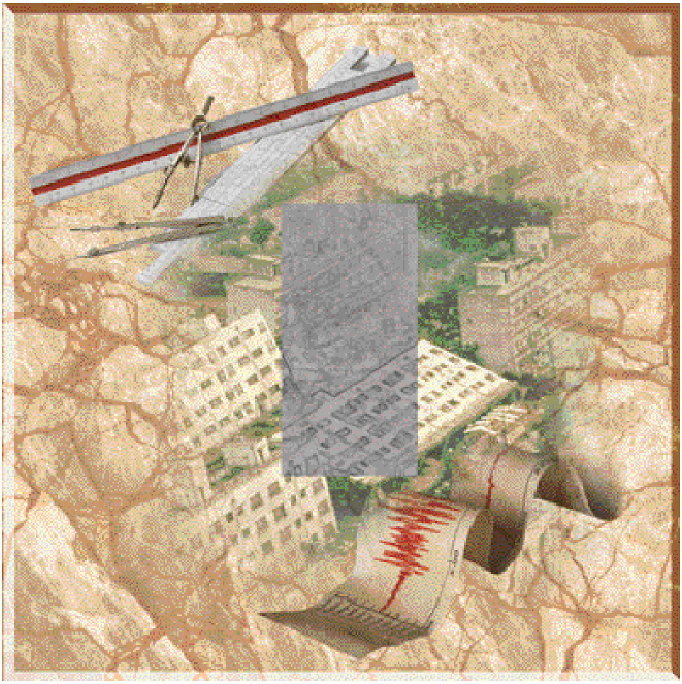
CyberQuake



User's Guide

Version 2.01

from the BRGM software range

Geoscience for a sustainable Earth

brgm

Contents

Chapter 1: Getting Started with CyberQuake

To use this software you must be familiar with either Windows 98, NT, 2000 or XP. You should refer to Microsoft Windows User's Guide for learning how to use these Windows operating instructions. **To install CyberQuake, refer to the Installation guide**.

Even though this software has been designed to be an easy-to-use tool for beginners, a minimum knowledge in Earthquake Engineering is required for an adequate use of it.

Two versions are available:

1. Engineering Analysis version.
2. Advanced Engineering Analysis version.

The second version covers the first one from the point of view of functionality and includes additional capabilities. To facilitate the use of the software, both versions are presented in the same environment. However, some commands are not enabled in the Engineering Analysis version.

Note: For each of the above versions, an Education version is also available.

All commands are accessed from a drop-down menu bar and toolbars are available for experienced users.

To choose a command:

1. with the mouse:
   - double click on the name of the command in the drop-down menu.

2. from the keyboard:
   - *either* press *ALT* followed by an underlined letter of the command name,
   - *or* press *ALT* to select the menu bar and use the arrow keys to move to the command and then press *ENTER*.

Two classes of operations may be performed by this software:

- basic operations on accelerograms (or any other curves) by using Tools,
- Soil Dynamic Analysis.

For practical purposes, several natural recordings are integrated in the Cyber Database available *via* the Import Accelerogram command in the File drop-down menu in any frame, i.e. Main Frame, Soil Column Frame, Equivalent Linear Frame and Control Point Frame.

To get familiar with the different frames, see sections dedicated to:

- Main Frame,
- Soil Column Frame,
- Equivalent Linear Frame,
- Control Point Frame.

User's own database of accelerograms may be also accessed to. They should be transformed into Cyber Formats by users out of the software or in it by using Convert Format in Operations on Curves from Tools menu commands.

The *Tools* menu commands are also available in all frames.

We advise users to start with simple seismic signals such as a Ricker Wavelet as Input Motion in order to get familiar with the software. It is also recommended to begin with an elastic behavior assumption for soil.

The dynamic analysis of multilayer soil needs the definition of:

- the underground geology (geometry),
- the (hydro)mechanical properties,
- the input motion and associated information.

The computed results may then be visualized, stored and analyzed as other created or imported curves by using Tools.

The underground geology is introduced easily in the Soil Column Frame, the Equivalent Linear Frame or the Control Point Frame, depending on the type of analysis to be performed.

The layers are arranged from top to bottom by adding lines in a table-type structure. To add, insert, delete, copy or paste layers, use commands in the Edit menu from the menu bar in each frame.

The (hydro)mechanical properties associated with each layer are also introduced in the same structure. The Define menu from the menu bar and its drop-down menu of commands complete the definition of the problem.

To perform an analysis:

1. Open either a Soil Column Frame, an Equivalent Linear Frame or a Control Point Frame.
2. Enter the soil layers and their (hydro)mechanical properties.

3. In transient analyses, in the Soil Column Frame, the nonlinear constitutive behavior may be assumed.
4. Enter the input motion.[1]
5. Enter the time history.
6. Start analysis.

Note: operations 2 to 5 may be performed in any order.

Use the checklist command in the Computing menu from the menu bar, to verify that all data required for the analysis have been entered.

Engineering Analysis

The Engineering Analysis version includes the commonly admitted hypotheses in practice of Soil Dynamics and Earthquake Engineering:

1. One of the horizontal components of the input acceleration is considered.
2. Input motion is assumed to be vertically incident.
3. Either elastic or equivalent linear (viscoelastic) behavior is adopted for the soil layer.
4. One-phase analysis is carried out.

However, new features used by expert engineers are introduced, they are:

1. Vertical components of the Input Motion is also introduced; i.e. two-dimensional kinematics.

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[1] The input motion may be an analytical curve, an imported natural accelerogram or an accelerogram obtained after deconvolution.

2. Nonlinear (elastoplastic) behavior of soil layers may be considered.

3. The totally undrained[2] condition is included.
4. The bedrock may be either Rigid[3] or Deformable[4].
5. The whole configuration may have a slope (for rigid bedrock only).

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[2] The totally undrained condition assumes no volumetric strain in the layer. In one-dimensional geometry the vertical strain is prevented. With elastoplastic assumption for the soil layer this will result is pore-pressure generation if the material is contracting (e.g. loose sand) and the liquefaction may occur. In this case the computation assuming a one-phase material with an additional constitutive relation representing the incompressibility. In the Engineering Analysis version the soil layer under the water table may be only modeled as an undrained material.

[3] A rigid bedrock represents an ideal medium with very strong mechanical characteristics compared to overlying multilayer soil structure.

[4] A deformable bedrock is modeled as a semi-infinite isotropic homogeneous elastic linear medium. It is characterized by the shear and compression body wave velocities and its mass density.

Note:
1. The vertical component of input acceleration is introduced with elastic and elastoplastic assumption for the soil layers (not for the equivalent linear approach).
2. The totally undrained condition corresponds to zero-permeability of materials during the seismic event. This hypothesis is very often verified in natural conditions. The pore-pressure time history is evaluated knowing the amount of irreversible volumetric plastic strain. The liquefaction of one or more soil layers may occur depending on their mechanical properties and more specifically with respect to their degree of compaction. Additionally, the total irreversible settlement at the ground surface, after the dissipation of pore-pressure generated during the earthquake, is furnished.
3. If the contrast between the velocity in the bedrock and the neighboring soil layer is high, the bedrock may be considered as rigid. This assumption has computational advantages.
4. The bedrock is always assumed to have the same slope as the soil layer. Hence, the effect of lateral heterogeneity (two and three-dimensional effects) are not considered.

Advanced Engineering Analysis

The Advanced Engineering Analysis version has several extra options compared to the other version.

The major features of this version are:

1. Three-dimensional kinematics.
2. Real two-phase computations.

All capabilities of the Engineering Analysis version are included in this version and, as both versions are presented in the same environment, it is easy to switch from one to another.

Education versions

This software may be used for educational purposes. It is suitable for Civil and Earthquake Engineering or Seismology teaching programs.

The Education versions **may not be used** in professional studies.

Soil Layer

The term of soil layer is associated with a physical soil layer characterized by its thickness and (hydro)mechanical properties. The elastic behavior of the layer is defined by the mass density and compression and shear wave velocities. Hence, linear elasticity is assumed. If the elastic properties vary with depth, one should subdivide the soil layer into several layers and introduce the appropriate velocities.

In the Soil Column Frame where Cyber (transient) Analysis is carried out, the soil layer may be assumed as either elastic or elastoplastic. The elastoplastic layer is considered as being either a sand, a clay or a gravel. These materials are taken into account by using the Cyber Constitutive Model. Default parameters are furnished for each type of these materials. One should verify whether the proposed parameters are appropriate or not by simulating the cyclic and monotonous tests, by using G-γ and D-γ curves and/or Simulator.

In the Equivalent Linear Frame and Control Point Frame, an equivalent linear analysis is carried out. The curves containing G/Gmax-γ and D-γ data are necessary for such analyses, when the soil layer material is set to Inelastic. These curves may be either experimental curves or those obtained from a numerical simulation for instance from a cyclic test in the Soil Column Frame. For a linear elastic analysis, no curves are required, when the soil layer material is set to Elastic.

Bedrock

Here, the bedrock represents the semi-infinite layer beneath the soil or the rock profile to be studied.

It is either considered as Rigid or Deformable depending on its mechanical characteristics; *i.e.* wave velocities.

For high contrast in velocities of the bedrock and the adjacent layer (*e.g.* 20 or more), it is recommended to use rigid option for numerical efficiency.

In **all versions** of CyberQuake*,* when using the Soil Column Frame and Equivalent Linear Frame, the Input Motion is considered to be defined at the outcropping bedrock which is itself a homogeneous, isotropic linear elastic material.

However, it is possible to define a Control Point on the surface of a multilayer viscoelastic rock. It is then possible to deconvoluate the Input Motion to the outcropping bedrock which is itself a homogeneous, isotropic linear elastic material. Therefore, Rigid or Deformable concerns only the deepest underlying material.

A rigid bedrock represents an ideal medium with very strong mechanical characteristics compared to overlying multilayer soil structure.

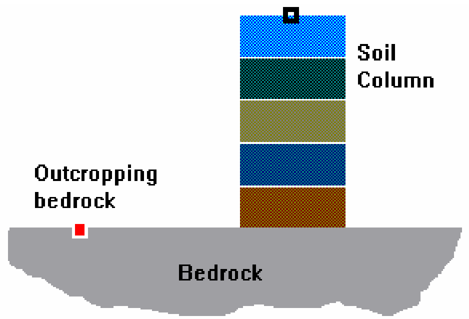
A deformable bedrock is modeled as a semi-infinite isotropic homogeneous elastic linear medium. It is characterized by the shear and compression body wave velocities and its mass density.

Note: when the bedrock is selected as deformable, it is check-marked in the menu. To disable this option, select this option a second time. The check-mark disappears to inform the user.

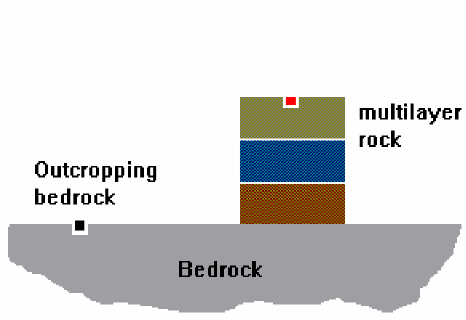
Input Motion

Different accelerations may be used for different Input Motion Components.

For the Soil Column Frame as well as the Equivalent Linear Frame, the input motion is supposed to be defined at the outcropping bedrock at the same altitude as the bedrock underlying the Soil Column, as presented in the figure below. If the bedrock is considered as Deformable, then it is assumed to be an isotropic and homogeneous linear elastic material.



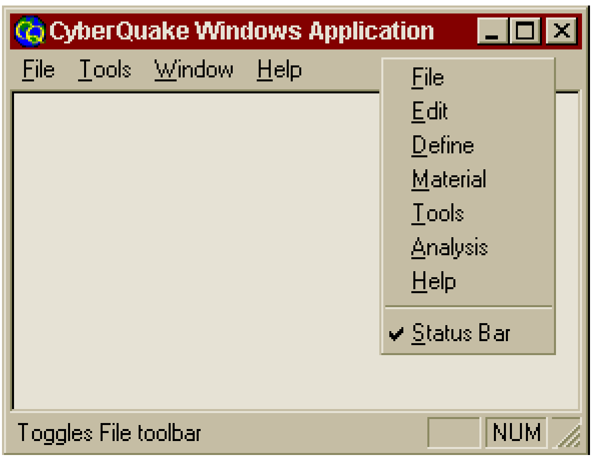
In the Control Point Frame, the input motion is assumed to be given at the surface of the multilayer (non)linear viscoelastic rock.



The outcropping bedrock is the location to where the input motion is deconvoluated from the control point and where the input motion is defined for the soil column analysis.

Menus of the various frames

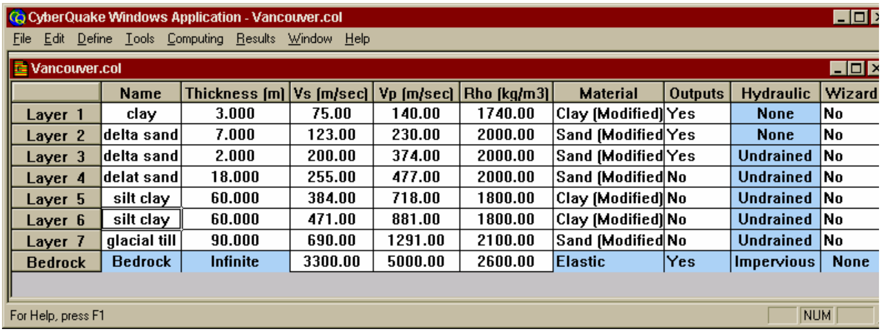
Main Frame



Main Frame Menus:

- File,
- Tools,
- Window,
- Help.

Soil Column Frame



	Name	Thickness [m]	Vs [m/sec]	Vp [m/sec]	Rho [kg/m3]	Material	Outputs	Hydraulic	Wizard
Layer 1	clay	3.000	75.00	140.00	1740.00	Clay (Modified)	Yes	None	No
Layer 2	delta sand	7.000	123.00	230.00	2000.00	Sand (Modified	Yes	None	No
Layer 3	delta sand	2.000	200.00	374.00	2000.00	Sand (Modified	Yes	Undrained	No
Layer 4	delat sand	18.000	255.00	477.00	2000.00	Sand (Modified	No	Undrained	No
Layer 5	silt clay	60.000	384.00	718.00	1800.00	Clay (Modified)	No	Undrained	No
Layer 6	silt clay	60.000	471.00	881.00	1800.00	Clay (Modified)	No	Undrained	No
Layer 7	glacial till	90.000	690.00	1291.00	2100.00	Sand (Modified	No	Undrained	No
Bedrock	Bedrock	Infinite	3300.00	5000.00	2600.00	Elastic	Yes	Impervious	None

Soil Column Frame Menus:

- File,
- Edit,
- Define,
- Tools[5],
- Computing,
- Results,
- Window,
- Help.

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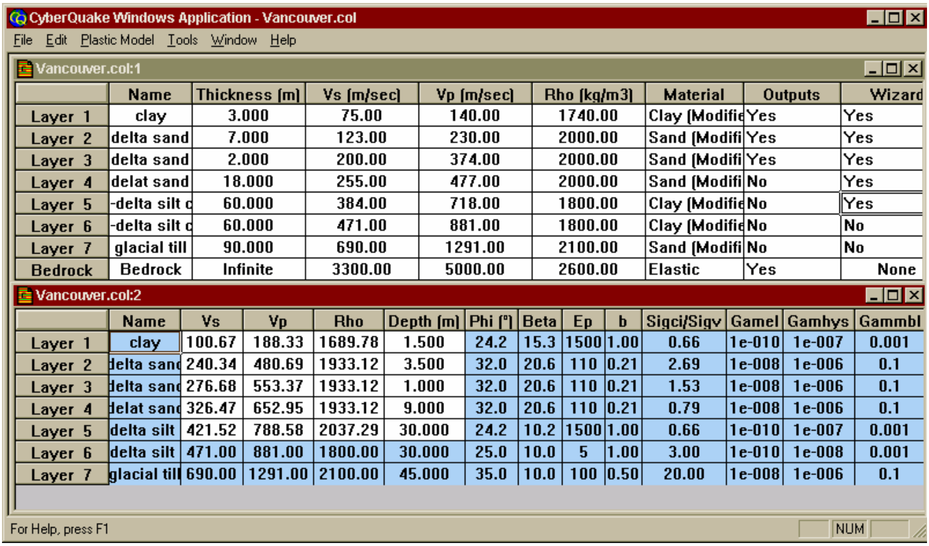
5 The same as in the Main Frame.

Parameter Wizard Frame



	Name	Thickness (m)	Vs (m/sec)	Vp (m/sec)	Rho (kg/m3)	Material	Outputs	Wizard
Layer 1	clay	3.000	75.00	140.00	1740.00	Clay (Modifie	Yes	Yes
Layer 2	delta sand	7.000	123.00	230.00	2000.00	Sand (Modifi	Yes	Yes
Layer 3	delta sand	2.000	200.00	374.00	2000.00	Sand (Modifi	Yes	Yes
Layer 4	delat sand	18.000	255.00	477.00	2000.00	Sand (Modifi	No	Yes
Layer 5	-delta silt c	60.000	384.00	718.00	1800.00	Clay (Modifie	No	Yes
Layer 6	-delta silt c	60.000	471.00	881.00	1800.00	Clay (Modifie	No	No
Layer 7	glacial till	90.000	690.00	1291.00	2100.00	Sand (Modifi	No	No
Bedrock	Bedrock	Infinite	3300.00	5000.00	2600.00	Elastic	Yes	None

	Name	Vs	Vp	Rho	Depth (m)	Phi (°)	Beta	Ep	b	Sigci/Sigv	Gamel	Gamhys	Gammbl
Layer 1	clay	100.67	188.33	1689.78	1.500	24.2	15.3	1500	1.00	0.66	1e-010	1e-007	0.001
Layer 2	delta sand	240.34	480.69	1933.12	3.500	32.0	20.6	110	0.21	2.69	1e-008	1e-006	0.1
Layer 3	delta sand	276.68	553.37	1933.12	1.000	32.0	20.6	110	0.21	1.53	1e-008	1e-006	0.1
Layer 4	delat sand	326.47	652.95	1933.12	9.000	32.0	20.6	110	0.21	0.79	1e-008	1e-006	0.1
Layer 5	delta silt	421.52	788.58	2037.29	30.000	24.2	10.2	1500	1.00	0.66	1e-010	1e-007	0.001
Layer 6	delta silt	471.00	881.00	1800.00	30.000	25.0	10.0	5	1.00	3.00	1e-010	1e-008	0.001
Layer 7	glacial till	690.00	1291.00	2100.00	45.000	35.0	10.0	100	0.50	20.00	1e-008	1e-006	0.1

Parameter Wizard Frame Menus:

- File,
- Edit,
- Plastic Model,
- Tools[6],
- Window,
- Help.

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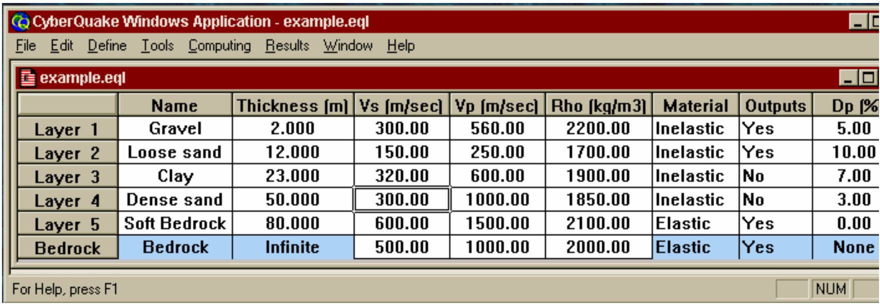
[6] The same as in the Main Frame.

Equivalent Linear Frame



	Name	Thickness [m]	Vs [m/sec]	Vp [m/sec]	Rho [kg/m3]	Material	Outputs	Dp [%
Layer 1	Gravel	2.000	300.00	560.00	2200.00	Inelastic	Yes	5.00
Layer 2	Loose sand	12.000	150.00	250.00	1700.00	Inelastic	Yes	10.00
Layer 3	Clay	23.000	320.00	600.00	1900.00	Inelastic	No	7.00
Layer 4	Dense sand	50.000	300.00	1000.00	1850.00	Inelastic	No	3.00
Layer 5	Soft Bedrock	80.000	600.00	1500.00	2100.00	Elastic	Yes	0.00
Bedrock	Bedrock	Infinite	500.00	1000.00	2000.00	Elastic	Yes	None

Equivalent-Linear Frame Menus:

- File,
- Edit[7],
- Define,
- Tools[8],
- Computing,
- Results,
- Window,
- Help.

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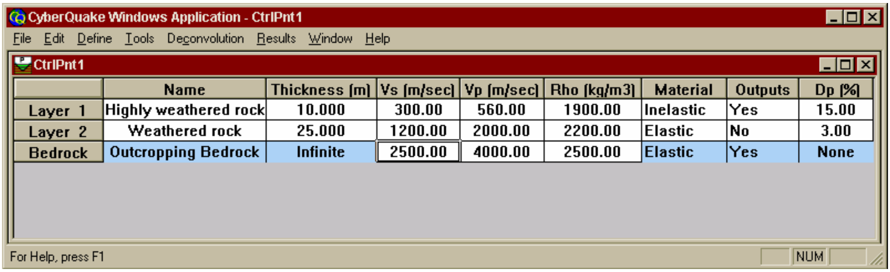
7 The same as in the Soil Column Frame.

8 The same as in the Main Frame.

Control Point Frame



Control Point Frame Menus:

- File,
- Edit[9],
- Define,
- Tools[10],
- Deconvolution,
- Results,
- Window[11],
- Help.

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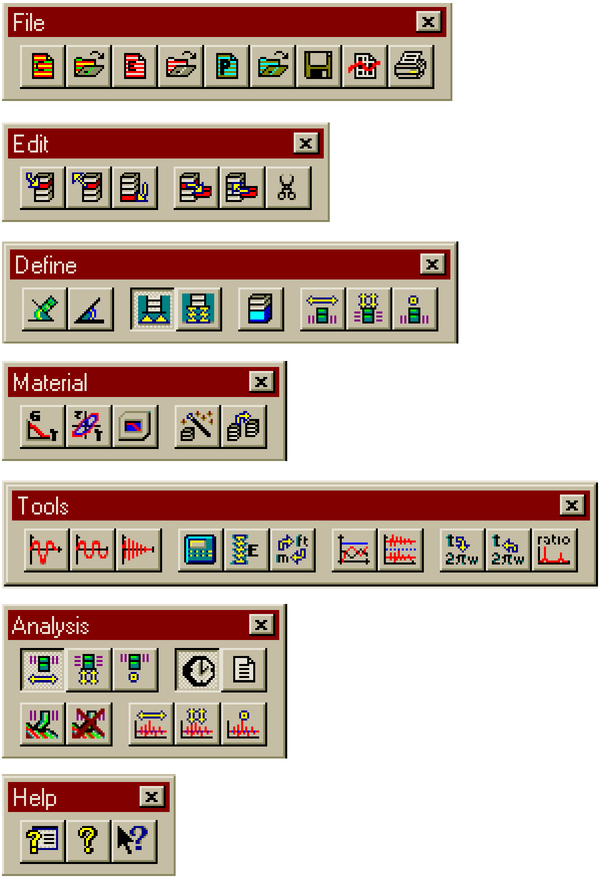
9 The same as in the Soil Column Frame.

10 The same as in the Main Frame.

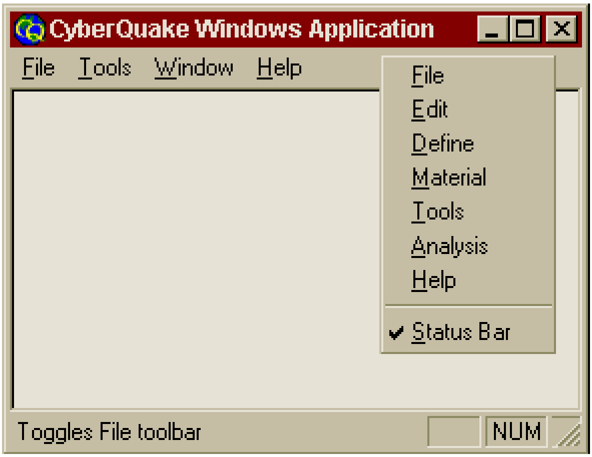
11 The same as in the Equivalent Linear Frame.

Dockable/Floating Toolbars

The following toolbars may be attached, or docked, to any side of the frame window, or they can be detached, or floated, in their own mini-frame window. Hereafter, they are presented as floating mini-frame windows. Their buttons represent shortcuts to the corresponding drop-down menu commands.



Chapter 2: Main Frame



Main Frame File Menu

In the Main Frame the following actions may be performed by using this menu.

New	Creates a document for a new multilayer soil column, for either a Cyber Analysis, an Equivalent Linear Analysis or a Deconvolution from a Control Point
Open	Opens an already existing multilayer soil column, for either a Cyber Analysis, an Equivalent Linear Analysis or a Deconvolution from a Control Point

Import Accelerogram	Gets an existing accelerogram from a database (Cyber Database or Other databases)
Export Cyber Curve	Exports a Cyber curve into a formatted curve with Cyber formats (*Professional versions Only)*
Exit	Closes all windows and returns you to the Program Manager.

Tools menu commands

Following operations may be performed by using this menu. The same menu is also available for Soil Column, Parameter Wizard, Equivalent linear and Control Point frames.

1. Create Analytical Function…
2. Operations on curves…
3. Fourier Transform
4. Inverse Fourier Transform
5. Response Spectrum
6. Spectral Ratio
7. Fourier Spectrum Smoothing
8. Frequency Filter
9. Base Line Correction
10. Moduli Conversion
11. Unit Conversion
12. Plot
13. Diagrams
14. Options

Create Analytical Function

Use this command to create the following analytical functions:

1. Ricker wavelet
2. Harmonic signal
3. Tsang signal
4. Step Function
5. Polynomial Function
6. Ramp Function
7. Piecewise Linear Function
8. Constant Function
9. Dirac Function
10. Decay Function

They are useful as simplified input motions for seismic analysis.

For all of these functions:

1. Enter the Time Description.
2. Enter specific parameters depending on the function.
3. A plot representing the resulting curve is presented.
4. Modify the plot features by using the toolbar buttons (to access the Graph utilities).
5. Use Saving Interval to save a portion of the curve on an x-axis interval. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the resulting curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.

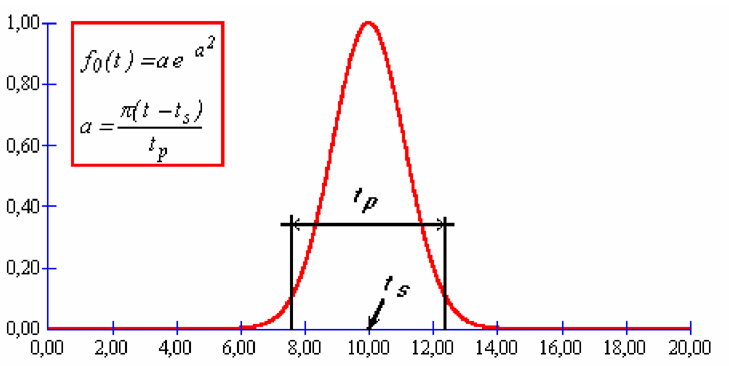
8. If saving, choose a name for the resulting curve.

Ricker Wavelet

The Ricker Wavelet is very often used in seismology as the input motion. It is in fact very simple in time domain and in frequency domain. It vanishes gently with respect to the frequency and it does not introduce any cut-off effects. The form of the signal depends on two parameters; t_s represents the time of maximum value and t_p is a characteristic period.

Different orders may be considered for this signal. The most commonly used orders are:

0th Order



1st Order

$$f_1(t) = -a\sqrt{2}\, f_0(t)\, e^{1/2}$$

2nd Order

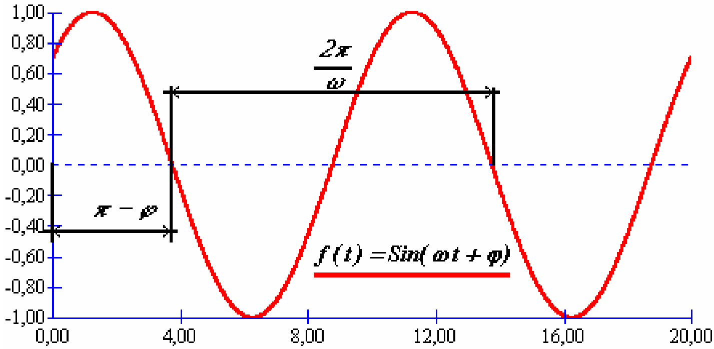
$$f_2(t) = \left(a^2 - 1/2\right) f_0(t) \frac{e^{3/2}}{2}$$

3rd Order

$$f_3(t) = -\left(a^3 - 3a/2\right) f_0(t) \frac{e^{3/2-\sqrt{3/2}}}{\sqrt{3/2-\sqrt{3/2}} \cdot \sqrt{3/2}}$$

Harmonic Signal

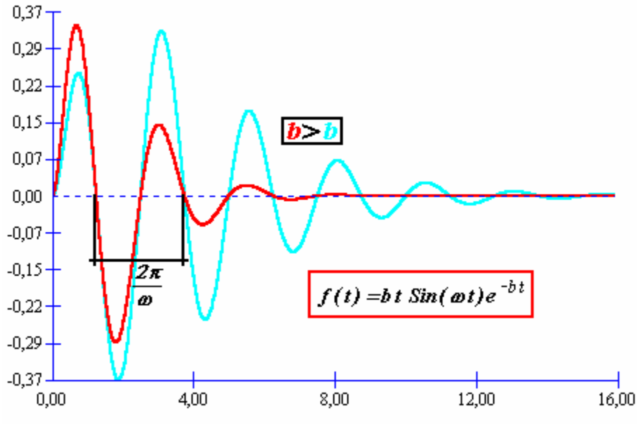
The harmonic signal is of certain interest in seismic computations. The parameters used in the definition of a harmonic function may be understood from the figure.



Tsang Signal

The Tsang signal is of certain interest in seismic computations. More specifically, the decay function results in a more realistic signal than the harmonic one in the context of seismic analysis.

The parameters used in the definition of a tsang function may be understood from the figure.

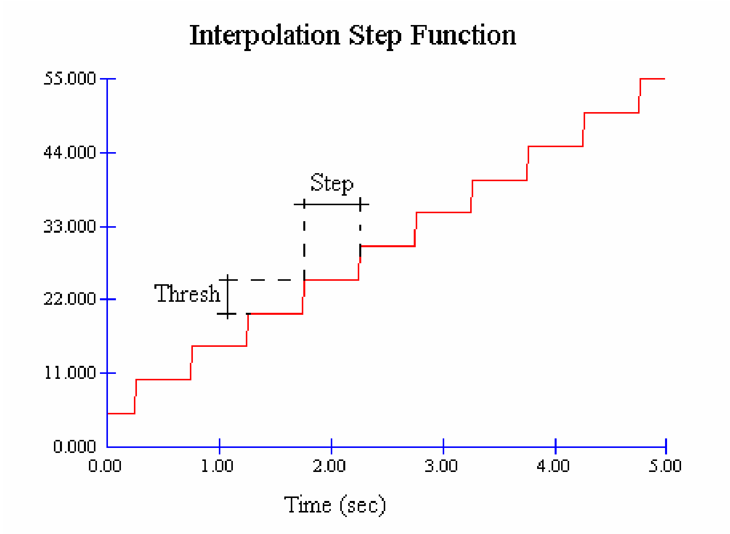


Step Function

The step function is defined as:

$$f(t) = Thresh \times Amplit \times E\left(\frac{t - t_0}{Dt}\right)$$

$$Dt = t - Step$$



Polynomial Function

The polynomial function is defined as:

$$f(t) = a_0 + a_1 t + \ldots + a_{10} t^{10}$$

Ramp Function

The ramp function is defined as:

$$f(t) = a_0 + a_1 t$$

Piecewise Linear Function

The piecewise linear function is composed of N ramp functions, defined as:

$$\forall i \in [1, N], \forall t \in [t_i, t_{i+1}],$$
$$f_i(t) = a_{i0} + a_{i1}t \text{ and } f_{i-1}(t_i) = f_i(t_i)$$

Constant Function

The constant function is defined as:

$$\forall t, \quad f(t) = f_0$$

Dirac Function

The dirac function is defined as:

$$f(t_i) = f_0 \text{ and } \forall t \neq t_i, \quad f(t_i) = 0$$

Decay Function

The decay function is defined as:

$$f(t) = Amplit \times e^{-ct}$$

Operation on curves

The following operations may be performed by using this menu:

1. Convert Format
2. Interpolate
3. Least Squares Fitting
4. Operators
5. Curve (X=f(x),Y=g(x))

Convert Format

Use this command from Operations on curves command in the Tools drop-down menu command to convert your files into Cyber Formats.

Using this command:

1. In the first dialog box that appears:
   - select the format-type of the file (either Cyber Formats or Other),
   - select the format-type of the input data ((x,f(x)) or f(Δx) given by constant step Δx),
   - select the separator-type of the input data and the decimal number format,
   - choose the format-type of the output data data ((x,f(x)) or f(Δx) given by constant step Δx).
2. If the input data is given with a constant step, enter the initial step and x values in the dialog box that appears. Then, if the output data is also required by a constant step, enter the interpolation step in the last dialog box that appears.
3. Open the file containing the curve.
4. Enter the number of lines to skip at the beginning of the original file.
5. Choose a file name for the resulting curve in the proposed directory, or use the mouse to scroll through a different drive or directory, until you see the directory where you want to save the curve in.

Cyber Formats

All files produced by CyberQuake are proprietary binary files. Use Export Cyber Curve from any File drop-down menu commands to convert them into Formatted files.

The files used by CyberQuake are either formatted or unformatted.

Use Convert Format command from the Tools drop-down menu command to convert your own data to Cyber Formats if necessary.

Two formats are possible:

f(∆x) type data:

```
#Cyber Format
#501 val, step = 0.01
0        0.01     501
             0             0   1.3438e-015    .
   1.2713e-014   1.8357e-014   2.6454e-014   3.
   2.2701e-013   3.2252e-013   4.5727e-013
   3.5587e-012    4.974e-012    6.938e-012   9.
   4.8952e-011    6.731e-011   9.2363e-011   1.
   5.9062e-010   7.9888e-010   1.0784e-009   1.
    6.247e-009   8.3115e-009   1.1036e-008   1.
   5.7888e-008   7.5754e-008   9.8926e-008   1.
   [illegible]
```

(x,f(x)) type data:

```
#Cyber Format
#501 val, step = 0
0       0       501
          0.01              0
          0.02     1.3438e-015
          0.03     1.9642e-015
          0.04     2.8652e-015
          0.05      4.171e-01
          0.06     6.0598e-01
          0.07     8.7859e-01
          0.08     1.2713e-01
          [illegible]
```

Note:

1. The unformatted curves generated by CyberQuake have *cyb* as extension. The default extension for formatted Cyber curves is cyt.

2. The Natural Accelerograms in the Cyber Database have a Cyber binary format and should not be converted to Cyber Format.

Interpolate

Use this command in the Operations on curves menu from Tools drop-down menu command to perform the interpolation of a function f(x) (curve) to the desired constant step.

Using this command:

1. Enter the interpolation step.
2. Open the file containing the function you want to operate on.
3. A plot representing the interpolated function will be presented.
4. Modify the plot features by using the toolbar buttons (to access the Graph utilities).
5. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the resulting curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, choose a name for the resulting curve.

Least Squares Fitting

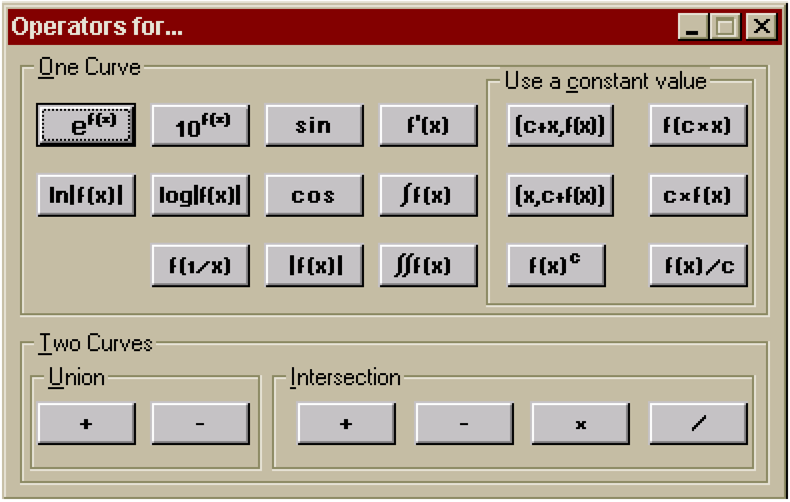
Use this command in the Operations on curves menu from Tools drop-down menu command to perform a least squares fitting of a function f(x) (curve) by a polynom of the desired order.

Using this command:

1. Open the file containing the function you want to operate.
2. A plot representing the initial curve will be presented.

3. Use Least Square Fitting to choose the order of the polynomial function.
4. A plot representing the initial curve as well as the polynomial function will be presented. Operations 3 and 4 may be repeated for other orders.
5. Modify the plot features by using the toolbar buttons.
6. Use Edit Curve(s) to edit the data values of the displayed curve(s). Use Save Curve(s) to keep the resulting curve(s).
7. Use Select Curve(s) or Delete Curve(s) to select or delete a set of curves.
8. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
9. Use Reset Graph to come back to the original curve(s).
10. Use Copy to Clipboard to copy the displayed curve(s) to the clipboard for further use in Windows environment.
11. Use Toggle Legends to enable/disable the legends for presented curves.
12. If saving, choose a name for the resulting curve.

Operators



Several operations may be used on curves by using the following basic operators:

1. Operations concerning a single curve.

|f(x)|	Absolute value of f(x)
|f(1/x)|	Expressing f(x) as a function of 1/x
cos(f(x))	Cosines of f(x)
sin(f(x))	Sinus of f(x)
$10^{f(x)}$	Ten to power of f(x)
Ln|f(x)|	Natural (or Napierian) Logarithm of |f(x)|
log|f(x)|	Logarithm of |f(x)|
$e^{f(x)}$	Exponential (or antilogarithm) of f(x)
f'(x)	Numerical derivation of f(x) with respect to x. An implicit one-step Theta method is used to perform the numerical derivation

∫f(x)	Numerical integration of f(x) with respect to x. An implicit one-step Theta method is used to perform the numerical integration.
∫∫f(x)	Numerical integration of f(x) with respect to x by using Newmark Integration Method.

Using either of these commands:

1. Open the file containing the curve f(x).
2. A plot representing the modified curve appears.
3. Modify the plot features by using the toolbar buttons (to access the Graph utilities).
4. Use Edit Curve to edit the data values of the displayed curve.
5. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. If saving, choose a name for the resulting curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. For double-integration of a curve, operations 3 to 7 are repeated for the second integration of f(x) with respect to x.

Newmark

The Newmark integration scheme is given as:

$$f'(x_1) = f'(x_0) + \Delta x\left[f''(x_0) + \gamma\left(f''(x_1) - f''(x_0)\right)\right]$$

$$f(x_1) = f(x_0) + \Delta x\left\{ f'(x_0) + \Delta x\begin{bmatrix} \frac{1}{2} f''(x_0) + \\ \beta\left(f''(x_1) - f''(x_0)\right)\end{bmatrix}\right\}$$

With a suitable choice of integration parameters (γ > 0.5, β >0.25) it is possible to introduce frequency-dependent numerical damping into computation.

This scheme is used in this software for integrating dynamic equations in transient domain. The default values are γ= 0.5, β =0.25. To select other values in the Time Description dialog box that appears when using Time History, press Coefficients *button.*

2. Operations involving a single curve and a scalar.

(c+x,f(x)) Translate the curve by adding a scalar following x-axis

(x,c+f(x)) Translate the curve by adding a scalar following y-axis

(x,f(c×x)) Multiply the curve by a scalar following x-axis

(x,c×f(x)) Multiply the curve by a scalar following y-axis

$f(x)^c$ Modify the curve by bringing the y-axis values to a power (c)

f(x)/c Divide the curve by a scalar following y-axis

Using either of these commands:

1. Enter the scalar quantity.
2. Open the file containing the curve f(x).
3. A plot representing the modified curve appears.

4. Modify the plot features by using the toolbar buttons (to access the Graph utilities).
5. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, choose a name for the resulting curve

3. Operations involving two curves.

Union:

f(x)+g(x) Add two curves f(x) and g(x)

f(x)-g(x) Subtract g(x) from f(x)

Intersection:

f(x)+g(x) Add two curves f(x) and g(x) on the common interval on x-axis

f(x)-g(x) Subtract g(x) from f(x) on the common interval on x-axis

f(x)×g(x) Multiply two curves f(x) and g(x) on the common interval on x-axis

f(x)/g(x) Divide f(x) by g(x) on the common interval on x-axis

In Union, the operation is made over the interval of x-axis representing the union of intervals of both curves.

In Intersection, the operation is made over the interval of x-axis representing the intersection of intervals of both curves.

For any operation, the curves are not supposed to have the same number of points and may have been defined on different abscissa (x-coordinate) intervals.

Selecting either of these commands:

1. Open the file containing the first curve.
2. Restart the operation for the second curve.
3. A plot representing the resulted curve appears.
4. Modify the plot features by using the toolbar buttons (to access the Graph utilities).
5. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, choose a name for the resulting curve.

Curve (X=f(x),Y=g(x))

Use this command menu to either:

- *Display* or *Rotate* two real functions f(x) and g(x), as a parametric real curve {C=Y(X), with X= f(x) and Y=g(x)},
- or *Display* one complex function Z(x), as a parametric real curve {C=Y(X), with X= Re[Z(x)] and Y=Im[Z(x)]},
- or create a *Complex* curve {C=Z(x), with Z(x) = f(x) + i g(x)} with f(x) and g(x), two real functions and $i^2 = -1$.

Display

Displays the parametric curve {C=Y(X), with X= f(x) and Y=g(x)} or {C=Y(X), with X= Re[Z(x)] and Y=Im[Z(x)]}.

To use this command:

1. Open the first file containing the real function X=f(x) or the file containing the complex curve.
2. Open the second file containing the real function Y=g(x), when dealing with two real functions.
3. A plot of the resulted curve (C) is shown.
4. Use Saving Interval to save a portion of the curve on an x-axis interval. The default is the whole interval.
5. Use Edit Curve to edit the data values of the displayed curve.
6. Click on Save Curve to save the curve on disk and exit, or on Close to quit the plot.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, choose a name for the resulting curve.

Rotate

Projects one parametric curve {C=Y(X), with X= f(x) and Y=g(x)} on a new basis obtained after rotation.

Using this command:

1. Open the first file containing the real function X=f(x).
2. Open the second file containing the real function Y=g(x).
3. Enter the scalar quantity representing the rotation angle (in degrees).
4. A plot representing the new curves appears.
5. Modify the plot features by using the toolbar.
6. Use Saving Interval to save a portion of the curve on an x-axis interval. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
7. Use Edit Curve to edit the data values of the displayed curve.
8. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
9. If saving, choose a name for the resulting curve.

Complex

Creates one complex curve {C=Z(x), with Z(x) = f(x) + i g(x)}, with f(x) and g(x), two real functions and $i^2 = -1$.

Using this command:

1. Open the first file containing the real function X=f(x).
2. Open the second file containing the real function Y=g(x).
3. A plot representing the imaginary part versus the real one of the complex curve appears.

4. Modify the plot features by using the toolbar.
5. Use Saving Interval to save a portion of the curve on an x-axis interval. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, choose a name for the resulting complex curve.

Fourier Transform

Use this command to compute the Fourier Transform of a curve.

The Fourier Transform used in CyberQuake is defined as:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-i\omega t} dt$$

Note: A Fast Fourier Transform is used to perform this operation. The minimum number of discrete values considered in FFT is 8192. If the curve results in less number of values, it will be completed by zeros. If it results in more values, the number of points to be considered will be the first power of two immediately over the number of points provided completed by zeros.

Using this command:

1. Select a Frequency Filter and define the type of output (Amplitude, Phase and/or Complex).
2. Open the file containing the curve.
3. One, two or four curves will be displayed sequentially depending on the type of output requested.
4. Modify the plot features by using the toolbar.

5. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve(s).
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, choose a name for the resulting curve.

Inverse Fourier Transform

Use this command to compute the Inverse Fourier Transform of a curve.

The Inverse Fourier Transform used in CyberQuake is defined as:

$$f(t) = -\frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega)e^{i\omega t}\,d\omega$$

Note: A Fast Fourier Transform is used to perform this operation. The function *F(ω)* is furnished either as Amplitude and Phase (in degrees) or as Complex. Therefore two curves should be provided. The minimum number of discrete values considered is 8192. If curves contain less number of values, they will be completed by zeros. If they contain more values the number of points to be considered will be the first power of two immediately over the number of points provided completed by zeros.

Using this command:

1. Define the nature of the curves containing data to be processed.
2. Open the file(s) containing the curves.

3. Click on the name of the first file containing the Amplitude values, then click on the Open button; or just double-click on the name of the file.
4. Click on the name of the second file containing the Phase values, then click on the Open button; or just double-click on the name of the file.
5. Click on the name of the file containing the Complex values (Real and Imaginary parts), then click on the Open button; or just double-click on the name of the file.
5. A plot representing the Inverse Fourier Transform appears.
6. Modify the plot features by using the toolbar.
7. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
8. Use Edit Curve to edit the data values of the displayed curve(s).
9. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
10. If saving, choose a name for the resulting curve.

Response Spectrum

Use this command from the Tools menu command in any frame to compute the response spectra. It corresponds to the response of a damped oscillator subjected to an acceleration. The maximum motion (Displacement, Velocity, Acceleration, Pseudo-velocity or Pseudo-acceleration) obtained for each value for the eigen frequency of the oscillator is displayed with respect to the eigen period, eigen frequency or eigen angular frequency.

The Pseudo-velocity response spectrum is the product of displacement with the eigen frequency of the oscillator. It is the most commonly used spectrum in engineering.

The Pseudo-acceleration response spectrum is the product of displacement with the square of the eigen frequency of the oscillator.

Several methods may be used to calculate the solution. In CyberQuake, a transient approach is used and the equation is resolved numerically.

Using this command:

1. Enter the damping ratio in percent (default is 5%), the number of discretization steps (default is 500), the interval for the frequency of the oscillator (default is 0.25 to 50 Hz) and select the output characteristics. Type Default to display default values. Type Cancel to quit.
2. Open the file containing the input acceleration.
3. The resulting curve will be displayed.
4. Modify the plot features by using the toolbar. In general the response spectra are presented in indifferently lin-lin, lin-log or log-log space. Here, the lin-lin presentation space is adopted. Use the Graph Icons to change the presentation.
5. Use Saving Interval to save the curve on a given interval of x-axis. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve(s).
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, then choose the names for the curves.

Note: in general the response spectra are computed with a 5% damping ratio.

Spectral Ratio

Use this command from the Tools menu command in all frames to compute the spectral ratio. The term Spectral Ratio is in general attributed to the ratio between the output results (e.g. acceleration) and input motion (e.g. input acceleration) presented in Fourier domain. Here, the ratios between the Fourier Amplitudes of two transient quantities with respect to frequency are presented.

Using this command:

1. Open the file containing the first **transient** curve.
2. Open the file containing the second **transient** curve.
3. Then, a dialog box appears asking whether the Fourier Amplitude of curves should be smoothed before the ratio is computed or not (see Fourier Spectrum Smoothing).
4. If Yes, enter the bandwidth of the running mean-square smoothing window
5. The resulting Spectral Ratio appears.
6. Modify the plot features by using the toolbar.
7. Use Saving Interval to save the curve on a given interval of x-axis. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
8. Use Edit Curve to edit the data values of the displayed curve.
9. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.

10. If saving, then choose the name for the resulting curve.

Note: f(x)/g(x) from Operators in the Operation on curves from the Tools drop-down menu command may be also used for this operation, by entering the files containing both **Fourier Amplitudes**.

Fourier Spectrum Smoothing

Use this command from the Tools menu command in all frames to smooth the Fourier Transform of a curve represented with respect to the frequency.

Note: The smoothing process is based on a sliding window technique. The size of the window (bandwidth) is selected by the user. The average of values is attributed to the middle point in the window. The window slides on the following point next to the point from which the previous window started and the average of points in the new interval defined by the bandwidth is attributed to the next middle point. The procedure continues until the last point on the x-axis. To strongly smooth a curve, various strategies may be adopted. It is possible to use a large bandwidth or perform several smoothing operations with a smaller bandwidth. We recommend the second technique.

Using this command:

1. Select the size of the sliding window (bandwidth) in Hz.
2. Open the file containing the curve.
3. The smoothed curve is displayed.
4. Modify the plot features by using the toolbar.
5. Use Saving Interval to save the curve on a given interval of x-axis. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, then choose the name for the resulting curve.

9. Repeat the operations from 1 to 8 with the last curve saved on 8, until obtaining the requested degree of smoothing.

Frequency Filter

Use this command:

1. ***Either*** from the Tools menu command in any frame to filter the frequency content of a transient curve.
2 ***Or*** in the list boxes proposed when using the Fourier Transform.

Using this command in the first case:

1. Select the minimum and maximum frequencies representing the interval in which the frequency content will not be affected. Enter also a range for each limit. Each range gives the frequency interval on which a decay function is applied to the curve.
2. Open the file containing the curve.
3. The transient filtered curve is plotted.
4. Modify the plot features by using the toolbar.
5. Use Saving Interval to save the curve on a given interval of x-axis. Use Save Curve to keep the resulting curve on disk and exit, or Close to quit.
6. Use Edit Curve to edit the data values of the displayed curve.
7. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
8. If saving, then choose the name for the resulting curve.

Using this command in the second case:

1. Select the minimum and maximum frequencies representing the interval in which the frequency content will not be affected. Enter also a range for each limit. Each range gives the frequency interval on which a decay function is applied to the curve.
2. Click on the OK button.

Note: a second order decay function is applied to the curve before the minimum and after the maximum frequency.

$$F = a\,f^2 + b$$

$$a = \frac{1}{2\beta f_\alpha R_\alpha - R_\alpha^2}$$

$$b = 1 - \frac{f_\alpha^2}{2\beta f_\alpha R_\alpha - R_\alpha^2}$$

where

$$\begin{cases} \alpha = M \\ \beta = -1 \end{cases} \qquad f \in \left[f_M, f_M + R_M\right]$$

$$\begin{cases} \alpha = m \\ \beta = 1 \end{cases} \qquad f \in \left[f_m - R_m, f_m\right]$$

with

f_M the maximum frequency

f_m the minimum frequency

R_M the range for the maximum frequency

R_m the range for the minimum frequency

Base Line Correction

Use this command from the Tools drop-down menu command to correct the base line of a natural accelerogram.

In fact, unrealistic displacements or velocities may occur when integrating accelerations due to errors in the acceleration data introduced either when it is recorded or in subsequent manipulations.

Three methods are available in CyberQuake:

1. **Least-Mean-Square-Velocity dv0** proposed by G.V. Berg and G.W. Housner (1961) in which initial velocity and displacement are assumed to be zero.
2. **Least-Mean-Square-Velocity d0** proposed by W.H. Boyce (1970) in which initial displacement is only assumed to be zero.
3. **End-Time-Zero** proposed by J.V. Poppitz (1968) in which the initial acceleration and the final acceleration, velocity and displacement are assumed to be zero.

The two first techniques, not sensitive to end conditions, are used in general with seismic data while the last one is recommended for use with (nuclear-) explosion-induced data.

Caution: this operation is performed on natural accelerograms (if necessary) before dynamic computation of the soil column and neither on computed results nor on analytical input motions.

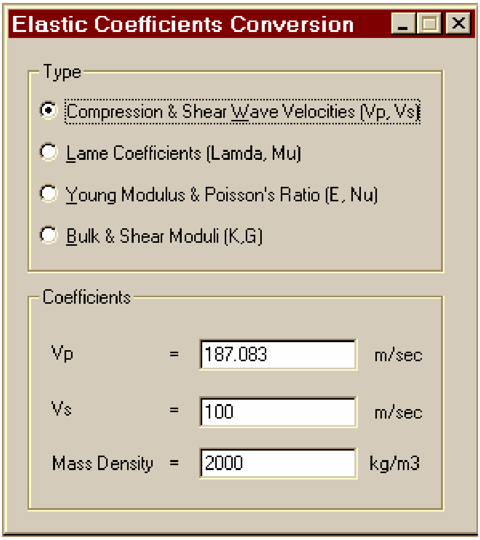
Using this command:

1. Select the method you want to use in the dialog box.
2. Open the file containing the curve you want to operate.
3. A plot representing the corrected displacement appears.
4. If the resulted displacement is satisfactory, use Save Curve to record the corresponding acceleration to disk

and exit, or type Close to quit. Use Saving Interval to save the acceleration on a given interval of x-axis.

5. Use Edit Curve to edit the data values of the displayed curve(s).
6. Use Refresh Graph to update the plot display, for instance after having loaded the file containing your Graph Templates.
7. If saving then you may choose a name for each corrected curve.

Moduli Conversion



Use this command to convert different moduli.

Selecting this command, you can convert following triples very often used indifferently in practice:

$$(\rho, Vp, Vs) \text{<-->} (\rho, E, \nu) \text{<-->} (\rho, \lambda, \mu) \text{<-->} (\rho, K, G)$$

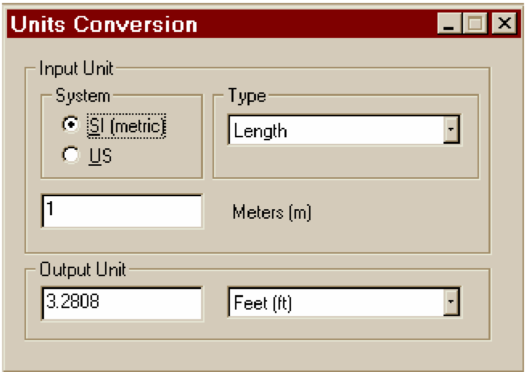
with:

ρ	The mass density
Vp	The compression (dilatational or first kind) body wave velocity
Vs	The shear (transverse or second kind) body wave velocity
E	The Elastic modulus
ν	The Poisson's ratio
λ, μ	The Lamé elastic coefficients

K The bulk (volumetric or isotropic) elastic modulus

G The shear elastic modulus (G = μ)

Unit Conversion

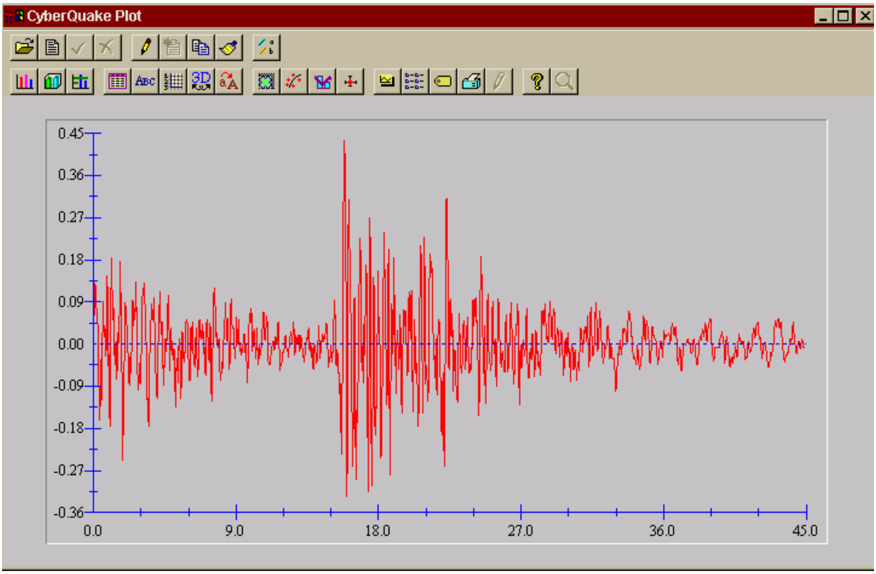


Use this command to convert Metric to U.S. Units and *vice versa.*

Selecting this command, you can convert Length, Area, Volume, Mass, Mass Density, Pressure and Force units used in the software.

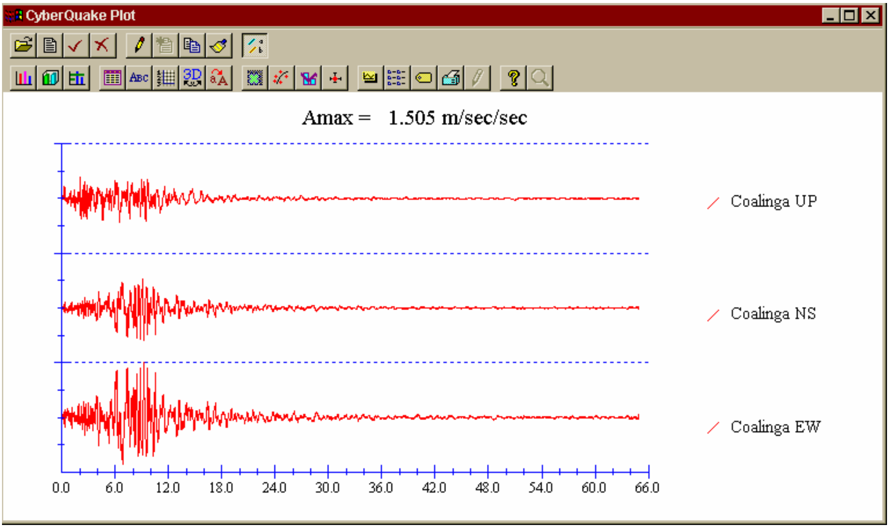
Plot

Use this command to plot one or several superimposed curves.



Diagrams

Use this command to plot one or several curves. The origin of each new curve is moved vertically in order to display a diagram containing curves at different depths on the soil column profile.



The maximum number of curves to be plotted simultaneously is 15.

To use either of these commands:

1. Select the command.
2. In the list box that appears, look for the file you want to plot.
   Use the mouse to scroll through the list of files, or to open directories (by double-clicking on them), or to select a different drive, until you see the file you want.
3. Select the filename(s), then click on the Open button; or just double-click on a filename.

4. Modify the plot features by using the toolbar.

Note: Refer to Graph Help (after pressing the toolbar button) for further information.

The following actions may be done when using the above commands:

Clear Graph	Clear all plotted graphs
Get Curve	Load curve(s) to be displayed
Edit Curve(s)	Edit the data values of the displayed curve(s)
Refresh Graph	Plot again all loaded curves (not hidden ones), to update any change in the settings
Reset Graph	Plot again all loaded curves (even hidden ones), except the deleted ones
Select...	Select (show or hide) curves to be displayed
Delete...	Delete selected curves
Toggle Legends	Enable/disable the presented legends
Copy to Clipboard	Copy a plot to the Clipboard for further use in the Windows environment. Once the object copied, you can open a Windows application and copy it from the Clipboard to a new or existing document
Saving Interval	Select an interval on the x-axis for which the displayed graph may be saved. Then to save the graph, use the Save Curve command of the Quick Plot

Save Curve	Save the curve(s) displayed with Quick Plot and exit
Close	Quit a Quick Plot

Main Frame Window menu

In the Main Frame, the following operations may be performed by using this menu:

Toolbar	Enables (disables) the Toolbars in any Frame
Status Bar	Enables (disables) the Status Bar in which a brief explanation of the command key is given

Main Frame Help menu

In the Main Frame, the following information may be obtained by using this menu:

Getting Started	Explains how to get started with CyberQuake
Contents	Gives the contents of the CyberQuake Help
Using Help	Starts the Windows help engine to give you help on how the help system works. There is no default command key
About CyberQuake	Shows the release version and the names of CyberQuake authors
Disclaimer	CyberQuake and the accompanying files are supplied on an "as-is" basis. It is continually being developed and improved. The authors are interested to hear about

any deficiencies in order to improve next versions

As with most software, the authors offer no warranty of its fitness for any purpose whatsoever, and accept no liability whatsoever for any loss or damage incurred by its use

Screen/Menu Help

Enters the interactive help system that lets you point the mouse cursor at the menu item or screen area you want help on.

Default command key: Shift+F1.

When you use this command, the mouse cursor will change to become an arrow-and-question mark, to show that interactive help is active.

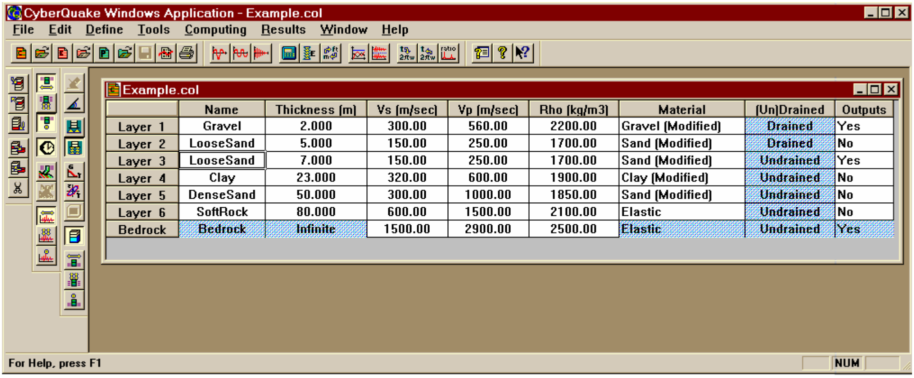
For help on an area of the status bar or on a tool bar button, point the mouse cursor at the appropriate part of the screen and click on the left button once. For help on a menu item, select the item as you would do actually to use the command, and click on the left button.

The software will start the Windows help engine, and will show the topic appropriate to where you clicked on the mouse button.

If you decide you don't want interactive help after using the command, you can return the mouse cursor to normal by pressing the Escape key.

When interactive help is operating, any keys you press will be ignored, and the toolbar, status bar and menu items will not have their normal effect.

Chapter 3: Soil Column Frame



Soil Column Frame Menu:

- File,
- Edit,
- Define,
- Tools,
- Computing,
- Results,
- Window,
- Help.

Soil Column File menu

In the Soil Column Frame the following actions may be performed by using this menu:

New Creates a document or sheet for a new multilayer soil profile for transient analysis

Open Opens an already existing multilayer soil profile for transient analysis

Close Closes the currently active document

Save Saves changes to the current document

Save As Saves the current document, prompting for a new name

Save Results Saves all results obtained after a computation

Load results Loads all results obtained and saved after a computation

Import Accelerogram Gets an existing accelerogram from any database

Export Exports a Cyber Curve into a formatted curve with Cyber Formats, or

Saves the current soil profile with a new format for a different analysis, or

Exports the elastoplastic constitutive model parameters into either a file or the clipboard

Print	Prints the current document
Print Plastic Model Parameters	Lists and prints all plastic constitutive model parameters of the current document
Page Setup	Sets up the page's configuration
Exit	Closes all windows and returns you to Program Manager

Save Results

Use this command to save all results obtained after a transient (Cyber) computation.

This may be useful when the user does not have enough time to save the results for each layer individually.

The results will be associated with the document and may be accessed when opening this document afterwards by using Load Results.

Caution: The name of the directory associated with the column should not be modified. Otherwise, the results may not be recovered.

Soil Column Edit menu

The following operations may be performed by using this menu:

Copy Layer	Copies a selected layer into the clipboard
Cut Layer	Deletes the selected layer from the column and copies it to the clipboard

Paste Layer	Pastes the copied or cut layer to the column
Add New Layer	Adds a new layer at the bottom of the column
Insert New Layer	Inserts and embeds a new layer in the column
Delete Layer	Deletes the selected layer
Copy To Clipboard	Copies the selected cells in the active column to the clipboard

Soil Column Define menu

In the Soil Column Frame, the following definitions may be introduced by using this menu:

Column	Further inputs for the Soil Column
Bedrock	Characteristics of the bedrock
Plastic Model	Access graphs and model parameters for the selected Soil Layer
Water Table Depth	Location of the water table in the Soil Column
	Definition of the analysis type : Two-Phase or Undrained (*Advanced Engineering Analysis version Only*)
Top Load Components	Definition of mechanical loading at the top of the Soil Column or display if a top load is set

Input Motion Components	Choice of the Input Motion and its components, or display if an Input Motion is defined
Time History	Definition of the initial time and duration of motion for the analysis

Column

(Advanced Engineering Analysis version Only)

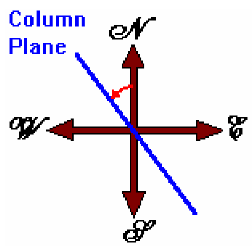
Use this command to introduce the Slope of the Soil Column.

Through the NS/Column Plane Angle command it is possible to introduce the angle between the Column Plane (i.e. The Column Plane is the plane of maximum slope) and North-South direction (Geographical 'absolute' North-South Direction).

NS/Column Plane Angle

(Advanced Engineering Analysis version Only)

The angle between the Column Plane; i.e. the Column Plane is the plane of maximum slope and the North-South direction is introduced by using this command. The angle (in degree) is positive in trigonometric direction from the North as presented in the figure.



Slope

The Soil Column may have a slope that can be introduced *via* the Define drop-down menu command in the Soil Column Frame.

This command is only applicable in the case of Rigid Bedrock.

Note that the whole configuration may have a slope (the bedrock is parallel to the ground surface).

When a Water Table Depth is indicated the Water table is assumed to be also parallel to the ground surface.

Plastic Model

Use this command to access to the constitutive model Simulator or to compute (G/D-γ) curves.

Simulator

To facilitate the work with the software, some soils have been already defined and their model parameters are furnished. However, in some conditions the model's response may not be satisfactory. For instance, the (G/D-γ) curves do not match experimental results. Therefore, it will be necessary to calibrate the model parameters.

This command is used either to simulate and to display the response of the constitutive model for soils or to modify model parameters.

The (G/D-γ) curves is used to the calculate the well-known (G-γ) and (D-γ) curves.

Click on Other curves to perform cyclic and monotonous tests on the soil.

The model parameters for the material may be modified by the user for a better calibration of model parameters.

Note:
1. (G/D-γ) curves as well as monotonous and cyclic tests are evaluated for the selected Soil Layer at the confining pressure corresponding to the vertical stress in the Soil Layer as situated in the Soil Column.
2. You should confirm the choice of the model parameters by clicking on Keep Parameters. Otherwise, computations of the Soil Column will not be enabled.

(G/D-Gamma) Curves

Use this command to compute and display the well-known (G-γ) and (D-γ) curves representing the variation of the secant shear modulus (G) and the plastic dissipation energy (also called the damping) with distortion (γ).

G is normalized with respect to Gmax representing the maximum elastic shear modulus. The dissipated energy is normalized by the elastic energy necessary for the same amount of deformation.

Selecting this command CyberQuake starts the computation of (G/D-γ) curves while showing a dialog box containing the button Break for aborting the computation. If the computation is aborted the results obtained before *Break* are displayed.

When results are displayed:

1. (G-γ) and (D-γ) curves appear.
2. Use Get (Curves menu) to plot if you wish to compare the computed results to other (G/D-γ) curves.
3. Use Edit (Curves menu) to edit the data values of the (G/D-γ) curves.
4. Use Save (Curves menu) to keep the resulting curves on disk and exit, or Quit.

5. If saving, choose a name for the resulting curves.
6. Use (G/Gmax,Gamma) Only (View Graphs menu) to display (G-γ) curve(s) only and modify the plot features by using the toolbar buttons ((to access the Graph utilities).
7. Use (D,Gamma) Only (View Graphs menu) to display (D-γ) curve(s) only and modify the plot features by using the toolbar buttons.
8. Use Both (View Graphs menu) to display (G-γ) and (D-γ) curves again.
9. Use Refresh (View Graphs menu) to update the plot display, for instance after having loaded the file containing your Graph Templates.
10. Use Reset (View Graphs menu) if you wish to plot the computed curves again, without the imported curves loaded in 2.

Water Table Depth

Use this command to introduce the Water Table Depth.

Selecting this command, a dialog box is opened in which the depth of the Water Table may be introduced. Consequently, the Water Table Depth is checked in the drop-down menu bar to remind the presence of a Water Table in the Soil Column and its current value is indicated. Moreover, a Hydraulic Condition column appears in the active transient column sheet and the layers below the Water Table will appear as Undrained or Two-Phase, depending on the analysis type.

This command can be disabled by pressing the mouse button when the Water Table Depth is selected again. The Hydraulic Condition column disappears then.

CyberQuake automatically divides the soil column into Drained (blue cells in the Hydraulic Condition column) and Undrained (or Two-Phase) parts. If the Water Table is located in a given soil layer, this layer is divided into two sub-layers. If the Water Table is removed these sub-layers are not merged into one layer automatically. However, the presence of two sub-layers with the same properties is equivalent to one layer with a thickness equal to the sum of sub-layers' thicknesses.

Caution: Depending on the version of CyberQuake, the saturated zone is handled differently. In the Engineering Analysis version a totally Undrained condition is assumed. In the Advanced Engineering Analysis version two approaches are possible:
1. ***either***, a totally Undrained assumption as in the earlier case.
2. ***or*** a Two-phase formulation for porous media. In the latter case, permeability coefficients are required for layers under the Water Table.

Two-phase

(Advanced Engineering Analysis version Only)

A Two-phase as opposed to One-phase material represents here a material in which the fluid phase (saturating water) should be considered as an independent phase.

This hypothesis is necessary in the following conditions:

1. The permeability of the soil is high.
2. The duration of the seismic event or the external load (Top load) is large.

The mass conservation equation of both solid and fluid phases has to be taken into account. In the formulation adopted here, the pore-pressure becomes a principal unknown and computations become more time-consuming. This option may be only used if physical properties and loading conditions do not permit a totally undrained hypothesis.

Top Load Components

Use this command to select a dynamic loading on the top of the Soil Column.

The loading may be introduced in two or three directions depending on the CyberQuake version:

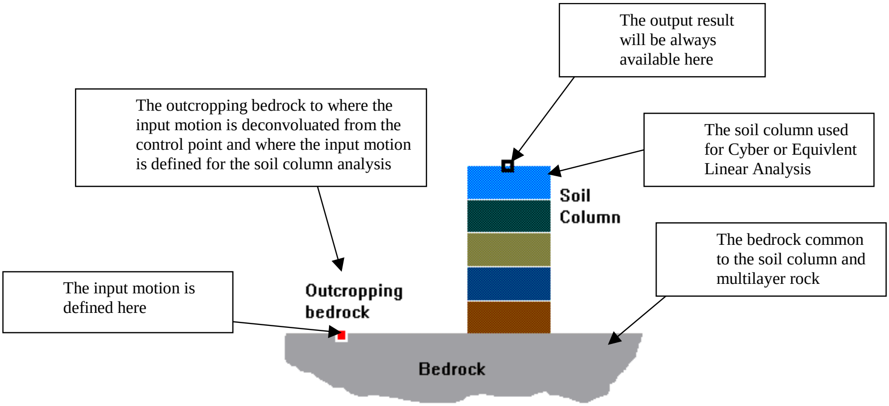
1. Engineering Analysis version
   - horizontal (Absolute Geographical Horizontal Direction) (in-plane) loading component,
   - vertical (Absolute Geographical Vertical Direction), both with respect to absolute referential.
2. Advanced Engineering Analysis version
   - NS: (Absolute Geographical) North-South horizontal loading component,
   - UP: (Absolute Geographical)Vertical loading component,
   - EW: (Absolute Geographical) East-West horizontal loading component.

Note: The load is considered in kPa. When a component is defined, it is check-marked. When a selected component is checked a second time it is disabled and the check-mark disappears.

Input Motion

Different accelerations may be used for different Input Motion Components.

The input motion is supposed to be defined at the outcropping bedrock at the same altitude as the bedrock underlying the Soil Column. as presented in the figure. If the bedrock is considered as Deformable[12] then it is assumed to be an isotropic and homogeneous linear elastic material.



Input Motion Components

Use this command to select the components of the Input Motion.

Note: In the Engineering Analysis version, Vertical and Horizontal components may be introduced. In the

---

[12] A deformable bedrock is modeled as a semi-infinite isotropic homogeneous elastic linear medium. It is characterized by the shear and compression body wave velocities and its mass density. When the bedrock is selected as deformable it is check-marked in the menu. To disable this option select this option a second time. The check-mark disappears to inform the user.

Advanced Engineering Analysis version, Vertical, North-South and East-West components may be introduced.

Vertical	An 'Absolute' Geographical Vertical Direction
Horizontal	An 'Absolute' Geographical Horizontal Direction
North-South	An 'Absolute' Geographical North-South Direction
East-West	An 'Absolute' Geographical East-West Direction

Time History

Use this command in the Define drop-down menu command to enter the time history for the computation.

Selecting this command, enter the starting time, ending time and the Saving Time Step.

You can also choose a Step Coefficient to which the Computation Time Step selected by CyberQuake will be multiplied. This will be useful if the computation seems to be diverging. For this frame it is also possible to select bottom Coefficients to access Newmark algorithm coefficients. Default values for these parameters are: γ=0.5 and β=0.25. Selecting higher values for these parameters introduce frequency-dependent numerical damping in computation.

It may be useful for nonlinear analysis in which very high frequencies due to the non linearity may be undesirable.

Soil Column Tools menu

See the Tools menu in the Main Frame (Chapter 2).

Soil Column Computing menu

Following actions may be performed by using this menu:

- Checklist,
- Start Cyber Analysis or Continue Cyber Analysis,
- Break Cyber Analysis.

Checklist

This command lists the data required for starting the computation.

Start Analysis

The command is enabled only if all data[13] needed for a computation have been furnished.

Using this command in a dialog box appears displaying some information such as the proposed Time Step, the Time History , the Maximum Frequency of the Input Motion and the Saving Time Step. These data may not be modified at this stage.

Type Cancel if you do not want to pursue the computation or if you want to modify the data.

Type Start to perform computations.

---

[13] The data needed for a computation are:

1- Thickness, Vs, Vp and ρ, for each layer. In elastoplastic computations using Cyber Constitutive Model the selected parameters should be confirmed by clicking on Keep parameters in the Constitutive Model Dialog Box.
2- Either an Input Motion (and/) or a Top Load
3- The Time History

Moreover, for at least one layer the Output must have been asked for.

Interrupt

Use this command from the dialog box displayed during a Cyber Analysis to interrupt the computation.

The results computed before interrupting are available and may be displayed by using Results drop-down command.

It is possible to perform calculations in other documents during the interruption and the results are not lost as far as the session or the interrupted document are not closed.

Use Continue Cyber Analysis to continue the interrupted computations.

Note: It is not possible to modify the data relative to the interrupted document.

Continue Cyber Analysis

Use this command from the Computing drop-down command to continue an interrupted Cyber Analysis.

It is possible to continue calculations as far as the session or the document containing the interrupted calculation are not closed.

Note: It is not possible to modify the data concerning the interrupted document.

Break Cyber Analysis

Use this command:

- either from the Computing drop-down command,
- or from the dialog box displayed during a Cyber Analysis,

to break down a Cyber Analysis.

The results computed before this command are available and may be displayed by using Results drop-down command.

Note: It is not possible to continue the computation after this command.

Soil Column Results menu

The following actions may be performed by using this menu:

- Current Layer,
- All Layers,
- Permanent Settlement At Ground Surface.

Current Layer

The following information may be obtained for each soil layer, by using this menu:

- Displacement,
- Velocity,
- Acceleration,
- Pore-Pressure,
- Total Stress,
- Effective Stress,
- Total Strain,
- Plastic Strain,

Note: this menu may be accessed by clicking on the right button of the mouse.

All Layers

The previous information may be also obtained for all the soil layers at once (see Current Layer drop-down menu).

Displacement

Use this command to plot the displacement time history computed at the top of the selected soil layer or for all the soil layers.

Velocity

Use this command to plot the velocity time history computed at the top of the selected soil layer or for all the soil layers.

Acceleration

Use this command to plot the acceleration time history computed at the top of the selected soil layer or for all the soil layers.

Pore-Pressure

Use this command to plot the pore-pressure time history computed at the middle of the selected soil layer or for all the soil layers.

Effective Stress

Use this command to plot the effective stress time history (volumetric and shear) computed at the middle of the selected soil layer or for all the soil layers.

The effective stress is expressed as:

$$\underline{\underline{\sigma}}' = \underline{\underline{\sigma}} - p\,\underline{\underline{I}}$$

where the first term in the right hand side is the total stress and the second is the pore pressure multiplied by the unit tensor.

Total Strain

Use this command to plot the total strain time history (volumetric and shear) computed at the middle of the selected soil layer or for all the soil layers.

Plastic Strain

Use this command to plot the time history of the plastic strain components (volumetric and shear) computed at the middle of the selected soil layer or for all the soil layers.

Note: These commands may be accessed by clicking on the right button of the mouse when a soil layer is selected.

Once the curve is displayed:

1. Modify the plot features by using the toolbar.
2. Use Saving Interval to save a portion of the curve on an interval of x-axis. The default is the whole interval. Use Save Curve to keep the curve on disk and exit, or Close to quit.
3. Use Edit Curve to edit the data values of the displayed curve(s).
4. If saving, choose a name for the resulting curve(s).
5. The data will be saved in Cyber Format and may be processed later.

Note: If the data is not saved before quitting the session it will be lost.

Permanent Settlement At Ground Surface

The permanent settlement is the irreversible vertical displacement at the end of the computation.

If the Water Table is defined in the Soil Column, the permanent settlement represents the irreversible vertical settlement after dissipation of the pore-pressure generated in the saturated elastoplastic material subjected to dynamic loading and under undrained condition.

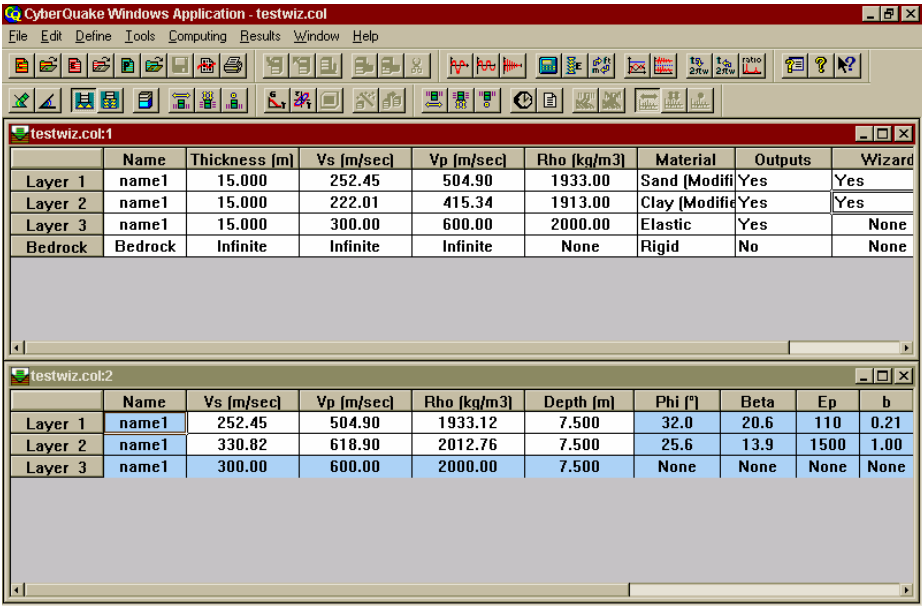
Soil Column Window Menu

New Window	Use this command from the Window drop-down menu command to make an exact copy of the current window. The duplicate window created by this command shows the same file, with the caret in exactly the same place. All aspects of the new window are identical to the original. You can produce as many duplicates of a window as you wish, and edit the same file in each of them. There is no default command key.
Toolbar	Enable (disable) the Toolbars in all Frames
Status Bar	Enable (disable) the Status Bar in which a brief explanation of the command key is given
Run-Time Plot	Use this command from Window drop-down menu command to display an interactive plot of a selected component of the computed Acceleration at the ground surface during calculation when performing a Cyber Analysis.

Soil Column Help Menu

Contents	Gives the contents of the CyberQuake Help
How to...	Explains how to reduce the computation time when performing transient calculations by CyberQuake.
Trouble Shootings	Explains the origin of some difficulties when using CyberQuake and proposes some solutions.
Using Help	Starts the Windows help engine to give you help on how the help system works. There is no default command key
About CyberQuake	Shows the release version and the names of CyberQuake authors
Disclaimer	CyberQuake and the accompanying files are supplied on an *as-is basis*. It is continually being developed and improved. The authors are interested to hear about any deficiencies in order to improve next versions As with most software, the authors offer no warranty of its fitness for any purpose whatsoever, and accept no liability whatsoever for any loss or damage incurred by its use

Chapter 4: Parameter Wizard Frame



	Name	Thickness [m]	Vs [m/sec]	Vp [m/sec]	Rho [kg/m3]	Material	Outputs	Wizard
Layer 1	name1	15.000	252.45	504.90	1933.00	Sand [Modifi	Yes	Yes
Layer 2	name1	15.000	222.01	415.34	1913.00	Clay [Modifie	Yes	Yes
Layer 3	name1	15.000	300.00	600.00	2000.00	Elastic	Yes	None
Bedrock	Bedrock	Infinite	Infinite	Infinite	None	Rigid	No	None

	Name	Vs [m/sec]	Vp [m/sec]	Rho [kg/m3]	Depth [m]	Phi [°]	Beta	Ep	b
Layer 1	name1	252.45	504.90	1933.12	7.500	32.0	20.6	110	0.21
Layer 2	name1	330.82	618.90	2012.76	7.500	25.6	13.9	1500	1.00
Layer 3	name1	300.00	600.00	2000.00	7.500	None	None	None	None

Parameter Wizard Frame Menu:

- File,
- Edit,
- Plastic Model,
- Tools,
- Window,
- Help.

Parameter Wizard File menu

In the Parameter Wizard Frame, the following actions may be performed by using this menu:

Close	Closes the currently active document or sheet (without saving).
Save Wizard Parameters	Saves the elastoplastic Constitutive Model Parameters to a text file.
Export Wizard Parameters	Exports the parameters computed by the Parameter Wizard, into the original soil profile.
Print	Prints the Parameter Wizard sheet.

Parameter Wizard Edit menu

In the Parameter Wizard Frame, the following action may be performed by using this menu:

Copy To Clipboard	Copies the document (sheet cells) to the Clipboard.

Parameter Wizard Plastic Model menu

In the Parameter Wizard Frame, the following actions may be performed by using this menu:

Simulator	Launches the Cyber Constitutive Model simulator.
(G/D-Gamma) Curves.	Computes the well-known (G-γ) and (D-γ) curves.

Simulator

See the Define Menu / Plastic Model / Simulator command in the Soil Column Frame (Chapter 3) for explanations on this command.

(G/D-Gamma) Curves

See the Define Menu / Plastic Model / (G-D-Gamma) Curves command in the Soil Column Frame (Chapter 3) for explanations on this command.

Parameter Wizard Tools menu

See the Tools menu in the Main Frame (Chapter 2).

Parameter Wizard Window menu

Toolbar	Enable (disable) the Toolbars in all Frames
Status Bar	Enable (disable) the Status Bar in which a brief explanation of the command key is given

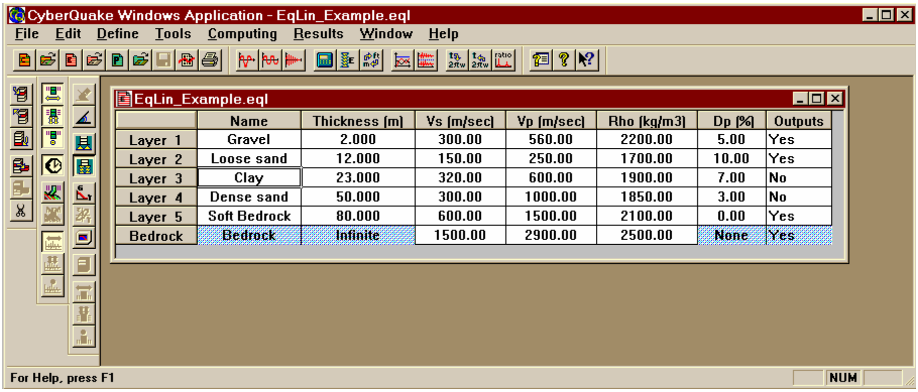
Parameter Wizard Help menu

Contents	Gives the contents of the CyberQuake Help
Using Help	Starts the Windows help engine to give you help on how the help system works. There is no default command key
About CyberQuake	Shows the release version and the names of CyberQuake authors
Disclaimer	CyberQuake and the accompanying files are supplied on an "as-is" basis. It is continually being developed and improved. The

authors are interested to hear about any deficiencies in order to improve next versions

As with most software, the authors offer no warranty of its fitness for any purpose whatsoever, and accept no liability whatsoever for any loss or damage incurred by its use

Chapter 5: Equivalent-Linear Frame



Equivalent-Linear Frame Menu:

- File,
- Edit,
- Define,
- Tools,
- Computing,
- Results,
- Window,
- Help.

Equivalent Linear File menu

In the following actions may be performed by using this menu:

New	Creates a document or sheet for a new multilayer soil profile for an Equivalent Linear Analysis
Open	Opens an already existing multilayer soil profile for an Equivalent Linear Analysis
Close	Closes the currently active document
Save	Saves changes to the current document
Save As	Saves the current document, prompting for a new name
Import Accelerogram	Gets an existing accelerogram from any database
Export	Exports a Cyber Curve into a formatted curve with Cyber Formats, or
	Saves the current soil profile with a new format for a different analysis
Print	Prints the current document
Page Setup	Sets up the page's configuration
Exit	Closes all windows and returns you to Program Manager

Equivalent Linear Edit menu

See the Edit menu in the Soil Column Frame (Chapter 3).

Equivalent Linear Define menu

The following definitions may be introduced by using this menu:

NS-axis/Column Plane Angle	Angle between the Column Plane[14] and the North-South[15] direction
Bedrock	Characteristics of the bedrock
(G/D-Gamma) Curves	Access (G/D-γ) curves for the selected layer
Input Motion Components	Choice of the Input Motion (only Horizontal Component in *Engineering Analysis version*), or display if an Input Motion is defined
Time History	Definition of the initial time and duration of motion for the analysis

(G/D-Gamma) Curves: use this command to either import, modify, create or only display a (G-γ) curve, a (D-γ) curve or Both (G-γ) and (D-γ) curves.

G is normalized with respect to Gmax representing the maximum elastic shear modulus. The dissipated energy is normalized by the elastic energy necessary for the same amount of deformation.

When results are displayed:

1. (G-γ) and (D-γ) curves appear.
2. Use Get (Curves menu) if you wish to compare your curves to other (G/D-γ) curves.

---

[14] The Column Plane is the plane of maximum slope.

[15] Geographical (absolute) North-South Direction.

3. Use Edit (Curves menu) to edit the data values of the displayed curves.
4. Use Save (Curves menu) to keep the curves on disk and exit, or Quit.
5. If saving, choose a name for the curves.
6. Use (G/Gmax,Gamma) Only (View Graphs menu) to display (G-γ) curve(s) only and modify the plot features by using the toolbar buttons ((to access the Graph utilities).
7. Use (D,Gamma) Only (View Graphs menu) to display (D-γ) curve(s) only and modify the plot features by using the toolbar buttons.
8. Use Both (View Graphs menu) to display (G-γ) and (D-γ) curves again.
9. Use Refresh (View Graphs menu) to update the plot display, for instance after having loaded the file containing your Graph Templates.
10. Use Reset (View Graphs menu) if you wish to plot your curves again, without the imported curves loaded in 2.

Equivalent Linear Tools menu

See the Tools menu in the Main Frame (Chapter 2).

Equivalent Linear Computing menu

The following action may be performed by using this menu.

Checklist

This command lists the data required for starting the computation.

Start Equivalent Linear Approximation

The command is enabled only if all data[16] needed for a computation have been furnished.

Equivalent Linear Results menu

The following actions may be performed by using this menu:

- Current Layer,
- All Layers.

Current Layer

The following information may be obtained for each soil layer, by using this menu:

- Displacement.
- Velocity.
- Acceleration.
- Total Stress.
- Total Strain.

---

[16] The data needed for a computation are:

1- Thickness, Vs, Vp and ρ, for all layers
2- (G-γ), (D-γ) Curves for all layers, except the Bedrock or Outcropping Bedrock
3- An Input Motion
4- The Time History

Note: This menu may be accessed by clicking on the right button of the mouse.

All Layers

The previous information may be also obtained for all the soil layers at once (see Current Layer drop-down menu).

Equivalent Linear Window menu

New Window	Use this command from the Window drop-down menu command to make an exact copy of the current window. The duplicate window created by this command shows the same file, with the caret in exactly the same place. All aspects of the new window are identical to the original. You can produce as many duplicates of a window as you wish, and edit the same file in each of them. There is no default command key.
Toolbar	Enable (disable) the Toolbars in all Frames
Status Bar	Enable (disable) the Status Bar in which a brief explanation of the command key is given

Equivalent Linear Help menu

Contents	Gives the contents of the CyberQuake Help
Using Help	Starts the Windows help engine to give you help on how the help

	system works. There is no default command key
About CyberQuake	Shows the release version and the names of CyberQuake authors
Disclaimer	CyberQuake and the accompanying files are supplied on an "as-is" basis. It is continually being developed and improved. The authors are interested to hear about any deficiencies in order to improve next versions As with most software, the authors offer no warranty of its fitness for any purpose whatsoever, and accept no liability whatsoever for any loss or damage incurred by its use

Chapter 6: Control Point Frame

Control Point Frame Menu:

- File,
- Edit,
- Define,
- Tools,
- Deconvolution,
- Results,
- Window,
- Help.

Control Point File menu

In the Control Point Frame the following actions may be performed by using this menu:

New	Creates a document or sheet for a new multilayer soil profile for a Deconvolution from a Control Point
Open	Opens an already existing multilayer soil profile for a Deconvolution from a Control Point
Close	Closes the currently active document
Save	Saves changes to the current document
Save As	Saves the current document, prompting for a new name
Import Accelerogram	Gets an existing accelerogram from any database
Export	Exports a Cyber Curve into a formatted curve with Cyber Formats, or
	Saves the current soil profile with a new format for a different analysis
Print	Prints the current document
Page Setup	Sets up the page's configuration
Exit	Closes all windows and returns you to Program Manager

Control Point Edit menu

See the Edit menu in the Soil Column Frame (Chapter 3).

Control Point Define menu

In the Control Point Frame, the following definitions may be introduced by using this menu:

NS-axis/Column Plane Angle	Angle between the Column Plane[17] and the North-South[18] direction
Bedrock	Characteristics of the bedrock
G/D-Gamma Curves	Access G/D-γ curves for the selected layer
Input Motion Components	Choice of the input motion (only Horizontal Component in *Engineering Analysis version*), or display if an Input Motion is defined
Time History	Definition of the initial time and duration of motion for the analysis

Input Motion

Different accelerations may be used for different Input Motion Components.

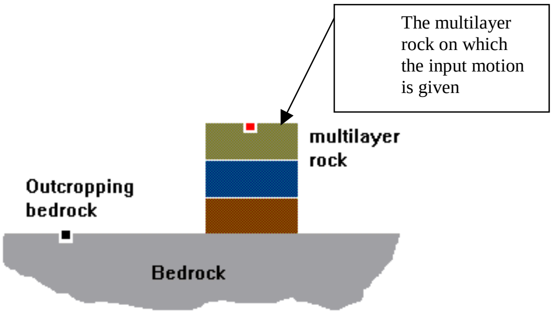
The input motion is supposed to be defined at the outcropping bedrock at the same altitude as the bedrock underlying the Soil Column. as presented in the figure. If

[17] The Column Plane is the plane of maximum slope.

[18] Geographical (absolute) North-South Direction.

the bedrock is considered as Deformable[19] then it is assumed to be an isotropic and homogeneous linear elastic material.

In the Control Point Frame the input motion is assumed to be given at the surface of the multilayer (non)linear viscoelastic rock.



Control Point Tools menu

See the Tools menu in the Main Frame (Chapter 2).

Control Point Deconvolution menu

The following operation may be performed by using this menu.

---

[19] A deformable bedrock is modeled as a semi-infinite isotropic homogeneous elastic linear medium. It is characterized by the shear and compression body wave velocities and its mass density. When the bedrock is selected as deformable it is check-marked in the menu. To disable this option select this option a second time. The check-mark disappears to inform the user.

Checklist

This command lists the data required for starting the computation.

Start Deconvolution

Use this command to start the Deconvolution of the Input Motion from the Control Point.

The command is enabled only if all data[20] needed for a computation have been furnished.

Control Point Results menu

See the Results menu in the Equivalent-Linear Frame (Chapter 5).

Control Point Window menu

See the Window menu in the Equivalent-Linear Frame (Chapter 5).

---

[20] The data needed for a computation are:

1- Thickness, Vs, Vp and ρ, for all layers
2- (G-γ), (D-γ) Curves for all layers, except the Bedrock or Outcropping Bedrock
3- An Input Motion
4- The Time History

Control Point Help menu

See the Help menu in the Equivalent-Linear Frame (Chapter 5).

Chapter 6: Theoretical Background

Two kinds of direct and one inverse analysis may be performed by CyberQuake:

1. Cyber Analysis (transient analysis).
2. Equivalent Linear Analysis.
3. Deconvolution.

In 1, soil layers may be considered as elastoplastic materials (with isotropic linear elasticity as a special case). True transient nonlinear analyses are carried out and, following the version, two or three-dimensional kinematics are assumed.

In 2 and 3, soil layers are treated by Equivalent Linear assumption and viscoelastic analyses are performed while the dependence of the shear modulus, as well as the damping, on distortion is incorporated. The computations are done in the frequency domain. It is also possible to perform direct linear (visco)elastic analyses in 2 and deconvolution in 3.

Cyber Dynamic Model

Governing equations for one-dimensional two-phase media

The dynamic equations of the model without body forces while neglecting the pore water compressibility in a reference (0-xyz) are given as:

$$\begin{cases} \partial_z \underline{\tau} = \rho \underline{a} \\ \partial_z \sigma' - \partial_z p = \rho a_z \\ \partial_z v_z - \partial_z \left(k \partial_z p \right) = 0 \end{cases}$$

with:

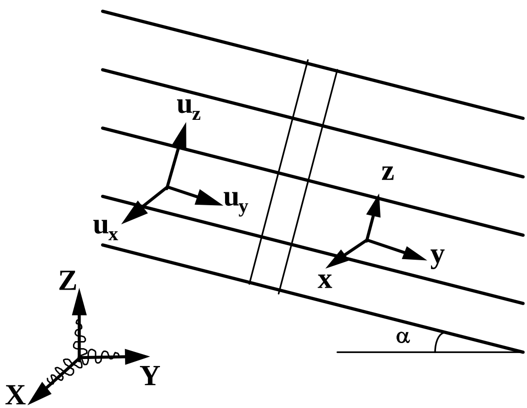
$\sigma' = \sigma + p$	The effective normal stress
$\underline{\tau}$	The shear stress in the soil layer plane
P	The pore pressure
$\underline{A} = \underline{a} + a_z \underline{e}_z$	The absolute acceleration vector
v_z	The normal velocity component
k	The isotropic permeability coefficient
$\rho = (1 - n) \rho_s + n \rho_w$	The overall mass density
n	The porosity
ρ_s	The mass density of solid component
ρ_w	The mass density of fluid component

Boundary conditions

The boundary conditions are defined by current engineering language (e.g. water table position, deformable/rigid bedrock, etc.) instead of using numerical modeling terminology. Therefore, standard boundary conditions are easily prescribed on the boundaries.

The rigid bedrock assumption simplifies computational aspects, as no absorbing boundaries have to be taken into account. With this assumption, the calculation can be done in a moving reference frame that results in a fixed base. The seismic loading is modeled as a prescribed displacement time history of the rigid bedrock, which results from the double integration of the input acceleration with respect to time.

In this case the soil profile may represent a slope as shown in the figure below.



Schematic presentation of the model with rigid bedrock

Due to the symmetry of the geometry, initial state and loading history, the problem appears to be purely one-dimensional, e.g. all points at a given depth have the same displacement, pore pressure, stress and strain histories.

Here, the displacement vector may be decomposed into two vectors: the sliding, along the slope direction, and the displacement normal to the slope surface. The related strain reduces to the shear strain vector and the normal strain. The related stress is characterized by the shear stress vector and the normal stress.

For deformable bedrock, absorbing boundaries are introduced. For transient analyses, it is possible to develop frequency independent local absorbing boundaries with respect to time and space.

The weak formulation of the governing equation is given as:

$$\begin{cases} \int_\Omega \rho \underline{a}.\,\underline{w} d\Omega + \int_\Omega \underline{\tau}(\underline{U}).\partial_z \underline{w} d\Omega = \int_{\Gamma_\sigma} \underline{\bar{t}}.\,\underline{w} \quad d\Gamma \\ \int_\Omega \rho a_z.w_z\, d\Omega + \int_\Omega \sigma'(\underline{U}).\partial_z w_z\, d\Omega - \int_\Omega p.\partial_z w_z\, d\Omega = \int_{\Gamma_\sigma} t_z.w_z \quad d\Gamma \\ \int_\Omega k\partial_z p.\partial_z q d\Omega + \int_\Omega \partial_z v_z.q\, d\Sigma = -\int_{\Gamma_\varphi} \bar{\varphi}.q\, d\Gamma_\varphi \end{cases}$$

with:

$\underline{U} = \underline{u} + u_z \underline{e}_z$	$\underline{U} \in \delta$	$\delta = \{\underline{U} \mid \underline{U} \text{ smooth in } \Omega\}$
$\underline{W} = \underline{w} + w_z \underline{e}_z$	$\underline{W} \in \vartheta$	$\vartheta = \{\underline{W} \mid \underline{W} \text{ smooth in } \Omega, \underline{W} = \underline{0} \text{ on } \Gamma_u\}$
	$p \in \Pi$	$\Pi = \{p \mid p \text{ smooth in } \Omega\}$
	$q \in \Theta$	$\Theta = \{q \mid q \text{ smooth in } \Omega, q = 0 \text{ on } \Gamma_p\}$

$\partial\Omega = \Gamma_\sigma \cup \Gamma_u = \Gamma_\varphi \cup \Gamma_p$ is the boundary of the studied domain Ω.

Γ_σ and Γ_u (respectively Γ_φ and Γ_p) represent the part of the boundary where stress and displacement (respectively flux and pore pressure) are prescribed.

$\underline{\bar{T}}(=\underline{\bar{t}}+\bar{t}\underline{e}_z)$ and $\bar{\varphi}$ are respectively the prescribed stress vector and flux on the boundary.

The interface between the modeled and underlying (semi-infinite) domain designated by Σ in the next paragraphs, may belong to either Γ_σ or Γ_u (respectively Γ_φ or Γ_p) depending on the assumption on the rigidity of the bedrock. If a water table is considered, we always assume that the bedrock is impervious. Therefore, no flux occurs across the interface boundary and the integral over Σ in the third equation is always zero.

The above formulation is then considered with finite-dimensional approximations for δ, ϑ, Π and Θ as $\delta^h, \vartheta^h, \Pi^h$ and Θ^h and identified in an abstract form as:

$$\begin{cases} \mathrm{a}(\underline{U}^h, \underline{W}^h) + \mathrm{b}(p^h, \underline{W}^h) = (\underline{\bar{T}}^h, \underline{W}^h)_{\Gamma_\sigma} \\ \mathrm{b}(\underline{U}^h, q^h) + \mathrm{c}(p^h, q^h) = (\underline{\bar{\varphi}}^h, q^h)_{\Gamma_\varphi} \end{cases}$$

Rigid Bedrock

For a rigid bedrock, the motion at the base is prescribed. Hence, the prescribed displacement time history is considered on the RHS of the equation system and the integral over Σ vanishes. The weak formulation for finite-dimensional spaces may be written as:

$$\begin{cases} \mathrm{a}(\underline{V}^h, \underline{W}^h) + \mathrm{b}(p^h, \underline{W}^h) = (\overline{\underline{T}}^h, \underline{W}^h)_{\Gamma_\sigma} - \mathrm{a}(\overline{\underline{U}}^h, \underline{W}^h) \\ \mathrm{b}(\underline{V}^h, q^h) + \mathrm{c}(p^h, q^h) = (\overline{\underline{\varphi}}^h, q^h)_{\Gamma_\varphi} \end{cases}$$

where:

$$\underline{U}^h = \underline{V}^h + \overline{\underline{U}}^h \text{ and } \underline{V}^h \in \vartheta^h$$

so that the boundary condition:

$$\underline{U}^h = \overline{\underline{U}}^h \text{ over } \Sigma$$

is satisfied (in the finite element sense).

Deformable Bedrock

As noted before, we assume that the bedrock is totally undrained, thus only the stress vector over Σ has to be evaluated. Here, this vector represents the transient impedance (action) imposed by the outer (semi-infinite) domain on the studied domain. Thus, the weak formulation becomes:

$$\begin{cases} \mathrm{a}(\underline{U}^h, \underline{W}^h) + \mathrm{b}(p^h, \underline{W}^h) = (\overline{\underline{T}}^h, \underline{W}^h)_{\Gamma_\sigma} + (\underline{T}^h, \underline{W}^h)_\Sigma \\ \mathrm{b}(\underline{U}^h, q^h) + \mathrm{c}(p^h, q^h) = (\overline{\underline{\varphi}}^h, q^h)_{\Gamma_\varphi} \end{cases}$$

Assuming an isotropic linear elastic behavior at the vicinity of the boundary Σ, we will split the total displacement vector into the *incident* and *radiant* (or *diffracted*) displacement fields:

$$\underline{U}^{E} = \underline{U}_{i}^{E} + \underline{U}_{r}^{E}$$

where superscript E designates the exterior domain.

Moreover, the displacement field must satisfy the Sommerfeld radiation condition:

$$\underline{U}^{E}(\underline{x}) = \underline{U}_{i}^{E} \text{ when } \underline{x} \to \infty$$

and the free field incident motion must be compatible with the free surface conditions.

Now, we will write the radiant field through the outer domain due to the diffraction over Σ. The continuity condition for the stress vector over Σ and the linearity hypotheses at its vicinity enables us to write, for one-dimensional geometry and vertically incident waves:

$$\begin{aligned}\underline{T} = -\underline{T}^{E}(\underline{U}^{E}) &= -\underline{T}^{E}(\underline{U}_{i}^{E}) - T^{E}(\underline{U}_{r}^{E}) \\ &= -2\rho C_{s}\underline{\dot{u}}_{i}^{E} - 2\rho C_{p}\dot{u}_{zi}^{E}\underline{e}_{z} - \rho C_{s}\underline{\dot{u}}^{E} - \rho C_{p}\dot{u}_{z}^{E}\underline{e}_{z} \\ &= -2\rho C_{s}\underline{\dot{u}}_{i}^{E} - 2\rho C_{p}\dot{u}_{zi}^{E}\underline{e}_{z} - \rho C_{s}\underline{\dot{u}} - \rho C_{p}\dot{u}_{z}\underline{e}_{z}\end{aligned}$$

The two last terms in RHS of the above equation are unknown. The weak formulation becomes:

$$\begin{cases} \mathrm{a}(\underline{U}^{h},\underline{W}^{h}) + \mathrm{b}(p^{h},\underline{W}^{h}) - (\underline{T}_{1}^{h},\underline{W}^{h})_{\Sigma} = (\overline{\underline{T}}^{h},\underline{W}^{h})_{\Gamma_{\sigma}} + (\underline{T}_{2}^{h},\underline{W}^{h})_{\Sigma} \\ \mathrm{b}(\underline{U}^{h},q^{h}) + \mathrm{c}(p^{h},q^{h}) = (\overline{\underline{\varphi}}^{h},q^{h})_{\Gamma_{\varphi}} \end{cases}$$

with:

$$\begin{cases} (\underline{T}_{1}^{h},\underline{W}^{h})_{\Sigma} = -\int_{\Sigma}(\rho C_{s}\underline{\dot{u}}^{h}.\underline{w}^{h} + \rho C_{p}\dot{u}_{z}^{h}.w_{z}^{h})d\Sigma \\ (\underline{T}_{2}^{h},\underline{W}^{h})_{\Sigma} = -\int_{\Sigma}2(\rho C_{s}\underline{\dot{u}}_{i}^{hE}.\underline{w}^{h} + \rho C_{p}\dot{u}_{zi}^{hE}.w_{z}^{h})d\Sigma \end{cases}$$

Note: The above formulation is general and may be degenerated to simpler ones depending on the draining condition. For totally drained condition, the pore-pressure is not to be considered in the formulation and the hydraulic equation disappears. In the case of the totally undrained formulation, the permeability coefficient is assumed to be zero. Therefore, an incompressibility condition presents. To deal with such a case, and to avoid numerical difficulties, the total stress is evaluated from the first equation and the pore-pressure is calculated as the difference between the effective and total normal stress. The incompressibility equation, representing the impervious soil layer, is introduced directly in the constitutive model. This methodology is presented hereafter. Totally undrained case at point z:

$$\begin{cases} \sigma^h = \rho \ddot{u}_{z\,i}^{h\,E}(z-H) \\ p^h = \rho \ddot{u}_{z\,i}^{h\,E}(z-H) - (\lambda + 2\mu)\varepsilon^p \end{cases}$$

with:

ε^p	The plastic strain
H	The depth of the layer

The final pore-pressure, when the seismic input motion is at rest is thus given by:

$$p^h(z,T) = -K\varepsilon^p(z,T)$$

Although there is no dynamic settlement in this model a permanent static settlement will occur after the end of the seismic event (t>T) from the distribution of pore pressure under quasi static conditions. In the case of partially undrained condition, the whole system of equations is resolved.

Time-Space discretization

The equations are discretized with respect to the *z* variable by finite elements, and numerically integrated with respect to time by an explicit Newmark scheme. The time step is computed with respect to stability and precision requirements of the integration scheme.

The velocity in the solid skeleton and pore water pressure (for two-phase computations) are considered as main unknowns. In that case, higher order approximations are used for velocities compared with the pore-pressure (i.e. *v3p2* elements).

The mass matrix for the quadratic element is diagonalized using the following procedure. The base functions are transformed using two additional parameters α' and β' as:

$$\begin{cases} W_1(r) = 0.5\left((1-\beta')r^2 - (1-\alpha')r - \alpha' r^3 + \beta' r^4\right) \\ W_2(r) = 0.5\left((1-\beta')r^2 + (1-\alpha')r + \alpha' r^3 + \beta' r^4\right) \\ W_3(r) = 1-(1-\beta')r^2 - \beta' r^4 \end{cases}$$

The consistent mass matrix is computed using these new base functions. The adding parameters are calculated so that the off-diagonal terms vanish, thus new base functions are obtained.

Cyber Constitutive Model

A linear elasticity is assumed here. With σ the vertical effective stress and $\underline{\tau}$ the shear effective stress vector, the elastic strain rate is then given by:

$$\begin{cases} \dot{\varepsilon}^e = \dfrac{\dot{\sigma}}{\rho c_p^2} \\ \underline{\dot{\gamma}}^e = \dfrac{\underline{\dot{\tau}}}{\rho c_s^2} \end{cases}$$

where c_p and c_s are velocities for compression and shear waves and ρ is the overall specific mass of the solid skeleton:

$$c_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} \qquad \text{and} \qquad c_s = \sqrt{\frac{\mu}{\rho}}$$

$\rho = (1-n)\rho_s + nS_w\rho_w$ with n the porosity and S_w the degree of saturation (=1 for saturated materials, =0 totally dry material).

Then the deviatoric yield surface is proposed as:

$$f = \left\| \underline{\tau} - \frac{\sigma \mathrm{F}}{\sigma_0 \mathrm{F}_0} \tau_0 \right\| + \sigma \mathrm{F} \left| \mathrm{r} - \mathrm{r}_0 \right|$$

The function F is introduced to take into account the volumetric hardening or softening with respect to the critical state of the material as:

$$\mathrm{F} = 1 - b\left(Ln\frac{\sigma}{\sigma_{ci}} - \beta\varepsilon^{p} \right)$$

with *b* a numerical parameter ($0 \le b \le 1$), β the plastic compressibility modulus and σ_{ci} the critical state pressure for the initial state.

Subscript *0* indicates the value of the variables at unloading/reloading.

The internal variable r (also called the degree of mobilized friction) introduces the effect of shear hardening of the soil.

It also permits the decomposition of the behavior domain into elastic, hysteretic and mobilized domains introduced by other model parameters called r_{el}, r_{hys} and r_{mob}. It is given as:

$$r = r_0 + \left(\frac{\int_0^t \left\| \underline{\dot{\gamma}}^p \right\| dt - \int_0^{t_0} \left\| \underline{\dot{\gamma}}^p \right\| dt}{\frac{(r_m - r_0)}{E_p} + \int_0^t \left\| \underline{\dot{\gamma}}^p \right\| dt - \int_0^{t_0} \left\| \underline{\dot{\gamma}}^p \right\| dt} \right)^{n_r} (r_m - r_0)$$

with $r_m = \tan\phi$ (ϕ being the friction angle at the critical state), *t* the current time, t_0 the time of the last change in the loading direction with its associated degree of mobilization r_0, $\left\| \underline{\dot{\gamma}}^p \right\|$ is the norm of shear plastic strain rate and finally n_r and E_p are model parameters governing the evolution of the yield surface towards the total plastic mobilization.

The plastic flow rule is defined as:

$$\begin{cases} \dot{\varepsilon}^p = \dot{\lambda} \cdot \Psi_v \\ \underline{\dot{\gamma}}^p = \dot{\lambda} \cdot \underline{\Psi}_d \end{cases}$$

The direction of plastic flow is obtained by assuming the normality rule for the deviatoric component and Roscoe's dilatancy rule is assumed for vertical plastic strain:

$$\begin{cases} \Psi_v = -\alpha_\psi \varsigma \left(\tan\psi - F\left|r - r_0\right|\right) \\ \underline{\Psi}_d = \partial_{\underline{\tau}} f \end{cases}$$

where ψ is the dilatancy angle corresponding to the characteristic line.

ς is function of r as:

$$\begin{cases} \varsigma = 0 & \text{if } r \le r_{hys} \\ \varsigma = \left[\dfrac{r - r_{hys}}{r_{mob} - r_{hys}}\right]^m & \text{if } r_{hys} \le r \le r_{mob} \\ \varsigma = 1 & \text{if } r > r_{mob} \end{cases}$$

Note:

1. α_ψ is a constant parameter introduced only to permit users to prevent any plastic contractance or dilatancy by putting it equal to zero. The plastic multiplier $\dot{\lambda}$ is evaluated from the persistency (or consistency) condition; i.e. $\dot{\lambda}\dot{f} = 0$, after introducing the evolution law for the internal variable r from its dependency upon the shear plastic strain rate $\underline{\dot{\gamma}}^p$.

Note that with the definition of $\underline{\Psi}_d$, we have $\dot{\lambda} = \left\|\underline{\dot{\gamma}}^p\right\|$

2. In the definition of the flow rule, ψ appears instead of ϕ. The former is known as the characteristic angle and the later as the friction angle at the critical state. The difference between the characteristic and critical state is a much debated question. The later describes the perfect plasticity state while the former represents the transition from the contracting to the dilating behavior under compression. The discussion about this topic is out of the scope of this paper. By choosing the same value for ϕ and ψ, the standard critical state approach may be recovered.

Constitutive Model Parameters

Besides elastic mechanical properties given by P and S wave velocities and the bulk density in a Soil Layer, other model parameters are necessary for nonlinear modeling.

These parameters are defined in the brief representation of the Cyber Constitutive Model given above.

To facilitate the work with the software, some soils have been already defined and their model parameters are furnished. However, the model's response may not be satisfactory. For instance, the G/D-γ curves do not match experimental results. Therefore, it will be necessary to calibrate the model parameters. This may be done by using Simulator command of the Plastic Model drop-down menu of Define menu command in Soil Column Frame.

The parameters have been classified in two categories.

The users are advised to start with modifying basic parameters.

The use of specified parameters requires a deeper knowledge of the constitutive model used here.

Basic parameters

These parameters may be considered as more influential in the simulation of the soil behavior.

φ	Friction angle at totally mobilized plasticity (the slope of the Critical State Line)
$E\rho$	Plastic stiffness (a hardening parameter affecting the initial plastic slope)
σ_{ci}/σ_v	Compaction ratio (a parameter representing the compaction state of the soil)
β	Plastic modulus (a parameter for isotropic hardening due to compaction)
C	Cohesion

Note: ***E****p* influences the initial slope of (*G/Gmax*-γ) curve, while σ_{ci}/σ_v affects its residual value for large strain. Smaller values for σ_{ci}/σ_v results in a looser soil. In drained conditions a loose soil densifies (settles down) and in undrained conditions it may liquefy.

Specific Parameters

These parameters permit a finer calibration of the model response:

b	Numerical parameter affecting the shape of the yield surface (1: Cam-Clay type, 0: Coulomb type)
n_r	Numerical parameter affecting the isotropic hardening due to shearing (default : 0.5)
γ_{ela}	Parameter representing the extent of the truly elastic domain
γ_{hys}	Parameter representing the extent of the hysteretic domain
γ_{mob}	Parameter representing the extent of the mobilized domain
ψ	The slope of the characteristic line (default: $\psi=\varphi$)
α_ψ	A parameter affecting the magnitude of the dilatancy (default : 1.0)

Note:

1. Small values are in general recommended for b in the case of sands (0-0.2) and large values for clays (0.8-1.0).

2. Small values for n_r results in stiffer G/Gmax-γ curves.

3. γ_{hys} and γ_{mob} may be used for a finer calibration of the liquefaction onset.

4. α_ψ = 0 results in zero dilatancy (or zero contractance).

Liquefaction

The liquefaction is a physical phenomenon that may occur generally in loose sands or silty soils under undrained conditions. In this software we are concerned with liquefaction due to cyclic loading (in opposition to static liquefaction).

The almost incompressibility of the saturated soil in undrained conditions and the contracting tendency in loose materials are the essential factors for liquefying a soil subjected to deviatoric cyclic loading.

When the mean effective pressure vanishes due to the pore-pressure generation the soil is no more able to sustain any shear resistance and behaves almost like a viscous (non)newtonian fluid.

In situ, observations sometimes show a strength recovery in liquefied soils. In fact, the pore pressure may dissipate after a while either due to its infiltration to neighboring zones or the large dilatation of the soil. The shear strength recovery after liquefaction is not included in this version of the software, as in engineering practice a liquefiable soil may be improved by appropriate techniques and it is not recommended to include a possible shear strength recovery in designs.

Equivalent Linear Model

The Equivalent Linear approach is performed assuming a system of homogeneous, multilayer, laterally infinite viscoelastic layers subjected to vertically incident shear and compression body waves (only out-of-plane shear waves in Engineering Analysis version).

The complex transfer functions computed for each layer depend on the complex wave velocities and the mass density of each layer.

The damping is assumed to be frequency independent and represents the plastic dissipation. This assumption is generally admitted for sands but may be questionable for clayey materials in which the presence of adsorbed water may induce some frequency-dependent viscosity.

In the Advanced Engineering version, where two horizontal components of motion are taken into account, we assume that the apparent shear modulus varies with the L_2-norm of the shear strain vector in the plane of the soil layer. Hence, it is assumed that the shear resistance reduces in all directions in an isotropic way and constitutes a strong hypothesis. However, in the seismic context it may be admitted that an averaging may be statistically realized.

The complex compression wave velocity is assumed to be constant and does not depend on distortion. This assumption is physically realistic.

As the apparent shear modulus and associated damping ratio vary with distortion, an iterative scheme is used.

The following flow-chart shows different steps of calculations:

1- $G = G_{max}$, $D = D_{min}$, $V_p = \sqrt{\frac{\lambda + 2G}{\rho}(1 + 2iD_p)}$

2- Compute the Fourier transform of the input motion

3- $G^* = G^k(1 + 2iD)$, $V_s = \sqrt{\frac{G^*}{\rho}}$

4- Compute the transfer functions

5- Convoluate the Input Motion with the transfer functions

6- Compute $\underline{\gamma}$ in the middle of each layer

7- Inverse Fourier transform of $\underline{\gamma}$ to obtain $\underline{\gamma}(t)$

8- Compute the norm of the shear strain vector $||\underline{\gamma}(t)||_{L2}$

9- Compute $\gamma = \chi \, Max(||\underline{\gamma}(t)||_{L2})$

10- Evaluate $G^{k+1}(\gamma)$ and $D^{k+1}(\gamma)$

11- Go to 3 if $\left|\frac{G^{k+1} - G^k}{G^k}\right| > \theta\%$ and if $k < \kappa$

12- Evaluate the acceleration, velocity and displacement vectors at the top of each layer

13- Evaluate the stress and strain vectors in the middle of each layer

In 3, it is possible to use:

either the equation proposed by Schnabel:

$$G^* = G(1 + 2iD)$$

or the equation proposed by Lysmer:

$$G^* = G(1 - 2D^2 + 2iD\sqrt{1 - D^2})$$

In general, less than κ = **10** iterations are necessary for the algorithm to converge and θ **= 5%** is used in practice. Moreover, the value of $\chi =$ **0.65** in 9, is very often adopted following recommendations from users of the program *SHAKE*, in which this approach has been introduced originally by Schnabel *et al.* (1972)[21] for out-of-plane vertically incident shear waves. The following equation may be also used to estimate χ:

$$\chi = \frac{\mathbf{M} - 1}{10}$$

in which **M** is the magnitude of the earthquake.

In CyberQuake, it is also possible to assume a rigid bedrock. For this purpose and in order to avoid unrealistic results due to the cut-off of the signal in the computing window, the following steps are added to the above algorithm:

2bis- Multiply the Fourier transform of the Input Motion by $e^{-\alpha t}$

4- Compute the transfer functions using the complex frequency $\omega^* = \omega - i\alpha$

The other steps are identical.

---

[21] Schnabel B., Lysmer J; and Seed H.B, SHAKE : A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report N°. EERC 72-12, UC-Berkeley, 1972.

The parameter α is not directly introduced in the program. It is included by a the numerical coefficient c given as:

$$\alpha = \frac{\log c}{t_{end} - t_{initial}} \qquad c \geq 1$$

The default value for c is 5. To suppress the effect of α, c should be taken equal to unity. This parameter may be accessed by selecting *Parameters* in the dialog box of *Time History* from *Define* drop-down menu command in Equivalent Linear Frame or Control Point Frame

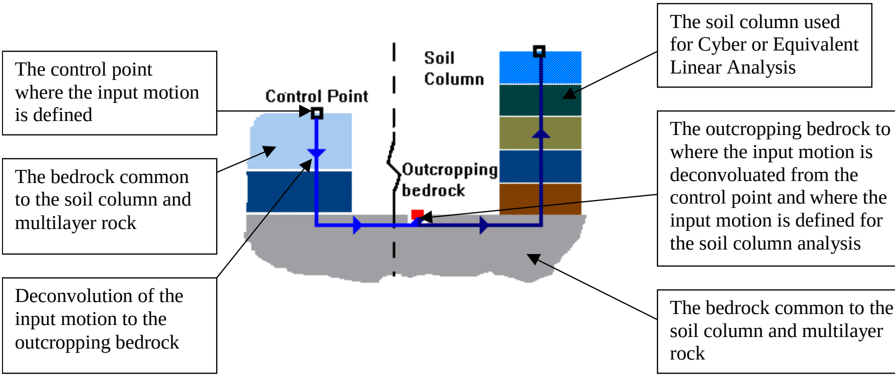
Control Point and Deconvolution

In general, the control point is where the Input Motion is defined.

In CyberQuake, when using the Soil Column Frame or the Equivalent Linear Frame, the Input Motion is assumed to be located at the outcropping bedrock at the same altitude as the underlying bedrock.

However, by using a Control Point Frame, it is always possible to assume an outcropping multilayer rock having its own geometry on which the Input Motion is defined. The behavior of this multilayer structure is assumed to be viscoelastic, but also nonlinear, as the elastic moduli and damping may vary with the level of shear strain.

The prescribed accelerogram is introduced *via* the Input Motion, assumed to be defined on the surface of the multilayer rock and deconvoluated to the outcropping bedrock assuming an Equivalent Linear type approximation for the rock.



To combine a deconvolution analysis with a direct computation of a Soil Column, one should first deconvoluate the motion from the Control Point to the outcropping rock as shown in the above figure, and then use the Results command in the Control Point Frame to visualize and save the computed acceleration components at the outcropping bedrock. Then, these acceleration components may be used as Input Motion for either a Cyber Analysis or Equivalent Linear Computation.

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Printed July 2006.