Towards Efficient Finite Element Model Review

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(based on the original presentation of Dr. Brinkgreve)
Topics

- FEA in geotechnical engineering
- Validation & verification
- FE modelling: illustrated traps & pitfalls
Introduction

Simple hand calculations

- Graphical / analytical methods

- Conventional design methods

- Simple numerical methods

- 2D finite element analysis (1990→)

- 3D finite element analysis (2000→)
FEA in geotechnical engineering

Design cycle:

- **Design phase**
  - Preliminary design
  - Final design
- **Tender phase**
  - Modified / alternative design
- **Construction phase**
  - Construction / observation
- **Maintenance phase**
  - Improvements
FEA in geotechnical engineering

Key success factors for geotechnical FEA:

- Sufficient data
  - Soil data
  - Construction details

- Model accuracy
  - Competence of engineer
  - Software features and logic

- Calculation performance
  - Efficiency and accuracy of software
  - Computer power

- Interpretation of results
  - Competence of engineer

- Validation & Verification
Validation & Verification

Validation is essential in finite element analysis

- **Validation**: Matching reality ➔ Engineer
- **Verification**: Matching known solutions ➔ Software

Geotechnical Committee (NAFEMS, etc)
- Document on parameter selection
- Document on Validation of FEA
- Case histories
- Literature reviews
- Supporting Validation & Verification in geotechnical FEA
FE modelling: Traps & pitfalls

Geometric modelling

- Loads & boundary conditions

- Material models + parameters

- Mesh generation

- Initial conditions

- Calculation phases

- Results (interpretation)
Traps & pitfalls: Geometric modelling

Type of model?
- Plane strain
- Axisymmetry
- Full 3D

What if 2D model is used?
- Conservative
- Optimistic
Traps & pitfalls: Geometric modelling

- Plane strain
- Axisymmetry
Traps & pitfalls: Geometric modelling

- Pile modelling

What is effectively being modeled

2D Plane Strain Model

Equivalent 3D

Real 3D

How it looks like in reality
Traps & pitfalls: Geometric modelling

Where to put your model boundaries?
Traps & pitfalls: Geometric modelling

Stability analysis

Drained deformation analysis

Undrained deformation analysis

Dynamic analysis
Traps & pitfalls: Interface elements

Interfaces:
- Soil-structure Interaction

Be careful:
- 3D situations in 2D
- Piles

Extended interfaces:
- No strength reduction
- Improve stress results at tip/corners
Traps & pitfalls: Material models

Which model to use?
- Consider stress paths, required features
- Possibilities & limitations of models

Selection of model parameters
- Sufficient soil data?
- Stress level, stress path, anisotropy
Traps & pitfalls: Material models choice

Simple vs advanced constitutive models

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mohr Coulomb</th>
<th>Hardening Soil</th>
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<tbody>
<tr>
<td>Moduli</td>
<td>$E$</td>
<td>$E_{50}^{ref}$</td>
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<tr>
<td></td>
<td>$-,$</td>
<td>$E_{oed}^{ref}$</td>
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<td>$-,$</td>
<td>$E_{ur}^{ref}$</td>
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<tr>
<td></td>
<td>Power $m$</td>
<td></td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>$\nu$</td>
<td>$\nu_{ur}$</td>
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<tr>
<td>Cohesion</td>
<td>$c$</td>
<td></td>
</tr>
<tr>
<td>Friction angle</td>
<td>$\phi$</td>
<td></td>
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<tr>
<td>Dilatancy angle</td>
<td>$\psi$</td>
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</tbody>
</table>
Traps & Pitfalls: Stress paths

- Illustration for excavation problem
Traps & pitfalls: Undrained behaviour

Drained or undrained behaviour?

- Dimensionless time factor $T$

\[
T = \frac{kE_{oed}}{\gamma_w D^2} t
\]

- $T < 10^{-4}$ (U < 1%) : Undrained conditions
- $T > 2$ (U > 99%) : Drained conditions

How to model undrained behaviour?

- A: Effective stress analysis + $K_w/n + \text{effective parameters}$
- B: Effective stress analysis + $K_w/n + E', \nu' + S_u$
- C: Total stress analysis + undrained parameters
Traps & pitfalls: Undrained behaviour

Appropriate pore pressure, effective stress, shear strength?

Undrained A:

- $S_u$ is a result of the calculation (depending on soil model)

![Diagram showing linear-elastic perfectly plastic behavior with terms $q$, $2s_u$, $u$, ESP, TSP, and $p$, $p'$]
Traps & pitfalls: Undrained behaviour

Appropriate pore pressure, effective stress, shear strength?

Undrained A:

- $S_u$ is a result of the calculation (depending on soil model)
Traps & pitfalls: Undrained behaviour

Appropriate pore pressure, effective stress, shear strength?

Undrained B:

- $S_u$ is an input value

![Diagram showing q, p, p', 2s_u, ESP, and TSP.]
Traps & pitfalls: Undrained behaviour

Appropriate pore pressure, effective stress, shear strength?

Undrained C:

- $S_u$ is an input value

\[
\begin{align*}
q & \uparrow \\
2s_u & \downarrow \\
\text{TSP} & \quad \rightarrow p
\end{align*}
\]
Traps & pitfalls: Mesh generation

Element type:
- Interpolation order
- Locking

Shape
Traps & pitfalls: Mesh generation

Global fineness
Local refinement

15-node triangles
Traps & pitfalls: Initial conditions

Initial stresses:
- Initial total stress
- Initial pore pressure
- Initial effective stress

Initial value of state parameters:
- Initial void ratio
- Pre-consolidation stress
- Other state parameters

$K_0$-procedure  Gravity loading
Traps & pitfalls: Initial conditions

Existing structures:
- Requires several phases to set up initial conditions

Diagram:
- Existing buildings
- New project
- Initial phase
- Phase 1
- Phase 2
- Phase 3 >

reset displacements
Traps & pitfalls: Pore pressures

Using general phreatic level

Using local phreatic level and cluster interpolation
Traps & pitfalls: Pore pressures

Using groundwater flow

Open bottom boundary

Closed bottom boundary
Traps & pitfalls: Calculation settings

- Tolerated error TE

\[ U_{\text{max}} = 42.2 \text{ mm} \]
\[ U_{\text{max}} = 23.3 \text{ mm} \]
Traps & pitfalls: Safety Factor Analysis

- Safety factor based on Phi-c reduction method has a different meaning that safety factor used by structural engineers

\[ \sum M_{sf} = \frac{\text{available soil resistance}}{\text{mobilized soil resistance}} \]

\[ \sum M_{sf} = \frac{\text{failure load}}{\text{working load}} \]
Traps & pitfalls: Phi-c Reduction Analysis

- **Mesh Sensitivity**
Conclusions

- FEM: powerful tool in different phases of design process
- Key success factors:
  - Sufficient data
  - Reliable & efficient software
  - Competence of engineer
- Plaxis currently working on a visual checklist for efficient model review
  - Make the engineers aware of the traps and pitfalls
  - Supported by visual example
Questions ?