A STUDY ON THE CLAY ADHESION FACTOR

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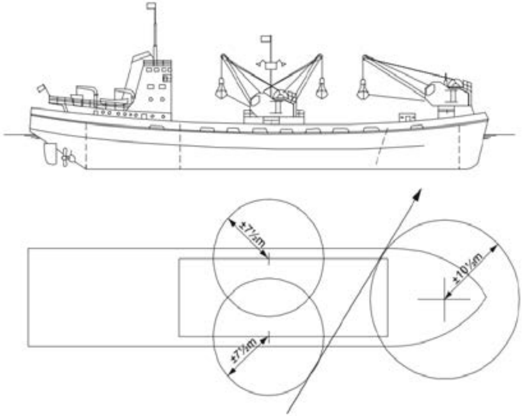
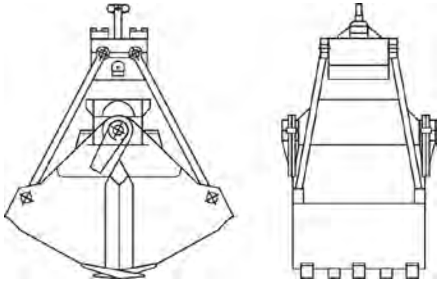
Introduction - the NEED in environmental dredging & trenching



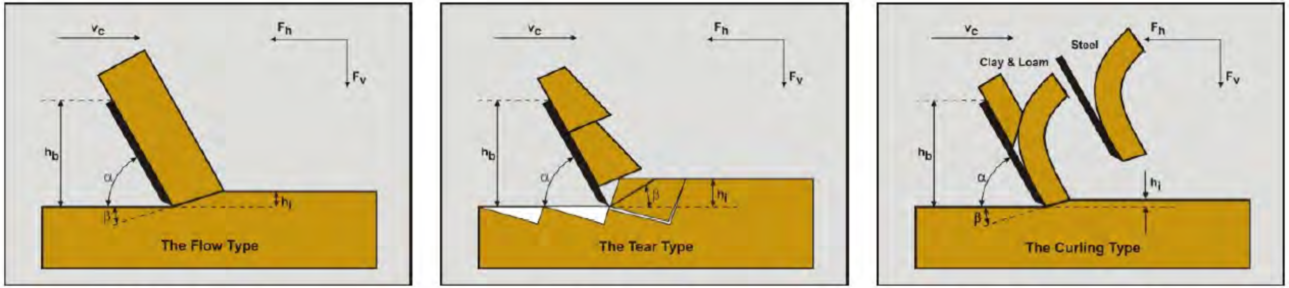


- Large surfaces on dredging tools can generate a lot of resistance (-> clamshell buckets, trenching for subsea cables)
- No relation between the internal shear strength (cohesion) and the external shear strength (adhesion or stickiness) in clay has been established yet
- Previous research by Thomas Combe

*Miedema, S.A. and Vlasblom, W.J. (2006). “The Closing Process of Clamshell Dredges in Water Saturated Sand”. CEDA African Section: Dredging Days 2006 – protection of the coastline, dredging sustainable development
*The PL3 V-shaped Pipe Burial Plough Designed by Royal IHC. Retrieved from IHC, 2009

Introduction

- Cutting forces on bucket edge:



(a) the flow type (b) the tear type (c) the curling type

$$F_h = \lambda * c * h_i * w * \frac{\frac{\sin(\alpha_a)}{\sin(\beta)} + r * \frac{\sin(\beta)}{\sin(\alpha_a)}}{\sin(\alpha_a + \beta)}$$

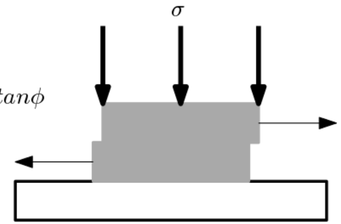
$$F_v = \lambda * c * h_i * w * \frac{\frac{\cos(\alpha_a)}{\sin(\beta)} - r * \frac{\cos(\beta)}{\sin(\alpha_a)}}{\sin(\alpha_a + \beta)}$$

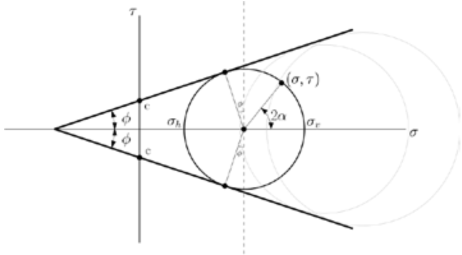
$$r = \frac{a * h_b}{c * h_i} = \boldsymbol{\alpha} * \frac{h_b}{h_i}$$

Let's find $\boldsymbol{\alpha}$

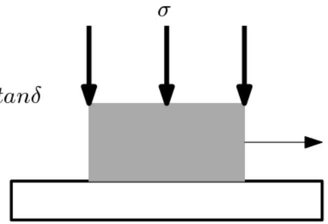
Introduction: Internal and External Shear Strength

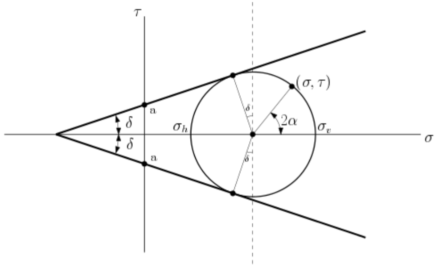
$\tau_c = c + \sigma \cdot tan\phi$





$\tau_a = a + \sigma \cdot tan\delta$





Adhesion

- Phenomenon of cohesive soil sticking to a foreign body
- Can vary between 100% of the internal shear strength down to 0%
- Sum of electro-chemical and mechanical effects, but the latter is strongly dominant

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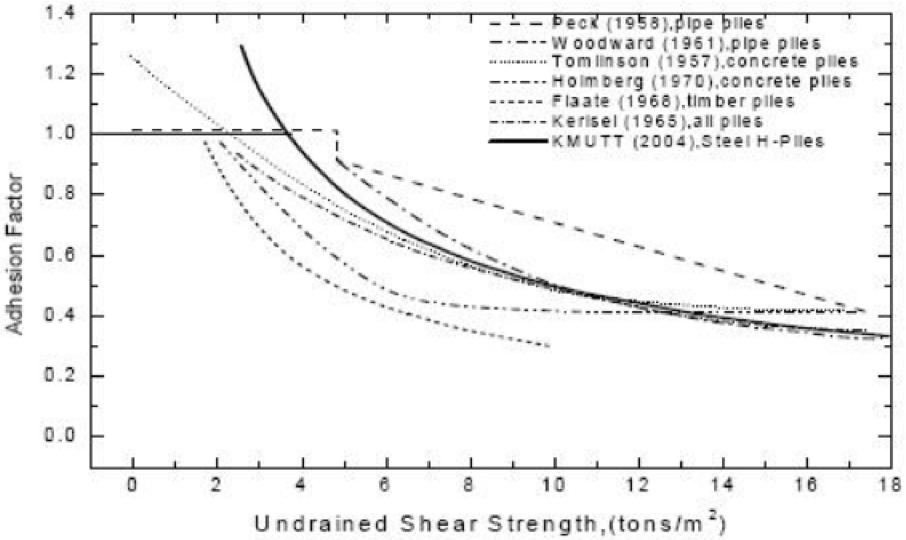
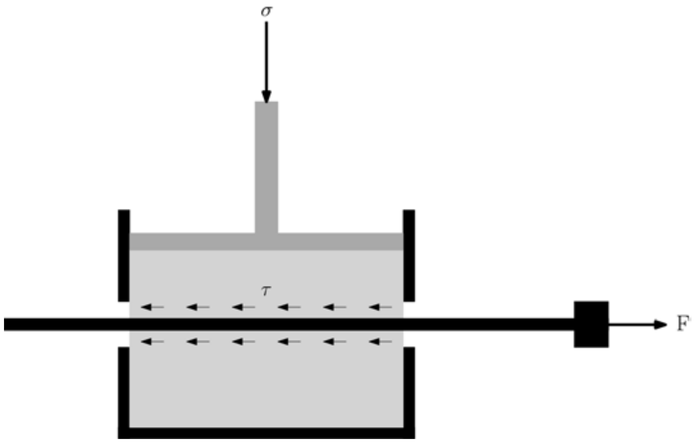
Introduction: Existing α-c_u Models

- Foundation Engineering & Agriculture: Back calculated from pile pullout force
- Measure for total tangential resistance, not ‘pure’ adhesion
  - -> effectively these are $\tau - c_u$ models

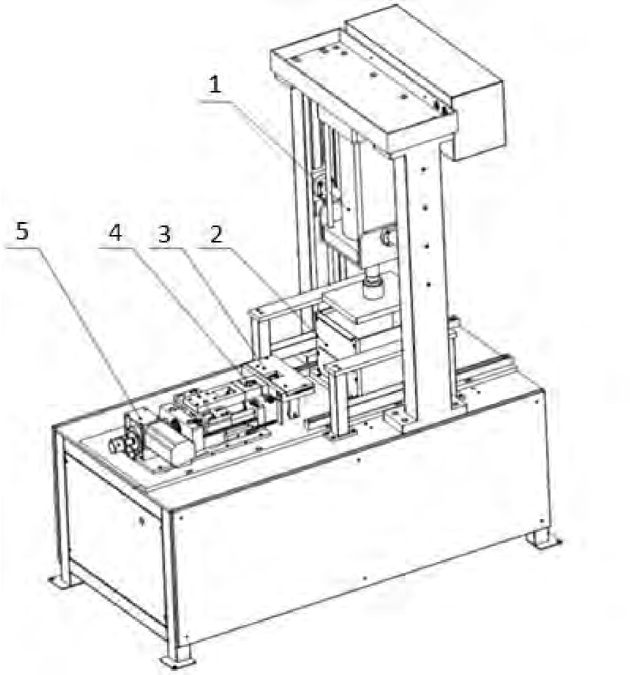


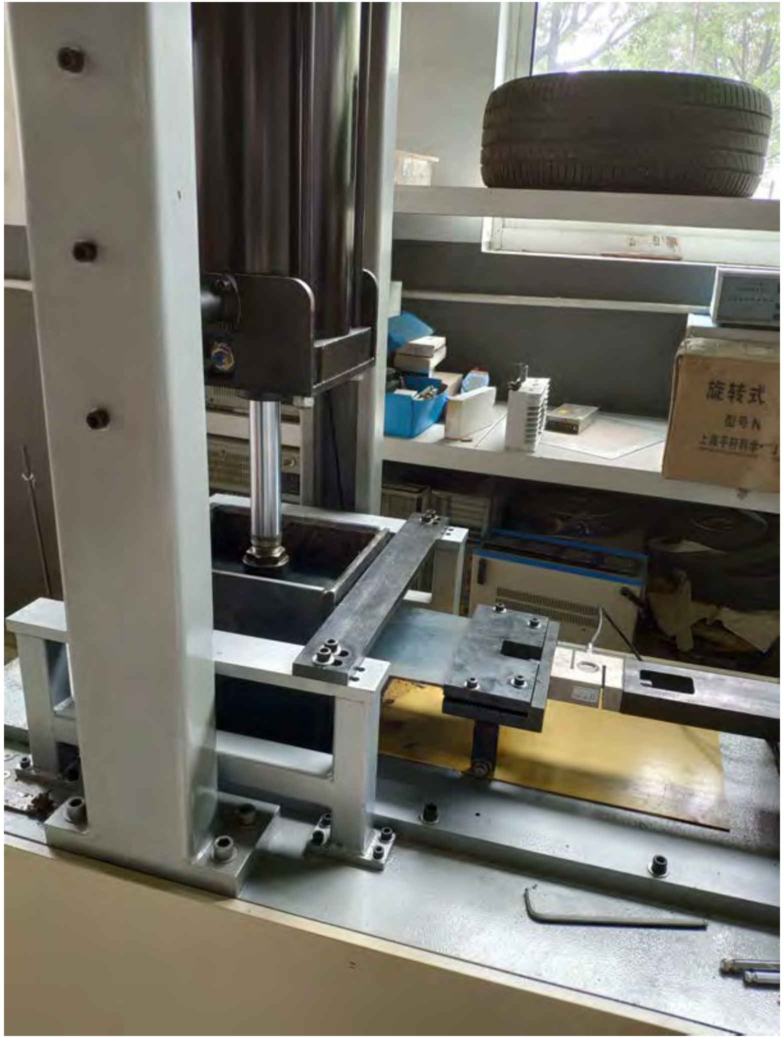
Experimental Study: Adhesion Test Setup (ATS)

- $\tau = \frac{F}{2A}$ where A is the area of the contact area
- $\tau = a + \sigma \tan \delta$



1. Pneumatic cylinder
2. Sample container
3. Blade attachment point
4. Force sensor
5. Electric drive

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Experimental Study: Test Matrix

Blade Pull-out Tests:

- Two ‘types’ of clay: pre-consolidated to 10 undrained shear strengths
- Tests at 5 normal pressures
- Test at 1 speed: 1mm/s

Undrained Direct Shear Tests:

- Tests at 4 normal pressures

Clay 1			Wuhan			
	c_u1	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u2	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u3	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u4	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u5	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
Clay 2			Lianyungang			
	c_u1	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u2	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u3	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u4	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$
	c_u5	$\sigma 1$	$\sigma 2$	$\sigma 3$	$\sigma 4$	$\sigma 5$

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Clay samples

Soil Types	Density in dry condition [kg/m³]	Mineralogy Analysis	Plastic Limit Liquid Limit [w / w / %]
1: Wuhan clay	2180	Quartz, Calcite, Graphite, Kyanite, Albite, Cordierite, Orthoclase, Anorthite, Anatase, Almadine	14.2 23.4
2: Lianyungang clay	1950	Quartz, Graphite, Sylvite, Spinel, Sodalite, Siderite, Rutile, Magnetite, Magnesite, Hematite, Calcite	12.2 25.7

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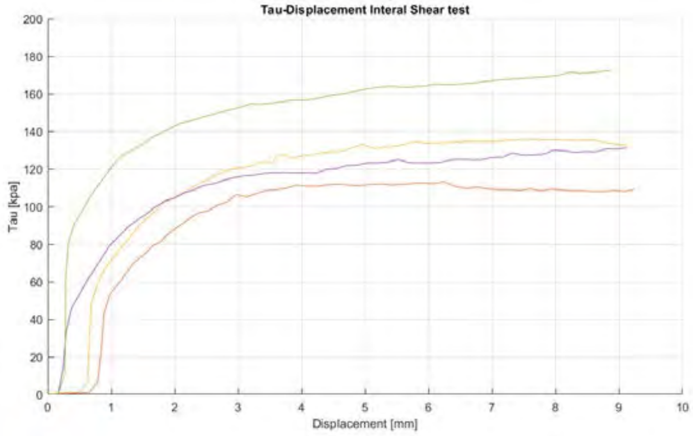
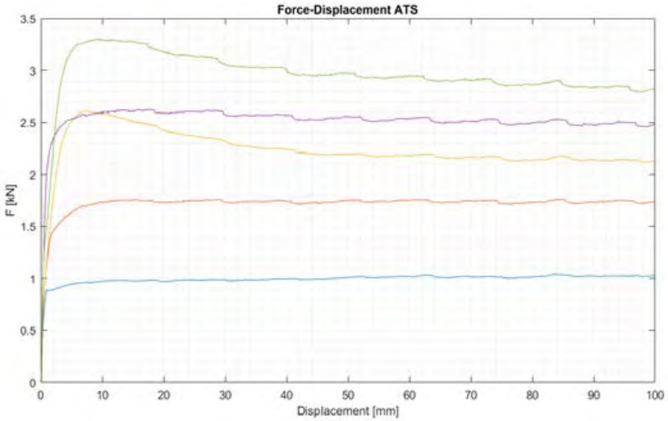
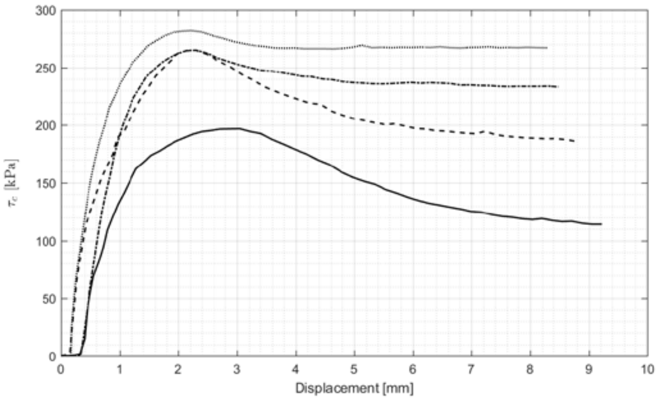
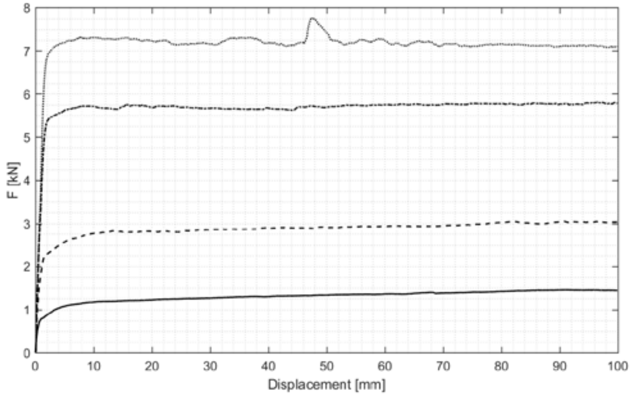
Direct Shear Tests

Results: Direct shear results and Blade Pull-out tests









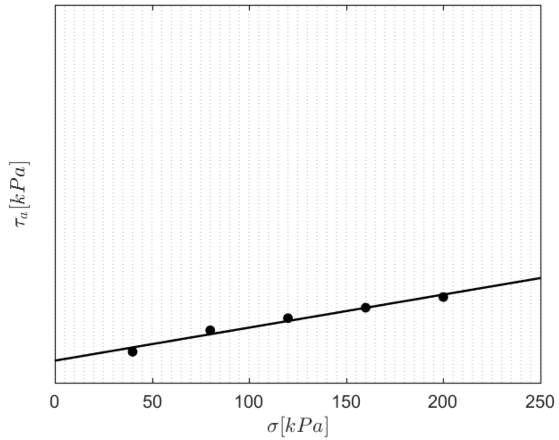
LHS: Direct shear results

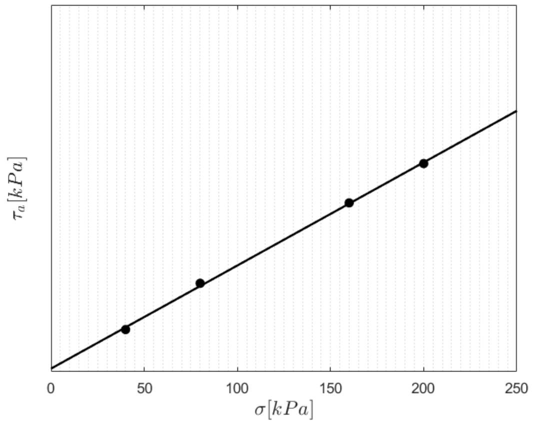
RHS: Blade pull-out test

Soil 1 -15.9% [w/w]

Soil 2 – 12.0% [w/w]

Results: Blade Pull-out tests

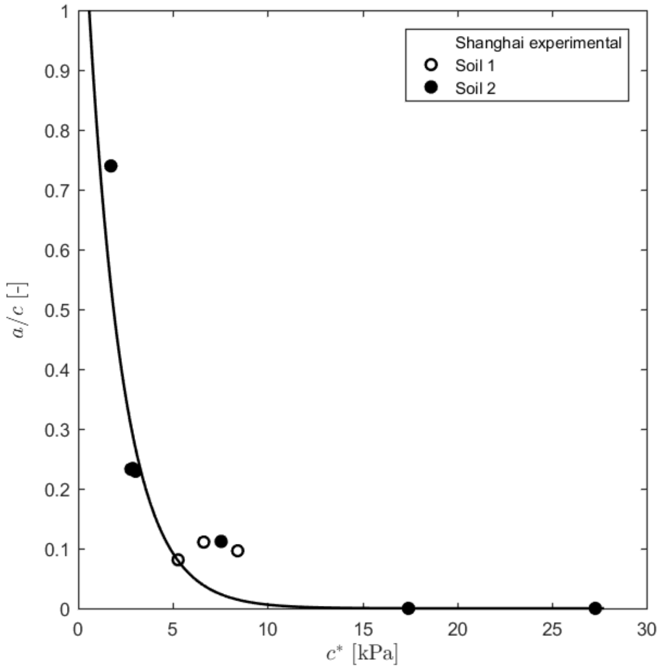




Normal Stress vs. shear stress with a linear fit according to the Mohr-Coulomb failure criterion
Soil 1 -15.9% [w/w]
Soil 2 – 12.0% [w/w]

The external friction angle could be up to 30º shall not be neglected!!!

Results: the α-c_u correlation



2 types of models: the adhesion factor models based on

- Total external shear resistance
- the true adhesion of the soil at zero normal stress.

- ***the exponential correlation*** provide the best description of the adhesion factor - undrained shear strength relation .

Dimensionless cohesion versus the adhesion factor.
The filled dots represent data obtained in tests on soil 1
circles represent data obtained in tests on soil 2. The black line represents the best Exponential fit.

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Conclusion

- The external friction angle could be up to 30º , shall not be neglected
- adhesion in medium-high strength clay is small, safe for environmental dredging practice
- adhesion factor in low strength cohesive soil could be up to 80%
- adhesion factor is exponentially correlated with undrained shear strength

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Conclusion

This leads to better, more efficient design of the environmental dredging equipment, requiring less power, MORE SUSTAINABLE!

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THANK YOU VERY MUCH!!!

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