



KIN SP 1.0

USER'S MANUAL Version 1.0

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1 INTRODUCTION KIN SP

In seismic areas, piles are commonly designed to resist to inertial forces due to the superstructure. Nevertheless, it's important to consider the kinematic effects to properly complete the design process of pile foundation.

The arise of kinematic interaction phenomena are due to the seismically induced deformations of the soil that interacts with the pile. One of the main important effect of these deformations is the arise of significant strains in soft soil that induce bending moments (kinematic bending moments) on piles. The research works realized about this topic have demonstrated that kinematic bending moments can be responsible for pile damage especially in case of presence of high stiffness contrast in a soil deposit profile (Fig. 1).

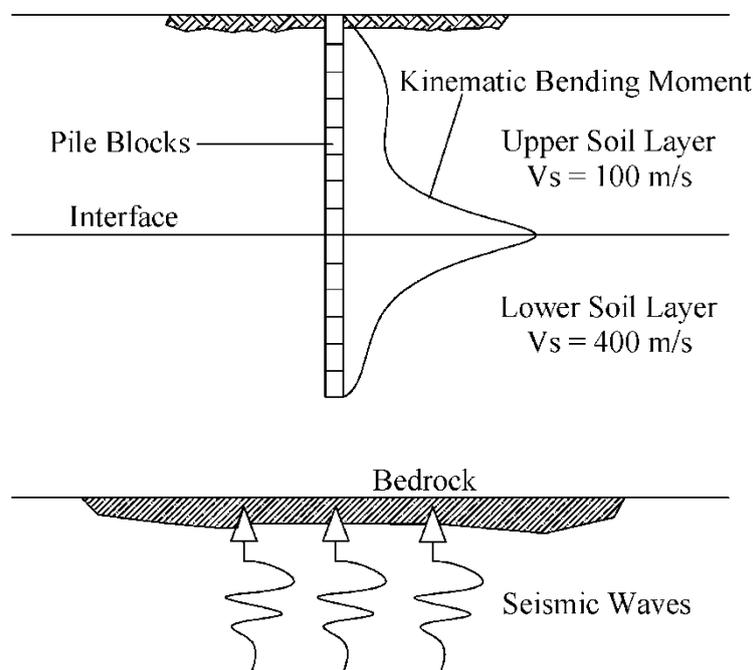


Figure 1 Pile-soil system scheme: two soil layers having a high stiffness discontinuity

The internal forces generated as a consequence of the seismic waves propagation in a pile are affected by: the pile-soil relative stiffness (E_{pile}/E_{soil}), the pile slenderness ratio ($L/D = \text{Length/Diameter}$), the pile-head restraint condition (free-head, fixed-head), the thickness and the mechanical properties of the subsoil layers and by the seismic event used as input.

Considering the available technical literature about the pile kinematic interaction, the following general remarks can be outlined:

- *Free-head pile embedded in a homogenous soil deposit*: the maximum bending moment occurs in a section located approximately at the middle of the total pile length;
- *Fixed-head pile embedded in a homogenous soil deposit*: the maximum bending moment occurs at the pile-head section (the top pile-section);
- *Pile embedded in a layered soil deposit*: the bending moment values along the pile-shaft increase at the interface between two adjacent soil-layers having different shear moduli (G) (or Shear Wave Velocities (V_s)). The subsequent bending increment is higher as the mechanical impedance increases;
- It's fully accepted by the scientific community that group-effects can be neglected in the pile kinematic interaction problem. The analysis is performed on a single pile subjected to the seismic event;

Here below are reported some of the formulations available in the technical literature in order to evaluate the pile bending moment induced by the kinematic interaction.

NEHRP (1997) method. This method relies on the following assumptions:

- the pile follows the soil movements during the seismic event (pile-soil interactions are neglected);
- the soil deposit is homogenous (the shear modulus or the shear wave velocity is considered constant for the whole deposit)

- this method should not be used in case of high stiffness contrast between two adjacent soil layers.

This method provides the expression (1) to evaluate the bending moment distribution along the pile shaft:

$$M(z, t) = E_p I_p \frac{a(z, t)}{V_s^2} \quad (1)$$

where: $M(z, t)$ is the value of the bending moment at a given time t at the depth z ; $E_p I_p$ is the flexural rigidity of the pile section (for a circular pile section made of concrete, $E_p I_p = E_c * (1/64) * \pi * D^4$, with E_c = Elastic modulus of the concrete, D = pile diameter); $a(z, t)$ is the *free-field* acceleration at a given time t and at a given depth z obtained from a ground response analysis; V_s is the shear wave velocity of the soil deposit.

Dobry & O'Rourke (1983) Method. This method assumes a linear elastic behaviour for the pile and the soil deposit. The expression (2) is useful to estimate the maximum bending moment at the interface between two layers having different stiffness.

$$M = 1.86(E_p I_p)^{3/4} (G_1)^{1/4} \gamma_1 F$$

$$F = \frac{(1 - c^{-4})(1 + c^3)}{(1 + c)(c^{-1} + 1 + c + c^2)}$$

$$c = \left(\frac{G_2}{G_1}\right)^{1/4}$$

$$\gamma_1 = \frac{\rho_1 h_1}{G_1} a_{max,s}$$
(2)

Where: G_1 and G_2 are the shear modulus of the upper and lower soil layers (that can be estimated using: $G = \rho V_s^2$); γ_1 is the shear strain at the upper layer base; ρ_1 is the soil

density (kg/m^3) of the upper layer; h_1 the upper layer thickness; $a_{max,s}$ is the maximum acceleration at the ground surface in *free-field* conditions.

Nikolaou et al. 2001 Method. This method suggests the expression (3) to evaluate the maximum bending moment at the interface between to soil layers having different stiffness in steady-state condition with a frequency approximately equal to the natural frequency of the soil deposit.

$$M = 0.042 \tau_c D^3 \left(\frac{L}{D}\right)^{0.3} \left(\frac{E_p}{E_1}\right)^{0.65} \left(\frac{V_{s2}}{V_{s1}}\right)^{0.5}$$

$$\tau_c = a_{max,s} \rho_1 h_1$$
(3)

Where: V_{s1} and V_{s2} are respectively the shear wave velocity of the upper and lower soil layer; E_1 is the Young Modulus of the upper layer. The expression (3) is valid when the interface between the two soil layers is located at a depth greater than the *pile active length* (L_a). L_a can be evaluated according to the expression (4) proposed by Randolph (1981) (that assumes a linear elastic behaviour for the soil and the pile).

$$L_a = 1.5 \left(\frac{E_p}{E_s}\right)^{1/4} D$$
(4)

To evaluate the maximum bending moment induced by the seismic action, Nikolaou et al. (2001) suggests the expression (5).

$$M_{max} = \eta M$$
(5)

Where M is given by the expression (3) and η is a reduction factor expressed as a function of the effective number of cycles (N_c) of the accelerogram according to:

$$\eta = 0.04 N_c + 0.23 \quad (6)$$

$$\eta = 0.015 N_c + 0.17 \quad (7)$$

The expression (6) should be used when the natural frequency of the deposit is approximately equal to the predominant frequency of the input motion. The expression (7) should be used when the natural frequency of the deposit is significantly different to the predominant frequency of the input motion.

Usually the solutions obtained with the *NEHRP method* underestimate the value of the bending moment, while the *Dobry & O'Rourke method* is more conservative. The bending moments evaluated using the expression (3) are closer to the solutions obtained with more rigorous approaches.

1.1 Model assumptions

The single pile kinematic analysis is based on the procedure proposed by Tabesh & Poulos (2001) and the problem is solved using the boundary element method (BEM). The kinematic analysis is preceded by a seismic ground response analysis performed in the time domain with the program ONDA, which provides the soil displacements and velocities at the center of each pile block at each time step. The model assumptions are:

- the soil deposit has a linear elastic behaviour (the soil non-linear behaviour was already taken into account in the seismic ground response analysis performed with ONDA);

- the soil elastic moduli are equivalent moduli corresponding to the secant moduli at shear strains equal to the 65% of the maximum shear strains obtained in the free-field ground response analysis;
- the stresses developed between the pile and soil act normal to the face of the pile;
- each pile-block is subject to a uniform horizontal stress, constant for all the width of the pile;
- the pile is modelled as a thin strip using the Euler-Bernoulli theory and is discretized in n blocks. The number n is a user-defined value. *Note: the analysis results are affected by the n value, because this problem is discretization-dependent. It is recommended to perform a sensitivity analysis (repeating the analysis increasing the pile block number until the convergence is obtained between two consecutive analyses) in order to guarantee the accuracy of the solution (for common situations a pile block size ranging between 0.25 and 1.00 meter should be appropriate);*
- the soil displacement induced by a uniform pressure acting over a pile-block is computed integrating the Mindlin equation (1936).
- the global equilibrium and the pile-soil displacement compatibility is imposed.

1.2 The Program KIN SP

The pile flexibility matrix (\mathbf{H}) is obtained using the elastic beam theory, and every coefficient of this matrix can be expressed using the expression (8) (see Fig.2).

if $z_i \leq z_j$

$$h_{ij} = \frac{z_i^3}{3E_p I_p} + \frac{z_i^2 (z_j - z_i)}{2E_p I_p}$$

if $z_i \geq z_j$

$$h_{ij} = \frac{z_j^3}{3E_p I_p} + \frac{z_j^2(z_i - z_j)}{2E_p I_p}$$

(8)

In this way, the incremental horizontal displacements $\{\Delta y\}$ of the pile-blocks can be obtained with the expression (9).

$$\{\Delta y\} = -\mathbf{H} \{\Delta P_p\} + \Delta y_0 + \Delta \theta_0 \{z\}$$

(9)

Where: $\{\Delta P_p\}$ is a column vector, containing the incremental load acting at each pile-block, and equal to $\{\Delta P_p\} = \{\Delta p\} (t D)$, where $\{\Delta p\}$ is the column vector of the incremental uniform pressures acting over each pile-block, t is the height of every pile-block and D is the pile diameter or the pile width; Δy_0 and $\Delta \theta_0$ are the unknown incremental displacement and rotation at the pile-head; $\{z\}$ is the column vector containing the depth of the center of each pile-block.

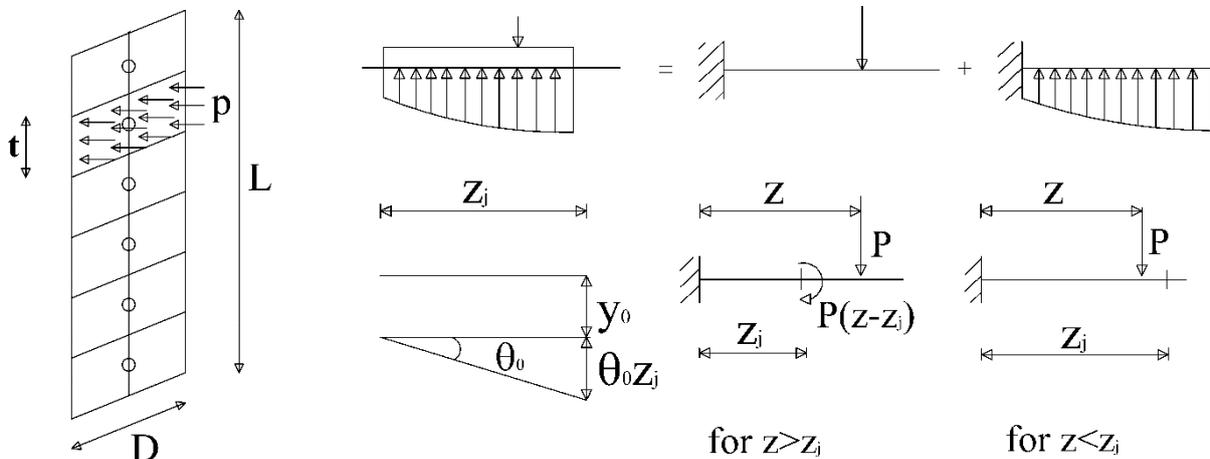


Figure 2 a) Pile discretization; b) Pile flexibility matrix using the auxiliary restraint method

The soil flexibility matrix (\mathbf{B}) is obtained using the Mindlin solution (1936) and every coefficient of this matrix can be expressed using the expression (10) (see Fig. 3).

$$b_{ij} = \frac{(1 + \nu)}{8\pi E_s(1 - \nu)} \left[\frac{3 - 4\nu}{R_{1ij}} + \frac{1}{R_{2ij}} + \frac{2cz}{R_{2ij}^3} + \frac{4(1 - \nu)(1 - 2\nu)}{R_{2ij} + z + c} \right] \quad (10)$$

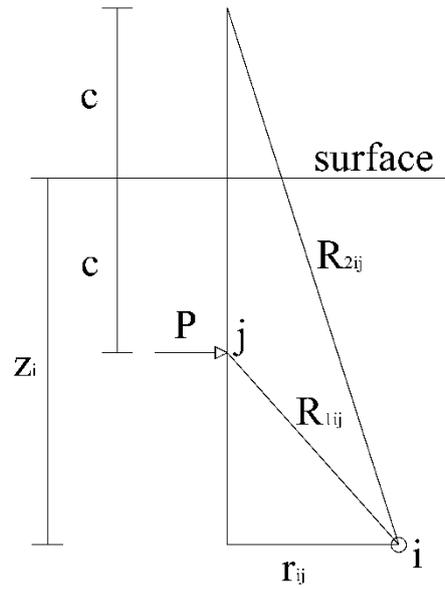


Figure 3 Mindlin solution scheme

The incremental horizontal displacements $\{\Delta s\}$ of the soil can be obtained with the expression (11).

$$\{\Delta s\} = \mathbf{B} \{\Delta P_s\} + \{\Delta x\} \quad (11)$$

Where: $\{\Delta P_s\}$ is a column vector, containing the incremental load acting at each pile-soil interface, and equal to $\{\Delta P_s\} = \{\Delta p_s\} (t D)$, where $\{\Delta p_s\}$ is the column vector of the incremental uniform pressures acting over each pile-soil interface, t is the height of every pile-block and D is the pile diameter or the pile width; $\{\Delta x\}$ is the column vector

of the incremental soil displacements obtained in the ground response analysis using ONDA.

The relationship between $\{\Delta P_p\}$ and $\{\Delta P_s\}$ is expressed by the equation (12).

$$\{\Delta P_p\} = \{\Delta P_s\} + \mathbf{M}_k \{\Delta \ddot{\mathbf{y}}\} + \mathbf{C}_k [\{\Delta \dot{\mathbf{y}}\} - \{\Delta \dot{\mathbf{x}}\}] \quad (12)$$

Where \mathbf{M}_k is the diagonal mass matrix of the pile; \mathbf{C}_k is the diagonal damping matrix; $\{\Delta \ddot{\mathbf{y}}\}$ and $\{\Delta \dot{\mathbf{y}}\}$ are respectively the column vector of the incremental acceleration and of the incremental velocity at the pile interface; $\{\Delta \dot{\mathbf{x}}\}$ is the column vector of the incremental soil velocities obtained in the seismic free-field analysis with ONDA.

The elements of the damping matrix are computed using the expression $5\rho_s V_s D t$ as proposed by Kaynia (1988) for radiation damping in his Winkler method, in which ρ_s is soil mass density, V_s is soil shear-wave velocity, and D is pile diameter (as in the model proposed by Tabesh and Poulos (2001)). The adoption of these coefficients is justified by the fact that they are rather conservative and are also frequency independent.

Combining equation (12) with equation (9) and imposing the compatibility between pile and soil incremental displacements ($\{\Delta \mathbf{y}\} = \{\Delta \mathbf{s}\}$) the expression (13) is obtained:

$$-\mathbf{H}[\{\Delta P_s\} + \mathbf{M}\{\Delta \ddot{\mathbf{y}}\} + \mathbf{C}(\{\Delta \dot{\mathbf{y}}\} - \{\Delta \dot{\mathbf{x}}\})] + \Delta y_0 + \Delta \theta_0 \{z\} = \mathbf{B}\{\Delta P_s\} + \{\Delta \mathbf{x}\} \quad (13)$$

This system is solved using the Newmark- β method. Using this method, the incremental acceleration and the incremental velocity are defined by the expressions (14) and (15).

$$\{\Delta\ddot{\mathbf{y}}\} = \frac{4}{\Delta t^2}\{\Delta\dot{\mathbf{y}}\} - \frac{4}{\Delta t}\{\dot{\mathbf{y}}\} - 2\{\ddot{\mathbf{y}}\} \quad (14)$$

$$\{\Delta\dot{\mathbf{y}}\} = \frac{2}{\Delta t}\{\Delta\mathbf{y}\} - 2\{\dot{\mathbf{y}}\} \quad (15)$$

Where $\{\dot{\mathbf{y}}\}$ and $\{\ddot{\mathbf{y}}\}$ are respectively the column vector of the velocity and of the acceleration at the end of the previous time step, and Δt is the time step. It's then possible to substitute $\{\Delta\ddot{\mathbf{y}}\}$ and $\{\Delta\dot{\mathbf{y}}\}$ in the equation (13) with the expressions (14) and (15), and as final substitution: $\{\Delta\mathbf{y}\} = \{\Delta\mathbf{s}\} = \mathbf{B} \{\Delta\mathbf{P}_s\} + \{\Delta\mathbf{x}\}$. The compatibility equations are finally written in this form:

$$\begin{aligned} & \left[\mathbf{B} + \mathbf{H} + \frac{4}{\Delta t^2} \mathbf{H} \mathbf{M} \mathbf{B} + \frac{2}{\Delta t} \mathbf{H} \mathbf{C} \mathbf{B} - \Delta y_0 - \Delta \theta_0 \{z\} \right] \{\Delta \mathbf{P}_s\} \\ & = - \left[\frac{4}{\Delta t^2} \mathbf{H} \mathbf{M} + \frac{2}{\Delta t} \mathbf{H} \mathbf{C} + \mathbf{1} \right] \{\Delta \mathbf{x}\} + \mathbf{H} \mathbf{C} \{\Delta \dot{\mathbf{x}}\} + \left[\frac{4}{\Delta t} \mathbf{H} \mathbf{M} + 2 \mathbf{H} \mathbf{C} \right] \{\dot{\mathbf{y}}\} + 2 \mathbf{H} \mathbf{M} \{\ddot{\mathbf{y}}\} \end{aligned} \quad (16)$$

The system (16) is expressed as function of $n+2$ unknowns: the n incremental loads acting at each pile-soil interface and the unknown incremental displacement and rotation at the pile-head Δy_0 and $\Delta \theta_0$. The system (16) is defined by n equations, the other 2 equations required are the global translational and rotational equilibrium equations. The solution system is solved at each time step and the results are plotted in terms of the envelope of the maximum bending moments along the pile shaft.

2 SYSTEM REQUIREMENT

- Windows XP, Windows Vista, Windows 7 or newer
- 32 or 64 bit

- Minimum 3 GB disk space to download and install

2.1 *Python environment*

KIN SP 1.0 has been developed in Python language. The program is available in an executable format. Not preliminary installation of python is required to run KIN SP 1.0.

2.2 *Installing and removing KIN SP*

To install the application run the executable file and follow the instructions. To remove the application, go to “Control Panel” → “Programs and Features” and uninstall the application.

3 RUNNING KIN SP

To perform a single pile kinematic analysis it's necessary to previously realize a seismic ground response analysis (see the ONDA 1.4 User Manual to properly create the txt files necessary to start the analysis procedure).

3.1 *Free-Field response analysis with ONDA*

To perform a ground response analysis with ONDA it's necessary to create 4 tab-delimited txt files (input data):

1. the first to load the soil profile;
2. the second to load the values of soil cohesion c' (in kPa);

3. the third to load the values of the angle of friction φ' (in degrees);
4. the fourth to load the input motion (acceleration in g).

You can find an example of all the txt files required to perform an analysis in the “Example” folder.

The first one is a txt file containing the main properties of the soil deposit (soil profile). Below an example.

Thick [m]	Unit W. [kN/m ³]	Vs [m/s]	G ₀ [MPa]	Damping D ₀ [-]	R [-]	alpha [-]	Tau Max [kPa]	OCR (1)	IP [%]	Label [#]
15	19	100	0	0.02	2.05	20.1	0	1	10	1
15	19	400	0	0.02	2.05	20.1	0	2	10	2
0.01	22	1200	0	0.02	0	0	0	2	10	1

The field “Label” is necessary to properly assign the values of cohesion c' (in kPa) and of angle of friction φ' (in degrees) to a specific soil layer.

For example, in the table above, has been assigned a “Label” value equal to 1 to the first soil layer and a “Label” value equal to 2 to the second layer. The txt file for the cohesion must be created writing on a single line (the first line) all the values of the cohesion separated by the ‘tab’. The first cohesion value will be related to all the soil layers having a “Label” value equal to 1, the second cohesion value will be related to all the soil layers having a “Label” value equal to 2 and so on.

The same procedure is valid for the txt file necessary to import the angle of friction values.

Note: to the bedrock layer assign always a “Label” value equal to 1.

The input motion file instead must be created writing a simple txt file with a single column (the first column) containing the acceleration data in gravity (g) unit.

After start the application, press the button “Load data for each macro-stratum” in the main tab “*ONDA Analysis*” and load the text file (format: tab delimited .txt) with the soil profile properties, then press the button “Load angle of internal friction” and load the angle of friction values, then press the button “Load cohesion” and load the cohesion values and then load the input motion using the “Load accelerogram” button. After that, insert manually in the main tab “*ONDA Analysis*” the following input data:

- *Pile Length [in meter]* = the embedded pile length;
- *Pile-blocks number* = insert an integer number. This is the number of elements (having equal height) in which you want to discretize the pile. This data is necessary to evaluate the free-field soil response (free-field displacement and free-field velocity time histories) at each center point of the pile-blocks to perform then the kinematic analysis.
- *Scale Factor [-]* = insert the scale factor that you want to apply to scale the input motion. Use a scale factor equal to 1 if you don't want to scale the accelerogram used.
- *Time interval [in sec]* = the sampling time of the input motion (the accelerogram in the example folder has a sampling time equal to 0.005 sec);
- *Time interval subdivision* = insert an integer number. Equal to 1 if you want to maintain the time interval equal to the sampling time, bigger than 1 if you want to subdivide every time interval in N time sub-intervals. If you are performing a Linear ground response analysis it's recommended to use a Time interval subdivision equal to 1; if you are performing a Non-Linear analysis it's strongly suggested to use a bigger value (for common situations a Time interval subdivision value equal to 4 should be appropriate to obtain the convergence of the solution);
- *Number of macro-strata including the base layer (or bedrock)* = is the total number of layers in the soil profile. In the example above the number of layers is 3 (including the bedrock);

- *Water table depth [in meters]* = specify here the water table depth;
- *Type of ONDA analysis* = insert 1 if you want to perform a non-linear analysis in time domain, insert 0 if you want to perform a linear analysis;
- *Procedure for n (Masing)* = enter 1 if you want to consider n variable; enter 0 if you want to consider n constant;
- *Input Motion type* = enter 1 if the input motion is an outcrop motion; enter 0 if the input motion is a within motion;
- *Damping ratio elastic response spectrum [in %]* = specify the damping ratio value for the calculation of the elastic response spectrum;
- *Output-Result Depth [in meter]* = enter the depth at which you prefer to automatically obtain the main output plots (acceleration time history, fourier spectrum and elastic response spectrum);

Then press the “Verify Input” button to import all the values inserted manually and to check if they are correct. Finally, you can press the “Start analysis” button. If the analysis has been correctly executed the message “Analysis completed” will appear in the same row of the Start Analysis button.

Using the next tabs “Accelerogram”, “Fourier spectrum”, “Elastic R-Spectrum”, “Strain and Displ Time History”, “Peak Profiles”, “Stress-Strain”, “Permanent displ” and “Other Outputs”, you can plot all the results of the seismic response analysis. In these tabs there are 2 “Plot” buttons. The first one called “Plot Viewer” works only to plot the results of an analysis already performed, using the txt files saved. The second one called “Plot”, instead, works only to see the results obtained in the current analysis. The zoom, pan and home buttons instead works in both cases.

After completing the free-field analysis save the results with *File* → *Save ONDA Results*. The results of computations are saved as tab delimited txt files in a user-defined folder as described in section 3.1.1 “ONDA Output Results”, but in addition the following txt files are generated:

- ***filename_KIN_max_strains.txt*** - such a file consists of 1 column:
 - *column 1*: peak shear strain at the middle height of each sublayer [-];

- ***filename_KIN_free_field_displ.txt*** - such a file consists of N columns (N = number of sublayers):
 - *column from 1 to N*: displacement time history at the middle height of the sublayer [m];

- ***filename_KIN_free_field_vel.txt*** - such a file consists of N columns (N = number of sublayers):
 - *column from 1 to N*: velocity time history at the middle height of the sublayer [m/s];

- ***filename_KIN_G0_profile.txt*** – such a file consists of five columns:
 - *column 1*: shear modulus G_0 at the middle height of each sublayer [kPa]
 - *column 2*: the τ_{\max} value at the middle height of each sublayer [kPa]
 - *column 3*: the parameter α of the Ramberg-Osgood model for each sublayer [-]
 - *column 4*: the parameter R of the Ramberg-Osgood model [-]
 - *column 5*: maximum shear stress at the middle height of each sublayer [kPa]

These txt files are input files necessary to perform the single pile kinematic analysis.

3.1.1 ONDA: Output results

The results of computations are saved as tab delimited txt files in a user-defined folder, using *File* → *Save ONDA results*.

A list of saved files and their contents and structure is reported in the following:

- ***filename_profiles.txt*** – such a file consists of eight columns:
 - *column 1*: sublayer thickness [m]
 - *column 2*: depth at the middle height of the sublayer [m]
 - *column 3*: vertical effective stress at the middle height of the sublayer [kPa]
 - *column 4*: peak acceleration of the sublayer in [m/s²]
 - *column 5*: maximum shear stress at the middle height of the sublayer [kPa]
 - *column 6*: peak shear strain at the middle height of the sublayer [-]
 - *column 7*: permanent shear strain at the middle height of the sublayer [-]
 - *column 8*: permanent displacement of the sublayer [cm]

- ***filename_input_acc_spec_depth_acc.txt*** - such a file consists of three columns:
 - *column 1*: time [s];
 - *column 2*: the input accelerogram [m/s²];
 - *column 3*: the accelerogram [m/s²] at the depth specified by the users in the “ONDA Analysis” Tab at the field “Output-Result Depth”.

- ***filename_input_acc_fs_spec_depth_acc_fs.txt*** - such a file consists of four columns:
 - *column 1*: frequency [Hz] related to the output in column 2;
 - *column 2*: fourier spectrum amplitude of the input accelerogram;
 - *column 3*: frequency [Hz] related to the output in column 4;
 - *column 4*: fourier spectrum amplitude of the accelerogram at the depth specified by the users in the “ONDA Analysis” Tab at the field “Output-Result Depth”.

- ***filename_strains_time_hist.txt*** - such a file consists of $N+1$ columns, where the number N is equal to the number of sublayers in which the soil has been discretized by the calculation program:
 - *column 1*: time [s];
 - *column from 2 to $N + 1$* : shear strain time history at the middle height of the sublayer.

- ***filename_stresses_time_hist.txt*** - such a file consists of $N+1$ columns:
 - *column 1*: time [s];
 - *column from 2 to $N + 1$* : stress time history at the middle height of the sublayer.

- ***filename_accel_time_hist.txt*** - such a file consists of $N+1$ columns:
 - *column 1*: time [s];
 - *column from 2 to $N + 1$* : acceleration time history at the middle height of the sublayer.

- ***filename_displ_time_hist.txt*** - such a file consists of $N+1$ columns:
 - *column 1*: time [s];
 - *column from 2 to $N + 1$* : displacement time history at the middle height of the sublayer.

- ***filename_vel_time_hist.txt*** - such a file consists of $N+1$ columns:
 - *column 1*: time [s];
 - *column from 2 to $N + 1$* : velocity time history at the middle height of the sublayer.

- ***filename_permanent_displ_profile.txt*** - such a file consists of 2 columns:

- *column 1*: permanent displacement at the middle height of each sublayer [m];
 - *column 2*: depth at the middle height of the sublayer [m]
- ***filename_spec_depth_Elastic_Spectrum.txt*** - such a file consists of 2 columns:
 - *column 1*: Period T [sec];
 - *column 2*: Elastic response spectrum PSA [g] at the depth specified by the users in the “ONDA Analysis” Tab at the field “Output-Result Depth”.

Additional results can be computed using the Tab “Other Outputs”. In this Tab it’s possible to calculate and plot: 1) the acceleration time history, 2) the fourier spectrum and 3) the elastic response spectrum for a specified sublayer number. This can be done filling the “Number of the layer” field and pushing the Plot button. Then these outputs can be saved as tab delimited txt files in a user-defined folder, using *File* → *Save Other results*.

A list of saved files and their contents and structure is reported in the following:

- ***filename_acc_other.txt*** - such a file consists of three columns:
 - *column 1*: time [s];
 - *column 2*: the input accelerogram [m/s²];
 - *column 3*: the accelerogram [m/s²] at the sublayer number specified by the user in the “Other Outputs” Tab.
- ***filename_acc_fs_other.txt*** - such a file consists of four columns:
 - *column 1*: frequency [Hz] related to the output in column 2;
 - *column 2*: fourier spectrum amplitude of the input accelerogram;
 - *column 3*: frequency [Hz] related to the output in column 4;

- *column 4*: fourier spectrum amplitude of the accelerogram at the sublayer number specified by the user in the “Other Outputs” Tab.
- ***filename_Elastic_Spectrum_other.txt*** - such a file consists of 2 columns:
 - *column 1*: Period T [sec];
 - *column 2*: Elastic response spectrum PSA [g] at the sublayer number specified by the user in the “Other Outputs” Tab.

The following plots are given:

- **“Accelerogram” Tab**: input accelerogram and that at the depth specified by the users in the “ONDA Analysis” Tab at the field “Output-Result Depth”.
- **“Fourier spectrum” Tab**: Fourier spectra of the input accelerogram and that at the depth specified by the users in the “ONDA Analysis” Tab at the field “Output-Result Depth”;
- **“Elastic R-Spectrum” Tab**: elastic response spectrum of SDOF at the depth specified by the users in the “ONDA Analysis” Tab at the field “Output-Result Depth”;
- shear strain time history at the selected layers;
- **“Strain Displ Time-History” Tab**: Strain and displacement time histories at the selected sublayer;
- **“Peak Profiles” Tab**: maximum acceleration and shear strain profiles;
- **“Stress-Strain” Tab**: stress-strain time histories at the sublayer specified and at the following 3 sublayers;
- **“Permanent displ” Tab**: permanent displacement profile;
- **“Other Outputs” Tab**: acceleration time history, fourier spectrum and elastic response spectrum at the specified sublayer number.

It's possible to re-load saved results using *View* → "Load...." and plot these results using the "PlotViewer" buttons in the plotting Tabs.

3.2 *Input data for the Kinematic Analysis*

After start the application, open the Tab "*Kinematic*" and load the 4 text files (format: tab delimited .txt) obtained in the free-field response analysis using ONDA:

- *filename_KIN_G0_profile.txt*
- *filename_KIN_max_strains.txt*
- *filename_KIN_free_field_displ.txt*
- *filename_KIN_free_field_vel.txt*

pushing the buttons "Load G0 Profile", "Load max strains", "Load free-field displ" and "Load free-field vel".

After that, insert manually in the main Tab "*Kinematic*" the following input data:

- *Pile Length [in m]* = the embedded pile length already used before in the Tab "ONDA Analysis";
- *Pile diameter [in m]* = the width of the pile section;
- *Pile head boundary condition at the top of the pile:* insert 1 if the pile head is fixed or 2 if the pile head is free to rotate;
- *Pile elastic modulus [in GPa]* = enter here the elastic modulus of the pile material;
- *Pile section-inertia [in m⁴]* = insert the area moment of inertia of the pile section;
- *Pile weight [in kN]* = enter here the total weight of the pile;

- *Pile-block number [-]* = insert an integer number. This is the number of elements (having equal height) in which you want to discretize the pile. This should be the same value used before in the Tab “ONDA Analysis”;
- *Block number of the interface [-]*: insert an integer number. This is the number of the block element where is located the interface between two soil sublayers having the main difference in terms of stiffness;
- *Mean Vs - Upper layer [m/s]* = insert the mean value of the shear velocity of the soil between the ground surface level and the depth where the interface is located. This value is used to compute an approximate value of the damping matrix elements using the relationship proposed by Kaynia (1988);
- *Mean unit weight – Upper layer [kN/m³]* = insert the mean value of the soil unit weight of the soil between the ground surface level and the depth where the interface is located. This value is used to compute an approximate value of the damping matrix elements using the relationship proposed by Kaynia (1988);
- *Mean Vs - Lower layer [m/s]* = insert the mean value of the shear velocity of the soil between the depth where the interface is located and the pile tip position. This value is used to compute an approximate value of the damping matrix elements using the relationship proposed by Kaynia (1988);
- *Mean unit weight – Lower layer [kN/m³]* = insert the mean value of the soil unit weight of the soil between the depth where the interface is located and the pile tip position. This value is used to compute an approximate value of the damping matrix elements using the relationship proposed by Kaynia (1988);
- *Time interval of the accelerogram [in s]* = the sampling time of the input motion (the accelerogram in the example folder has a sampling time equal to 0.005 sec);
- *Time interval subdivision* = insert an integer number. Use the same value used previously to perform the ground response analysis

Then press the “Verify Input” button to load in the program all the values inserted manually and to check if they are correct. Finally, you can press the “Start analysis”

button. If the analysis has been correctly executed the message “Analysis completed” will appear in the same row of the Start Analysis button.

In the Tab “Bending Envelope” you can press the “Plot Bending Envelope” button to plot the result of the single pile kinematic analysis in terms of envelope of the bending moment [in kNm] along the pile shaft.

You can use the “Plot Bending Envelope Viewer” button only if you load a previously saved txt files with the results of the single pile kinematic analysis. In this case press *View* → *Load Bending Envelope* to import a saved result and then press the “Plot Bending Envelope Viewer” button in the Tab “Bending Envelope” to plot these data.

3.3 *Output results*

The results of computations are saved in a tab delimited txt file in a user-defined folder, using *File* → *Save Bending results*.

The saved file and its content and structure is:

- ***filename_Bending.txt*** – such a file consists of two columns:
 - *column 1*: depth [m]
 - *column 2*: maximum absolute bending moment at the middle height of each pile-block [kNm]

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