Detrimental Effects of Lateral Soil Movements on Pile Behaviour

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Sustainable Technologies

science + technology + innovation

KNOW ING

Active vs Passive piles

a) Relatively few attempts have been made to distinguish pile behaviour subjected to active and passive loadings quantitatively

b) Limiting soil pressure p_y proposed by Poulos and Davies (1980) and Broms (1964) for a laterally loaded pile (active) have been used for the analyses of passive piles subjected to lateral soil movement caused by embankment loading (Goh et al., 1997) and excavation (Poulos and Chen, 1997), even though the former is a loading process while the latter is an unloading process

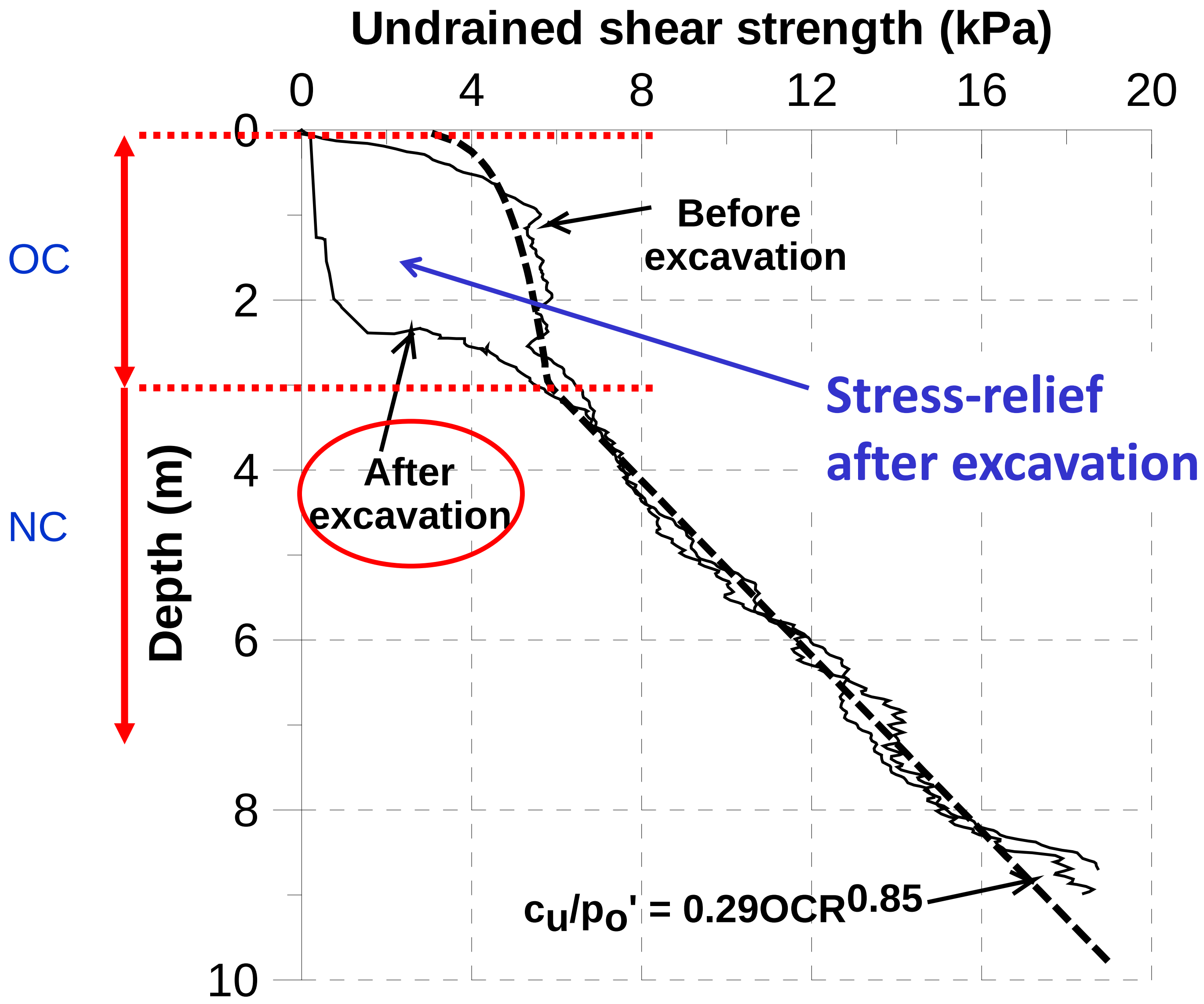
c) The main reason many researchers tried to relate p_y to the methods proposed by Poulos and Davies (1980) and Broms (1964) is because of its simplicity of use

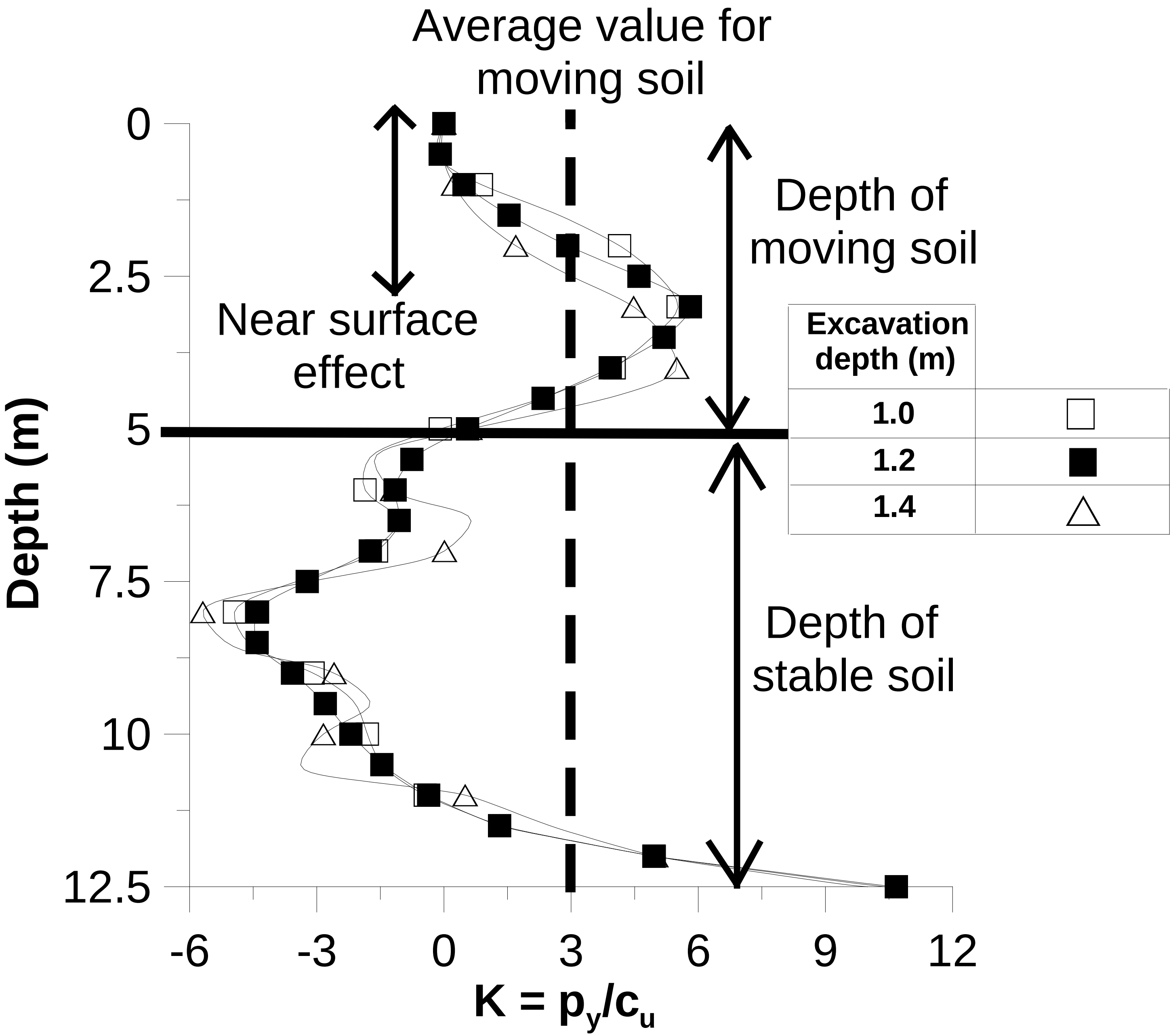
d) **But are the p_y for active and passive piles similar?? If not, how are they different?**

“Controversial” issues regarding limiting soil pressures on piles

Reference	$K = p_y/c_u$ value	Method of analysis	Situation	Type of loading on pile
Chen and Poulos (1994)	11.4 for piles near a cut	2-D FEM	Similar to piles used for landslide stablisation	Passive
Viagianni (1981)	2.8-4 (sliding soil) 8 (stable soil)	Empirical	Piles used for landslide stabilisation	Passive
Maugeri et al. (1994)	3.33 (sliding soil); 6.26 (stable soil	Empirical, field data	Piles used for landslide stabilisation	Passive
Chow (1996)	3-4 (sliding soil); 8-12 (stable soil)	Empirical, numerical	Piles used for landslide stabilisation	Passive
Poulos and Chen (1997)	9	Empirical	Piles adjacent to an **excavation**	Passive
Goh et al. (1997)	9	Empirical	Single pile adjacent to **embankment**	Passive

T-bar tests carried out in the centrifuge





Average value for moving soil
Near surface effect
Depth of moving soil
Depth of stable soil
Excavation depth (m)
1.0
1.2
1.4
Depth (m)
0
2.5
5
7.5
10
12.5
-6
-3
0
3
6
9
12
K = p_y/c_u

Some comparison of K values for the analysis of active and passive piles

1) General application
Active; K=8.24 – 11.14
Passive; K=4 - 11.94

2) Laterally loaded piles
Active; K=8.28 – 12.56

3) Small scale test
Passive; K=1.7 – 8.6

4) Embankment loading
Passive; K=4 - 10

5) Landslide and creeping slopes
Sliding soil - Passive;
K=3 – 6.26
Stable soil
K= 8 – 12

Closer to the case of landslide

6) Collapsed excavation
Soil flow, tension crack;
Passive; K=???

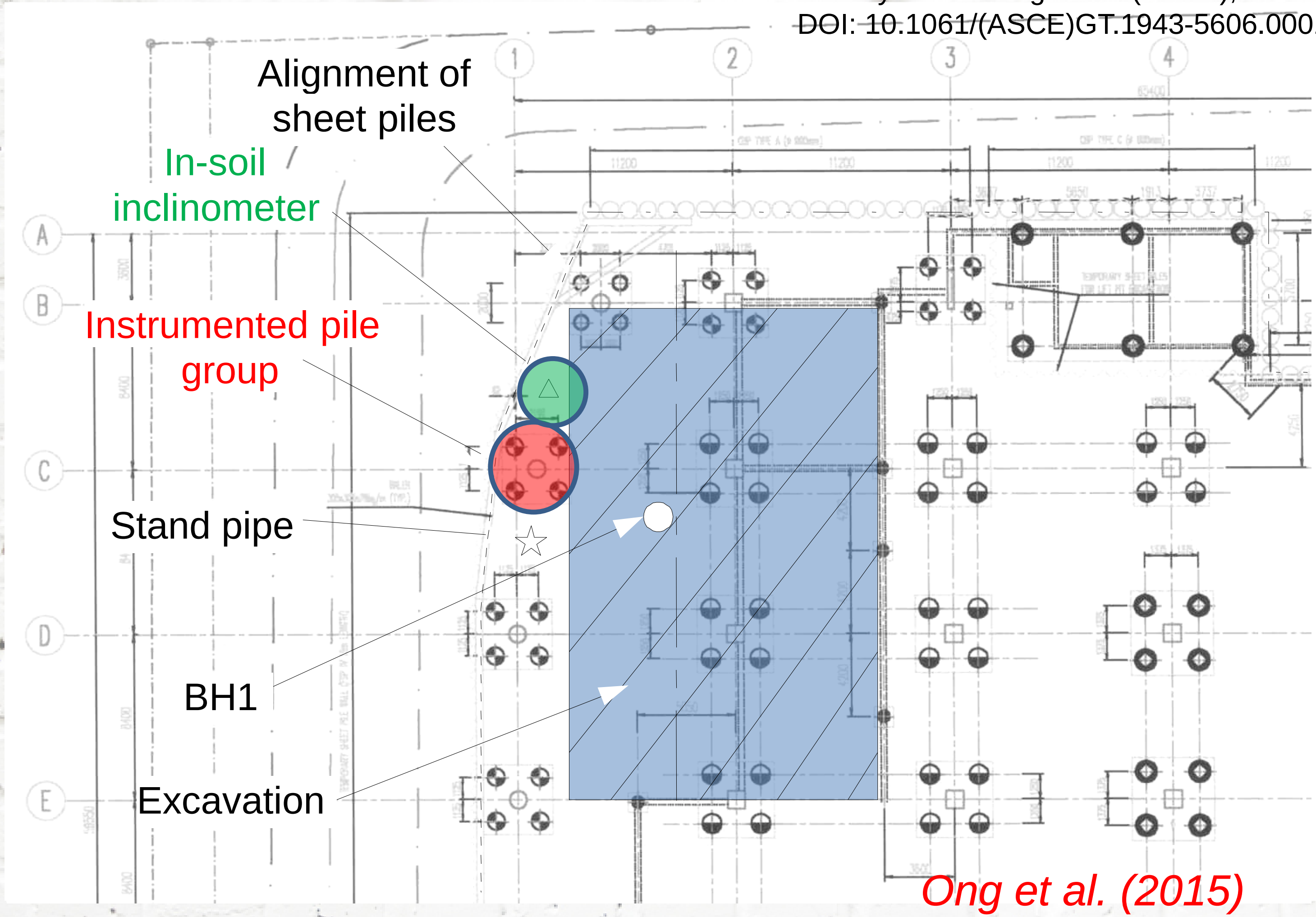
K=0 (near surface effect) – 6.5 with average of about 3.0

Case Study 1

Failure of 4-pile group due to slope movement

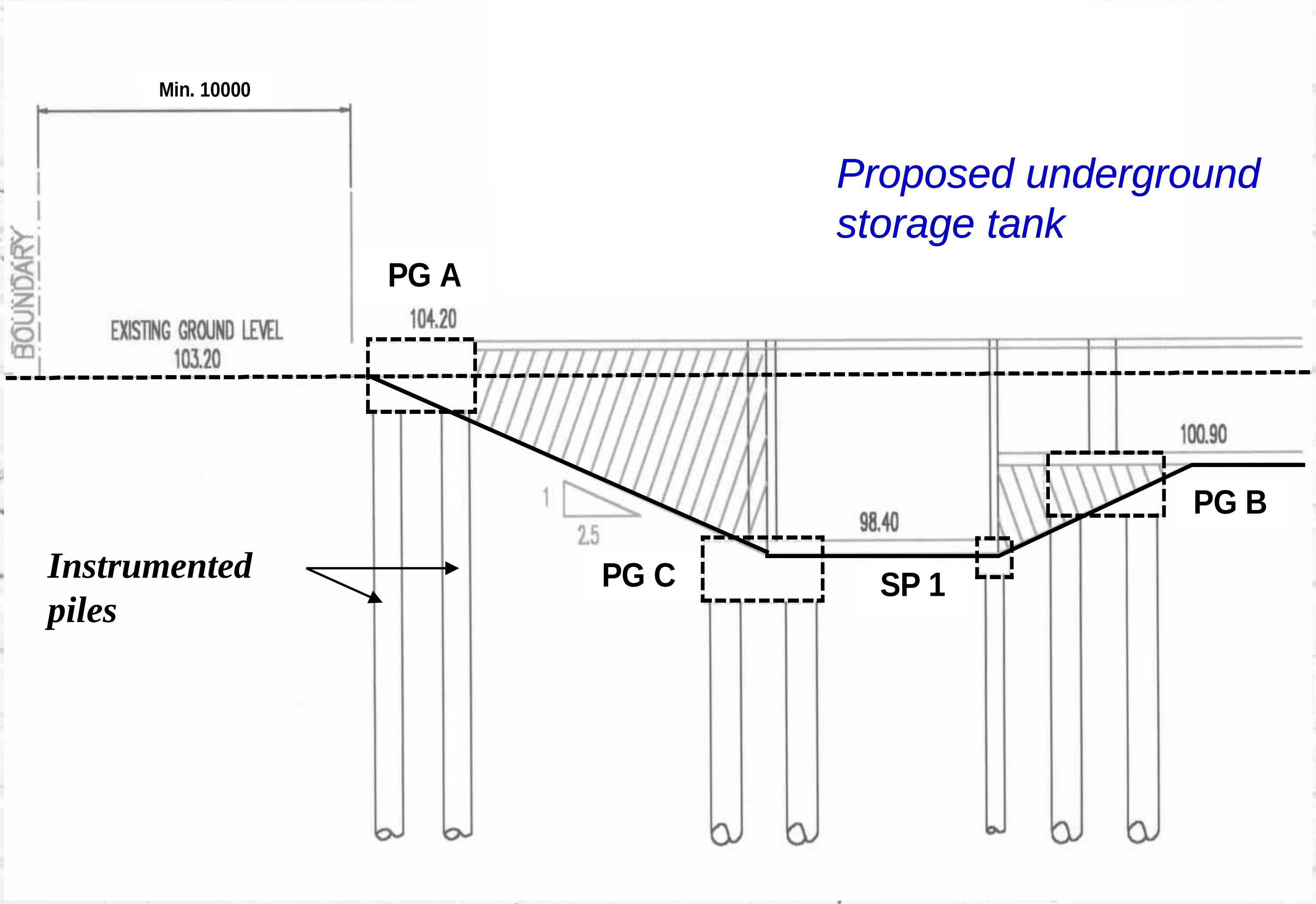
Site layout

Ong, D.E.L., Leung, C.F., Chow, Y.K. and Ng. T.G. (2015). "Severe Damage of a Pile Group Due to Slope Failure". Journal of Geotechnical and Geoenvironmental Engineering, American Society of Civil Engineers (ASCE), Vol. 141, No. 5, 04015014, DOI: 10.1061/(ASCE)GT.1943-5606.0001294



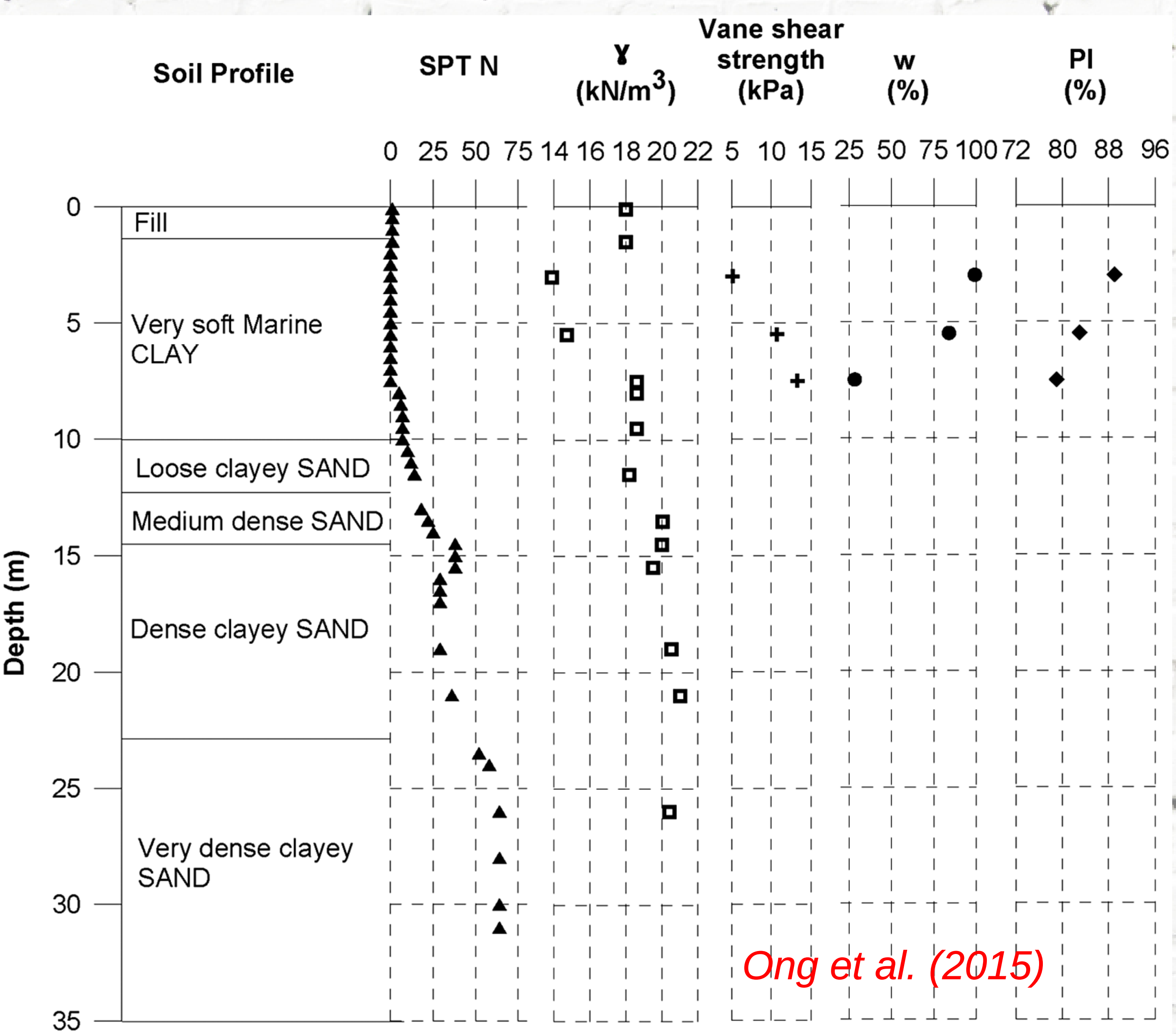
Plan view showing the locations of instruments and instrumented pile group at the site

Proposed excavation for construction of underground storage tank



Ong et al. (2015)

KNOW ING



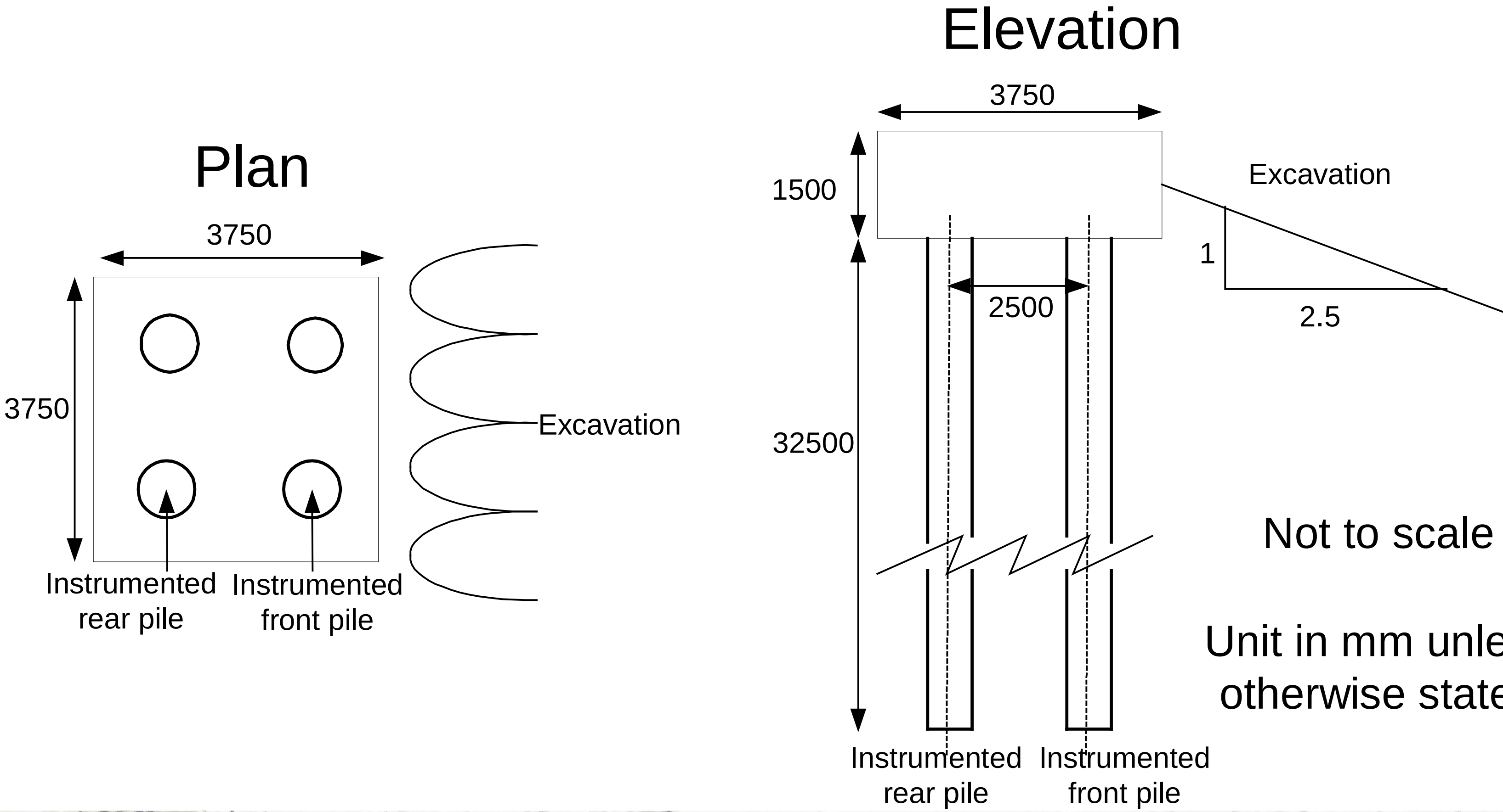
Interpreted subsurface soil profile at site

Instrumentation – strain gauges

Strain gauges fastened on reinforcement cage of bored piles

Ong et al. (2015)

Configuration of instrumented piles

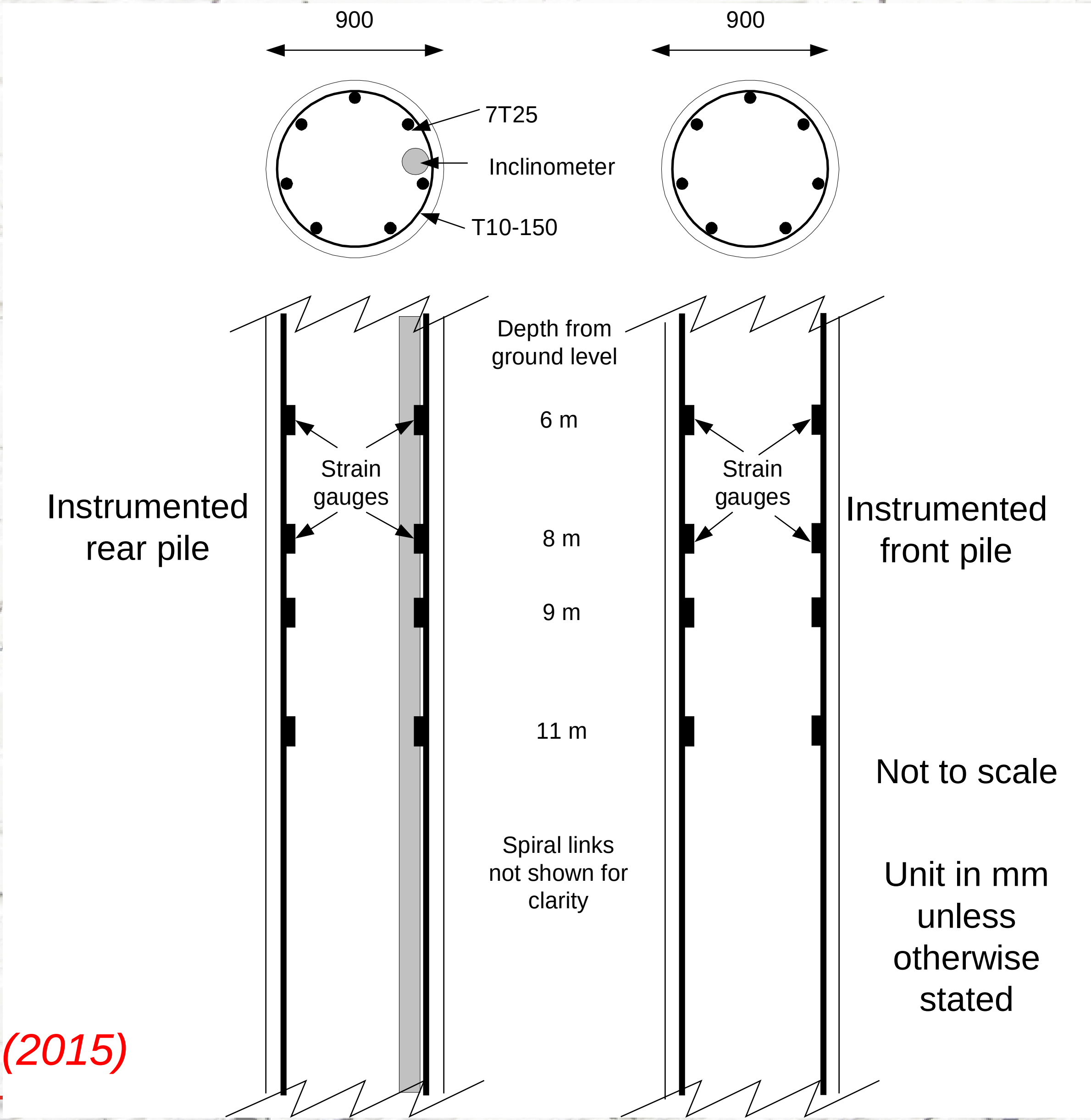


Not to scale

Unit in mm unless otherwise stated

Ong et al. (2015)

Layout of instruments



Ong et al. (2015)

Construction sequence (2) – Unanticipated slope failure around instrumented pile group

Unexpected** slope failure next to instrumented pile group due to **heavy overnight rain

Ong et al. (2015)

Construction sequence (4) - Unanticipated large soil movement

***Struts** are installed when soil movement showed no sign of reduction (neither sheet piles nor struts were proposed in the original design)*

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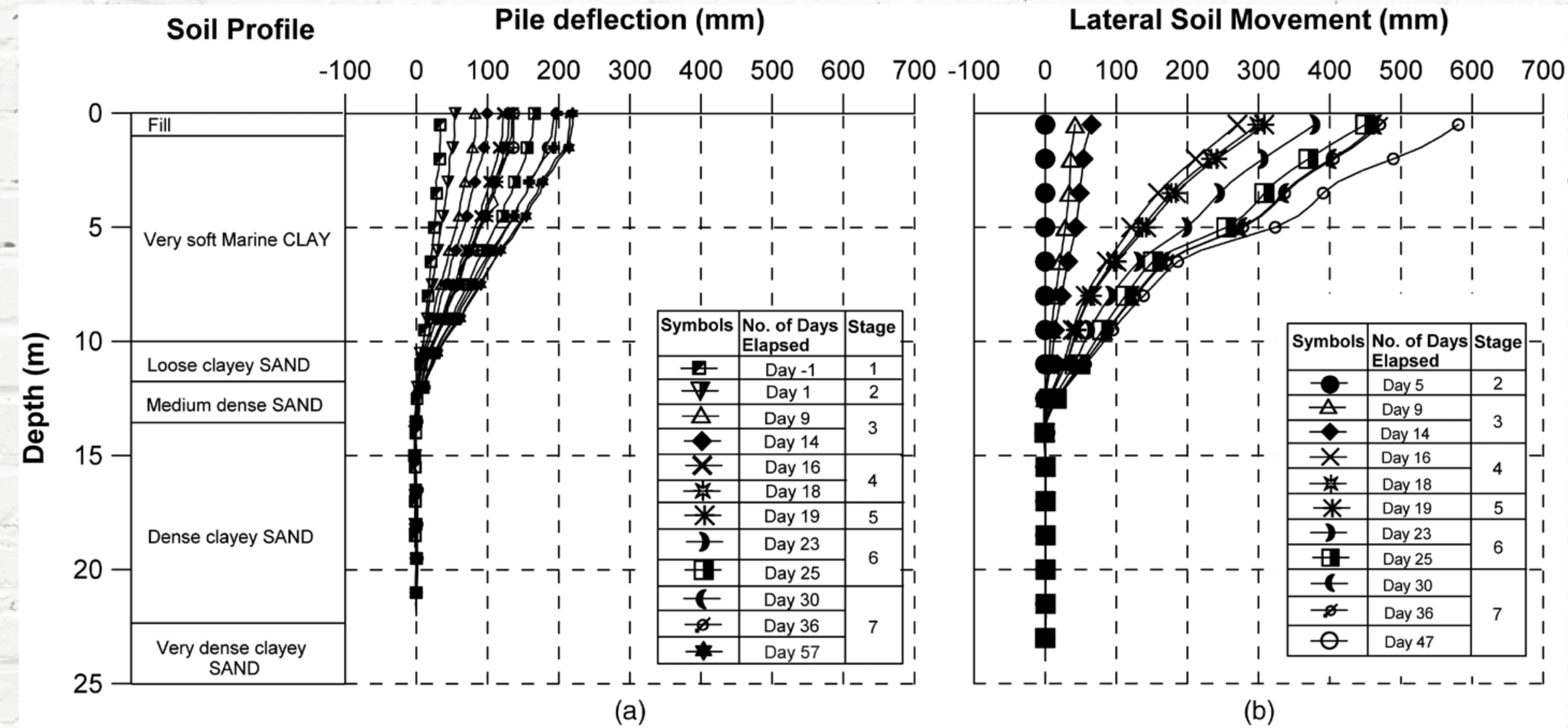
Ong et al. (2015)



Measured (a) rear pile deflection (b) lateral soil movement profiles over the excavation period

Ong et al. (2015)

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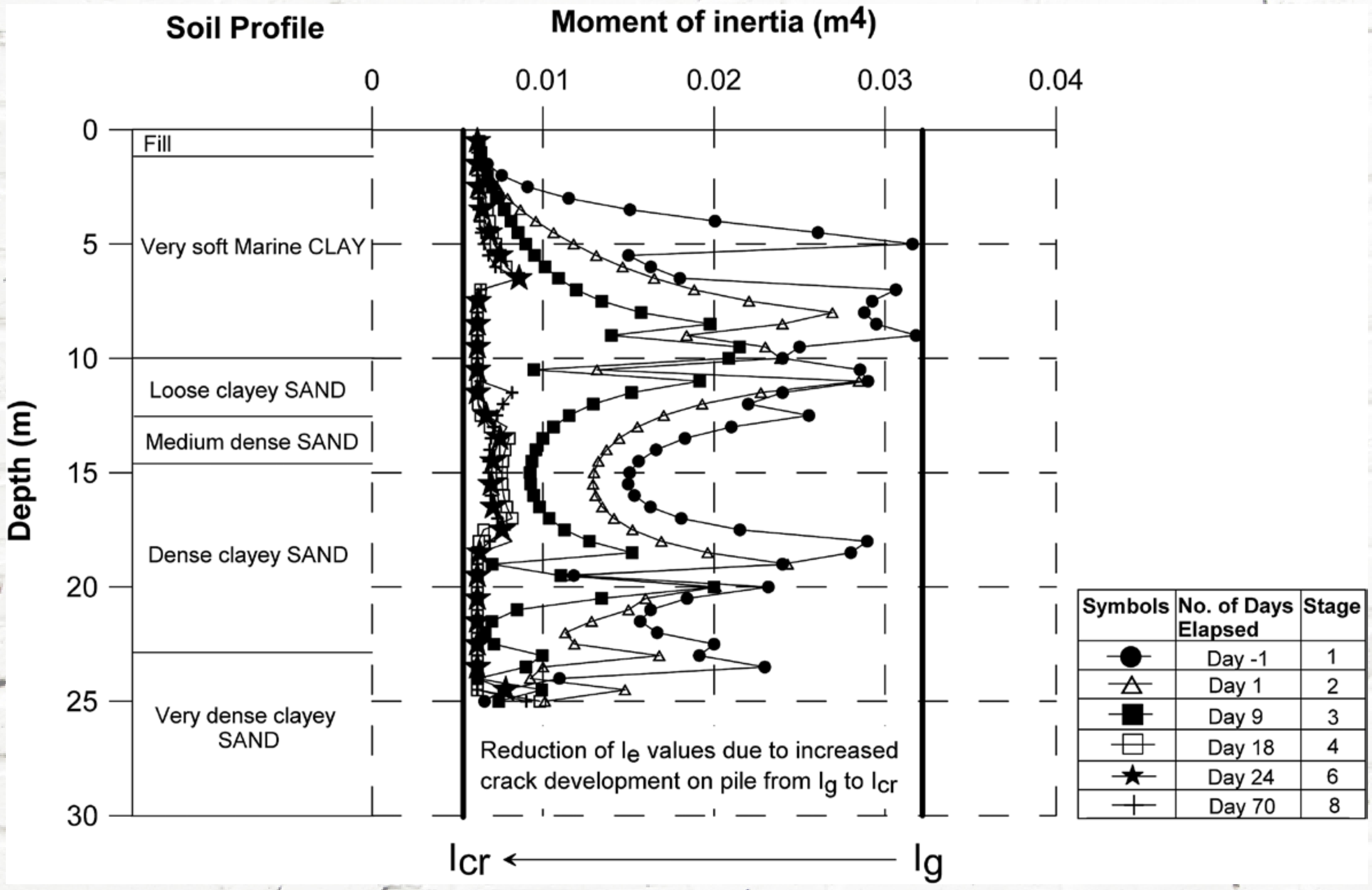
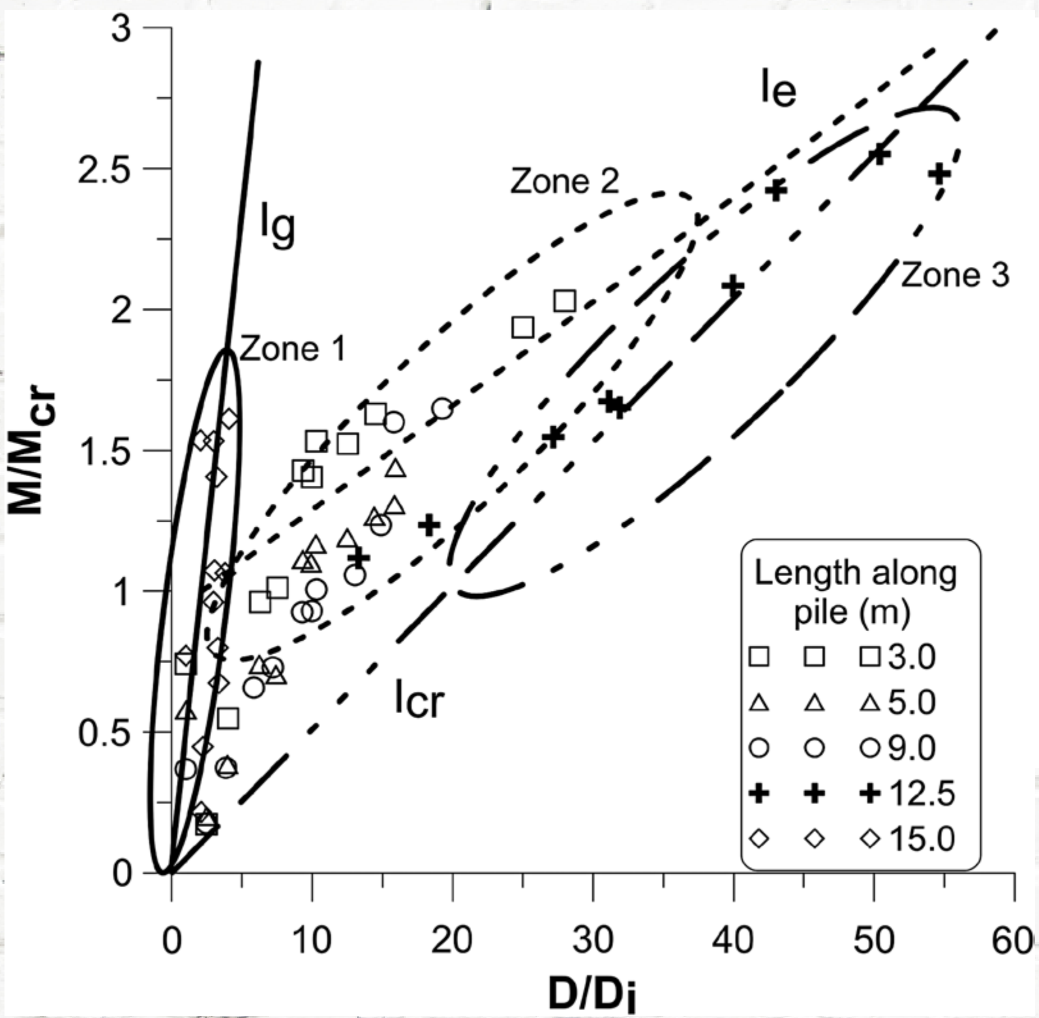
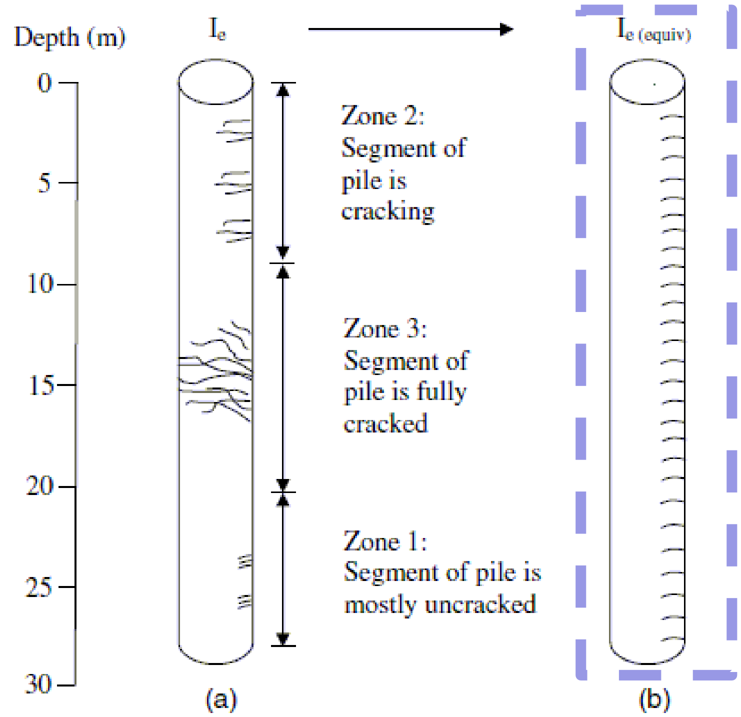


Computed profiles of effective moment of inertia, I_e, along the instrumented rear pile over the excavation period

Ong et al. (2015)



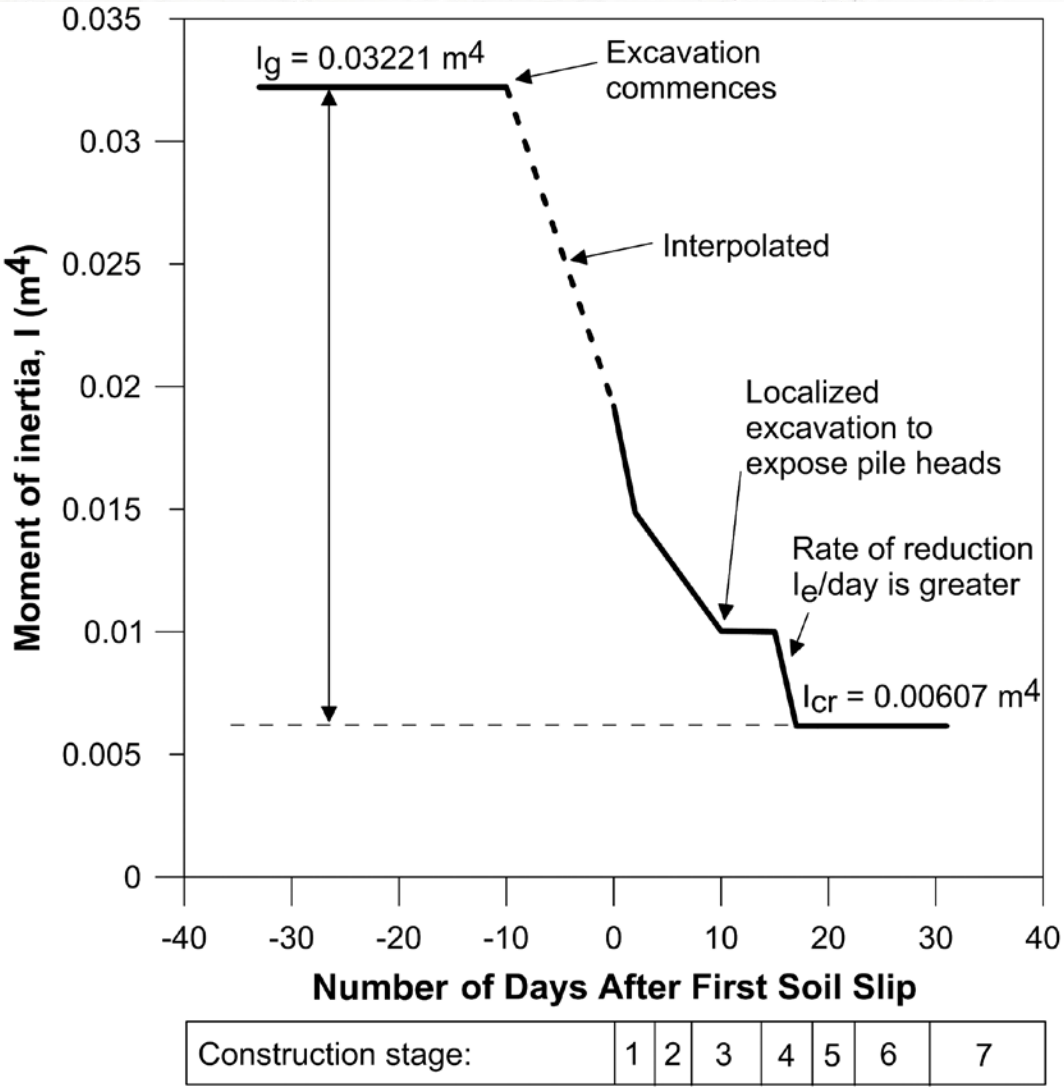
Interpreted **bilinear moment-deflection** curve



a) Possible development of different crack intensities on the instrumented pile;

(b) idealized cracked pile used for back-analysis

Ong et al. (2015)



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Deterioration of pile moment of inertia after soil slip

Ong et al. (2015)

Attributes of various analytical methods

Methods of analysis	***Source of soil movement as input***	***Limiting soil pressure***
Method 1: *2-D FE analysis & method of smearing of 3-D pile properties*	*FE analysis*	***Cannot*** *be considered*
Method 2: *Established numerical method*	*Field in-soil inclinometer*	*Can be considered*

Method 1

2-D FE analysis & method of smearing of 3-D pile properties

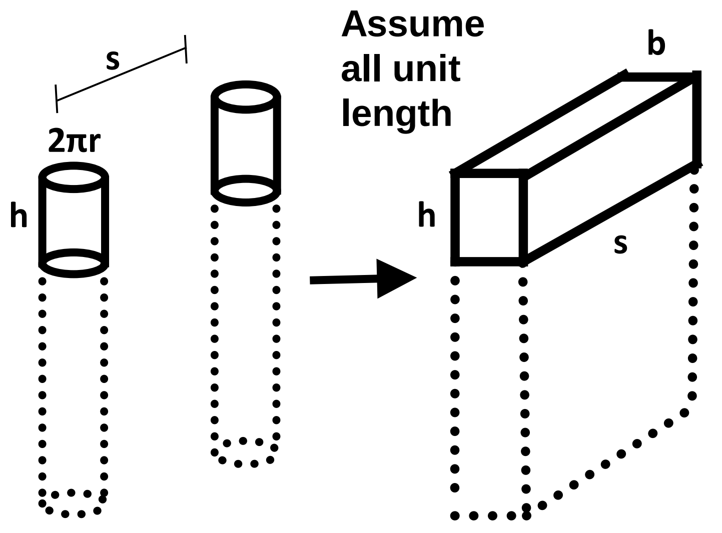
Pile group

Pile property	**2-D equivalent wall**
Axial rigidity	$n(E_pA_p)/[(n-1)(s)]$
Bending rigidity	$n(E_pI_p)/[(n-1)(s)]$

n = no. of piles

s = pile spacing in plane-strain direction

Pile response	**Quantity per linear m of wall as output**	**Conversion to quantity per pile**
Bending moment	BM in kNm/m	BM*[(n-1)*s]/n to obtain kNm
Axial or shear forces	F in kN/m	F*[(n-1)*s]/n to obtain kN



Ong, D.E.L., Leung, C.F., and Chow, Y.K. (2007). "Effect of Horizontal Limiting Soil Pressures on Pile Behaviour". 16th South-East Asian Geotechnical Conference (SEAGC), 8-11 May 2007, Kuala Lumpur, Malaysia. pp. 427-437.

Method 2

Established numerical method (Ong et al., 2006)

Concept of analysis

Single pile (Chow and Yong, 1996)

– based on FEM where pile is represented by beam elements and soil is idealised using modulus of subgrade reaction

$$\left(\left[K_p\right]+\left[K_s\right]\right)\left\{y\right\}=\int_0^L K_h\left\{N\right\}y_o(z)dz$$

Pile element matrix ($[K_p]$)

Soil element matrix ($[K_s]$)

Lateral soil movement ($\{y\}$)

Induced lateral forces acting on the pile as a result of lateral soil movement

Ong, D.E.L., Leung, C.F. and Chow, Y.K. (2006). "Pile behaviour due to excavation-induced soil movement in clay: I: Stable wall". Journal of Geotechnical and Geoenvironmental Engineering, American Society of Civil Engineers (ASCE), Vol. 132, No. 1, pp. 36-44.

Pile BM analysis

Differentiation

Pressure ⇆ Shear ⇆ ψ ⇆ Rotation ⇆ Deflection

Integration (with BCs)

$$M = \psi E_c I$$

Curvature; obtained from measured deflection profile or from SG

Young's modulus of concrete

Moment of inertia; will vary according to degree of cracking

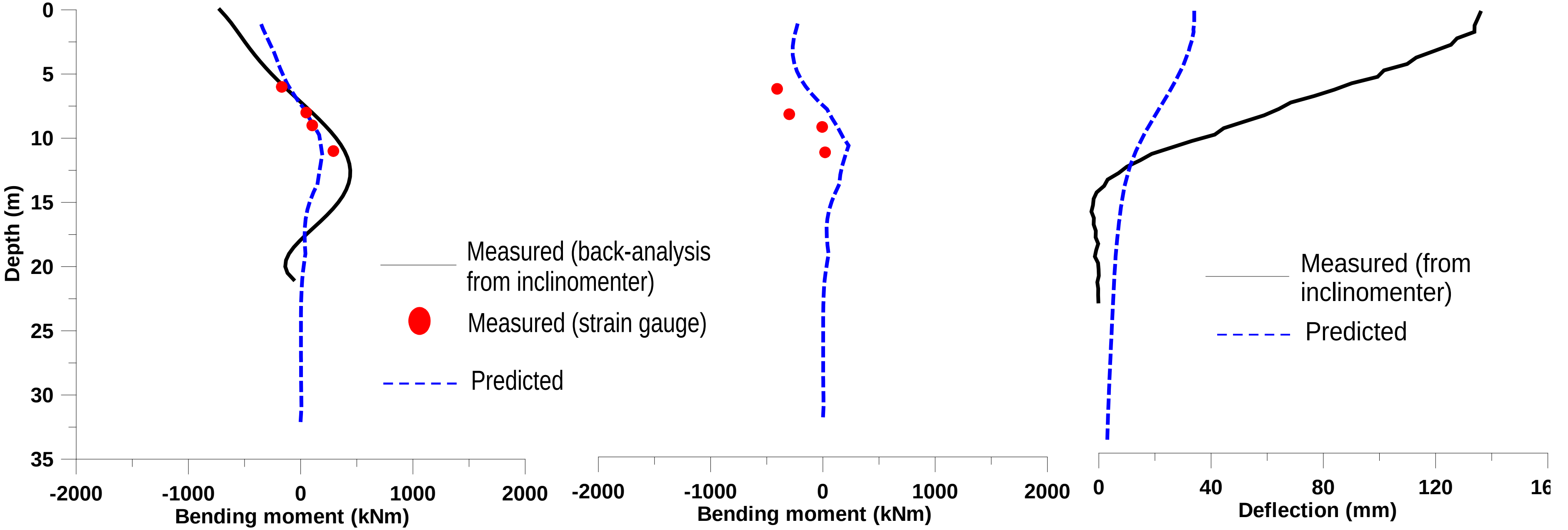
Analyses of cases performed

Analysis cases	***Pile:*** ***I_g or I_{cr}***	***Limiting pressure, p_y***
Case 1 (Method 1): *simulates ignorance of soil flow phenomenon*	I_g	*Not considered*
Case 2 (Method 2): *simulates available knowledge on I and p_y*	I_{cr}	p_y=6c_u
Case 3 (Method 2): *simulates available knowledge on p_y but not on I*	I_g	p_y=6c_u
Case 4 (Method 2): *simulates absence of knowledge on I and p_y*	I_g	p_y=K_h

Ong, D.E.L., Leung, C.F. and Chow, Y.K. (2010). “Effect of limiting soil pressure on pile group adjacent to a failed excavation”. Proc. of International Conference on Geotechnical Challenges in Megacities, Vol. 3, pp. 785-792, 7-10 June 2010, Moscow, Russia.

Case 1 (Method 1): FEM – 2-D smearing of pile

Simulates ignorance of soil flow phenomenon



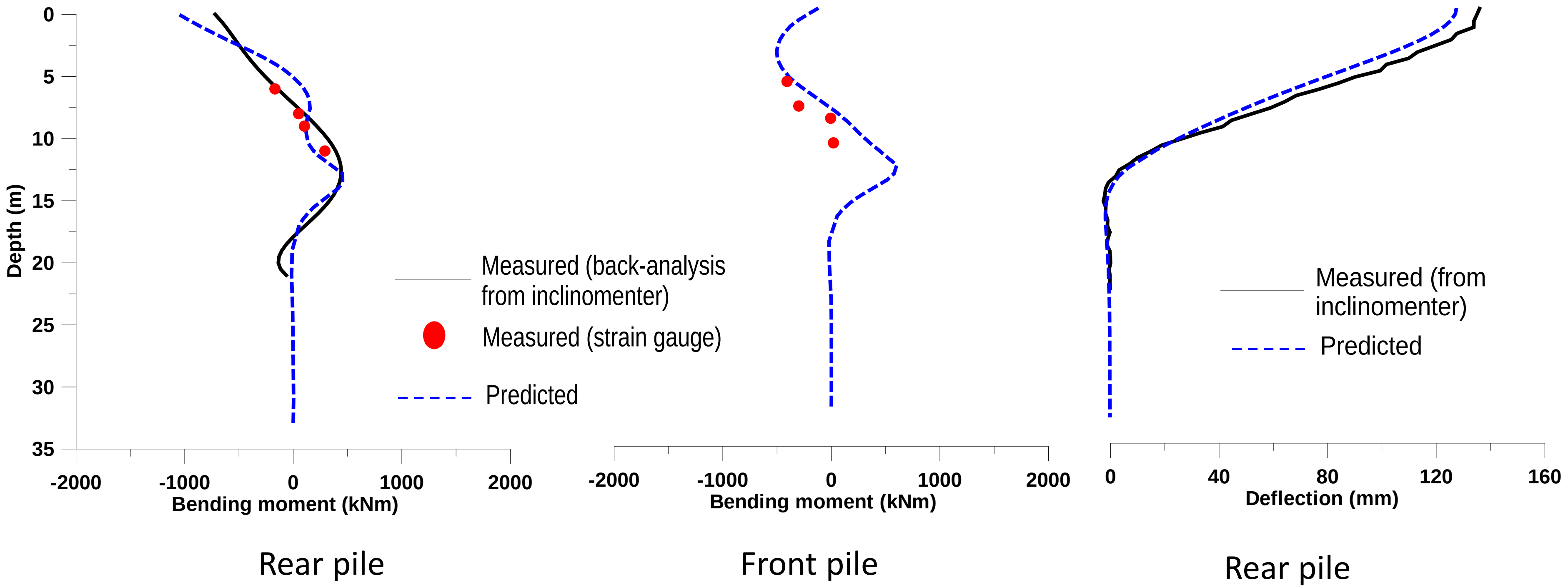
Rear pile   Front pile   Rear pile

Predicted pile responses (BM and deflection) are both very much under-predicted, leading to inappropriate design of pile to resist lateral soil movement.

Ong et al. (2010)

Case 2 (Method 2): Established numerical method

Simulates available knowledge on I and p_y

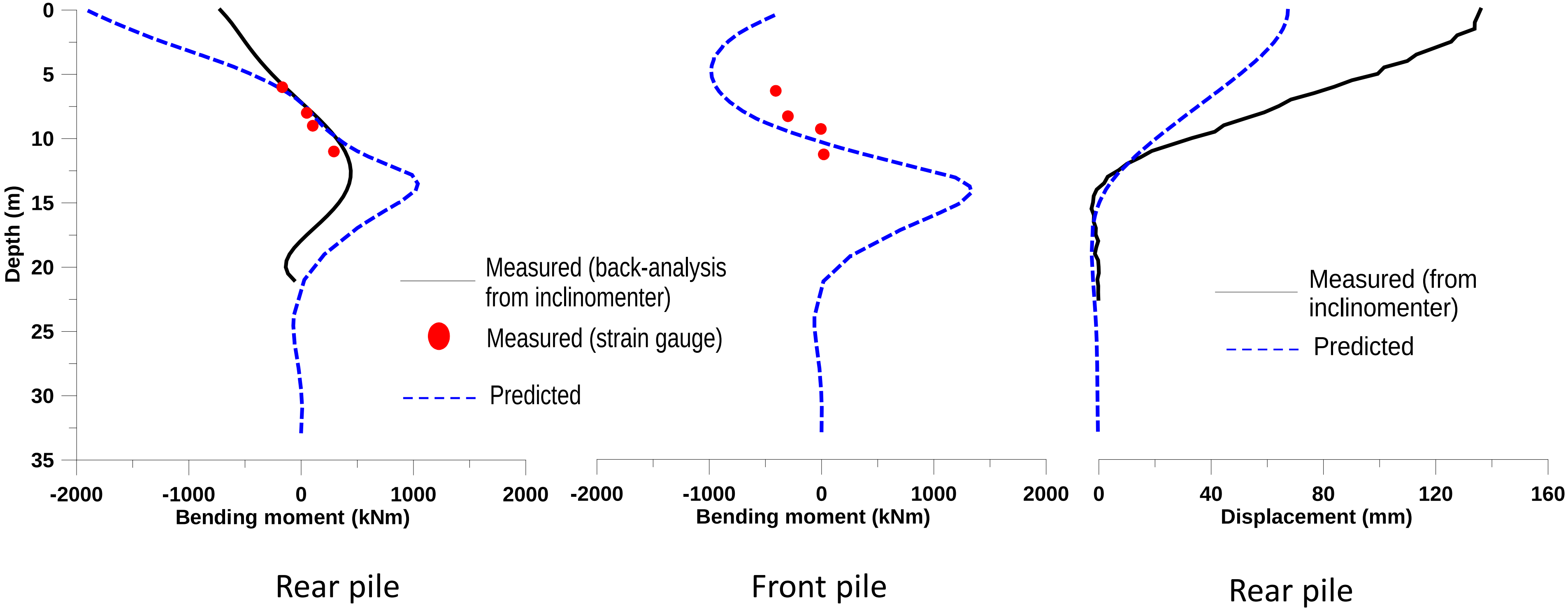


If both I_{cr} and p_y are correctly adopted, the prediction of pile responses is very reasonable. This simulates the available and appropriate level of understanding of the back-analysis carried out considering the development on site.

Ong et al. (2010)

Case 3 (Method 2): Established numerical method

Simulates available knowledge on p_y but not on I



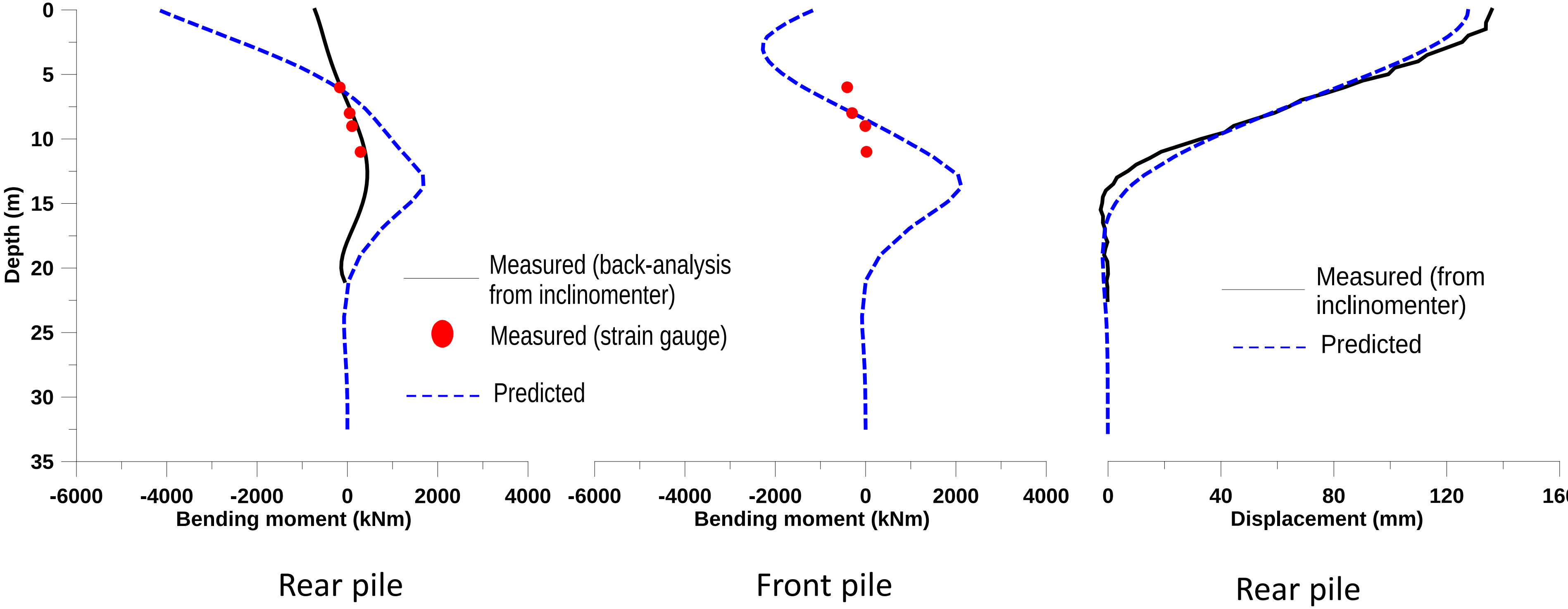
The pile BM tends to be over-predicted, but the deflection is under-predicted. This is due to the pile being assumed to be uncracked (much stiffer) thus attracting high BM and low deflection, which does not simulate the behaviour on site as the pile cracking capacity has already been exceeded (as shown previously).

This highlights the importance of estimating the pile condition on site when performing back-analysis.

Ong et al. (2010)

Case 4 (Method 2): Established numerical method

Simulates absence of knowledge on I and p_y



If the back-analysis is carried out without having prior knowledge of estimating limiting soil pressure and pile moment of inertia, I on site, the predicted pile bending moment will be grossly over-predicted. The 'reasonable' estimation of pile deflection is merely a coincidence.

Ong et al. (2010)

Case Study 2: Challenges in riverine construction

Challenges in riverine construction

"Remains" of a collapsed wharf

Challenges ahead

- Riverine infrastructure failures pose risks to public and require high remedial costs
- Only few studies examined the effects of repetitive soil movements due to tidal fluctuations on piles

Objective

- Understand the response of an individual single pile subjected to repetitive soil movements due to tidal fluctuations

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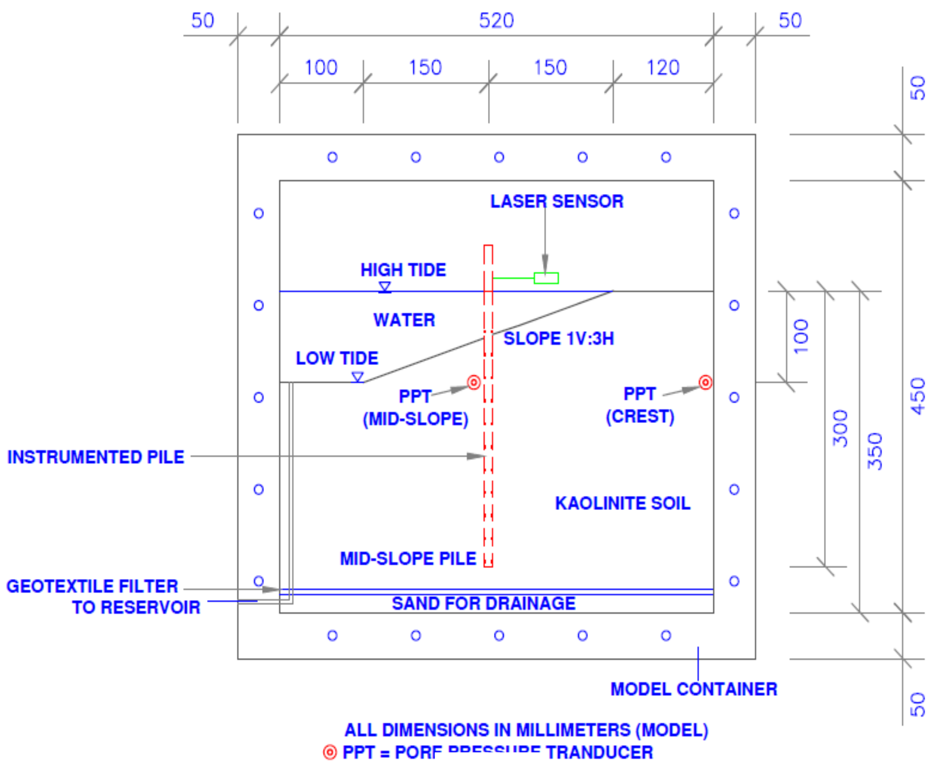
Centrifuge model



(a)

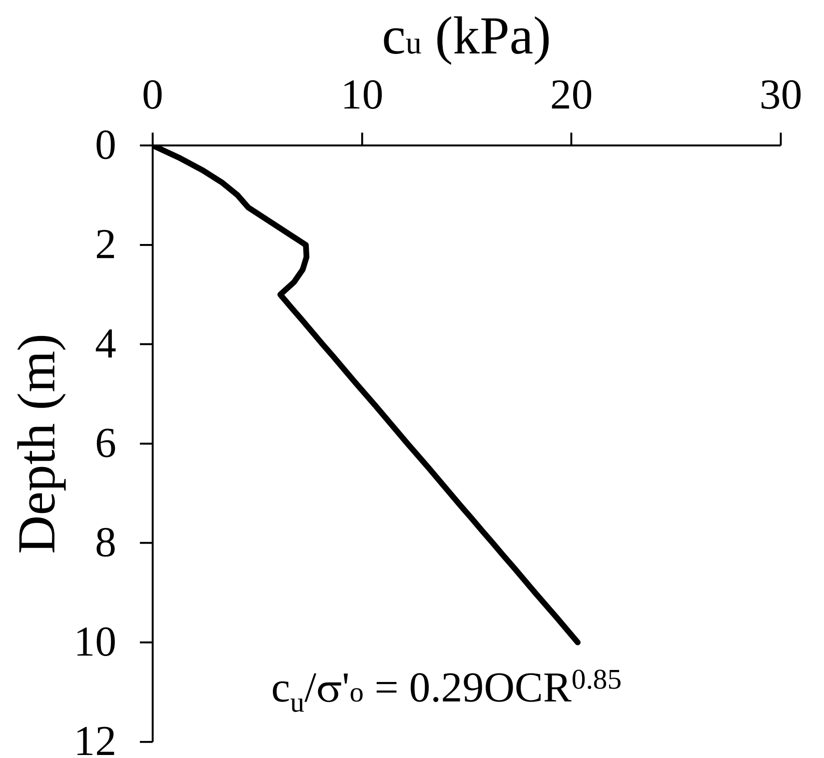
Test Procedure

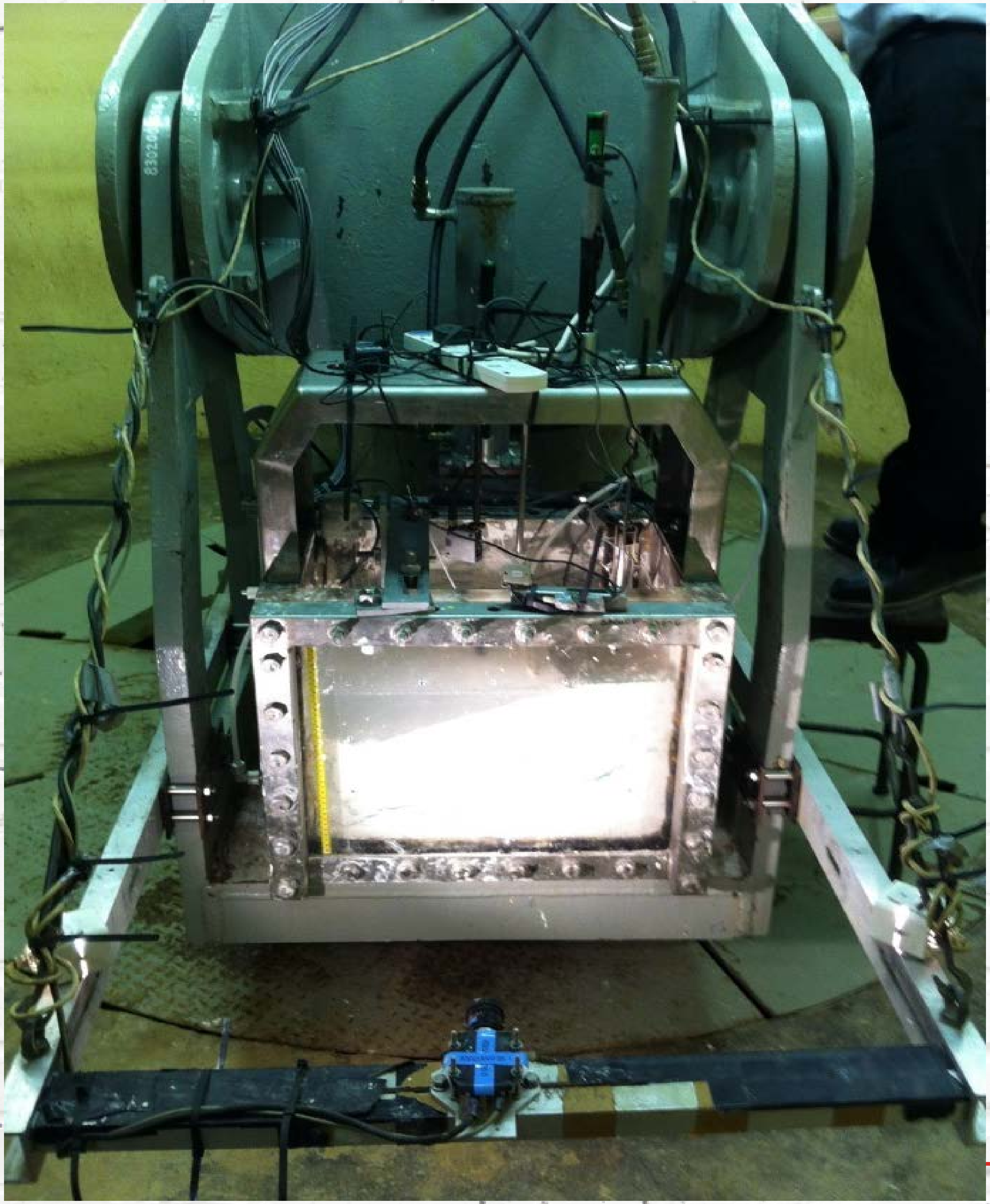
Model pile

- Hollow square aluminium tube: 10 mm sides, 1 mm thick
- 10 strain gauges
- Pile is 350 mm (17.5 m) with an embedment depth of 250 mm (12.5 m) at mid-slope
- EI = 212.2 kNm^2
- Simulates a 600 mm dia. G35 concrete bored pile

Model soil

- OC crust
- Mainly NC
- Slope gradient 1V:3H
- 5m height & 15m length
- Beads for PIV analysis





Complete model set up

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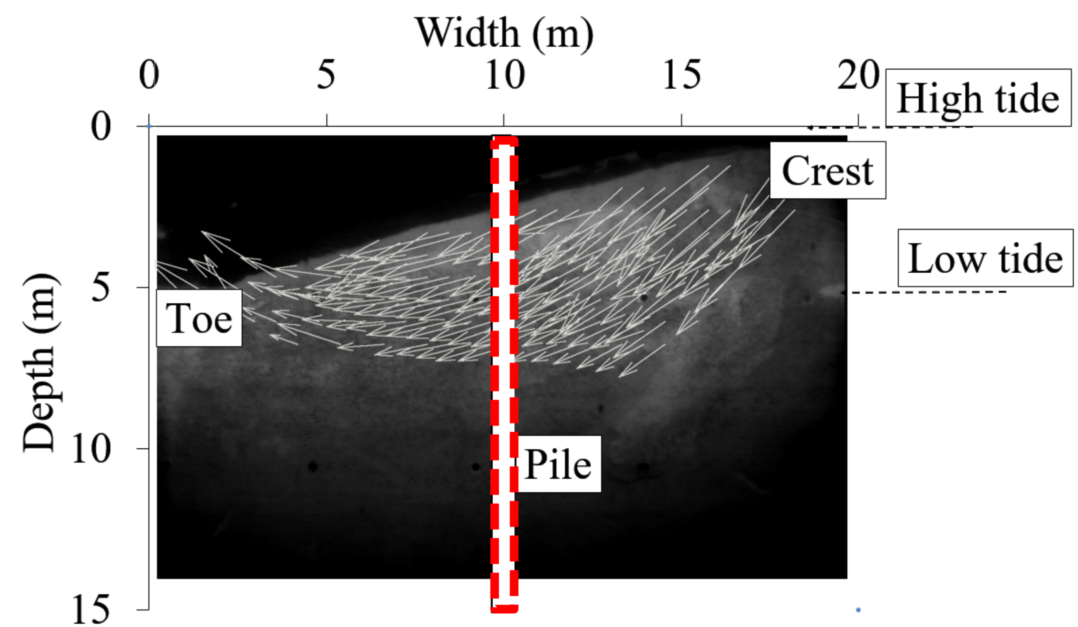
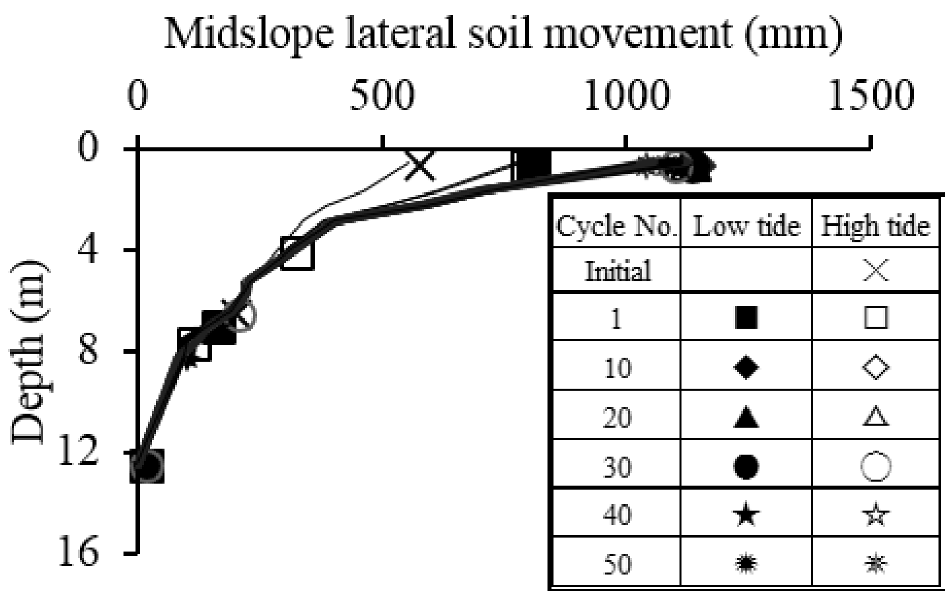
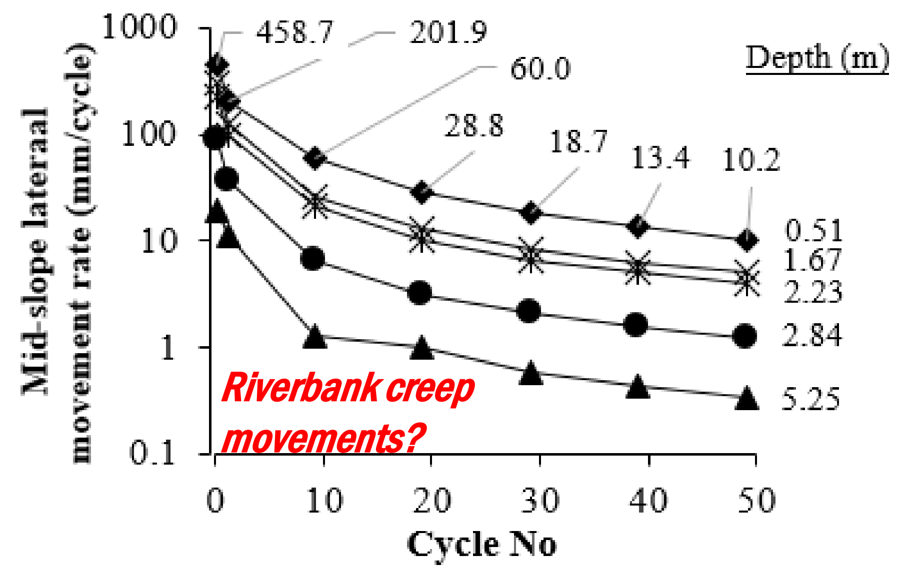
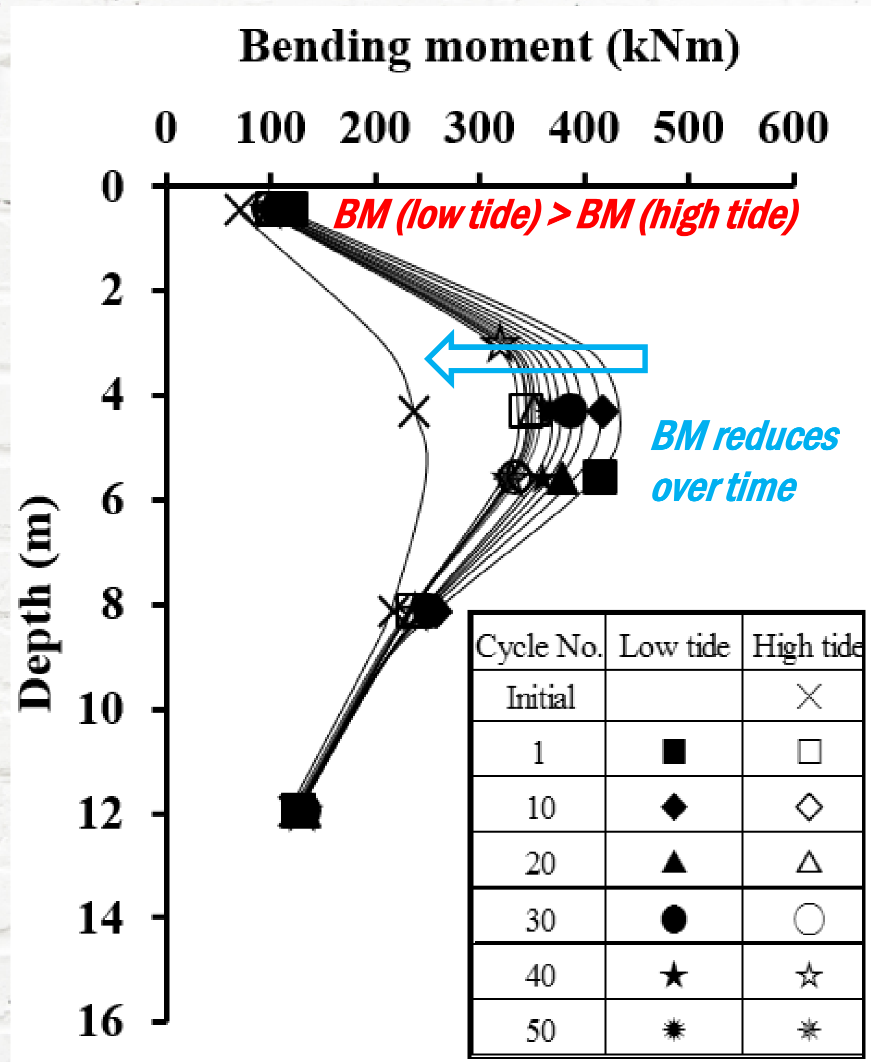
Free-field lateral soil movement by PIV

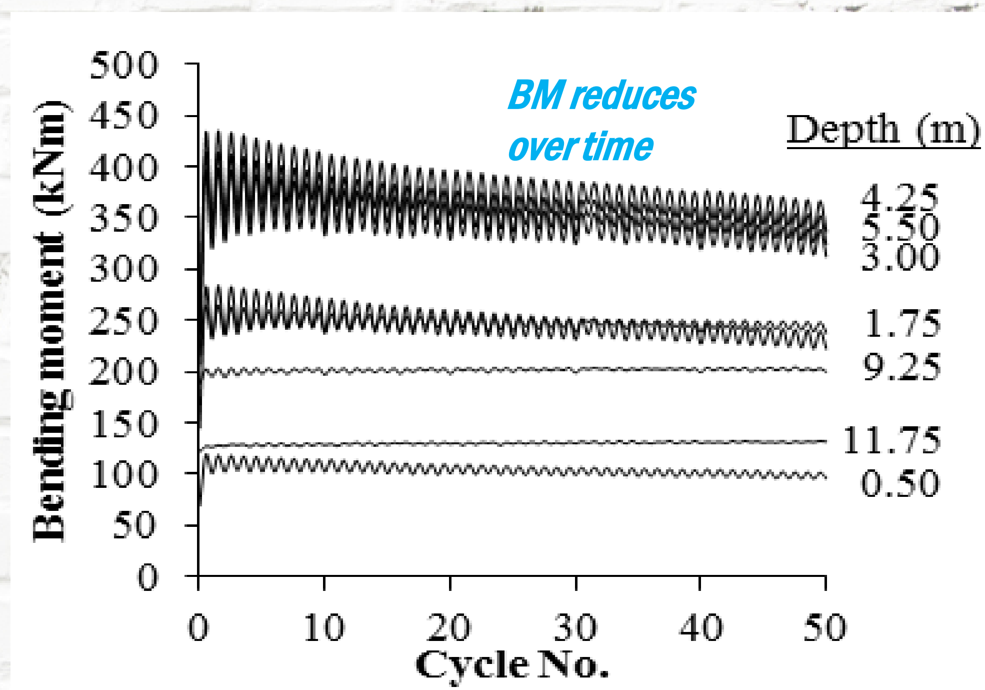






Time-dependent pile BM

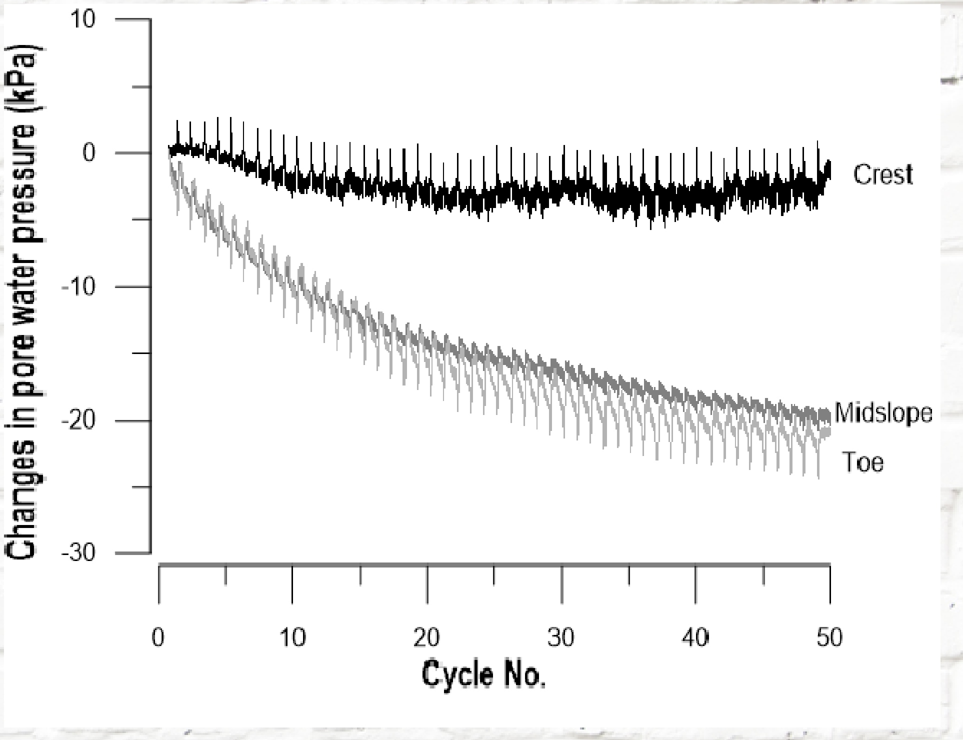




Dissipation of excess PWP

PWP

- Slope crest shows only slight decrease in the excess PWP, thus mainly undrained
- Mid-slope excess PWP continues to decrease, thus soil shear strength expected to increase
- This explains why pile BM reduces over time



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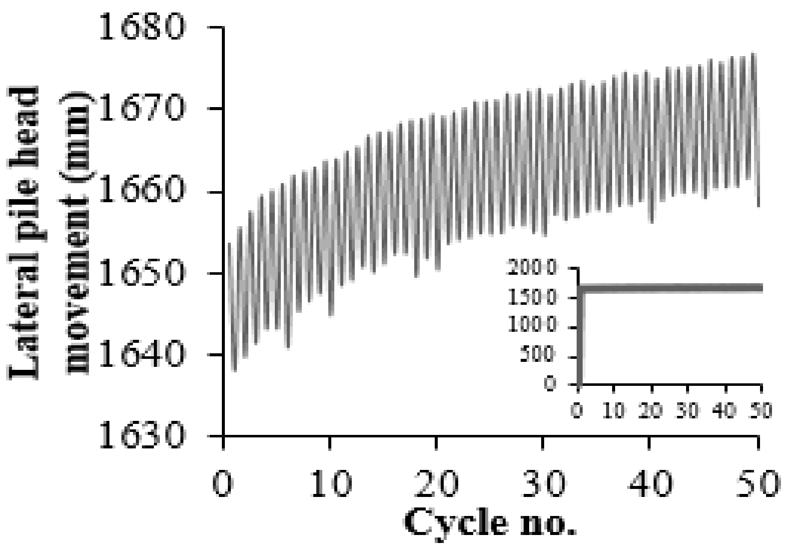
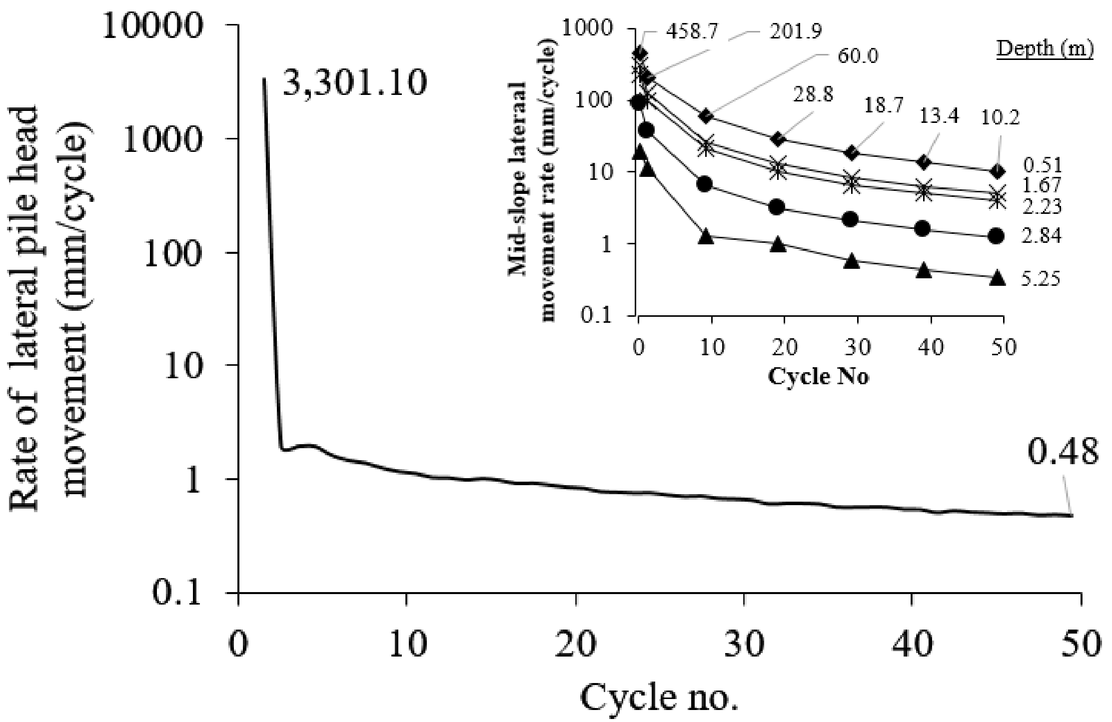
Time-dependent pile head movements



Riverbank creep movements



Conclusions

Pile BM
• Pile BM largest at first low tide as the soil body was in an undrained condition and thus, largest lateral soil pressures acting on pile
• Pile BM reduces due to the dissipation of excess PWP that causes gradual increase in soil strength over time
• Thus, pile BM is short-term critical
• Need to design for strength

Pile head deflection
• Pile head increases with number of tidal fluctuations
• Rate of pile head movement reduces over time, but does not approach zero due to creeping riverbank slopes as a result of tidal fluctuation
• Thus, pile head deflection is long-term critical
• Need to design for serviceability

KNOW ING

Thank you!