Demi-Journée Scientifique et Technique du CFMS
06 OCTOBRE 2022
A procedure to estimate the lateral force in clay-pipe interaction after breakout
A procedure to estimate the lateral force in clay-pipe interaction after breakout

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https://doi.org/10.1051/geotech/2021013

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Introduction

Long subsea pipelines tend to move over time due to temperature variations in connection with interruptions in production.

Displacements occur when the soil/pipe friction is exceeded – Lateral buckling.

If uncontrolled, lateral buckling can create strains and cyclic loads that may cause damage to the flowline.

Source: https://www.upstreamonline.com/upstreamtechnology/anchor-issues/2-1-187160
Introduction

As the pipeline moves, soil berms develop leading to a restriction of lateral pipeline displacements.

Rigid Pipeline diameters from 0.1 m to 1.5 m
Introduction

Objective: to study the lateral clay-pipe interaction
Conditions: at large deformations – this means the formation of berms
Parameters: different burial depths (w/D).

Randolph and Gourvenec, 2011
Centrifuge tests set up - Equipment

LM2C - UFRJ geotechnical centrifuge
Fabricated by Broadbent
Max g-level = 300 g
Diameter= 1.2 m

Model container
0.100 m wide, 0.300 m long and 0.180 m high
Centrifuge tests set up

G-level N=33g – D=0.3 m and 0.5 m
Instrumentation: Pore Pressure Transducer (PPT), Load cells (horizontal and vertical), T-bar for characterization
Soil parameters and model preparation

To obtain two strength profiles, pre-consolidation pressures of

19.7 kPa and 118.4 kPa
Consolidation at N=100 g
Monitoring by LVDT and PPT
Clay Speswhite kaolin

<table>
<thead>
<tr>
<th>Main elements</th>
<th>42.1% of SiO₂; 36.2% of Al₂O₃</th>
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</thead>
<tbody>
<tr>
<td>Atterberg limits</td>
<td>w_L = 54%, w_P = 20%</td>
</tr>
<tr>
<td>USCS classification</td>
<td>CL-CH</td>
</tr>
<tr>
<td>Cam-Clay parameters</td>
<td>λ = 0.107; κ = 0.015; M = 0.93</td>
</tr>
<tr>
<td>Coefficient of consolidation</td>
<td>c_v = 6.48 x 10⁻⁷ m²/s</td>
</tr>
</tbody>
</table>
Soil parameters and model preparation

(a) Profile 1  (b) Profile 2

Undrained shear strength profiles

D=5mm
L=20 mm
Test results: experimental programme

31 centrifuge tests varying the w/D ratio (burial depth) – 25%, 50% and 75%

16 tests on profile 1

15 tests on profile 2

Procedure: Pipe moved laterally forward and backwards for a distance equivalent to 3 diameters and 12 cycles were applied.

\[ v = 0.86 \text{ mm/s and } v = 1.44 \text{ mm/s for the 15 mm and 9 mm diameter pipes.} \]
Test results: Lateral force for w/D = 25% D=0.3m
Test results: Normalized lateral breakout forces versus normalized embedment
Test results: Comparison between Oliveira et al. (2010) (data and linear fit) and lateral normalized force data at breakout

Eq. (1):

\[ H_b = 5 \cdot S_u \cdot D \cdot L \cdot \tan \left( \frac{n_0 W}{D} \right) \]

\( n_0 \) – depends on the soil type 1.0 Guanabara bay clay and 0.5 for Speswhite kaolin
A procedure to evaluate clay-pipe interaction lateral forces: Proposed model of berm increase with \( u/D \)

\[ \alpha = \text{Berm increasing Rate} \]

\[ D_S = f(\alpha, u/D, D) \]

\[ L = \text{length of the pipeline} \]

\[ N_h = 5 \cdot \text{atan}\left(\frac{n_0 \cdot w}{D}\right) + \frac{\chi(a-u)^2}{2} + 2 \cdot S_u \cdot (a \cdot u) \cdot \frac{S_u \cdot L}{L} \]
Comparisons between experimental values (points) and the proposed model for Lateral Normalized Forces (lines)

\[ n_0 = 0.50 \text{ and } a = 0.10 \]
Comparisons between experimental and proposed model values

(a) Profile 1

(b) Profile 2
Comparison between test results and envelopes proposed by Lee et al. (2011)

The horizontal (H) and vertical (V) forces reach very quickly the yield surface, where a hardening phase begins associated with a berm formation in front of the pipe.

a) Profile 1  
b) Profile 2
Conclusions

- The normalized lateral breakout forces were compared with predictions showing a good agreement.

- The tests also proved to be in accordance with envelope curves proposed by Lee et al. (2011) showing that the forces reach very quickly the yield surface, where a hardening phase begins associated with a berm formation in front of the pipe.

- A simplified procedure was presented to estimate the normalized lateral force, taking into account the breakout resistance and the increase in the force due to berm formation.

- Comparisons between the experimental data and the equation proposed in this work show good correlation but further investigation is needed to validate this approach.
Acknowledgements

The authors would like to acknowledge FINEP and TECHNIP for the financial support and the interest in this study. This research was financed in part by the “Coordenação de Aperfeiçoamento de Pessoal de Nível Superior” (CAPES) and by CNPq, Brazilian Research Council.