WINSASW VERSION 2.0

USER'S GUIDE

Data Interpretation and Analysis FOR SASW MEASUREMENTS

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DEPT. OF CIVIL ENGINEERING
CHUNG-ANG UNIVERSITY, ANSEONG, KOREA

Contents

1. Installation

WinSASW 2.0 is distributed with a mini-sized CD and a hardware lock key. The CD includes the installation files, example files of SASW measurements and a power point file to describe the theory of SASW method. To install WinSASW 2.0, the hardware lock-key should be plugged into the parallel port, and then click on the file `setup.exe` on the root directory of the CD.

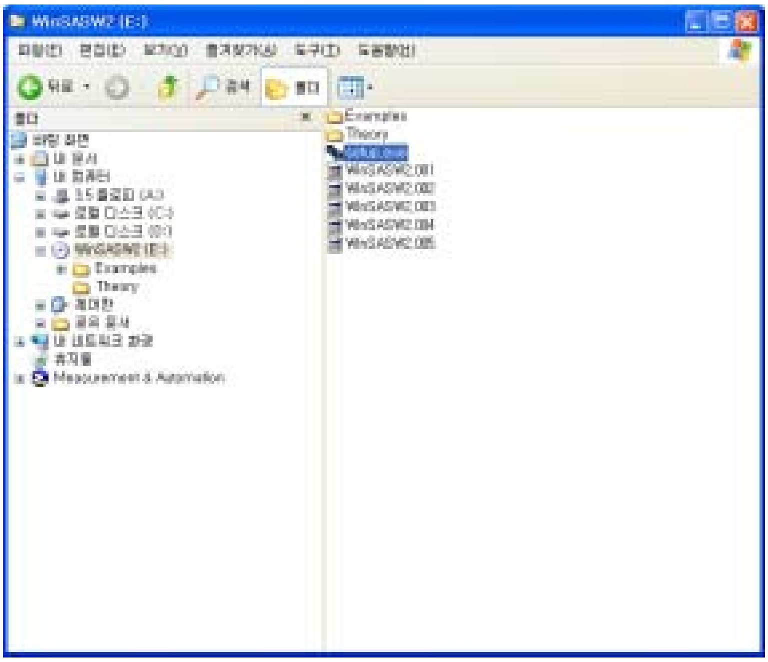


Fig. 1.1 Contents of WinSASW 2.0 CD

The first step of the installation is to set the directory of WinSASW 2.0, as shown in Fig. 1.2. It is recommended to take a default value given in the installation window.

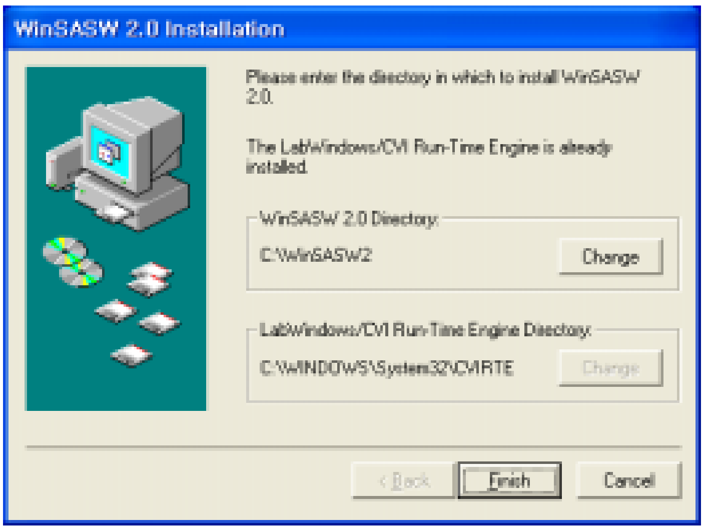


Fig. 1.2 The First Step of the Installation

When the installation of WinSASW 2.0 is finished, the system driver of the hardware lock key is installed. The installation of the system driver is guided by the installation wizard as shown in Fig. 1.3.

Fig. 1.3 The Installation Wizard of the System Driver for the Hardware Lock Key

WinSASW 2.0 checks the hardware lock key in running intermittently. The incomplete installation of the hardware lock-key system driver results in the halt of the WinSASW 2.0. It would be very important to plug in the hardware lock key and to install its system driver properly.

When all the installation procedure is completed, program in the `start` button shows the item of WinSASW 2.0. Now it is ready to run WinSASW 2.0.

2. Overview

2.1 Data Interpretation and Analysis

SASW testing has an objective to evaluate the shear-wave velocity profile of subsurface. In the field, the measurements acquire the site-specific phase spectra, which indicate the phase difference between two receivers for a series of steady-state stress wave with different frequencies.

The data interpretation and analysis of the measurements follows the procedure shown in Fig. 2.1. The raw data collected in the field are the phase spectra for a set of receiver spacings. Three major categories of the data interpretation and analysis are the interactive masking, the determination of the representative experimental dispersion curve and the inversion analysis.

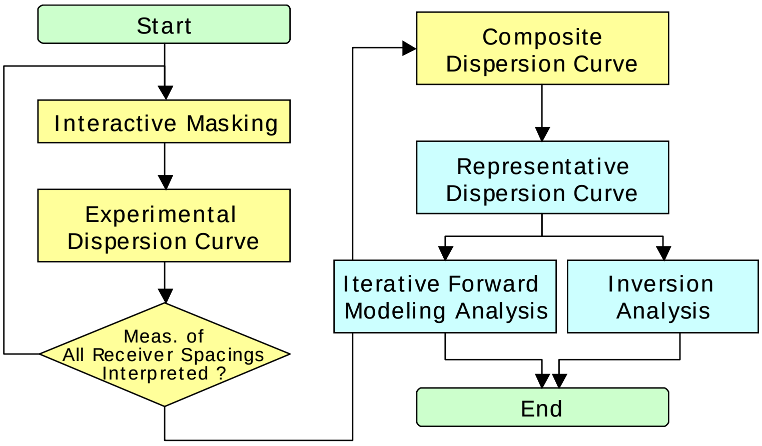


Fig. 2.1 Data Interpretation and Analysis Procedure of SASW Measurements

2.2 Description on Main Menu

The major procedures of the data interpretation and analysis are organized as items in the main menu. Figure 2.2 shows the menu `File`, which deals with the input and output operation. The measurement data in the text format (or ASCII format) can be loaded into WinSASW 2.0. The accepted data files are time histories, transfer functions, and cross power spectra. These data files can be two-channel data, or multi-channel data. Also, the case that the source is instrumented to enhance the signal quality can be handled. The details are described in Chapter 3.

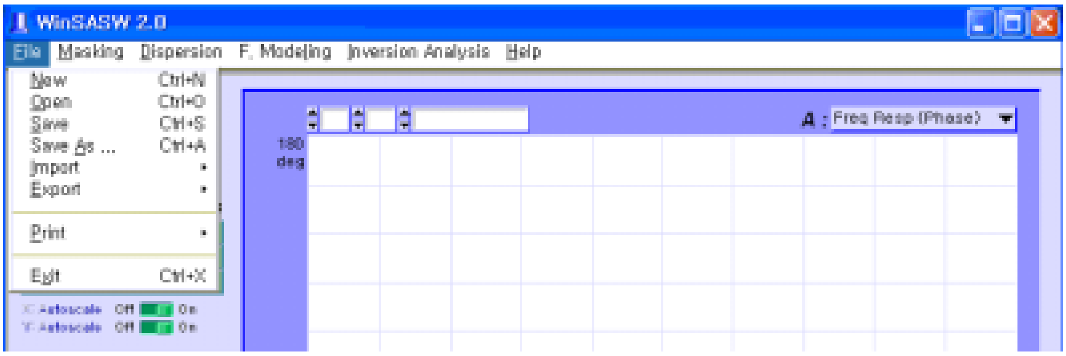


Fig. 2.2 The Menu `File` of WinSASW 2.0

The first step of the data interpretation and analysis is the interactive masking. The masking can be set using the menu item `Masking` of the main menu. To make a rational judgment in the masking, the Gabor spectrum can be used. More buttons and edit boxes are provided in the left panel of the measurement window. The details on the masking procedure are provided in Chapter 4.

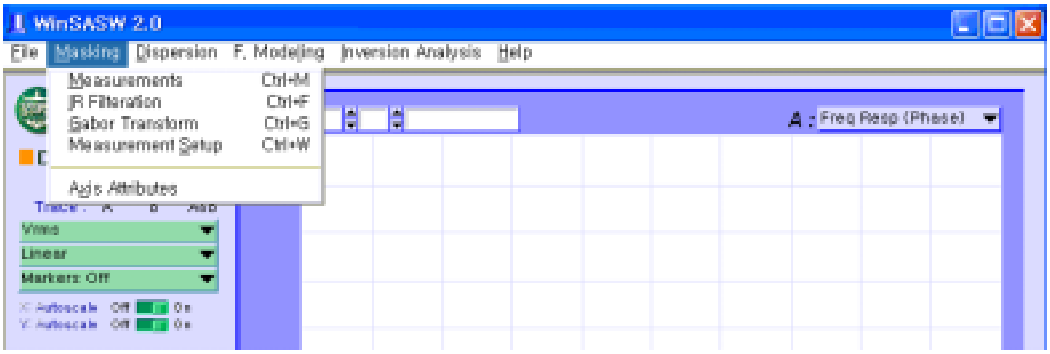


Fig. 2.3 The Menu `Masking` of WinSASW 2.0

After the experimental dispersion curves determined for all the different receiver spacings, the representative experimental dispersion curves should be determined for the inversion analysis. The inversion analysis adopted in WinSASW 2.0 requires both the global and array representative dispersion curve (Joh, 1996). The menu item in the `Dispersion` gives access to the function panel to build the representative curves.

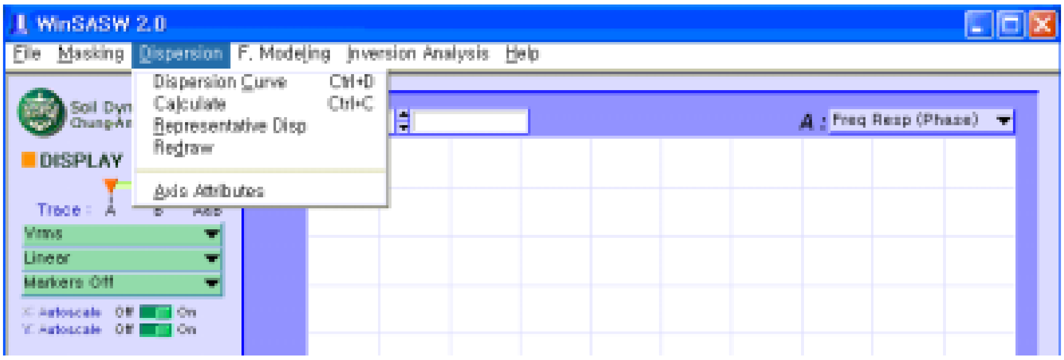


Fig. 2.4 The Menu `Dispersion` of WinSASW 2.0

Inside WinSASW 2.0, the modified version of `SASWFI` is included. The menu `F. Modeling` provides the feature to generate a 2-D, 3-D or enhanced 3-D theoretical dispersion curve for a given soil profile. The theoretical curve is calculated using the algorithm of the dynamic stiffness matrix method implemented in `SASWFI`.

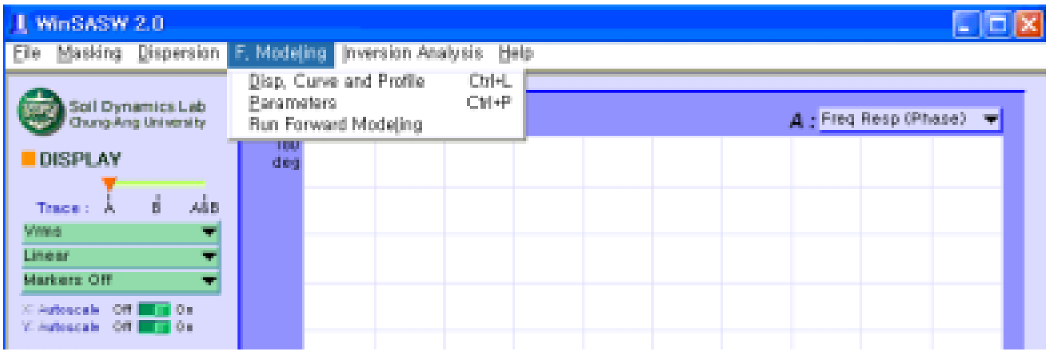


Fig. 2.5 The Menu `Forward Modeling` of WinSASW 2.0

The shear-wave velocity profile can be evaluated for the representative dispersion curve by the menu items in `Inversion Analysis`. The inversion is performed in one of two algorithms: Global or Array.

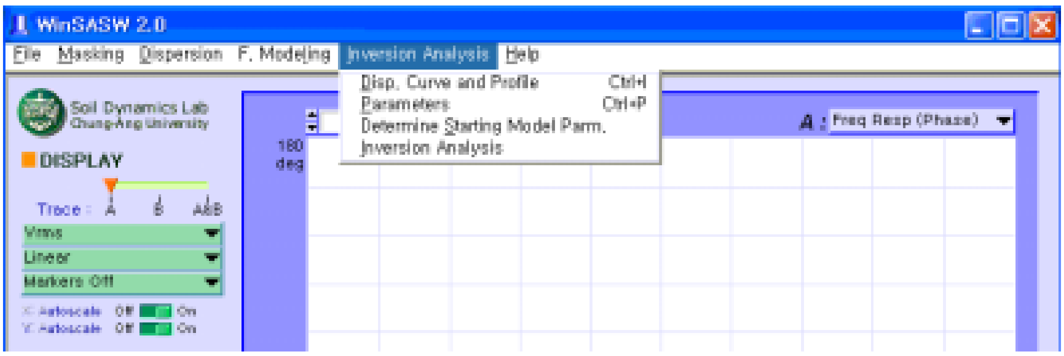


Fig. 2.6 The Menu `Inversion Analysis` of WinSASW 2.0

3. Load Measurement Data

3.1 ASCII Format Data

SASW measurements are usually performed with the aid of the dynamic signal analyzer. Most of the dynamic signal analyzer has a feature to store the acquired data in its own binary format or in a general text format (or ASCII format). WinSASW 2.0 requires the text-formatted data.

Figure 3.1 shows the menu item to load the ASCII-formatted data into WinSASW 2.0. When `ASCII Format Data` are selected, the dialog window in Fig. 3.2 is opened. Choosing the menu leads to the dialog box in Fig. 3.3.

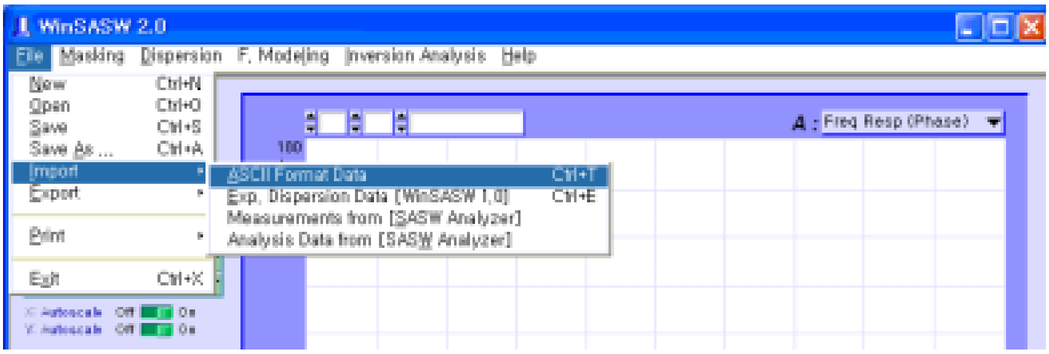


Fig. 3.1 The Menu Item `ASCII Format Data` of WinSASW 2.0

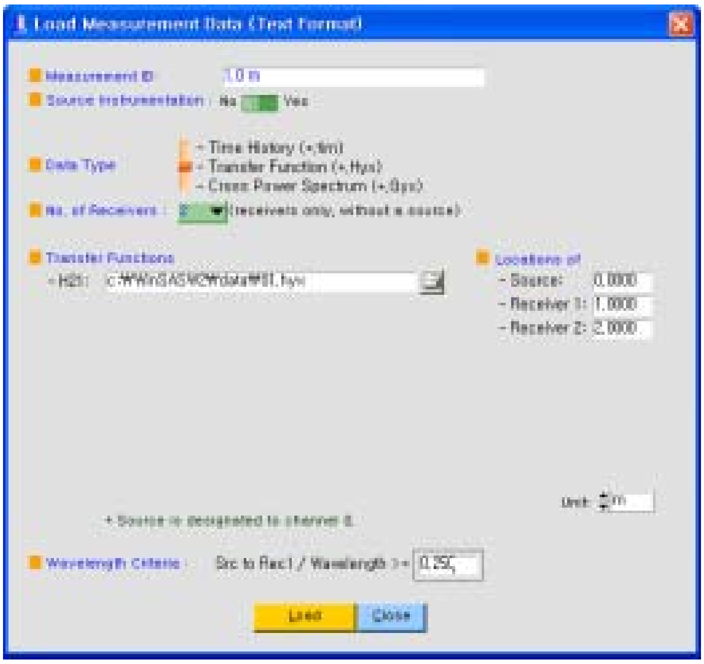


Fig. 3.2 The Menu Item `ASCII Format Data` of WinSASW 2.0

Measurement ID, data type, number of receivers, data file name, locations of source and receivers and the wavelength criteria should be given to load the data correctly. When the load of the data is properly done, the measurement window is refreshed with a newly loaded data as shown in Fig. 3.3.

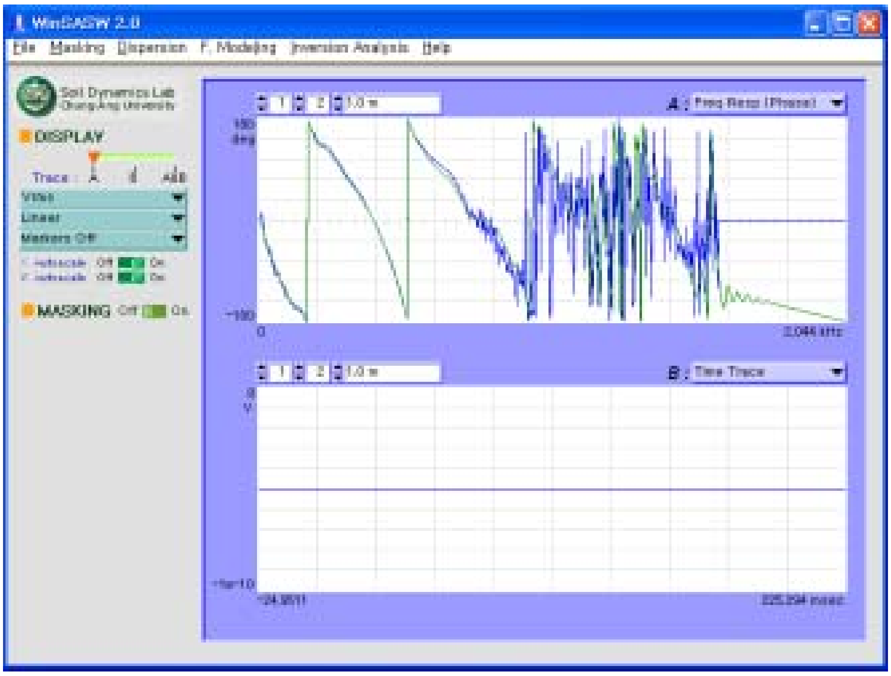


Fig. 3.3 The Menu Item `ASCII Format Data` of WinSASW 2.0

3.2 Experimental Dispersion Data from WinSASW 1.0

The experimental dispersion data stored in WinSASW version 1.0 can be loaded into WinSASW 2.0. The menu item `Exp. Dispersion Data [WinSASW 1.0]` is selected, or `control-E` is typed, the file-open dialog box is popped up. In the dialog box, if you specify the file name for the experimental dispersion data which has the extension "`*.exd`", the dispersion data are loaded and another dialog box is displayed in the center of the window to ask for the source and receiver locations, as shown in Fig. 3.5. It is required to give the source and receiver locations for all the measurements.

Now, when the dispersion curve is opened by choosing the menu item `dispersion curve` under `Dispersion` menu, the retrieved dispersion curve is displayed as in Fig. 3.6.

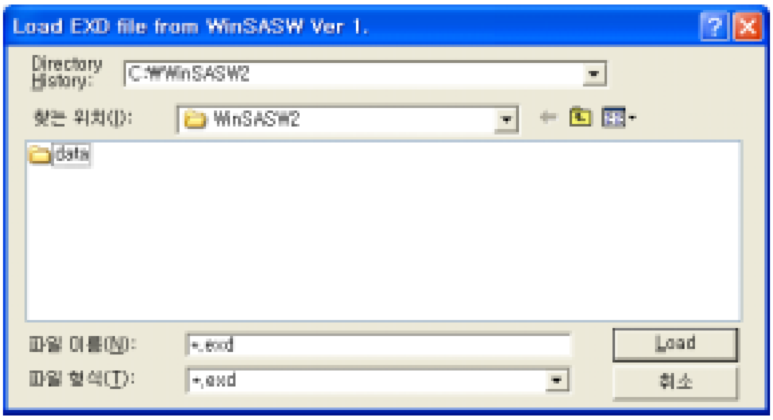


Fig. 3.4 Dialog Box to Specify the File to Contain Experimental Dispersion Data

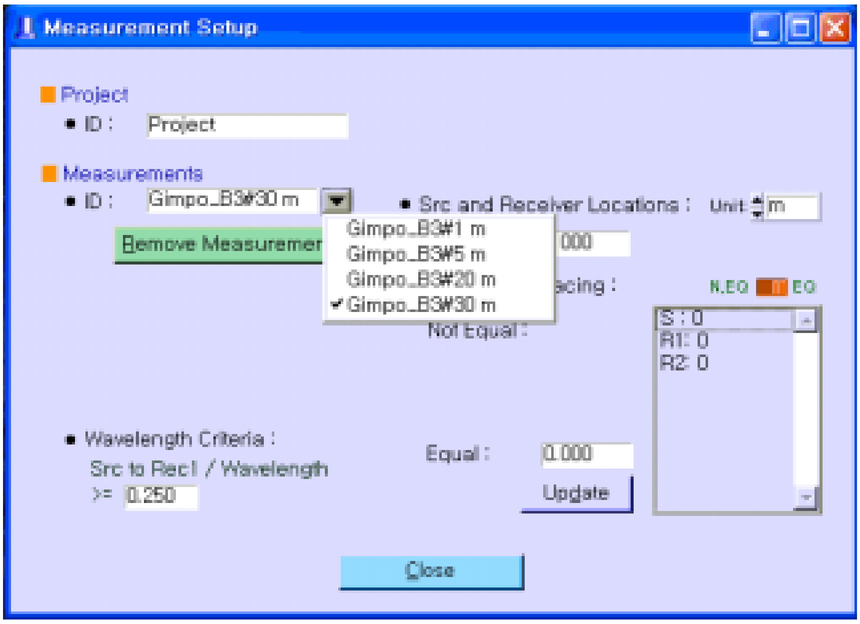


Fig. 3.5 Measurement Setup to Specify Source and Receiver Locations

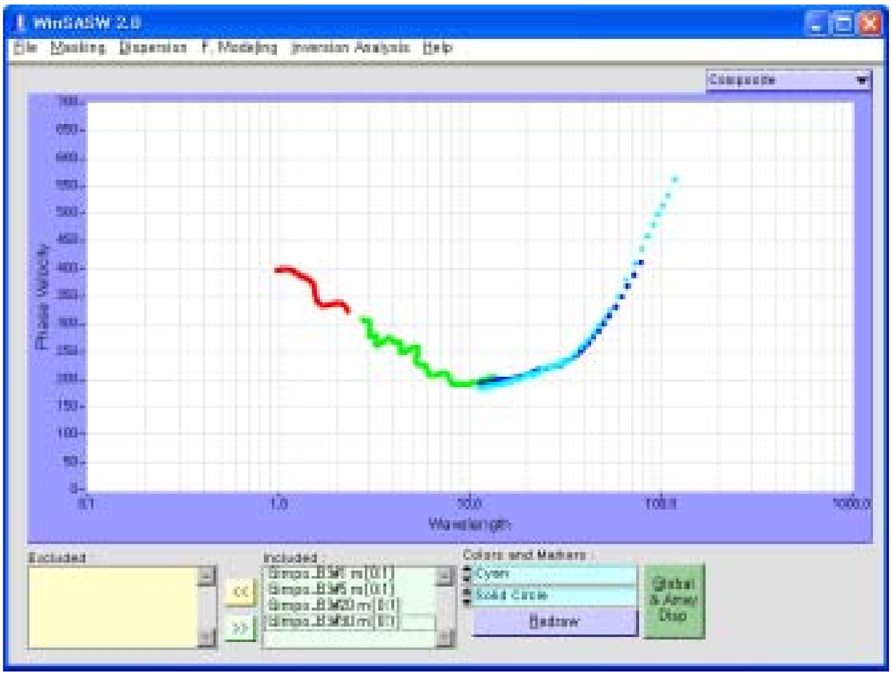


Fig. 3.6 The Existing Experimental Dispersion Curve Loaded into WinSASW 2.0

4. Interactive Masking

The interactive masking is the most important step in the data interpretation and analysis procedures. The masking procedure masks out the undesirable data and assign a proper jump number of the wrapped phase spectrum. The masked phase spectrum is unfolded to give a full-scale phase spectrum, which is used to calculate the phase velocities. The first step for the interactive masking is to turn on the masking mode by clicking on the switch by the text "`MASKING` " which is at the middle-left area of the measurement window. Turning on the masking mode activates the buttons and edit boxes for the masking task. To mask out the undesirable portion of the phase spectrum, click on the button marker selection. The marker selection button is showing "`Markers Off`" on Fig. 4.1. The marker selection button is a list control to give three different options. Selection of "`Dual Marker`" brings two different marker lines on the display of the phase spectrum. The magenta marker line is used to specify the initial frequency for the masking region, and the red marker line is for the final frequency. And the jump number should be given also. The number of jumps, where the phase angle changes from –180 degree to 180 degree, is counted from zero frequency to the final marker line. Sometimes when the measurement is mixed with a higher mode wave, the phase spectrum is messed up. In that case, the rational judgment should be incorporated to get the right number of jumps. When the marking of the masking region is properly specified, press the button "`New`" to register. Figure 4.1 is an example of the masked region.

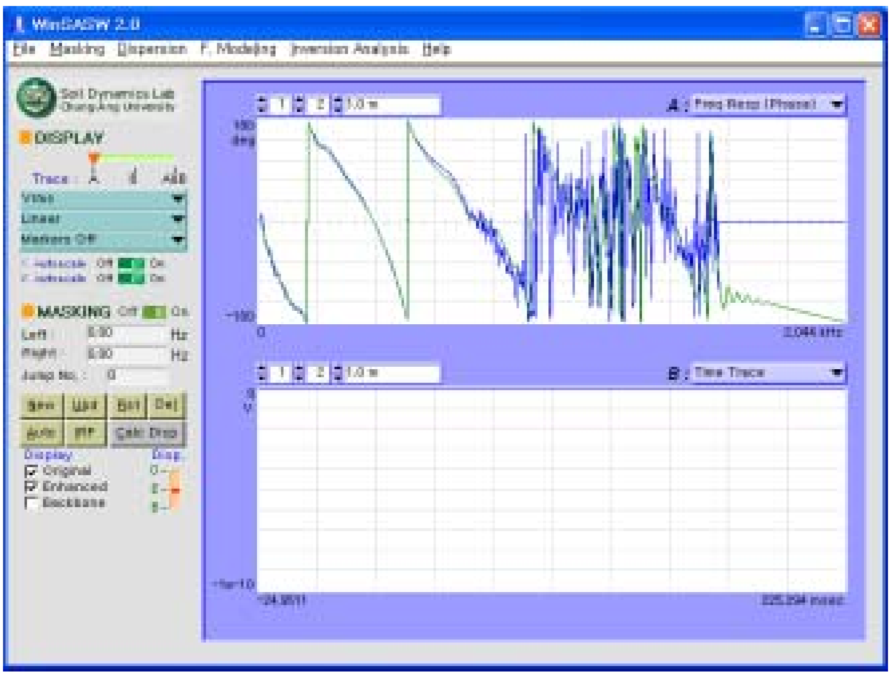


Fig. 4.1 The Masking Mode Turned on for the Interpretation of Phase Spectrum

Modification of the existing masking region can be done by the buttons `Upd` (update) and `Del` (delete). To get the information of the masked region, move the mouse pointer to the inside of the masked region and click on the right mouse button. The information of the masked region is displayed on the editor boxes on the left-center area of the measurement window.

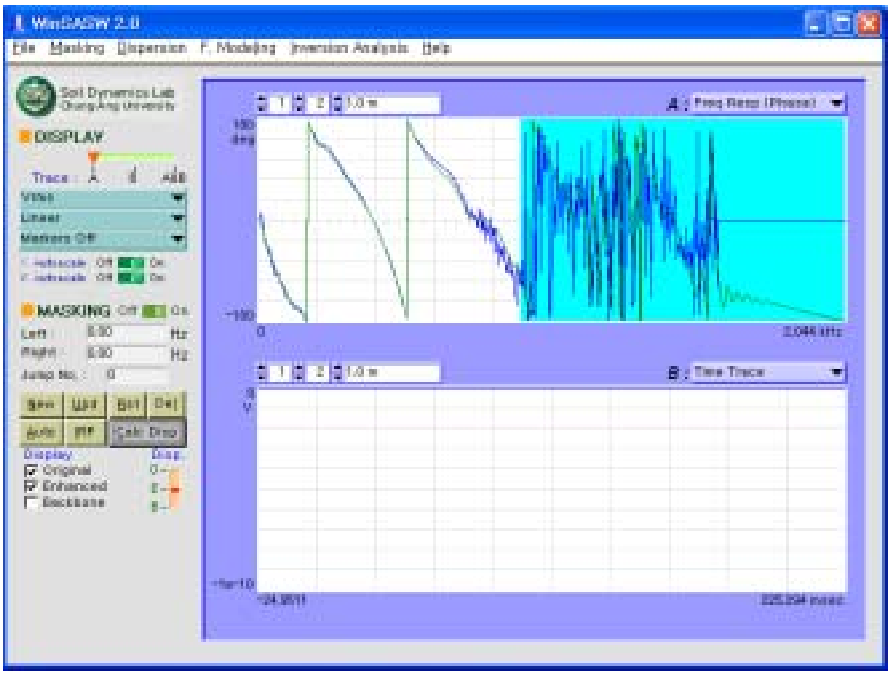


Fig. 4.2 Example of the Interactive Masking of the Phase Spectrum

The most difficult part in the interpretation and analysis of SASW measurements is to set the proper jump number. In the case the testing site is so complex, the governing mode is mixed with other higher modes, which introduces misleading jumps in the phase spectrum. In this situation, Gabor spectrum would be helpful to get rid of the misleading jumps and to make a rational judgment on the jump numbers. To utilize the feature of Gabor spectrum, first of all, click on the button “`Auto`” at the middle-left area of the measurement window. It will redo the masking tasks and refreshes the phase spectrum, as shown in Fig. 4.2. Gabor spectrum can be displayed by selecting Gabor spectrum at the list control on the display B (Fig. 4.3), and it can be used to get the right filter parameters for the impulse filtration. The impulse response filtration technique (IRF, Fig. 4.4) is used to enhance the phase spectrum and to get rid of the intervened higher mode components. For the detailed discussion on the IRF, refer to the dissertation of Dr. Joh (Joh, 1996).

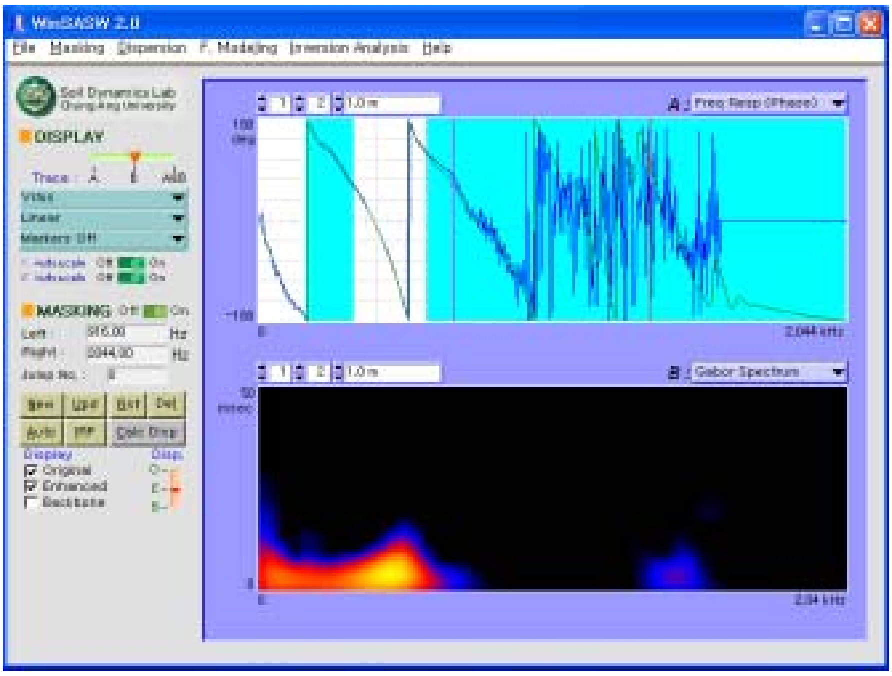


Fig. 4.3 Example of the Automatic Masking of the Phase Spectrum and Gabor Spectrum

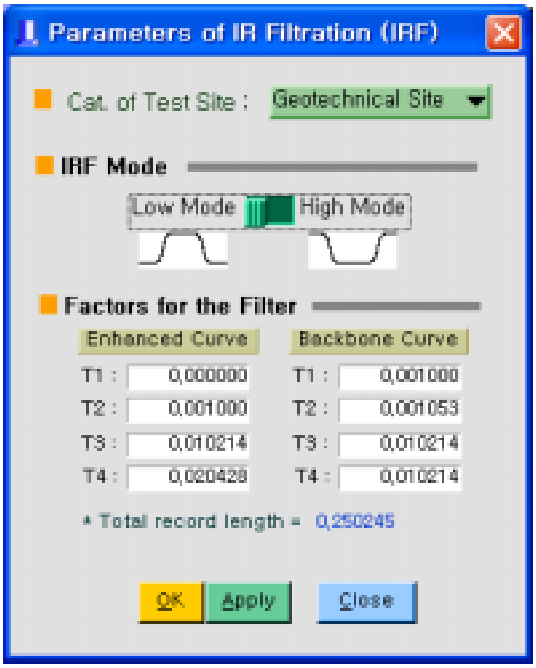


Fig. 4.4 Parameters of Impulse Filtration to Enhance the Phase Spectrum

Based on the IRF, the phase spectrum is finally interpreted as shown in Fig. 4.5, and the corresponding masking region is also shown together. The phase spectrum processed by the interactive masking is now used to calculate the phase velocities.

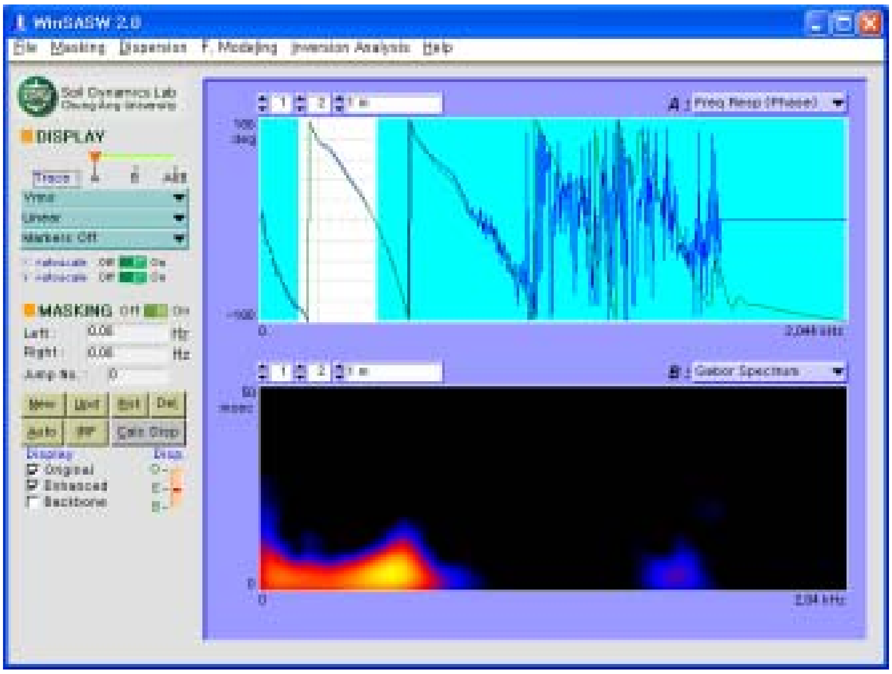


Fig. 4.5 The phase Spectrum Processed by the Interactive Masking and Prepared for the Calculation of Phase Velocities

5. Determination of Phase Velocity Dispersion Curve

The phase velocities for frequencies or wavelengths can be calculated by clicking on the button "`Calc Disp`" at the middle-left area. Figure 5.1 shows the calculated phase velocities from the phase spectrum shown in Fig. 4.5, which is determined for a receiver spacing of 1 m.

The relationships between wavelength (or frequency) and phase velocity is called a phase-velocity dispersion curve. When the dispersion curve is determined experimentally in the field, then it is called an experimental dispersion curve. Also, when a series of SASW measurements are performed using different receiver spacings, the dispersion curves for all the different receiver spacings are combined into one dispersion curve to give a complete dispersion curve for the given site. The combined experimental dispersion curve is called a composite experimental dispersion curve, as shown in Fig. 5.2.

Also, the plot of the experimental dispersion curve can be customized to give a different look. For the x-axis domain, frequency rather than wavelength can be employed. The minimum and maximum values of the x- and y-axis can be changed. Also, the logarithmic and the linear representation can be available by just one click. The change of the plot attributes can be done by the double click of the left mouse button at the inside of the graph.

Usually a composite experimental dispersion curve contains more than 1,000 data points in one plot. It is not good at all to use all the data in the composite curve for the inversion analysis to evaluate the shear-wave velocity dispersion curve. It is because the inversion analysis requires a lot of forward modeling, so it is too much time-consuming. Therefore, it is recommended to produce the representative curve of the composite experimental dispersion curve, which contains a lot less number of points in it. In WinSASW 2.0, two different types of the representative curves are required. One is the global dispersion curve as shown in Fig. 5.5, and the other is the array dispersion curve as shown in Fig. 5.6. Global dispersion curve is a dispersion curve to represent all the dispersion data in the composite experimental dispersion curves, and it does not consider the position of receivers used to measure the dispersion curve. On the other hand, the array dispersion curve is the combination of all the independent representative dispersion curves, which represent the individual experimental dispersion curve for each different receiver spacing. The array representative dispersion curve has an advantage to hold the source and receiver positions used to determine the individual experimental dispersion curve. The representative dispersion curves can be customized for the number of data points in the dispersion curve, the shape of the curve, the x-axis domain and etc. The parameters to determine the representative dispersion curves are listed and customized at the dialog box of Fig. 5.4.

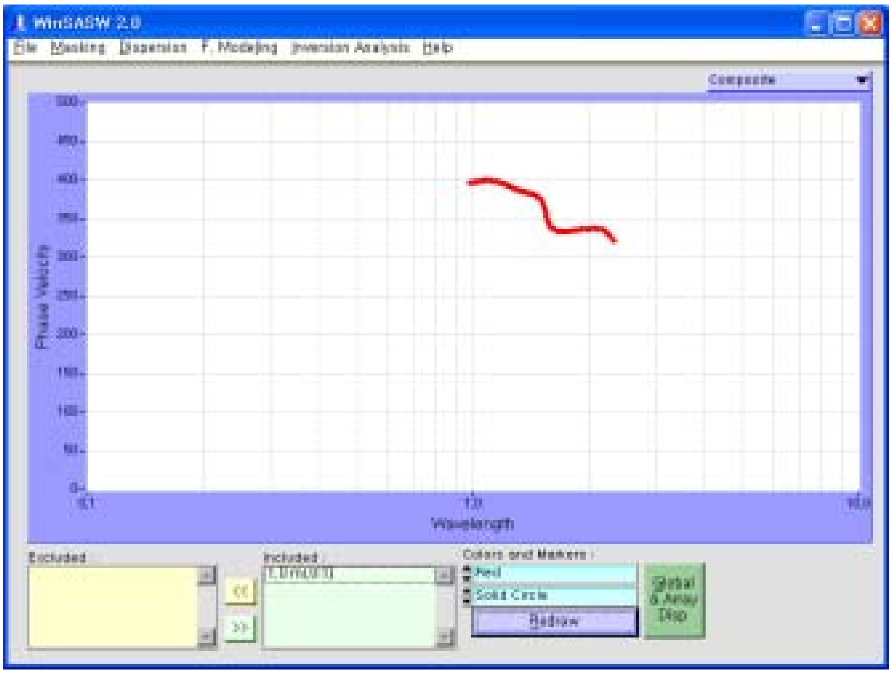


Fig. 5.1 Experimental Dispersion Curve for the Receiver Spacing of 1 m

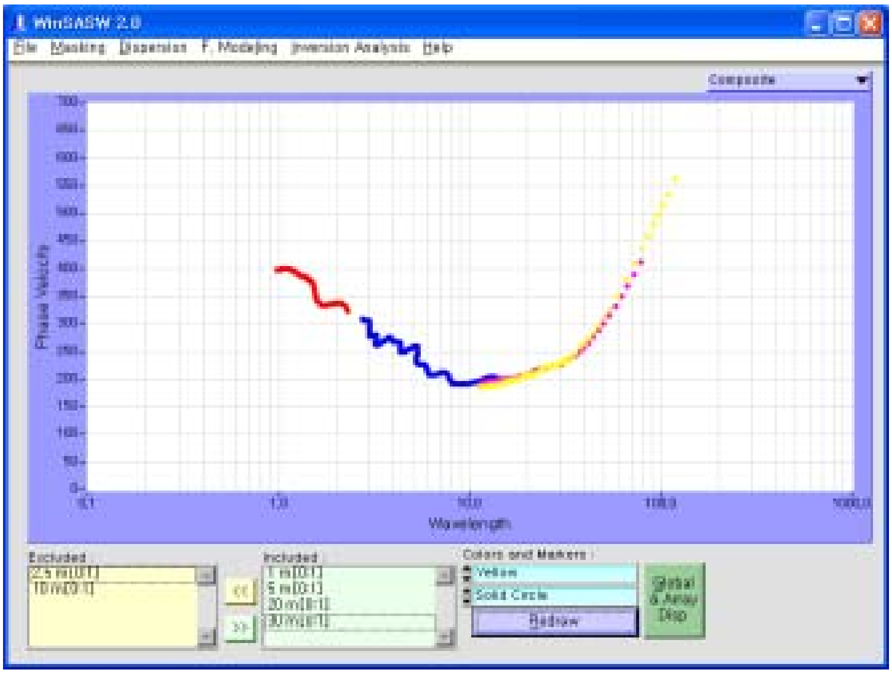


Fig. 5.2 Composite Experimental Dispersion Curve for the Receiver Spacings of 1, 5, 20 and 30 m

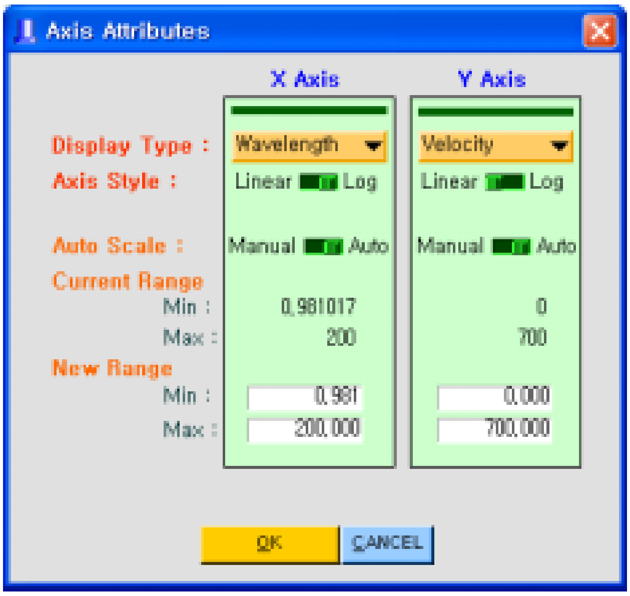


Fig. 5.3 The Change of the Attributes of a Dispersion Curve

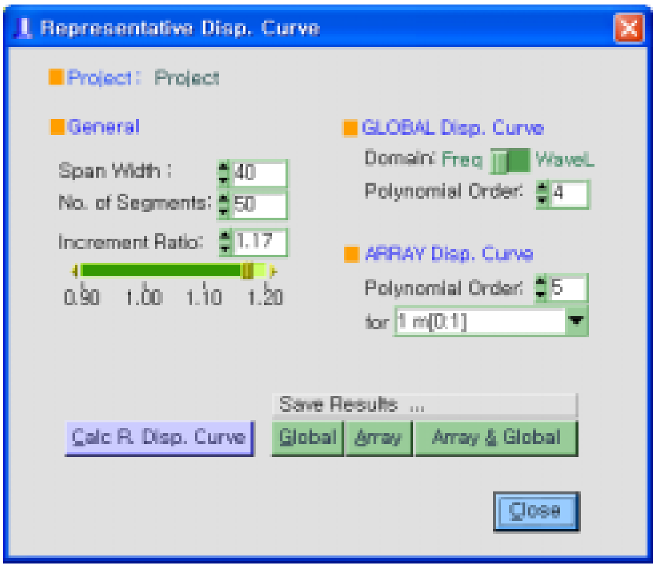


Fig. 5.4 Parameters to Determine the Representative Dispersion Curve

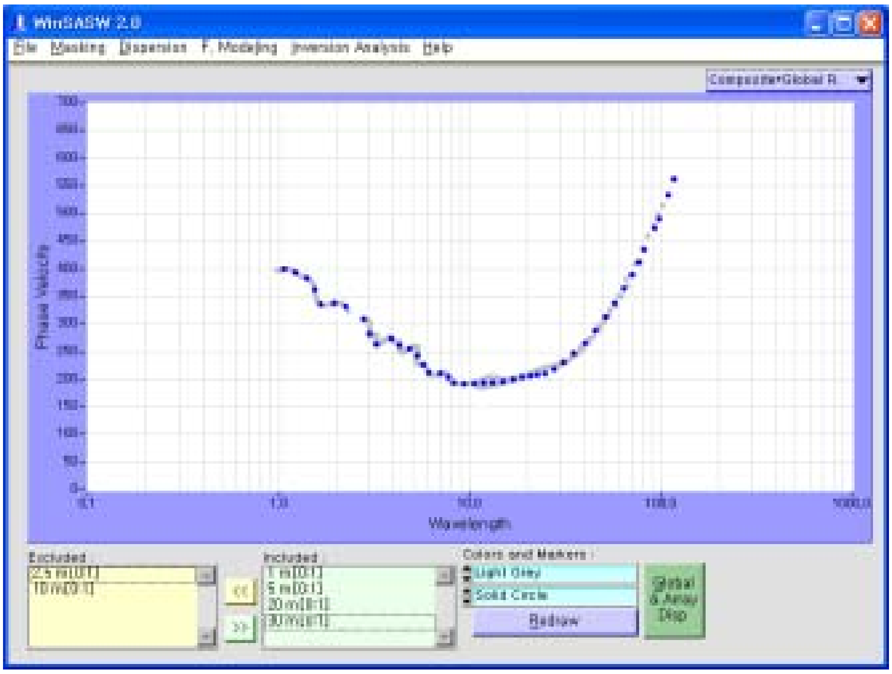


Fig. 5.5 Global Experimental Dispersion Curve for the Composite Experimental Dispersion Curve Shown in Fig. 5.2

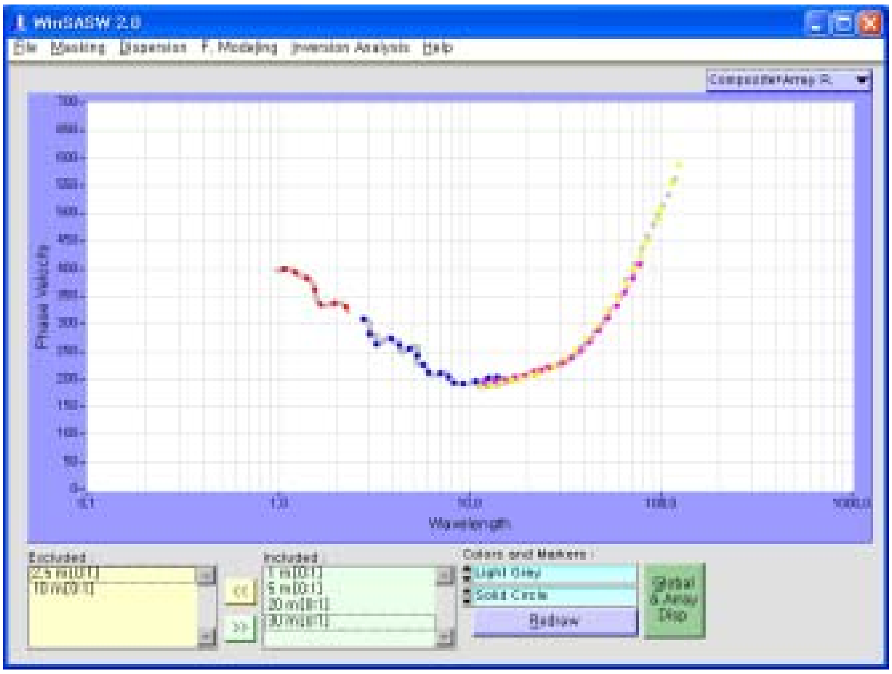


Fig. 5.6 Array Experimental Dispersion Curve for the Composite Experimental Dispersion Curve Shown in Fig. 5.2

6. Inversion Analysis

The menu item “`Disp. Curve and Profile`“ in the main menu invokes the major window for the operation of the inversion analysis. Figure 6.1 is a major window to control inversion analysis. The inversion analysis consists of three major steps: the assumption of subsurface layering and dispersion data, the determination of the starting model parameters, and the inversion analysis by the maximum likelihood method.

6.1 Subsurface Layering and Dispersion Data for Inversion Analysis

The inversion analysis in WinSASW 2.0 requires the subsurface layering given. The number of layers, layer thickness, mass density, Poisson’s ratio and damping factor should be provided to perform the inversion analysis. The inversion analysis is not much sensitive to mass density, Poisson’s ratio and damping factors. These parameters are given to be reasonable values.

The click on the button `Profile & Disp. C.` pops up a window to set up the analysis type, soil layering, and the experimental dispersion curve. Figure 6.2 and Fig. 6.3 show the typical setup windows, and Fig. 6.4 and Fig. 6.5 display an example of the layering and the dispersion data.

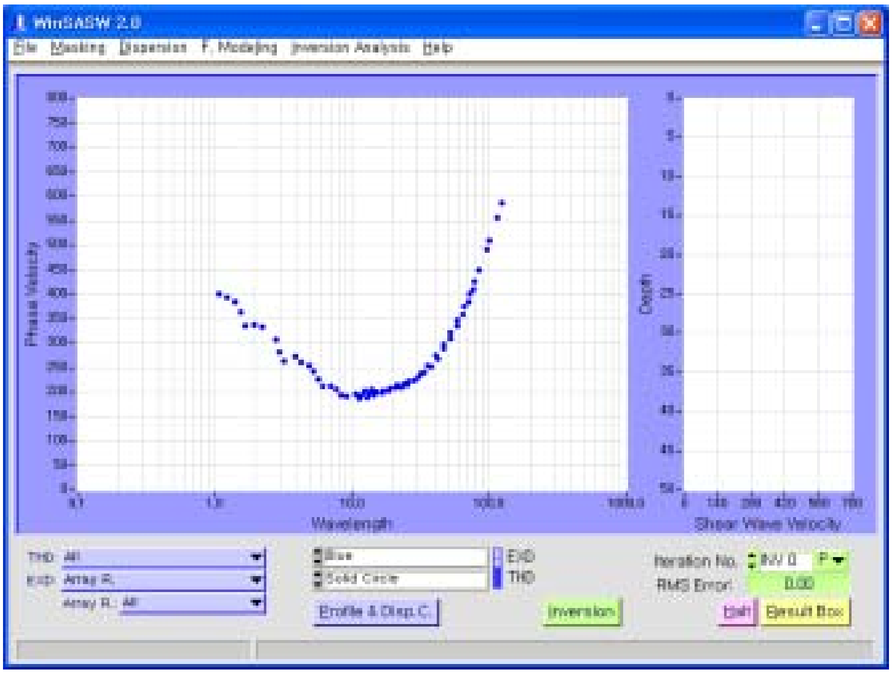


Fig. 6.1 The Main Window for the Operation of Inversion Analysis

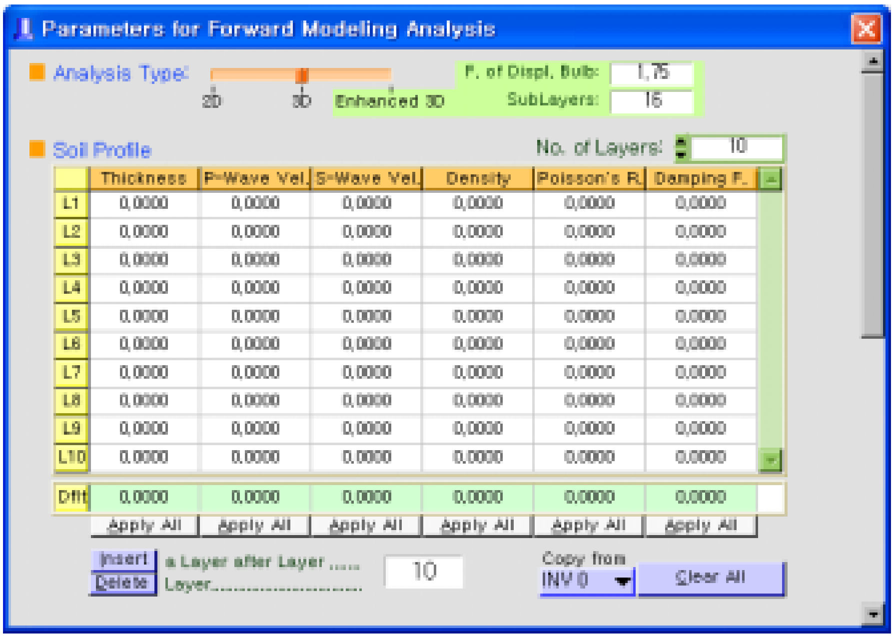


Fig. 6.2 Parameters for Forward Modeling and Inversion Analysis: Setup of Analysis Type and Soil Profile

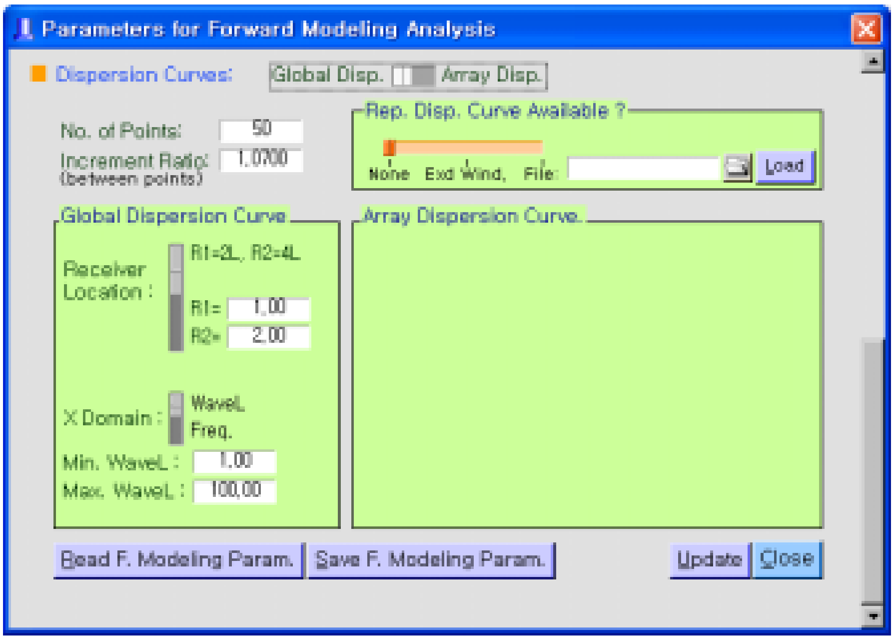


Fig. 6.3 Parameters for Forward Modeling and Inversion Analysis: Dispersion Curve Type and Dispersion Data Employed

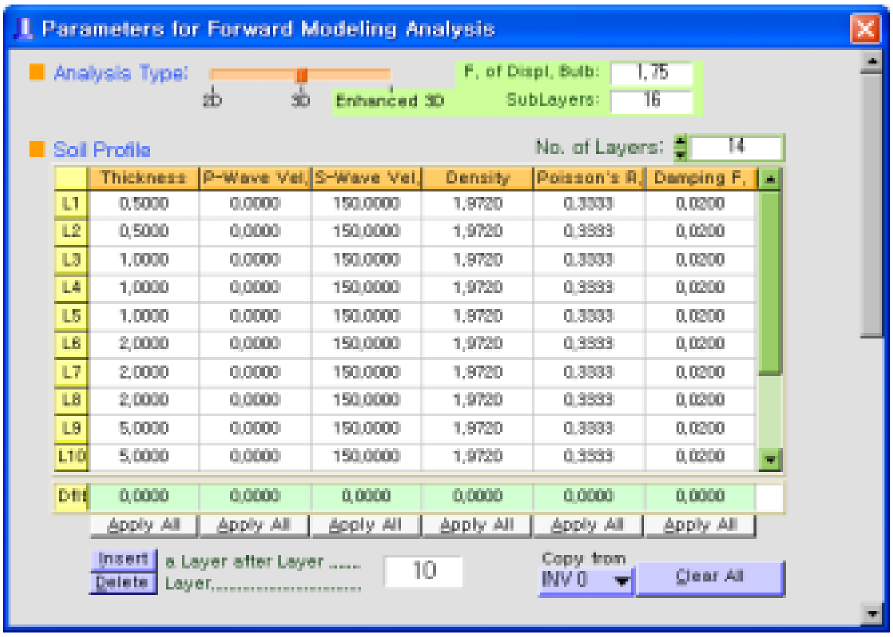


Fig. 6.4 Example of Analysis Type and Soil Layering Used for the Inversion Analysis

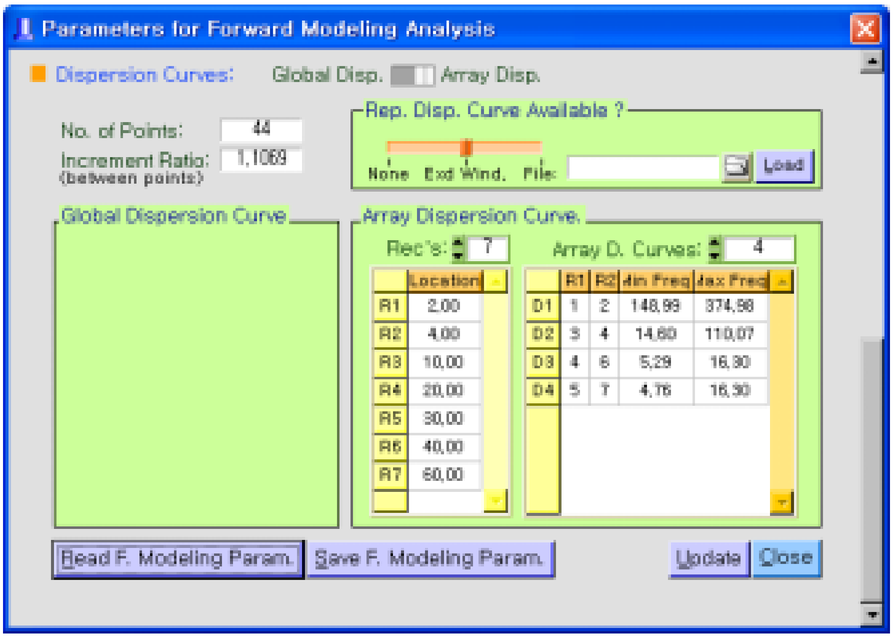


Fig. 6.5 Example of Dispersion Curve Used for the Inversion Analysis

6.2 Determination of the Starting Model for Inversion Analysis

The inversion analysis in WinSASW 2.0 requires a starting model, which is the initial value of model parameters. If the inversion analysis inverts only the shear velocities, then the starting model is the initial shear-wave velocity profile. Figure 6.6 shows the dialog box to control inversion analysis. A starting model of shear-wave velocity profile can be obtained by the click on the button `Run`, which is located by the text “`1. Starting Model Parameters`.” In case of Fig. 6.6, five starting model parameters are obtained for different depth-to-wavelength ratios ranging from 0.51 to 0.59.

Figure 6.7 shows the result of the starting model parameter. The left plot is comparing the experimental dispersion curve and the theoretical dispersion curve. The theoretical dispersion curve is calculated using the estimated starting model parameters. The right plot is showing RMS-error variation with the iteration number. The RMS error is a measure to tell how far the theoretical forward dispersion curve is from the measured forward dispersion data. Therefore, the smaller the RMS error is, the better the starting model parameters are. In case of Fig. 6.7, the fourth starting model parameter (named SMP4 in Fig. 7) has the smallest RMS error, 25.57, where the estimated shear wave profile is as shown in Fig. 6.8. These starting model parameters are going to be used for the inversion analysis.

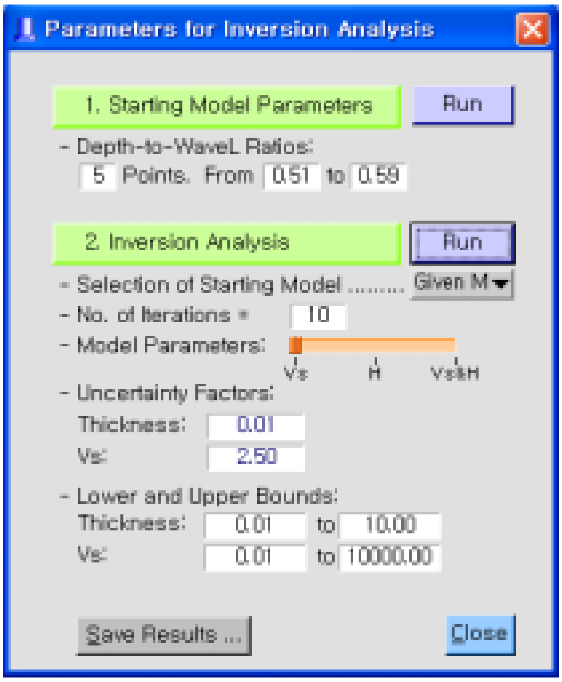


Fig. 6.6 Parameters to Control the Inversion Analysis

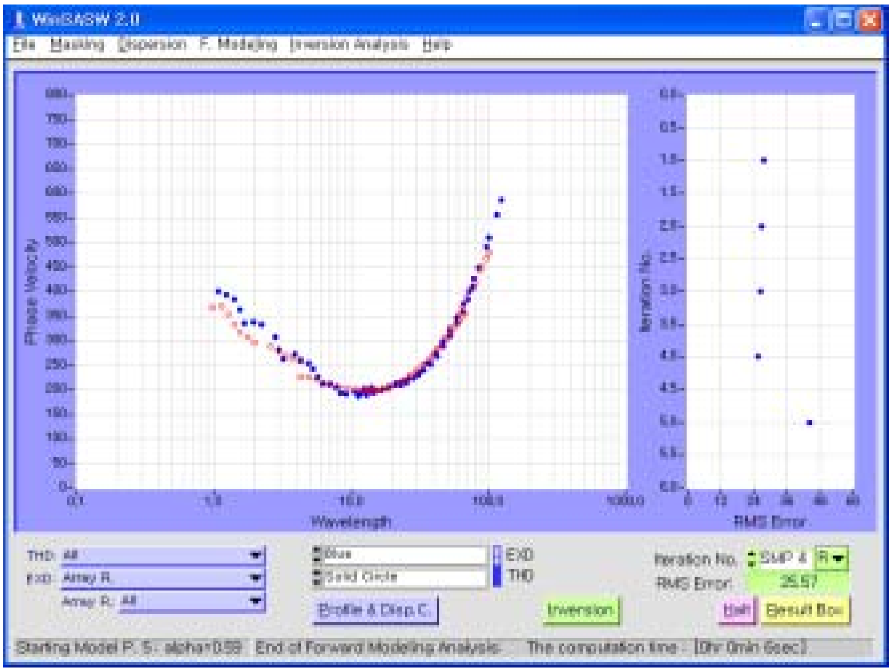


Fig. 6.7 Search of the Starting Model Parameters: Comparison of Experimental and Theoretical Dispersion Curves and Variation of RMS Errors with Iterations

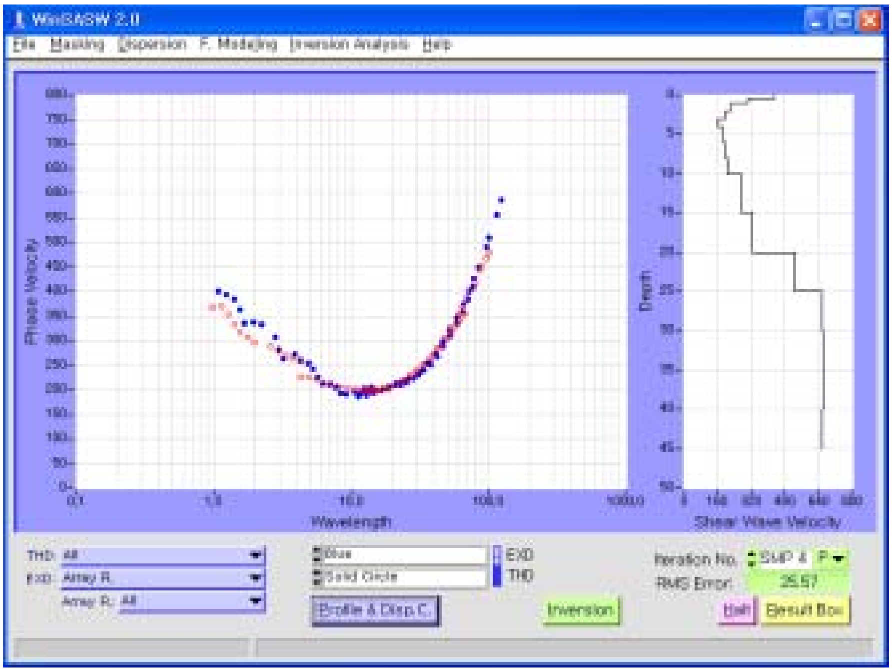


Fig. 6.7 Search of the Starting Model Parameters: Shear-Wave Velocity Profile

For the inversion analysis, WinSASW 2.0 has three options of model parameters. It can evaluate shear-wave velocity profile only, thickness profile only, or shear-wave velocity and thickness together. However, at a starting point, it is a better strategy to invert shear-wave velocity only. Later, once a reasonable shear-wave velocity profile is obtained, move to the joint inversion of shear-wave velocity and thickness.

Figure 6.8 shows the RMS error variation with the iteration number. The 10^{th} iteration shows the lowest RMS error, which indicates the profile of the 10^{th} iteration is the best among three iterations. The shear-wave velocity profile corresponding to the 10^{th} iteration is shown in Fig. 6.9.

One of the most important things in the inversion analysis is how deep we can resolve the shear-wave velocity. A key to this problem is the resolution of model parameters. That is, the resolution of model parameters (shear-wave velocity in the case of Fig. 6.10) indicates how well the model parameters are resolved in the scale of 0 to 1.

The text-format results are also available by clicking on the button `Result Box` located at the lower-right corner of the inversion analysis window. It is possible to copy the contents of the result box to clipboard, which can be pasted on a word processor, a spreadsheet program, and etc.

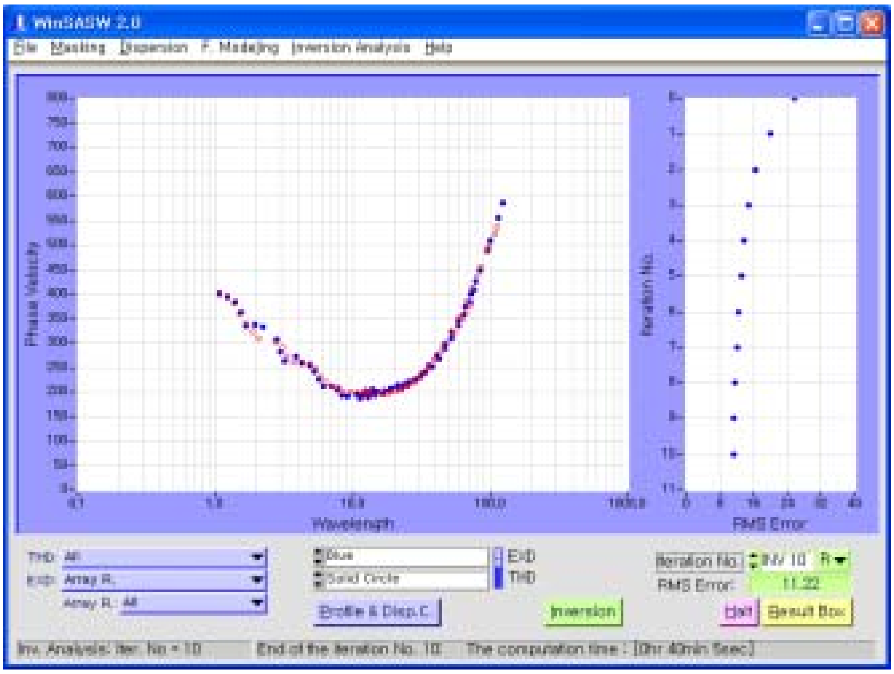


Fig. 6.8 Result of the Inversion Analysis: Comparison of Experimental and Theoretical Dispersion Curves, Shear-Wave Velocity Profile

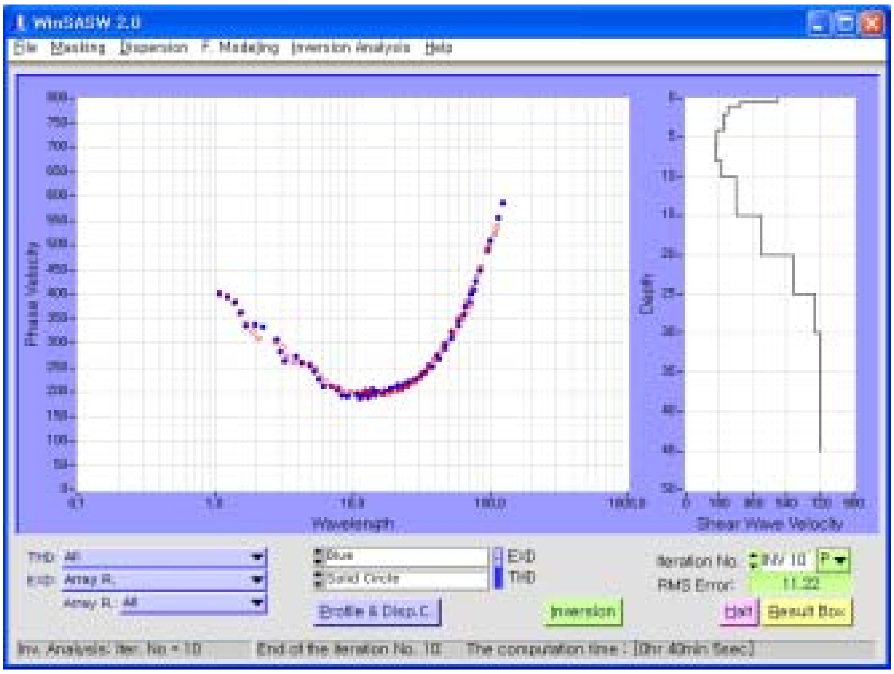
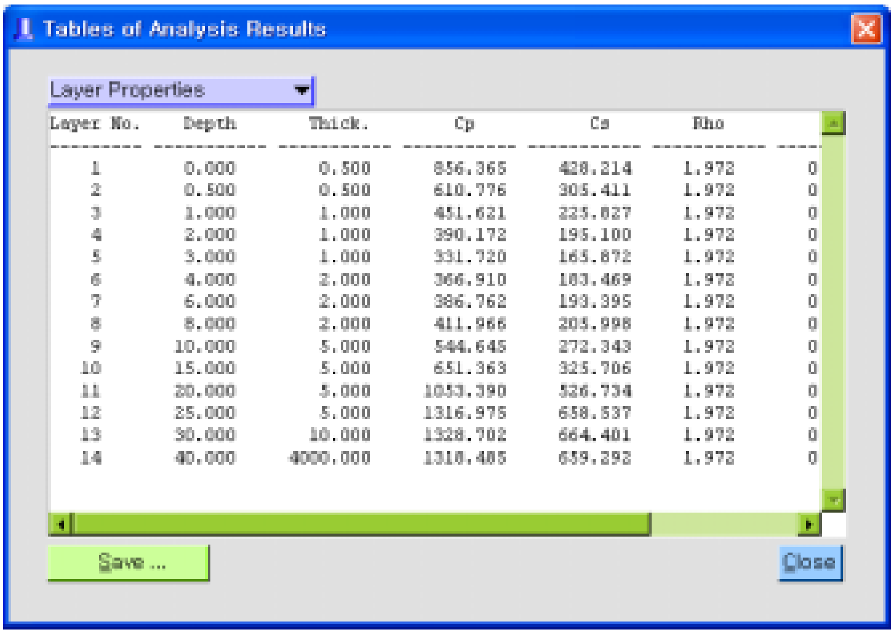


Fig. 6.9 Result of the Inversion Analysis: Shear-Wave Velocity Profile

Fig. 6.10 Result of the Inversion Analysis: Resolution of Shear-Wave Velocity



Layer No.	Depth	Thick.	Cp	Cs	Rho	
1	0.000	0.500	856.365	428.214	1.972	0
2	0.500	0.500	610.776	305.411	1.972	0
3	1.000	1.000	451.621	225.827	1.972	0
4	2.000	1.000	390.172	195.100	1.972	0
5	3.000	1.000	331.720	165.872	1.972	0
6	4.000	2.000	366.910	183.469	1.972	0
7	6.000	2.000	386.762	193.395	1.972	0
8	8.000	2.000	411.966	205.998	1.972	0
9	10.000	5.000	544.645	272.343	1.972	0
10	15.000	5.000	651.363	325.706	1.972	0
11	20.000	5.000	1053.390	526.734	1.972	0
12	25.000	5.000	1316.975	658.537	1.972	0
13	30.000	10.000	1328.702	664.401	1.972	0
14	40.000	4000.000	1318.485	659.292	1.972	0

Fig. 6.11 Text-Format Result of the Inversion Analysis

7. Forward Modeling

Forward modeling in SASW method is to calculate the theoretical phase-velocity dispersion curve for a given soil layering. Here in WinSASW 2.0, the dynamic stiffness method (Kausel and Roësset, 1981; Kausel and Peek, 1982) is employed. Selection of the menu item `F. Modeling` in the main menu changes the window to Fig. 7.1.

7.1 Soil Profile and Dispersion Curves for Forward Modeling

To calculate the theoretical phase velocities, the soil properties of each layer are required. The required soil properties are shear-wave velocity, compression-wave velocity, Poisson's ratio, mass density and damping factor. Figure 7.2 is an example of the soil profile. In the profile, it is important to give a big number for the half-space thickness. Usually it is a good idea to have 100 times of the depth of the last layer.

The compression-wave velocity in Fig. 7.2 is set to all zeros. This is because shear-wave velocity, compression-wave velocity and Poisson's ratio are related with each other, and only two entities have only to be given. In the case of Fig. 7.2, shear-wave velocity and Poisson's ratio are given and compression-wave velocity is automatically calculated inside of the program.

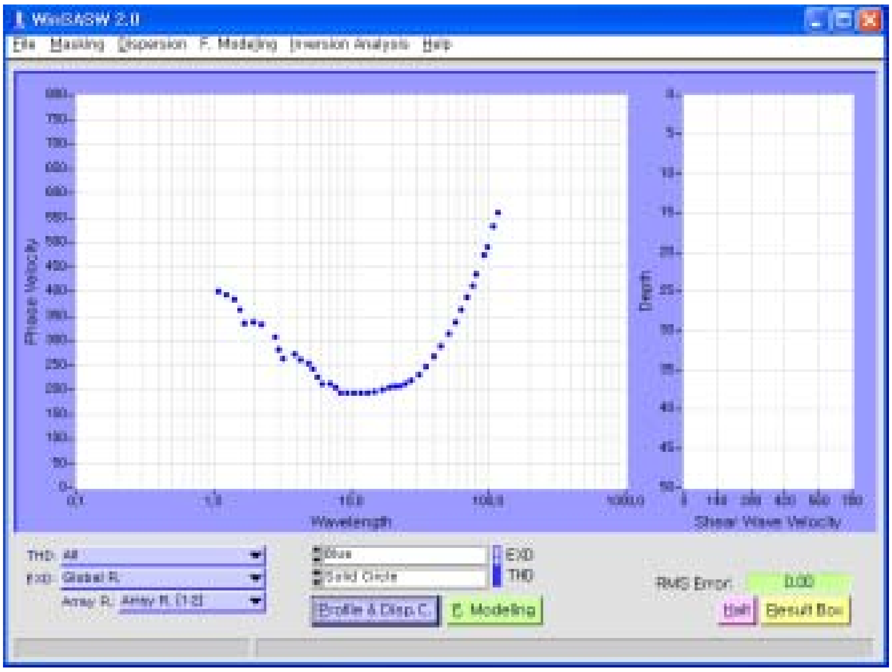


Fig. 7.1 The Main Window to Perform Forward Modeling

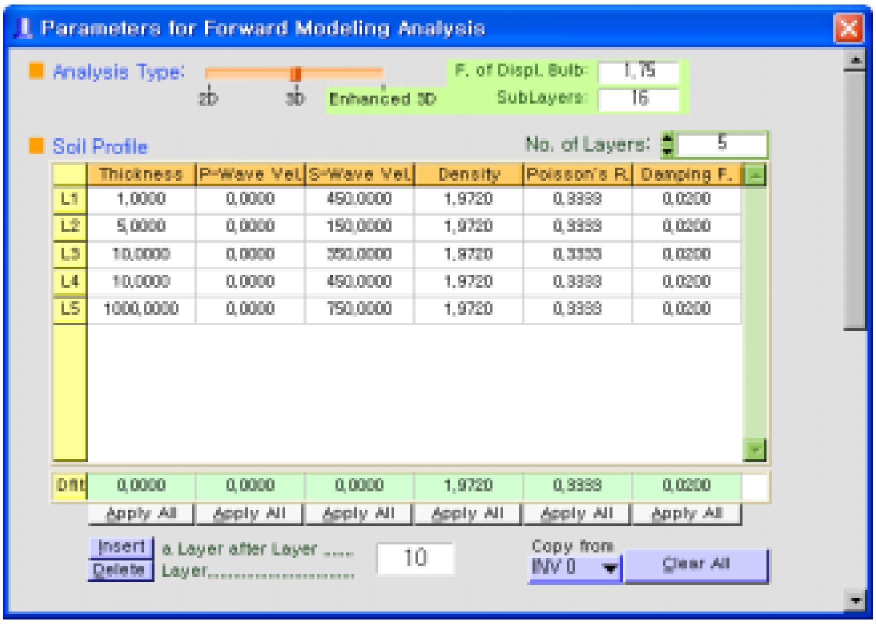


Fig. 7.2 Parameters for Forward Modeling Analysis: Analysis Type and Soil Profile

7.2 Representative Experimental Dispersion Data

The calculation of phase velocity is based on a given frequency. If the dispersion data exist, the phase velocities corresponding to the frequencies of the dispersion data can be calculated. The existing dispersion data can be specified by selecting the button in the box of “`Rep. Disp. Curve Available ?`”. The option `Exd Wind` means the experimental dispersion data displayed in the dispersion curve window. The option `File` indicates that the dispersion data are retrieved from the file specified by the next edit box. If no existing dispersion data are used, then choose the option `None`.

Other attributes of the theoretical dispersion curve can be specified in the same window. Dispersion curve type, number of dispersion data, the increment ratio between frequencies or wavelengths and details of global or array dispersion curve can be given.

Figure 7.4 shows the calculated theoretical dispersion curve. In the dispersion curve window, two curves are compared. The blue one and the red one are presented. The blue curve is the result of 2-D analysis, and the red one is the result of 3-D analysis. When the existing dispersion curve options are not selected, the 2-D analysis is first performed to give the initial values to the 3-D analysis.

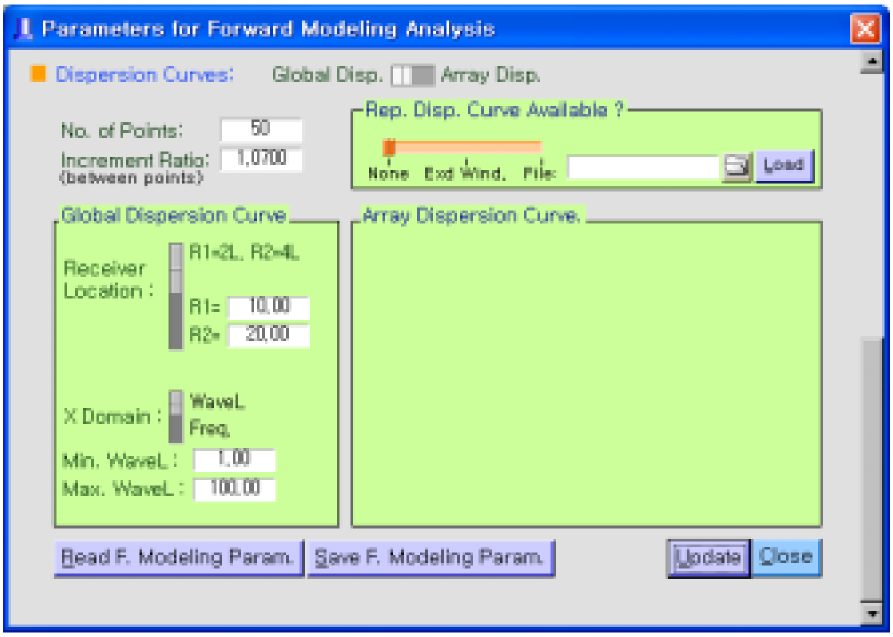


Fig. 7.3 Parameters for Forward Modeling Analysis: Dispersion Data

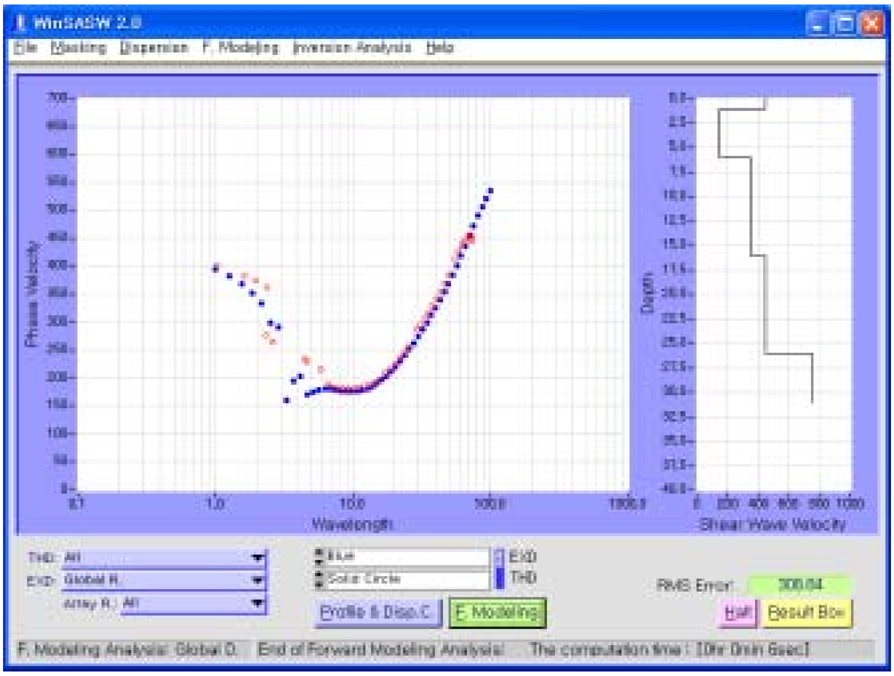


Fig. 7.4 Results of the Forward Modeling: Theoretical Dispersion Curve

When the existing dispersion curve option is selected as in Fig. 7.5, the results of the forward modeling looks like Fig. 7.6. Unlike Fig. 7.4, the blue curve in the dispersion curve plot is the representative experimental dispersion curve, and is compared with the calculated theoretical dispersion curve.

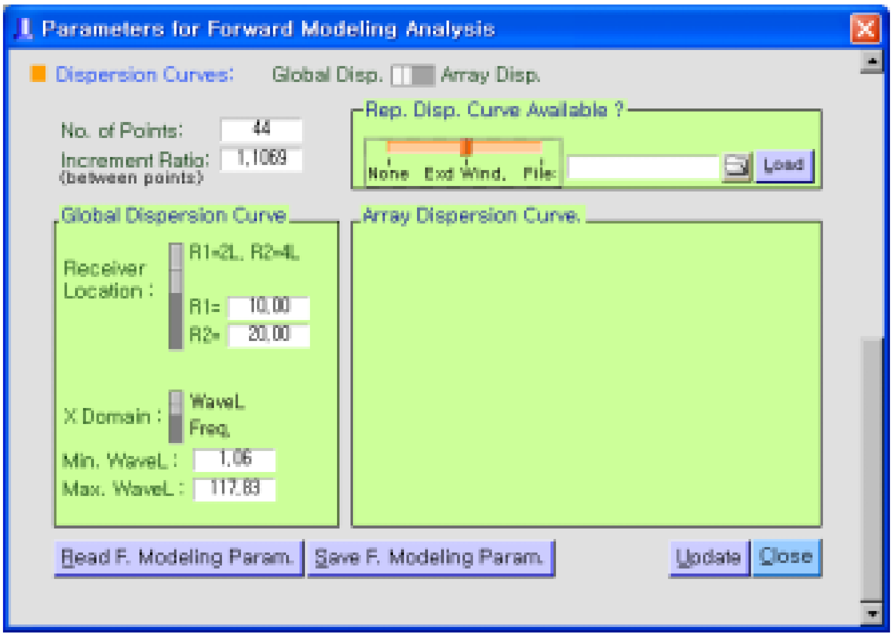


Fig. 7.5 Options of the Forward Modeling: Representative Dispersion Curve Given

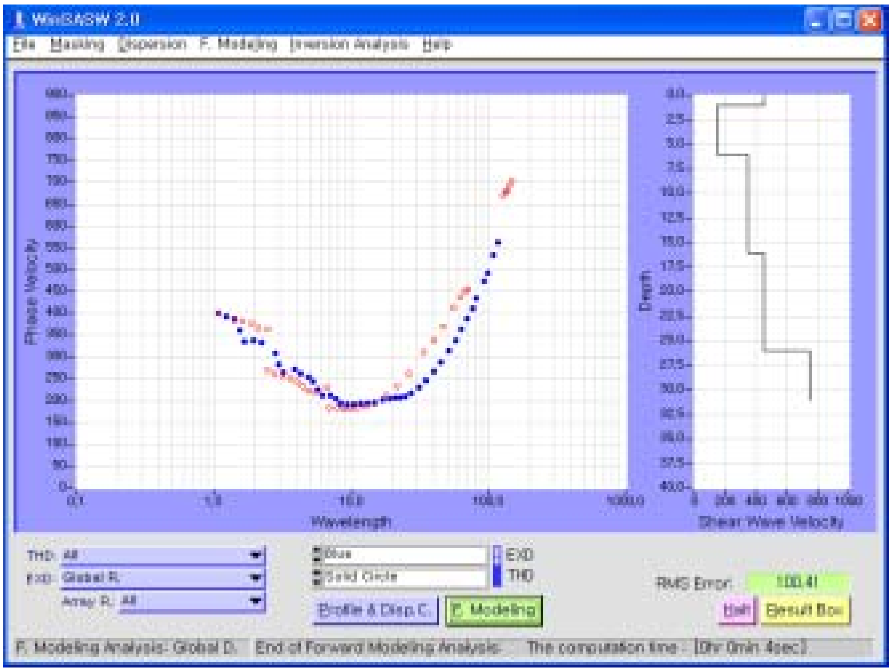


Fig. 7.6 Results of the Forward Modeling When the Representative Dispersion Curve Is Given

When the array dispersion curve is chosen as a analysis type, the section for an array dispersion curve is visible as in Fig. 7.7. In the section of the array dispersion curve, information on receivers and array dispersion curves should be provided. In the case of Fig. 7.7, information on the existing array dispersion curve is employed. The results of forward modeling analysis for the options given in Fig. 7.7 look like Fig. 7.8.

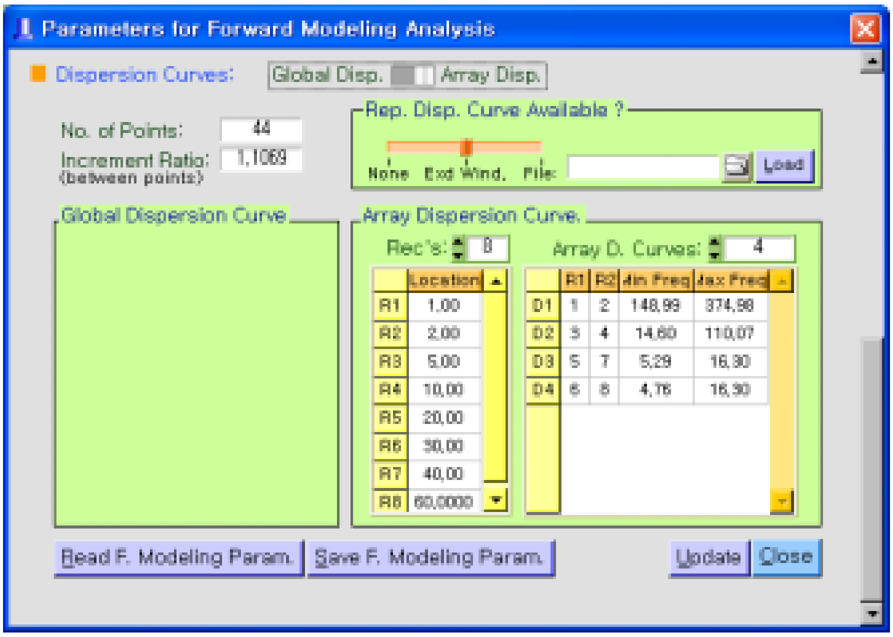


Fig. 7.7 Options of Forward Modeling Analysis for the Array Dispersion Curve

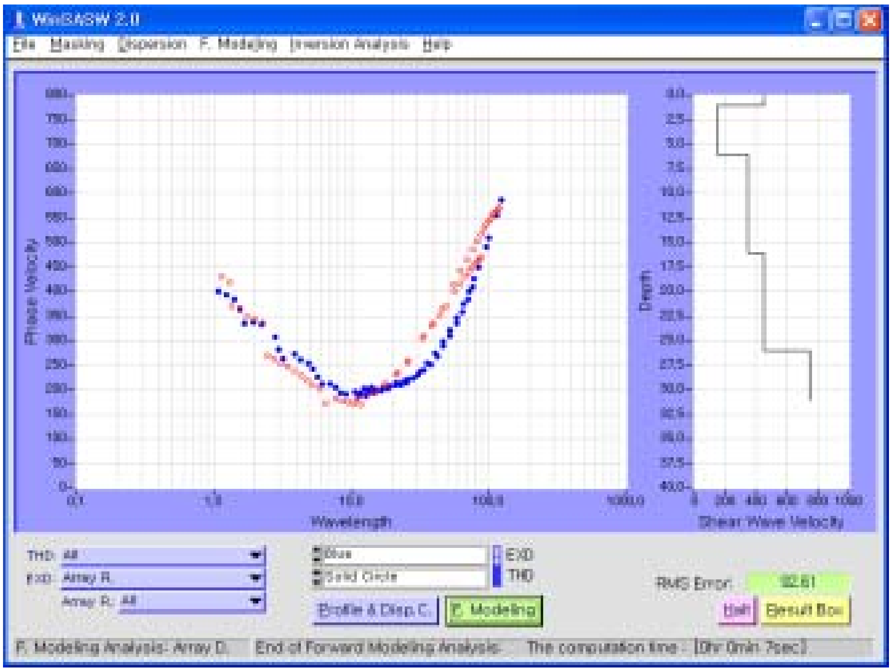


Fig. 7.8 Results of Forward Modeling Analysis for the Array Dispersion Curve Option

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