# Axial pipe model testing

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NGI

# Overview of presentation

- Why investigate pipe model behaviour
- Experience with pipe model testing at NGI
- Current research project
  - Preparation of material and testing equipment
  - Penetration and consolidation
  - Pipe sweeping
  - Analysis
  - Results
- Conclusions

# Why investigate pipe model behaviour

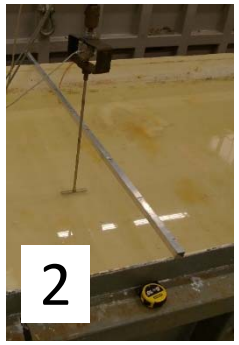
- Movement of pipe line during operational life time
- Drainage conditions
- Mobilised sliding resistance of surface foundation
  - Stability and buckling design of pipeline
- Mobilised friction
- Soil history of movements effects
- Site specific analysis

# Experience and current research at NGI

- Rate effects
- Pause phases
- Roughness effects
- Effective stress

- Soil hardening or softening
- Axial resistance behaviour


1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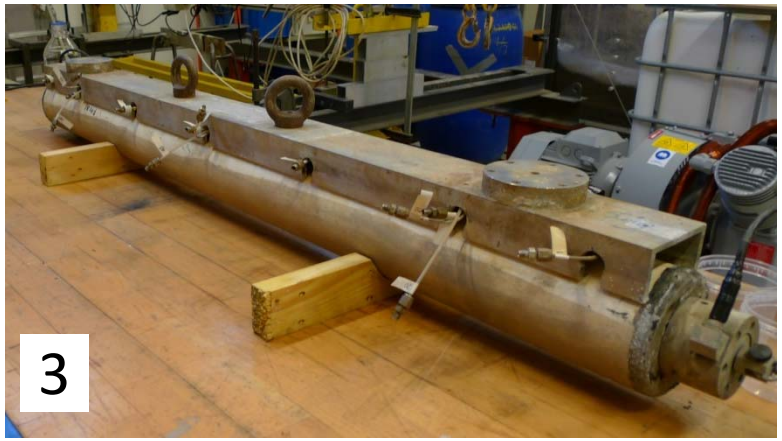
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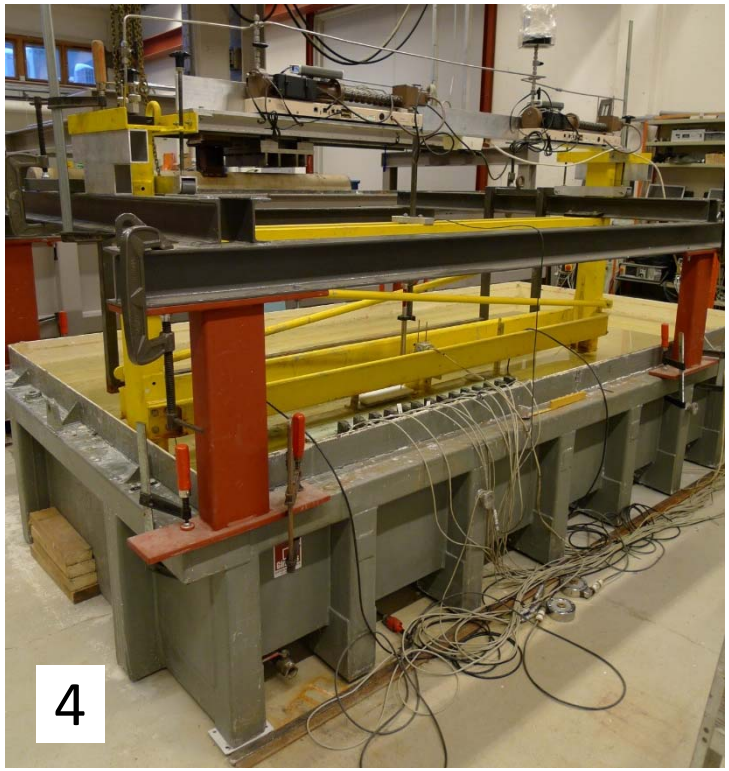
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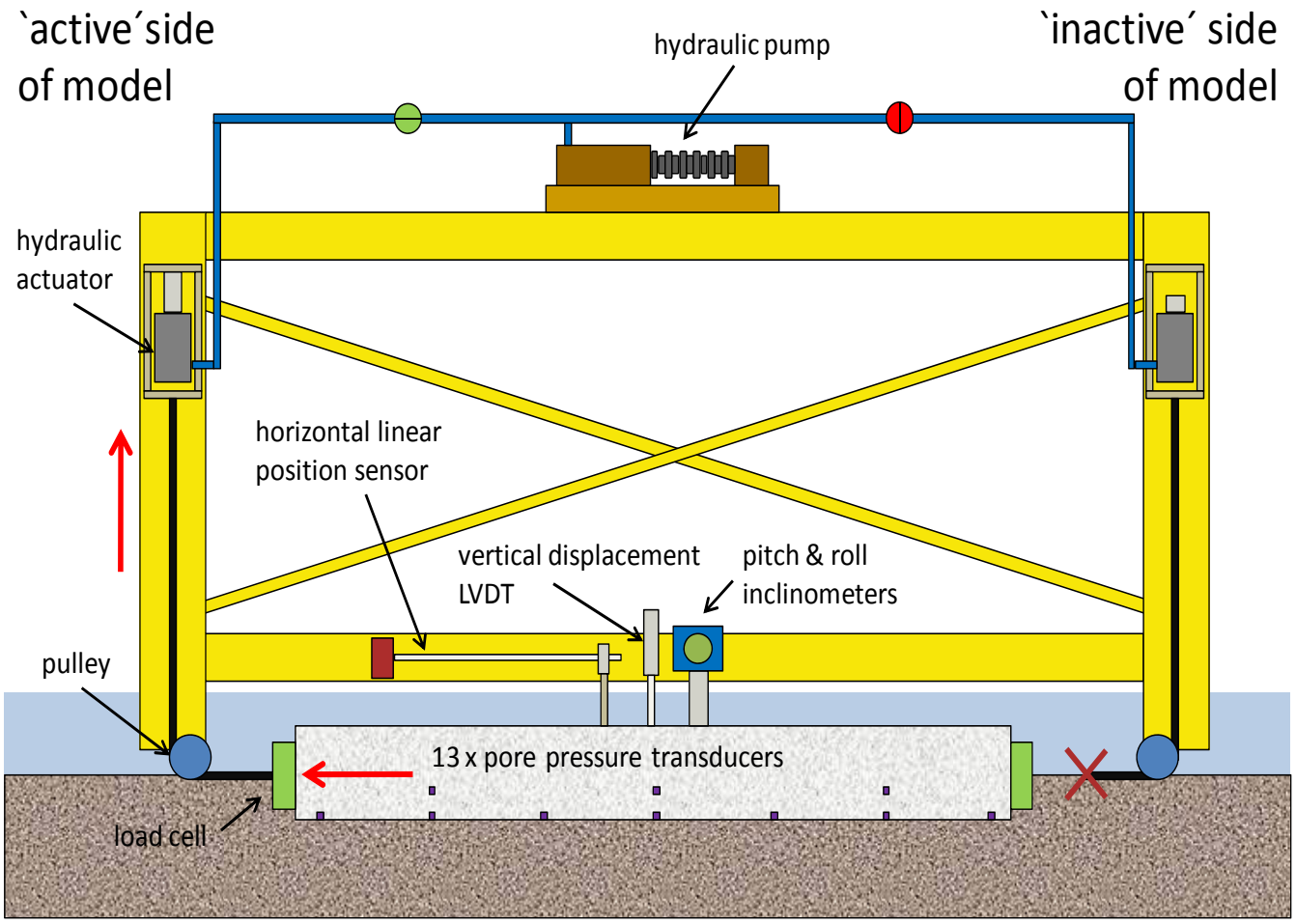
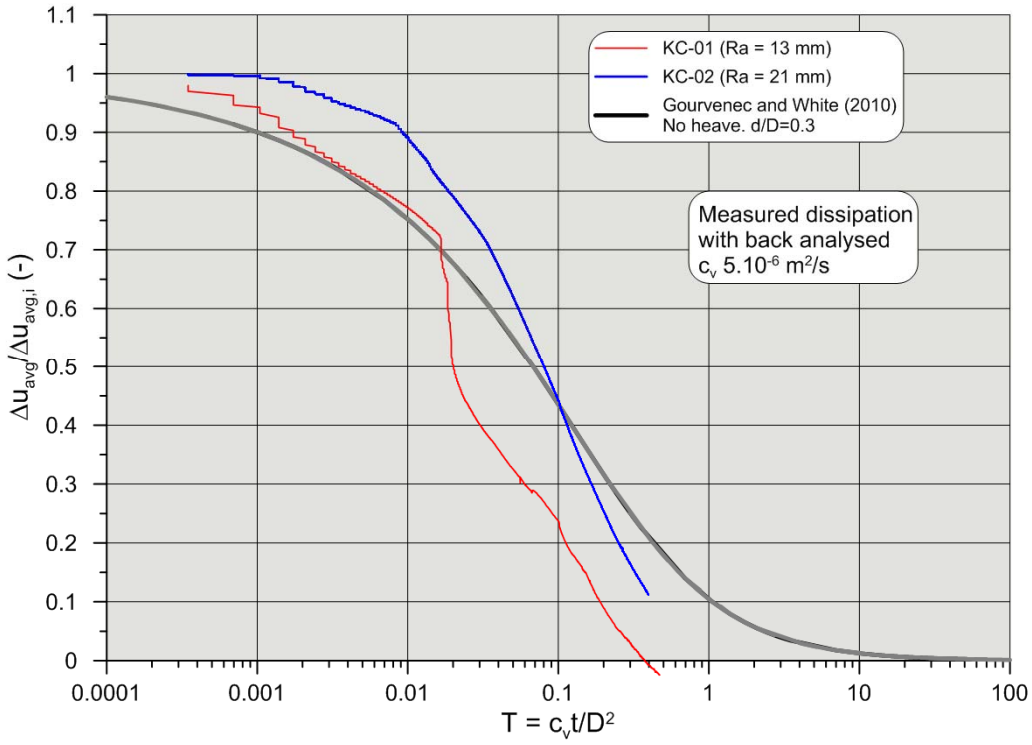
# Material properties and testing equipment

- Kaolin clay powder
- $w_i$ 125 %  (1.85 $w_L$)
- $w_f$ 65 %
- $\sigma'_p$ 35 kPa
- $c_v$ $3.10^{-8}$ – $5.10^{-8}$ $m^2/s$ at 4 kPa
- $I_p$ 36 %
- $s_u$ 1.5-2.5 kPa

- Tank: 3.4 m x 1.75 m
- Consolidation and swelling: 2-3 weeks
- Material depth: 435 mm - 285 mm
- Rates: 0.0005 mm/s – 1 mm/s
- Diameter (D): 0.12 m
- Length: 1.2 m
- Roughness: 13-21 μm
- Embedment: 0.3D


`active´side
of model
hydraulic pump
`inactive´ side
of model
hydraulic
actuator
horizontal linear
position sensor
vertical displacement
LVDT
pitch & roll
inclinometers
pulley
13 x pore pressure transducers
load cell

# Consolidation of pipe model



# Estimation of sliding resistance

- Undrained ‘alpha’ approach*
- Fully drained ‘beta’ approach*

Sliding resistance analysis does not consider

- Change in undrained shear strength ($s_u$) with time
- Effect of rate and duration of movement

* White and Randolph (2007), Oliphant and Maconochie (2007), White and Cathie (2011)

# Axial resistance per unit length (H)

$$H = \alpha \cdot s_u \cdot A_s$$

As a proportion of the undrained shear strength of the soil acting on the pipe-soil contact surface

**$\alpha$ = undrained adhesion coefficient**

$s_u$ = undrained shear strength of the soil

$A_s$ = pipe-soil contact area per unit length of pipeline

$$H = \mu \cdot N$$

As a sum of the normal forces acting around the pipe multiplied by the pipe-soil interface friction coefficient

**$\mu$ = pipe-soil interface friction coefficient**

N = $\zeta \cdot V$ = total normal force per unit pipe length

where:

- $\zeta$ = factor to account for enhancement of the normal pipe-soil contact force due to 'wedging' action
- V = vertical load per unit pipe length

3 pipe soil interface friction coefficients assessed:

- Effective stress, pipeline and total stress ($\mu'$, $\mu$, $\mu_\zeta$ ). Latter influenced by $\Delta$u.

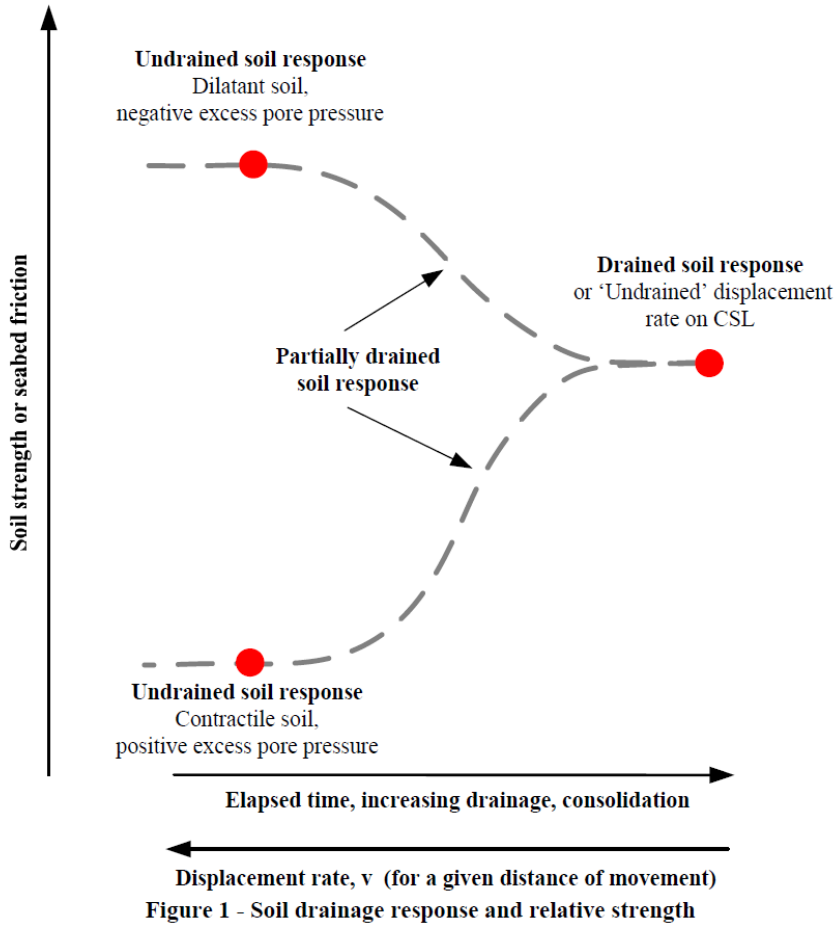



**Figure 1 - Soil drainage response and relative strength**

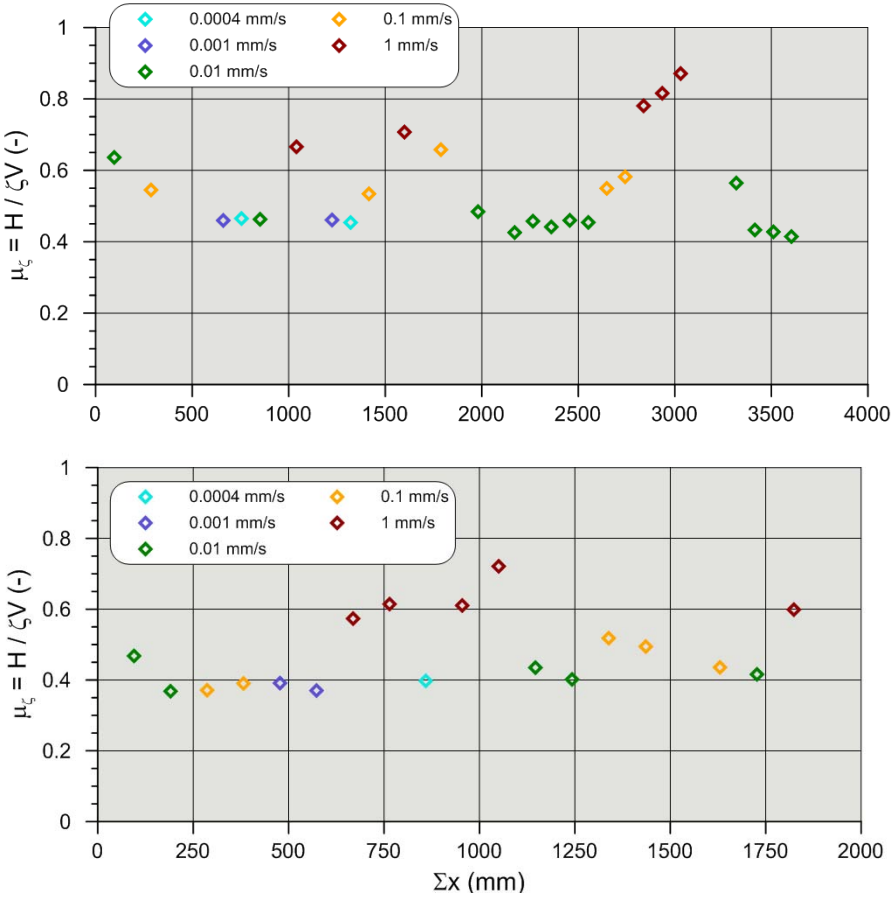
Boylan et al. (2014)

# Friction coefficients versus cumulative axial displacement

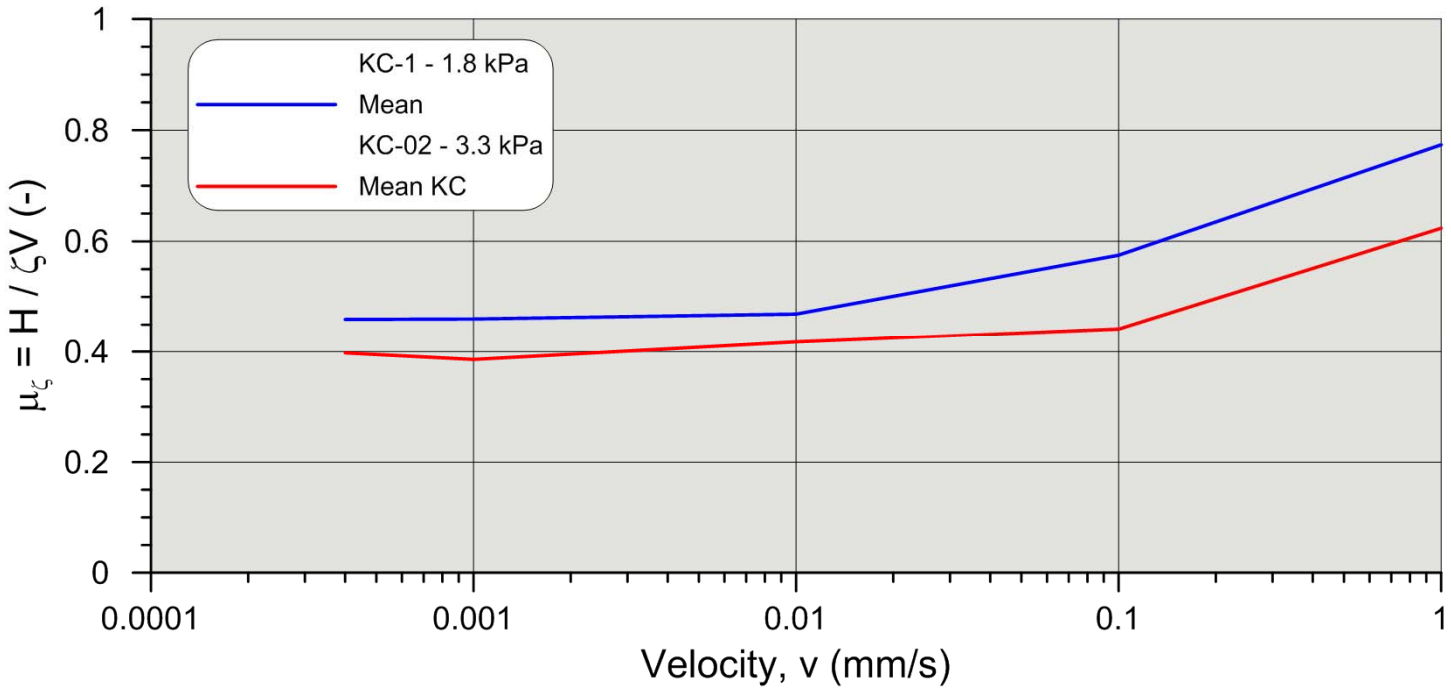
Upper: V/D - 1.8 kPa

Lower: V/D – 3.3 kPa

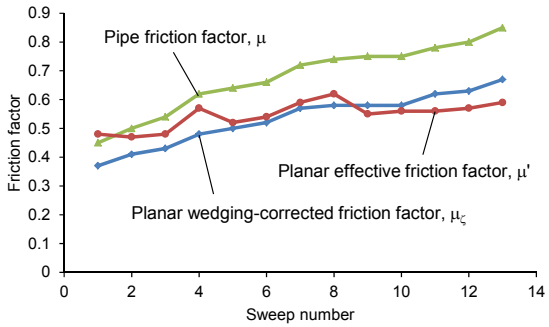
Variation in rates



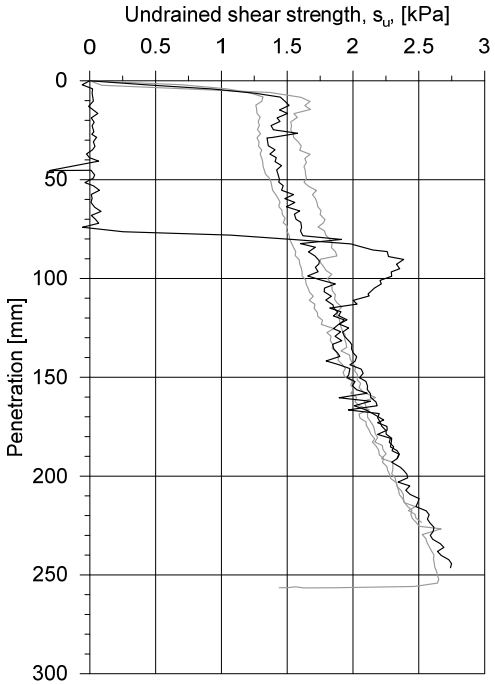
# Friction coefficient and velocity

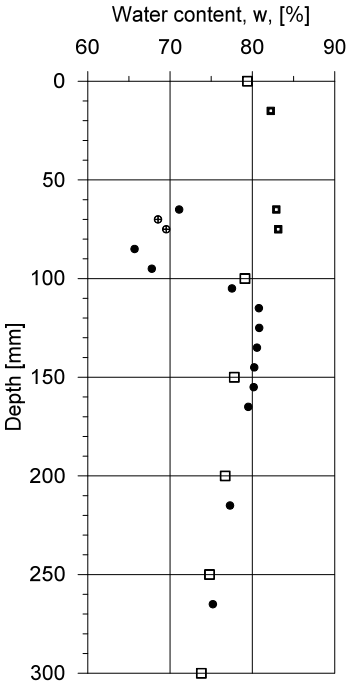


# Before and after pipe model testing




Volumetric soil hardening




Smith and White (2014)

# Conclusions

- Site specific analysis – friction and resistance
  - Improved design and appropriate mitigation measures
- Account for change in $s_u$
- Include analysis for rate, time and consolidation
- Established framework
- Publish experience for verification
  - Interpretation or back calculation of field observations
- Universal soil for research comparison

# Acknowledgements


- Offshore Division NGI
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