF.** A **command** file for creating an executable of ***BNY** is shown in Figure 5. ***BNY** requires 'INCLUDE' files **SMODPAR.FOR, SIOUNIT.FOR,** and **SCOMFD8.FOR.** It uses subroutines **DATIM, SLOGOUT, SRDMPAR,** and **SOPNCOM** which are described in the subroutine section. The progress of the ***BNY** file is summarized in the log file, ***MDLID*.LG2.**

Figure 5: The **command** file for creating an executable of **CAI03BNY** on the **VAX8600/9000**

```
$!
$!      Link command file for CAI03BNY
$!
$  SET VERIFY
$  FOR  CAI03BNY
$  FOR  DATIM
$  FOR  SLOGOUT
$  FOR  SOPNCOM
$  FOR  SRDMPAR
$  LINK  CAI03BNY,DATIM,SLOGOUT,SOPNCOM,SRDMPAR
$  SET NOVERIFY
$  EXIT
$!
$! End of command file
```

Examples of ***BNY** which generate a variety of standard profiles are included in PR19_DISK:[STEPHEN.BENCH.FPS.BNY]. These are summarized in Figure 6. In designing new profiles it is best to make changes to an existing code. Also note that the free surface is at grid point 2. For each model, **SCNTPREP** should be rerun and the ***BNY** program should be recompiled using the **command** file, to insure that the arrays in **SCOMFD8.FOR** have the correct dimensions.

Figure 6. Some examples of ***BNY** files.

CAI01BNY - A homogeneous half space (acoustic or elastic) below a homogeneous liquid layer. (Good for testing.)

CAI03BNY - A layered elastic halfspace below a liquid layer. (This code has layer parameters corresponding to a model for Andrea Caiti.)

AKA01BNY - A layered elastic halfspace below a liquid layer. (This code has layer parameters corresponding to a model for Tuncay Akal.)

ELL01BNY - A layered elastic halfspace below a liquid layer. (This code has layer parameters corresponding to a model for Dale Ellis.)

HOV01BNY - A layered elastic halfspace below a liquid layer. (This code has layer parameters corresponding to a model for Jens Hovem.)

3c) The finite difference calculations - SCNTDIF

SCNTDIF does the major calculations. The code resides in PR19_DISK:[STEPHEN.BENCH.FPS.DIF]. It takes parameters from the **_MDLID_.PAR** file and profiles (in 2-D) from the **_MDLID_.BNY** file and generates timeseries files (**_MDLID_.TSV** for vertical displacement, **_MDLID_.TSH** for horizontal displacement, and **_MDLID_.TSP** for pressure), and snapshot files (**_MDLID_TTTT.DIV** for compressional energy density, **_MDLID_TTTT.CRL** for shear energy density, **_MDLID_TTTT.VRT** for vertical displacement and **_MDLID_TTTT.HRZ** for horizontal displacemnet - **TTTT** is a four character field representing the time step). A **command** file for creating an executable of **SCNTDIF** is shown in Figure 7. **SCNTDIF** requires 'INCLUDE' files **SMODPAR.FOR, SIOUNIT.FOR, SCBLCK.FOR** and **SCOMFD8.FOR**. It uses subroutines **SCNTTS9, SCNTSUB7, SFSETUP, ZSNPOUT, ZDIVCRL, ZTSOUT, TINIT, DATIM, SLOGOUT, SRDMPAR**, and **SOPNCOM** which are described in the subroutine section. The preprocessor, **SCNTPREP**, should be run, and **SCNTDIF** recompiled for every new model to insure that correct array dimensions are being used. Results of **SCNTDIF** are output to the log file **_MDLID_.LG4**.

Figure 7. The **command** file for creating an executable of **SCNTDIF** for the **FPS264**

```
$!
$!      Link command file for SCNTDIF                   10 May 1990
$  SET VERIFY
$  APFTN64/OPT=3/XOFF=ALL  SCNTDIF.FOR
$  APFTN64/OPT=3/XOFF=ALL  SCNTTS9.FOR
$  APFTN64/OPT=3/XOFF=ALL  SCNTSUB7.FOR
$  APFTN64/OPT=3/XOFF=ALL  DATIM.FOR
$  APFTN64/OPT=3/XOFF=ALL  SFSETUP.FOR
$  APFTN64/OPT=3/XOFF=ALL  SLOGOUT.FOR
$  APFTN64/OPT=3/XOFF=ALL  SOPNCOM.FOR
$  APFTN64/OPT=3/XOFF=ALL  SRDMPAR.FOR
$  APFTN64/OPT=3/XOFF=ALL  ZSNPOUT.FOR
$  APFTN64/OPT=3/XOFF=ALL  ZDIVCRL.FOR
$  APFTN64/OPT=3/XOFF=ALL  ZTSOUT.FOR
$  APFTN64/OPT=3/XOFF=ALL  TIMIT.FOR
$  APLINK64/IMAGE=SCNTDIF/list=scntdif.lis  SCNTDIF, -
        DATIM,SCNTTS9,SCNTSUB7,SFSETUP, -
        SLOGOUT,SOPNCOM,SRDMPAR,ZSNPOUT, -
        ZDIVCRL,ZTSOUT,TIMIT
$  SET NOVERIFY
$  EXIT
$!
$! End of command file
$!
```

3d) Use on the **VAX9000**

SCNTDIF on the **VAX9000** is very similar to the version run on the **FPS264**. Some timing and date routines work on the **VAX9000** that had been disabled on the **FPS264** and the file labelling works better on the **VAX9000**. To run **SCNTDIF** on the **VAX9000** use the code in PR12_DISK:[AKAL.RALPH.FINDIF]. Copy all the files from this area into your own work space and edit the ***MDLID*.PAR** and **FINDIF COM** files for your own applications. An example of **FINDIF.COM** for the **VAX9000** version is given in Figure 8.

Figure 8. The **command** file for creating an executable of **SCNTDIF** for the **VAX9000**

```
$!      Command file to run 2D finite differences programs
$!      at SACLANTCEN by Ralph Stephen
$!      08 AUGUST, 1991
$!
$!      RUN THIS COMMAND FILE ON LINE AS:
$!      @FINDIF MDLID MDLIDBNY
$!      OR ON THE BATCH QUEUE AS:
$!      SUBMIT/QUEUE=VAXPEGASO$BATCH -
$!         FINDIF/PARAM=(MDLID,MDLIDBNY),CPUTIME=0
$!
$!      FINDIF USERS SHOULD COPY ALL THE FILES FROM
$!        [AKAL.RALPH.FINDIF] TO A SUB-DIRECTORY IN THEIR
$!        AREA AND THEN EDIT THE 'SET DEF' IN THIS FILE
$!        TO REFER TO THEIR OWN WORK AREA.
$!
$  SET VERIFY
$!
$!      Define directories
$!
$!
$  SET DEF [AKAL.RALPH]
$  PURGE
$!
$  ASSIGN  'P1'.PAR  FOR055       !input parameter file
$  ASSIGN  'P1'.BNY  FOR054       !output data file
$  @SCNTPREP.LNK
$  PURGE
$  RUN  SCNTPREP
$!
$  @'P2'. LNK
$  PURGE
$  RUN  'P2'
```

```
$!
$  @SCNTDIF.LNK
$  PURGE
$  RUN  SCNTDIF
$  SH DEF
$  DIR
$  EXIT
$!
       $! End of command file
$!
```

3e) Summary of Subroutines and 'INCLUDE' Files

A summary of **SCNTDIF** subroutines and the 'INCLUDE' files, which contain 'COMMON' blocks, are listed below.

DATIM	- obtains the date and time of the run which is written in the log files (this capability is disabled for the **FPS264** but can be easily implemented again on the **VAX 9000**);
SCNTS9	- applies the finite difference template to the grid;
SCNTSUB7	- defines constants used in the template calculations;
SFSETUP	- opens the ***.BNY** file;
SLOGOUT	- outputs model parameters in a standard format for all log files;
SOPNCOM	- opens the 'COMMON' block files;
SRDMPAR	- reads the ***.PAR** file;
ZDIVCRL,ZSNPOUT	- outputs the snapshot files;
ZTSOUT	- outputs the time series files;
TIMIT	- calls machine routines to obtain run time paramaters during execution (this capability is disabled for the **FPS264** but can be easily implemented again on the **VAX 9000**);
SCOMFD8.FOR	- 'INCLUDE' file which contains 'COMMON' blocks of working arrays with dimensions which are model dependent;
SMODPAR.FOR	- 'INCLUDE' file which contains 'COMMON' blocks of the model parameters;
SIOUNIT.FOR	- 'INCLUDE' file which contains 'COMMON' blocks of all logical unit names for **SCNTDIF**;
SCBLCK.FOR	- 'INCLUDE' file which contains 'COMMON' blocks of the constants used in the wave equation template.

4. Running SCNTDIF

The first step in running **SCNTDIF** is to design the model on a sheet of paper (Figure 9). First decide what peak frequency (in Hz) you would like to consider (see the note above on scaling). Aim for models that are at most 40 water wavelengths deep and 70 water wavelengths long. These will take about 20 hours on the **FPS264.** (This assumes 10 gridpoints per water wavelength. If finer spacing is used to model shear and Stoneley waves in soft sediments the model dimensions should change accordingly.). The grid increment, DELX, should be at most one tenth of a wavelength. Remember that for shear and interface waves in sediments the wavelengths can be quite small. Now decide the range and depth values (in km) that you would like and compute the grid dimensions. Remember that the absorbing boundary region takes 90 gridpoints on the right side and on the bottom.

For stability DELT must be less than DELR/[(root 2)*vpmax)] where vpmax is the largest velocity on the grid. It is nice to choose a DELT which divides evenly into one second (eg. .01, .0125,.01666 ,etc). Now determine to what time duration you would like results and compute the number of time steps. You will now have the basic model size defined.

The next step is to determine the dimensions for the 'transition zone' and to decide on velocity and density values for the upper and lower homogeneous regions. Make decisions on receiver locations, the time series sampling rate and the frequency and type of snapshots.

The next step is to conceive the structure for the transition zone region and to modify or write the ***BNY** code to generate the matrices of elastic parameters and density.

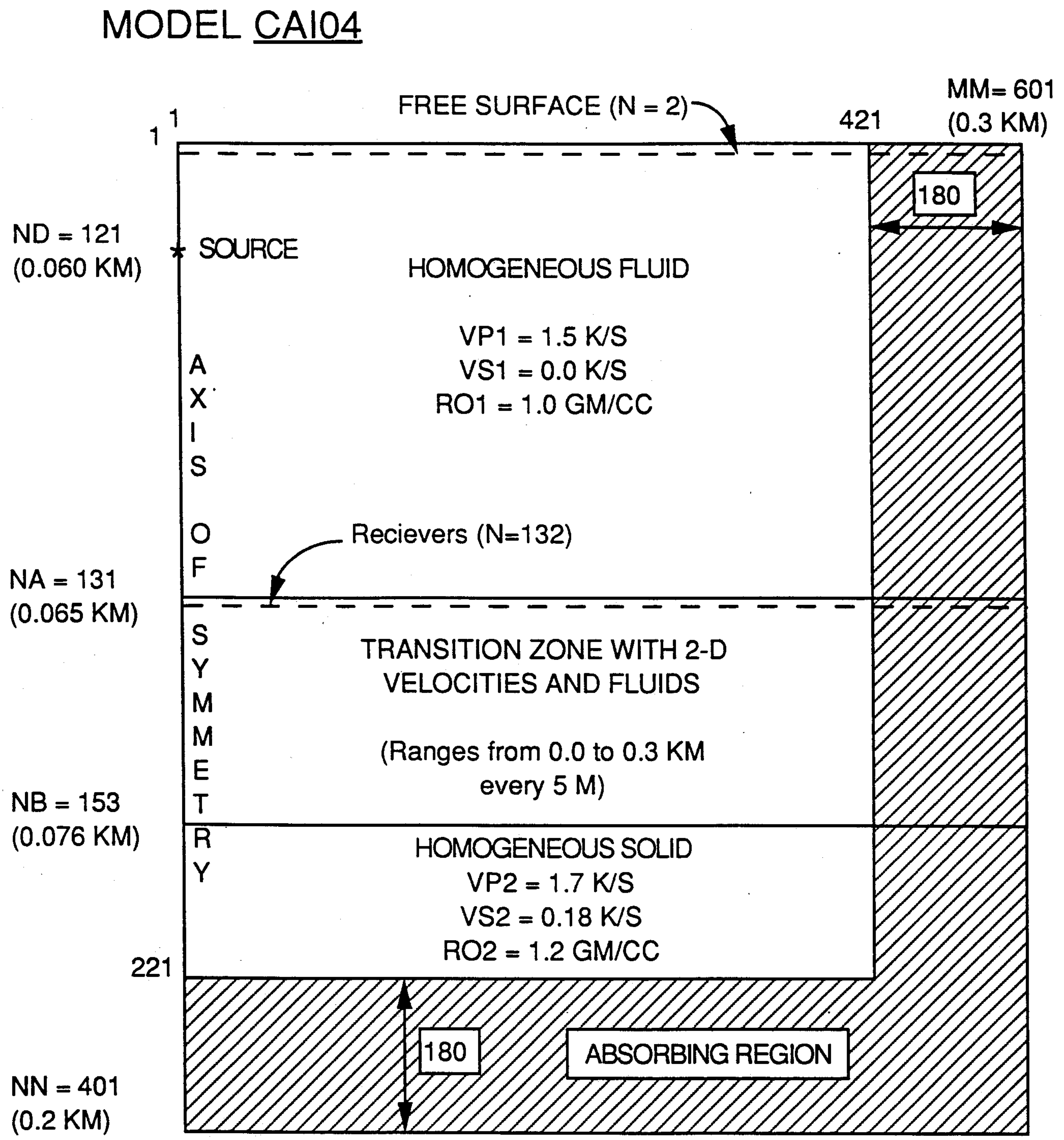
Go through the list of input parameters and confirm that each one is specifying what you want. You are now ready to go the computer.

Set up a sub-directory for each model. Choose an example that is close to what you want to do and copy the example ***.PAR** and ***.BCH** files to the new directory. (An example of a ***.PAR** file was given in Figure 3 and an example of a ***.BCH** file is given in Figure 10.) Edit the ***.PAR** file to contain the new model name and the new parameters. Edit the ***.BCH** file to use the new model name (***MDLID***) and confirm that the correct ***BNY** file is being used.

If you are modifying an existing ***BNY** file or writing a new one, make the changes to the file in the PR19_DISK:[STEPHEN.BENCH.FPS.BNY] directory (or in your own work area if running on the **VAX9000**). Edit the **command** file in this directory to change the program name (eg. change every occurence of **CAI01BNY** with the new name). Then run the **command** file in PR19_DISK:[STEPHEN.BENCH.FPS.BNY] to insure that the code compiles.

Now go back to the model directory and submit the **.BCH** file to the FPS queue (or **FINDIF.COM** to the batch queue on the **VAX9000, VAXPEGASO$BATCH.**

FIGURE 9: MODEL CAI04



DELR: 0.0005 KM
SOURCE PEAK FREQUENCY: 100 HZ (PLSWID = 6.5746)
WATER WAVELENGTHS (1.5/FPEAK): 15M
GRIDPOINTS/WAVELENGTH: 30 for P-WAVES IN WATER
STABILITY: {DELT = 0.0001} < {DELR/(SQRT(2)*VPMAX) = 0.00021}
DURATION = {KK = 20,000}*DELT = 2.0 SEC
RECEIVER LOCATIONS: N=132: M=1, 601,10

Figure 10. Example of the **CAI04.BCH** file.

```
$!
$!     Command file to run 2D finite differences programs
$!     10 May 1990
$!
$  SET VERIFY
$!
$!     Define directories
$!
$  DEFINE BNY   PR19_DISK:[STEPHEN.BENCH.FPS.BNY]
$  DEFINE CAI04 US47:[STEPHEN.BENCH.CAI01]
$  DEFINE DIFF  PR19_DISK:[STEPHEN.BENCH.FPS.DIF]
$  DEFINE PREP  PR19_DISK:[STEPHEN.BENCH.VAX.PRP]
$!
$  PURGE
$!
$  ASSIGN CAI04:CAI04.PAR FOR055        !input parameter file
$  ASSIGN CAI04:CAI04.BNY FOR054        !output data file
$  RUN PREP:SCNTPREP
$!
$  COPY CAI04:*.FOR BNY:*.*
$  SET DEFAULT BNY
$  @CAI03BNY.LNK
$  SET DEFAULT CAI04
$  RUN BNY:CAI03BNY
$!
$  COPY CAI04:*.FOR DIFF:*.*
$  SET DEFAULT DIFF
$  @SCNTDIF.LNK
$  COPY SCNTDIF.IMG CAI04
$  SET DEFAULT CAI04
$  SH DEF
$  DIRS
$  SJE/ECHO
   ATT/W
   ACC :STEPHEN
   DELETE CAI04.LG4
   DELETE CAI04.TSP
   DELETE CAI04.TSV
   DELETE CAI04.TSH
   COPYIN/BIN SCNTDIF.IMG,SCNTDIF
   COPYIN CAI04.PAR,FTN055
   COPYIN CAI04.BNY,FTN054
   SCNTDIF
   DIR
   COPYOUT CAI04.LG4
```

```
   COPYOUT CAI04.TSV
   DET
   QUIT
$!
$  set noverify
$!
$  EXIT
$!
$! End of command file
$!
```

If the job has finished properly, snapshot and time series files should have appeared in your model directory. The **MDLID.LG4** file should contain run time information and may have error messages if the job stopped early. Andrea Caiti has experience plotting the time series files using a format similar to **SAFARI**. One set of snapshot files were plotted for Tuncay Akal (AKA02). These should be used in conjunction with the time series to get insight into the multi-pathing and scattering effects.

5. Examples

Preliminary models, addressing particular research issues at the Centre, were run for a number of investigators. The objective was to set up basic models that could be subsequently modified by individual investigators to meet their research needs. Most of these models were run on the **VAX8600/FPS264** because the **VAX9000** arrived only a month before the contract period finished. We discuss these models below. For convenience they are organized under the name of the investigator most closely related each study.

5a) Andrea Caiti

The first example considered was run for Andrea Caiti and represents a near bottom point source at 100Hz in shallow water over a sedimentary bottom consisting of two layers and a halfspace (Figure C-1). The model name is **CAI04. CAI04.PAR** is given in Figure 3 and **CAI04.BCH** is given in Figure 10. The values in the transition zone are defined using **CAI03BNY.FOR** and this is given in Figure C-2. Time series for the vertical particle velocity, horizontal particle velocity, and pressure for a horizontal line of receivers on the seafloor are shown in Figure C-3.

The second example, **CAI05**, is the same as **CAI04** but the source frequency has been changed to 10Hz. The time series results are shown in Figure C-4.

For comparison, Figure C-5 shows examples of the field data that Andrea is studying. The major phases (direct water wave, water wave multiples, Stoneley wave and higher order Stoneley waves) are present in both the field data and synthetics. Note that the water waves are not supported by the shallow wave guide in the low frequency case. Also note that since the code is solving the line source problem body wave amplitudes in the synthetics decay as (1./SQRT(R)) rather than (1/R) for the point source used in the field. (A two dimensional code in cylindrical co-ordinates, which does not have this problem, is available but is not yet implemented at SACLANTCEN.)

CAI01 was a preliminary test model for a 100Hz source in shallow water (65m) over a homogeneous sediment (V_p=1.7k/s, V_s=0.45k/s and density=1.42gm/cc) out to ranges of 300m for a duration of 0.2sec. **CAI02** was the same as **CAI01** but with a shear velocity in the sediment of 0.18k/s, which was more representative of sediments in Andrea's test area. **CAI03** was the same as

CAI02 but had a layered bottom with parameters corresponding to Andrea's test area. **CAI04** was the same as **CAI03** but was run to 2.0sec duration to show the Stoneley wave better. **CAI05** was the same as **CAI04** but for a 10Hz source. **CAI09** was the same as **CAI02** (soft, homogeneous bottom) but for a 10Hz source.

CAI06 was a homogeneous water model with the same source/receiver geometry as the previous runs. **CAI06** was run to determine the far-field source strength in homogeneous water for the 100Hz case and to check the amplitude decay with range. **CAI07** was a similar normalization test for a broadband pulse from 10 -100Hz. This source could be used to combine the low and high frequency effects (**CAI04** and **CAI05**) in the same model. This study was not finished.

CAI10 and **CAI11** were hard, homogeneous bottom examples (shear velocity in the bottom higher than water velocity, V_p=4.0k/s, V_s=2.3k/s and density=2.3gm/cc) with the same source/ receiver geometry as **CAI01** for 100Hz and 10Hz sources respectively. They demonstrate the change in behaviour of the Stoneley and pseudo-Rayleigh waves for hard bottoms.

CAI08 was a hard, homogeneous bottom test for a 10Hz source in a 100m channel for comparison with some results from WHOI. CAI12 was the same as **CAI08** but the top free surface was replaced with a plane of symmetry. **CAI08** and **CAI12** had receivers on the top surface. **CAI13** was the same as **CAI12** for receivers on the seafloor.

On-going work in this 'Caiti' area involved running a standard flat model with both **SAFARI** and **SCNTDIF** for comparison. Also the flat model could be further refined to agree better with the field data. Andrea had computed dispersion plots (group velocity versus frequency) to help in this area. Ultimately the study would include range dependent structure, such as bathymetry or volume heterogeneities in the sediment.

5b) Tuncay Akal

The work with Tuncay Akal was similar to the work with Andrea Caiti. In Tuncay's case the frequency was 100Hz but the water depth was only 18m and there were eight layers in the sub-bottom. **AKA01** had the source midway in the water column and **AKA02** had the source 0.5m above the seafloor. **AKA02** was used as a test model for plotting the divergence and curl snapshots. The snapshot plots look fine and it is highly recommended that these be plotted and used for interpretation.

5c) Jens Hovem

One model was run for Jens Hovem (**HOV01**) to study tunnelling effects, interface waves and shear waves in thin, soft sediment layers over-lying hard basalt. This model is similar to the Caiti and Akal models in that it uses a pulsed point source in the water over a stratified bottom and a horizontal line of recievers. It has a thick water layer to avoid interference of the free surface reflection with the bottom interacting path.

5d) Dale Ellis

One model was also run for Dale Ellis (**ELL01**) to study the effects of backscattering from rough seafloors to a vertical array. This model set the stage for summer work by Nicolas Kampanis which is outlined in the report, "Bottom backscattering calculations using a time-domain finite-difference code for the elastic wave equation - by Kampanis, N.A., Ellis, D.D. and Stephen, R.A."

5e) Dan Lott

The work for Dan Lott focussed on comparing the response of the seafloor to omni-directional point sources (explosions) and vector point forces (weight drops). The code was modified to handle the point force as an option. We used the same bottom model as in **AKA01**. **LOT01** is a point force applied in the sediment. **LOT02** is an omni-directional point source applied in the sediment. **LOT03** is a point force applied on the surface of the sediment. In all cases the time dependence is a 100Hz Gaussian pulse.

5f) John Preston

Models were set up for John Preston in his work area on the **VAX9000** to study basin reverberation.

6. Computation Time

Table 1 summarizes some typical run times for **SCNTDIF** on the **FPS264**. Computation time is dependent on the number of range points (MM), the number of depth points (NN), the number of time points (KK), and the width of the transition zone region (NB-NA+1). Roughly speaking the time in microminutes for a job is 0.2*(NN+NB-NA+1)*MM*KK.

Table 1: Typical Run Times for the **SCNTDIF** code on the **VAX8600/FPS264** at SACLANTCEN (These are elapsed times and will vary for a particular job depending on the load on the system.)

Model Name	MM	NN	KK	NB-NA+1	ELAPSED TIME	ELAPSED TIME	FORMULA TIME
AKA01	601	401	20,001	45	16h52m	1,012m	1,072m
CAI01	601	401	2,001	103	03h09m	189m	121m
CAI04	601	401	20,001	23	20h31m	1,231m	1,019m
ELL01	601	501	2,501	31	01h50m	110m	160m
CAI08	601	401	2,001	2	01h31m	90m	97m
HOV01	1001	801	12,001	39	2d04h16m	3,136m*	2,018m

(* - this job was running on the FPS260 with many other jobs.)

Run times on the **VAX9000**, in scalar mode, are about a factor of three less than on the **FPS264.** The code as currently configured runs in about the same time in scalar and vector modes on the **VAX9000.**

7. Recommended Modifications

There are a number of modifications that would make **SCNTDIF** more useful for some projects at SACLANTCEN:

a) Adding the capability to treat a cylindrical coordinate geometry;
b) Adding intrinsic attenuation;
c) Adding a broader bandwidth source;
d) Putting a point force in the **VAX9000** code;
e) Putting an absorbing boundary on the left hand side of the Cartesian coordinate system code.

8. References

Hunt,M.M. and Stephen,R.A.,1986,WHOI-4-86.
Levander,A.R.,1985,Bull.Seism.Soc.Am.,**75**,1847-1852.
Nicoletis,L.M.,1981,PhD Thesis, U of Paris VI.
Stephen,R.A.,1983,Geophys.J.R.astr.Soc.,**72**,39-58.
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Stephen,R.A.,1988a,J.Geophys.Res.,**93**,6571-6584.
Stephen,R.A.,1988b,Rev.Geophys.,**26**,445-458.
Stephen,R.A.,1990,J.acoust.Soc.Am.,**87**,1527-1534.
Stephen,R.A. et al,1985,Geophysics,**50**,1588-1609.
Virieux,J.,1986,Geophysics,**51**,889-901.

FIGURE C-1:

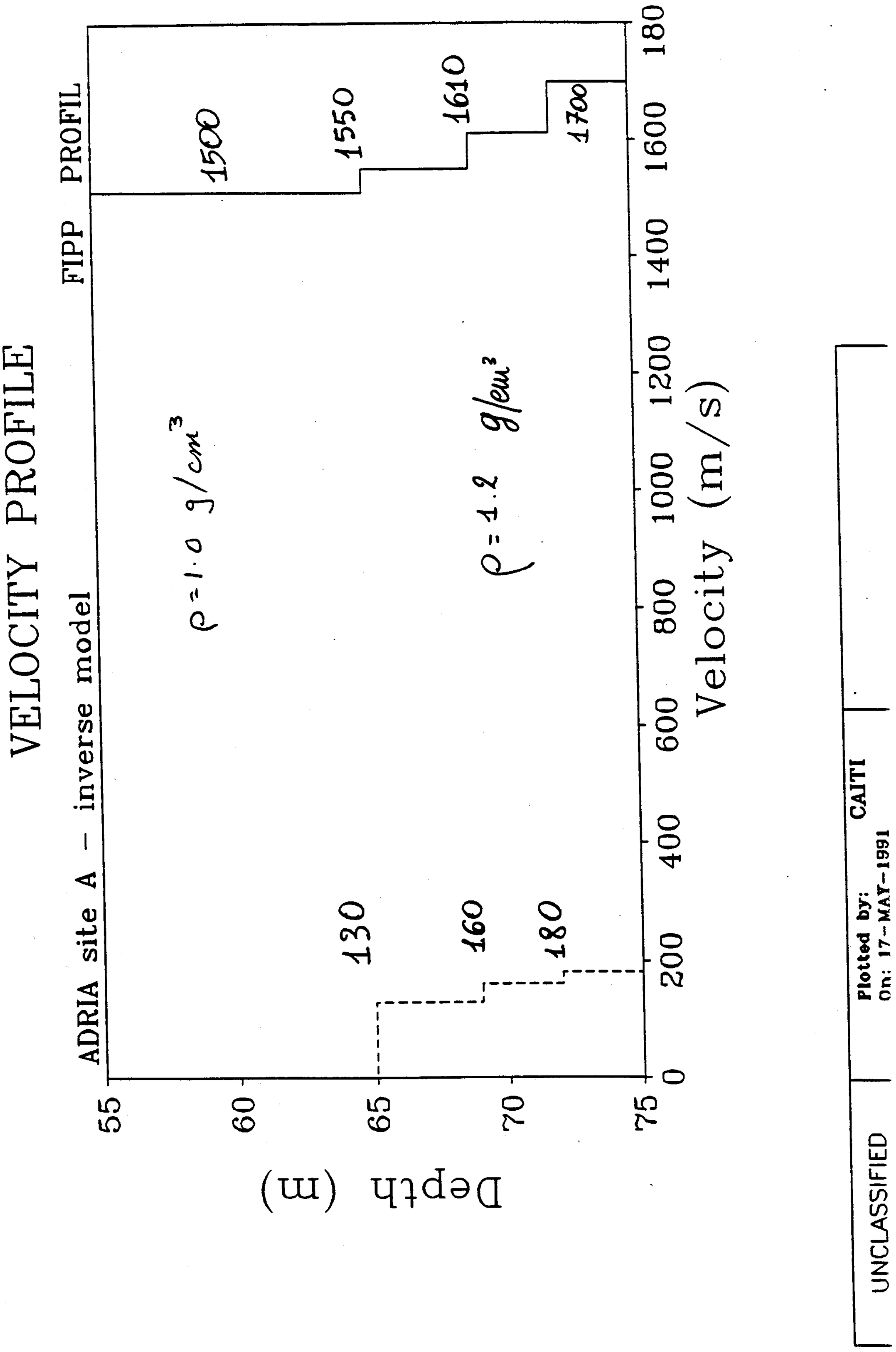

VELOCITY PROFILE
ADRIA site A – inverse model
FIPP PROFIL
Velocity (m/s)
0
200
400
600
800
1000
1200
1400
1600
1800
Depth (m)
55
60
65
70
75
1500
1550
1610
1700
130
160
180
$\rho = 1.0$ g/cm^3
$\rho = 1.2$ g/cm^3
Plotted by: CAITI
On: 17-MAY-1991
UNCLASSIFIED

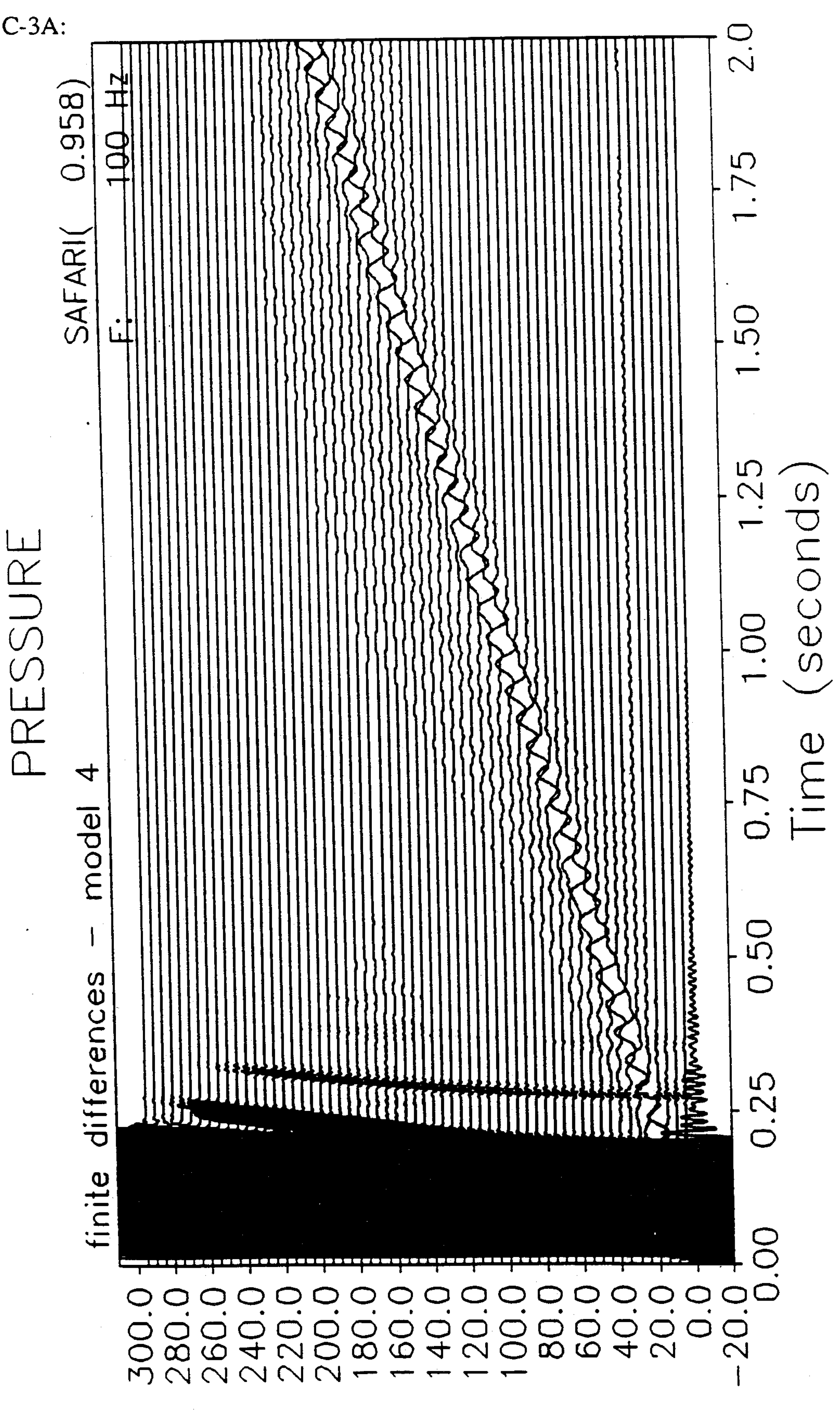
FIGURE C-2: CAI03BNY.FOR

```
C           PROGRAM CAI03BNY.FOR
C
C           FDBNY       JULY 9, 1983
        PROGRAM FDBNY
C
C           COPYRIGHT WOODS HOLE OCEANOGRAPHIC INSTITUTION 1988
C           ALL RIGHTS RESERVED
C
C           ORIGINAL VERSION 1 SEPT 1980
C               BY RALPH STEPHEN
C
C       SETS UP TRANSITION ZONE VELOCITY STRUCTURE FOR FINDIF8
C
C       RETURNS MATRICES OF P- AND S- VELOCITY SQUARED AND DENSITY FOR
C           THE MODEL GIVEN.
C       THE DIMENSIONS ARE MM AND NBNDY  ( NBNDY=NB-NA+3).
C       THE TOP AND BOTTOM ROWS OF VP32 AND VS32 MUST BE VP1**2,  VS1**2
C       AND VP2**2 AND VS2**2 RESPECTIVELY.
C
C       COSMETIC SURGERY BY MARY HUNT, JUNE 1983
C
C  ************************
C
        INCLUDE 'SCOMFD8.FOR'
        INCLUDE 'SMODPAR.FOR'
        INCLUDE 'SIOUNIT.FOR'
C
        CHARACTER*5  FILEID
        CHARACTER*9  VERDAT
        CHARACTER*12 FILNAM
C
        DATA VERDAT  / ' 9-JUL-83' /
C
C    ************************
C
C               SET UP I/O UNIT NUMBERS
C
        LUINP = 55
        LUBNY = 54
        LULOG = 66
        LUTRM = 6
C
C               READ INPUT PARAMETERS, START LOG FILE.
C
        CALL RDMPAR ( LUINP, FILEID, 'FDBNY ' )
```

```
      CALL LOGOUT ( LULOG, FILEID, ‘FDBNY ‘, VERDAT )
C
C           START OUTPUT OF BOUNDARY FILE
C
      FILNAM = FILEID//’.BNY’
      OPEN ( UNIT=LUBNY,
     +        FILE = FILNAM,
     +        STATUS = ‘NEW’)
C
      WRITE (LUBNY,*)  IEXPL, IDENS, MM, NA, NB
      WRITE (LUBNY,*)  VP1, VS1, RO1, VP2, VS2, RO2
C
C           START COMPUTATIONS
C
      NBNDY = NB - NA + 3
      IF ( ITRAN .EQ. 1 .OR. ITRAN .EQ. 2 )  NBNDY = NBNDY - 1
      NBM1 = NBNDY - 1
      NBM2 = NBM1-1
      XNBM1 = NBM1
C
C           COMPUTATIONS FOR TWO HOMOGENEOUS LAYERS
C
      IF (VPT .EQ. 0.0) VPT=VP1
      IF (VST .EQ. 0.0) VST=VS1
      IF (ROT .EQ. 0.0) ROT=RO1
      DO 1 I=1,MM
         VP32(I,1)=VP1**2
         VP32(I,2)=VP1**2
         VP32(I,NBM1)=VP2**2
         VP32(I,NBNDY)=VP2**2
            IF (IDENS .EQ. 1) THEN
               RO3(I,1)=RO1
               RO3(I,2)=RO1
               RO3(I,NBM1)=RO2
               RO3(I,NBNDY)=RO2
            END IF
         VS32(I,1)=VS1**2
         VS32(I,2)=VS1**2
         VS32(I,NBM1)=VS2**2
         VS32(I,NBNDY)=VS2**2
  1   CONTINUE
C
      VPT2=1.61
      VST2=0.16
      ROT2=1.2
```

```
C
      VPT1=1.55
      VST1=0.13
      ROT1=1.2
C
      JST1=3
      JEN1=10
      JST2=11
      JEN2=16
C
      DO 801 I=1,MM
         DO 805 J=JST1,JEN1
            VP32(I,J)=VPT1**2
            VS32(I,J)=VST1**2
            RO3(I,J)=ROT1
 805     CONTINUE
         DO 806 J=JST2,JEN2
            VP32(I,J)=VPT2**2
            VS32(I,J)=VST2**2
            RO3(I,J)=ROT2
 806     CONTINUE
         DO 808 J=JEN2+1,NBM2
            VP32(I,J)=VP2**2
            VS32(I,J)=VS2**2
            RO3(I,J)=RO2
 808     CONTINUE
 801  CONTINUE
C
C           OUTPUT TO LOG FILE AND BOUNDARY FILE.
C
      ID = MM/10 + 1
      WRITE (LULOG,2000)  MM, ID, NBNDY
 2000    FORMAT ( 1X,’VP**2 IN TRANSITION ZONE,
     +                   (I,J), I = 1,’,I4,’,’,I3,’ J = 1,’, I4 )
      WRITE (LULOG,2010)  ( (VP32(I,J),I=1,MM,ID),J=1,NBNDY)
 2010    FORMAT ( 1X, 10F7.2 )
C
      WRITE (LUBNY,*)  VP32
      WRITE (LUBNY,*)  VS32
      IF (IDENS .EQ. 1)  WRITE (LUBNY,*)  RO3
C
      CLOSE (UNIT=LUBNY)
      CLOSE (UNIT = LULOG)
C
      STOP
      END
```

FIGURE C-3A:



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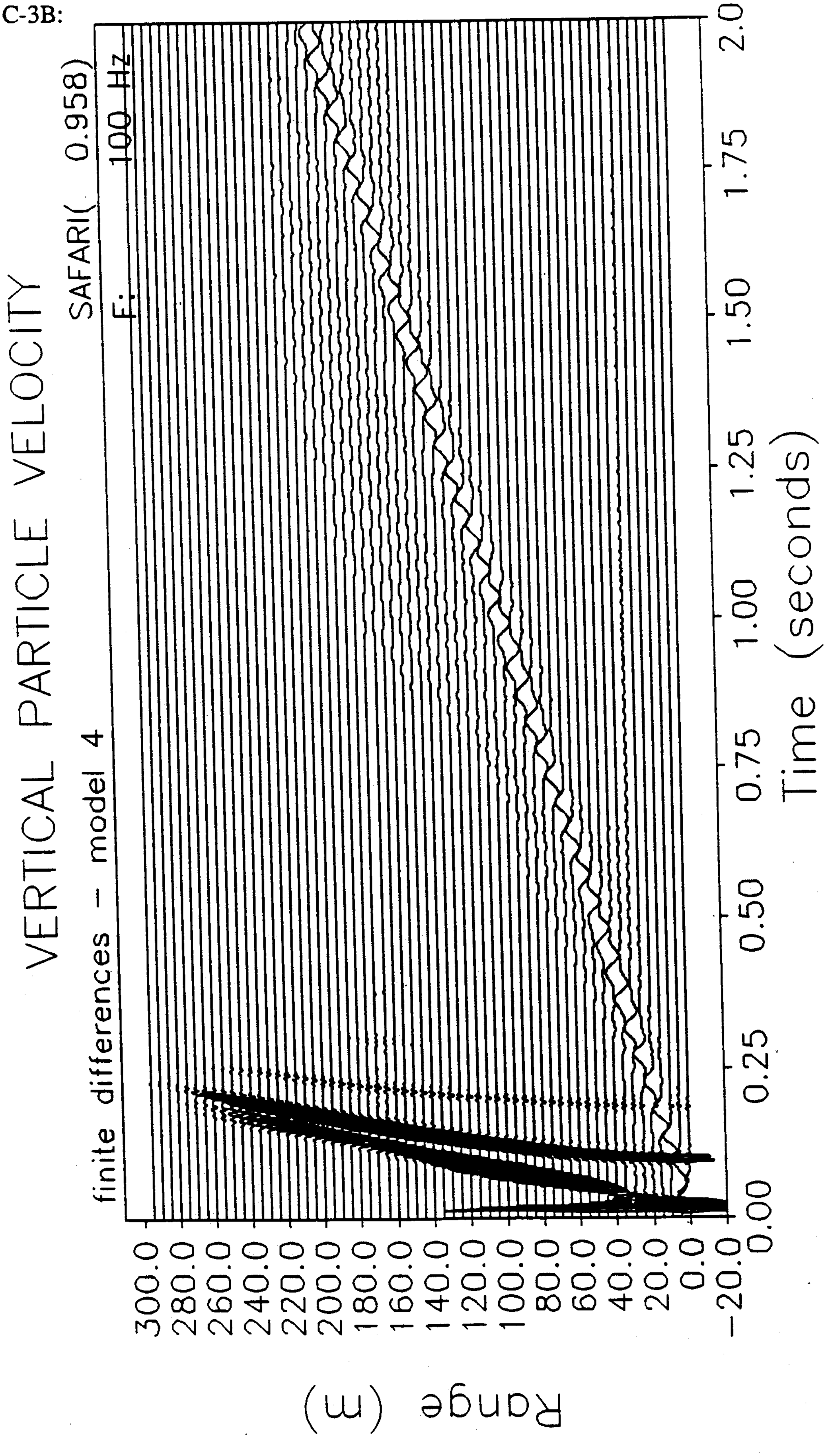
Plotted by: **CAITI**
On: 16-MAY-1991

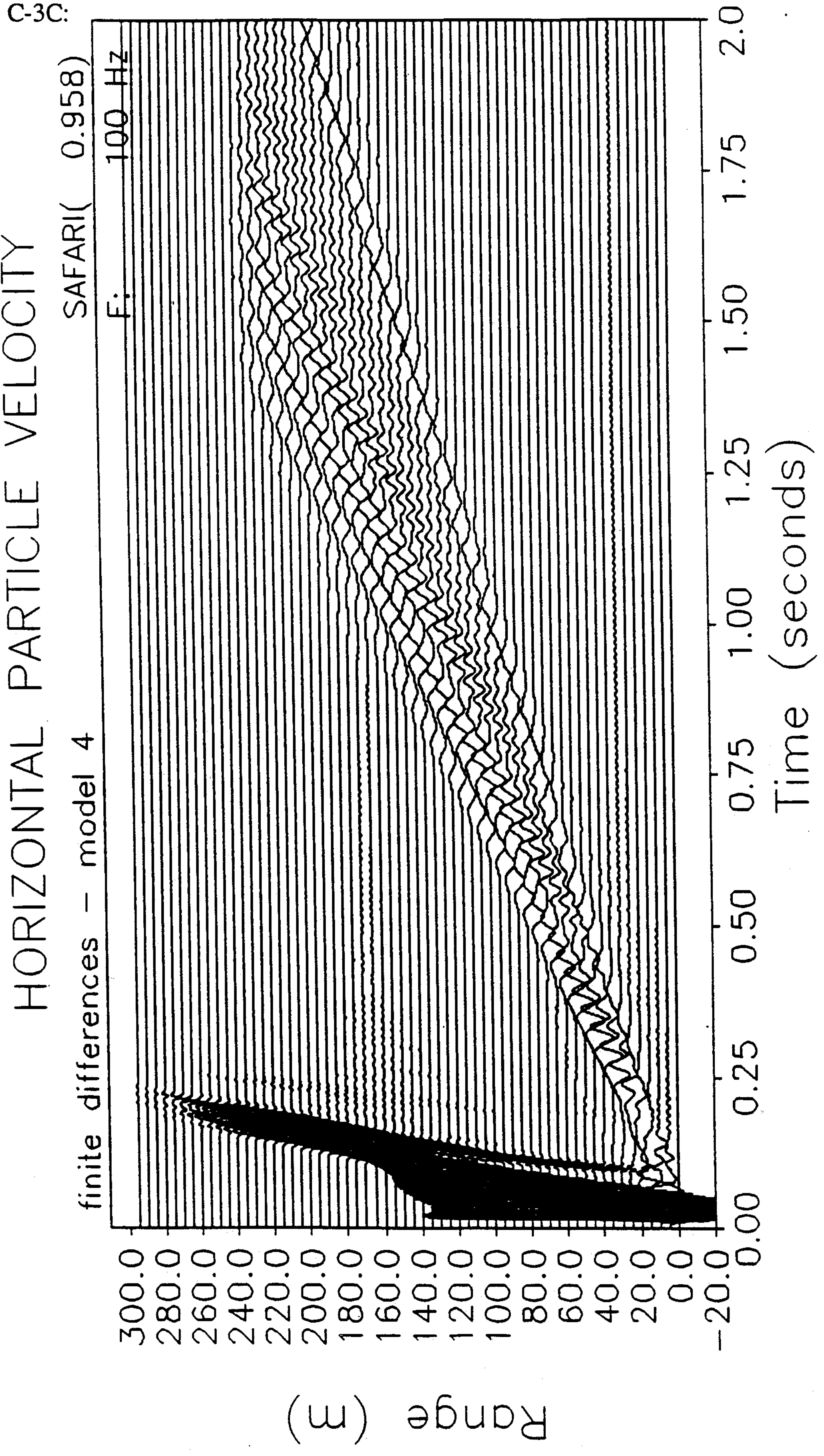
FIGURE C-3B:



UNCLASSIFIED

Plotted by: CAJTI
On: 15-MAY-1991

FIGURE C-3C:



UNCLASSIFIED

Plotted by: CAITI
On: 16-MAY-1991

FIGURE C-4A:

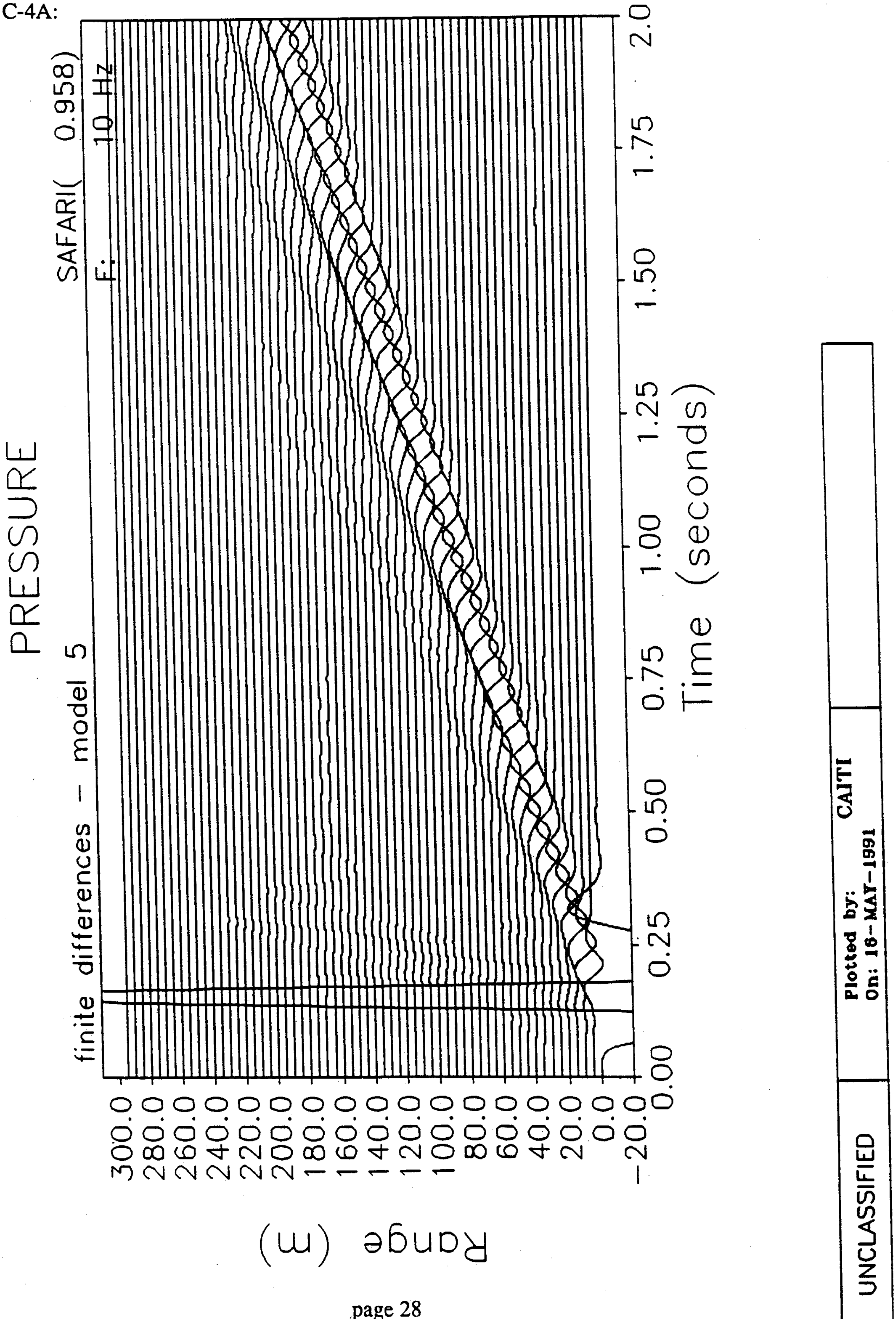
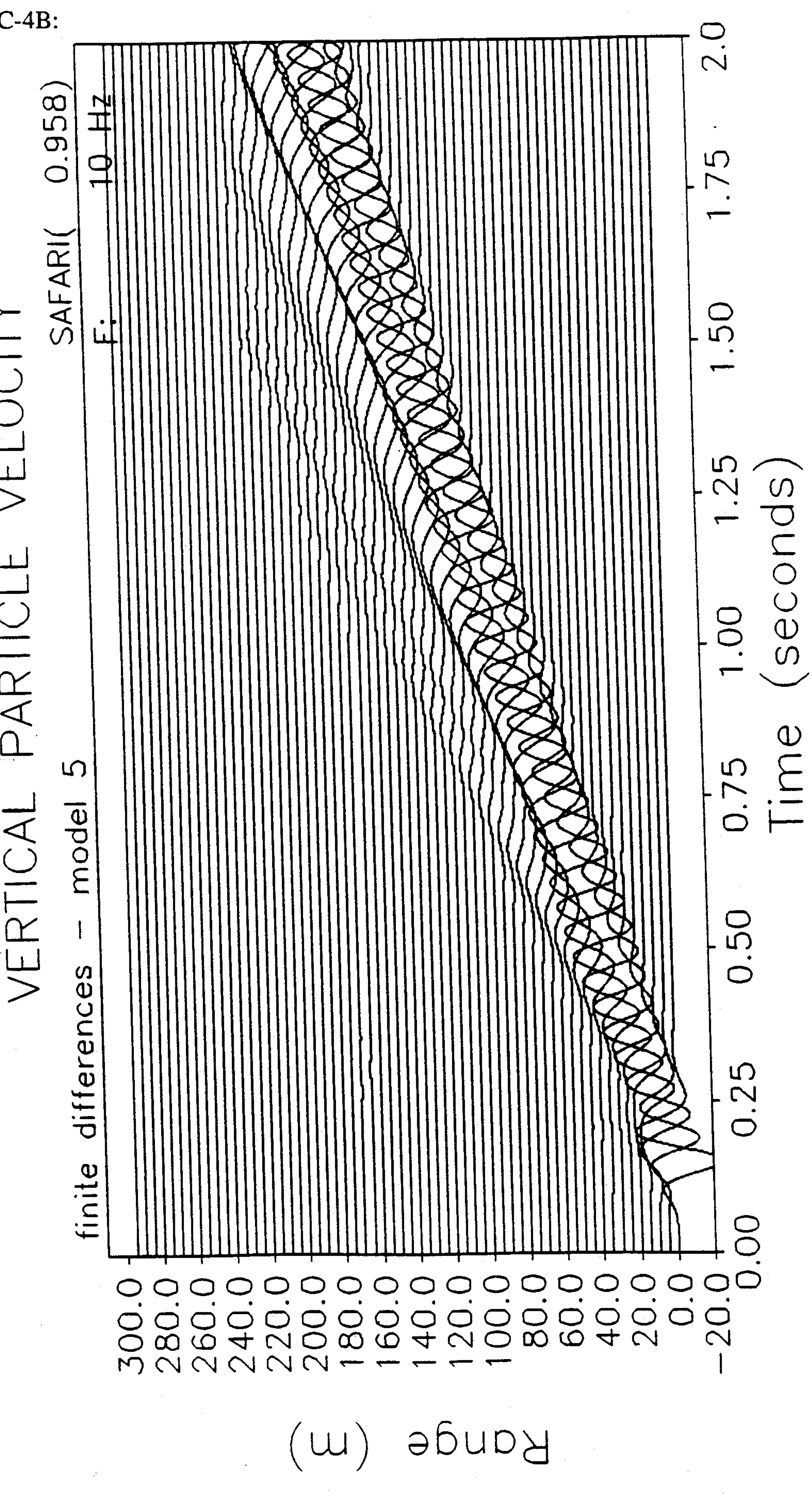
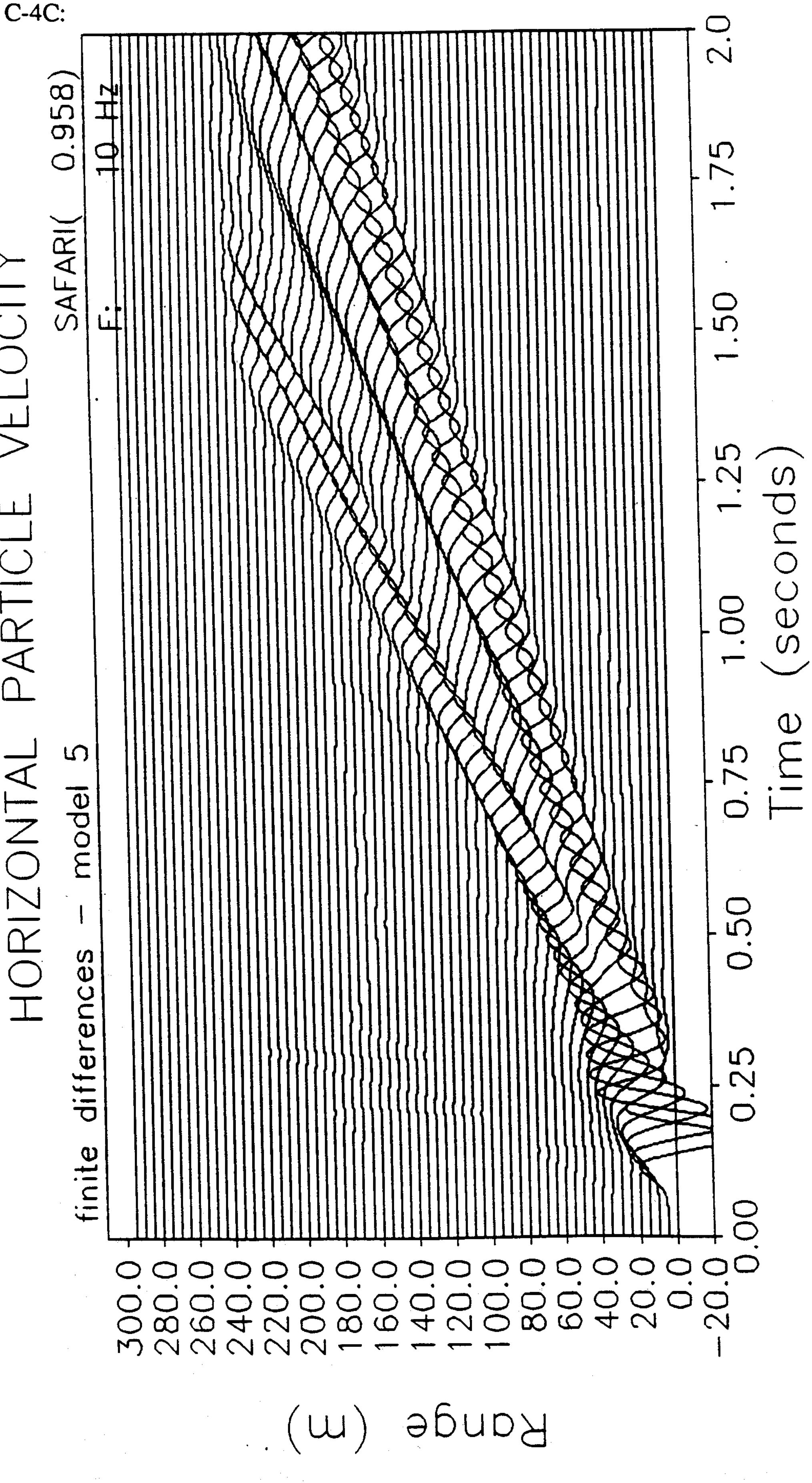

PRESSURE
finite differences - model 5
SAFARI(0.958)
F: 10 Hz
Range (m)
300.0
280.0
260.0
240.0
220.0
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
Time (seconds)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.0
Plotted by: CAITI
On: 16-MAY-1991
UNCLASSIFIED

FIGURE C-4B:



UNCLASSIFIED	**Plotted by:** CAITI **On: 15-MAY-1991**	

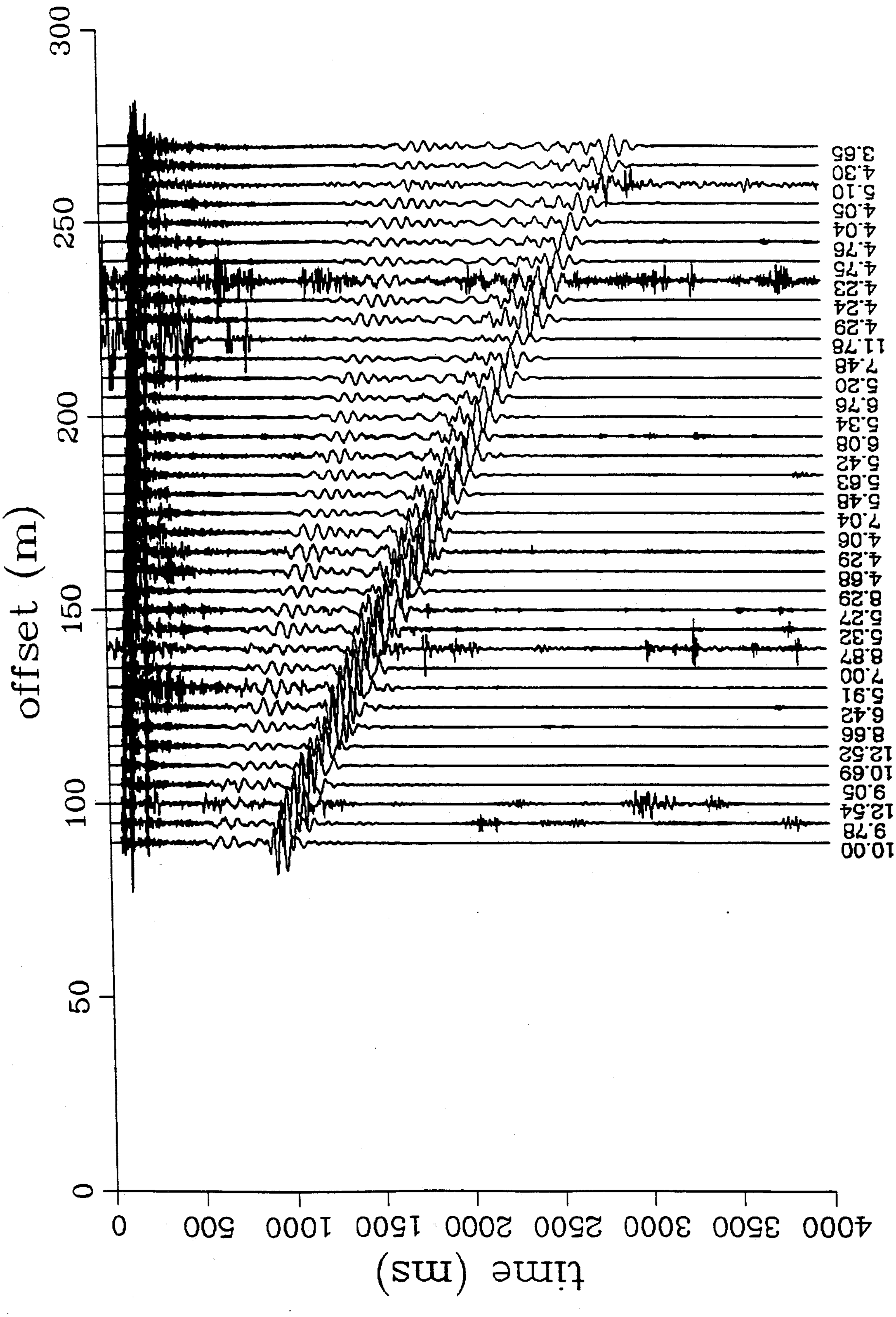
FIGURE C-4C:



UNCLASSIFIED

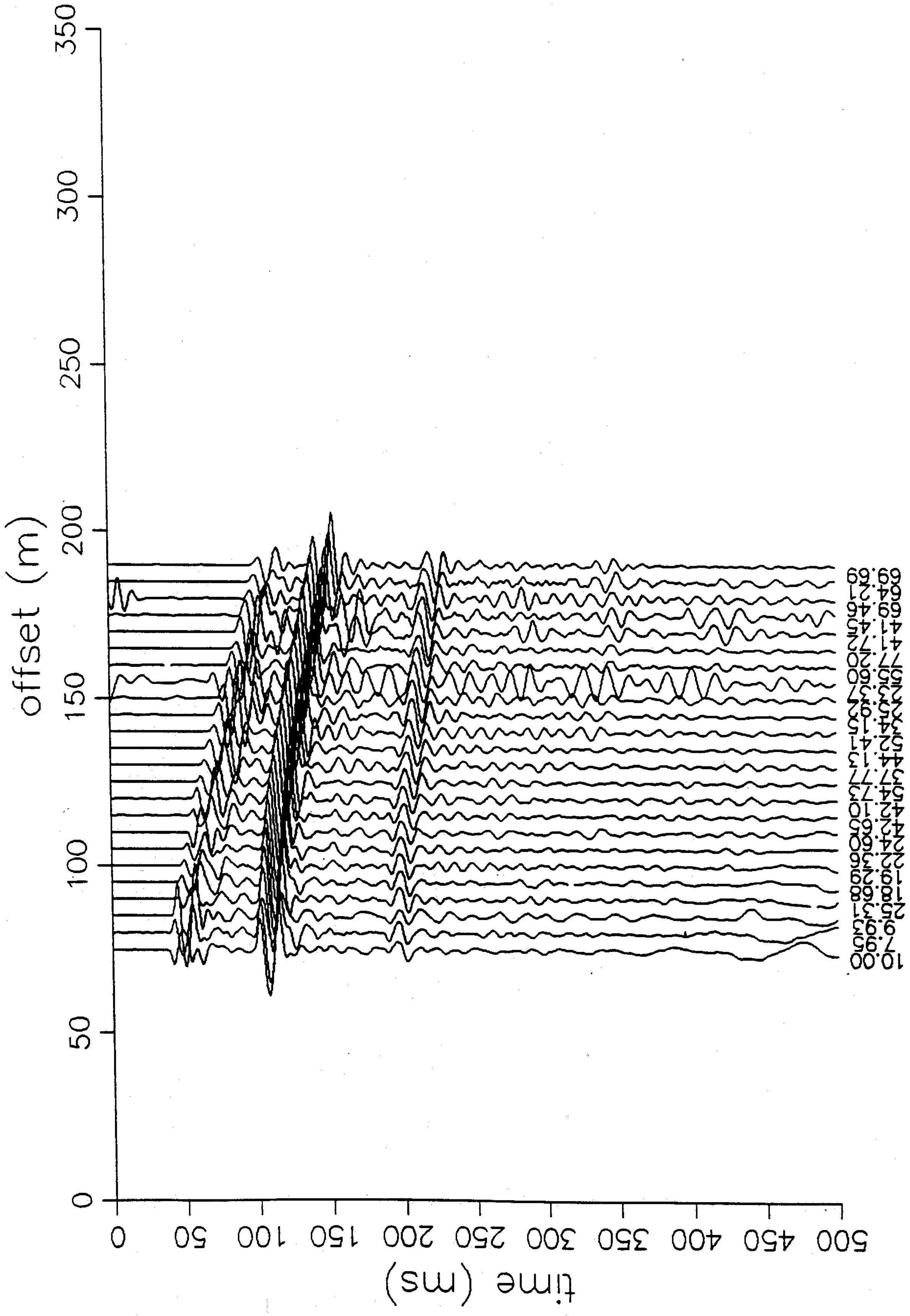
Plotted by: CAITI
On: 16-MAY-1991

FIGURE C-5A:



program: taup; 5-27-1990; 17:22:34
ADRIATIC - 1990 - SITE NEAR GAS WELL BARBARA
19my1953.dat, tcor= -7ms, xcor=-25m; 19my1334.dat, -7ms, -20m
recording gain, spherical divergence corrections applied

FIGURE C-5B:



program: taup; 11- 7-1990; 17:58:51
19my1949.dat, tcor= -9ms
spherical divergence correction applied