Load-transfer method
vs.
Continuum solution
in pile group analysis and design

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PILE GROUP DESIGN

Efficient design of a pile group involves consideration of a number of factors including:

- **Interaction effects between piles**
- **Group stiffening effects**
- **Interaction between vertical and horizontal loading**
- **Soil nonlinearity effects**
- **Different geometry/mechanical properties of group piles**
- **Soil-cap interaction effects**
- **Finite rigidity of the pile cap**

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The complexity of the above problem necessitates the use of computer-based methods of analysis

PILE GROUP SOFTWARE: AN OVERVIEW

- **LOAD-TRANSFER METHOD** (‘*T-z*’ and ‘*P-y*’ curves)
  - GROUP (Reese *et al*., 2000)

- **CONTINUUM-BASED METHODS:**

  1. Finite Element / Finite Difference methods
  2. Boundary Element Method (BEM)
     a) Simplified analyses using interaction factors
        - MPILE, Piglet (Randolph, 1980)
        - DEFPIG (Poulos, 1980)

     b) Full continuum analyses
        - PGROUP (Banerjee & Driscoll, 1976)
        - Repute / PGroupN (Basile, 2001)

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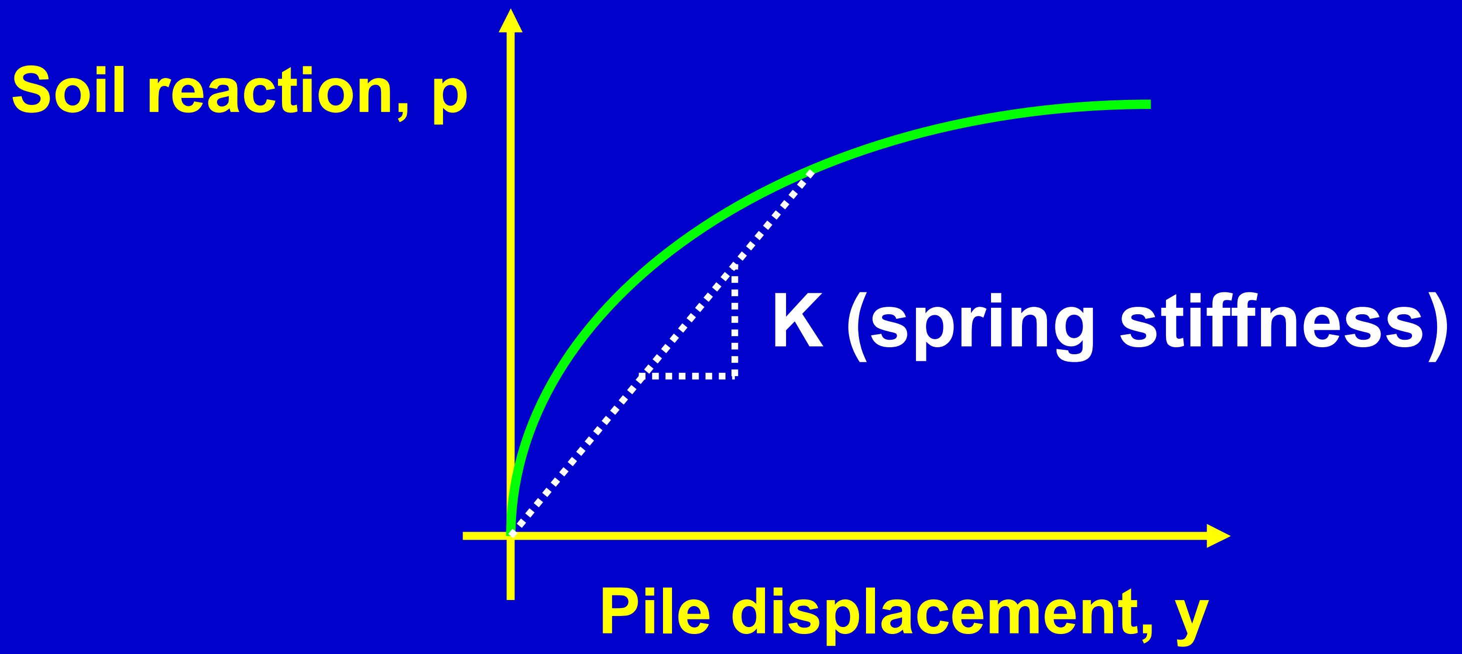
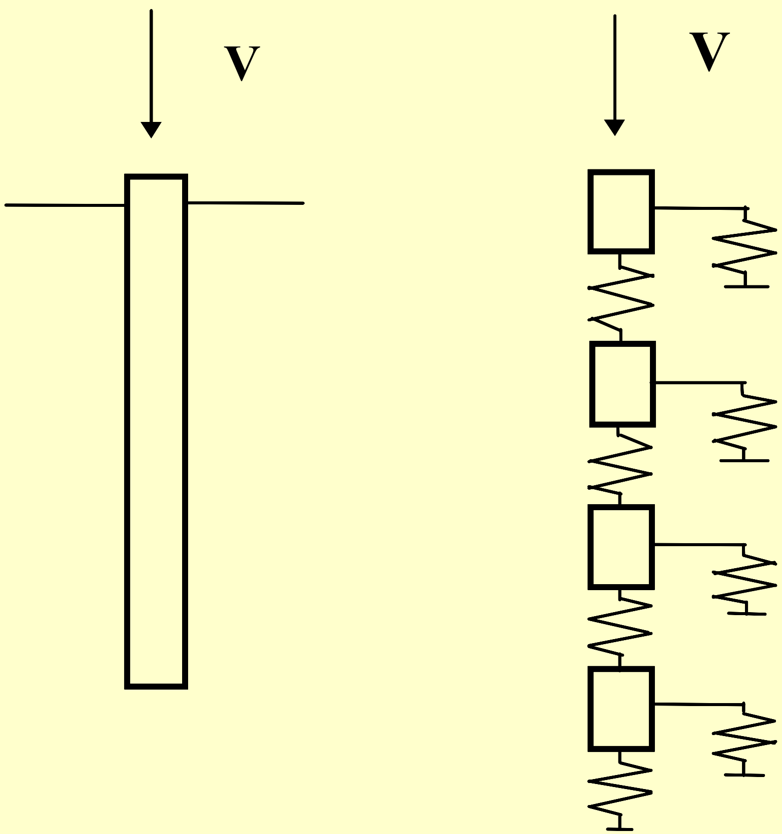
LOAD-TRANSFER METHOD



This method is based on the Winkler model in which the soil is described as a series of independent springs

LOAD-TRANSFER METHOD: VERTICAL LOAD (*t-z curves*)



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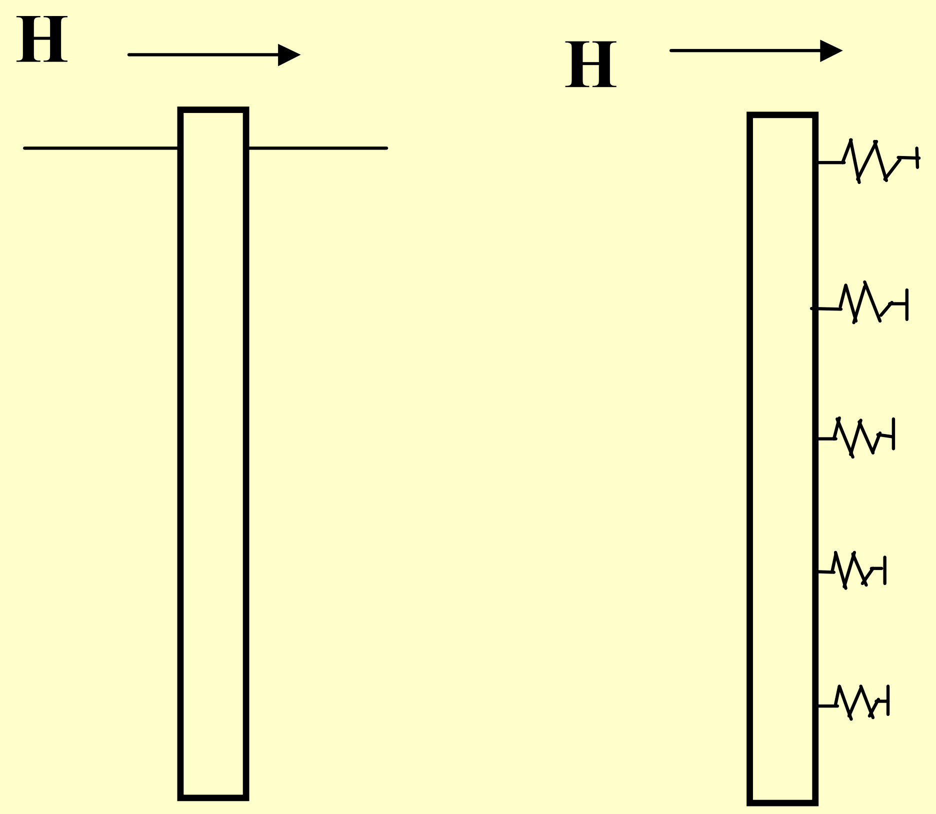
LOAD-TRANSFER METHOD: HORIZONTAL LOAD (*p-y curves*)



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LOAD-TRANSFER METHOD

--- CONS ---

- The spring stiffness **K** is not an intrinsic soil property but it also depends on the pile properties and loading conditions

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There is no “direct” soil testing to determine **K**

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LOAD-TRANSFER METHOD

--- CONS ---

- How to determine **K** then???

  1. Field test on fully instrumented pile (very expensive)

  2. Use standard load-transfer curves obtained for "similar" sites, pile types and loading conditions, and hence a large amount of engineering judgement is needed

- It is uncertain how load-transfer curves are affected by pile-head fixity

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LOAD-TRANSFER METHOD

--- CONS ---

- Soil is modelled as a series of independent springs

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Disregard of soil continuity makes it impossible to find a rigorous way to quantify the interaction effects between piles in a group (unless hybrid methods are used)

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LOAD-TRANSFER METHOD

--- CONCLUSION ---

The load-transfer approach may be regarded as a **link** between the interpretation of full-scale pile tests and the design of similar piles rather than a general tool for pile group design

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CONTINUUM-BASED METHODS

- FEM (Finite Element Method)
- FDM (Finite Difference Method)
- BEM (Boundary Element Method)

These methods model the soil as a continuum and hence remove the limitations of the load-transfer method:

• The analysis is now based on "real" soil properties, i.e. the soil stiffness Es rather than the spring stiffness K

• As the soil is treated as a continuum, pile group effects can be analysed as a matter of course

CONTINUUM-BASED METHODS

FINITE ELEMENT & FINITE DIFFERENCE METHODS

- Too laborious and expensive in terms of CPU time for a 3D problem such as a pile group

EXAMPLE: Using FLAC-3D, a 9-pile group problem runs in 85 hours on a Pentium III

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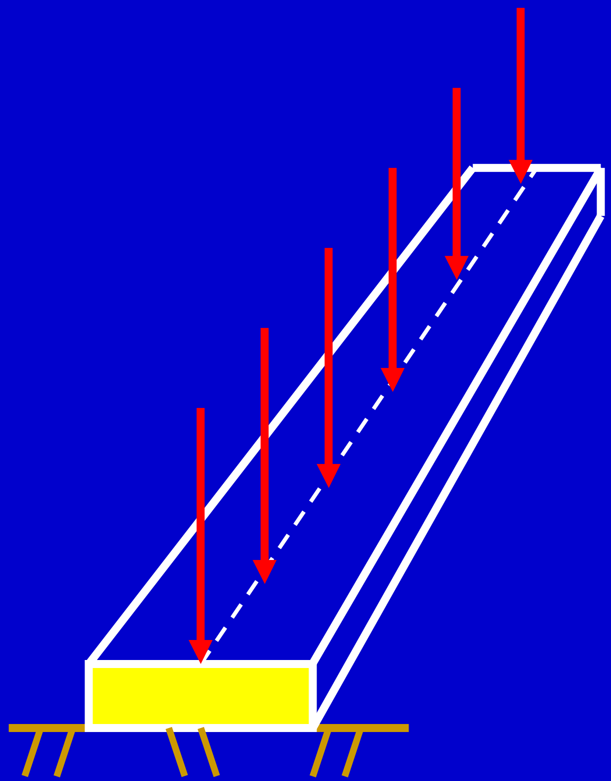
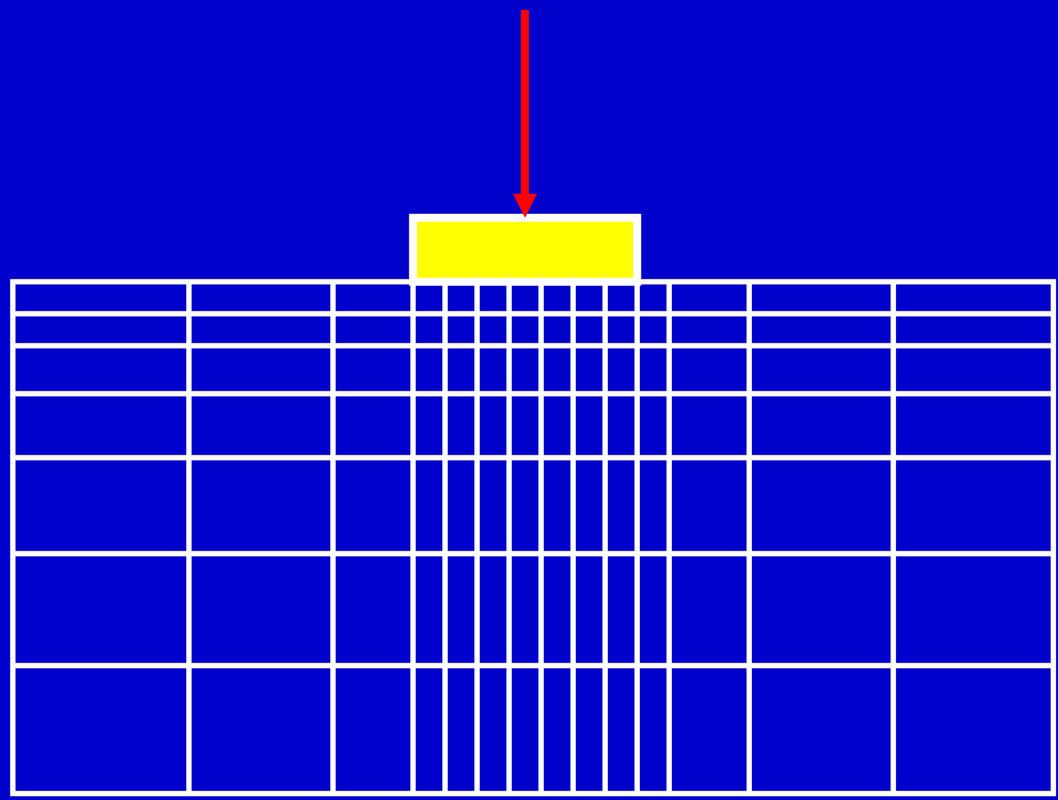
The high CPU time makes these methods not practical for routine design

FEM (Finite Element Method)

2D Modelling: Strip foundation



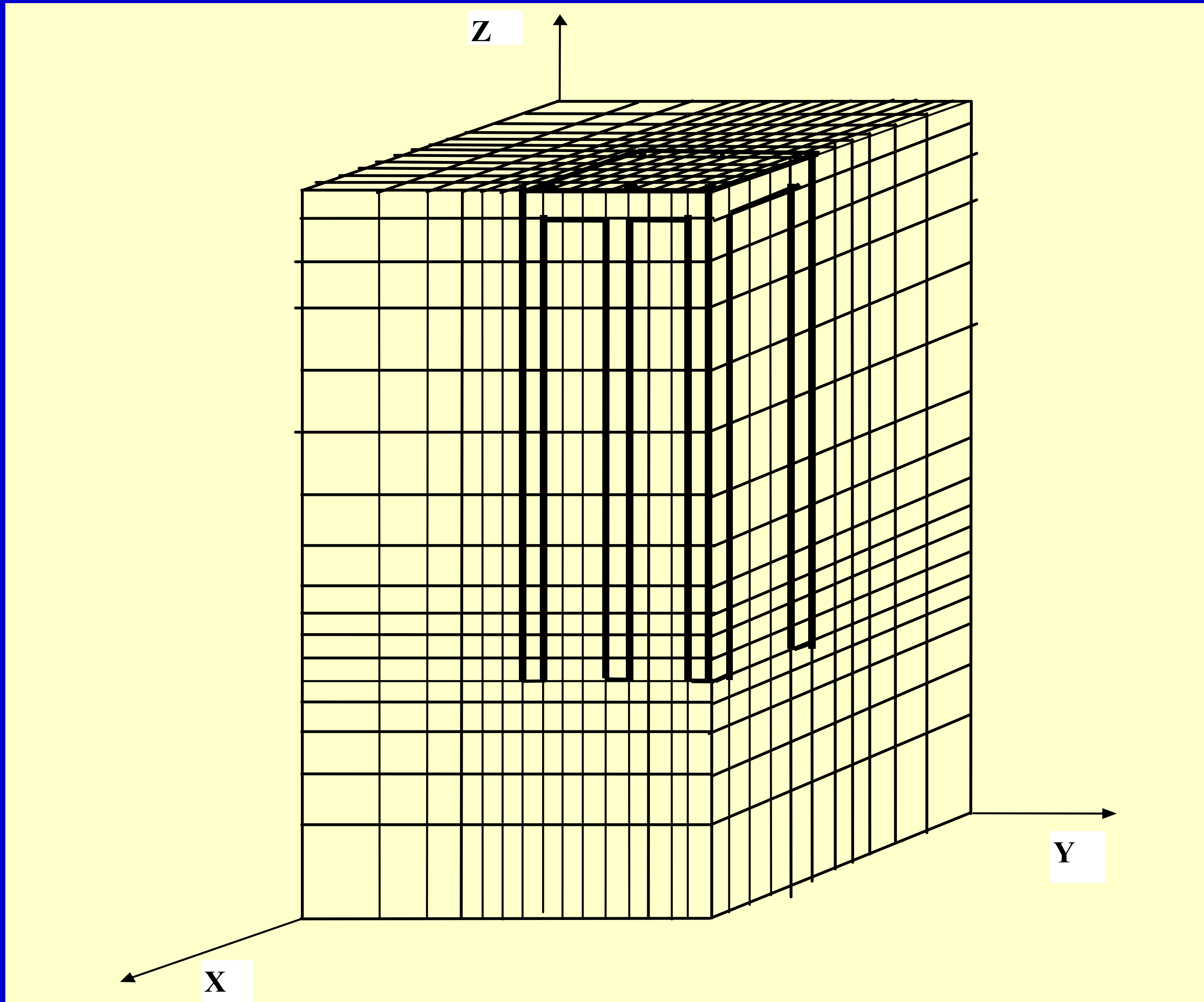
Real 2D problem



FEM mesh 2D

FEM (Finite Element Method)

3D Modelling: Pile group



CONTINUUM-BASED METHODS

BOUNDARY ELEMENT METHOD (BEM)

- It is a compromise between unacceptable simplicity of load-transfer method and disproportionate complexity of finite element and finite difference methods

- It is the most effective method, both in terms of analytical rigour and computational efficiency to analyse and design a pile group

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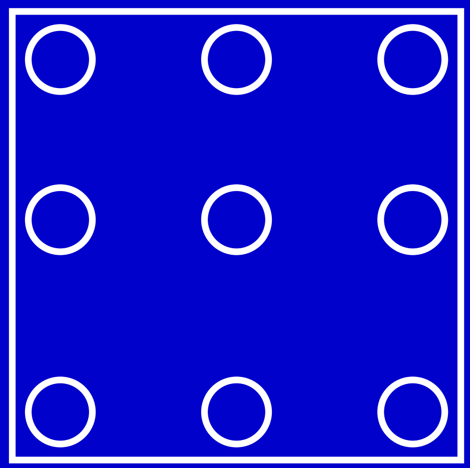
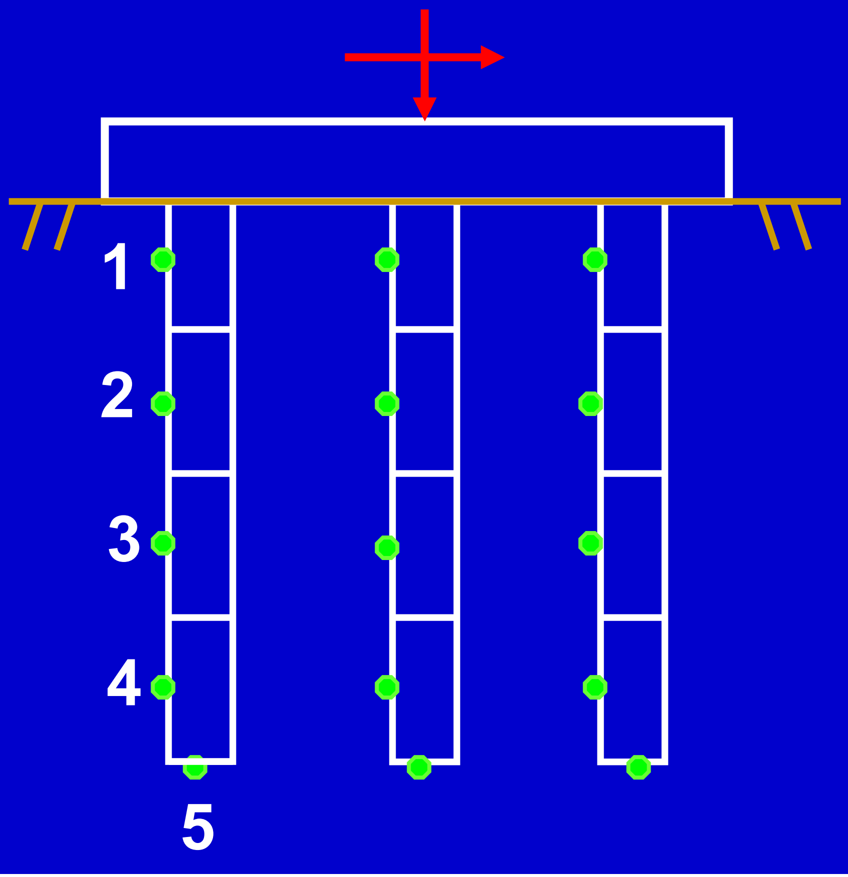
BEM (Boundary Element Method)

- Only the pile-soil interface is discretized into elements (Example: a group of 9 piles each discretized into 5 elements results in a BEM mesh of only $9 \times 5 = 45$ elements)

Plan





PROGRAMS BASED ON THE BOUNDARY ELEMENT METHOD (BEM)

- **Simplified BEM analyses**
  - **- MPILE / Piglet (Randolph, 1980)**
  - **- DEFPIG (Poulos, 1980)**

CONS: 1. The interaction factor method is approximate
2. Soil nonlinearity is neglected

- **Full BEM analyses**
  - **- PGROUP (Banerjee & Driscoll, 1976)**

CONS: 1. Too expensive in terms of CPU time
2. Soil nonlinearity is neglected

- Repute / PGroupN (Basile, 2001)

NOTE: PGroupN is the calculation engine of Repute (Geocentrix Ltd, 2002)

Features of Repute

ANALYSIS METHOD

Repute is based on the full boundary element method and is the most rigorous of current pile-group design programs. CPU time is not a restriction for any size of group

VERSATILITY

Repute is able to deal with multilayered soil profiles and with piles of different geometry and/or mechanical properties within the same group. Consideration of these aspects leads to a more realistic picture of the deformation behaviour and load distribution between the piles

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Features of Repute

INCLUSION OF NON-LINEAR SOIL MODEL

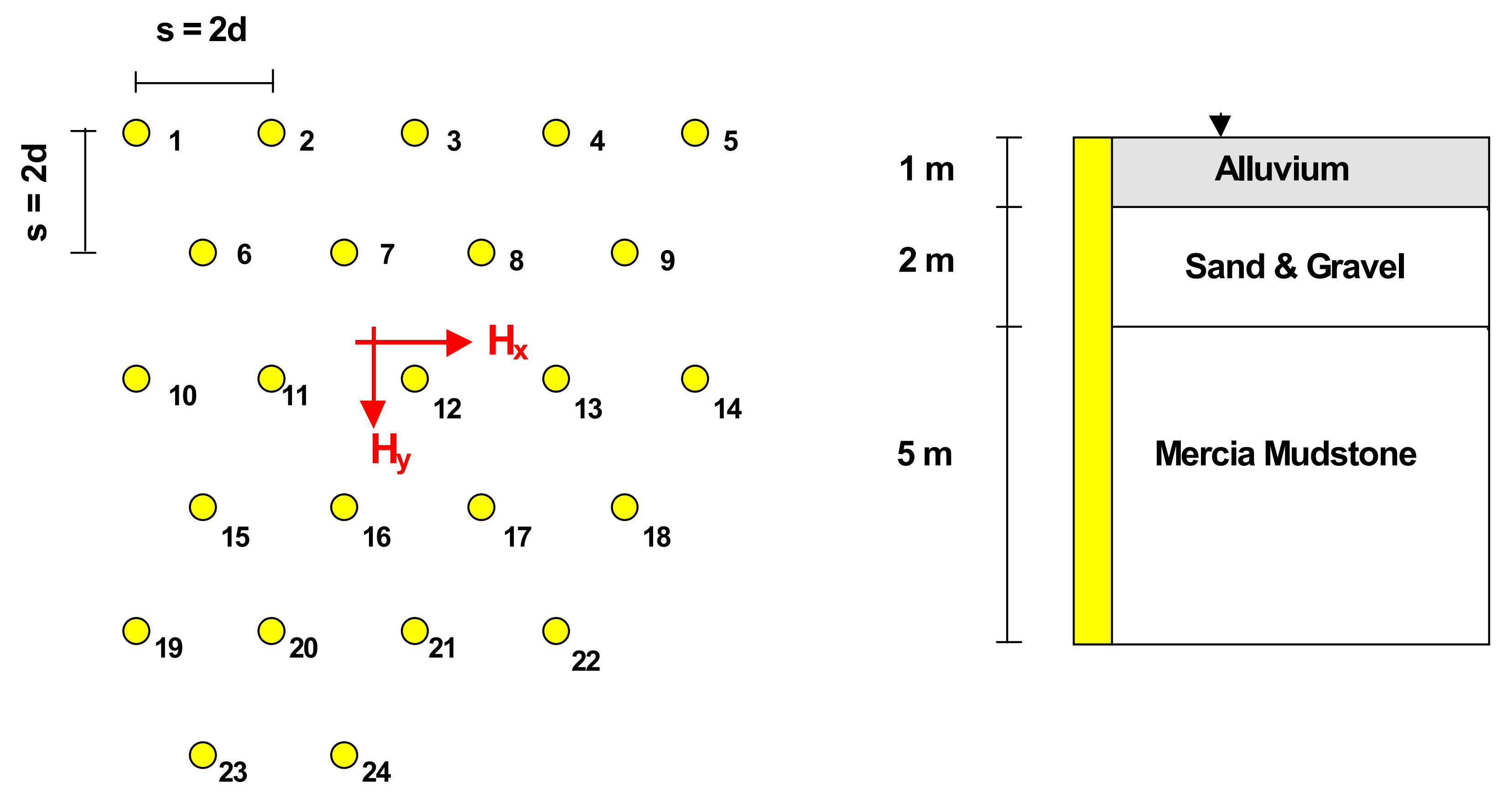
- The response of soil to applied loading is NON-LINEAR
- Repute is the first pile-group design program which accounts for a non-linear soil model in a rational way
- Current continuum-based programs can only use linear elastic soil model. This leads to an overprediction of loads at group corners and therefore significant construction costs
- Use of Repute non-linear soil model is of crucial importance in practice, as it demonstrates a relative reduction of loads at group corners, thereby resulting in a more cost-effective design

LOAD DISTRIBUTION IN PILE GROUPS

FEATURE	Corner load	Repute	MPILE	DEFPIG	GROUP
Pile-to-pile interaction	↑	Yes	Yes	Yes	Yes
Group stiffening effects	↓	Yes			
Loading-deform. coupling	↑	Yes			
Soil non-linearity	↓	Yes			Yes

APPLICATION OF REPUTE TO THE NEWARK DYKE PROJECT (UK)

(Skanska Cementation Foundations Ltd, 2000)



RESULTS & CONCLUSIONS

	MPILE	Repute (linear)	Repute (Non-linear)
Max axial load in kN (at corner pile)	1750	1500	1400

Use of a more rigorous tool leads to a better understanding of pile group behaviour

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Improved design techniques

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Economies in construction costs