Deltares
Enabling Delta Life

Application of a Quasi-Static Material Point Method in Geomechanics

GEO-INSTALL   Modelling Installation Effects in Geotechnical Engineering

Dipl.-Ing. Lars Beuth   Deltares / University of Stuttgart

August 9, 2010

1. Quasi-Static MPM

2. Moving Block

3. Soil-Structure Interaction

4. Cone Penetration in Undrained Clay

5. Outlook

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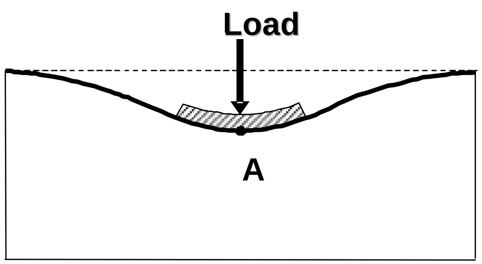
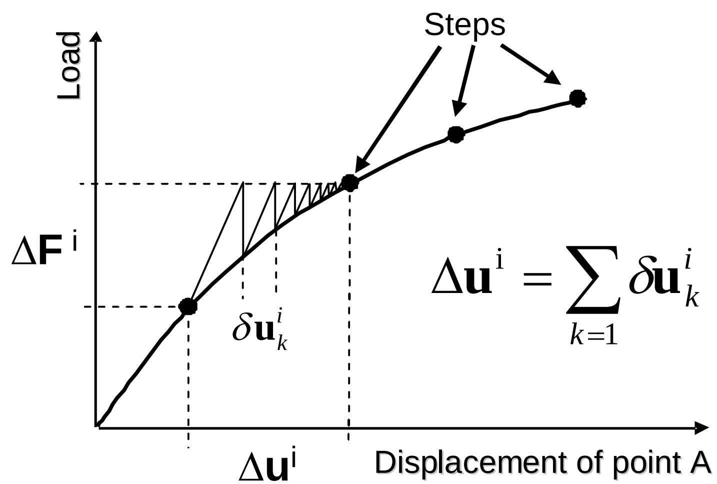
Quasi-static MPM & Updated Lagrangian FEM with implicit integration for load step i

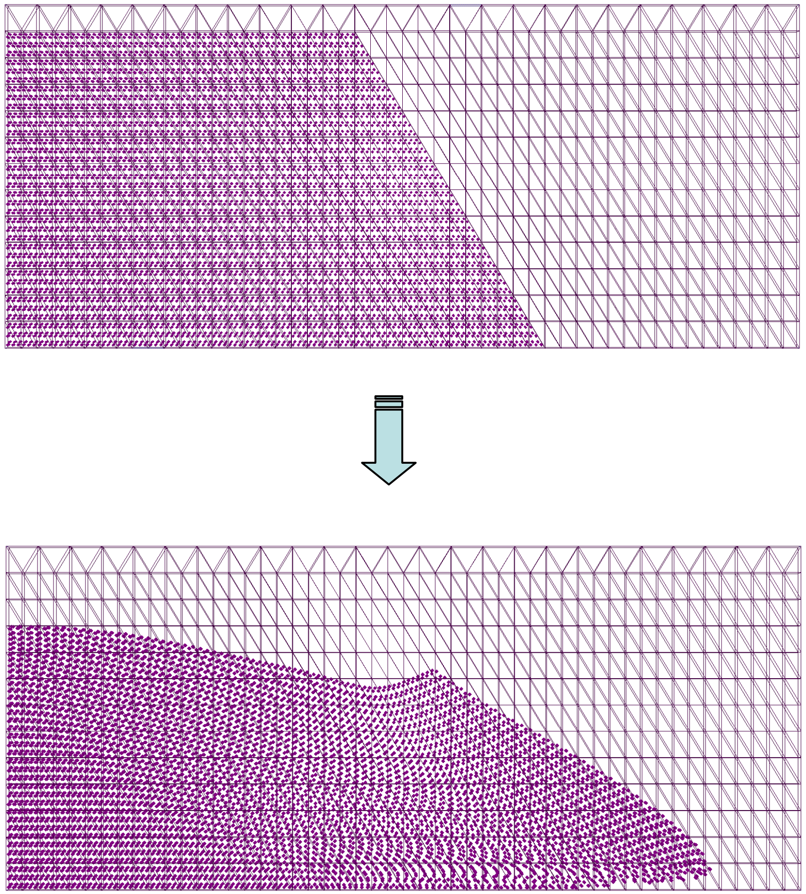
$$\mathbf{K}^{i}\ \delta\mathbf{u}^{i}_{k+1} = \mathbf{F}^{i}_{\text{external},k} - \mathbf{F}^{i}_{\text{internal},k}$$

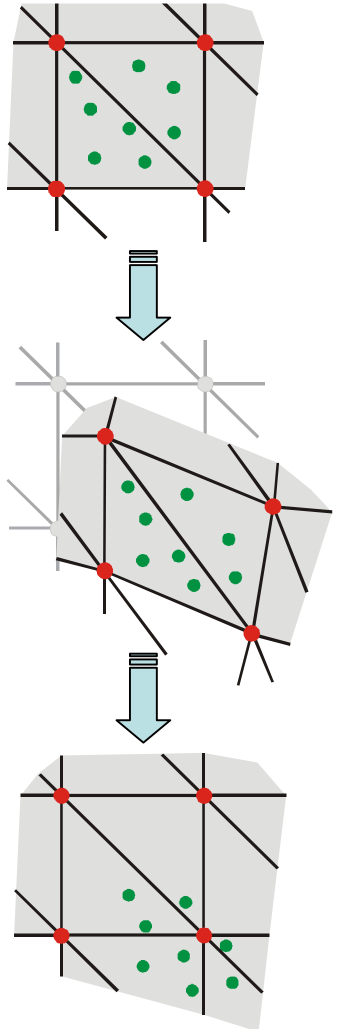
- Subincremental displacement vector
- Load step number
- Iteration number
- Elastic stiffness matrix





Particles represent the deforming solid body inside a finite element mesh





Beginning of load step

Mesh distortion during load step

Resetting at end of load step

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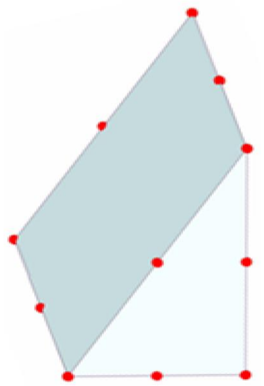
2. Moving Block



15-noded prismatic element
with near-quadratic interpolation

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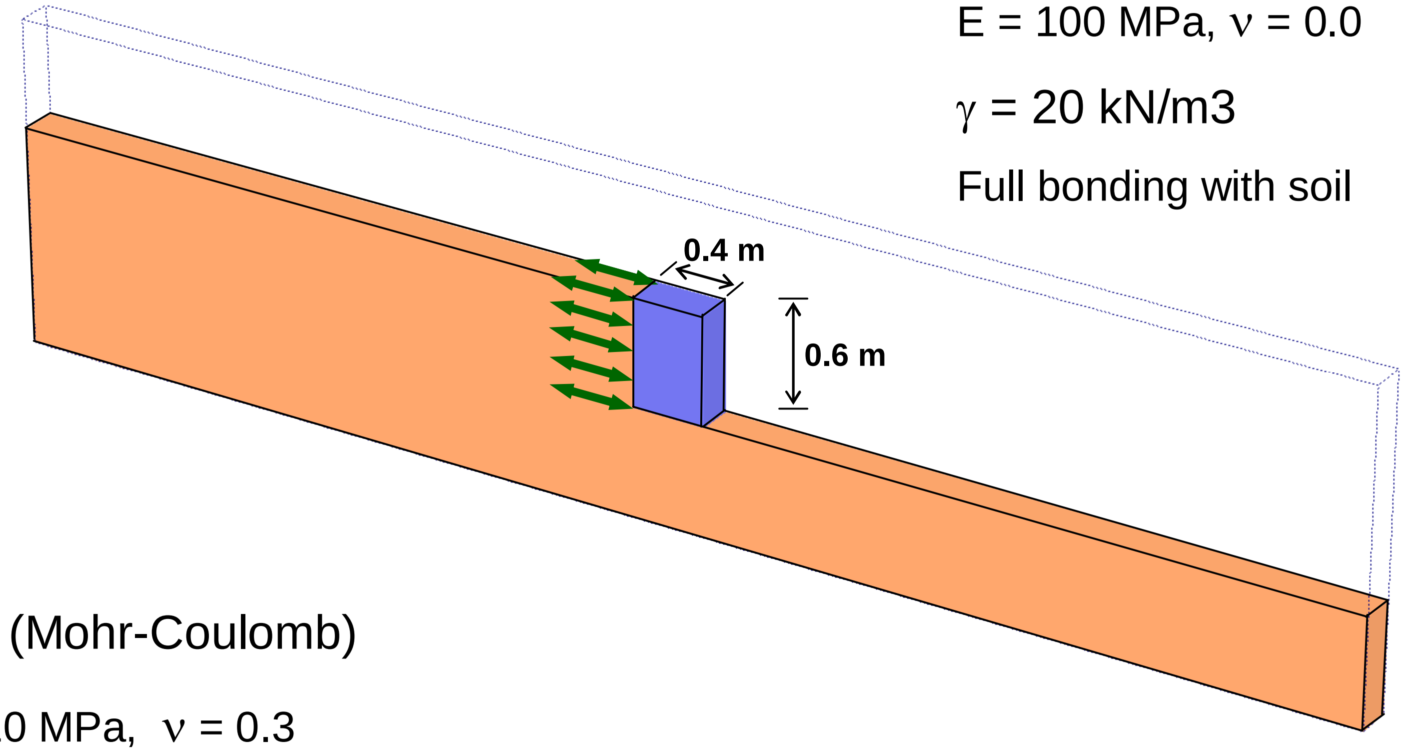
Active block movement

Elastic block

E = 100 MPa, ν = 0.0

γ = 20 kN/m3

Full bonding with soil



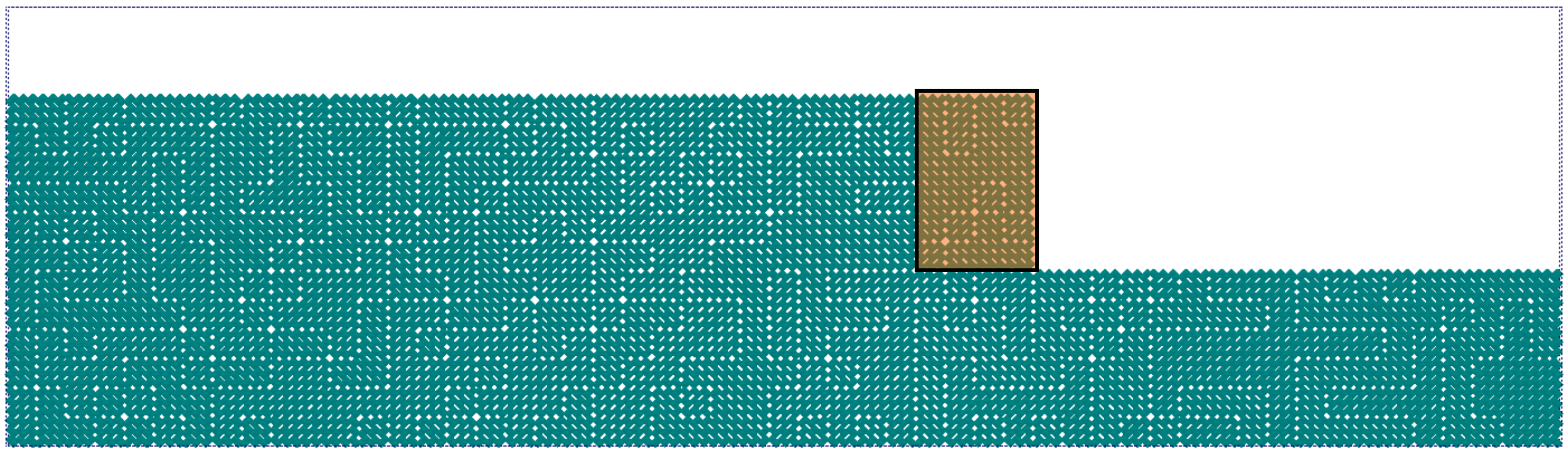
Soil (Mohr-Coulomb)

E = 10 MPa, ν = 0.3

c = 10 kPa, φ = 30°

γ = 20 kN/m^3

Active block movement



Shift of block = 0 cm

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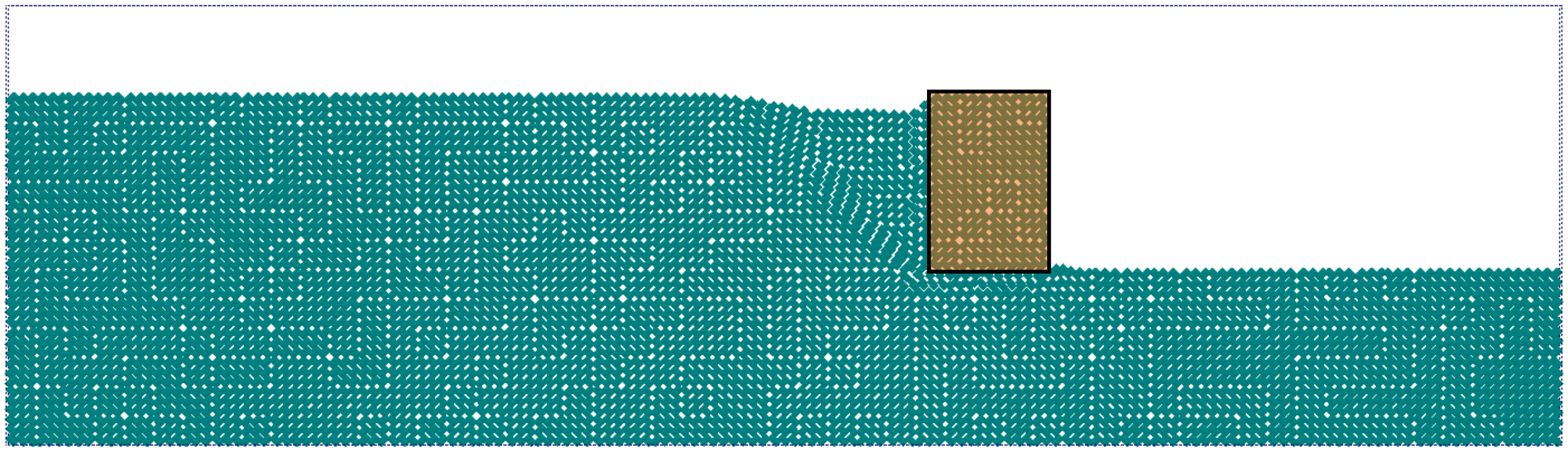
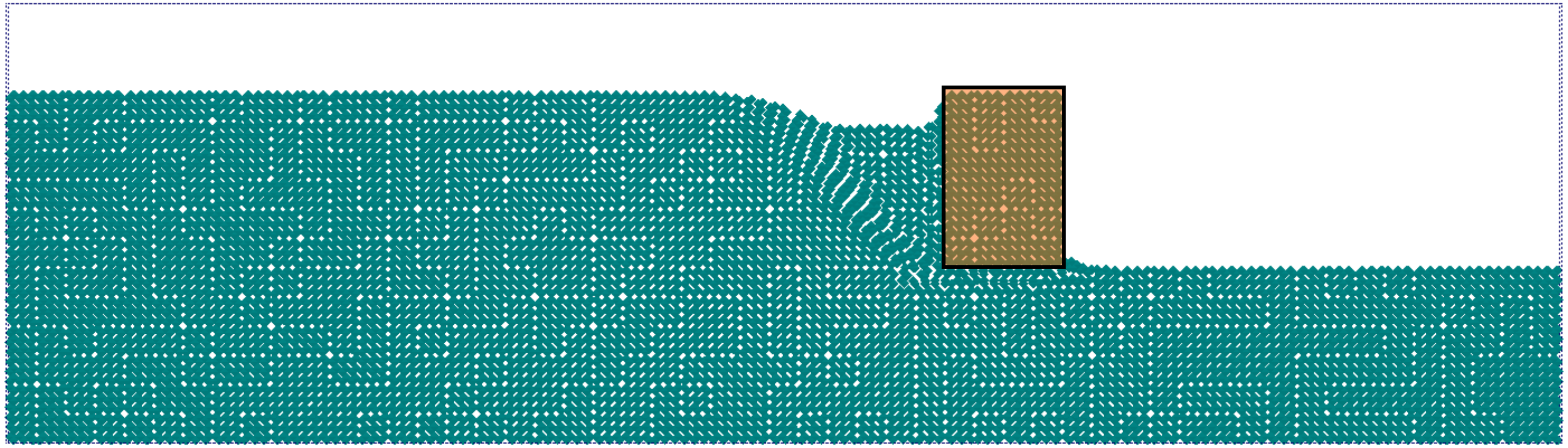
Active block movement



Shift of block = 5 cm

Deltares

Active block movement

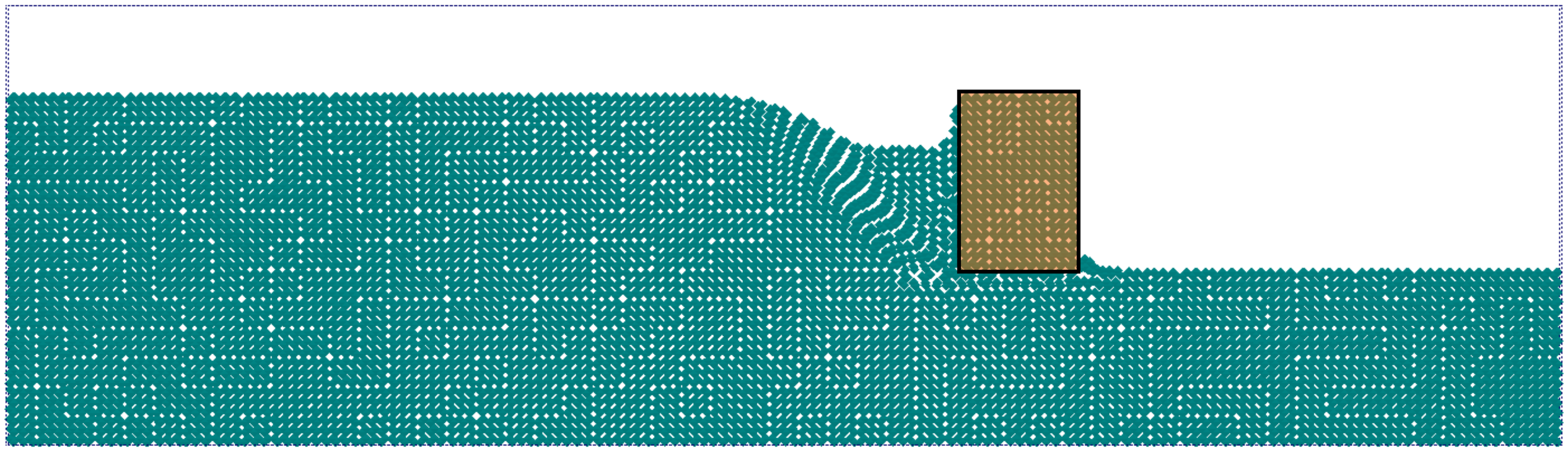


Shift of block = 10 cm

Deltares

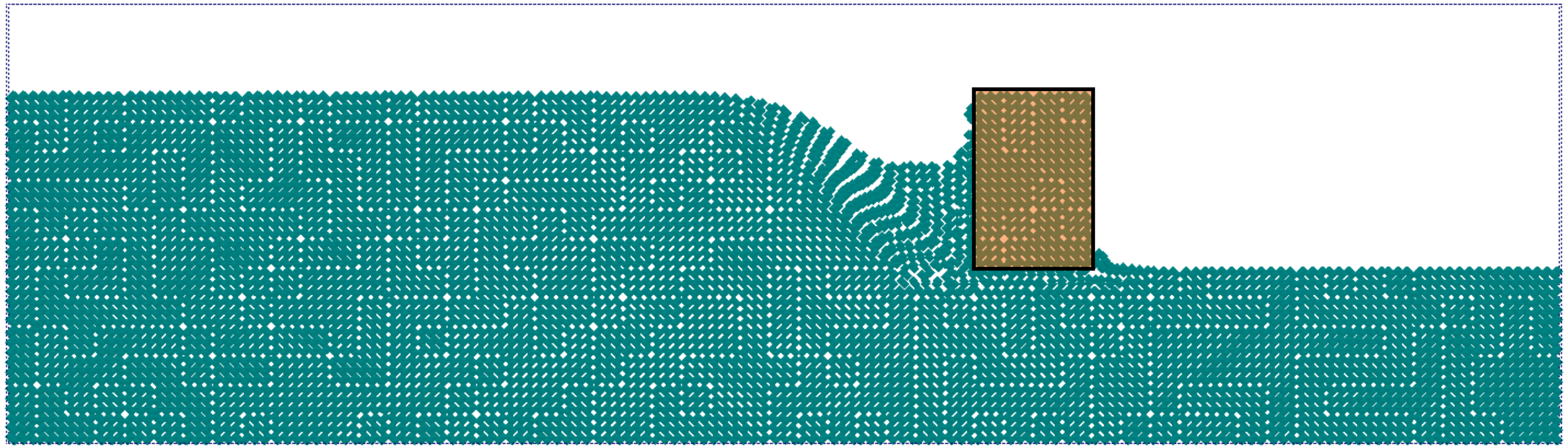
2. Moving Block

Active block movement



Shift of block = 15 cm

Active block movement

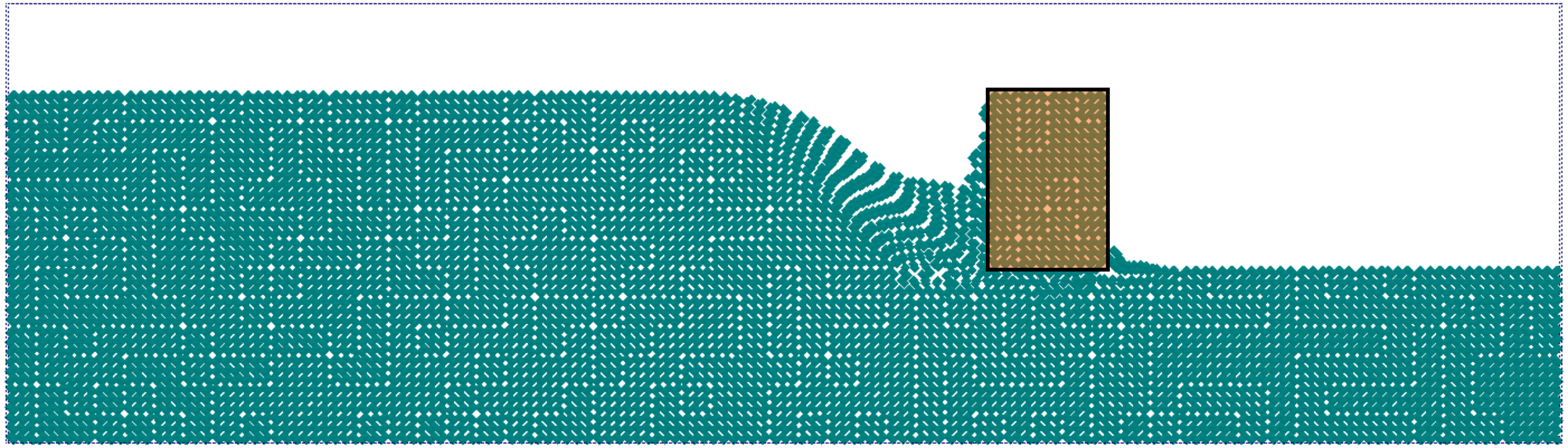


Shift of block = 20 cm

Deltares

Active block movement

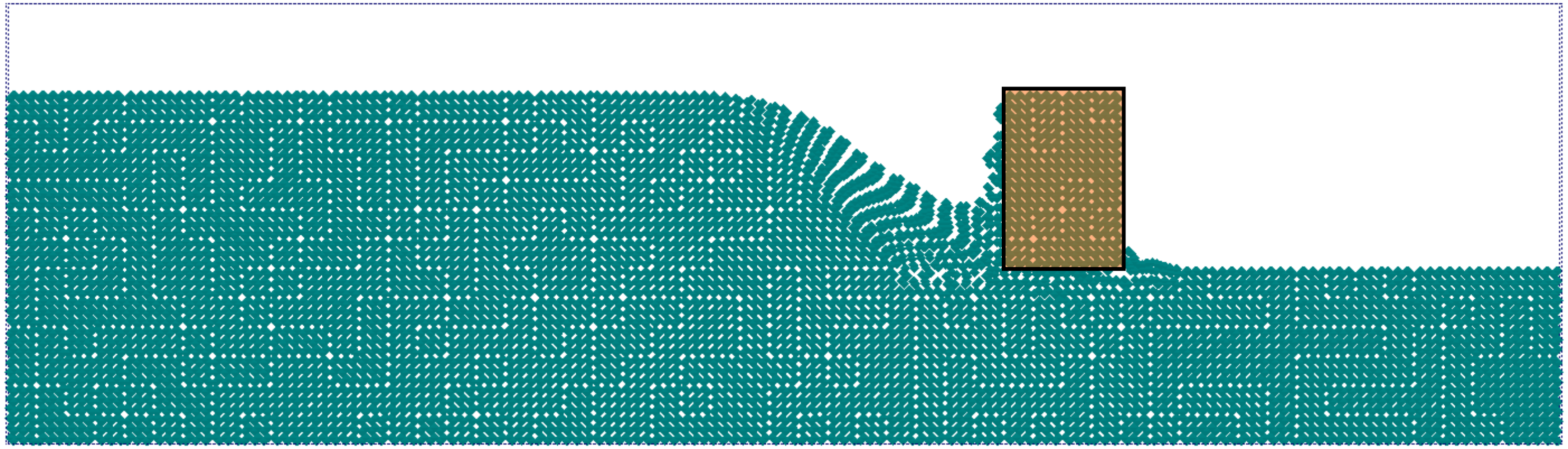
The block is loosing its contact to the soil, a free slope is forming. Soil is slightly heaving up in front of the block.



Shift of block = 25 cm

Active block movement

The block is loosing its contact to the soil, a free slope is forming. Soil is slightly heaving up in front of the block.

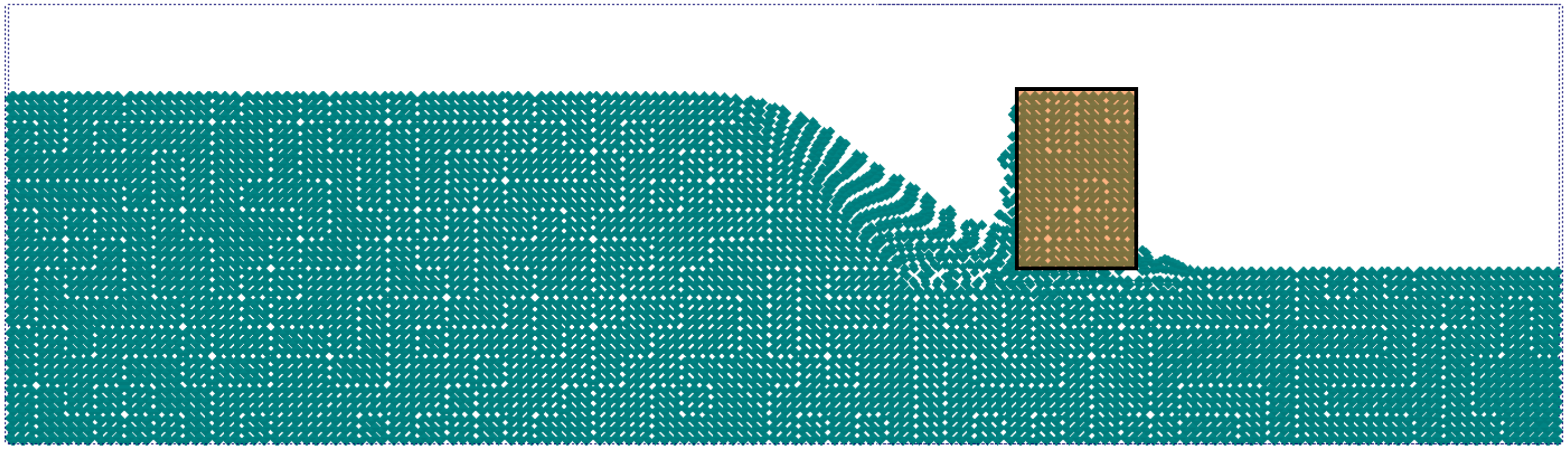


Shift of block = 30 cm

Deltares

Active block movement

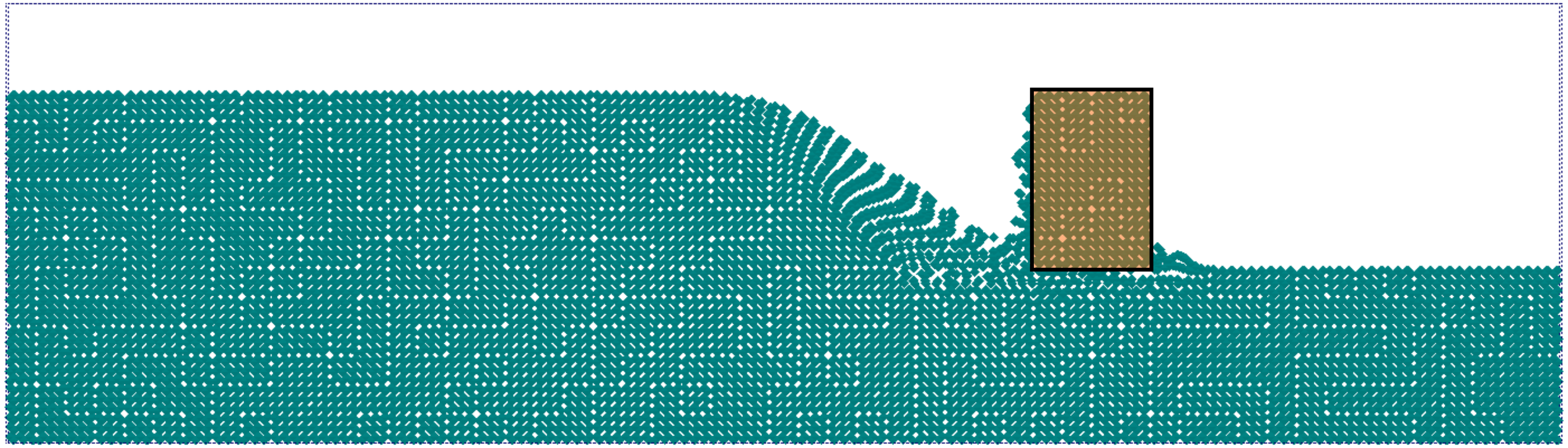
The block is loosing its contact to the soil, a free slope is forming. Soil is slightly heaving up in front of the block.



Shift of block = 35 cm

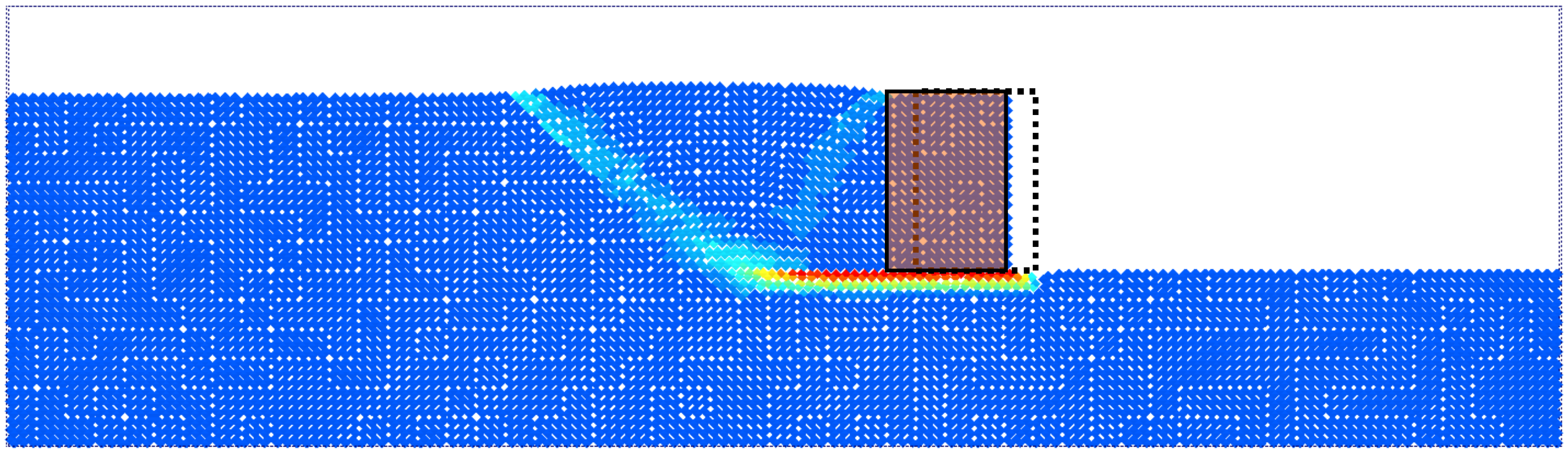
Active block movement

A few soil particles are still sticking to the block, due to soil cohesion and adhesion between soil and block.



Shift of block = 40 cm

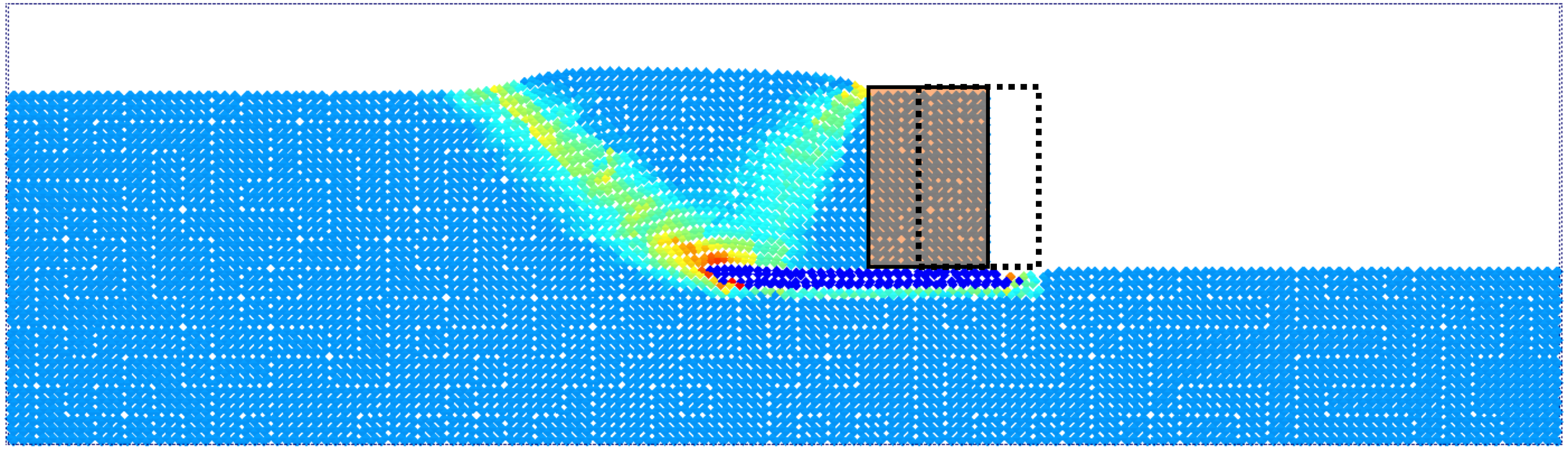
Passive block movement



Shift of block = 15 cm

Deltares

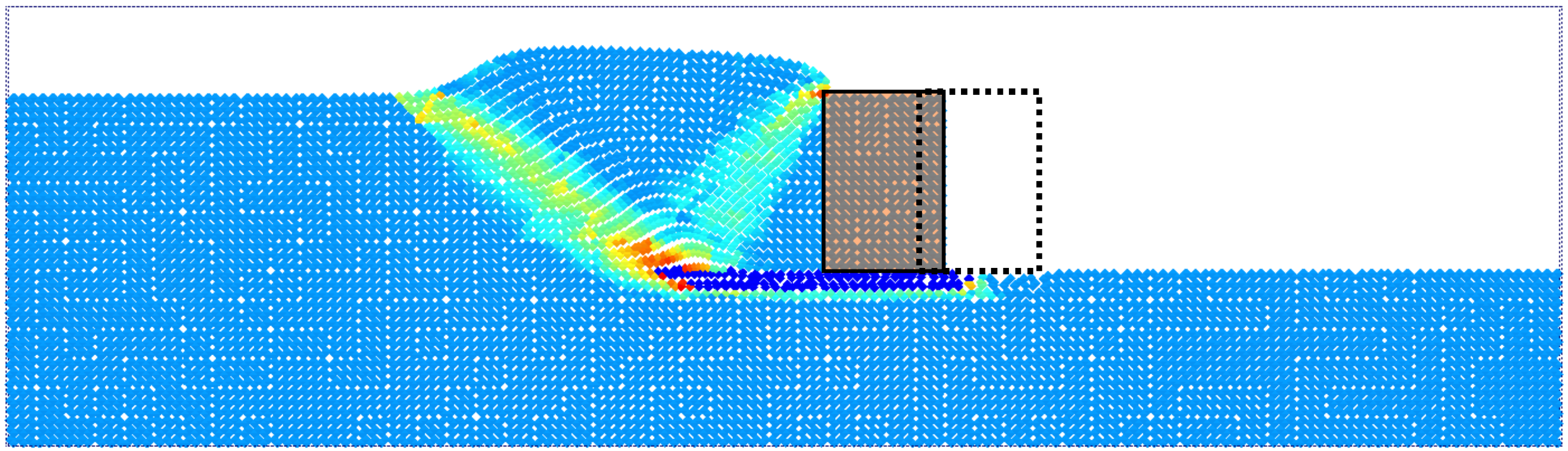
Passive block movement



Shift of block = 22.5 cm

Deltares

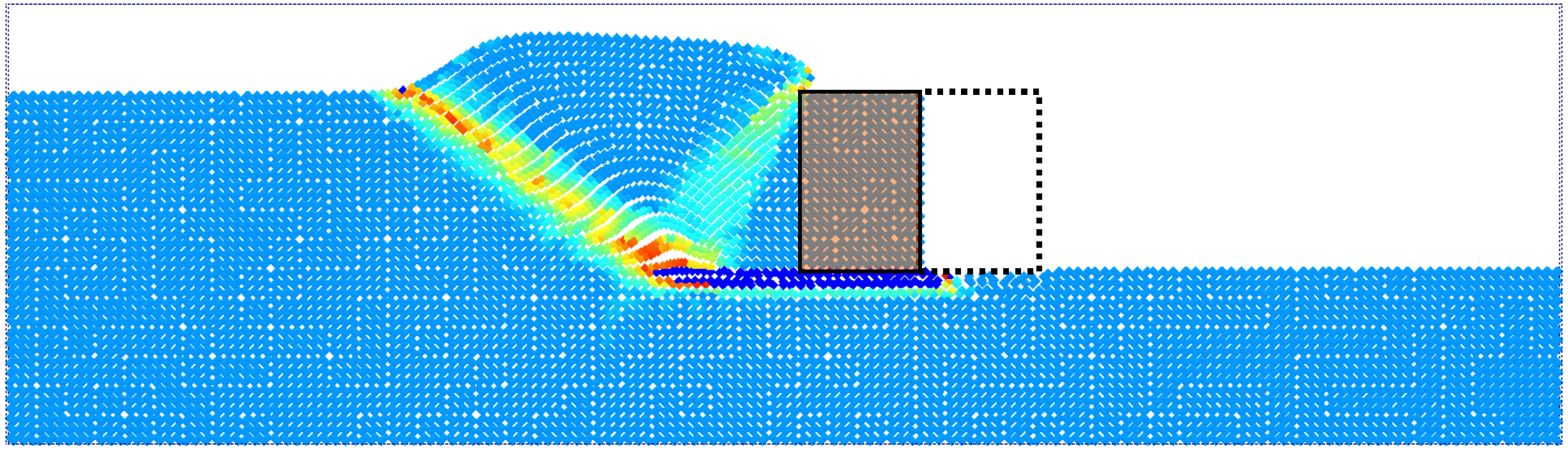
Passive block movement



Shift of block = 30 cm

Deltares

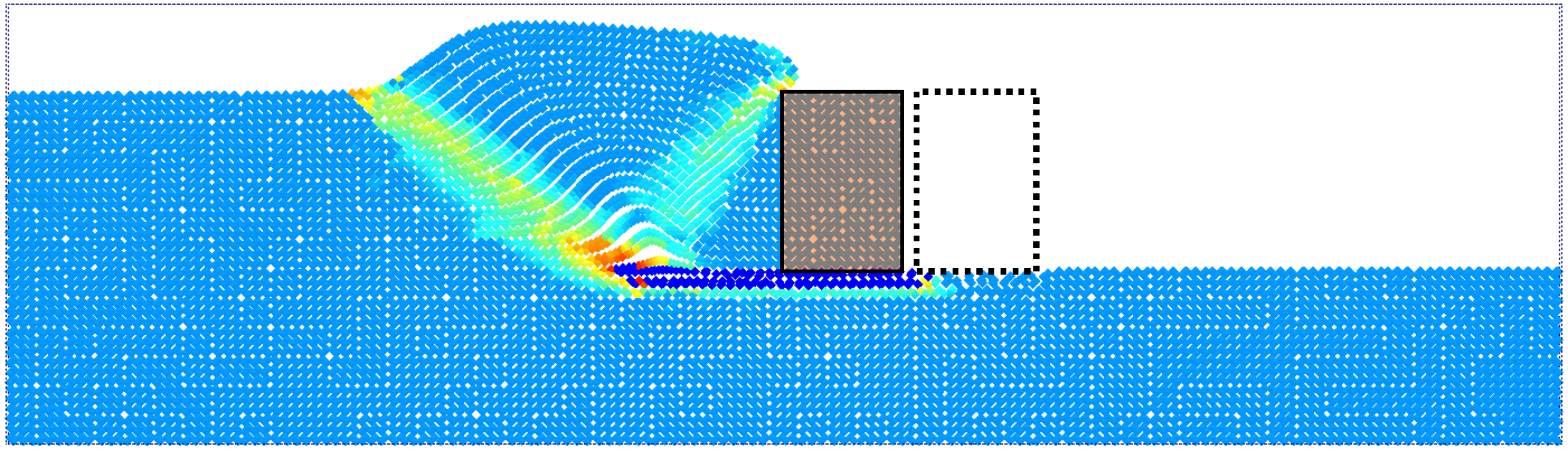
Passive block movement



Shift of block = 37.5 cm

Deltares

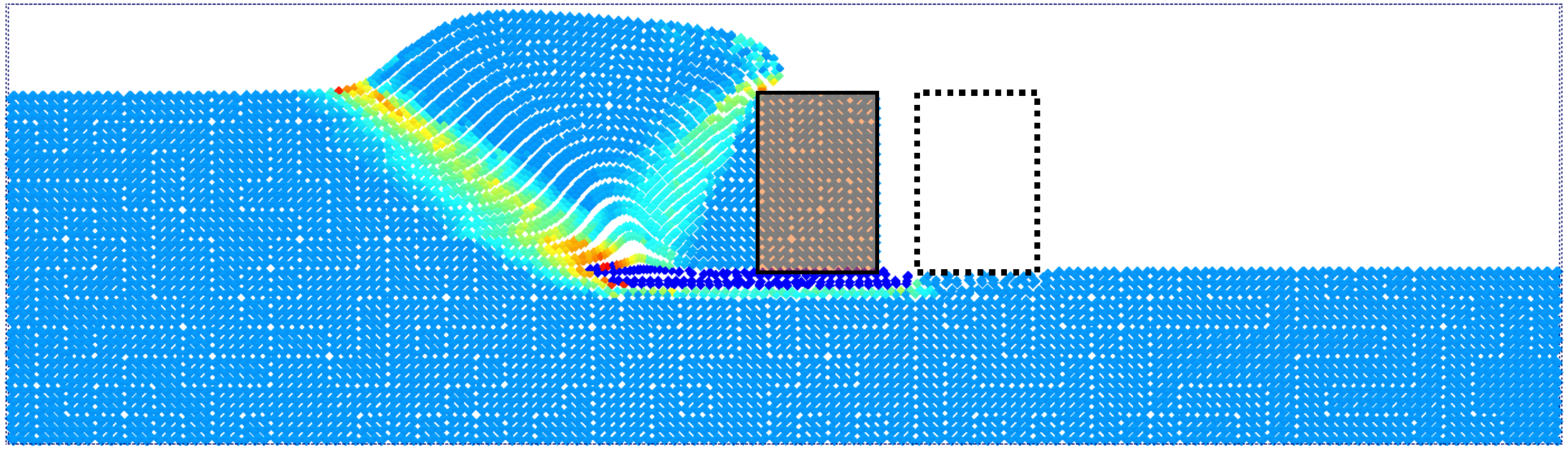
Passive block movement



Shift of block = 45 cm

Deltares

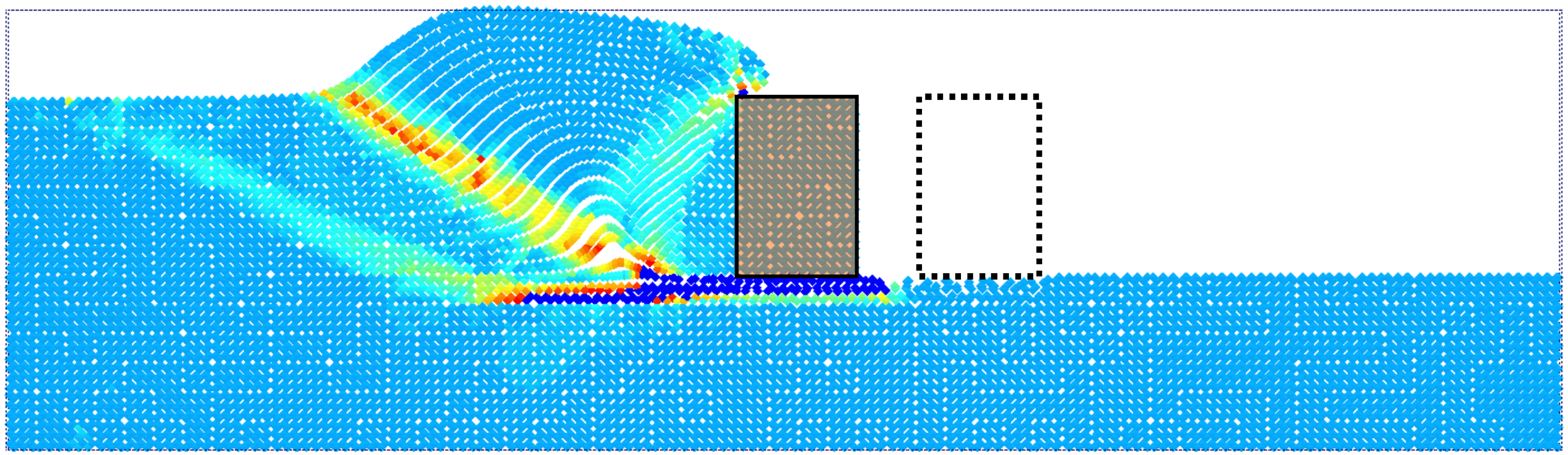
Passive block movement



Shift of block = 52.5 cm

Deltares

Passive block movement



Shift of block = 60 cm

End of movement

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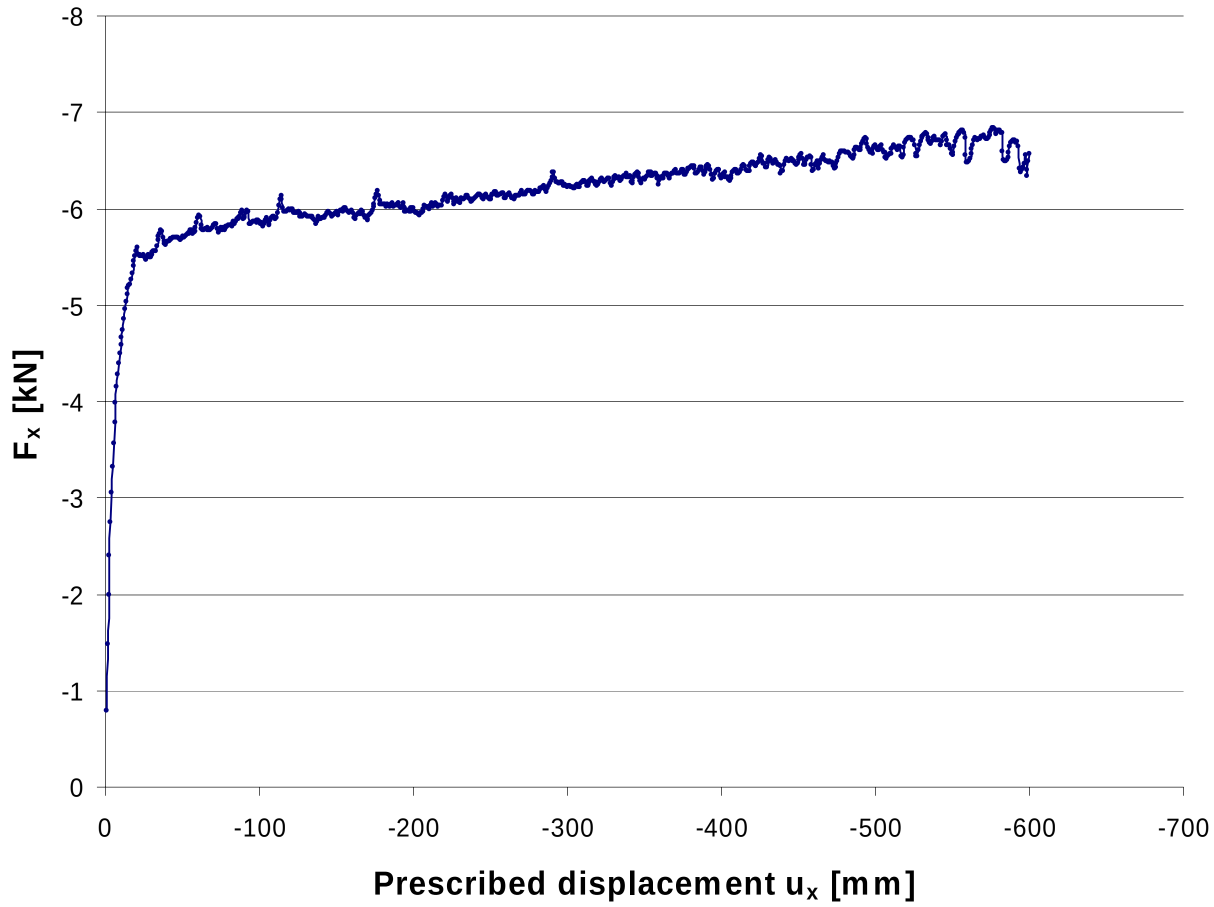
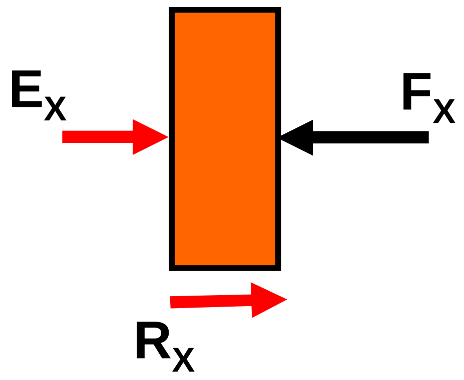
Passive block movement – reaction forces



Horizontal Equilibrium



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3. Soil-Structure Interaction

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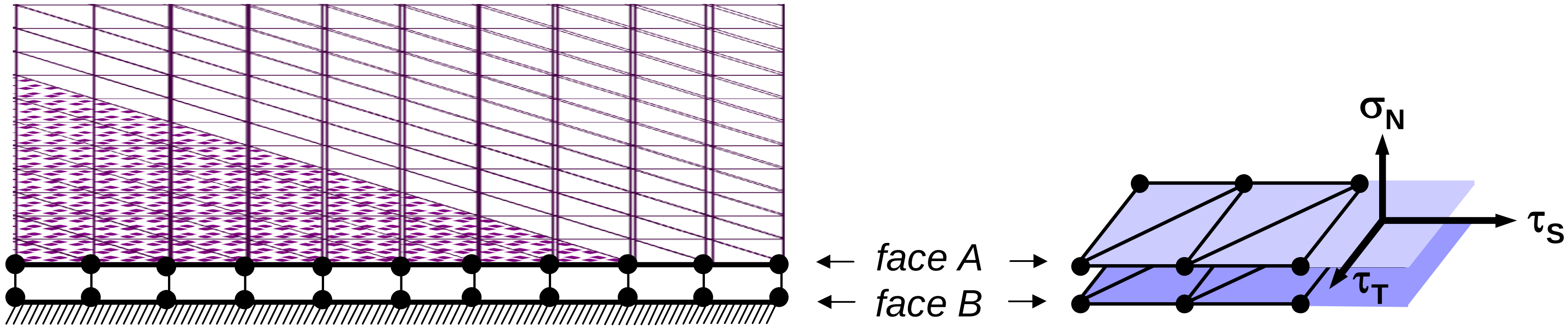
Application of interface elements with the MPM



Interface tractions: $\dot{\mathbf{t}} = \mathbf{D}\,\dot{\mathbf{w}}$ with $\dot{\mathbf{w}} = \dot{\mathbf{u}}_{face\,A} - \dot{\mathbf{u}}_{face\,B}$

Elastic-plastic stiffness matrix: $\mathbf{D} = \mathbf{D}^e - \frac{1}{d}\,\mathbf{D}^e \frac{\partial g}{\partial \mathbf{t}} \frac{\partial f}{\partial \mathbf{t}}^T \mathbf{D}^e$

$f(\mathbf{t})$ ... yield function $g(\mathbf{t})$ ... plastic potential function $d = \frac{\partial f}{\partial \mathbf{t}}^T \mathbf{D}^e \frac{\partial g}{\partial \mathbf{t}}$

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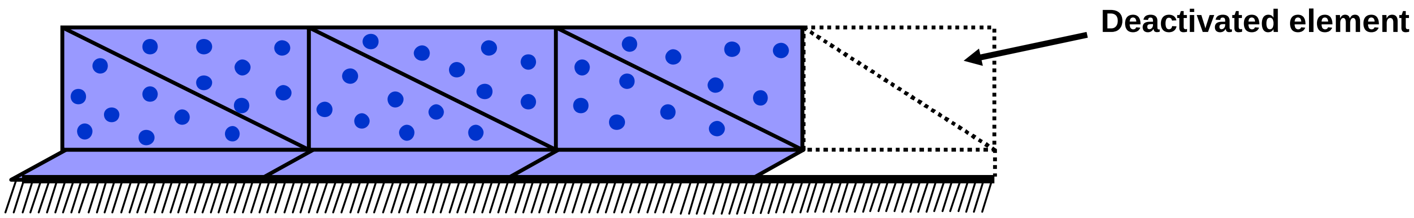
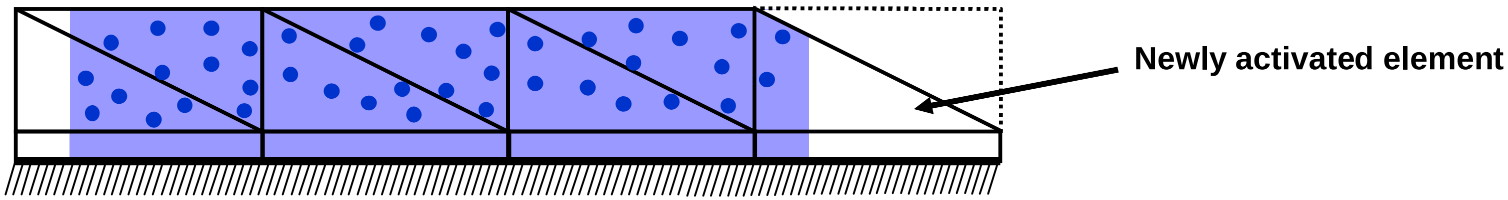
Application of interface elements with the MPM

Deformed mesh at end of load step



Reset mesh at end of load step



Activated volume elements contain particles which carry the stresses.

Activated interface elements have no particles !

New interface stresses need to be computed after mesh resetting.

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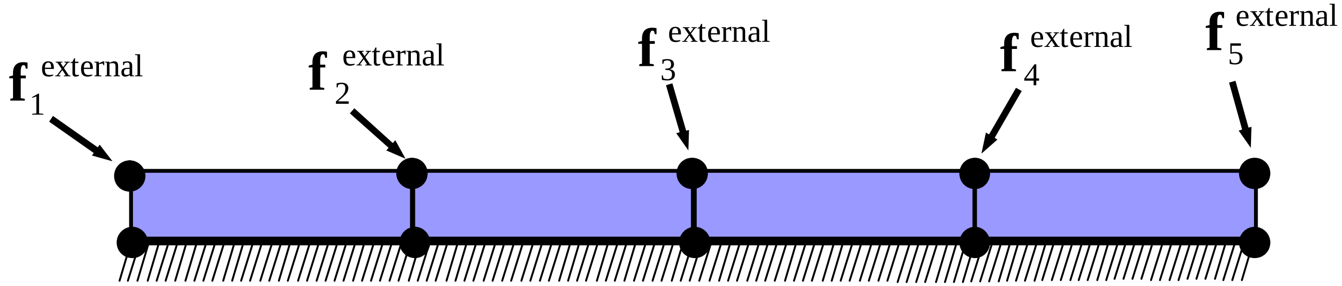
Application of interface elements with the MPM



Supervector of external nodal forces:
$$\mathbf{F}^{\text{external}}_{\text{interface}} = \int_{V_{\text{soil}}} \mathbf{B}^{\text{T}} \boldsymbol{\sigma}\, dV + \int_{V_{\text{soil}}} \mathbf{N}^{T} \boldsymbol{\gamma}\, dV$$

$\mathbf{B}$ = strain interpolation matrix

$\boldsymbol{\sigma}$ = soil stresses

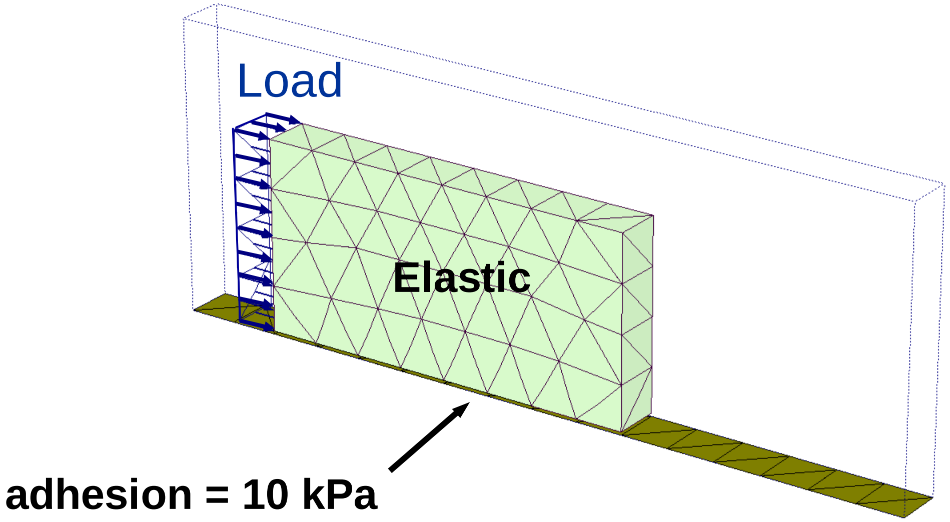
$\mathbf{N}$ = shape function matrix

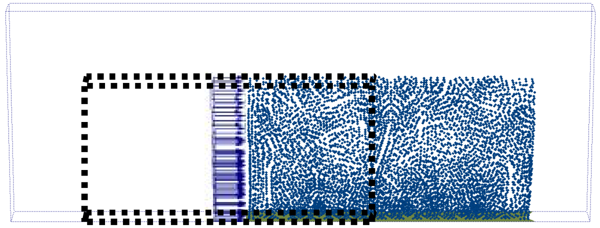
$\boldsymbol{\gamma}$ = soil weight

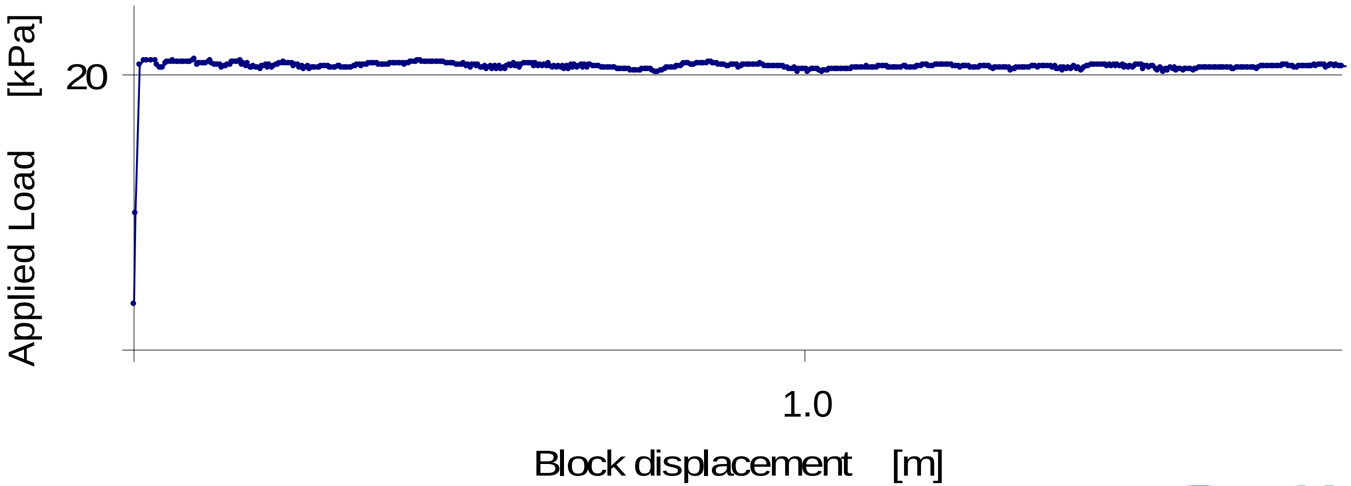
Supervector of internal nodal forces:
$$\mathbf{F}^{\text{internal}}_{\text{interface}} = \int_{S_{\text{interface}}} \mathbf{N}^{T}\, \mathbf{t}\, dS$$

Unknown tractions are obtained through solving system of equilibrium equations for t at (Newton-Cotes) integration points.

Sliding of elastic block







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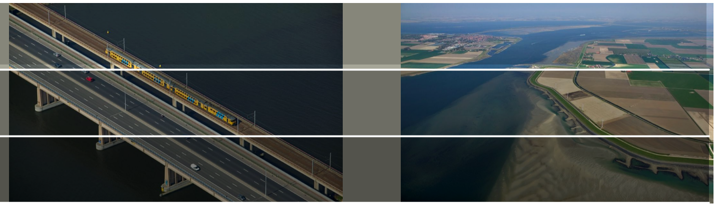
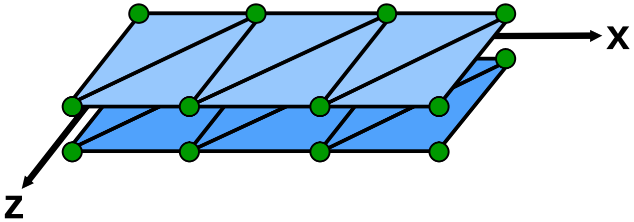
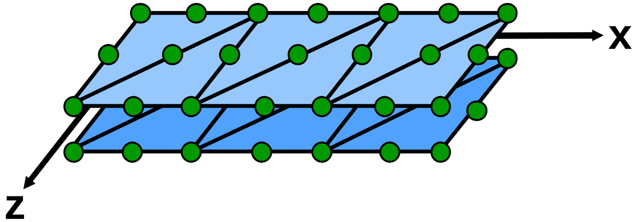
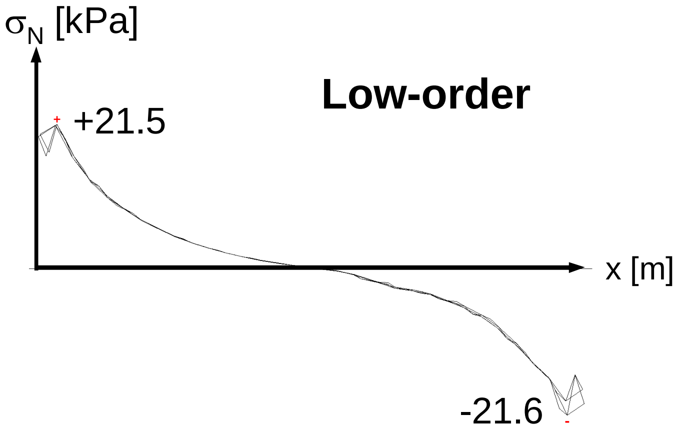
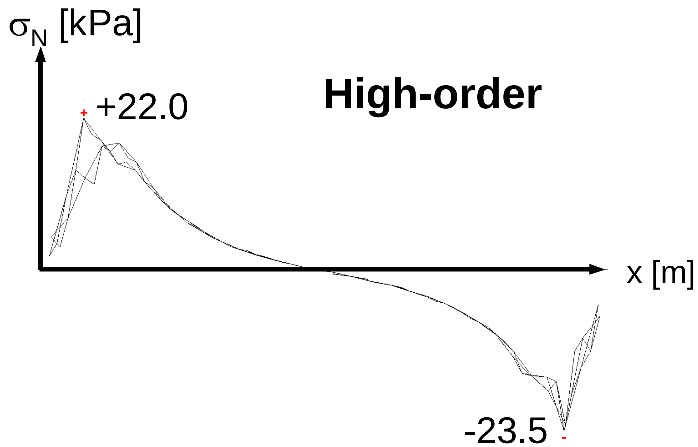


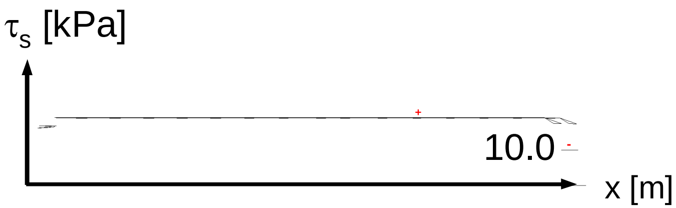
Sliding of elastic block

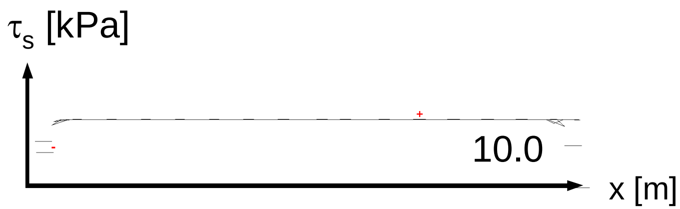












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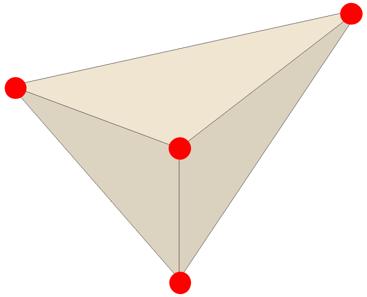
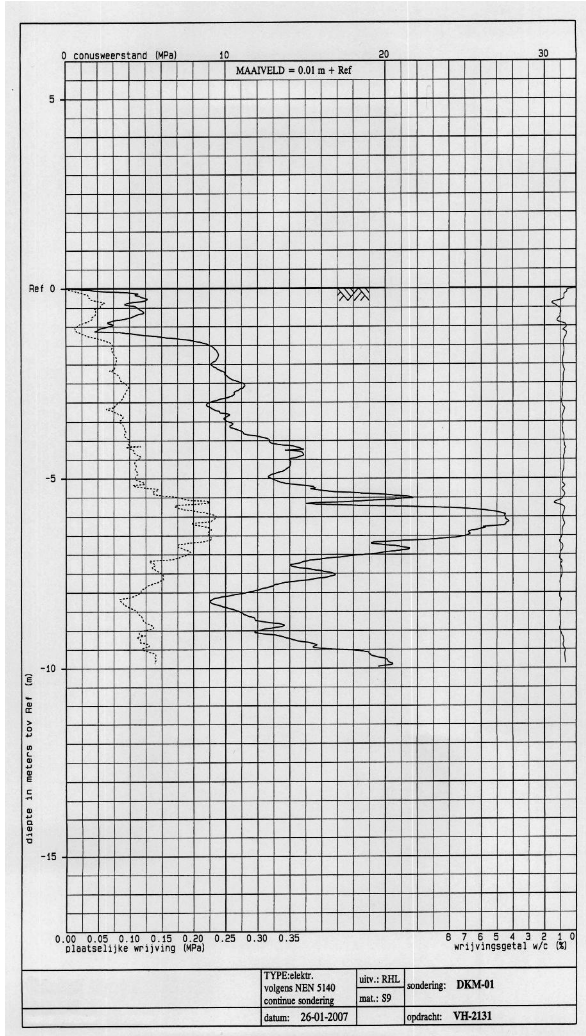
4. Cone Penetration in Undrained Clay



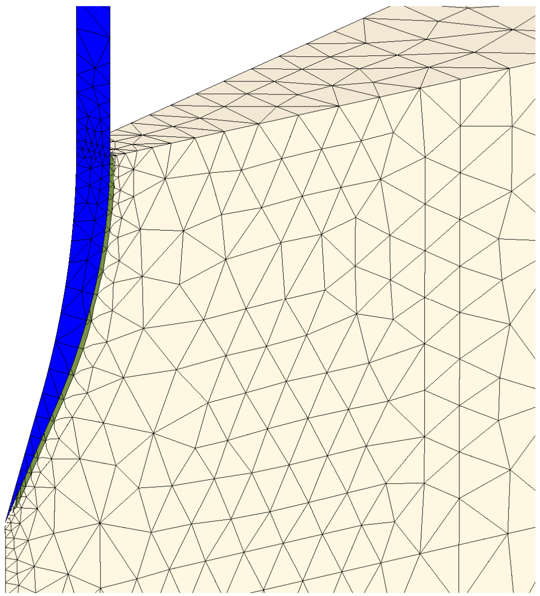
4-noded tetrahedral element
with linear interpolation

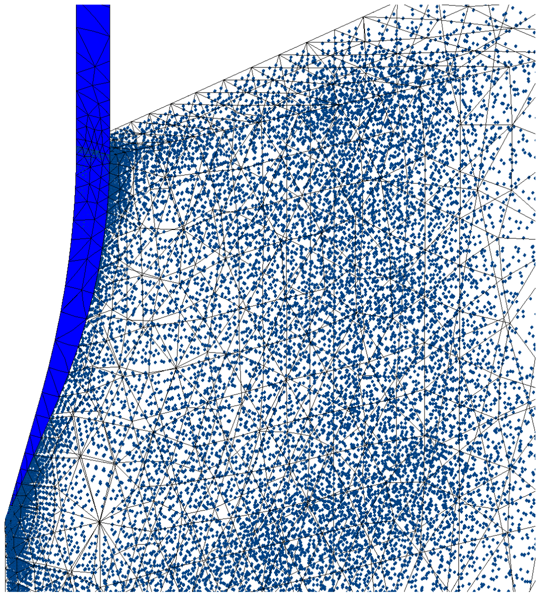
4. Cone Penetration in Undrained Clay

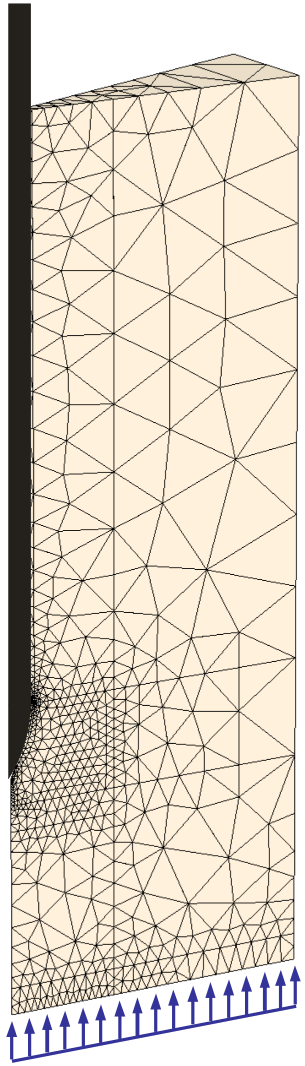
In-situ site investigation with cone penetration test



Discretisation of Cone Penetrometer







E_U = 6 MPa ν_U = 0.40 c_U = 20 kPa φ_U = 0°

Segment discretised with 4-noded tetrahedral elements

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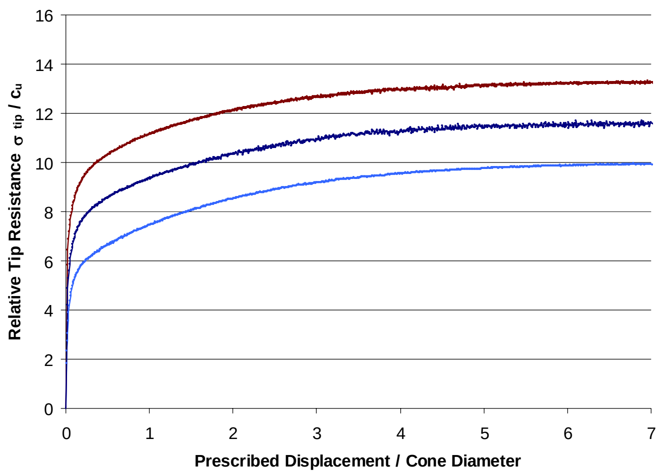
Results



Rough contact: adhesion = c_u

Adhesion = c_u / 2

Smooth contact: adhesion = 0

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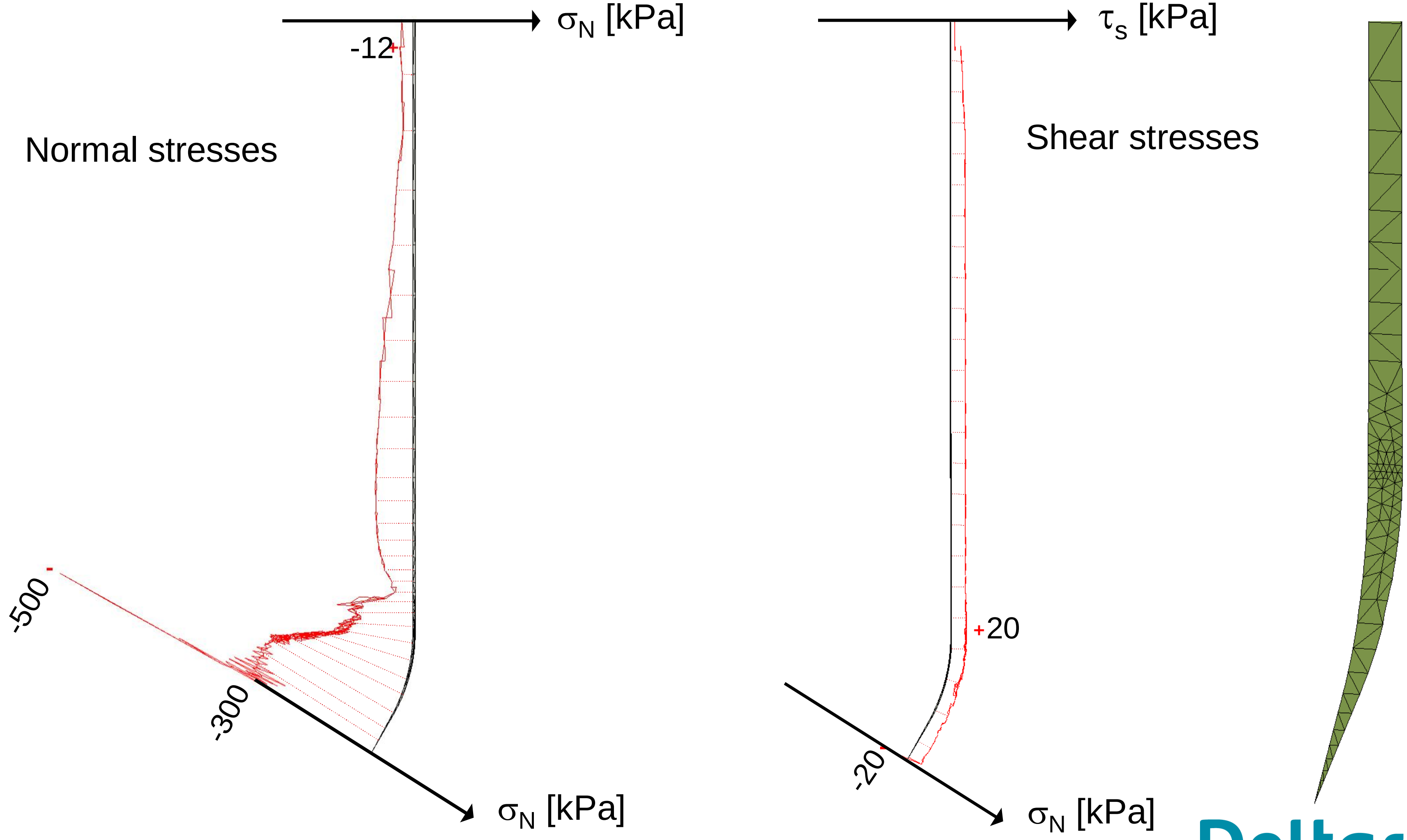
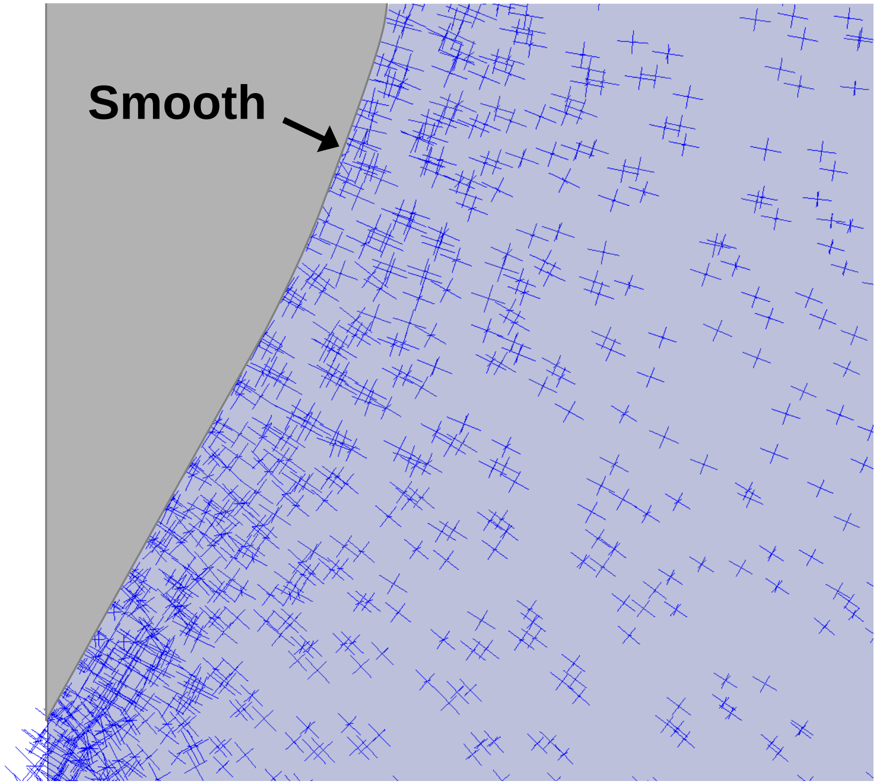
Results

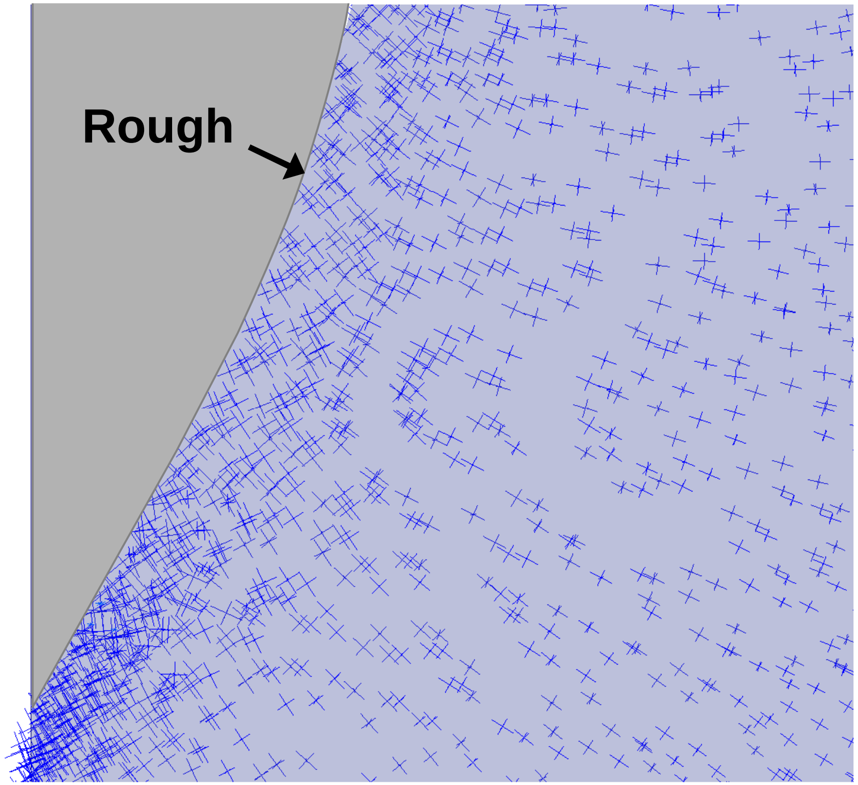
Rough contact



Results

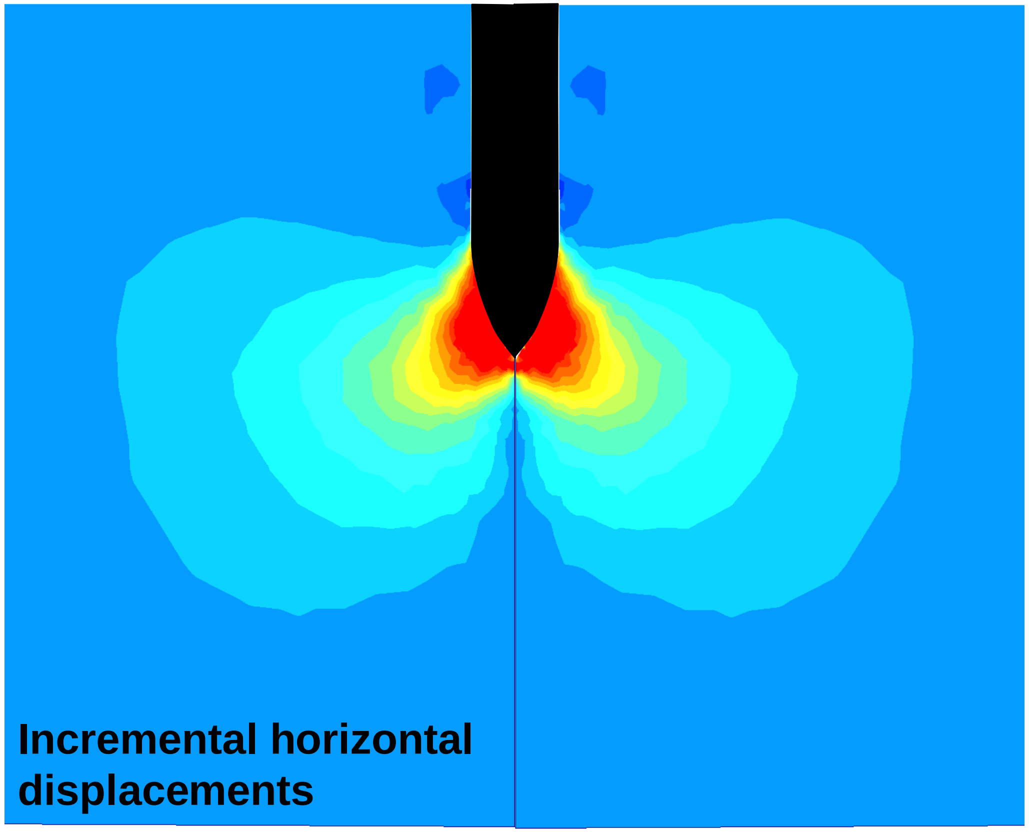
Principal stresses





Results

Rough contact at 4 D



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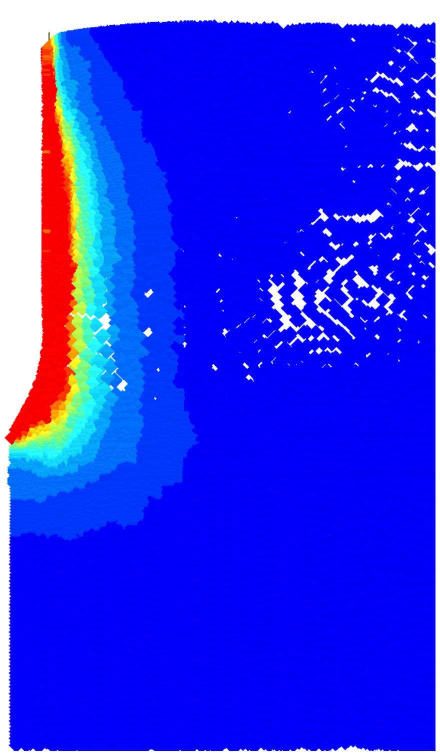
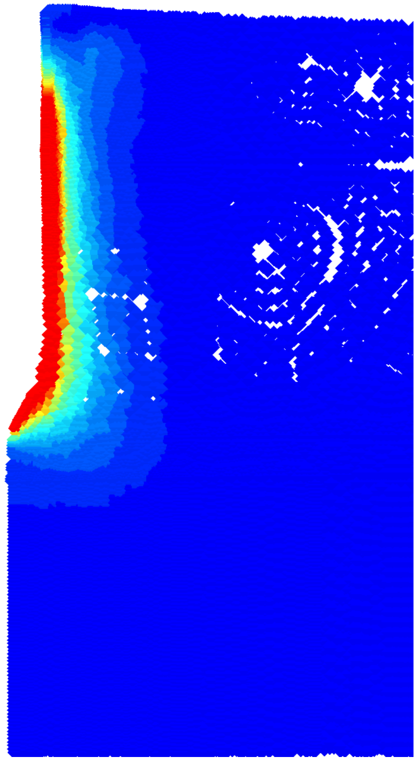
Results

Accumulated shear strain at 4 D



Rough contact



Smooth contact

5. Outlook

5. Outlook

- Pore pressure dissipation
- Going beyond Mohr-Coulomb (Hardening)
- Get experience in layered soil
- In future also interaction between piles


The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° PIAG-GA-2009-230638.

Workshop on Geotechnical Installation

1 September 2010

Introduction

This workshop is jointly organized by the **Geo-Install** consortium and the Plaxis Development Community. The Geo-Install consortium concentrates on the modelling of installation effects in geotechnical engineering, which includes the development of advanced material and computational models. Geo-Install consists of the universities of Delft, Stellenbosch, Strathclyde and Stuttgart, whereas from the research institutes and industrial side Deltares, the Norwegian Geotechnical Institute, Plaxis BV and Keller UK take part. The consortium is supported by funding from the European Commission. The Plaxis Development Community is a consortium of companies that focuses on the development of the Plaxis software for the analysis of geotechnical structures.

It is the aim of this workshop to present the state-of-the-art on constitutive modelling as well as on the numerical simulation of large-deformation processes in geotechnical engineering. In order to do so, specialists from computational geomechanics and applied geotechnical engineering will lecture during this workshop.

For organisation purposes, all participants are required to register **before 18 August 2010** and pay the workshop fee for lunch etc. of 30 € on arrival. The website www.delfthotels.nl is recommended for those who need accommodation. You will have to book early, as Delft is a tourist city!

Venue & Contact

Deltares, Stieltjesweg 2, 2600 MH Delft, The Netherlands
E-Mails: fursan.hamad@deltares.nl

Agenda

09:15 – 09:30 **Coffee**
09:30 – 09:45 **Opening** Prof. Pieter Vermeer / University of Stuttgart / Deltares

General Morning Session

09:45 – 10:15 **Large deformation / Installation effects**
Dr. Lars Andresen
Norwegian Geotechnical Institute

10:15 – 10:35 **Mechanical behaviour of clay**
Dr. Minna Karstunen
University of Strathclyde

10:35 – 10:55 **Mechanical behaviour of sand**
Prof. Frans Molenkamp
Delft University of Technology

10:55 – 11:30 **Break**

11:30 – 12:00 **The material point method (MPM)**
Dr. Corné Coetzee
Stellenbosch University

12:00 – 12:30 **Analysis of failure of Aznalcollar dam using MPM** / Prof. Eduardo Alonso
University of Barcelona

12:30 – 13:30 **Lunch**

Afternoon Pile Session

13:30 – 14:00 **Driven pile behaviour**
Prof. Frits van Tol
Delft University of Technology

14:00 – 14:30 **Bored pile behaviour**
Prof. Christian Moormann
University of Stuttgart

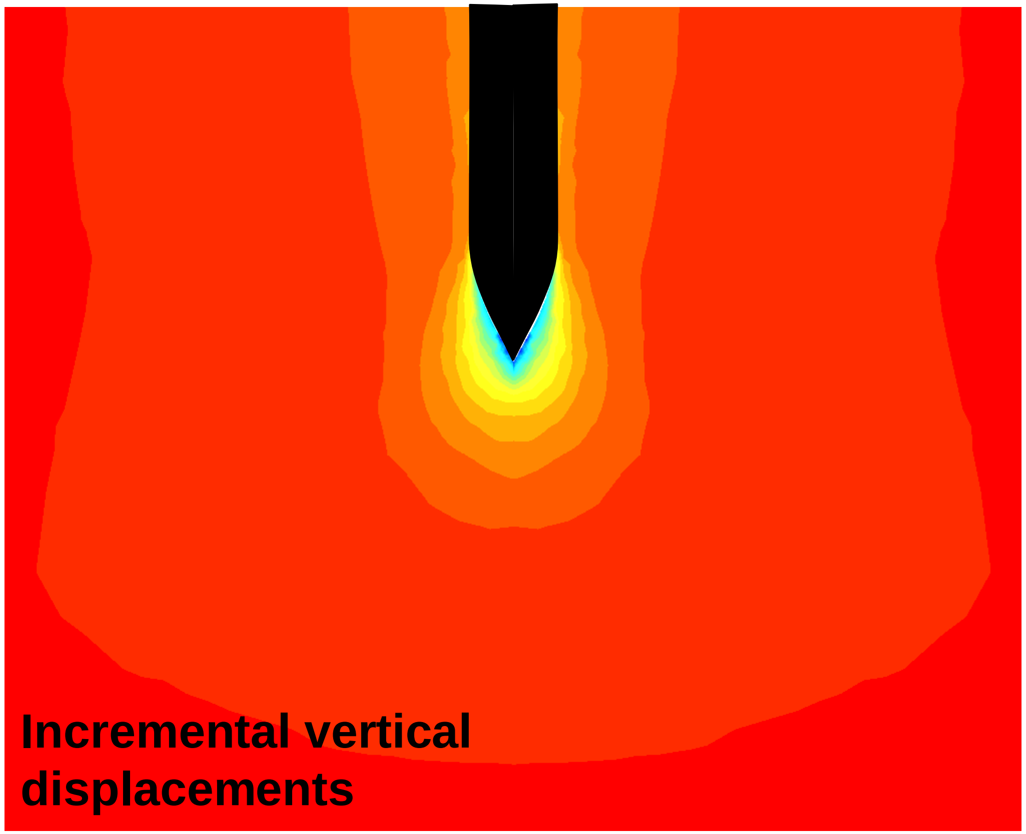
14:30 – 15:00 **State of the art in experimental research**
Dr. Jelke Dijkstra
Delft University of Technology

15:00 – 15:30 **Break**

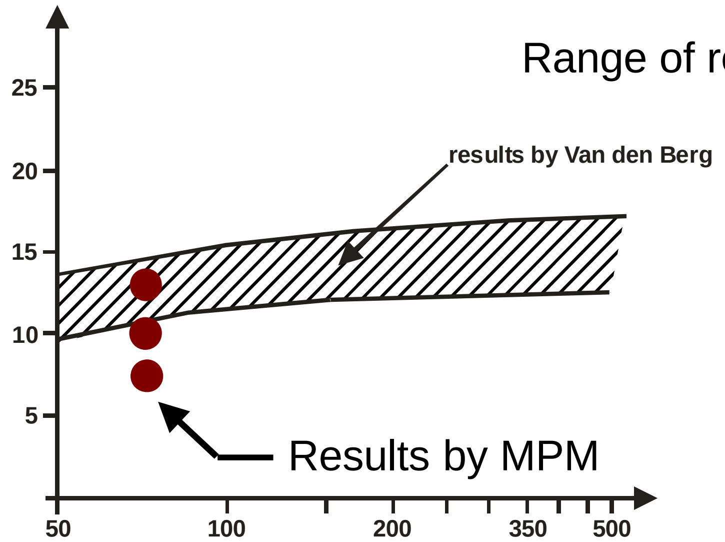
15:30 – 16:00 **State of the art of numerical modelling**
Dr. Ronald Brinkgreve
Plaxis bv

16:00 – 16:30 **Modelling soil heterogenity**
Prof. Michael Hicks
Delft University of Technology

Rough contact at 4 D



$$N_c = q_c / c_u$$



Range of results by Van den Berg

rough

smooth

$$I_r = G / c_u$$

Van Den Berg (1994), ‘Analysis of soil penetration’, Technical University Delft

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Appendix

VERMEER, P.A., BEUTH, L., BENZ, T. A New Numerical Method for Large Deformation Problems in Geomechanics, *Proceedings of the International Conference of IACMAG, Goa, India,* 2008; 12:55-63.

YUAN, Y., BEUTH, L., VERMEER, P.A. Frictional contact formulation for large deformation analyses in geomechanics. *Proceedings of the 2nd international workshop on geotechnics of soft soil, Glasgow*, 2008; 2:95-103.

STOLLE, D., JASSIM, I., VERMEER, P.A. Accurate simulation of incompressible problems in geomechanics, *Proceedings of the International Conference on Computer Methods in Mechanics, Zielona Góra, Poland*, 2009, 18:89-90.

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