PLAXIS

essential for geotechnical professionals

Towards Efficient Finite Element Model Review

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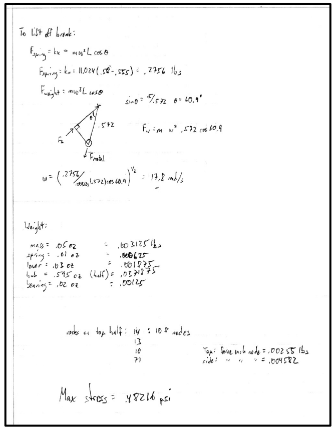
(based on the original presentation of Dr. Brinkgreve)

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→)

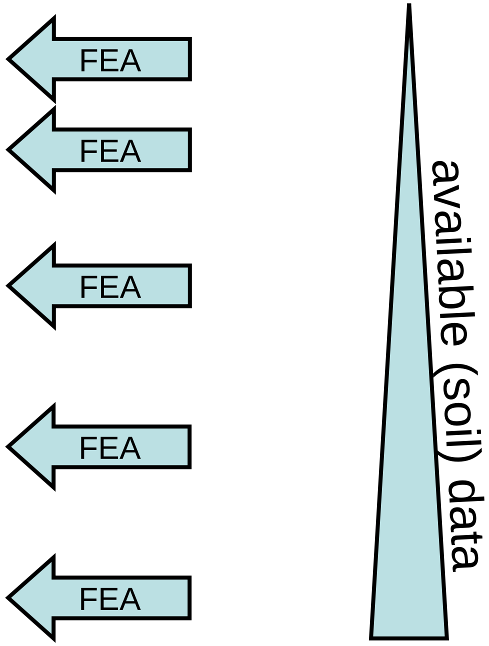
↘

3D finite element analysis (2000→)

FEA in geotechnical engineering

Design cycle:

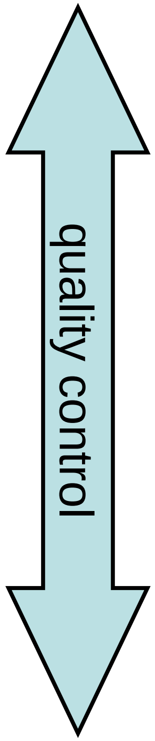
- **Design phase**
  - **Preliminary design**
  - **Final design**
- **Tender phase**
  - **Modified / alternative design**
- **Construction phase**
  - **Construction / observation**
- **Maintenance phase**
  - **Improvements**



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)

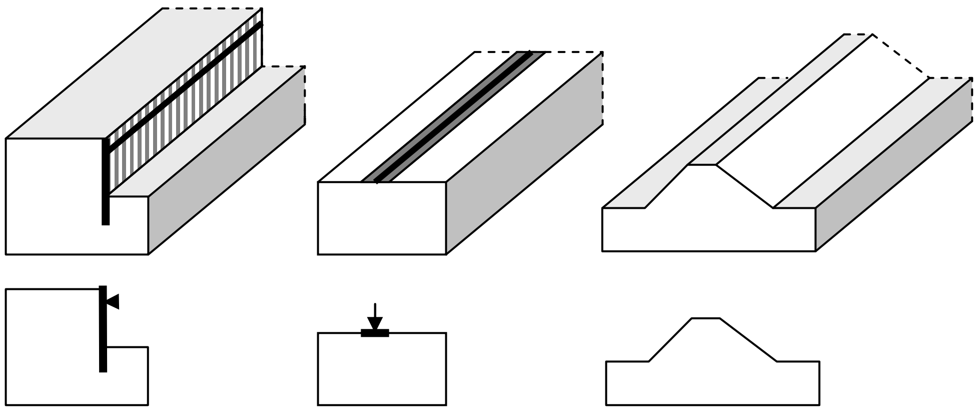
Traps & pitfalls: Geometric modelling

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

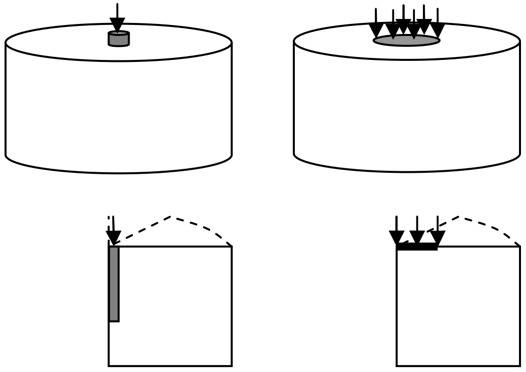
What if 2D model is used?
- Conservative
- Optimistic

Traps & pitfalls: Geometric modelling

- **Plane strain**

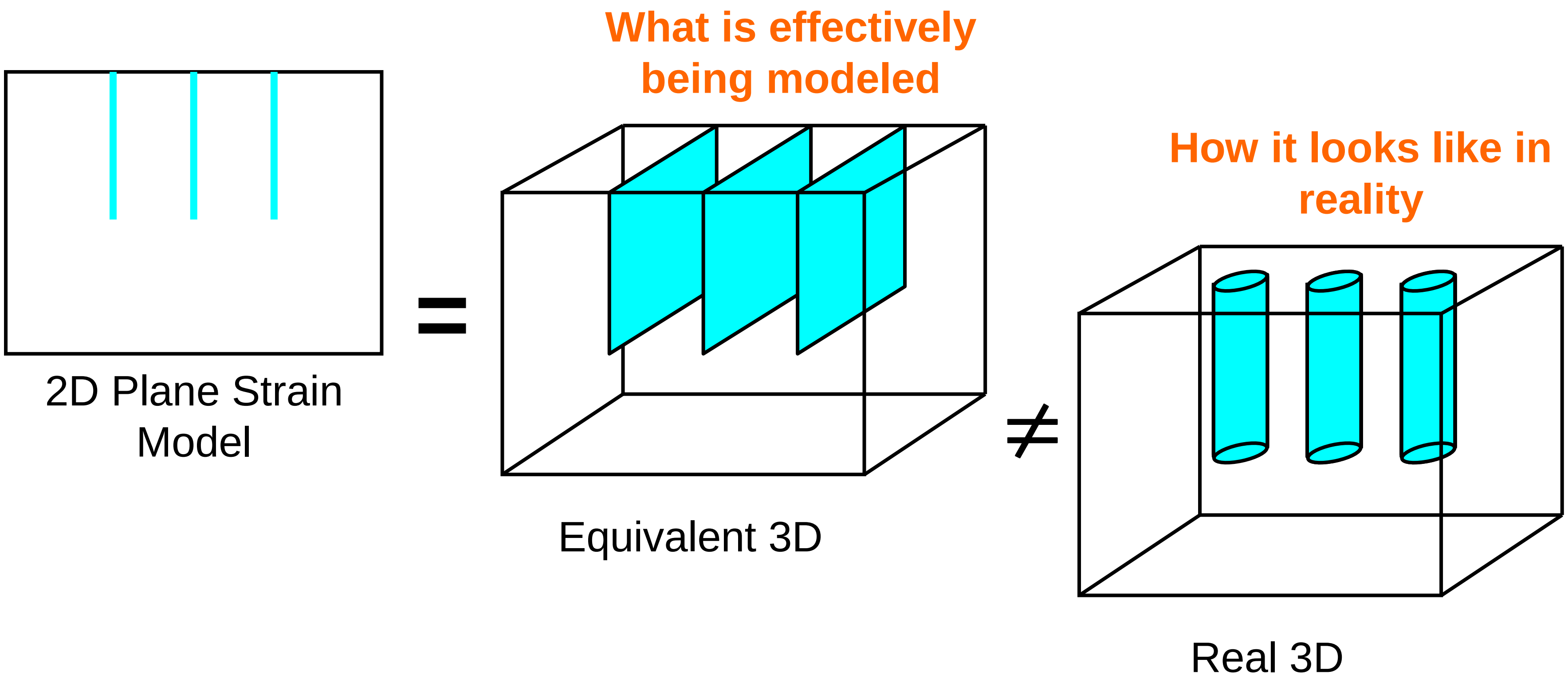


- **Axisymmetry**



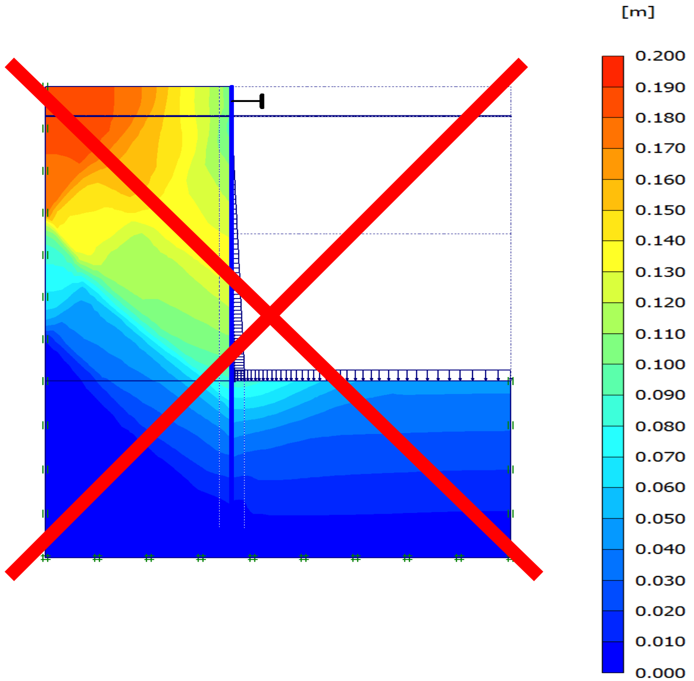
Traps & pitfalls: Geometric modelling

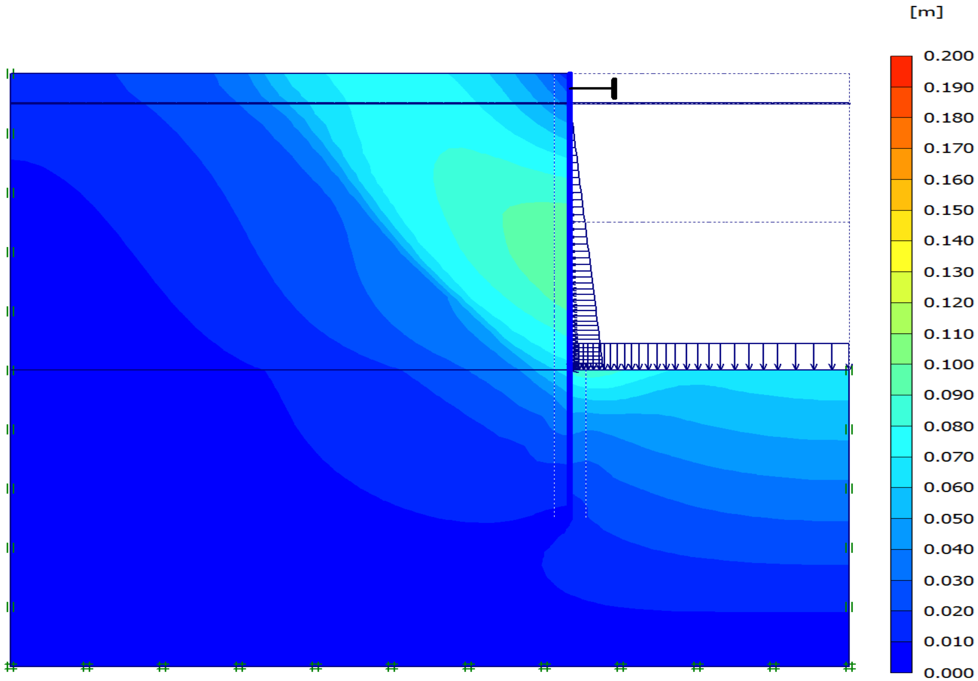
- **Pile modelling**



Traps & pitfalls: Geometric modelling

Where to put your model boundaries?





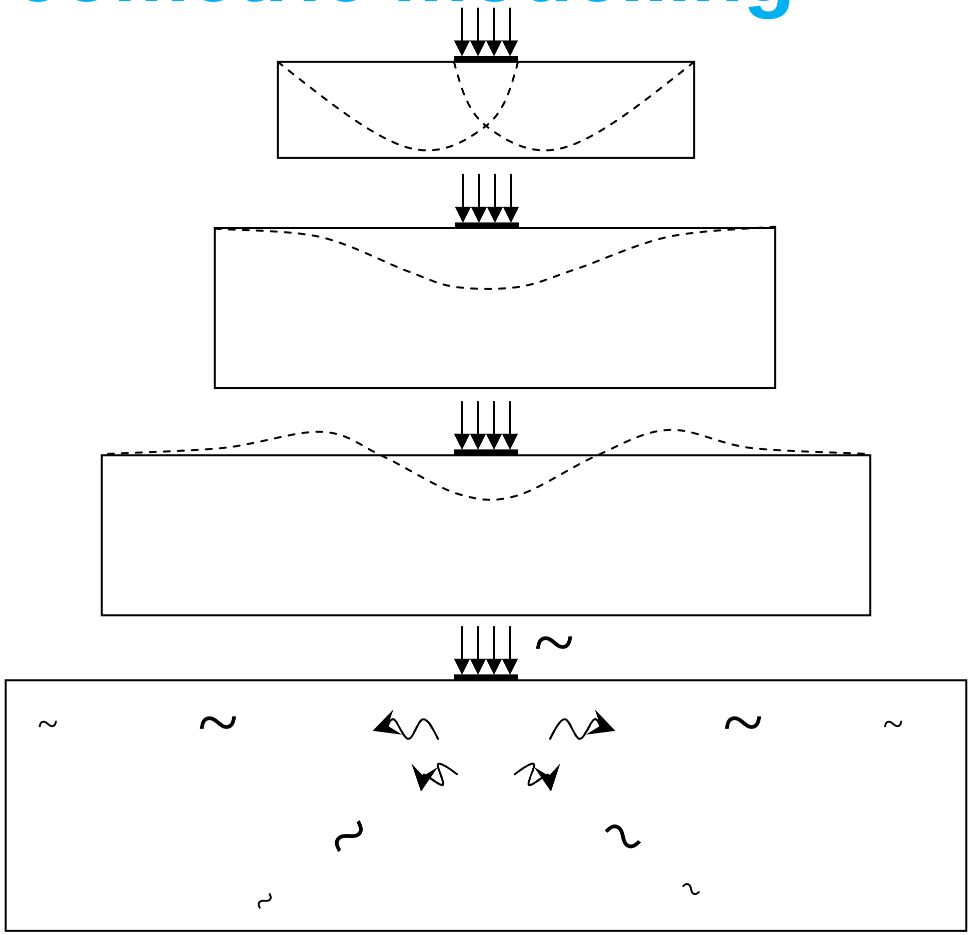
Traps & pitfalls: Geometric modelling

Stability analysis

Drained deformation analysis

Undrained deformation analysis

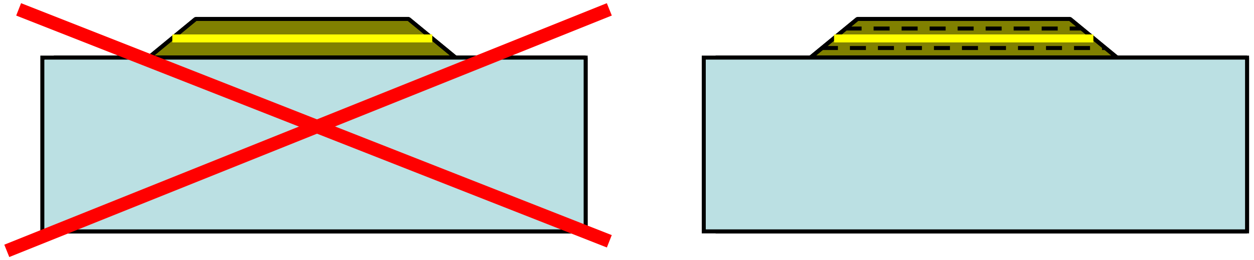
Dynamic analysis



Traps & pitfalls: Interface elements

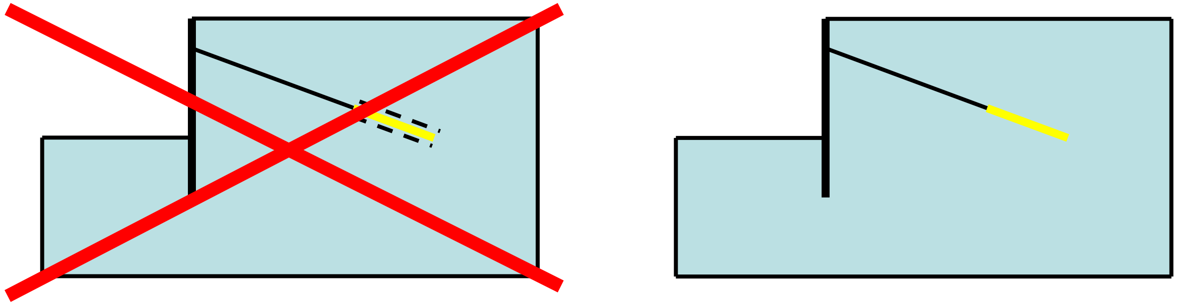
Interfaces:

- **Soil-structure Interaction**



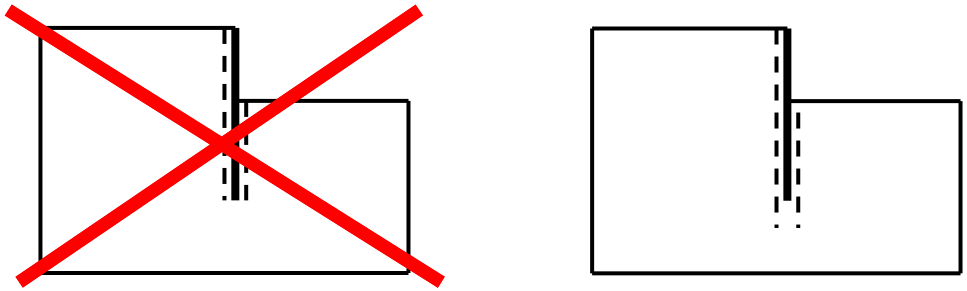
Be careful:

- **3D situations in 2D**
- **Piles**



Extended interfaces:

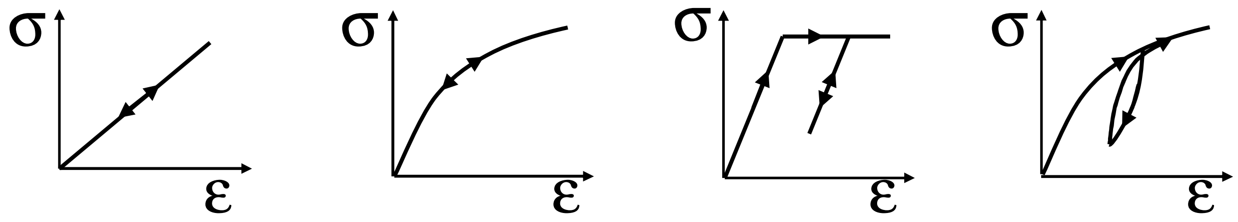
- **No strength reduction**
- **Improve stress results at tip/corners**



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**

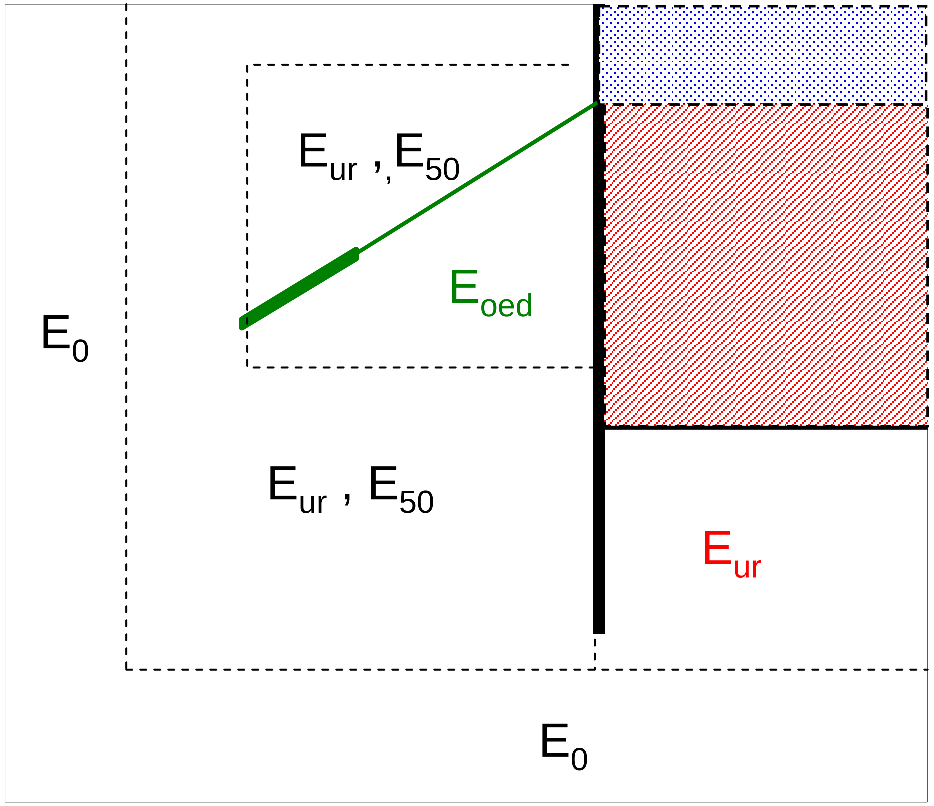
Traps & pitfalls: Material models choice

Simple vs advanced constitutive models

Parameters	Mohr Coulomb	Hardening Soil
Moduli	E	E_{50}^{ref}
	-	E_{oed}^{ref}
	-	E_{ur}^{ref}
	-	Power m
Poisson ratio	ν	ν_{ur}
Cohesion	c	
Friction angle	φ	
Dilatancy angle	ψ	

Traps & Pitfalls: Stress paths

- **Illustration for excavation problem**



Traps & pitfalls: Undrained behaviour

Drained or undrained behaviour?

- Dimensionless time factor T

$$T = \frac{k\,E_{oed}}{\gamma_w\,D^2}\,t$$

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

How to model undrained behaviour?

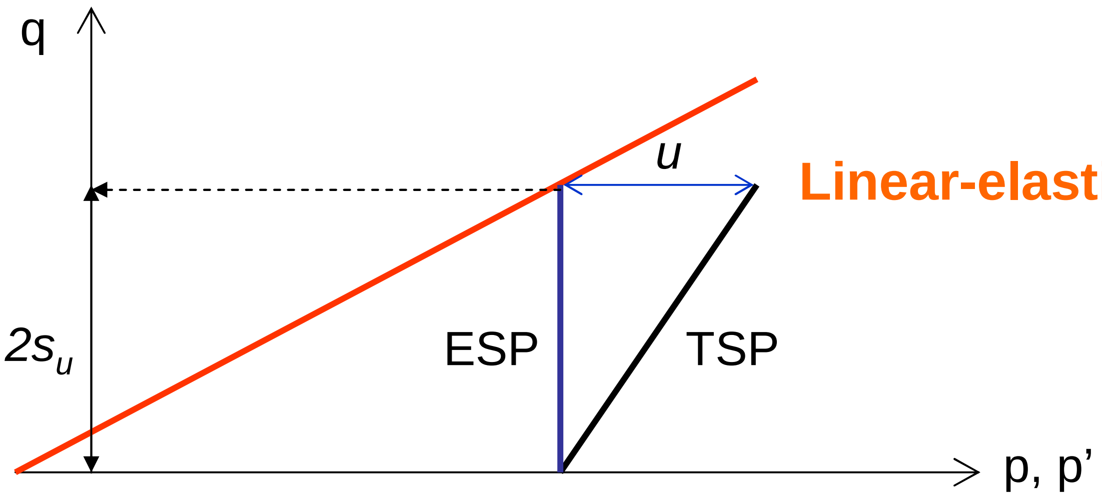
- A: Effective stress analysis + K_w/n + effective parameters
- B: Effective stress analysis + K_w/n + E', ν' + S_u
- C: Total stress analysis + undrained parameters

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)**



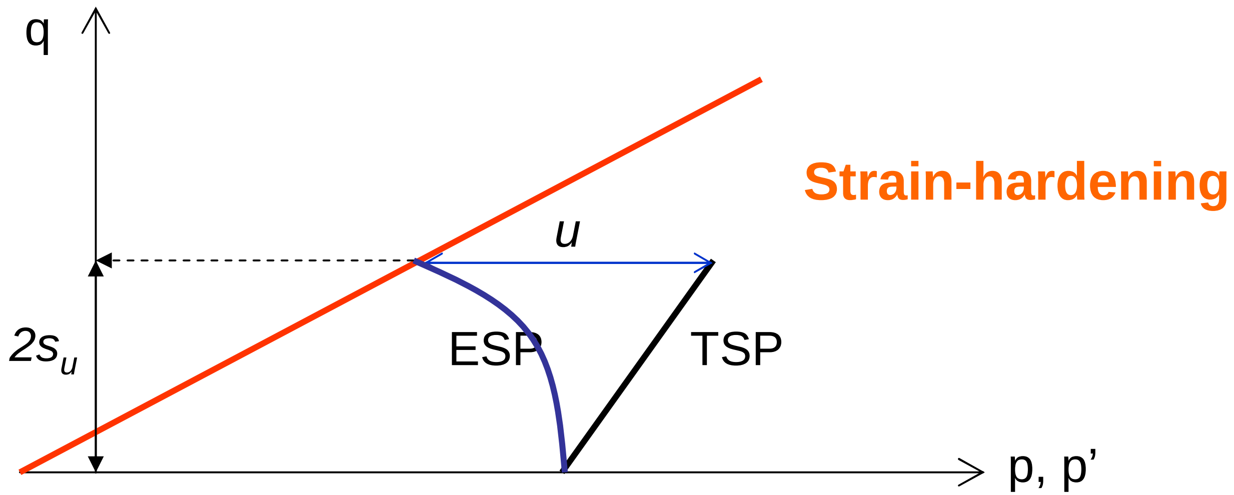
Linear-elastic perfectly plastic

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)**

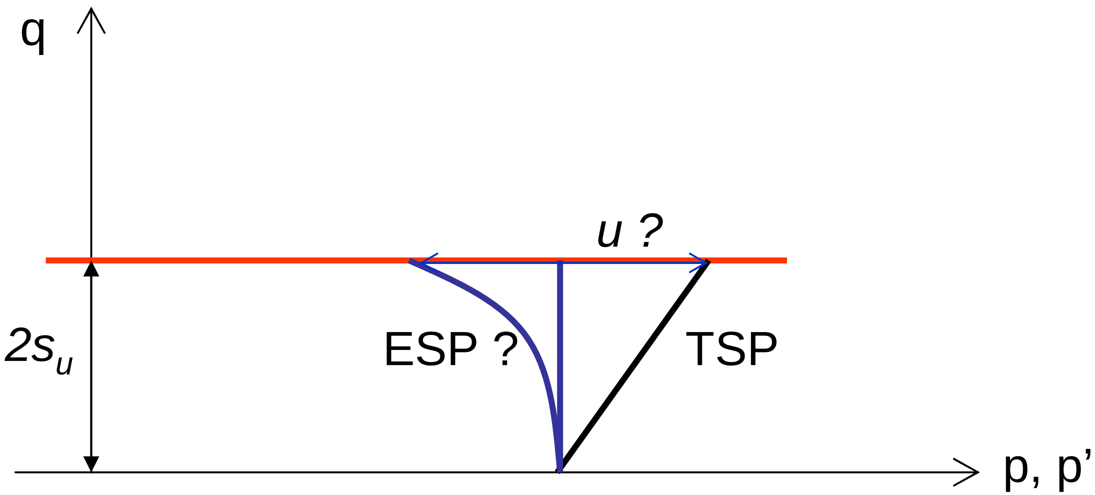


Traps & pitfalls: Undrained behaviour

Appropriate pore pressure, effective stress, shear strength?

Undrained B:

- ***S_u*** **is an input value**

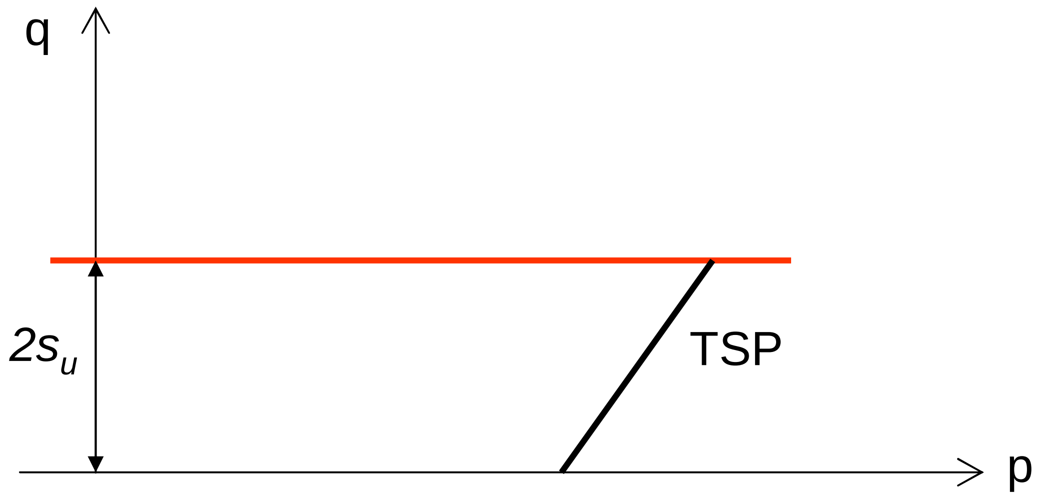


Traps & pitfalls: Undrained behaviour

Appropriate pore pressure, effective stress, shear strength?

Undrained C:

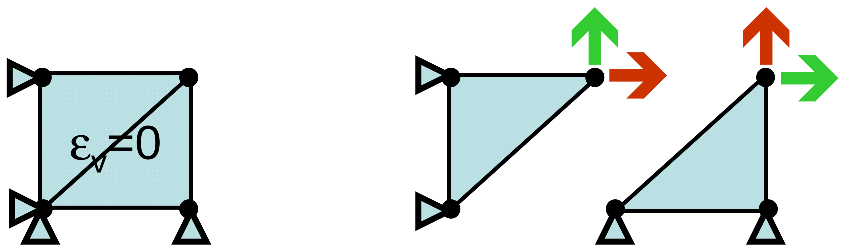
- ***S_u* is an input value**



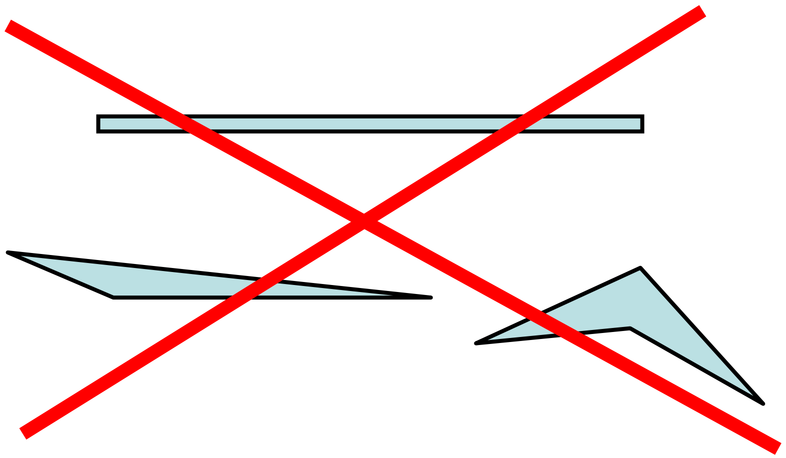
Traps & pitfalls: Mesh generation

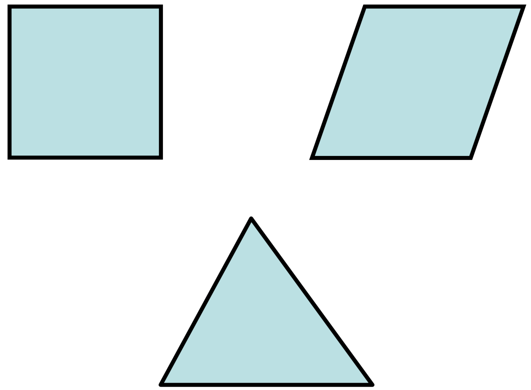
Element type:

- Interpolation order
- Locking



Shape





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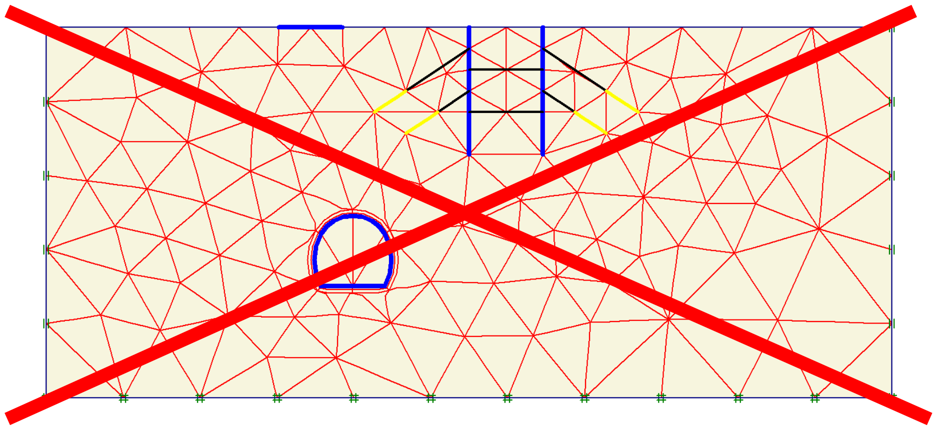
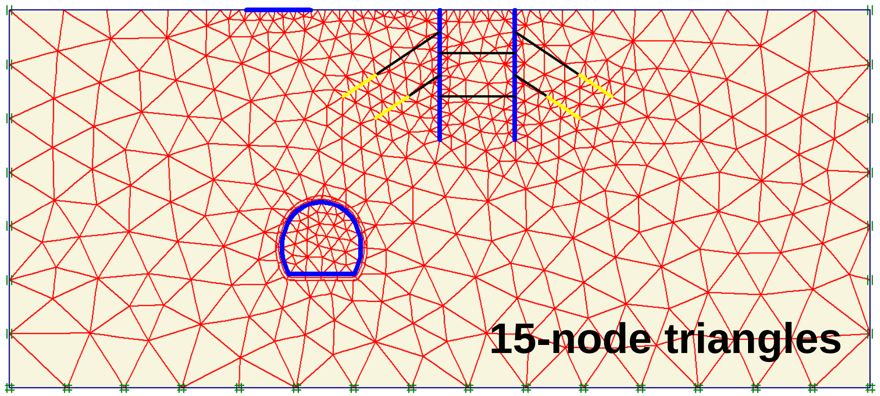
Traps & pitfalls: Mesh generation

Global fineness

Local refinement





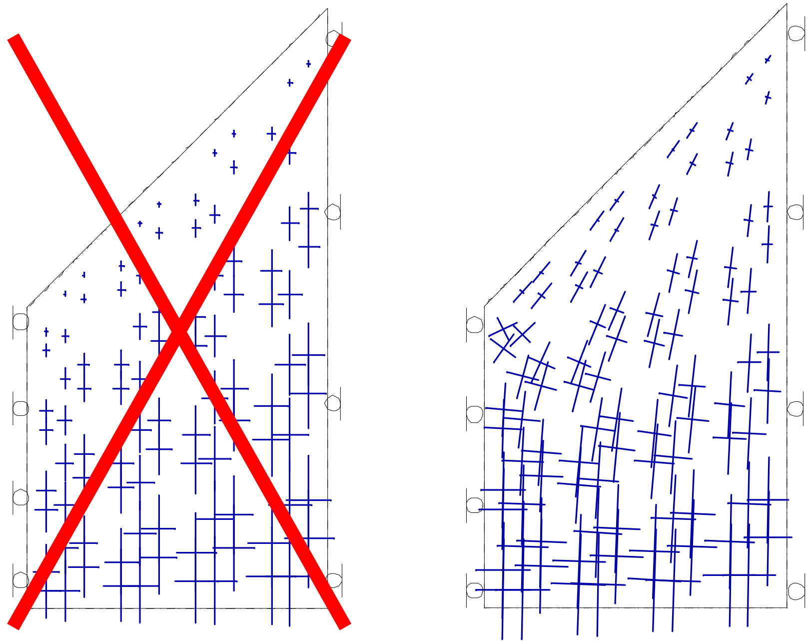
Traps & pitfalls: Initial conditions

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

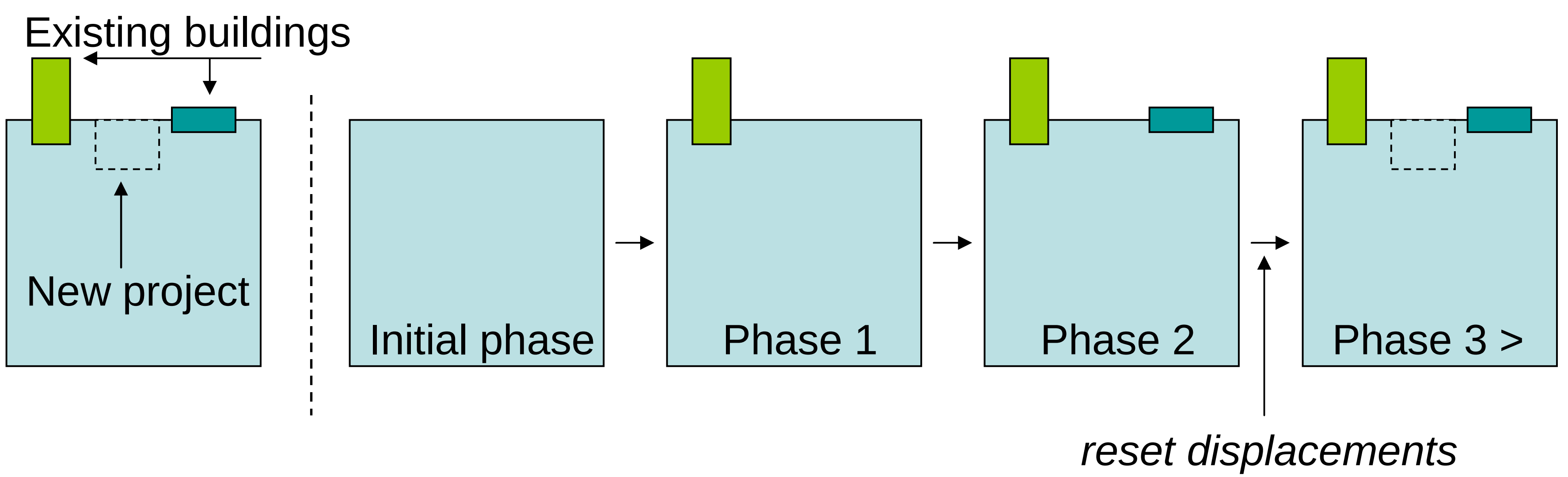


K_0-procedure Gravity loading

Traps & pitfalls: Initial conditions

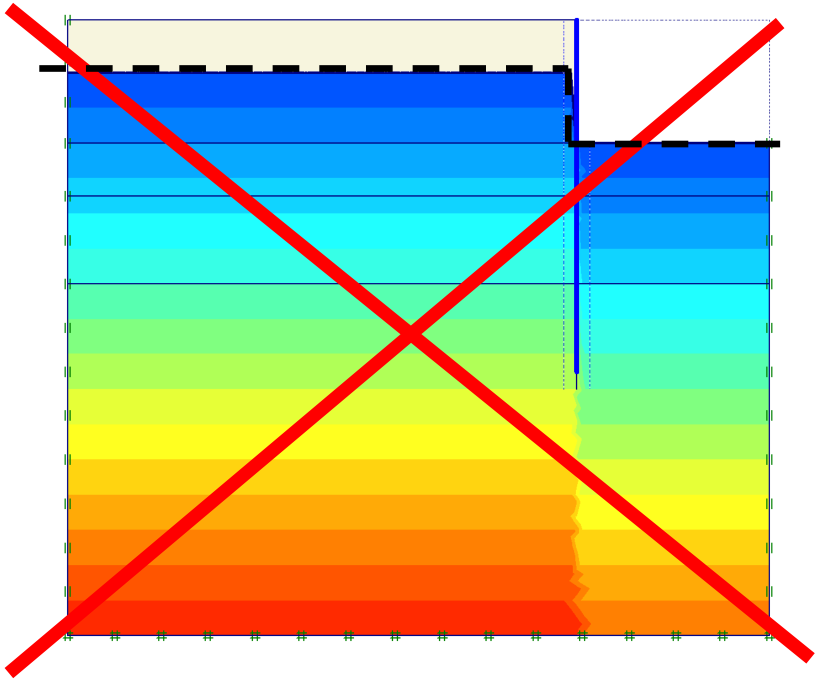
Existing structures:

- **Requires several phases to set up initial conditions**

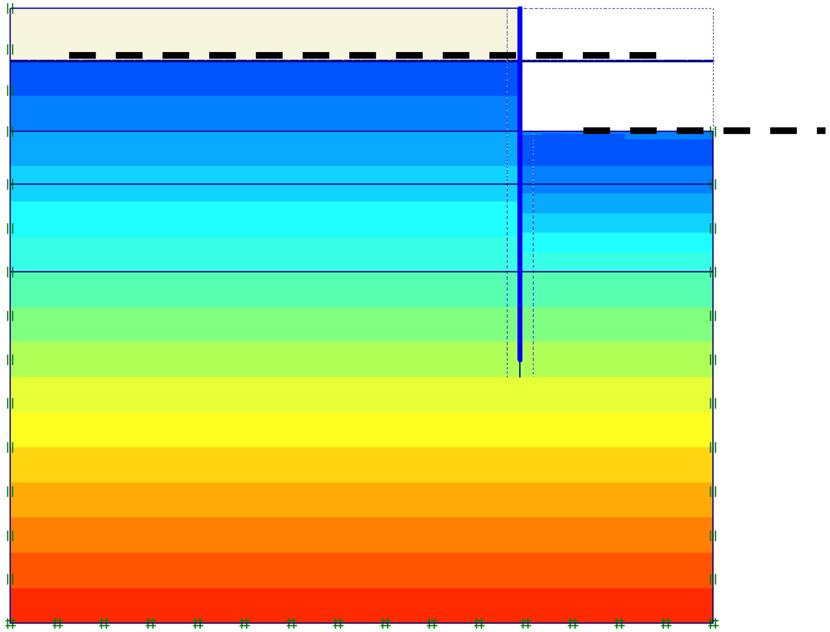


Traps & pitfalls: Pore pressures

Using general phreatic level

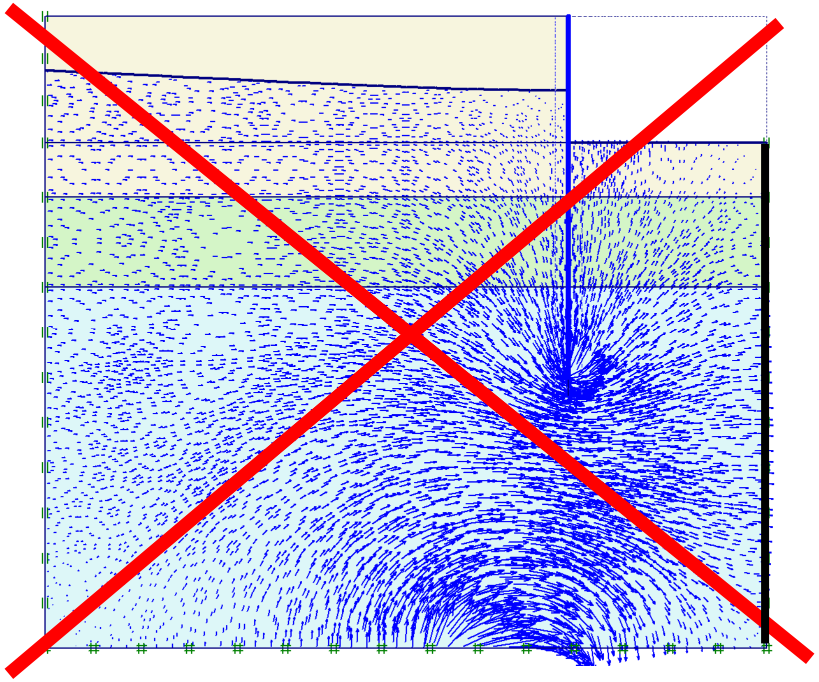


Using local phreatic level and cluster interpolation

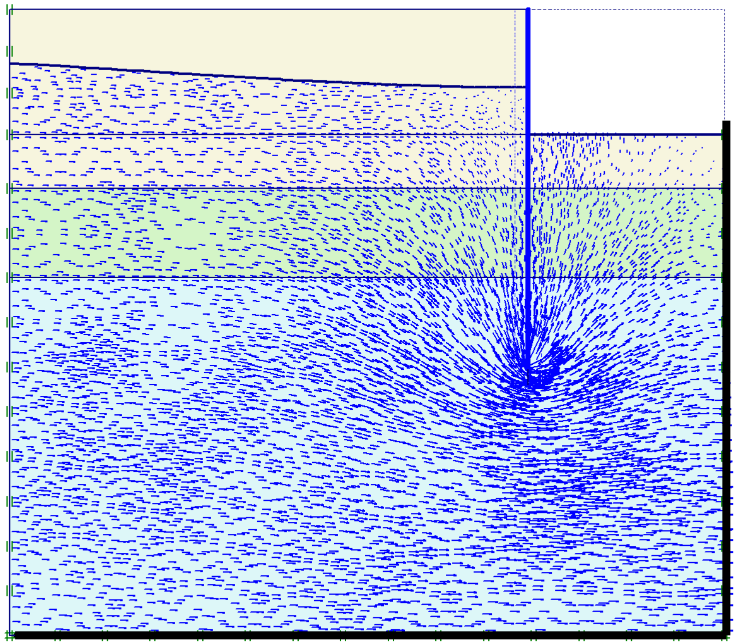


Traps & pitfalls: Pore pressures

Using groundwater flow



Open bottom boundary

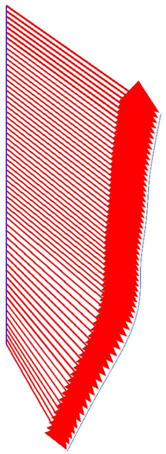


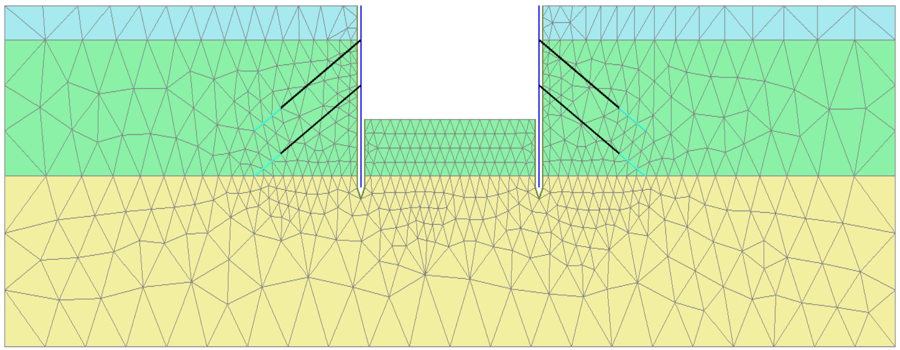
Closed bottom boundary

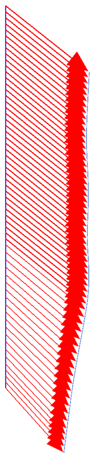
Traps & pitfalls: Calculation settings

- **Tolerated error TE**

TE = 1% **TE = 20%**







U_{max} = 42.2 mm **U_{max} = 23.3 mm**

Traps & pitfalls: Safety Factor Analysis

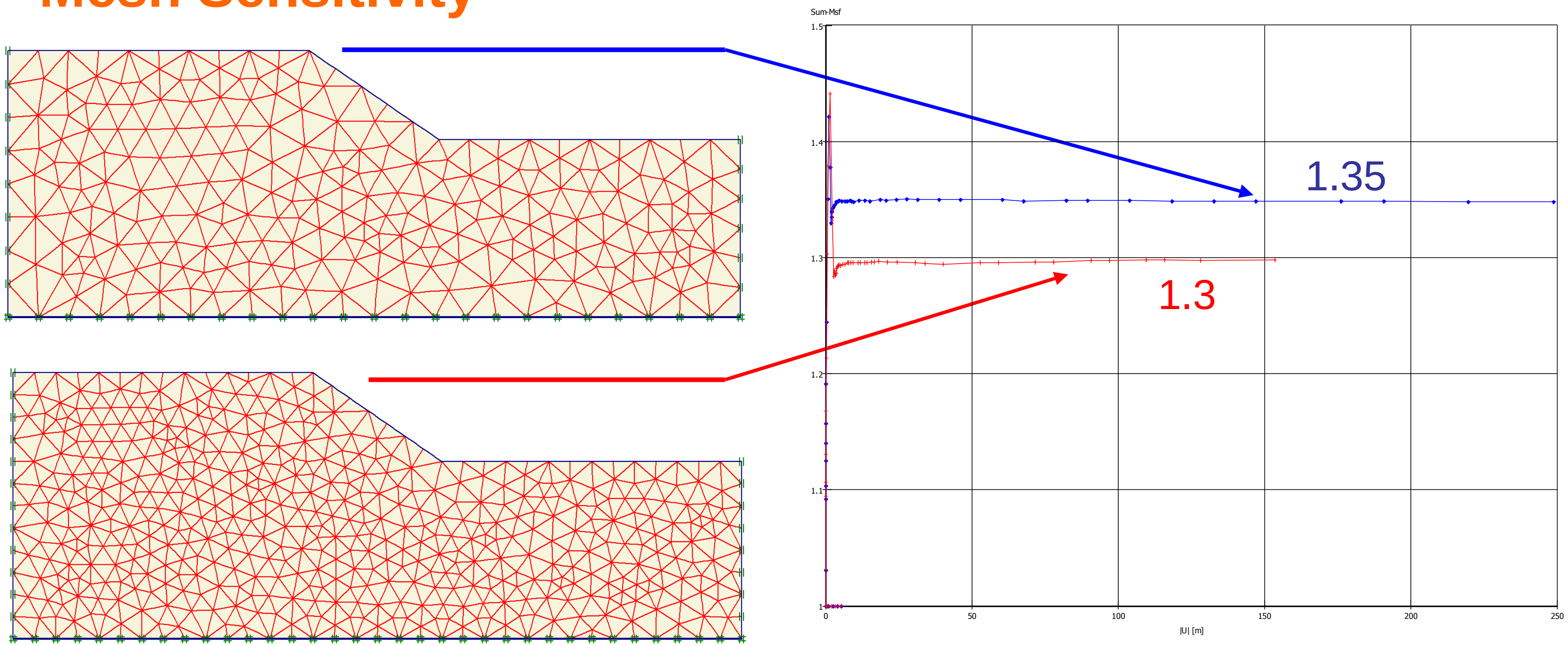
- **Safety factor based on Phi-c reduction method has a different meaning that safety factor used by structural engineers**

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

$$\cancel{\sum M_{sf} = \frac{\text{failure load}}{\text{working load}}}$$

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

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Questions ?

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