

# **COMPUTER PROGRAM DYNAN Version 3.0**

*A Program for Dynamic Analysis of Both Shallow and Deep  
Foundations Under Harmonic, Transient and Random Loading Using  
Improved Novak's method  
(User's Manual)*

by

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# CHAPTER 1. **Introduction**

## 1.1 General Description

A powerful computer program should be founded on advanced theory and be verified by tests and practice. The DYNAN program follows these guidelines. DYNAN is based on the improved Novak's method where a non-reflective boundary is formed between the near field and the far field to account for the mass of soil in the boundary. The program yields the dynamic response of both shallow and deep foundations under harmonic, transient, and random loadings. Such loadings can be produced by rotating or reciprocating machines, earthquake, wind, blast, sea waves, and other sources.

The foundations (or caps on piles) are assumed to be rigid, and all six degrees of freedom are considered as coupled. The foundation stiffness and damping constants are also returned for possible use in soil-structure interaction analyses.

The stiffness of the supporting soil along with damping constants needed for the analysis are evaluated in the program for surface foundations, embedded foundations, and pile foundations. Soil layering, a possible weakened zone (see Fig. 5.3) around a foundation, and pile-soil-pile interaction are all taken into account. Dynamic experiments have been done on full-scale shallow foundations and pile foundations to investigate the soil-structure interaction. DYNAN program was developed based on the impedance function method and used the model of soil-structure interaction with nonreflective boundary between the near field and the far field to account for the nonlinearity of soil.

## 1.2 Application of Program

The computational method has been applied to many important problems in engineering practice (Han, 1987, and Han, et al, 1999). To investigate soil-structure interaction, a series of dynamic experiments were performed on full-scale mat foundations (Han, 1989) and on full-scale piles (Han and Novak, 1989, 1992). The elastic wave energy from foundation vibration was dissipated in three dimensions as radiation damping. The soil is not a perfect elastic medium as assumed in the theory and the experiments showed that damping was overestimated in the computation. For practical purposes, the damping is reduced in DYNAN based on experimental results.

To match more rigorous solutions, the theory of soil reactions is modified in the low frequency range. At the dimensionless frequency  $a_0 = \omega r/V_s$  less than 0.3 for piles under lateral loading, the soil stiffness is taken as constant and the damping is taken as linear ( $\omega$  is the circular frequency in rad/s,  $r$  is the pile radius and  $V_s$  is the soil shear-wave velocity). In general, the dynamic stiffness of soil is close to the static stiffness in the low frequency range (less than 0.05 Hz).

DYNAN can be used for the dynamic analysis under transient and random loading in the time domain (see Han and Cathro, 1997). It also can be used for harmonic loading in the frequency domain. The substructure concept based on the impedance function of foundations has been introduced in the structural analysis and is frequently used by the structural engineers for the time-history analysis in seismic studies. By means of a substructure method, the dynamic response of superstructure is calculated using a finite element program, such as SAP2000, and the stiffness and damping of foundation generated by the DYNAN program (see Han, 2001) are used for representing the foundation reaction.

### 1.3 Program Features

Program DYNAN 3.0 was developed based on MicroSoft Windows operation systems and uses a graphics interface for data entry. The user may read the screen information, then type the data at the specified entry field. The entered data can be changed freely by moving the mouse to the field location on the screen.

DYNAN 3.0 integrates the input modules, main-computation module, and graphics module into one system. Therefore, the user may freely call each module inside Windows for operation. In general, after entering the input data, the user may call the computation module to execute the input data. The user may also call on the graphics module to plot the computed pile-head stiffnesses versus loading frequencies.

- The program employed well-established analytical solutions for soil-structure interaction under dynamic loading condition.
- The program can analyze four types of foundations: (1) footing on homogeneous half-space (half-space option); (2) footing on homogeneous layer (stratum option); (3) footing embedded in layered medium (multilayer option); and (4) deep foundation (pile option).
- The program was developed based on the improved Novak's method and a non-reflective boundary is formed between the near field and the far field to account for the mass of soil in the boundary zone.
- The foundations (or caps on piles) are assumed to be rigid, and all six degrees of freedom are considered as coupled.
- The group effect of piles is accounted for by using the method of interaction factors in the DYNAN program.
- In DYNAN, the harmonic excitation can be of two types: constant amplitude excitation and frequency-dependent or quadratic excitation.
- The program accepts either S.I. units or English units.
- DYNAN can be used for the dynamic analysis under transient and random loading in the time

domain (see Han and Cathro, 1997). It also can be used for harmonic loading in the frequency domain.

- The program generates the output data for each frequency of harmonic loads on the foundation.
- The Graphics menu allows quick observations of results contained in the output file.
- The files of input data and output data are text based and may be directly accessed from within the DYNAN program, employing the user's preferred text editor or word processor.
- A well-documented manual is provided with the relevant theoretical background and guidance to input screens.

## 1.4 Units, Notation and Sign Convention

Any unit notations may be used, but the notations must be consistent. The output calculated should be of the same unit notation as that of the input data. Consider that in the SI measuring system, the units for measuring force, mass, length, and time are, respectively, kN, Kg, m, and s, where  $Mg = 1,000 \text{ Kg}$  and  $\text{gravity} = 9.81 \text{ m/s}^2$ . For the English measuring system, the units are lb, slug, ft, and s, where  $\text{gravity} = 32.2 \text{ ft/s}^2$ , and  $\text{mass slug} = \text{lb}/32.2$ .

The input forces, moments, and response components follow the sequence of labels shown in Fig. 1. For instance, labels 1 and 2 indicate horizontal direction along the X and Y axes. The force and moment are defined with regard to the center of gravity (C.G.). The 'center of gravity' means the center of gravity of the machine/foundation system.  $X_c$ ,  $Y_c$  and  $Z_c$  are the coordinates for the center of the foundation base, (C.B.).

The forces and translations are positive if they move in the positive direction of the corresponding axis. When being observed from the origin in a positive direction of the pertinent axis, moments and rotations are positive if they act in a clockwise direction. Thus, two positive horizontal forces  $P_1$  and  $P_2$  acting above the C.G. in the direction +X, +Y result in moments  $M_4 < 0$  and  $M_5 > 0$ . Stiffness constants, defined to be external forces, follow the same sign convention; consequently, the cross-stiffness constants of symmetrical foundations differ in signs.

## 1.5 Company Background

Ensoft, Inc., USA signed an agreement with Dyna Tech (Canadian Company) to develop a Windows-based pre- and post- processor for operating DYNAN on a Windows platform. The computation code of DYNAN has been copyrighted and registered with Canadian Intellectual Property Office in July 2001.

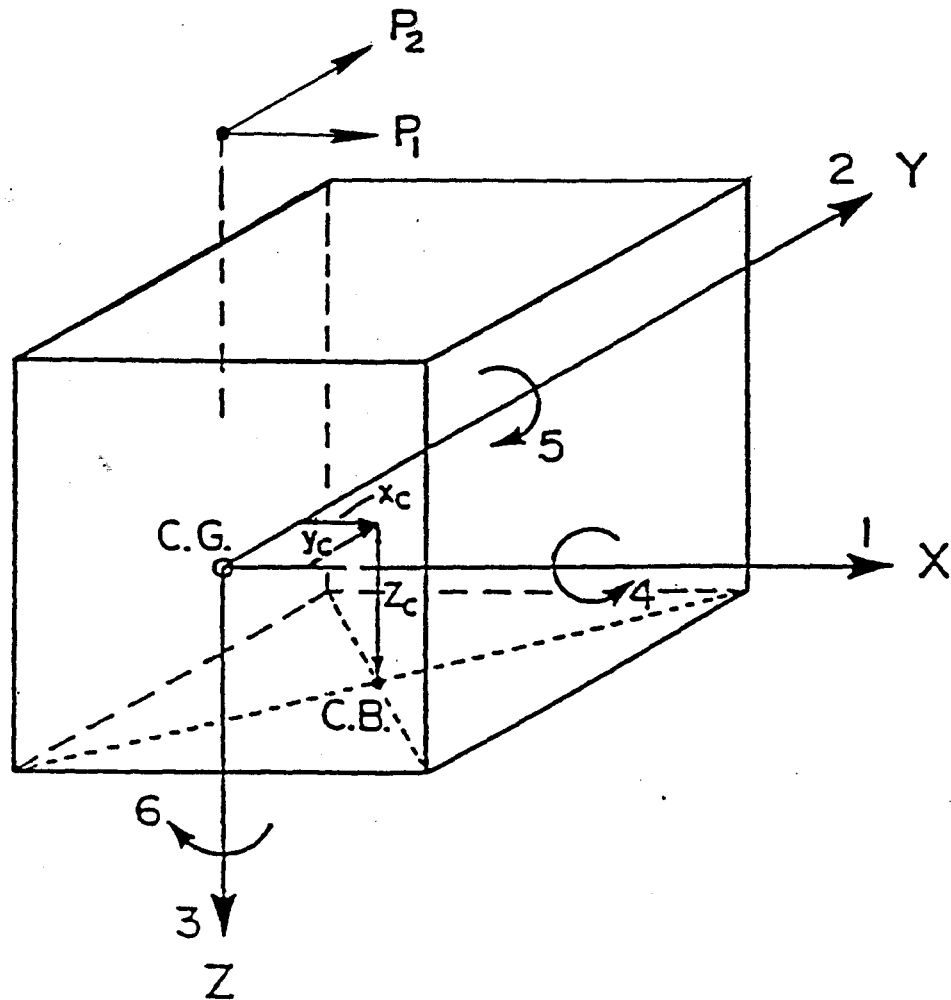


Figure 1.1 Notation and sign convention used by DYNAN 3.0

Both Dyan Tech and Ensoft cannot take responsibility for correct results from the codes; hence, the user is to employ independent means, such as calculations by hand, to verify the results of any computation. Hand calculations made by knowledgeable engineers employing basic engineering principles may yield approximate values for comparison with values from computer codes, even for complex problems. Both companies are committed to continuing the development and maintenance of the usefulness and availability of the program for businesses and professionals.

## CHAPTER 2. **Installation and Getting Started**



## 2.1 Installation Procedures

Program DynaN 3.0 is distributed with a hardware lock (USB dongle). The hardware lock consists of an electronic device that is attached to the USB port of the computer in use. This method of software protection has been found to provide compatibility with existing operating systems, better stability than other alternatives, and it allows users to obtain software updates or replacements via downloads from the internet.

The file *setup.exe*, contained in the distribution media, is a Windows-based program which will assist the user in installing all the program modules into an user-selected directory with all the proper settings used for the Windows environment. The user is assumed to have the basic knowledge for running applications under Windows. The following steps are recommended for a successful installation.

### 2.1.1 Installation of Single-User Version

Users are normally supplied with software manuals (in electronic pdf format), CDROM, and USB dongle. This version of DynaN has been tested to be compatible with the following versions of Windows: Win 2000, Windows XP, Windows Vista, and Windows 7.

The following guidelines are recommended to be followed during the installation process of DynaN v3.0 for single-user licenses.

1. It is our recommendation that the hardware lock (USB dongle) should not be plugged in the computer prior to the software-installation process. The USB dongle can be plugged into the computer after the software has been installed successfully and the computer should recognize the USB device immediately.
2. Start Windows. ® Insert the distribution CD-ROM in the appropriate tray. If the main installation program does not start automatically, click on the Start button and select Run. On the command line, type *d:\setup.exe* or *e:\setup.exe*, where *d:* or *e:* represents the drive that contains the distribution CD. Press e or click OK to execute the command and start the main installation program for ENSOFT's software. A screen similar to the one in Figure 2.1 should appear.
3. Click anywhere on the DynaN 3.0 icon and then click on the Install Standard button to start the installation of the single-user version of DynaN v3.0.
4. The user should read the license agreement shown in Figure 2.2. Please click "Yes" if you agree and would like to proceed.
5. The user will be provided with an option to select a drive and directory for the installation of DynaN 3.0; the default is *c:\Program Files\ensoft\DynaN*. If the desired directory does not exist, the installation program will automatically create a new directory in the chosen hard drive.

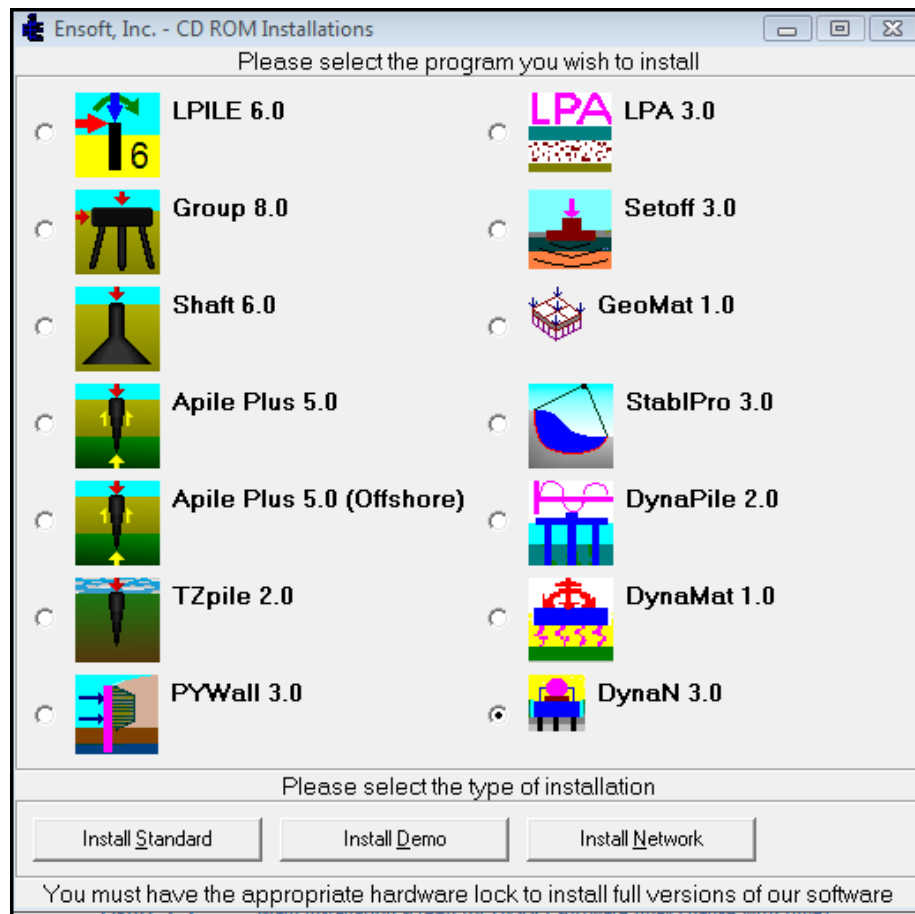


Figure 2.1 Main installation screen for ENSOFT software (may change with time)



Figure 2.2 Main installation screen for ENSOFT software (may change with time)

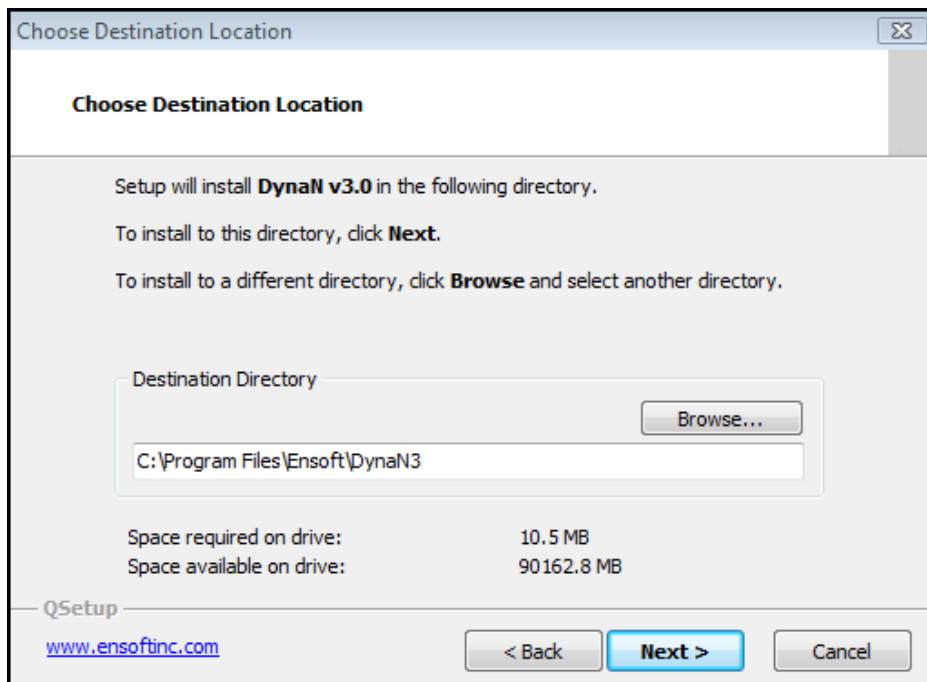


Figure 2.3 Main installation screen for ENSOFT software (may change with time)

If your license is for a single-user, select the "Single-User License" option and click Next. Follow the dialog boxes until the installation finishes. After the installation is completed, insert the USB dongle into any USB port and follow USB driver installation if it shows up. In some cases, the user may be requested to restart Windows before executing the program.

6. Most distribution files will be copied to the installation directory (either the default or the one selected by the user). However, certain files are copied to system directories in Windows and some Windows services are started during installation.

7. After the installation is finished, it is usually not necessary to reboot Windows for the program to run. The user may plug the USB dongle into the computer and run the program by double-clicking its icon in the ENSOFT/DynaN folder located in the Start/Programs menu.

### 2.1.2 Network License

Special network licenses and hardware locks are available for users that desire to operate DynaN 3.0 on a Windows network. The network version is limited to users with two or more licenses at the same physical site. Discounted rates apply for users purchasing multiple licenses for the same site.

Network versions of DynaN 3.0 have special subroutines written for installations in "software servers" and for installations of "individual clients".

The "software server" is known as the computer that will be carrying the network lock provided by ENSOFT, INC. The software server is not necessarily the same as the existing network server. Any computer in the existing Windows network may be designated software server for DynaN 3.0 as long as the network lock is attached to its USB port and the "server" version of the software is installed in its hard drive.

Software "clients" may be all other computers of the network that have the program installed as clients. Software clients do not need any hardware lock attached to their USB port. The program installed in "software clients" will be allowed to run as long as the computer designated as "software server" is running on the network with the proper operating system and with its network USB lock secured in the appropriate place.

Users of the network version of DynaN 3.0 are allowed to have the software installed in as many computers as they have on their local Windows network. However, only a number of users equal to the total number of purchased licenses (minimum two for networks) will be able to operate the program at the same time.

### 2.1.3 Installation of Network Version

To install this program, the user must have network privileges to modify the Windows registry. In large computer networks, this is usually only available to network administrators. They are the ones recommended to proceed with these installations.

1. The network administrator must first define the computer that will be carrying the network lock (USB dongle) for this software. The computer carrying the network lock is known as the "server" for this particular computer program. Notice that the "server" may be any computer in the network, and not necessarily the existing file server or network server.

2. INSTALLATION TO A "SERVER": Please attach the USB dongle to any USB port of the software server. The "server" computer must be turned on and logged into the network to enable other users (ie, "clients") to access this computer program.
3. INSTALLATION TO "CLIENTS": It is not necessary to connect the USB dongle to client computers during installation nor during program executions. Once the program is executed, the installed network protocols will automatically recognize the computer where the network key is residing and the number of simultaneous users.
4. Start Windows and Insert the distribution CD-ROM in the appropriate tray.
5. If the main installation program does not start automatically, click on the Start button and select Run. On the command line, type *d:\setup.exe* or *e:\setup.exe*, where *d:* or *e:* represents the drive that contains the distribution CD. Press *e* or click OK to execute the command and start the main installation program for ENSOFT's software. A screen similar to the one previously shown in Figure 2.1 should appear.
6. Click anywhere on the DynaN 3.0 icon and then click on the Install Network button to start the installation of the network version of DynaN v3.0.
7. The user will be provided with an option to select a drive and directory for the installation of DynaN 3.0; the default is *c:\Program Files\ensoft\DynaN*. If the desired directory does not exist, the installation program will automatically create a new directory in the chosen hard drive.
8. The installation program will automatically recognize the version of Windows that is running in the destination computer. The user will be prompted to select an installation to a Client or to a Server computer. If desired, the network administrator may install the program to a single directory in a file server. In this case, the software must first be installed in the file server as a "software server" and icons pointing to the *DynaN.exe* file (residing in the server) can later be created in each individual client computer.
9. Most distribution files will be copied to the installation directory (either the default or the one selected by the user). However, certain files are copied to system directories in Windows and some Windows services are started during installation.
10. After the installation is finished, it is usually not necessary to reboot Windows for the program to run. The user may run the program by double-clicking its icon in the ENSOFT/DynaN folder located in the Start/Programs menu.

#### 2.1.4 Backup of Original Software

The distributed software may be copied for backup purposes. The program may be installed in several computers at the same time. However, unless network licenses are purchased, the program will only operate in computers that carry the appropriate USB lock.

### 2.1.5 Software Updates on the Internet

Occasionally, ENSOFT will produce software improvements and/or fixes and place the latest software programs on ENSOFT's internet site. Software users may download the latest program update from the following site if the user has the valid maintenance policy:

*<http://www.ensoftinc.com>*

## 2.2 Getting Started

A general diagram showing the menu choices and operational flow chart of program DynaN 3.0 is presented in Fig. 2.4. The following paragraphs provide a short description of the operational features and should quickly enable the user to get started with the program.

### 2.2.1 Starting the Program

The program is started by double clicking the left mouse button anywhere in the DynaN 3.0 icon. A new window will appear on the screen, with several top menu choices: File, Data, Computation, Graphics, View Geometry, Window, and Help. As a standard Windows feature, all underlined letters of top menu operations indicate that choices may also be accessed by keyboard combinations of alt+[letter] (where [letter] represents the desired underlined letter).

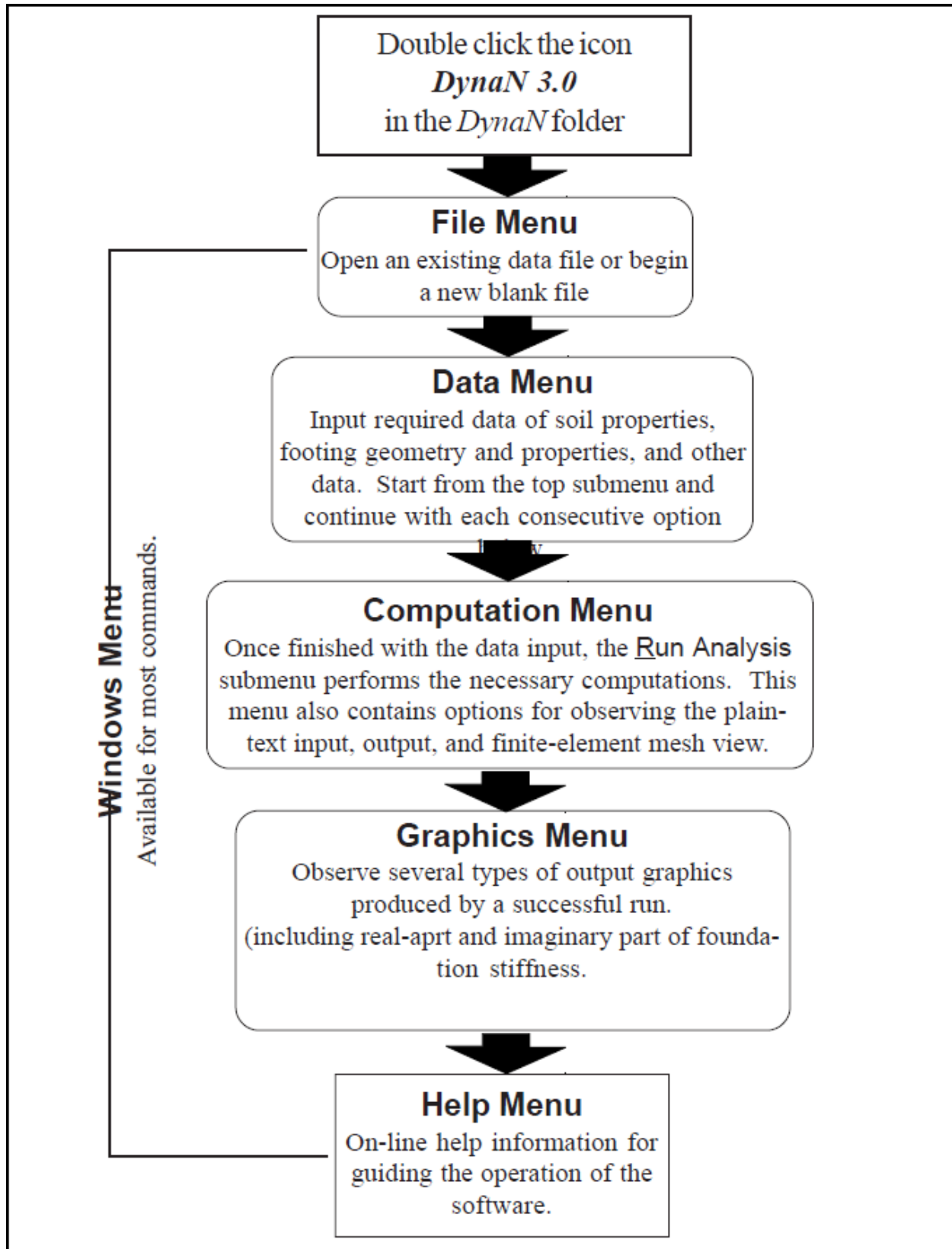


Figure 2.4 Main installation screen for ENSOFT software (may change with time)

### 2.2.2 File Management

The File menu contains four submenus, followed by a list of the last four recently-opened files, and an option for exiting the program. A sample of submenu options are included in Fig. 2.5. A brief description of submenu choices follows below:

- **New** : to create a new data file.
- **Open...**: to open an existing data file.
- **Save** : to save input data under the current file name.
- **Save As...**:to save input data under a different file name.
- **Exit** : to exit the program.

The last four files that were opened recently are also listed under the File menu. Clicking on any of the four files opens the selected file and instructs the program to use the directory of the opened file as the location for creating all output files.

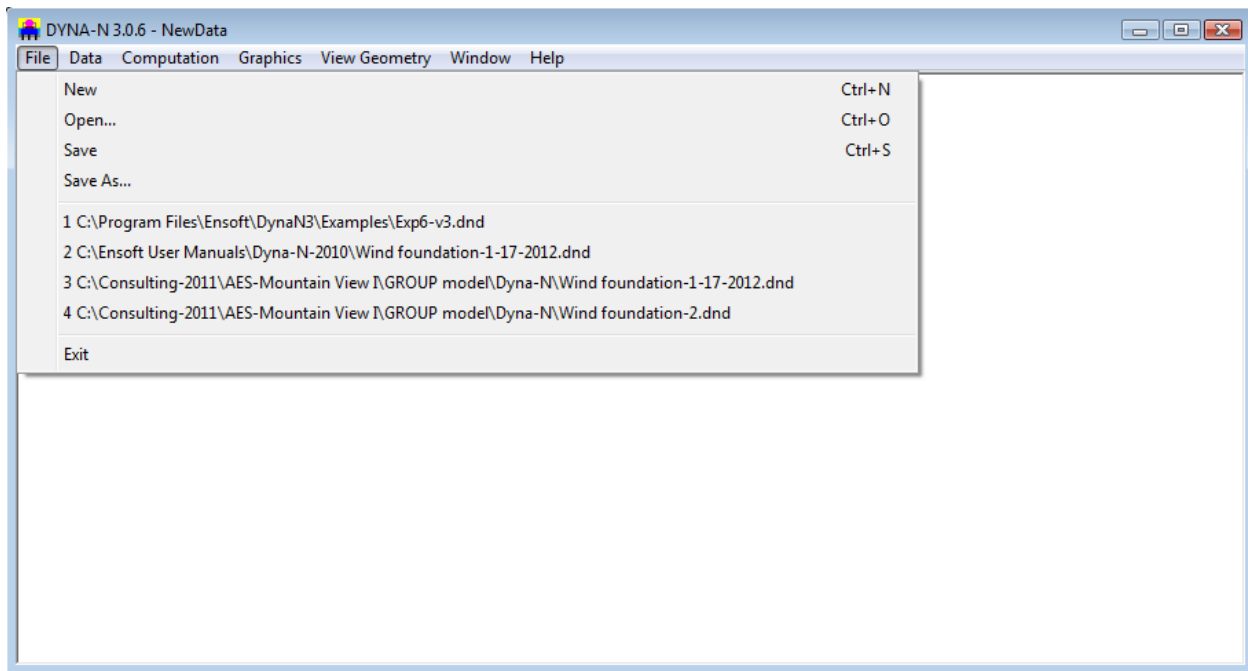


Figure 2.5 Options contained in the File menu



Several additional files are created in every new DynaN 3.0 run. A short description of these files is presented in Table 2.1. In general, every successful run generates five?? text files in the same drive and directory where the input-data file was saved. Any of these files may be opened with standard text editors or word-processing programs.

**Table 2.1 Files created in standard DynaN 3.0 runs**

File Name Extension	Usage Description	File Format	Example Files
*.dnd	Input-data file	Text file	<i>example1.dnd</i> <i>example2.dnd</i>
*.dno	Output-data file	Text file	<i>example1.dno</i> <i>example2.dno</i>
*.dnp	Plot-data file	Text file	<i>example1.dnp</i> <i>example2.dnp</i>
*.dnr	Processor-data file	Text file	<i>example1.dnr</i> <i>example2.dnr</i>

### 2.2.3 Data Input of Application Problem

The Data menu contains several submenus, as shown in Fig. 2.6. The submenu choices are listed below, along with a general description of their use.

- **Title** : to input the project description.
- **Units** : this option allows the user to select either English Units (using pound and foot, and slug), S. I. Units (using kiloNewtons, meters, and Mg), or any other consistent set of units of Force and Length. English units are enabled, as a default, for all new runs. The user may change the system of units as many times as desired, and values that were previously inputted will be automatically converted by the program from English to S.I. units or viceversa.
- **Option of Foundation System** : to select one of four available foundation types, i.e. half-space, stratum, multi-layer, and pile.
- **Option of Loading** : to select one of three available loading types, i.e. harmonic loading, transient loading, and random loading.
- **Option of Foundation Shape** : to select a circular foundation or a rectangular foundation.
- **Footing Mass parameters** : to input mass moment of inertia, total mass, and cross-product of inertia.
- **Foundation Dimension and Constants** : to input the foundation dimension related to the center of gravity.
- **Foundation Layer** : this submenu is used to enter the soil layers and soil properties for the multi-layer type of foundation.
- **Pile Cap Shape/Dimension** : to select a circular pile-cap or a rectangular pile-cap.
- **Pile Cap Mass Properties** : to input mass moment of inertia, total mass, and cross-product of inertia of the pile cap.

- **Pile Coordinates** : to input the pile-head coordinates and battered angle for each pile.
- **Pile Properties** : to input the material properties, [the] pile-cap dimension related to the center of gravity, pile length and other pile-related data.
- **Pile Elements** : to input the radius, moment of inertia, layer increments, and torsional coefficient.
- **Soil Layer Data** : to input the properties of soils that are next to the side of the foundation. The parameters of [the] weak zone in the side soil can be specified.
- **Soil Data Below Footing/Pile Tip** : to input the properties of the soil that are below the footing or pile tip.
- **Side Soil of Pile Cap** : to input the properties of soils that are next to the side of the pile cap. The parameters of the weak zone in the side soil can be specified.
- **Soil Column Layer** : to input the properties of the soil layers that are below the multi-layer type of foundation.
- **Harmonic Loading Data** : this submenu is used to input data for harmonic loading.
- **Transient Loading Data** : this submenu is used to input data for transient loading.
- **Random Loading Data** : this submenu is used to input data for random loading.
- **Control Options** : this option provides a window submenu where the user may select the available software as the text editor for input and output files. The user should input in this box the complete path and command line for the preferred text editor or word processor that will be used to examine and print the input, output, and processor plain text files created by the program. As a default, the command line `c:\windows\notepad.exe` is used to operate the standard text editor Microsoft Notepad included with Windows 2000, Vista, XP or 7. However, there may be some instances when the output files are too large for Notepad and a different text editor or word processor should be used. In such cases it is generally suggested to use Microsoft WordPad (`c:\windows\write.exe`).

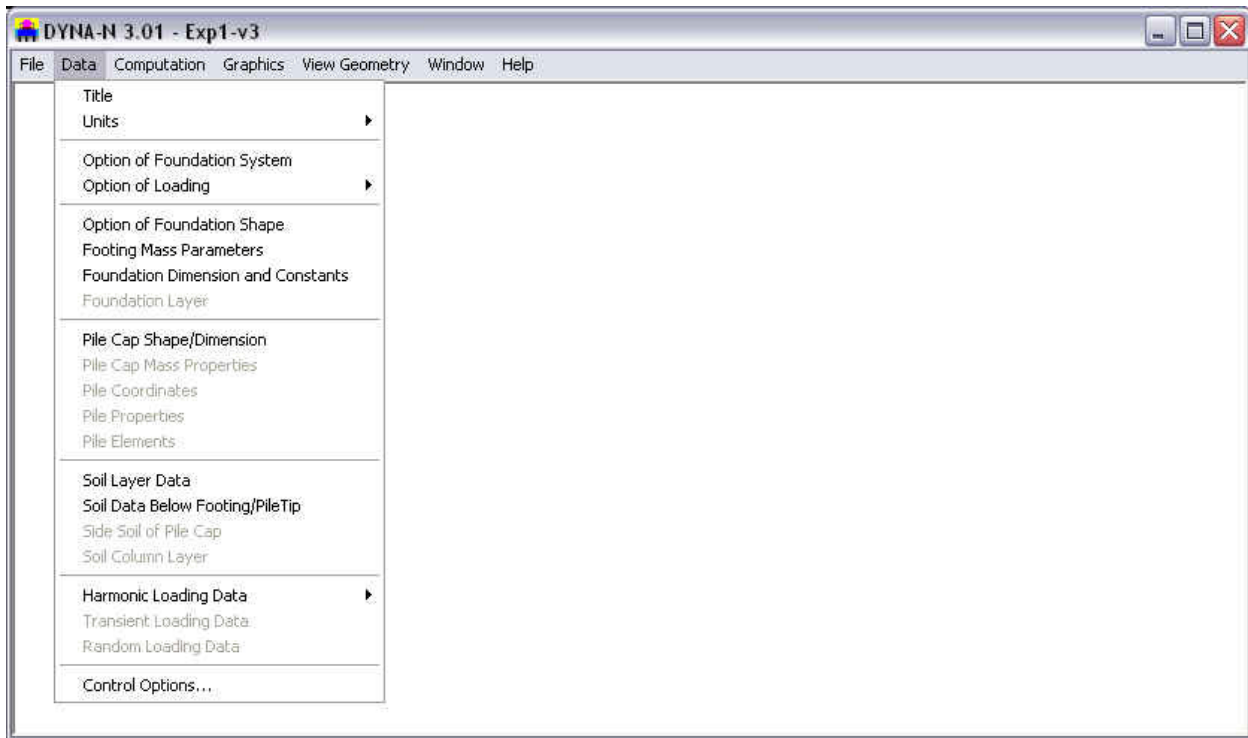


Figure 2.6 Options contained in the Data menu

### 2.2.4 Computation Options

The Computation menu is provided to run the analytical computations after all data are entered and saved. After the computation is executed successfully, this menu additionally provides options for the reviews of plain-text input data, notes produced during computation, and output data. It also provides an option for graphical observation of the automatically-generated meshes. Submenu choices, shown in Fig. 2.7, are briefly described below.

- **Run Analysis** : this option is chosen to run the analytical computations. This option should be selected after all data have been entered and saved.
- **Edit Input Text** : this option calls the previously-chosen Text Editor (selected under the Control Options submenu in the Data menu) to observe and/or edit the analytical input data in plain-text format. The option becomes available after the input data has been saved to disk, or when opening an existing input-data file.
- **Edit Processor Run-Note** : this option calls the previously-chosen Text Editor (selected under the Control Options submenu in the Data menu) to observe and/or edit the error message in plain-text format if the program can not be executed.
- **Edit Output Text** : this option calls the previously chosen Text Editor (selected under the Control Options submenu in the Data menu) to observe, format, and/ or print the analytical-output data. The option becomes available only after a successful run has been made. Certain output files may be too large for the Microsoft Notepad editor, so other text editors would have to be used (Microsoft WordPad should be able to open most text files).

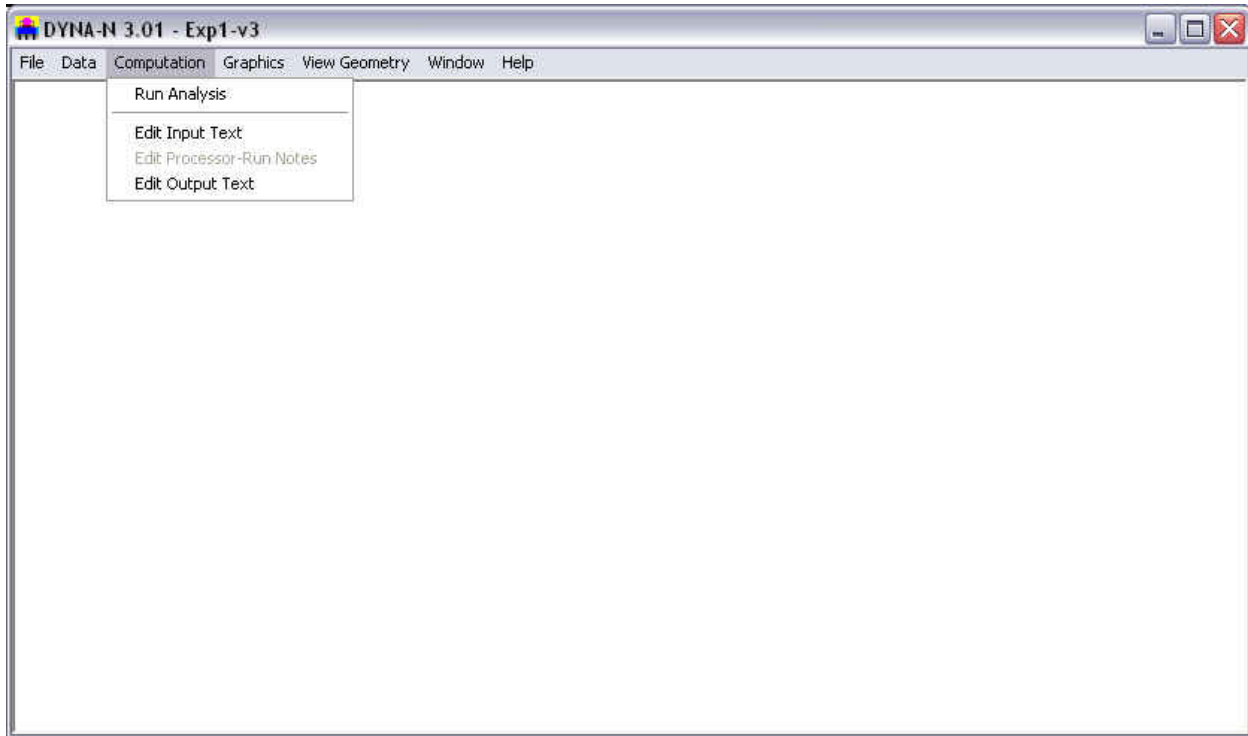


Figure 2.7 Options contained in the Computation menu

### 2.2.5 Graphics

The Graphics menu is used to observe plots of output data provided by a successful program run. Options for the observation of output curves under this menu are only enabled after a successful run has been made. Even after performing successful runs, some options may still be disabled since the required amount of output data depends on specifications provided in the input file of each program run.

Submenu choices, shown in Fig. 2.8, are briefly described below.

- **Translation Stiffness (Kxx, Kyy, and Kww)** : this option provides a plot of translation stiffness in the x-direction, y-direction, and z-direction of the foundation vs. loading frequencies.
- **Rotation Stiffness (Kppx, Kppy, and Kzt)** : this option provides a plot of rotational stiffness about the x-axis, y-axis, and z-axis of the foundation vs. loading frequencies.
- **Translation Damping (Cxx, Cyy, and Cww)** : this option provides a plot of translation stiffness in the x-direction, y-direction, and z-direction of the foundation vs. loading frequencies.
- **Rotation Damping (Cppx, Cppy, and Czt)** : this option provides a plot of rotational stiffness about the x-axis, y-axis, and z-axis of the foundation vs. loading frequencies.
- **Footing Response Amplitude (Translation)** : this option provides a plot of translation amplitude in the x-direction, y-direction, and z-direction of the foundation vs. loading frequencies at c.g. location.
- **Footing Response Amplitude (Rotation)** : this option provides a plot of rotation amplitude about the x-axis, y-axis, and z-axis of the foundation vs. loading frequencies at c.g. location.

- **Interactive Footing Response Amplitude** : this option provides a plot of translation/rotation amplitude about the x-axis, y-axis, and z-axis of the foundation vs. loading frequencies at the user specified location.

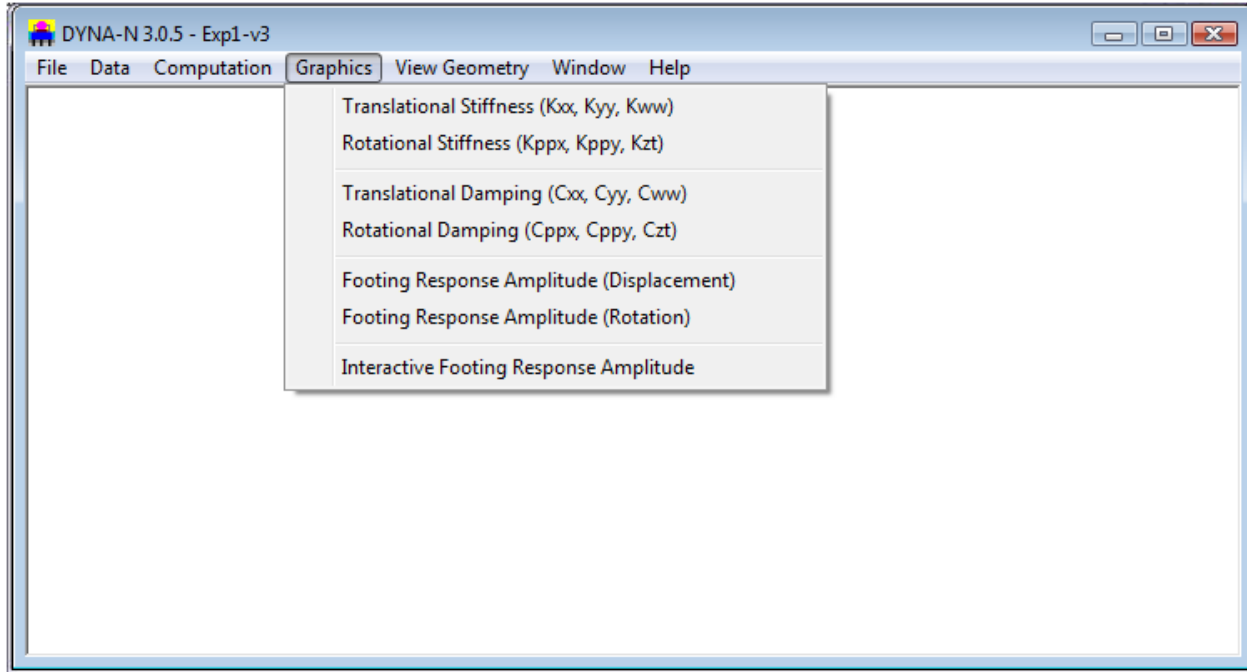


Figure 2.8 Options contained in the Graphics menu

### 2.2.6 Arrangement of Windows

The Window menu provides two standard functions for organizing open-screen windows and/or minimized screen-window icons. Submenu options, shown in Fig. 2.9, are briefly described below.

- **Cascade** : this option organizes all open-windowed menus so that all become visible with their tops cascading from the upper left portion of the screen.
- **Arrange Icons** : this option organizes the icons of all minimized windowed menus so that all become visible and align at the bottom portion of the screen.

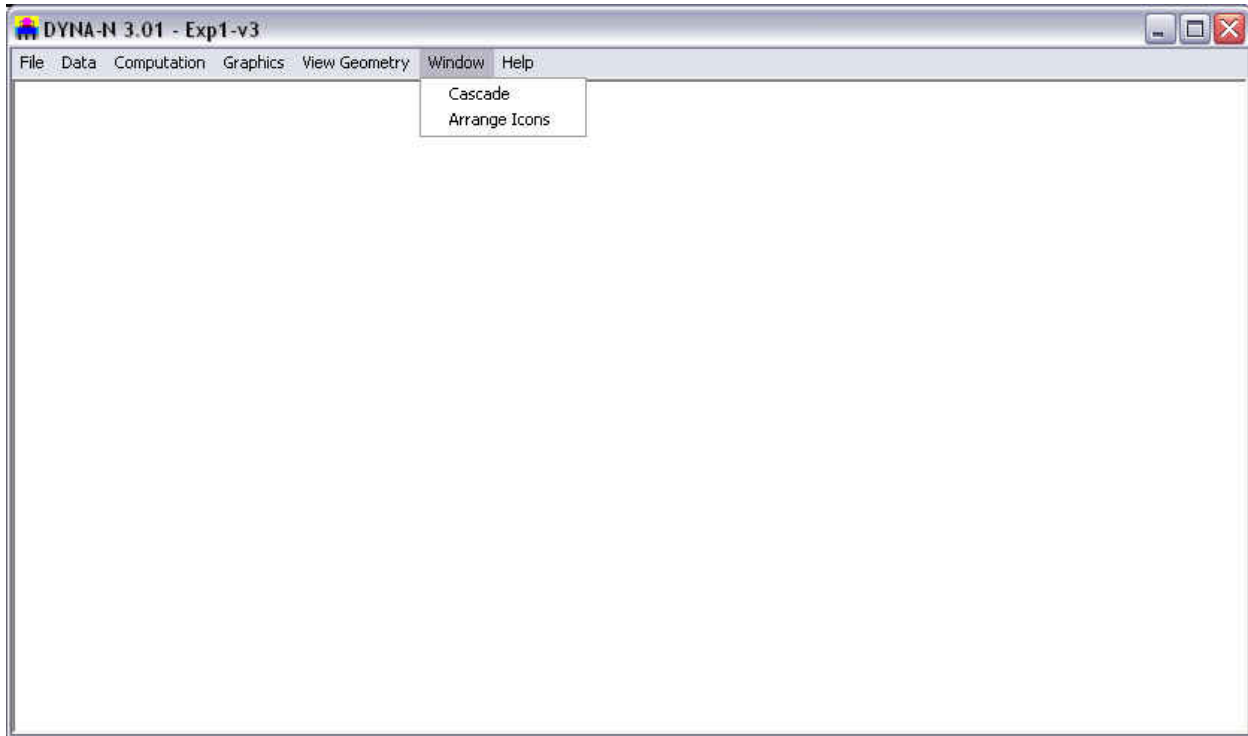


Figure 2.9 Options contained in the Window menu

### 2.2.7 Help Files

The Help menu provides an online help reference on topics such as: using the program, entering data, information about variables used in the program, and methods of analyses. Submenu options, shown in Fig. 2.10, are briefly described below. The Help menu may be accessed at any time while in DynaN.

- **Contents** : the main reference files for help are accessed through this submenu option. Clicking on this option provides a screen with reference help for the following topics: File Menu, Data Menu, Computation Menu, Graphics Menu, and Help Menu. Under each topic are additional subtitles that correspond to data-entry headings. If the user selects one of these, a help screen on the topic is displayed.
- **About** : this provides a screen describing the program version, date, and methods for accessing technical support.

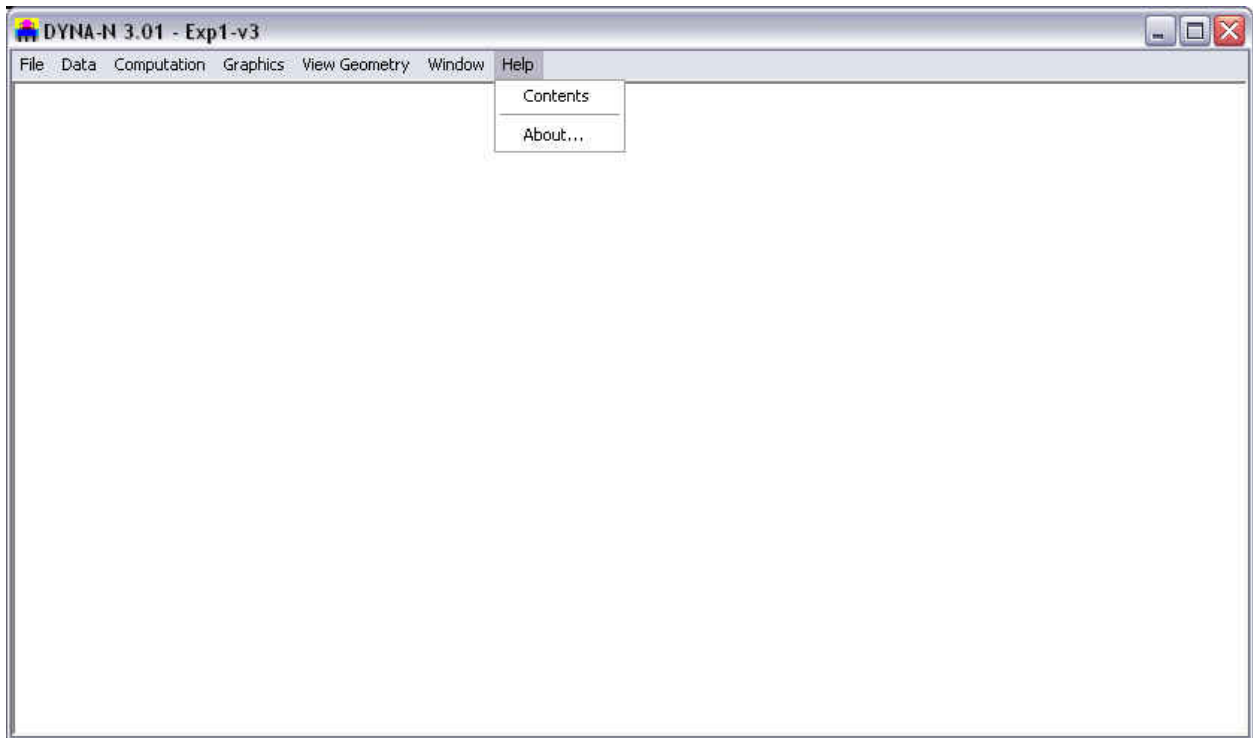


Figure 2.10 Options contained in the Help menu

## CHAPTER 3. **Data Input**



### 3.1 File Menu

This menu contains options related to the management of input-data files and exiting the program. Input-data files created for DynaN 3.0 are provided with a standard file-name extension in the form of \*.dnd (where \* represents any acceptable file name). All input-data files are standard text files and may be edited with any text editor or word-processing program.

#### 3.1.1 File-New

Once the program is started, default values are used for certain operating parameters, and a blank input-data file is created. Selecting New under the File menu resets all DynaN 3.0 variables to either default or blank values, as appropriate. This option should be selected when desiring to create a new data file from a blank form.

#### 3.1.2 File-Open

This is used to open a file that had been previously prepared and saved to disk. The File -Open window dialog, shown in Fig. 3.1, is used to search for an existing input-data file. By default, the file is initially searched in the directory where DynaN 3.0 was installed. Standard Windows-navigation procedures may be used to locate the name and directory of the desired project file.

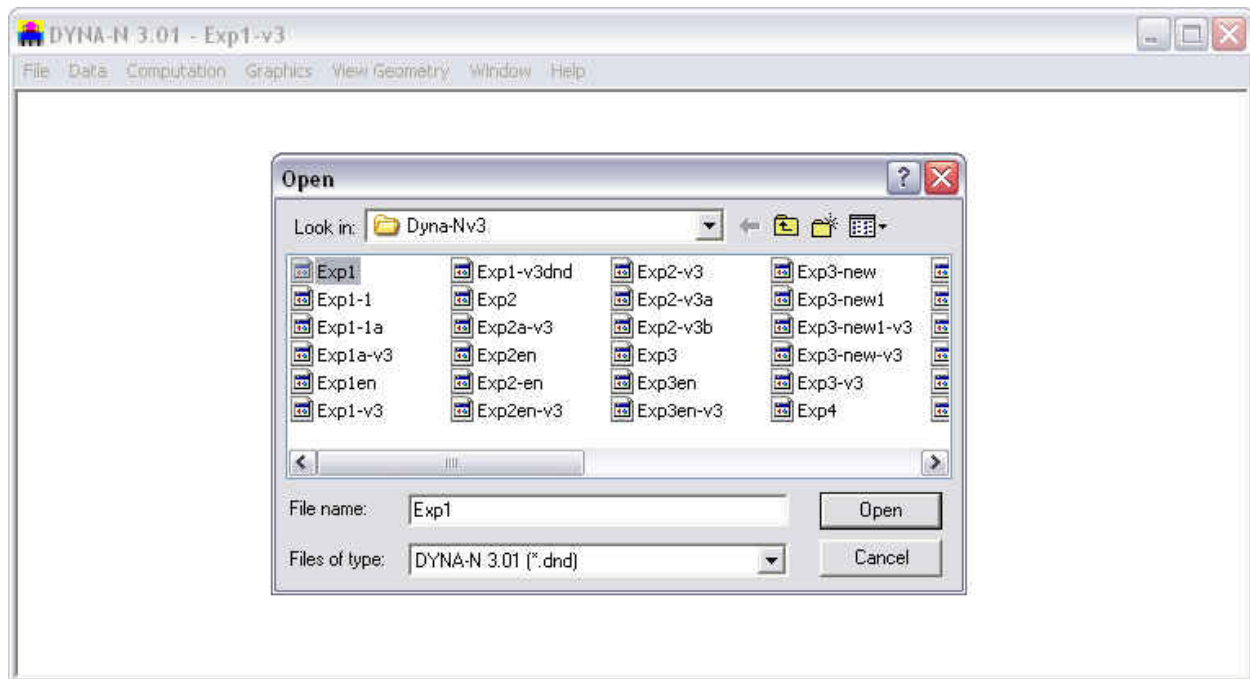
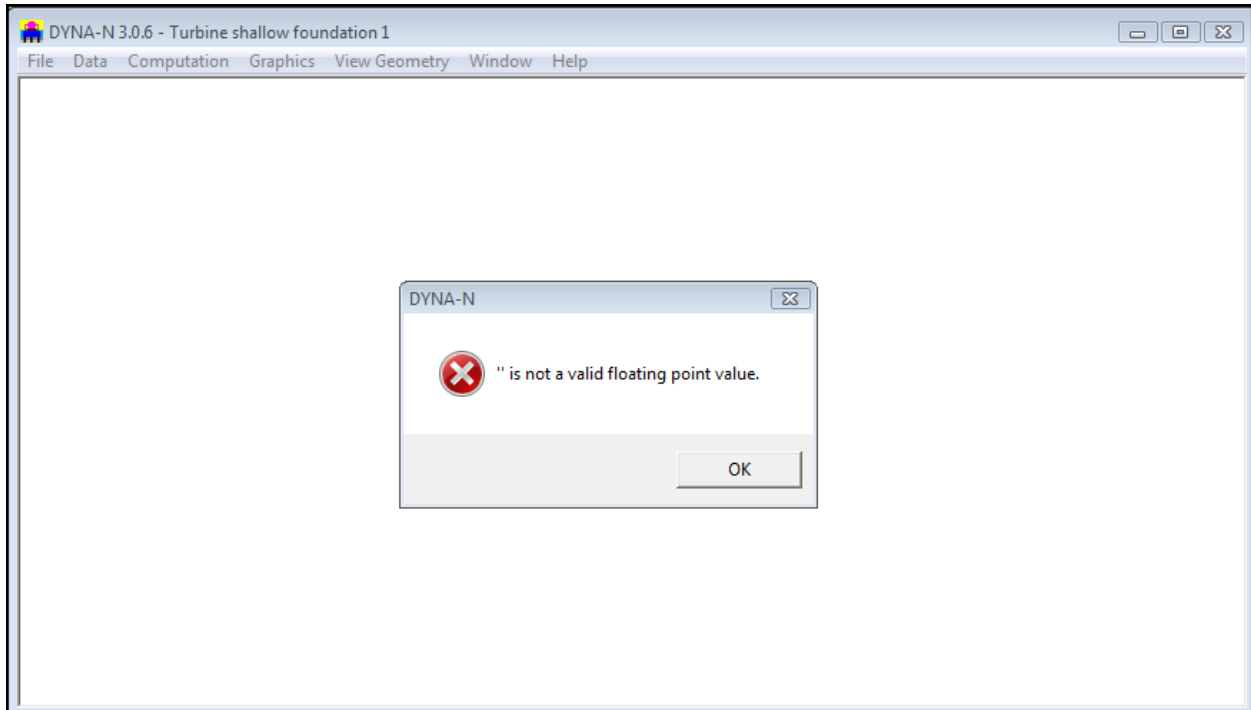


Figure 3.1 Window screen for the File – Open dialog

Every analytical run of DynaN 3.0 produces several additional files (as described in Table 2.1 of this manual). The name of the input-data file indicates the names of all related files produced by a successful execution (output, graphics, and processor-text files). All the additional program files will be

created in the same directory as the input file. Input-data files that are partially completed may be saved and opened later for completion, run, and view of results.

Opening some partially-completed DynaN 3.0 input files or invalid data files may produce an information window reporting that an “invalid or incomplete” file is being opened (see Fig. 3.2). The user should click “OK,” and all partial-input data that was previously prepared should become available.



**Figure 3.2** Message window for incomplete or invalid files

### 3.1.3 File -Save

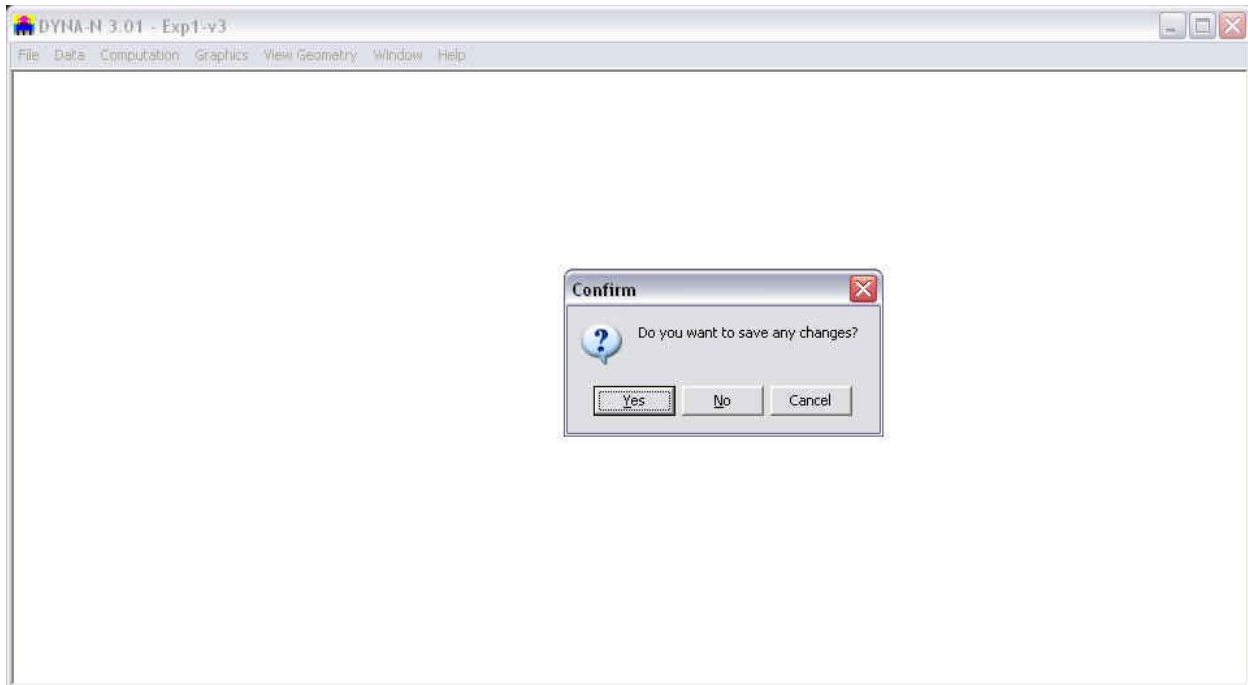
This option is used to save input data under the current file name. With this method of storing data to disk, any input data that was previously saved with the same file name is replaced with the current parameters. Input-data files should be saved every time before proceeding with runs for analytical computation.

### 3.1.4 File - Save As

This option allows the user to save any opened or new input-data file under a different file name or directory. Any input-data file saved under an existing file name will replace the contents of the existing file.

### 3.1.5 File - Exit

This is selected to exit DynaN 3.0. If any input-data file that was modified is not yet saved to disk while the option is selected, a confirmation window will appear before the program closes (see Fig. 3.3).



**Figure 3.3** Message window advising that changes were not saved to disk

## 3.2 Data Menu

The input of specific parameters for an application is controlled under options contained within this menu (shown in Fig. 3.4). It is recommended that the user choose each enabled submenu and enter parameters in a consecutive manner starting from the top option. Selecting or clicking any of the submenu choices contained in the Data menu produces various types of windows.

As a reminder for standard commands of Microsoft Windows®, open windows may be closed by all or some of the following methods:

- clicking the OK button (if available), or
- clicking the X box on the upper-right corner of the window, or
- double-clicking the DynaN 3.0 icon on the upper-left corner of the window, or
- clicking once on the DynaN 3.0 icon on the upper-left corner of the window and then choosing "Close."

Open windows may be left open on the screen by option. The selection of other menu options will then produce new windows on top of those that are left open.

Many sub-windows of the Data menu will show an Add Row, Insert Row and/or Delete Row buttons. The Add Row button always adds new rows at the end of all existing rows. The Insert Row button always insert a new row right after an existing row highlighted by the mouse. Clicking on the Delete Row button deletes the row where the cursor is located.

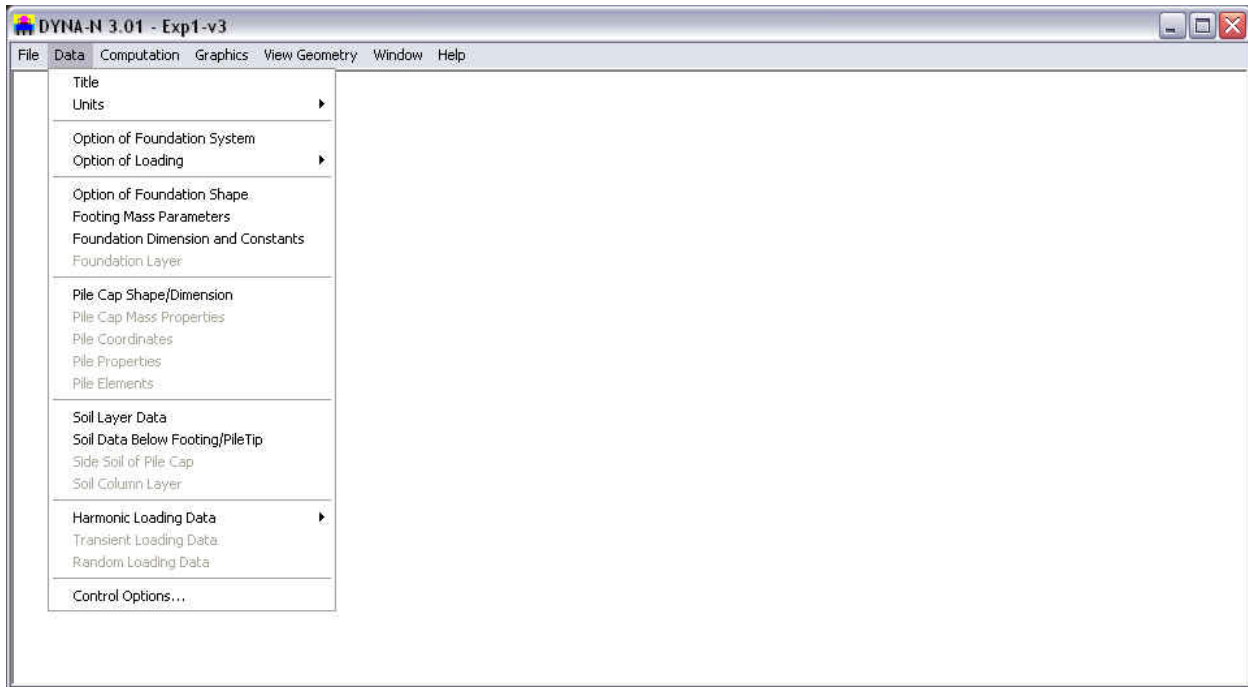


Figure 3.4 Options contained in the Data menu

### 3.2.1 Numeric Data Entries

In addition to simple numeric entries, cells that require numeric data may also accept entries of mathematical expressions. Entering a mathematical expression works similarly to entering normal numeric data. The user types the expressions that represent the data and presses the “e” key to calculate the entered expression and to display the numeric result in the same cell.

Table 3.1 shows the list of supported operations and constants. The order of operations follows the order in the list of Table 3.1. Note that implicit multiplication (i.e.  $2(4+6)$ ) is not supported (instead, use  $2*(4+6)$  for the previous example).

Table 3.1 Supported mathematical operations and constants

<b>OPERATORS</b>	
<b>Symbol</b>	<b>Description</b>
<b>()</b>	Parenthesis (may be nested)
<b>^</b>	Exponentiation
<b>*</b>	Multiplication
<b>/</b>	Division
<b>+</b>	Addition
<b>-</b>	Subtraction
<b>-</b>	Negation (same as subtraction)
<b>CONSTANTS</b>	
<b>Symbol</b>	<b>Value</b>
<b>PI (or pi)</b>	3.1415927
<b>e (or E)</b>	2.7182818

The two constants that are currently supported are PI and e. Implicit multiplications using constants are not supported (use 2\*e instead of 2e). Negation of the constants PI or e is not allowed. For instance, instead of entering -PI the user must enter -(PI).

Scientific notation (i.e., 1.65e8 or 1.65e-8) may be used to input very large or very small numbers. After an expression is calculated, very large or very small numbers will be displayed using scientific notation.

### 3.2.2 Data -Title

This option activates the window shown in Fig. 3.5, where the user can enter a line of text containing a general description for the application problem. Any combination of characters may be entered into the text box in order to describe a particular application. The user input will be restrained automatically once the maximum length of text is reached. This is done to prevent the user from going beyond the maximum permissible length of characters allowed for the title line.

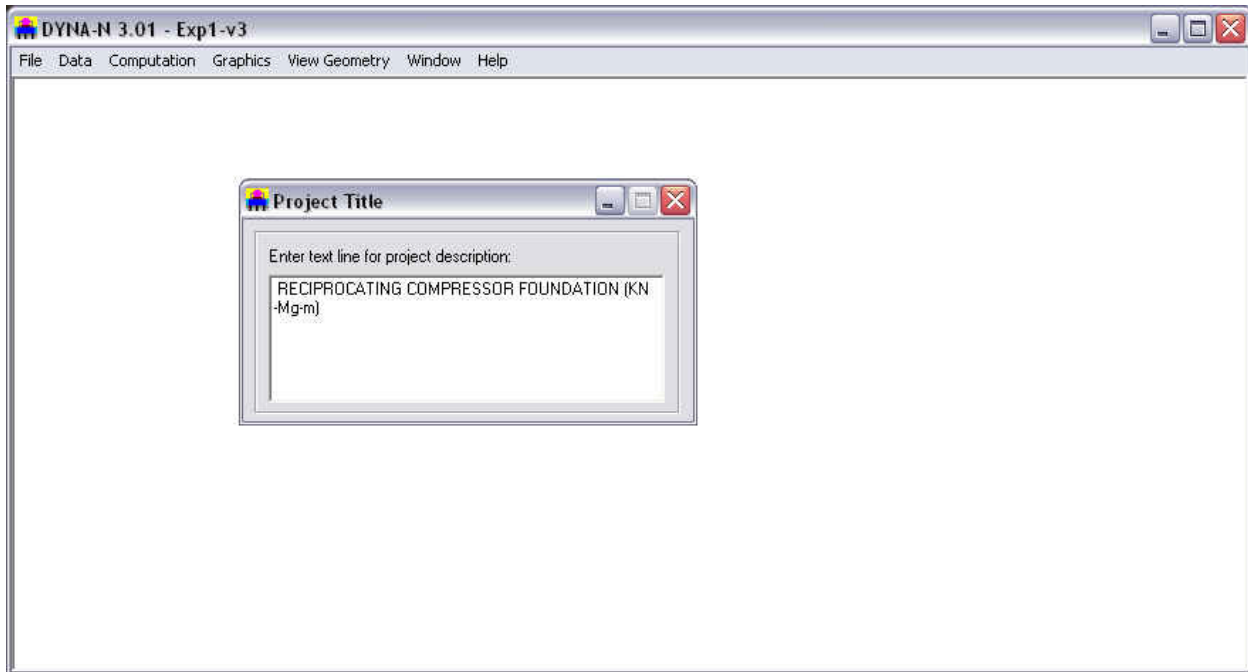


Figure 3.5 Window screen for sample Data - Title

### 3.2.3 Data - Units

This option provides the user with a choice of specifying input data in English Units, and S. I. Units (International UnitsSystem). In general, the following specific units of measurements will be used throughout the program:

Units	Length	Force	Mass
English	ft	lbs	Slug
International	m	kiloNewtons (kN)	Mg

The user should always check the unit specification, which is affixed to each variable, for data input. For instance, *psf* or *kPa* are issued for the elastic modulus of materials.

The user may change from one system of units to the other as many times as desired. The program will automatically convert all the appropriate inputs that were already specified by the user before the time of selection of a different system of units. Small conversion errors may appear if multiple changes of units are performed. The user must always check that input data have been converted appropriately.

### 3.2.4 Data - Option of Foundation System

This submenu option allows the user to select one of four available foundation types, i.e. half-space, stratum, multi-layer, and pile. A sub-window appears on the screen when the option is clicked (Fig. 3.6). The user can simply pull down the list box on the windows screen and make the selection. For each selection, an illustration of this type of foundation system will be shown on the screen. The sketch on the screen can help the user to understand the characteristic of each foundation system.

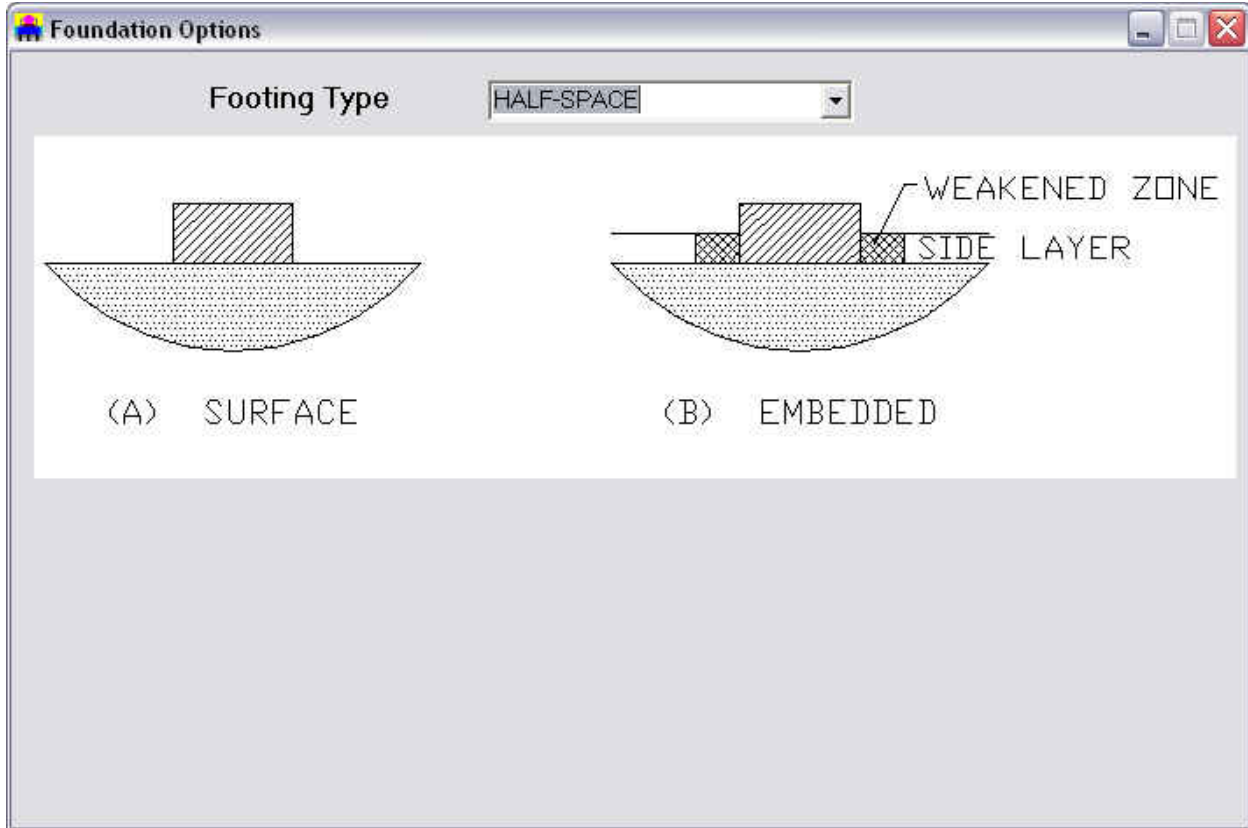
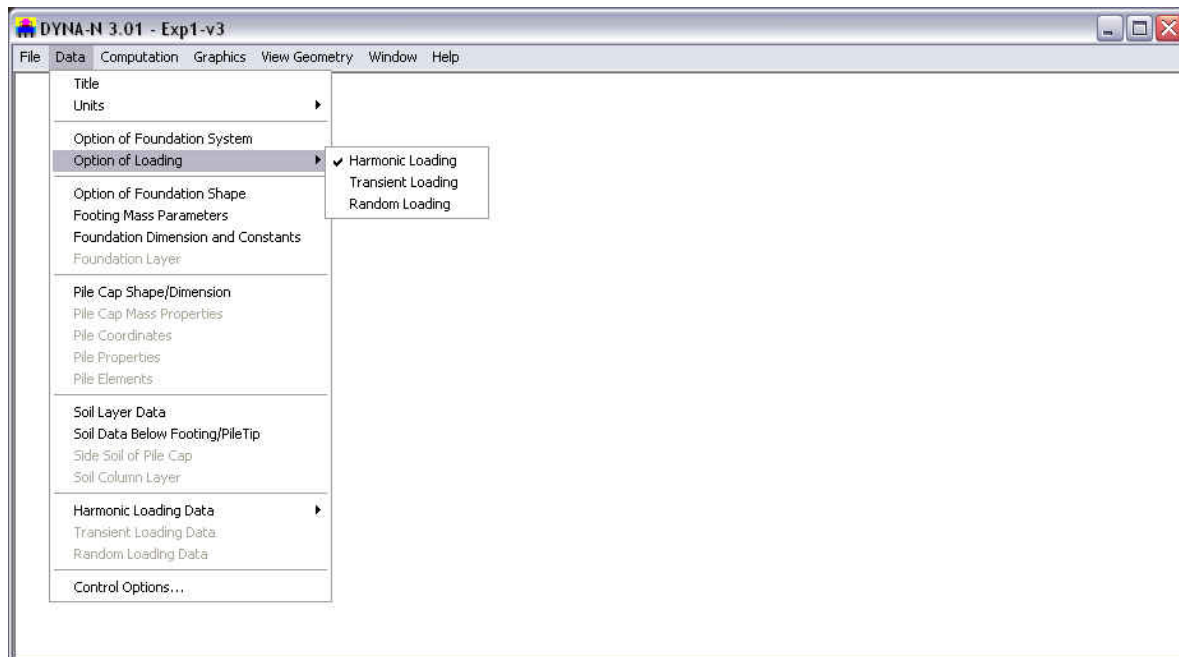


Figure 3.6 Window screen for sample Data – Footing type

### 3.2.5 Data - Option of Loading

This submenu option allows the user to select one of three available loading types, i.e. harmonic loading, transient loading, and random loading. A sub-menu appears on the screen when the option is clicked (Fig. 3.7). The user can simply use the mouse to click on the intended loading type. In correspondance to the user's selection, an menu item provided for entering the specific loading data will be enabled in the lower portion of the Data Menu as shown in Fig. 3.7, which will be described later.

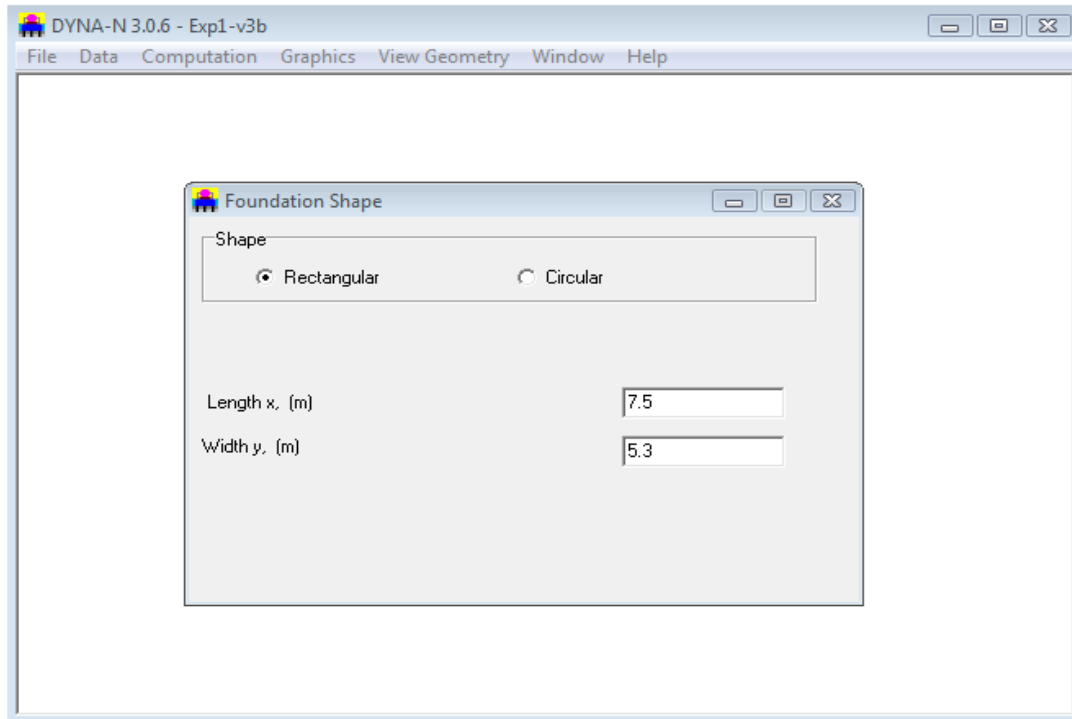


**Figure 3.7** Window screen for sample Data – Option of Loading

### 3.2.6 Data - Option of Foundation Shape

This submenu option allows the user to select a circular foundation or a rectangular foundation. A sub-window appears on the screen when the option is clicked (Fig. 3.8). The user can simply click one of radio buttons for the intended foundation shape. The user needs to enter the radius of the foundation in correspondance to the circular shape and then enter the length and width in correspondance to the rectangular shape.





**Figure 3.8** Window screen for sample Data – Option of Foundation Shape

### 3.2.7 Data - Footing Mass Parameters

This submenu option allows the user to input the mass moment of inertia, total mass, and cross-product of inertia. A sub-window appears on the screen when the option is clicked (Fig. 3.9). The following parameters are needed for the completion of data entry:

- Total mass of footing
- Mass moment of inertia about x-axis
- Mass moment of inertia about y-axis
- Mass moment of inertia about z-axis
- Mass cross product x-y (product of inertia)
- Mass cross product x-z (product of inertia)
- Mass cross product y-z (product of inertia)

If the data of mass moments of inertia have been figured out, the user should directly enter those data into the entry field as shown at the right side of Figure 3.9. If the user does not have a tool to calculate the center of gravity of the whole foundation system and the associated mass moment of inertia, the program provides a tool for making those computations.

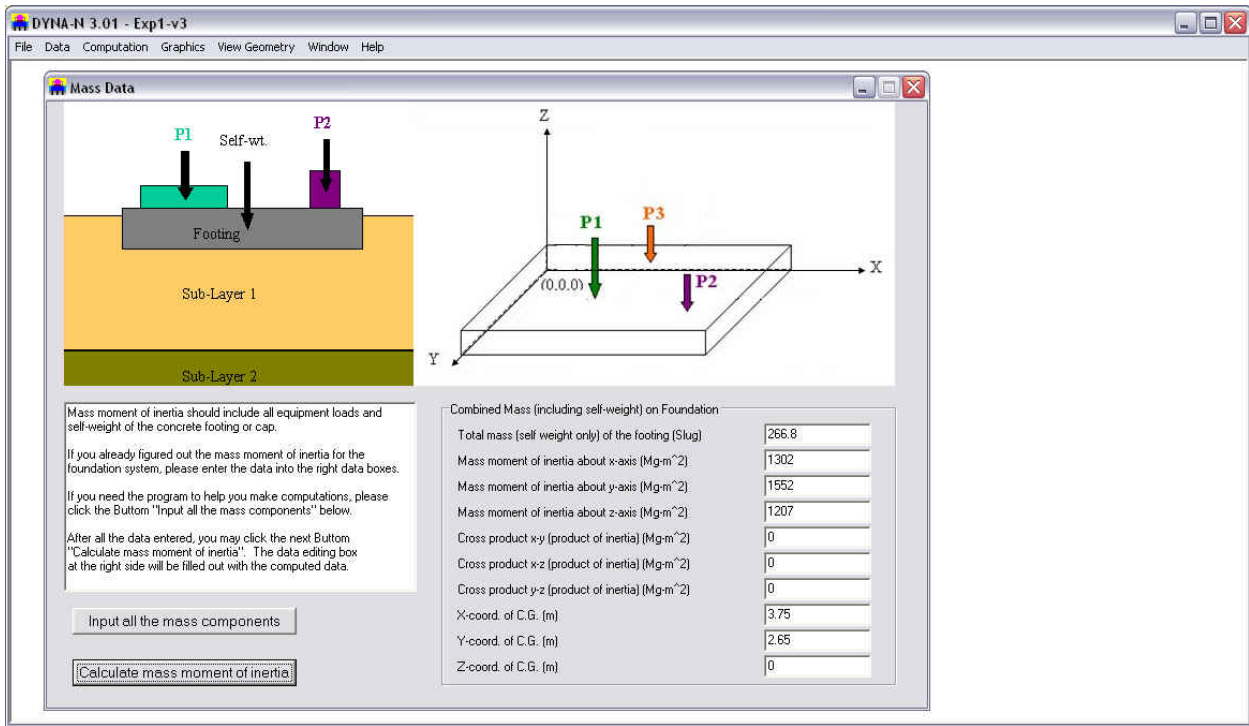


Figure 3.9 Window screen for sample Data – Option of Mass Parameters

Mass moment of inertia should include all equipment loads and selfweightof the concrete footing or cap. If you need the program to help you make computations, please click the Button “Input all the mass components” located on the bottomleft corner of the window screen for Footing Mass parameters as shown on Figure 3.9. After all the data is entered, you may click the next Button “Calculate mass moment of inertia”. The data editing box at the right side will be filled with computed data.

The example shown on Figure 3.10 and Figure 3.11 is provided for the user to better understand how to use Dyna-N v3.0 to compute the mass moment of inertia of a footing or cap. The system characterization consists of 2 lumped masses (motor and pump) and 3 rectangular concrete blocks.

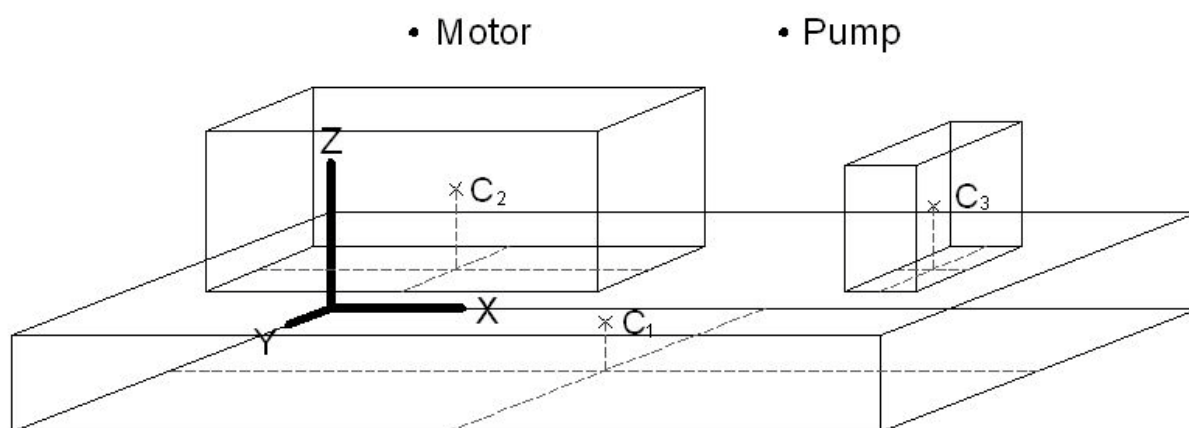


Figure 3.10 Illustration example for computation of mass parameters

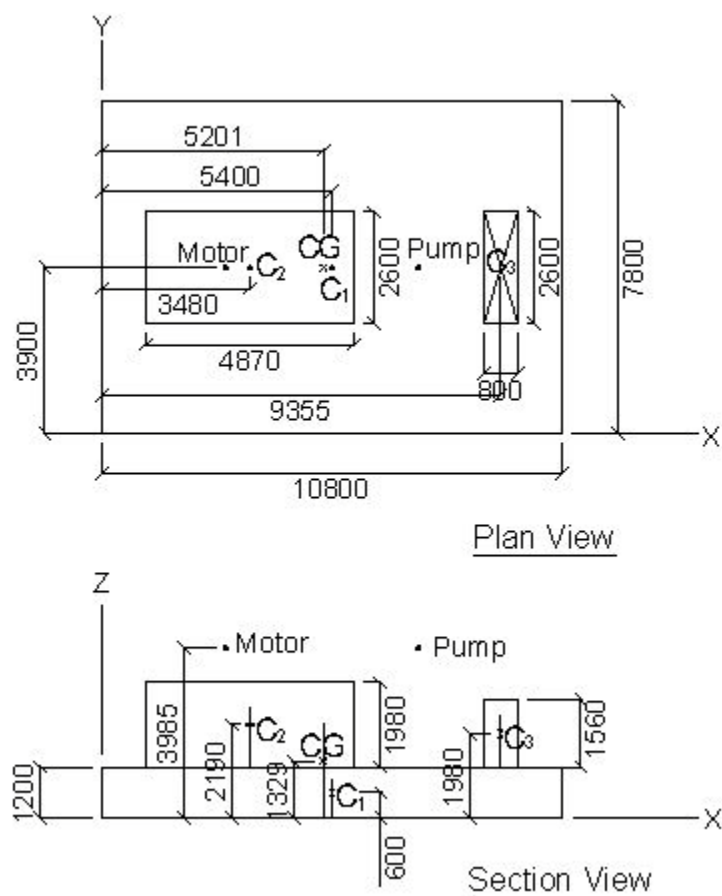


Figure 3.11 Physical dimensions of the illustrated example

The parameter for the lumped masses are:

No.	Mass	X-Coord.	Y-Coord.	Z-Coord.
1	0.180E+05	0.289E+01	0.390E+01	0.399E+01
2	0.290E+05	0.746E+01	0.390E+01	0.399E+01

The parameters for the rectangular concrete blocks are:

No.	Mass	X-Length	Y-Length	Z-Length
1	252720	0.108E+02	0.780E+01	0.120E+01
2	62677	0.487E+01	0.260E+01	0.198E+01
3	8112	0.800E+00	0.260E+01	0.156E+01

Center of Masses

No.	X-Coord.	Y-Coord.	Z-Coord.
1	0.540E+01	0.390E+01	0.600E+00
2	0.348E+01	0.390E+01	0.219E+01
3	0.936E+01	0.390E+01	0.198E+01

The dimension s (Length, Width, and Thickness) for the lumped masses are significantly smaller than those of the rectangular concrete blocks, so these values can be neglected on this example. You can see all the input parameters in Figure 3.12. After all the data is entered, just click the Button “Calculate mass moment of inertia” and the program will compute the values for you. The data editing box at the right side of the Footing Mass Parameter window will be filled out with the computed data.

The results for this example are provided below for comparison purposes.

Total Mass = 0.3705E+06

Mass Moment of Inertia:

I(XX) = 0.1889E+07

I(YY) = 0.3729E+07

I(ZZ) = 0.4482E+07

I(XY) = 0.0000E+00

I(XZ) = 0.4409E+05

I(YZ) = 0.0000E+00

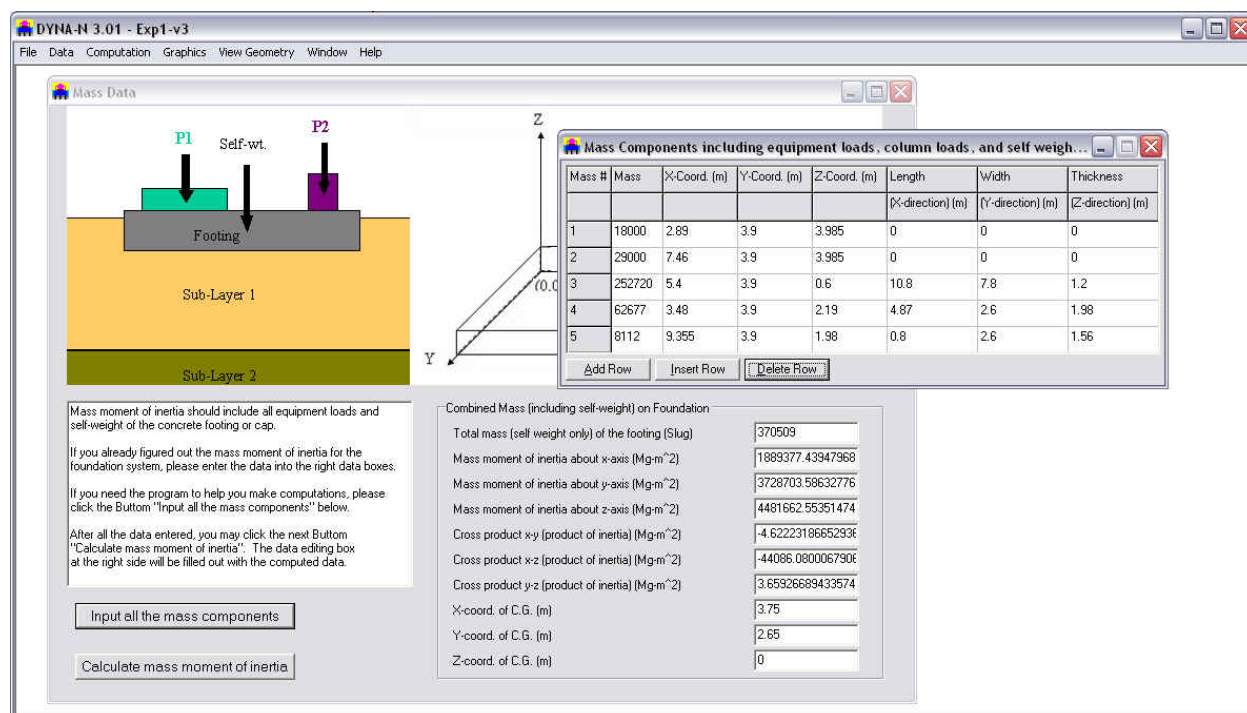


Figure 3.12 Window screen for sample Data –Internally-Calculated Mass Parameters

### 3.2.8 Data - Foundation Dimen. and Constants

This submenu option allows the user to input the foundation dimensions related to the center of gravity. A sub-window appears on the screen when the option is clicked (Fig. 3.13). The following parameters are needed for the completion of data entry:

- Distance from center of foundation base to center of gravity (Xc)
- Distance from center of foundation base to center of gravity (Yc)
- Height of center of gravity (Zc)

The following two items are only required for Stratum foundations

- Depth from ground surface to base of foundation (Df)
- Depth from ground surface to bed rock (rigid underlying layer) (Dr)

Extra items are also needed for Multilayer Foundation, which can be reviewed in the example - EXP61.dyd.

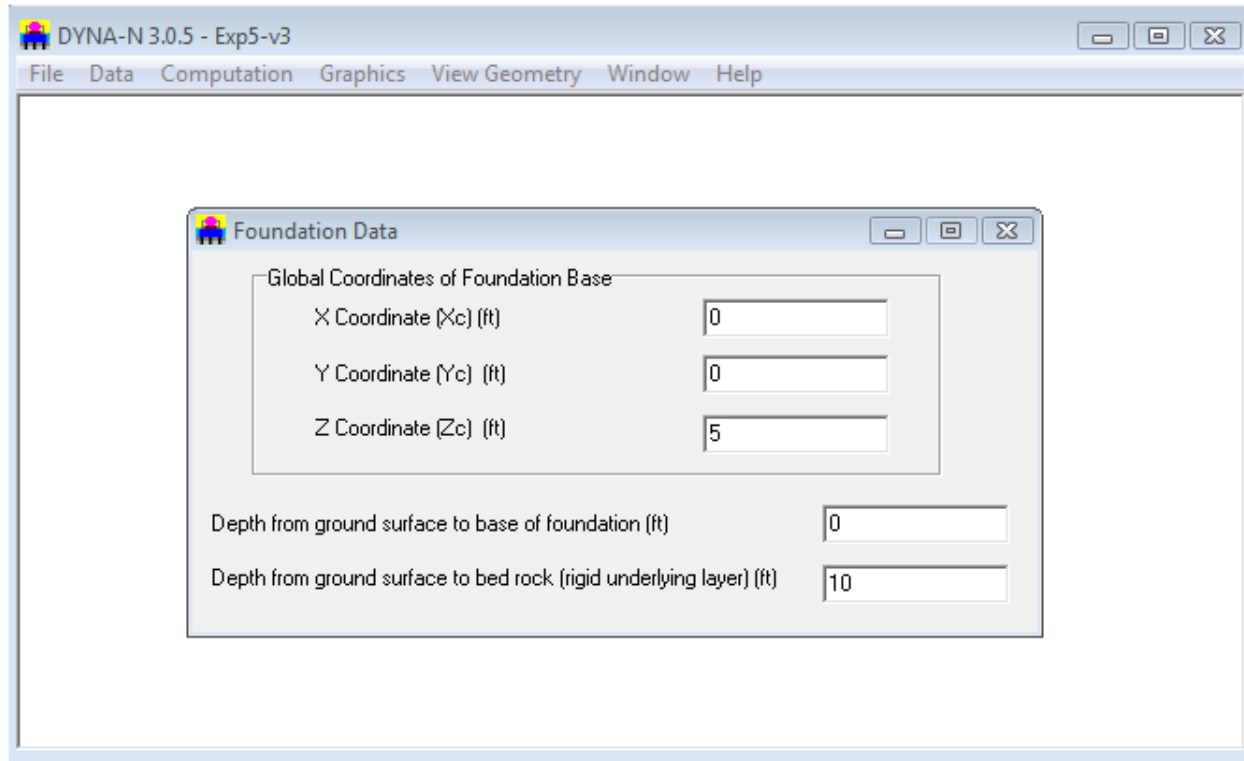


Figure 3.13 Window screen for sample Data – Option of Foundation Dimension and Constant

### 3.2.9 Data - Foundation Layer Data (Multilayer Foundation)

This submenu allows the user to enter the foundation layers and geometric properties for a multi-layer type of foundation. An illustration of the Foundation Layer Data window for an example application is shown in Fig. 3.14.

The following parameters are needed for the completion of data entry:

- **Layer number:** The user may divide the foundation into several layers (increments) based on the variation of dimension versus the embedment. This is a sequential number that is provided to each foundation layer. This number is automatically provided by the program as new rows of foundation layers are added. The maximum number of foundation layers that may be used in a program is limited to 20.
- **Layer thickness:** The Layer thickness option allows the user to define the thickness of each layer. The English unit for this variable is “ft”, while “meter” is used for SI unit notations.
- **Radius of foundation (X):** This is the radius of foundation along the x-direction.
- **Radius of foundation (Y):** This is the radius of foundation along the y-direction.
- **Cross-sectional area:** This is the area of foundation.
- **Cross-sectional moment of inertia (X-direction):** This is the moment of inertia of the foundation along the x-direction.
- **Cross-sectional moment of inertia (Y-direction):** This is the moment of inertia of the foundation along the y-direction.
- **Cross-sectional torsion coefficient:** This is the moment of inertia of the torsional resistance.

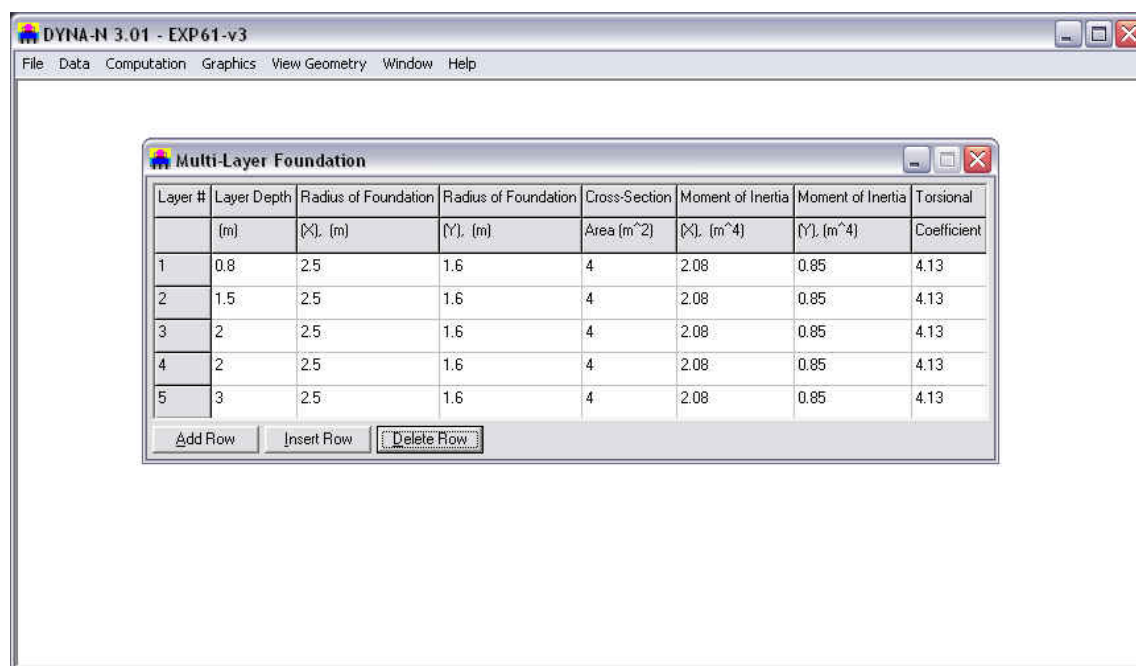


Figure 3.14 Window screen for sample Data – Option of Foundation Layer

### 3.2.10 Data - Pile Cap Shape/Dimension

This submenu option allows the user to select a circular pile cap or a rectangular pile cap. A sub-window appears on the screen when the option is selected (Fig. 3.15). The user can simply click one of radio buttons to indicate the intended the shape. The user needs to enter the radius of the foundation in correspondance to the circular shape and the length and width in correspondance to the rectangular shape. Mass parameters for the pile cap are similar to Section 3.2.7.

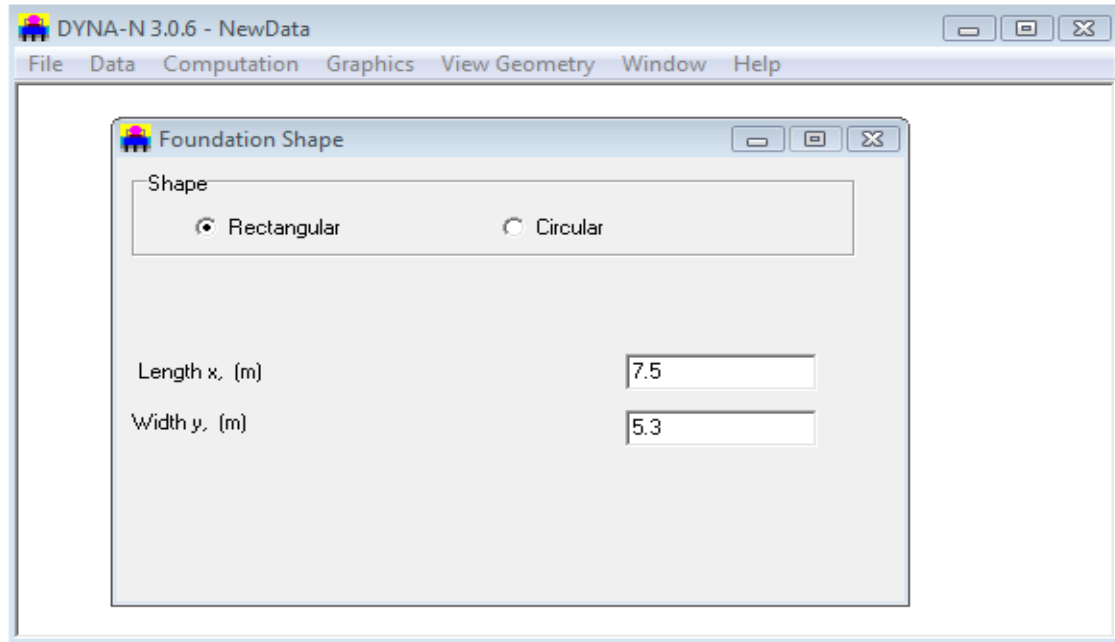


Figure 3.15 Window screen for sample Data – Option of Pile Cap Shape/Dimension

### 3.2.11 Data - Pile Cap Mass Properties

Mass parameters for the pile cap are similar to Section 3.2.7.

### 3.2.12 Data - Pile Coordinates

The origin for the coordinate system is set up at the geometric center of the top of the pile cap. This option allows the user to define the coordinates of the pile heads and the battered angles of each pile. A sub-window (Fig. 3.16) appears on the screen when the option is clicked. The following sections will provide general description on data needed for each entry:

- **Pile number:** This is a sequential number that is provided to identify each pile. This number is automatically provided by the program as new rows of piles are added. The maximum number of piles that may be used in a program run is 200.
- **Xc:** In this entry, the user may specify the x-coordinate of the pile head measured from the origin. The English unit for this variable is the inch, while meters are used for SI notation.
- **Yc:** In this entry, the user may specify the x-coordinate of the pile head measured from the origin. The English unit for this variable is the inch, while meters are used for SI notation.
- **Batter Plane:** When a pile is driven at an angle to the vertical (Z-direction), the pile may be battered on the XZ-plane or the YZ-plane. The user can make a selection by pulling down the list items in the cell.
- **Battered Angle:** The battered angle is specified as the deviation in degrees from the vertical (z-axis).



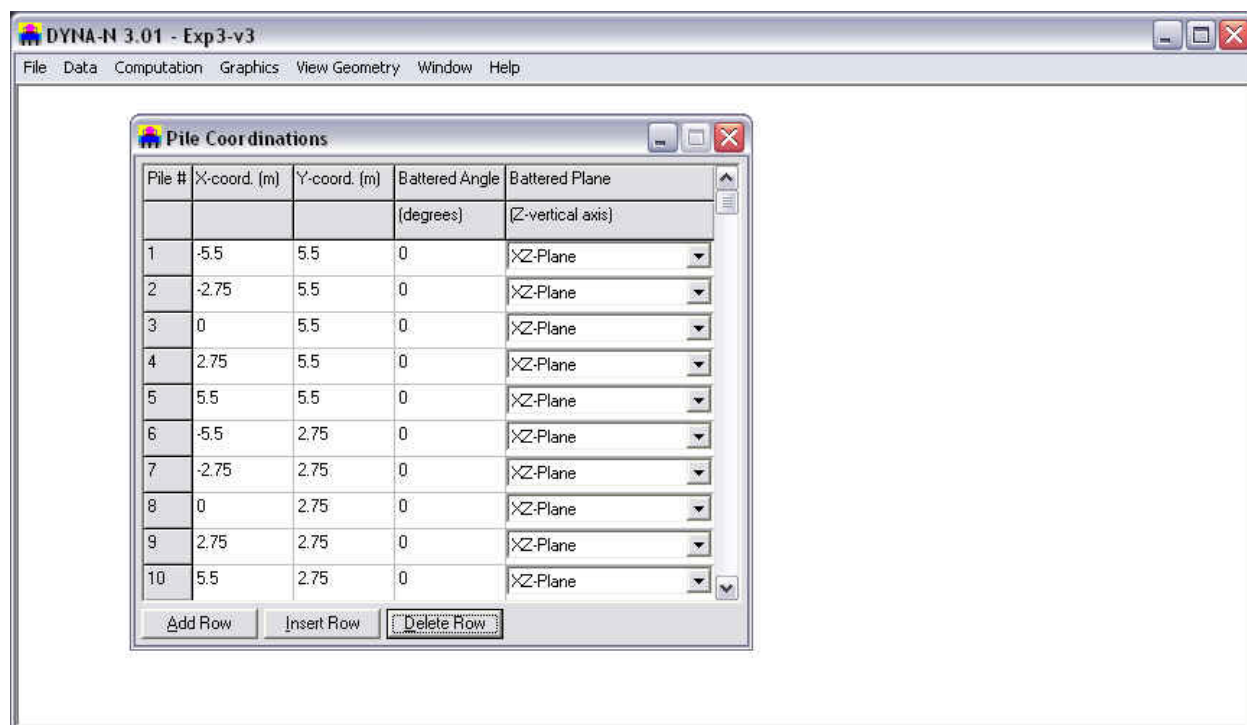


Figure 3.16 Window screen for sample Data – Option of Pile Coordinates

### 3.2.13 Data - Pile Properties

This option allows the user to define the material properties, the pile-cap dimension related to the center of gravity, the pile length, and other pile-related data. A sub-window (Fig. 3.17) appears on the screen when the option is clicked. The following parameters are needed for the completion of data entry.

- **Xc:** Distance from center of foundation base to center of gravity in X direction. The English unit for this variable is the inch, while meters are used for SI notation.
- **Yc:** Distance from center of foundation base to center of gravity in Y direction. The English unit for this variable is the inch, while meters are used for SI notation.
- **Zc:** Height of center of gravity.
- **PW:** In this entry the user may specify the unit weight of the pile. The English notation for this variable is lb/ cubic inch, while the SI notation is kN/cubic meter.
- **PL:** Total length of pile. The English unit for this variable is the inch, while meters are used for SI notation.
- **Poisson's Ratio:** In this entry the user may specify the Poisson's ratio for a given pile.
- **Material Damping:** In this entry the user may specify the damping ratio for a given pile.
- **Cross-sectional Coefficient of Rigidity for Shear Effect:** The data can be used to consider the effect of shear. Typically use 1.334 for solid circular sections, and 1.52 for rectangular sections.
- **SLD:** In this entry the user may specify the static load on each pile. The English notation for this variable is lbs, while the SI notation is kN.

- **Connection on the Pile head:** In this entry the user may specify either pinned or fixed connection between the pile head and the pile cap.
- **Method of Pile Support:** In this entry the user may specify that piles behave as either end bearing piles or floating piles.
- **Consider the interaction of pile-soil-pile:** In this entry the user may specify pile-soil-pile interaction to be considered in the analysis.

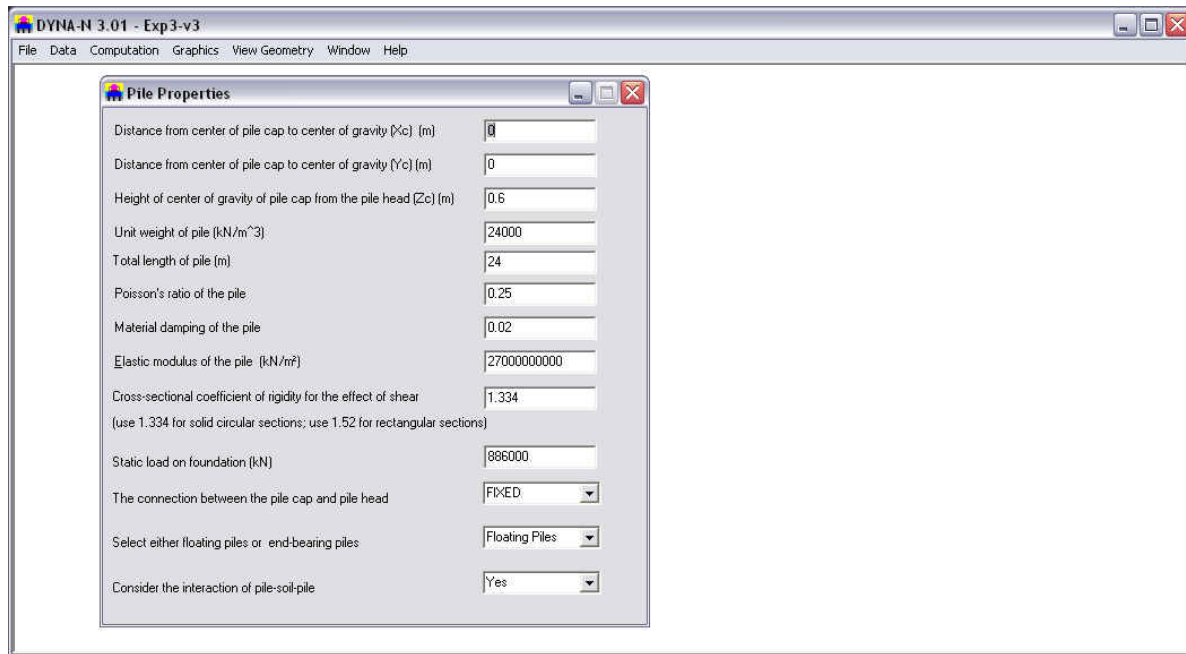


Figure 3.17 Window screen for sample Data – Option of Pile Properties

### 3.2.14 Data - Pile Elements

This option allows the user to define the radius, the moment of inertia, the layer increments, and the torsional coefficient. A sub-window (Fig. 3.18) appears on the screen when the option is clicked. The following sections will provide general descriptions on data needed for each entry.

- **Layer number:** The user may divide the pile into several layers (increments) based on the variation of dimension versus the penetration. This is a sequential number that is provided for each pile layer (increment). This number is automatically provided by the program as new rows of pile layers are added. The maximum number of pile layers that may be used in a program is 30.
- **Layer thickness:** The Layer thickness option allows the user to define the thickness of each layer. The English notation for this variable is “in” (inch), while the SI notation is “m” (meter).
- **Radius of Pile (X):** This is the radius of the pile along the x-direction.
- **Radius of Pile (Y):** This is the radius of the pile along the y-direction.
- **Cross-sectional area:** This is the area of the pile cross-section at that particular layer.
- **Cross-sectional moment of inertia (X-direction):** This is the moment of inertia of the pile along the x-direction.
- **Cross-sectional moment of inertia (Y-direction):** This is the moment of inertia of the pile along the y-direction.

- **Cross-sectional torsion coefficient.**

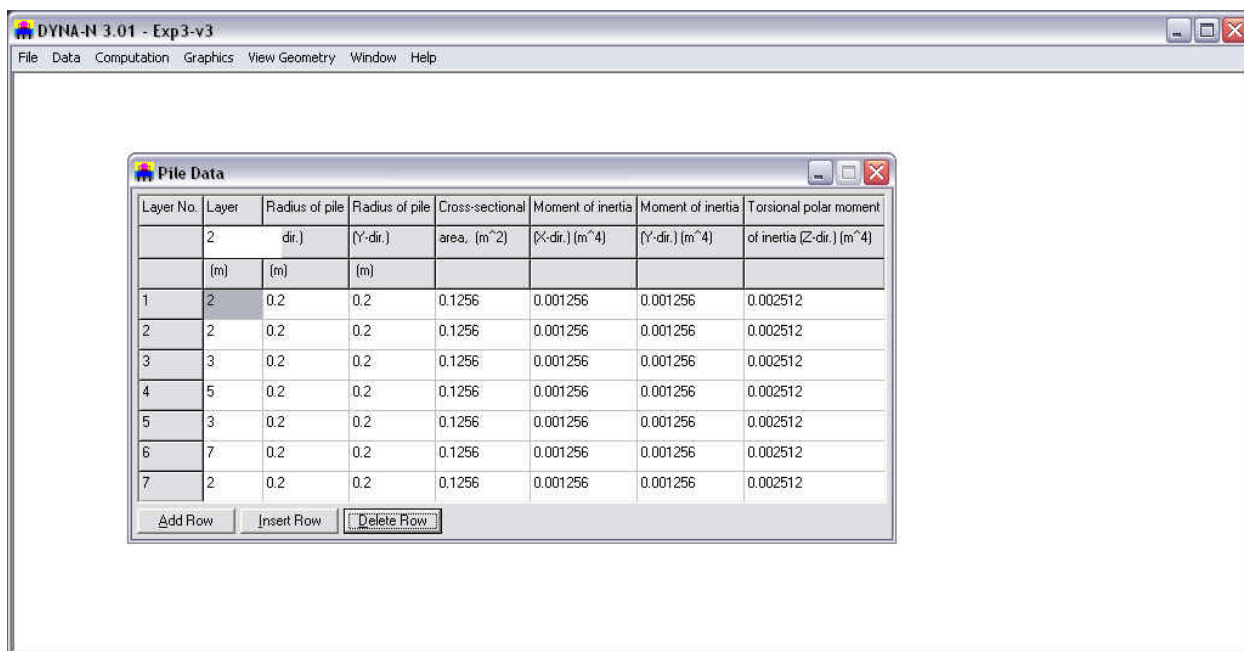


Figure 3.18 Window screen for sample Data – Option of Pile Elements

### 3.2.15 Data - Soil Layer Data

This option allows the user to input the properties of soils that are next to the side of the foundation. The parameters of the weak zone in the side soil can be specified. A sub-window (Fig. 3.19) appears on the screen when the option is clicked. The following sections will provide general description on data needed for each entry.

- **Layer number:** The user may divide the soil into several layers (increments) based on the variation of soils. This is a sequential number that is provided for each soil layer (increment). This number is automatically provided by the program as new rows of soil layers are added. The maximum number of soil layers that may be used in a program is 30. The arrangement of soil layers should be consistent with the foundation layers or pile layers mentioned earlier.
- **Layer thickness (not required in this version):** The Layer thickness option allows the user to define the thickness for each layer. The thickness of soil layers should be consistent with the foundation layers or pile layers mentioned earlier. The English notation for this variable is inch, while the SI notation is meter.
- **Shear Wave Velocity:** In this entry the user may specify the shear wave velocity for a given layer. The English notation for this variable is ft/sec, while the SI notation is meter/sec.
- **Unit Weight:** In this entry the user may specify the unit weight for a given layer. The English unit for this variable is "lb/cu. ft", while "kN/cu. m" is for the SI unit.
- **Poisson's ratio:** In this entry the user may specify the Poisson's ratio for a given stratum. The Poisson's ratio typically is between 0.35 to 0.5 for soils. Poisson's ratio near 0.5 is recommended for liquefied soils.
- **Material Damping:** In this entry the user may specify the material damping for each soil layer.

- Weak Shear Modulus Ratio:** In this entry the user may specify the reduction ratio for the shear modulus of soils next to the side of the foundation. The weakened zone input was reduced to use only one parameter (shear modulus ratio) in this latest version. If the user enters 1.0 for the ratio of shear modulus ( $G_i/G_o$ ) in the weakened zone, it represents no weakened zone. If the user enter any value between 0.0 and 1.0 for the shear modulus ratio, the program will assume a weakened zone existed. For machine vibration, shear modulus ratio ( $G_i/G_o$ ) = 0.25 - 0.5 is commonly used. For seismic applications, strong vibration may reduced the shear modulus ratio ( $G_i/G_o$ ) to be less than 0.25. The damping ratio in the weakened zone will be twice of the original damping ratio and the thickness of the weak zone will be one pile radius if the shear modulus ratio is less than 1.0.

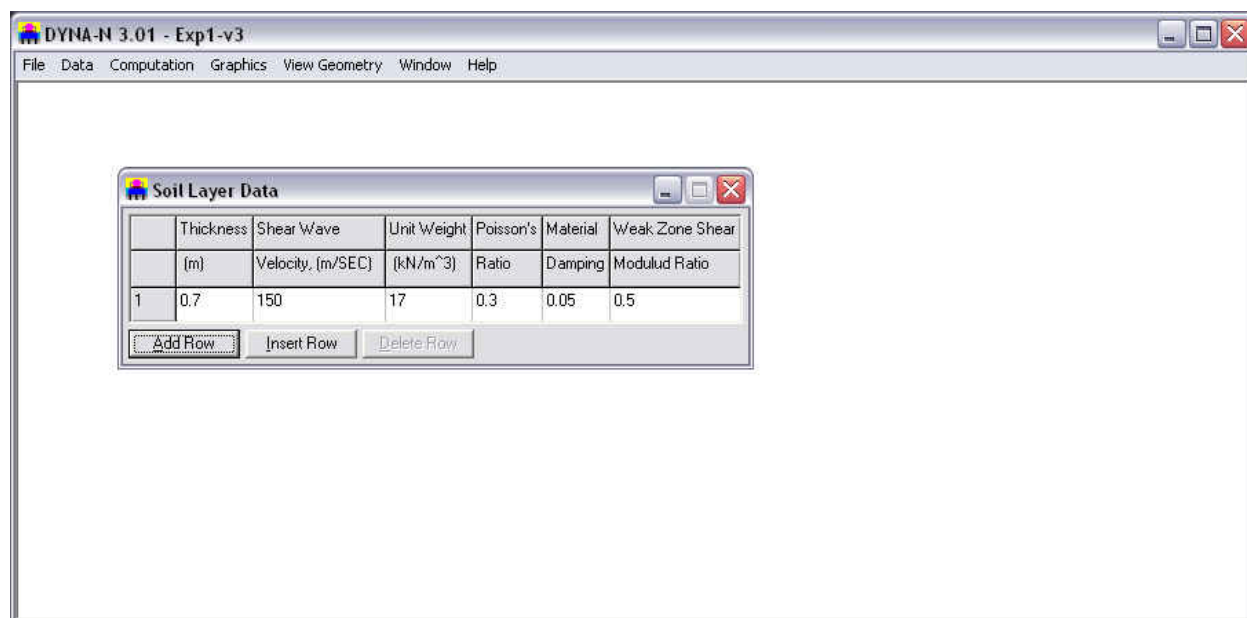


Figure 3.19 Window screen for sample Data – Option of Side Soil of Foundation

### 3.2.16 Data - Soil Data Below Footing/Pile Tip

This option allows the user to input the properties of the soil that are below the footing or pile tip. A sub-window (Fig. 3.20) appears on the screen when the option is clicked. The following sections will provide general descriptions for data needed for each entry.

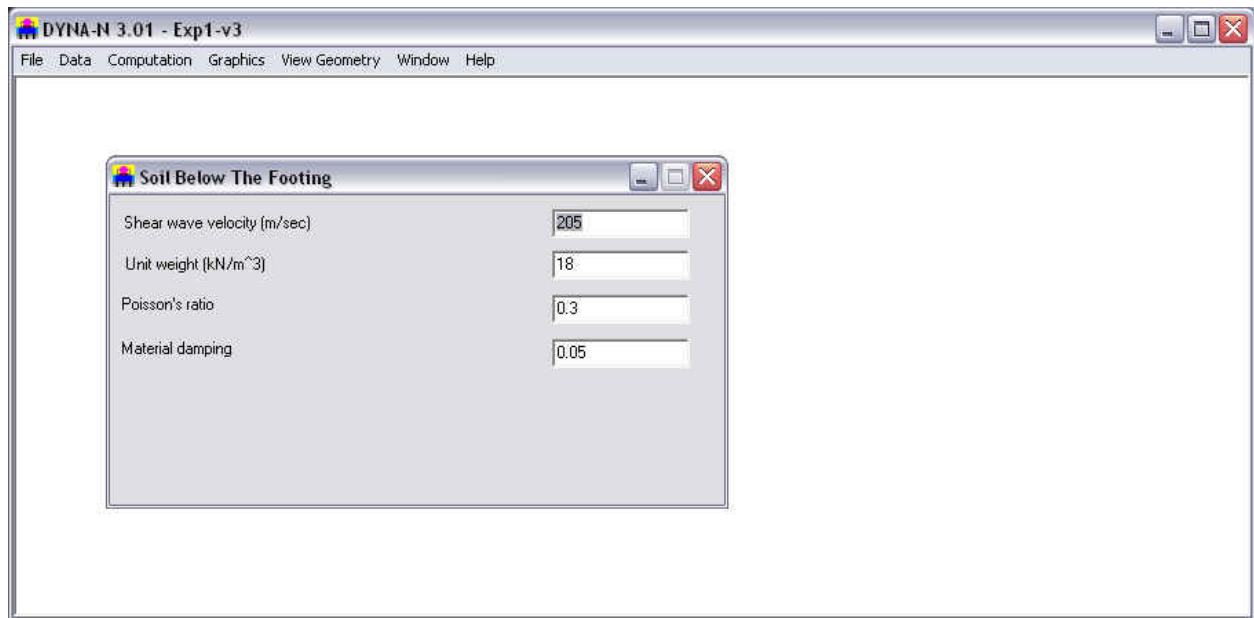


Figure 3.20 Window screen for sample Data – Option of Soil Data below Fo0ting/Pile Tip

- **Shear Wave Velocity:** In this entry the user may specify the shear wave velocity for the soil below the footing or pile tip. The English notation for this variable is ft/sec, while the SI notation is meter/sec.
- **Unit Weight:** In this entry the user may specify the unit weight for the soil below the footing or pile tip. The English notation for this variable is lb/cu.ft., while the SI notation is kN/cu. m.
- **Poisson's ratio:** In this entry the user may specify the Poisson's ratio for the soil below the footing or pile tip. The Poisson's ratio typically is between 0.35 to 0.5 for soils. Poisson's ratio near 0.5 is recommended for liquefied soils. Poisson's ratio near 0.5 is recommended for liquefied soils.
- **Material Damping:** In this entry the user may specify the material damping for the soil below the footing or pile tip.

### 3.2.17 Data - Side Soils Next to Pile Cap

This option allows the user to input the properties of the soil that are next to the pile cap. The parameters of weak zone in the side soil can be specified. A sub-window (Fig. 3.21) appears on the screen when the option is clicked. The following sections will provide general descriptions on data needed for each entry.

- **Layer number:** The user may divide the soil into several layers (increments) based on the variation of soils. This is a sequential number that is provided for each soil layer (increment). This number is automatically provided by the program as new rows of soil layers are added. The maximum number of soil layers that may be used in a program is 30. The arrangement of soil layers should be consistent with the foundation layers or pile layers mentioned earlier.
- **Layer thickness:** The Layer thickness option allows the user to define the thickness for each layer. The thickness of soil layers should be consistent with the foundation layers or pile layers mentioned earlier. The English notation for this variable is in inches, while the SI notation is in meters.

- **Shear Wave Velocity:** In this entry the user may specify the shear wave velocity for a given layer. The English notation for this variable is in ft/sec, while the SI notation is in meter/sec.
- **Unit Weight:** In this entry the user may specify the unit weight for a given layer. The English notation for this variable is in lb/cu. ft., while the SI notation is in kN/cu. m.
- **Poisson's ratio:** In this entry the user may specify the Poisson's ratio for a given stratum. The Poisson's ratio typically is between 0.35 to 0.5 for soils.
- **Material Damping:** In this entry the user may specify the material damping for each soil layer.
- **Weak Shear Modulus Ratio:** In this entry the user may specify the reduction ratio for the shear modulus of soils next to the side of the foundation. The weakened zone input was reduced to use only one parameter (shear modulus ratio) in this latest version. If the user enters 1.0 for the ratio of shear modulus ( $G_i/G_o$ ) in the weakened zone, it represents no weakened zone. If the user enter any value between 0.0 and 1.0 for the shear modulus ratio, the program will assume a weakened zone existed. For machine vibration, shear modulus ratio ( $G_i/G_o$ ) = 0.25 - 0.5 is commonly used. For seismic applications, strong vibration may reduced the shear modulus ratio ( $G_i/G_o$ ) to be less than 0.25. The damping ratio in the weakened zone will be twice of the original damping ratio and the thickness of the weak zone will be one pile radius if the shear modulus ratio is less than 1.0.

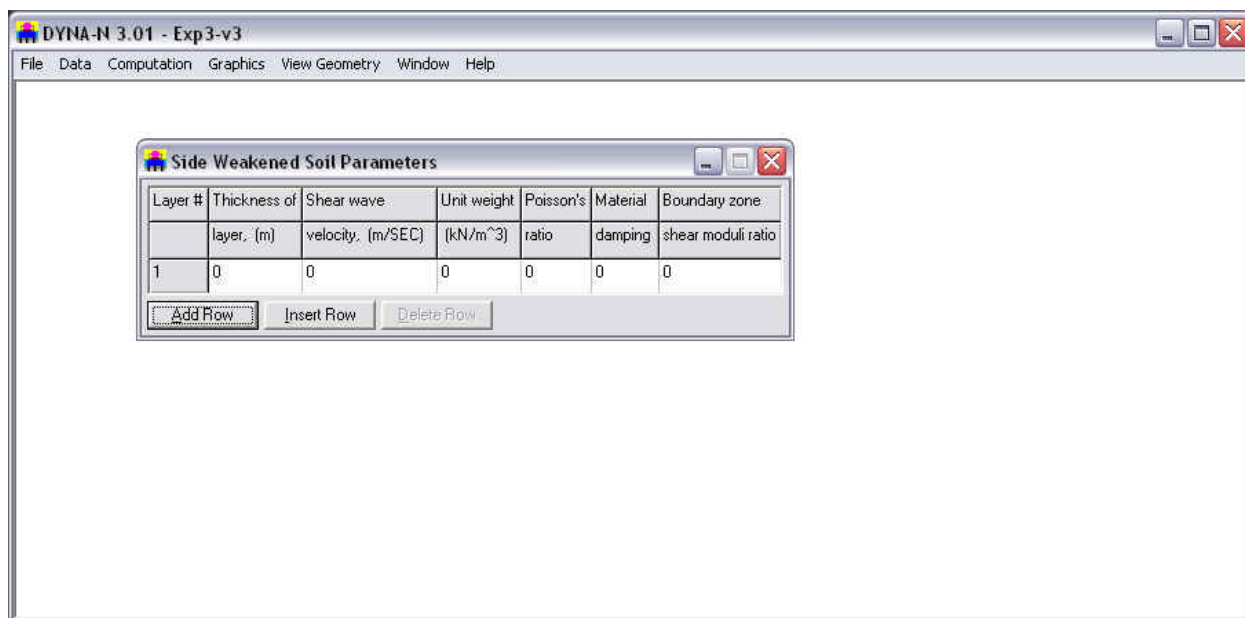


Figure 3.21 Window screen for sample Data – Option of Side Soil Next to Pile Cap

### 3.2.18 Data - Soil Column Layer

This option allows the user to input the properties of the soil layers that are below the multi-layer type of foundation. A sub-window (Fig. 3.22) appears on the screen when the option is clicked. The following sections will provide general descriptions on data needed for each entry.

- **Layer number:** The user may divide the soil into several layers (increments) based on the variation of soils. This is a sequential number that is provided for each soil layer (increment).

This number is automatically provided by the program as new rows of soil layers are added. The maximum number of soil layers that may be used in a program is 30. The arrangement of soil layers should be consistent with the foundation layers or pile layers mentioned earlier.

- **Shear Wave Velocity:** In this entry the user may specify the shear wave velocity for a given layer. The English notation for this variable is in ft/sec, while the SI notation is in meter/sec.
- **Unit Weight:** In this entry the user may specify the unit weight for a given layer. The English notation for this variable is in lb/cu. ft., while the SI notation is in kN/cu. m.
- **Poisson's ratio:** In this entry the user may specify the Poisson's ratio for a given stratum. The Poisson's ratio is typically between 0.35 to 0.5 for soils. Poisson's ratio near 0.5 is recommended for liquefied soils.
- **Material Damping:** In this entry the user may specify the material damping for a given stratum. There are several different definitions for the term of damping coefficient in technical literature. The material damping defined in this program is directly related to the energy loss, and the typical coefficient of damping can be found in technical section (Chapter 5).
- **Weak Shear Modulus Ratio:** In this entry the user may specify the reduction ratio for the shear modulus of soils next to the side of the foundation. The weakened zone input was reduced to use only one parameter (shear modulus ratio) in this latest version. If the user enters 1.0 for the ratio of shear modulus ( $G_i/G_o$ ) in the weakened zone, it represents no weakened zone. If the user enter any value between 0.0 and 1.0 for the shear modulus ratio, the program will assume a weakened zone existed. For machine vibration, shear modulus ratio ( $G_i/G_o$ ) = 0.25 - 0.5 is commonly used. For seismic applications, strong vibration may reduced the shear modulus ratio ( $G_i/G_o$ ) to be less than 0.25. The damping ratio in the weakened zone will be twice of the original damping ratio and the thickness of the weak zone will be one pile radius if the shear modulus ratio is less than 1.0.

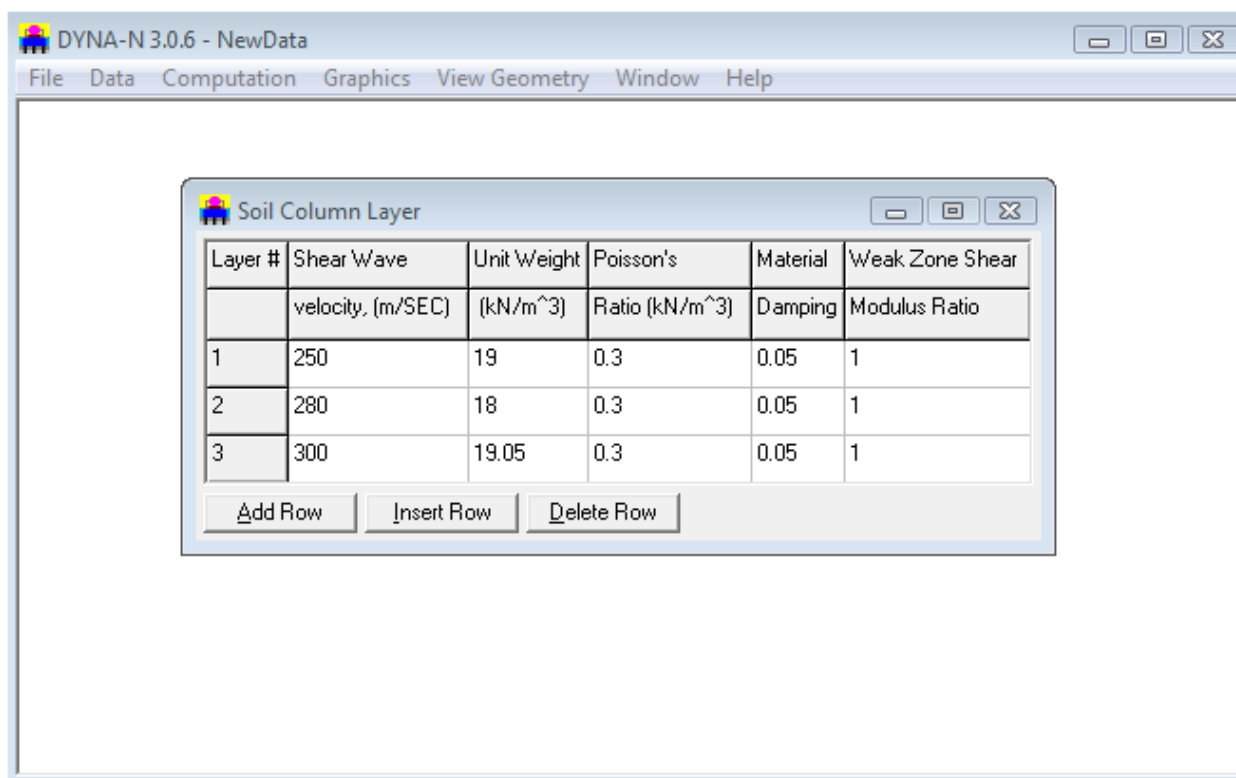


Figure 3.22 Window screen for sample Data – Option of Soil Column Layer

### 3.2.19 Data - Harmonic Loading Data

This option allows the user to input data for harmonic loading. A sub-window (Fig. 3.23) appears on the screen when the option is clicked. The user can select Quadratic load, which varies with frequency, or Nonquadratic load, which is a constant load. The following parameters are required for the completion of the data entry:

- Maximum frequency
- Minimum frequency
- Step frequency
- Force in x-direction
- Force in y-direction
- Force in z-direction
- Moment about x-axis
- Moment about y-axis
- Moment about z-axis

The unit for the frequency input is in Hz and some output data may use rad/sec for the unit.



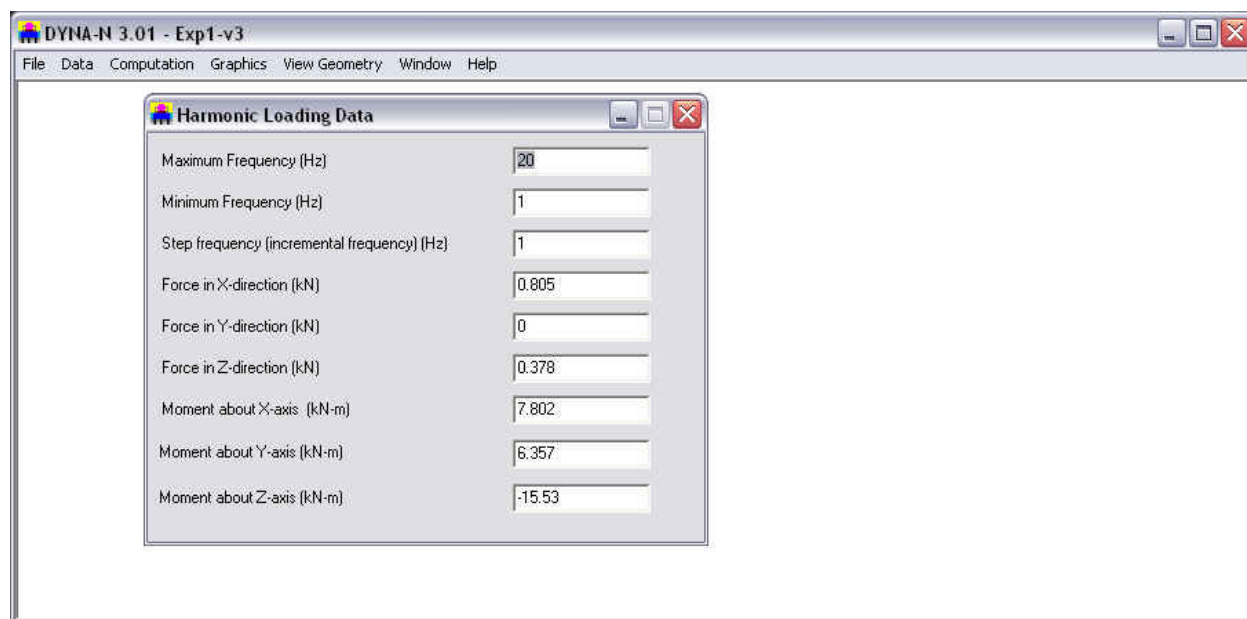
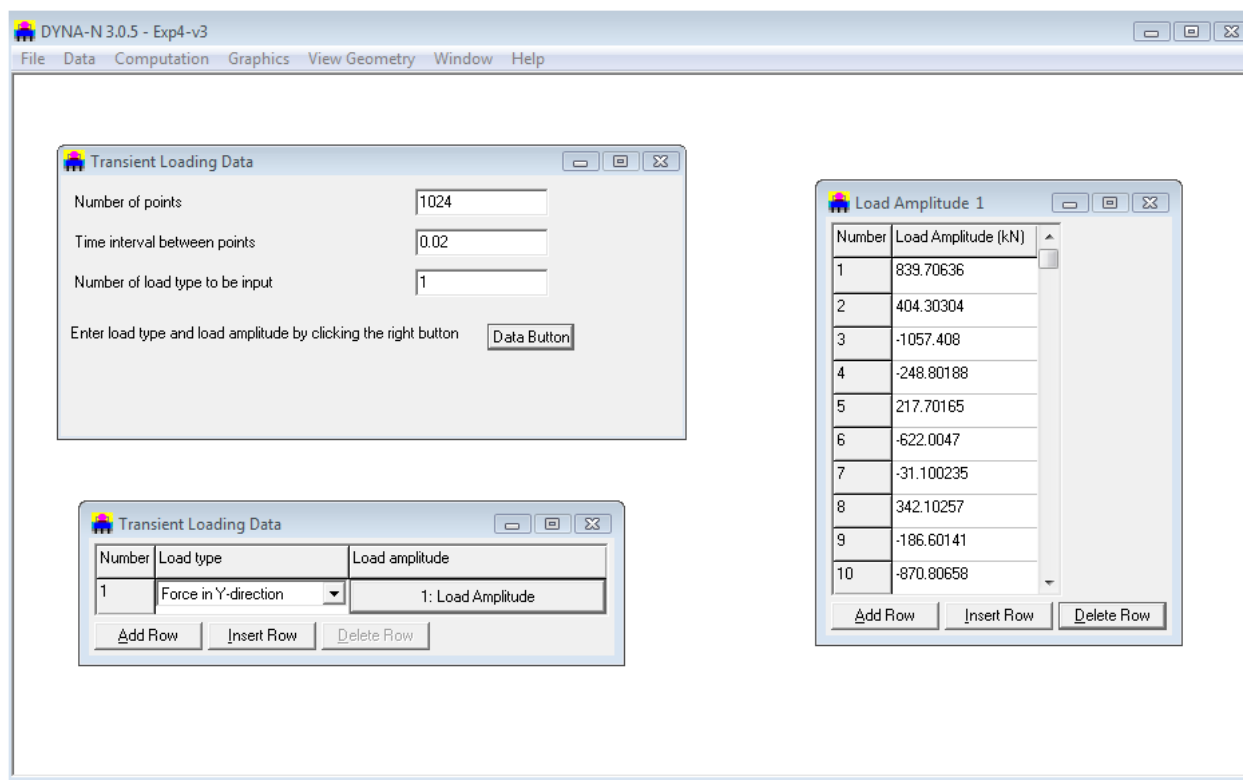


Figure 3.23 Window screen for sample Data – Option of Harmonic Loading

### 3.2.20 Data - Transient Loading Data

This option allows the user to input data for transient loading. A sub-window (Fig. 3.24) appears on the screen when the option is clicked. The following sections will provide general descriptions on data needed for each entry:



**Figure 3.24** Window screen for sample Data – Option of Transient Loading

- **Number of Points:** In this entry the user may specify the total number of data points to be used for defining the load.
- **Time Interval Between Points:** In this entry the user may specify the time interval between the loading points. It should be noted that the time interval is the same between the points.
- **Enter the Load Type and Load Amplitude:** The user can simply click the Data Button to display a sub-window on the screen as shown in Fig. 3.24.

For all windows within this submenu, the Add Row button always adds new rows at the end of all existing rows. Clicking on the Delete Row button deletes the row where the cursor is currently located.

A general description for the data needed under each column for the submenu option - Transient Loading Data is listed below:

- **Set:** This is a sequential number that is provided for each set of loading curves. This number is automatically provided by the program as new sets of transient load curves are added. The maximum number of sets of transient load curves that may be used in the analysis is 6.
- **Load Types:** In this entry the user may specify a loading type by pulling down the list box shown in the cell. The list box contains a total of 6 choices, i.e. force in x-direction, force in y-direction, force in z-direction, moment about x-axis, moment about y-axis, and moment about z-axis.
- **Load Amplitude:** Clicking of this button provides an additional window where the user inputs the points for each set of transient load curves. An illustration of the specific input information for transient load curve 1 is shown in Fig. 3.24. Options contained within the windows for Transient Loading Data are the following:

- **Point:** this is a sequential number that is provided for each point of the transient load curve being defined. This number is automatically provided by the program as new rows are added. The maximum number of points that may be used in each curve is 2000.
- **Load:** input the magnitude of the transient load at each point.

### 3.2.21 Data - Random Loading Data

This option allows the user to input data for random loading. A subwindow (Fig. 3.25) appears on the screen when the option is clicked.

The following sections will provide general description on data needed for each entry:

- **Maximum Frequency:** In this entry the user may specify the maximum frequency for the random load.
- **Minimum Frequency:** In this entry the user may specify the minimum frequency for the random load.
- **Number of Points to Be Read:** In this entry the user may specify the total number of points to be read for each loading set.
- **Observation Period:** In this entry the user may specify the observation set.
- **Number of Spectrum:** In this entry the user may specify the number of spectrum.
- **Enter Spectrum Coordinates and Spectrum Amplitude:** The user can simply click the Data Button to display a sub-window on the screen as shown in Fig. 3.25.

For all windows within this submenu, the Add Row button always adds new rows at the end, after all existing rows. Clicking on the Delete Row button deletes the row where the cursor is currently located.

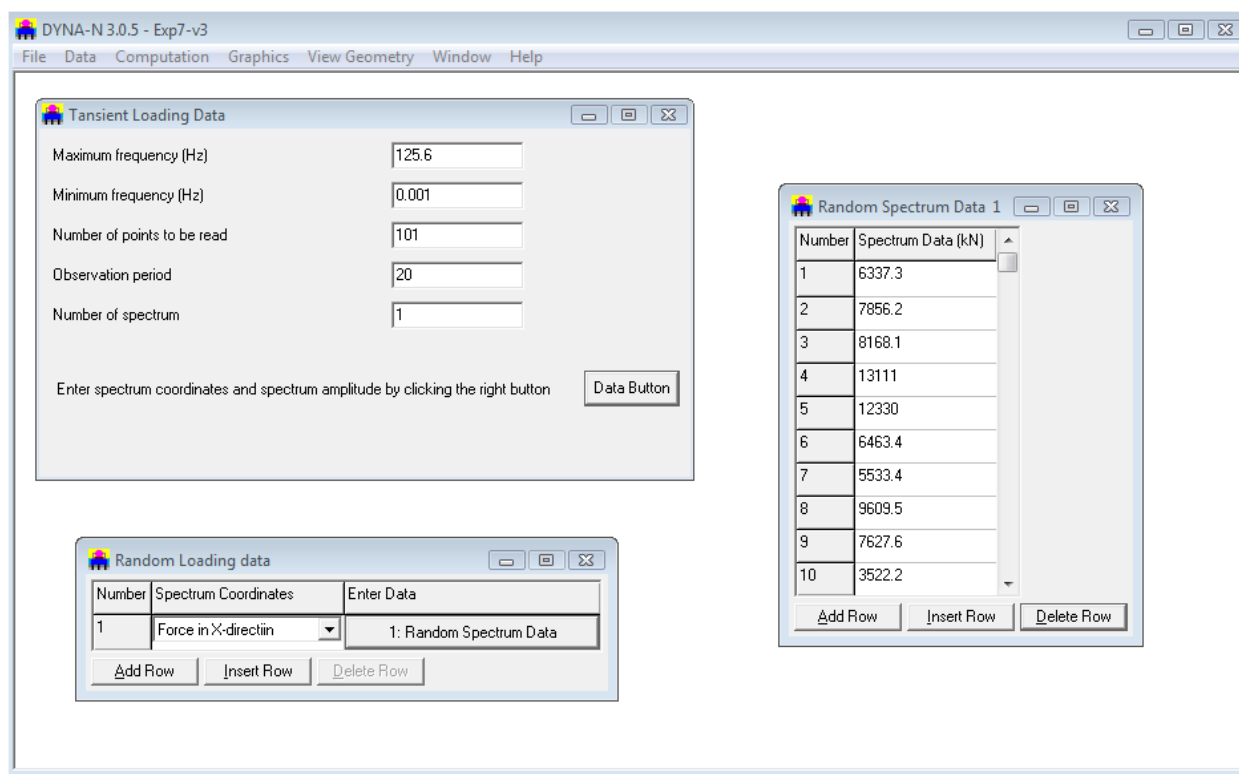


Figure 3.25 Window screen for sample Data – Option of Random Loading

A general description for the data needed under each column for the submenu option -Random Loading Data is listed below:

- **Set:** This is a sequential number that is provided for each set of loading curves. This number is automatically provided by the program as new sets of transient load curves are added. The maximum number of sets of transient load curves that may be used in the analysis is 6.
- **Spectrum Coordinates:** In this entry the user may specify the spectrum coordinates by pulling down the list box shown in the cell. The list box contains a total of 6 choices, i.e. force in x-direction, force in y-direction, force in z-direction, moment about x-axis, moment about y-axis, and moment about z-axis.
- **Load Amplitude:** Clicking of this button provides an additional window where the user inputs the points for each set of random load curves. An illustration of the specific input information for random load curve 1 is shown in Fig. 3.25. Options contained within the windows for Random Loading Data are the following:
- **Point:** this is a sequential number that is provided for each point of the transient load curve being defined. This number is automatically provided by the program as new rows are added. The maximum number of points that may be used in each curve is 2000.
- **Spectrum Ordinates:** values of spectrum ordinates.

### 3.2.22 Data - Control Options...

The user should input in this box the complete path and command line for the preferred-text editor or word processor that will be used to examine and print the input, output, and the processor, plain-text files created by the program (Fig. 3.26). As a default, the command line *c:\windows\notepad.exe* is used to operate the standard-text editor. Microsoft Notepad is included with Windows 2000, Vista, XP or 7. However, there may be some instances when the output files are too large for Notepad and a different text editor or word processor should be used. In those cases it is suggested that one use Microsoft WordPad (*c:\windows\write.exe*)

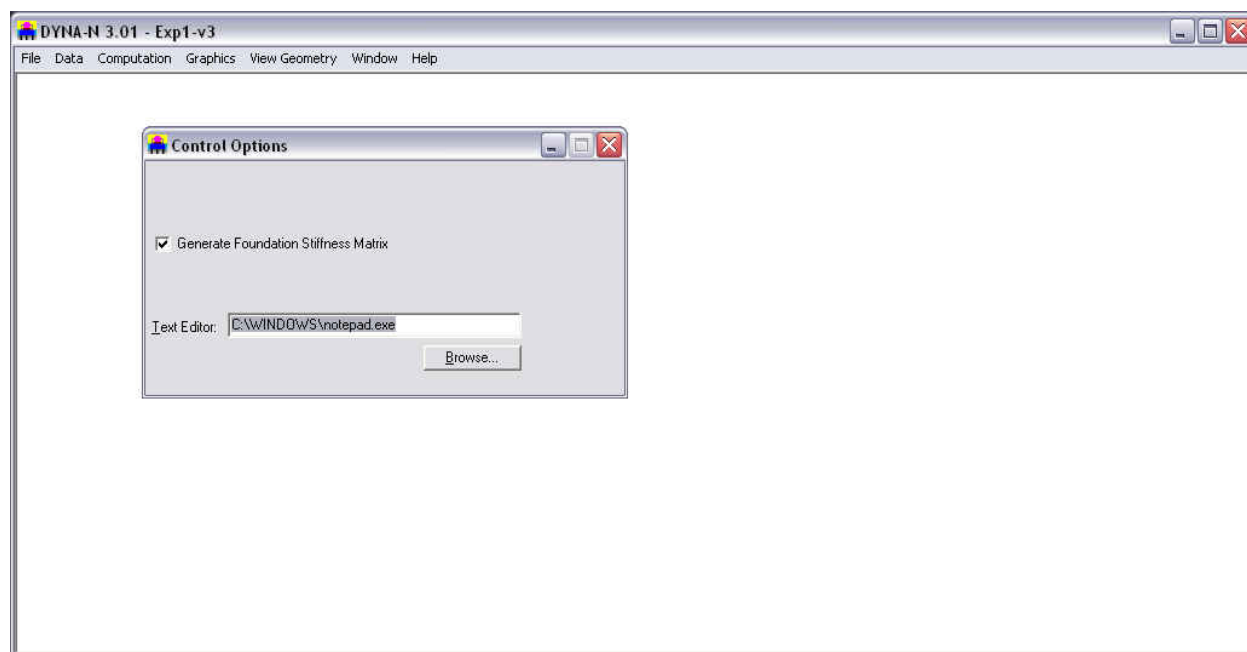


Figure 3.26 Window screen for sample Data – Control Option

## CHAPTER 4.    **Program Execution and Output Reviews**

## 4.1 Introduction

Chapter 4 presents options related to execution of the program and includes methods of addressing run-time errors. This chapter also includes suggestions for reviewing input, output, and processor text files. The final section of this chapter includes descriptions about all the output curves that may be observed in graphical form. The commands covered in this chapter are contained in the top menu, under the Computation and the Graphics titles.

## 4.2 Computation Menu

This menu option is selected to execute the program using the parameters that were saved in the input-data file. Within the options contained under this menu, shown in Fig. 4.1, there are commands that facilitate the reviews of the text files produced for storing input data, output results, and processor notes. Detailed descriptions of the submenu options contained under the Computation menu are explained in the following topics.

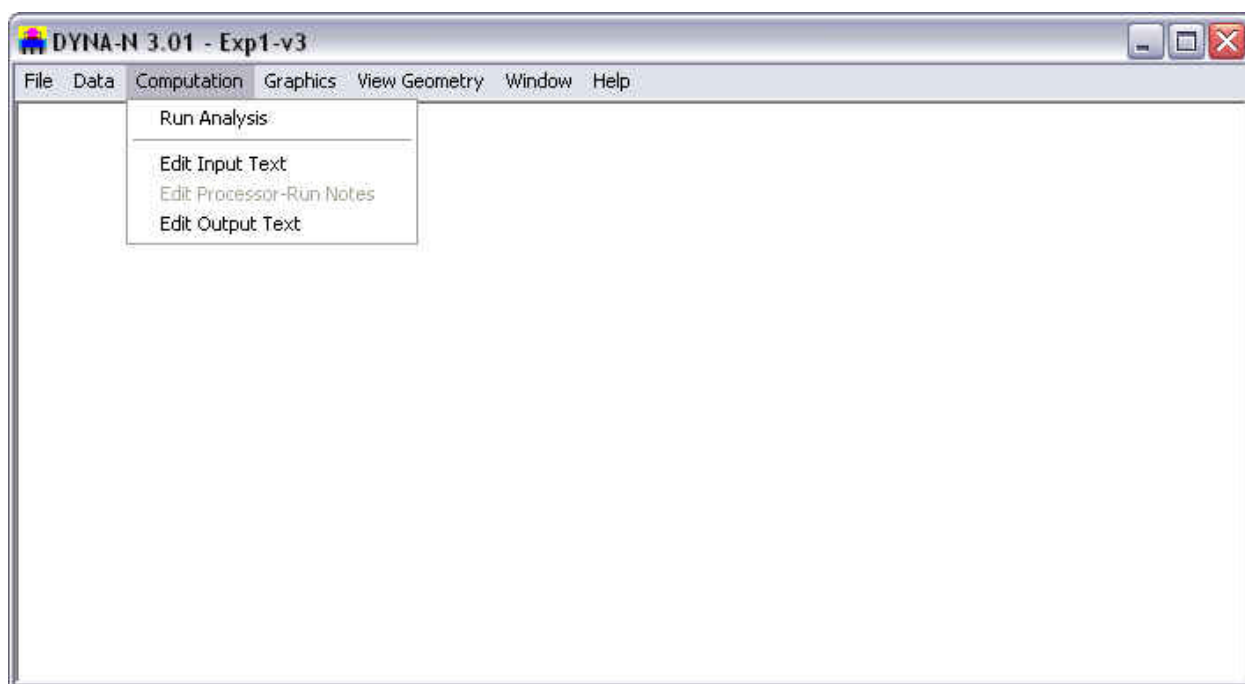


Figure 4.1 Command options contained in the Computation menu

## 4.3 Computation - Run Analysis

An input file, after preparation or modification, must be saved to disk before selecting the Computation - Run Analysis submenu option, which executes the analytical portion of program DYNAN 3.0. The module, a stand-alone program routine, is called for execution by the “shell” process of the environment in Microsoft Windows®.

**The user should remember to save the input data under an user-specified name before executing the analytical module.** When saving data to disk, DYNAN 3.0 will automatically add an extension of the type *\*.dnd* to the name of the input file.

A sub-window is usually produced during the execution of the module. When the module's execution process is finished, the sub-window automatically disappears, and the active command is returned to the main DYNAN 3.0 program.

At the beginning of the run, the analytical module will read the saved input data progressively, showing the line number being read. If an input-data format is incorrect during reading, the analytical module will stop immediately, and, in many cases, it saves an error message and a status report in a file with the extension *\*.dnr*. This file may be accessed by selecting Edit Processor-Run Notes in the Computation menu.

Within the processor-run notes, if all input data was read correctly, the analytical module will show the message THE EXECUTION IS IN PROGRESS..... The analytical module automatically creates an output file with the same name as the input and with the extension *\*.dno*. Once a successful run is produced, the user may proceed to the next items for observation of results.

#### 4.3.1 Computation - Edit Input Text

This submenu option is used to edit the input-data file in plaintext mode. This command becomes active after new data files have been saved to disk or when opening existing data files. The command is helpful for experienced users who may just want to change one or two parameters quickly using the text editor or for those users wishing to observe the prepared input data in text mode.

This submenu automatically invokes the word processor or text editor specified in Control Options... under the Data menu. The default setting is to use the utility program named *notepad.exe* provided by Microsoft Windows®.

Input-data files are automatically saved to disk with the extension of *\*.dnd* by program DYNAN 3.0. Use of the notepad for editing the input data for Example Problem 1 is shown in Fig. 4.2.

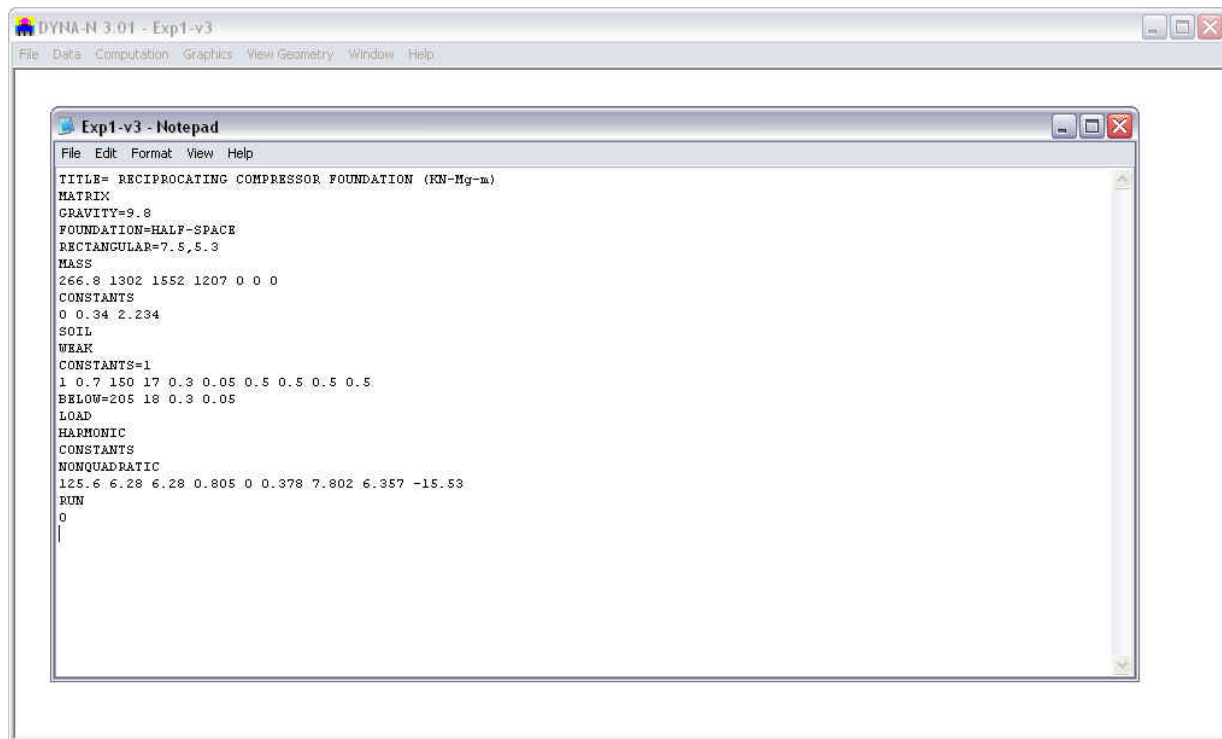


Figure 4.2 Sample use of Microsoft Notepad for editing input text file



### 4.3.2 Computation - Edit Processor Run Notes

This submenu option is used to edit an intermediate text file that is automatically produced during each analytical run. This file only includes notes produced during the processing of the input data. This submenu option becomes active after new-data files have been saved to disk and executed, or when opening previously-executed data files.

This submenu automatically invokes the word processor or text editor specified in Control Options, under the Data menu. The default setting is to use the utility program named *notepad.exe* provided by Microsoft Windows®. Files containing processor-run notes are automatically saved to disk with the same file name as the input-data file but with the extension *\*.dnr*. Observation of the notes produced during a processor run may become helpful when debugging a data file that did not produce a successful run.

### 4.3.3 Computation - Edit Output Text

This submenu option is used to edit the output-text file that is automatically produced during each analytical run. This command becomes active after new data files have been saved to disk and successfully executed or when opening previously-executed data files.

The submenu automatically invokes the word processor or text editor that was previously specified in Control Options, under the Data menu. The default setting is to use the utility program named *notepad.exe* provided by Microsoft Windows®.

Output files are automatically saved to disk with the same file name as the input-data file but with the extension *\*.dno*. Use of Microsoft Notepad® for editing the output file for Example Problem 1 is shown in Fig. 4.3.

FOOTING RESPONSE AMPLITUDES

FREQ. Rad/Sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
6.28	1.7875E-06	1.5741E-06	4.7638E-07	7.0644E-07	4.3566E-07	6.6197E-07
12.56	1.8693E-06	1.6787E-06	4.9515E-07	7.3810E-07	4.5465E-07	6.7457E-07
18.84	2.0181E-06	1.8712E-06	5.3070E-07	7.9501E-07	4.8786E-07	6.9367E-07
25.12	2.2592E-06	2.1979E-06	5.8989E-07	8.9047E-07	5.4043E-07	7.1969E-07
31.40	2.6421E-06	2.7678E-06	6.9010E-07	1.0565E-06	6.2300E-07	7.5407E-07
37.68	3.2720E-06	3.8879E-06	8.8166E-07	1.3833E-06	7.5838E-07	7.9982E-07
43.96	4.3936E-06	6.8025E-06	1.3752E-06	2.2375E-06	9.9994E-07	8.6377E-07
50.24	6.5734E-06	2.1410E-05	3.8425E-06	6.4825E-06	1.4711E-06	9.5952E-07
56.52	9.3538E-06	9.4952E-06	1.5772E-06	2.6533E-06	2.0679E-06	1.0409E-06
62.80	7.0318E-06	4.4586E-06	7.5290E-07	1.1660E-06	1.5481E-06	9.7482E-07
69.08	4.3400E-06	2.8692E-06	5.3471E-07	7.2285E-07	9.6169E-07	1.0090E-06
75.36	2.9603E-06	2.1000E-06	4.4253E-07	5.3224E-07	6.6744E-07	1.0996E-06
81.64	2.1921E-06	1.6451E-06	3.8744E-07	4.4013E-07	5.0608E-07	1.2150E-06
87.92	1.7163E-06	1.3420E-06	3.4628E-07	3.9455E-07	4.0327E-07	1.3504E-06
94.20	1.4037E-06	1.1226E-06	3.1209E-07	3.7203E-07	3.2563E-07	1.5009E-06
100.48	1.1974E-06	9.5364E-07	2.8226E-07	3.6039E-07	2.5539E-07	1.6511E-06
106.76	1.0648E-06	8.1721E-07	2.5554E-07	3.5295E-07	1.8351E-07	1.7672E-06
113.04	9.7388E-07	7.0312E-07	2.3117E-07	3.4603E-07	1.1114E-07	1.8041E-06
119.32	8.9219E-07	6.0550E-07	2.0873E-07	3.3773E-07	5.7227E-08	1.7377E-06

Figure 4.3 Sample use of Microsoft Notepad for editing output text file

## 4.4 Graphics Menu

This menu option is selected to observe the different graphical representations of the program results contained in the output file. Submenu options contained under this menu are shown in Fig. 4.4. Not all of the graphics may be enabled for observation; active curves depend on specifications contained in the input.

All of the graphical representation of output data that may be produced by the program are contained in the following commands of the Graphics menu:

- **Translation Stiffness (Kxx, Kyy, Kww)...**: this option provides a plot of translation stiffness of foundations vs. loading frequencies.
- **Rotational Stiffness (Kppx, Kppy, Kzt)...**: this option provides a plot of rotational stiffness of foundations vs. loading frequencies.
- **Translation Damping (Cxx, Cyy, Cww)...**: this option provides a plot of translation damping of foundations vs. loading frequencies.
- **Rotational Damping (Cppx, Cppy, Czt) ...**: this option provides a plot of rotational damping of foundations vs. loading frequencies.
- **Foundation Response Amplitude in Displacement...**: this option provides a plot of response amplitude in displacement of foundations vs. loading frequencies.
- **Foundation Response Amplitude in Rotation...**: this option provides a plot of response amplitude in rotation of foundations vs. loading frequencies.

The observation of any of the above-listed curves will activate the graphics mode of DYNAN 3.0. Several changes occur during use of the graphics mode, such as new mouse commands are enabled and a new top-menu option becomes available.

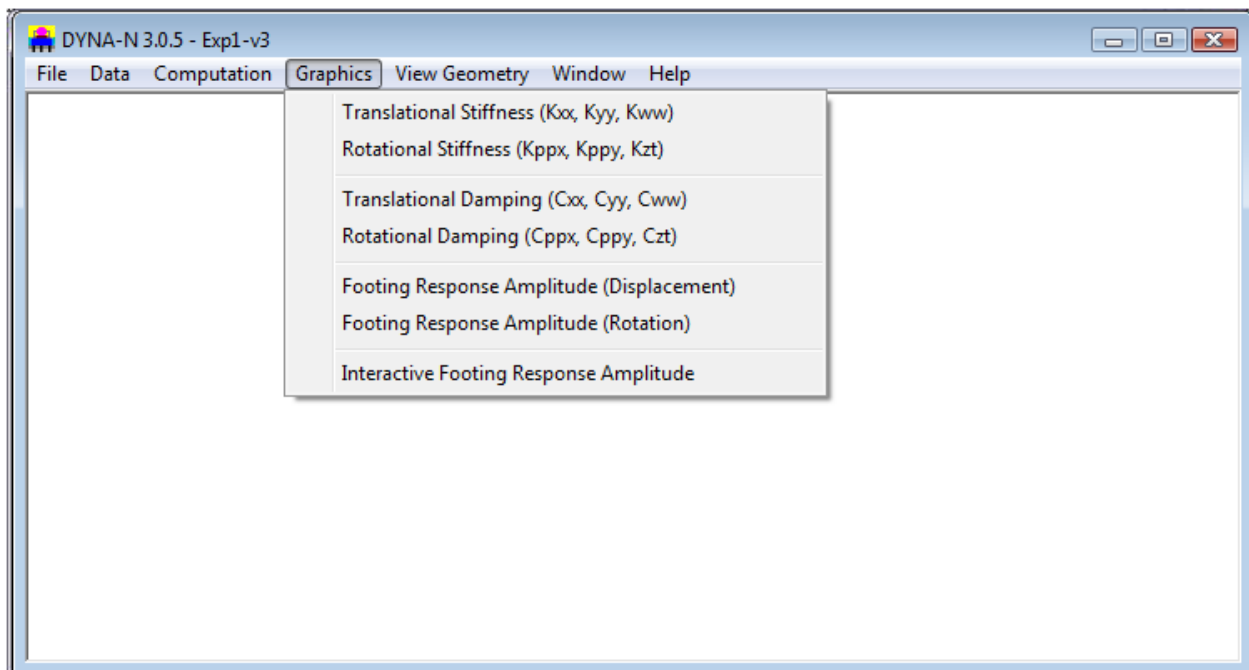


Figure 4.4 Command option contained in the Graphics menu

#### 4.4.1 Mouse Commands in the Graphics Mode

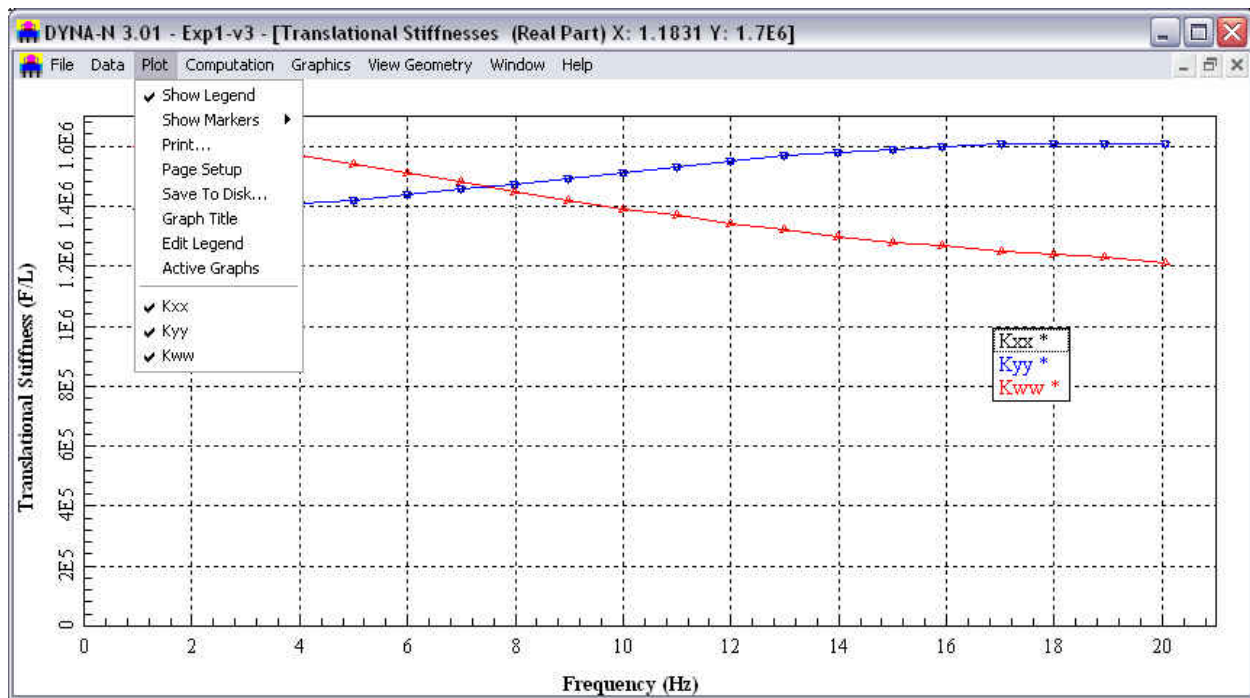
Table 4.1 describes mouse commands that become enabled automatically during all graphical observations of output curves.

**Table 4.1 Mouse commands in the graphics mode**

Event	Description
Mouse Left Click	Zooms in on the graphics at the clicked position (up to five zoom levels)
Mouse Right Click	Zooms out from the graphics
Mouse Double Click on Legend	Turns the selected curve on/off at every click

#### 4.4.2 Plot Menu

This new menu command only appears in the top-menu bar during graphics mode. Command options contained in this menu, shown in Fig. 4.5, are explained below.



**Figure 4.5 Command option contained in the Plot menu**

- **Show Legend:** This activates or deactivates the floating legend included in the graphics mode. The legend box can be moved with click-and-drag operations of the mouse to any position in the graphics screen. Despite its location in the screen, the legend is always located at the right-bottom corner of the printouts.

- **Show Markers:** This menu provides the option to activate or deactivate the markers for each point of all the curves displayed in the active screen of the graphics mode. The user may optionally select to show markers every 1, 2, 3, 5, or 10 increments of unit. The type of markers used in each curve is automatically selected by the program. Once activated, the markers are enabled for all visible curves of the active graphics screen.
- **Print...:** This command is used to produce a hard copy of the active graphics screen. The Print sub-windows includes a drop-down menu that allows the user to select any of the installed Windows printers, allows for change of printer properties, and allows the selection of the total number of copies to be printed. The printed graphics is sized according to the margins that the user specifies in the Plot - Page Setup menu.
- **Page Setup:** The user can here specify the printed size of the active-graphics screen. The size of the plot is base on the specified margins and selection of paper orientation. The parameters selected here are not saved with the output file and must be changed each time that the graphics is plotted.
- **Save to Disk...:** This command is used to save the active-graphics screen to disk. The format of the saved file is as *bmp* graphics (bitmap file), which is the internal-file format used in Microsoft Windows®. **Graph Title:** The user may add a title to the active graphics using this command. The parameters selected here are not saved with the output file and must be changed each time the file is opened.
- **Edit Legend:** The user may change the text of the legend in the active graphics using this command. The modified names are not saved with the output file and must be changed each time the file is opened.

#### 4.4.3 Graphics - Translation Stiffness (Kxx, Kyy, Kww)

This option provides a plot of translation stiffness of foundations vs. loading frequencies. A sample graphics screen of the Translation Stiffness of Foundation command option is shown in Fig. 4.6.

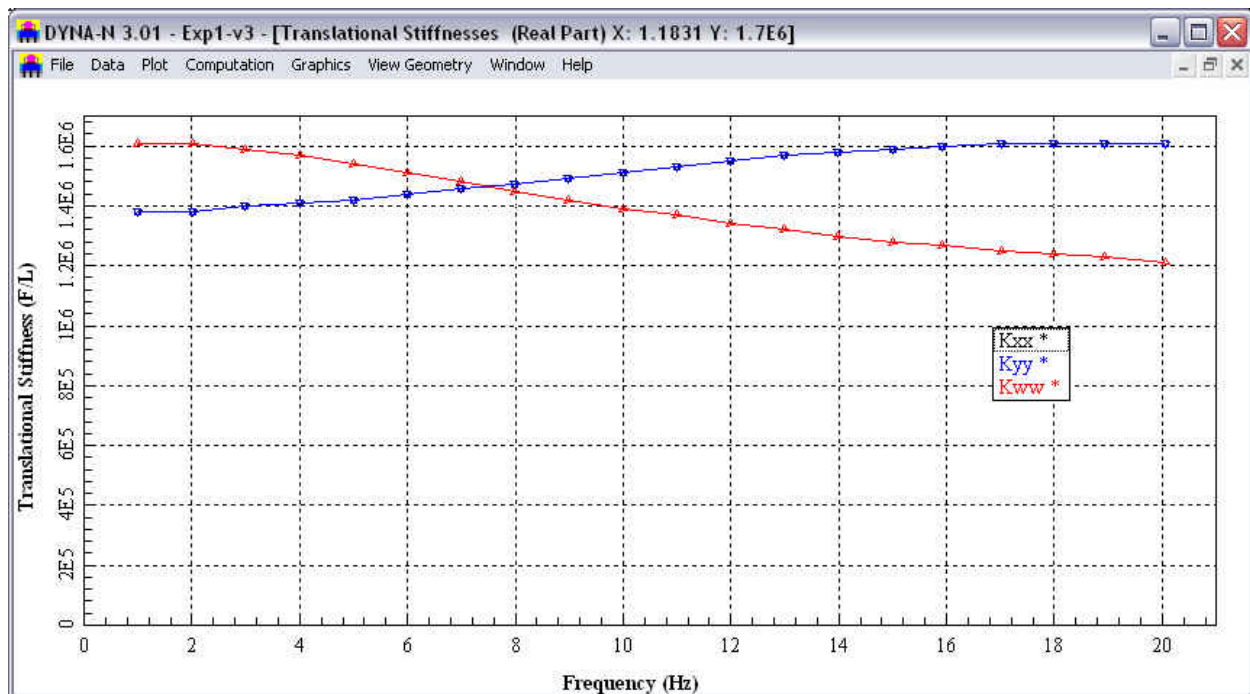


Figure 4.6 Translation stiffness command option for Example 1

#### 4.4.4 Graphics - Rotational Stiffness ( $K_{xx}$ , $K_{yy}$ , $K_{ww}$ )

This option provides a plot of rotational stiffness of foundations vs. loading frequencies. A sample graphics screen of the Rotational Stiffness of Foundation command option is shown in Fig. 4.7.

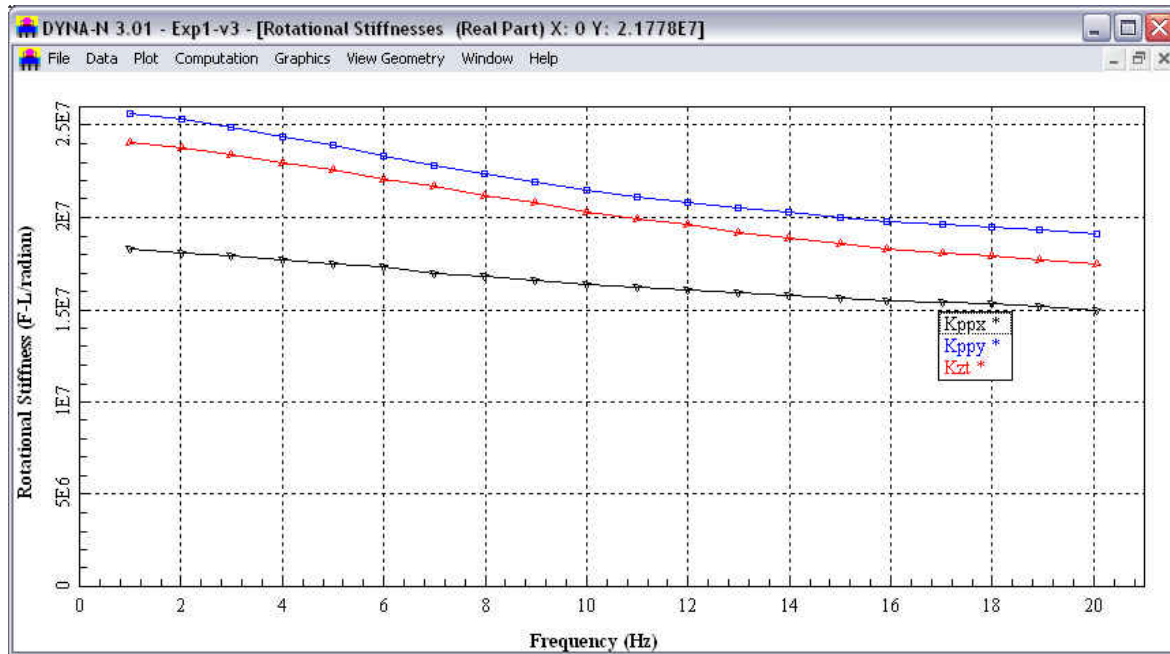


Figure 4.7 TranslationRotational stiffness command option for Example 1

#### 4.4.5 Graphics - Translation Damping ( $C_{xx}$ , $C_{yy}$ , $C_{ww}$ )

This option provides a plot of translation damping of foundations vs. loading frequencies. A sample graphics screen of the Translation Damping of Foundation command option is shown in Fig. 4.8.



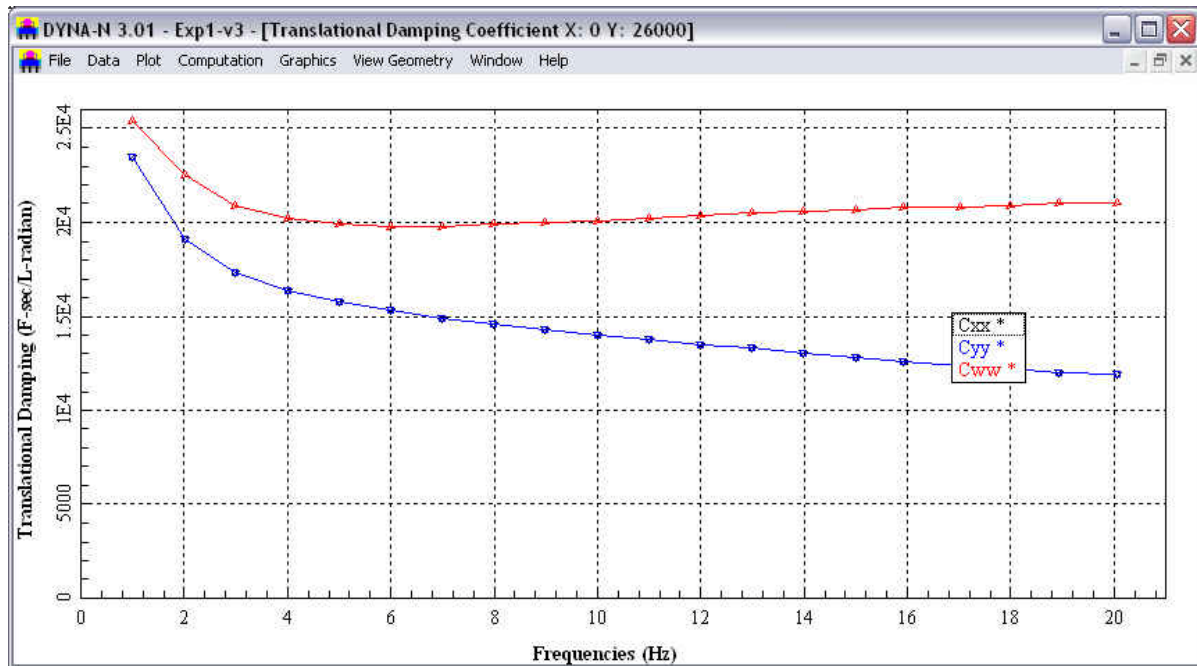


Figure 4.8 Translation damping command option for Example 1

#### 4.4.6 Graphics - Rotational Damping (Cpxx, Cpyy, Crt)

This option provides a plot of rotational damping of foundations vs. loading frequencies. A sample graphics screen of the Rotational Damping of Foundation command option is shown in Fig. 4.9.

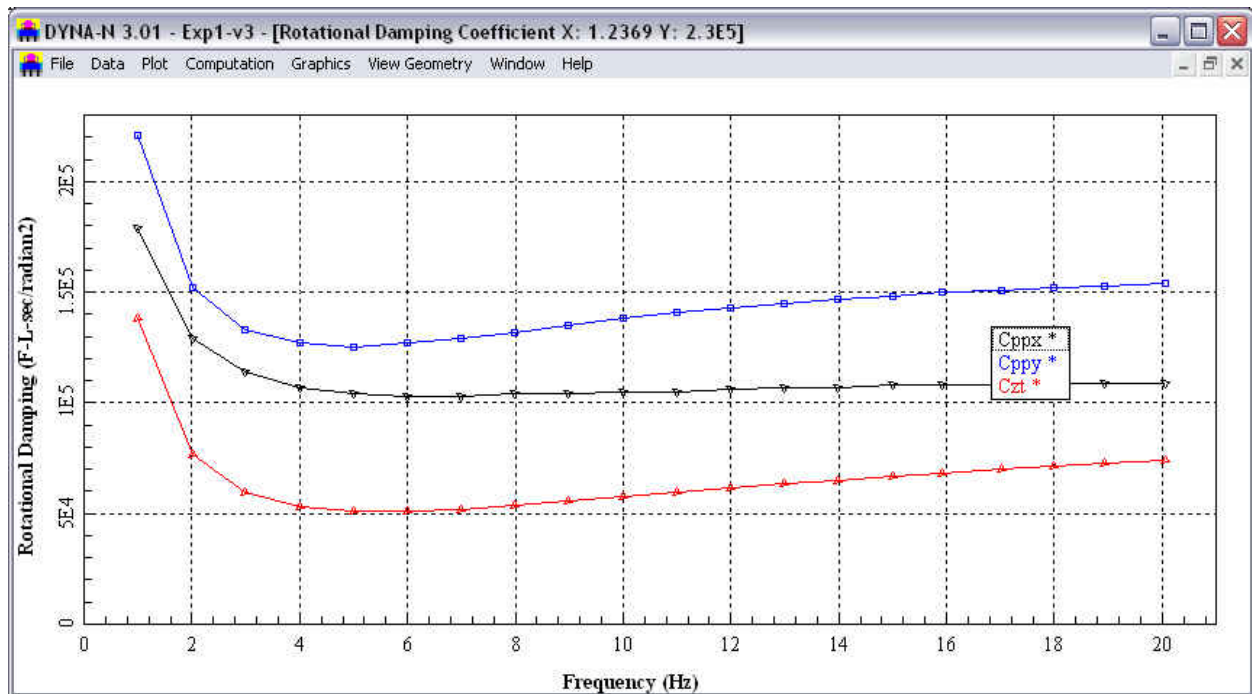


Figure 4.9 Rotational damping command option for Example 1

#### 4.4.7 Graphics - Foundation Response Amplitude in Displacement

The user may select this command option to observe a graphical representation of the foundation response amplitude in displacement vs. loading frequencies at c.g. for the modeled foundation. This curve is automatically generated in all analytical runs of a foundation. A sample graphics screen of the Foundation Response Amplitude in Displacement command option is shown in Fig. 4.10.

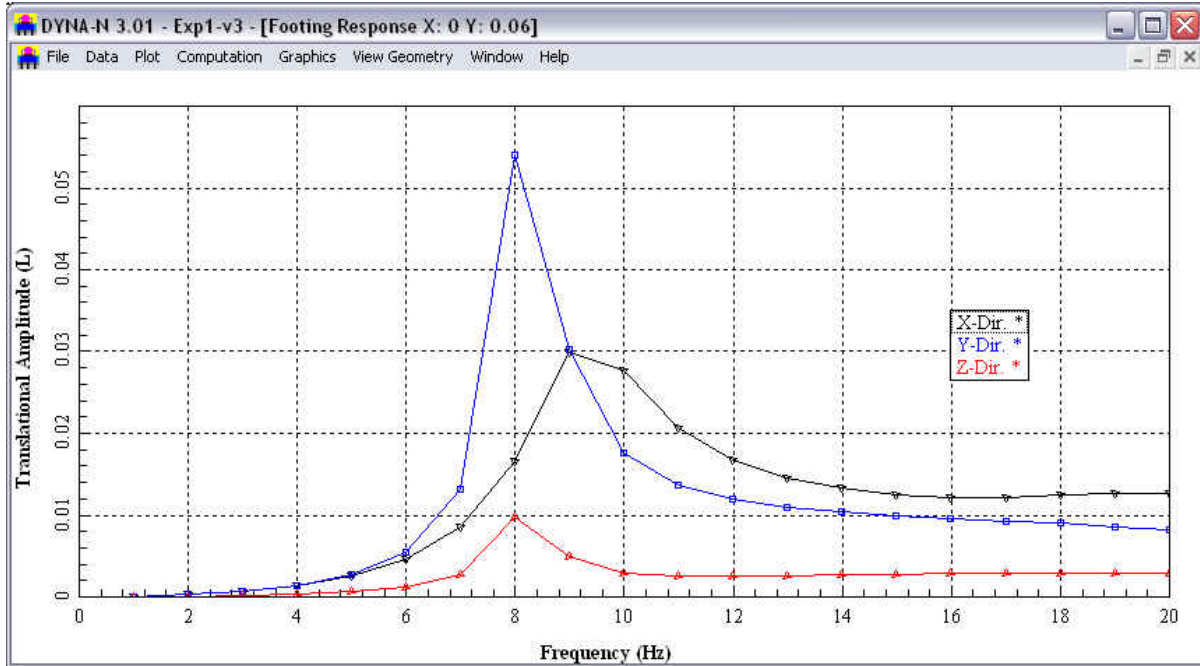


Figure 4.10 Foundation response amplitude in displacement command option for Example 1

#### 4.4.8 Graphics - Foundation Response Amplitude in Rotation

The user may select this command option to observe a graphical representation of the foundation response amplitude in rotation vs. loading frequencies at c.g. for the modeled foundation. This curve is automatically generated in all analytical runs of a foundation. A sample graphics screen of the Foundation Response Amplitude in Rotation command option is shown in Fig. 4.11.

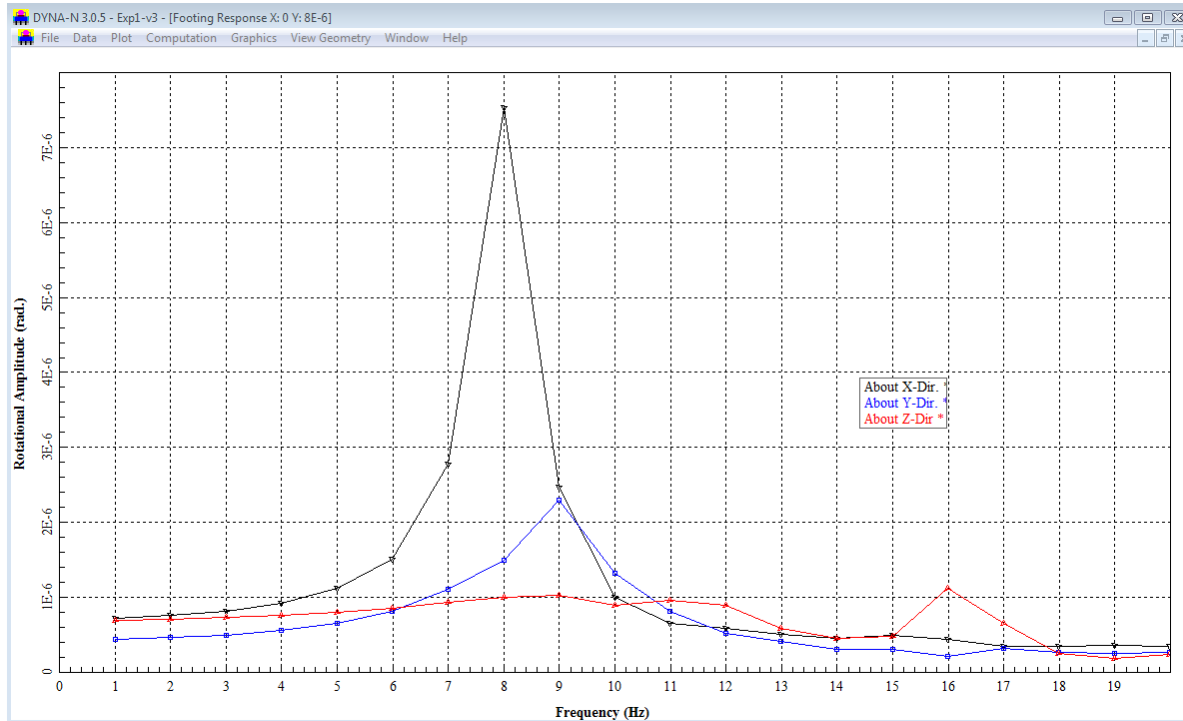


Figure 4.11 Foundation response amplitude in rotation command option for Example 1

#### 4.4.9 Graphics – Interactive Footing Response Amplitude

The user may select this command option to observe a graphical representation of the foundation response amplitude at locations different from the c.g. for the modeled foundation. The user can enter the coordinates of the reference point and the curves automatically reflect the results based on the new assigned reference point in on the foundation. A sample graphics screen of the Interactive Footing Response Amplitude command option is shown in Fig. 4.12.



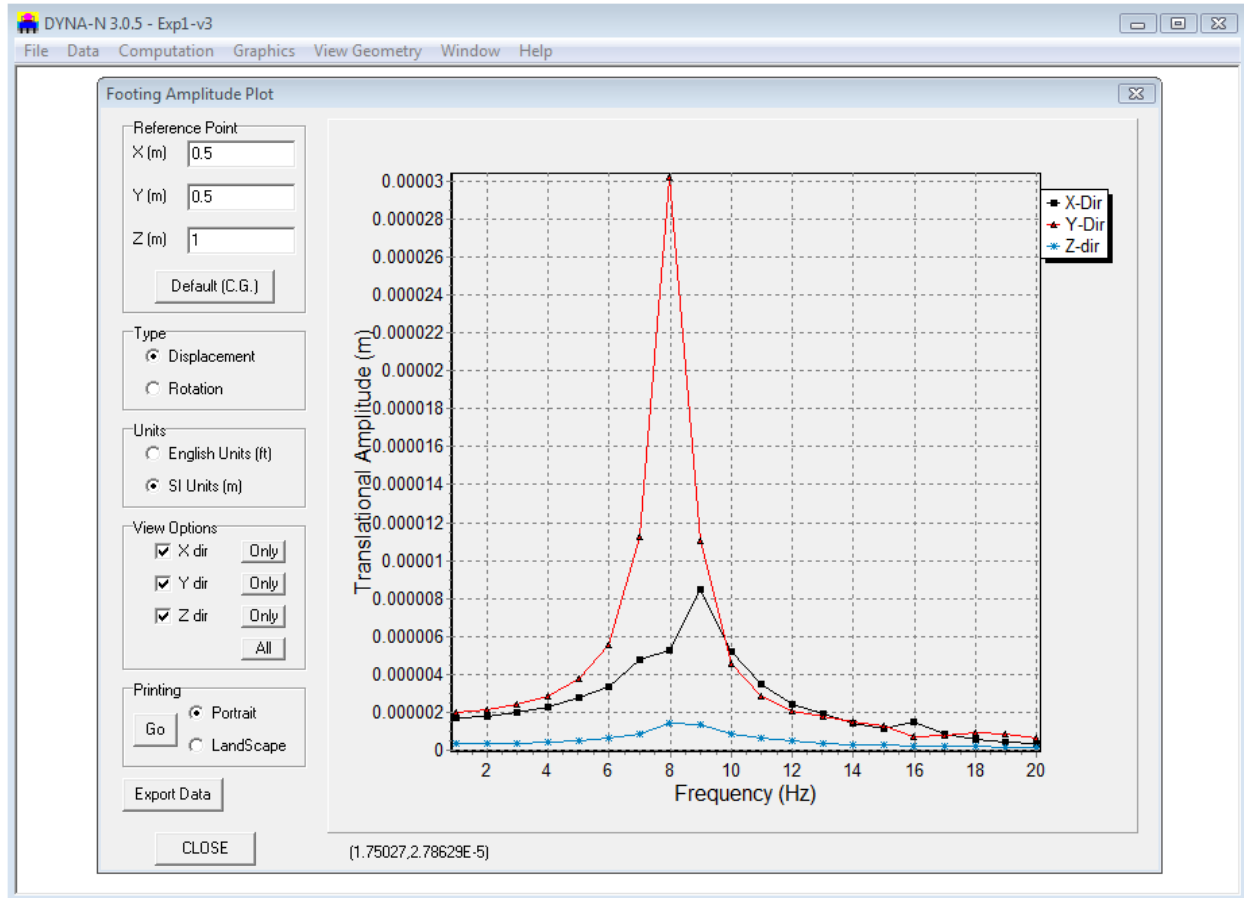


Figure 4.12 Foundation response amplitude in rotation command option for Example 1

## 4.5 View Geometry

The View menu is used to review, in proportional graphical form, the geometric shape and configuration for the modeled foundation. Submenu options are shown in Fig. 4.12 along with additional sub-window showing the side view of the foundation described in Example 1. The three submenu options are described below.

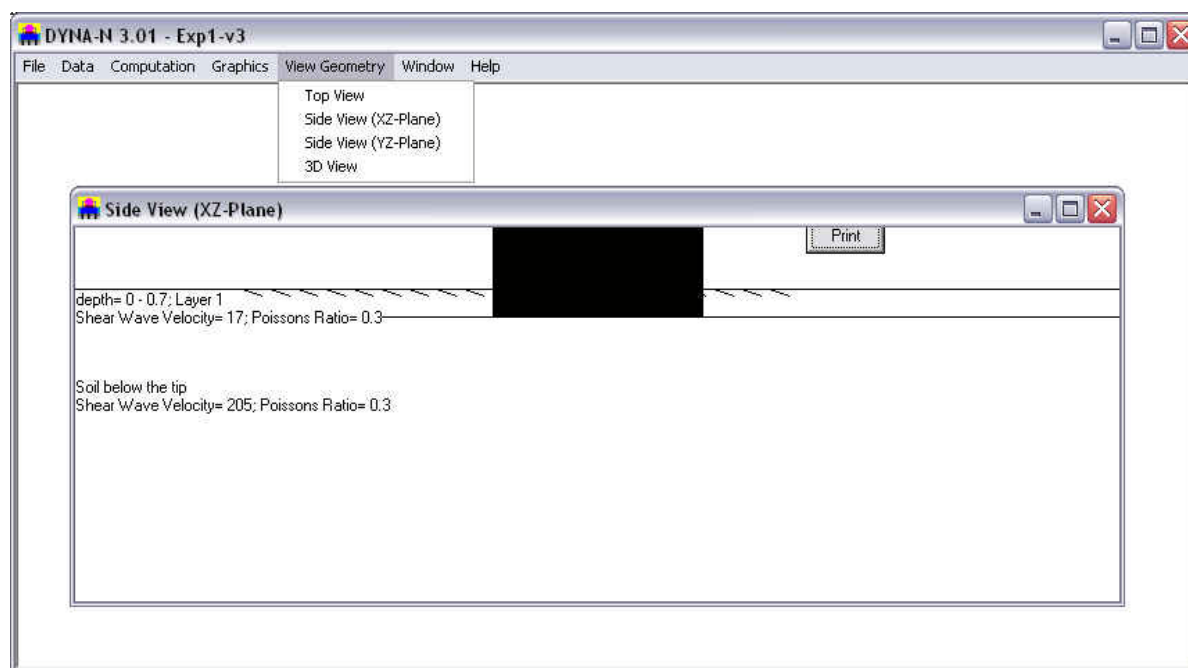


Figure 4.13 Command option contained in the View Geometry menu

**Top View:** This option provides a plan view of the foundation model, as observed from the top. For the example shown in Fig. 4.13, the pile group from left-to-right are composed of three piles in each row.

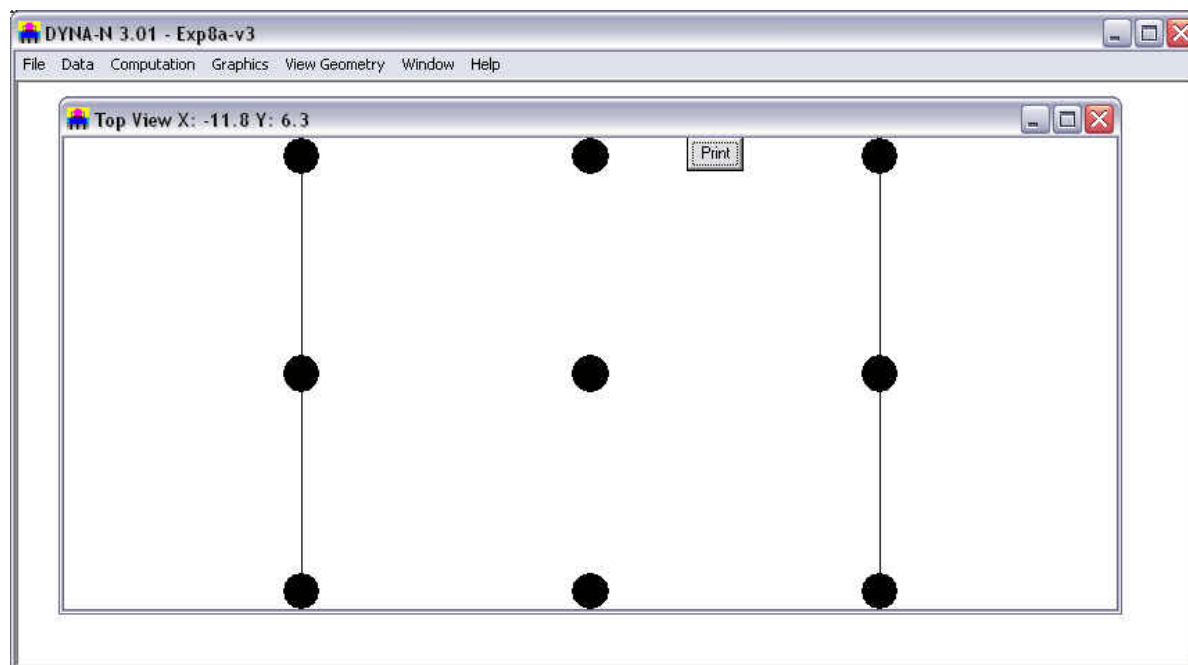


Figure 4.14 View Geometry menu – Top view

**Side View (XZ-plane):** This option provides a lateral view of the foundation model projected on XZ-plane as shown in Fig. 4.14. This drawing will include soil layers which are defined by the user.

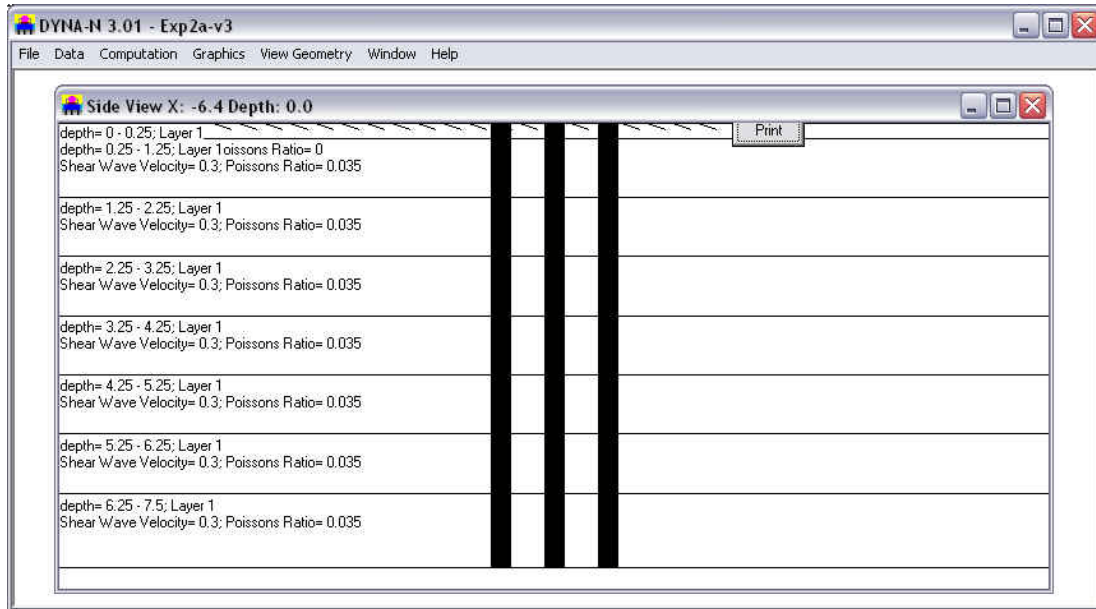


Figure 4.15 View Geometry menu – Side view (XZ plane)

**Side View (YZ-plane):** This option provides a lateral view of the foundation model projected on YZ-plane as shown in Fig. 4.15. This drawing will include soil layers which are defined by the user.

**3D View:** This option provides a three-dimensional view of the foundation model created by the user as shown in Fig. 4.14. This drawing will be helpful for reviewing pile groups, especially battered piles involved in the model.

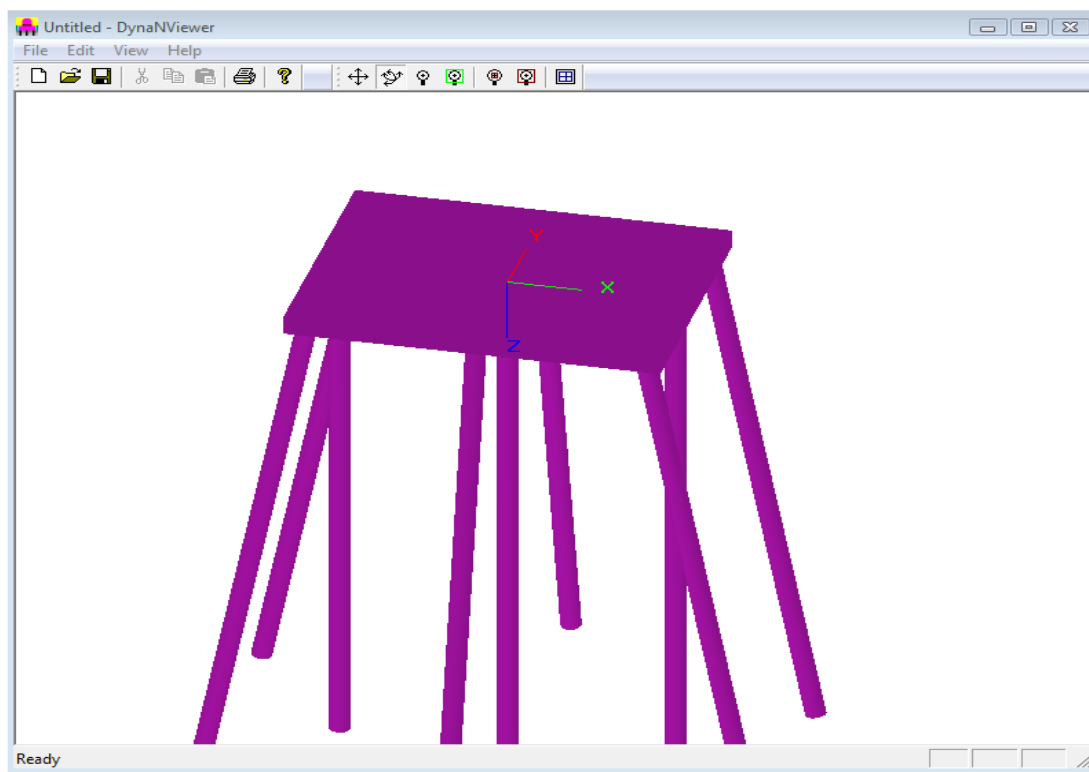


Figure 4.16 View Geometry menu – Three-dimensional view

## CHAPTER 5.    **Engineering Document**

## 5.1 Introduction

The design of foundations for vibrating machines and foundations subject to other dynamic forces requires an accurate prediction of the foundation response to these loads. A complete and rigorous analysis must account for the following: the three-dimensional nature of the problem, material and radiation damping of soil, variation of soil properties with depth, embedment effects, and interaction effects between multiple foundations through the soil.

The dynamic stiffness of foundations is also referred to as the impedance function of the foundations under dynamic loading. In current methods of dynamic analysis of soil-foundation-structure systems under seismic or machine-type inertial loading, a key step is to estimate the (dynamic) impedance functions associated with a rigid but massless foundation. During the past 20 years, a number of techniques have been developed for computing and using foundation impedances; extensive reviews of these developments were presented by Lysmer (1978), Roessett (1980a, b), Luco (1982), Gazetas (1983), Novak (1987), and Pais and Kausel (1988).

The presently available methods include: (1) analytical solutions based on integral transform techniques; (2) semi-analytical and boundary- element formulations requiring discretization of only the top surface; (3) dynamic finite-element methods using special wave-transmitting lateral boundaries; and (4) hybrid methods combining analytical and finite element approaches.

A comprehensive summary on the behavior of shallow rigid foundations under dynamic loads was recently presented by Gazetas in 1991. In the paper, Gazetas introduced general terminology to define the impedance functions (dynamic stiffness) of surface and embedded foundations. He additionally suggested an approximation based on formulas and charts published in the technical literatures to calculate the impedance functions for the practicing engineer.

## 5.2 Definition of Impedance Functions

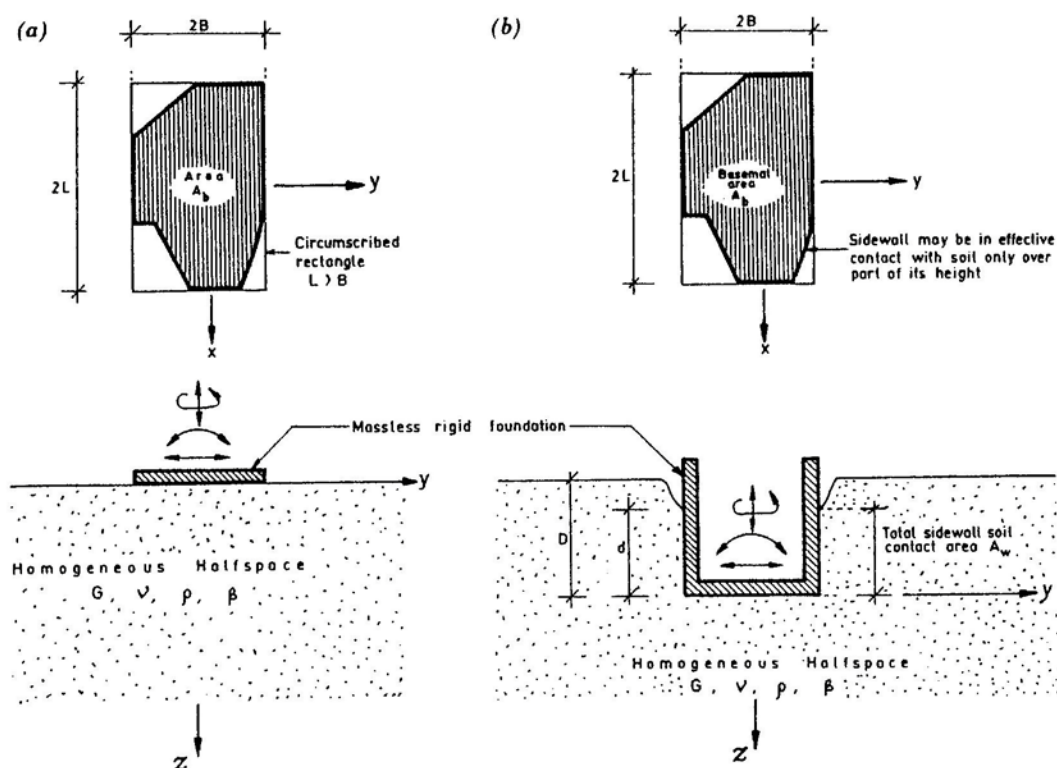
The geometry of the rigid but massless foundations addressed in Gazetas's (1991) paper is sketched in Fig. 1(a) (surface foundation) and in Fig. 1(b) (embedded foundation). The steady-state response of such systems to harmonic external forces and moments can be computed with well-established methods of structural dynamics once the matrix of dynamic impedance functions  $[S(\omega)]$  has been determined for the frequency(ies) of interest.

For each particular harmonic excitation, the dynamic impedance is defined as the ratio between force (or moment)  $R$  and the resulting steady-state displacement (or rotation)  $U$  at the centroid of the base of the massless foundation. For example, the vertical impedance is defined by

$$S_z = R_z(t) / U_z(t) \quad (5.1)$$

in which  $R_z(t) = R_z \exp(i\omega t)$  = harmonic vertical force; and  $U_z(t) = U_z \exp(i\omega t)$  harmonic vertical displacement of the soil-foundation interface. The quantity  $R_z$  is the total dynamic soil reaction against

the foundation; it is made up of normal tractions against the basemat plus shear tractions along any vertical side walls.



**Figure 5.1** Examples of surface and embedded foundations of arbitrary shapes (from Gazetas, 1991)

Similarly, the following impedances are defined:  $S_y$  = lateral swaying impedance (force-displacement ratio), for horizontal motion in the short direction;  $S_x$  = longitudinal swaying impedance (force-displacement ratio), for horizontal motion in the long direction;  $S_{rx}$  = rocking impedance (moment-rotation ratio), for rotational motion about the long centroidal axis (x) of the foundation basemat;  $S_{ry}$  = rocking impedance (moment-rotation ratio), for rotational motion about the short centroidal axis (y) of the foundation basemat; and  $S_t$  = torsional impedance (moment-rotation ratio), for rotational oscillation about the vertical axis (z).

Moreover, in mainly embedded foundations, horizontal forces along principal axes induce rotational (in addition to translational) oscillations; hence, two more “cross-coupling” horizontal-rocking impedances  $S_{x-ry}$  and  $S_{y-rx}$ . They are negligibly small in surface and shallow foundations, but their effects may become appreciable for greater depths of embedment owing to the moments about the base axes produced by horizontal soil reactions against the side walls.

As with most literature, all impedances refer to axes passing through the centroid of the foundation basemat-soil interface. Because of the presence of radiation and material damping in the

system for all modes of vibration,  $\mathbf{R}$  is generally out of phase with  $\mathbf{U}$ . It has become traditional to introduce complex notation and to express each impedance in the form

$$\mathbf{S} = \mathbf{k} + i \omega \mathbf{C} \quad (5.2)$$

in which both  $\mathbf{k}$  and  $\mathbf{C}$  = functions of the frequency  $\omega$ . The real component,  $\mathbf{k}$ , termed “dynamic stiffness,” reflects the stiffness and inertia of the supporting soil; its dependence on frequency is attributed solely to the influence that frequency exerts on inertia, since soil properties are practically frequency independent. The imaginary component,  $\omega \mathbf{C}$ , is the product of the (circular) frequency  $\omega$  times the “dashpot coefficient,”  $\mathbf{C}$ ; the latter reflects the radiation and material damping generated in the system (due to energy carried by waves spreading away from the foundation and energy dissipated in the soil by hysteretic action, respectively). If the coefficient of the soil hysteretic damping ( $\beta$ ) is given separately, the expression of the dashpot coefficient (**Total C**) of the foundation system can incorporate the  $\beta$  coefficient as:

$$\text{Total } \mathbf{C} = \text{radiation } \mathbf{c} + 2k(\beta)/\omega \quad (5.3)$$

Eq. 5.2 suggests for each mode of oscillation an analogy between the actual foundation-soil system and the system that consists of the same foundation but is supported on a “spring” and “dashpot” with characteristic moduli equal to  $\mathbf{k}$  and  $\mathbf{C}$ , respectively. A number of powerful computational techniques have been developed for calculating the dynamic stiffness and damping coefficients of foundations in linear soil. They include analytical approaches such as the integral transform method (Kausel, 1974; Luco and Westmann, 1971; and Veletsos and Wei, 1971), several rigorous and approximate semi-analytical procedures such as the boundary element method (Dominguez and Roesset, 1978), and dynamic finite elements (Kausel, 1974; Lysmer and Kuhlemeyer, 1969). These techniques can be applied to the analysis of machine foundations and to other dynamic soil-structure interaction problems encountered in earthquake and offshore engineering. Although further extensions and refinements of these methods are being published continuously, they have already attained a great degree of sophistication and may handle foundation and soil configurations of great complexity. Shallow foundations can be solved for different vibration modes, for exciting forces covering a wide range of frequencies, and for soil conditions ranging from a uniform deposit to an arbitrary layered profile on rigid rock.

### 5.3 Simplified Methods

Over the years, several researchers have developed simplified methods, presented results in dimensionless graphical or tabular form, or fitted simple equations to their numerical results. The classical example of such a simple method is the single-degree-of-freedom with frequency-independent parameters proposed in 1966 by Lysmer and Richart for the vertical vibration of a rigid circular footing on an elastic halfspace. Similar simple systems or “analogs” were later developed for the other modes of vibration of the same circular footing, and these analogs are widely used today (Richart et al, 1970; Whitman and Richart, 1967). Later, Kausel, Novak, Roesset, Veletsos and others have fitted equations and charts to their analytical results and have proposed simple procedures to take into account the variation with frequency of the equivalent dynamic springs and dashpots, and the influence of factors



such as embedment and presence of a shallow rigid rock base (Kausel, 1974; Novak and Beredugo, 1971; Roesset, 1980; Veletsos and Wei, 1971; and Veletsos and Verbic, 1974).

These simple methods, based on physically sound, conceptual frameworks and calibrated with exact solutions, are feasible and should be encouraged. These simple methods are very helpful in performing parametric studies, checking the results of complicated computer codes and developing engineering insight into the expected dynamic behavior of foundation systems. However, these methods are only for reasonably deep and uniform soil deposits that can be modeled as a homogeneous half-space.

In practical applications, the selection of an appropriate method depends to a large extent on the size and economics of the project, as well as the availability of pertinent computer codes. Moreover, the method to be selected must adequately reflect the following key characteristics of the foundation-soil system and the excitation.

- The shape of the foundation-soil interface (circular, strip, rectangular, arbitrary).
- The amount of embedment (surface, partially or fully embedded foundation, piles).
- The nature of the soil profile (deep uniform or layered deposit, shallow stratum over bedrock).
- The mode of vibration and the frequency(ies) of excitation.

## 5.4 Improved Novak's Method With Non-Reflective Boundary

### 5.4.1 Deep Foundation (Pile Option)

Both theoretical and experimental studies have shown that the dynamic response of the piles is very sensitive to the properties of the soil in the vicinity of the pile shaft. The measured dynamic response of a single pile was compared with the computed curves and shown in Fig. 5.2 (Han and Novak, 1988).

A number of approaches are available to account for dynamic soil-pile interaction, but they are usually based on the assumption that the soil behavior is governed by the law of linear elasticity or viscoelasticity and that the soil is perfectly bonded to a pile (Novak, 1991). In practice, however, the bonding between the soil and the pile is rarely perfect, and slippage or even separation often occurs in the contact area. Furthermore, the soil region immediately adjacent to the pile can undergo a large degree of straining, which would cause the soil-pile system to behave in a nonlinear manner.

A rigorous approach to the non-linearity of a soil-pile system is extremely difficult and time consuming. Approximate theories, therefore, have to be used for practice. As for the approximate analysis, The Baranov-Novak method is generally considered as an efficient technique for solving the problem of coupled vibration (Luco 1982). The relationship between the foundation vibration and the resistance of the side soil layers was derived using the elastic theory of Baranov (1967).

Novak and Sheta (1980) proposed including a cylindrical annulus of softer soil (an inner weakened zone or so called boundary zone) around the pile in a plane strain analysis. One of the simplifications involved in the original boundary zone concept was that the mass of the inner zone was neglected to avoid the wave reflections from the interface between the inner boundary zone and the outer zone. To overcome this problem, Veletsos and Dotson (1988) proposed a scheme that can account for the mass of the boundary zone. Some of the effects of the boundary zone mass were investigated by Novak and Han (1990), who found that a homogeneous boundary zone with a nonzero mass yields undulation impedance due to wave reflections from the fictitious interface between the two media.

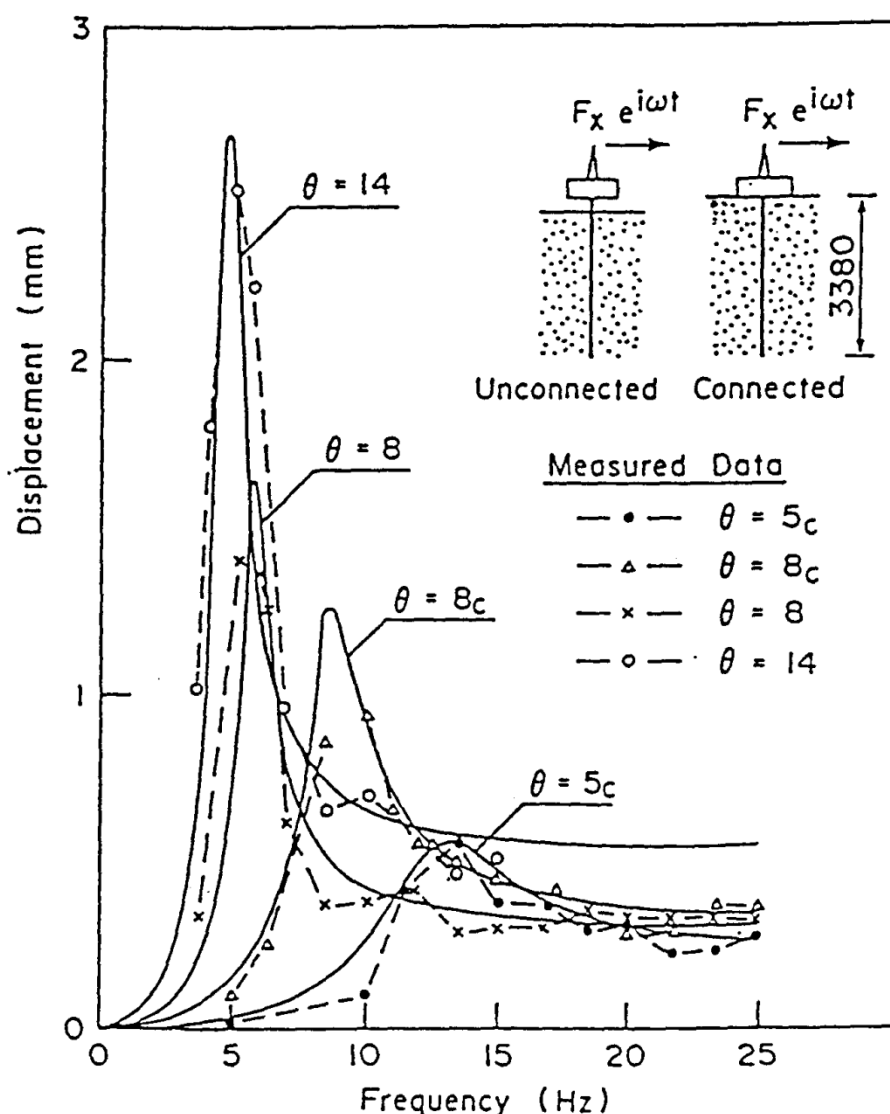
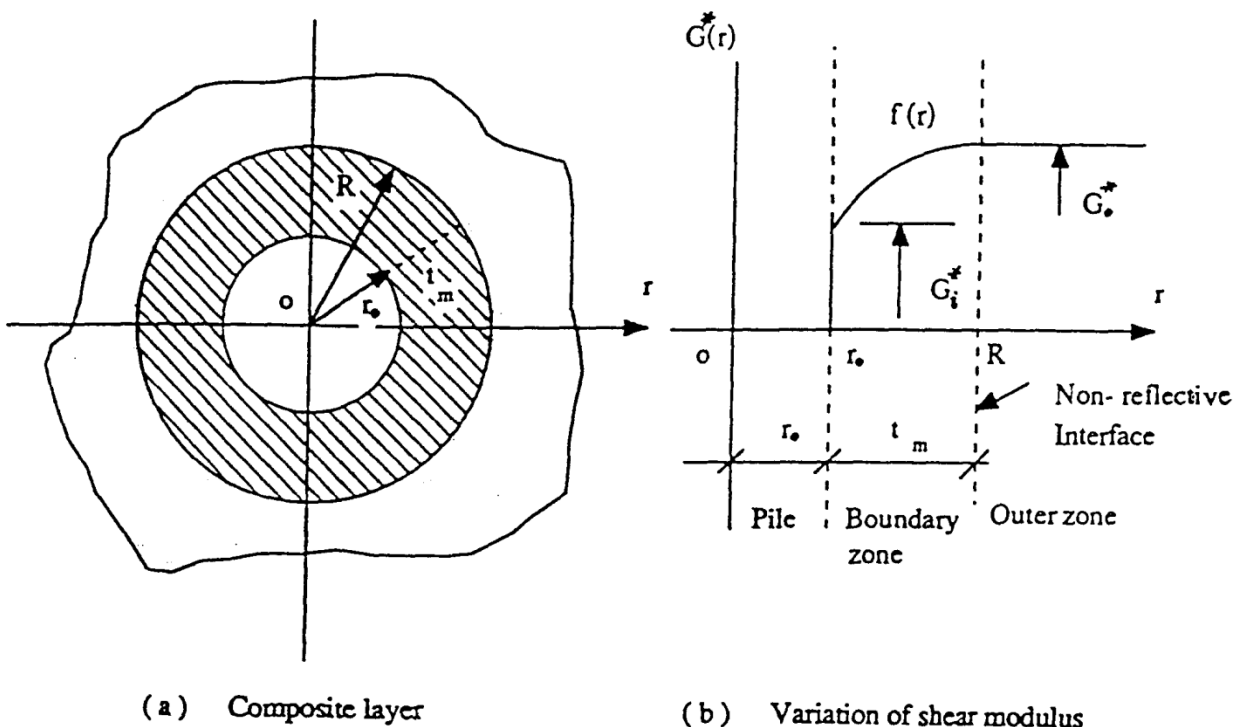


Figure 5.2 Predicted and measured horizontal response curves (Han and Novak, 1988, "Dynamic behavior of single piles under strong harmonic excitation", Canadian Geotechnical J., 25 (3), 523-534))

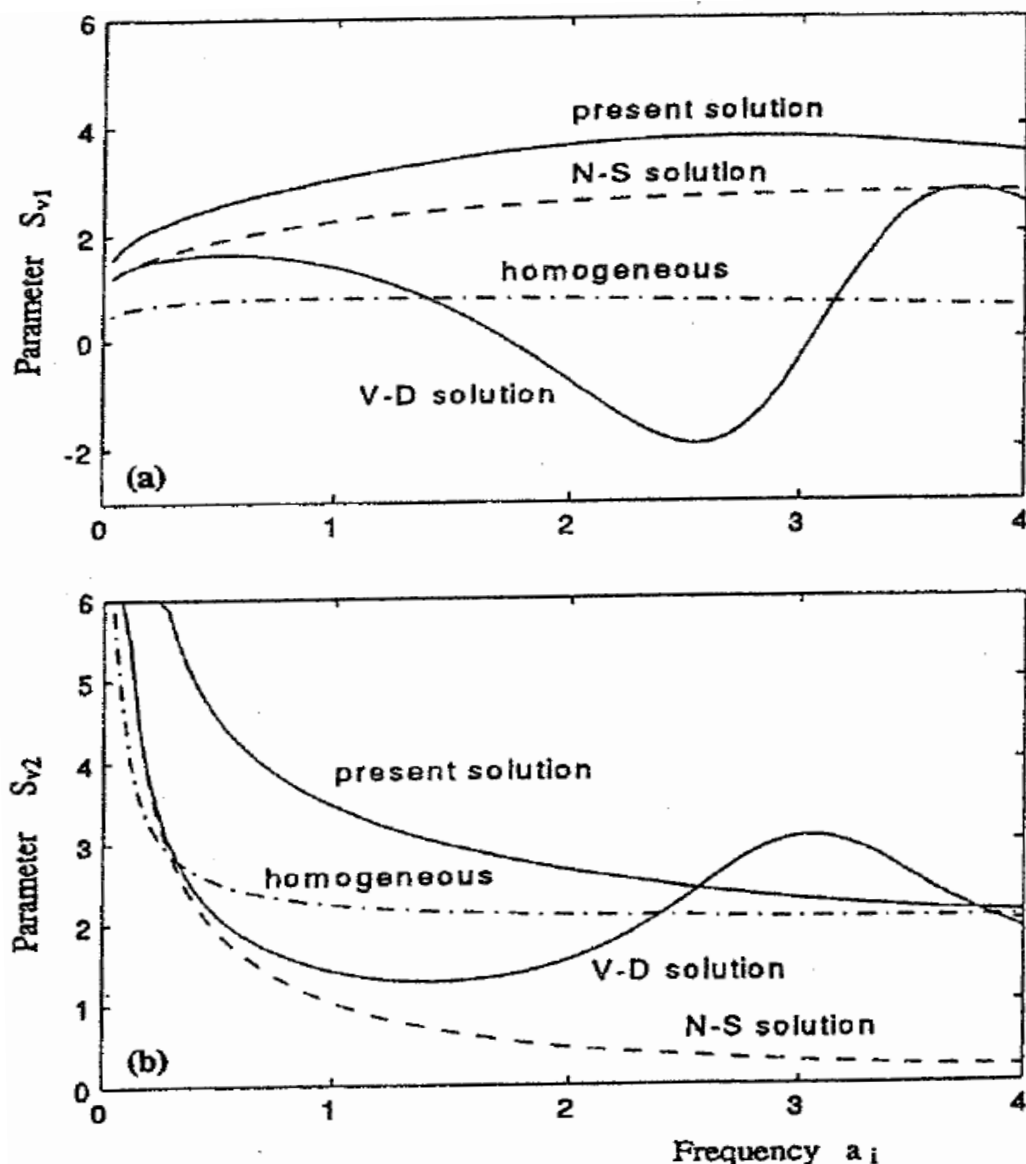
The ideal model for the boundary zone should have properties smoothly approaching those of the outer zone to alleviate wave reflections from the interface. Consequently, Han and Sabin (1995) proposed such a model for the boundary zone with non-reflective interface. A model of the boundary zone with non-reflective interface is shown in Fig. 5.3. The model of non-reflective interface assumes that the boundary zone has a nonzero mass and a smooth variation into the outer zone by introducing a parabolic variation function, which may be best fit with use of experimental data. Dynamic investigations of piles indicated that the boundary zone model is applicable to both granular and cohesive soils (El-Marsafawi et al, 1992; Han, 1997).



**Figure 5.3** Concept of boundary zone with non-reflective interface

The analytical solution of the non-reflective boundary model is combined with the numerical solution in DYNAN program. With the impedance of the soil layer, the element stiffness matrix of soil-pile system can be formed in the same way as the general finite element method. Then the overall stiffness matrix of a single pile can be assembled for different modes of vibration, included three translations and three rotations.

The stiffness and damping factors for vertical vibrations,  $S_{v1}$ , and  $S_{v2}$ , obtained from the present analysis are compared with those obtained for the Novak-Sheta (N-S) and Veletsos-Dotson (V-D) idealizations, as shown in Fig 5.4. These solutions are for a soil layer with  $t_m/r_0 = 1.0$ ;  $G_i/G_0 = 0.25$ ;  $\beta_i = 0.1$  and  $\beta_0 = 0.05$ . The mass density for the inner zone is taken to be equal to that for the outer region in the present solution and the V-D solution; for the N-S solution the mass density for the inner zone is assumed to be zero, an unrealistic assumption. It can be observed that the three sets of results are significantly different; the V-D solution results in pronounced oscillations (undulations) caused by wave reflections from the interface between the two media. It should be noted that Veletsos and Dotson (1988) also included a model with a continuously increasing shear modulus with radial distance to remove the undulations in the impedances. The differences between the present solution and that solution are that the modulus was varied unboundedly, i.e., without a boundary zone in their model, and in the present model the modulus varies only in the boundary zone and is constant in the outer zone as one might expect. The nonreflective boundary between the boundary zone and the outer zone is formulated in the present solution. It should be explained that the convergence of the power series used to express the displacement in this study is rapid; however, the convergence for the derivative of the series is slow. To obtain a satisfactory solution, the first 10 to 12 terms of the series are needed. The results from the present analysis are smooth curves over a wide range, the value of  $a_i$  from 0.0 to 4.0, which indicates that the wave reflections from the interface are alleviated because it embodies a continuous variation in soil properties in the boundary zone with smooth (continuous derivatives) transition into the outer zone. For comparison, the results for a homogeneous layer are also included in Fig. 5.4.



**Figure 5.4** Comparison of impedance functions for vertical vibration with Novak-Sheta (N-S) and Veletsos-Dotson (V-D) solutions,  $t_m/t_o=1.0$ ;  $G_i/G_o=0.25$ ;  $\beta_o=0.05$ ; (a) stiffness factor  $S_{v1}$  and (b) damping factor  $S_{v2}$

The stiffness and damping factors for torsional vibrations,  $S_{\theta 1}$  and  $S_{\theta 2}$ , obtained from the present analysis are compared with those obtained for the Novak-Sheta (N-S) and Veletsos-Dotson (V-D) idealizations, as shown in Fig. 5.5. These solutions are for a soil layer with  $t_m/r_0 = 1.0$ ;  $G_i/G_0 = 0.25$ ;  $\beta_i = \beta_0 = 0.0$ . The mass density for the inner zone is taken to be equal to that for the outer region in the present solution and the V-D solution; for the N-S solution the mass density for the inner zone is assumed to be zero. It can be observed that similar to the case of vertical vibration, the V-D solution results in pronounced oscillations (undulations) caused by wave reflections from the interface between the two media. In the same way as in the vertical vibration case, Veletsos and Dotson (1988) proposed a continuously increasing shear modulus to eliminate the undulations in the impedances. The results from

the present analysis are smooth curves over a wide range parameter values, indicating that the wave reflections from the interface have been removed. For comparison, the results for a homogeneous layer are also included in Fig. 5.5.

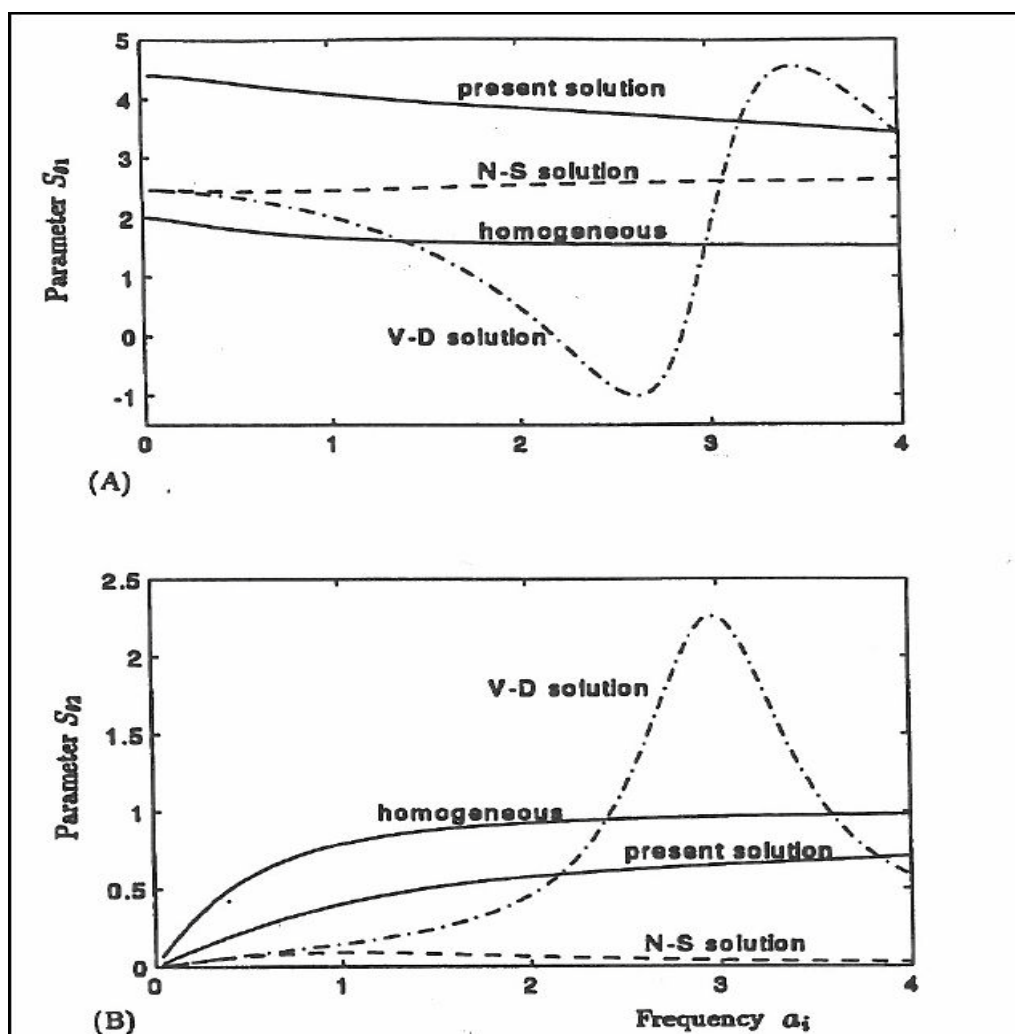


Figure 5.5 Comparison of torsional impedance functions with Novak-Sheta (N-S) and Veletsos-Dotson (V-D) solutions,  $t_m/t_o=1.0$ ;  $G_i/G_o=0.25$ ;  $\beta_i=\beta_o=0.05$ ; (a) stiffness factor  $S_{v1}$  and (b) damping factor  $S_{v2}$

The results from the present analysis are smooth curves over a wide range parameter values, indicating that the wave reflections from the interface have been removed. For comparison, the results for a homogeneous layer are also included in Fig. 5.5.

Dynamic investigations of piles indicated that the boundary zone model is applicable to both granular and cohesive soils (El-Marsafawi et al., 1992; Han, 1997). The harmonic vibration tests of a full-scale pile were conducted on the campus of the University of Western Ontario. The soil consisted of a layered noncohesive stratum of silty fine sand with a gravel seam, resting on the dense silty till at a

depth of 2.9 m from the ground surface. Measurement of shear wave velocity at the site was conducted using the cross-hole technique and the steady-state vibration technique. The shear-wave velocity in the top 0.5-m soil layer was lower due to the loss of confining pressure toward the surface, and an average value of 65 m/s was taken in the analysis. A linear distribution of the shear wave velocity was observed for depths below 0.5 m, with 80 and 180 m/s corresponding to depths of 0.5 and 2.9 m. The bulk densities of the noncohesive soil and the underlying till were 1,780 and 1,960 kg/m<sup>3</sup>, respectively. Details of the experiment were reported by El-Marsafawi et al. (1992), but the nonlinear effects of the soil-pile system were not accounted for. In the new study, the nonlinear effects were observed and investigated to verify the validity of the boundary-zone model with non-reflective interface.

The pile is a steel pipe having a length of 2.9 m, an outside diameter of 101.6 mm, and wall thickness of 6.35 mm. Poisson's ratio for the pile is assumed to be 0.25 and the damping ratio is 0.005. The length-to-diameter ratio of the pile  $L/d = 28.5$  and  $E_p/E_s = 1,370$ , where  $E_s$  is the soil elastic modulus. The pile was provided with conical plugs and driven hydraulically to a depth of 2.75 m below the ground surface. The total mass of the pile cap and exciter is 1,035 kg, and the bottom face of the cap is 0.15 m above the ground surface.

The soil below the pile tip is considered as an elastic half-space, having a shear wave velocity of 190 m/s and a unit weight of 1,900 kg/m<sup>3</sup>. The measured results under different excitation intensities are shown in Fig. 5.6. The maximum vertical displacement amplitude was measured to be 0.07 mm, and the maximum acceleration was 0.57 *g*. This is a smaller amplitude vibration but has strong acceleration. From Fig. 5.6 it can be seen that the resonant frequency is 50 Hz under an excitation intensity of  $m_e e = 2.45$  kg-mm, 47 Hz under an excitation of 4.92 kgmm, and 45 Hz under an excitation of 9.84 kg-mm. Due to the repeated and strong excitation, even at very small amplitudes, the pile-soil system was softened so that the resonant frequencies reduced with the increase of excitation intensities. Obviously, the nonlinear behavior occurred in the dynamic response of the pile-soil system, say moderate nonlinear effects, although it is not a very strong nonlinear response.

The boundary-zone model with non-reflective interface is used to simulate dynamic response of the pile in nonlinear soil. Comparisons of the theoretical predictions by DYNAN with the measured data in different excitations are shown in Fig. 5.6.

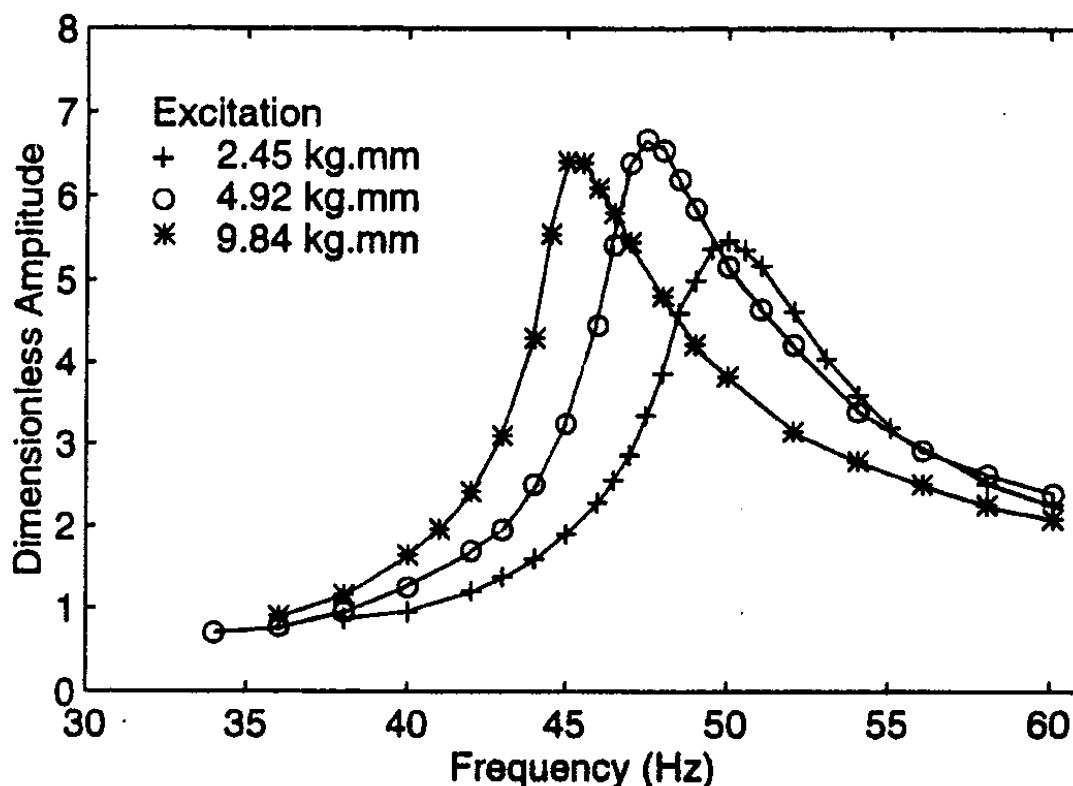


Figure 5.6 Measured dynamic response of a pile subjected to different excitation intensities

The analytical solution of non-reflective boundary model is combined with the numerical solution in DYNAN program. With the impedance of the soil layer, the element stiffness matrix of soil-pile system can be formed in the same way as the general finite element method. Then the overall stiffness matrix of a single pile can be assembled for different modes of vibration, including three translations and three rotations.

The group effect of piles is accounted for using the method of interaction factors in the DYNAN program. The vertical static interaction factors are based on fitting the charts of Poulos and Davies (1980). The horizontal static interaction factors are due to El-Sharnouby and Novak (1986). The dynamic interaction factors are derived from the static interaction factors multiplied by a frequency variation, and the frequency variation of interaction factors is based on the charts of Kaynia and Kausel (1982). The pile foundation with rigid cap is shown in Fig. 5.7.



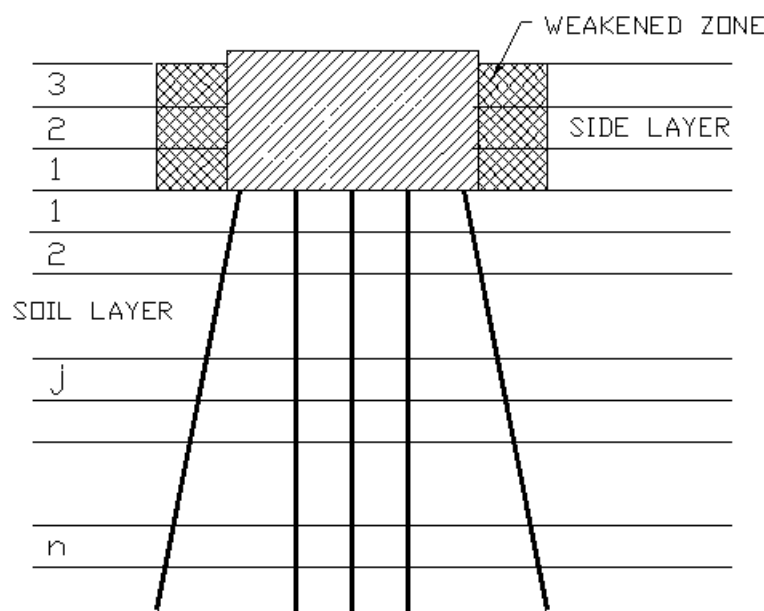


Figure 5.7 Pile foundation model with a rigid cap

## 5.4.2 Shallow Foundation

### 5.4.2.1 Footing on homogeneous halfspace

In the option shown in Fig. 5.8, the footing rests on the surface of, or is embedded in a deep homogeneous deposit considered as halfspace. A stratum whose depth is greater than about five equivalent footing radii may be treated as halfspace using this option. The vibration of embedded foundation was investigated by many researchers, such as Roesset (1980), Gazetas (1983), Han (1983), Wolf and Weber (1986).

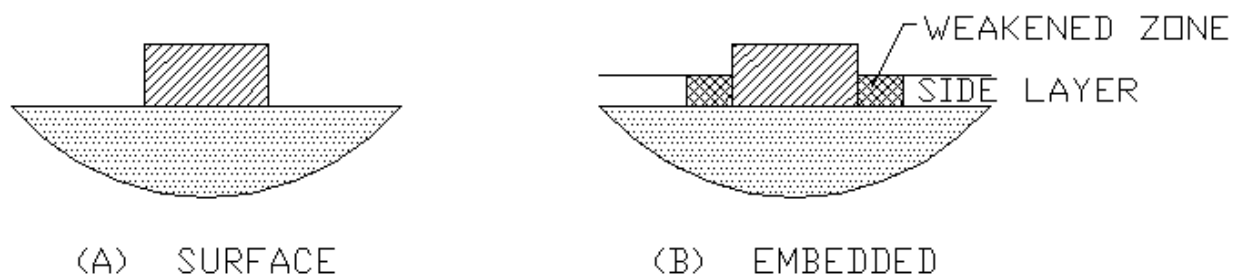
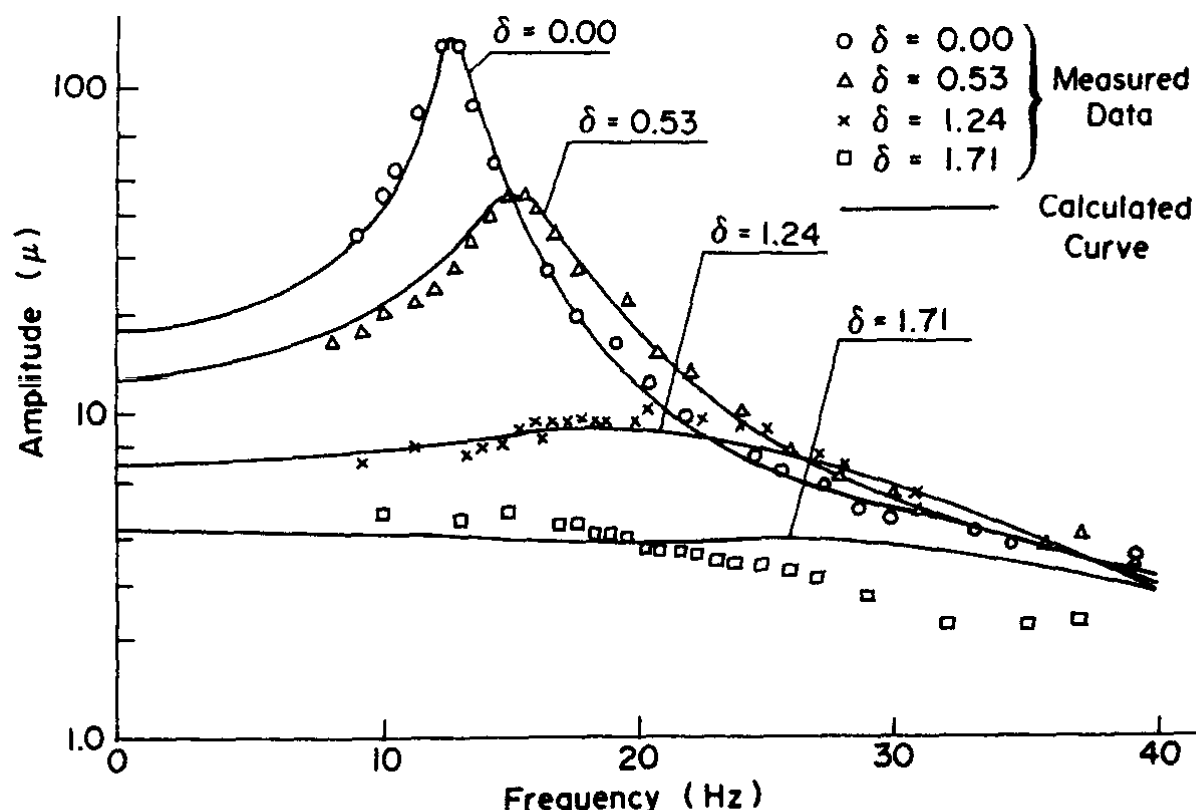


Figure 5.8 Footing on homogeneous halfspace

Comparisons of the predictions with the measured data for different embedments are shown in Fig. 5.9 for horizontal vibration and Fig. 5.10 for rocking vibration. For details see Han (1989), "Coupled Vibration of Embedded Foundation," J. of Geotechnical Eng., ASCE, 115 (9), 1227-1238.

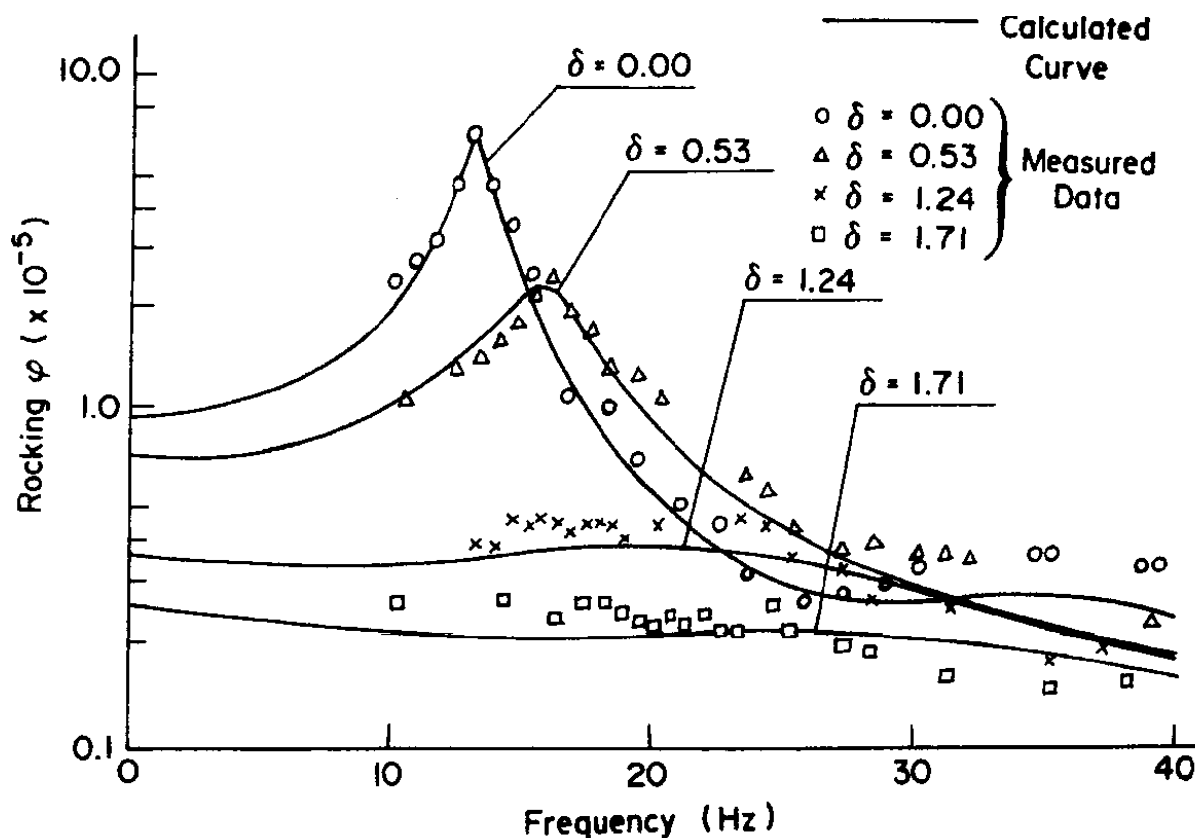


**Figure 5.9** Theoretical response curves calculated by Han (1989) and measured data for horizontal displacement at top of foundation

Dynamic experiments were conducted in the field to determine the behavior of an embedded foundation. The soil in situ was a sandy clay of yellow and brown color extending from the ground surface to a depth of 18 m. The soil properties within 5 m of the ground surface are: mass density,  $\rho = 1,700 \text{ kg/m}^3$ , void ratio,  $e = 0.95$ , Poisson's ratio,  $\nu = 0.3$ ; and shear wave velocity,  $V_s = 130\text{-}150 \text{ m/s}$ .

The experimental foundation consisted of a concrete block with dimensions of  $150 \times 150 \times 150 \text{ cm}^3$  and weight of 82.8 kN. The square foundation is regarded as circular footing with equivalent radius of 84.6 cm in analysis. The foundation was constructed in a pit 3.0 m long, 3.0 m wide and 1.5 m deep. The void between the foundation and the side soil was backfilled in three stages, at each stage about one third the depth of the pit was filled. Tests were conducted at four stages of backfill height: 0.00 cm,

45 cm, 105 cm and 145 cm. Thus, the embedment ratios used for testing were  $\delta = l/r_0 = 0.00, 0.53, 1.24$  and  $1.71$  respectively. As  $\delta = 0.00$ , the foundation is considered to rest on the surface of the elastic half-space.



**Figure 5.10** Theoretical response curves calculated by Han (1989) and measured data for rocking displacement of foundation

An exciter with two counter-rotating eccentric masses was used to produce horizontal harmonic excitation at the top of the foundation. The amplitude converted for the exciting force was 450 N in this analysis. The displacement pickups were arranged on top of the footing so as to measure the horizontal and rocking vibrations. The dynamic response of the foundation was measured for the four cases of embedment noted previously.

#### 5.4.2.2 Footing on homogeneous layer (Stratum)

For the option shown in Fig. 5.11, the footing rests on the surface of, or is embedded in, a shallow, homogeneous layer underlain by a rigid medium (bedrock). The layer stiffness and damping constants are calculated using the formulae due to Kausel and Ushijima (1979). The most prominent feature of this case is that the geometric damping of the foundation can be considerably reduced if the dominant frequency of the response is lower than the first natural frequency of the layer. The material damping becomes to be important and should be considered.

The range of problem parameters is limited. Such as, the ratio of embedment depth  $h$  with layer depth  $H$  should be  $h/H < 0.75$ , and  $R/H < 0.5$  (as shown in Fig. 5.11), where  $R$  is the equivalent radius of footing.

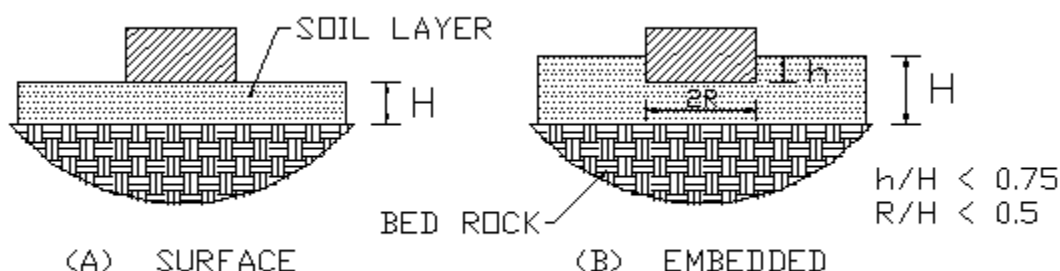


Figure 5.11 Footing on homogeneous layer (Stratum)

#### 5.4.2.3 Footing embedded in layered medium

This option as shown in Fig. 5.12 is for a rather deep footing such as a caisson that may be embedded in and underlain by a layered medium. The properties of the soil layers may be different but constant within each layer except for the soil column under the footing in which the soil properties may differ from those of the outer part of the layer. This feature makes it possible to take an approximate account of the increased confining pressure under the footing.

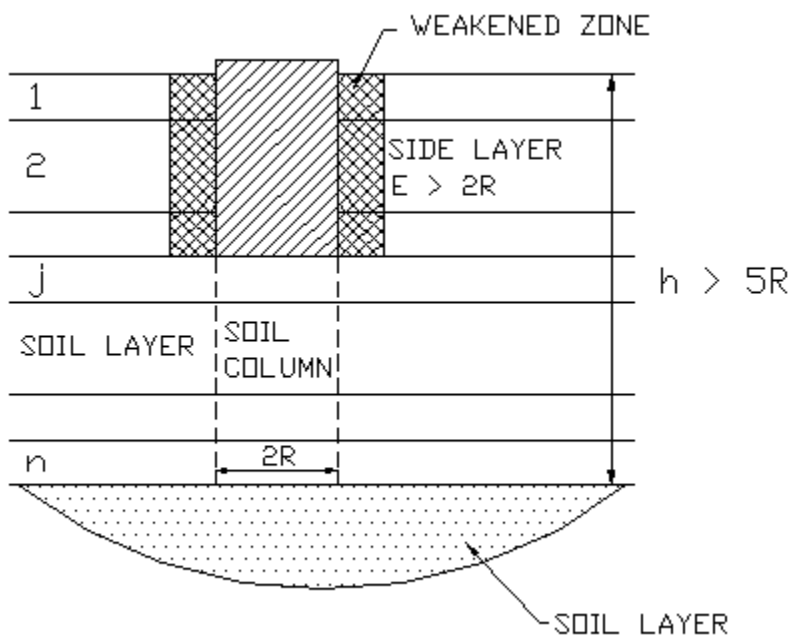


Figure 5.12 Footing embedded in multi-layered medium

This option is treated as a special case of a thick pile and should not be applied to a shallow foundation. For instance, the embedment depth of foundation  $E$  should be  $E/R > 2$  and the total foundation length  $h$  (included the soil column under the foundation) should be  $h > 5R$  (as shown in Fig. 5.12), where  $R$  is the equivalent radius of footing.

## 5.5 Dynamic Loading

A rigid body can be supported by any of the above types of foundation and be analyzed for the three types of loading. These are transient, random and harmonic loading. All loads are referred to the reference point, usually the center of gravity of the whole system (including the machine, if present) and can act in all six degree of freedom.

### 5.5.1 Transient Loading

An irregular but specific time history of limited duration, characterizes transient loading. Some machines such as crushers, pumps, hammers or presses and can cause such a loading, as well as by earthquakes, blasts, and explosions.

The response to transient loading is also transient and is calculated using the Fast Fourier Transform (FFT). Information on this method can be found from Clough and Penzien (1975).

The program returns the complete time history of the response in six degree of freedom as well as its maximum.

### 5.5.2 Random Loading

Random loading is characterized by an irregular time history, which is best described by the corresponding power spectral density (power spectrum). The random excitation included in DYNAN is assumed to be stationary, i.e., its statistical characteristics do not vary with time. This type of loading may stem, for example, from crushers, pumps, traffic, and wind and approximately from earthquakes.

Its power spectral density given for a number of points (frequencies) describes the excitation. The maximum number of data points is 200. The program returns the mean peak values of the response expected to occur during the period of observation  $T$ . This peak value of the response is

$$Q_i = g s_u \quad (5.4)$$

In which  $g$  is the peak factor and  $s_u$  is the standard deviation (rootmean-square value) of the response. The peak factor is calculated from the spectra. The period  $T$  may typically be 20 to 60 seconds for earthquakes and 600 to 3600 seconds for machine or wind loading.

### 5.5.3 Harmonic Loading

Harmonic loading is caused by unbalanced masses of rotating and reciprocating machines such as turbines, generators, compressors, fans, diesel engines and many others. It is the most common type of excitation. This excitation may have one harmonic component and consequently, a sinusoidal time history, or more harmonic components. If there are more harmonic components the response has to be calculated for each component separately and the results added.

In DYNAN, the harmonic excitation can be of two types: the constant amplitude excitation and the frequency dependent or quadratic excitation.

The constant amplitude excitation is defined as

$$P(t) = P_o \sin \omega t \quad (5.5)$$

In which  $P_o$  is the excitation force amplitude,  $\omega$  is the circular frequency of excitation and  $t$  is time.

The quadratic excitation is more often present and is usually caused by centrifugal forces of rotating unbalanced masses and is defined as

$$P(t) = m_e e \omega^2 \sin \omega t \quad (5.6)$$

In which  $m_e$  is unbalanced mass,  $e$  is eccentricity and  $\omega$  is circular frequency. This type of excitation is defined by  $m_e e$  and the frequency range.

## 5.6 Available Methods for Dynamic Analysis of Shallow and Deep Foundations.

Dynamic behaviors of foundations have been observed under earthquake, wind, blast, waves and vibrating machines. In many cases, a large dynamic response will cause the superstructure or the machine system to fail. A number of approaches are available to account for dynamic soil-pile interaction but they are usually based on the assumption that the soil behavior is governed by the law of linear elasticity or visco-elasticity and the soil is perfectly bonded to a pile. In practice, however, the bonding between the soil and the pile is rarely perfect and slippage or even separation often occurs in the contact area. Furthermore, the soil region immediately adjacent to the pile can undergo a large degree of straining, which would cause the soil-pile system to behave in a nonlinear manner.

### 5.6.1 Finite element or boundary element method

Many efforts have been spent on the numerical analysis to model the soil-pile interaction using the Finite Element Method (FEM) or boundary element method. Both the pile and the soil are modeled by solid elements. However, it is too complex, especially for group piles in nonlinear soil. A rigorous approach to the nonlinearity of a soil-pile system is extremely difficult and time consuming.

### 5.6.2 Impedance Function method

Both theoretical and experimental studies have shown that the dynamic response of piles is very sensitive to the properties of the soil in the vicinity of the pile shaft ( Han and Novak, 1988). The impedance functions are derived for the soil-pile system based on a boundary zone model with non-reflective interface by Han and Sabin (1995). The soil properties in the boundary zone (near field) may be different from that in the far field to indicate the nonlinearity of soil. The procedure is a half analytical and half numerical solution, and details are described by Han (1997). DYNAN program is

developed based on the impedance function method and uses the model of soil-structure interaction with nonreflective boundary between the near field and the far field to account for the nonlinearity of soil.

The program computes dynamic response of both shallow and deep foundations under dynamic loading. The foundation stiffness and damping constants are also computed for possible use in soil-structure interaction analysis for simulating the dynamic behavior of the structures (such as bridges, high-rise buildings, and wind-turbine towers). Soil layering, boundary zone around embedded foundations and piles, pile interaction in a group and other features can be considered in this method. To simplify the input data related to soil properties of the weak zone, the program only requires the user to enter the ratio of the weak-zone shear modulus over the non-weak-zone shear modulus in Version 3. The program will assume the thickness (lateral distance from the pile) of the weak zone is equal to the pile radius. The Poisson's ratio is unchanged.

The soil in the weak zone usually has a high damping ratio. Therefore, the program will use the damping ratio in the weak zone to be twice of the damping ratio in the original soil. The foundations (or caps of pile) are assumed to be rigid, and all six degrees of freedom are considered as coupled. It should be noted that, in most cases, the superstructures are flexible rather than rigid. The substructure concept based on the impedance function of foundations has been introduced in the structural analysis and is frequently used by the structural engineers for the time-history analysis in seismic studies. By means of the substructure method, the dynamic response of the superstructure is analyzed using a nonlinear finite-element program, such as SAP2000 or other similar one, and the real part and the imaginary part of the foundation stiffness generated by Dyna-N program being entered as the boundary condition, which represent the substructure in modeling..

The superstructure can be subject to harmonic, transient and random loading, and the stiffness and damping of the foundation can be generated in frequency domain from this program.

## CHAPTER 6. **Example Problems**



### 6.1 Example 1: Harmonic Load Applied to Half-Space (Embedded Foundation)

A reciprocating compressor was installed on a concrete block foundation (half-space), with a primary frequency of 7 Hz and a secondary frequency of 14 Hz. The dynamic response under the primary frequency is calculated in this example.

The foundation base is 7.5 m by 5.3 m with a thickness of 0.7 m, as shown in the figure. The embedment is 0.7 m. The shear wave velocity of the side soil is 150 m/s. The shear wave velocity of soil beneath the foundation is 205 m/s.

In this example, the unit for force is kN; for mass it is Mg and for length it is m. The total mass is 266.8 Mg (included machine mass). The height of C.G. (Center of Gravity) is 2.234 m. The nonquadratic harmonic response is calculated. Use SI units: kN, Mg = 1,000 kg, m.

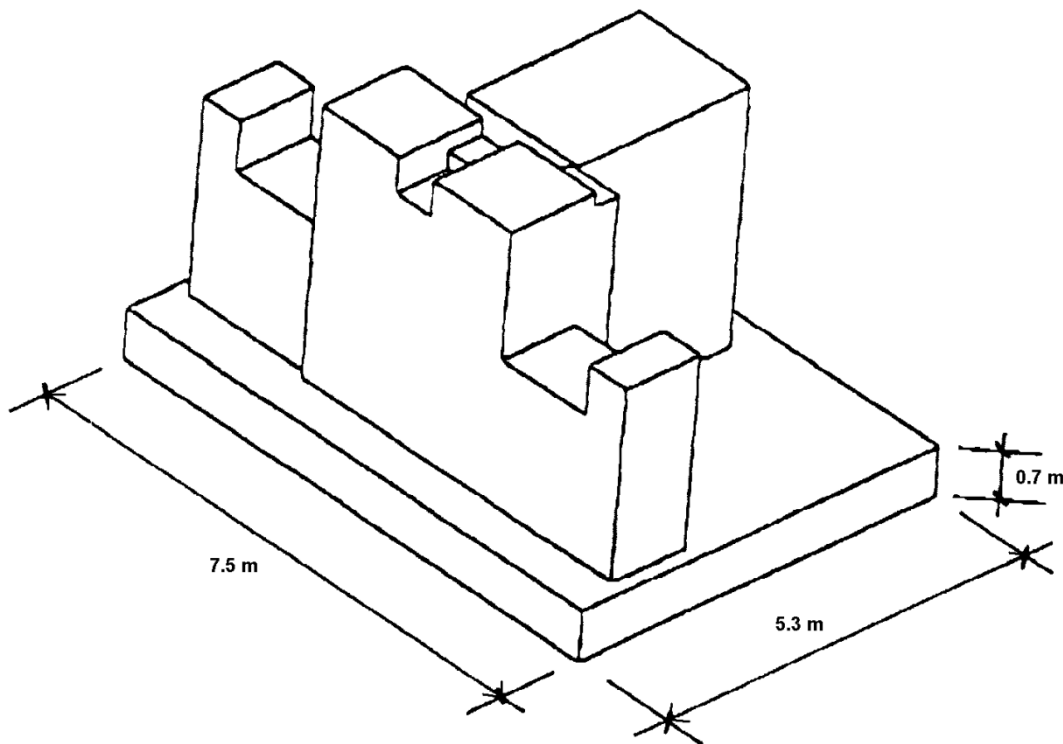


Figure 6.1 Dimension of the foundation for seismic response analysis demonstrated in Example 1

### 6.1.1 Input Data

```

TITLE= RECIPROCATING COMPRESSOR FOUNDATION (KN-Mg-m)
MATRIX
GRAVITY=9.8
FOUNDATION=HALF-SPACE
RECTANGULAR=7.5,5.3
MASS
266.8 1302 1552 1207 0 0 0
CONSTANTS
0 0.34 2.234
SOIL
WEAK
CONSTANTS=1
1 0.7 150 17 0.3 0.05 0.5 0.3 0.1 1
BELOW=205 18 0.3 0.05
LOAD
HARMONIC
CONSTANTS
NONQUADRATIC
125.6 6.28 6.28 0.805 0 0.378 7.802 6.357 -15.53
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.1.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

## RECIPROCATING COMPRESSOR FOUNDATION (KN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - HALF-SPACE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 7.500 m BY 5.300 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	.....	2.66800E+02	Mg
MASS MOMENT ABOUT X-AXIS	.....	1.30200E+03	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	.....	1.55200E+03	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	.....	1.20700E+03	Mg-m**2
CROSS PRODUCT X-Y	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	.....	0.00000E+00	Mg-m**2

HALF-SPACE FOUNDATION  
\*\*\*\*\*

X-LOCATION CENTRE OF GRAV	.....	0.00000	m
Y-LOCATION CENTRE OF GRAV	.....	0.34000	m
HEIGHT OF CENTRE OF GRAV	.....	2.23400	m

SOIL CONSTANTS NUMBER OF SIDE LAYERS - 1  
\*\*\*\*\*

LAYER NO.	LAYER DEPTH	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
	m	m/s	kN/m**3		
1	0.700	150.000	17.000	0.300	0.050

NONLINEARITY OF SOIL (WEAKENED ZONE)  
\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
1	0.500

HALF-SPACE SOIL  
\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
2.05E+02	18.0000	0.300	0.050

## RECIPROCATING COMPRESSOR FOUNDATION (KN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - HALF-SPACE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 7.500 m BY 5.300 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	2.66800E+02	Mg
MASS MOMENT ABOUT X-AXIS	1.30200E+03	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	1.55200E+03	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	1.20700E+03	Mg-m**2
CROSS PRODUCT X-Y	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	0.00000E+00	Mg-m**2

HALF-SPACE FOUNDATION  
\*\*\*\*\*

X-LOCATION CENTRE OF GRAV	0.00000	m
Y-LOCATION CENTRE OF GRAV	0.34000	m
HEIGHT OF CENTRE OF GRAV	2.23400	m

SOIL CONSTANTS NUMBER OF SIDE LAYERS - 1  
\*\*\*\*\*

LAYER NO.	LAYER DEPTH	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
	m	m/s	kN/m**3		
1	0.700	150.000	17.000	0.300	0.050

NONLINEARITY OF SOIL (WEAKENED ZONE)  
\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
1	0.500

HALF-SPACE SOIL  
\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
2.05E+02	18.0000	0.300	0.050

## HARMONIC LOAD, NON QUADRATIC

\*\*\*\*\*

MAXIMUM FREQUENCY ..... 2.000E+01 Hz  
 MINIMUM FREQUENCY ..... 1.000E+00 Hz  
 STEP FREQUENCY ..... 1.000E+00 Hz  
 FORCE IN X-DIRECTION ..... 8.050E-01 kN.  
 FORCE IN Y-DIRECTION ..... 0.000E+00 kN.  
 FORCE IN Z-DIRECTION ..... 3.780E-01 kN.  
 MOMENT ABOUT X-AXIS ..... 7.802E+00 kN-m  
 MOMENT ABOUT Y-AXIS ..... 6.357E+00 kN-m  
 MOMENT ABOUT Z-AXIS ..... -1.553E+01 kN-m

\*\*\*\*\*

```

*
*      S O I L - F O U N D A T I O N      *
*
*      D Y N A M I C   S I M U L A T I O N   *
*      D Y N A N
*
*      RUN DATE - 21-MAR-12
*      TIME    - 14:37:09
*      Copyright Canadian No.492911 - 2001/7/13
*
*
*****

```

RECIPROCATING COMPRESSOR FOUNDATION (KN-Mg-m)

## RESULTS

\*\*\*\*\*

FREQUENCY - 1.0000 Hz ( 6.2800 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) .. 1.36938E+06 kN/m  
 HORIZONTAL TRANSLATION (KYY) .. 1.36938E+06 kN/m  
 VERTICAL TRANSLATION (KWW) ... 1.60930E+06 kN/m  
 ROTATION (KPPX) ..... 1.79763E+07 kN-m/rad  
 ROTATION (KPPY) ..... 2.51842E+07 kN-m/rad  
 TORSION (KZT) ..... 2.28663E+07 kN-m/rad  
 CROSS-STIFFNESS (KXP) ..... 3.03133E+06 kN/rad  
 CROSS-STIFFNESS (KYP) ..... -3.03133E+06 kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) .. 2.16971E+04 kN/m/sec  
 HORIZONTAL TRANSLATION (CYY) .. 2.16971E+04 kN/m/sec  
 VERTICAL TRANSLATION (CWW) ... 2.48570E+04 kN/m/sec  
 ROTATION (CPPX) ..... 1.71574E+05 kN-m/rad/sec  
 ROTATION (CPPY) ..... 2.12495E+05 kN-m/rad/sec  
 TORSION (CZT) ..... 1.08133E+05 kN-m/rad/sec  
 CROSS-STIFFNESS (CXP) ..... 4.69692E+04 kN/rad/sec  
 CROSS-STIFFNESS (CYP) ..... -4.69692E+04 kN/rad/sec

FREQUENCY - 2.0000 Hz ( 12.5600 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	1.37579E+06	kN/m
HORIZONTAL TRANSLATION (KYY) ..	1.37579E+06	kN/m
VERTICAL TRANSLATION (KWW) ....	1.59990E+06	kN/m
ROTATION (KPPX) .....	1.78492E+07	kN-m/rad
ROTATION (KPPY) .....	2.49045E+07	kN-m/rad
TORSION (KZT) .....	2.26225E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	3.04262E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-3.04262E+06	kN/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.56636E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.56636E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ....	2.14454E+04	kN/m/sec
ROTATION (CPPX) .....	1.15205E+05	kN-m/rad/sec
ROTATION (CPPY) .....	1.37708E+05	kN-m/rad/sec
TORSION (CZT) .....	5.83851E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	3.43419E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-3.43419E+04	kN/rad/sec

FREQUENCY - 3.0000 Hz ( 18.8400 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	1.35329E+06	kN/m
HORIZONTAL TRANSLATION (KYY) ..	1.35329E+06	kN/m
VERTICAL TRANSLATION (KWW) ....	1.57913E+06	kN/m
ROTATION (KPPX) .....	1.75618E+07	kN-m/rad
ROTATION (KPPY) .....	2.43961E+07	kN-m/rad
TORSION (KZT) .....	2.22660E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.99942E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.99942E+06	kN/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.34281E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.34281E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ....	1.98352E+04	kN/m/sec
ROTATION (CPPX) .....	9.74547E+04	kN-m/rad/sec
ROTATION (CPPY) .....	1.16111E+05	kN-m/rad/sec
TORSION (CZT) .....	4.53761E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	2.97101E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-2.97101E+04	kN/rad/sec

FREQUENCY - 4.0000 Hz ( 25.1200 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	1.28975E+06	kN/m
HORIZONTAL TRANSLATION (KYY) ..	1.28975E+06	kN/m
VERTICAL TRANSLATION (KWW) ....	1.55013E+06	kN/m
ROTATION (KPPX) .....	1.70833E+07	kN-m/rad

ROTATION (KPPY) ..... 2.36506E+07 kN-m/rad  
 TORSION (KZT) ..... 2.18136E+07 kN-m/rad  
 CROSS-STIFFNESS (KXP) ..... 2.87891E+06 kN/rad  
 CROSS-STIFFNESS (KYP) ..... -2.87891E+06 kN/rad

#### DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) .. 1.25907E+04 kN/m/sec  
 HORIZONTAL TRANSLATION (CYY) .. 1.25907E+04 kN/m/sec  
 VERTICAL TRANSLATION (CWW) ... 1.91897E+04 kN/m/sec  
 ROTATION (CPPX) ..... 9.10348E+04 kN-m/rad/sec  
 ROTATION (CPPY) ..... 1.09683E+05 kN-m/rad/sec  
 TORSION (CZT) ..... 4.42956E+04 kN-m/rad/sec  
 CROSS-STIFFNESS (CXP) ..... 2.79223E+04 kN/rad/sec  
 CROSS-STIFFNESS (CYP) ..... -2.79223E+04 kN/rad/sec

#### RECIPROCATING COMPRESSOR FOUNDATION (KN-Mg-m)

#### RESULTS

\*\*\*\*\*

#### FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
1.00	6.28	1.8225E-06	1.6117E-06	4.8285E-07	7.2268E-07	4.4422E-07	6.9745E-07
2.00	12.56	1.9099E-06	1.7209E-06	5.0279E-07	7.5494E-07	4.6362E-07	7.1048E-07
3.00	18.84	2.0926E-06	1.9354E-06	5.4096E-07	8.1431E-07	4.9878E-07	7.3164E-07
4.00	25.12	2.4325E-06	2.3362E-06	6.0631E-07	9.1863E-07	5.5778E-07	7.6207E-07
5.00	31.40	3.0066E-06	3.0828E-06	7.2375E-07	1.1199E-06	6.5716E-07	8.0448E-07
6.00	37.68	3.7429E-06	4.4913E-06	9.5009E-07	1.5028E-06	8.1162E-07	8.5838E-07
7.00	43.96	5.4070E-06	8.9447E-06	1.6937E-06	2.7728E-06	1.1091E-06	9.3551E-07
8.00	50.24	6.2289E-06	2.3180E-05	4.4552E-06	7.5350E-06	1.4895E-06	9.9981E-07
9.00	56.52	1.0228E-05	9.0766E-06	1.4545E-06	2.4688E-06	2.3018E-06	1.0266E-06
10.00	62.80	6.0692E-06	4.0076E-06	7.0025E-07	1.0036E-06	1.3169E-06	8.9716E-07
11.00	69.08	3.8134E-06	2.6675E-06	5.3770E-07	6.5394E-07	8.2037E-07	9.6414E-07
12.00	75.36	2.5287E-06	1.9062E-06	5.1269E-07	5.8961E-07	5.2490E-07	8.9419E-07
13.00	81.64	2.0048E-06	1.5676E-06	4.1994E-07	5.0138E-07	4.1080E-07	5.9111E-07
14.00	87.92	1.5369E-06	1.2694E-06	3.8223E-07	4.6049E-07	3.0945E-07	4.4762E-07
15.00	94.20	1.2264E-06	9.8565E-07	3.5994E-07	4.9501E-07	3.0175E-07	4.8129E-07
16.00	100.48	1.1406E-06	8.1134E-07	2.9501E-07	4.4037E-07	2.0780E-07	1.1207E-06
17.00	106.76	8.3259E-07	7.7216E-07	2.4069E-07	3.4899E-07	3.1528E-07	6.5874E-07
18.00	113.04	7.2331E-07	6.7980E-07	2.2385E-07	3.4667E-07	2.6333E-07	2.5637E-07
19.00	119.32	6.0207E-07	5.5896E-07	2.0685E-07	3.5515E-07	2.5352E-07	1.9160E-07
20.00	125.60	4.6214E-07	3.7751E-07	1.8084E-07	3.5350E-07	2.6185E-07	2.3616E-07

## 6.2 Example 2: Harmonic Load Applied to Pile Foundation

The pile cap is a 2.5 m (length) by 1.6 m (width) by 0.5 m (thickness) concrete block, with a total mass of 5,000 kg. Six concrete piles are fixed to the cap, each with a diameter of 0.32 m and a length of 7.5 m.

The soil is divided into 8 layers. The top layer (0.25 m) is a void.

The dynamic pile-soil-pile interaction is accounted for. The horizontal response is calculated in a frequency domain from 5 Hz ( $\omega = 31.4$ ) to 30 Hz ( $\omega = 188.4$ )

Use SI units: kN, mg, m.

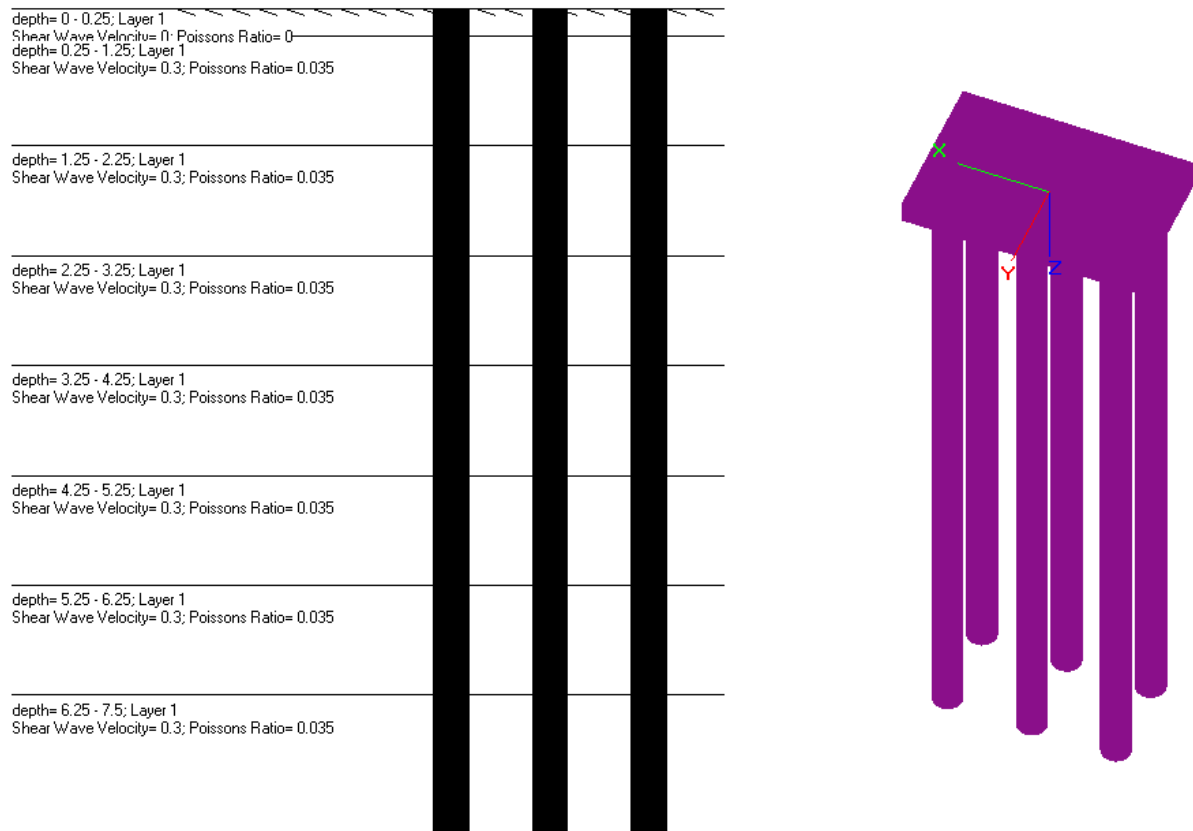


Figure 6.2 Pile foundation for dynamic response analysis demonstrated in Example 2

### 6.2.1 Input Data

TITLE=DYNAMIC RESPOSE OF PILE GROUP (kN-Mg-m)

MATRIX

GRAVITY=9.8

FOUNDATION=PILE

RECTANGULAR=2.5,1.6

MASS



```

5 1.17 2.71 3.87 0 0 0
LAYERS=8
FIXED=6
1 -0.9 0.45
2 0 0.45
3 0.9 0.45
4 0.9 -0.45
5 0 -0.45
6 -0.9 -0.45
CONSTANTS
0 0 0.26 7.5 24.5
50 0.25 0.01 1.334 27000000
ELEMENT
1 0.25 0.16 0.16 0.0804 0.000515 0.000515 0.00103
2 1 0.16 0.16 0.0804 0.000515 0.000515 0.00103
3 1 0.16 0.16 0.0804 0.000515 0.000515 0.00103
4 1 0.16 0.16 0.0804 0.000515 0.000515 0.00103
5 1 0.16 0.16 0.0804 0.000515 0.000515 0.00103
6 1 0.16 0.16 0.0804 0.000515 0.000515 0.00103
7 1 0.16 0.16 0.0804 0.000515 0.000515 0.00103
8 1.25 0.16 0.16 0.0804 0.000515 0.000515 0.00103
FLOATING
INTERACTION
SOIL
WEAK
CONSTANTS
1 0 0 0 0 0 0 1
2 130 20.2 0.3 0.035 0.5 0.3 0.07 1
3 193 20.2 0.3 0.035 0.5 0.3 0.07 1
4 200 18.5 0.3 0.035 0.5 0.3 0.07 1
5 180 18.5 0.3 0.035 0.5 0.3 0.07 1
6 234 19.7 0.3 0.035 0.5 0.3 0.07 1
7 272 19.7 0.3 0.035 0.5 0.3 0.07 1
8 272 20 0.3 0.035 0.5 0.3 0.07 1
BELOW=280 20 0.3 0.035
LOAD
HARMONIC
CONSTANTS
QUADRATIC
188.4 31.4 6.28 0 0.000259 0 -0.000114 0 0
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

## 6.2.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

DYNAMIC RESPOSE OF PILE GROUP (kN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - PILE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 2.500 m BY 1.600 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	.....	5.00000E+00	Mg
MASS MOMENT ABOUT X-AXIS	.....	1.17000E+00	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	.....	2.71000E+00	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	.....	3.87000E+00	Mg-m**2
CROSS PRODUCT X-Y	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	.....	0.00000E+00	Mg-m**2

NUMBER OF LAYERS OR ELEMENTS - 8  
\*\*\*\*\*

LOCATION OF PILES  
\*\*\*\*\*

PILE NO.	X LOCATION m	Y LOCATION m
1	-0.900	0.450
2	0.000	0.450
3	0.900	0.450
4	0.900	-0.450
5	0.000	-0.450
6	-0.900	-0.450

## PILE PROPERTIES

\*\*\*\*\*

X-LOCATION CENTRE OF GRAV. .... 0.00000 m  
 Y-LOCATION CENTRE OF GRAV. .... 0.00000 m  
 HEIGHT OF CENTRE OF GRAV. .... 0.26000 m  
 TOTAL LENGTH ..... 7.50000 m  
 UNIT WEIGHT ..... 24.50000 kN/m\*\*3  
 STATIC LOAD ON BODY ..... 5.00000E+01 kN.  
 POISSONS RATIO ..... 0.25000  
 MATERIAL DAMPING ..... 0.01000  
 COEFF. OF RIGIDITY ..... 1.33400  
 YOUNGS MODULUS ..... 2.70000E+07 kPa

## ELEMENT

\*\*\*\*\*

LAYER NO.	LAYER DEPTH m	PILE RADIUS (X) m	PILE RADIUS (Y) m	CROSS SECTIONAL AREA m**2	MOMENT OF INERTIA '(X) m**4	MOMENT OF INERTIA (Y) m**4	TORSIONAL STIFFNESS m**4
1	0.250	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
2	1.000	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
3	1.000	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
4	1.000	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
5	1.000	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
6	1.000	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
7	1.000	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03
8	1.250	0.160	0.160	8.040E-02	5.150E-04	5.150E-04	1.03E-03

## SOIL CONSTANTS

\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY m/s	UNIT WEIGHT kN/m**3	POISSONS RATIO	MATERIAL DAMPING
1	0.000	0.000	0.000	0.000
2	130.000	20.200	0.300	0.035
3	193.000	20.200	0.300	0.035
4	200.000	18.500	0.300	0.035
5	180.000	18.500	0.300	0.035
6	234.000	19.700	0.300	0.035
7	272.000	19.700	0.300	0.035
8	272.000	20.000	0.300	0.035

## NONLINEARITY OF SOIL (WEAKENED ZONE)

\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
1	0.000
2	0.500
3	0.500
4	0.500
5	0.500
6	0.500
7	0.500
8	0.500

## SOIL BELOW PILE

\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
2.80E+02	20.0000	0.300	0.035

## HARMONIC LOAD, QUADRATIC

\*\*\*\*\*

MAXIMUM FREQUENCY	3.000E+01	Hz
MINIMUM FREQUENCY	5.000E+00	Hz
STEP FREQUENCY	1.000E+00	Hz
FORCE COEFF. IN X-DIRECTION	0.000E+00	Mg-m
FORCE COEFF. IN Y-DIRECTION	2.590E-04	Mg-m
FORCE COEFF. IN Z-DIRECTION	0.000E+00	Mg-m
MOMENT COEFF. ABOUT X-AXIS	-1.140E-04	Mg-m**2
MOMENT COEFF. ABOUT Y-AXIS	0.000E+00	Mg-m**2
MOMENT COEFF. ABOUT Z-AXIS	0.000E+00	Mg-m**2

```

*****
*                                     *
*           S O I L - F O U N D A T I O N           *
*                                     *
*           D Y N A M I C   S I M U L A T I O N       *
*                                     *
*                                     *
*                                     *
*           RUN DATE - 22-MAR-12                     *
*           TIME    - 16:04:30                       *
*           Copyright Canadian No.492911 - 2001/7/13 *
*                                     *
*****

```

## DYNAMIC RESPOSE OF PILE GROUP (kN-Mg-m)

## RESULTS

\*\*\*\*\*

FREQUENCY - 5.0000 Hz ( 31.4000 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX)	1.48084E+05	kN/m
HORIZONTAL TRANSLATION (KYY)	1.58020E+05	kN/m
VERTICAL TRANSLATION (KWW)	9.68566E+05	kN/m
ROTATION (KPPX)	8.82724E+05	kN-m/rad
ROTATION (KPPY)	1.70445E+06	kN-m/rad
TORSION (KZT)	2.49211E+05	kN-m/rad
CROSS-STIFFNESS (KXP)	1.40843E+05	kN/rad
CROSS-STIFFNESS (KYP)	-1.34349E+05	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX)	5.69305E+02	kN/m/sec
HORIZONTAL TRANSLATION (CYY)	6.21632E+02	kN/m/sec
VERTICAL TRANSLATION (CWW)	2.04594E+03	kN/m/sec

```

ROTATION (CPPX) ..... 1.14968E+02 kN-m/rad/sec
ROTATION (CPY) ..... 1.52918E+03 kN-m/rad/sec
TORSION (CZT) ..... 5.92594E+02 kN-m/rad/sec
CROSS-STIFFNESS (CXP) ..... 4.58830E+02 kN/rad/sec
CROSS-STIFFNESS (CYP) ..... -4.25740E+02 kN/rad/sec

```

FREQUENCY - 6.0000 Hz ( 37.6800 rad./sec.)

\*\*\*\*\*

#### STIFFNESS CONSTANTS (K)

\*\*\*\*\*

```

HORIZONTAL TRANSLATION (KXX) .. 1.48245E+05 kN/m
HORIZONTAL TRANSLATION (KYY) .. 1.58241E+05 kN/m
VERTICAL TRANSLATION (KWW) ... 9.80709E+05 kN/m
ROTATION (KPPX) ..... 8.86458E+05 kN-m/rad
ROTATION (KPPY) ..... 1.70765E+06 kN-m/rad
TORSION (KZT) ..... 2.49551E+05 kN-m/rad
CROSS-STIFFNESS (KXP) ..... 1.41151E+05 kN/rad
CROSS-STIFFNESS (KYP) ..... -1.34598E+05 kN/rad

```

#### DAMPING CONSTANTS (C)

\*\*\*\*\*

```

HORIZONTAL TRANSLATION (CXX) .. 5.76877E+02 kN/m/sec
HORIZONTAL TRANSLATION (CYY) .. 6.28690E+02 kN/m/sec
VERTICAL TRANSLATION (CWW) ... 2.25558E+03 kN/m/sec
ROTATION (CPPX) ..... 1.88357E+02 kN-m/rad/sec
ROTATION (CPY) ..... 1.55390E+03 kN-m/rad/sec
TORSION (CZT) ..... 5.67400E+02 kN-m/rad/sec
CROSS-STIFFNESS (CXP) ..... 4.65094E+02 kN/rad/sec
CROSS-STIFFNESS (CYP) ..... -4.32274E+02 kN/rad/sec

```

FREQUENCY - 7.0000 Hz ( 43.9600 rad./sec.)

\*\*\*\*\*

#### STIFFNESS CONSTANTS (K)

\*\*\*\*\*

```

HORIZONTAL TRANSLATION (KXX) .. 1.48403E+05 kN/m
HORIZONTAL TRANSLATION (KYY) .. 1.58454E+05 kN/m
VERTICAL TRANSLATION (KWW) ... 9.92580E+05 kN/m
ROTATION (KPPX) ..... 8.89509E+05 kN-m/rad
ROTATION (KPPY) ..... 1.70882E+06 kN-m/rad
TORSION (KZT) ..... 2.49998E+05 kN-m/rad
CROSS-STIFFNESS (KXP) ..... 1.41469E+05 kN/rad
CROSS-STIFFNESS (KYP) ..... -1.34863E+05 kN/rad

```

#### DAMPING CONSTANTS (C)

\*\*\*\*\*

```

HORIZONTAL TRANSLATION (CXX) .. 5.81785E+02 kN/m/sec
HORIZONTAL TRANSLATION (CYY) .. 6.33208E+02 kN/m/sec
VERTICAL TRANSLATION (CWW) ... 2.41655E+03 kN/m/sec
ROTATION (CPPX) ..... 2.30114E+02 kN-m/rad/sec
ROTATION (CPY) ..... 1.53772E+03 kN-m/rad/sec
TORSION (CZT) ..... 5.48111E+02 kN-m/rad/sec
CROSS-STIFFNESS (CXP) ..... 4.69110E+02 kN/rad/sec
CROSS-STIFFNESS (CYP) ..... -4.36517E+02 kN/rad/sec

```

DYNAMIC RESPOSE OF PILE GROUP (kN-Mg-m)

RESULTS  
\*\*\*\*\*

FOOTING RESPONSE AMPLITUDES

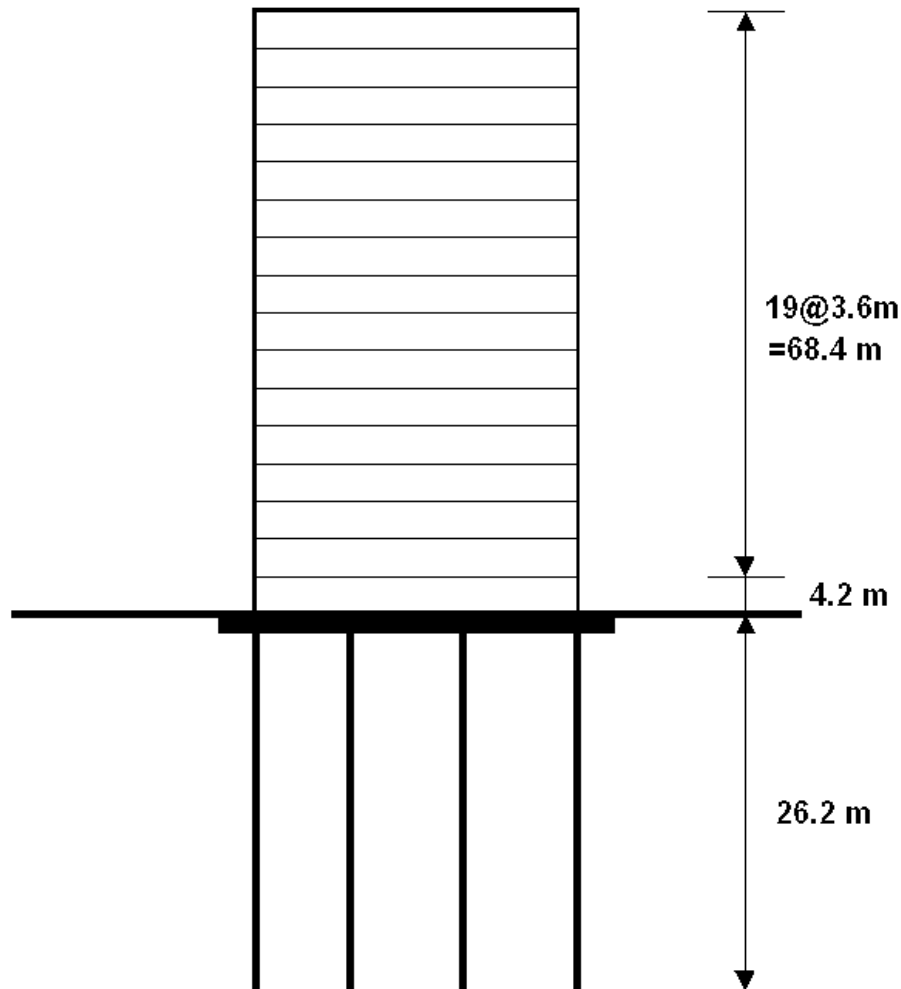
FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
5.00	31.40	7.1105E-15	2.0757E-06	5.4442E-15	4.6254E-07	7.5593E-15	9.5773E-14
6.00	37.68	3.4276E-14	3.0213E-06	1.5094E-14	6.7221E-07	3.5836E-14	2.7306E-14
7.00	43.96	4.0658E-14	4.1676E-06	6.5684E-15	9.2665E-07	4.1679E-14	2.9296E-13
8.00	50.24	7.7629E-16	5.5306E-06	5.8783E-14	1.2301E-06	7.7792E-16	3.8616E-13
9.00	56.52	2.0883E-14	7.1325E-06	1.4254E-13	1.5895E-06	2.0398E-14	1.0014E-13
10.00	62.80	7.3832E-14	8.9994E-06	8.0107E-14	2.0121E-06	7.0099E-14	1.3691E-13
11.00	69.08	2.0790E-14	1.1162E-05	1.3733E-13	2.5067E-06	1.9133E-14	1.1415E-12
12.00	75.36	7.9727E-14	1.3660E-05	1.4049E-13	3.0838E-06	7.0932E-14	1.8463E-13
13.00	81.64	2.3280E-13	1.6537E-05	5.4536E-14	3.7558E-06	1.9973E-13	4.3629E-13
14.00	87.92	6.8274E-14	1.9845E-05	2.1826E-13	4.5375E-06	5.6357E-14	1.0612E-12
15.00	94.20	2.9341E-13	2.3651E-05	9.8977E-14	5.4462E-06	2.3253E-13	1.3059E-12
16.00	100.48	5.0695E-13	2.8023E-05	1.3715E-13	6.5018E-06	3.8505E-13	2.7140E-12
17.00	106.76	1.6781E-13	3.3042E-05	1.8369E-13	7.7267E-06	1.2200E-13	2.8560E-12
18.00	113.04	4.9927E-13	3.8792E-05	3.4897E-13	9.1449E-06	3.4719E-13	2.3183E-12
19.00	119.32	2.0582E-13	4.5349E-05	5.7236E-13	1.0780E-05	1.3692E-13	9.9399E-13
20.00	125.60	3.9518E-13	5.2890E-05	7.5860E-13	1.2664E-05	2.5149E-13	1.3056E-12
21.00	131.88	4.5520E-13	6.1499E-05	5.4263E-13	1.4820E-05	2.7735E-13	1.1461E-12
22.00	138.16	9.4868E-13	7.1065E-05	1.4062E-13	1.7232E-05	5.5516E-13	9.6875E-12
23.00	144.44	1.2998E-12	8.1361E-05	1.7887E-12	1.9849E-05	7.3428E-13	6.0453E-12
24.00	150.72	1.0353E-12	9.1911E-05	8.1426E-13	2.2558E-05	5.6875E-13	1.0325E-11
25.00	157.00	6.3603E-13	1.0195E-04	4.3150E-13	2.5171E-05	3.4301E-13	1.8202E-11
26.00	163.28	5.6751E-13	1.1054E-04	1.6686E-12	2.7454E-05	3.0388E-13	8.7344E-12
27.00	169.56	1.0868E-12	1.1684E-04	6.8786E-13	2.9190E-05	5.8501E-13	1.2068E-11
28.00	175.84	7.7272E-13	1.2042E-04	1.2915E-12	3.0263E-05	4.2347E-13	6.6250E-12
29.00	182.12	1.7866E-12	1.2139E-04	1.0269E-12	3.0691E-05	1.0086E-12	9.7591E-12
30.00	188.40	2.0092E-12	1.2028E-04	1.0232E-12	3.0595E-05	1.1805E-12	1.7669E-11

### 6.3 Example 3: Pile Foundation of a Tall Building

To calculate the seismic response of a 20-story building as shown in Figure 6.3, a substructure method is used. The detailed analysis is described by Han and Cathro (1997), "Seismic Behavior of Tall Buildings Supported on Pile Foundations", ASCE, Geotechnical Special Publication No. 70, 36-51.

In this example, the stiffness and damping of the pile foundation are shown. The pile cap is a 11.5 m (length) by 11.5 m (width) by 1.2 m (thickness) concrete block, with a mass of 387,000 kg. Twenty-five concrete piles are fixed to the cap, each with a diameter of 0.4 m and a length of 24 m.

The soil is divided into 7 layers. The boundary zone around the pile is included to simulate a seismic environment. The dynamic pile-soil-pile interaction is accounted for. The stiffness and damping of pile group are shown at a frequency  $W = 5.0$  (0.8 Hz) that is a main frequency for the seismic input in this case.



**Figure 6.3** Foundation dimension for seismic response analysis demonstrated in Example 3

### 6.3.1 Input Data

TITLE=PILE FD. OF TALL BUILDING (kN-Mg-m)

MATRIX

GRAVITY=9.8

FOUNDATION=PILE

RECTANGULAR=11.5,11.5

MASS

387 4450 4450 8530 0 0 0

LAYERS=7

FIXED=25

1 -5.5 5.5

2 -2.75 5.5

3 0 5.5

4 2.75 5.5

5 5.5 5.5

6 -5.5 2.75

7 -2.75 2.75

8 0 2.75

9 2.75 2.75

10 5.5 2.75

11 -5.5 0

12 -2.75 0

13 0 0

14 2.75 0

15 5.5 0

16 -5.5 -2.75

17 -2.75 -2.75

18 0 -2.75

19 2.75 -2.75

20 5.5 -2.75

21 -5.5 -5.5

22 -2.75 -5.5

23 0 -5.5

24 2.75 -5.5

25 5.5 -5.5

CONSTANTS

0 0 0.6 24 24

886 0.25 0.02 1.334 27000000

ELEMENT

1 2 0.2 0.2 0.1256 0.001256 0.001256 0.002512

2 2 0.2 0.2 0.1256 0.001256 0.001256 0.002512

3 3 0.2 0.2 0.1256 0.001256 0.001256 0.002512

4 5 0.2 0.2 0.1256 0.001256 0.001256 0.002512

5 3 0.2 0.2 0.1256 0.001256 0.001256 0.002512

6 7 0.2 0.2 0.1256 0.001256 0.001256 0.002512

7 2 0.2 0.2 0.1256 0.001256 0.001256 0.002512



```

FLOATING
INTERACTION
SOIL
WEAK
CONSTANTS
1 0 19 0.3 0.05 0.25 0.3 0.1 1
2 90 18 0.3 0.05 0.25 0.3 0.1 1
3 150 19.5 0.3 0.05 0.25 0.3 0.1 1
4 180 19.5 0.3 0.05 0.25 0.3 0.1 1
5 210 18 0.3 0.05 0.25 0.3 0.1 1
6 210 19 0.3 0.05 0.25 0.3 0.1 1
7 240 20 0.3 0.05 0.25 0.3 0.1 1
BELOW=460 22 0.3 0.05
LOAD
HARMONIC
CONSTANTS
QUADRATIC
25 5 1 0 1 0 0 0 0
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.3.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

FILE FD. OF TALL BUILDING (kN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - PILE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 11.500 m BY 11.500 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	.....	3.87000E+02	Mg
MASS MOMENT ABOUT X-AXIS	.....	4.45000E+03	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	.....	4.45000E+03	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	.....	8.53000E+03	Mg-m**2
CROSS PRODUCT X-Y	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	.....	0.00000E+00	Mg-m**2

NUMBER OF LAYERS OR ELEMENTS - 7  
\*\*\*\*\*

LOCATION OF PILES  
\*\*\*\*\*

FILE NO.	X LOCATION m	Y LOCATION m
1	-5.500	5.500
2	-2.750	5.500
3	0.000	5.500
4	2.750	5.500
5	5.500	5.500
6	-5.500	2.750
7	-2.750	2.750
8	0.000	2.750
9	2.750	2.750
10	5.500	2.750
11	-5.500	0.000
12	-2.750	0.000
13	0.000	0.000
14	2.750	0.000
15	5.500	0.000

16	-5.500	-2.750
17	-2.750	-2.750
18	0.000	-2.750
19	2.750	-2.750
20	5.500	-2.750
21	-5.500	-5.500
22	-2.750	-5.500
23	0.000	-5.500
24	2.750	-5.500
25	5.500	-5.500

## FILE PROPERTIES

\*\*\*\*\*

X-LOCATION CENTRE OF GRAV. .... 0.00000 m  
 Y-LOCATION CENTRE OF GRAV. .... 0.00000 m  
 HEIGHT OF CENTRE OF GRAV. .... 0.60000 m  
 TOTAL LENGTH ..... 24.00000 m  
 UNIT WEIGHT ..... 24.00000 kN/m\*\*3  
 STATIC LOAD ON BODY ..... 8.86000E+02 kN.  
 POISSONS RATIO ..... 0.25000  
 MATERIAL DAMPING ..... 0.02000  
 COEFF. OF RIGIDITY ..... 1.33400  
 YOUNGS MODULUS ..... 2.70000E+07 kPa

## ELEMENT

\*\*\*\*\*

LAYER NO.	LAYER DEPTH m	PILE RADIUS (X) m	PILE RADIUS (Y) m	CROSS SECTIONAL AREA m**2	MOMENT OF INERTIA ' (X) m**4	MOMENT OF INERTIA (Y) m**4	TORSIONAL STIFFNESS m**4
1	2.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03
2	2.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03
3	3.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03
4	5.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03
5	3.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03
6	7.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03
7	2.000	0.200	0.200	1.256E-01	1.256E-03	1.256E-03	2.51E-03

## SOIL CONSTANTS

\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY m/s	UNIT WEIGHT kN/m**3	POISSONS RATIO	MATERIAL DAMPING
1	0.000	19.000	0.300	0.050
2	90.000	18.000	0.300	0.050
3	150.000	19.500	0.300	0.050
4	180.000	19.500	0.300	0.050
5	210.000	18.000	0.300	0.050
6	210.000	19.000	0.300	0.050
7	240.000	20.000	0.300	0.050

## NONLINEARITY OF SOIL (WEAKENED ZONE)

\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
-----------	---------------------

1	0.250
2	0.250

```

3      0.250
4      0.250
5      0.250
6      0.250
7      0.250

```

## SOIL BELOW PILE

\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
4.60E+02	22.0000	0.300	0.050

## HARMONIC LOAD, QUADRATIC

\*\*\*\*\*

```

MAXIMUM FREQUENCY ..... 3.981E+00 Hz
MINIMUM FREQUENCY ..... 7.962E-01 Hz
STEP FREQUENCY ..... 1.592E-01 Hz
FORCE COEFF. IN X-DIRECTION ... 0.000E+00 Mg-m
FORCE COEFF. IN Y-DIRECTION ... 1.000E+00 Mg-m
FORCE COEFF. IN Z-DIRECTION ... 0.000E+00 Mg-m
MOMENT COEFF. ABOUT X-AXIS .... 0.000E+00 Mg-m**2
MOMENT COEFF. ABOUT Y-AXIS .... 0.000E+00 Mg-m**2
MOMENT COEFF. ABOUT Z-AXIS .... 0.000E+00 Mg-m**2

```

```

*****
*                               *
*      S O I L - F O U N D A T I O N      *
*                               *
*      D Y N A M I C   S I M U L A T I O N      *
*      D Y N A N                               *
*                               *
*      RUN DATE - 22-MAR-12                      *
*      TIME    - 16:19:28                      *
*      Copyright Canadian No.492911 - 2001/7/13 *
*                               *
*****

```

FILE FD. OF TALL BUILDING (kN-Mg-m)

## RESULTS

\*\*\*\*\*

FREQUENCY - 0.7962 Hz ( 5.0000 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

```

HORIZONTAL TRANSLATION (KXX) .. 9.80944E+04 kN/m
HORIZONTAL TRANSLATION (KYY) .. 9.80943E+04 kN/m
VERTICAL TRANSLATION (KWW) .... 1.90863E+06 kN/m
ROTATION (KPPX) ..... 8.25860E+07 kN-m/rad
ROTATION (KPPY) ..... 8.25860E+07 kN-m/rad
TORSION (KZT) ..... 4.83050E+06 kN-m/rad
CROSS-STIFFNESS (KXP) ..... 2.41715E+05 kN/rad
CROSS-STIFFNESS (KYP) ..... -2.41715E+05 kN/rad

```

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	7.63921E+02	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	7.63922E+02	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	4.49567E+03	kN/m/sec
ROTATION (CPPX) .....	1.96862E+05	kN-m/rad/sec
ROTATION (CPPY) .....	1.96862E+05	kN-m/rad/sec
TORSION (CZT) .....	3.76435E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.59641E+03	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.59641E+03	kN/rad/sec

FREQUENCY - 0.9554 Hz ( 6.0000 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	9.80442E+04	kN/m
HORIZONTAL TRANSLATION (KYY) ..	9.80443E+04	kN/m
VERTICAL TRANSLATION (KWW) ...	1.90854E+06	kN/m
ROTATION (KPPX) .....	8.25822E+07	kN-m/rad
ROTATION (KPPY) .....	8.25822E+07	kN-m/rad
TORSION (KZT) .....	4.82898E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.41647E+05	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.41647E+05	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	6.73987E+02	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	6.73986E+02	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.88639E+03	kN/m/sec
ROTATION (CPPX) .....	1.70198E+05	kN-m/rad/sec
ROTATION (CPPY) .....	1.70198E+05	kN-m/rad/sec
TORSION (CZT) .....	3.32537E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.40117E+03	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.40117E+03	kN/rad/sec

FREQUENCY - 1.1146 Hz ( 7.0000 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	9.79819E+04	kN/m
HORIZONTAL TRANSLATION (KYY) ..	9.79819E+04	kN/m
VERTICAL TRANSLATION (KWW) ...	1.90844E+06	kN/m
ROTATION (KPPX) .....	8.25778E+07	kN-m/rad
ROTATION (KPPY) .....	8.25778E+07	kN-m/rad
TORSION (KZT) .....	4.82702E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.41556E+05	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.41556E+05	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	6.09622E+02	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	6.09622E+02	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.45120E+03	kN/m/sec

PILE FD. OF TALL BUILDING (kN-Mg-m)

RESULTS  
\*\*\*\*\*

FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
0.80	5.00	1.1569E-14	2.8476E-04	7.7678E-13	8.3544E-07	4.2315E-15	4.2629E-12
0.96	6.00	5.3878E-14	4.3114E-04	1.5655E-13	1.2655E-06	1.8752E-14	3.6855E-12
1.11	7.00	7.1982E-13	6.2481E-04	1.0644E-13	1.8349E-06	2.3550E-13	7.3539E-12
1.27	8.00	2.0186E-13	8.8190E-04	1.0747E-12	2.5914E-06	6.1173E-14	3.1334E-12
1.43	9.00	4.9582E-13	1.2284E-03	5.4185E-13	3.6118E-06	1.3671E-13	2.2754E-12
1.59	10.00	5.4479E-13	1.7084E-03	2.5217E-12	5.0266E-06	1.3358E-13	4.0841E-11
1.75	11.00	2.4883E-13	2.3155E-03	1.0916E-12	7.2130E-06	5.3519E-14	1.2911E-11
1.91	12.00	9.0531E-12	3.2865E-03	3.4709E-12	1.0336E-05	1.6334E-12	9.2612E-11
2.07	13.00	5.2529E-12	4.8384E-03	2.4188E-12	1.5369E-05	7.5711E-13	9.3157E-11
2.23	14.00	1.9574E-11	7.5304E-03	8.0443E-12	2.4175E-05	2.1118E-12	3.0947E-10
2.39	15.00	5.9973E-12	1.2169E-02	2.8938E-11	3.9508E-05	4.6136E-13	1.2762E-10
2.55	16.00	4.7510E-11	1.5674E-02	5.1006E-11	5.1490E-05	3.1560E-12	8.1286E-11
2.71	17.00	2.6522E-11	1.2806E-02	2.4025E-11	4.2587E-05	2.3672E-12	4.7724E-10
2.87	18.00	1.5269E-12	9.6363E-03	5.2237E-12	3.2458E-05	2.0168E-13	1.6439E-10
3.03	19.00	3.3653E-12	7.7054E-03	1.3284E-11	2.6290E-05	6.1820E-13	4.0801E-10
3.18	20.00	7.6498E-12	6.5139E-03	1.4495E-11	2.2501E-05	1.8393E-12	2.1681E-10
3.34	21.00	3.7531E-12	5.7265E-03	9.1686E-12	2.0036E-05	1.1294E-12	1.2593E-10
3.50	22.00	1.0684E-12	5.1743E-03	6.6853E-13	1.8344E-05	3.8960E-13	1.6948E-10
3.66	23.00	4.1595E-13	4.7683E-03	6.2859E-12	1.7128E-05	1.7939E-13	4.2450E-10
3.82	24.00	1.7421E-12	4.4588E-03	1.6467E-11	1.6228E-05	8.7205E-13	2.0749E-10
3.98	25.00	8.0344E-13	4.2159E-03	6.9259E-12	1.5551E-05	4.5997E-13	5.1859E-11

### 6.4 Example 4: Seismic Loads applied to Half-Space Foundation (Transient Load)

A 2-story concrete frame structure is seated on a homogeneous halfspace. A substructure method can be used to calculate the seismic or dynamic response of the flexible superstructure. A detailed analysis procedure is described by Han et al (1999) "Design of an Elevated Compressor Table Top Structure Considering Soil-Pile-Structure Interaction", 27 Annual Conference of Canadian Society for Civil Engineering, 291-300.

In this example, the frame is assumed as a rigid structure in order to show how to use the program for calculating the seismic response of a half-space foundation (transient load).

The foundation is a concrete block that is 5 m (length) by 5 m (width) by 1.0 m (thickness). The total mass of frame structure and foundation is 152.5 mg, and the height of C.G. is 2.81 m.

The foundation rests on half-space. The depth of the embedded side soil is 1.0 m.

A seismic time history record is used as transient load input. The number of points is 1024, and the time interval between points is 0.02 second. One type of load is input, horizontal force in y-direction. The 1024 input loads are the ground acceleration multiplied by mass.

Use SI units: kN, Mg, m.

#### 6.4.1 Input Data

```
TITLE= SEISMIC LOADS HALF-SPACE (kN-Mg-m)
MATRIX
GRAVITY=9.8
FOUNDATION=HALF-SPACE
RECTANGULAR=5,5
MASS
152.5 1151 1151 600.4 0 0 0
CONSTANTS
0 0 2.81
SOIL
CONSTANTS=1
1 1 120 17 0.3 0.05
BELOW=180 18 0.3 0.05
LOAD
TRANSIENT
CONSTANTS
1024
0.02
1
2
839.70636
404.30304
```

-1057.408  
-248.80188  
217.70165  
-622.0047  
-31.100235  
342.10257  
-186.60141  
-870.80658  
-559.8042  
-497.60376  
-1586.1119  
-2799.0212  
-2239.2168  
-373.20282  
1368.4103  
2177.0164  
1648.3124  
-62.20047  
-1586.1119  
-2674.6204  
-2394.718  
-497.60376  
901.9068  
653.10492  
124.40094  
901.9068  
2145.9163

-----  
-----

---



### 6.4.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

SEISMIC LOADS HALF-SPACE (kN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - HALF-SPACE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 5.000 m BY 5.000 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	1.52500E+02	Mg
MASS MOMENT ABOUT X-AXIS	1.15100E+03	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	1.15100E+03	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	6.00400E+02	Mg-m**2
CROSS PRODUCT X-Y	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	0.00000E+00	Mg-m**2

HALF-SPACE FOUNDATION  
\*\*\*\*\*

X-LOCATION CENTRE OF GRAV	0.00000	m
Y-LOCATION CENTRE OF GRAV	0.00000	m
HEIGHT OF CENTRE OF GRAV	2.81000	m

SOIL CONSTANTS NUMBER OF SIDE LAYERS - 1  
\*\*\*\*\*

LAYER NO.	LAYER DEPTH m	SHEAR WAVE VELOCITY m/s	UNIT WEIGHT kN/m**3	POISSON'S RATIO	MATERIAL DAMPING
1	1.000	120.000	17.000	0.300	0.050

HALF-SPACE SOIL  
\*\*\*\*\*

SHEAR WAVE VELOCITY m/s	UNIT WEIGHT kN/m**3	POISSON'S RATIO	MATERIAL DAMPING
1.80E+02	18.0000	0.300	0.050

## TRANSIENT LOAD

\*\*\*\*\*

NUMBER OF POINTS ..... 1024  
 TIME INTERVAL BETWEEN POINTS ... 0.020  
 NUMBER OF LOADS ..... 1

LOAD TYPE CODE - 2 (FORCE IN Y-DIRECTION)

LOAD AMPLITUDES kN.

8.397E+02  
 4.043E+02  
 -1.057E+03  
 -2.488E+02  
 2.177E+02  
 -6.220E+02  
 -3.110E+01  
 3.421E+02  
 -1.866E+02  
 -8.708E+02  
 -5.598E+02  
 -4.976E+02  
 -1.586E+03  
 -2.799E+03  
 -2.239E+03  
 -3.732E+02  
 1.368E+03  
 2.177E+03  
 1.648E+03  
 -6.220E+01  
 -1.586E+03  
 -2.675E+03  
 -2.395E+03  
 -4.976E+02  
 9.019E+02  
 6.531E+02  
 1.244E+02  
 9.019E+02  
 2.146E+03  
 2.612E+03  
 1.057E+03  
 1.244E+02  
 5.598E+02  
 -4.665E+02  
 -2.146E+03  
 -1.959E+03  
 3.110E+01  
 7.153E+02  
 1.026E+03  
 2.644E+03  
 3.328E+03  
 2.270E+03  
 1.648E+03  
 1.244E+03  
 7.775E+02  
 -3.732E+02  
 -2.737E+03  
 -4.074E+03  
 -2.053E+03  
 -6.842E+02  
 1.244E+02  
 1.866E+03  
 1.742E+03

## SEISMIC LOADS HALF-SPACE (kN-Mg-m)

## RESULTS

\*\*\*\*\*

FREQUENCY - 0.0016 Hz ( 0.0100 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	8.74819E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	8.74819E+05	kN/m
VERTICAL TRANSLATION (KWW) ....	9.98982E+05	kN/m
ROTATION (KPPX) .....	1.26049E+07	kN-m/rad
ROTATION (KPPY) .....	1.26049E+07	kN-m/rad
TORSION (KZT) .....	9.93182E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.41583E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.41583E+06	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	3.07230E+06	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	3.07230E+06	kN/m/sec
VERTICAL TRANSLATION (CWW) ....	3.50927E+06	kN/m/sec
ROTATION (CPPX) .....	4.41878E+07	kN-m/rad/sec
ROTATION (CPPY) .....	4.41878E+07	kN-m/rad/sec
TORSION (CZT) .....	3.47614E+07	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	8.48233E+06	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-8.48233E+06	kN/rad/sec

FREQUENCY - 0.0488 Hz ( 0.3066 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	8.74760E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	8.74760E+05	kN/m
VERTICAL TRANSLATION (KWW) ....	9.98894E+05	kN/m
ROTATION (KPPX) .....	1.26042E+07	kN-m/rad
ROTATION (KPPY) .....	1.26042E+07	kN-m/rad
TORSION (KZT) .....	9.93145E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.41566E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.41566E+06	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.10275E+05	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.10275E+05	kN/m/sec
VERTICAL TRANSLATION (CWW) ....	1.26848E+05	kN/m/sec
ROTATION (CPPX) .....	1.50929E+06	kN-m/rad/sec
ROTATION (CPPY) .....	1.50929E+06	kN-m/rad/sec
TORSION (CZT) .....	1.13386E+06	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	3.02638E+05	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-3.02638E+05	kN/rad/sec

### 6.5 Example 5: Mat Foundation on Stratum under Harmonic Load

A circular foundation with radius of 5 ft rests on the surface of a stratum of dense sand with a shear wave velocity of 643 ft/sec and a unit weight of 112 pcf. A rotating mass machine is fixed on the circular foundation, and the total weight of machine and foundation is 140,000 lb. The height of the C.G. is 5 ft.

The sand layer is 10 ft thick underlain by bed rock.

The vertical harmonic response is calculated. The dynamic response is sensitive to the material damping of soil for the case of stratum. In this example the material damping ratio is 0.05. Users can change the value of material damping to examine the effects on dynamic response.

Use Imperial units: lb, slug = lb/32.2, ft.

#### 6.5.1 Input Data

```

TITLE= MAT FOUNDATION ON STRATUM (lb-Slug-ft)
MATRIX
GRAVITY=32.2
FOUNDATION=STRATUM
CIRCULAR=5
MASS
4348 27200 27200 54350 0 0 0
CONSTANTS
0 0 5 0 10
SOIL
CONSTANTS
643 112 0.25 0.05
LOAD
HARMONIC
CONSTANTS
QUADRATIC
188.4 6.28 6.28 0 0 0.02282 0 0 0
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.5.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

MAT FOUNDATION ON STRATUM (lb-Slug-ft)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 32.20 ft/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - STRATUM  
\*\*\*\*\*

CIRCULAR FOUNDATION - RADIUS = 5.000 ft  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	4.34800E+03	slug
MASS MOMENT ABOUT X-AXIS	2.72000E+04	slug-ft**2
MASS MOMENT ABOUT Y-AXIS	2.72000E+04	slug-ft**2
MASS MOMENT ABOUT Z-AXIS	5.43500E+04	slug-ft**2
CROSS PRODUCT X-Y	0.00000E+00	slug-ft**2
CROSS PRODUCT X-Z	0.00000E+00	slug-ft**2
CROSS PRODUCT Y-Z	0.00000E+00	slug-ft**2

STRATUM PROPERTIES  
\*\*\*\*\*

X-LOCATION CENTRE OF GRAV	0.00000	ft
Y-LOCATION CENTRE OF GRAV	0.00000	ft
HEIGHT OF CENTRE OF GRAV	5.00000	ft
DEPTH OF EMBEDMENT	0.00000	ft
DEPTH OF LAYER	10.00000	ft

SOIL CONSTANTS  
\*\*\*\*\*

SHEAR WAVE VELOCITY	643.00000	ft/s
UNIT WEIGHT	112.00000	lb/ft**3
POISSONS RATIO	0.25000	
MATERIAL DAMPING	0.05000	

HARMONIC LOAD, QUADRATIC  
\*\*\*\*\*

MAXIMUM FREQUENCY ..... 3.000E+01 Hz  
 MINIMUM FREQUENCY ..... 1.000E+00 Hz  
 STEP FREQUENCY ..... 1.000E+00 Hz  
 FORCE COEFF. IN X-DIRECTION ... 0.000E+00 slug-ft  
 FORCE COEFF. IN Y-DIRECTION ... 0.000E+00 slug-ft  
 FORCE COEFF. IN Z-DIRECTION ... 2.282E-02 slug-ft  
 MOMENT COEFF. ABOUT X-AXIS .... 0.000E+00 slug-ft\*\*2  
 MOMENT COEFF. ABOUT Y-AXIS .... 0.000E+00 slug-ft\*\*2  
 MOMENT COEFF. ABOUT Z-AXIS .... 0.000E+00 slug-ft\*\*2

\*\*\*\*\*  
 \* SOIL - FOUNDATION \*  
 \* \*  
 \* DYNAMIC SIMULATION \*  
 \* DYNAN \*  
 \* \*  
 \* RUN DATE - 23-MAR-12 \*  
 \* TIME - 13:51:49 \*  
 \* Copyright Canadian No.492911 - 2001/7/13 \*  
 \* \*  
 \*\*\*\*\*

MAT FOUNDATION ON STRATUM (Ib-Slug-ft)

RESULTS  
\*\*\*\*\*

FREQUENCY - 1.0000 Hz ( 6.2800 rad./sec.)  
 \*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) .. 4.10880E+07 lb/ft  
 HORIZONTAL TRANSLATION (KYY) .. 4.10880E+07 lb/ft  
 VERTICAL TRANSLATION (KWW) ... 6.28921E+07 lb/ft  
 ROTATION (KPPX) ..... 1.65122E+09 lb-ft/rad  
 ROTATION (KPPY) ..... 1.65122E+09 lb-ft/rad  
 TORSION (KZT) ..... 9.52495E+08 lb-ft/rad  
 CROSS-STIFFNESS (KXP) ..... 1.99277E+08 lb/rad  
 CROSS-STIFFNESS (KYP) ..... -1.99277E+08 lb/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) .. 2.29221E+05 lb/ft/sec  
 HORIZONTAL TRANSLATION (CYY) .. 2.29221E+05 lb/ft/sec  
 VERTICAL TRANSLATION (CWW) ... 3.50720E+05 lb/ft/sec  
 ROTATION (CPPX) ..... 9.20967E+06 lb-ft/rad/se  
 ROTATION (CPPY) ..... 9.20967E+06 lb-ft/rad/se  
 TORSION (CZT) ..... 5.30972E+06 lb-ft/rad/se  
 CROSS-STIFFNESS (CXP) ..... 1.11172E+06 lb/rad/sec  
 CROSS-STIFFNESS (CYP) ..... -1.11172E+06 lb/rad/sec

FREQUENCY - 2.0000 Hz ( 12.5600 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	4.10877E+07	lb/ft
HORIZONTAL TRANSLATION (KYY) ..	4.10877E+07	lb/ft
VERTICAL TRANSLATION (KWW) ....	6.28918E+07	lb/ft
ROTATION (KPPX) .....	1.64444E+09	lb-ft/rad
ROTATION (KPPY) .....	1.64444E+09	lb-ft/rad
TORSION (KZT) .....	9.46266E+08	lb-ft/rad
CROSS-STIFFNESS (KXP) .....	1.99275E+08	lb/rad
CROSS-STIFFNESS (KYP) .....	-1.99275E+08	lb/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.14956E+05	lb/ft/sec
HORIZONTAL TRANSLATION (CYY) ..	1.14956E+05	lb/ft/sec
VERTICAL TRANSLATION (CWW) ....	1.75671E+05	lb/ft/sec
ROTATION (CPPX) .....	4.59666E+06	lb-ft/rad/sec
ROTATION (CPPY) .....	4.59666E+06	lb-ft/rad/sec
TORSION (CZT) .....	2.63936E+06	lb-ft/rad/sec
CROSS-STIFFNESS (CXP) .....	5.57536E+05	lb/rad/sec
CROSS-STIFFNESS (CYP) .....	-5.57536E+05	lb/rad/sec

FREQUENCY - 3.0000 Hz ( 18.8400 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	4.10872E+07	lb/ft
HORIZONTAL TRANSLATION (KYY) ..	4.10872E+07	lb/ft
VERTICAL TRANSLATION (KWW) ....	6.28913E+07	lb/ft
ROTATION (KPPX) .....	1.63766E+09	lb-ft/rad
ROTATION (KPPY) .....	1.63766E+09	lb-ft/rad
TORSION (KZT) .....	9.40037E+08	lb-ft/rad
CROSS-STIFFNESS (KXP) .....	1.99273E+08	lb/rad
CROSS-STIFFNESS (KYP) .....	-1.99273E+08	lb/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	7.70325E+04	lb/ft/sec
HORIZONTAL TRANSLATION (CYY) ..	7.70325E+04	lb/ft/sec
VERTICAL TRANSLATION (CWW) ....	1.17462E+05	lb/ft/sec
ROTATION (CPPX) .....	3.06403E+06	lb-ft/rad/sec
ROTATION (CPPY) .....	3.06403E+06	lb-ft/rad/sec
TORSION (CZT) .....	1.75014E+06	lb-ft/rad/sec
CROSS-STIFFNESS (CXP) .....	3.73608E+05	lb/rad/sec
CROSS-STIFFNESS (CYP) .....	-3.73608E+05	lb/rad/sec

FREQUENCY - 4.0000 Hz ( 25.1200 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	4.10864E+07	lb/ft
HORIZONTAL TRANSLATION (KYY) ..	4.10864E+07	lb/ft
VERTICAL TRANSLATION (KWW) ....	6.28907E+07	lb/ft

MAT FOUNDATION ON STRATUM (Ib-Slug-ft)

RESULTS  
\*\*\*\*\*

## FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) ft	TRANS. Y DIRECTION (UOY) ft	VERTICAL (UOZ) ft	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
1.00	6.28	0.0000E+00	0.0000E+00	1.4340E-08	0.0000E+00	0.0000E+00	0.0000E+00
2.00	12.56	0.0000E+00	0.0000E+00	5.7835E-08	0.0000E+00	0.0000E+00	0.0000E+00
3.00	18.84	0.0000E+00	0.0000E+00	1.3195E-07	0.0000E+00	0.0000E+00	0.0000E+00
4.00	25.12	0.0000E+00	0.0000E+00	2.3925E-07	0.0000E+00	0.0000E+00	0.0000E+00
5.00	31.40	0.0000E+00	0.0000E+00	3.8365E-07	0.0000E+00	0.0000E+00	0.0000E+00
6.00	37.68	0.0000E+00	0.0000E+00	5.7081E-07	0.0000E+00	0.0000E+00	0.0000E+00
7.00	43.96	0.0000E+00	0.0000E+00	8.0868E-07	0.0000E+00	0.0000E+00	0.0000E+00
8.00	50.24	0.0000E+00	0.0000E+00	1.1085E-06	0.0000E+00	0.0000E+00	0.0000E+00
9.00	56.52	0.0000E+00	0.0000E+00	1.4862E-06	0.0000E+00	0.0000E+00	0.0000E+00
10.00	62.80	0.0000E+00	0.0000E+00	1.9653E-06	0.0000E+00	0.0000E+00	0.0000E+00
11.00	69.08	0.0000E+00	0.0000E+00	2.5807E-06	0.0000E+00	0.0000E+00	0.0000E+00
12.00	75.36	0.0000E+00	0.0000E+00	3.3873E-06	0.0000E+00	0.0000E+00	0.0000E+00
13.00	81.64	0.0000E+00	0.0000E+00	4.4757E-06	0.0000E+00	0.0000E+00	0.0000E+00
14.00	87.92	0.0000E+00	0.0000E+00	6.0064E-06	0.0000E+00	0.0000E+00	0.0000E+00
15.00	94.20	0.0000E+00	0.0000E+00	8.2922E-06	0.0000E+00	0.0000E+00	0.0000E+00
16.00	100.48	0.0000E+00	0.0000E+00	1.2032E-05	0.0000E+00	0.0000E+00	0.0000E+00
17.00	106.76	0.0000E+00	0.0000E+00	1.9151E-05	0.0000E+00	0.0000E+00	0.0000E+00
18.00	113.04	0.0000E+00	0.0000E+00	3.7202E-05	0.0000E+00	0.0000E+00	0.0000E+00
19.00	119.32	0.0000E+00	0.0000E+00	1.0229E-04	0.0000E+00	0.0000E+00	0.0000E+00
20.00	125.60	0.0000E+00	0.0000E+00	5.4493E-05	0.0000E+00	0.0000E+00	0.0000E+00
21.00	131.88	0.0000E+00	0.0000E+00	2.9905E-05	0.0000E+00	0.0000E+00	0.0000E+00
22.00	138.16	0.0000E+00	0.0000E+00	2.1191E-05	0.0000E+00	0.0000E+00	0.0000E+00
23.00	144.44	0.0000E+00	0.0000E+00	1.6845E-05	0.0000E+00	0.0000E+00	0.0000E+00
24.00	150.72	0.0000E+00	0.0000E+00	1.4254E-05	0.0000E+00	0.0000E+00	0.0000E+00
25.00	157.00	0.0000E+00	0.0000E+00	1.2532E-05	0.0000E+00	0.0000E+00	0.0000E+00
26.00	163.28	0.0000E+00	0.0000E+00	1.1291E-05	0.0000E+00	0.0000E+00	0.0000E+00
27.00	169.56	0.0000E+00	0.0000E+00	1.0301E-05	0.0000E+00	0.0000E+00	0.0000E+00
28.00	175.84	0.0000E+00	0.0000E+00	7.6516E-06	0.0000E+00	0.0000E+00	0.0000E+00
29.00	182.12	0.0000E+00	0.0000E+00	7.4616E-06	0.0000E+00	0.0000E+00	0.0000E+00
30.00	188.40	0.0000E+00	0.0000E+00	7.2904E-06	0.0000E+00	0.0000E+00	0.0000E+00



## 6.6 Example 6: Shallow Foundation in Layered Soil (Multilayer Option)

The shallow foundation is a 2.5 m (length) by 1.6 m (width) by 2.3 m (thickness) concrete block embedded into layered soil. The soil is divided into 5 layers, including 2 adjacent layers (side soil) and 3 soil layers beneath the foundation underlain by an elastic halfspace. The boundary zones in the side soil are considered around the concrete block.

Harmonic loads applied to the foundation, and the vertical dynamic response output.

Use SI units: kN, Mg, m.

depth= 0 - 0.8; Layer 1 Shear Wave Velocity= 0.3; Poissons Ratio= 0.05	
depth= 0.8 - 2.3; Layer 1 Shear Wave Velocity= 0.3; Poissons Ratio= 0.05	
depth= 2.3 - 4.3; Layer 1 Shear Wave Velocity= 0.3; Poissons Ratio= 0.05	
depth= 4.3 - 6.3; Layer 1 Shear Wave Velocity= 0.3; Poissons Ratio= 0.05	
depth= 6.3 - 9.3; Layer 1 Shear Wave Velocity= 0.3; Poissons Ratio= 0.05	

**Figure 6.4** Shallow Foundation in layered soils for dynamic response analysis demonstrated in Example 6

### 6.6.1 Input Data

```

TITLE=SHALLOW FOUNDATION IN LAYERED SOIL (kN-Mg-m)
MATRIX
GRAVITY=9.8
FOUNDATION=MULTILAYER
RECTANGULAR=2.5,1.6
MASS
24.5 5.837 13.54 19.375 0 0 0
LAYER=5
CONSTANTS
0 0 1.15 9.3 24.5
50 0.25 0.01 1.334 27000000
ELEMENT
1 0.8 2.5 1.6 4 2.08 0.85 4.13
2 1.5 2.5 1.6 4 2.08 0.85 4.13
3 2 2.5 1.6 4 2.08 0.85 4.13
4 2 2.5 1.6 4 2.08 0.85 4.13
5 3 2.5 1.6 4 2.08 0.85 4.13
SOIL
WEAK
CONSTANTS=2
1 90 20.6 0.3 0.05 0.25 0.3 0.1 1
2 120 18.9 0.3 0.05 0.25 0.3 0.1 1
3 250 19 0.3 0.05 1 1
4 280 18 0.3 0.05 1 1
5 300 19.05 0.3 0.05 1 1
BELOW=380 21.6 0.3 0.05
LOAD
HARMONIC
CONSTANTS
NONQUADRATIC
251.2 6.28 6.28 0 0 1 0 0 0
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.6.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

SHALLOW FOUNDATION IN LAYERED SOIL (kN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - MULTILAYER  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 2.500 m BY 1.600 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	2.45000E+01	Mg
MASS MOMENT ABOUT X-AXIS	5.83700E+00	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	1.35400E+01	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	1.93750E+01	Mg-m**2
CROSS PRODUCT X-Y	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	0.00000E+00	Mg-m**2

NUMBER OF LAYERS OR ELEMENTS - 5  
\*\*\*\*\*

FOUNDATION PROPERTIES  
\*\*\*\*\*

X-LOCATION CENTRE OF GRAV.	0.00000	m
Y-LOCATION CENTRE OF GRAV.	0.00000	m
HEIGHT OF CENTRE OF GRAV.	1.15000	m
TOTAL LENGTH	9.30000	m
UNIT WEIGHT	24.50000	kN/m**3
STATIC LOAD ON BODY	5.00000E+01	kN.
POISSONS RATIO	0.25000	
MATERIAL DAMPING	0.01000	
COEFF. OF RIGIDITY	1.33400	
YOUNGS MODULUS	2.70000E+07	kPa

ELEMENT  
\*\*\*\*\*

LAYER NO.	LAYER DEPTH	PILE RADIUS (X)	PILE RADIUS (Y)	CROSS SECTIONAL AREA	MOMENT OF INERTIA (X)	MOMENT OF INERTIA (Y)	TORSIONAL STIFFNESS
	m	m	m	m**2	m**4	m**4	m**4
1	0.800	2.500	1.600	4.000E+00	2.080E+00	8.500E-01	4.13E+00
2	1.500	2.500	1.600	4.000E+00	2.080E+00	8.500E-01	4.13E+00
3	2.000	2.500	1.600	4.000E+00	2.080E+00	8.500E-01	4.13E+00
4	2.000	2.500	1.600	4.000E+00	2.080E+00	8.500E-01	4.13E+00
5	3.000	2.500	1.600	4.000E+00	2.080E+00	8.500E-01	4.13E+00

SOIL CONSTANTS                      NUMBER OF ADJACENT LAYERS -        2  
\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSONS RATIO	MATERIAL DAMPING
	m/s	kN/m**3		
1	90.000	20.600	0.300	0.050
2	120.000	18.900	0.300	0.050

NONLINEARITY OF SOIL (WEAKENED ZONE)  
\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
1	0.250
2	0.250

SOIL PROPERTIES BELOW FOUNDATION  
\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING	SHEAR MODULUS RATIO(IN/OUT)	DAMPING RATIO (IN/OUT)
	m/s	kN/m**3				
3	250.000	19.000	0.300	0.050	1.000	1.000
4	280.000	18.000	0.300	0.050	1.000	1.000
5	300.000	19.050	0.300	0.050	1.000	1.000

SOIL BELOW MULTILAYER SYSTEM  
\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
3.80E+02	21.6000	0.300	0.050

HARMONIC LOAD, NON QUADRATIC  
\*\*\*\*\*

MAXIMUM FREQUENCY .....	4.000E+01 Hz
MINIMUM FREQUENCY .....	1.000E+00 Hz
STEP FREQUENCY .....	1.000E+00 Hz
FORCE IN X-DIRECTION .....	0.000E+00 kN.
FORCE IN Y-DIRECTION .....	0.000E+00 kN.
FORCE IN Z-DIRECTION .....	1.000E+00 kN.

## SHALLOW FOUNDATION IN LAYERED SOIL (kN-Mg-m)

## RESULTS

\*\*\*\*\*

FREQUENCY - 1.0000 Hz ( 6.2800 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	4.89874E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	4.35185E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	6.12598E+05	kN/m
ROTATION (KPPX) .....	5.75970E+06	kN-m/rad
ROTATION (KPPY) .....	7.42691E+06	kN-m/rad
TORSION (KZT) .....	3.04194E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	1.45191E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-1.62459E+06	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.27461E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	8.21509E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	1.47449E+04	kN/m/sec
ROTATION (CPPX) .....	7.25560E+04	kN-m/rad/sec
ROTATION (CPPY) .....	1.19118E+05	kN-m/rad/sec
TORSION (CZT) .....	1.64074E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	2.26953E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-3.53150E+04	kN/rad/sec

FREQUENCY - 2.0000 Hz ( 12.5600 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	5.23623E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	4.54386E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	6.58640E+05	kN/m
ROTATION (KPPX) .....	5.88215E+06	kN-m/rad
ROTATION (KPPY) .....	7.63063E+06	kN-m/rad
TORSION (KZT) .....	3.00824E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	1.50023E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-1.71324E+06	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	9.79945E+03	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	6.25233E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	8.76310E+03	kN/m/sec
ROTATION (CPPX) .....	5.68625E+04	kN-m/rad/sec
ROTATION (CPPY) .....	9.53817E+04	kN-m/rad/sec
TORSION (CZT) .....	8.85001E+03	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.77233E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-2.79492E+04	kN/rad/sec

## SHALLOW FOUNDATION IN LAYERED SOIL (kN-Mg-m)

## RESULTS

\*\*\*\*\*

## FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
1.00	6.28	0.0000E+00	0.0000E+00	1.6165E-06	0.0000E+00	0.0000E+00	0.0000E+00
2.00	12.56	0.0000E+00	0.0000E+00	1.5061E-06	0.0000E+00	0.0000E+00	0.0000E+00
3.00	18.84	0.0000E+00	0.0000E+00	1.4389E-06	0.0000E+00	0.0000E+00	0.0000E+00
4.00	25.12	0.0000E+00	0.0000E+00	1.3695E-06	0.0000E+00	0.0000E+00	0.0000E+00
5.00	31.40	0.0000E+00	0.0000E+00	1.3020E-06	0.0000E+00	0.0000E+00	0.0000E+00
6.00	37.68	0.0000E+00	0.0000E+00	1.2408E-06	0.0000E+00	0.0000E+00	0.0000E+00
7.00	43.96	0.0000E+00	0.0000E+00	1.2184E-06	0.0000E+00	0.0000E+00	0.0000E+00
8.00	50.24	0.0000E+00	0.0000E+00	1.2078E-06	0.0000E+00	0.0000E+00	0.0000E+00
9.00	56.52	0.0000E+00	0.0000E+00	1.2038E-06	0.0000E+00	0.0000E+00	0.0000E+00
10.00	62.80	0.0000E+00	0.0000E+00	1.2057E-06	0.0000E+00	0.0000E+00	0.0000E+00
11.00	69.08	0.0000E+00	0.0000E+00	1.2126E-06	0.0000E+00	0.0000E+00	0.0000E+00
12.00	75.36	0.0000E+00	0.0000E+00	1.2238E-06	0.0000E+00	0.0000E+00	0.0000E+00
13.00	81.64	0.0000E+00	0.0000E+00	1.2385E-06	0.0000E+00	0.0000E+00	0.0000E+00
14.00	87.92	0.0000E+00	0.0000E+00	1.2553E-06	0.0000E+00	0.0000E+00	0.0000E+00
15.00	94.20	0.0000E+00	0.0000E+00	1.2732E-06	0.0000E+00	0.0000E+00	0.0000E+00
16.00	100.48	0.0000E+00	0.0000E+00	1.2901E-06	0.0000E+00	0.0000E+00	0.0000E+00
17.00	106.76	0.0000E+00	0.0000E+00	1.3043E-06	0.0000E+00	0.0000E+00	0.0000E+00
18.00	113.04	0.0000E+00	0.0000E+00	1.3132E-06	0.0000E+00	0.0000E+00	0.0000E+00
19.00	119.32	0.0000E+00	0.0000E+00	1.3147E-06	0.0000E+00	0.0000E+00	0.0000E+00
20.00	125.60	0.0000E+00	0.0000E+00	1.3067E-06	0.0000E+00	0.0000E+00	0.0000E+00
21.00	131.88	0.0000E+00	0.0000E+00	1.2879E-06	0.0000E+00	0.0000E+00	0.0000E+00
22.00	138.16	0.0000E+00	0.0000E+00	1.2581E-06	0.0000E+00	0.0000E+00	0.0000E+00
23.00	144.44	0.0000E+00	0.0000E+00	1.2180E-06	0.0000E+00	0.0000E+00	0.0000E+00
24.00	150.72	0.0000E+00	0.0000E+00	1.1693E-06	0.0000E+00	0.0000E+00	0.0000E+00
25.00	157.00	0.0000E+00	0.0000E+00	1.1144E-06	0.0000E+00	0.0000E+00	0.0000E+00
26.00	163.28	0.0000E+00	0.0000E+00	1.0556E-06	0.0000E+00	0.0000E+00	0.0000E+00
27.00	169.56	0.0000E+00	0.0000E+00	9.9523E-07	0.0000E+00	0.0000E+00	0.0000E+00
28.00	175.84	0.0000E+00	0.0000E+00	9.3504E-07	0.0000E+00	0.0000E+00	0.0000E+00
29.00	182.12	0.0000E+00	0.0000E+00	8.7644E-07	0.0000E+00	0.0000E+00	0.0000E+00
30.00	188.40	0.0000E+00	0.0000E+00	8.2035E-07	0.0000E+00	0.0000E+00	0.0000E+00
31.00	194.68	0.0000E+00	0.0000E+00	7.6735E-07	0.0000E+00	0.0000E+00	0.0000E+00
32.00	200.96	0.0000E+00	0.0000E+00	7.1771E-07	0.0000E+00	0.0000E+00	0.0000E+00
33.00	207.24	0.0000E+00	0.0000E+00	6.7152E-07	0.0000E+00	0.0000E+00	0.0000E+00
34.00	213.52	0.0000E+00	0.0000E+00	6.2874E-07	0.0000E+00	0.0000E+00	0.0000E+00
35.00	219.80	0.0000E+00	0.0000E+00	5.8922E-07	0.0000E+00	0.0000E+00	0.0000E+00
36.00	226.08	0.0000E+00	0.0000E+00	5.5278E-07	0.0000E+00	0.0000E+00	0.0000E+00
37.00	232.36	0.0000E+00	0.0000E+00	5.1919E-07	0.0000E+00	0.0000E+00	0.0000E+00
38.00	238.64	0.0000E+00	0.0000E+00	4.8824E-07	0.0000E+00	0.0000E+00	0.0000E+00
39.00	244.92	0.0000E+00	0.0000E+00	4.5973E-07	0.0000E+00	0.0000E+00	0.0000E+00
40.00	251.20	0.0000E+00	0.0000E+00	4.3345E-07	0.0000E+00	0.0000E+00	0.0000E+00

## 6.7 Example 7: Random Loads Applied to Half-Space Foundation

Use the same 2-story concrete frame structure as shown in Example 4. The frame is assumed to be a rigid structure in order to show how to use the program for calculating the expected peak response of the structure rested on half-space (random load).

The foundation is a concrete block with the following dimensions: 5 m (length) by 5 m (width) by 1.0 m (thickness). The total mass of frame structure and foundation is 152,500 kg, and the height of the C.G. is 2.81 m.

The foundation rests on half-space. The depth of embedded side soil is 1.0 m.

A seismic time history record is translated to a power spectrum using the FFT approach. The values of the power spectrum are given for 101 points (frequencies). The maximum frequency is  $w = 125.6$  rad/sec and the minimum frequency is  $w = 0.01$  rad/sec. One spectrum is used in the X-direction.

Use SI units: kN, mg, m.

### 6.7.1 Input Data

TITLE= RANDOM LOADS HALF-SPACE (N-kg-m)

MATRIX

GRAVITY=9.8

FOUNDATION=HALF-SPACE

RECTANGULAR=5,5

MASS

152500 1151000 1151000 600400 0 0 0

CONSTANTS

0 0 2.81

SOIL

WEAK

CONSTANTS=1

1 1 120 17 0.3 0.05 0.5 0.3 0.1 1

BELOW=180 18 0.3 0.05

LOAD

RANDOM

CONSTANTS

125.6

0.001

101

20

1

1 1

6337.3

7856.2

8168.1  
13111  
12330  
6463.4  
5533.4  
9609.5  
7627.6  
3522.2  
2636.2  
2398.1  
5065.8  
6971.7  
5004.2  
3898.9  
4187.5  
2754.4  
1417.7  
847.65  
1120.6  
1217.9  
1087  
1046.8  
868.78  
1307.8  
1393.7  
1115.2  
1122.7  
543.33  
441.18  
609.65  
703.71  
481.49  
276.38  
152.16  
154.69  
139.83  
145.73  
101.63  
60.821  
86.569  
123.27  
107.61  
89.154  
53.422  
67.257  
64.295  
57.325  
28.1



```

26.72
15.903
15.995
0
11.806
14.962
20.362
2.6891
6.6034
0
4.0074
0
3.7997
0 TITLE= RANDOM LOADS HALF-SPACE (N-kg-m)
MATRIX
GRAVITY=9.8
FOUNDATION=HALF-SPACE
RECTANGULAR=5,5
MASS
152500 1151000 1151000 600400 0 0 0
CONSTANTS
0 0 2.81
SOIL
WEAK
CONSTANTS=1
1 1 120 17 0.3 0.05 0.5 0.3 0.1 1
BELOW=180 18 0.3 0.05
LOAD
RANDOM
CONSTANTS
125.6
0.001
101
20
1
1 1
6337.3
7856.2
8168.1
13111
12330
6463.4
5533.4
9609.5
7627.6
3522.2
2636.2
2398.1

```

5065.8  
6971.7  
5004.2  
3898.9  
4187.5  
2754.4  
1417.7  
847.65  
1120.6  
1217.9  
1087  
1046.8  
868.78  
1307.8  
1393.7  
1115.2  
1122.7  
543.33  
441.18  
609.65  
703.71  
481.49  
276.38  
152.16  
154.69  
139.83  
145.73  
101.63  
60.821  
86.569  
123.27  
107.61  
89.154  
53.422  
67.257  
64.295  
57.325  
28.1  
26.72  
15.903  
15.995  
0  
11.806  
14.962  
20.362  
2.6891  
6.6034  
0

4.0074  
0  
3.7997  
0

### 6.7.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

RANDOM LOADS HALF-SPACE (N-kg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - HALF-SPACE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 5.000 m BY 5.000 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	.....	1.52500E+05	Mg
MASS MOMENT ABOUT X-AXIS	.....	1.15100E+06	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	.....	1.15100E+06	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	.....	6.00400E+05	Mg-m**2
CROSS PRODUCT X-Y	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	.....	0.00000E+00	Mg-m**2

HALF-SPACE FOUNDATION  
\*\*\*\*\*

X-LOCATION CENTRE OF GRAV	.....	0.00000	m
Y-LOCATION CENTRE OF GRAV	.....	0.00000	m
HEIGHT OF CENTRE OF GRAV	.....	2.81000	m

SOIL CONSTANTS NUMBER OF SIDE LAYERS - 1  
\*\*\*\*\*

LAYER NO.	LAYER DEPTH	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
	m	m/s	kN/m**3		
1	1.000	120.000	17.000	0.300	0.050

NONLINEARITY OF SOIL (WEAKENED ZONE)  
\*\*\*\*\*

LAYER SHEAR MODULUS  
NO. RATIO

1 0.500

HALF-SPACE SOIL  
\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
1.80E+02	18.0000	0.300	0.050

RANDOM LOAD  
\*\*\*\*\*

MAXIMUM FREQUENCY (Hz)	2.000
MINIMUM FREQUENCY (Hz)	0.000
NUMBER OF POINTS	101
NUMBER OF SPECTRA	1

LOCATION OF SPECTRA - 1 1

LOAD AMPLITUDES kN.

0.634E+04  
0.786E+04  
0.817E+04  
0.131E+05  
0.123E+05  
0.646E+04  
0.553E+04  
0.961E+04  
0.763E+04  
0.352E+04  
0.264E+04  
0.240E+04  
0.507E+04  
0.697E+04  
0.500E+04  
0.390E+04  
0.419E+04  
0.275E+04  
0.142E+04  
0.848E+03  
0.112E+04  
0.122E+04  
0.109E+04  
0.105E+04  
0.869E+03  
0.131E+04  
0.139E+04  
0.112E+04  
0.112E+04  
0.543E+03  
0.441E+03  
0.610E+03  
0.704E+03  
0.481E+03

RANDOM LOADS HALF-SPACE (N-kg-m)

RESULTS

\*\*\*\*\*

FREQUENCY - 0.0002 Hz ( 0.0010 rad./sec.)

\*\*\*\*\*

STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	8.42230E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	8.42230E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	9.87736E+05	kN/m
ROTATION (KPPX) .....	1.22054E+07	kN-m/rad
ROTATION (KPPY) .....	1.22054E+07	kN-m/rad
TORSION (KZT) .....	9.00165E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.34055E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.34055E+06	kN/rad

DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	3.01994E+07	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	3.01994E+07	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.35820E+07	kN/m/sec
ROTATION (CPPX) .....	4.39584E+08	kN-m/rad/sec
ROTATION (CPPY) .....	4.39584E+08	kN-m/rad/sec
TORSION (CZT) .....	2.37124E+08	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	8.35879E+07	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-8.35879E+07	kN/rad/sec

FREQUENCY - 0.2002 Hz ( 1.2570 rad./sec.)

\*\*\*\*\*

STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	8.43274E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	8.43274E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	9.91537E+05	kN/m
ROTATION (KPPX) .....	1.22084E+07	kN-m/rad
ROTATION (KPPY) .....	1.22084E+07	kN-m/rad
TORSION (KZT) .....	8.99912E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.34284E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.34284E+06	kN/rad

DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	3.64101E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	3.64101E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.54016E+04	kN/m/sec
ROTATION (CPPX) .....	4.31072E+05	kN-m/rad/sec
ROTATION (CPPY) .....	4.31072E+05	kN-m/rad/sec
TORSION (CZT) .....	1.88908E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	9.79233E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-9.79233E+04	kN/rad/sec

FREQUENCY - 0.4002 Hz ( 2.5130 rad./sec.)  
 \*\*\*\*\*

STIFFNESS CONSTANTS (K)  
 \*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	8.47348E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	8.47348E+05	kN/m
VERTICAL TRANSLATION (KWW) ....	9.95412E+05	kN/m
ROTATION (KPPX) .....	1.22247E+07	kN-m/rad
ROTATION (KPPY) .....	1.22247E+07	kN-m/rad
TORSION (KZT) .....	8.99284E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.35212E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.35212E+06	kN/rad

DAMPING CONSTANTS (C)  
 \*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	2.39793E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	2.39793E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ....	2.23248E+04	kN/m/sec
ROTATION (CPPX) .....	2.54300E+05	kN-m/rad/sec
ROTATION (CPY) .....	2.54300E+05	kN-m/rad/sec
TORSION (CZT) .....	9.48675E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	6.37112E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-6.37112E+04	kN/rad/sec

FREQUENCY - 0.6002 Hz ( 3.7690 rad./sec.)  
 \*\*\*\*\*

STIFFNESS CONSTANTS (K)  
 \*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	8.53061E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	8.53061E+05	kN/m
VERTICAL TRANSLATION (KWW) ....	9.97703E+05	kN/m
ROTATION (KPPX) .....	1.22474E+07	kN-m/rad
ROTATION (KPPY) .....	1.22474E+07	kN-m/rad
TORSION (KZT) .....	8.98358E+06	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.36519E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.36519E+06	kN/rad

DAMPING CONSTANTS (C)  
 \*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.92129E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.92129E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ....	1.81004E+04	kN/m/sec
ROTATION (CPPX) .....	1.92198E+05	kN-m/rad/sec
ROTATION (CPY) .....	1.92198E+05	kN-m/rad/sec
TORSION (CZT) .....	6.36638E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	5.08674E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-5.08674E+04	kN/rad/sec

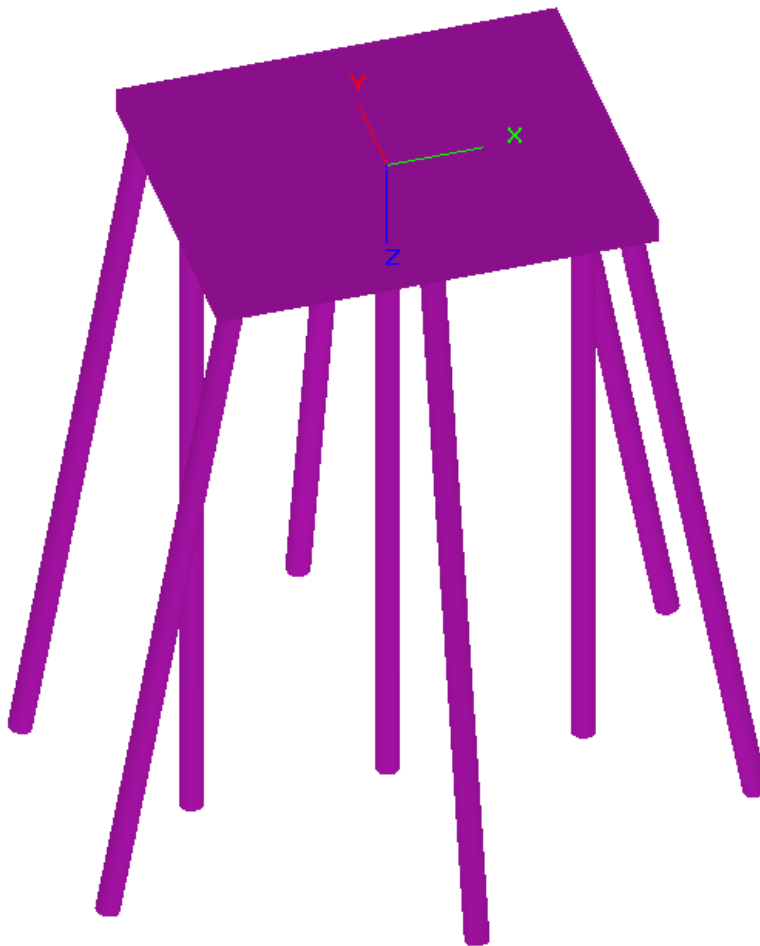
### 6.8 Example 8: Harmonic Load Applied to Pile Group (Battered Piles Included)

The group consists of 9 piles, of which 6 are battered and 3 are vertical piles, as shown in Figure 6-5. Each pile's diameter is 1.0 m and the length is 24 m. The pile cap is 18 m in length, 14 m in width, and 1.5 m in thickness, with a total mass of 908 Mg. The height of the C.G. is 0.75 m. The concrete piles are fixed to the cap.

The soil is divided into 7 layers. The top layer (1.5 m) is a void. The boundary zones are considered around the piles. The pile cap is embedded by two side soil layers. The angle between the battered pile and vertical is 10 degrees in the XZ plane and 12 degrees in the YZ plane. The positive and negative symbols of angle are shown in Figure 6-3.

The dynamic pile-soil-pile interaction is accounted for. The dynamic response in 6 degree freedoms is calculated in a frequency domain from  $\omega = 0.01$  rad/sec to  $\omega = 50.24$  rad/sec (8 Hz).

Use SI units: kN, Mg, m.



**Figure 6.5** Pile foundation for dynamic response analysis demonstrated in Example 8

### 6.8.1 Input Data

TITLE=BATTERED PILE GROUP UNDER HARMONIC LOAD (KN-Mg-m)

MATRIX

GRAVITY=9.8

FOUNDATION=PILE

RECTANGULAR=18,14

MASS

908 16100 25700 39300 0 0 0

LAYERS=7

FIXED=9

1 -8 6

2 0 6

3 8 6

4 -8 -6

5 0 -6

6 8 -6

7 -8 0

8 0 0

9 8 0

CONSTANTS

0 0 0.75 30 77

5000 0.25 0.01 2 27000000

ELEMENT

1 1.5 0.5 0.5 0.12 0.0139 0.0139 0.0278

2 0.5 0.5 0.5 0.12 0.0139 0.0139 0.0278

3 0.5 0.5 0.5 0.12 0.0139 0.0139 0.0278

4 0.5 0.5 0.5 0.12 0.0139 0.0139 0.0278

5 6 0.5 0.5 0.12 0.0139 0.0139 0.0278

6 10 0.5 0.5 0.12 0.0139 0.0139 0.0278

7 11 0.5 0.5 0.12 0.0139 0.0139 0.0278

FLOATING

BATTERED

1 XZ

-10

2 YZ

12

3 XZ

10

4 XZ

-10

5 YZ

-12

6 XZ

10



```

7 XZ
0
8 XZ
0
9 XZ
0
INTERACTION
SOIL
WEAK
CONSTANTS
1 0 0 0.45 0.05 0.3 0.45 0.1 1
2 100 16 0.45 0.05 0.3 0.45 0.1 1
3 120 17 0.45 0.05 0.3 0.45 0.1 1
4 140 18 0.45 0.05 0.3 0.45 0.1 1
5 180 19 0.45 0.05 0.3 0.45 0.1 1
6 220 20 0.45 0.05 0.3 0.45 0.1 1
7 250 20 0.45 0.05 0.3 0.45 0.1 1
BELOW=300 21 0.45 0.05
EMBEDDED
2
1 0.5 100 16 0.3 0.05
2 0.5 50 16 0.3 0.05
LOAD
HARMONIC
CONSTANTS
NONQUADRATIC
50.24 0.01 3.14 5 3 20 -4.5 7.5 0
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.8.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

BATTERED PILE GROUP UNDER HARMONIC LOAD (KN-Mg-m)

DATA ECHO  
\*\*\*\*\*

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - PILE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 18.000 m BY 14.000 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	9.08000E+02	Mg
MASS MOMENT ABOUT X-AXIS	1.61000E+04	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	2.57000E+04	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	3.93000E+04	Mg-m**2
CROSS PRODUCT X-Y	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	0.00000E+00	Mg-m**2

NUMBER OF LAYERS OR ELEMENTS - 7  
\*\*\*\*\*

LOCATION OF PILES  
\*\*\*\*\*

PILE NO.	X LOCATION m	Y LOCATION m
1	-8.000	6.000
2	0.000	6.000
3	8.000	6.000
4	-8.000	-6.000
5	0.000	-6.000
6	8.000	-6.000
7	-8.000	0.000
8	0.000	0.000
9	8.000	0.000

## FILE PROPERTIES

\*\*\*\*\*

X-LOCATION CENTRE OF GRAV. .... 0.00000 m  
 Y-LOCATION CENTRE OF GRAV. .... 0.00000 m  
 HEIGHT OF CENTRE OF GRAV. .... 0.75000 m  
 TOTAL LENGTH ..... 30.00000 m  
 UNIT WEIGHT ..... 77.00000 kN/m\*\*3  
 STATIC LOAD ON BODY ..... 5.00000E+03 kN.  
 POISSONS RATIO ..... 0.25000  
 MATERIAL DAMPING ..... 0.01000  
 COEFF. OF RIGIDITY ..... 2.00000  
 YOUNGS MODULUS ..... 2.70000E+07 kPa

## ELEMENT

\*\*\*\*\*

LAYER NO.	LAYER DEPTH	PILE RADIUS (X)	PILE RADIUS (Y)	CROSS SECTIONAL AREA	MOMENT OF INERTIA (X)	MOMENT OF INERTIA (Y)	TORSIONAL STIFFNESS
	m	m	m	m**2	m**4	m**4	m**4
1	1.500	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02
2	0.500	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02
3	0.500	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02
4	0.500	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02
5	6.000	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02
6	10.000	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02
7	11.000	0.500	0.500	1.200E-01	1.390E-02	1.390E-02	2.78E-02

## BATTERED PILES

\*\*\*\*\*

PILE NO. 1 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = -10.00 deg.  
 PILE NO. 2 BATTERED IN YZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = 12.00 deg.  
 PILE NO. 3 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = 10.00 deg.  
 PILE NO. 4 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = -10.00 deg.  
 PILE NO. 5 BATTERED IN YZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = -12.00 deg.  
 PILE NO. 6 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = 10.00 deg.  
 PILE NO. 7 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = 0.00 deg.  
 PILE NO. 8 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = 0.00 deg.  
 PILE NO. 9 BATTERED IN XZ PLANE  
 ANGLE BETWEEN PILE AND VERTICAL = 0.00 deg.

## SOIL CONSTANTS

\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSONS RATIO	MATERIAL DAMPING
	m/s	kN/m**3		
1	0.000	0.000	0.450	0.050
2	100.000	16.000	0.450	0.050
3	120.000	17.000	0.450	0.050
4	140.000	18.000	0.450	0.050
5	180.000	19.000	0.450	0.050

6	220.000	20.000	0.450	0.050
7	250.000	20.000	0.450	0.050

## NONLINEARITY OF SOIL (WEAKENED ZONE)

\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
-----------	---------------------

1	0.300
2	0.300
3	0.300
4	0.300
5	0.300
6	0.300
7	0.300

## SOIL BELOW PILE

\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
3.00E+02	21.0000	0.450	0.050

## EMBEDDED OPTION

\*\*\*\*\*

NUMBER OF SIDE LAYERS - 2

LAYER NO.	THICKNESS OF LAYER	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSONS RATIO	MATERIAL DAMPING
	m	m/s	kN/m**3		
1	0.500	100.00	16.000	0.300	0.050
2	0.500	50.00	16.000	0.300	0.050

## HARMONIC LOAD, NON QUADRATIC

\*\*\*\*\*

MAXIMUM FREQUENCY	8.000E+00 Hz
MINIMUM FREQUENCY	1.592E-03 Hz
STEP FREQUENCY	5.000E-01 Hz
FORCE IN X-DIRECTION	5.000E+00 kN.
FORCE IN Y-DIRECTION	3.000E+00 kN.
FORCE IN Z-DIRECTION	2.000E+01 kN.
MOMENT ABOUT X-AXIS	-4.500E+00 kN-m
MOMENT ABOUT Y-AXIS	7.500E+00 kN-m
MOMENT ABOUT Z-AXIS	0.000E+00 kN-m

## BATTERED PILE GROUP UNDER HARMONIC LOAD (KN-Mg-m)

## RESULTS

\*\*\*\*\*

FREQUENCY - 0.0016 Hz ( 0.0100 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	3.33445E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.30963E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	1.62257E+06	kN/m
ROTATION (KPPX) .....	5.83427E+07	kN-m/rad
ROTATION (KPPY) .....	1.10725E+08	kN-m/rad
TORSION (KZT) .....	4.01244E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	7.88813E+05	kN/rad
CROSS-STIFFNESS (KYP) .....	-7.96554E+05	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	7.42321E+05	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	7.38240E+05	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	1.19559E+06	kN/m/sec
ROTATION (CPPX) .....	7.19380E+07	kN-m/rad/sec
ROTATION (CPPY) .....	9.52449E+07	kN-m/rad/sec
TORSION (CZT) .....	9.67019E+07	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.34957E+06	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.35936E+06	kN/rad/sec

FREQUENCY - 0.5016 Hz ( 3.1500 rad./sec.)

\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	3.34457E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.31970E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	1.63010E+06	kN/m
ROTATION (KPPX) .....	5.81025E+07	kN-m/rad
ROTATION (KPPY) .....	1.10340E+08	kN-m/rad
TORSION (KZT) .....	3.94566E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	7.89753E+05	kN/rad
CROSS-STIFFNESS (KYP) .....	-7.97510E+05	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.26544E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.26236E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	1.25174E+04	kN/m/sec
ROTATION (CPPX) .....	4.67184E+05	kN-m/rad/sec
ROTATION (CPPY) .....	6.28996E+05	kN-m/rad/sec
TORSION (CZT) .....	6.66912E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.06238E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.07020E+04	kN/rad/sec

FREQUENCY - 1.0016 Hz ( 6.2900 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	3.37904E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.35408E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	1.63450E+06	kN/m
ROTATION (KPPX) .....	5.79308E+07	kN-m/rad
ROTATION (KPPY) .....	1.10100E+08	kN-m/rad
TORSION (KZT) .....	3.88704E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	7.92791E+05	kN/rad
CROSS-STIFFNESS (KYP) .....	-8.00575E+05	kN/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.05362E+04	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.05120E+04	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	1.01466E+04	kN/m/sec
ROTATION (CPPX) .....	3.88541E+05	kN-m/rad/sec
ROTATION (CPPY) .....	5.30635E+05	kN-m/rad/sec
TORSION (CZT) .....	6.02690E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	8.08929E+03	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-8.15167E+03	kN/rad/sec

FREQUENCY - 1.5016 Hz ( 9.4300 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	3.39732E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.37220E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	1.64563E+06	kN/m
ROTATION (KPPX) .....	5.80676E+07	kN-m/rad
ROTATION (KPPY) .....	1.10515E+08	kN-m/rad
TORSION (KZT) .....	3.85584E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	7.96046E+05	kN/rad
CROSS-STIFFNESS (KYP) .....	-8.03876E+05	kN/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	9.81232E+03	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	9.79042E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	9.32201E+03	kN/m/sec
ROTATION (CPPX) .....	3.70290E+05	kN-m/rad/sec
ROTATION (CPPY) .....	5.10235E+05	kN-m/rad/sec
TORSION (CZT) .....	5.95751E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	7.19704E+03	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-7.25379E+03	kN/rad/sec

FREQUENCY - 2.0016 Hz ( 12.5700 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	3.46356E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.43369E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	1.71672E+06	kN/m
ROTATION (KPPX) .....	5.75126E+07	kN-m/rad

## BATTERED PILE GROUP UNDER HARMONIC LOAD (KN-Mg-m)

RESULTS  
\*\*\*\*\*

## FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
0.00	0.01	1.5418E-05	9.5539E-06	1.2326E-05	2.0633E-07	1.7866E-07	1.8748E-14
0.50	3.15	1.5692E-05	9.7303E-06	1.2334E-05	2.1036E-07	1.8175E-07	3.4555E-14
1.00	6.29	1.6668E-05	1.0355E-05	1.2501E-05	2.2180E-07	1.9073E-07	6.1708E-14
1.50	9.43	1.8789E-05	1.1713E-05	1.2760E-05	2.4339E-07	2.0757E-07	4.2671E-14
2.00	12.57	2.0299E-05	1.2757E-05	1.2379E-05	2.7611E-07	2.3318E-07	1.2076E-13
2.50	15.71	2.2538E-05	1.4198E-05	1.2408E-05	3.0515E-07	2.5393E-07	3.6877E-13
3.00	18.85	2.2028E-05	1.3781E-05	1.2458E-05	2.9688E-07	2.4420E-07	1.2462E-13
3.50	21.99	1.7989E-05	1.1124E-05	1.2499E-05	2.4434E-07	1.9828E-07	1.6215E-13
4.00	25.13	1.3484E-05	8.2848E-06	1.2501E-05	1.9041E-07	1.5111E-07	6.2897E-14
4.50	28.27	1.0109E-05	6.1995E-06	1.2445E-05	1.5412E-07	1.1943E-07	1.5913E-13
5.00	31.41	7.7916E-06	4.7783E-06	1.2327E-05	1.3302E-07	1.0136E-07	2.9962E-14
5.50	34.55	6.1861E-06	3.7960E-06	1.2166E-05	1.2200E-07	9.2189E-08	4.4907E-14
6.00	37.69	5.0396E-06	3.0945E-06	1.1998E-05	1.1751E-07	8.8284E-08	2.1726E-14
6.50	40.83	4.1948E-06	2.5767E-06	1.1872E-05	1.1733E-07	8.7150E-08	2.3287E-14
7.00	43.97	3.5539E-06	2.1828E-06	1.1843E-05	1.2005E-07	8.7159E-08	3.7989E-14
7.50	47.11	3.0554E-06	1.8748E-06	1.1966E-05	1.2474E-07	8.7285E-08	2.5930E-14
8.00	50.25	2.6590E-06	1.6277E-06	1.2295E-05	1.3054E-07	8.6968E-08	3.8252E-15

### 6.9 Example 9: Validation based on Dynamic Tests on Pile Foundation

To verify the validity of the boundary zone model, a series of dynamic experiments have been done on full-scale piles in the field (see El-Marsafawi et al, 1992). In this study the results from a set of tests on a single steel pile are used to verify the validity of the boundary zone model and to estimate the parameters of the boundary zone. The details of the experimental setup are described in what follows (see Han & Novak, 1988).

The pile tested was a steel pipe with a diameter of 133 mm and a length of 3.38 m. The pile was placed in a pit with a depth of 3.6 m and a diameter of 1.5 m. The pile cap was a concrete block 200 mm thick, with a mass of 250 kg. An exciter was fixed on the cap and its mass was 120 kg. The centre of gravity of the cap-exciter system was 3 mm below the cap surface.

The washed medium sand was placed into the pit and compacted. The soil properties were measured in the laboratory and in situ for both the sandy-soil fill and the undisturbed natural deposit around the pit.

The shear wave velocity of sand soil measured was 93 m/s at the pile tip and the mass density was 1700 kg/m<sup>3</sup>. It was assumed that the distribution of shear modulus in sand is parabolic with depth.

The soil profile around the pit was established from the ground surface to a depth of 20 m. The soil was homogeneous sandy clay. The shear wave velocity of the clay outside the pit was about twice that of the sand backfill and therefore the effect of the interface between the two media had to be assessed. In a low frequency domain, the differences in the dynamic deflections were quite small between the two cases, a horizontal homogeneous medium comprising of only the sand and a composite medium comprising of the inner zone of sand in the pit and the outer zone of clay.

Displacement pickups, strain gauges and compressive stress transducers were fixed along the pile shaft. Displacement and acceleration pickups were mounted on the pile cap.

A mechanical-type exciter was used to produce the harmonic excitation in both the horizontal and vertical directions. The magnitude of the unbalanced force was changed by adjusting the angle of the eccentric masses. In this case, the unbalanced force was  $0.0606 \omega^2$  (N), where  $\omega$  is the circular frequency. The unbalanced force was increased with  $\omega^2$ .

The displacements were measured on the pile cap at different frequencies as the unbalanced force varied from low frequencies to high frequencies. The data from the horizontal amplitudes measured are shown by dots in Fig. 6.6.

The soil is divided into 5 layers. The layer thickness is 0.5 m for the top 4 layers and the bottom layer has 1.38 m in thickness. For the linear case the boundary zones are not considered and the weak zone shear modulus ratio should be entered as 1.0. However, the boundary zones are considered around the piles for taking into account the nonlinear soil condition.

The real line (in blue) in Fig.1 represents the response of pile with the boundary zone, and the nonlinear property of soil is accounted for. The dash line (in red) represent the response of pile with the linear property of soil,  $G_r/G_o = 1$ . It can be seen that the real line matches the measured data very well, and



the dynamic response calculated is very different for linear soil and nonlinear soil. The frequencies corresponding to the peak value and the maximum amplitudes are also varied with the cases of linear soil and nonlinear soil.

Use SI units: kN, Mg, m.

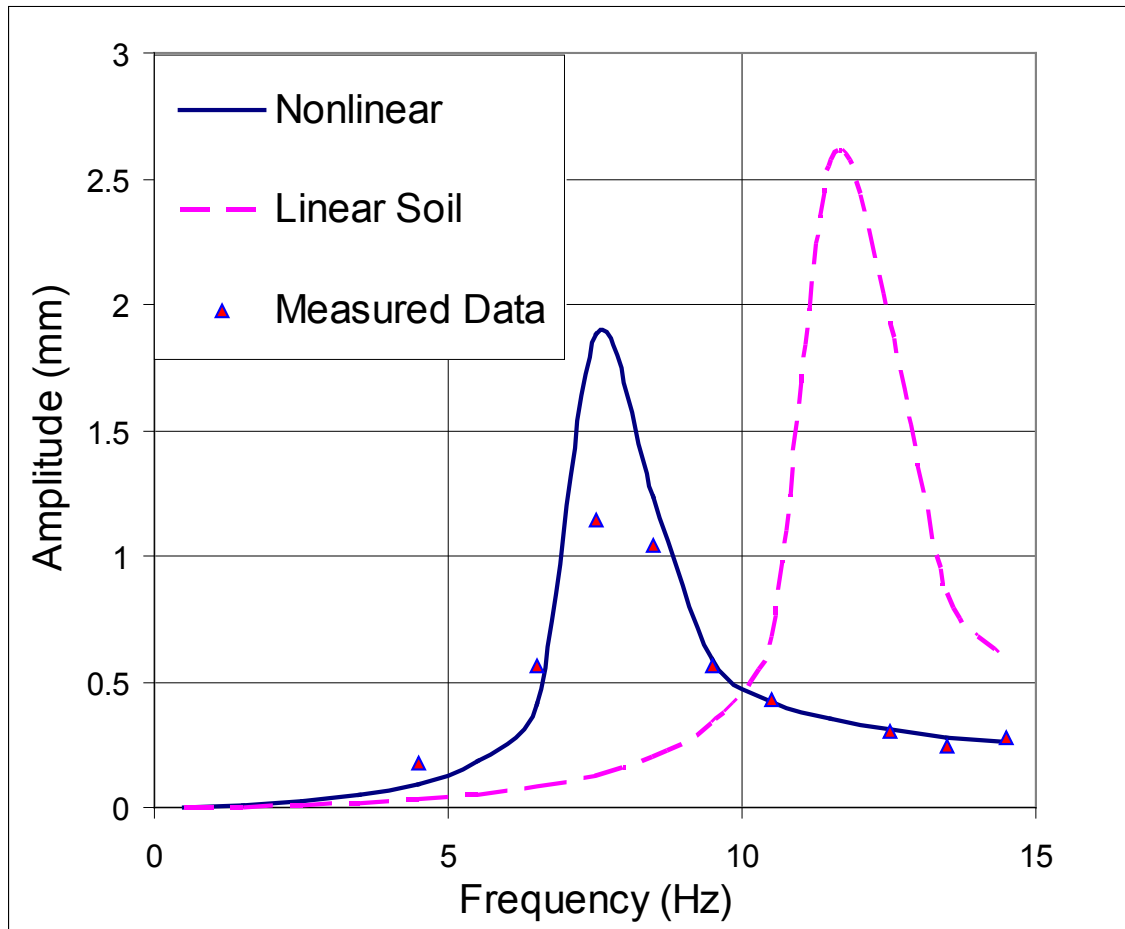


Figure 6.6 Comparison of predicted and measured pile amplitudes of a single pile presented in Example 9

### 6.9.1 Input Data

TITLE=Singel Steel Pile, Nonlinear soil  
 MATRIX  
 GRAVITY=9.8  
 FOUNDATION=PILE  
 RECTANGULAR=0.77,0.69

```

MASS
0.375 0.01831 0.02079 0.02272 0 0 0
LAYERS=5
FIXED=1
1 0 0
CONSTANTS
0 0 0.196 3.38 77
1 0.3 0.02 1.334 2E8
ELEMENT
1 0.5 0.0665 0.0665 0.00239 4.84E-6 4.84E-6 9.68E-6
2 0.5 0.0665 0.0665 0.00239 4.84E-6 4.84E-6 9.68E-6
3 0.5 0.0665 0.0665 0.00239 4.84E-6 4.84E-6 9.68E-6
4 0.5 0.0665 0.0665 0.00239 4.84E-6 4.84E-6 9.68E-6
5 1.38 0.0665 0.0665 0.00239 4.84E-6 4.84E-6 9.68E-6
FLOATING
INTERACTION
SOIL
WEAK
CONSTANTS
1 35 16.7 0.45 0.05 0.03 0.45 0.1 1
2 35 16.7 0.45 0.05 0.03 0.45 0.1 1
3 40 16.7 0.45 0.05 0.03 0.45 0.1 1
4 50 16.7 0.45 0.05 0.03 0.45 0.1 1
5 70 16.7 0.45 0.05 0.03 0.45 0.1 1
BELOW=93 16.8 0.3 0.05
LOAD
HARMONIC
CONSTANTS
QUADRATIC
94.2 3.14 6.28 0 6.06E-5 6.06E-5 -1.236E-5 0 0
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.9.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

Singel Steel File

DATA ECHO  
\*\*\*\*\*

UNRECOGNIZED KEYWORD - Non

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - FILE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 0.770 m BY 0.690 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	.....	3.75000E-01	Mg
MASS MOMENT ABOUT X-AXIS	.....	1.83100E-02	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	.....	2.07900E-02	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	.....	2.27200E-02	Mg-m**2
CROSS PRODUCT X-Y	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	.....	0.00000E+00	Mg-m**2

NUMBER OF LAYERS OR ELEMENTS - 5  
\*\*\*\*\*

LOCATION OF FILES  
\*\*\*\*\*

FILE NO.	X LOCATION m	Y LOCATION m
1	0.000	0.000

FILE PROPERTIES

\*\*\*\*\*

X-LOCATION CENTRE OF GRAV. .... 0.00000 m  
Y-LOCATION CENTRE OF GRAV. .... 0.00000 m  
HEIGHT OF CENTRE OF GRAV. .... 0.19600 m  
TOTAL LENGTH ..... 3.38000 m  
UNIT WEIGHT ..... 77.00000 kN/m\*\*3  
STATIC LOAD ON BODY ..... 1.00000E+00 kN.  
POISSONS RATIO ..... 0.30000  
MATERIAL DAMPING ..... 0.02000  
COEFF. OF RIGIDITY ..... 1.33400  
YOUNGS MODULUS ..... 2.00000E+08 kPa

ELEMENT

\*\*\*\*\*

LAYER NO.	LAYER DEPTH m	PILE RADIUS (X) m	PILE RADIUS (Y) m	CROSS SECTIONAL AREA m**2	MOMENT OF INERTIA '(X) m**4	MOMENT OF INERTIA (Y) m**4	TORSIONAL STIFFNESS m**4
1	0.500	0.067	0.067	2.390E-03	4.840E-06	4.840E-06	9.68E-06
2	0.500	0.067	0.067	2.390E-03	4.840E-06	4.840E-06	9.68E-06
3	0.500	0.067	0.067	2.390E-03	4.840E-06	4.840E-06	9.68E-06
4	0.500	0.067	0.067	2.390E-03	4.840E-06	4.840E-06	9.68E-06
5	1.380	0.067	0.067	2.390E-03	4.840E-06	4.840E-06	9.68E-06

SOIL CONSTANTS

\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY m/s	UNIT WEIGHT kN/m**3	POISSONS RATIO	MATERIAL DAMPING
1	35.000	16.700	0.450	0.050
2	35.000	16.700	0.450	0.050
3	40.000	16.700	0.450	0.050
4	50.000	16.700	0.450	0.050
5	70.000	16.700	0.450	0.050

NONLINEARITY OF SOIL (WEAKENED ZONE)

\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
-----------	---------------------

1	0.030
2	0.030
3	0.030
4	0.030
5	0.030

SOIL BELOW PILE

\*\*\*\*\*

SHEAR WAVE VELOCITY m/s	UNIT WEIGHT kN/m**3	POISSON'S RATIO	MATERIAL DAMPING
9.30E+01	16.8000	0.300	0.050

HARMONIC LOAD, QUADRATIC  
\*\*\*\*\*

MAXIMUM FREQUENCY ..... 1.500E+01 Hz  
MINIMUM FREQUENCY ..... 5.000E-01 Hz  
STEP FREQUENCY ..... 1.000E+00 Hz  
FORCE COEFF. IN X-DIRECTION ... 0.000E+00 Mg-m  
FORCE COEFF. IN Y-DIRECTION ... 6.060E-05 Mg-m  
FORCE COEFF. IN Z-DIRECTION ... 6.060E-05 Mg-m  
MOMENT COEFF. ABOUT X-AXIS .... -1.236E-05 Mg-m\*\*2  
MOMENT COEFF. ABOUT Y-AXIS .... 0.000E+00 Mg-m\*\*2  
MOMENT COEFF. ABOUT Z-AXIS .... 0.000E+00 Mg-m\*\*2

\*\*\*\*\*  
\*  
\*           S O I L - F O U N D A T I O N           \*  
\*  
\*       D Y N A M I C   S I M U L A T I O N       \*  
\*                   D Y N A N                   \*  
\*  
\*           RUN DATE - 22-MAR-12           \*  
\*           TIME     - 18:19:29           \*  
\*   Copyright Canadian No.492911 - 2001/7/13   \*  
\*  
\*\*\*\*\*

Singel Steel File

RESULTS  
\*\*\*\*\*

FREQUENCY -     0.5000 Hz ( 3.1400 rad./sec.)  
\*\*\*\*\*

STIFFNESS CONSTANTS (K)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) .. 2.66723E+03 kN/m  
HORIZONTAL TRANSLATION (KYY) .. 2.66723E+03 kN/m  
VERTICAL TRANSLATION (KWW) .... 1.87464E+04 kN/m  
ROTATION (KPPX) ..... 2.50522E+03 kN-m/rad  
ROTATION (KPPY) ..... 2.50522E+03 kN-m/rad  
TORSION (KZT) ..... 7.94600E+01 kN-m/rad  
CROSS-STIFFNESS (KXP) ..... 2.08665E+03 kN/rad  
CROSS-STIFFNESS (KYP) ..... -2.08665E+03 kN/rad

DAMPING CONSTANTS (C)  
\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) .. 4.52626E+01 kN/m/sec  
HORIZONTAL TRANSLATION (CYY) .. 4.52626E+01 kN/m/sec  
VERTICAL TRANSLATION (CWW) .... 7.29672E+01 kN/m/sec  
ROTATION (CPPX) ..... 2.37252E+01 kN-m/rad/sec  
ROTATION (CPPY) ..... 2.37252E+01 kN-m/rad/sec  
TORSION (CZT) ..... 1.27053E+00 kN-m/rad/sec  
CROSS-STIFFNESS (CXP) ..... 2.80138E+01 kN/rad/sec  
CROSS-STIFFNESS (CYP) ..... -2.80138E+01 kN/rad/sec

FREQUENCY - 1.5000 Hz ( 9.4200 rad./sec.)

\*\*\*\*\*

STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	2.66876E+03	kN/m
HORIZONTAL TRANSLATION (KYY) ..	2.66876E+03	kN/m
VERTICAL TRANSLATION (KWW) ...	1.87411E+04	kN/m
ROTATION (KPPX) .....	2.50608E+03	kN-m/rad
ROTATION (KPPY) .....	2.50608E+03	kN-m/rad
TORSION (KZT) .....	7.94404E+01	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.08773E+03	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.08773E+03	kN/rad

DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.81675E+01	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.81675E+01	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.45229E+01	kN/m/sec
ROTATION (CPPX) .....	9.00048E+00	kN-m/rad/sec
ROTATION (CPPY) .....	9.00048E+00	kN-m/rad/sec
TORSION (CZT) .....	4.23537E-01	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.10264E+01	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.10264E+01	kN/rad/sec

FREQUENCY - 2.5000 Hz ( 15.7000 rad./sec.)

\*\*\*\*\*

STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	2.67404E+03	kN/m
HORIZONTAL TRANSLATION (KYY) ..	2.67404E+03	kN/m
VERTICAL TRANSLATION (KWW) ...	1.87898E+04	kN/m
ROTATION (KPPX) .....	2.50828E+03	kN-m/rad
ROTATION (KPPY) .....	2.50828E+03	kN-m/rad
TORSION (KZT) .....	7.94030E+01	kN-m/rad
CROSS-STIFFNESS (KXP) .....	2.09088E+03	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.09088E+03	kN/rad

DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	1.26871E+01	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	1.26871E+01	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	2.70317E+01	kN/m/sec
ROTATION (CPPX) .....	6.03337E+00	kN-m/rad/sec
ROTATION (CPPY) .....	6.03337E+00	kN-m/rad/sec
TORSION (CZT) .....	2.54156E-01	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	7.59472E+00	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-7.59472E+00	kN/rad/sec

FREQUENCY - 3.5000 Hz ( 21.9800 rad./sec.)

\*\*\*\*\*

STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	2.68257E+03	kN/m
HORIZONTAL TRANSLATION (KYY) ..	2.68257E+03	kN/m
VERTICAL TRANSLATION (KWW) ...	1.89822E+04	kN/m
ROTATION (KPPX) .....	2.51163E+03	kN-m/rad

Singel Steel File

RESULTS  
\*\*\*\*\*

## FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
0.50	3.14	0.0000E+00	7.5475E-07	3.1876E-08	6.7813E-07	0.0000E+00	0.0000E+00
1.50	9.42	0.0000E+00	7.0196E-06	2.8740E-07	6.3001E-06	0.0000E+00	0.0000E+00
2.50	15.70	0.0000E+00	2.0881E-05	7.9869E-07	1.8697E-05	0.0000E+00	0.0000E+00
3.50	21.98	0.0000E+00	4.5785E-05	1.5566E-06	4.0846E-05	0.0000E+00	0.0000E+00
4.50	28.26	0.0000E+00	8.9929E-05	2.5503E-06	7.9817E-05	0.0000E+00	0.0000E+00
5.50	34.54	0.0000E+00	1.7571E-04	3.7521E-06	1.5491E-04	0.0000E+00	0.0000E+00
6.50	40.82	0.0000E+00	3.8925E-04	5.1854E-06	3.4028E-04	0.0000E+00	0.0000E+00
7.50	47.10	0.0000E+00	1.5894E-03	6.8571E-06	1.3751E-03	0.0000E+00	0.0000E+00
8.50	53.38	0.0000E+00	1.3416E-03	8.7766E-06	1.1463E-03	0.0000E+00	0.0000E+00
9.50	59.66	0.0000E+00	6.0436E-04	1.0955E-05	5.0883E-04	0.0000E+00	0.0000E+00
10.50	65.94	0.0000E+00	4.2997E-04	1.3408E-05	3.5583E-04	0.0000E+00	0.0000E+00
11.50	72.22	0.0000E+00	3.5313E-04	1.6154E-05	2.8647E-04	0.0000E+00	0.0000E+00
12.50	78.50	0.0000E+00	3.1033E-04	1.9212E-05	2.4606E-04	0.0000E+00	0.0000E+00
13.50	84.78	0.0000E+00	2.8266E-04	2.2608E-05	2.1787E-04	0.0000E+00	0.0000E+00
14.50	91.06	0.0000E+00	2.6377E-04	2.6370E-05	1.9681E-04	0.0000E+00	0.0000E+00

### 6.10 Example 10: Seismic Response of Vacuum Tower Structure

A vacuum tower structure shown in Fig. 6.7 was built for a petrochemical plant in a seismically active area. Details of the steel structure are described in what follows. Four columns using WWF 400x243 (400 x 400 mm, weight of 243 kg/m) and a height of 20m are arranged in a rectangle with a center to center spacing of 8.55m. The vacuum vessel is supported directly by a top frame using beams of WWF 1400x358 (1400 x 400 mm, weight of 358 kg/m) on top and beams of W610x155 at bottom. There are three layers of beams beneath the top frame and the main beam is W460x82. The concrete mat foundation is 12 x 12 m and thickness is 1.2 m.

The vacuum vessel is modeled as an elastic column with the mass distributed uniformly along its height. The steel structure is modeled using frame elements, and the mat foundation is modeled using shell elements, as shown in Fig. 6.7. The thickness of the vessel wall is 25.4 mm (one inch). The seismic response of the structure is calculated using the substructure method. The deflection of the structure, the base shear, and the overturning moments for different base conditions are of importance in the design consideration.

The structure is in a seismically active area, and the range of peak horizontal ground acceleration is equal to 0.13 g. At the site, the surface soil is soft clay with a depth of 2 m, followed by a layer of saturated fine sand with a depth of 2 m, then some clay, sand, and finally bedrock. The depth to the bedrock is about 30 m. Soil properties vary with depth and are characterized by the shear wave velocity,  $V_s$ , and unit weight,  $\gamma$ , as shown in Table 6.1.

The washed medium sand was placed into the pit and compacted. The soil properties were measured in the laboratory and in situ for both the sandy-soil fill and the undisturbed natural deposit around the pit.

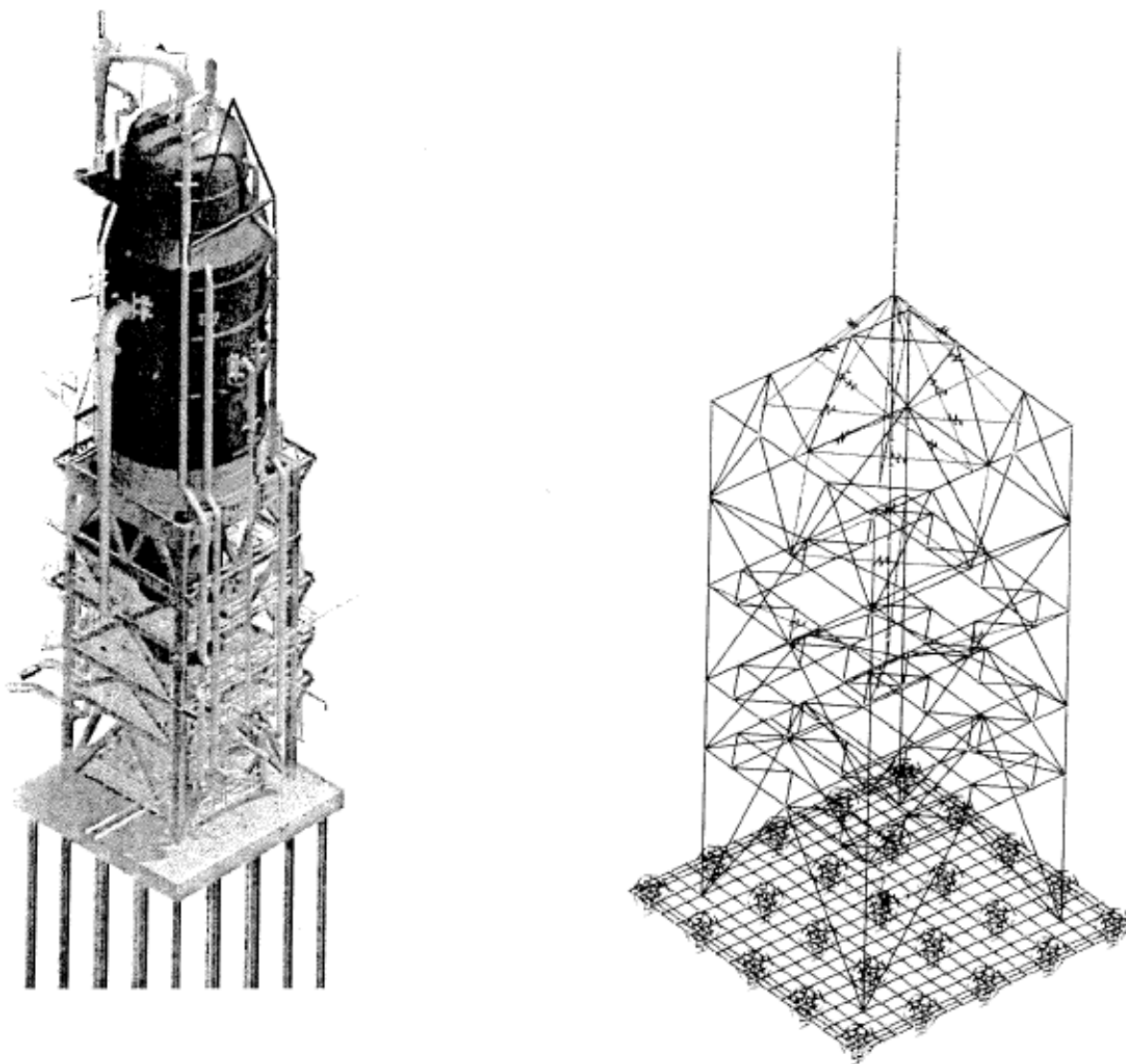
The stiffness and damping of the pile foundation are calculated for different base conditions. In the first case a nonlinear soil-pile system is assumed, and the boundary zone model is used around the piles. The parameters of the weakened zone are selected as:  $G_i / G_o = 0.3$ ,  $t_m / r_o = 1.0$ ,  $\beta_i = 2 \times \beta_o$ . In the second case, liquefaction is assumed in the saturated fine sand layer, and the top layer of soft clay has not yielded. However, both stiffness and damping of these two layers are reduced to very small values due to liquefaction effects.

As known, great amount of effort has been spent on the numerical analysis with 3D Finite Element Method (FEM) to model a soil-pile-structure interaction together. However, it is too complex, especially for the sub-structure (pile and soil) with nonlinear behavior. The computation time costs are substantial and the results are not reliable. The substructure concept based on the impedance function of foundations has been introduced in the structural analysis and is frequently used by the structural engineers for the time-history analysis in seismic studies. By means of the substructure method, the dynamic response of the superstructure (the vacuum tower) is analyzed using a nonlinear finite-element program, such as SAP2000 or other similar one, and the stiffness and damping of foundation generated by DynaN program being entered as the boundary condition, which represent the substructure in modeling.



The maximum amplitude of the vacuum tower will vary with each of the different foundation-soil systems (linear vs. nonlinear, with and without liquefaction zone). The natural periods of the structural vibration also have the similar effects from the assumed foundation condition as expected.

Use SI units: kN, Mg, m.



**Figure 6.7** Pile foundation for dynamic response analysis demonstrated in Example 8

Table 6.1 Soil profile and properties for Example 10

Depth (m)	Soil	Unit Weight (kN / m <sup>3</sup> )	Shear Wave Velocity (m / s)
0 - 2	Soft Clay	18	130
2 - 4	Fine Sand	18	140
4 - 12	Stiff Clay	20	300
12 - 16	Silty Sand	19	240
16 - 20	Silty Clay	18	300
20 - 25	Weathered Shale	18	200
25 - 30	Dense Sand	20	300
Below 30	Bedrock	21.5	370

### 6.10.1 Input Data

TITLE= OPTI VACUUM TOWER, Nonlinear soil

MATRIX

GRAVITY=9.8

FOUNDATION=PILE

RECTANGULAR=12,12

MASS

2288 29980 106600 118700 0 0 0

LAYERS=8

FIXED=25

1 -5.5 -5.5

2 -2.75 -5.5

3 0 -5.5

4 2.75 -5.5

5 5.5 -5.5

6 -5.5 -2.75

7 -2.75 -2.75

8 0 -2.75

9 2.75 -2.75

10 5.5 -2.75

11 -5.5 0

12 -2.75 0

13 0 0

14 2.75 0

15 5.5 0

16 -5.5 2.75

17 -2.75 2.75

18 0 2.75

```

19 2.75 2.75
20 5.5 2.75
21 -5.5 5.5
22 -2.75 5.5
23 0 5.5
24 2.75 5.5
25 5.5 5.5
CONSTANTS
0 -1.738 2.396 30 77
150 0.3 0.02 1.2 2E8
ELEMENT
1 0.5 0.18 0.18 0.014 0.000303 0.000108 0.000832
2 1.5 0.18 0.18 0.014 0.000303 0.000108 0.000832
3 2 0.18 0.18 0.014 0.000303 0.000108 0.000832
4 8 0.18 0.18 0.014 0.000303 0.000108 0.000832
5 4 0.18 0.18 0.014 0.000303 0.000108 0.000832
6 4 0.18 0.18 0.014 0.000303 0.000108 0.000832
7 5 0.18 0.18 0.014 0.000303 0.000108 0.000832
8 5 0.18 0.18 0.014 0.000303 0.000108 0.000832
FLOATING
INTERACTION
SOIL
WEAK
CONSTANTS
1 0 0 0.35 0.02 0.3 0.35 0.04 1
2 130 18 0.35 0.02 0.3 0.35 0.04 1
3 140 18 0.35 0.02 0.3 0.35 0.04 1
4 300 20 0.4 0.02 0.3 0.4 0.04 1
5 240 18 0.4 0.02 0.3 0.4 0.04 1
6 300 18 0.3 0.02 0.3 0.3 0.04 1
7 200 18 0.4 0.02 0.3 0.4 0.04 1
8 300 20 0.4 0.02 0.3 0.4 0.04 1
BELOW=370 21.5 0.4 0.02
SIDE-CAP
EMBEDDED
2
1 0.5 100 18 0.3 0.02 0.1 0.3 0.04 1
2 0.3 80 18 0.3 0.02 0.1 0.3 0.04 1
LOAD
HARMONIC
CONSTANTS
NONQUADRATIC
62.8 6.28 6.28 104700 0 27720 333400 417700 -673600
RUN
0
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000
0.000000000000000E+0000 0.000000000000000E+0000 0.000000000000000E+0000

```

### 6.10.2 Output Results

Only small portions of output are shown here. Please run the example data file and view the complete output from the computer screen.

OPTI VACUUM TOWER

DATA ECHO  
\*\*\*\*\*

UNRECOGNIZED KEYWORD - Non

STIFFNESS AND DAMPING CONSTANTS TO BE PRINTED  
\*\*\*\*\*

GRAVITATIONAL CONSTANT SET TO 9.80 m/s\*\*2  
\*\*\*\*\*

FOUNDATION TYPE - FILE  
\*\*\*\*\*

RECTANGULAR FOUNDATION - 12.000 m BY 12.000 m  
\*\*\*\*\*

MASS CONSTANTS  
\*\*\*\*\*

TOTAL MASS OF FOOTING	.....	2.28800E+03	Mg
MASS MOMENT ABOUT X-AXIS	.....	2.99800E+04	Mg-m**2
MASS MOMENT ABOUT Y-AXIS	.....	1.06600E+05	Mg-m**2
MASS MOMENT ABOUT Z-AXIS	.....	1.18700E+05	Mg-m**2
CROSS PRODUCT X-Y	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT X-Z	.....	0.00000E+00	Mg-m**2
CROSS PRODUCT Y-Z	.....	0.00000E+00	Mg-m**2

NUMBER OF LAYERS OR ELEMENTS - 8  
\*\*\*\*\*

LOCATION OF FILES  
\*\*\*\*\*

FILE NO.	X LOCATION m	Y LOCATION m
1	-5.500	-5.500
2	-2.750	-5.500
3	0.000	-5.500
4	2.750	-5.500
5	5.500	-5.500
6	-5.500	-2.750
7	-2.750	-2.750
8	0.000	-2.750
9	2.750	-2.750

10	5.500	-2.750
11	-5.500	0.000
12	-2.750	0.000
13	0.000	0.000
14	2.750	0.000
15	5.500	0.000
16	-5.500	2.750
17	-2.750	2.750
18	0.000	2.750
19	2.750	2.750
20	5.500	2.750
21	-5.500	5.500
22	-2.750	5.500
23	0.000	5.500
24	2.750	5.500
25	5.500	5.500

## FILE PROPERTIES

\*\*\*\*\*

X-LOCATION CENTRE OF GRAV.	0.00000	m
Y-LOCATION CENTRE OF GRAV.	-1.73800	m
HEIGHT OF CENTRE OF GRAV.	2.39600	m
TOTAL LENGTH	30.00000	m
UNIT WEIGHT	77.00000	kN/m**3
STATIC LOAD ON BODY	1.50000E+02	kN.
POISSONS RATIO	0.30000	
MATERIAL DAMPING	0.02000	
COEFF. OF RIGIDITY	1.20000	
YOUNGS MODULUS	2.00000E+08	kPa

## ELEMENT

\*\*\*\*\*

LAYER NO.	LAYER DEPTH	PILE RADIUS (X)	PILE RADIUS (Y)	CROSS SECTIONAL AREA	MOMENT OF INERTIA (X)	MOMENT OF INERTIA (Y)	TORSIONAL STIFFNESS
	m	m	m	m**2	m**4	m**4	m**4
1	0.500	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
2	1.500	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
3	2.000	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
4	8.000	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
5	4.000	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
6	4.000	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
7	5.000	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04
8	5.000	0.180	0.180	1.400E-02	3.030E-04	1.080E-04	8.32E-04

## SOIL CONSTANTS

\*\*\*\*\*

LAYER NO.	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSONS RATIO	MATERIAL DAMPING
	m/s	kN/m**3		
1	0.000	0.000	0.350	0.020
2	130.000	18.000	0.350	0.020
3	140.000	18.000	0.350	0.020
4	300.000	20.000	0.400	0.020
5	240.000	18.000	0.400	0.020
6	300.000	18.000	0.300	0.020
7	200.000	18.000	0.400	0.020
8	300.000	20.000	0.400	0.020

## NONLINEARITY OF SOIL (WEAKENED ZONE)

\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
-----------	---------------------

1	0.300
2	0.300
3	0.300
4	0.300
5	0.300
6	0.300
7	0.300
8	0.300

## SOIL BELOW FILE

\*\*\*\*\*

SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSON'S RATIO	MATERIAL DAMPING
m/s	kN/m**3		
3.70E+02	21.5000	0.400	0.020

## EMBEDDED OPTION

\*\*\*\*\*

NUMBER OF SIDE LAYERS - 2

LAYER NO.	THICKNESS OF LAYER	SHEAR WAVE VELOCITY	UNIT WEIGHT	POISSONS RATIO	MATERIAL DAMPING
	m	m/s	kN/m**3		
1	0.500	100.00	18.000	0.300	0.020
2	0.300	80.00	18.000	0.300	0.020

## SIDE-CAP (WEAKENING) OF SIDE LAYERS

\*\*\*\*\*

LAYER NO.	SHEAR MODULUS RATIO
-----------	---------------------

1	0.100
2	0.100

## HARMONIC LOAD, NON QUADRATIC

\*\*\*\*\*

MAXIMUM FREQUENCY	1.000E+01	Hz
MINIMUM FREQUENCY	1.000E+00	Hz
STEP FREQUENCY	1.000E+00	Hz
FORCE IN X-DIRECTION	1.047E+05	kN.
FORCE IN Y-DIRECTION	0.000E+00	kN.
FORCE IN Z-DIRECTION	2.772E+04	kN.
MOMENT ABOUT X-AXIS	3.334E+05	kN-m
MOMENT ABOUT Y-AXIS	4.177E+05	kN-m
MOMENT ABOUT Z-AXIS	-6.736E+05	kN-m

## OPTI VACUUM TOWER

## RESULTS

\*\*\*\*\*

FREQUENCY - 1.0000 Hz ( 6.2800 rad./sec.)  
\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	5.88978E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.91419E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	2.85513E+06	kN/m
ROTATION (KPPX) .....	1.14315E+08	kN-m/rad
ROTATION (KPPY) .....	1.17502E+08	kN-m/rad
TORSION (KZT) .....	2.79589E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	1.28537E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.02970E+06	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	4.15757E+03	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	3.10695E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	6.28702E+03	kN/m/sec
ROTATION (CPPX) .....	2.34824E+05	kN-m/rad/sec
ROTATION (CPPY) .....	2.45171E+05	kN-m/rad/sec
TORSION (CZT) .....	1.45751E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	8.47482E+03	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.21242E+04	kN/rad/sec

FREQUENCY - 2.0000 Hz ( 12.5600 rad./sec.)  
\*\*\*\*\*

## STIFFNESS CONSTANTS (K)

\*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	5.72304E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.72561E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	2.87585E+06	kN/m
ROTATION (KPPX) .....	1.12008E+08	kN-m/rad
ROTATION (KPPY) .....	1.15227E+08	kN-m/rad
TORSION (KZT) .....	2.78735E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	1.25185E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-2.00454E+06	kN/rad

## DAMPING CONSTANTS (C)

\*\*\*\*\*

HORIZONTAL TRANSLATION (CXX) ..	5.42428E+03	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	3.75056E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	2.90049E+04	kN/m/sec
ROTATION (CPPX) .....	1.21945E+05	kN-m/rad/sec
ROTATION (CPPY) .....	1.03372E+05	kN-m/rad/sec
TORSION (CZT) .....	1.04746E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.14807E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-1.75202E+04	kN/rad/sec

FREQUENCY - 3.0000 Hz ( 18.8400 rad./sec.)  
 \*\*\*\*\*

STIFFNESS CONSTANTS (K)  
 \*\*\*\*\*

HORIZONTAL TRANSLATION (KXX) ..	5.44193E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.44124E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	2.87174E+06	kN/m
ROTATION (KPPX) .....	1.09811E+08	kN-m/rad
ROTATION (KPPY) .....	1.13037E+08	kN-m/rad
TORSION (KZT) .....	2.84553E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	1.19535E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-1.94955E+06	kN/rad

DAMPING CONSTANTS (C)  
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HORIZONTAL TRANSLATION (CXX) ..	7.60744E+03	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	5.83988E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.21717E+04	kN/m/sec
ROTATION (CPPX) .....	1.90837E+04	kN-m/rad/sec
ROTATION (CPPY) .....	3.31395E+02	kN-m/rad/sec
TORSION (CZT) .....	4.91623E+04	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.58931E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-2.22529E+04	kN/rad/sec

FREQUENCY - 4.0000 Hz ( 25.1200 rad./sec.)  
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STIFFNESS CONSTANTS (K)  
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HORIZONTAL TRANSLATION (KXX) ..	5.50328E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	3.49808E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	2.87772E+06	kN/m
ROTATION (KPPX) .....	1.08747E+08	kN-m/rad
ROTATION (KPPY) .....	1.11987E+08	kN-m/rad
TORSION (KZT) .....	2.83116E+07	kN-m/rad
CROSS-STIFFNESS (KXP) .....	1.20523E+06	kN/rad
CROSS-STIFFNESS (KYP) .....	-1.96212E+06	kN/rad

DAMPING CONSTANTS (C)  
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HORIZONTAL TRANSLATION (CXX) ..	8.86062E+03	kN/m/sec
HORIZONTAL TRANSLATION (CYY) ..	7.03764E+03	kN/m/sec
VERTICAL TRANSLATION (CWW) ...	3.42949E+04	kN/m/sec
ROTATION (CPPX) .....	1.59313E+05	kN-m/rad/sec
ROTATION (CPPY) .....	1.79268E+05	kN-m/rad/sec
TORSION (CZT) .....	4.26462E+05	kN-m/rad/sec
CROSS-STIFFNESS (CXP) .....	1.85359E+04	kN/rad/sec
CROSS-STIFFNESS (CYP) .....	-2.50859E+04	kN/rad/sec

FREQUENCY - 5.0000 Hz ( 31.4000 rad./sec.)  
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STIFFNESS CONSTANTS (K)  
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HORIZONTAL TRANSLATION (KXX) ..	6.14106E+05	kN/m
HORIZONTAL TRANSLATION (KYY) ..	4.13088E+05	kN/m
VERTICAL TRANSLATION (KWW) ...	2.87175E+06	kN/m
ROTATION (KPPX) .....	1.15092E+08	kN-m/rad



OPTI VACUUM TOWER

RESULTS  
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## FOOTING RESPONSE AMPLITUDES

FREQ. Hz	FREQ. rad/sec	TRANS. X DIRECTION (UOX) m	TRANS. Y DIRECTION (UOY) m	VERTICAL (UOZ) m	ROT ABOUT X AXIS (EPOX) rad	ROT ABOUT Y AXIS (EPOY) rad	TORSIONAL (EPOZ) rad
1.00	6.28	2.4328E-01	1.3194E-02	1.0006E-02	3.0953E-03	8.0389E-03	2.9072E-02
2.00	12.56	6.4886E-01	9.1218E-02	1.0872E-02	3.5122E-03	1.7382E-02	7.6258E-02
3.00	18.84	3.2958E-01	8.4166E-03	1.2886E-02	3.2836E-03	5.4496E-03	4.5910E-02
4.00	25.12	1.2391E-01	4.2691E-03	1.6528E-02	3.6615E-03	5.4743E-03	1.3741E-02
5.00	31.40	6.6318E-02	2.3665E-03	2.1377E-02	3.0435E-03	4.2723E-03	3.9858E-03
6.00	37.68	4.1385E-02	2.0335E-05	1.9319E-02	3.3706E-05	3.3448E-05	1.8106E-04
7.00	43.96	2.9111E-02	1.0137E-05	1.1903E-02	2.1244E-05	2.2231E-05	1.9326E-05
8.00	50.24	2.1096E-02	3.7631E-06	7.7836E-03	1.0801E-05	1.1742E-05	1.1504E-05
9.00	56.52	1.5790E-02	3.1346E-07	5.4749E-03	1.3709E-06	1.5713E-06	1.6986E-05
10.00	62.80	1.2250E-02	1.1803E-06	4.0555E-03	7.9921E-06	9.5036E-06	1.3742E-05

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