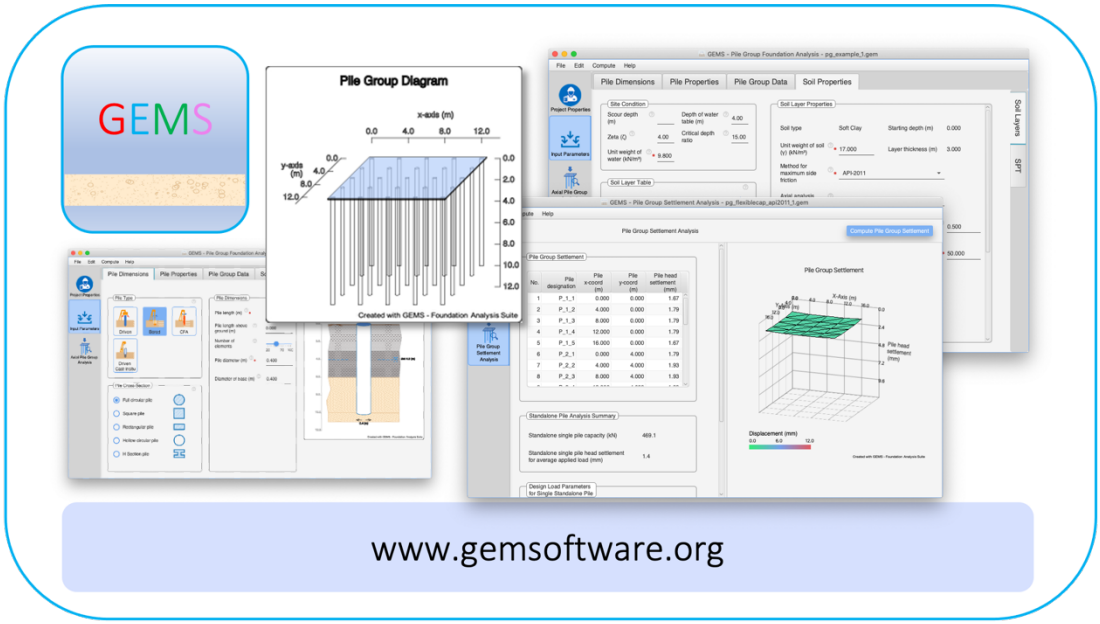
Geotechnical Engineering Modelling Software (GEMS)

Pile Group Settlement Analysis



GEMS Overview

Geotechnical Engineering Modelling Software (GEMS) develops advanced and intuitive Computer Aided Design & Engineering (CAD & E) software for foundation analysis & design.

GEMS foundation analysis suite employs finite element modelling techniques for analysis & design of shallow and deep foundations. The foundation analysis suite includes modules for

- Comprehensive Pile Foundation Analysis (Land, Bridge & Waterfront Structures)
- Pile Group Settlement Analysis
- Offshore pile foundations
- Beam foundations

GEMS foundation analysis suite is available for download on Windows, MacOS based computers. It is also available on the cloud (for use online using a browser).

Windows 10 Mac GEMS CLOUD

Pile Group Settlement Analysis

Overview

Piles are often used in groups to carry greater loads to deeper, stronger soil strata. For the same average load per pile, groups settle more than single piles due to overlapping of deformations in the soil medium. The 'GEMS – Pile Group Settlement Analysis' software uses modern analytical techniques based on the subsurface soil profile, pile dimensions and group geometry to estimate the pile group settlement. The software can also be used to choose pile length, cross-section, and pile spacing towards optimizing the group design.

Background Information

The vertical movement in soil medium surrounding a single pile loaded vertically decreases gradually from the pile shaft in the radial direction. Considering soil to be elastic, 'shear stress decrease' to be only in the radial direction, and following concentric cylindrical assumption, Randolph and Wroth (1978) showed that the decrease in vertical displacement is logarithmic and extends to a radial distance r_m of the order of pile length. Further using rigid circular punch model for the tip settlement, and considering axial pile stiffness they derived settlement expression for a single pile under axial load.

A loaded vertical pile has a deformation field around it. Similarly loaded adjacent piles in a group also have their own deformation fields. Superposition of the deformation fields of piles in a group renders piles in a group to settle more than a single pile.

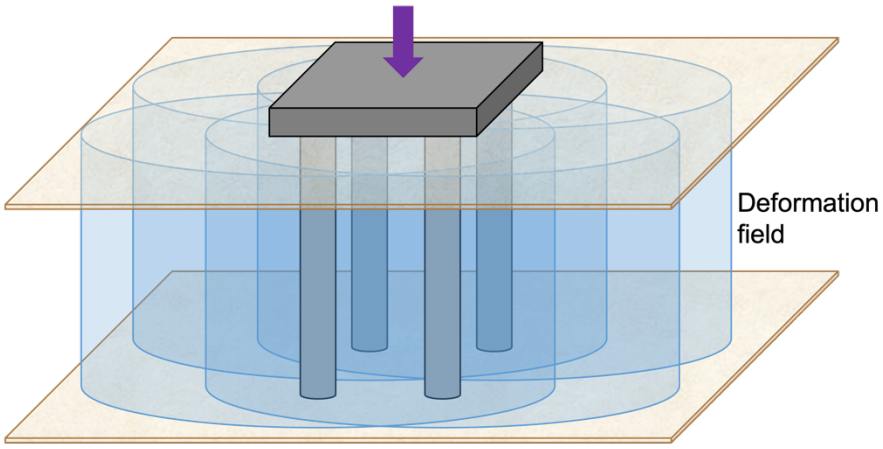


Figure 1Deformation field around piles

Apart from the behaviour of single pile, this superposition effect depends on the number piles, spacing of piles in the group and the rigidity of the cap connecting them. Usually the group settlement is required under a total load approximately equal to $n \times P_d$ where n is the number of piles in the group and P_d is the design load. Group geometry and the behaviour of single pile under the design load are required for the group settlement estimate.

Pile Cap Consideration

Flexible cap

If the piles are connected at the head by a relatively flexible cap, there will be no transfer of loads through the cap and each pile will experience the load imposed on it. The group deflection will depend on the load distribution among piles. The software provides for

a) Equal load on all piles
b) Variable load on piles.

Pile deflections at all pile heads are computed considering group effect. A consequence of interaction between piles is that, for uniformly loaded pile groups, the central pile will undergo maximum displacement and corner piles least displacement.

Rigid cap

When the piles are connected by a rigid cap, all the loads imposed on the cap may be combined in to a resultant vertical load. The resultant load may be centric or may be eccentric with respect to the centroid of the group. If the loading is centric, the cap redistributes the load among piles so as to result in uniform group settlement. Due to the redistribution, the edge piles will carry greater load than the central piles.

In the case of eccentric loading two requirements need to be met. Firstly the loads carried by piles need to satisfy vertical and moment equilibrium requirements of the group. Secondly the distribution of loads should result in a planar settlement profile of the cap comprising a vertical settlement of the centroid of the group s_g along with two rotations $\theta_x \; and \; \theta_y$ rotations about x and y axis respectively.

Using a special stiffness formulation, the software computes the settlement the centroid of the group, rotations $\theta_x \; and \; \theta_y$ and the individual pile loads.

Pile Considerations

The Piles of circular, square, rectangular, circular-hollow and I or H cross sections can be analysed. Piles of different types of cross-sections are approximated to a circular pile of an equivalent diameter for analysis.

Circular **Square** **Rectangular** **Hollow circular** **I or H Section**

Bored piles (Cast-insitu-concrete) and driven piles (Precast concrete, Cast-insitu-concrete, Steel) can also be analysed.

Soil Considerations.

The software can take into account layered soil profiles which may consist of soft clay, stiff clay, sand, soft rock, hard rock layers. Soil scour around the piles and pile lengths projecting above the ground can be specified. These provisions are especially useful in analysing piles used in foundations of bridges

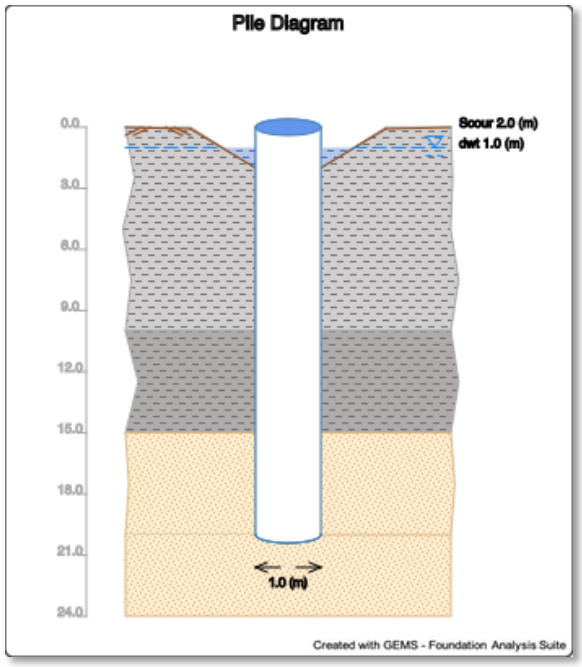
and waterfront structures. Depth of ground water table in the subsoil can also be considered for land based piles.

Field Test Data

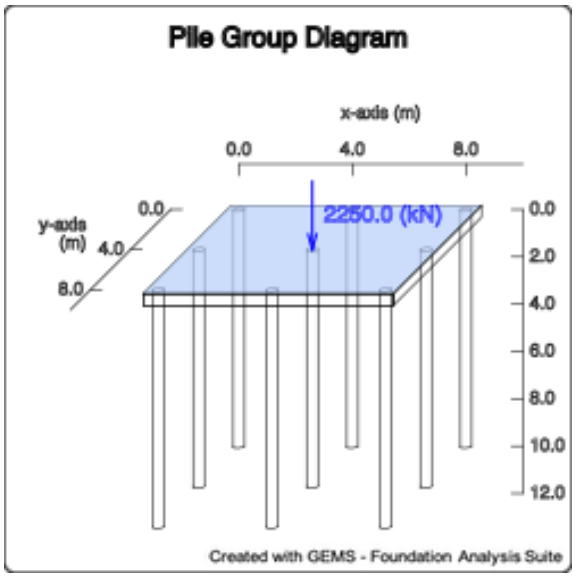
Pile load test data comprising of pile head settlement under design load along with base soil properties or pile base stiffness estimated from load test data can also be used in lieu of sub surface soil profile.

Key Features

- One click computation and analysis
- Rigid cap & Flexible cap piles can be analysed.
- Group settlement, pile cap rotation and individual pile loading for pile group with rigid cap. 3D graphical representation of pile loading.
- Individual pile settlement for pile group with flexible cap. 3D graphical representation of pile settlement.
- Axial single pile capacity & design load estimation
- Single pile settlement under design load
- Facility to use load test results
- Supported on Windows, Mac and Cloud
- 3D representation of the pile group
- Pile group cross-section diagram
- Pictorial representation of the pile and soil layers.
- Linear & Non-linear analysis models
- Piles of circular, square, rectangular, circular-tubular & I or H cross sections can be analysed.
- Local scour & ground water table considerations.
- Export of results to Microsoft Word, Excel & PDF
- Data can be input in either SI units or 'Commonly used American units' (*kips for force and foot for length*).



Pile diagram



Pile group diagram

Analysis Methods & Details

Pile Group Settlement analysis

Under the design load, the pile behaviour will be nearly elastic except for some shaft length near the top of the pile, where the ultimate interface friction may be reached and the pile may slide through soil. The parameters that are required for the group settlement estimate under the design load are the pile head displacement, load carried by the pile tip, pile tip displacement and the radius r_m which may be approximated as equal to pile length. The software makes use of *Randolph and Wroth (1978) approach* along with *Mylonakis and Gazetas (1998) procedure* for including the diffraction effect.

A three step approach is followed to obtain the group vertical settlement.

I. *Based on the soil profile, pile dimension and properties, the ultimate pile capacity is estimated. Making use of the factor of safety, design load P_d for the pile is obtained. The design load P_d can also be specified based on field test data.*
II. *Pile head stiffness and the pile tip stiffness under the design load are obtained by carrying out axial pile analysis based on either i) t-z curves based on elastic properties of soil layers or ii) t-z curves based on API recommendations. Alternatively, field test data for pile head stiffness under design load along with pile base stiffness estimated from load test data or base soil properties can be specified.*
III. *Pile Group settlement is computed using the RWMG (Randolph, Wroth, Mylonakis and Gazetas) model using the pile head stiffness (Obtained from results of axial pile analysis under design load or from field test data), pile base stiffness (Obtained from results of axial pile analysis under design load or estimated from load test data or specified base soil properties), group geometry, cap conditions and pile group loading data.*

Pile Capacity Estimation

The pile capacity estimation is based on the sub-soil layer properties and the methods chosen for the assessment of shaft friction and base capacity. The design load is computed from the pile capacity taking into account the design factor of safety.

Procedures available in the software for pile capacity estimation

Clay	**Sand**	**Rock**
Side Friction		
• API-2011 • α method (IS-2911) • Semple & Rigden method • Kolk & Van-der-velde method	• β method (API-2011) • K-δ method (API-2000) • K-δ-Zc method (IS-2911) • Meyeroff SPT method (IS-2911)	• Approach based on unconfined strength is adopted
Base Capacity		
• Nc = 9	• Nq-qlim method (API-2011, API-2000) • Nq - Zc method (IS-2911) • Nq-Berezantev-Zc method • Meyeroff SPT method (IS-2911)	• Approach based on unconfined strength is adopted

There are options available in the software to prescribe user defined parameters.

A distance of 3D is used for developing full base resistance in strong layers. A safe distance of 3D from pile tip is adopted to preclude punch through underlying weak layers.

Axially Pile Deformation Analysis

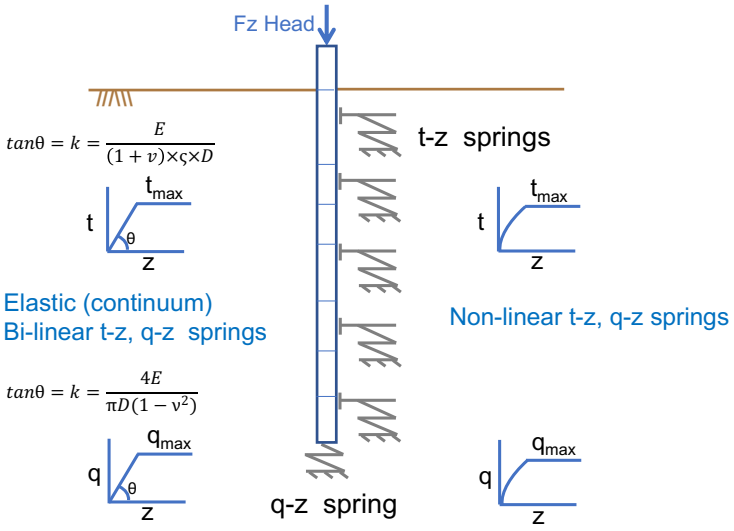
The Axial pile deformation analysis is performed to determine the pile head and pile tip stiffness under the design load.

Pile is modelled as an elastic structural member having the cross section of the pile and the elastic properties of the pile material. The soil support providing the shaft friction is modelled by a set of side springs based on t-z curves. The tip resistance provided by the pile base the base is modelled by a spring based on q-z curve.

The software supports both 'Elastic Bi-linear' and 'Non-Linear' approaches for modelling the soil layers and any one of them can be selected for analysis.

In the 'Non-Linear' approach' for the soil layer, based on the t_{max} and q_{max} values calculated , non-linear t-z curves (interface shear stress- vertical pile movement at that point) and q-z curve (bearing stress and toe displacement) are developed based on API-2011 guidelines. API based methods, also account for reduction in post peak adhesion in clay layers through a factor R.

In the 'Elastic Bi-linear' approach, for the soil layer, t-z and q-z relationships are modelled by bilinear elastic – plastic curves based on the elastic modulus, Poisson ratio ,t_{max} and q_{max} for the layer.



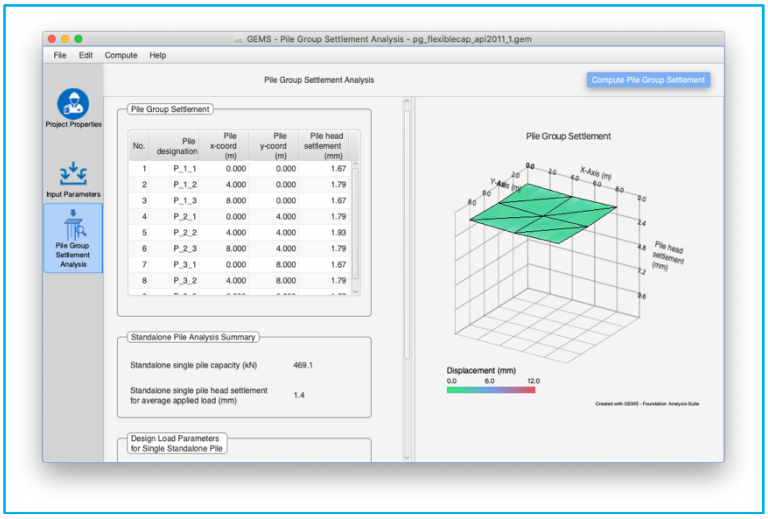
Modelling of soil support using t-z, q-z springs

In the case of rock layers, using the t_{max} and q_{max} values, t-z and q-z relationships are modelled by a bilinear elastic – plastic curve based on the elastic modulus and Poisson ratio of the rock layer.

The axial pile analysis follows a non-linear finite element model using the axial rigidity of the pile and the nonlinear soil support based on the t-z curves and q-z curve. . The analysis uses an Iterative approach to achieve convergence.

The analysis provides displacement of the pile head and pile tip under design load, and the load transferred at the pile base.

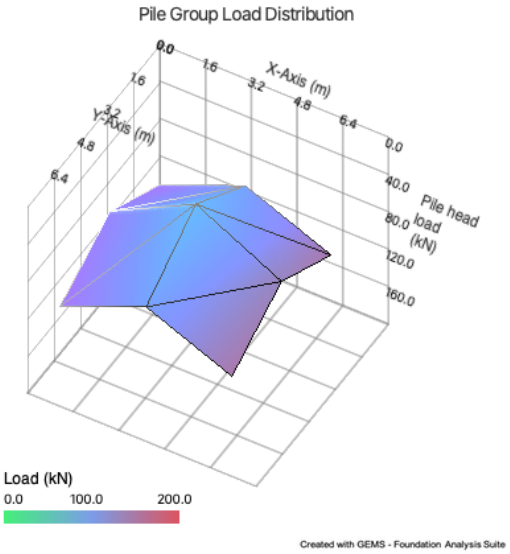
Analysis



Pile Group Analysis – Rigid Cap

The Pile Group Settlement Analysis for Piles with Rigid Cap gives the

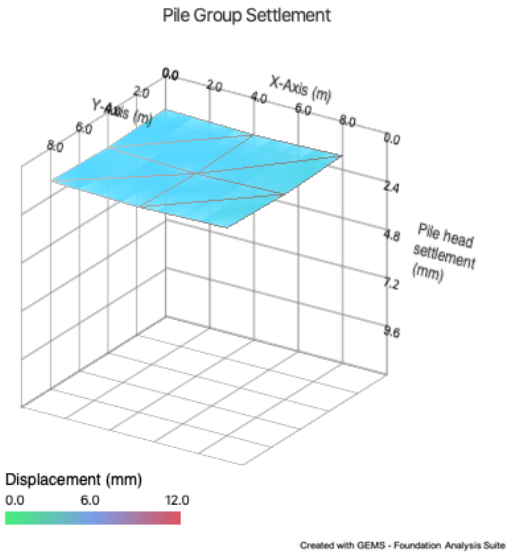
- Pile group settlement
- Pile group load distribution in tabular and graphical format
- Standalone pile analysis summary
- Design load parameters for single standalone pile



Pile Group Analysis – Flexible Cap

The Pile Group Settlement Analysis for Piles with Flexible Cap gives the

- Settlement of each pile in the group in tabular and graphical format
- Standalone pile analysis summary
- Design load parameters for single standalone pile



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