Dredging Processes

Dr.ir. Sape A. Miedema

5. Clay Cutting

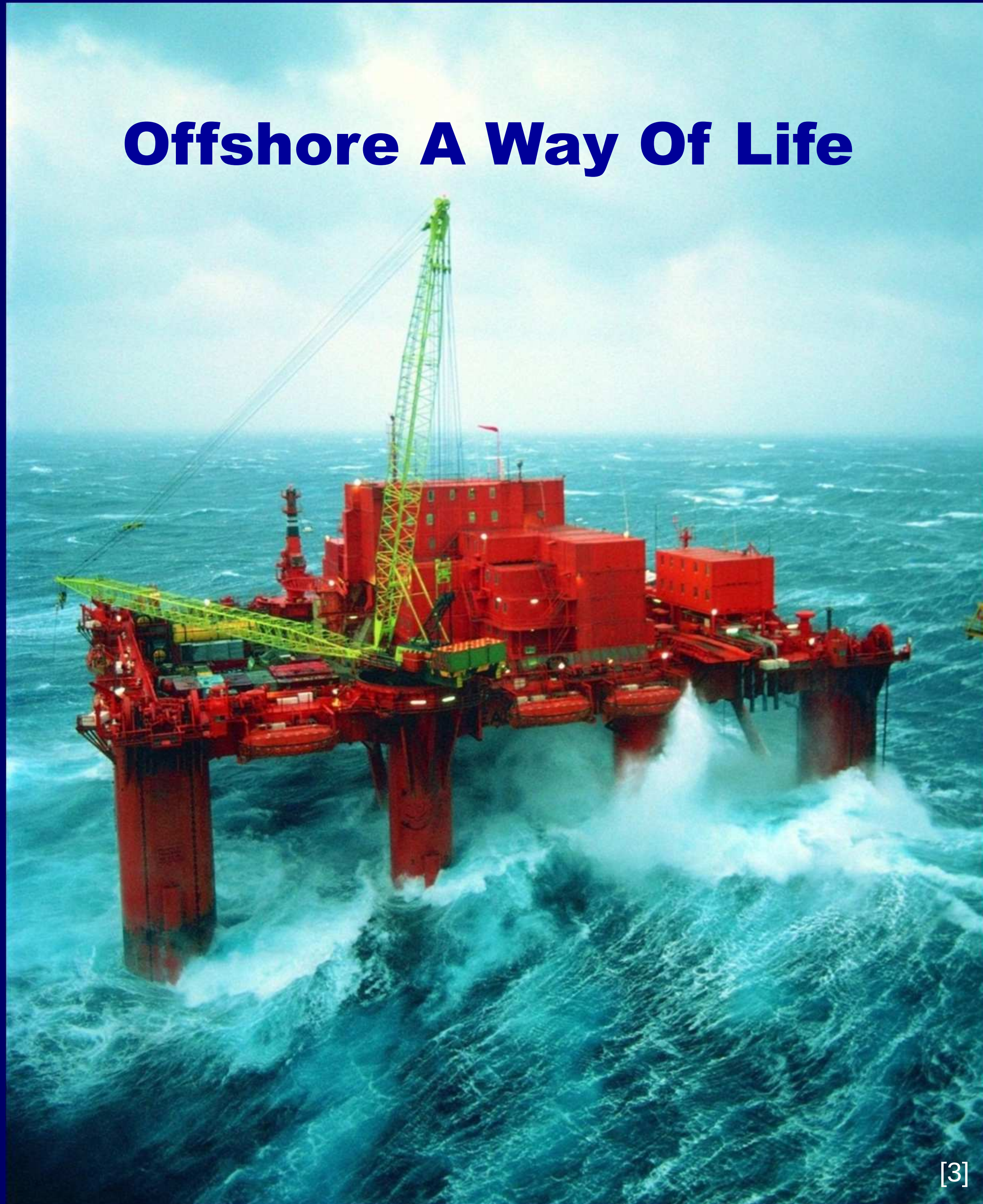
TU Delft

Dredging A Way Of Life

Delft University of Technology – Offshore & Dredging Engineering

Offshore A Way Of Life

[2]



[3]

Delft University of Technology – Offshore & Dredging Engineering

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Offshore & Dredging Engineering

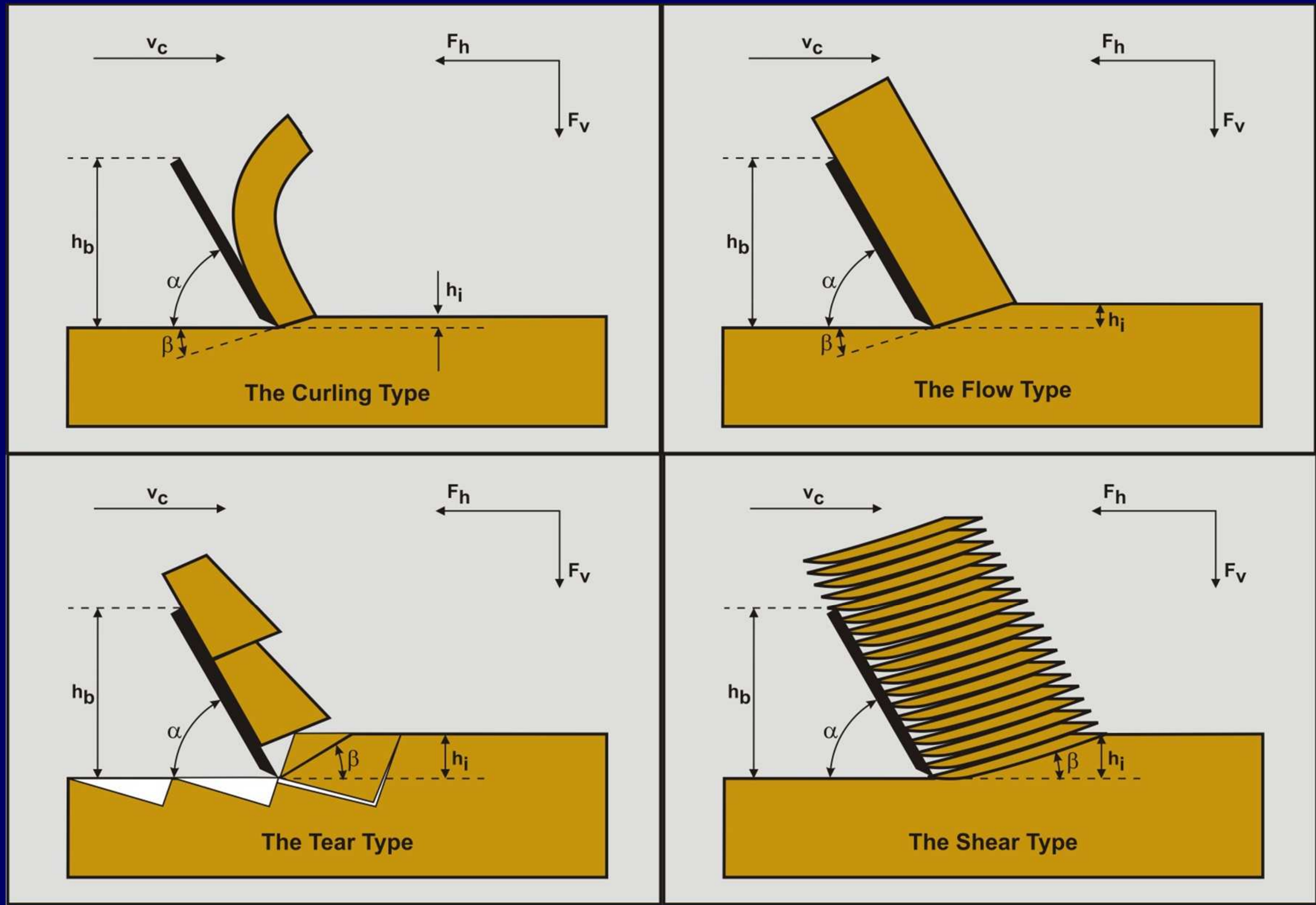
Dr.ir. Sape A. Miedema
Educational Director

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

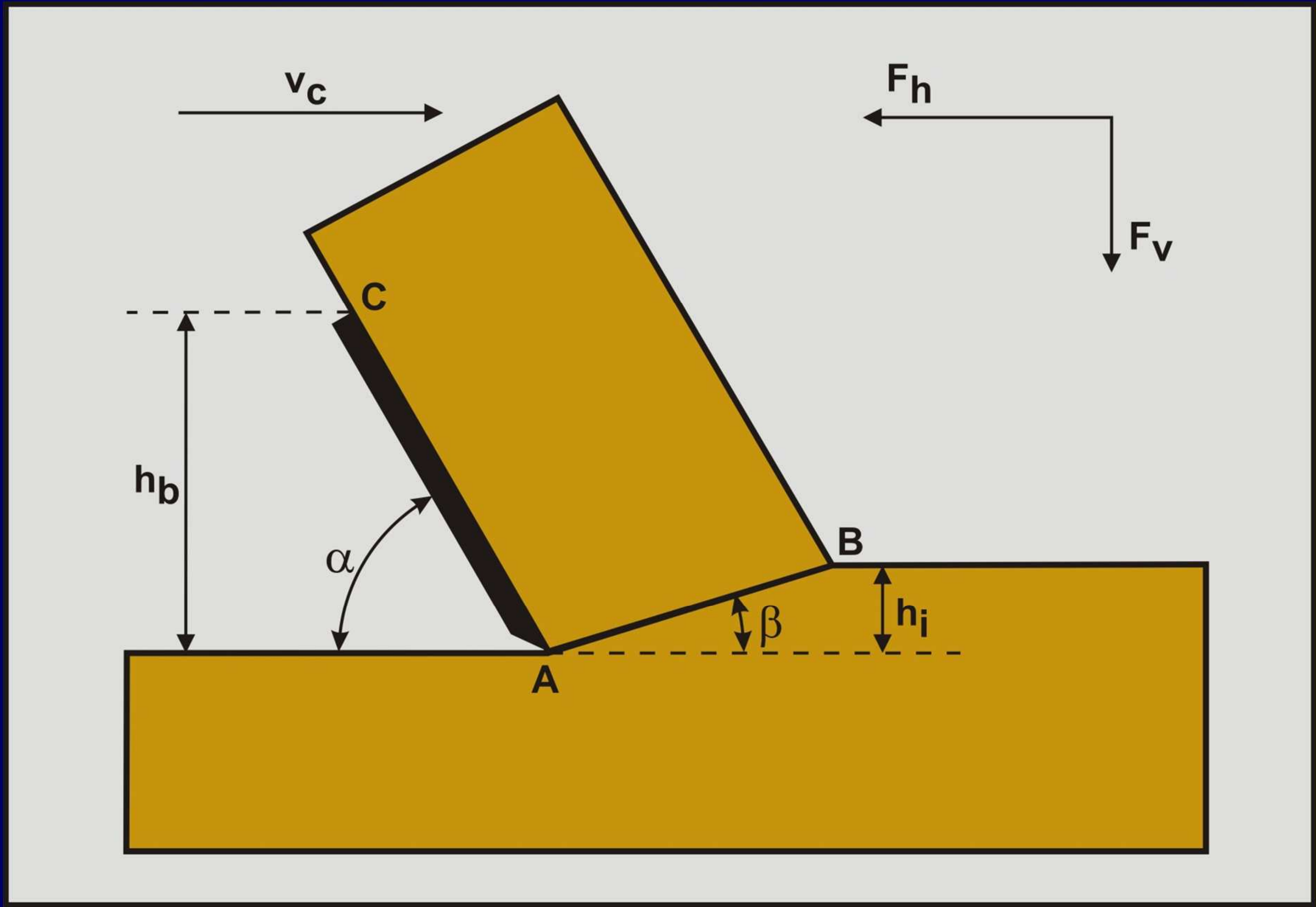
Clay Cutting

Mechanisms

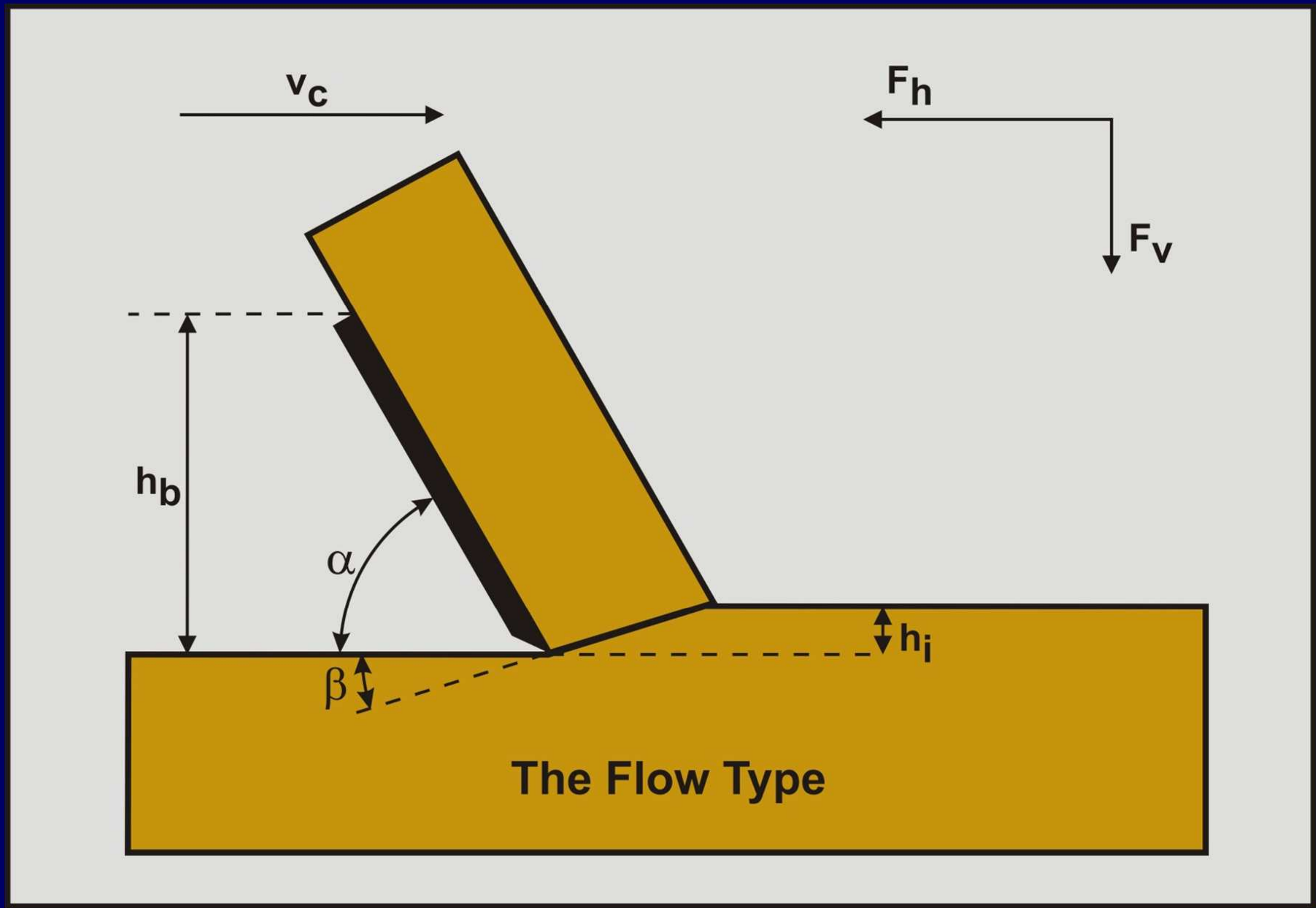


Delft University of Technology
Offshore & Dredging Engineering

Definitions

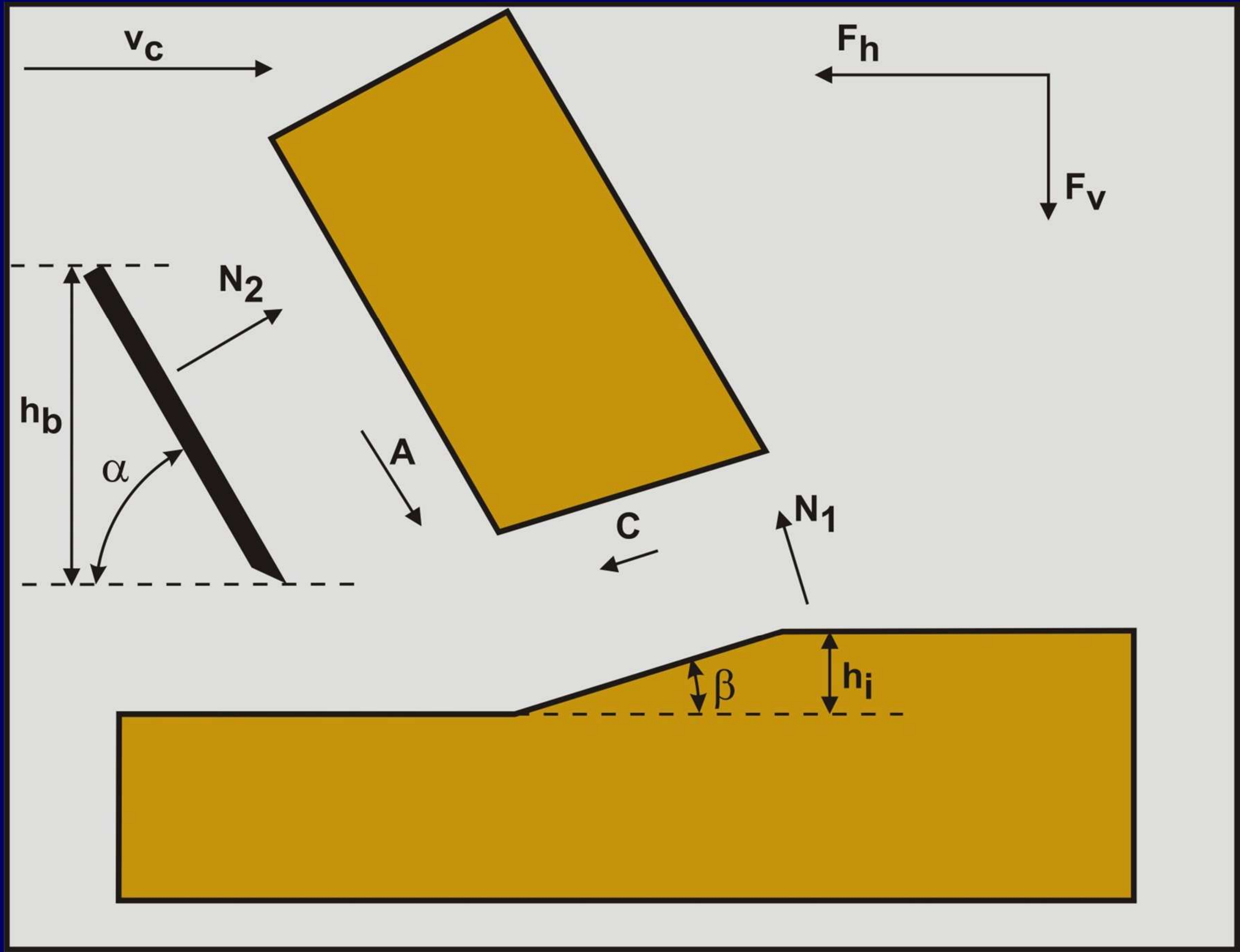


The Flow Type

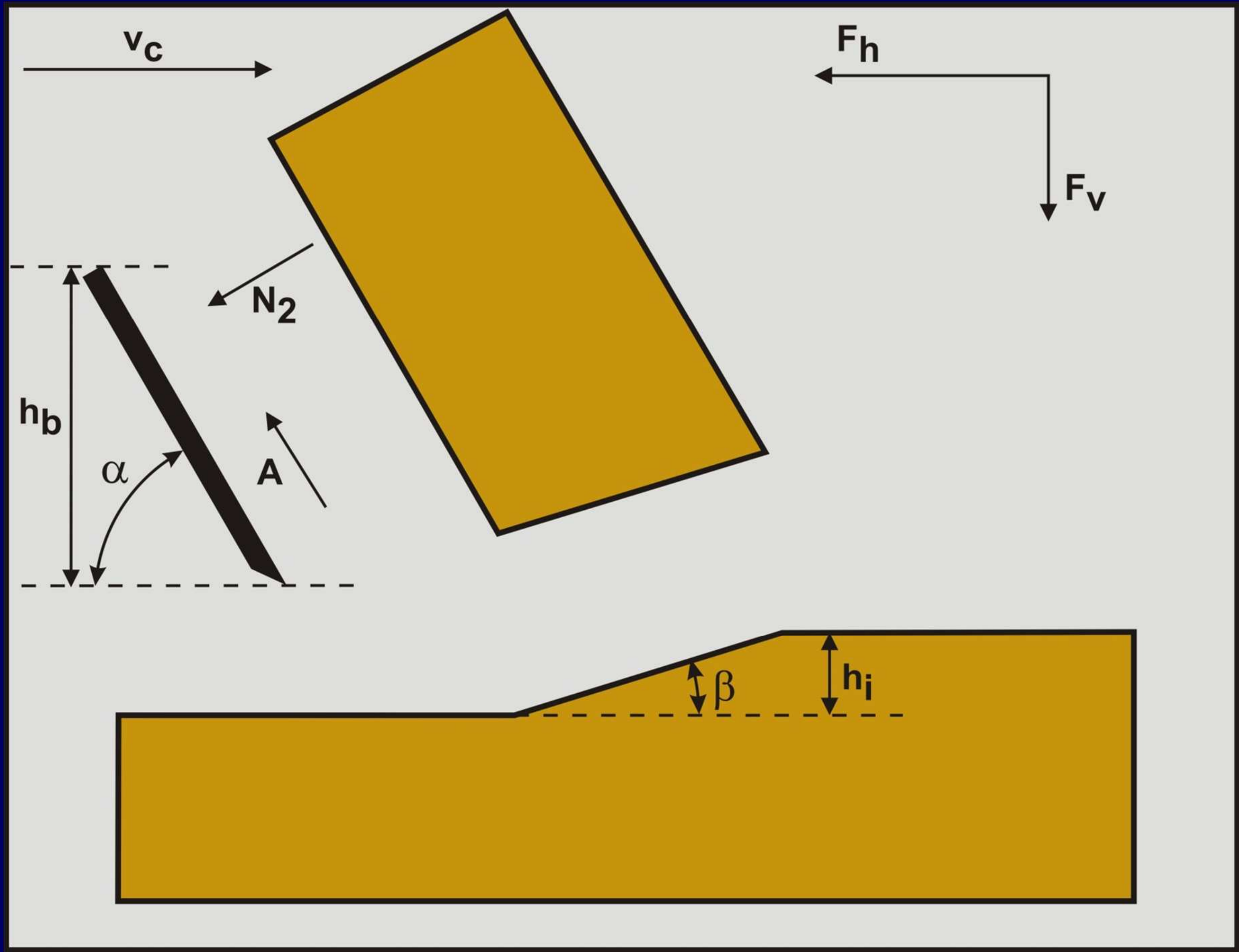


TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Forces on the Layer Cut

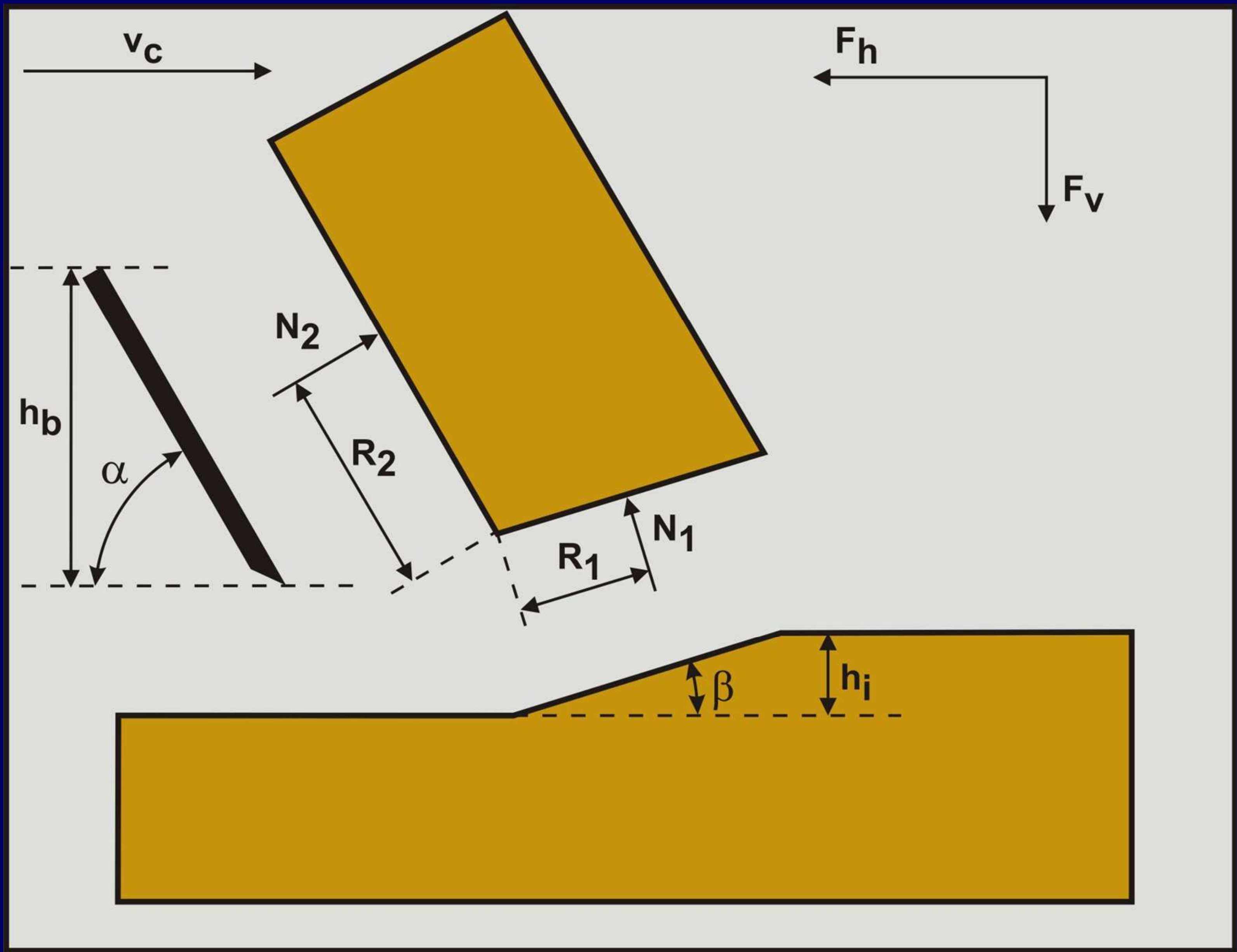


Forces on the Blade



Delft University of Technology
Offshore & Dredging Engineering

Moments



Resulting Equations

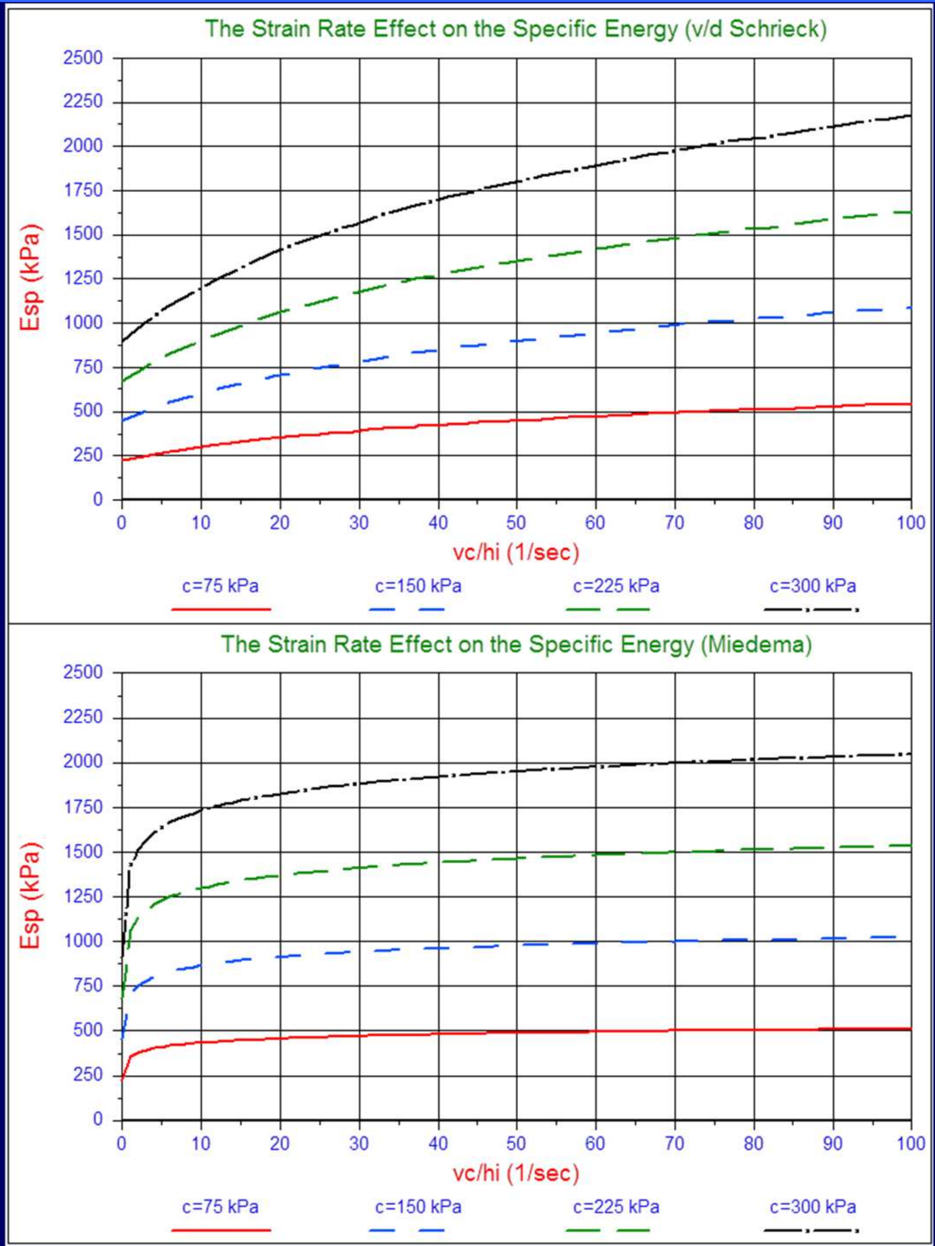
$$K_2 = \frac{C - A \cdot \cos(\alpha + \beta)}{\sin(\alpha + \beta)}$$

$$F_h = K_2 \cdot \sin(\alpha) + A \cdot \cos(\alpha)$$

$$F_v = K_2 \cdot \cos(\alpha) - A \cdot \sin(\alpha)$$

Delft University of Technology
Offshore & Dredging Engineering

Strain Rate Effect



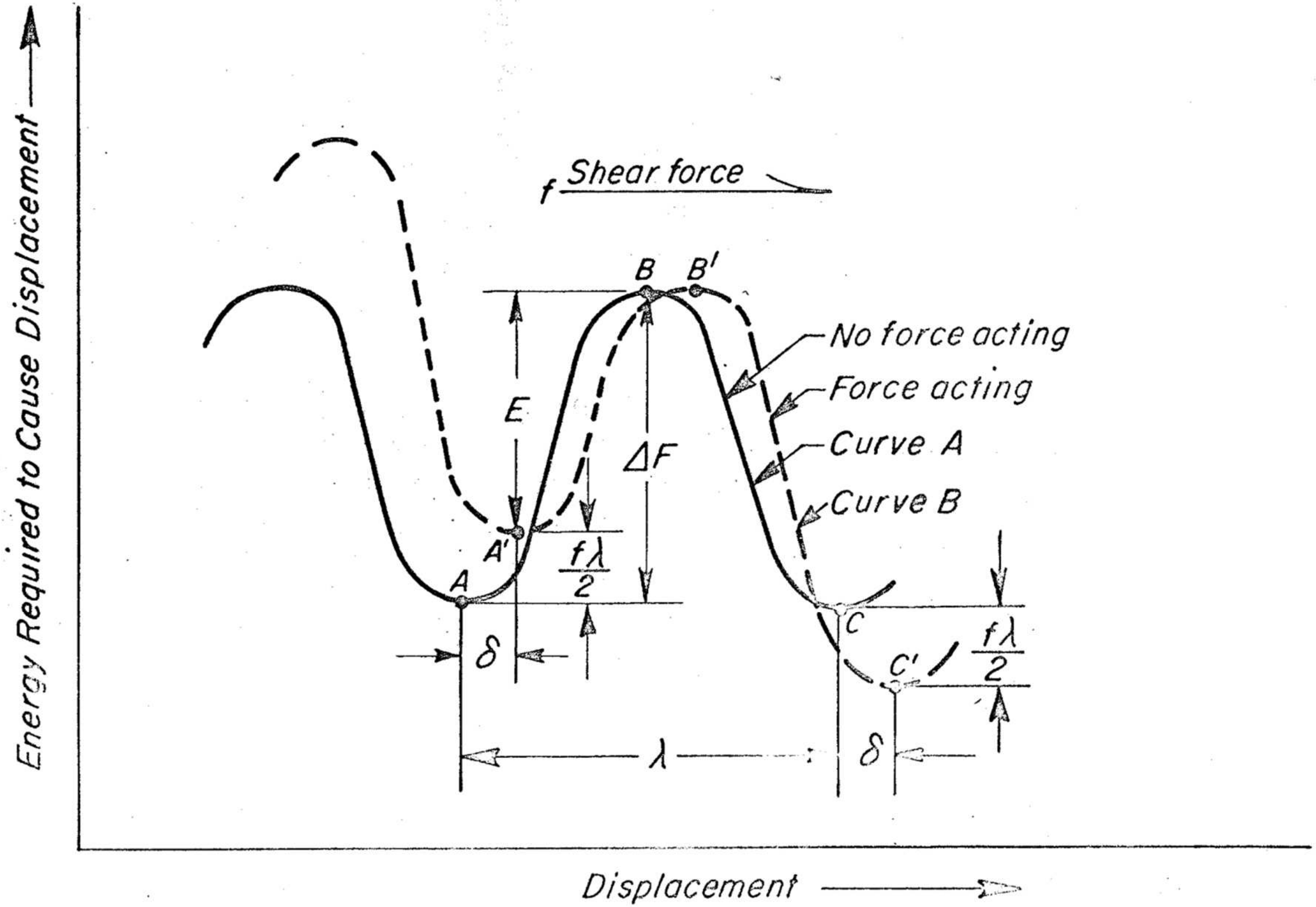
Delft University of Technology
Offshore & Dredging Engineering

Problem Definition

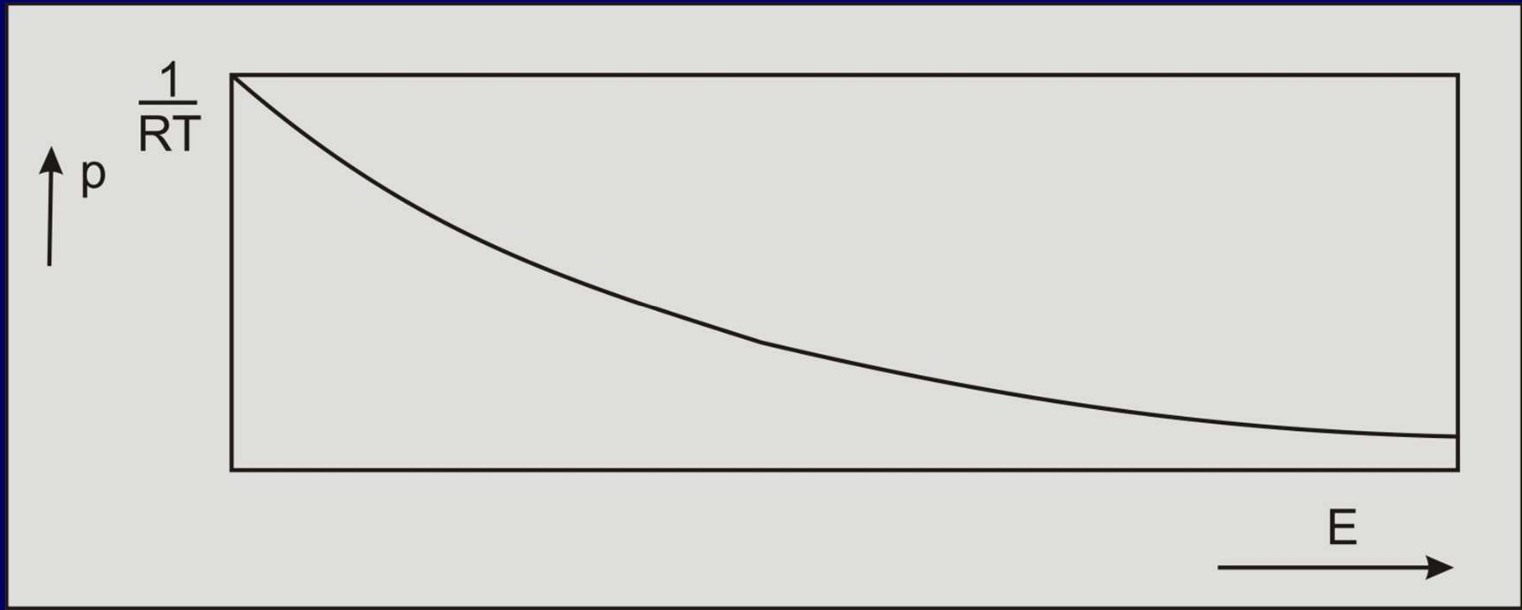
How to model the strengthening of clay as a function of the strain rate

$$\tau = \tau_y + \tau_0 \cdot \ln\left[1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$$

Energy Barriers Mitchell 1976



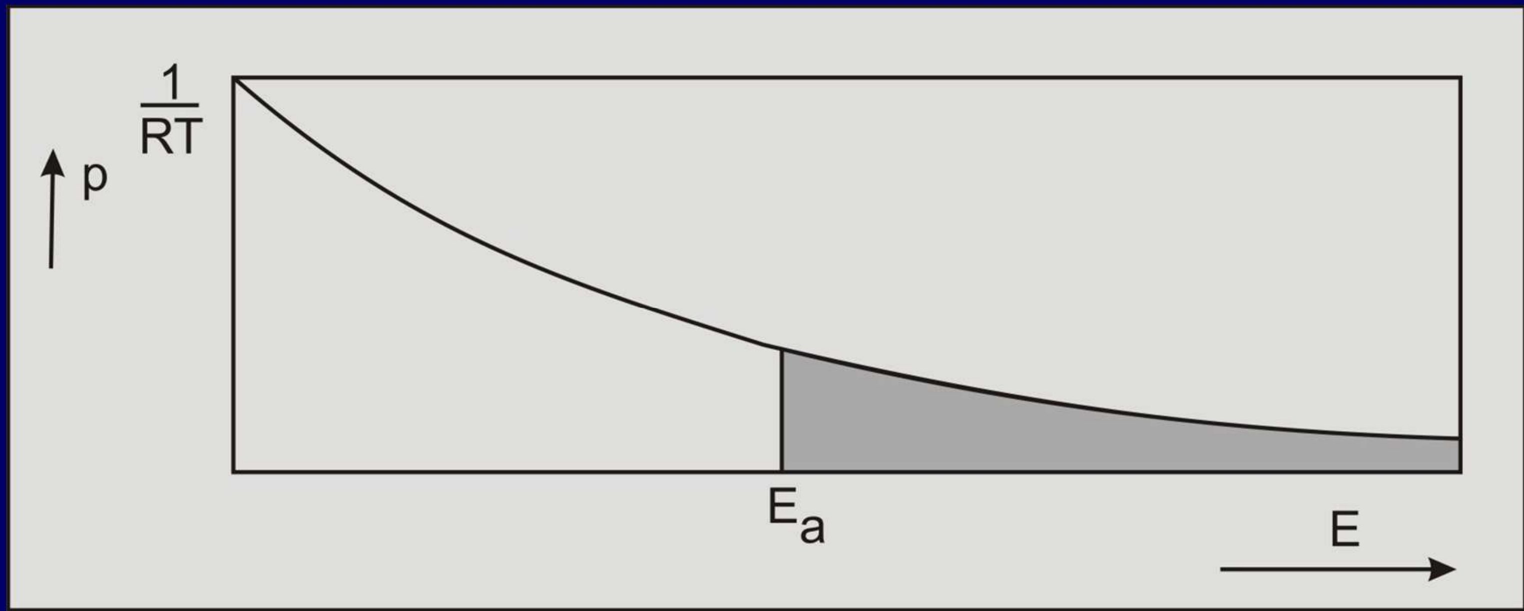
The Bolzman Distribution



$$p(E) = \frac{1}{R \cdot T} \cdot \exp\left[\frac{-E}{R \cdot T}\right]$$

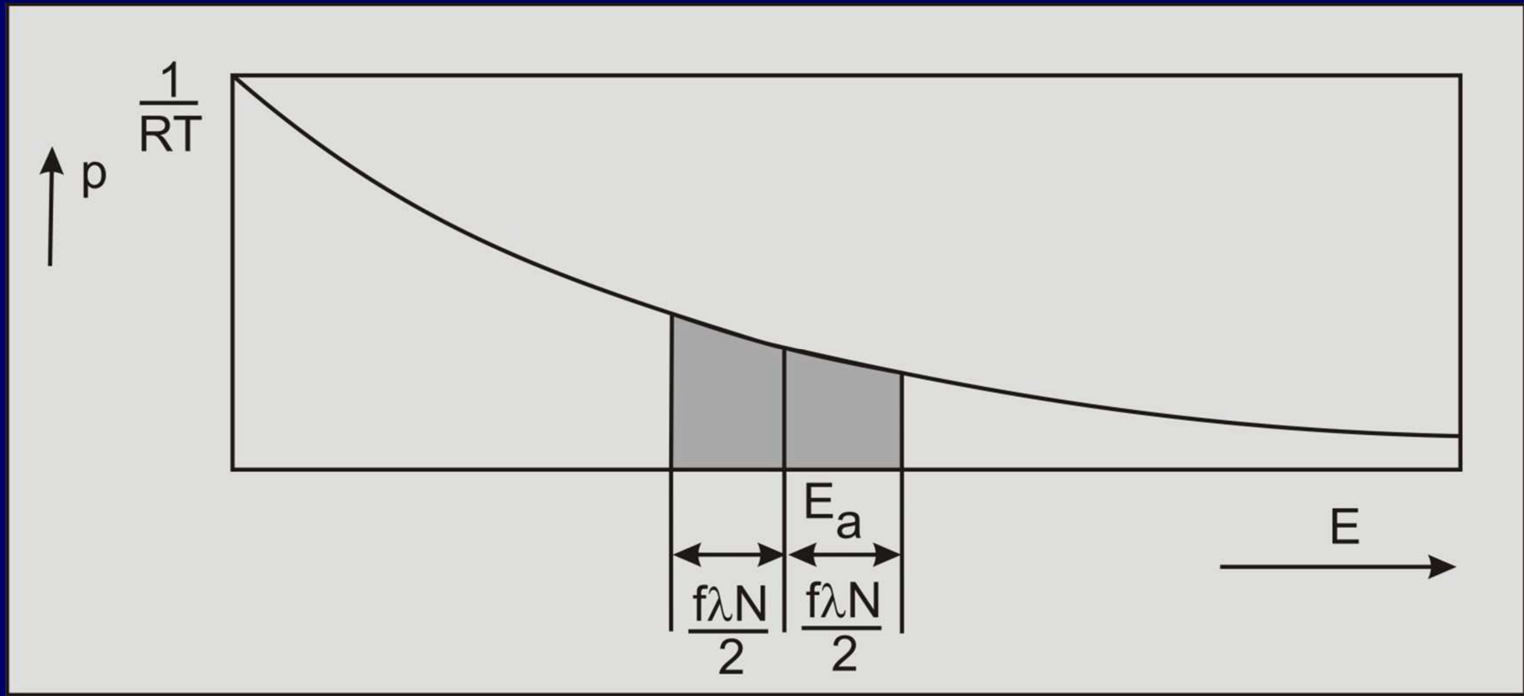
Delft University of Technology
Offshore & Dredging Engineering

Probability of Exceeding



$$p_{E>E_a} = \exp\left[\frac{-E_a}{R \cdot T}\right]$$

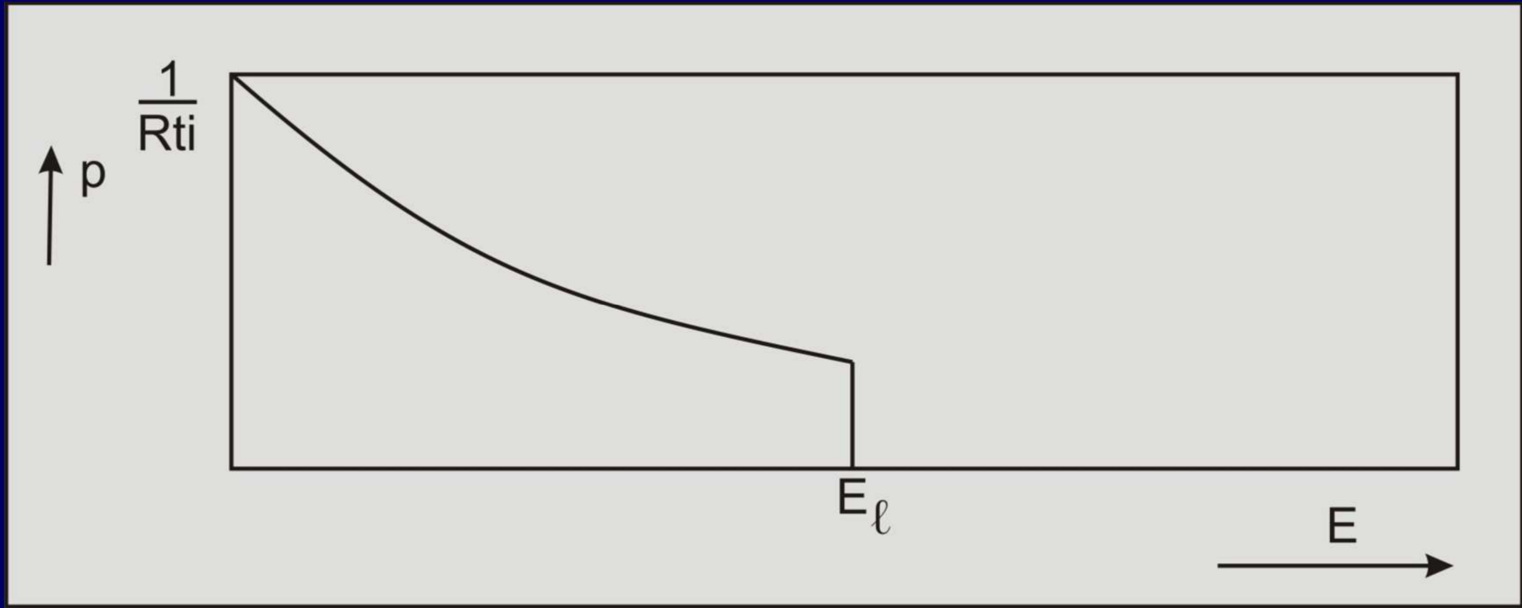
Strain Rate



$$\dot{\varepsilon} = 2 \cdot X \cdot \frac{k \cdot T}{h} \cdot \exp\left[\frac{-E_a}{R \cdot T}\right] \cdot \sinh\left[\frac{\tau \cdot \lambda \cdot N}{2 \cdot S \cdot R \cdot T}\right]$$

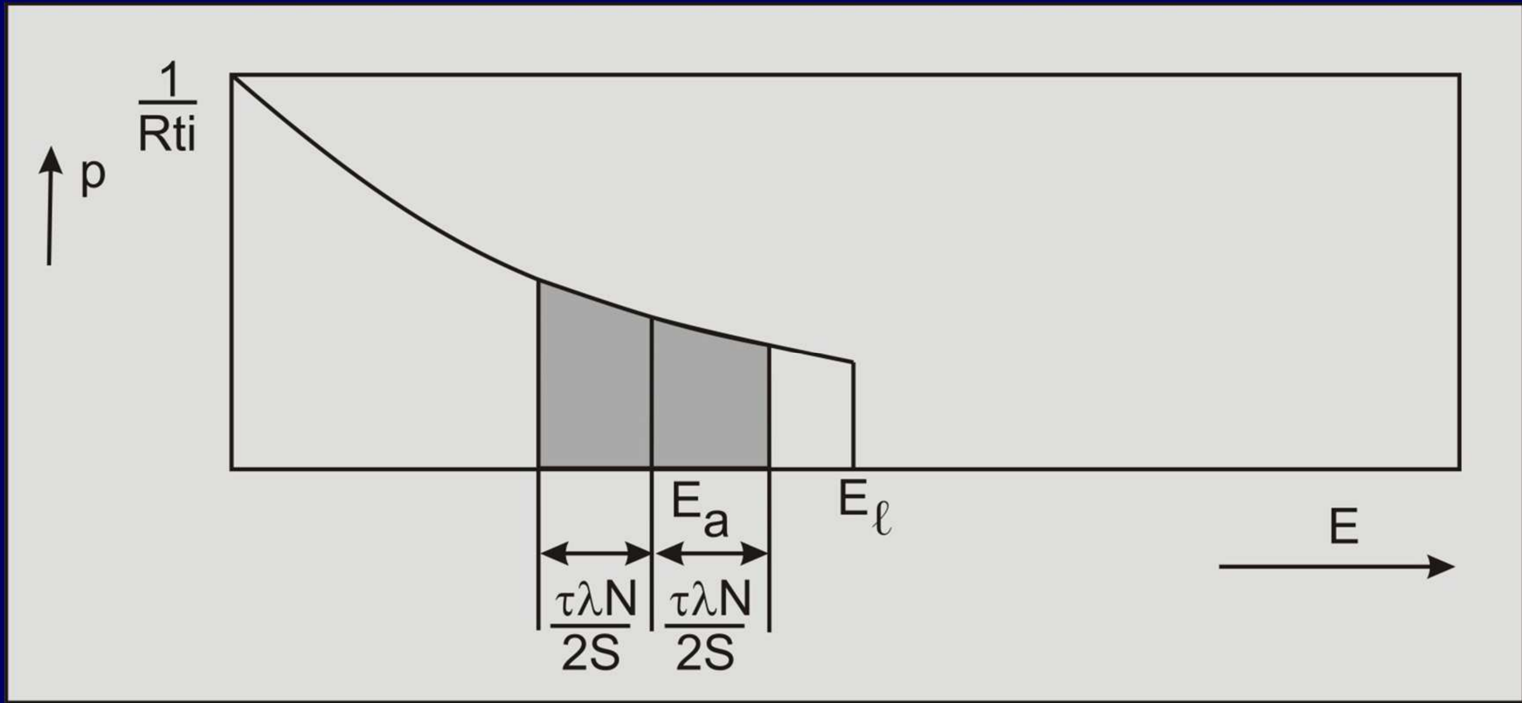
TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Theory Proposed



$$p_{E>E_a} = \frac{\exp\left[\frac{-E_a}{R \cdot T}\right] - \exp\left[\frac{-E_\ell}{R \cdot T}\right]}{1 - \exp\left[\frac{-E_\ell}{R \cdot T}\right]}$$

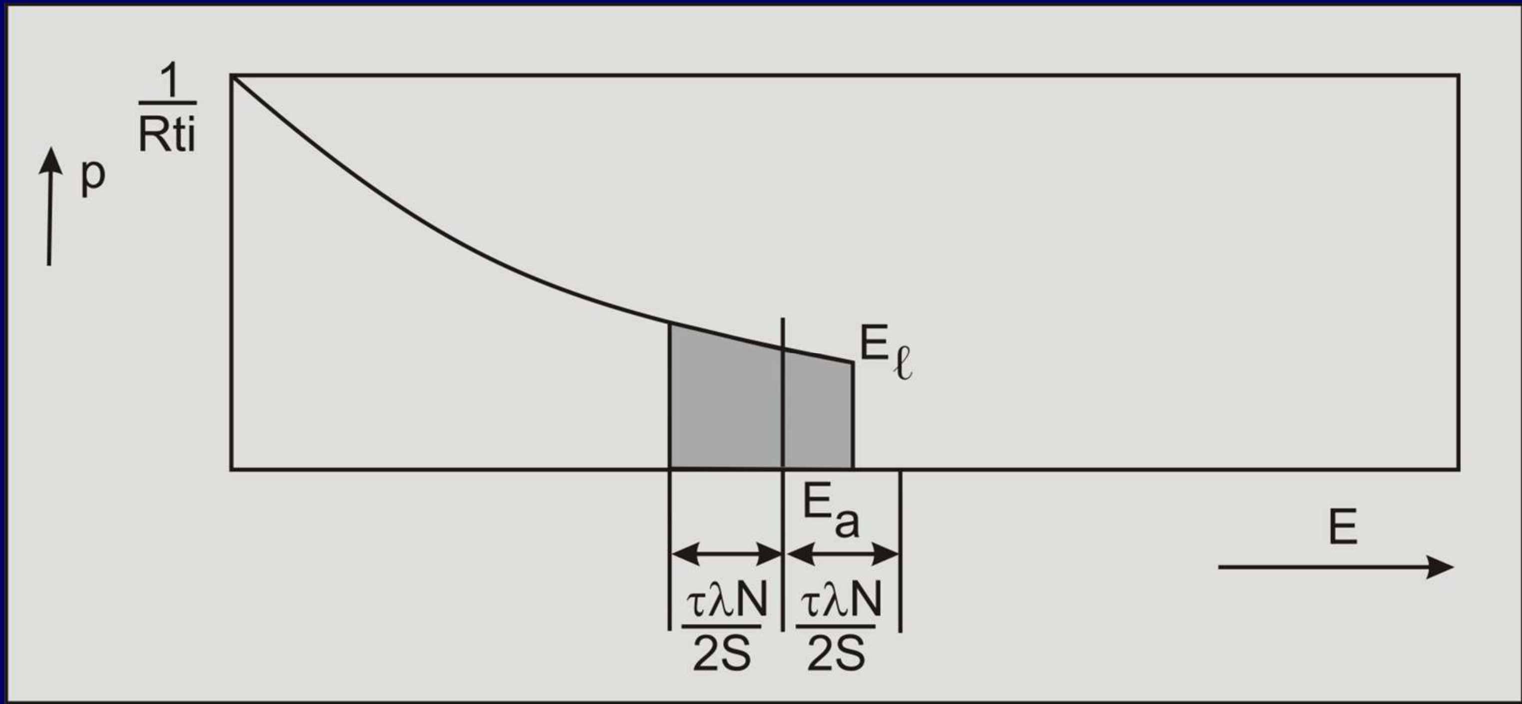
Case 1



$$\dot{\varepsilon} = 2\cdot X\cdot \frac{k\cdot T}{h\cdot i}\cdot \exp\left[\frac{-E_a}{R\cdot T}\right]\cdot \sinh\left[\frac{\tau\cdot\lambda\cdot N}{2\cdot S\cdot R\cdot T}\right]$$

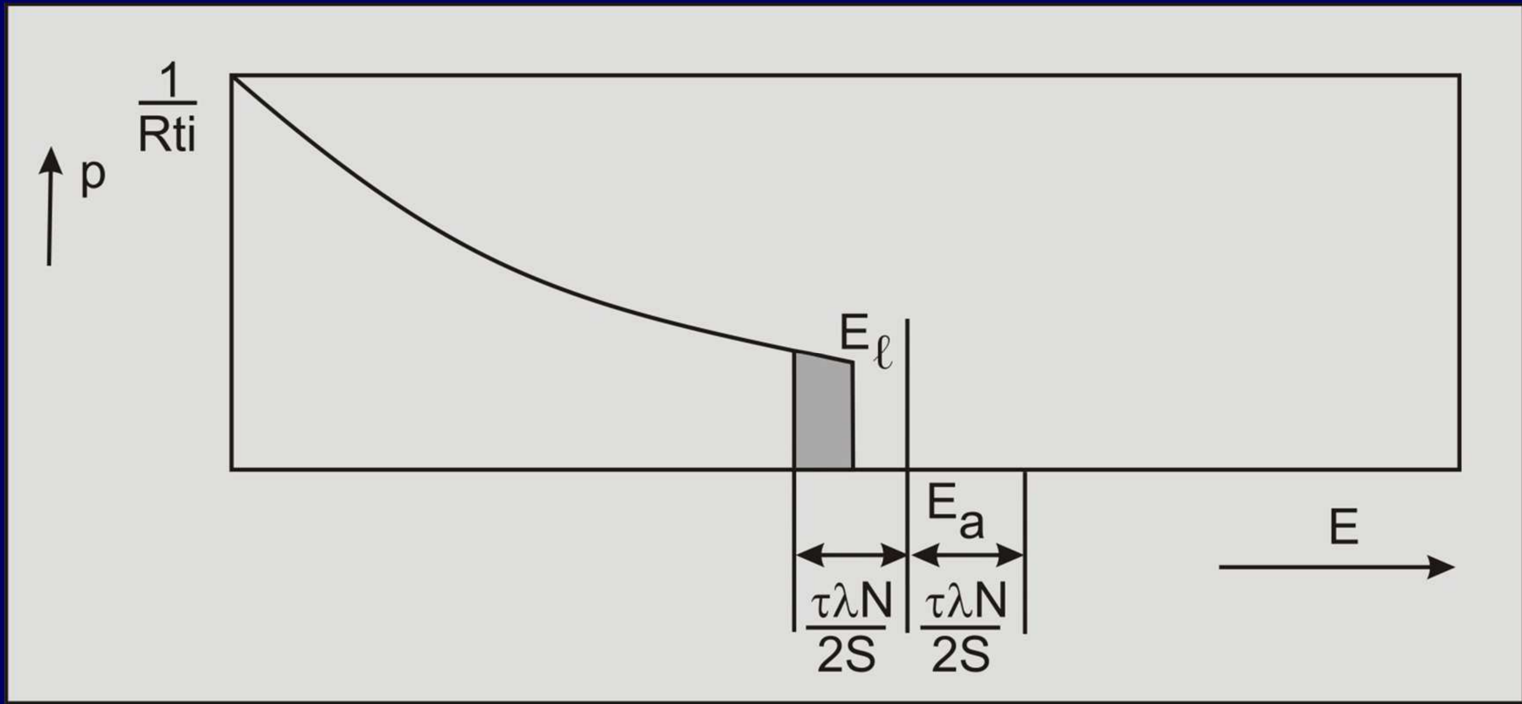
TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Case 2



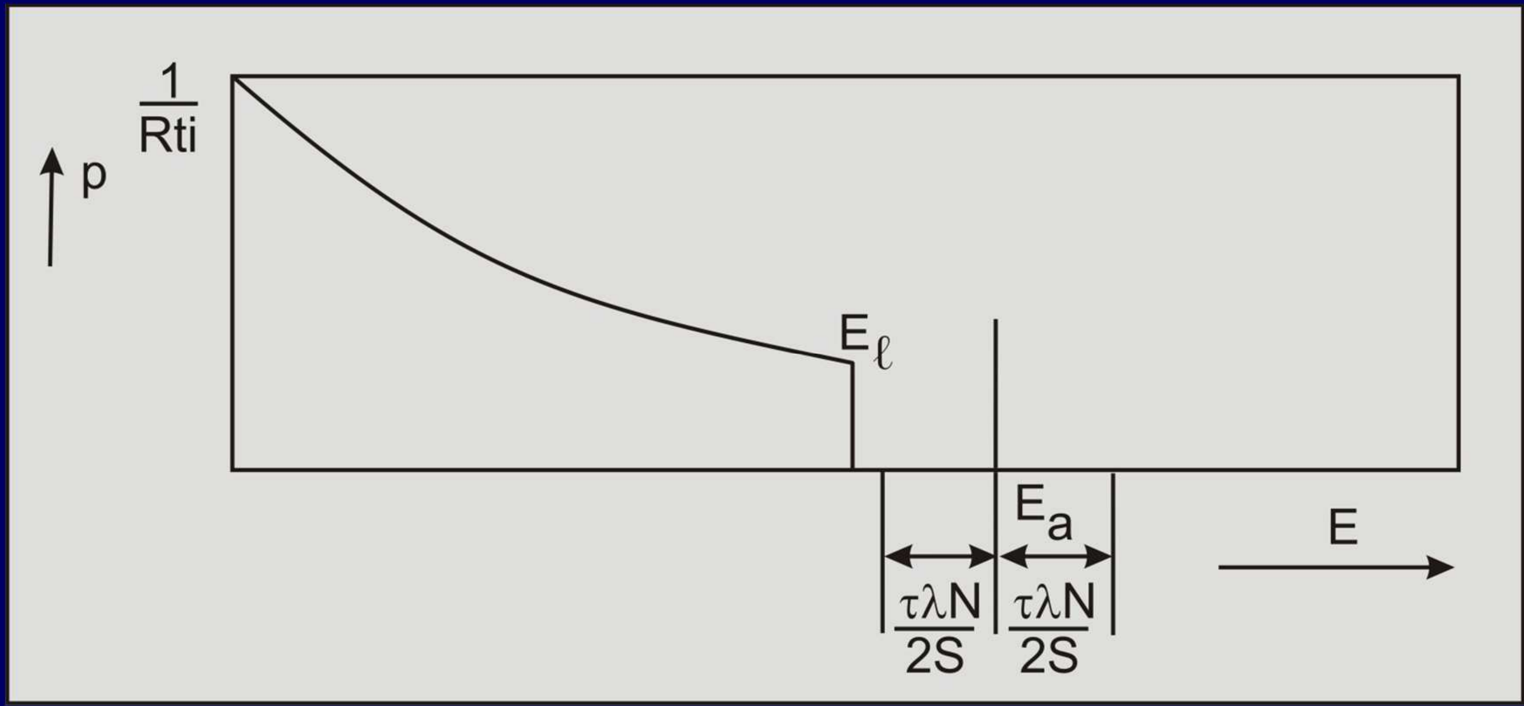
$$\dot{\varepsilon} = X \cdot \frac{k \cdot T}{h \cdot i} \cdot \left\{ \exp\left[-\left(\frac{E_a}{R \cdot T} - \frac{\tau \cdot \lambda \cdot N}{2 \cdot S \cdot R \cdot T} \right) \right] - \exp\left[\frac{-E_\ell}{R \cdot T} \right] \right\}$$

Case 3



$$\dot{\varepsilon} = X \cdot \frac{k \cdot T}{h \cdot i} \cdot \left\{ \exp\left[-\left(\frac{E_a}{R \cdot T} - \frac{\tau \cdot \lambda \cdot N}{2 \cdot S \cdot R \cdot T} \right) \right] - \exp\left[\frac{-E_\ell}{R \cdot T} \right] \right\}$$

Case 4



Case 3

$$\tau = \left(E_a - E_\ell\right) \cdot \frac{2 \cdot S}{\lambda \cdot N} + R \cdot T \cdot \frac{2 \cdot S}{\lambda \cdot N} \cdot \ell n \left[1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right]$$

$$\dot{\varepsilon}_0 = \left[\frac{X \cdot k \cdot T}{h \cdot i} \cdot \exp\left[\frac{-E_\ell}{R \cdot T} \right] \right]$$

Mitchell 1976

$$S = a + b.\sigma_e$$

$$\tau = a \cdot \left\{ (E_a - E_\ell) \cdot \frac{2}{\lambda \cdot N} + R \cdot T \cdot \frac{2}{\lambda \cdot N} \cdot \ell n \left[1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right] \right\}$$

$$+ b \cdot \left\{ (E_a - E_\ell) \cdot \frac{2}{\lambda \cdot N} + R \cdot T \cdot \frac{2}{\lambda \cdot N} \cdot \ell n \left[1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right] \right\} \cdot \sigma_e$$

$$\tau = \tau_c + \sigma_e . \tan(\phi)$$

$$\tau = a \cdot \left\{ E_a \cdot \frac{2}{\lambda \cdot N} + R \cdot T \cdot \frac{2}{\lambda \cdot N} \cdot \ell n \left[\frac{\dot{\varepsilon}}{B} \right] \right\} + b \cdot \left\{ E_a \cdot \frac{2}{\lambda \cdot N} + R \cdot T \cdot \frac{2}{\lambda \cdot N} \cdot \ell n \left[\frac{\dot{\varepsilon}}{B} \right] \right\} \cdot \sigma_e$$

Simplifications

$$\tau = \tau_y + \tau_0 \cdot \ln\left[1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$$

$(d\varepsilon/dt)/(d\varepsilon_0/dt) << 1$,

$$\tau = \tau_y + \tau_0 \cdot \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}$$

$(d\varepsilon/dt)/(d\varepsilon_0/dt) >> 1$

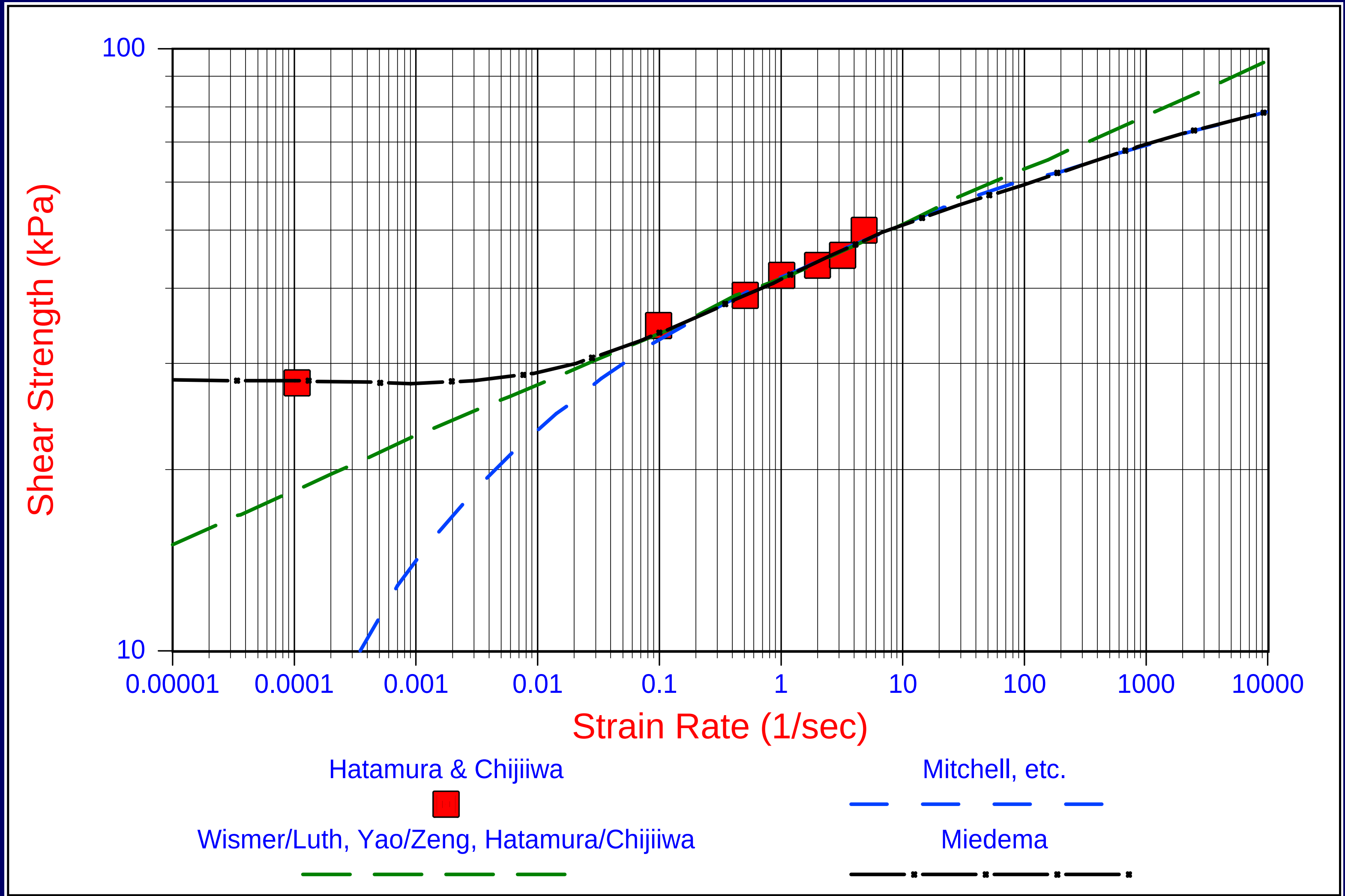
$$\tau = \tau_y + \tau_0 \cdot \ln\left[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$$

$(d\varepsilon/dt)/(d\varepsilon_0/dt) >> 1$

$\tau - \tau_y << \tau_y$

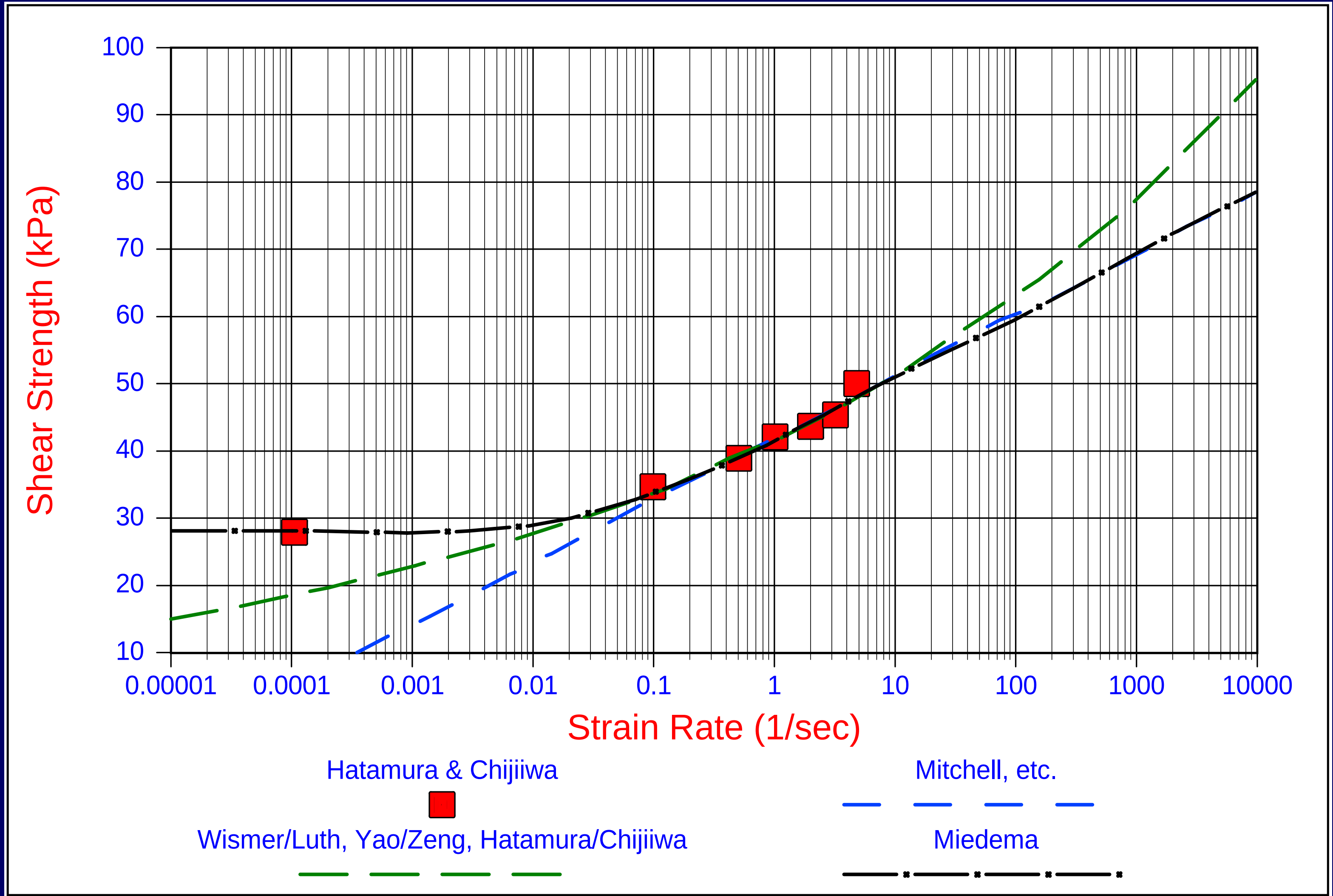
$$\tau = \tau_y \cdot \left[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]^{\tau_0 / \tau_y}$$

Shear Strength vs Strain Rate

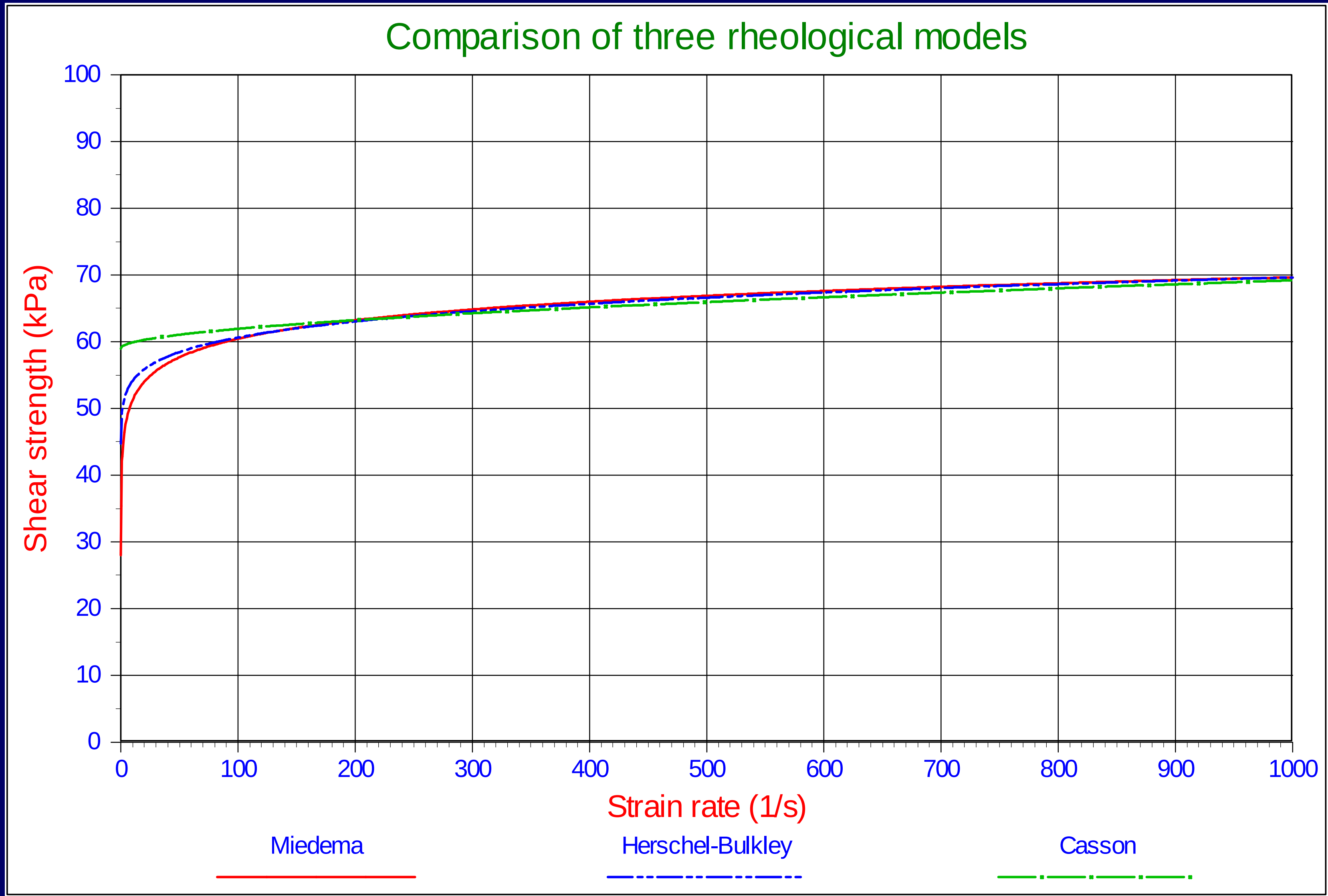


Delft University of Technology
Offshore & Dredging Engineering

Shear Strength vs Strain Rate



Rheological models



Conclusions

- The new shear strength equation matches the measurements very well
- The new shear strength equation can be simplified to match existing equations
- For dredging applications the dynamic shear strength (cohesion) is about two times the static shear strength

Resulting Equations, Clay Cutting

$$K_2 = \frac{C - A \cdot \cos(\alpha + \beta)}{\sin(\alpha + \beta)}$$

$$F_h = K_2 \cdot \sin(\alpha) + A \cdot \cos(\alpha)$$

$$F_v = K_2 \cdot \cos(\alpha) - A \cdot \sin(\alpha)$$

$$C = \frac{c \cdot h_i \cdot w}{\sin(\beta)}$$

$$A = \frac{a \cdot h_b \cdot w}{\sin(\alpha)}$$

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Resulting Equations, Clay Cutting

$$F_h = \left\{ \frac{c_d \cdot h_i}{\sin(\beta) \cdot \sin(\alpha+\beta)} + \frac{a \cdot h_b \cdot \sin(\beta)}{\sin(\alpha) \cdot \sin(\alpha+\beta)} \right\} \cdot w$$

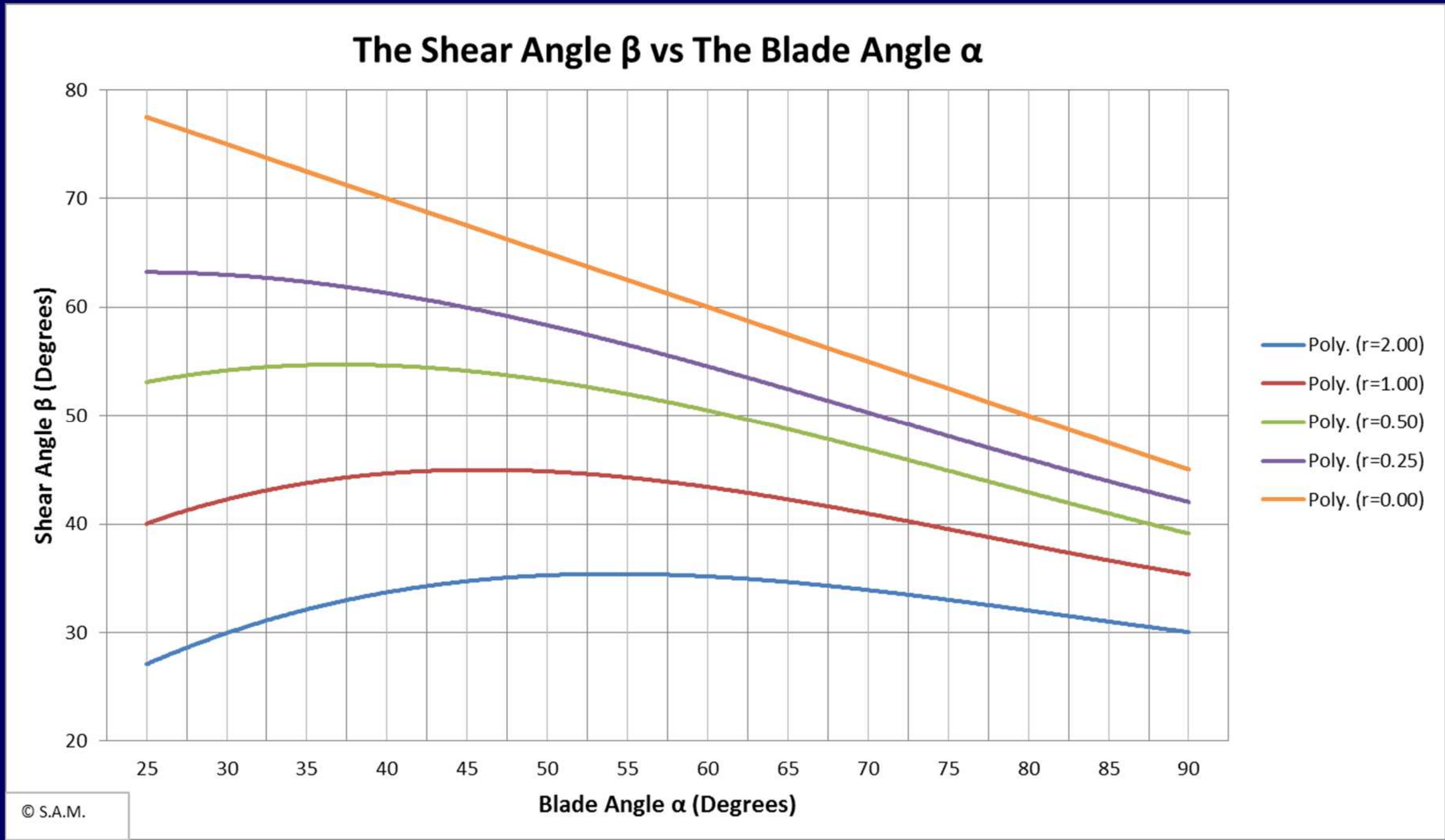
$$k_a = \frac{a \cdot h_b}{c_d \cdot h_i}$$

$$F_h = \left\{ \frac{1}{\sin(\beta) \cdot \sin(\alpha+\beta)} + \frac{k_a \cdot \sin(\beta)}{\sin(\alpha) \cdot \sin(\alpha+\beta)} \right\} \cdot c_d \cdot h_i \cdot w$$

Delft University of Technology

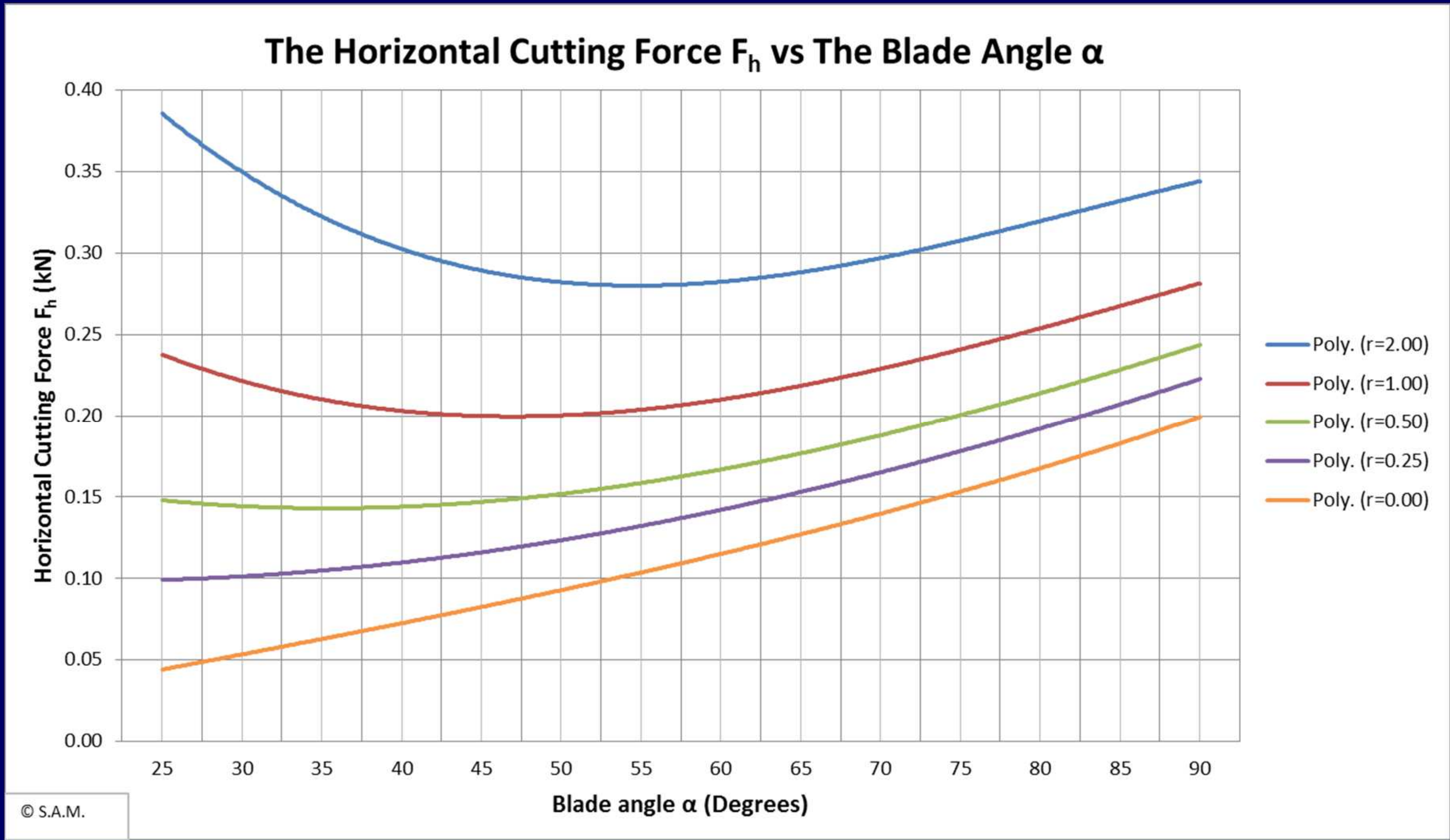
Offshore & Dredging Engineering

The Shear Angle β

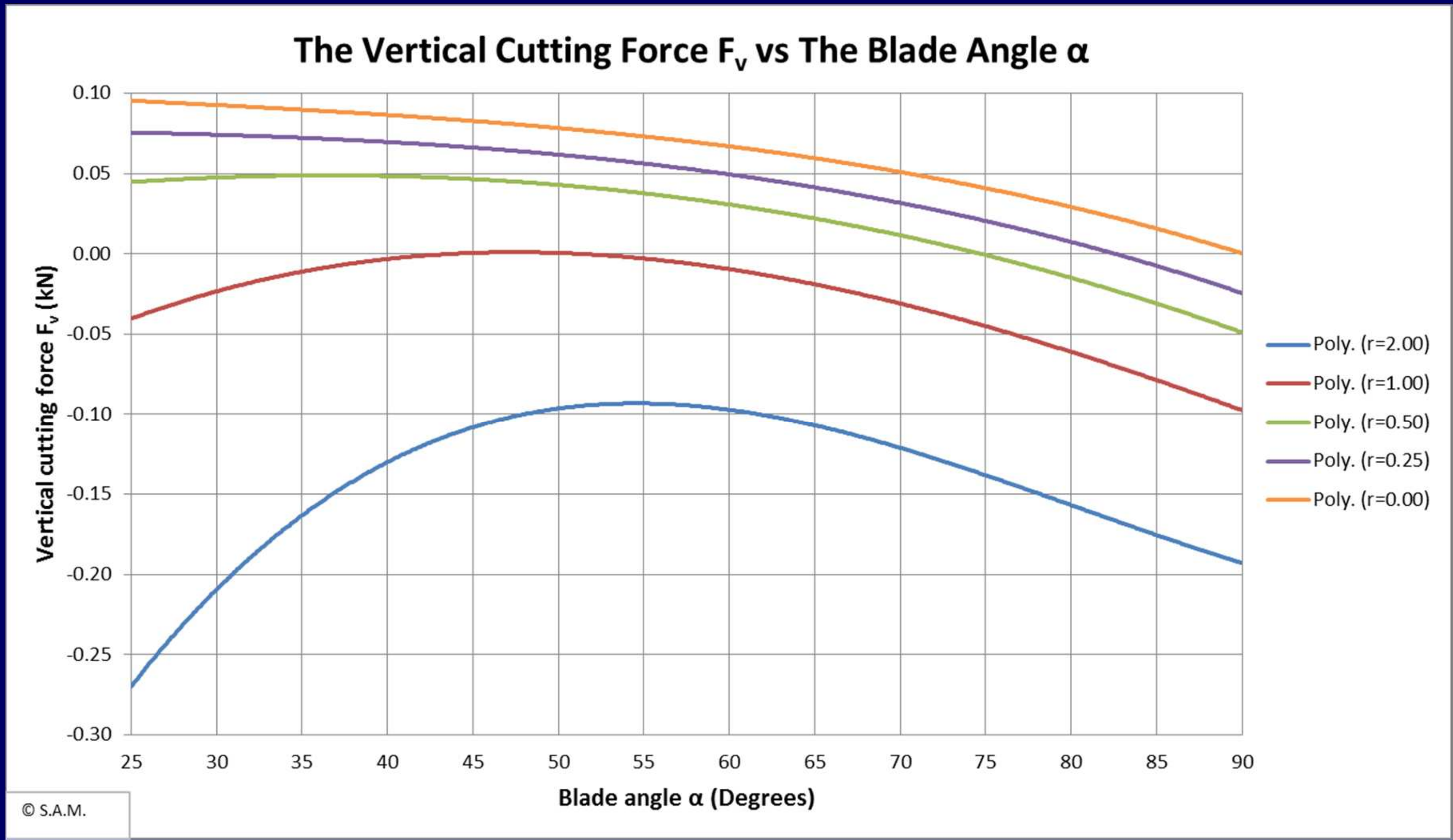


Delft University of Technology
Offshore & Dredging Engineering

The Horizontal Cutting Force F_h (c=1 kPa)



The Vertical Cutting Force F_v (c=1 kPa)



Delft University of Technology
Offshore & Dredging Engineering

Forces in Clay, SPT Relation

$$c_d = c_y + c_0 \cdot \ln\left(1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right) \approx 2 \cdot c_y$$

$$c_y \approx 6 \cdot SPT \quad \Rightarrow \quad c_d \approx 12 \cdot SPT$$

$$E_{sp} = \frac{F_h \cdot v_c}{h_i \cdot w \cdot v_c} \qquad Q = \frac{P}{E_{sp}}$$

$$E_{sp} = \left\{ \frac{1}{\sin(\beta) \cdot \sin(\alpha+\beta)} + \frac{k_a \cdot \sin(\beta)}{\sin(\alpha) \cdot \sin(\alpha+\beta)} \right\} \cdot 12 \cdot SPT$$

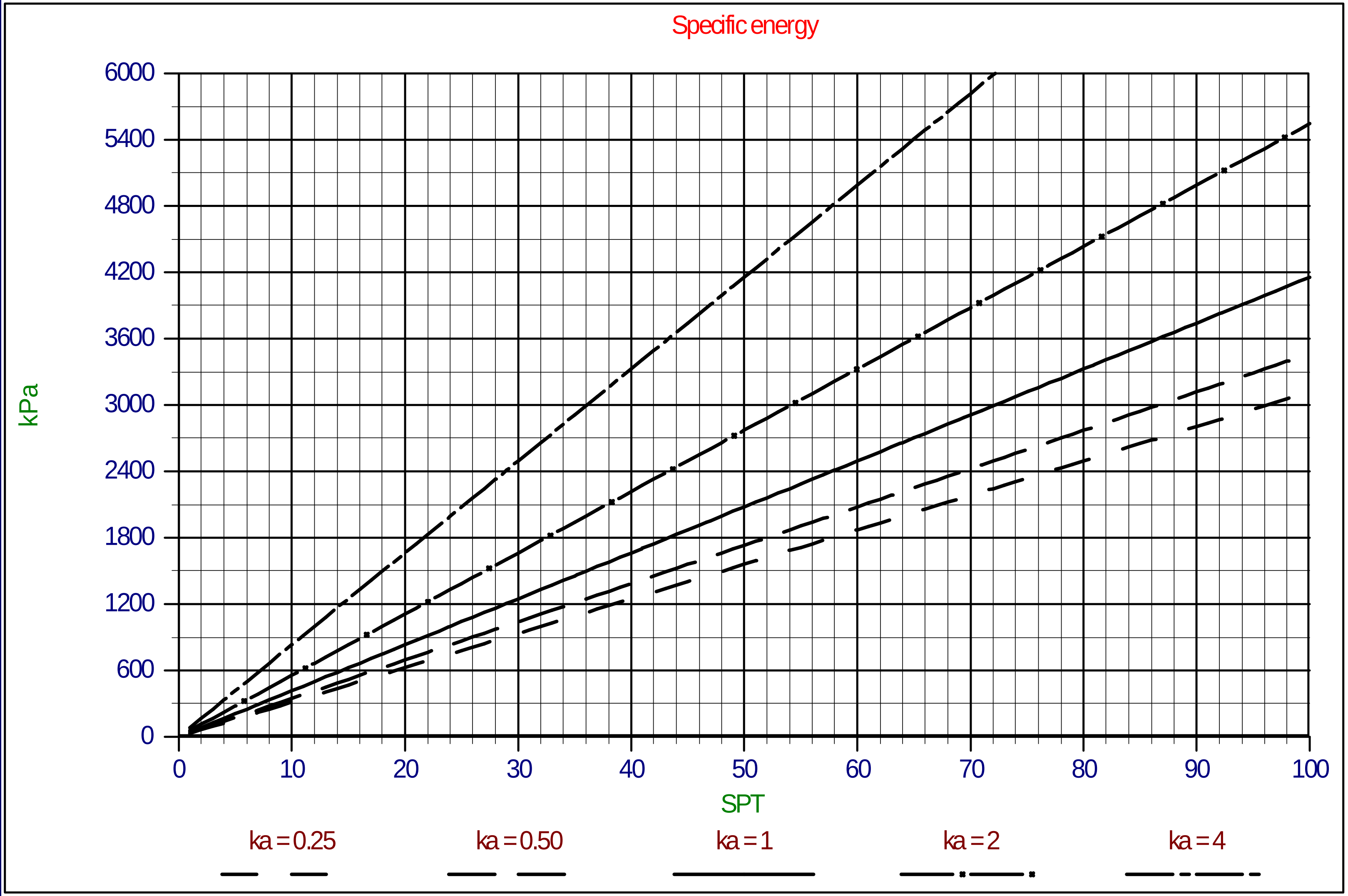
Strain Rate Coefficients

$$\dot{\varepsilon}_c = 1.4 \cdot \frac{v_c}{h_i} \cdot \frac{\sin(\alpha)}{\sin(\alpha+\beta)}$$

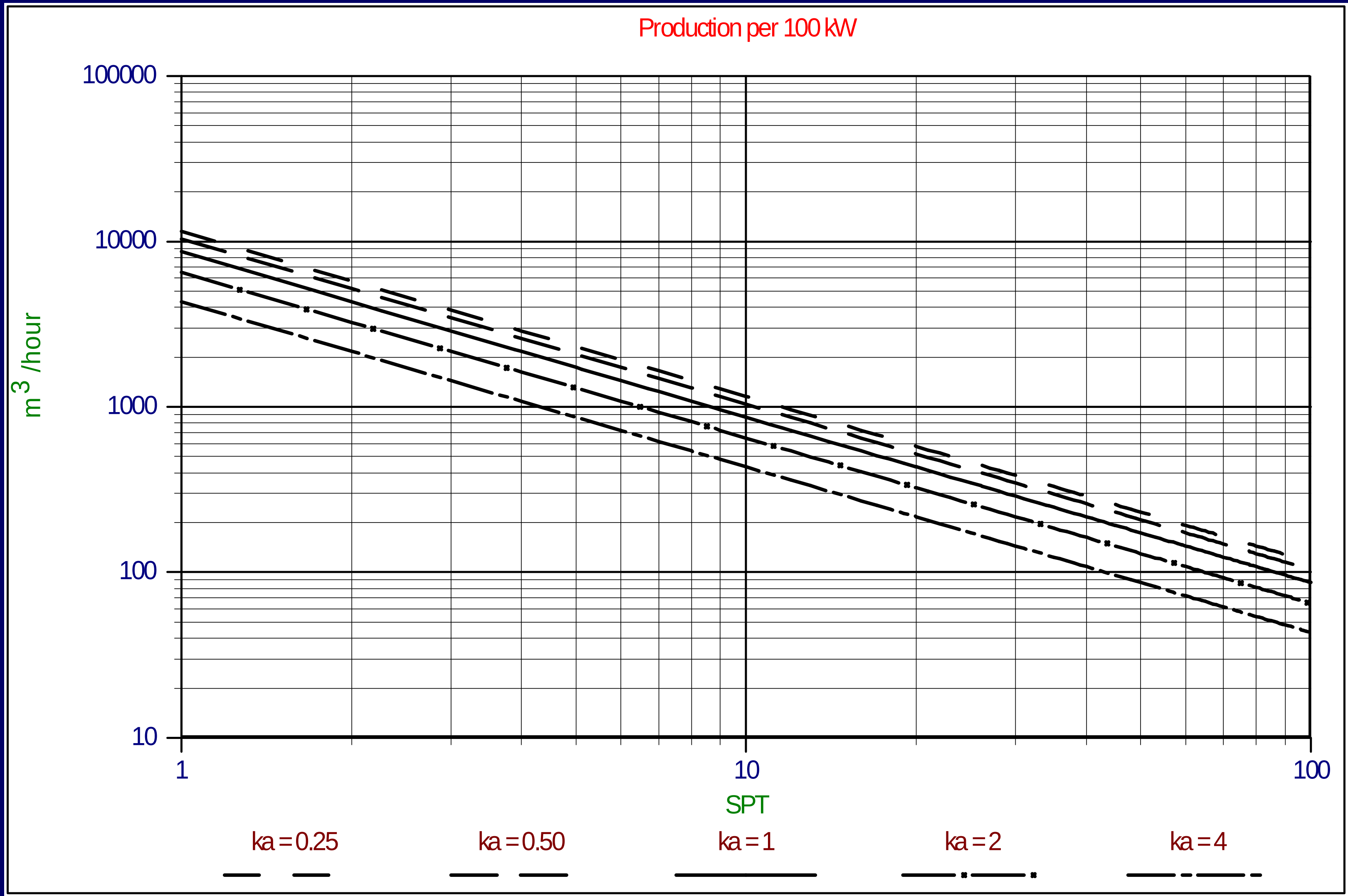
$$\dot{\varepsilon}_a = 1.4 \cdot \frac{v_c}{h_i} \cdot \frac{\sin(\beta)}{\sin(\alpha+\beta)}$$

$$\tau_0 / \tau_y = 0.1428, \quad \dot{\varepsilon}_0 = 0.03$$

Specific Energy in Clay, 30 Degree Blade

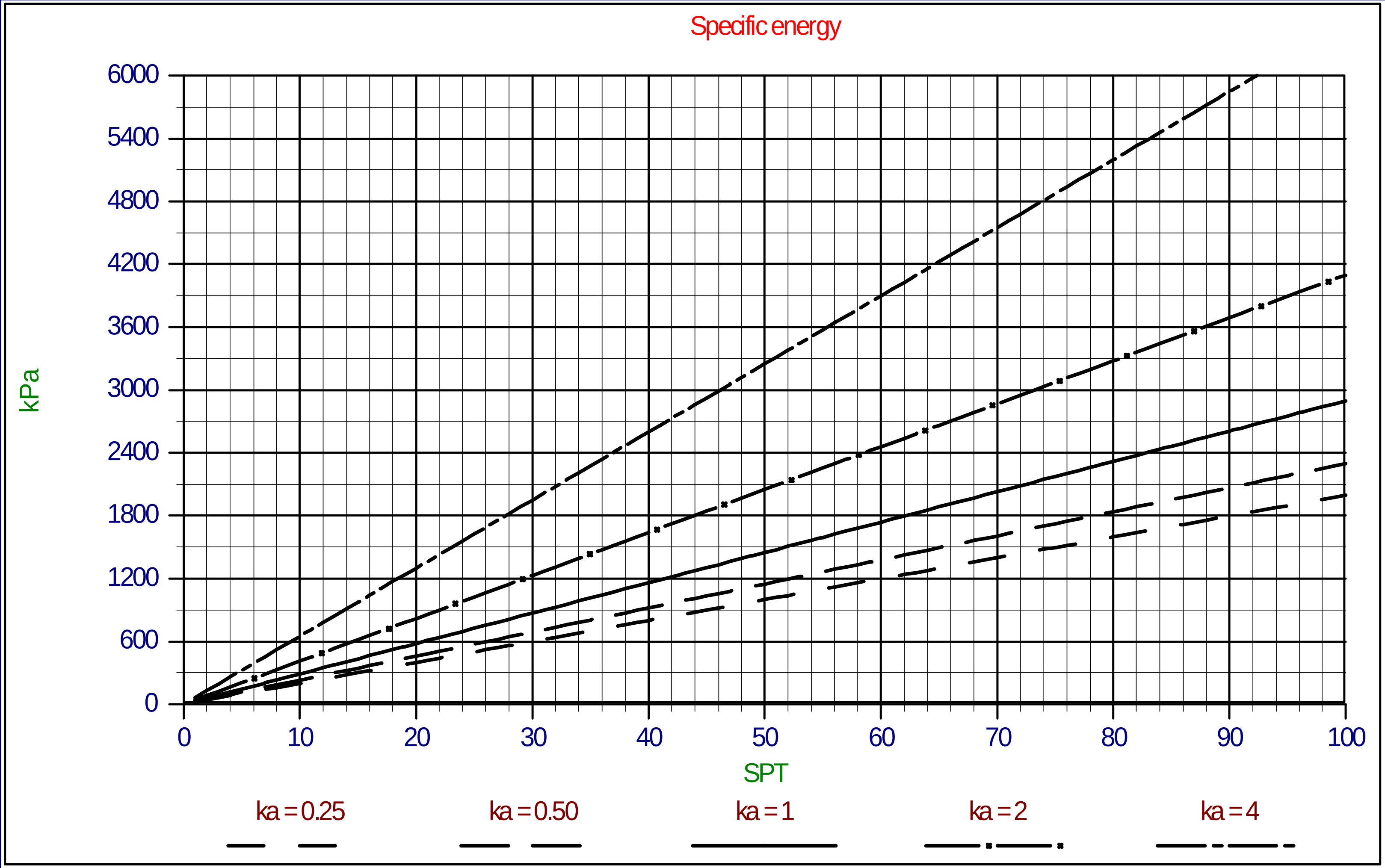


Production in Clay, 30 Degree Blade

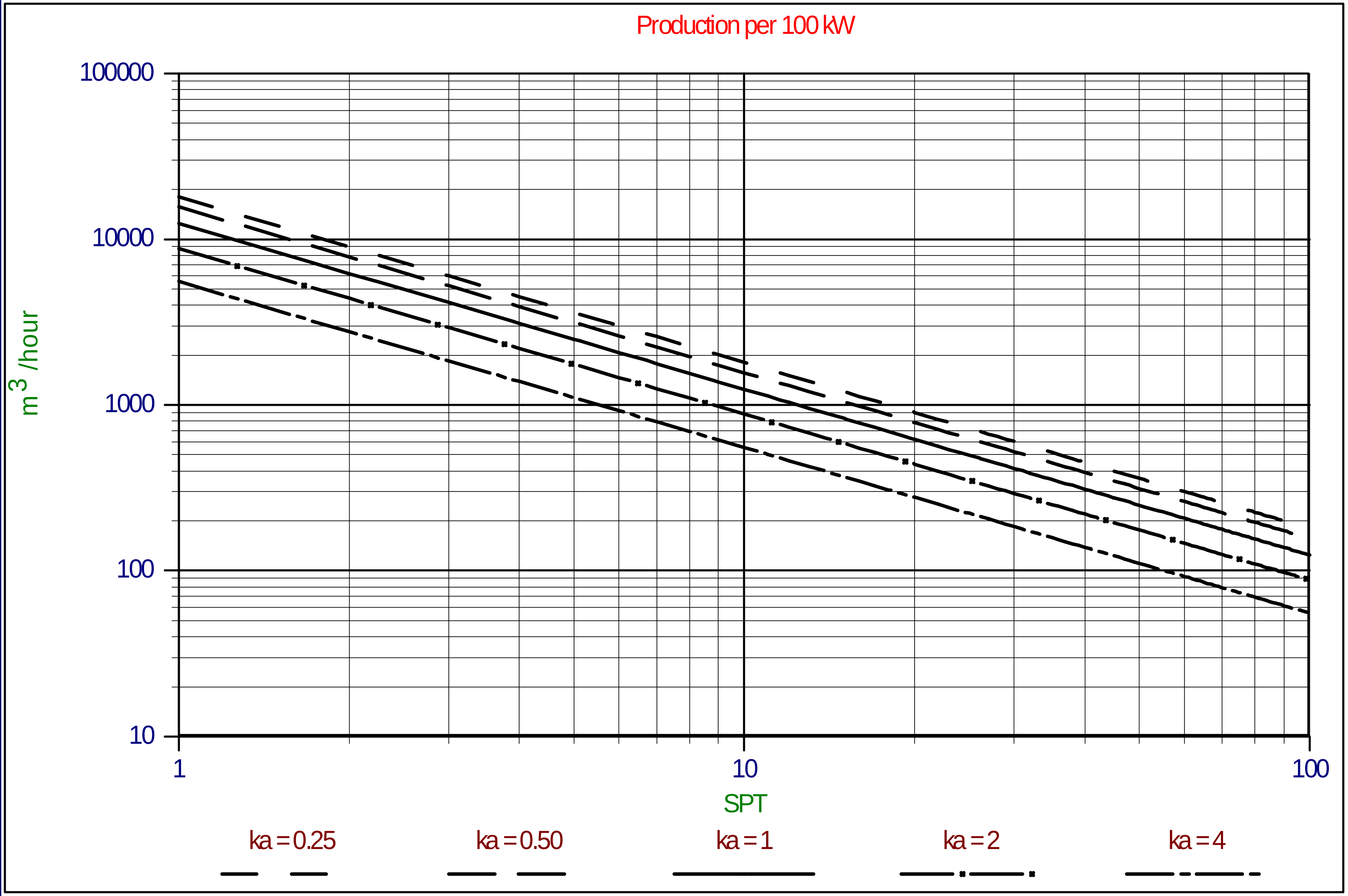


TU Delft
Delft University of Technology
Offshore & Dredging Engineering

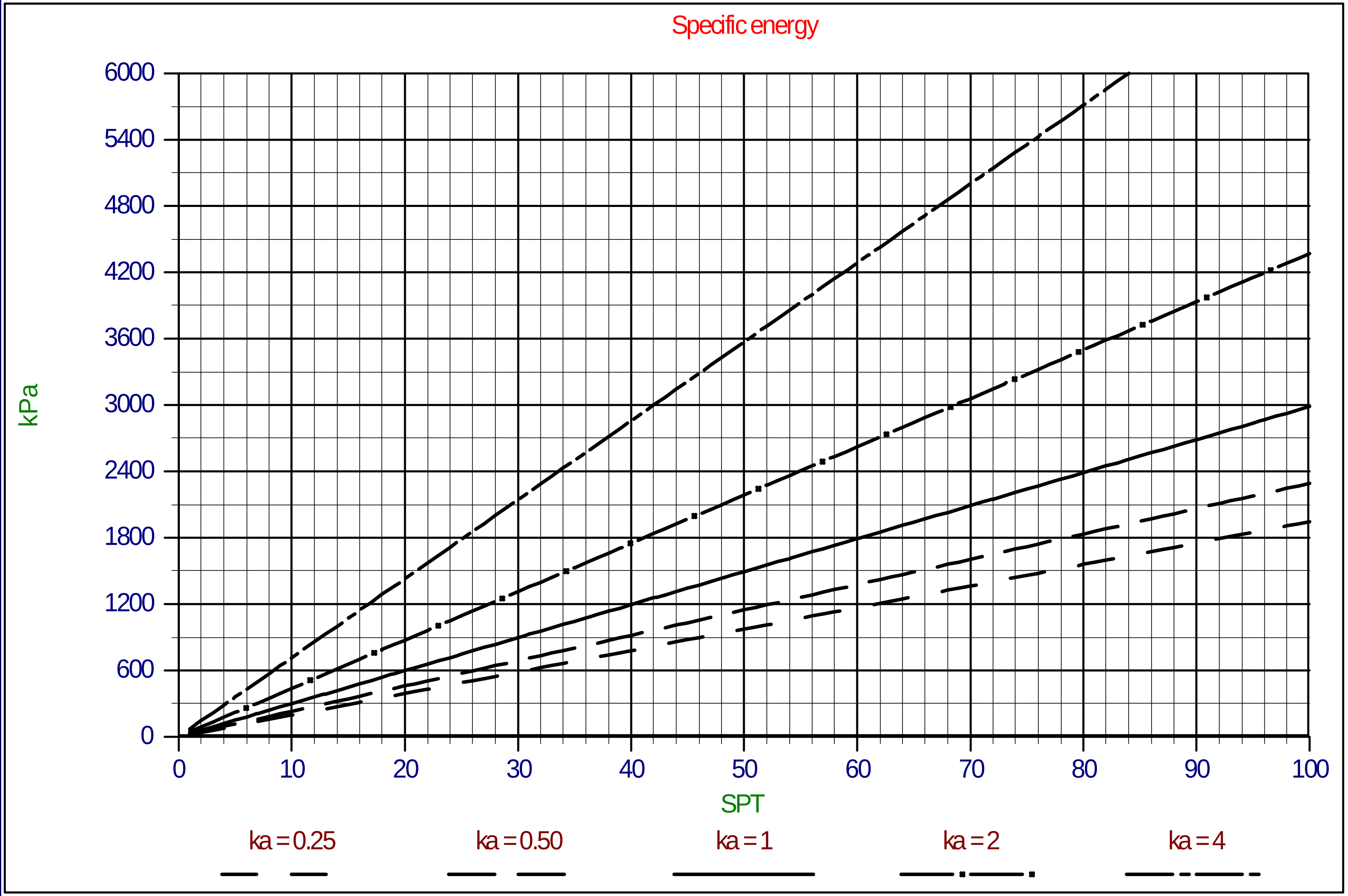
Specific Energy in Clay, 45 Degree Blade



Production in Clay, 45 Degree Blade

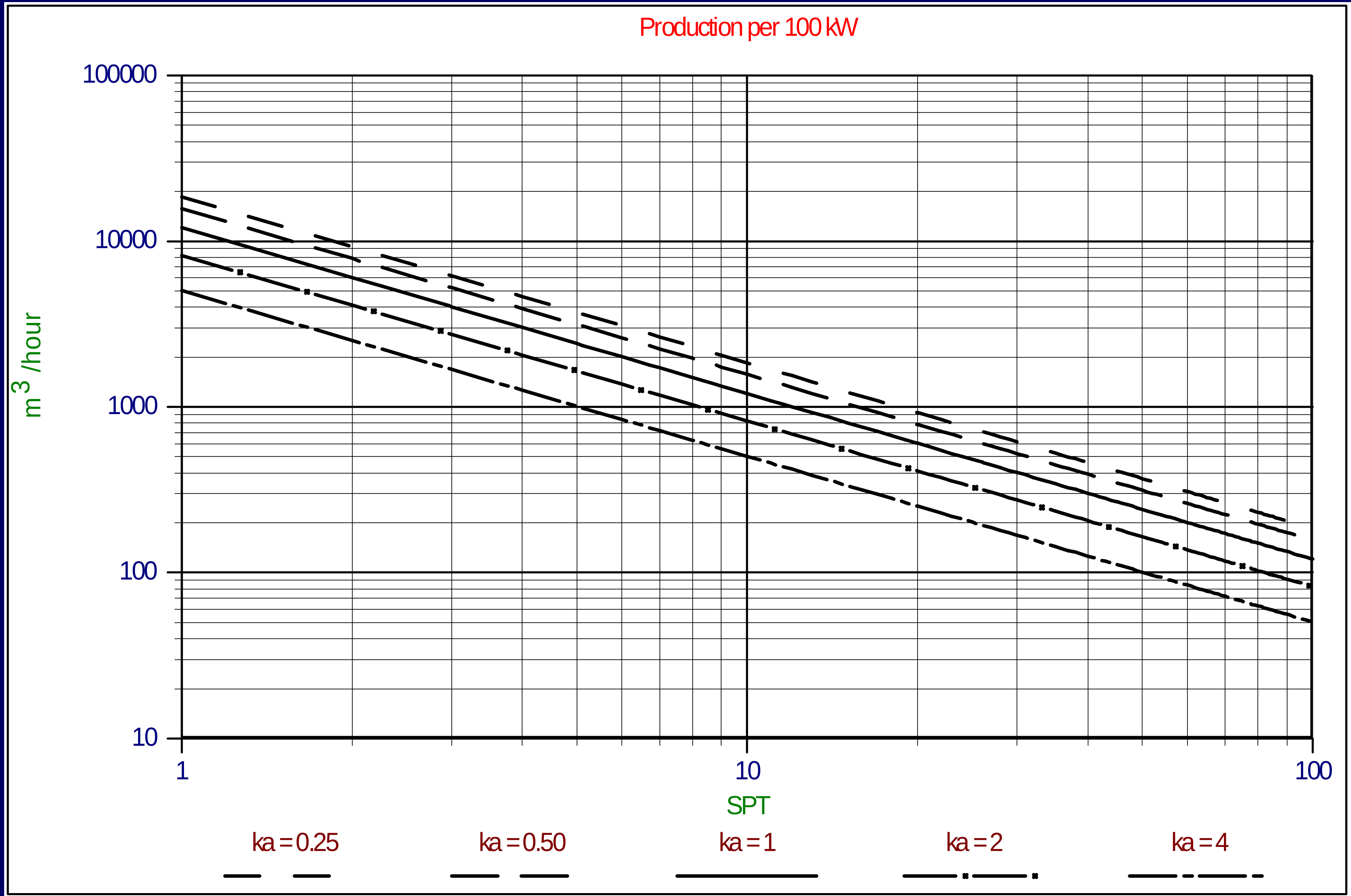


Specific Energy in Clay, 60 Degree Blade



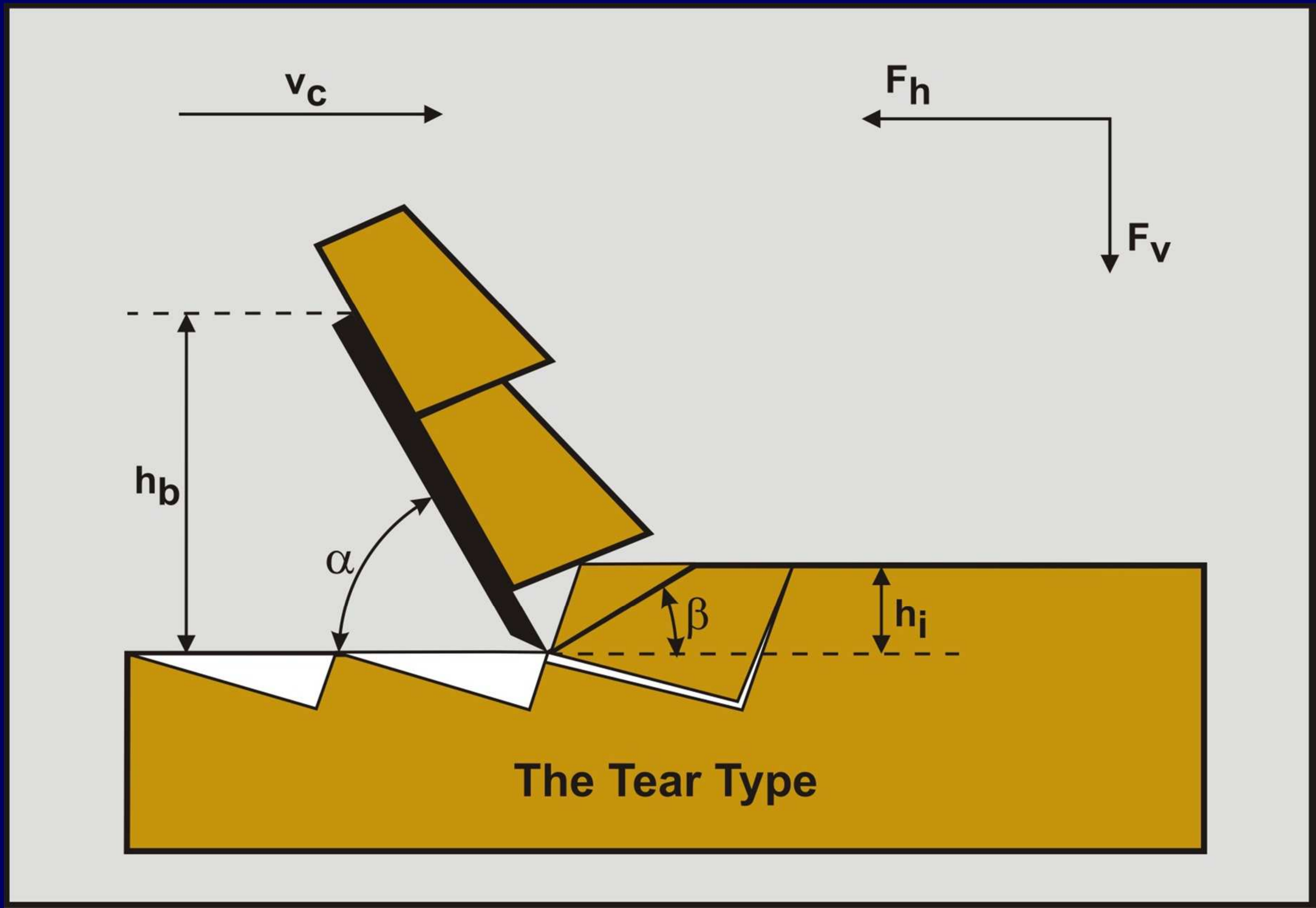
Delft University of Technology
Offshore & Dredging Engineering

ProDuction in Clay, 60 Degree Blade



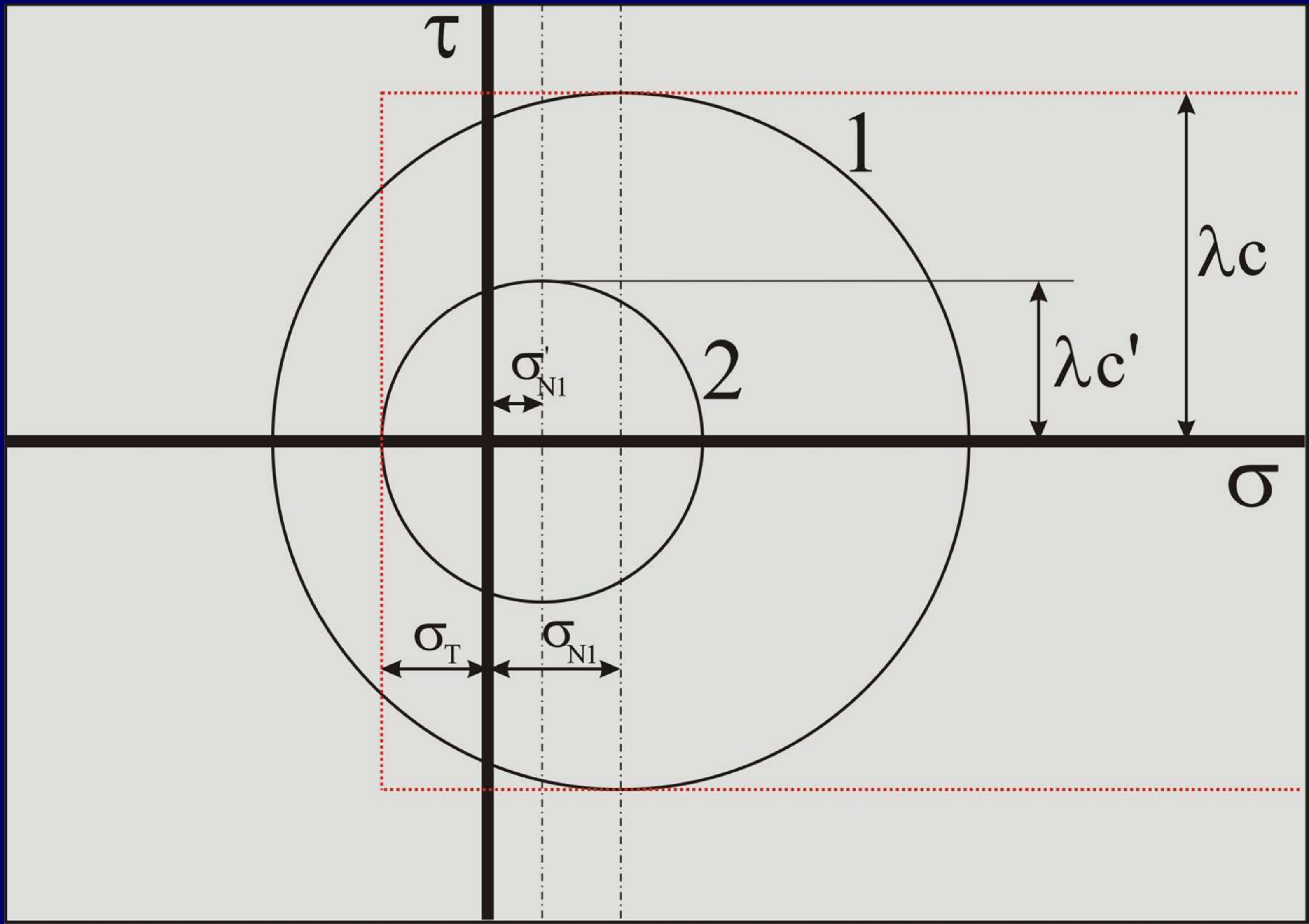
Delft University of Technology
Offshore & Dredging Engineering

The Tear Type

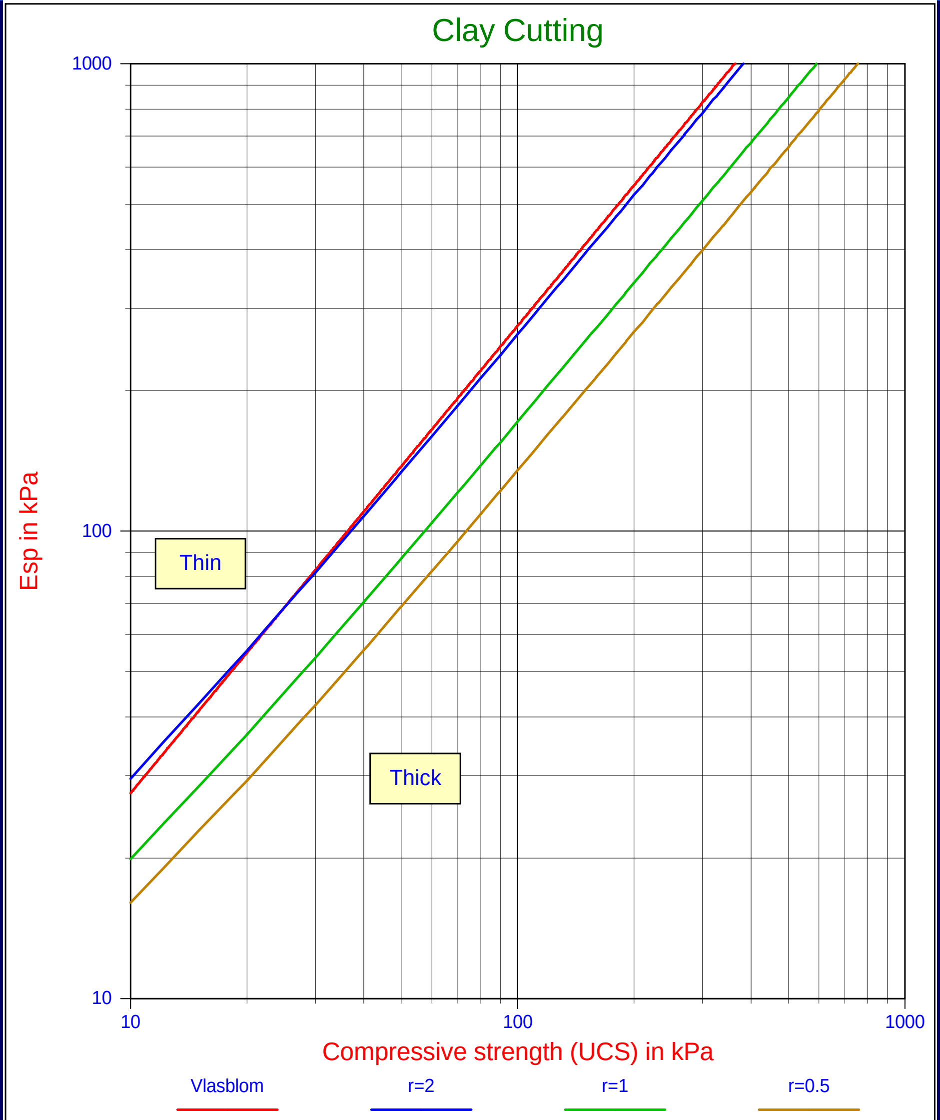


TU Delft
Delft University of Technology
Offshore & Dredging Engineering

The Reduced Mohr Circle

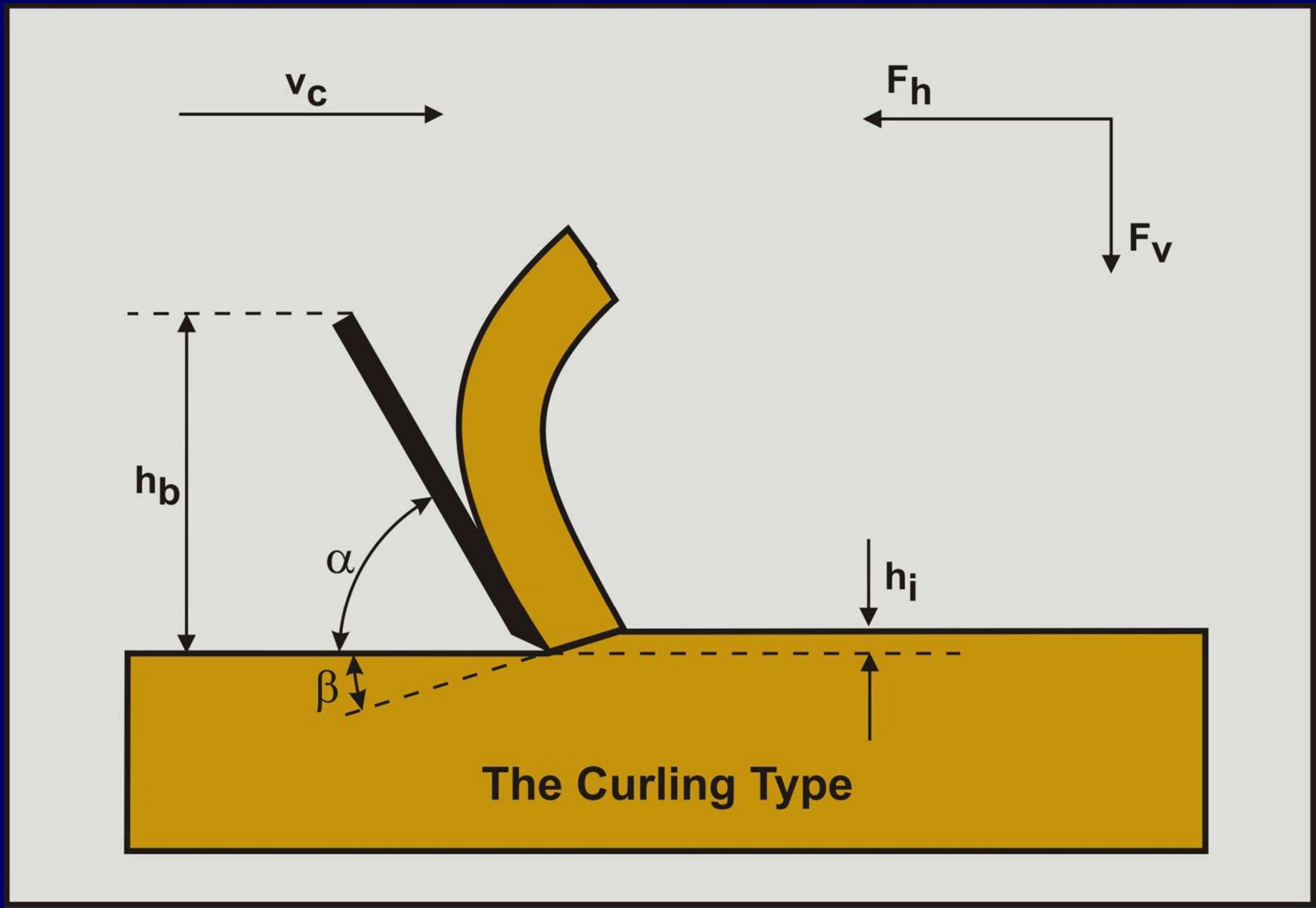


Specific Energy

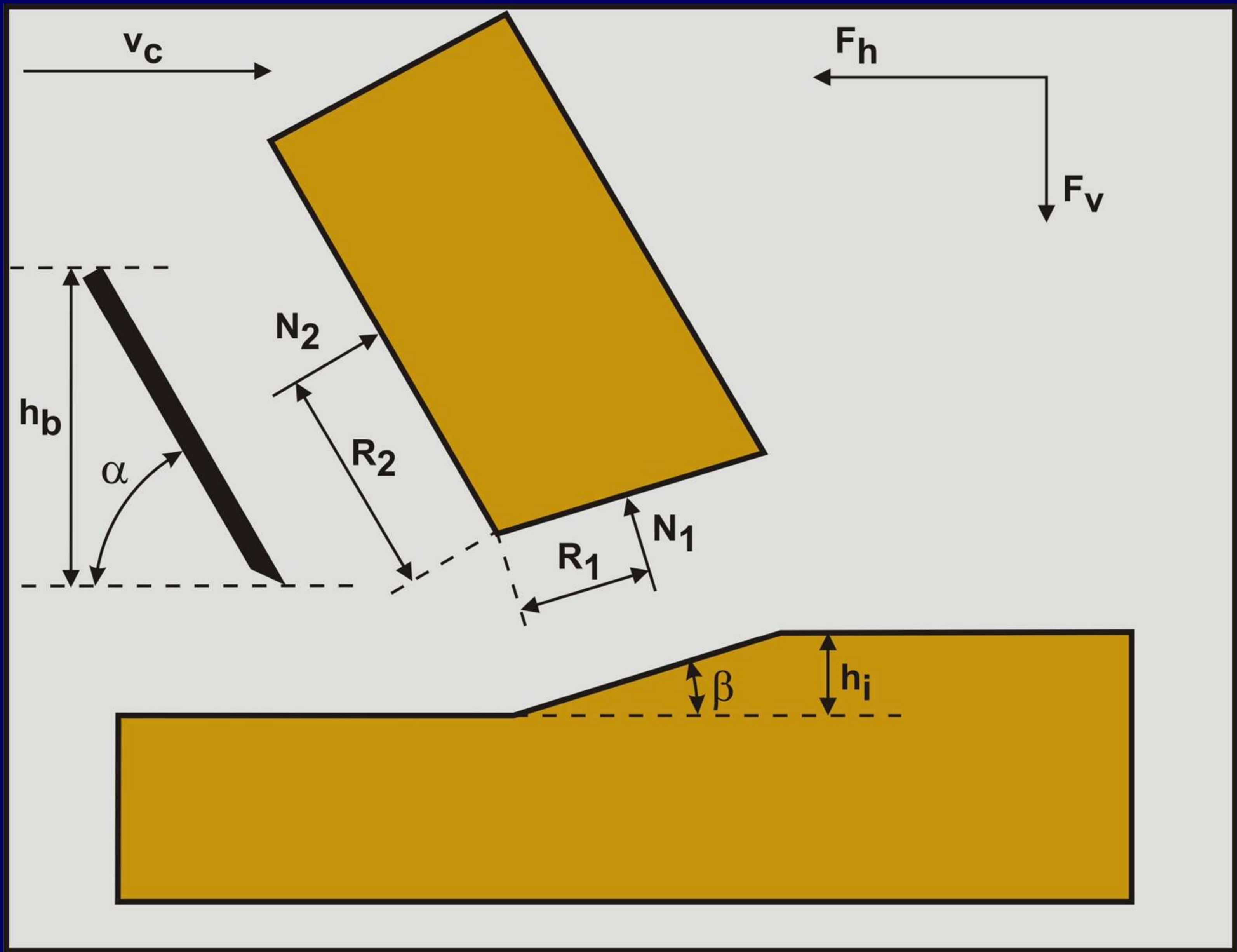


The specific energy Esp as a function of the compressive strength of clay,
for different layer thicknesses at vc=1 m/s for a 60 degree blade.

The Curling Type



Moments



Equilibrium of Moments

$$\left(\frac{A - C\cdot\cos(\alpha+\beta)}{\sin(\alpha+\beta)}\right)\cdot\frac{\lambda_1\cdot h_i}{\sin(\beta)} = \left(\frac{C - A\cdot\cos(\alpha+\beta)}{\sin(\alpha+\beta)}\right)\cdot\frac{\lambda_2\cdot h_b^{'}}{\sin(\alpha)}$$

$$A\cdot x^2 + B\cdot x + C = 0$$

$$h_b^{'} = x = \frac{-B - \sqrt{B^2 - 4\cdot A\cdot C}}{2\cdot A}$$

$$A = \frac{\lambda_2\cdot a\cdot\cos(\alpha+\beta)}{\sin(\alpha)\cdot\sin(\alpha)}$$

$$B = \frac{\lambda_1\cdot a - \lambda_2\cdot c}{\sin(\alpha)\cdot\sin(\beta)}\cdot h_i$$

$$C = -\frac{\lambda_1\cdot c\cdot\cos(\alpha+\beta)}{\sin(\beta)\cdot\sin(\beta)}\cdot h_i\cdot h_i$$

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Questions?

Sources images

1. A model cutter head, source: Delft University of Technology.
2. Off shore platform, source: Castrol (Switzerland) AG
3. Off shore platform, source: http://www.wireropetraining.com