Modelling of large deformation in geomechanics

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GEER report

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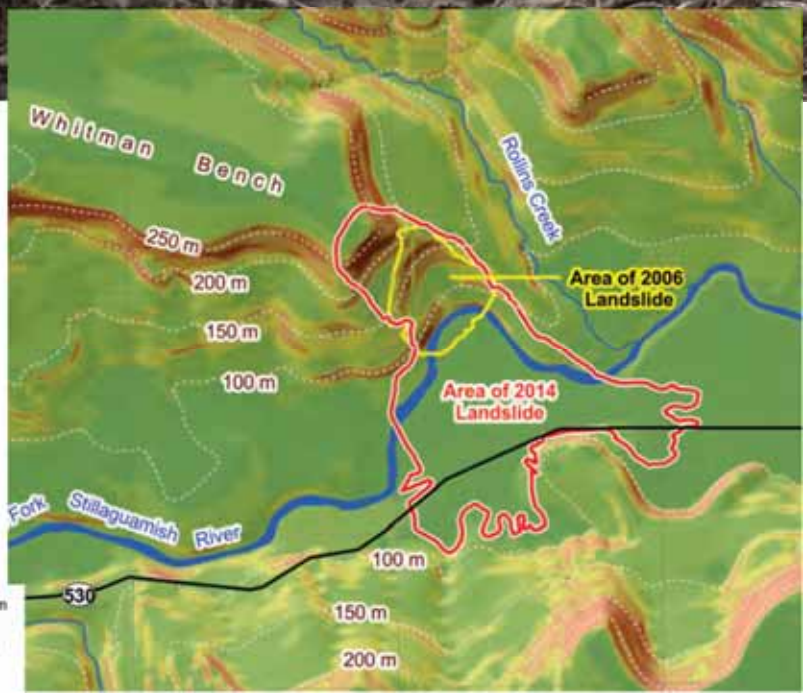
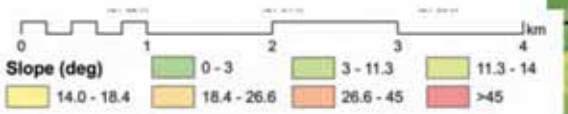
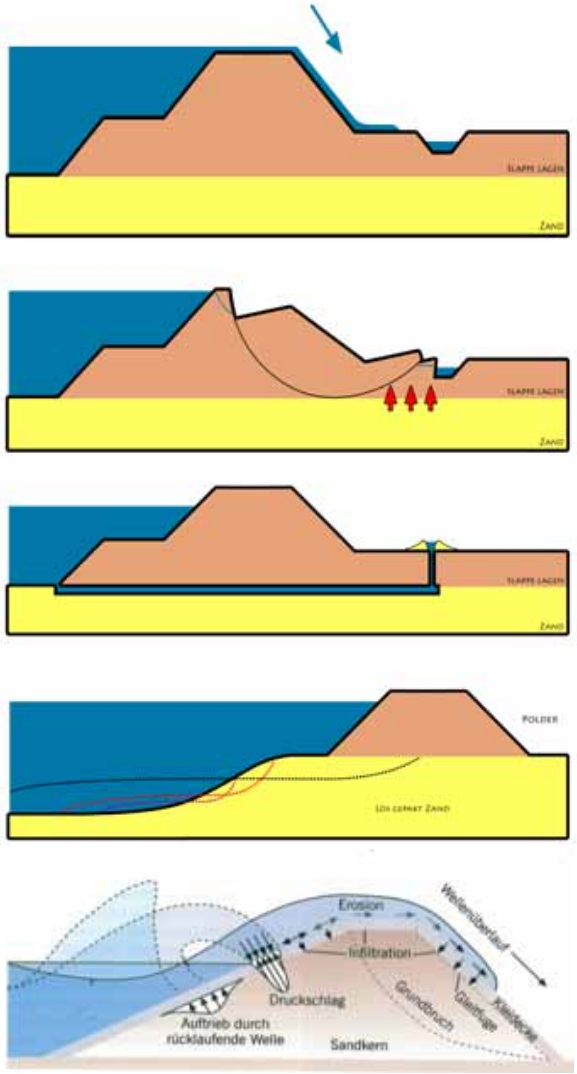
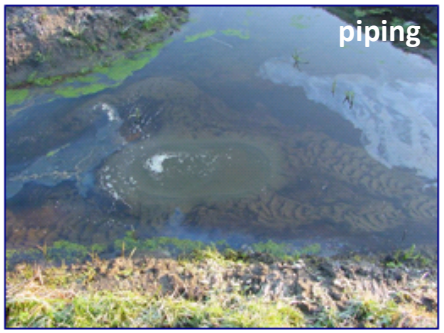


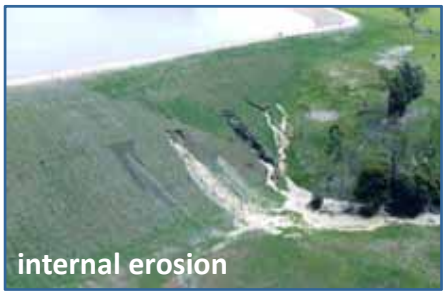


Failure of levees

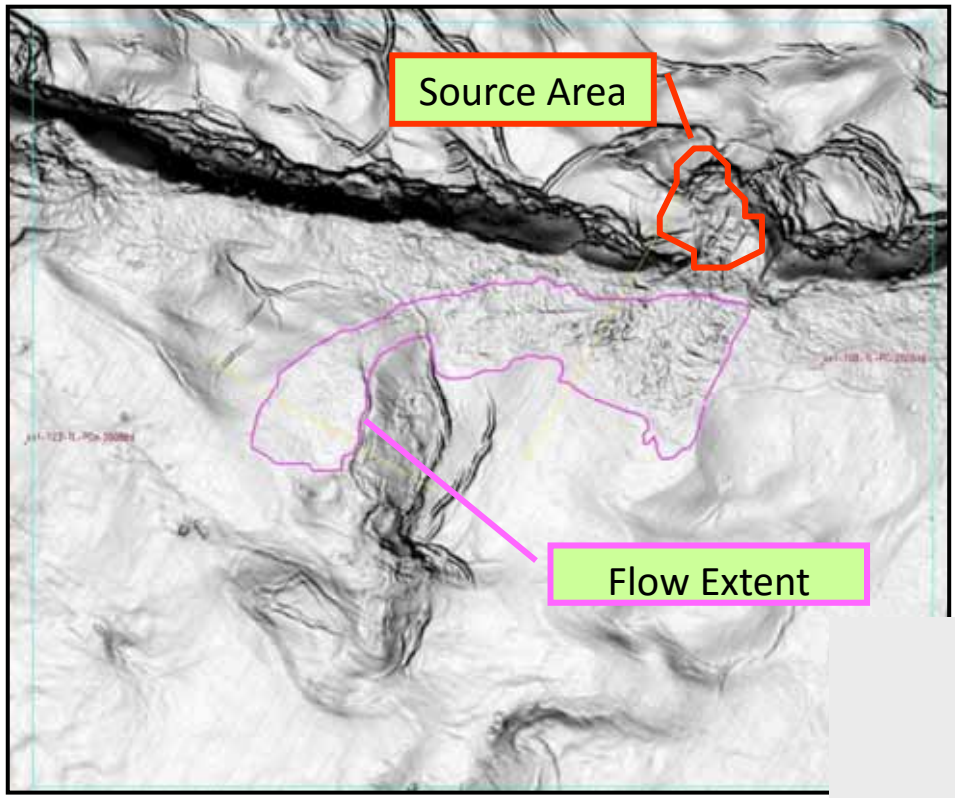


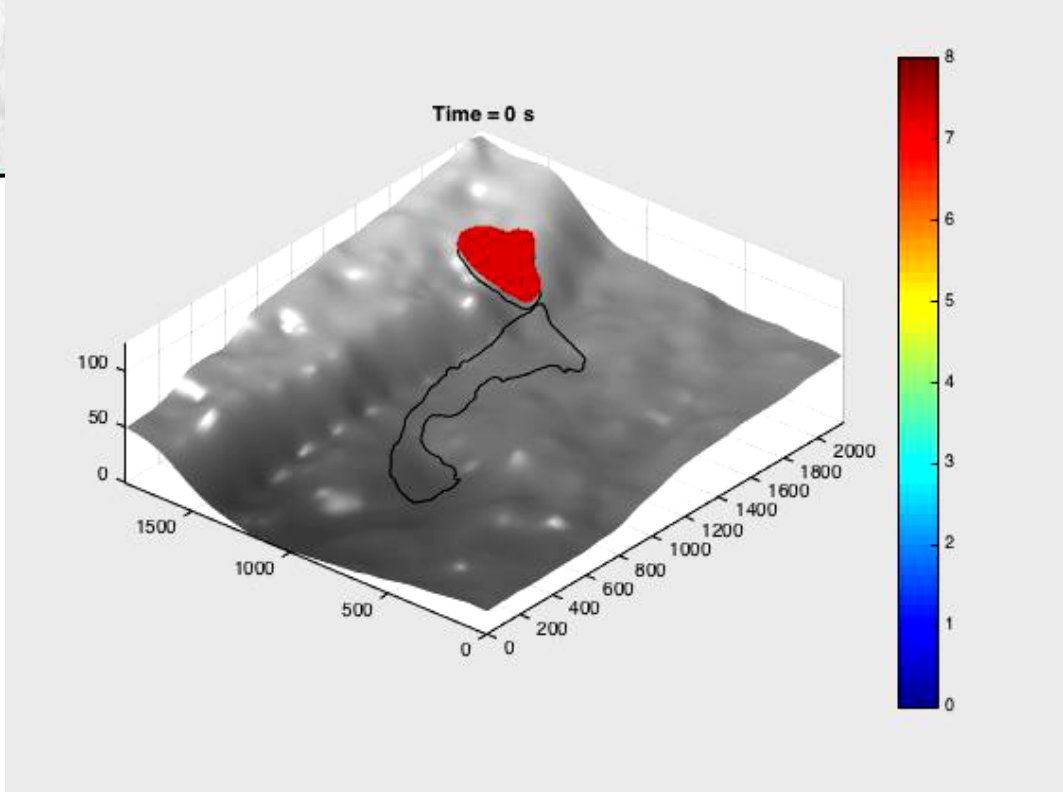

overtopping


piping


internal erosion

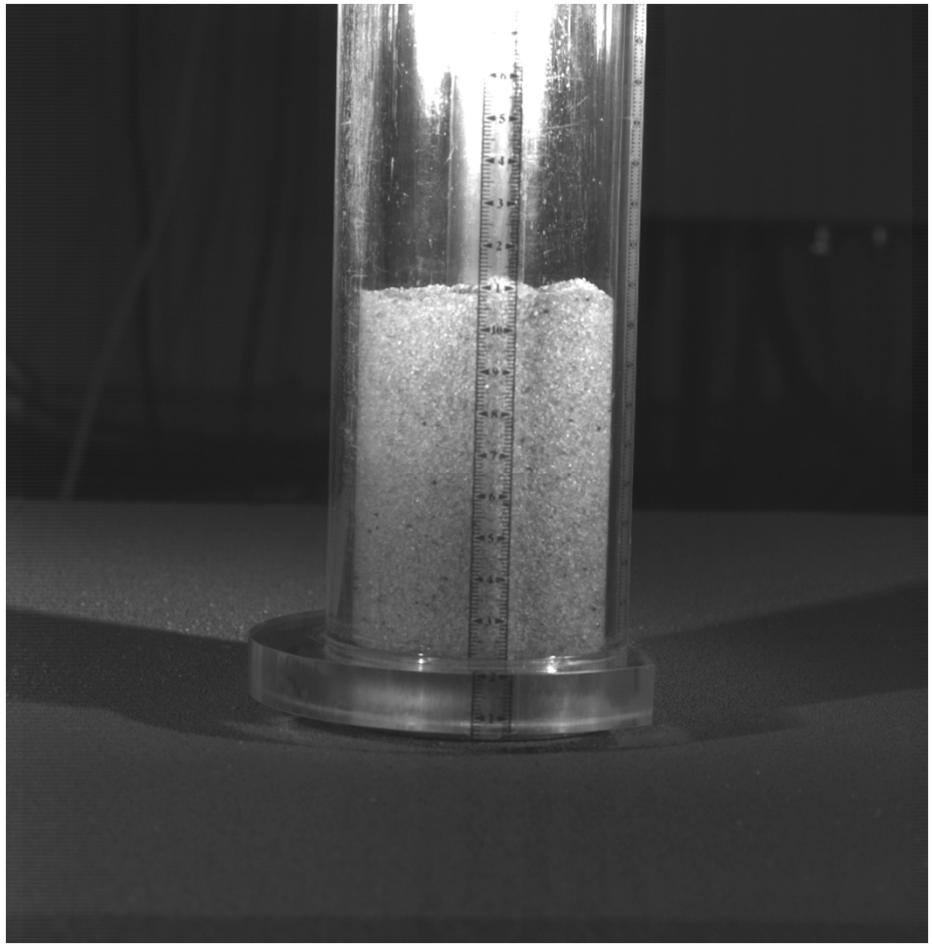
Submarine landslides

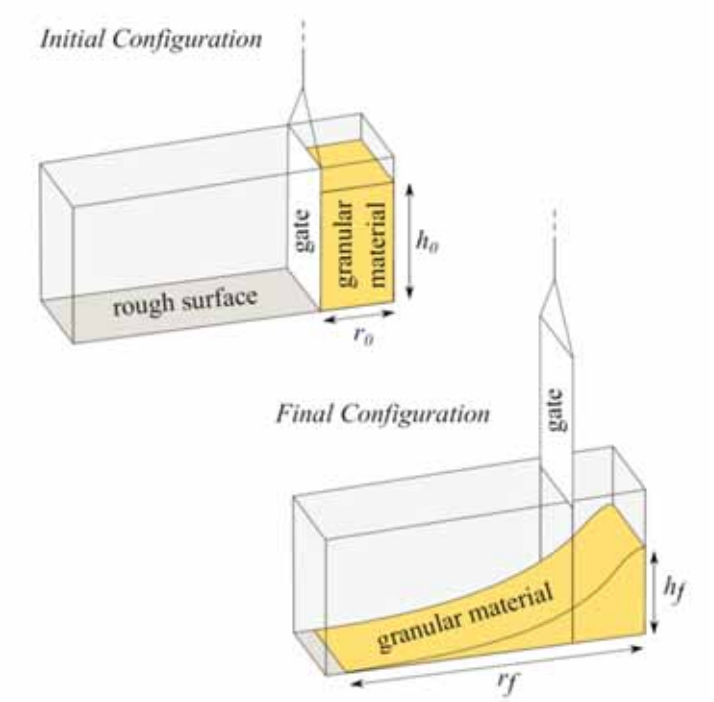




Taka Kobayashi

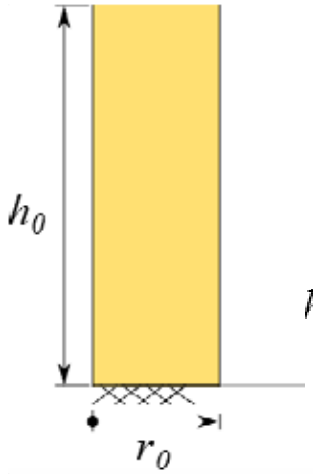
COLUMN COLLAPSE





Initial configuration

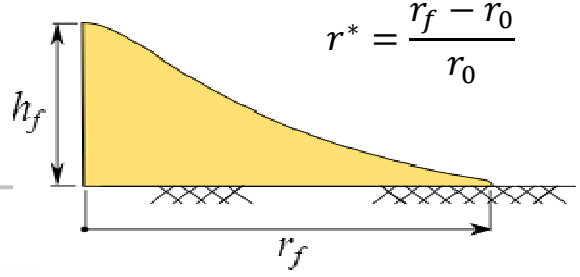
$$a = \frac{h_0}{r_0}$$



Final configuration

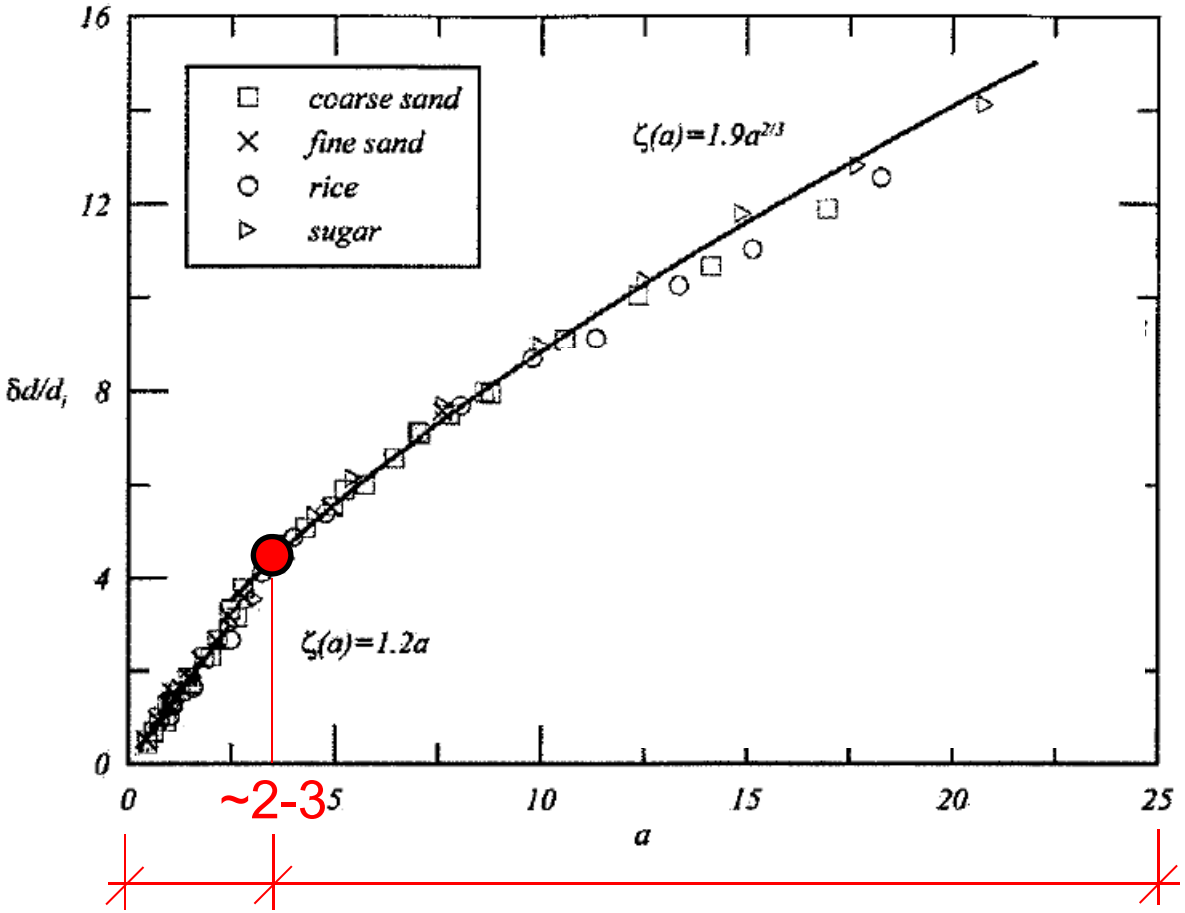
$$h^* = \frac{h_0 - h_f}{h_0}$$

$$r^* = \frac{r_f - r_0}{r_0}$$



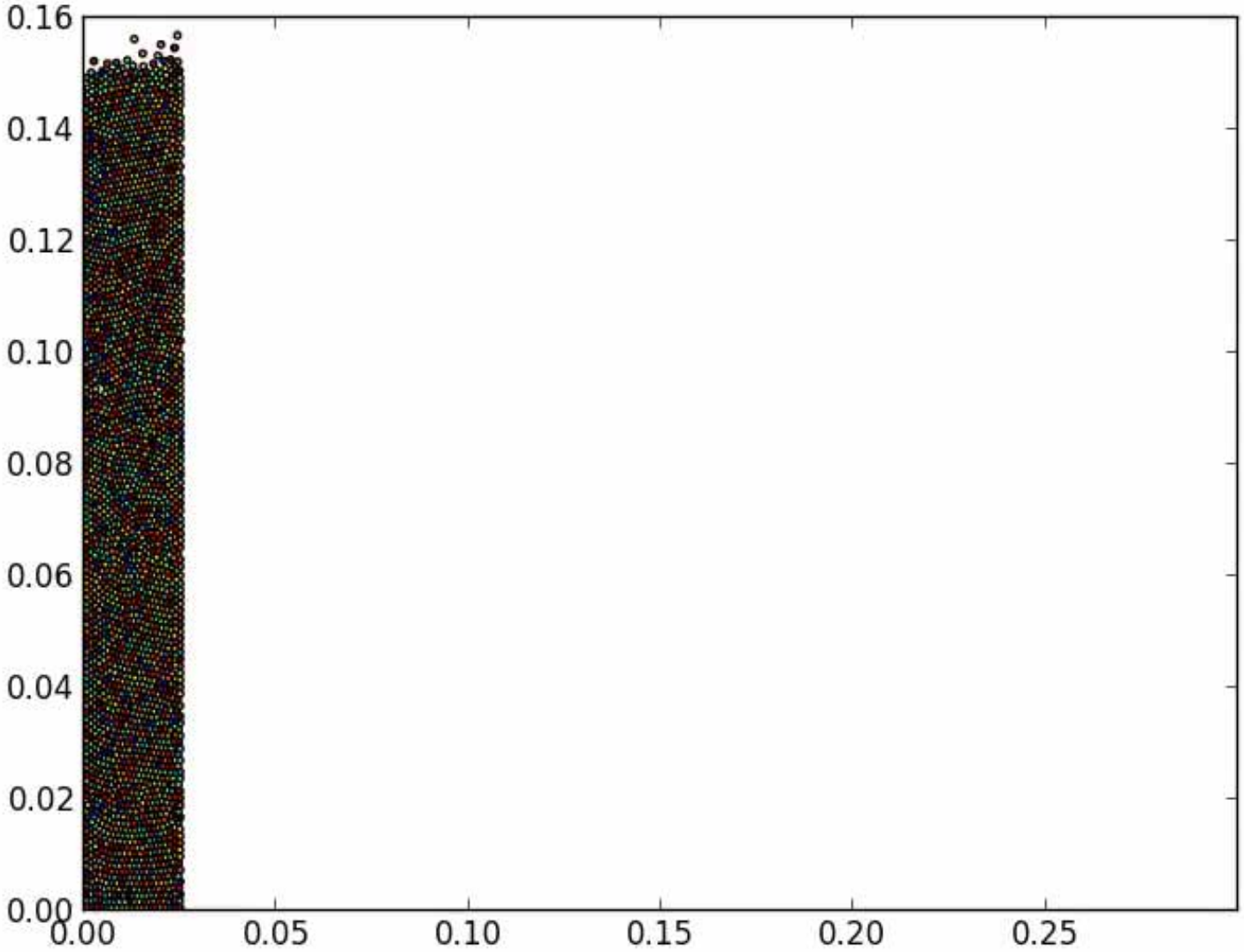
EXPERIMENTAL RESULTS

Run-Out Distance



(Lube et al. 2005)

Collapse of Granular Column (a=6)



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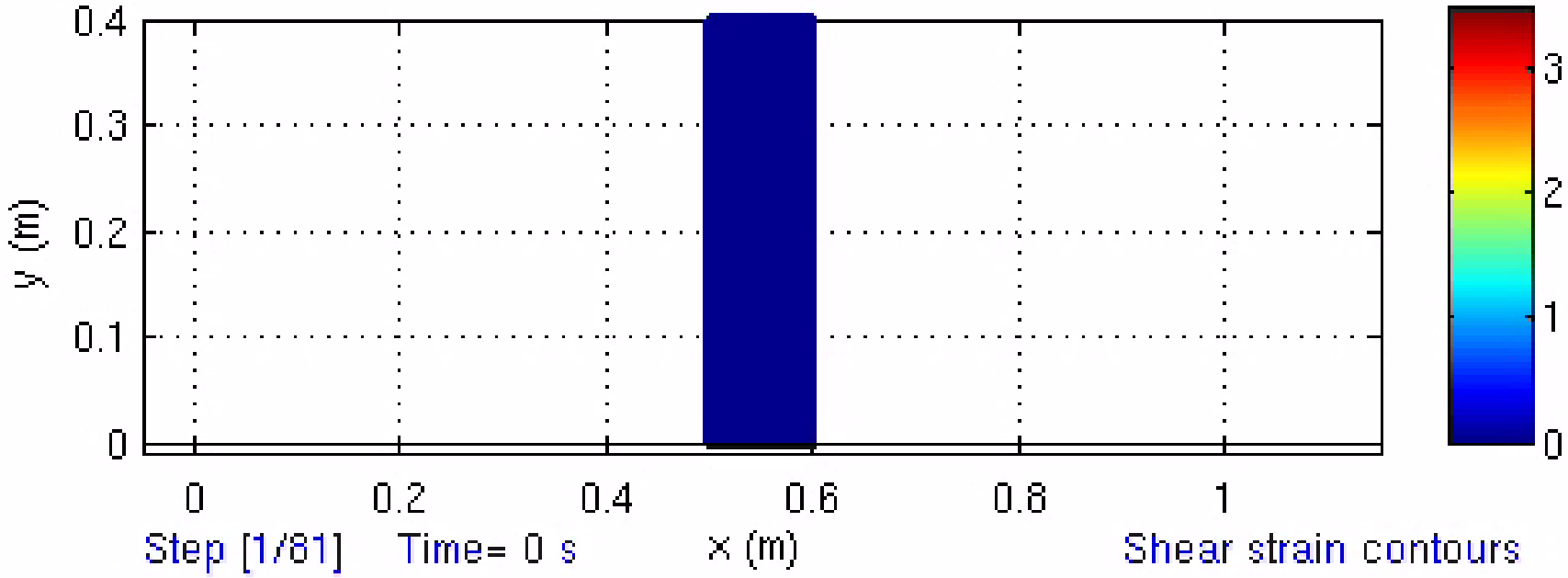
Plane strain simulation

Mohr-Coulomb model



Samila Bandara

Material Point Method (MPM)

Conservation of momentum

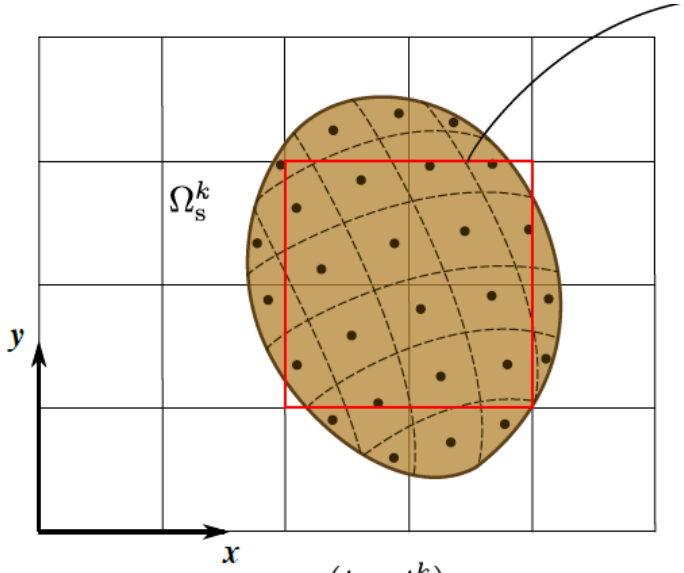
$$\rho \mathrm{a} = \nabla \cdot \sigma + \rho \mathrm{b}$$

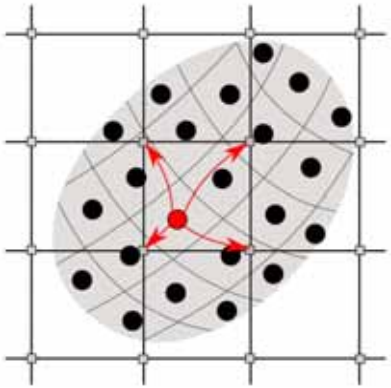
Conservation of mass

$$\frac{d\rho}{dt} + \nabla \cdot \mathrm{v} = 0$$

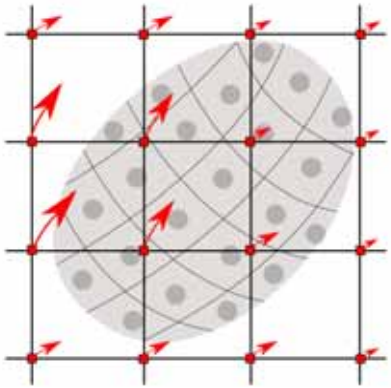
Use computational grid

$$\mathbf{x} = \sum_{i=1}^{N_n} \mathbf{x}_i(t) N_i(\mathbf{x})$$

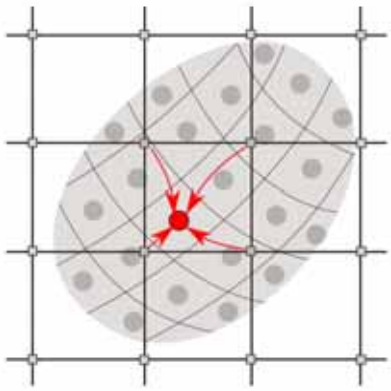




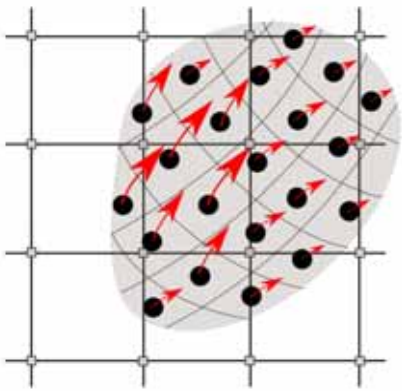
Map MP info to nodes



Solve equilibrium equations

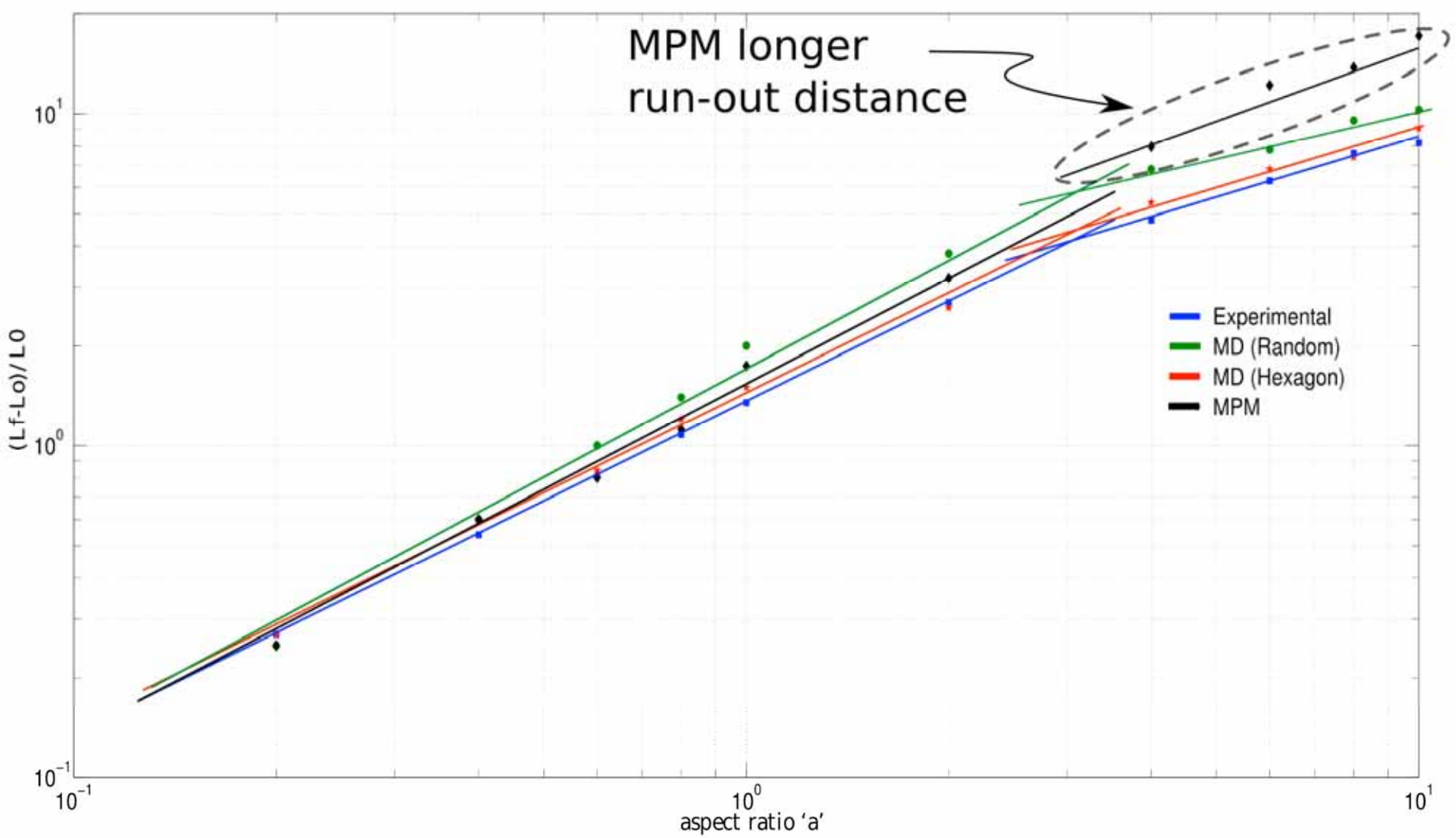


Map acceleration field to MPs



Update position and info of MPs

Runout



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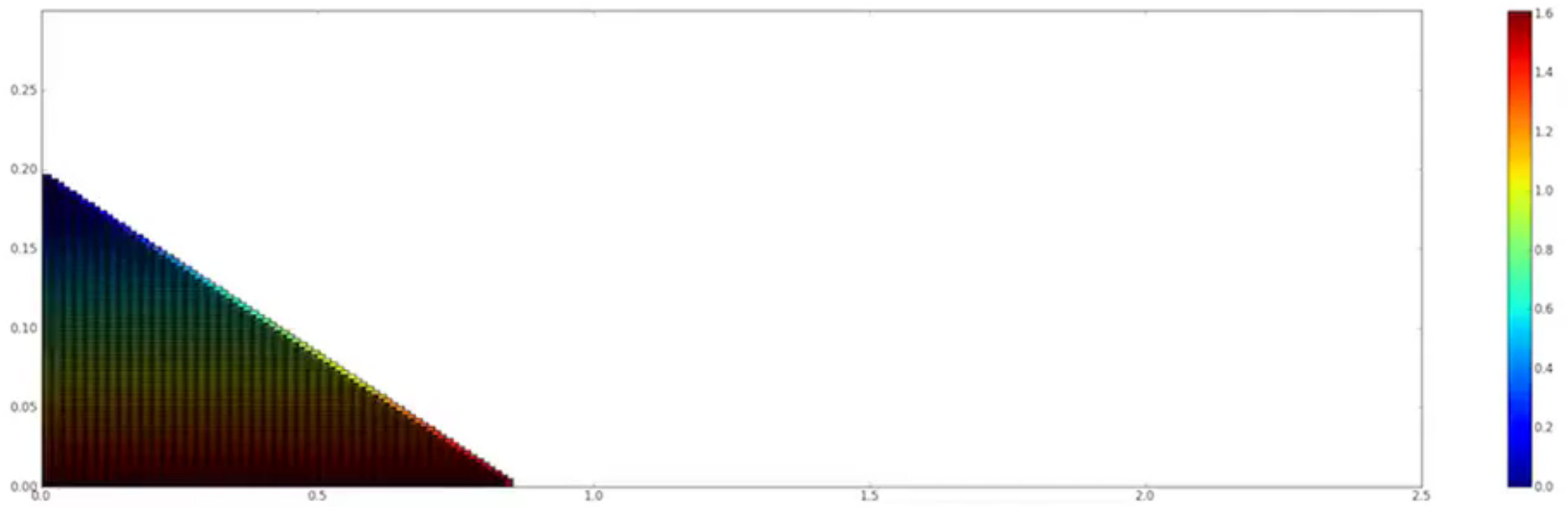
Granular Slope subjected to Impact (MPM Simulation)



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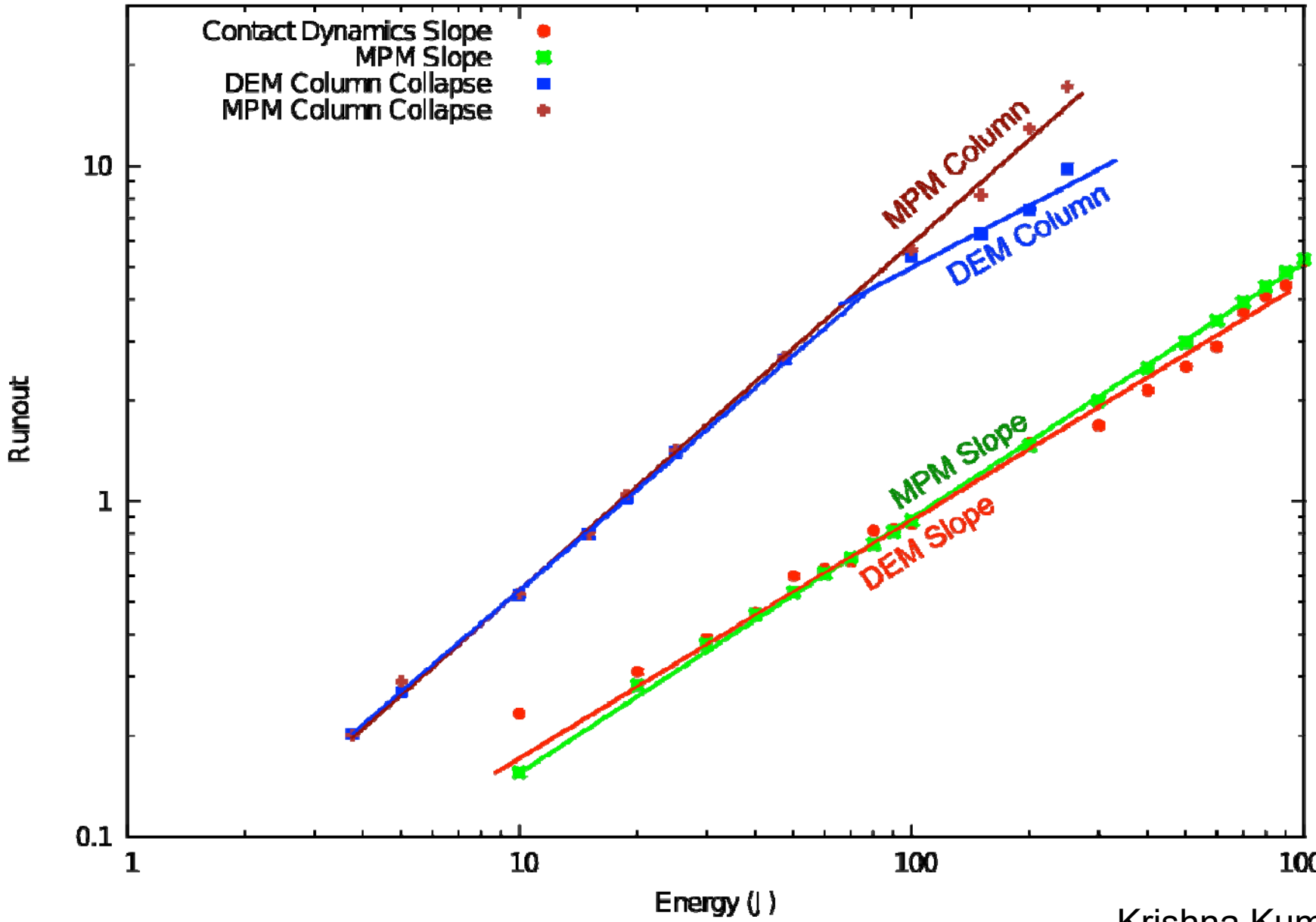
Column Collapse vs Slope subjected to Impact



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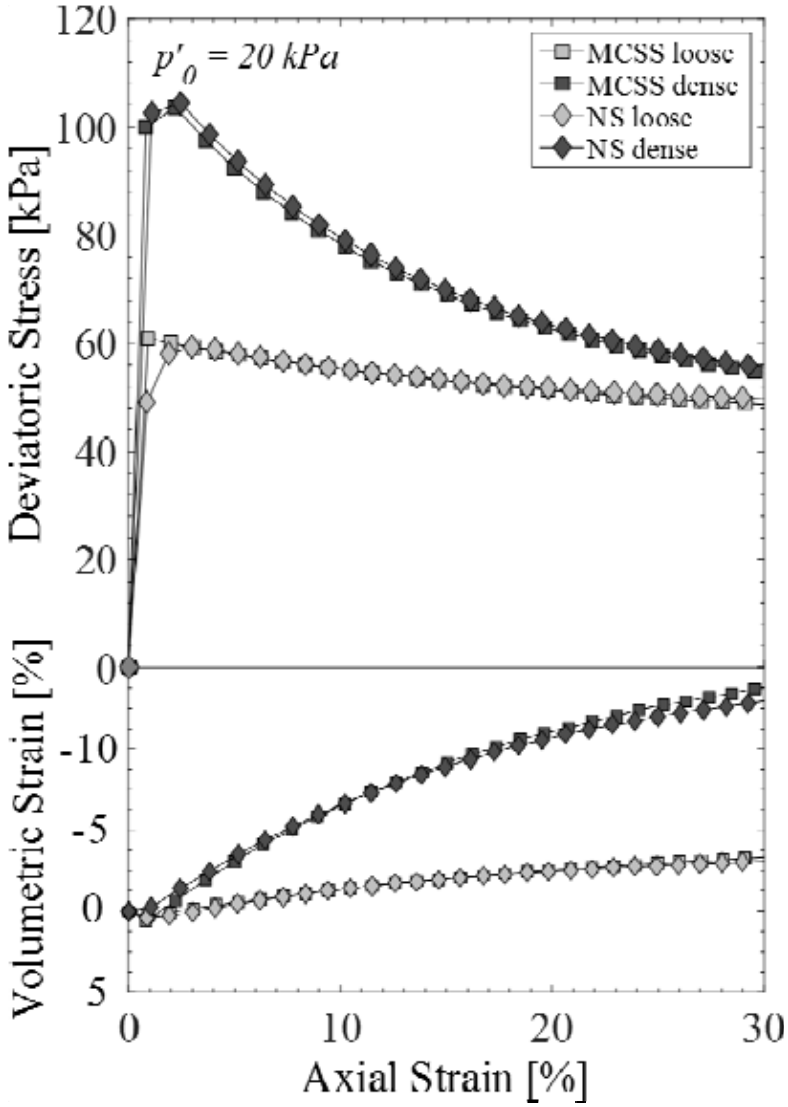
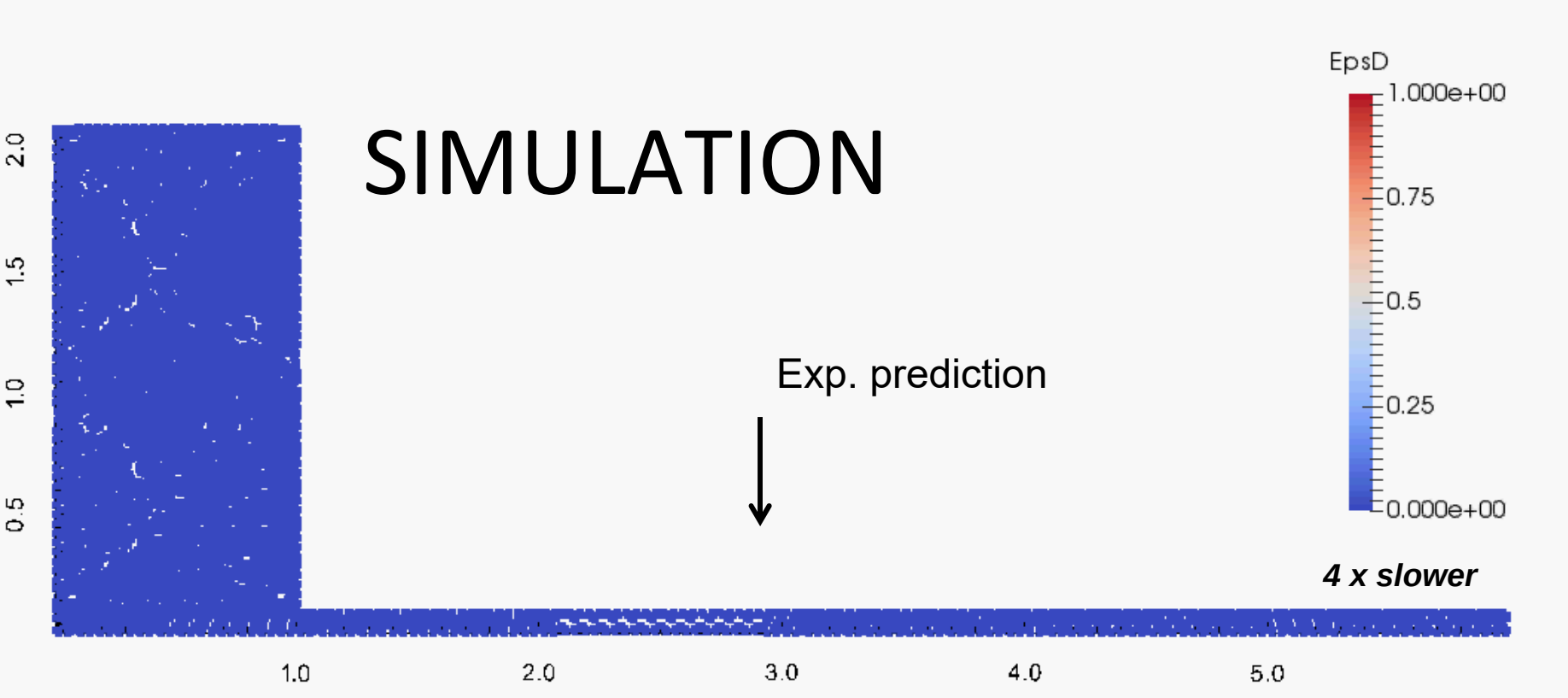
CONSTITUTIVE MODELS

- Mohr-Coulomb & Nor-Sand
- Drained TC at $p_0 = 20$ kPa
- Dry Chiba Sand *(Fern et al. 2015)*
  - *Loose:* $e = 0.800$ ($I_D = 33\%$)
  - *Dense:* $e = 0.600$ ($I_D = 78\%$)



James Fern

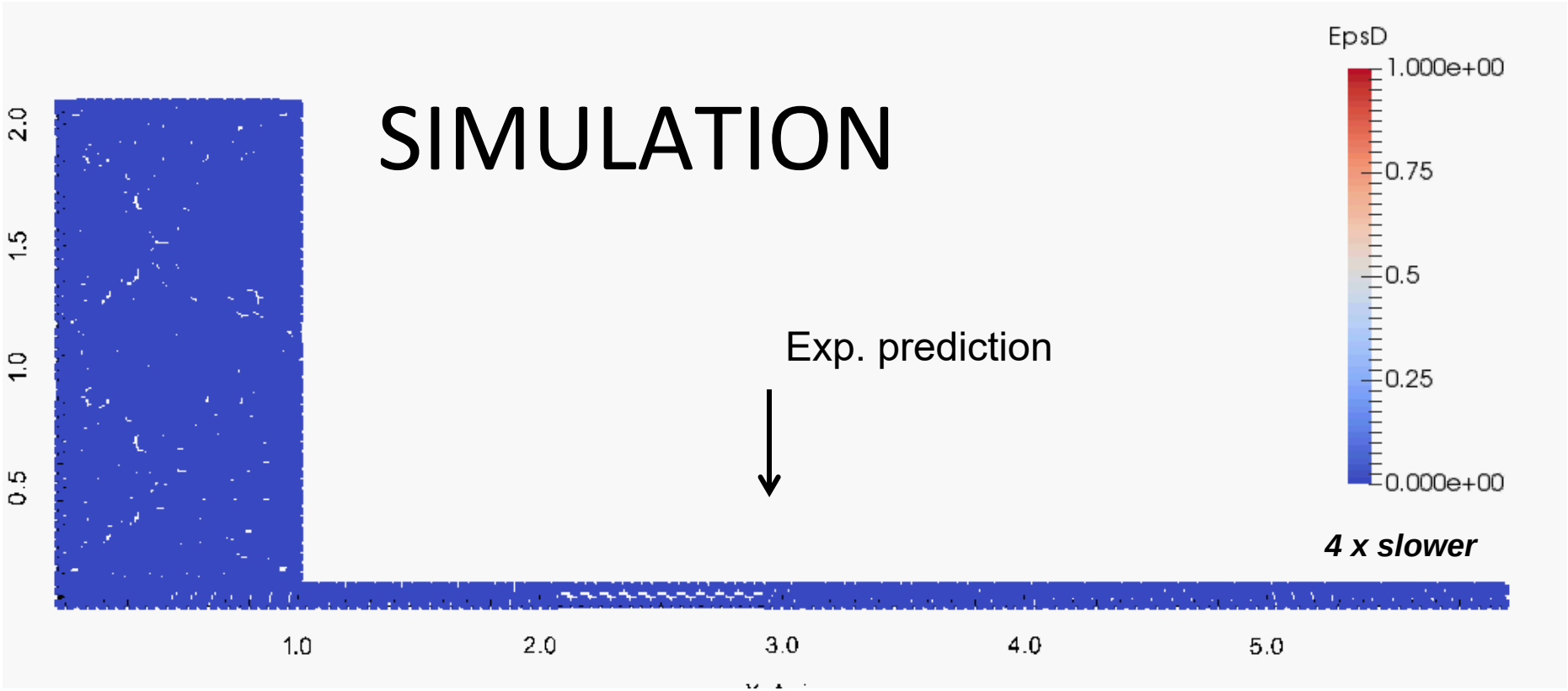
MOHR-COULOMB STRAIN SOFTENING - LOOSE SAND



no numerical damping

James Fern

NOR-SAND - LOOSE SAND

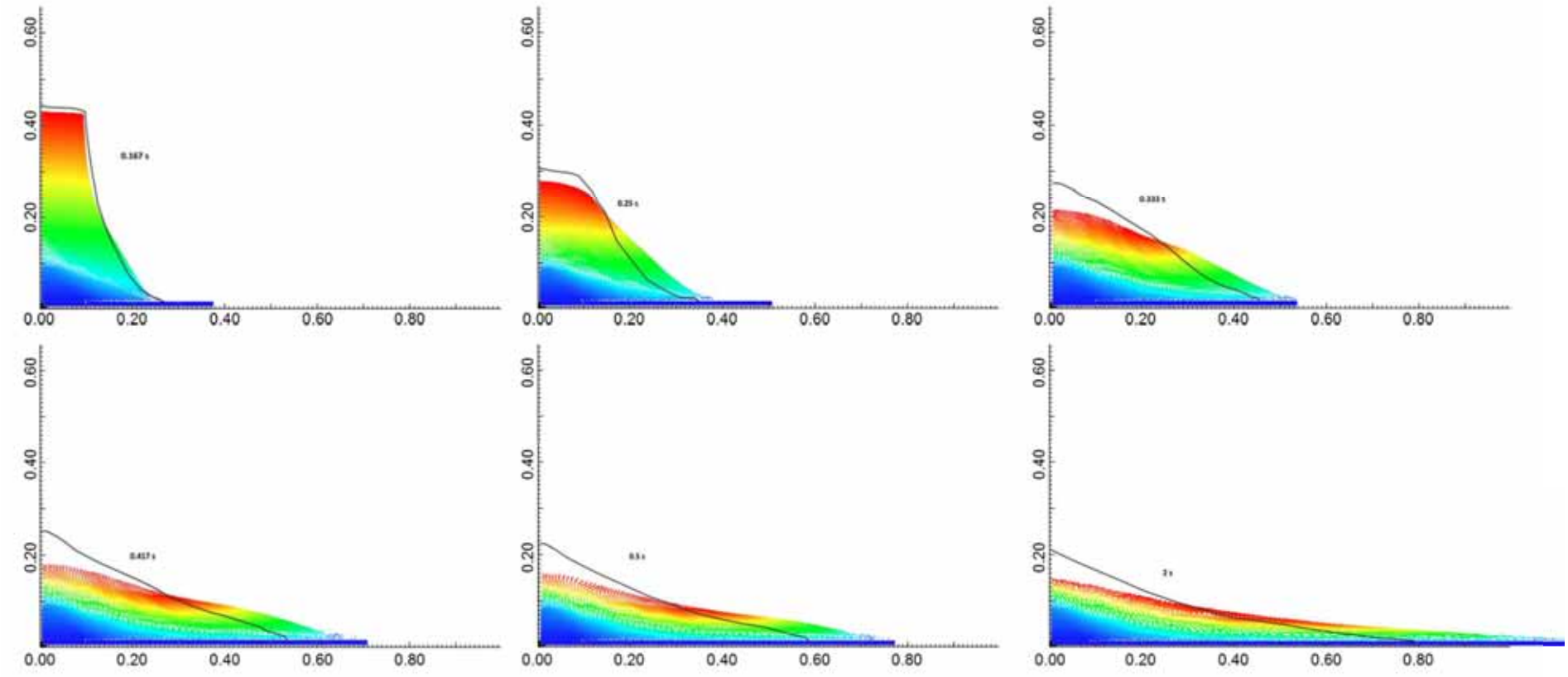


no numerical damping

James Fern

SIMULATING EXPERIMENTAL DATA

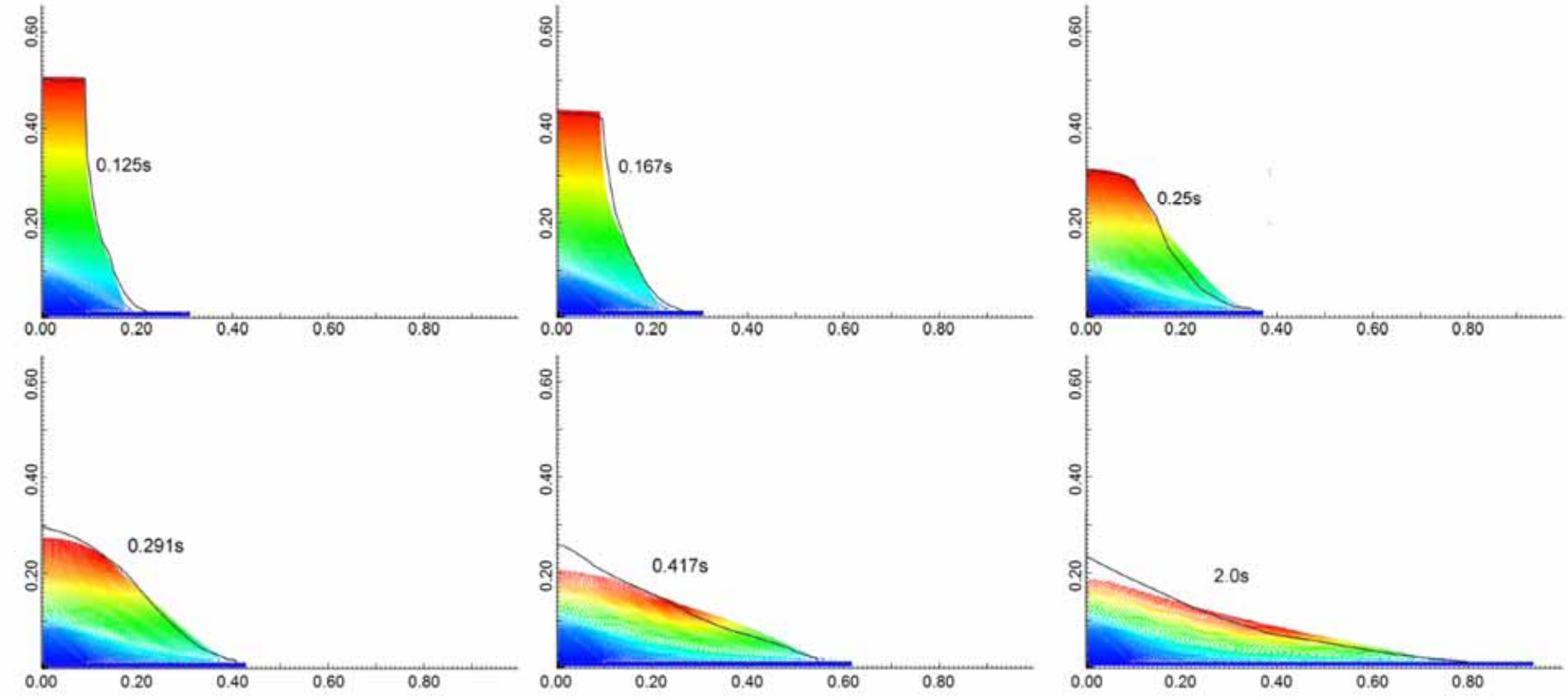
Column 7, *Mohr-Coulomb (Solowski & Sloan, 2015)* *without numerical damping*



(experimental data from Lube et al., 2005, 2007)

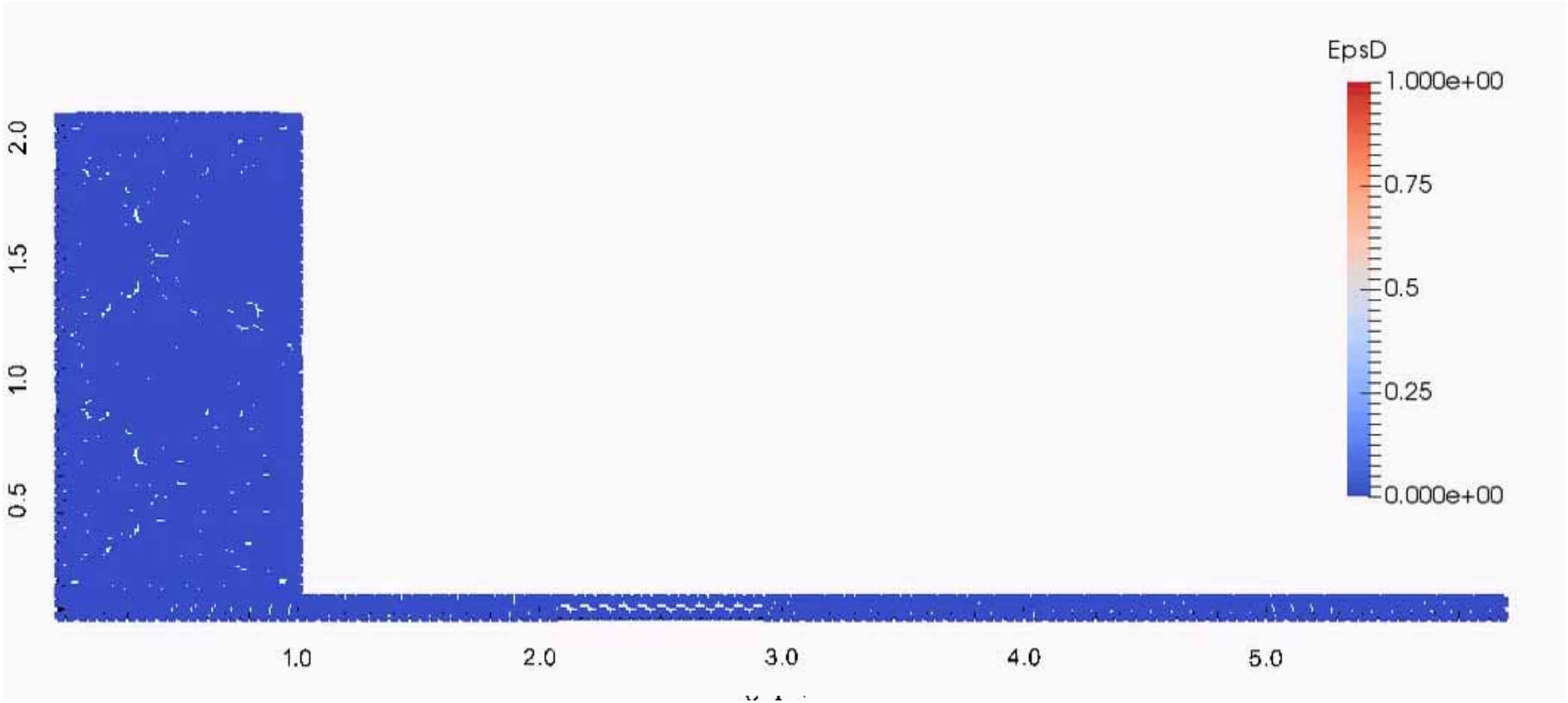
SIMULATING EXPERIMENTAL DATA

Column 7, *Mohr-Coulomb (Solowski & Sloan, 2015)* *with numerical damping*



(experimental data from Lube et al., 2005, 2007)

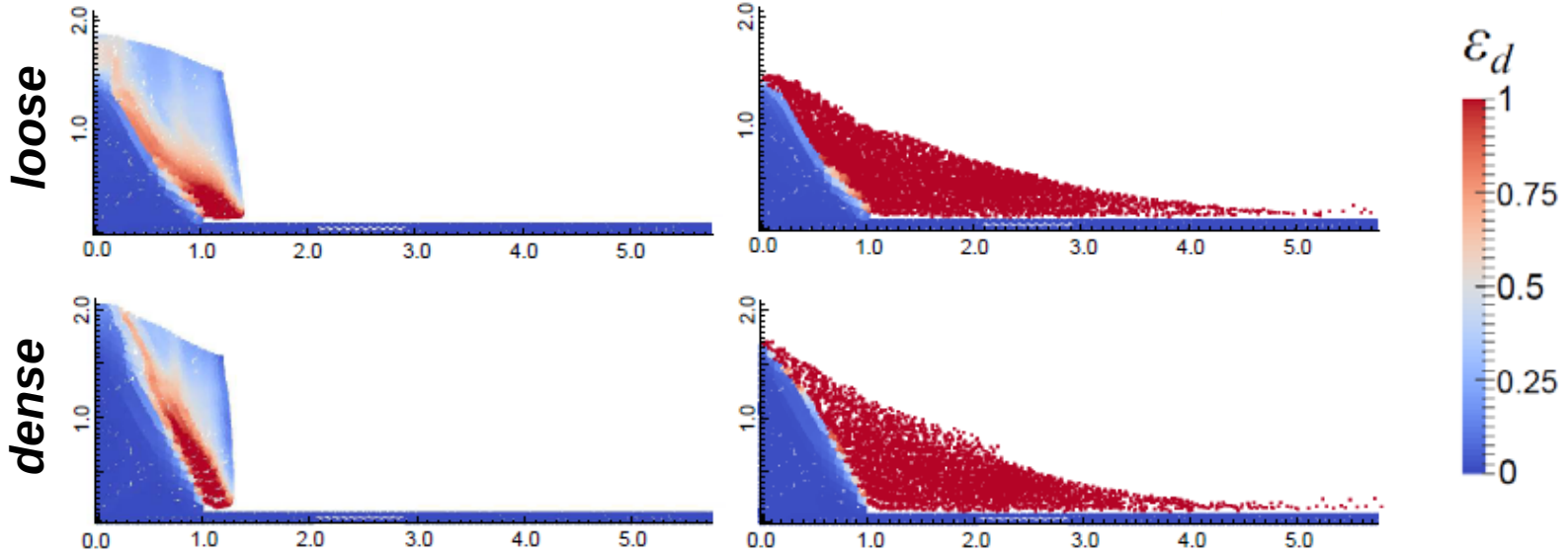
NOR-SAND - DENSE SAND



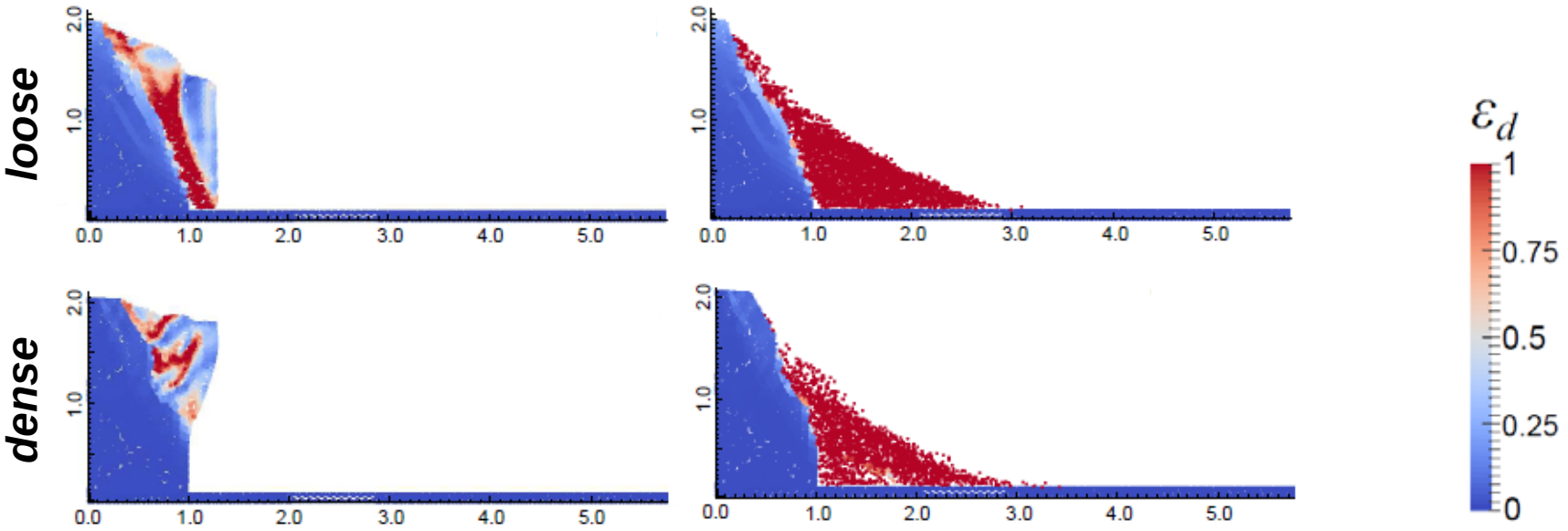
James Fern

James Fern

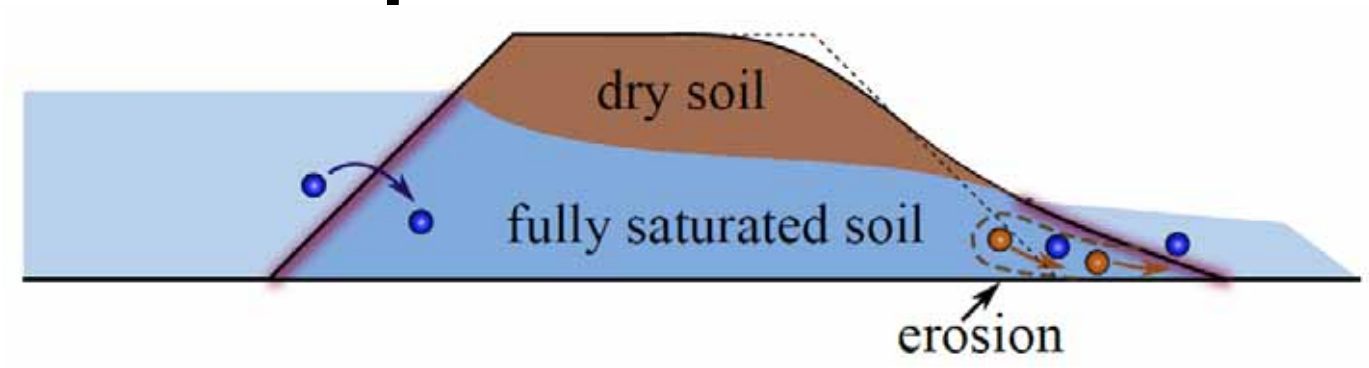
MOHR-COULOMB

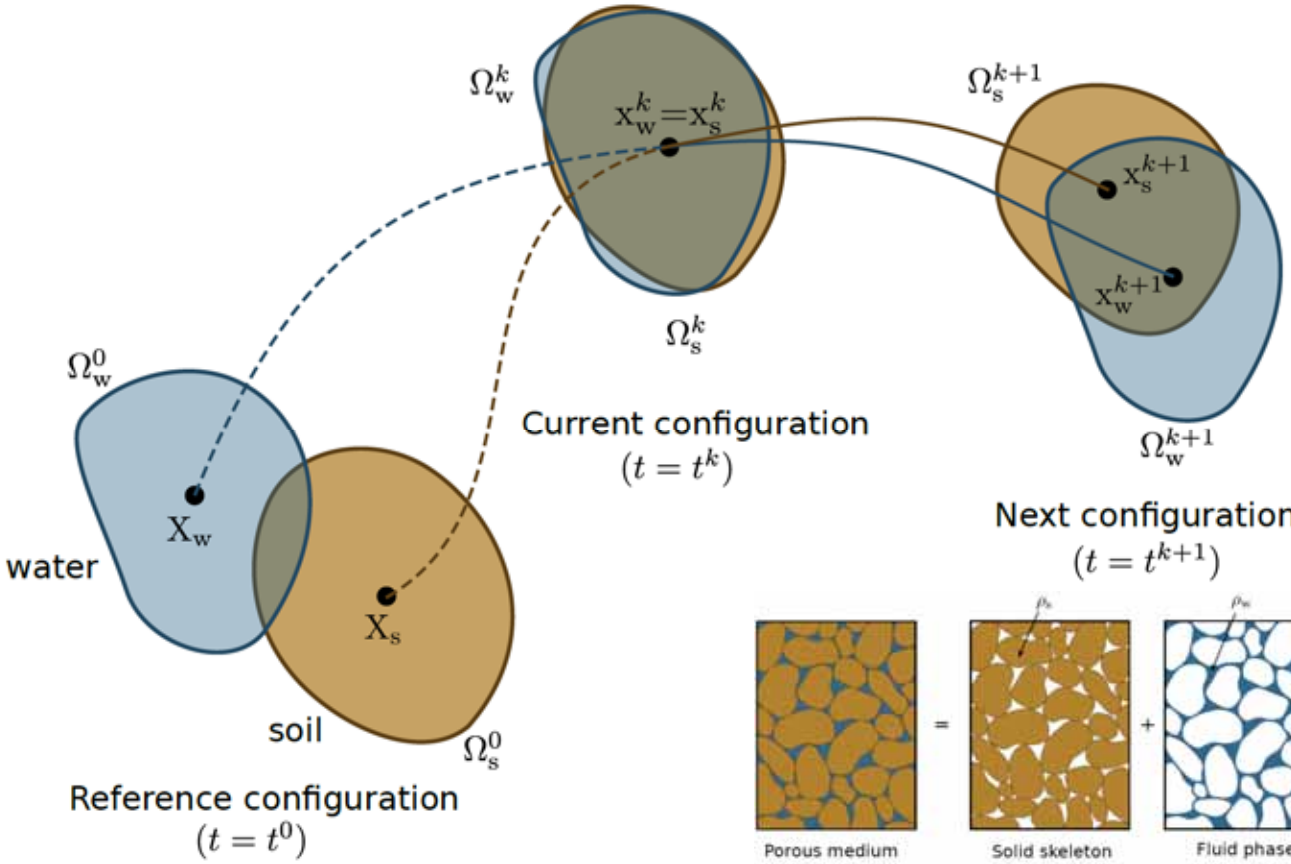


NOR-SAND



MPM Coupled Consolidation formulation





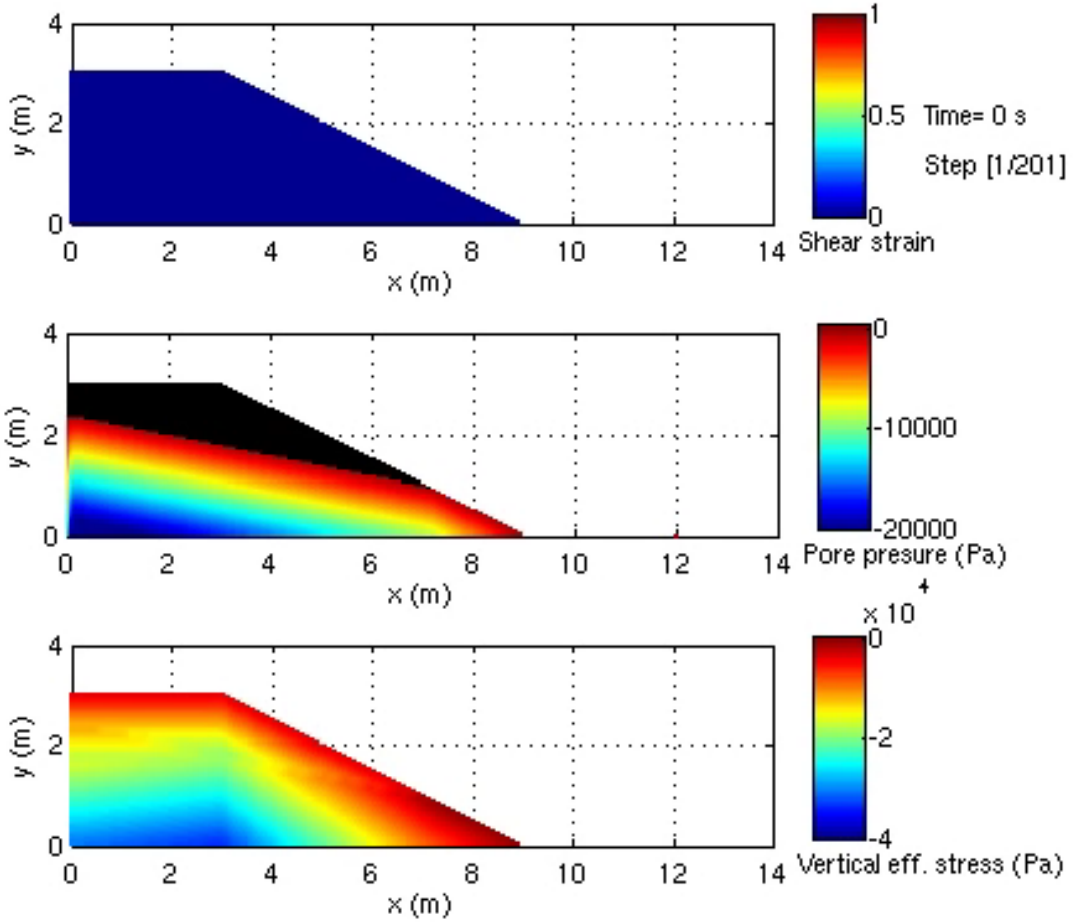
Samila Bandara

Modelling Partially saturated soil

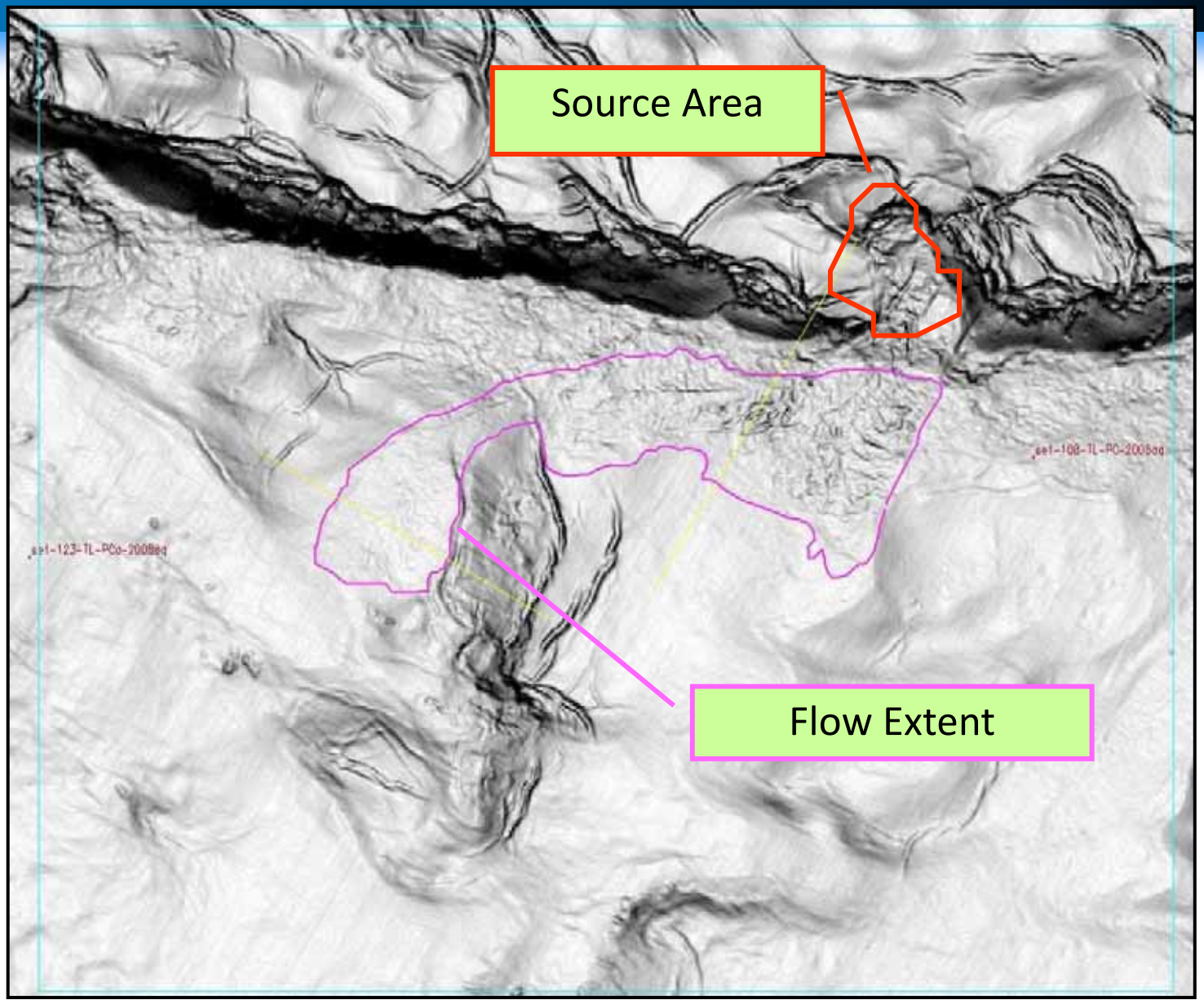
Samila Bandara

- Model large deformations

Properties	
E	10 MPa
ϕ	30.8º
C'$_u$	2.0 kPa
ψ_{peak}	-5.0º
γ_{peak}	0.01
γ_f	0.2
s_u (suction)	2.7 kPa
n (porosity)	0.45
μ (boundary)	0.3
k (permeability)	5×10^{-4} m/s
K_w (bulk modulus)	1×10^9 Pa



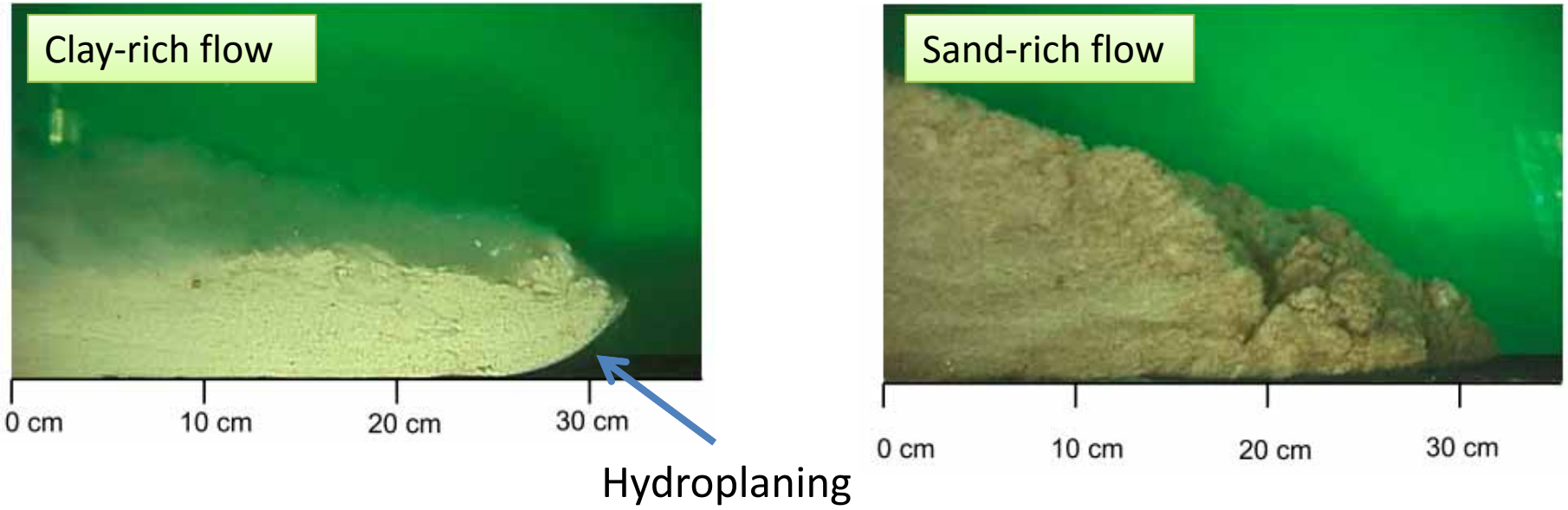
Submarine landslide



Mechanism of Submarine Run-out

Modelling Test at 1g Condition

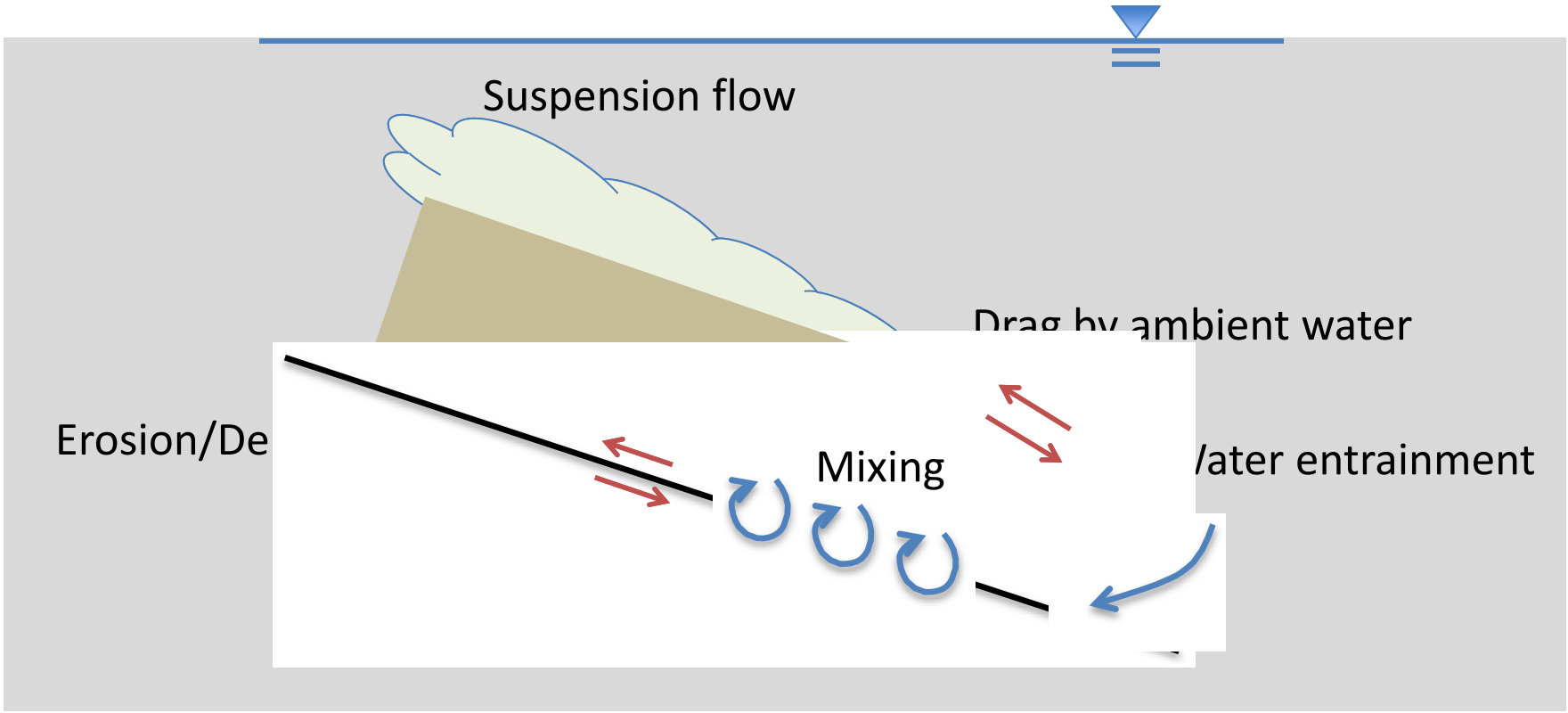
(From Ilstad et al. 2004)



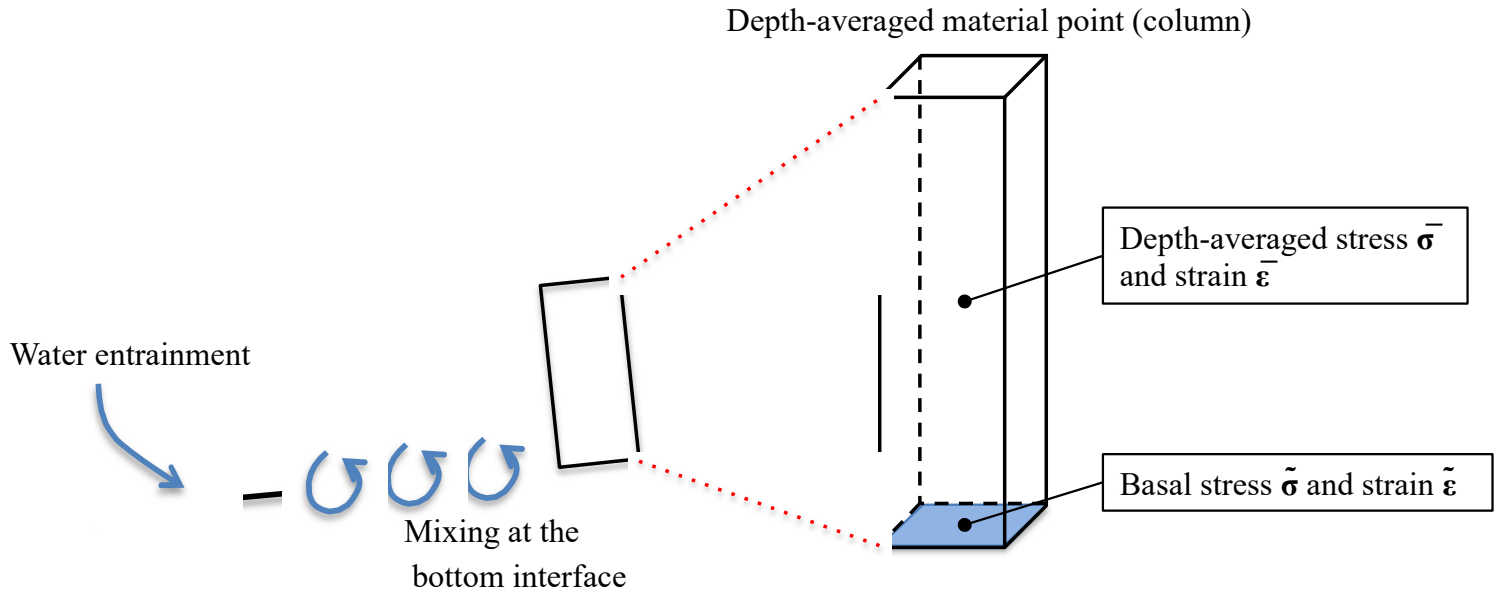
- Material type influences the mode of the flow.
- Target: Clay-rich flow (Less diffusive, Hydroplaning)

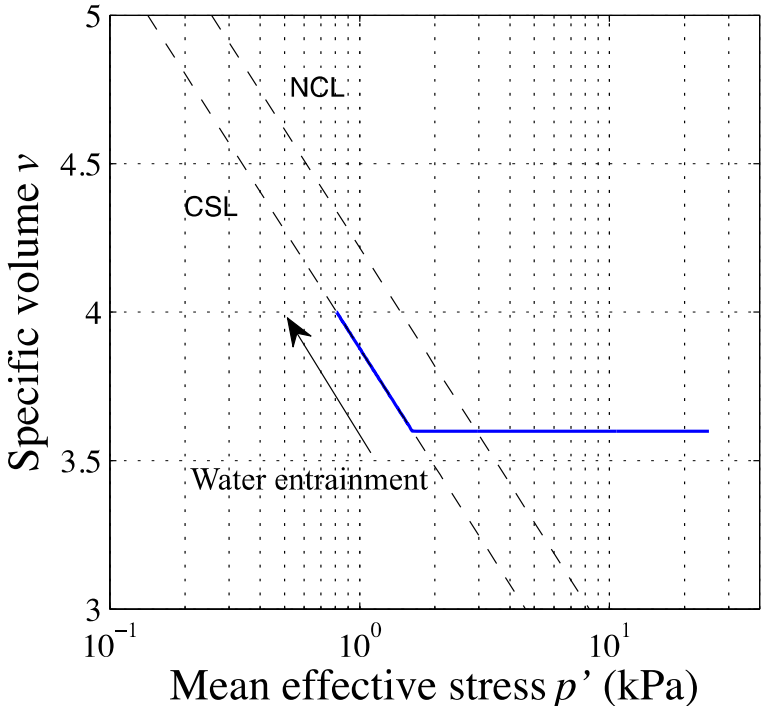
Mechanism of Submarine Run-out

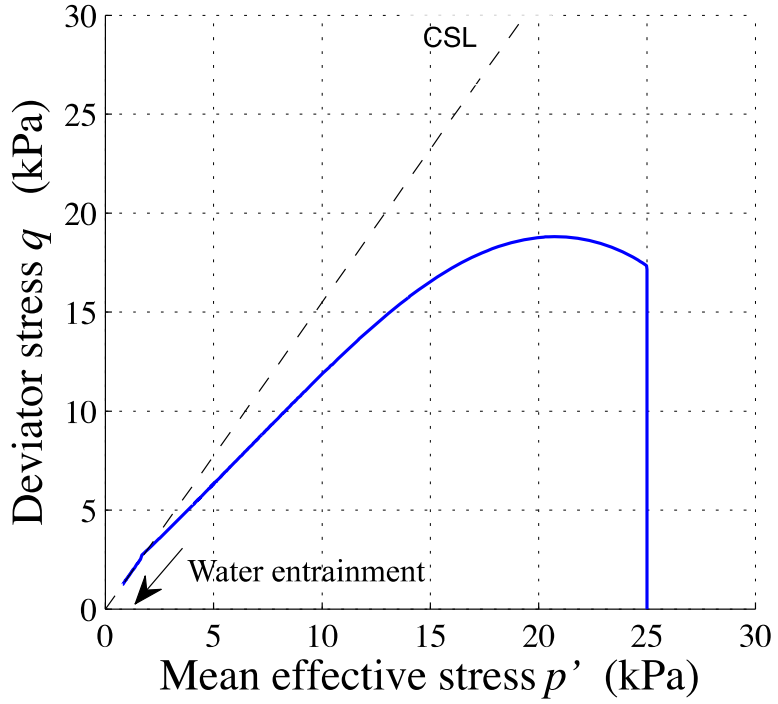
Possible Boundary Conditions of Submarine Run-out

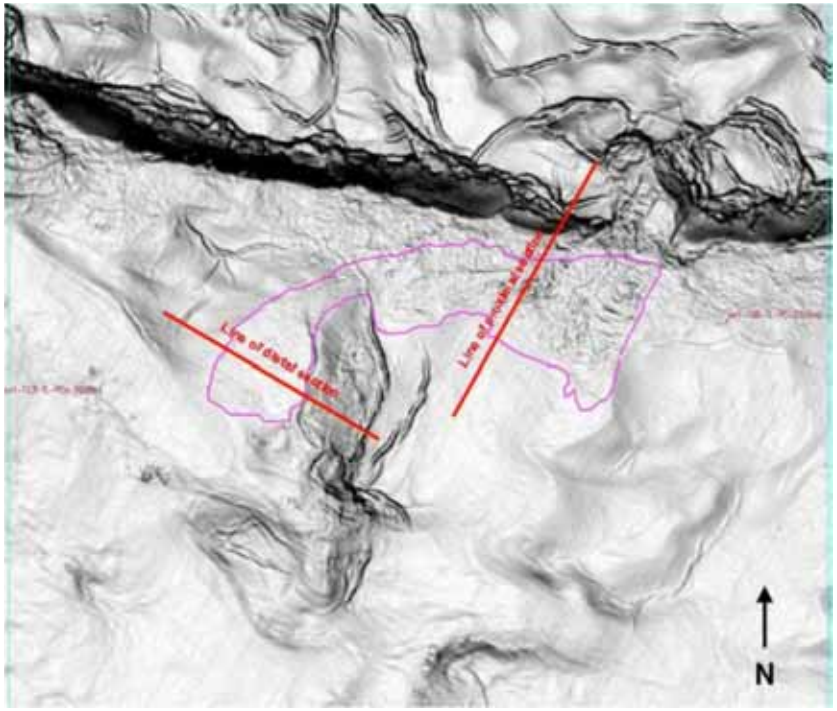


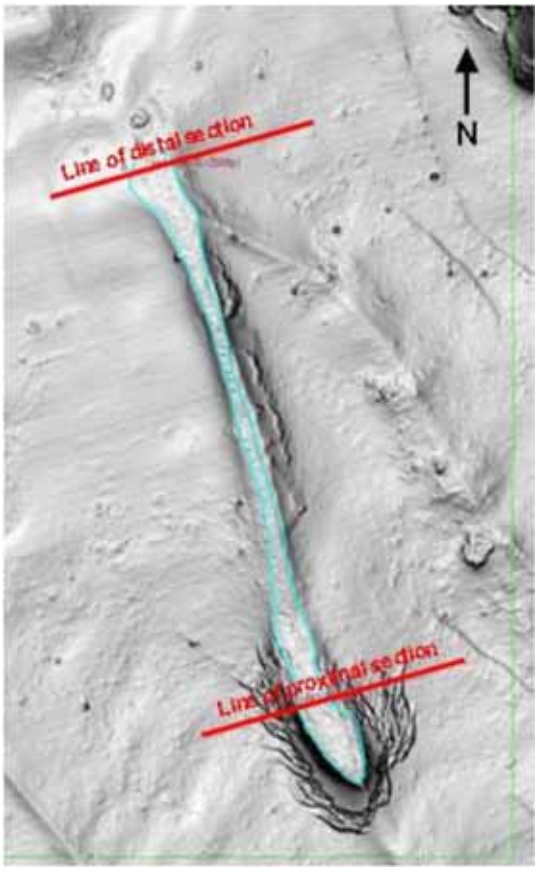
- Presence of ambient water (larger drag force & less gravity)
- Water entrainment
- Pore pressure does not dissipate

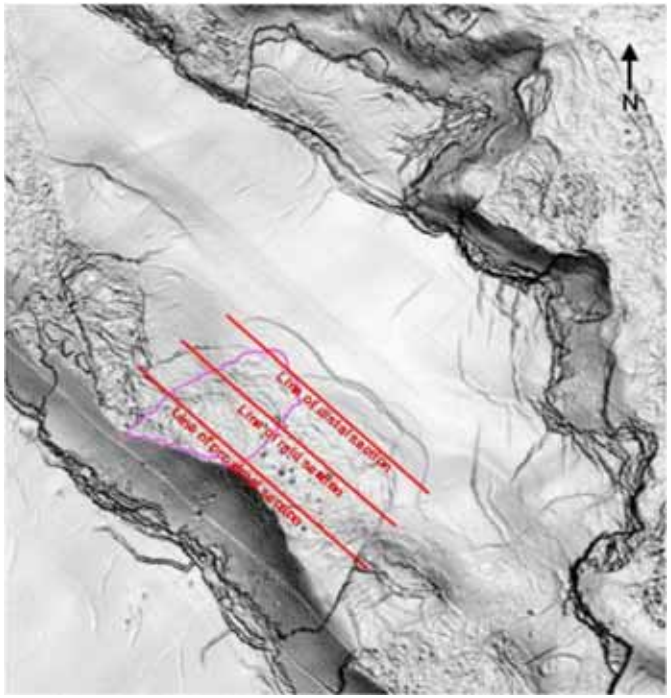

Depth-averaged material point (column)
Depth-averaged stress $\bar{\boldsymbol{\sigma}}$ and strain $\bar{\boldsymbol{\varepsilon}}$
Basal stress $\tilde{\boldsymbol{\sigma}}$ and strain $\tilde{\boldsymbol{\varepsilon}}$
Water entrainment
Mixing at the bottom interface

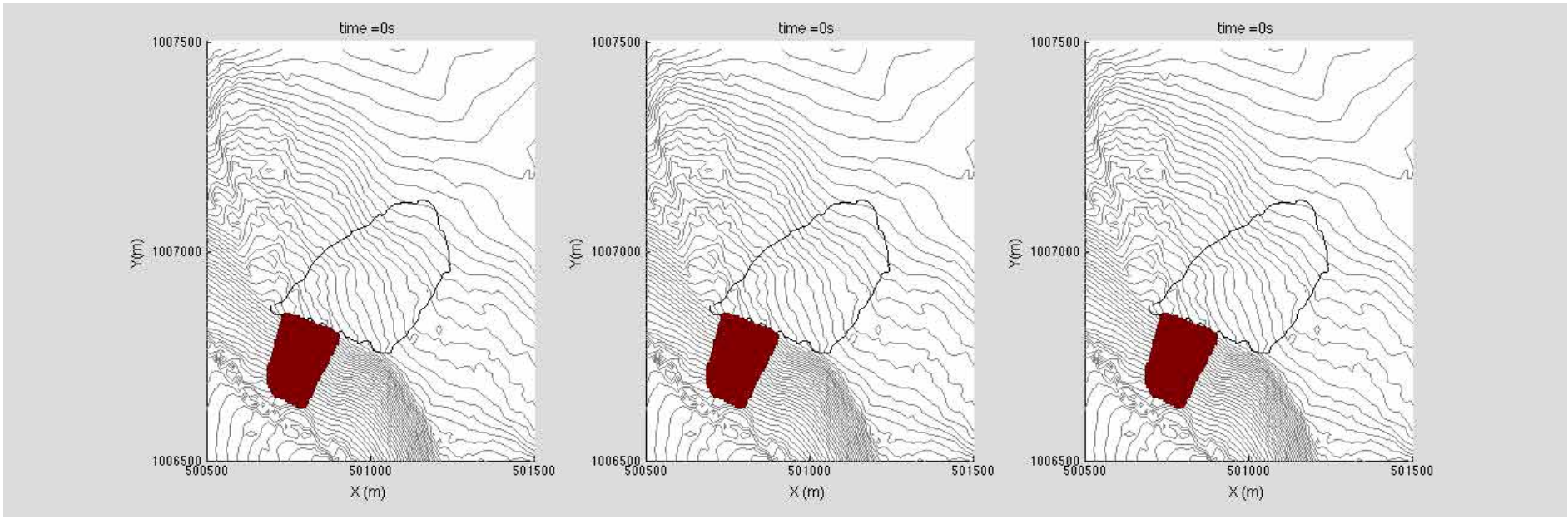

NCL
CSL
Water entrainment
Specific volume v
Mean effective stress p' (kPa)
5
4.5
4
3.5
3
10^{-1}
10^{0}
10^{1}

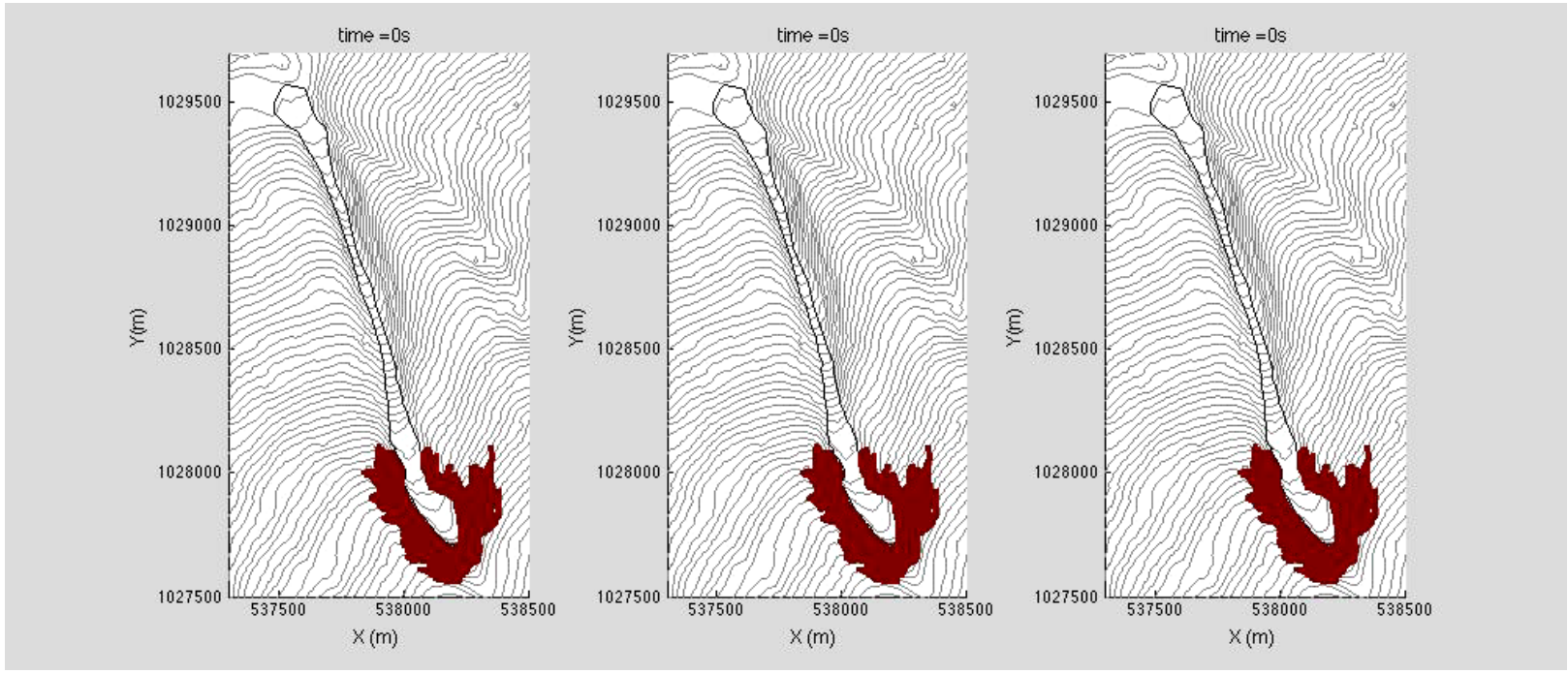

CSL
Water entrainment
Deviator stress q (kPa)
Mean effective stress p' (kPa)
30
25
20
15
10
5
0
0
5
10
15
20
25
30


Line of distal section
N


Line of distal section
N
Line of proximal section


N



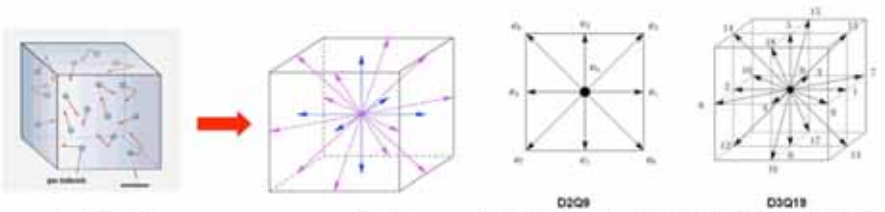


Taka Kobayashi

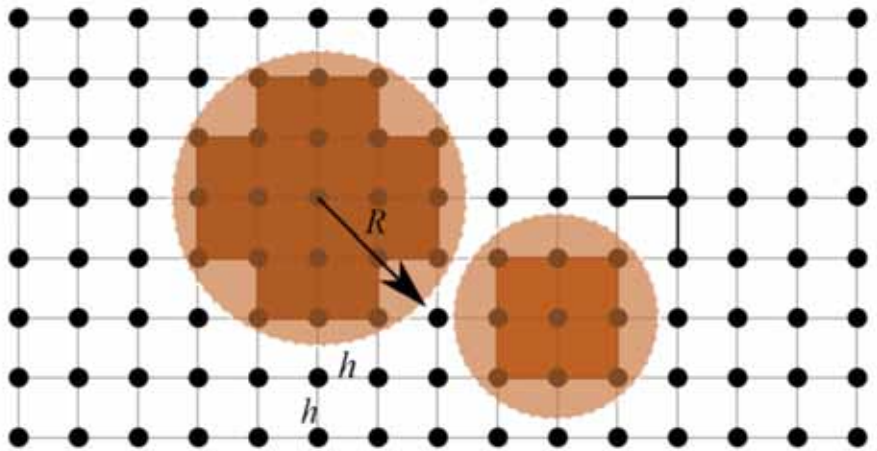
Collapse in Fluid: Aspect Ratio of 8

- 2D poly-disperse system of circular discs
~ Up to 5000 discs and a contact friction angle of 26 degrees
- Up to 9 million LBM nodes (appx. 10 x 10 nodes per particle size)

Lattice Boltzmann Method



$$f_i(x+dx,t+\Delta t) = f_i(x,t) - S_{ai}(f_i(x,t) - f_i^e(x,t))$$



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Granular Collapse in Fluid

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a=0.4

a=4

Permeability

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Dirichlet boundary conditions constrain the pressure/density at the boundaries (Zou and He, 1997)

$$\rho_0 = \sum f_a \text{ and } u = \frac{1}{\rho_0} \sum f_a$$

Bounceback holds in the direction normal to the boundary

$$f_3 - f_3^{eq} = f_1 - f_1^{eq}$$

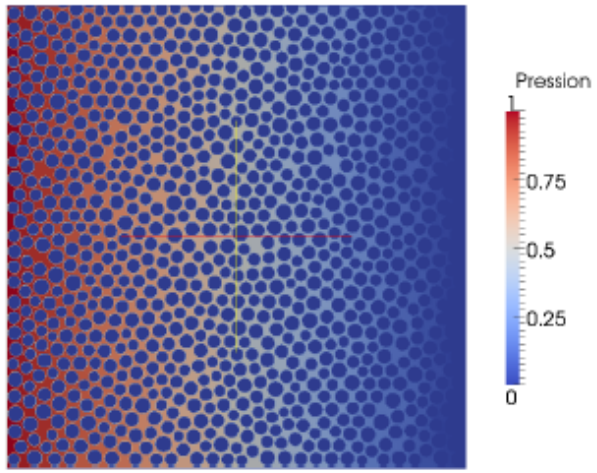


Figure: LBM-DEM Dirichlet Pressure Boundary

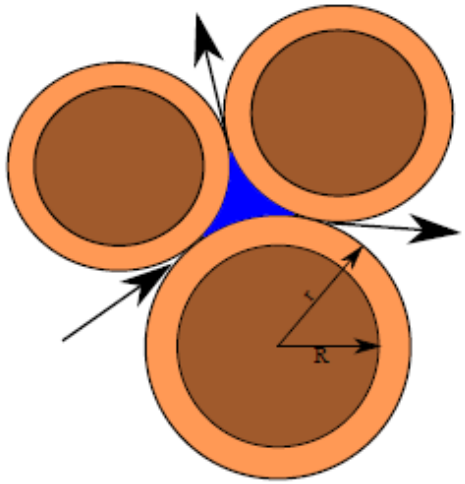


Figure: Reduction in radius

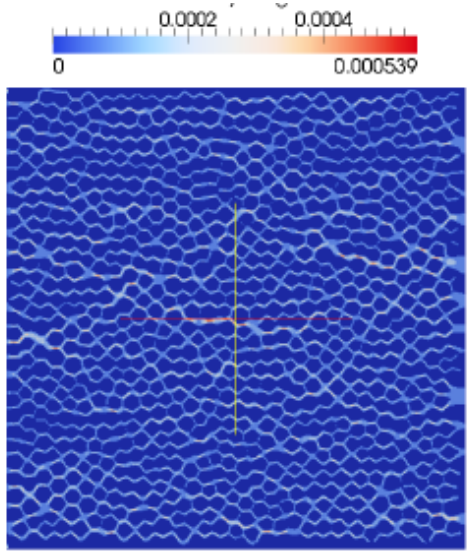
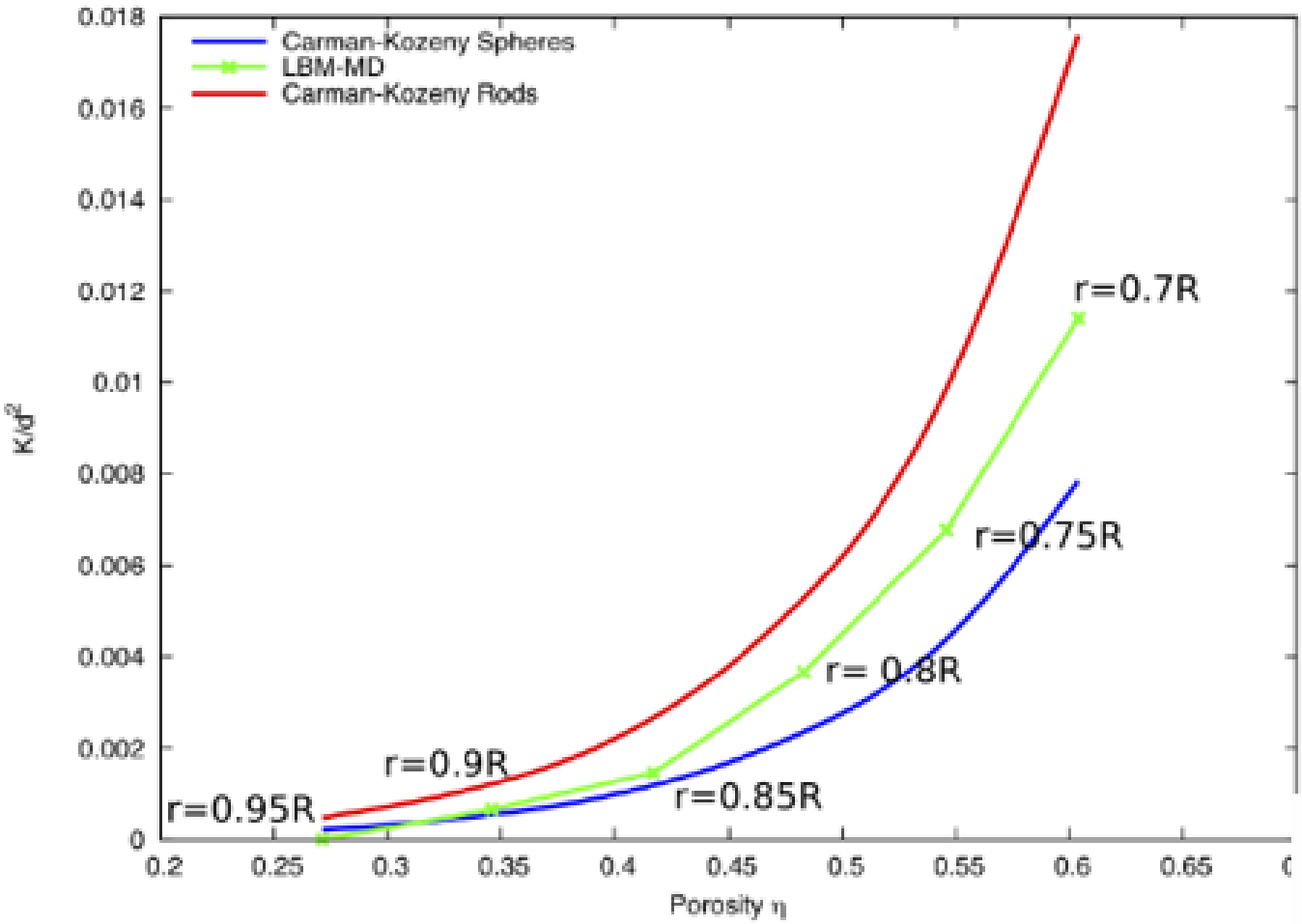
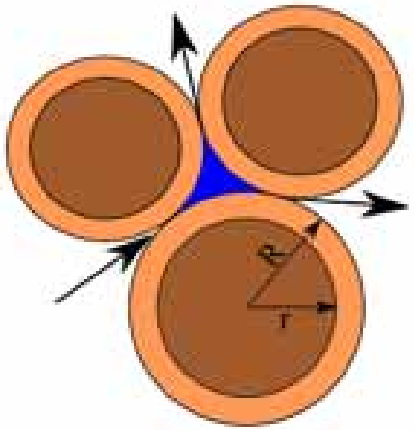


Figure: Stream lines





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Effect of Permeability

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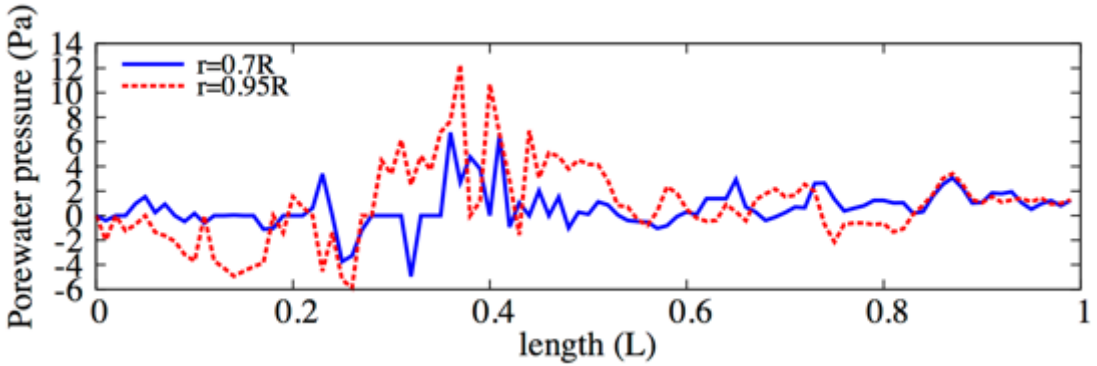
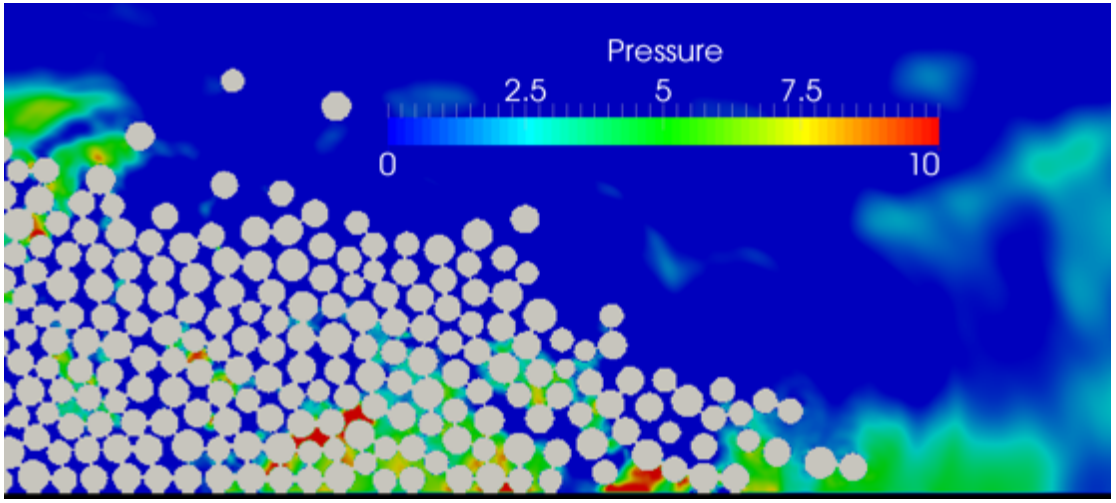
r=0.7R (high permeability)

r=0.95R (low permeability)



High permeability



Low permeability

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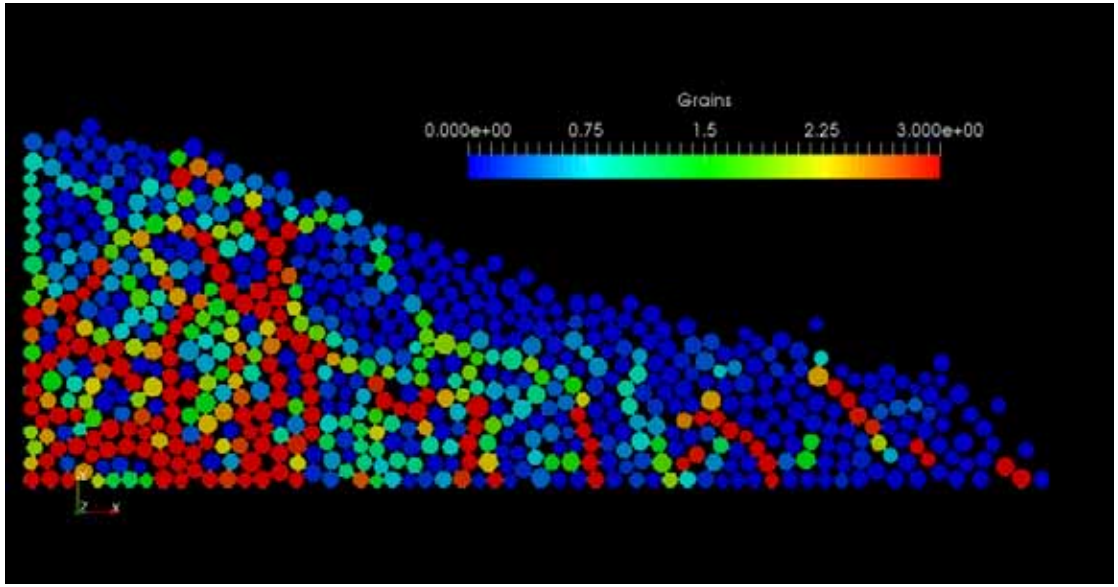
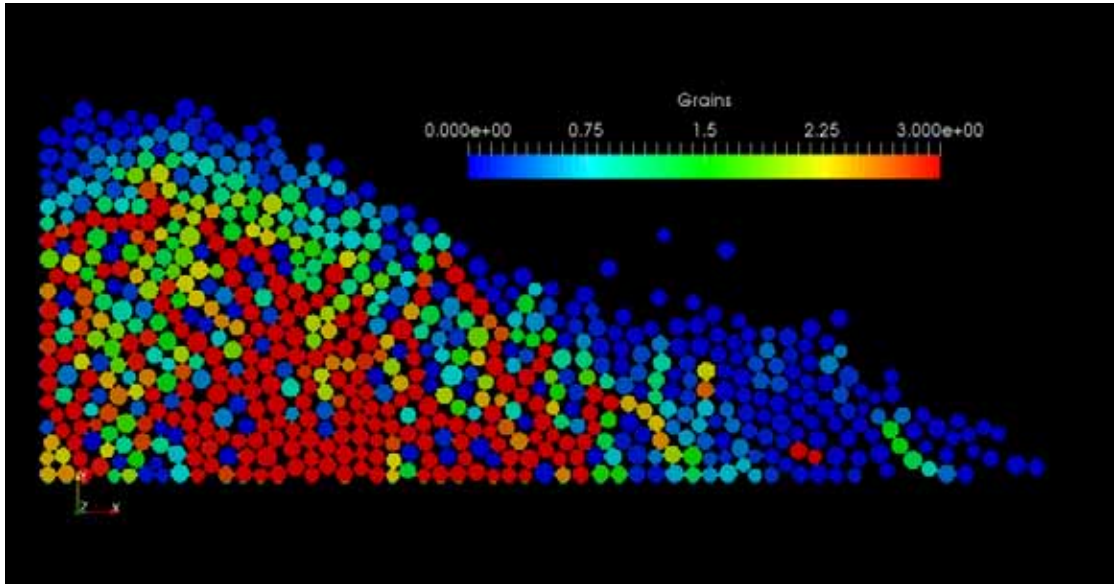


High permeability



Low permeability

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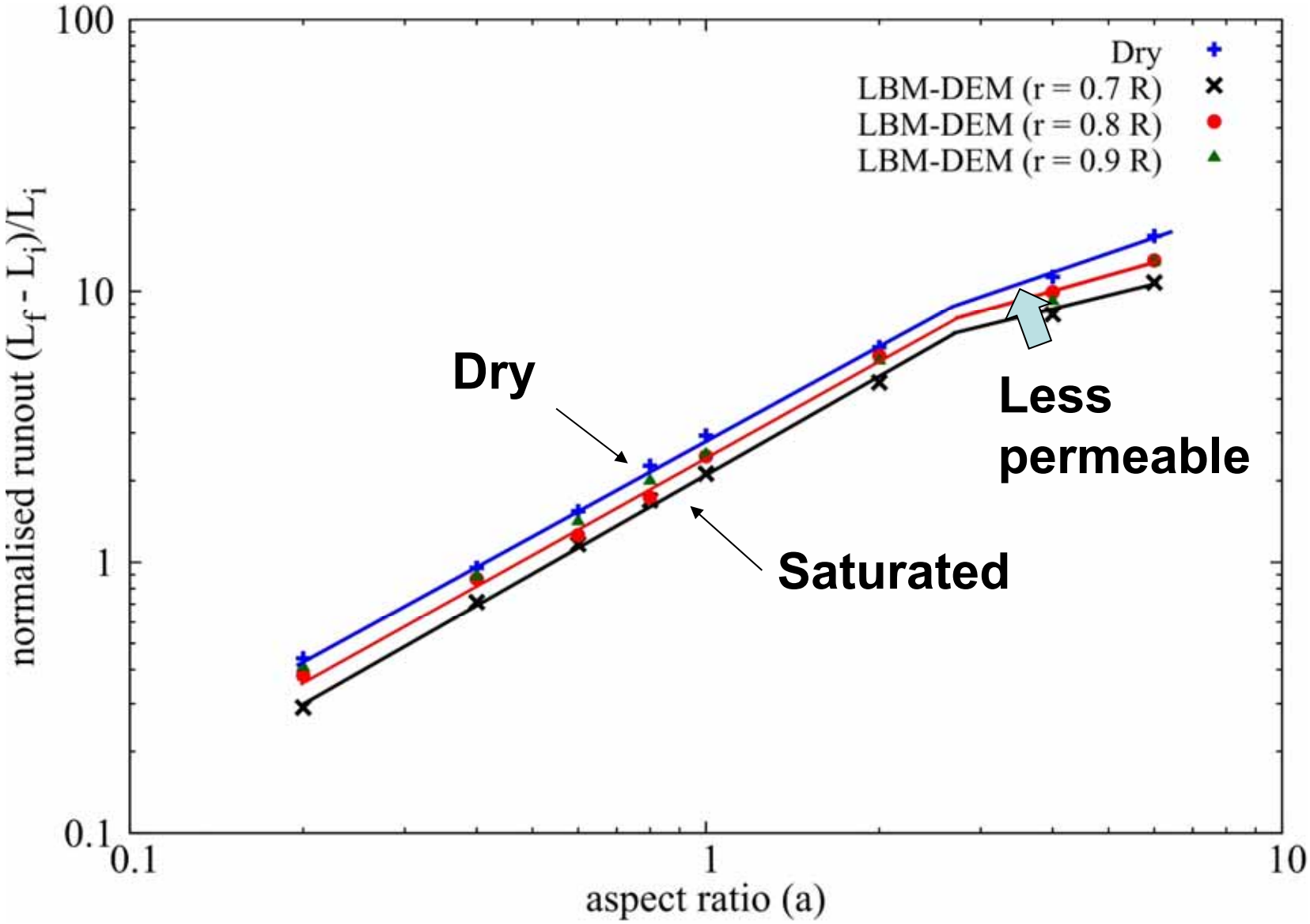

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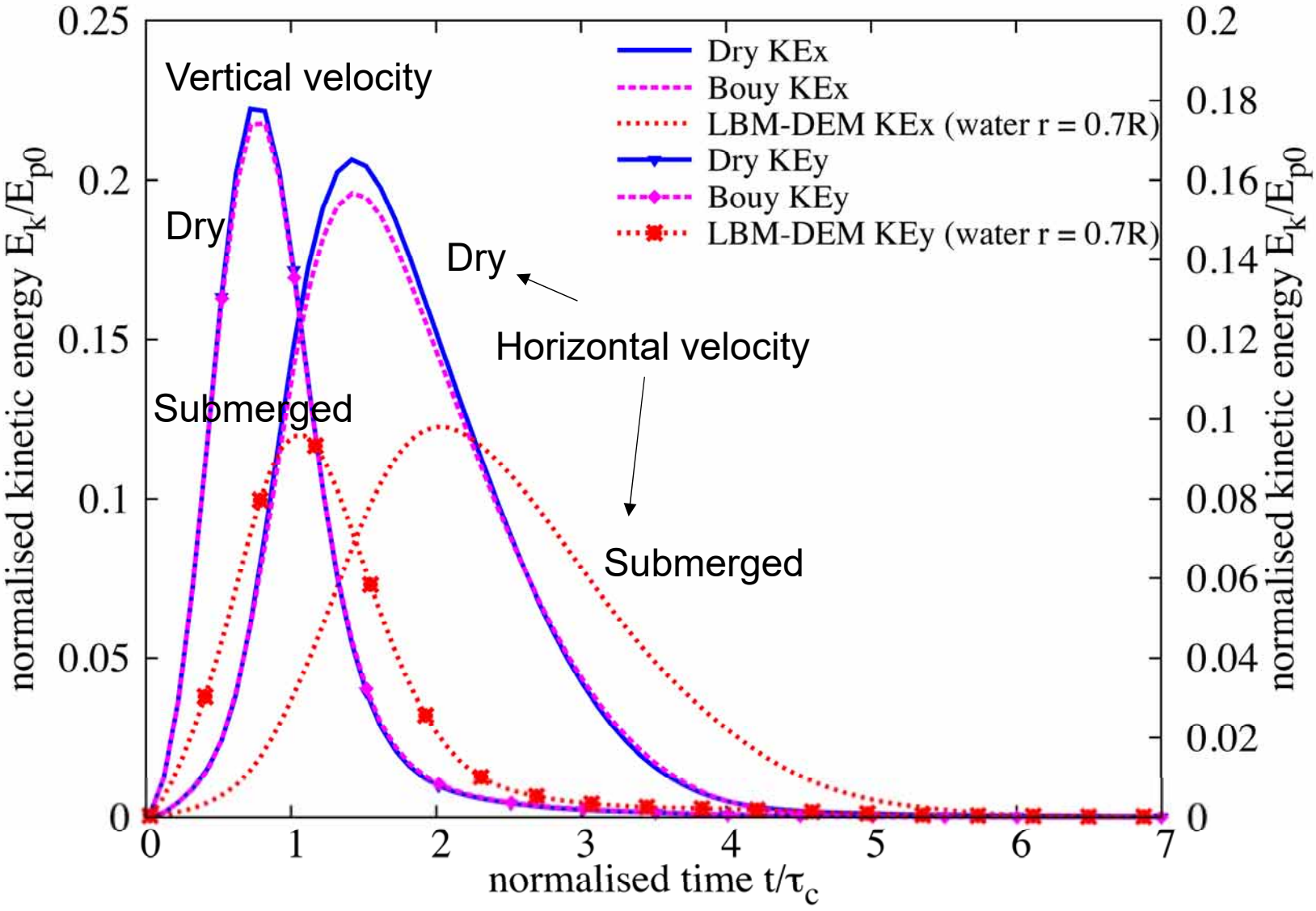
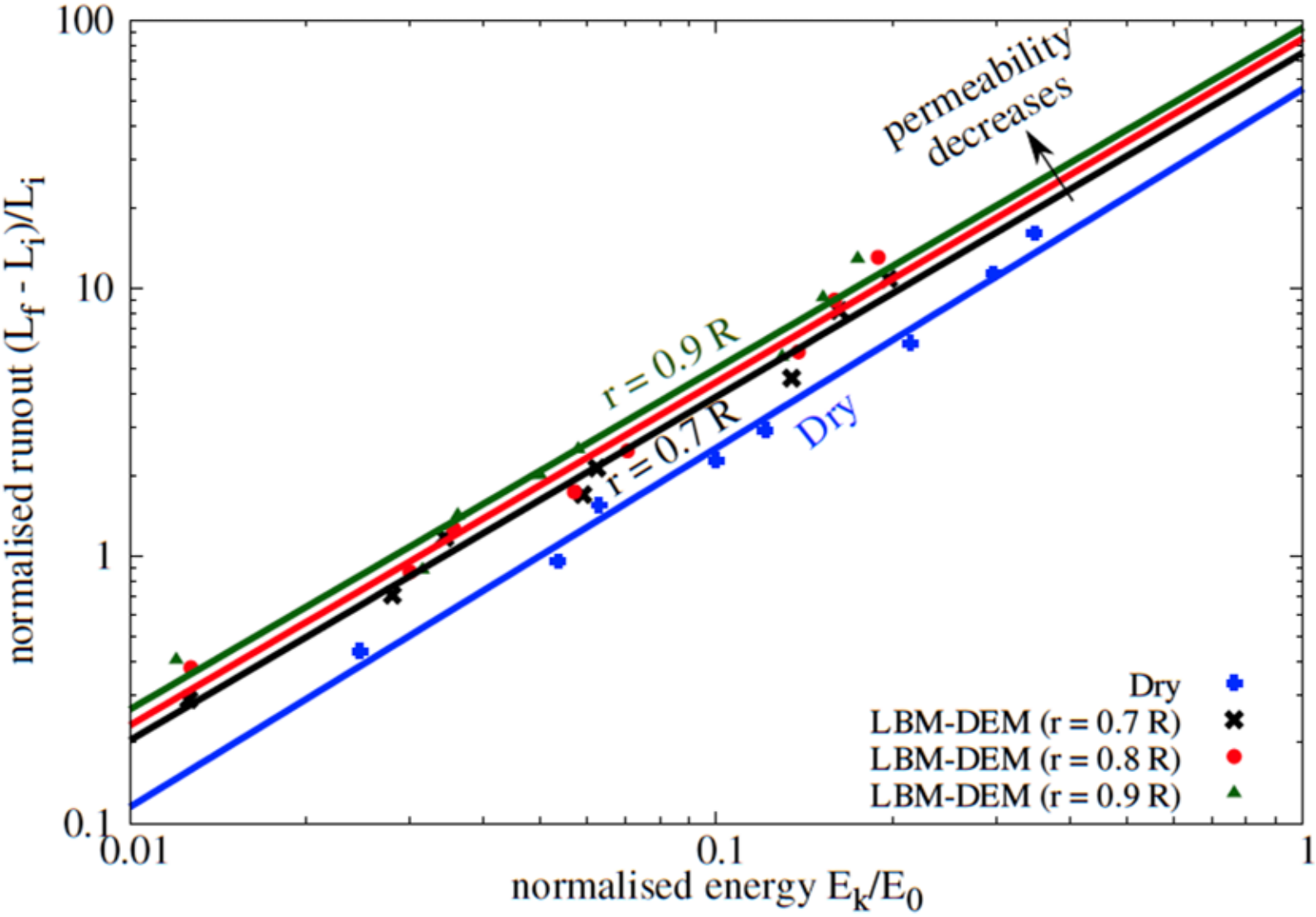

Vertical velocity
Dry
Submerged
Dry
Horizontal velocity
Submerged
Dry KEx
Bouy KEx
LBM-DEM KEx (water r = 0.7R)
Dry KEy
Bouy KEy
LBM-DEM KEy (water r = 0.7R)
normalised kinetic energy E_k/E_{p0}
normalised time t/τ_c
0.25
0.2
0.15
0.1
0.05
0
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
6
7



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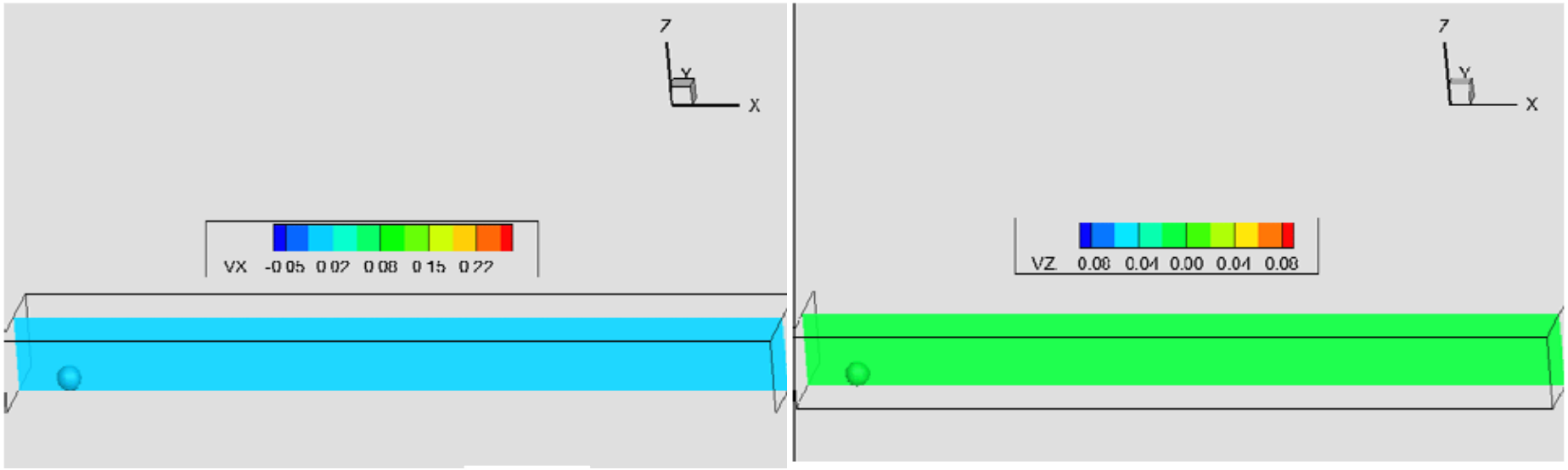
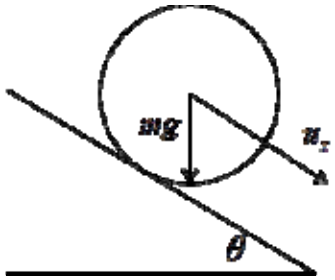
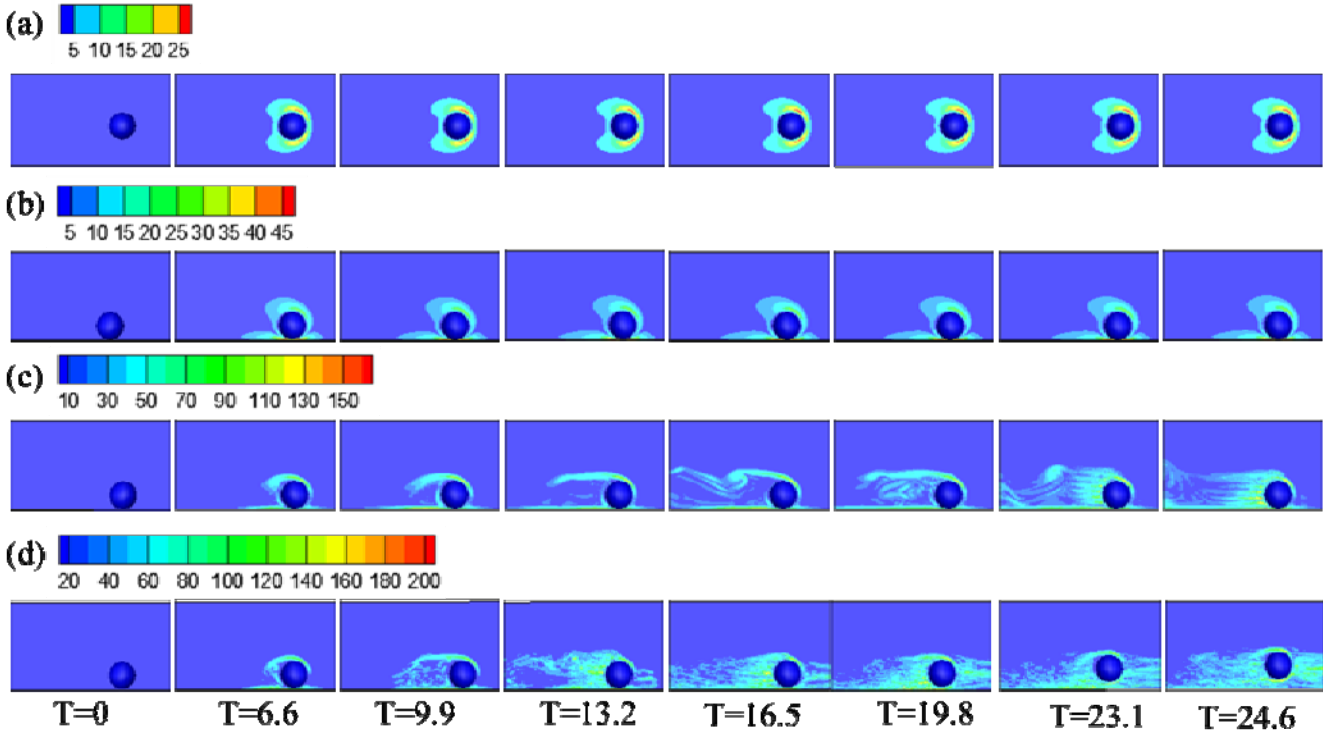
2D to 3D


Z
Y
X
VX -0.05 0.02 0.08 0.15 0.22
Z
Y
X
VZ 0.08 0.04 0.00 0.04 0.08


mg
u_x
θ


(a)
5 10 15 20 25
(b)
5 10 15 20 25 30 35 40 45
(c)
10 30 50 70 90 110 130 150
(d)
20 40 60 80 100 120 140 160 180 200
T=0
T=6.6
T=9.9
T=13.2
T=16.5
T=19.8
T=23.1
T=24.6

MPM Research Community

Modelling large deformation and soil–water–stucture interaction

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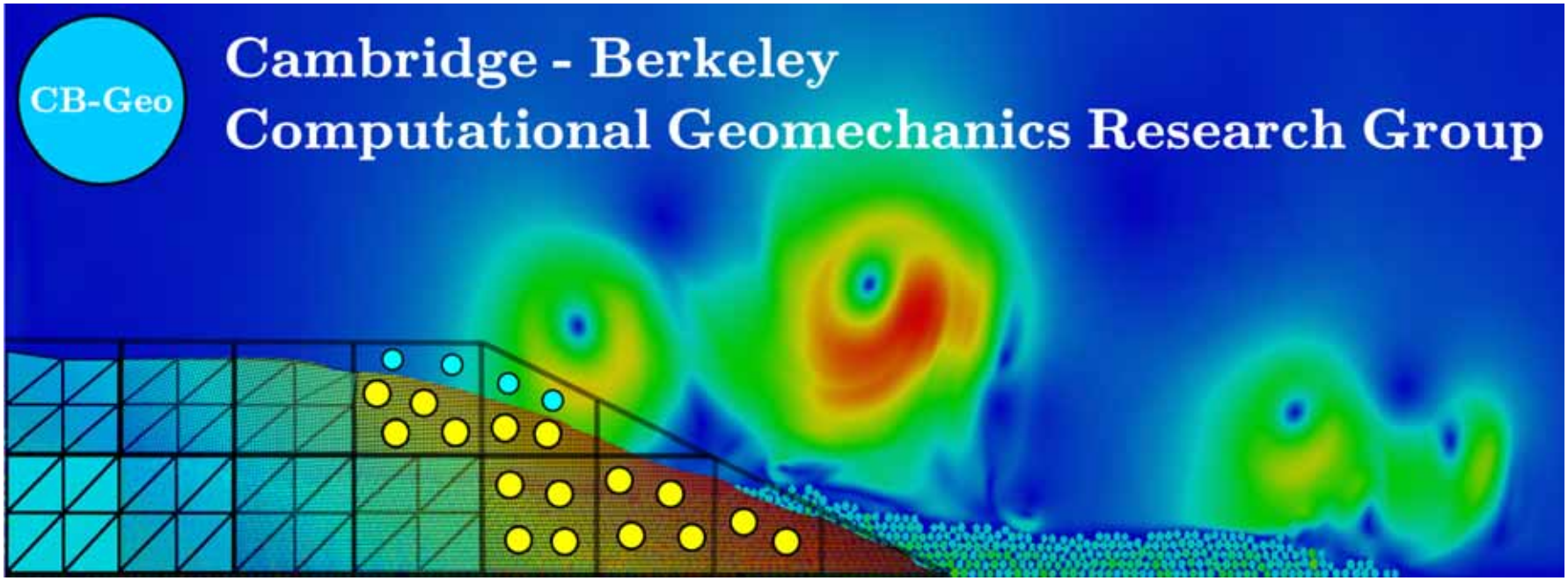
Deltares



Thank you