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

B. Cerfontaine, F. Collin and R. Charlier

University of Liege, Belgium

26th of May, 2016
Outline

1. Context
2. Description of the case study
3. Results
4. Conclusions and perspectives
1. Context

2. Description of the case study

3. Results
   - Reaction modes
   - Monotonic simulations
   - Cyclic simulations

4. Conclusions and perspectives
Motivations

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

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

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

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

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

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
Table of contents

1. Context

2. Description of the case study

3. Results
   - Reaction modes
   - Monotonic simulations
   - Cyclic simulations

4. Conclusions and perspectives
Description of the case study

Geometry

Published in Cerfontaine et al. (2016), Géotechnique

Modelling (axisymmetric)
Description of the case study

Geometry

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

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

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

- $n = 0.36$
Description of the case study

Prevost model for cohesionless soils - Kinematic hardening

Implementation in LAGAMINE code published in Cerfontaine et al. (2014) 
*NUMGE2014 Proceedings*
Description of the case study

Prevost model for cohesionless soils - Volumetric behaviour

Non-associated plastic volumetric behaviour

\[ \dot{\varepsilon}_v^p = \frac{1}{3} \cdot \frac{\eta^2 - \overline{\eta}^2}{\eta^2 + \overline{\eta}^2} \cdot \dot{\lambda} \]

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

Very simple (only 1 param.)
\( \Rightarrow \) satisfactory to a 1st approx.
Two distinct behaviours from two initial deviatoric stress invariants

Full calibration process published in Cerfontaine (2014), *PhD thesis*
Description of the case study

Hydro-mechanically coupled interface element

Mechanical behaviour

\[ |t_T| \]

\[ p'_N \]

Plastic surface

Elastic domain

No contact

\[ \mu \]

- Penalty method

Flow behaviour

Side 1

\[ g_N \]

Inside

\[ f_{wt2} \]

\[ f_{wl} \]

\[ f_{wt1} \]

Side 2

Couplings

- Effective stress
- Storage
- Permeability

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

1 Context

2 Description of the case study

3 Results
   • Reaction modes
     • Monotonic simulations
     • Cyclic simulations

4 Conclusions and perspectives
Reaction of the caisson to applied vertical load

**Resistance to compressive load** $\Delta F_{tot}$
- $\Delta F_{in}$, inner friction;
- $\Delta F_{out}$, outer friction;
- $\Delta F_{pw}$, pore water pressure ($> 0$);
- $\Delta F_{top}$, top effective stress;
- $\Delta F_{tip}$, tip effective stress.

**Resistance to extension load** $\Delta F_{tot}$
- $\Delta F_{in}$, inner friction;
- $\Delta F_{out}$, outer friction;
- $\Delta F_{pw}$, pore water pressure ($< 0$).
Table of contents

1. Context

2. Description of the case study

3. Results
   - Reaction modes
   - Monotonic simulations
   - Cyclic simulations

4. Conclusions and perspectives
Monotonic simulations

Monotonic extension simulations (load controlled)

Drained

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

Partially drained (8kPa/s)

- $\Delta F_{in}$ and $\Delta F_{out}$ bounded
- $\Delta F_{in} < \Delta F_{out}$ (unloading)
- $\Delta F_{pw}$ increasing
Pore water pressure generation during extension

\[ P_{\text{load}} = 55.5\text{kPa} \]
Table of contents

1 Context

2 Description of the case study

3 Results
   - Reaction modes
   - Monotonic simulations
   - Cyclic simulations

4 Conclusions and perspectives
Pseudo-random and equivalent loadings

\[ \Delta P_{\text{load}} = 45 \text{kPa} \]

\[ P_{\text{load,av}} = 20 \text{kPa} \]
Results

Cyclic simulations

Pseudo-random and equivalent loadings

Extreme event

$\Delta P_{\text{load}} = 45\text{kPa}$

$P_{\text{load,av}} = 20\text{kPa}$

Half-cycle analysis

B. Cerfontaine, F. Collin and R. Charlier

RUGC2016

26/05/16 17 / 24
Pseudo-random and equivalent loadings

<table>
<thead>
<tr>
<th></th>
<th>Batch 1</th>
<th>Batch 2</th>
<th>Batch 3</th>
<th>Batch 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb. cycles [-]</td>
<td>50</td>
<td>28</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>T [s]</td>
<td>4.6</td>
<td>11</td>
<td>11.6</td>
<td>11.1</td>
</tr>
<tr>
<td>ΔP [kPa]</td>
<td>4.5</td>
<td>13.5</td>
<td>22.5</td>
<td>40.5</td>
</tr>
</tbody>
</table>

ΔP_{load}=45kPa
P_{load,av}=20kPa

Half-cycle analysis
Pseudo-random and equivalent loadings
Cyclic partially drained behaviour

- Envelope and tendency curves: permanent and transient
- Loading mainly sustained by pore water pressure (PWP)
- Accumulation of PWP (max 5 kPa)
- 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
Table of contents

1 Context

2 Description of the case study

3 Results

4 Conclusions and perspectives
Conclusions and perspectives

- 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
Conclusions and perspectives

- 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

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


