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PILEDYN: a boundary element - finite element software package for PILE group linear DYNamic analysis - N°11

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Introduction: What is PILEDYN?

- **PILEDYN [1] is a software package based on a Boundary Element - Finite Element Method (BEM-FEM) for pile group linear dynamic analysis [2]**
- **Features**: Able to obtain the pile group impedance in any topography (including stratified soils with several layers and rigid rocky beds).
- **BEM-FEM model main characteristics**:
  - Simplified, but rigorous!
  - This model has been used in many soil-structure interaction problems such as the determination of dynamic stiffnesses [3, 5] and seismic response of pile foundations [3, 6] and piled buildings [4].

Program structure

- **Pre-processor** (MATLAB [7]): it generates input files for the solver. MESH2D [8] and gmsh [9] are used as meshing tools.

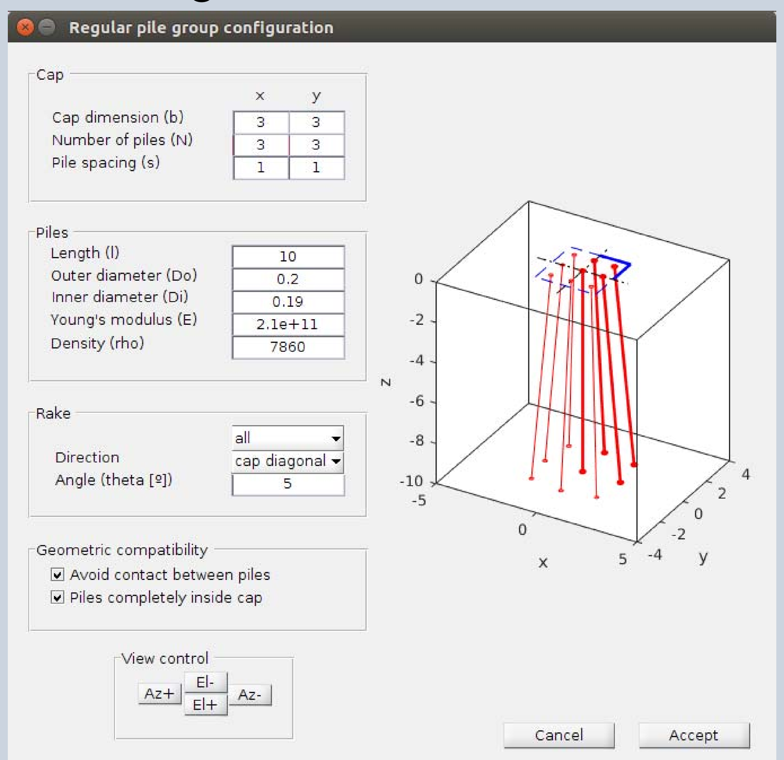

Figure: GUI appearance: pile group configuration menu.

- **Solver** (Fortran): uses BEM-FEM methodology to obtain the group response.
- **Post-processor** (MATLAB): from the response, rearranges the impedances.

Methodology

- **FEM** (Pile): Euler-Bernoulli beam (3 nodes finite element). If $\mathbf{K}$ and $\mathbf{M}$ are the stiffness (complex) and mass matrices, ω the circular frequency of the excitation, $\mathbf{u}_p$ the vector of nodal translations and rotations amplitudes and $\mathbf{F}$ the vector of nodal forces amplitudes and considering a pile with zero internal damping:

$$(\mathbf{K} - \omega^2 \mathbf{M})\, \mathbf{u}^P = \mathbf{F} = \mathbf{F}^{ext} + \mathbf{Q}\, \mathbf{q}^p$$

where $\mathbf{F}_{ext}$ include the forces at the top $\mathbf{F}_{top}$ and the axial force at the tip of the pile $\mathbf{F}_p$; and $\mathbf{F}_{eq}$ is the vector of the equivalent nodal forces from the pile-soil interaction, where $\mathbf{Q}$ is the matrix that transforms nodal force components to equivalent nodal forces and $\mathbf{q}^p$ the tractions along the pile-soil interface.

- **BEM** (Soil): a continuum, homogeneous or zoned homogeneous, semi-infinite, isotropic, linear, viscoelastic medium. Only the free-surface and interfaces between strata, if any, are discretized. For a certain pile j and applying an unit load on pile i:

$$\mathbf{D}\mathbf{u}_b^{pi} + \mathbf{H}_e^{p_i s}\mathbf{u}^s - \sum_{j=1}^{n_p} \mathbf{G}_e^{p_i p_j}\mathbf{q}^{s_j} + \sum_{j=1}^{n_p} \gamma_{b3}^{pj} F_{p_j} = \mathbf{0}$$

where $\mathbf{u}_b^{pi}$ is the vector of nodal displacements at the bottom element nodes of the pile i, $\mathbf{H}_e^{p_i s}$ is the matrix obtained by integration over the boundary of the 3D elastodynamic fundamental solution times the shape functions of the boundary elements, $\mathbf{u}^s$ is the vector of nodal displacements on the surface, n_p is the total number of piles, $\mathbf{G}_e^{p_i p_j}$ is the matrix obtained by integration over the pile-soil interface of the 3D elastodynamic fundamental solution times the interpolation functions, γ_{b3}^{pj} is a 3 components vector that represents the contribution of the axial force F_{p_j} at the tip of the jth pile, when the concentrated load is applied at the bottom element nodes of the pile i. $\mathbf{D}$ is the vector $1/8\,\{0,0,3,0,0,6,0,0,1\}$.

- **BEM - FEM coupling**: Welded contact conditions at the pile-soil interface.

$$\mathbf{u}^s = \mathbf{u}^p\,;\; \mathbf{q}^s = -\mathbf{q}^p \quad \rightarrow \quad (\mathbf{K} - \omega^2 \mathbf{M})\, \mathbf{u}^p - \mathbf{F}_p + \mathbf{Q}\, \mathbf{q}^s = \mathbf{F}_{top}$$

Results: Pile group foundation impedances

The lateral K_h, vertical K_v, rocking K_r and cross K_c impedances (normalized stiffness and damping coefficients) calculated for a 3x3 pile group are shown, where L and d are the pile's length and diameter, α is the rake angle, s is the distance between piles, μ_s is the soil shear modulus and the c_s is the is the soil shear-wave velocity.

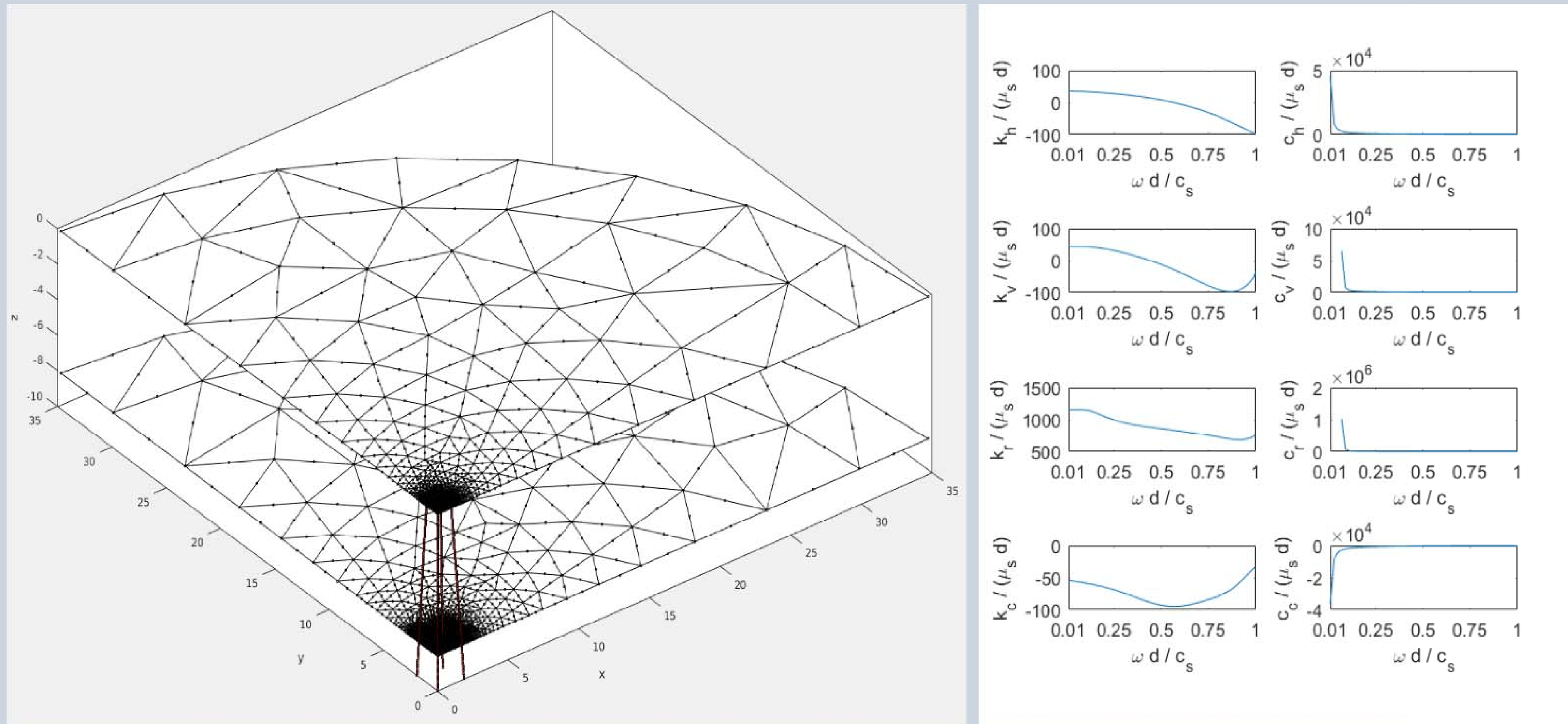

Figure: (Left) Mesh (1/4 symmetry). (Right) Impedances obtained with PILEDYN, with $L/d = 15$, $\alpha = 5$ and $s/d = 5$.

Forthcoming Research

- **More features**: pile group's envelopes and seismic response
- **Better GUI**: Octave suitable GUI, more input and output options

References

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