Transient behaviour of a suction caisson in sand: axisymmetric numerical modelling

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Outline

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Motivations

1. EU 2020 objectives (greenhouse gas, **renewable energy**, energy efficiency)

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2. Basic working of soil-caisson system upon both monotonic and cyclic loading (serviceability)

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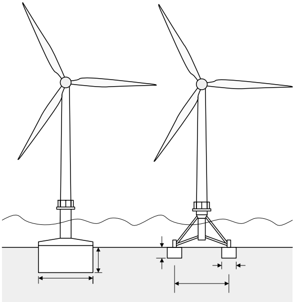
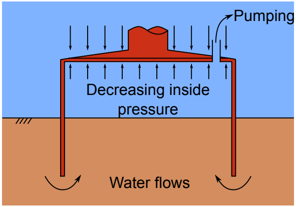
2. Basic working of soil-caisson system upon both monotonic and cyclic loading (serviceability)
3. Identifications of components of reaction : first step to the elaboration of a macro-element

Suction caissons for offshore foundations

Houlsby et al. (2005)





Offshore wind turbines specificities

- light structure
- high overturning moment

Suction caissons specificities

- hollow steel cylinder open towards the bottom
- extensively used as anchors in the North Sea
- monopod or tetra/tri-pod superstructure
- cheaply and quickly installed, reusable, Senders (2008)
- limited extension resistance by suction

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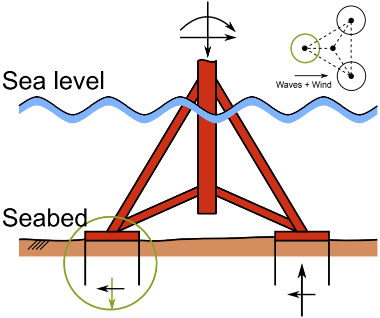
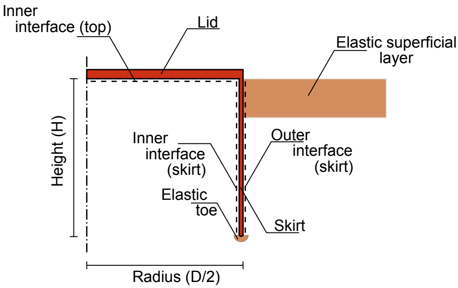
Geometry



Published in Cerfontaine et al. (2016), *Géotechnique*

Modelling (axisymmetric)



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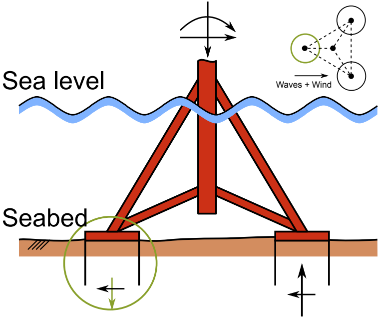

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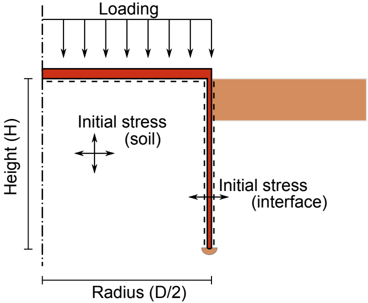

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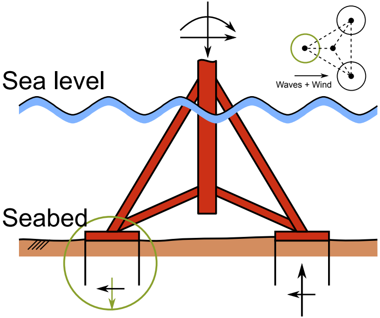

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Size

D=7.8m and H=4m

Soil-steel friction coefficient

$\mu = 0.5$

Permeability

$k = 5 \cdot 10^{-12} m^2$

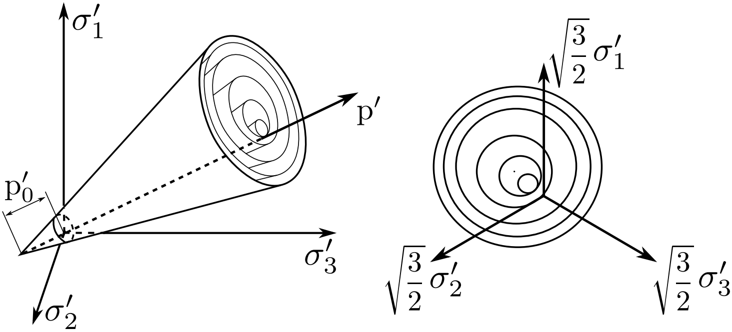
Coefficient of lateral earth pressure at rest

$K_0 = 1.0$

Porosity

n= 0.36

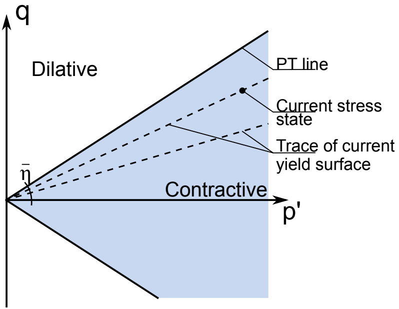
Prevost model for cohesionless soils - Kinematic hardening



After Elgamal (2003)

Implementation in LAGAMINE code published in Cerfontaine et al. (2014)
NUMGE2014 Proceedings

Prevost model for cohesionless soils - Volumetric behaviour



Non-associated plastic volumetric behaviour

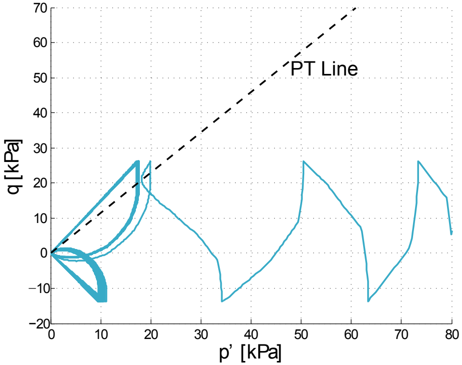
$$\dot{\epsilon}_v^p = \frac{1}{3} \cdot \frac{\eta^2 - \bar{\eta}^2}{\eta^2 + \bar{\eta}^2} \cdot \dot{\lambda}$$

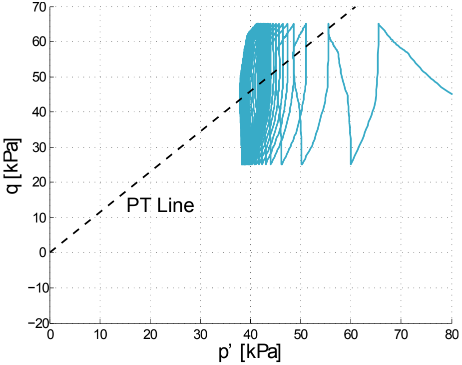
- $\eta = \mathrm{q}/\mathrm{p}'$
- $\dot{\lambda}$ continuous plastic multiplier
- $\bar{\eta}$ phase transformation ratio, Ishihara (1975)

Very simple (only 1 param.)
⇒ satisfactory to a 1st approx.

Cyclic triaxial tests (Lund Sand, Dr= 90%, Ibsen & Jakobsen (1996))

Two distinct behaviours from two initial deviatoric stress invariants

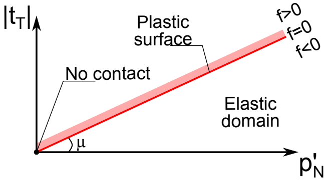




Full calibration process published in Cerfontaine (2014), *PhD thesis*

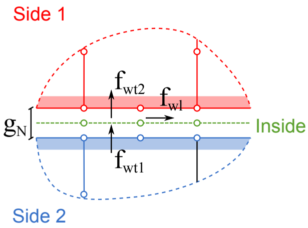
Hydro-mechanically coupled interface element

Mechanical behaviour



+ Penalty method

Flow behaviour



Couplings

- Effective stress
- Storage
- Permeability

Published in Cerfontaine et al. (2015) *Computers and Geotechnics*

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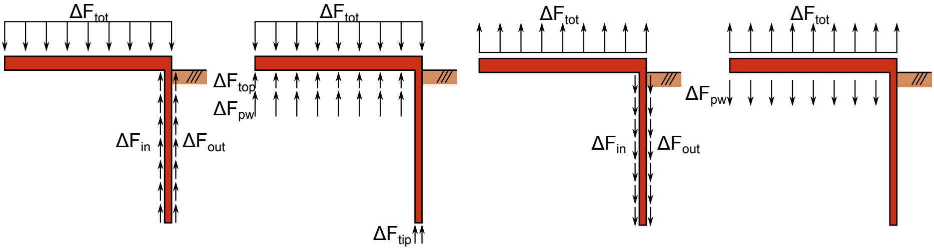
Reaction of the caisson to applied vertical load



Resistance to compressive load ΔF_{tot}

- ΔF_{in}, inner friction ;
- ΔF_{out}, outer friction ;
- ΔF_{pw}, pore water pressure (> 0) ;
- ΔF_{top}, top effective stress ;
- ΔF_{tip}, tip effective stress.

Resistance to extension load ΔF_{tot}

- ΔF_{in}, inner friction ;
- ΔF_{out}, outer friction ;
- ΔF_{pw}, pore water pressure (< 0).

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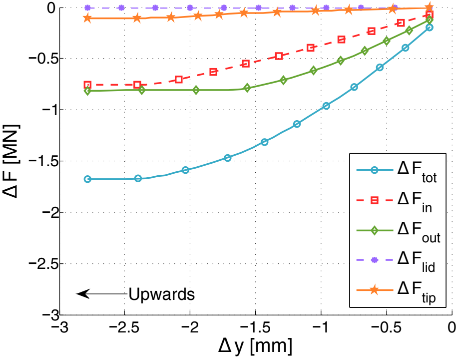
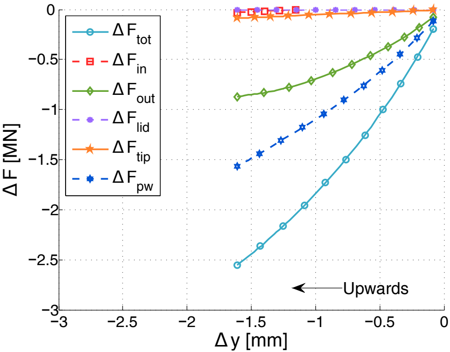
Monotonic extension simulations (load controlled)

Drained



Partially drained (8kPa/s)



- ΔF_{in} and ΔF_{out} bounded
- $\Delta F_{in} < \Delta F_{out}$ (unloading)

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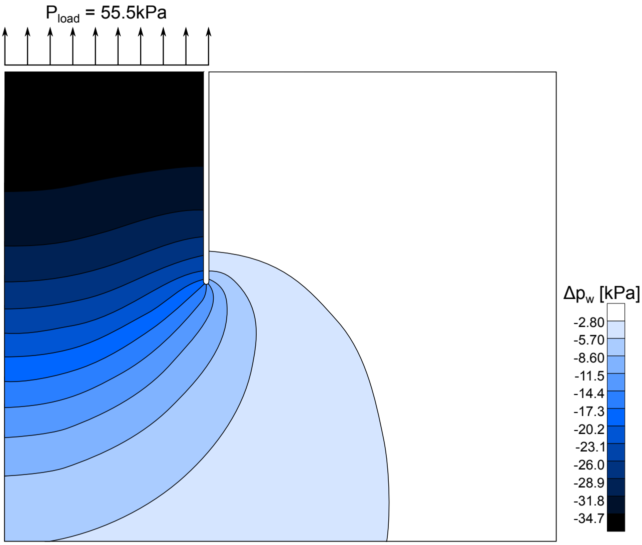
- $\Delta F_{in} < \Delta F_{out}$ (unloading)
- ΔF_{pw} increasing

Pore water pressure generation during extension



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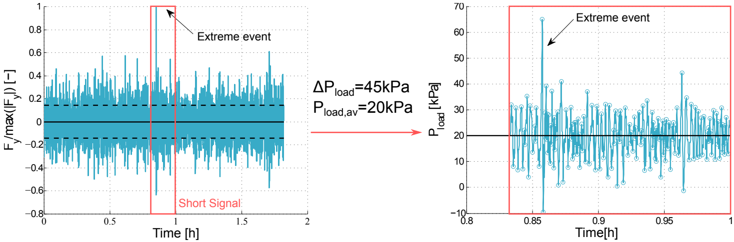
Pseudo-random and equivalent loadings



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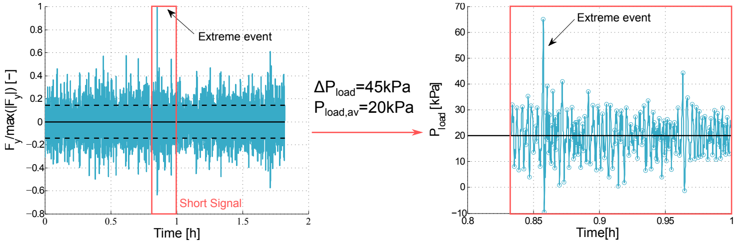
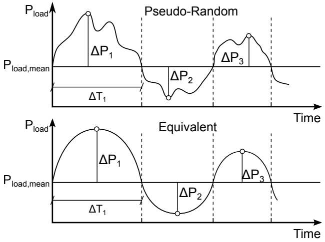
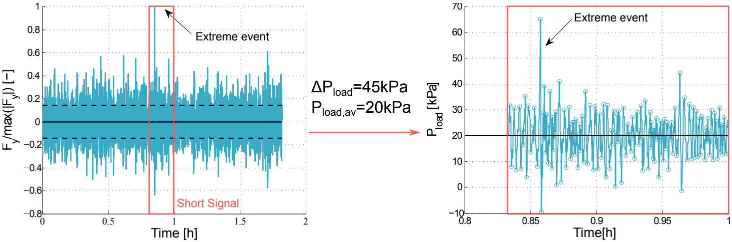


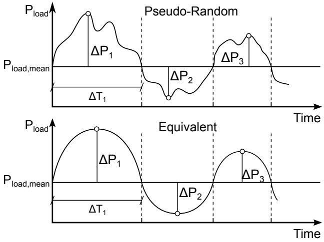


Half-cycle analysis

Pseudo-random and equivalent loadings



	Batch 1	Batch 2	Batch 3	Batch 4
Nb. cycles [-]	50	28	4	1
T [s]	4.6	11	11.6	11.1
ΔP [kPa]	4.5	13.5	22.5	40.5



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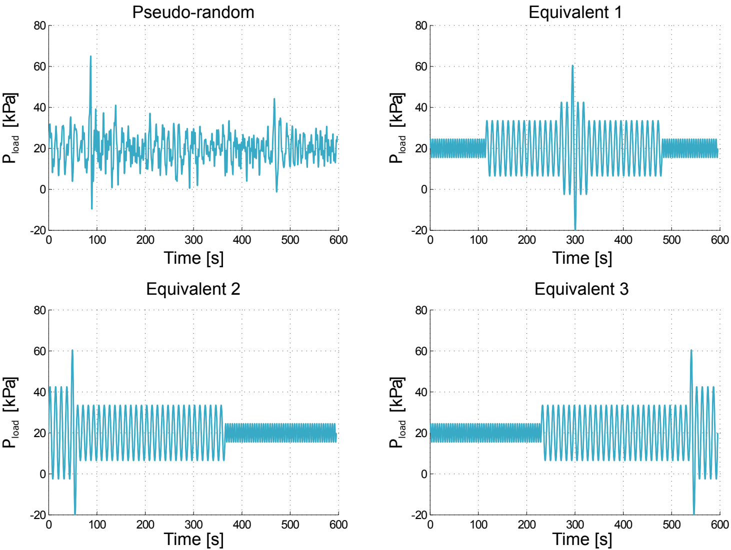
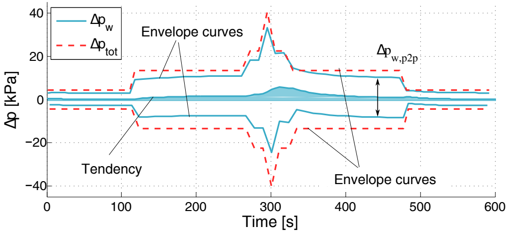
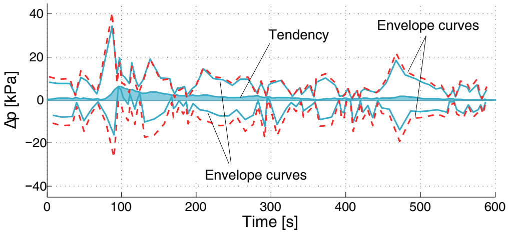


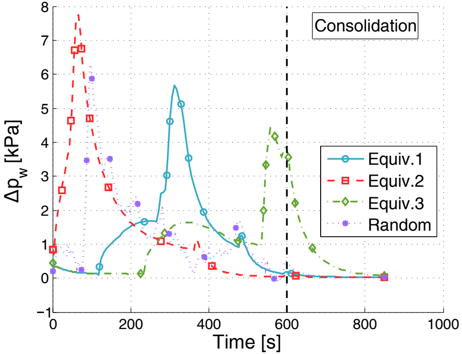
Cyclic partially drained behaviour

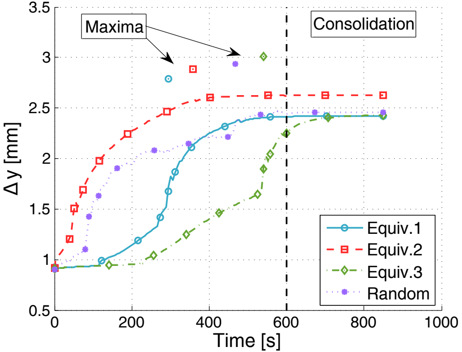




- Envelope and tendency curves : permanent and transient
- Loading mainly sustained by pore water pressure (PWP)
- Accumulation of PWP (max 5kPa)
- Highest accumulation during extreme event

Cyclic partially drained behaviour : displacement and PWP accumulation

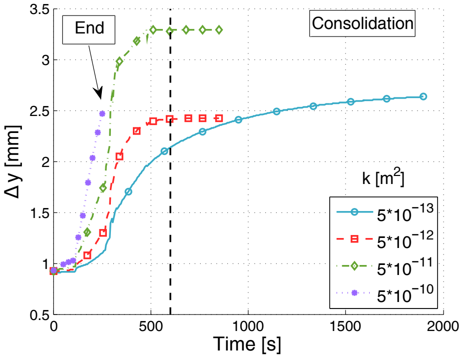


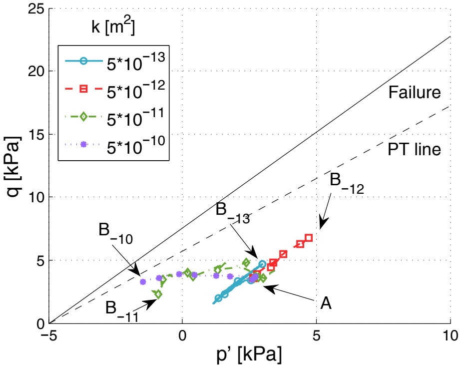


- Max PWP (extreme event sooner)
- Lowest PWP (random)
- Almost no effect of small cycles

- Linear and non-linear parts
- High accumulation for extreme event
- All displacements converge

Cyclic partially drained behaviour : influence of permeability





- No linear trend with permeability evolution
- Local failure for the highest permeability (high effective stress variations)
- Different stress paths under the lid centre with permeability
- Decrease of p' due to PWP increase or contractancy

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- Coupled modelling of a suction caisson upon monotonic and cyclic loading
- Importance of the partially drained behaviour (both monotonic and cyclic)
- Identification of different modes of resistance not activated all at the same time
- Complex behaviour and accumulation of settlement during a short-time storm event

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- Perspectives
  - Calibration procedure and validation of the model
  - Elaboration of a macro-element
  - 3D simulations including lateral loading

References

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