ViewWave manual

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by

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1. Introduction

ViewWave is a simple viewer for strong motion data. ***ViewWave*** can read several file formats of strong motion data and will show waveforms. ***ViewWave*** can perform basic analyses such as a Fourier analysis and a response spectrum. You may control sizes and appearances of the graphs as you like. The graphs are sent to the Windows clipboard as EMF (Enhanced Metafile) data, so you can paste it in your document while keeping its quality.

The following description is based on the environment of Windows 10. There will be differences in terms and file paths according to the environment under other operation systems.

1.1. System requirements

ViewWave requires Microsoft .NET Framework 4.5. System requirements will accord with those of .NET Framework 4.5. Considering some margins, ***ViewWave*** may run in the following conditions;

(1) Operating Systems

- Windows 7 SP1 (x86 and x64)
- Windows 8 (x86 and x64)
- Windows 8.1 (x86 and x64)
- Windows 10 (x86 and x64)

Windows Vista SP2 (x86 and x64) and Windows Server families (2008 and 2012) are also supported by .NET Framework 4.5, but behavior of ***ViewWave*** on those operating systems has not been verified.

(2) Hardware

- 1 GHz and faster CPU
- 2 GB and more RAM
- 1 GB and larger Hard Disk (x86)
- 2 GB and larger Hard Disk (x64)

(3) Language

ViewWave has two language modes, i.e. English and Japanese. Japanese messages will appear only under the Japanese versions of Windows.

1.2. Installation and uninstallation

1.2.1. Installation

Installation package will be provided as a Windows Installer file (vw2*xx*.msi). The portion "2*xx*" in the filename represents a version of a release. By double-clicking the installer file, ***ViewWave*** is installed in "*%ProgramFiles%*\Strong Motion Tools\ViewWave" (the root folder becomes "*%ProgramFiles(x86)%*" in 64-bit Windows). Shortcuts to ***ViewWave*** are added on the desktop and program menu "**Strong Motion Tools**."

Uninstallation of ***ViewWave*** 1.xx is not necessary to install ***ViewWave*** 2.xx. Both can coexist because the installation folder and program group were different.

1.2.2. *Uninstallation*

ViewWave can be uninstalled from [**Control Panel**] -> [**Programs and Features**].

1.3. Copyright and support

The copyright of ***ViewWave*** is held by T. Kashima, BRI. The author is not responsible for any losses caused by ***ViewWave***.

The up-to-date information and support on ***ViewWave*** will be provided on the website http://smo.kenken.go.jp/. Any comments and requests are welcomed to kashima@kenken.go.jp.

1.4. Development tools

ViewWave is being developed using the following tools;

- Microsoft Visual Studio Community 2015 Version 14.0.24720.00 Update 1
- Microsoft .NET Framework Version 4.6.01038
- GNU Fortran (i686-posix-dwarf-rev0, Built by MinGW-W64 project) 5.2.0 Copyright (C) 2015 Free Software Foundation, Inc.

1.5. Changes and new features from ViewWave 1.xx

ViewWave 2.xx basically follows the features of the previous version. In addition, some new features are added and some functions are improved.

- The development environment was changed from Visual Basic 6.0 to Visual C# and Visual Studio 2013. So the entire code was rewritten.
- English and Japanese versions were integrated into the same package. The language is selected according to the current language setting of Windows.
- Information on strong motion stations and events can be obtained from database files that are Microsoft Access and Excel files.
- Extra data can be plotted on spectrum graphs in addition. For instance, you can compare spectra of recoded strong motion data to design spectra.
- The settings are saved in files rather than the Windows registry. This version does not use the Windows registry.
- Plural reports defined by users can be held. New report types, i.e. channel and combination reports, are implemented.

1.6. Readable data files

ViewWave can read following strong motion data files;

- BRI strong motion data files (*.ac)
- NIED K-NET and KiK-net files (*.ew;*.ew1)
- JMA 95 Hexa-ASCII files (YMDDhhmm.*) and JMA CSV files (*.csv)
- Mitutoyo (and Akashi) SMAC-MD/MDU files (*.md)
- Tokyo Sokushin binary files (*.t3w;*.dbl)
- Kinemetrics Altus K2/Etna event files (*.evt)

- USGS (NSMP) files (*.smc)
- CGS (CSMIP) files (*.raw; *.v2)
- COSMOS files (*.v1c; *.v2c)
- PEER files (*.at2)
- New Zealand GeoNet files (*.v1a; *.v2a)
- General CSV and text files (*.csv; *.txt)

For more information, please refer to Section 4.1 and Section 4.2.

2. Basic Usage

A sample dataset that is used in this chapter can be obtained at the following website. Please download vw_sample.zip and extract files to some place if necessary.

- http://smo.kenken.go.jp/~kashima/viewwave/

2.1. Starting/terminating ViewWave

You can start ***ViewWave*** by double-clicking its shortcut on the desktop or in the program menu folder "**Strong Motion Tools**." After starting up, you can open a strong motion data file from the menu **[File] -> [Open...]**. ***ViewWave*** reads a strong motion data file and initially displays acceleration waveforms in the main window. When you read 199301152006KSR.ac in the sample dataset, the following waveforms will appear.

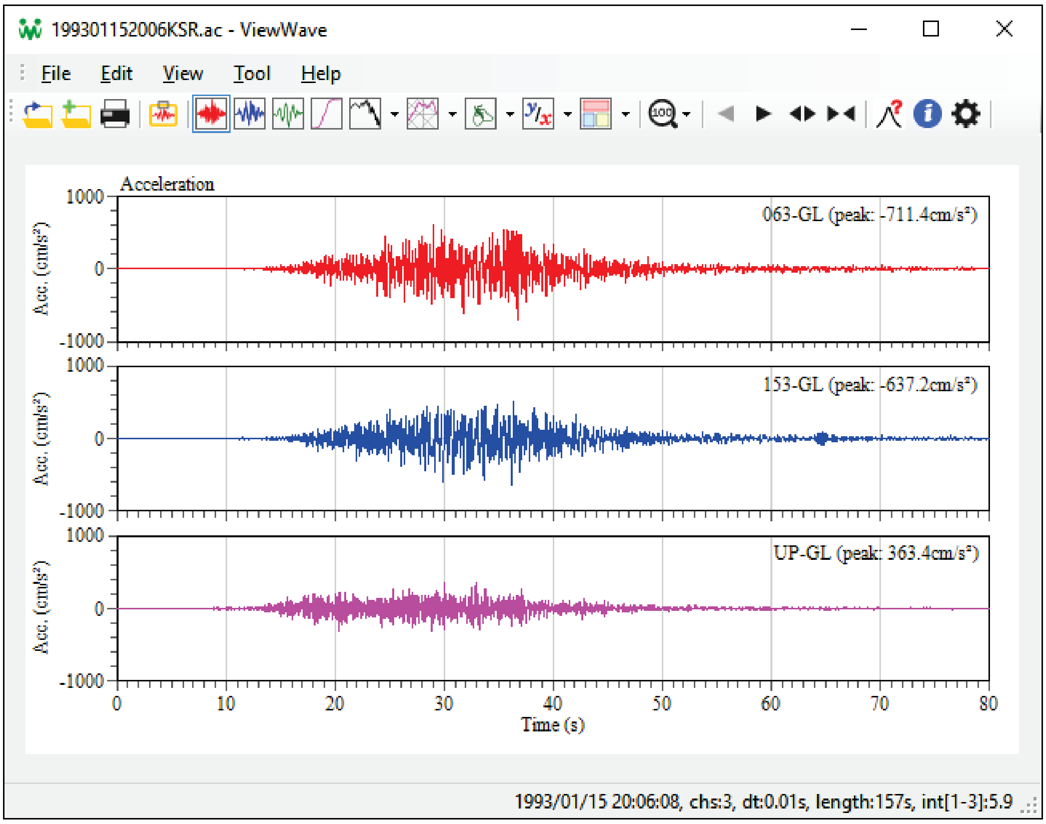


Fig. 1 ViewWave shows acceleration waveforms after reading a strong motion data file

> ***ViewWave*** opens a data file dragged and dropped on the background window as a new file. A file dropped on the graph is opened as an appending file.

You can terminate ***ViewWave*** by selecting [**Exit**] in the [**File**] menu. [**Close**] in the [**File**] menu discards the current strong motion data and clears the graph window.

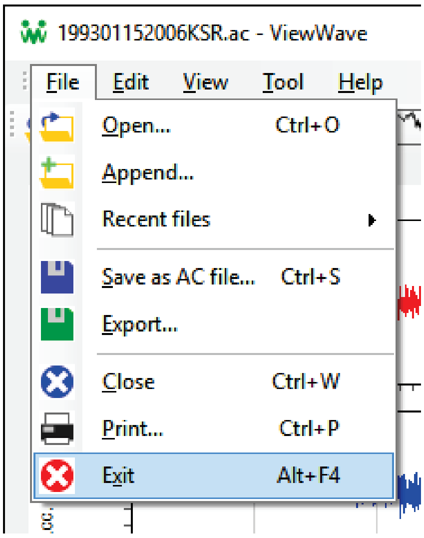


Fig. 2 ViewWave is terminated by the menu [File] -> [Exit]

2.2. Displaying velocity and displacement waveforms

ViewWave can display velocity and displacement waveforms that are calculated from the acceleration data by the integration. By choosing [**Velocity**] or [**Displacement**] in the [**View**] menu, velocity or displacement waveforms will appear in the main window.

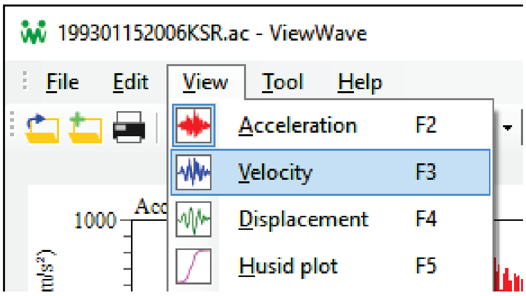
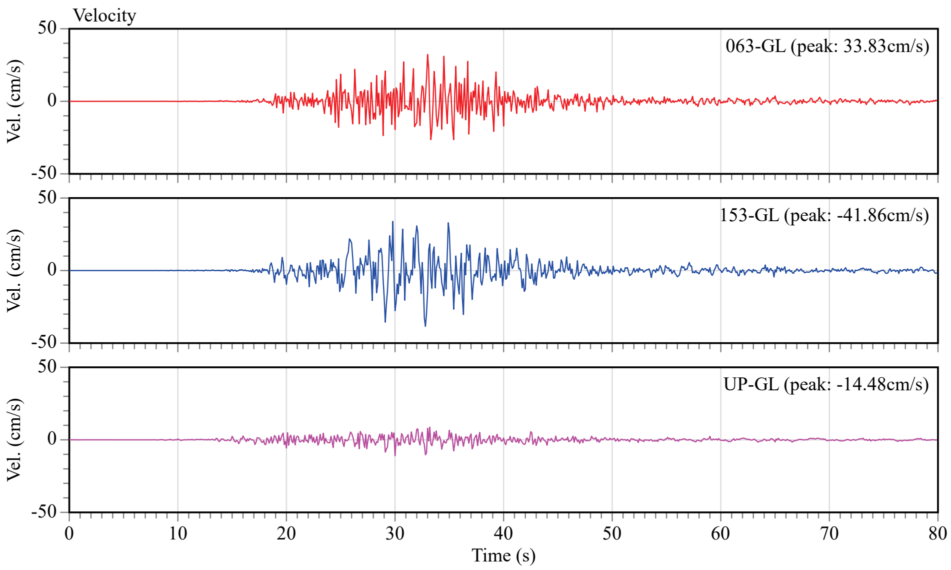
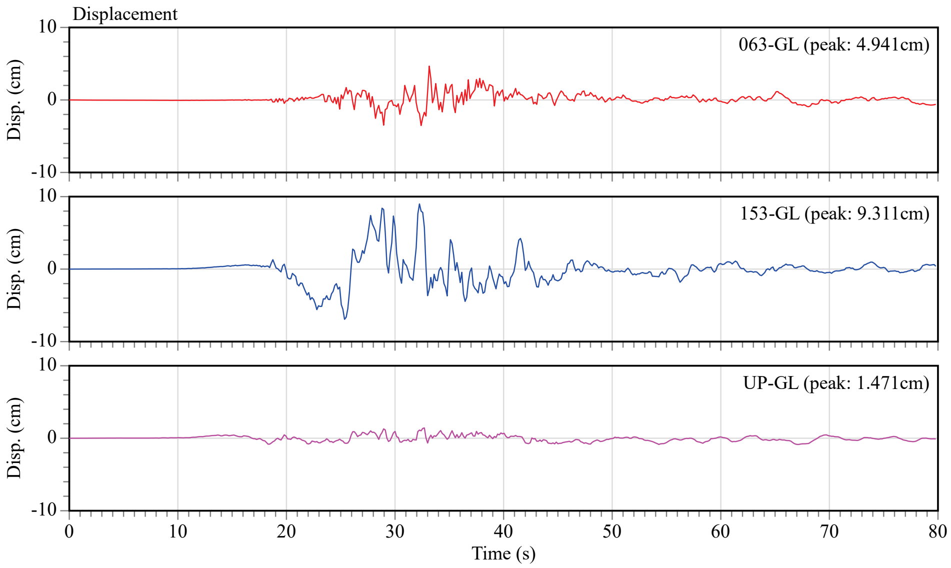


Fig. 3 Velocity or displacement waveforms are selectable in the [View] menu



(a) A sample of velocity waveforms



(b) A sample of displacement waveforms

Fig. 4 A sample of velocity and displacement waveforms

ViewWave provides some methods of integration. The integration method can be selected from the [**Calculation**] tab in the [**Option**] dialog box that can be opened from the menu [**Tool**] -> [**Option**].

2.3. Displaying Fourier spectra

To display Fourier spectra of the strong motion data, select the menu [**View**] -> [**Fourier analysis**] -> [**Fourier Spectrum [amplitude]**]. The Fourier spectra of all channels will appear in the window.

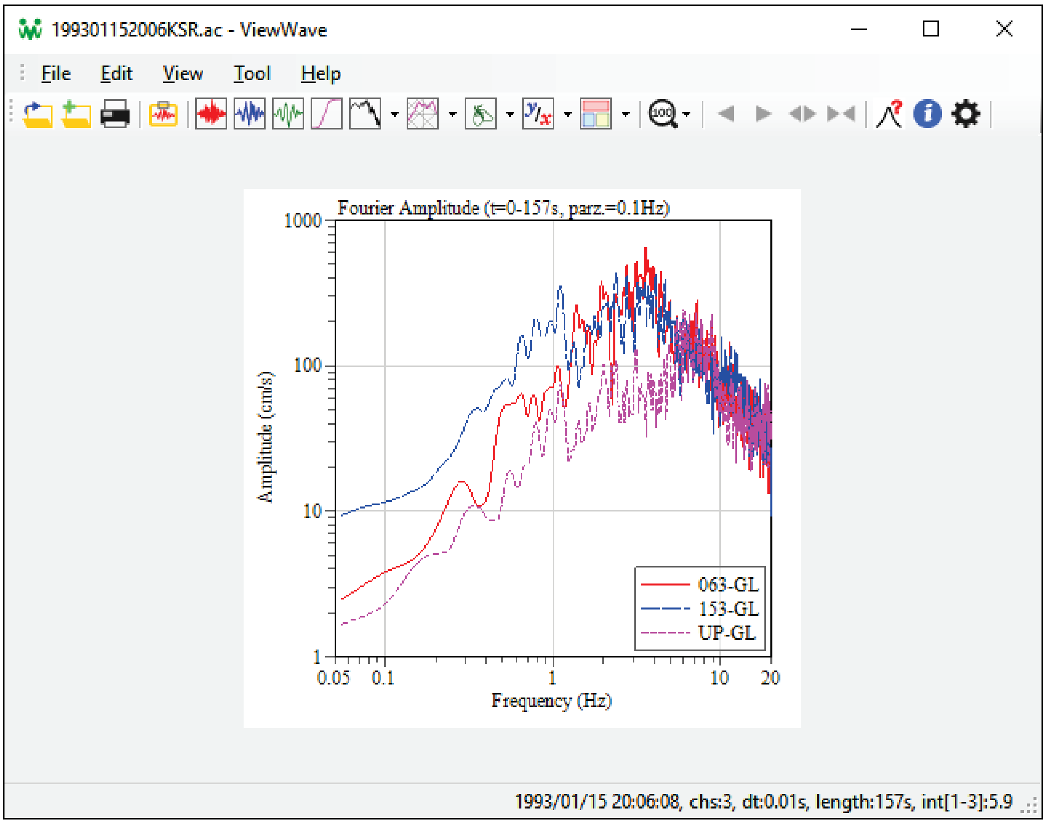


Fig. 5 A sample of Fourier spectrum graph

The time scope of the Fourier analysis can be changed on the [**Calculation**] tab in the [**Option**] dialog box. The spectra are smoothed using the Parzen window. The width of Parzen window can be changed on the [**Calculation**] as well.

2.4. Displaying response spectra

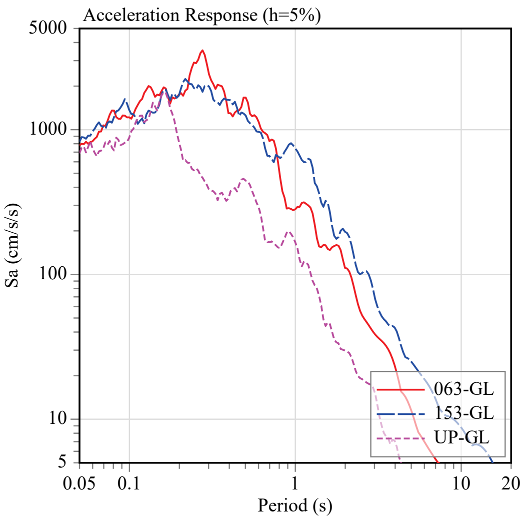
ViewWave has a function to compute and display response spectra. You can choose a type of response spectra from the [**Response spectrum**] submenu in the [**View**] menu. There are;

- Acceleration response spectrum (Sa)
- Velocity response spectrum (Sv)
- Displacement response spectrum (Sd)
- Pseudo velocity response spectrum (on tripartite-axis, pSv)
- Energy spectrum (Ve)
- Sa-Sd curve

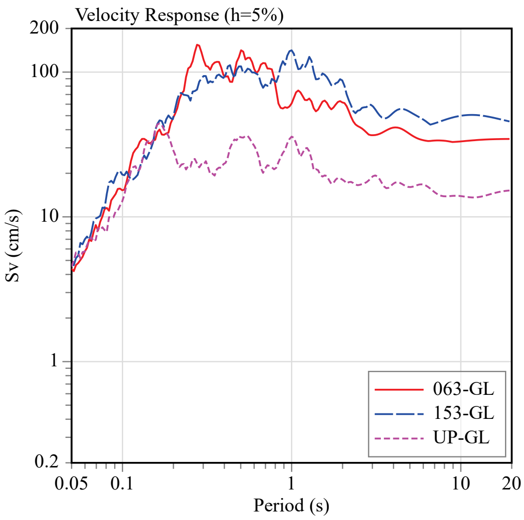
Response spectra is usually plotted as the multi-channel single-damping spectra. The channels specified on the [**Channel**] tab in the [**Option**] dialog are plotted in a response spectrum.

Damping ratios of the response spectra can be set from the [**Calculation**] tab in the [**Option**] dialog. There are two damping ratios for the response spectra (Sa, Sv, Sd and pSv), and for the energy spectrum (Ve).

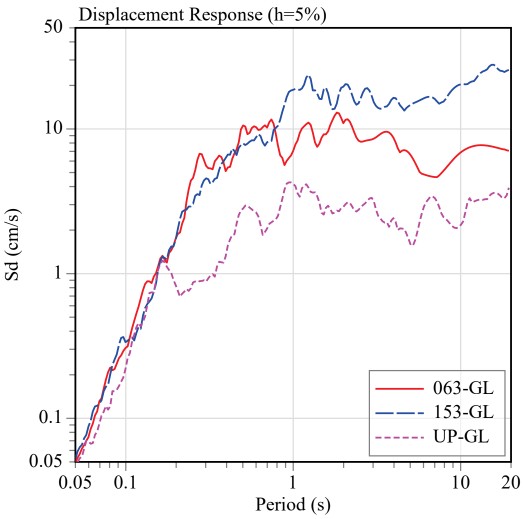
Samples of available response spectra are shown in Fig. 6.



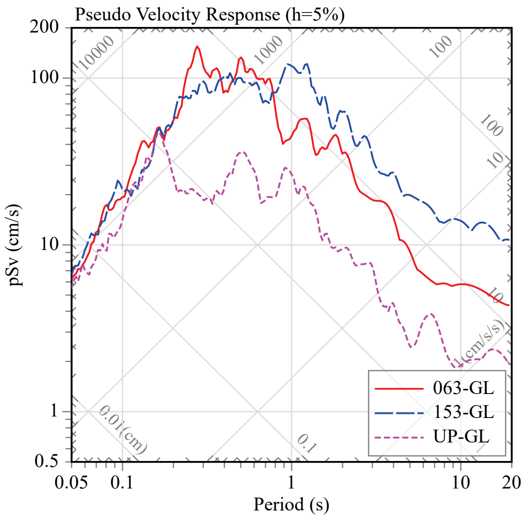
(a) Acceleration response spectrum (Sa)



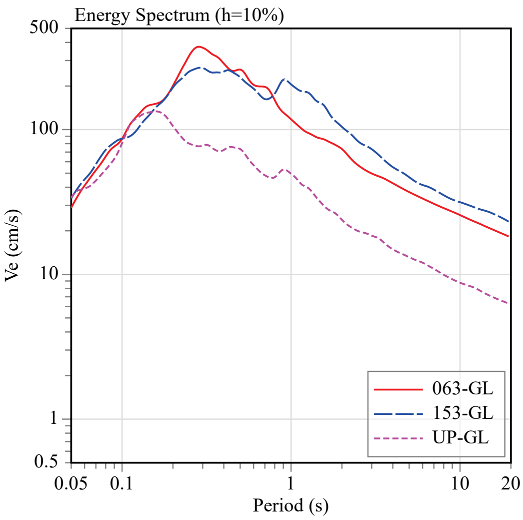
(b) Velocity response spectrum (Sa)



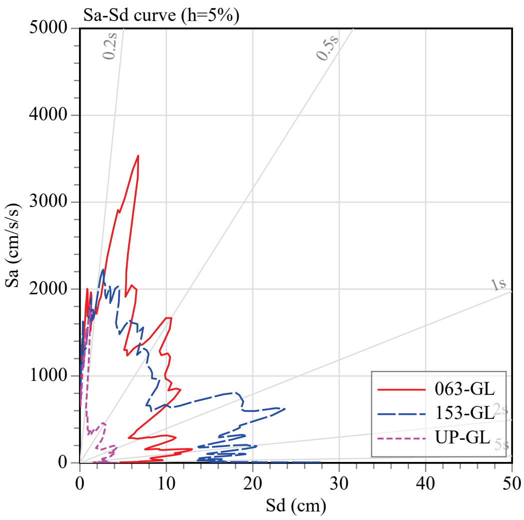
(c) Displacement response spectrum (Sd)



(d) Pseudo velocity response spectrum (pSv)



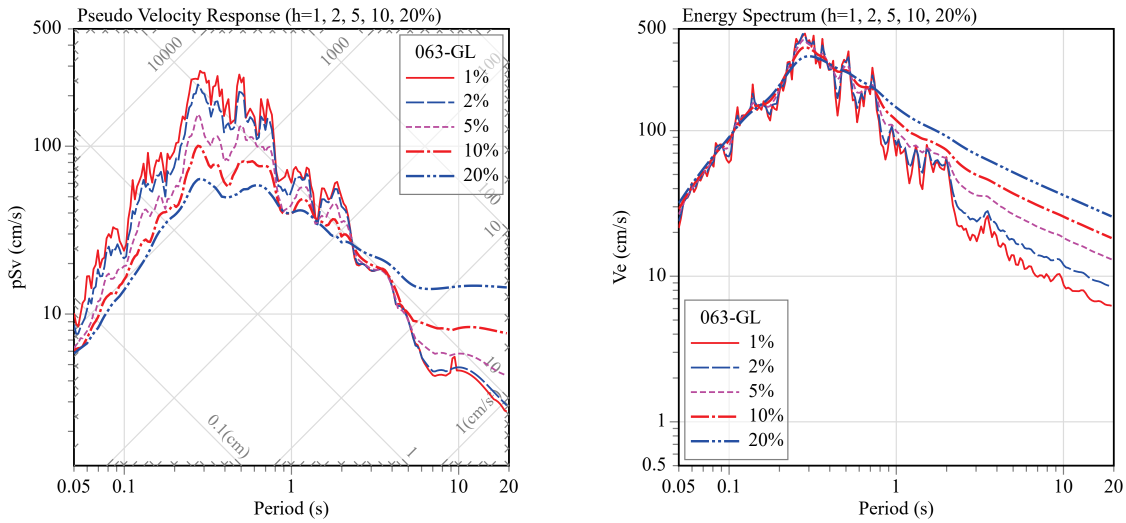
(e) Energy spectrum (Ve)



(f) Sa-Sd curve

Fig. 6 Samples of graphs of response spectra

ViewWave can plot multi-damping response spectra by selecting "**Multi-damping spectra**" on the [**Calculation**] tab in the [**Option**] dialog. For the multi-damping response spectra, you need to choose a single channel to be plotted from the [**Channel**] tab in the [**Option**] dialog. The damping ratios of the multi-damping response spectra can be set from the [**Calculation**] tab in the [**Option**] as well. Values must be separated by commas. Samples of multi-damping response spectra are shown in Fig. 7.



(a) Multi-damping pSv *(b) Multi-damping Ve*

Fig. 7 Samples of multi-damping response spectra

2.5. Displaying particle orbit

A particle orbit, which is a projection of sensor movement to a plane, can be selected in the menu [**View**] -> [**Particle orbit**]. There are three choices, namely, [**Acceleration**], [**Velocity**] and [**Displacement**].

If the data file has two or more channels, *ViewWave* initially assigns the first and second channels to the vertical and horizontal axes of the particle orbit. Channels to be assigned can be selected on the [**Channel**] tab in the [**Option**] dialog box. If the data file has data of a single channel, the particle orbit is not available.

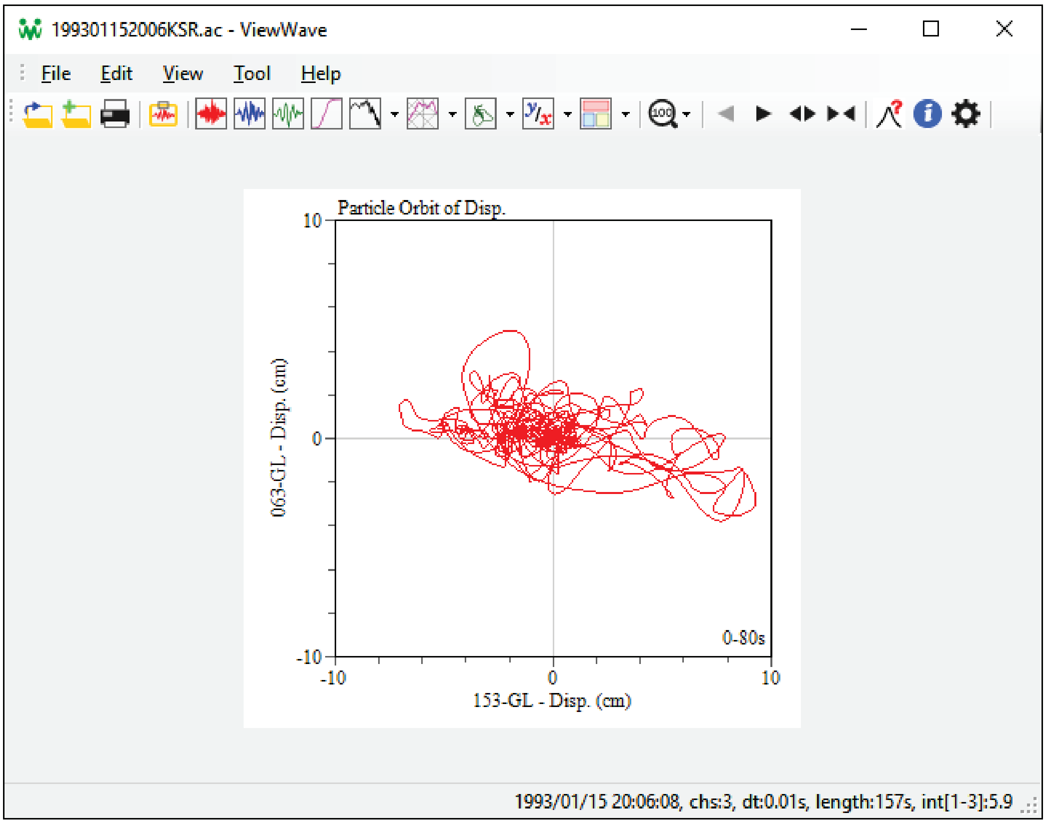


Fig. 8 A sample of a displacement particle orbit graph

2.6. Displaying Fourier spectrum ratio

If there are two or more channels, ***ViewWave*** can analyze the relation between two channels of data. For example, amplitudes of the Fourier spectrum ratio between two channels can be plotted by choosing the menu [**View**] -> [**Relation analysis**] -> [**Fourier spectrum ratio [amplitude]**].

If two channels can be considered as input and output, the Fourier spectrum ratio represents the transfer function. The phase, real part and imaginary part of the Fourier spectrum ratio can be also selected from the [**View**] -> [**Relation analysis**] submenu.

Channels for the relation analysis can be set in the [**Channel**] tab in the [**Option**] dialog box. If the data file has a single channel data, the relation analysis is not available.

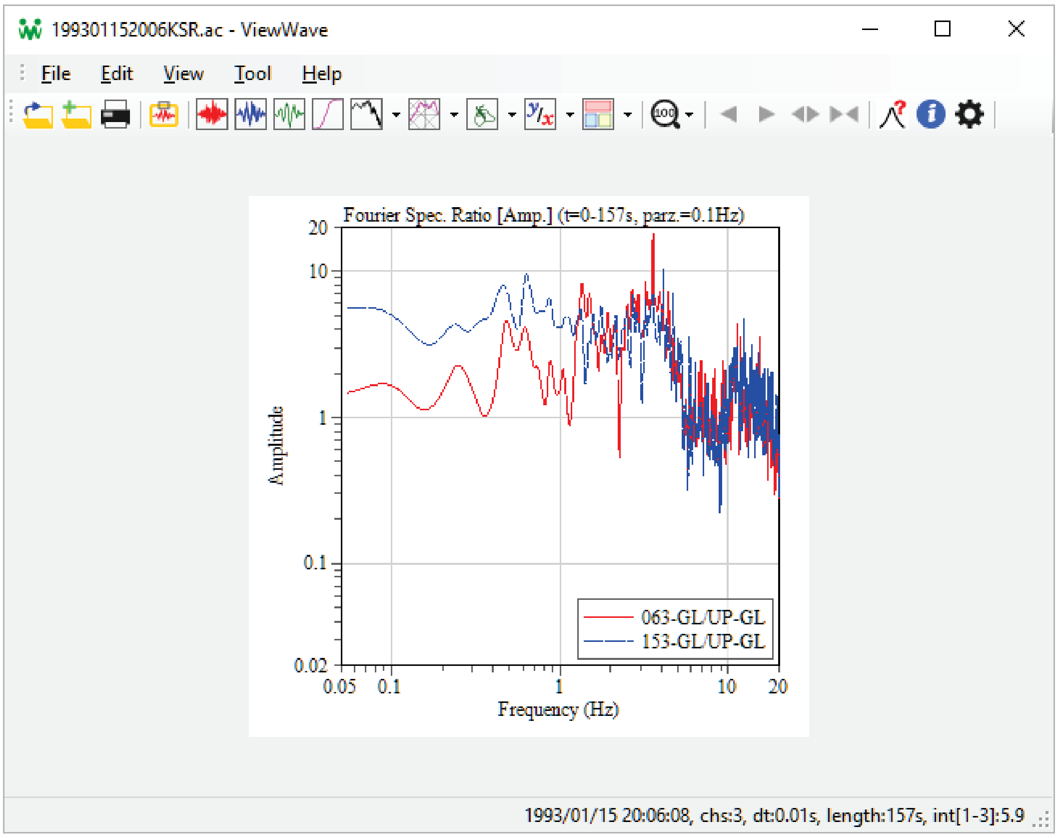
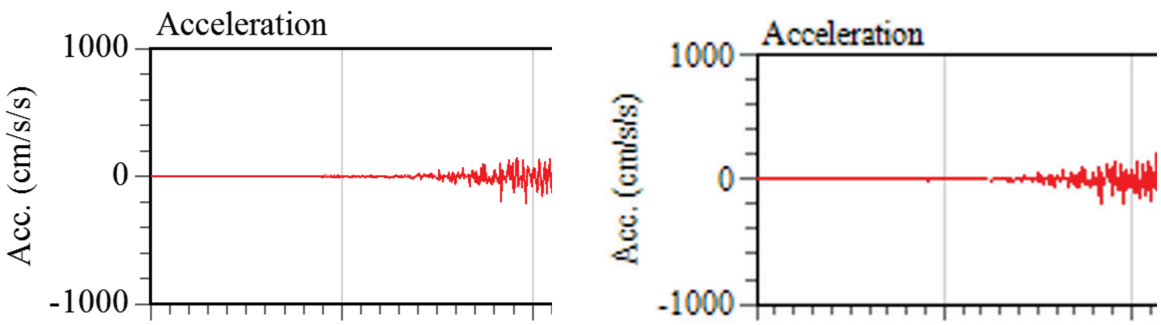


Fig. 9 A sample of Fourier spectrum ratios

2.7. Copying and pasting graphs

There are two ways to send a graph to Windows clipboard. The [**Copy**] submenu in the [**Edit**] menu sends the current graph to the clipboard as a Windows enhanced metafile (EMF) data. The [**Copy as image**] submenu in the [**Edit**] menu sends the current graph to the clipboard as a bitmap image. Shortcut keys [**Ctrl**] + [**C**] and [**Ctrl**] + [**Shift**] + [**C**] are allocated to [**Copy**] and [**Copy as image**] functions, respectively.

The graph sent to the clipboard can be pasted into your document as usual.



(a) Copied and pasted as EMF *(b) Copied and pasted as image*

Fig. 10 Graphs copied as EMF can retain its quality even enlarged

3. Usage

3.1. Menu

This section explains the functions of ***ViewWave*** according to the menu structure. ***ViewWave*** has five main menus as follows;

Fig. 11 Main menu of ViewWave

3.1.1. File menu

The [**File**] menu has the following submenus.

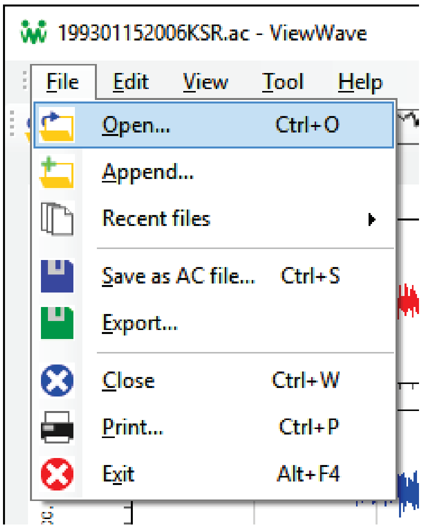


Fig. 12 File menu

(1) Open…

The [**Open…**] menu opens a new data file. This shows an open file dialog box. ***ViewWave*** discards current data if existing, and reads a specified data file.

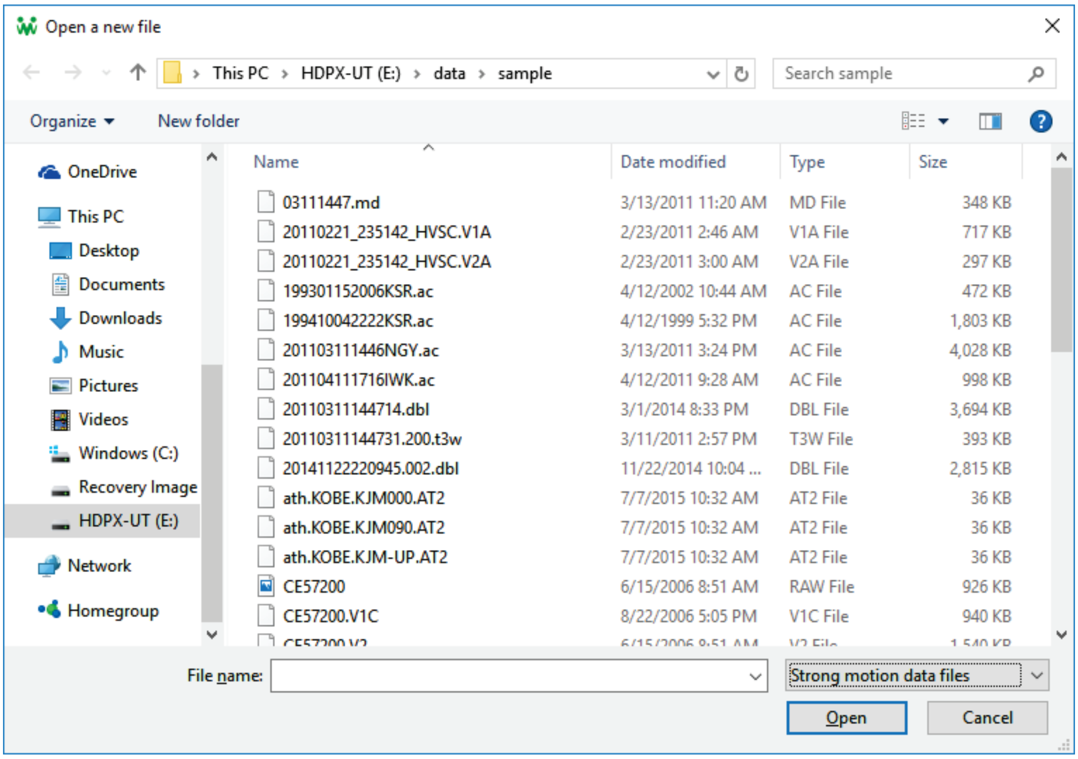


Fig. 13 Open file dialog box to read a strong motion data file

File filters on the open file dialog box make it easy to select a target file.

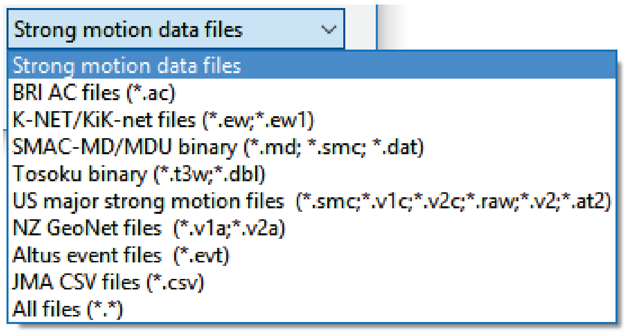


Fig. 14 File filters to read a strong motion data file

For strong motion data files supported by ***ViewWave***, please refer to Section 4.1.

(2) Append…

This appends a data file to the current dataset. This shows the open file dialog box as well. The data channels in the specified file are added after the current channels. This will be useful to merge data files provided separately, e.g. USGS SMNP "SMC" files and PEER "AT2" files.

(3) Recent files

The files that were recently used are listed as the sub-submenus. ***ViewWave*** can hold up to 10 files as the recently used files.

(4) Save as AC file…

This menu saves the current dataset to a file following the "AC" file format. This shows a file save dialog box to specify the output file.

(5) Export…

This menu saves the current dataset as an ASCII text file. Further information will be given in Section 3.7.

(6) Close

This menu discards the current data and clears the graph.

(7) Print…

This menu prints the current graph. A print dialog box will appear to select a printer and set options.

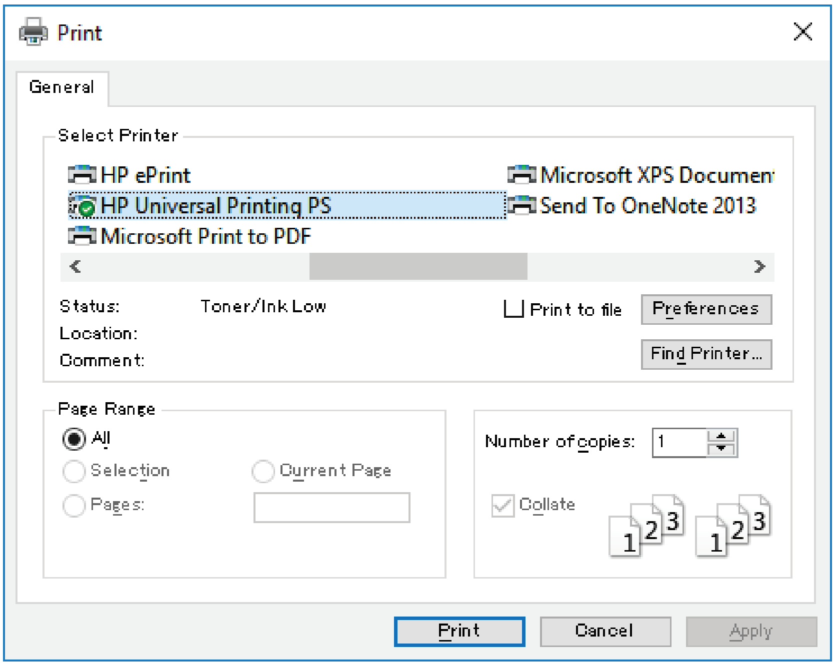


Fig. 15 [Print…] submenu calls a print dialog box to print the current graph

(8) Exit

This submenu terminates ***ViewWave***.

3.1.2. Edit menu

The **[Edit]** menu contains three submenus;

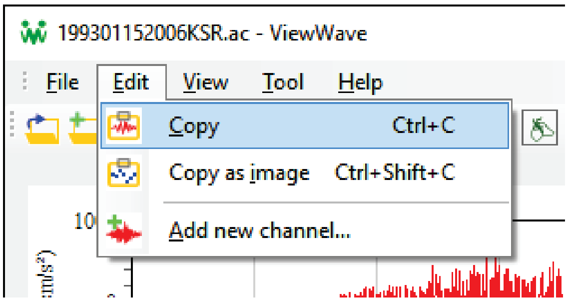


Fig. 16 Edit menu

(1) Copy

This submenu sends the current graph to the clipboard as a Windows enhanced metafile (EMF). ***ViewWave*** creates the EMF data as full vector graphics, so its quality is retained even enlarged.

(2)　Copy as image

This submenu sends the current graph to the clipboard as a bitmap image. For the difference between [**Copy**] and [**Copy as image**], please refer to Section 2.7.

(3)　Add new channel…

This creates a new channel of data by an arithmetic operation of two existing channels. You need to specify two channels and multiplying factors to add a new channel.

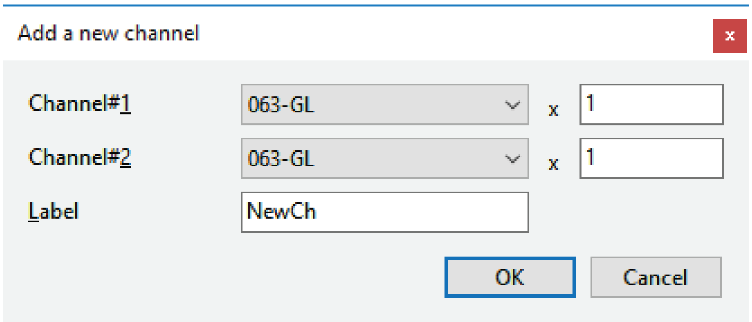


Fig. 17　[Add a new channel] dialog box requires parameters

The arithmetic operation is as follows;

$$x_{new}(t) = a_1 x_1(t) + a_2 x_2(t) \quad (1)$$

where $x_{new}(t)$ is acceleration data of a new channel, $x_1(t)$ and $x_2(t)$ are acceleration data of the existing channels, a_1 and a_2 are multiplier factors.

The channels #1 and #2 can be selected from the drop-down list boxes and the multiplier factors can be set in the text boxes on the right side. A label to identify the new channel is also required to be set.

3.1.3.　View menu

The [**View**] menu has submenus to select graphs and to change some visual settings on graphs. Most of submenus are titled graph types. By selecting a submenu, the specified graph is plotted as the current graph.

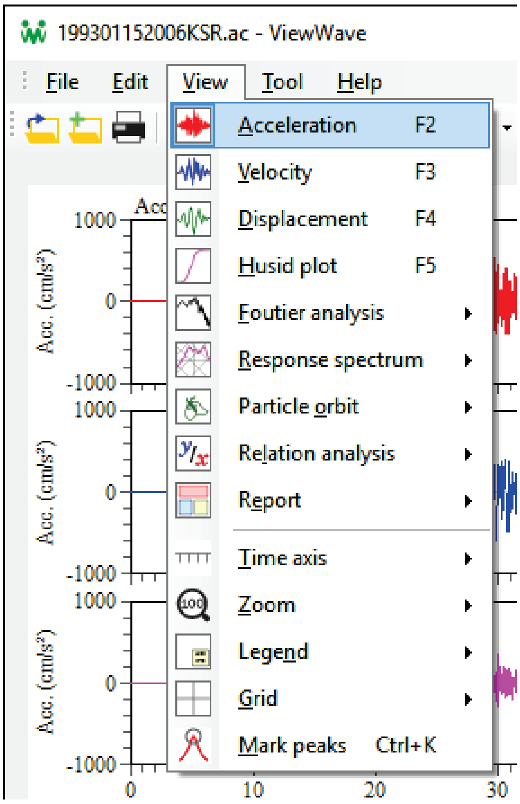


Fig. 18 View menu

(1) Acceleration

This submenu shows acceleration waveforms.

(2) Velocity

This submenu shows velocity waveforms. The integration method to calculate the velocity can be selected from the [**Calculation**] tab in the [**Option**] dialog box that can be opened from the menu [**Tool**] -> [**Option**].

(3) Displacement

This submenu shows displacement waveforms. The integration method to calculate the displacement can be selected from the [**Calculation**] tab in the [**Option**] dialog box.

(4) Husid plot

This submenu shows Husid plots. A Husid plot is the time history of the normalized Arias intensity. For more information, please refer to Section 5.5.

(5) Fourier analysis

This submenu contains the following sub-submenus. Those are results of the Fourier analysis (See Section 5.6).

- Fourier spectrum [amplitude]
- Power spectrum
- Auto correlation coefficient

(6) Response spectrum

This submenu contains the following sub-submenus to select a type of response spectra.

- Acceleration response spectrum [Sa]
- Velocity response spectrum [Sv]
- Displacement response spectrum [Sd]
- Tripartite pseudo Sv [pSv]
- Energy spectrum [Ve]
- Sa-Sd curve

The response spectrum is a plot of the maximum response of a single-degree-of-freedom system having a certain damping ratio as a function of its natural period. Three types of movement, i.e. acceleration, velocity and displacement, are treated as the response. So ***ViewWave*** can display the acceleration [Sa], velocity [Sv] and displacement [Sd] response spectra.

Another response spectrum, which is called the pseudo response spectrum [pSv], is usually utilized in the tripartite plot of the response spectrum. The tripartite plot has horizontal and vertical axes scaled in logarithm and diagonal axes representing acceleration and displacement scales. If you specify a linear axis for the horizontal or vertical axis, the diagonal axes are not drawn. The pseudo response spectrum in ***ViewWave*** is calculated from the acceleration response spectrum. Further information will be given in Section 5.7.

The energy spectrum [Ve] is a plot of the total energy input to a single-degree-of-freedom system having a certain damping ratio as a function of its natural period. More information is given in Section 5.8.

The Sa-Sd curve is a plot representing the relation between the maximum acceleration response [Sa] and maximum displacement response [Sd] of various periods. It is sometimes called the Acceleration-Displacement Response Spectra (ADRS) format.

(7) Particle orbit

A type of the particle orbit can be selected from the following three sub-submenus.

- Acceleration
- Velocity
- Displacement

An acceleration sensor normally has three channels of data in the three directions orthogonal to each other. So the movement of a sensor is in three dimensions and can be projected to a plane. ***ViewWave*** calls such projection a particle orbit. This is also referred to as a Lissajous plot (or curve). As a particle orbit, ***ViewWave*** takes two channels being orthogonal and plots on an X-Y graph. Acceleration, velocity and displacement can be selected as the plotting data. A pair of channels for a particle orbit can be set in the [**Channel**] tab on the [**Option**] dialog box.

(8) Relation

This submenu contains the following sub-submenus. Those are results of the relation analysis (See Section 5.9).

- Fourier spectral ratio [amplitude]

- Fourier spectral ratio [phase]
- Cross spectrum
- Cross-correlation coefficient
- Coherence
- Response spectral ratio
- Fourier spectral ratio [real]
- Fourier spectral ratio [imaginary]

Plural pairs of channels can be plotted in a graph and the combination of channels can be specified in the [**Channel**] tab on the [**Option**] dialog box.

(9) Report

A report that is a combination of various graphs can be selected. Please refer to Subsection 3.4.6 and Section 3.6 for further information.

(10) Time axis

Selecting one of the following sub-submenus, time axis of waveforms can be controlled.

- **Backward**: shifts waveforms backward.
- **Forward**: shifts waveforms forward.
- **Magnify**: magnifies time of waveforms.
- **Reduce**: reduces time of waveforms.

(11) Zoom

Selecting one of the following sub-submenus, the graph is zoomed in or out.

- **50%**: zooms out to 50% of original.
- **75%**: zooms out to 75% of original.
- **100%**: returns to original.
- **125%**: zooms in to 125% of original.
- **150%**: zooms in to 150% of original.
- **200%**: zooms in to 200% of original.

(12) Legend

Selecting one of the following sub-submenus, the legend position is changed.

- **None**: hides the legend.
- **Upper left**: places the legend on the upper left corner.
- **Upper right**: places the legend on the upper right corner.
- **Lower left**: places the legend on the lower left corner.
- **Lower right**: places the legend on the lower right corner.
- **Change cyclically**: changes the legend place cyclically.

(13) Grid

Selecting one of the following sub-submenus, the grid style is changed.

- **None**: hides the grid.
- **Major**: plots grid lines at the positions of major ticks.

- **Full**: plots grid lines at the positions of all ticks.
- **Change cyclically**: changes the grid style cyclically.

(14) Mark/Unmark peaks

This submenu switches visibility of marks on peaks of waveforms and spectra. The shape of marks can be specified on the [**Appearance**] tab in the [**Option**] dialog box.

3.1.4. Tool menu

The [**Tool**] menu has several submenus related to settings and information. Submenus that control visibilities of the tool bar, status bar and menu bar are also placed here.

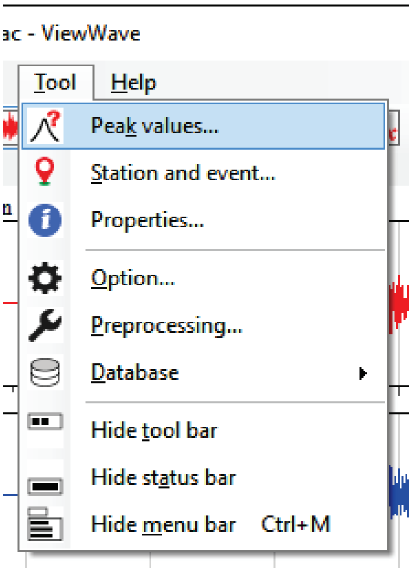


Fig. 19 Tool menu

(1) Peak values…

This submenu shows a window containing the peak values of data on the current graph.

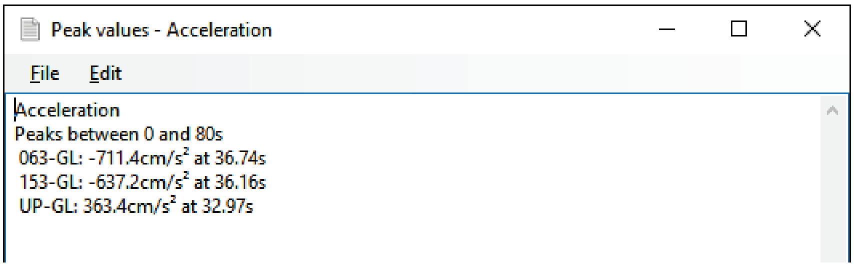


Fig. 20 A sample of a window showing peak values

(2) Station and event…

This submenu shows the [**Station and event**] dialog box. In the dialog box, you can see information on the strong motion station and the seismic event. The information is obtained from the data file and can be inquired to databases. Use of databases is explained in Chapter 3.9.

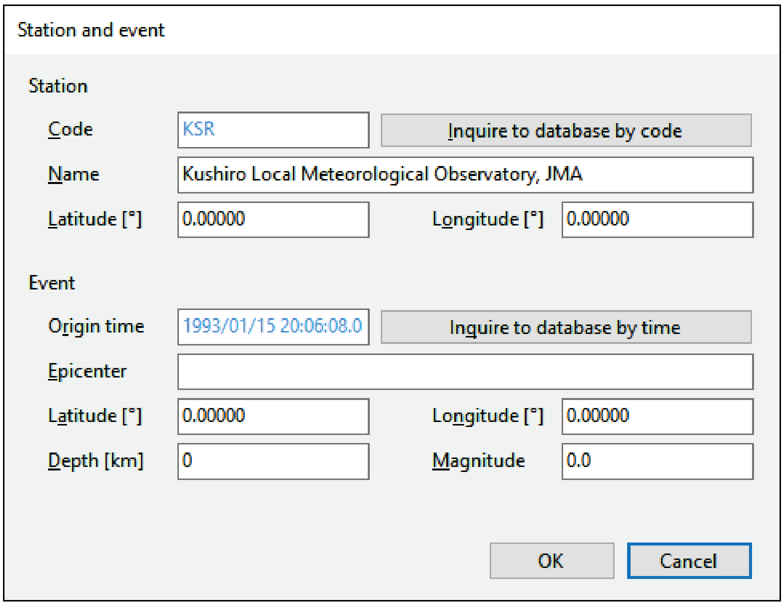


Fig. 21 A sample of station and event dialog box

(3) Properties…

This submenu shows a window to show the information on the strong motion data.

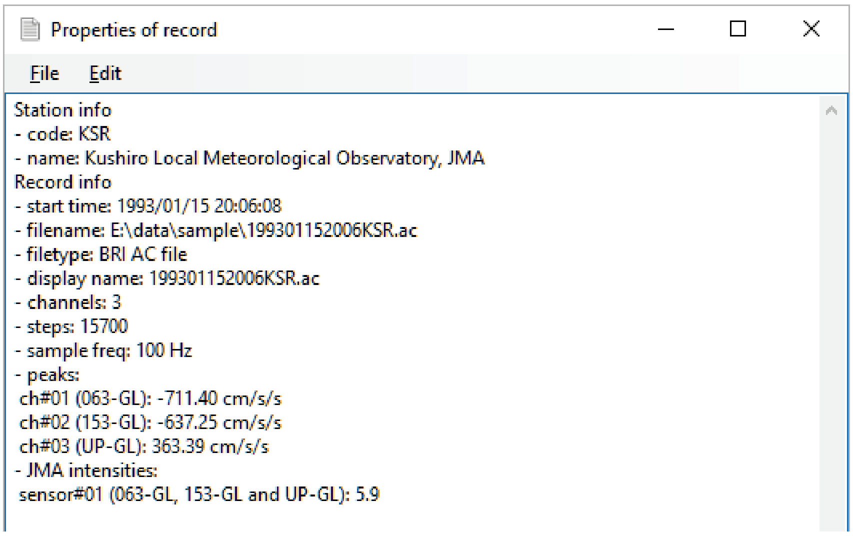


Fig. 22 A sample of a window showing properties

(4) Option…

This submenu shows the [**Option**] dialog box. Please refer to Chapter 3.4.

(5) Preprocessing…

This submenu shows the [**Preprocessing**] dialog box. Please refer to Chapter 3.5.

(6) Database

This submenu has two sub submenus to specify database settings for stations and events.

ViewWave can use databases to get information on strong motion stations and seismic events. The databases for the strong motion stations and the seismic events are specified individually.

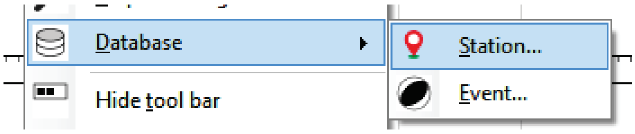


Fig. 23 Databases for station and events can be selected

The station database requires the following parameters;

- ☐ **Use station database**: enables to set the following parameters if checked.
- **Source**: is a database filename.
- **Table**: is a table name.
- **Fields**: requires following fields to be specified.
  - **Code**: is a field of station codes. This will be a unique identifier.
  - **Name**: is a field of station names.
  - **Latitude**: is a field of station latitudes.
  - **Longitude**: is a field of station longitude.

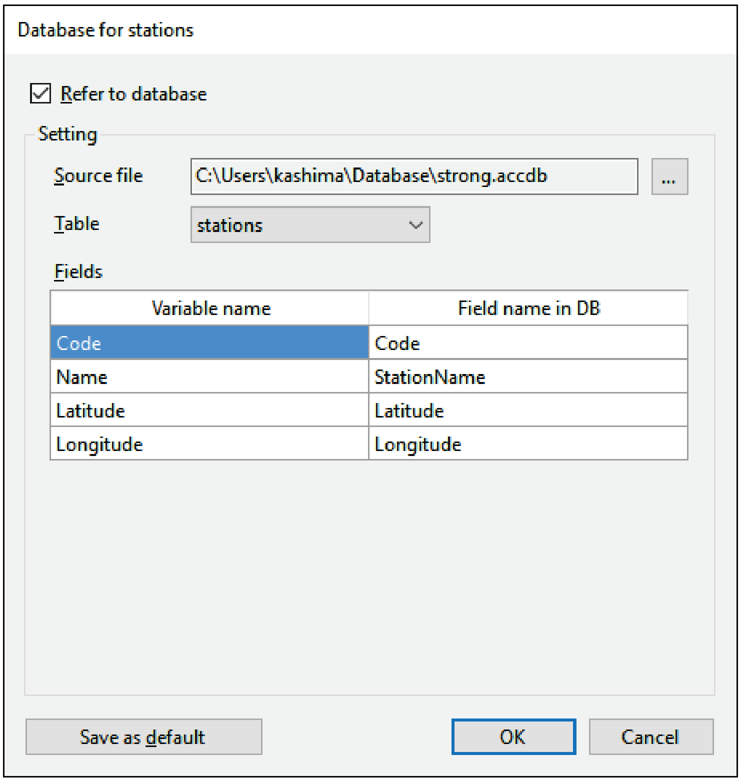


Fig. 24 Database tab in the Option dialog box

The event database requires the following parameters;

- ☐ **Use event database**: enables to set the following parameters if checked.
- **Source**: is a database filename.
- **Table**: is a table name.
- **Fields**: require following fields to be specified.
  - **Origin time**: is a field of origin time.
  - **Epicenter**: is field of epicenter names or event names.
  - **Latitude**: is a field of event latitudes.

- **Longitude**: is a field of event longitudes.
- **Depth**: is a field of event depths.
- **Magnitude**: is a field of event magnitudes.

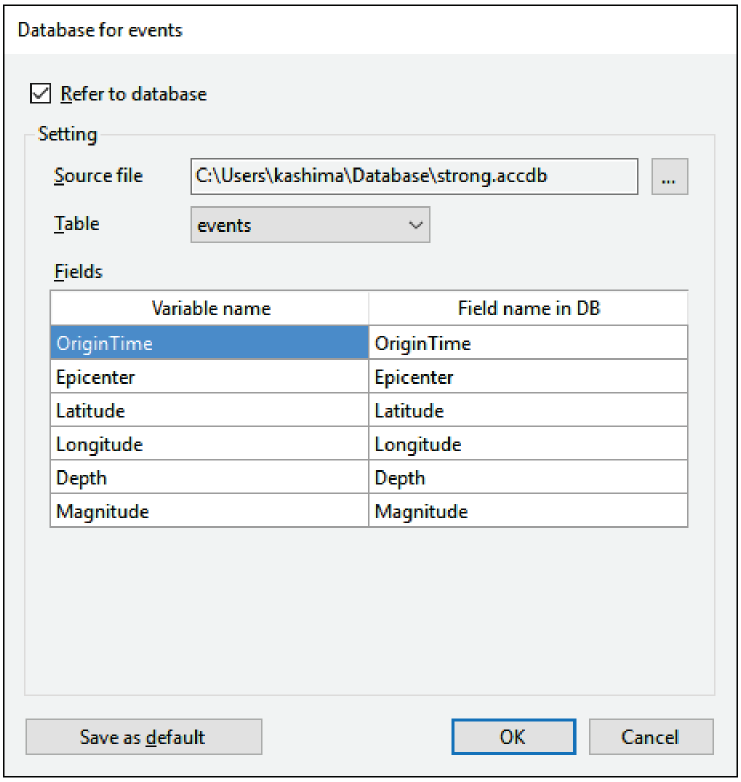


Fig. 25 Database tab in the Option dialog box

(7) Hide/Show tool bar

This submenu switches visibility of the tool bar.

(8) Hide/Show status bar

This submenu switches visibility of the status bar.

(9) Hide/Show menu bar

This submenu switches visibility of the main menu.

3.1.5. Help menu

The Help menu has the following submenus;

(1) Visit website

This submenu opens the ViewWave website using the default browser.

(2) About…

This submenu shows you a typical about box as follows.

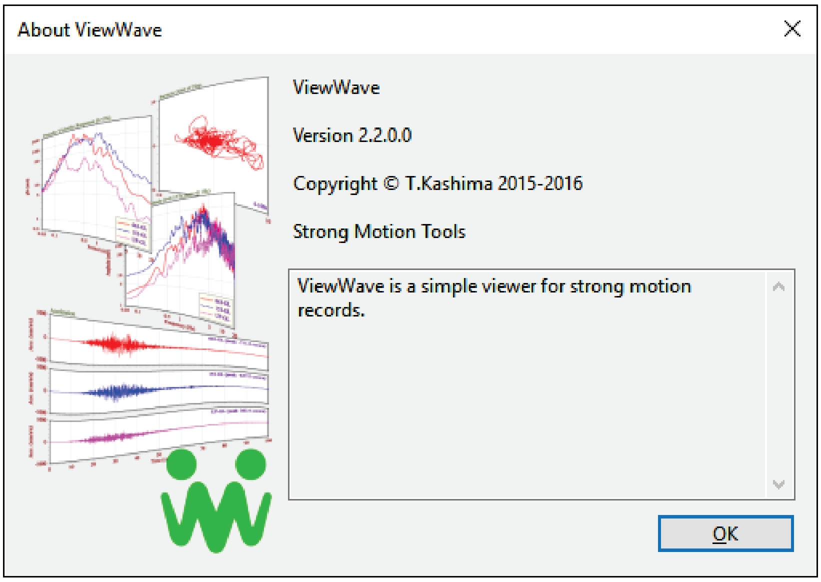


Fig. 26 About box

3.2. Tool bar

Buttons on the tool bar can be used as shortcuts to the function assigned to the submenus.

Fig. 27 ViewWave tool bar

Each button has a function which is allocated the following menu;

[File] -> [Open…]

[File] -> [Append…]

[File] -> [Print…]

[Edit] -> [Copy]

[View] -> [Acceleration]

[View] -> [Velocity]

[View] -> [Displacement]

[View] -> [Fourier analysis] Inverted triangle (▾) shows submenus.

[View] -> [Response spectrum] Inverted triangle (▾) shows submenus.

[View] -> [Particle orbit] Inverted triangle (▾) shows submenus.

[View] -> [Relation] Inverted triangle (▾) shows submenus.

[View] -> [Report] Inverted triangle (▾) shows submenus.

[View] -> [Zoom] Inverted triangle (▾) shows submenus.

[View] -> [Time axis] -> [Backward]

[View] -> [Time axis] -> [Forward]

[View] -> [Time axis] -> [Magnify]

 [View] -> [Time axis] -> [Reduce]

 [Tool] -> [Peak values…]

 [Tool] -> [Properties…]

 [Tool] -> [Options…]

3.3. Shortcut key

ViewWave assigns the following shortcut keys;

[Ctrl] + [C]	Copy a current graph and send it to the clipboard as EMF
[Ctrl] + [Shift] + [C]	Copy a current graph and send it to the clipboard as image
[Ctrl] + [G]	Change grid style
[Ctrl] + [K]	Switch visibility of peak marks
[Ctrl] + [L]	Change legend position
[Ctrl] + [M]	Hide/show menu bar
[Ctrl] + [O]	Open a new data file
[Ctrl] + [P]	Print a current graph
[Ctrl] + [S]	Save current data to a file as AC file
[Ctrl] + [W]	Close current data
[Alt] + [F4]	Terminate ViewWave
[F2]	Show acceleration waveforms
[F3]	Show velocity waveforms
[F4]	Show displacement waveforms
[F5]	Show Husid plot
[F6]	Show Fourier spectrum [amplitude]
[F7]	Show power spectrum
[F8]	Show auto-correlation coefficient
[Shift] + [F2]	Show acceleration response spectrum
[Shift] + [F3]	Show velocity response spectrum
[Shift] + [F4]	Show displacement response spectrum
[Shift] + [F5]	Show pseudo velocity response spectrum as tripartite plot
[Shift] + [F6]	Show energy spectrum
[Ctrl] + [F2]	Show acceleration particle orbit
[Ctrl] + [F3]	Show velocity particle orbit
[Ctrl] + [F4]	Show displacement particle orbit

3.4. Settings

Various settings can be controlled from the [**Option**] dialog box that is opened by choosing the menu **[View] -> [Option...]**. The [**Option**] dialog has nine tabs as follows.

- **Axis**
- **Appearance**
- **Channel**
- **Size**

- **Calculation**
- **Report**
- **Extra**
- **Misc.**

There are four buttons on the lower side of the [**Option**] dialog box to deal with the settings.

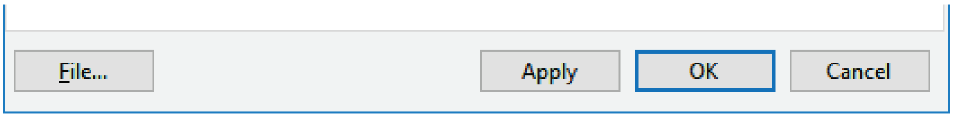


Fig. 28 Buttons on the Option dialog box

- **[File…]**: Load or save settings from/to a file, set current setting as default, or delete default settings.
- **[Apply]**: Apply changes and refresh the graph
- **[OK]**: Close the dialog and apply changes.
- **[Cancel]**: Cancel all changes and close the dialog.

The settings, which can be changed in the [**Option**] dialog box, can be saved as the default settings or to a setting file. By clicking [File…] button, the menu will appear as follows;

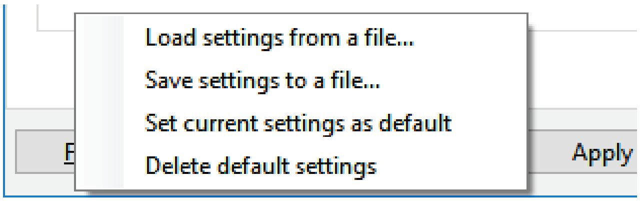


Fig. 29 File menu in the Option dialog box

- **[Load settings from a file…]**: loads settings from a file which was saved previously.
- **[Save settings to a file…]**: saves current settings to a file.
- **[Set current settings as default]**: saves current settings as the default settings. This saves settings to the special file that is loaded when *ViewWave* starts.
- **[Delete default settings]**: deletes the default setting file.

3.4.1. Axis tab

A scale and a label of an individual axis can be edited on the [**Axis**] tab. Available axes are listed in the list box on the left side. By selecting an axis, axis parameters appear on the right side.

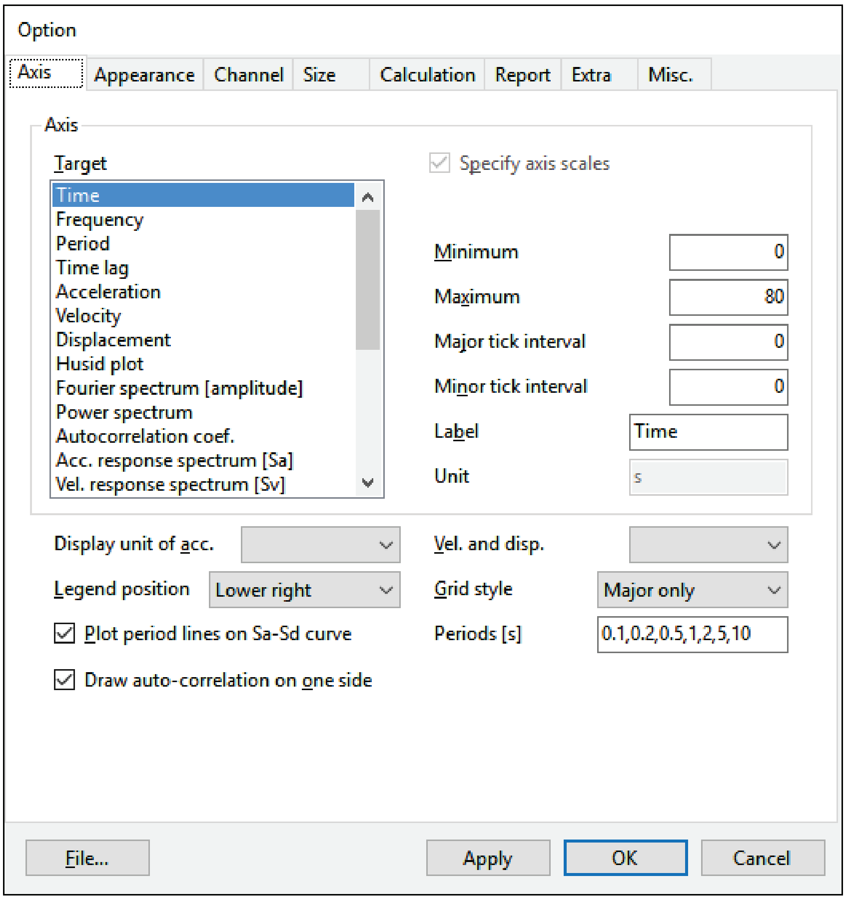


Fig. 30 Axis tab in the Option dialog box

There are eight axis parameters.

- ☐ **Specify axis scales**: uses parameters specified if checked. If not checked, the parameters suitably adjusted by ***ViewWave***. In cases of [**Time**], [**Frequency**], [**Period**] and [**TimeLag**] axes, the parameters must be specified by users.
- ☐ **Scale in logarithm**: uses a logarithm axis if checked. It disappears when the logarithm axis is not available, such as the [**Time**] axis, the [**Acceleration**] axis, etc.
- **Minimum**: specifies the minimum value of the axis. In some cases, it disappears because only the maximum value is necessary. In case of waveforms, the minimum value is always a negative of the maximum value. In case of linear vertical axis of a spectrum, the minimum value is always zero.
- **Maximum**: specifies the maximum value of the axis.
- **Major tick interval**: sets the interval of major ticks. Ticks and annotating values are drawn. Zero to leave it to ***ViewWave***. If the logarithm axis is selected, it cannot be specified.
- **Minor tick interval**: sets the interval of minor ticks. Only ticks are drawn. Zero to leave it to ***ViewWave***. If the logarithm axis is selected, it cannot be specified.
- **Label**: sets the label of the axis.
- **Unit**: displays the unit of the current axis. This is not editable.

In addition, [**Axis**] tab has the following settings.

- **Display unit of acc.**: selects a display unit of acceleration from "cm/s²", "cm/s/s", "m/s²", "m/s/s", "gal", "g" and "G".
- **Vel. and disp.**: selects display units of velocity and displacement "cm/s, cm" and "m/s, m".
- **Legend position**: select a legend position from "None", "Lower-left", "Upper-left", , "Lower-right" and "Upper-right".
- **Grid style**: select a grid style from "None", "Major only" and "Full".
- **Periods to be plotted on Sa-Sd curve**: Specifies periods to be plotted on a Sa-Sd curve.
- **☐ Draw auto-correlation on one side**: plots auto-correlation coefficients on the single side if checked. The auto-correlation coefficients are also calculated in the negative range, but it must be symmetric.

3.4.2. Appearance tab

Appearance of most elements of graphs can be controlled in the [**Appearance**] tab. The elements appear in the list box on the left side.

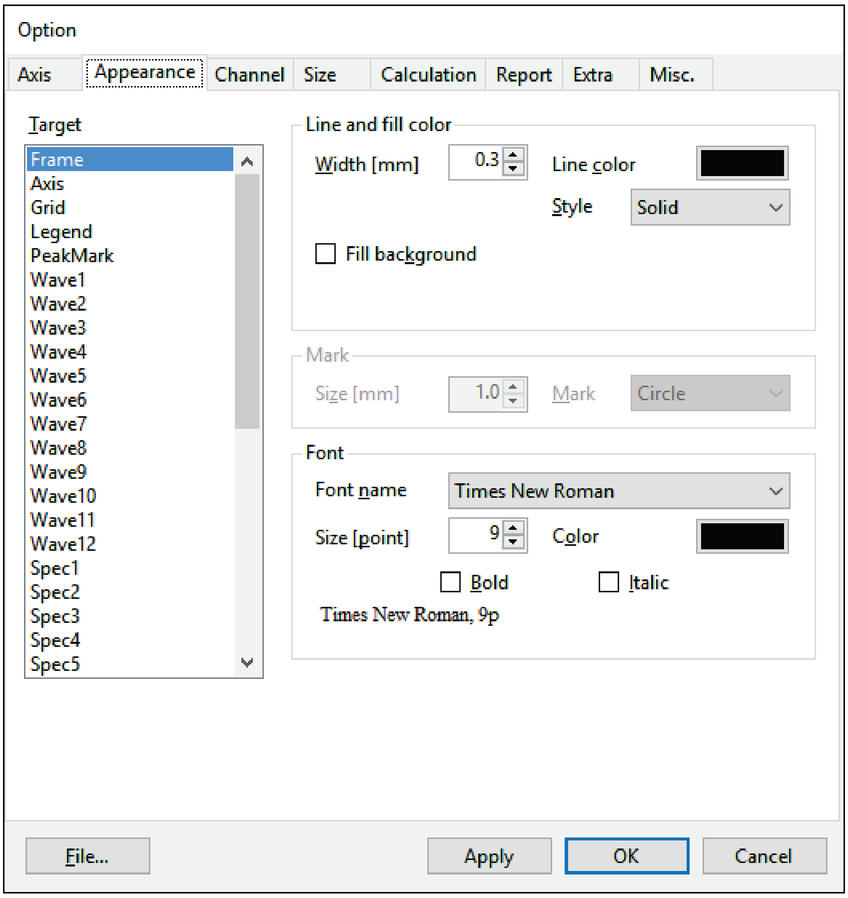


Fig. 31 Appearance tab in the Option dialog box

After selecting an element in the list box on the left hand side, you can see and change line attributes, namely, width, color and style. The elements are;

- **Frame**: affects an outer frame of a graph. The font affects a graph title.
- **Axis**: affects X and Y axes of a graph. The font affects axis annotations and labels.
- **Grid**: affects grid lines of a graph. The font affects annotations on diagonal axes.
- **Legend**: affects an area to plot a legend. The font affects legend labels.

- **PeakMark**: affects marks plotted on peak positions.
- **Wave1 ~ Wave12**: affects lines to draw waveforms.
- **Spec1 ~ Spec12**: affects lines to draw spectra.
- **Extra1 ~ Extra12**: affects lines to draw extra data.

In the case of **Frame** and **Legend**, a fill color and an alpha value can be specified by checking [☐ **Fill background**]. The alpha value indicates the transparency effect in the range between 0 and 255, where 0 is fully transparent color and 255 is fully opaque color. In the case of **Frame**, **Axis**, **Grid** and **Legend**, font parameters can be edited as well. Those fonts affect the graph elements described in the list above. For **PeakMark**, the line attributes, fill color, size and shape of marks can be specified.

3.4.3. Channel tab

On the [**Channel**] tab, you can select channels to be plotted. Pairs of channels to draw particle orbits and to perform relation analysis can be set as well.

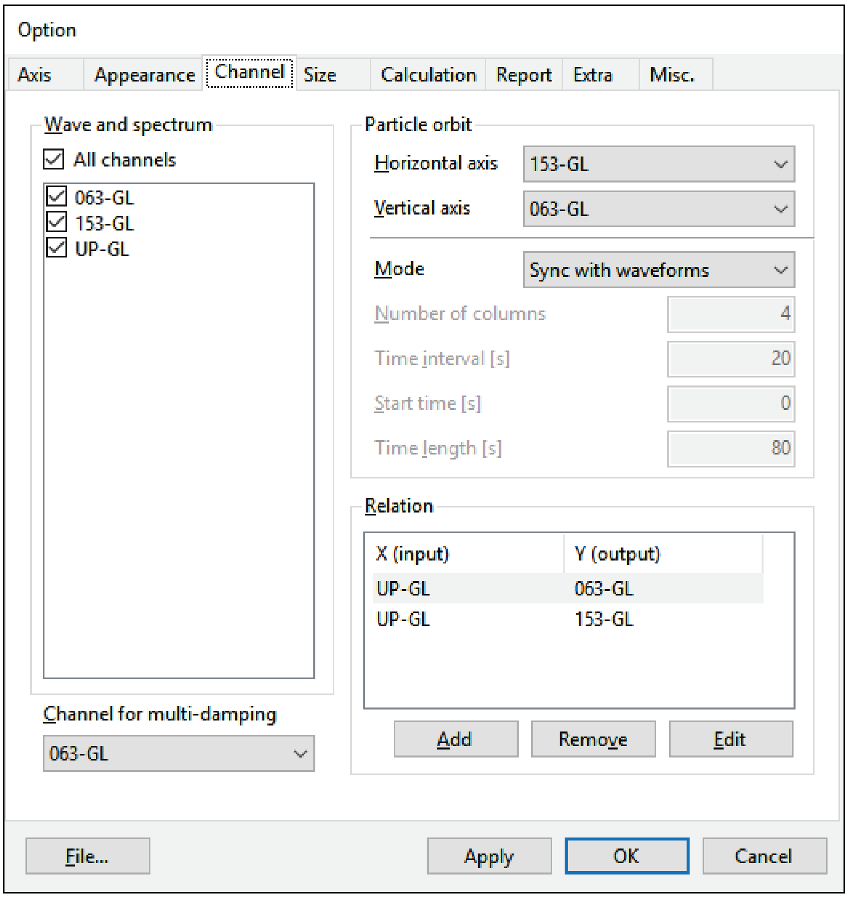


Fig. 32 Channel tab in the Option dialog box

The channels checked in the list box on the left side are plotted as waveforms, Fourier spectra and response spectra. By clicking on a label twice (or pressing [**F2**] key) like renaming in the Windows Explorer, you can edit the channel label.

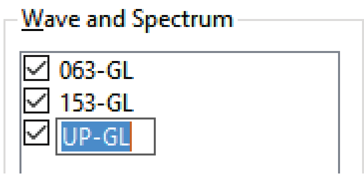


Fig. 33 Twice-clicking allows you to edit channel label

The channel to be used to plot multi-damping response spectra can be selected from the drop-down box at the lower left.

The pair of channels for the particle orbit can be selected in the upper-left group box. Two channels for the horizontal and vertical axes need to be selected from the dropdown boxes. In addition, the mode of plotting particle orbits can be chosen from the followings.

- **All time of record**: plots all time of the record.
- **Specified time**: plots the time range specified by [**Start time**] and [**Time length**].
- **Sync with waveforms**: plots the time range same with waveforms.
- **Multiple graph**: plots multiple graphs spliced by the specified time intervals.

Moreover, the [**Specified time**] and [**Multiple graph**] graphs require some parameters;

- **Number of columns**: sets the number of columns for plotting the [**Multiple graph**] graphs.
- **Time interval [s]**: sets the time intervals for slicing of the [**Multiple graph**] graphs.
- **Start time [s]**: sets the start time of [**Specified time**] and [**Multiple graph**] graphs to be plotted.
- **Time length [s]**: sets the time length of [**Specified time**] and [**Multiple graph**] graphs to be plotted.

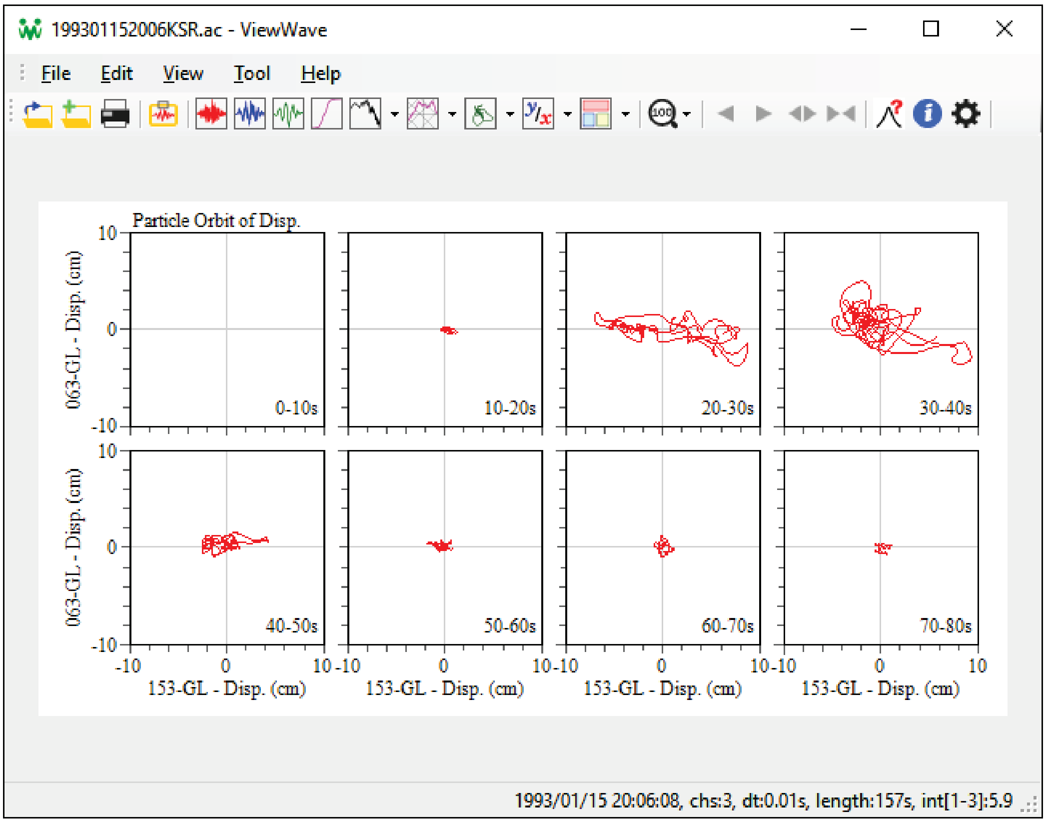


Fig. 34 A sample of multiple graphs of particle orbit

In the [**Relation**] group box, the channel pairs of the relation analysis can be set. Clicking [**Edit**] button after selecting a pair (or double clicking on it), a dialog box appears as follows. You may select a pair of channels for X (input) and Y (output) from this dialog box. The [**Add**] button adds a new channel pair and the [**Remove**] button removes selected channel pear.

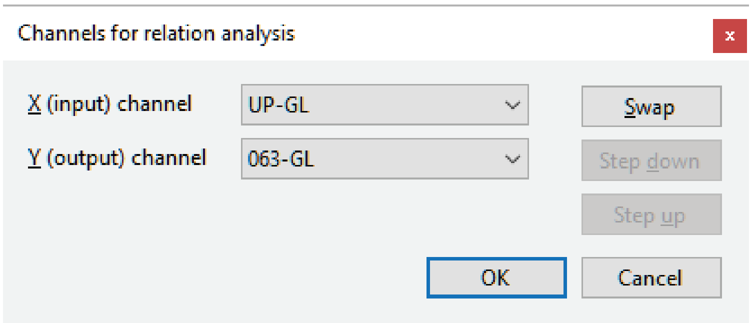


Fig. 35   Channel setting dialog box for relation analysis

3.4.4. Size tab

Sizes of graphs and graph elements can be set on the [**Size**] tab.

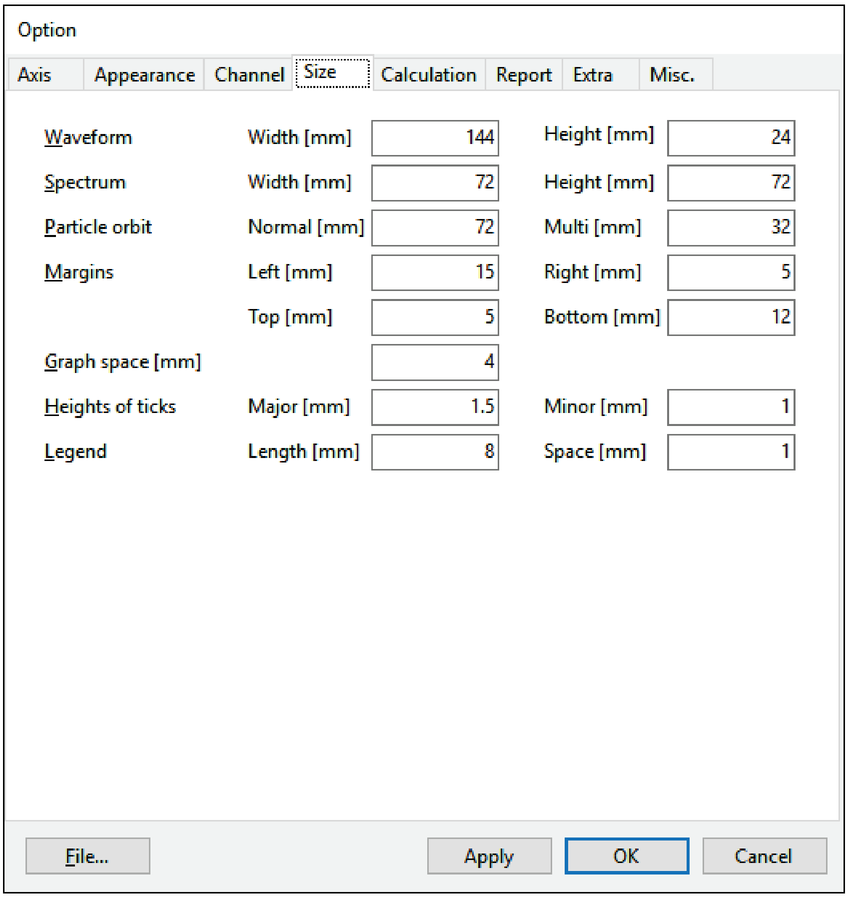


Fig. 36   Size tab in the Option dialog box

- **Waveform**: sets the width and height of waveforms.
- **Spectrum**: sets the width and height of graphs excepting waveforms and particle orbits.
- **Particle orbit**: sets the length of the sides of the normal and multiple orbit graphs (those are square).

- **Margins**: sets the left, right, top and bottom margins of the page.
- **Graph space**: sets the vertical spacing between two waveforms.
- **Heights of ticks**: sets the heights of major and minor ticks.
- **Legend**: sets the length of sample lines and space around the legend.

3.4.5. Calculation tab

On the [**Calculation**] tab, parameters for the integration, Fourier analysis and response spectrum are editable.

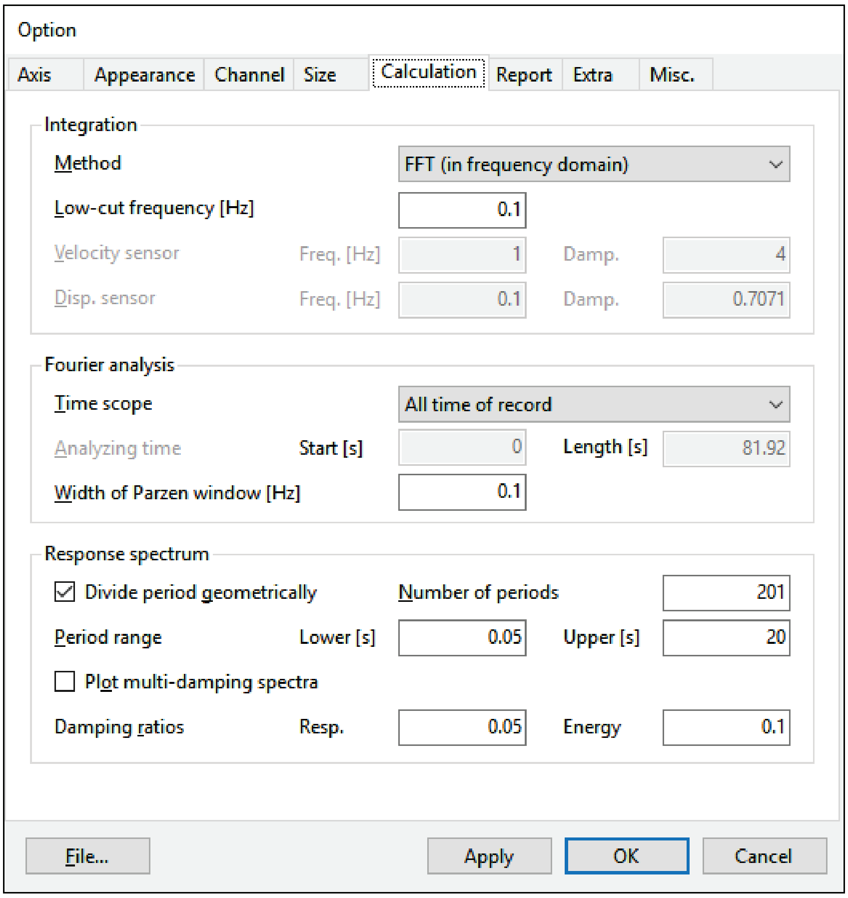


Fig. 37 Calculation tab in the Option dialog box

(1) Integration

As the integration method, there are choices as follows;

- **FFT (in frequency domain)**: integrates in the frequency domain using the Fast Fourier Transform (FFT).
- **Seismograph simulation**: integrates by simulating traditional seismographs.
- **Trapezoidal rule**: integrates based on the trapezoidal rule with the linear baseline correction of velocity.

[**Low-cut frequency**] needs to be set if [**FFT**] is selected. The natural frequencies and damping ratios of the velocity sensor and the displacement sensor must be specified if [**Seismograph simulation**] is selected. Please refer to Section 5.4 for more details.

(2) Fourier analysis

In the Fourier analysis, analyzing time can be selected as [**Time scope**] from the followings;

- **All time of record**: analyzes all time of the record.
- **Specified time**: analyzes the time range specified by [**Start time**] and [**Time length**].
- **Sync with waveforms**: analyzes the time range same with waveforms.

Specifying the [**Width of Parzen window**] is necessary in all cases. In addition, the start time and time length for analysis are required if [**Specified time**] is selected.

Further information is given in Section 5.6.

(3) Response spectrum

For response spectrum, the following parameters are needed.

- ☐ **Divide period geometrically**: divides period geometrically if checked. Otherwise it is divided arithmetically.
- **Number of periods**: sets the number of periods to be calculated.
- **Period range**: sets the calculation period range by the [**Lower**] and [**Upper**] periods.
- ☐ **Plot multi-damping spectra**: plots response spectra of a single channel with multi-damping instead of single-damping multi-channel spectra.
- **Damping ratio**: sets the damping ratios for Sa, Sv, Sd and pSv in the [**Resp.**] textbox, and for Ve in the [**Energy**] textbox. If the "multi-damping spectra" is selected, set damping ratios separated by commas.

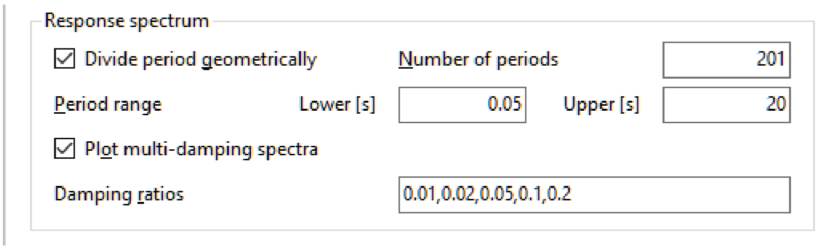


Fig. 38 Damping ratios for multi-damping spectra

Further information is given in Section 5.7.

3.4.6. Report tab

A report is a combination of various graphs. ***ViewWave*** can have several reports defined by users.

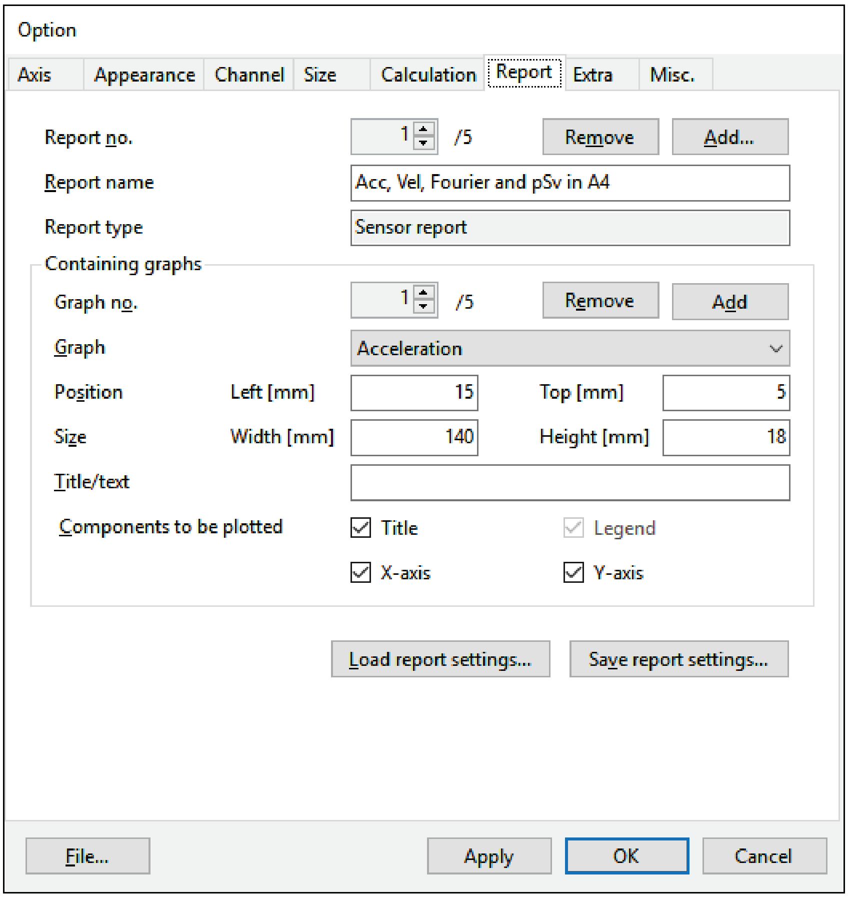


Fig. 39 Report tab in the Option dialog box

There are three types of report;

- **Combination report**: contains some of present graphs. It can contain relation graphs and particle orbit graphs in addition to waveforms and spectra.
- **Channel report**: contains waveforms and spectra of a single channel.
- **Sensor report**: contains waveforms and spectra of a single sensor. A sensor consists of three channels of records sequentially stored.

To add a report, click [**Add…**] button on the upper right corner. A context menu asks you to choose a report type.

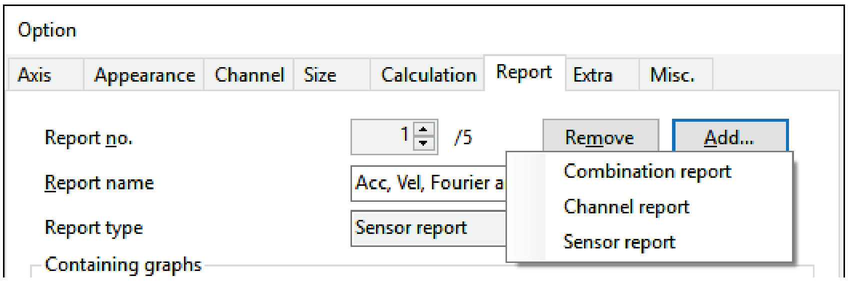


Fig. 40 Context menu to ask report type on the Report tab

An added report primarily has an acceleration waveform. You may change the graph type, the position and the size of the graph. The upper left corner is the origin of the coordinate system. The position of the graph is specified by the coordinates of the upper-left point of the graph. The unit of the position and size of graphs is millimeter. In addition, you may control visibilities of the title, legend, X-axis label and Y-axis label of each graph by checking the checkboxes. You can add another graph by clicking [**Add**] button in the [**Containing graphs**] group box.

In addition to the graphs of strong motion data, [**Text box**] can be selected as a graph. You can add some message to the report and use the placeholders (see Section 3.10) in the message.

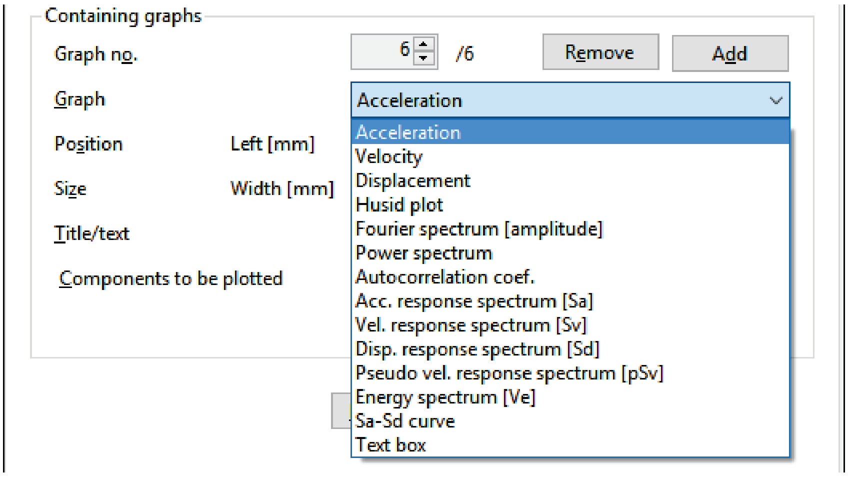


Fig. 41 Selectable graphs on the Report tab

For more information, please refer to Section 3.6.

3.4.7. Extra tab

In addition to graphs of the current strong motion data, you can add plots of extra data. For instance, if you have data of design spectra or response spectra of other strong motion data, you can compare with your data by overlaying those on your graph. The [Extra] tab manages the extra data to be plotted additionally.

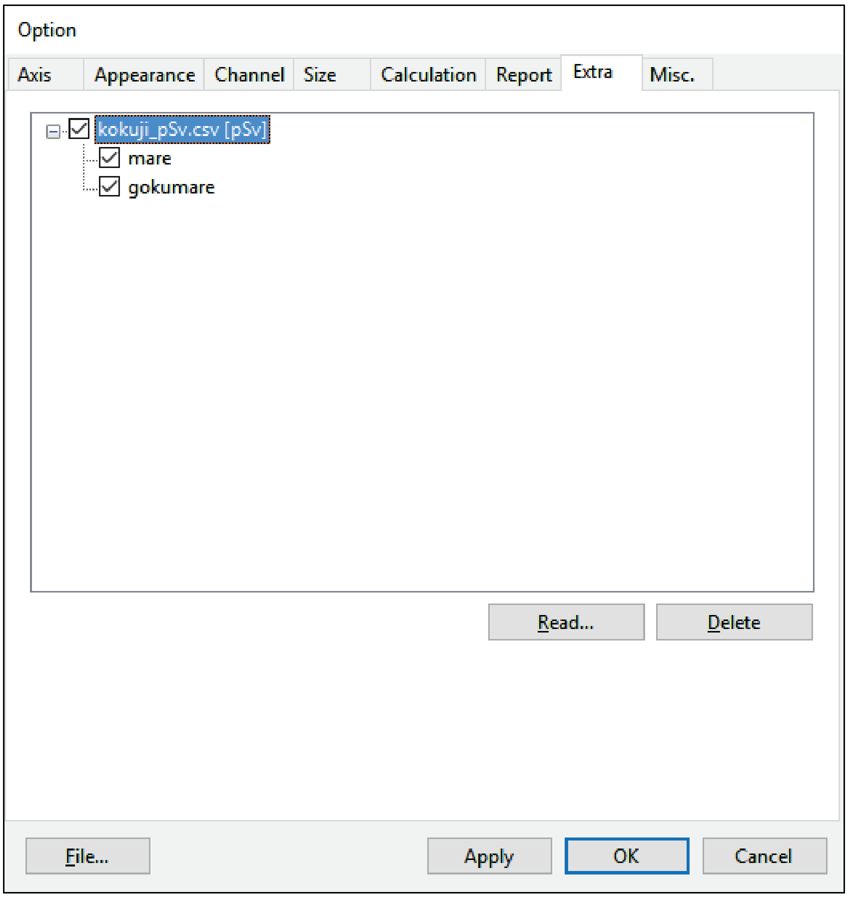


Fig. 42 Extra tab in the Option dialog box

Clicking the [**Read…**] button opens a file open dialog box to select an extra data file. After reading extra data files, data are listed in the tree view. To edit a data label, click on the label twice like renaming on the Windows Explorer. You can control the plotting by checking or unchecking those check boxes. [**Delete**] button deletes extra data currently focused.

For further information, please refer to Chapter. 3.8.

3.4.8. Misc. tab

Miscellaneous settings are arranged on the [**Misc.**] tab.

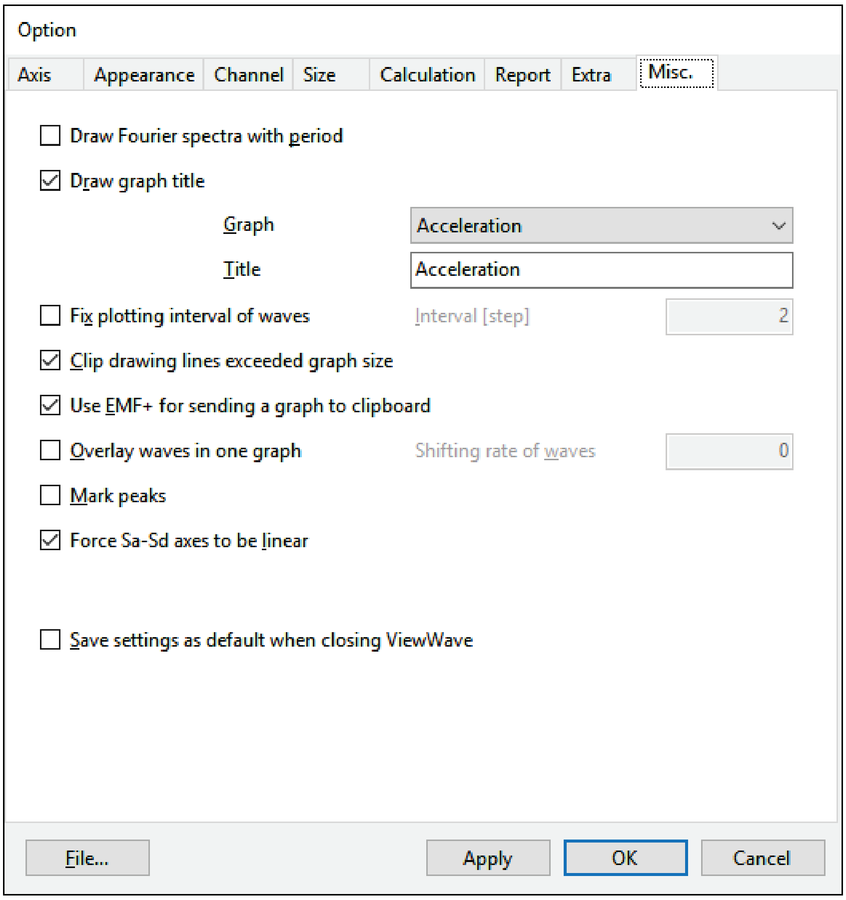
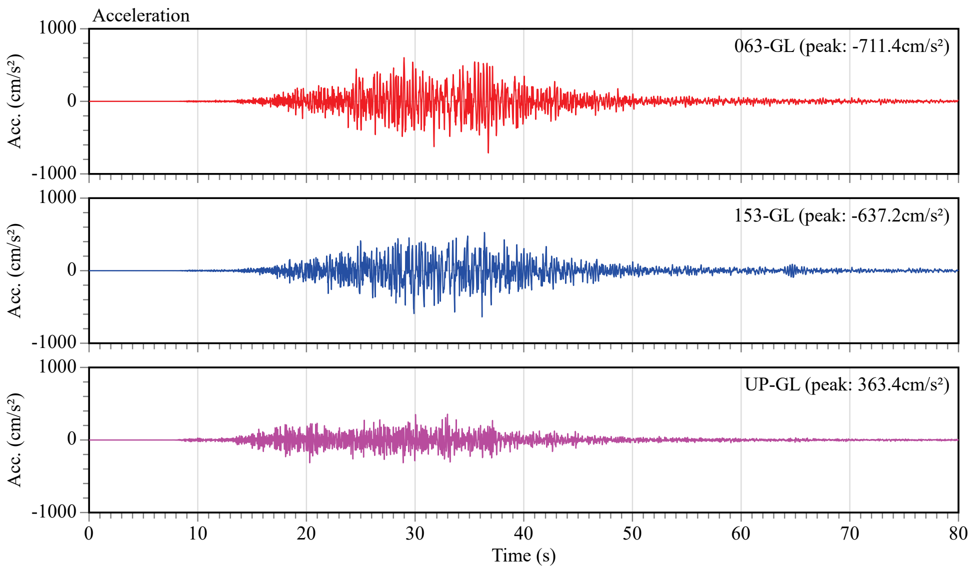


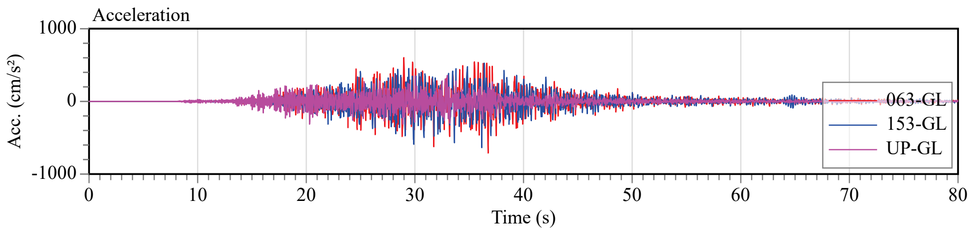
Fig. 43 Misc. tab in the Option dialog box

There are following items;

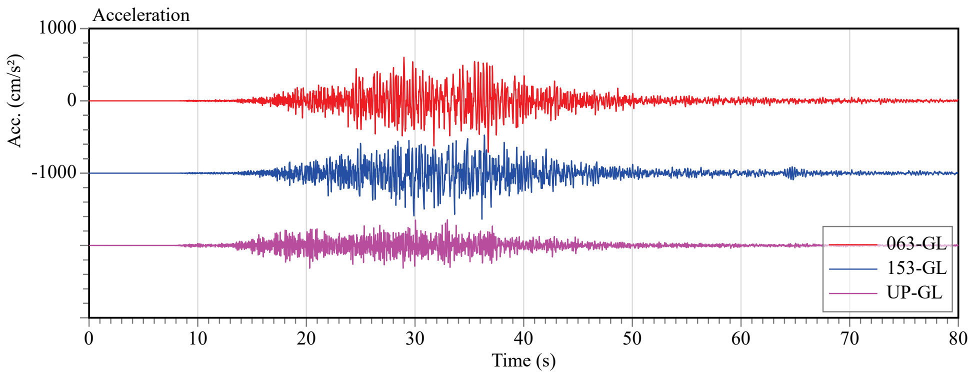
- ☐ **Draw Fourier spectra with period**: takes periods as the horizontal axis for spectra that are functions of frequencies, e.g. Fourier spectrum and Fourier spectrum ratio.
- ☐ **Draw graph title**: draws a title of a graph if checked. The title is drawn above the graph. You can edit the title of each graph.
- ☐ **Fix plotting interval of waves**: fixes an interval of plotting steps for waveforms to the given value if checked. It will be adjusted according to the spacing of plotting intervals if unchecked.
- ☐ **Clip drawing lines exceeded graph size**: clips drawing lines of waves and spectra if checked.
- ☐ **Use EMF+ for sending a graph to clipboard**: uses EMF+ when copy a graph and send to the clipboard, if checked. This is a reminder of development process, and will be needless. Anyway it is kept for the future.
- ☐ **Overlay waves in one graph**: plots all waveforms on one graph if checked. Usually those are plotted on separated graphs. If it is checked, you may specify the shifting rate of waves. When zero is set as the shifting rate, waves completely overlaid. The shifting rate 0.5 vertically shifts the next wave a half of the p-p value.



(a) [☐Overlay waves in one graph] is unchecked



(b) [☑Overlay waves in one graph] is checked (Shifting rate is 0)



(b) [☑Overlay waves in one graph] is checked (Shifting rate is 0.5)

Fig. 44 Appearance of waves

- ☐ **Mark peaks**: puts marks on the peak positions of waveforms and spectra.
- ☐ **Force Sa-Sd curve to be linear**: forces linear axes for both Sa and Sd even it logarithm axes are specified.
- ☐ **Save settings as default when closing ViewWave**: saves current settings as default if checked. Those are usually discarded when ***ViewWave*** terminates.

3.5. Preprocessing

Preprocessing means processes applying before displaying waveforms. The preprocessing parameters can be confirmed and changed in the [**Preprocessing setting**] dialog box that can be called from the menu [**Tool**] -> [**Preprocessing…**].

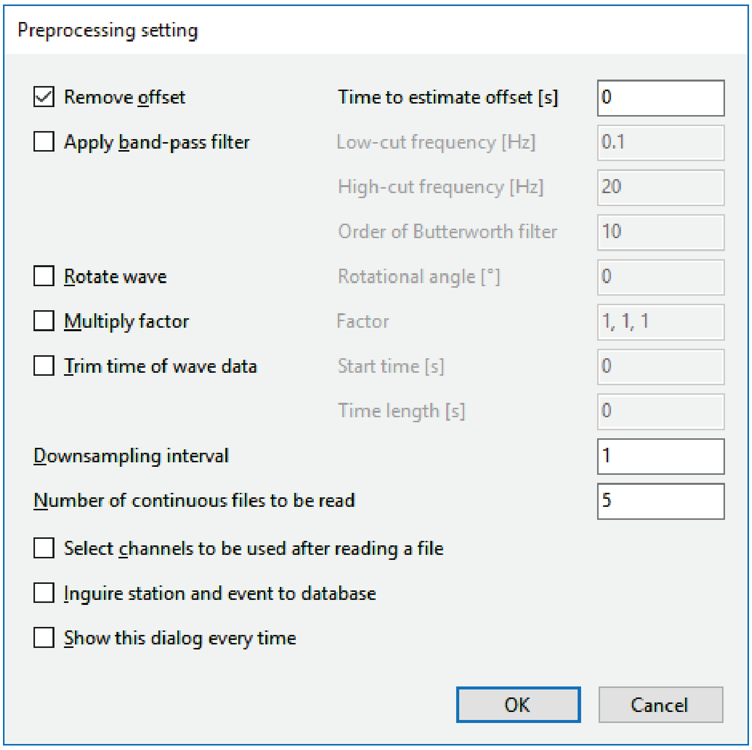


Fig. 45 Preprocessing setting dialog box

There are the following items;

- ☐ **Remove offset**: removes offsets of strong motion data using average values for the time given as [**Time to estimate offset**], if checked. If zero is given, the averages in the whole time are used as the offsets.
- ☐ **Use band-pass filter**: applies the band pass filter with given low-cut and high-cut frequencies to strong motion data if checked. The gain characteristics of the low- and high-cut filter are the Butterworth filter (amplitude only), so you may specify the order of the Butterworth filter as well. If zero is set to the order, JMA filters, that is used to calculate JMA intensity, are utilized instead. For further information, see Section 5.10.1.
- ☐ **Rotate wave**: rotates the strong motion data in the horizontal plane if checked. Channels must be stored in order of Y (North-South), X (East-West) and Z (Up-Down). [**Rotational angle**] gives the rotational angle in degrees. If [**Rotational angle**] is zero and the data file is a BRI AC file, the data is converted to the N000°E and N090°E directions. For further information, see Section 5.10.25.10.1.
- ☐ **Multiply factor**: multiplies strong motion data by given factors. Plural factors separated by commas can be given. Those factors are applied sequentially and cyclically.
- ☐ **Trim time of wave data**: trims the strong motion data by specified [**Start time**] and [**Time length**] if checked.

- **Downsampling interval**: specifies an interval of the downsampling of the strong motion data. If 1 is set, the downsampling is not made. If the original sampling frequency is 100 Hz, it will be reduced to 50 Hz if 2 is set as the downsampling interval.
- **Number of continuous files to be read**: specifies a number of files to be read in case of data files that can have continuous files, such as JMA-95 intensity meter files, Tokyo Sokushin T3W files.
- ☐ **Select channels to be used after reading a file**: shows a dialog box to pick channels to be used after reading a data file, if checked. The dialog box is like below. The left list box has a list of channels contained in the data file. You can move channels that you want to use by double-clicking on the label or the [->] button. Only the channels contained in the list box on the right side are used in *ViewWave*. This can be utilized to change the channel order from the original one.

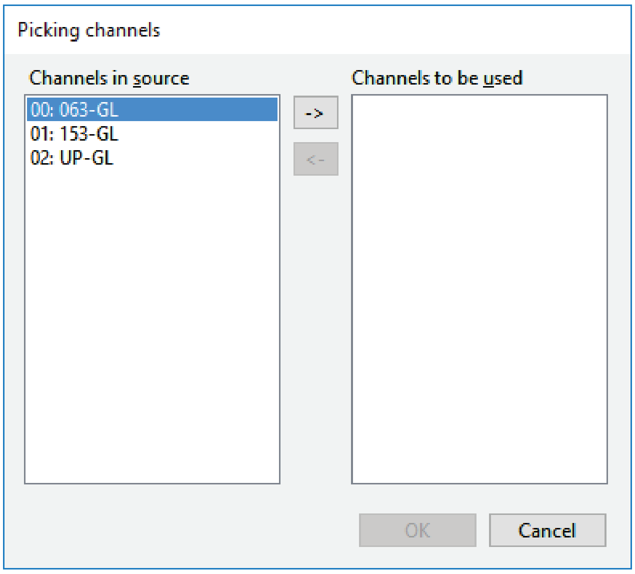


Fig. 46 Picking channels dialog box

- ☐ **Inquire station and event to database**: inquires information on station and event after reading a data file if checked.
- ☐ **Show this dialog every time**: shows this dialog every time after reading a data file if checked.

3.6. Report

ViewWave has a function to draw a report containing some graphs as mentioned in Subsection 3.4.6. There are three types of reports;

- **Combination report**: is a report contains some of present graphs. It can contain relation graphs and particle orbit graphs in addition to waveforms and spectra.
- **Channel report**: is a report contains waveforms and spectra of a single channel.
- **Sensor report**: is a report contains waveforms and spectra of a single sensor. A sensor consists of three channels of records sequentially stored.

ViewWave initially has four sample reports which are named;

- **Acc, Vel, Fourier and pSv in A4**: is a report similar with the report of *ViewWave* 1.xx.

- **Acc and pSv of a sensor in line**: is a sensor report containing acceleration waveforms and pseudo velocity response spectrum.
- **Waves of a channel**: is a channel report containing acceleration, velocity and displacement waveforms, and a Husid plot.
- **Transfer Functions (Amp-Phase and Real-Imaginary)**: is a combination graph containing amplitude, phase, real part and imaginary part of the Fourier spectral ratio.

As a sample of the channel reports, the report [**Waves of a channel**] is shown in Fig. 47. If a channel report is selected, a dropdown textbox appears on the right side on the main menu in order to select a channel quickly.

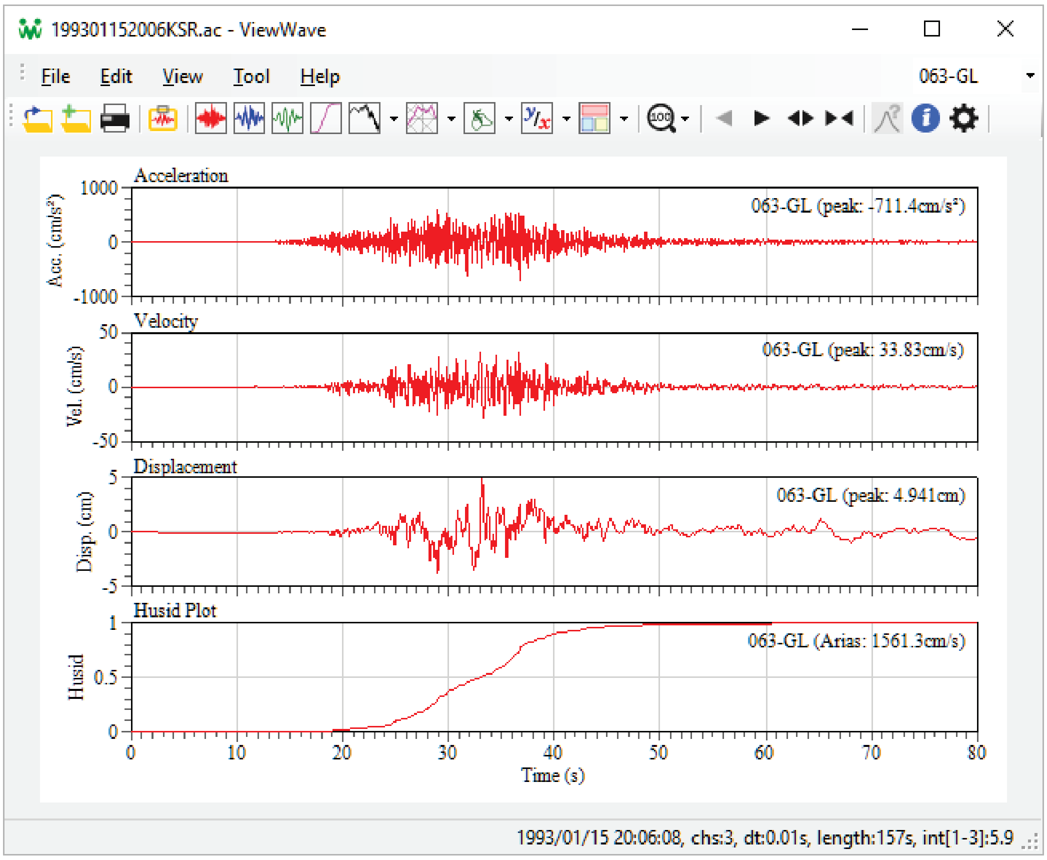


Fig. 47 A sample of channel reports (199301152006KSR.ac)

As a sample of the sensor reports, the report [**Acc and pSv of a sensor in line**] is shown in Fig. 48. If a sensor report is selected, a dropdown textbox appears on the right side on the main menu for quick selection of a sensor.

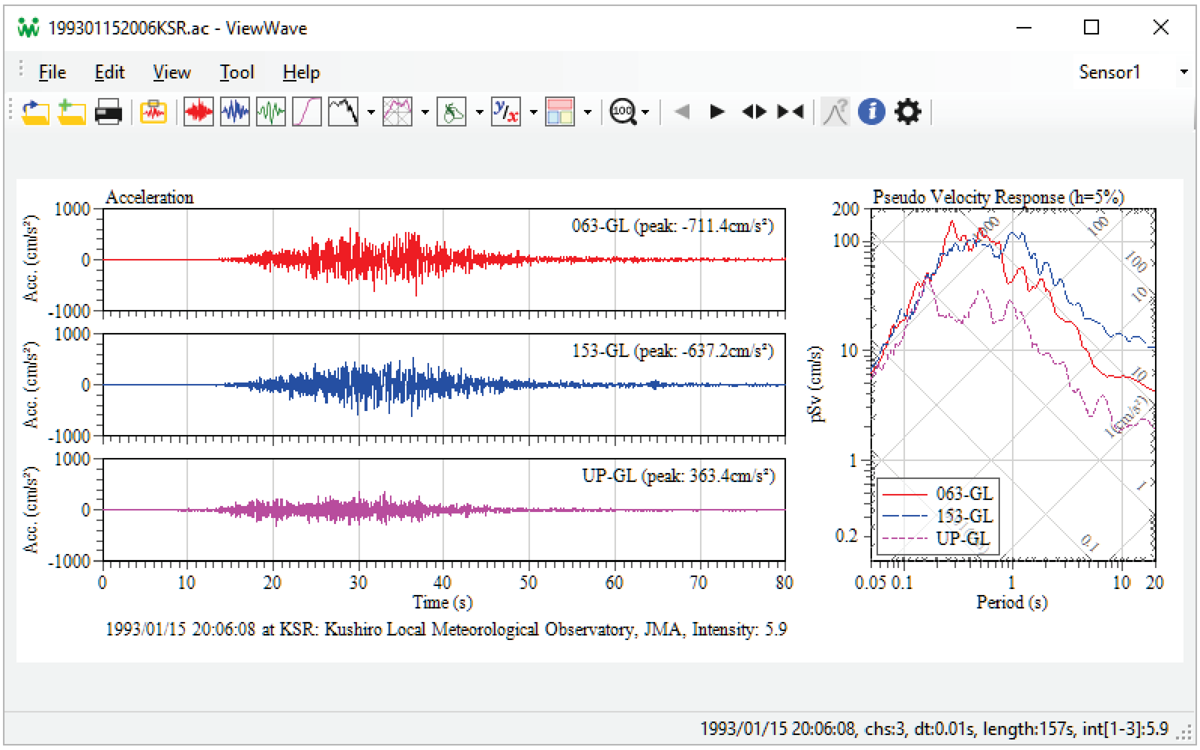


Fig. 48 A sample of sensor reports (199301152006KSR.ac)

As a sample of the combination reports, the report named [**Transfer Functions (Amp-Phase and Real-Imaginary)**] is shown in Fig. 49.

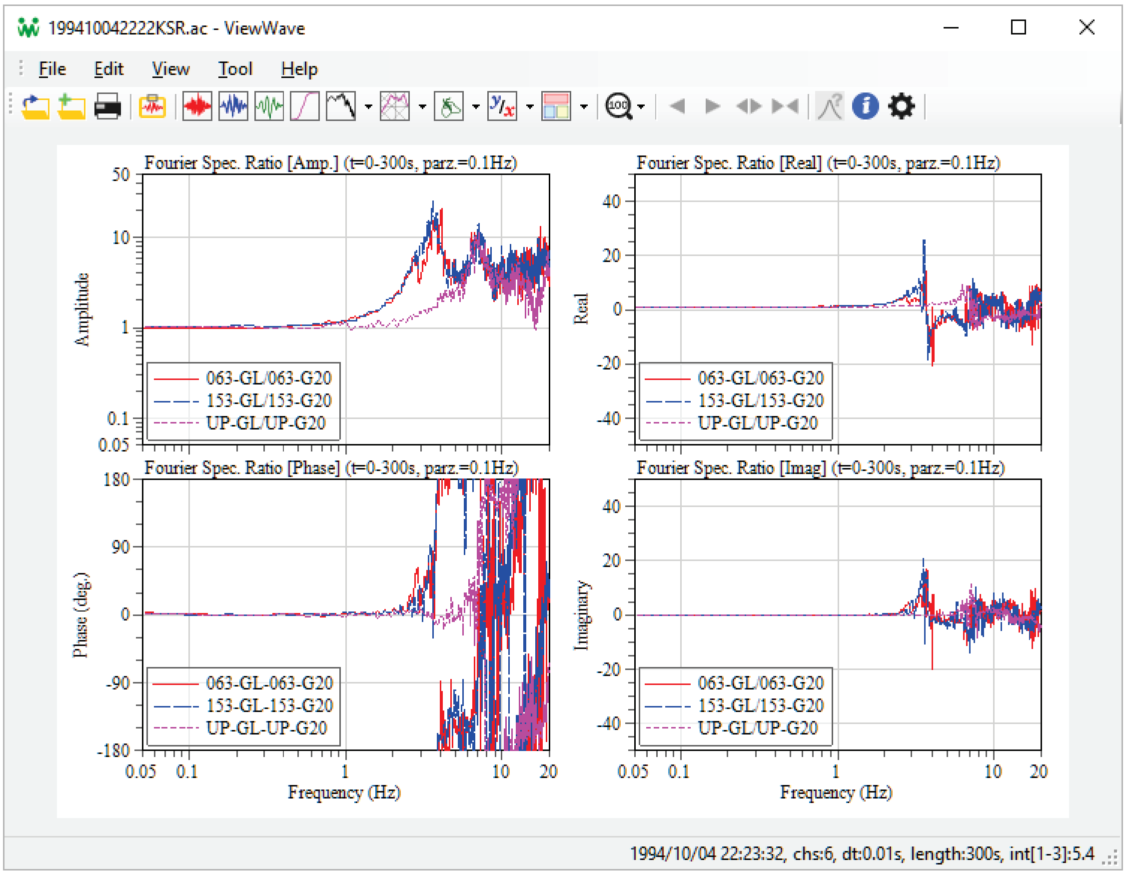


Fig. 49 A sample of combination reports (199410042222KSR.ac)

3.7. Export of data

All data that *ViewWave* has can be output to a file. To export some data, select the menu [**File**] -> [**Export…**]. *ViewWave* shows a dialog box to select the exporting data and file form.

Available data are listed in the drop down box which is labeled [**Exporting data**].

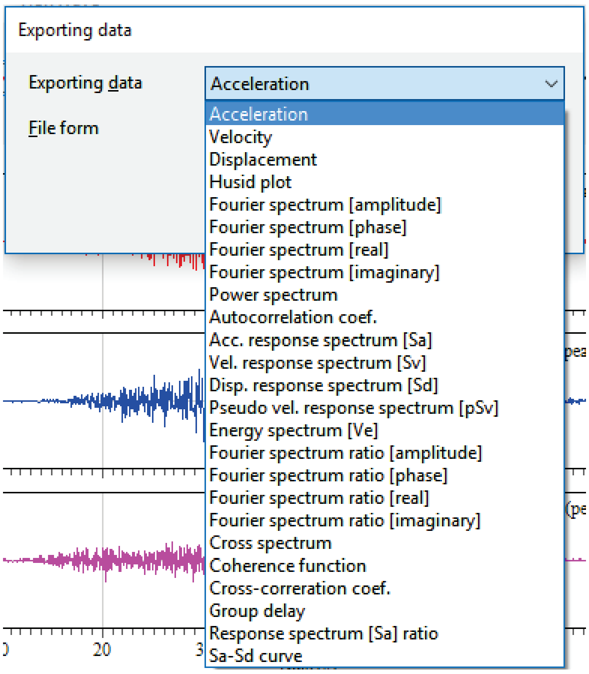


Fig. 50 Export data dialog box – available data

As a file form, there are three choices;

- **CSV (comma-separated-value) file**: is a file having the row-column structure. Each data is separated by comma. The file extension becomes ".csv."
- **TSV (tab-separated-value) file**: is a file having the row-column structure. Each data is separated by tab. The file extension becomes ".tsv."
- **Text (blocked text) file**: is a file having the channel-blocked structure. Each data has a fixed width. The file extension becomes ".txt."

When the [**OK**] button is clicked, a dialog box to specify an output file will appear.

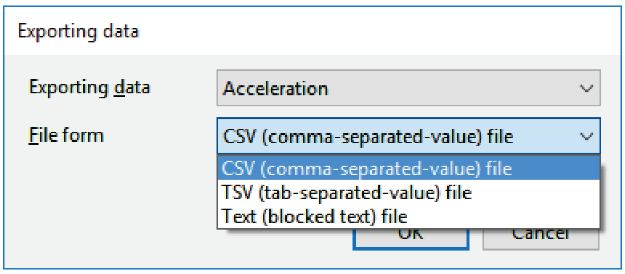


Fig. 51 Export data dialog box – file forms

Fig. 52 to Fig. 54 show samples of exported data files.

```
Sa - 199301152006KSR.ac
3,201
Period(s),063-GL,153-GL,UP-GL
0.0500,7.79555e+02,8.24798e+02,6.87348e+02
0.0515,7.98907e+02,8.88687e+02,7.50852e+02
0.0531,7.94407e+02,8.84150e+02,7.63344e+02
0.0547,8.25074e+02,8.65764e+02,6.96613e+02
0.0564,7.98642e+02,9.10080e+02,7.60011e+02
0.0581,8.21047e+02,9.08989e+02,8.31120e+02
0.0598,8.30904e+02,9.71435e+02,7.43404e+02
0.0617,8.63603e+02,1.01370e+03,6.94255e+02
0.0635,8.90775e+02,1.07676e+03,6.55854e+02
0.0655,9.70367e+02,1.12468e+03,7.08700e+02
0.0675,9.71469e+02,1.06264e+03,7.16422e+02
0.0695,1.07218e+03,1.04733e+03,7.43857e+02
0.0716,1.06161e+03,1.01046e+03,8.18442e+02
0.0738,1.15156e+03,1.11292e+03,7.87680e+02
0.0761,1.27118e+03,1.14262e+03,8.36992e+02
0.0784,1.35789e+03,1.11770e+03,7.51543e+02
0.0807,1.35590e+03,1.22319e+03,7.18125e+02
0.0832,1.22240e+03,1.33923e+03,8.81456e+02
0.0857,1.18985e+03,1.35933e+03,8.51492e+02
0.0883,1.18774e+03,1.42165e+03,7.84052e+02
0.0910,1.25453e+03,1.50457e+03,7.93264e+02
0.0938,1.25083e+03,1.62780e+03,8.13613e+02
0.0966,1.21623e+03,1.51436e+03,8.22576e+02
0.0996,1.21793e+03,1.37149e+03,8.78917e+02
0.1026,1.19039e+03,1.28254e+03,9.76938e+02
0.1057,1.28020e+03,1.27934e+03,1.01636e+03
 (snipped...)
```

Fig. 52 A sample of exported CSV data files

```
Sa - 199301152006KSR.ac
3	201
Period(s)	063-GL	153-GL	UP-GL
0.0500	7.79555e+02	8.24798e+02	6.87348e+02
0.0515	7.98907e+02	8.88687e+02	7.50852e+02
0.0531	7.94407e+02	8.84150e+02	7.63344e+02
0.0547	8.25074e+02	8.65764e+02	6.96613e+02
0.0564	7.98642e+02	9.10080e+02	7.60011e+02
0.0581	8.21047e+02	9.08989e+02	8.31120e+02
0.0598	8.30904e+02	9.71435e+02	7.43404e+02
0.0617	8.63603e+02	1.01370e+03	6.94255e+02
0.0635	8.90775e+02	1.07676e+03	6.55854e+02
0.0655	9.70367e+02	1.12468e+03	7.08700e+02
0.0675	9.71469e+02	1.06264e+03	7.16422e+02
0.0695	1.07218e+03	1.04733e+03	7.43857e+02
0.0716	1.06161e+03	1.01046e+03	8.18442e+02
0.0738	1.15156e+03	1.11292e+03	7.87680e+02
0.0761	1.27118e+03	1.14262e+03	8.36992e+02
0.0784	1.35789e+03	1.11770e+03	7.51543e+02
0.0807	1.35590e+03	1.22319e+03	7.18125e+02
0.0832	1.22240e+03	1.33923e+03	8.81456e+02
0.0857	1.18985e+03	1.35933e+03	8.51492e+02
0.0883	1.18774e+03	1.42165e+03	7.84052e+02
0.0910	1.25453e+03	1.50457e+03	7.93264e+02
0.0938	1.25083e+03	1.62780e+03	8.13613e+02
0.0966	1.21623e+03	1.51436e+03	8.22576e+02
0.0996	1.21793e+03	1.37149e+03	8.78917e+02
0.1026	1.19039e+03	1.28254e+03	9.76938e+02
0.1057	1.28020e+03	1.27934e+03	1.01636e+03
 (snipped...)
```

Fig. 53 A sample of exported TSV data files. Values are separated by tabs.

```
Sa - 199301152006KSR.ac
         3        201
Period(s)
      0.0500      0.0515      0.0531      0.0547      0.0564      0.0581
      0.0598      0.0617      0.0635      0.0655      0.0675      0.0695
      0.0716      0.0738      0.0761      0.0784      0.0807      0.0832
      0.0857      0.0883      0.0910      0.0938      0.0966      0.0996
      0.1026      0.1057      0.1090      0.1123      0.1157      0.1192
      0.1228      0.1266      0.1304      0.1344      0.1385      0.1427
      0.1470      0.1515      0.1561      0.1608      0.1657      0.1708
(snipped...)
      6.4068      6.6016      6.8024      7.0092      7.2224      7.4420
      7.6683      7.9015      8.1418      8.3894      8.6445      8.9074
      9.1783      9.4574      9.7450     10.0414     10.3467     10.6614
     10.9856     11.3197     11.6639     12.0186     12.3841     12.7607
     13.1488     13.5487     13.9607     14.3852     14.8227     15.2735
     15.7379     16.2165     16.7097     17.2178     17.7414     18.2810
     18.8369     19.4097     20.0000
063-GL
  7.79555e+02  7.98907e+02  7.94407e+02  8.25074e+02  7.98642e+02  8.21047e+02
  8.30904e+02  8.63603e+02  8.90775e+02  9.70367e+02  9.71469e+02  1.07218e+03
  1.06161e+03  1.15156e+03  1.27118e+03  1.35789e+03  1.35590e+03  1.22240e+03
  1.18985e+03  1.18774e+03  1.25453e+03  1.25083e+03  1.21623e+03  1.21793e+03
(snipped...)
```

Fig. 54 A sample of exported text data files

3.8. Extra data

In addition to graphs of the current strong motion data, you can add plots of extra data. For instance, if you have data of design spectra or response spectra of other strong motion data, you can compare with your data by overlaying those on your graph. The extra data to be added can be specified in the [**Extra**] tab of [**Option**] dialog box.

The extra data will be read from a file and a format of the extra data file must be a comma-separated-value file (*.csv) or a tab-separated-value file (*.tsv). An example of extra files is shown below (kokuji_psv.csv in the sample data).

```
2,154
Period(s),Mare,Gokumare
0.1026,2.050306552,10.25153276
0.1057,2.143545565,10.71772783
0.109,2.24481681,11.22408405
0.1123,2.348167892,11.74083946
0.1157,2.456826155,12.28413078
0.1192,2.570986404,12.85493202
0.1228,2.690849175,13.45424587
0.1266,2.820056251,14.10028125
0.1304,2.952021163,14.76010582
0.1344,3.093910978,15.46955489
0.1385,3.24251936,16.2125968
0.1427,3.398081221,16.9904061
0.147,3.560837204,17.80418602
0.1515,3.734944754,18.67472377
0.1561,3.916918696,19.58459348
0.1608,4.094738376,20.47369188
0.1657,4.219515851,21.09757926
0.1708,4.349386285,21.74693142
0.176,4.481803197,22.40901599
0.1813,4.616766589,23.08383295
(snipped)
```

Fig. 55 A sample of extra data files (kokuji_psv.csv)

The first line must have a keyword indicating a data type as the first word. The keyword of each data type is described in the list below. The second line has a number of data columns and a number of data steps. The third line has labels of data. The data part starts from the fourth line.

The first value must be frequencies or periods. The second and following values are data. Number of data lines must be the same as the number of data steps in the second line. Please note that the number of data columns in the second line does not include frequencies or periods. This format is the same as the export files of ***ViewWave***.

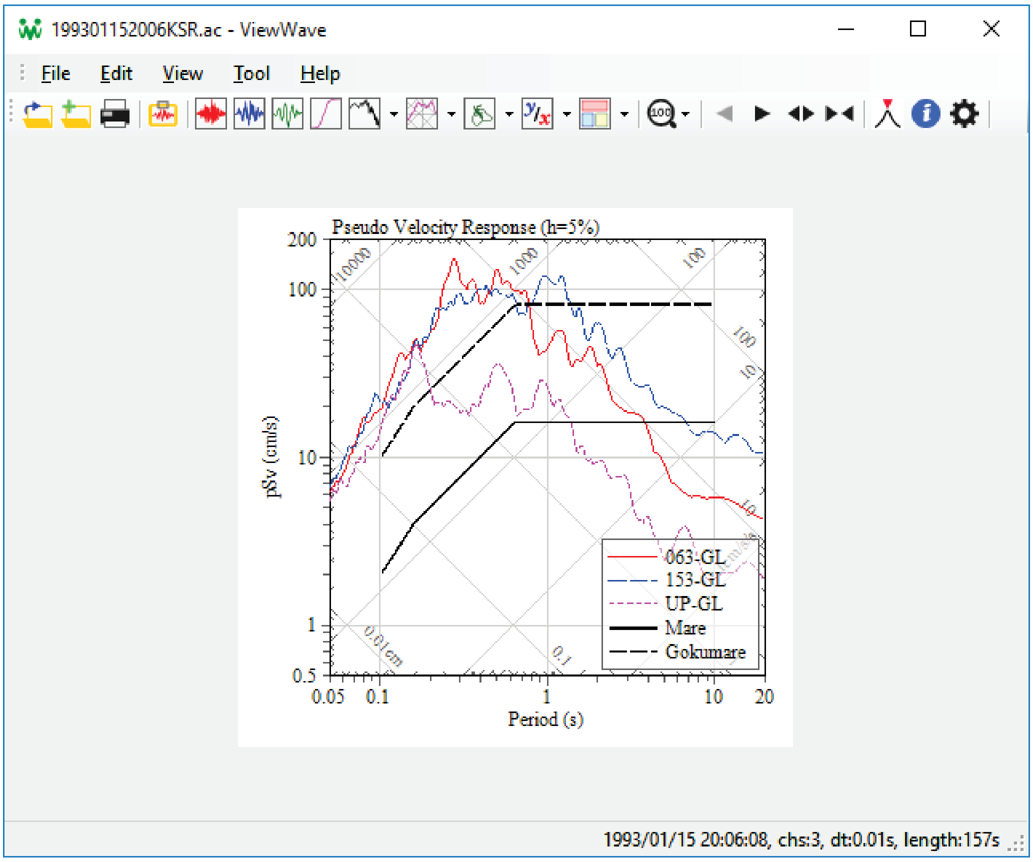


Fig. 56 A sample of displaying extra data on pSv

ViewWave supports following data type as an extra data;

- **FspAmp**: is overlaid with the Fourier spectrum [amplitude].
- **Power**: is overlaid with the power spectrum.
- **Sa**: is overlaid with the acceleration response spectrum.
- **Sv**: is overlaid with the velocity response spectrum.
- **Sd**: is overlaid with the displacement response spectrum.
- **pSv**: is overlaid with the pseudo velocity response spectrum.
- **Ve**: is overlaid with the energy spectrum.
- **SaSd**: is overlaid with the Sa-Sd curve.
- **FspRatioAmp**: is overlaid with the Fourier spectrum ratio [amplitude].
- **FspRatioPhase**: is overlaid with the Fourier spectrum ratio [phase].
- **FspRatioReal**: is overlaid with the Fourier spectrum ratio [real].
- **FspRatioImag**: is overlaid with the Fourier spectrum ratio [imaginary].

- **Cross**: is overlaid with the cross spectrum.
- **Coherence**: is overlaid with the coherence function.
- **RespRatio**: is overlaid with the response spectrum ratio.

3.9. Information on station and event

Information on the strong motion station and seismic event, which can be obtained from the data file, can be confirmed on the [**Station and event**] dialog box. The [**Database…**] button calls the [**Database**] tab in the [**Option**] dialog box to change the settings.

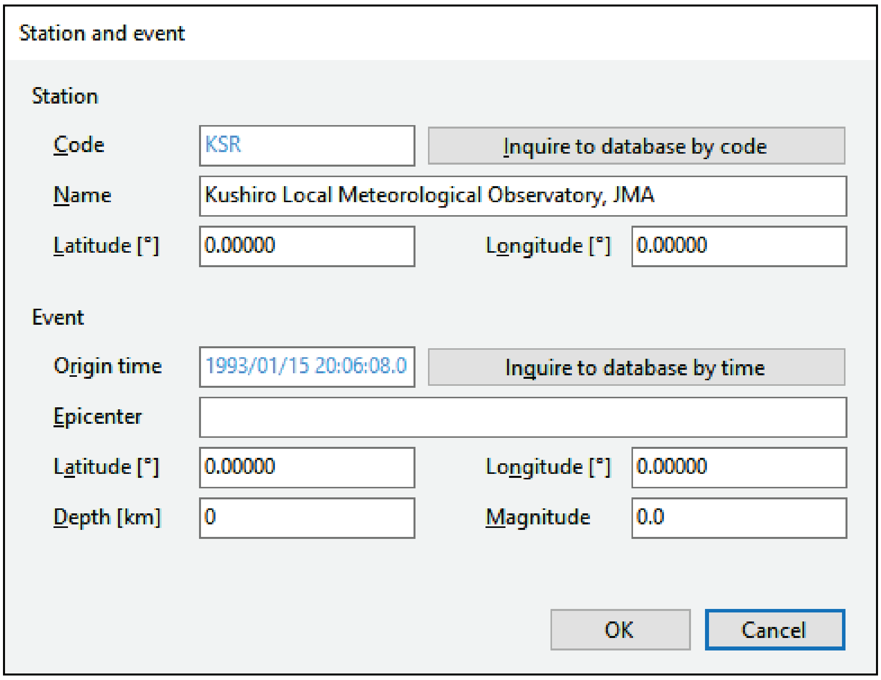


Fig. 57 Station and event dialog box

If the database files are already specified, additional information can be get from the databases by clicking the [**Inquire to database by code**] or [**Inquire to database by time**] button.

To inquire station information to the database, the station code in the [**Code**] textbox is used as a search key. *ViewWave* searches a station having the same station code from the database.

To inquire event information to the database, origin time, which is time starting an event, in the [**Origin time**] textbox is used as a search key. If the database doesn't have the origin time of the event, *ViewWave* sets record time in the textbox. You may set a feasible time by yourself. *ViewWave* searches events having the near origin time to the given time from the database.

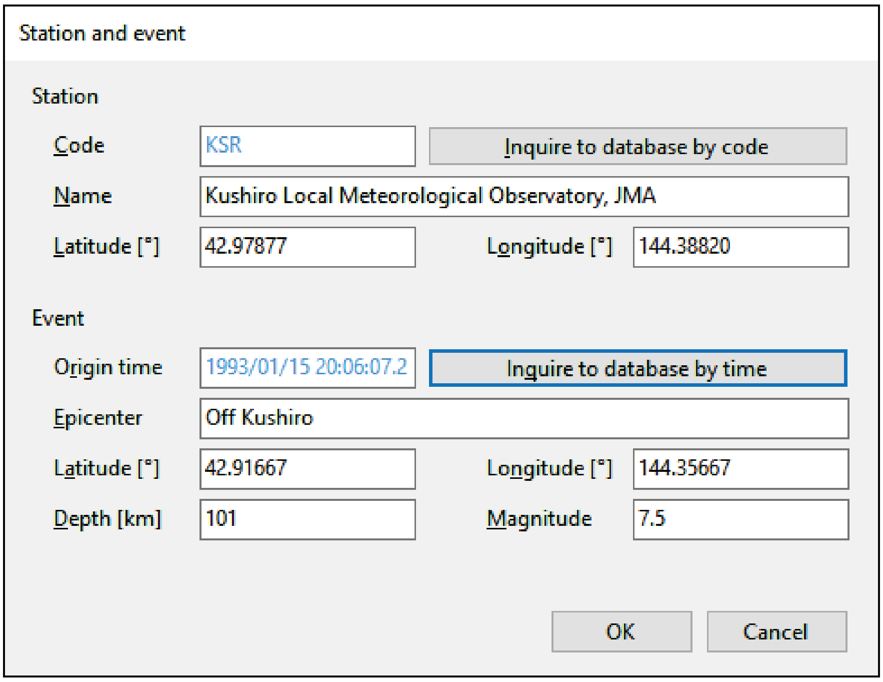


Fig. 58 Station and event dialog box after inquiring to databases

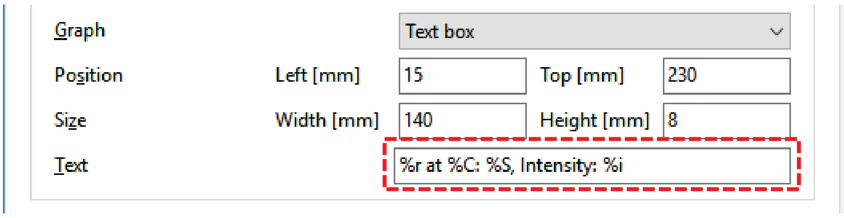
If [☐ **Inquire station and event to database**] in the [**Preprocessing**] dialog box is checked, the database inquiry is performed just after reading a data file.

3.10. Placeholder

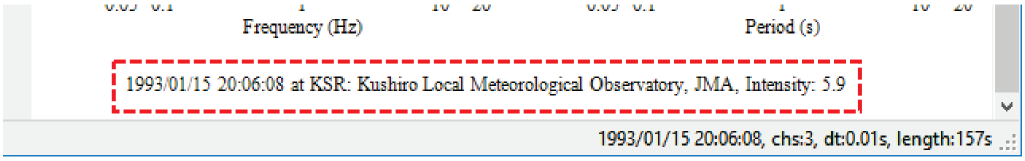
The graph titles and report texts can contain some placeholders that is replaced with actual information when the title or text is displayed. Available placeholders are as follows;

- **%c**: is replaced with the number of channels of the acceleration data.
- **%C**: is replaced with the station code.
- **%d**: is replaced with the sampling time interval of the acceleration data.
- **%D**: is replaced with the depth of the event with a unit [km].
- **%e**: is replaced with the damping ratio of energy spectrum in percent.
- **%E**: is replaced with the event description in a form "[Origin Time] at [Epicenter] (h=[Depth]km, M[Magnitude])".
- **%f**: is replaced with the sampling frequency with a unit [Hz].
- **%F:** is replaced with the full filename of the strong motion data.
- **%h**: is replaced with the damping ratio of response spectra in percent.
- **%i**: is replaced with the JMA seismic intensity. If a sensor report is selected as the current graph, the intensity of the target sensor of the report is used. If a channel report is selected, the intensity of the sensor having the target channel of the report is used. Otherwise, the intensity of the first sensor is used.
- **%M**: is replaced with the magnitude of the event.
- **%n**: is replaced with the number of steps of the acceleration data.
- **%N:** is replaced with the short filename of the strong motion data.
- **%o**: is replaced with the time range of particle orbit.
- **%O**: is replaced with the origin time of the event.

- **%Q**: is replaced with the epicenter of the event.
- **%r**: is replaced with the start time of record.
- **%R**: is replaced with the new line. So the following text goes to the next line.
- **%S**: is replaced with the station name.
- **%t**: is replaced with the time range used in Fourier analysis with a unit [s].
- **%w**: is replaced with the width of Parzen window with a unit [Hz].



(a) Message specified in the report setting



(b) Message appeared on the report

Fig. 59 Use of placeholders

4. Technical Information

4.1. Supported data file

ViewWave can read various strong motion data files. ViewWave can treat strong motion data having the unit of cm/s^2. So the unit of data is converted to cm/s^2 when those are read.

4.1.1. BRI strong motion data files

Building Research Institute, Japan is providing strong motion data obtained that strong motion network. The data file has a file extension (ac) and consists multi-channel data recorded at a station. Please refer to;

- BRI Strong motion observation: http://smo.kenken.go.jp/
- Strong motion data file (.ac file): BRI Strong motion observation: http://smo.kenken.go.jp/smn/acfile

4.1.2. NIED K-NET and KiK-net files

The National Research Institute for Earth Science and Disaster Prevention (NIED) is operating two large strong motion networks in Japan. The networks, which are called K-NET and KiK-net, provide strong motion data at the website.

A station of K-NET has a strong motion instrument on the ground and the instrument has a three-component acceleration sensor. A strong motion record consists of three files with file extensions, "EW", "NS" and "UD."

A KiK-net station has two acceleration sensors on the ground and in the borehole. The borehole sensor is usually placed on the seismic bedrock. Each sensor measures three-component accelerations. A strong motion record consists of six files with file extensions, "EW1," "NS1," "UD1," "EW2," "NS2" AND "UD2."

In case of both K-NET and KiK-net, ***ViewWave*** tries to read all files if one of data files is specified. Please refer to;

- NIED strong-motion seismograph networks: http://www.kyoshin.bosai.go.jp/
- About K-NET ASCII format: http://www.kyoshin.bosai.go.jp/kyoshin/man/knetform_en.html

4.1.3. JMA data files

The Japan Meteorological Agency (JMA) deploys seismic intensity meters throughout Japan. The seismic intensity meter is an equipment to measure the JMA seismic intensity scale and works as a strong motion instrument as well. The strong motion records of the JMA seismic intensity meters are annually published from the Japan Meteorological Business Support Center (JMBSC). The publication, usually by CD or DVD, may include some strong motion data obtained in the seismic information networks of the local governments. There are two types of data files, i.e. a Hexa-ASCII converted file and a CSV file. A Hexa-ASCII file doesn't have a fixed file extension, because that portion is occupied by the station code. ***ViewWave*** can read those data files.

- JMA 95 Hexa-ASCII files (YMDDhhmm.*)
- JMA CSV files (*.csv)

There are several types of seismic intensity meters and there are differences of sensitivity among those. Unfortunately, there is no way to know the intensity meter type from the data file. So ***ViewWave*** adjusts the amplitudes based on comparison of the peak values of the data and on the file header.

For more information, please refer to;

- Japan Meteorological Agency (JMA): http://www.jma.go.jp/
- Japan Meteorological Business Support Center (JMBSC): http://www.jmbsc.or.jp/

4.1.4. Binary files

Some strong motion instruments or dedicated software make binary files having peculiar formats. ***ViewWave*** can read some of such files directly. Currently, ***ViewWave*** supports the following binary files;

- Mitutoyo (and Akashi) SMAC-MD/MDU files (*.md)
- Tokyo Sokushin win32 binary files (*.t3w)
- Tokyo Sokushin binary files (*.dbl)
- Kinemetrics Altus K2/Etna event files (*.evt)

Mitutoyo, which merged Akashi, SMAC-MD/MDU instruments make a data file having a file extension "SMC" and some utility software puts "DAT" as a file extension. I usually replace the file extensions with "md" to avoid confusion. ***ViewWave*** checks file contents if those file extensions are found, therefore you don't need to rename your data files.

ViewWave may read Kinemetrics "EVT" files, probably only made by K2 and Etna. Unfortunately, I never have an opportunity to try other instruments.

4.1.5. Major database files in United States

The United States of America leads the world in the field of strong motion instrumentation. There are several databases accessible on the Internet. ***ViewWave*** supports three major file formats as follows.

- USGS (NSMP) files (*.smc)
- CGS (CSMIP) files (*.raw; *.v2)
- COSMOS files (*.v1c; *.v2c)

Further information on those data files is available at the following website;

- NSMP Data - USGS: http://earthquake.usgs.gov/monitoring/nsmp/data.php
- SMC-format Data Files: http://escweb.wr.usgs.gov/nsmp-data/smcfmt.html
- Center for Engineering Strong Motion Data: http://strongmotioncenter.org/
- Data Format in "About CESMD": http://strongmotioncenter.org/aboutcesmd.html

4.1.6. PEER database files

Another often referred database in the United States will be the PEER Ground Motion Database at the University of California, Berkeley. ***ViewWave*** can read those acceleration files which have the file extension "AT2."

- PEER Ground Motion Database: http://ngawest2.berkeley.edu/

4.1.7. *New Zealand GeoNet files*

GeoNet in New Zealand is operating the strong motion network covering the country. ***ViewWave*** can read those files having file extensions "V1A" and "V2A."

- Strong-Motion Data - GeoNet: http://info.geonet.org.nz/display/appdata/Strong-Motion+Data

4.2. General CSV and text files

There is a possibility that ***ViewWave*** can read ASCII-coded text files having different format. ***ViewWave*** assumes that there are two styles of data structure. One is a row-column style, and another is a channel-block style.

In the row-column style, a line has all channel data sampled at the same time, and data at the next step are in the following line. The row-column style may have some header lines. As the first data, after the header lines, channel labels can be placed. Comma-separated-values (CSV) files are usually in this style.

In the channel-block style, all data of each channel are written in a block, and blocks are stored in a file sequentially. The channel-block style files can have some header lines and each channel block can have some channel header lines. BRI AC files and major US strong motion files are in this style.

ViewWave shows a dialog box to ask the way to read the data file, if an unknown file is specified. To read a CSV file, the following parameters are required.

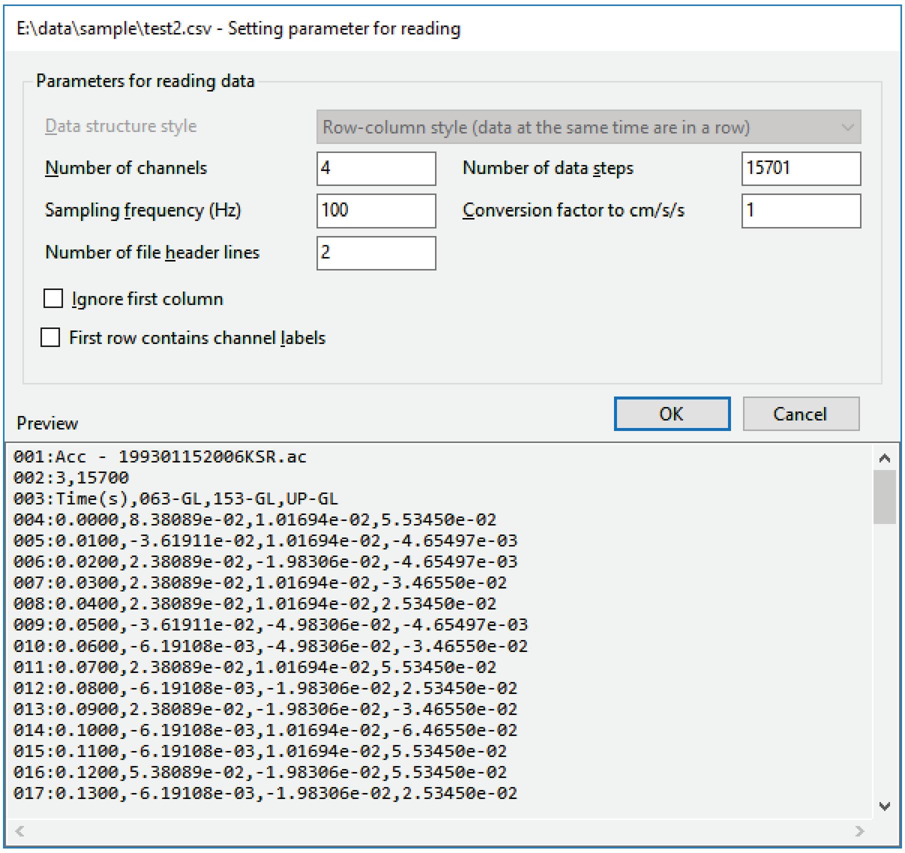


Fig. 60 Setting parameter dialog box for reading a row-column (CSV) data file

- **Data structure style**: specifies data style described above. This is fixed to "**Row-column style**" in case of CSV files.
- **Number of channels**: is a number of channels containing in the data file, excluding ignored first column.
- **Number of data steps**: is a number of steps of data, excluding a channel label line.
- **Sampling frequency**: is a sampling frequency of data.
- **Conversion factor to cm/s/s**: is a value to be multiplied by data.
- **Number of header lines**: is a number of header lines to be skipped. If the file has a row of channel labels, exclude it.
- ☐ **Ignore first column**: ignores the first data in each line if checked. When each line has time as the first value, it must be checked.
- ☐ **First row contains channel labels**: let *ViewWave* get channel labels from the first line if checked.

To read a text file, [**Data structure style**] can be selected from "**Row-column style**" and "**Channel-block style**." If "**Channel-block style**" is selected, some other parameters are required.

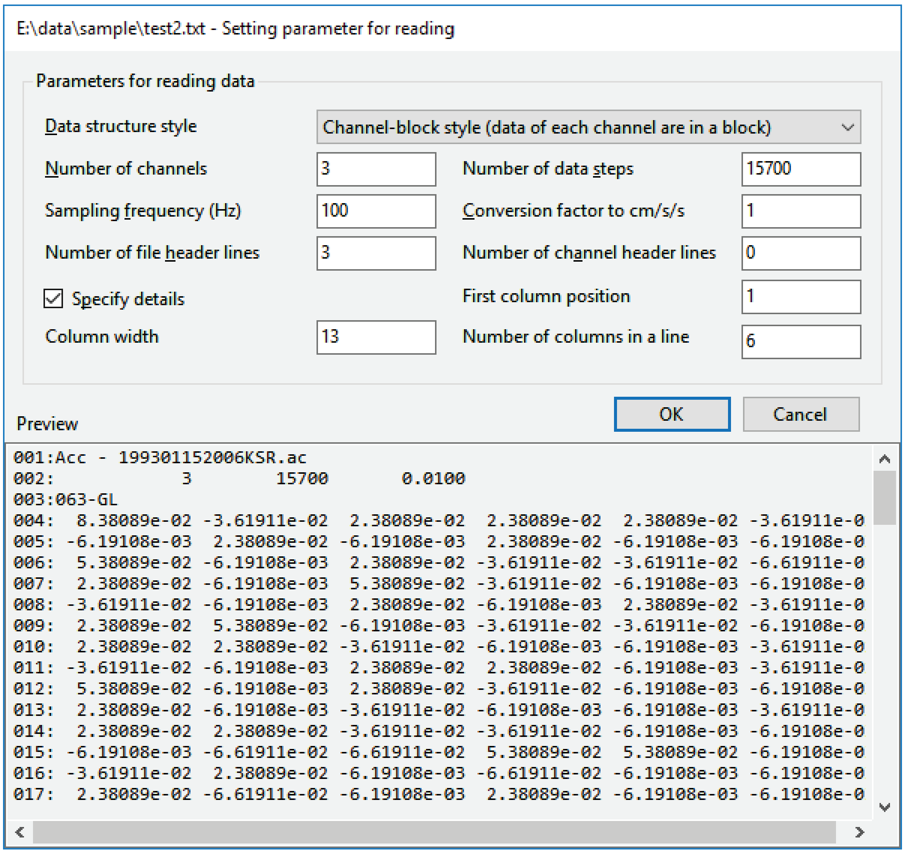


Fig. 61 Setting parameter dialog box for reading a channel-block data file

- **Number of channel header lines**: is a number of channel headers in each channel block to be skipped.
- ☐ **Specify details**: enables to set the following options in addition;
  - **First column position**: specifies start position of data in each line.
  - **Column width**: is a width of each column.
  - **Number of columns in a line**: is a number of data written in a line.

5. Analysis Method

This chapter briefly explains how ***ViewWave*** analyzes strong motion data. And furthermore, the principles are not described herein; therefore, please refer to the references or technical books if necessary.

The variable names used in this chapter are not sufficiently unified. For instance, time histories of acceleration, velocity and displacement are normally represented by $a(t)$, $v(t)$ and $d(t)$, respectively. However, $\ddot{x}(t)$, $\dot{x}(t)$ and $x(t)$ are used for acceleration, velocity and displacement when talking about seismic response. Also T sometimes represents the natural period and sometimes the duration time.

5.1. Fourier transform

ViewWave frequently uses the Fourier transform and inverse Fourier transform in the analysis. A function $a(t)$ of time t can be transformed to a function $A(f)$ of frequency f by Eq. (2)[1), 2)]. $A(f)$ can transformed by $a(t)$ using Eq. (3). Eqs. (2) and (3) are known as the Fourier transform and inverse Fourier transform, respectively.

$$A(f) = \int_{-\infty}^{\infty} a(t) e^{-i2\pi f t} dt \tag{2}$$

$$a(t) = \int_{-\infty}^{\infty} A(f) e^{i2\pi f t} df \tag{3}$$

In case of discretely sampled data having a finite duration, the Fourier transforms are given by the following equations;

$$A_k = \frac{1}{N} \sum_{j=0}^{N-1} a_j e^{-i\left(\frac{2\pi}{N}\right)kj}, \quad (k = 0, 1, \ldots, N-1) \tag{4}$$

$$a_j = \sum_{k=0}^{N-1} A_k e^{i\left(\frac{2\pi}{N}\right)kj}, \quad (j = 0, 1, \ldots, N-1) \tag{5}$$

Based on Eq. (4), the Fourier transform in ***ViewWave*** is performed in the following procedure;

1) Set the number of data N that is greater than or equal to the original number of data N_0 and is a power of 2.
2) Add zeros to a_{N_0} to a_{N-1}, if necessary.
3) Perform the Fast Fourier Transform (FFT)[3)].

5.2. Seismic response of SDOF system

In some analyses, seismic response of a single-degree-of-freedom (SDOF) system is calculated. The equation of motion a SDOF system as shown in Fig. 62 is given by Eq. (6). The equation of motion can be also written as Eq. (7) using a natural circular frequency ω_0 and a damping ratio h.

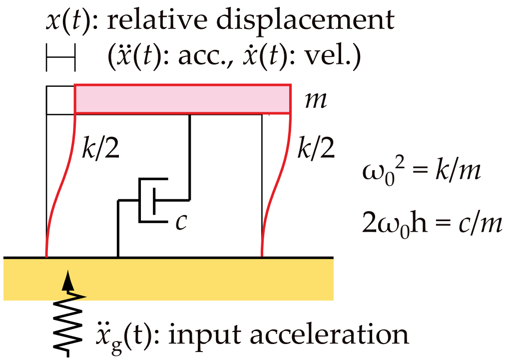


Fig. 62 Single-degree-of-freedom system

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = -m\ddot{x}_g(t) \tag{6}$$

$$\ddot{x}(t) + 2h\omega_0\dot{x}(t) + \omega_0{}^2x(t) = -\ddot{x}_g(t) \tag{7}$$

where m is mass, k is stiffness, c is a damping coefficient, $\omega_0 = \sqrt{k/m}$ is a natural circular frequency and $h = c/(2m\omega_0)$ is a damping ratio. $\ddot{x}(t)$, $\dot{x}(t)$ and $x(t)$ are time series of response acceleration, velocity and displacement of the system, respectively. $\ddot{x}_g(t)$ is a time series of input acceleration.

The response of the SDOF system to the input motion $\ddot{x}_g(t)$ can be calculated by the following equations;

$$x(t) = -\frac{1}{\omega_d}\int_0^t \ddot{x}_g(\tau)e^{-h\omega_0(t-\tau)}\sin\omega_d(t-\tau)\,d\tau \tag{8}$$

$$\dot{x}(t) = -\int_0^t \ddot{x}_g(\tau)e^{-h\omega_0(t-\tau)}\left[\cos\omega_d(t-\tau) - \frac{h}{\sqrt{1-h^2}}\sin\omega_d(t-\tau)\right]d\tau \tag{9}$$

$$\begin{aligned}\ddot{x}(t) + \ddot{x}_g(t) \\ &= \omega_d\int_0^t \ddot{x}_g(\tau)e^{-h\omega_0(t-\tau)}\left[\left(1 - \frac{h^2}{1-h^2}\right)\sin\omega_d(t-\tau)\right. \\ &\left. - \frac{2h}{\sqrt{1-h^2}}\cos\omega_d(t-\tau)\right]d\tau\end{aligned} \tag{10}$$

where ω_d is the damped natural circular frequency ($\omega_d = \sqrt{1-h^2}\omega_0$).

ViewWave calculates the seismic response of a SDOF system by the Nigam and Jennings method[4)] assuming that the initial velocity $\dot{x}(0)$ and displacement $x(0)$ are zero.

5.3. JMA Seismic intensity scale

The Japan Meteorological Agency (JMA) defined the seismic intensity scale by the following equation[5)];

$$I_{\mathrm{JMA}} = 2\log a_0 + 0.94 \tag{11}$$

where I_{JMA} is the JMA seismic intensity scale, and a_0 is the maximum of a that satisfies the following equation.

$$\int_0^{T_d} w(t,a)dt \geq 0.3 \tag{12}$$

where T_d is the duration of acceleration record. $w(t,a) = 0$ when $v(t) < a_0$, and $w(t,a) = 1$ when $v(t) \geq a_0$. $v(t)$ is a time history of the vectorial amplitude given by the following equation.

$$v(t) = \sqrt{{a'_X}^2(t) + {a'_Y}^2(t) + {a'_Z}^2(t)} \tag{13}$$

where ${a'_X}^2(t)$, ${a'_Y}^2(t)$, and ${a'_Z}^2(t)$ are filtered accelerations in the three directions N-S, E-W, and U-D on the ground, respectively. The three types of filters shown in Eq. (14) to Eq. (16) are applied using the FFT and the inverse FFT conversions.

$$W_T(f) = (1/f)^{1/2} \tag{14}$$

$$W_L(f) = (1 - e^{-(f/f_L)^3})^{1/2} \tag{15}$$

$$W_H(f) = (1 + 0.694y^2 + 0.241y^4 + 0.0557y^6 + 0.009664y^8 + 0.00134y^{10} + 0.000155y^{12})^{-\frac{1}{2}}, \quad y = \frac{f}{f_H} \tag{16}$$

$$A'_j(f) = A_j(f)W_T(f)W_L(f)W_H(f), \quad j = X, Y \textit{ and } Z \tag{17}$$

where $W_T(f)$, $W_L(f)$ and $W_H(f)$ are the weight functions of the three types of filters.

$W_T(f)$ emphasizes the low frequency components in consideration of human feeling. $W_L(f)$ and $W_H(f)$ are the low-cut and the high-cut filters, respectively. f_L and f_H are the corner frequencies of the low-cut and high-cut filters. For the calculation of the JMA seismic intensity, $f_L = 0.5$Hz and $f_H = 10$Hz are used. The shapes of the three filters and the overall frequency characteristics are illustrated in Fig. 63.

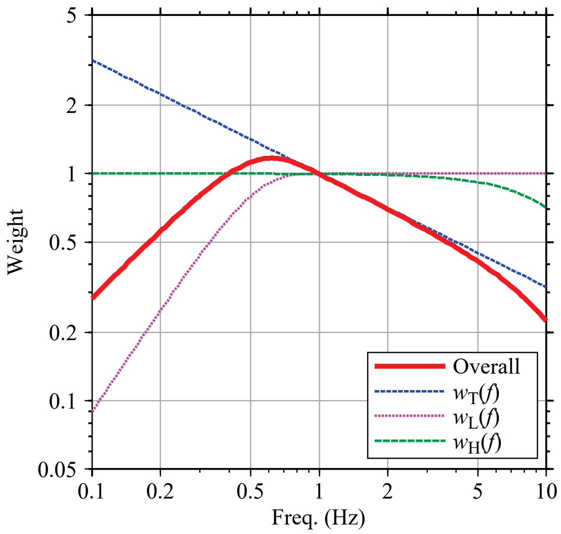


Fig. 63 Characteristics of filters used to calculate JMA seismic intensity

Based on the definition of the JMA seismic intensity above, ***ViewWave*** applies the following procedure for every 40 seconds of the strong motion data and adopts the maximum one as the JMA seismic intensity.

1) Calculate Fourier transforms $A_X(f), A_Y(f), A_Z(f)$ from the three time histories of acceleration data $a_X(t), a_Y(t), a_Z(t)$ using the fast Fourier transform (FFT).
2) Apply the filters $W_T(f)$, $W_L(f)$ and $W_H(f)$ to $A_j(f)$ in the frequency domain as shown in Eq. (17).
3) Calculate the filtered time histories $a'_X(t), a'_Y(t), a'_Z(t)$ from $A'_X(f), A'_Y(f), A'_Z(f)$ by the inverse Fourier transform using FFT.
4) Calculate the vectorial amplitude $v(t)$ by Eq. (13).
5) Search a_0 that satisfies Eq. (12) using the bisection method.
6) Calculate the JMA seismic intensity by Eq. (11).

The calculation of the JMA intensity requires three component accelerations of a sensor, so ***ViewWave*** calculates the JMA intensity using consecutive three channels assuming that those are in the three directions of one sensor. If the assumption is not satisfied, the values don't make sense. If the total number of channels is less than three, the calculation of the JMA seismic intensities is skipped.

5.4. Integration

ViewWave basically deals with acceleration data, so velocity and displacement data are calculated from acceleration data by the integration. ***ViewWave*** provides some integration methods.

5.4.1. FFT (in frequency domain)

The integration in the frequency domain is as follows using Fourier transforms;

$$V(f) = \frac{A(f)}{i2\pi f} \tag{18}$$

$$D(f) = -\frac{A(f)}{(2\pi f)^2} \tag{19}$$

where $V(f)$, $D(f)$ and $A(f)$ are Fourier transforms of the velocity $v(t)$, displacement $d(t)$ and acceleration $a(t)$, respectively. i is the imaginary unit ($i = \sqrt{-1}$).

This method may be also applied together with a low-cut (high-pass) filter to reduce the drift due to the magnification of low frequency noises. So the procedure will be as follows;

1) Calculate the Fourier transform $A(f)$ of the acceleration time history $a(t)$ using FFT.
2) Integrate $A(f)$ in the frequency domain by Eq.(18) and Eq.(19).
3) Low-cut filtering ($V'(f) = W_L(f)V(f)$, $D'(f) = W_L(f)D(f)$, where $W_L(f)$ is the low-cut filter).
4) Calculate the velocity and displacement time histories $v(t)$ and $d(t)$ from $V'(f)$ and $D'(f)$ by the inverse Fourier transform using FFT.

The low-cut filter indicated in Eq. (15) is utilized here and the cut-off frequency f_L can be specified as a parameter.

5.4.2. Seismograph simulation

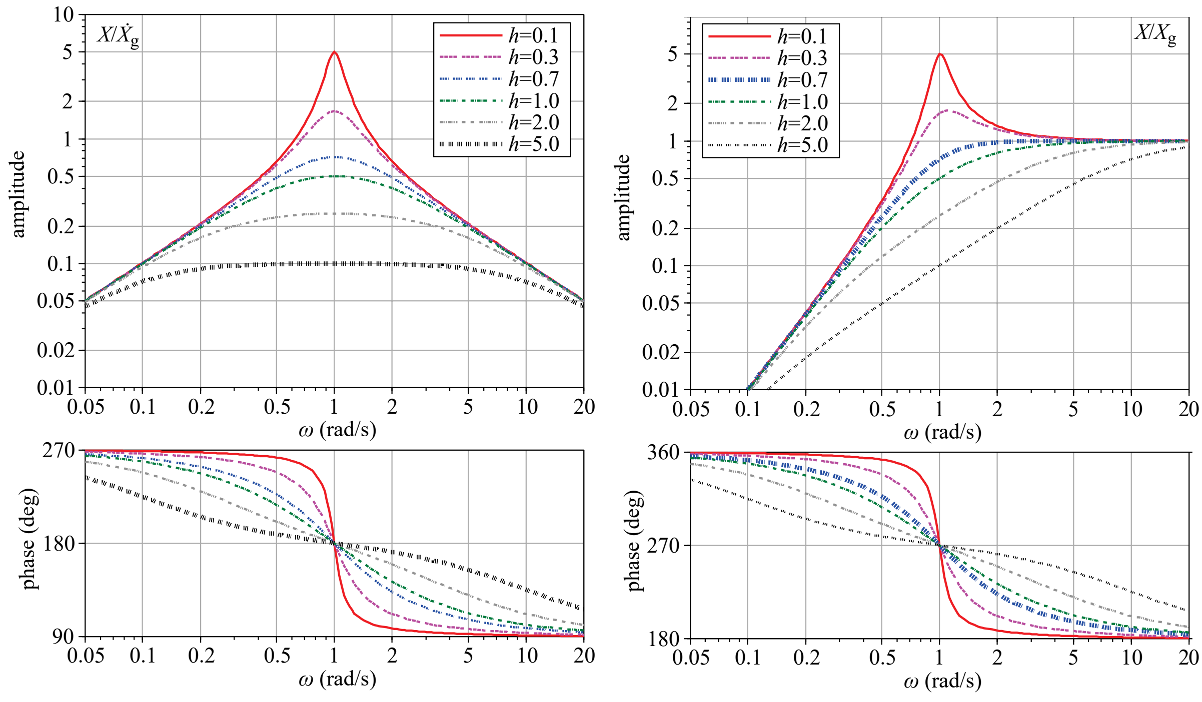
A simple seismograph is an application of a mass-spring-damper system as shown in Fig. 62. Such a system is also called a single-degree-of-freedom (SDOF) system. The movement of the mass can represent ground acceleration, ground velocity or ground displacement, according to the natural frequency and the damping ratio of the system. In the frequency domain, the ratios of the response displacement $X(\omega)$ to the ground acceleration $\ddot{X}_g(\omega)$, velocity $\dot{X}_g(\omega)$ and displacement $X_g(\omega)$ can be formulated as Eq.(20) to Eq.(22) using a circular frequency ($\omega = 2\pi f$).

$$\frac{X(\omega)}{\ddot{X}_g(\omega)} = -\frac{1}{\omega_0{}^2 - \omega^2 + 2ih\omega_0\omega} \tag{20}$$

$$\frac{X(\omega)}{\dot{X}_g(\omega)} = -\frac{i\omega}{\omega_0{}^2 - \omega^2 + 2ih\omega_0\omega} \tag{21}$$

$$\frac{X(\omega)}{X_g(\omega)} = \frac{\omega^2}{\omega_0{}^2 - \omega^2 + 2ih\omega_0\omega} \tag{22}$$

where ω_0 and h are the natural circular frequency ($\omega_0 = 2\pi f_0$) and the damping ratio of the system, respectively. The frequency characteristics of Eq.(21) and Eq.(22) for $\omega_0 = 1.0$ are shown in Fig. 64. Looking at the case of $h = 5$ in the graph of $X(\omega)/\dot{X}_g(\omega)$, there is the flat part of the amplitude in the middle range of the circular frequency. In that frequency range, it can work as a velocity meter. So the response displacement $x(t)$ can represent the ground velocity $\dot{x}_g(t)$. The graph of $X(\omega)/X_g(\omega)$ also suggests that the system with the damping ratio of about 0.7 can work as the displacement meter in the high frequency range.



(b) $X(\omega)/\dot{X}_g(\omega)$ *(a)* $X(\omega)/X_g(\omega)$

Fig. 64 Frequency characteristics of the response of a SDOF system ($\omega_0 = 1.0$)

To use the seismograph simulation as the integration method, you need to specify the natural frequencies and damping ratios of velocity and displacement meters. ***ViewWave*** calculates the seismic response of the system using the Nigam and Jennings method following the procedure below;

1) Compute the response displacement $x_{\mathrm{V}}(t)$ of the system with a natural frequency f_{V} and a damping ratio h_{V}. The initial values of f_{V} and h_{V} are 1.0 Hz and 4.0.
2) Convert the response displacement $x_{\mathrm{V}}(t)$ to the integrated velocity $\dot{x}_{\mathrm{g}}(t)$. $\dot{x}_{\mathrm{g}}(t) = -4\pi f_{\mathrm{V}} h_{\mathrm{V}} x_{\mathrm{V}}(t)$
3) Compute the response displacement $x_{\mathrm{D}}(t)$ of the system with a natural frequency f_{D} and a damping ratio h_{D}. The initial values of f_{D} and h_{D} are 0.1 Hz and 0.7071.
4) Convert the response displacement $x_{\mathrm{D}}(t)$ to the integrated displacement $x_{\mathrm{g}}(t)$. $x_{\mathrm{g}}(t) = -x_{\mathrm{D}}(t)$

5.4.3. *Trapezoidal rule*

The integration in the time domain can be formulized as follows;

$$v(t) = \int_{-\infty}^{t} a(\tau)d\tau \tag{23}$$

where $v(t)$ and $a(t)$ are velocity and acceleration time histories, respectively.

For discrete acceleration sampled at the equal-interval, the velocity at the k-th step (v_k) can be approximated using the trapezoidal rule as follows;

$$v_k = v_{k-1} + \frac{(a_{k-1} + a_k)}{2}\Delta t \tag{24}$$

where v_{k-1} and v_k are velocities at $(k-1)$-th and k-th steps, a_{k-1} and a_k are accelerations at $(k-1)$-th and k-th steps, Δt is a sampling interval.

The integrated velocity by Eq. (23) may drift, so a baseline correction and/or a low-cut filter are usually used together. In ***ViewWave***, the integration procedure using the trapezoidal rule is as follows;

1) Integrate the acceleration to get velocity by the trapezoidal rule ($a(t) \to v(t)$, $v(0) = 0$).
2) Correct the baseline of the velocity using the linear regression ($v(t) \to v'(t)$).
3) Integrate the velocity to get displacement by the trapezoidal rule ($v'(t) \to d(t)$, $d(0) = 0$).

ViewWave holds $v'(t)$ and $d(t)$ as the results. Actually, the integrated displacement still seems to have some unneeded drift.

5.5. Husid plot

A Husid plot[6] is the time history of the Arias intensity[7] normalized by its maximum value. The Arias intensity is defined by the following equation.

$$I_A = \frac{\pi}{2g}\int_{0}^{T_d} a^2(t)dt \tag{25}$$

where I_A is the Arias intensity, T_d is the duration time.

So the Husid plot is expressed by the following equation.

$$H(t) = \frac{\int_0^t a^2(\tau)d\tau}{\int_0^{T_d} a^2(\tau)d\tau} \tag{26}$$

In ***ViewWave***, the Husid plot is calculated as follows;

$$h_k = \frac{\sum_{j=0}^{k} {a_j}^2}{\sum_{j=0}^{N-1} {a_j}^2} \tag{27}$$

where h_k is the Husid plot at the *k*-th step, a_j is the acceleration at the *j*-th step and *N* is the number of steps of acceleration data.

5.6. Fourier analysis

5.6.1. Fourier and power spectra

A power spectrum is defined as follows;

$$P(f) = \lim_{T \to \infty} \frac{1}{T} A(f) A^*(f) \tag{28}$$

To estimate the time average of strong motion data, ***ViewWave*** applies a spectrum window to a power spectrum. The spectrum window has an effect of smoothing the spectrum.

ViewWave displays the smoothed Fourier spectrum $\hat{F}(f)$ and the power spectrum $\hat{P}(f)$ obtained from the acceleration data $a(t)$ by the following procedure;

1) Calculate the Fourier transform $A(f)$ of the acceleration time history $a(t)$ represented by Eq. (2) using the Fast Fourier Transform (FFT).
2) Calculate the raw power spectrum $P(f)$ by Eq. (29), where $A^*(f)$ is the complex conjugation of $A(f)$, T is the duration time.
3) Calculate the smoothed power spectrum $\hat{P}(f)$ by Eq. (30), where $W(f)$ is the Parzen window defined by Eq. (31).
4) Calculate the smoothed Fourier spectrum $\hat{F}(f)$ by Eq. (32).

$$P(f) = \frac{1}{T} A(f) A^*(f) \tag{29}$$

$$\hat{P}(f) = \int_{-\infty}^{\infty} P(f - \phi) W(\phi) d\phi \tag{30}$$

$$W(f) = \frac{3}{4} u \left(\frac{\sin \frac{\pi u f}{2}}{\frac{\pi u f}{2}} \right)^4 \tag{31}$$

$$\hat{F}(f) = \sqrt{\hat{P}(f) T} \tag{32}$$

5.6.2. Autocorrelation coefficient

The autocorrelation function and the power spectrum have the following relation via the Fourier transform. So ***ViewWave*** calculates the autocorrelation from the power spectrum using FFT.

$$C(\tau) = \int_{-\infty}^{\infty} \hat{P}(f) e^{i 2\pi f \tau} df \tag{33}$$

where $C(\tau)$ is the autocorrelation function, $\hat{P}(f)$ is the smoothed power spectrum and τ is the time lag.

ViewWave plots graphs of the autocorrelation coefficient $R(\tau)$ that is the normalized autocorrelation function by $C(0)$.

$$R(\tau) = \frac{C(\tau)}{C(0)} \tag{34}$$

5.7. Response spectrum

The response spectra are defined as functions of the natural period $T(= 2\pi/\omega_0)$ and the damping ratio h of a SDOF system (see Fig. 62) as shown in Eq.(35) to Eq.(37), taking the maximum values of the responses. A plots of the natural period versus $S_\mathrm{d}(T,h)$, $S_\mathrm{v}(T,h)$ and $S_\mathrm{a}(T,h)$ for a certain damping ratio are called the displacement, velocity and acceleration response spectra, respectively.

$$S_\mathrm{d}(T,h) = |x(t)|_{max} \tag{35}$$

$$S_\mathrm{v}(T,h) = |\dot{x}(t)|_{max} \tag{36}$$

$$S_\mathrm{a}(T,h) = \left|\ddot{x}(t) + \ddot{x}_g(t)\right|_{max} \tag{37}$$

Among the acceleration, velocity and displacement response spectra, there are relations as shown in Eq.(38) to Eq.(40). A tripartite plot makes it possible to indicate three response spectra in a graph, utilizing those relations. In a tripartite plot of ***ViewWave***, the pseudo velocity spectrum ${}_\mathrm{p}S_\mathrm{v}$ calculated from S_a using Eq. (40) is adopted.

$$S_\mathrm{d}(T,h) \approx \frac{T}{2\pi} S_\mathrm{v}(T,h) \tag{38}$$

$$S_\mathrm{a}(T,h) \approx \frac{2\pi}{T} S_\mathrm{v}(T,h) \tag{39}$$

$${}_\mathrm{p}S_\mathrm{v}\,(T,h) = \frac{T}{2\pi} S_\mathrm{a}(T,h) \tag{40}$$

5.8. Energy spectrum

In terms of energy, the seismic response of the SDOF can be expressed as follows[8)];

$$\int_0^{T_d} m\ddot{x}(t)\dot{x}(t)dt + \int_0^{T_d} c\dot{x}^2(t)dt + \int_0^{T_d} kx(t)\dot{x}(t)dt = -\int_0^{T_d} m\ddot{x}_g(t)\dot{x}(t)dt \tag{41}$$

where m, c and k are a mass, a damping coefficient and a spring constant of the system, T_d is the duration time, $\ddot{x}(t)$, $\dot{x}(t)$ and $x(t)$ are acceleration, velocity and displacement of the response, and $\ddot{x}_g(t)$ is an input earthquake motion. The left hand side of the equation is the energy consumed by the system and the right hand side is the total energy exerted on the system by the earthquake motion. Therefore, the total energy input E is defined as follow;

$$E = -\int_0^{T_d} m\ddot{x}_g(t)\dot{x}(t)dt \tag{42}$$

The total energy input can be expressed by an equivalent velocity V_{E} as follows;

$$V_{\mathrm{E}} = \sqrt{\frac{2E}{m}} = \sqrt{-2\int_0^{T_d} \ddot{x}_g(t)\dot{x}(t)dt} \tag{43}$$

V_{E} is a function of the parameters of the SDOF system. So the energy spectrum is defined as the function of the natural period T and the damping ratio h.

5.9. Relation analysis

We often need to discuss relation between two channels of the strong motion data. There several ways to investigate the relation between two sets of time history data.

5.9.1. Cross spectrum and Fourier spectrum ratio

The cross spectrum of two time histories of acceleration data $x(t)$ and $y(t)$ is defined from those Fourier transforms $F_{\mathrm{X}}(f)$ and $F_{\mathrm{Y}}(f)$ as follows;

$$P_{\mathrm{XY}}(f) = \lim_{T\to\infty}\frac{1}{T}F_{\mathrm{X}}^{*}(f)F_{\mathrm{Y}}(f) \tag{44}$$

Following the similar procedure to the power spectrum, a cross spectrum is estimated by applying the spectrum window.

$$P_{\mathrm{XY}}(f) = \frac{1}{T}F_{\mathrm{X}}^{*}(f)F_{\mathrm{Y}}(f) \tag{45}$$

$$\begin{aligned} Re\left[\hat{P}_{\mathrm{XY}}(f)\right] &= \int_{-\infty}^{\infty} Re[P_{\mathrm{XY}}(f-\phi)]W(\phi)d\phi \\ Im\left[\hat{P}_{\mathrm{XY}}(f)\right] &= \int_{-\infty}^{\infty} Im[P_{\mathrm{XY}}(f-\phi)]W(\phi)d\phi \end{aligned} \tag{46}$$

where $P_{\mathrm{XY}}(f)$ is the raw cross spectrum, $F_{\mathrm{X}}(f)$ and $F_{\mathrm{Y}}(f)$ are the Fourier transforms of $x(t)$ and $y(t)$. $\hat{P}_{\mathrm{XY}}(f)$ is the smoothed cross spectrum, $W(f)$ is the spectrum window.

The process for calculating the cross spectrum and Fourier spectrum ratio is as follow;

1) Calculate the raw cross spectrum $P_{\mathrm{XY}}(f)$ from $F_{\mathrm{X}}(f)$ and $F_{\mathrm{Y}}(f)$ (Eq. (45)).
2) Smooths the real and imaginary parts of $P_{\mathrm{XY}}(f)$ with the Parzen window (Eq. (46)).
3) Calculate the amplitude $\left|\hat{H}_{\mathrm{XY}}(f)\right|$ and phase $\hat{\theta}_{\mathrm{XY}}(f)$ of the Fourier spectrum ratio from the smoothed cross spectrum $\hat{P}_{\mathrm{XY}}(f)$ (Eqs. (47) and (48)).

$$\left|\hat{H}_{\mathrm{XY}}(f)\right| = \sqrt{\frac{\hat{P}_{\mathrm{YY}}(f)}{\hat{P}_{\mathrm{XX}}(f)}} \tag{47}$$

$$\hat{\theta}_{\mathrm{XY}}(f) = arg\left[\hat{H}_{\mathrm{XY}}(f)\right] = \tan^{-1}\left\{-\frac{Im\left[\hat{P}_{\mathrm{XY}}(f)\right]}{Re\left[\hat{P}_{\mathrm{XY}}(f)\right]}\right\}, \quad -\pi < \theta_{\mathrm{XY}}(f) \le \pi \tag{48}$$

The Fourier spectral ratio is complex number, so there are two expression ways, the amplitude and phase, and the real part and imaginary part. The cross spectrum is also complex number and its phase is the same as that of the Fourier spectral ratio.

5.9.2. *Coherence*

The coherence is calculated from the power spectra and cross spectrum of two time histories of acceleration data. The definition is as follows;

$$Coh_{\mathrm{XY}}(f) = \frac{\left|\hat{P}_{\mathrm{XY}}(f)\right|}{\sqrt{\hat{P}_{\mathrm{X}}(f)\hat{P}_{\mathrm{Y}}(f)}} \tag{49}$$

where $Coh_{\mathrm{XY}}(f)$ is the coherence function, $\hat{P}_{\mathrm{X}}(f)$ and $\hat{P}_{\mathrm{Y}}(f)$ are the smoothed power spectra of $x(t)$ and $y(t)$.

5.9.3. *Cross correlation coefficient*

The cross correlation coefficient is the normalized cross correlation function and is calculated by the similar way to the autocorrelation coefficient. ***ViewWave*** calculates the cross correlation function by the inverse Fourier transform of the cross spectrum using FFT.

$$C_{\mathrm{XY}}(\tau) = \int_{-\infty}^{\infty} \hat{P}_{\mathrm{XY}}(f) e^{i2\pi f\tau} df \tag{50}$$

$$R_{\mathrm{XY}}(\tau) = \frac{C_{\mathrm{XY}}(\tau)}{C_{\mathrm{XY}}(0)} \tag{51}$$

where $C_{\mathrm{XY}}(\tau)$ is the cross correlation function and $R_{\mathrm{XY}}(\tau)$ is the cross correlation coefficient.

5.9.4. *Response spectrum ratio*

The response spectrum ratio is simply calculated as the ratio between the response spectra of two acceleration data. ***ViewWave*** adopts the acceleration response spectrum to calculate the ratio;

$$R_{S_{\mathrm{XY}}}(T,h) = \frac{S_{a_{\mathrm{Y}}}(T,h)}{S_{a_{\mathrm{X}}}(T,h)} \tag{52}$$

where $R_{S_{\mathrm{XY}}}(T,h)$ is the response spectrum ratio, $S_{a_{\mathrm{X}}}(T,h)$ and $S_{a_{\mathrm{Y}}}(T,h)$ are the acceleration response spectra of $x(t)$ and $y(t)$.

5.10. Preprocessing

5.10.1. *Band-pass filter*

If the band-pass filter is enabled, acceleration data is transformed using the FFT and filtered in the frequency domain. Then it is transformed into the time domain using the inverse FFT. The filter has real gain, so the phase is not affected. The band-pass filter is a product of a low-cut filter and a high-cut filter as shown in Eq. (53). The low-cut and high-cut filters are defined by Eq. (54) and Eq. (55), respectively, utilizing amplitudes of the Butterworth filter.

$$G_{\mathrm{B}}(f) = G_{\mathrm{L}}(f)G_{\mathrm{H}}(f) \tag{53}$$

$$G_{\mathrm{L}}(f) = \sqrt{\frac{(f/f_{\mathrm{L}})^{2n}}{1+(f/f_{\mathrm{L}})^{2n}}} \tag{54}$$

$$G_{\mathrm{H}}(f) = \sqrt{\frac{1}{1+(f/f_{\mathrm{H}})^{2n}}} \tag{55}$$

where $G_L(f)$ and $G_H(f)$ are gains of the low-cut and high-cut filters, f_L and f_H are the low-cut and high-cut frequencies.

The filter shapes are determined by the cut-off frequencies f_L, f_H and the order n. If zero is given as the order, ***ViewWave*** uses the filters given by Eqs. (15) and (16) that are used in the calculation of the JMA seismic intensity. The filter shapes for n=5, n=10 and n=20 are shown in Fig. 65, together with that of the JMA filter.

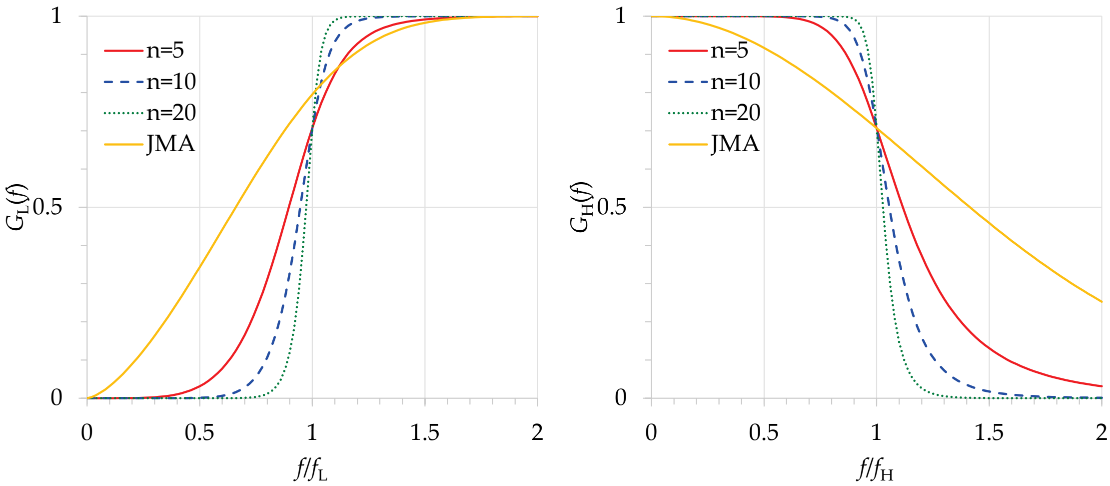


Fig. 65 Characteristics of low-cut (left) and high-cut (right) filters

5.10.2. Rotation of acceleration data

The installation azimuth of the strong motion instrument in buildings usually accords with the building axis. Therefore, we sometimes need to rotate strong motion data in the horizontal plane in order to discuss movements in North-South and East-West directions. ***ViewWave*** can rotate strong motion data after reading it assuming that the first and second channels are orthogonal horizontal directions. The rotation is made by the following coordinate transformation.

$$\begin{aligned} x_{new}(t) &= \cos\theta\, x_{org}(t) - \sin\theta\, y_{org}(t) \\ y_{new}(t) &= \sin\theta\, x_{org}(t) + \cos\theta\, y_{org}(t) \end{aligned} \quad (56)$$

where $x_{org}(t)$ and $y_{org}(t)$ are the original orthogonal horizontal components, $x_{new}(t)$ and $y_{new}(t)$ are the rotated horizontal components, and θ is the rotational angle.

The rotation of the data in the N063°E and N153°E directions at 63° gives the data in the N000°E and N090°E directions, as shown in Fig. 66.

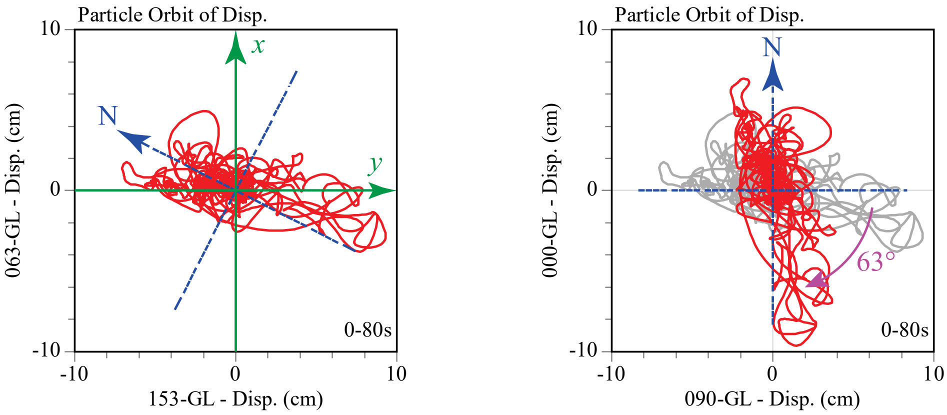


Fig. 66 Rotation of strong motion data in the horizontal plane

6. References

Representative references and resources are listed below.

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6.2. Programming

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11) C# によるプログラミング入門 | ++C++; // 未確認飛行 C: http://ufcpp.net/study/csharp/
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13) Code Project: http://www.codeproject.com/