Cutter Head Spillage

Dr.ir. Sape A. Miedema
Head of Studies
MSc Offshore & Dredging Engineering
&
Marine Technology
Associate Professor of
Dredging Engineering

Thursday, June 13, 2019

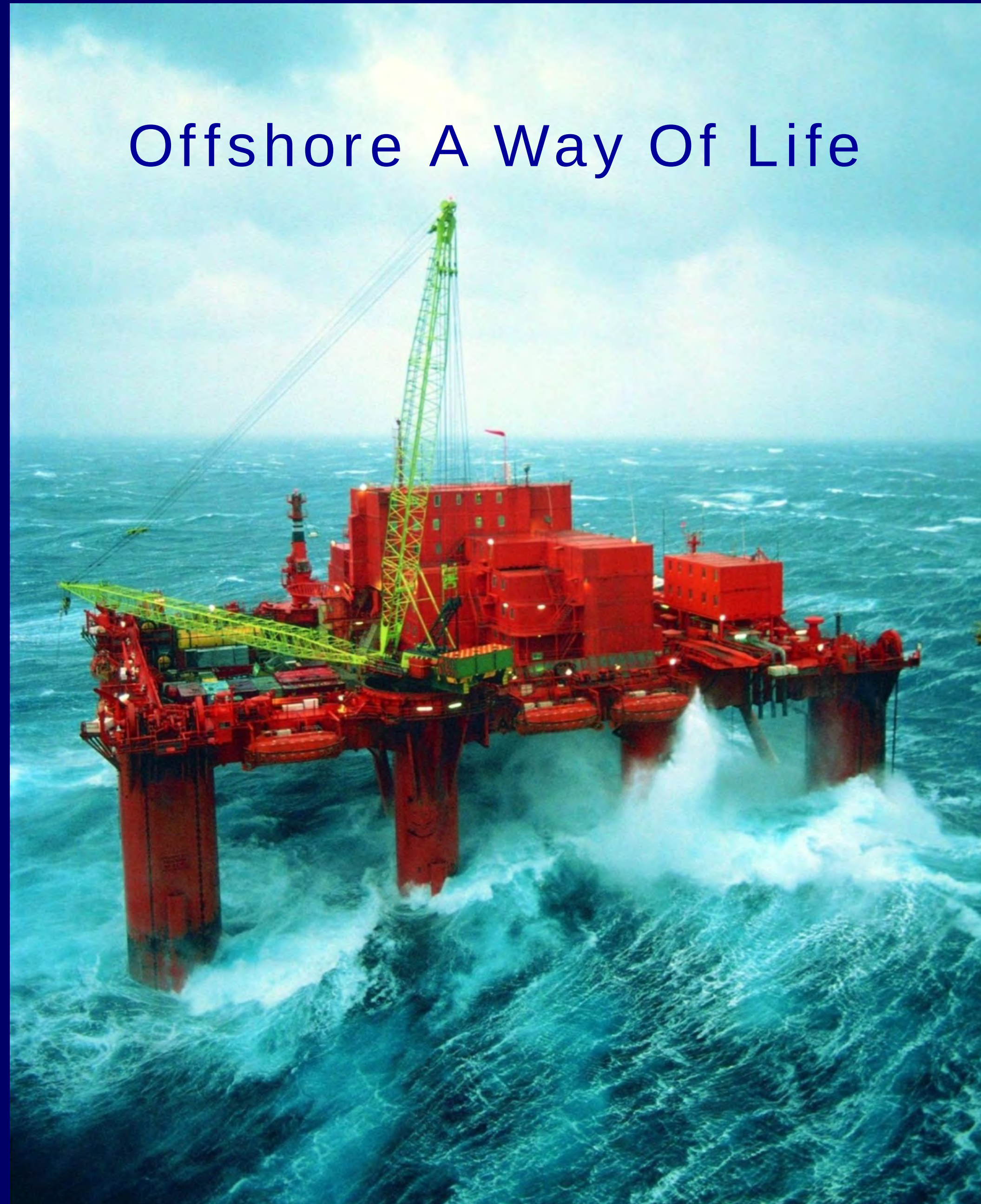
TU Delft
Delft University of Technology
Offshore & Dredging Engineering

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Dredging A Way Of Life

Delft University of Technology – Offshore & Dredging Engineering

TU Delft
Delft University of Technology
Offshore & Dredging Engineering



Delft University of Technology
Offshore & Dredging Engineering

Delft University of Technology – Offshore & Dredging Engineering

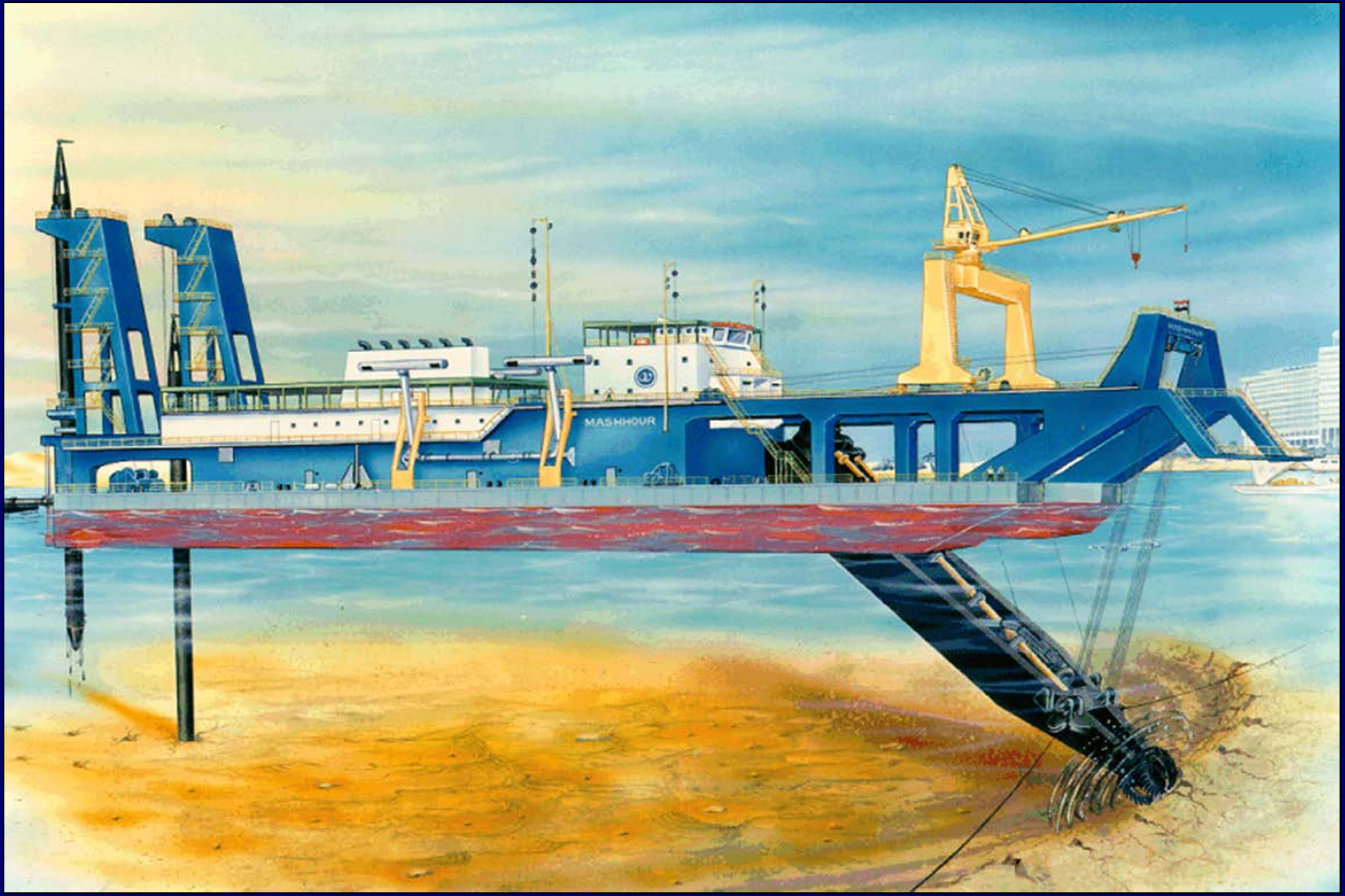
What is Offshore & Dredging Engineering?

Offshore & Dredging Engineering covers everything at sea that does not have the purpose of transporting goods & people and no fishery.

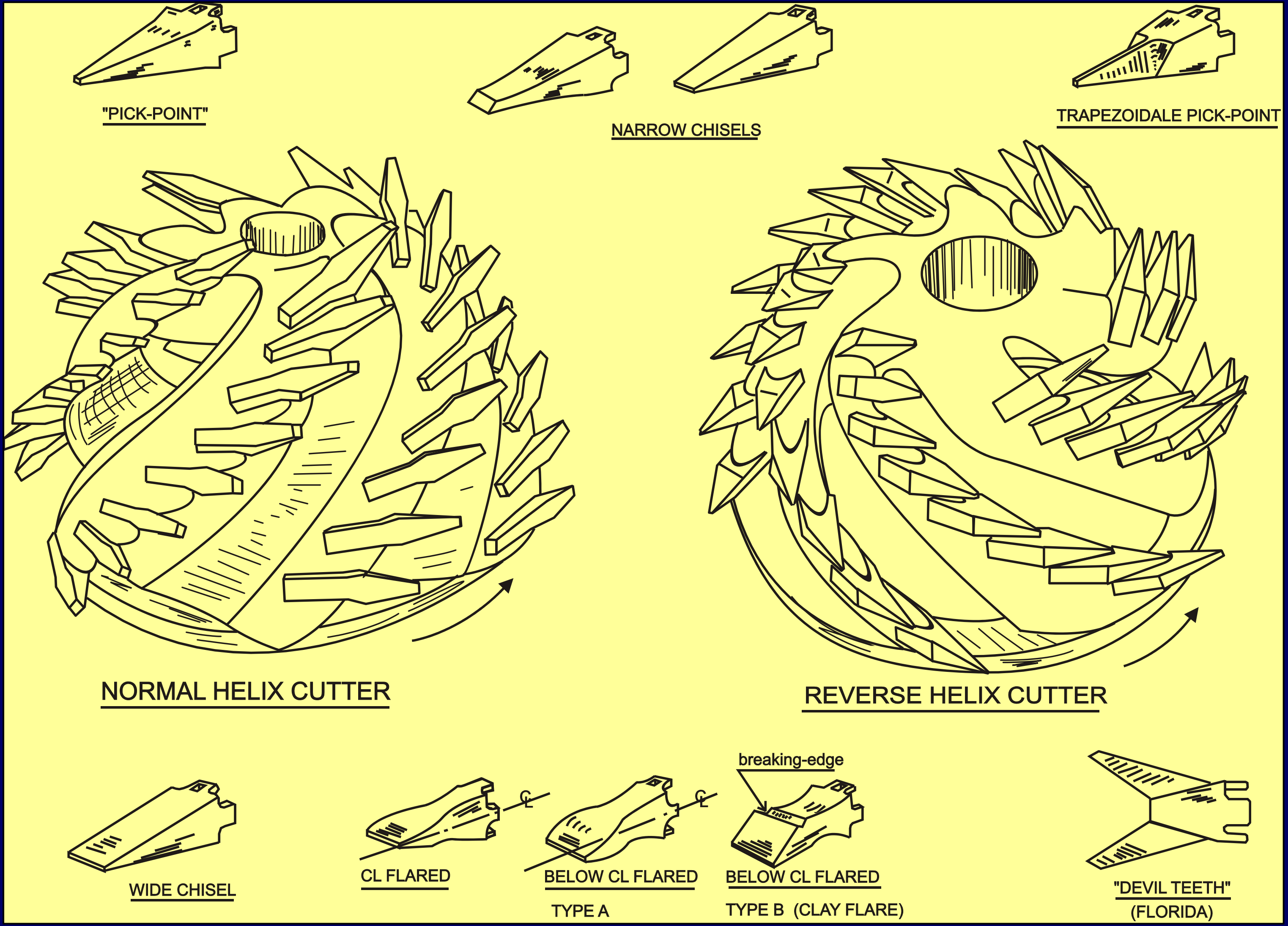
The Cutter Head

Delft University of Technology
Offshore & Dredging Engineering

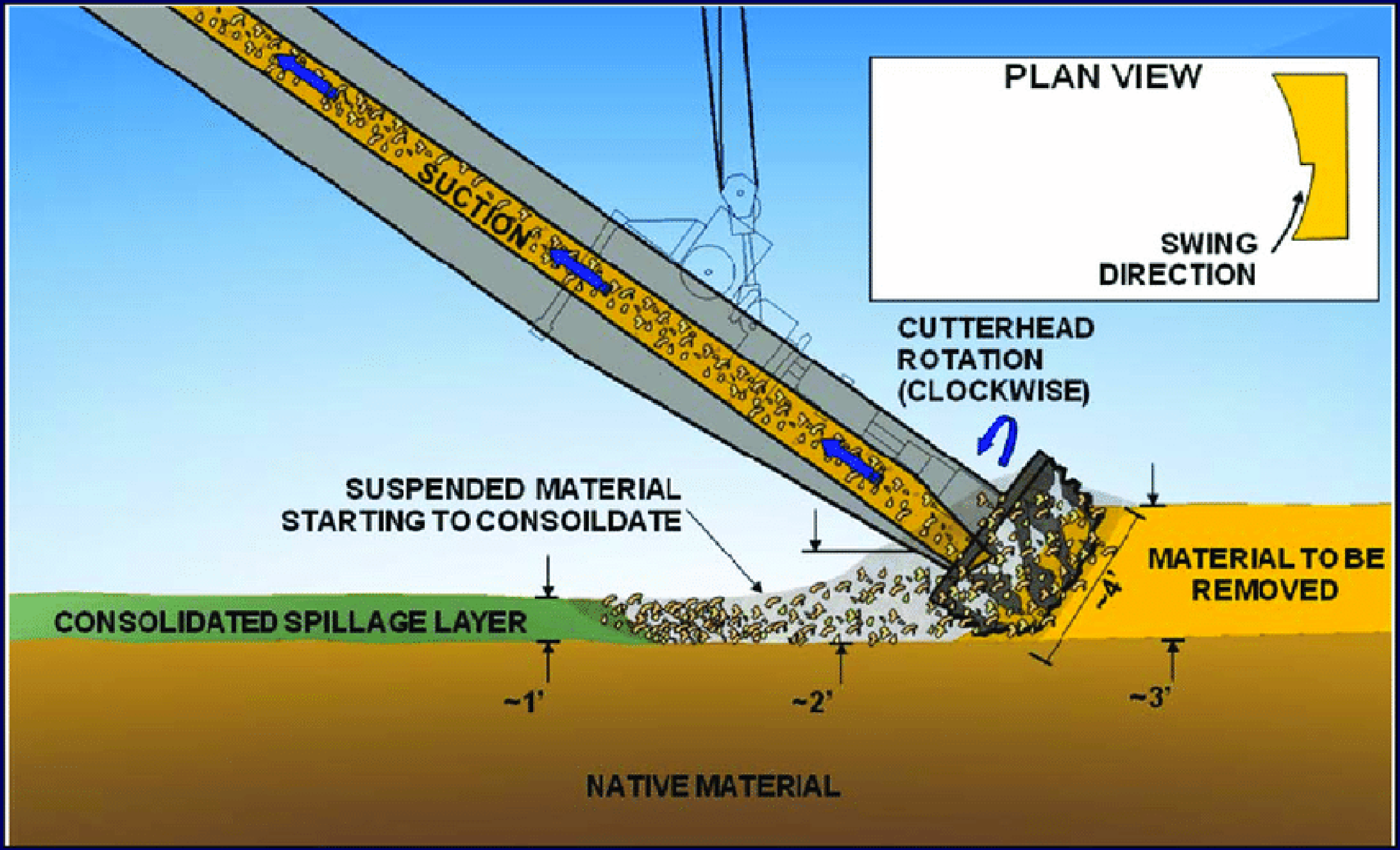
The Mashour



Rock Cutter Heads

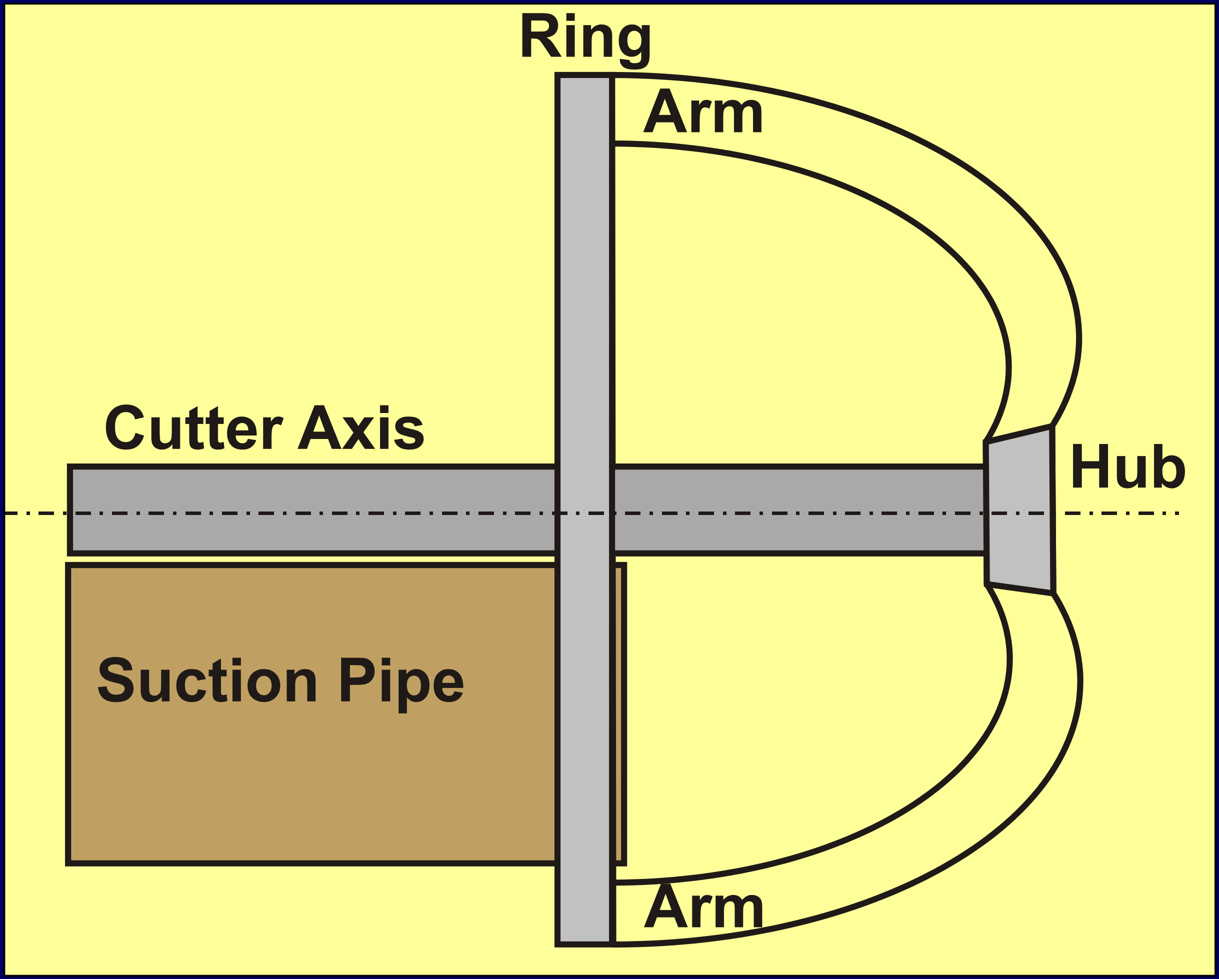


Spillage



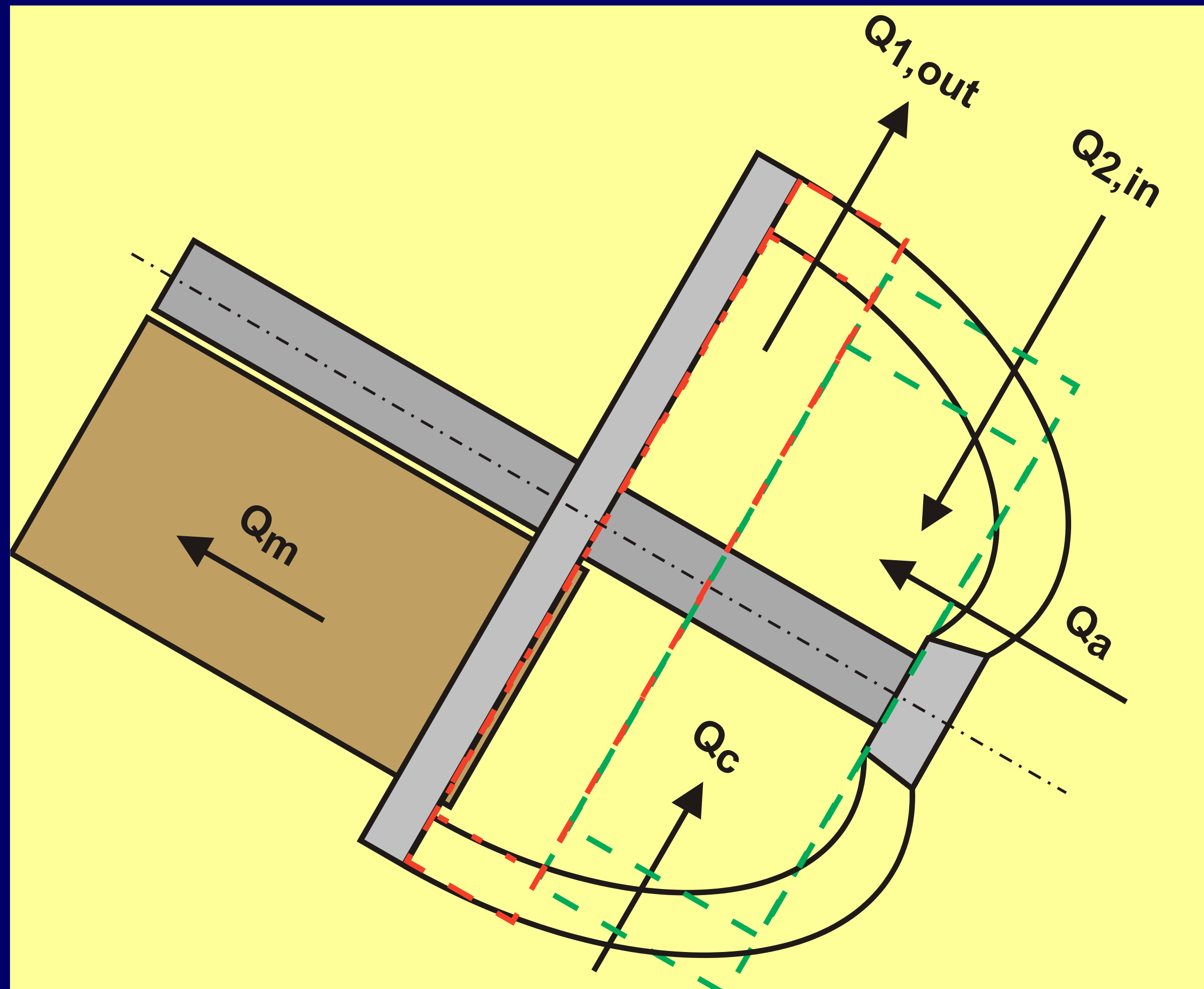
TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Definitions



TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Different Flows in a Drag Head



Affinity Law Model

Affinity Laws

$$F = m \cdot \omega^2 \cdot R \qquad \text{with: } m = \rho_m \cdot \frac{\pi}{4} \cdot D^2 \cdot w$$

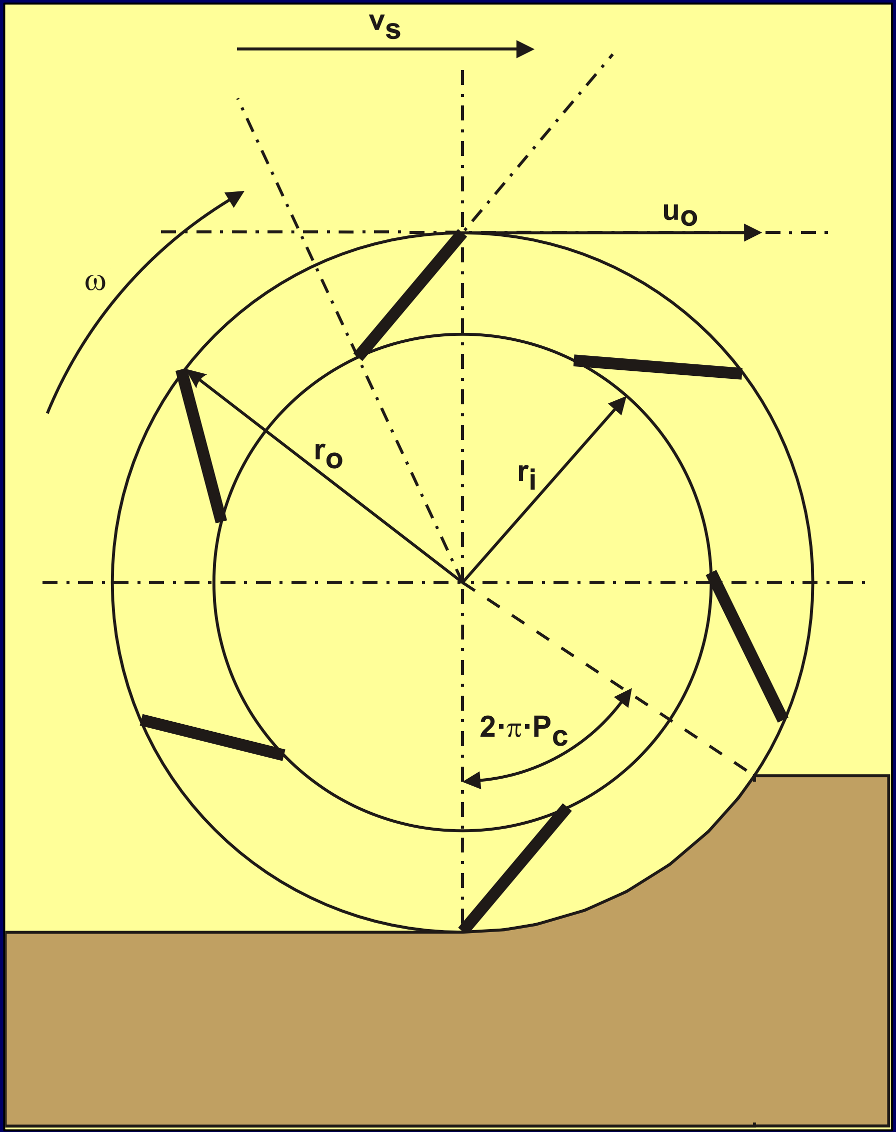
$$p = \frac{F}{A} = \frac{\rho_m \cdot \frac{\pi}{4} \cdot D^2 \cdot w \cdot \omega^2 \cdot R}{\pi \cdot D \cdot w} = \frac{1}{8} \cdot \rho_m \cdot \omega^2 \cdot D^2$$

$$Q = \omega \cdot R \cdot \pi \cdot D \cdot w = \frac{\pi}{2} \cdot \omega \cdot D^2 \cdot w$$

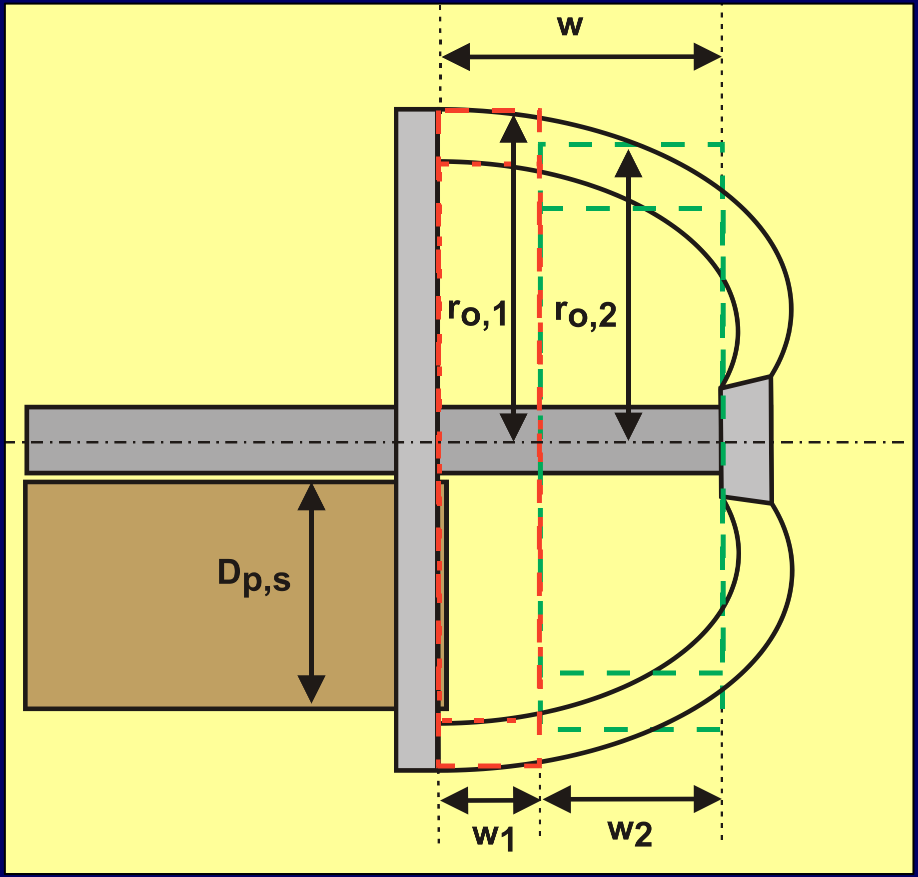
$$\frac{\eta_1}{\eta_2} = 1 \quad \text{and} \quad \frac{p_1}{p_2} = \frac{n_1^2}{n_2^2} \cdot \frac{D_1^2}{D_2^2} \cdot \frac{\rho_{m1}}{\rho_{m2}} \quad \text{and} \quad \frac{Q_1}{Q_2} = \frac{n_1}{n_2} \cdot \frac{D_1^2}{D_2^2} \cdot \frac{w_1}{w_2}$$

$$\frac{P_1}{P_2} = \frac{n_1^3}{n_2^3} \cdot \frac{D_1^4}{D_2^4} \cdot \frac{\rho_{m1}}{\rho_{m2}} \cdot \frac{w_1}{w_2} \quad \text{and} \quad \frac{T_1}{T_2} = \frac{n_1^2}{n_2^2} \cdot \frac{D_1^4}{D_2^4} \cdot \frac{\rho_{m1}}{\rho_{m2}} \cdot \frac{w_1}{w_2}$$

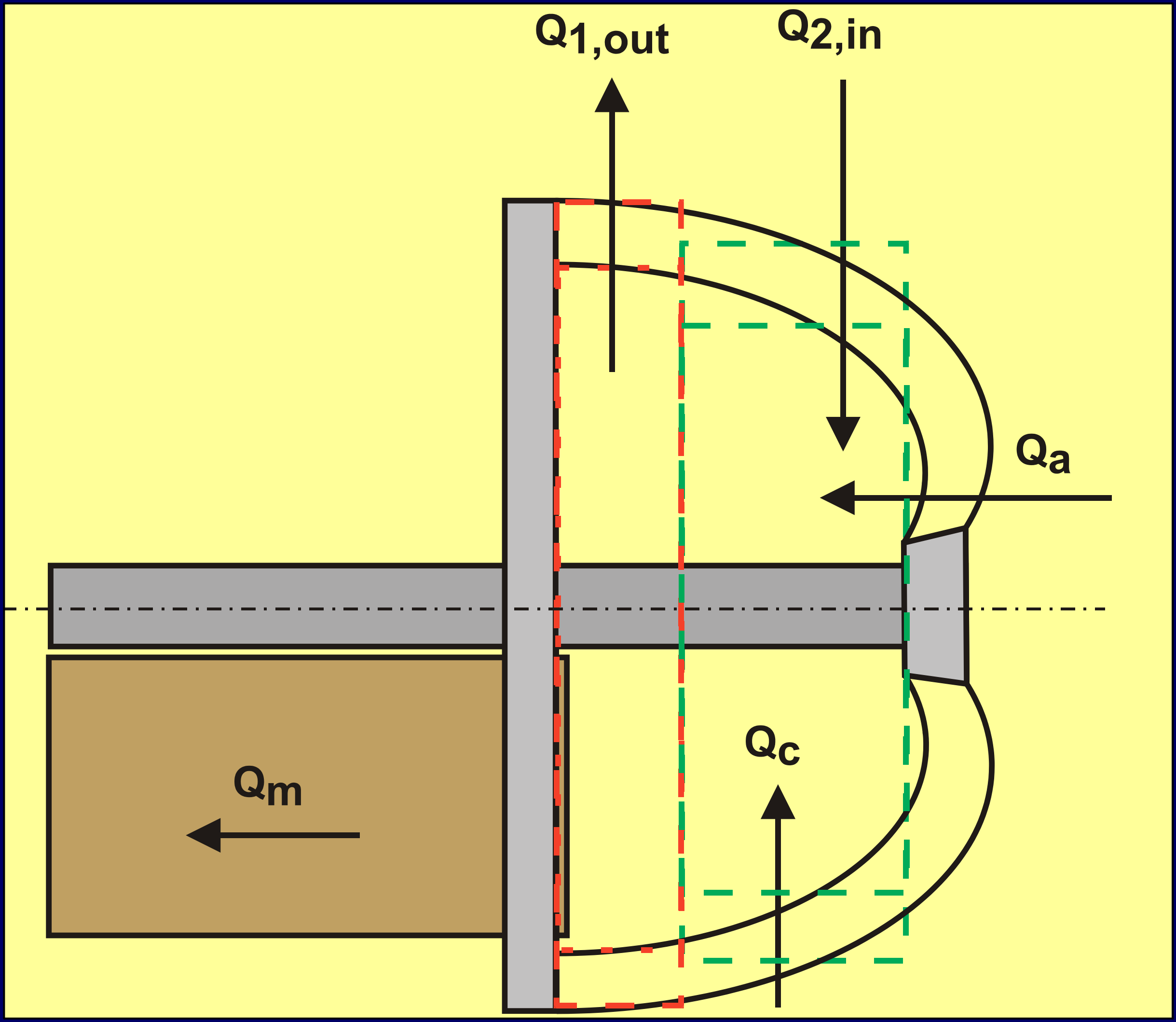
Cutter Head Dimensions



Cutter Head Segments



The Flows in a Cutter Head



Flows & Spillage Homogeneous

$$Q_{1,out} = \alpha \cdot 2 \cdot \pi \cdot \omega \cdot r_{o,1}^2 \cdot$$

$$\left(\frac{f}{(1+f)} \cdot w - \frac{1}{(1+f)} \cdot \frac{1}{2 \cdot \pi \cdot \alpha \cdot \omega} \cdot \left(\frac{Q_m - Q_c - Q_a}{r_{o,1}^2 \cdot (1 - P_c)} \right) \right) \cdot (1 - P_c)$$

$$Q_{2,in} = 2 \cdot \pi \cdot \alpha \cdot \omega \cdot \left(r_{o,1}^2 - r_{o,2}^2 \right) \cdot$$

$$\left(\frac{1}{(1+f)} \cdot w + \frac{1}{(1+f)} \cdot \frac{1}{2 \cdot \pi \cdot \alpha \cdot \omega} \cdot \left(\frac{Q_m - Q_c - Q_a}{r_{o,1}^2 \cdot (1 - P_c)} \right) \right) \cdot (1 - P_c)$$

$$\text{Spillage} = \frac{Q_{1,out}}{Q_m + Q_{1,out}} = \frac{Q_{1,out} \cdot C_{vs}}{Q_s}$$

$$C_{vs} = \frac{Q_s}{Q_m + Q_{1,out}}$$

Production den Burger

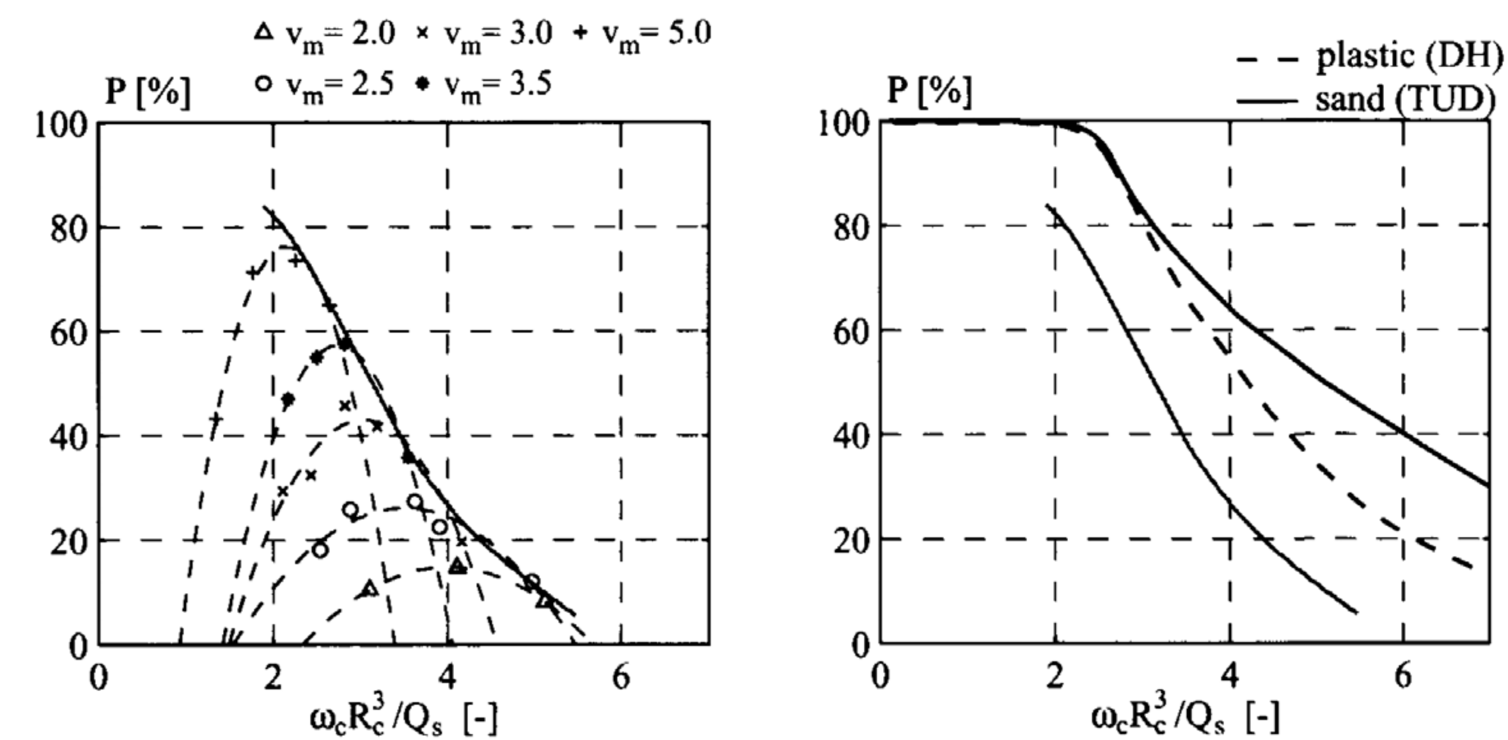


Figure 6.7: Production percentage vs. inverse of the flow number in the under-cut situation for cutting of gravel (left plot) and the results of the sand and plastic particles (right plot)

Scale Laws

$$\frac{Q_c \cdot (1-n)}{Q_m} = \text{constant}$$

$$Bu = \frac{\omega \cdot r_r^3}{Q_m} = \text{constant}$$

$$\frac{v_t \cdot r_r^2}{Q_m} = \text{constant}$$

$$\frac{\omega \cdot r_r}{v_t} = \text{constant}$$

Spillage Non-Homogeneous

$$\text{Spillage} = \frac{Q_{1,out}}{Q_m + Q_{1,out}} = \frac{Q_{1,out} \cdot C_{vs}}{Q_s}$$

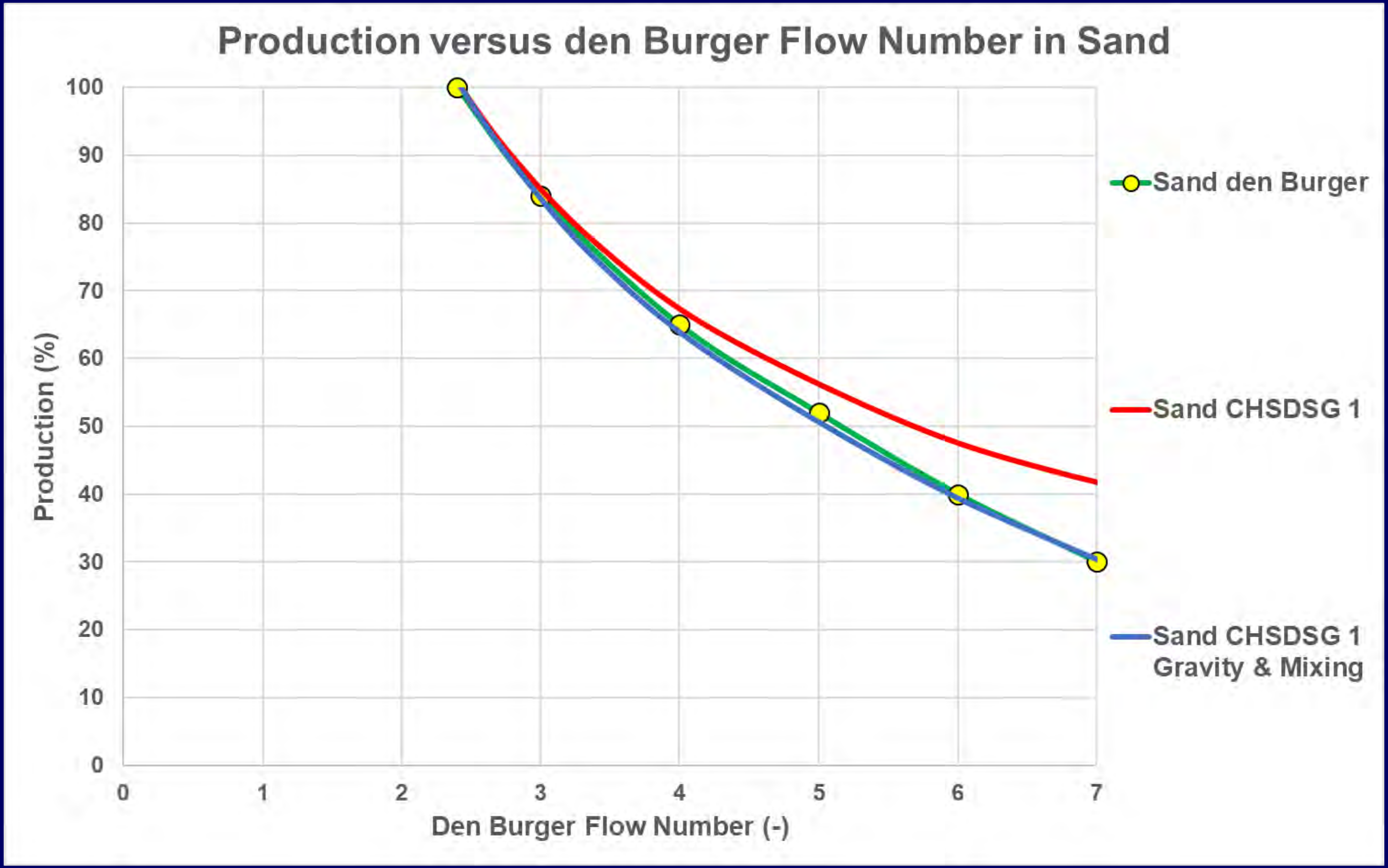
$$\text{Spillage} = \frac{Q_{1,out} \cdot \left(C_{vs} + \left(C_{vs,max} - C_{vs}\right) \cdot \text{Factor}\right)}{Q_s}$$

$$\text{With :} \quad C_{vs,max} = \frac{Q_s}{Q_{1,out}} \quad \text{and} \quad C_{vs,max} < 0.5$$

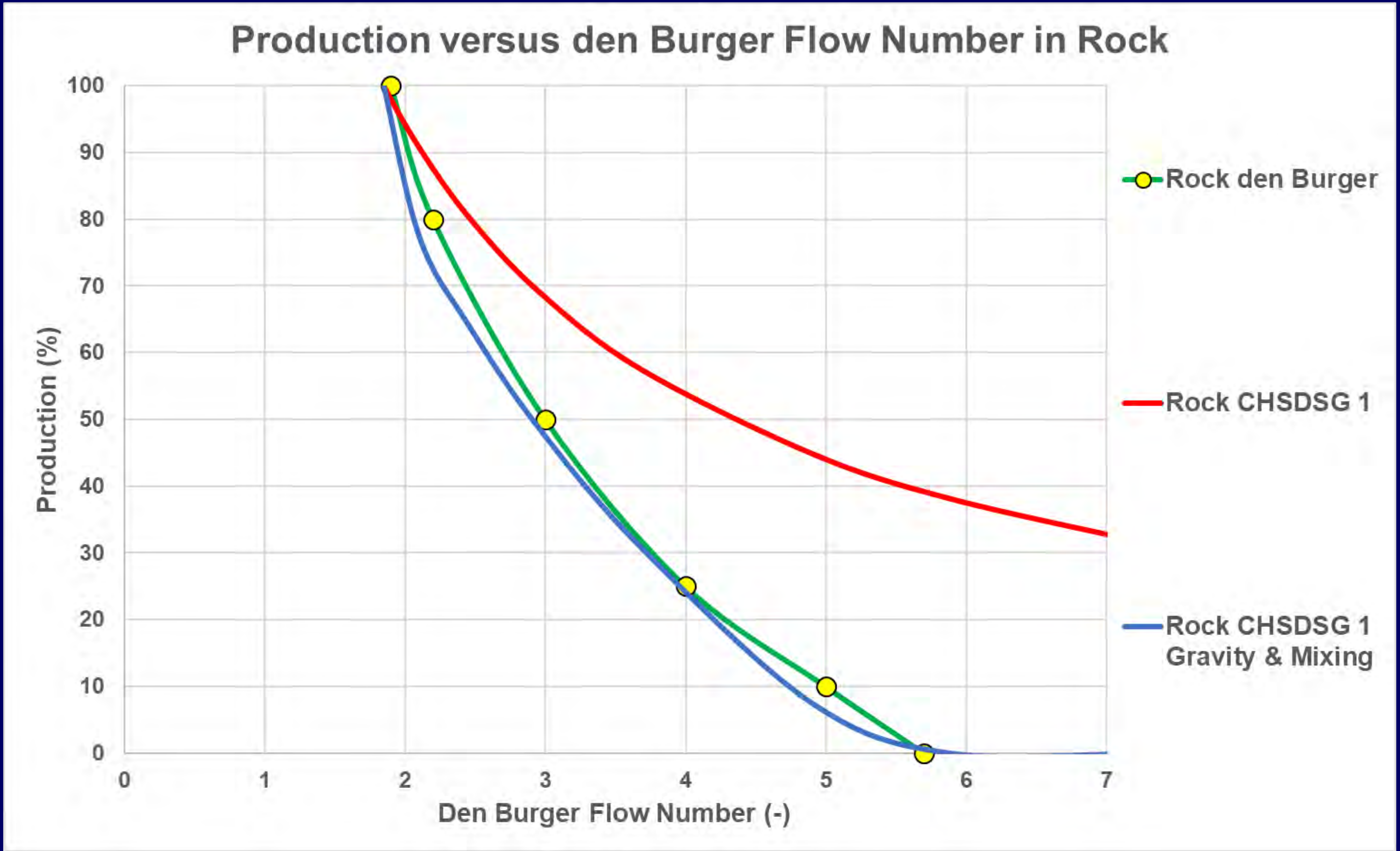
$$\text{Factor} = 0.1 \cdot \left(\frac{v_t \cdot \sin(\theta) \cdot \pi \cdot r_r^2}{Q_m}\right)^2 + \left(\frac{Bu}{10.8}\right)^3$$

$$\text{Factor} \leq 1$$

Model versus Experiments in Sand



Model versus Experiments in Rock



Euler Equation Model

Euler Equation

$$\Delta p_E = \rho_m \cdot u_o \cdot \left(u_o - \frac{Q \cdot \cot(\beta_o)}{2 \cdot \pi \cdot r_o \cdot w} \right) - \rho_m \cdot u_i \cdot \left(u_i - \frac{Q \cdot \cot(\beta_i)}{2 \cdot \pi \cdot r_i \cdot w} \right)$$

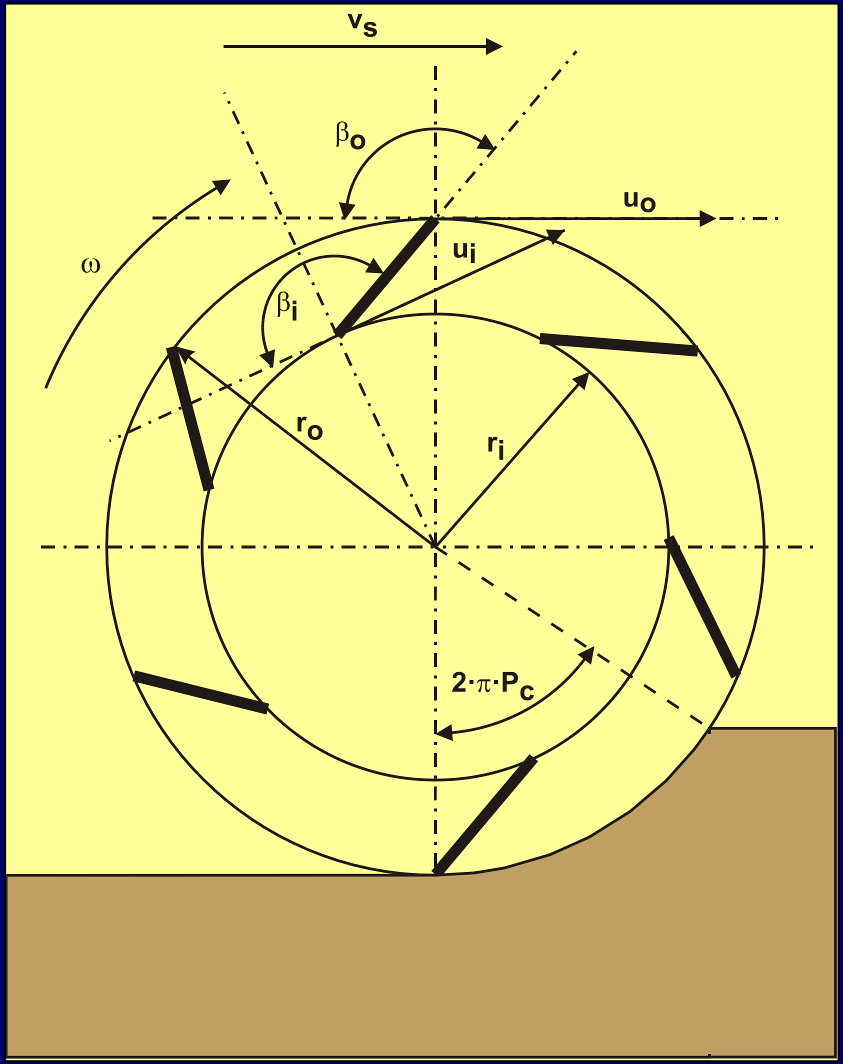
$$\Delta p_E = \rho_m \cdot \omega^2 \cdot \left(r_o^2 - r_i^2 \right) - \frac{\rho_m \cdot \omega \cdot Q}{2 \cdot \pi \cdot w} \cdot \left(\cot\left(\beta_o\right) - \cot\left(\beta_i\right) \right)$$

$$Q = \alpha \cdot 2 \cdot \pi \cdot \omega \cdot r_o^2 \cdot w$$

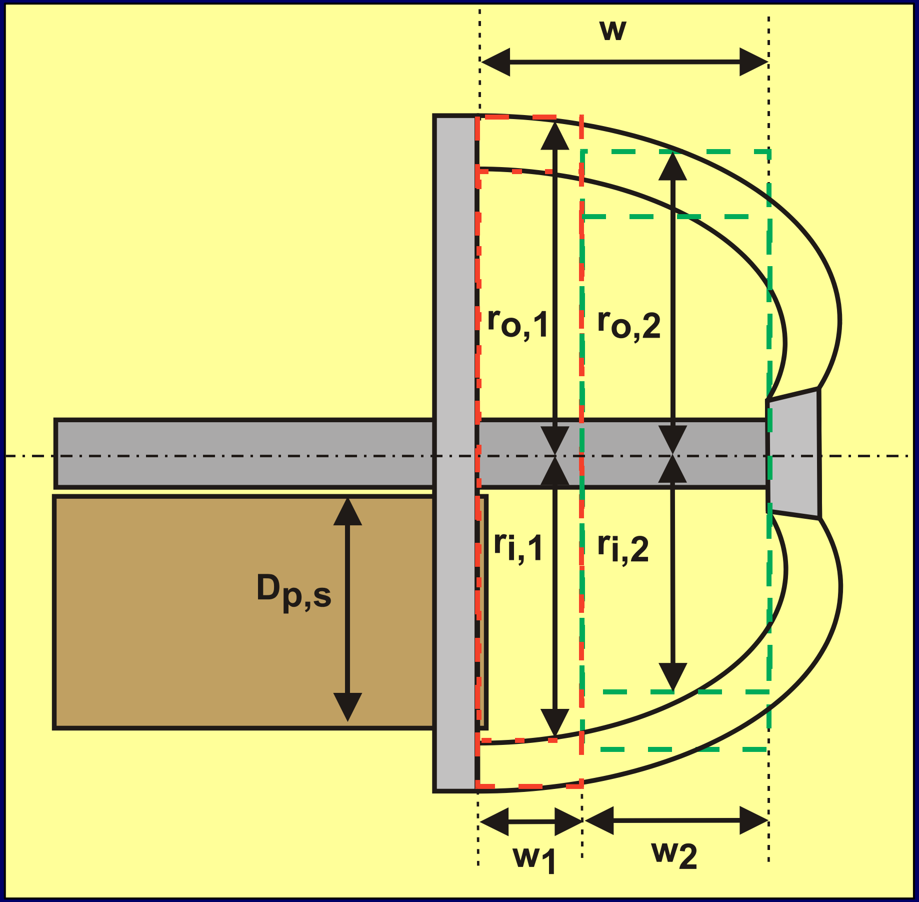
$$\Delta p_E = \rho_m \cdot \omega^2 \cdot \left(r_o^2 - r_i^2 \right) - \alpha \cdot \rho_m \cdot \omega^2 \cdot r_o^2 \cdot \left(\cot\left(\beta_o\right) - \cot\left(\beta_i\right) \right)$$

$$\Delta p_E = \rho_m \cdot \omega^2 \cdot \left(\left(r_o^2 - r_i^2 \right) - \alpha \cdot r_o^2 \cdot \left(\cot\left(\beta_o\right) - \cot\left(\beta_i\right) \right) \right)$$

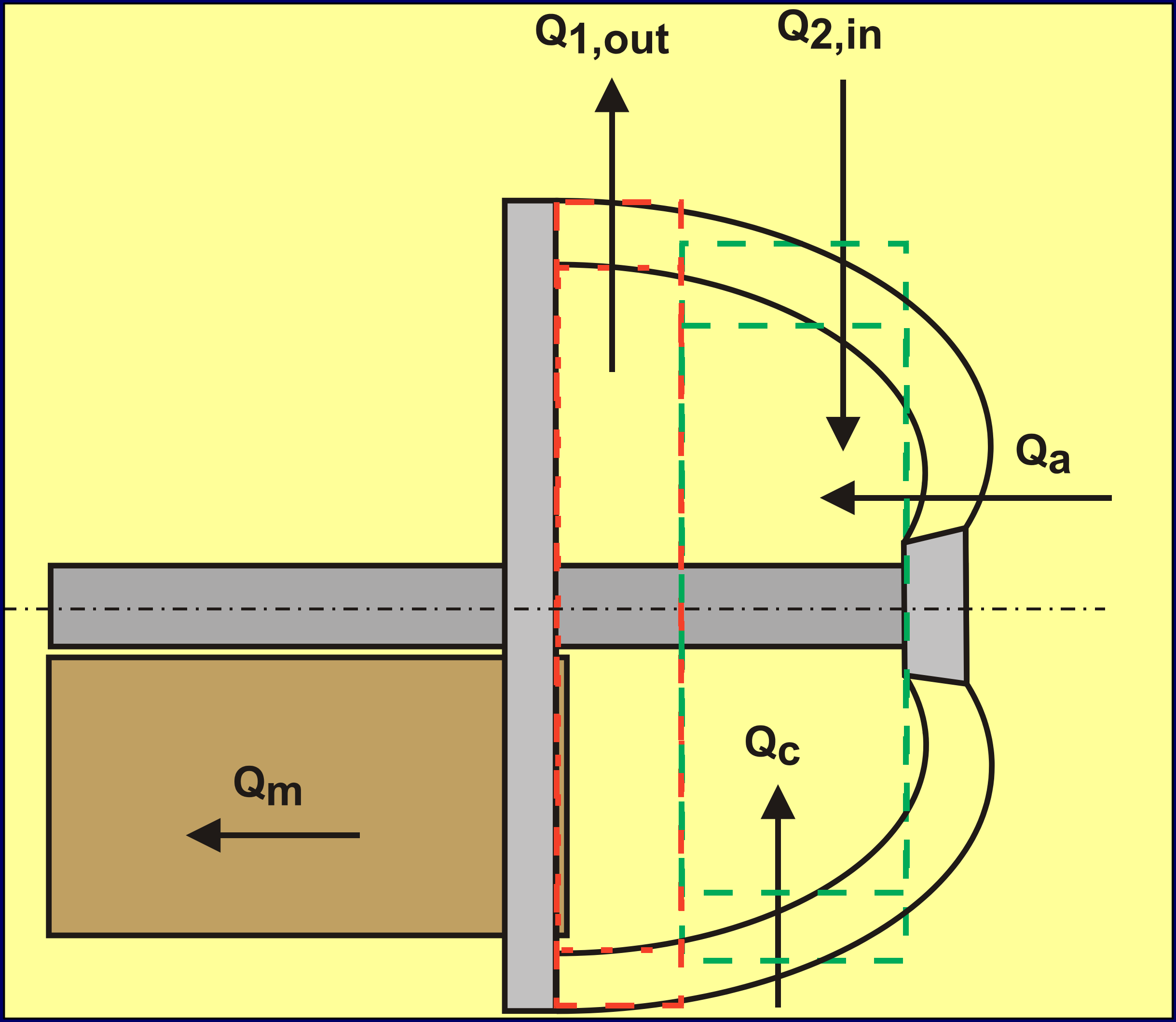
Cutter Head Dimensions



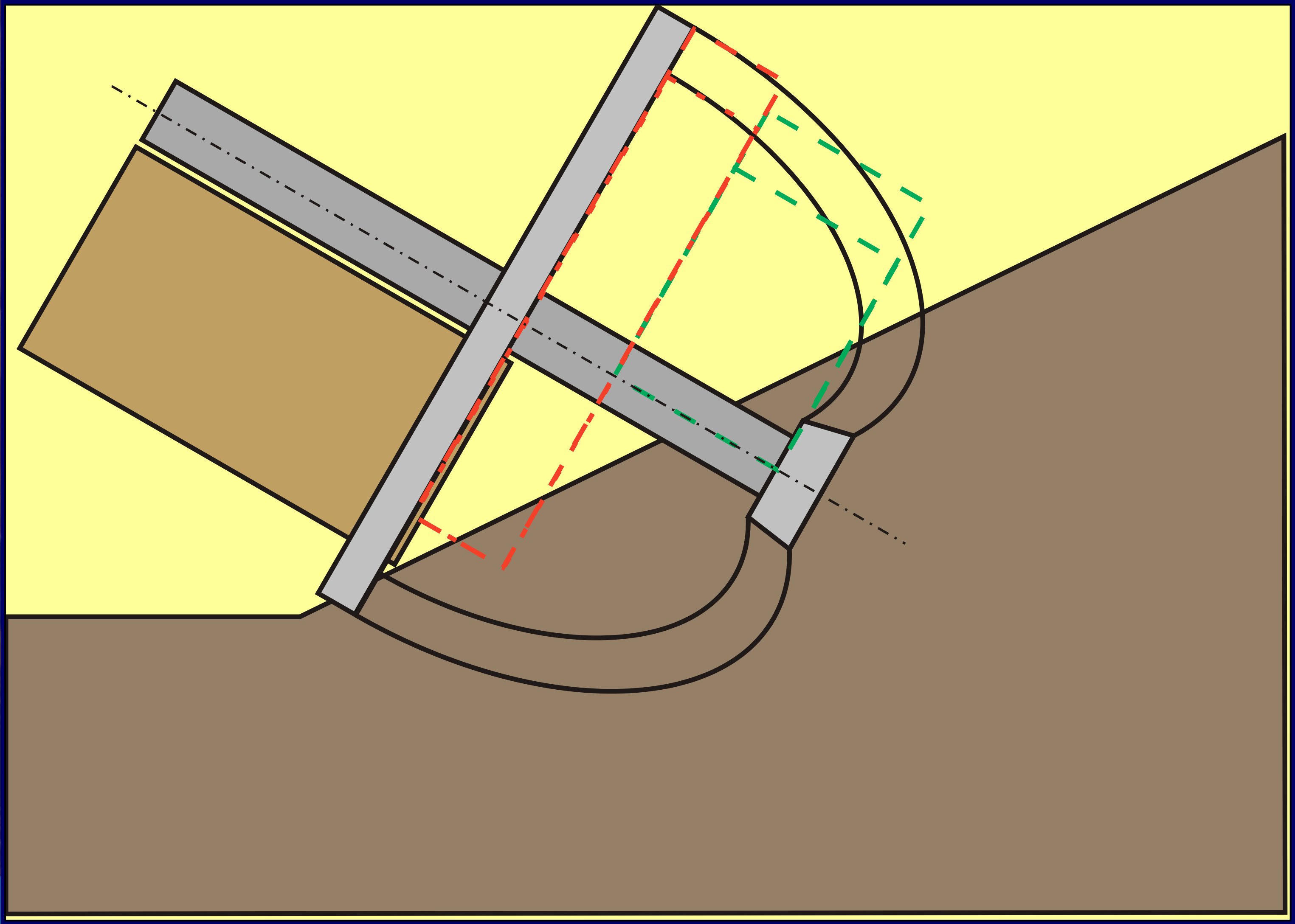
Cutter Head Segments



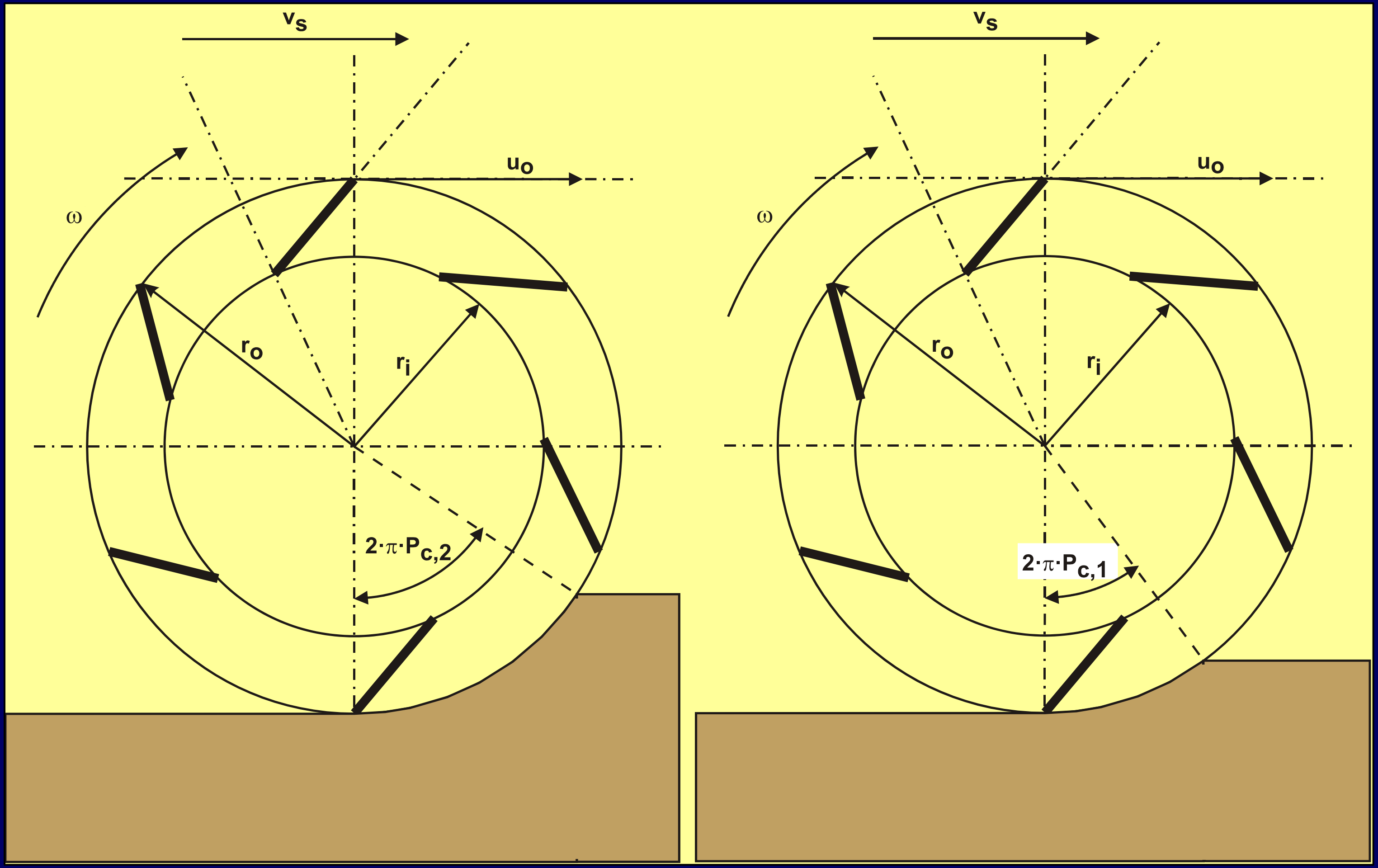
The Flows in a Cutter Head



The Cutter Head in the Bank



The Cutter Head in the Bank



Flows

$$Q_{1,out} = \alpha \cdot 2 \cdot \pi \cdot \omega \cdot r_{o,1}^2 \cdot \left(1 - P_{c,1}\right) \cdot$$

$$\left(\frac{f}{(1+f)} \cdot w - \frac{1}{(1+f)} \cdot \frac{1}{2 \cdot \pi \cdot \alpha \cdot \omega} \cdot \left(\frac{Q_m - Q_c - Q_a}{r_{o,1}^2 \cdot \left(1 - P_{c,1}\right)} \right) \right)$$

$$Q_{2,in} = 2 \cdot \pi \cdot \alpha \cdot \omega \cdot \left(r_{o,1}^2 - r_{o,2}^2\right) \cdot \left(1 - P_{c,2}\right) \cdot$$

$$\left(\frac{1}{(1+f)} \cdot w + \frac{1}{(1+f)} \cdot \frac{1}{2 \cdot \pi \cdot \alpha \cdot \omega} \cdot \left(\frac{Q_m - Q_c - Q_a}{r_{o,1}^2 \cdot \left(1 - P_{c,1}\right)} \right) \right)$$

Spillage Non-Homogeneous

$$\text{Spillage} = \frac{Q_{1,out}}{Q_m + Q_{1,out}} = \frac{Q_{1,out} \cdot C_{vs}}{Q_s}$$

$$\text{Spillage} = \frac{Q_{1,out} \cdot \left(C_{vs} + \left(C_{vs,max} - C_{vs}\right) \cdot \text{Factor}\right)}{Q_s}$$

$$\text{With:} \quad C_{vs,max} = \frac{Q_s}{Q_{1,out}} \quad \text{and} \quad C_{vs,max} < 0.5$$

$$\text{Factor} = 0.1 \cdot \left(\frac{v_t \cdot \sin(\theta) \cdot \pi \cdot r_r^2}{Q_m}\right)^2 + \left(\frac{Bu}{10.8}\right)^3$$

$$\text{Factor} \le 1$$

Delft University of Technology – Offshore & Dredging Engineering

Production den Burger

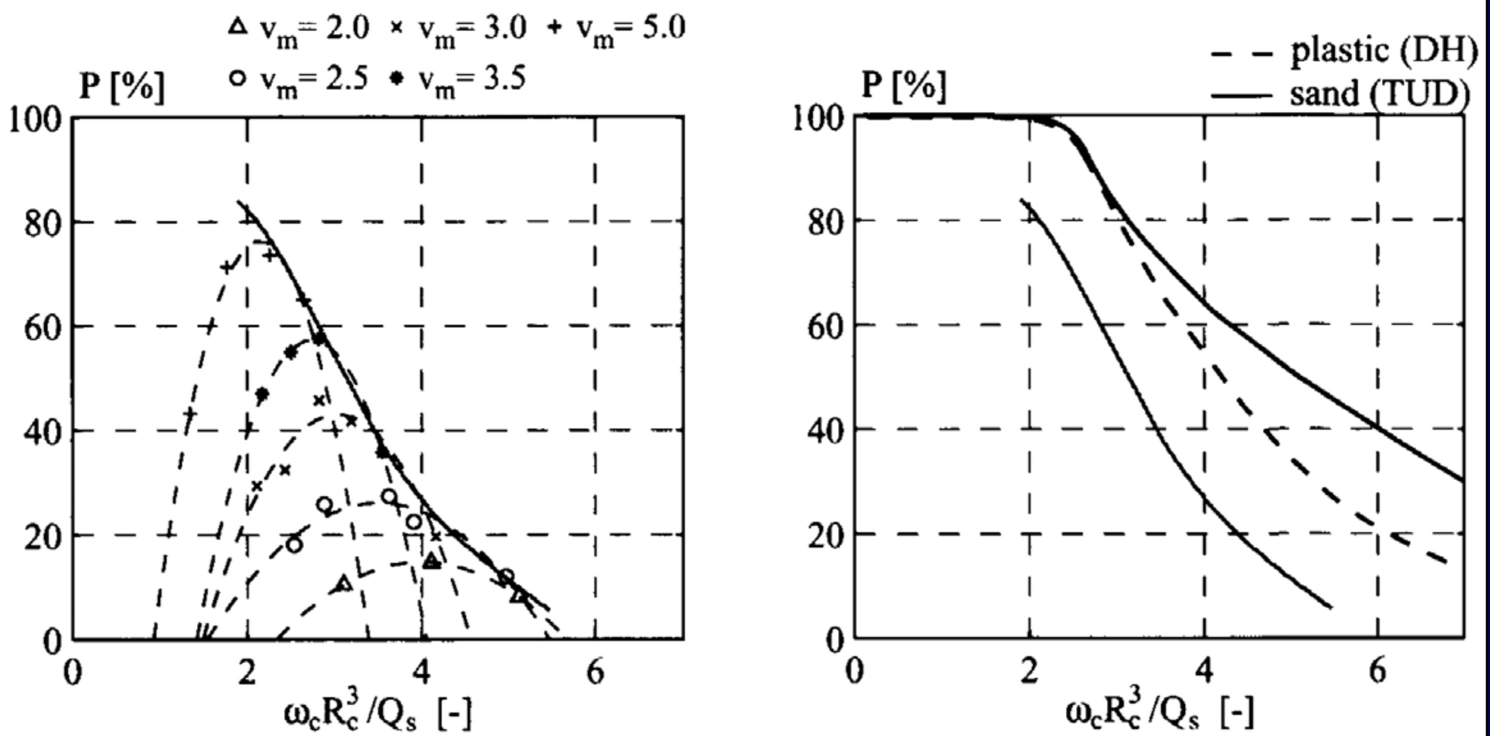
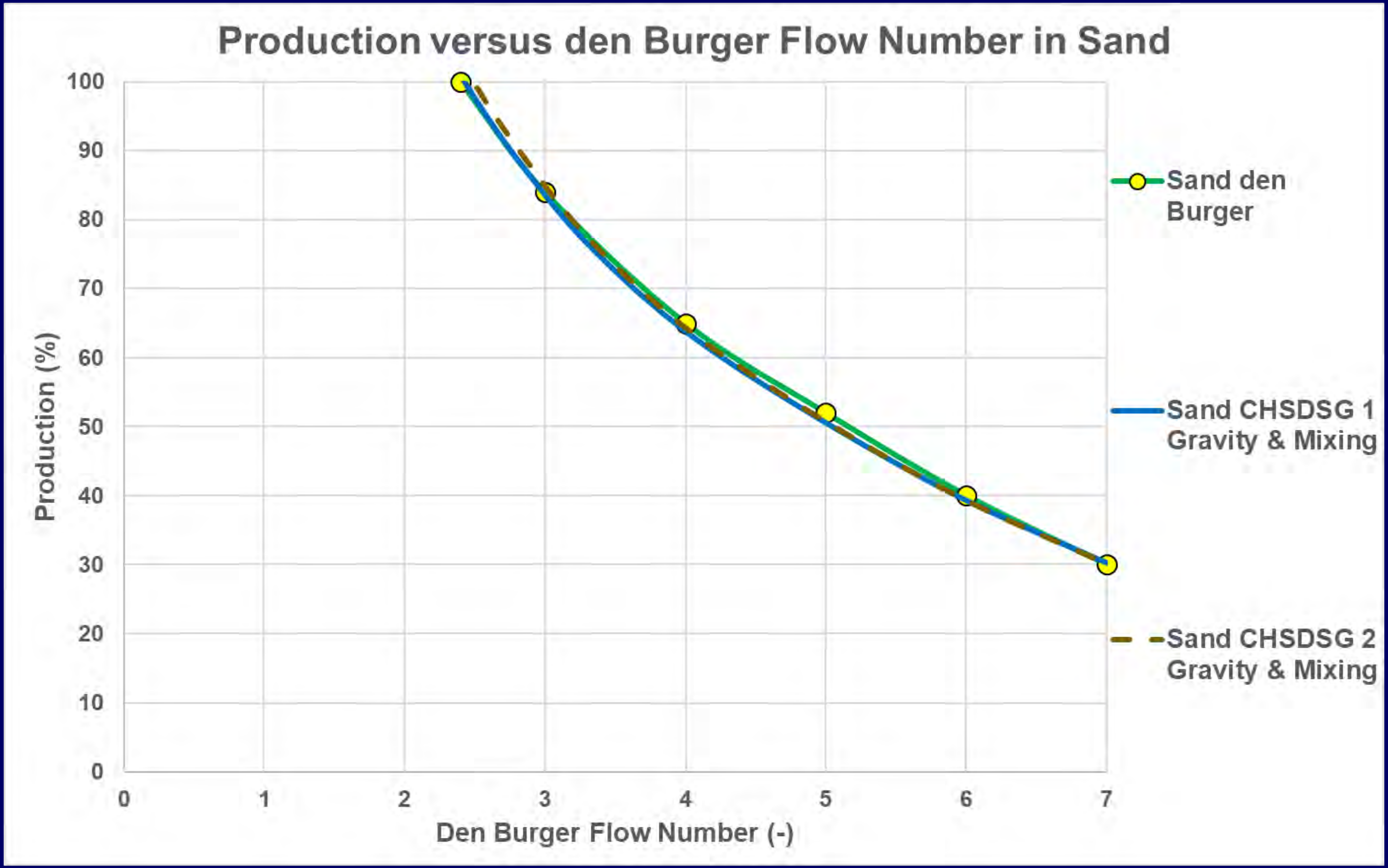
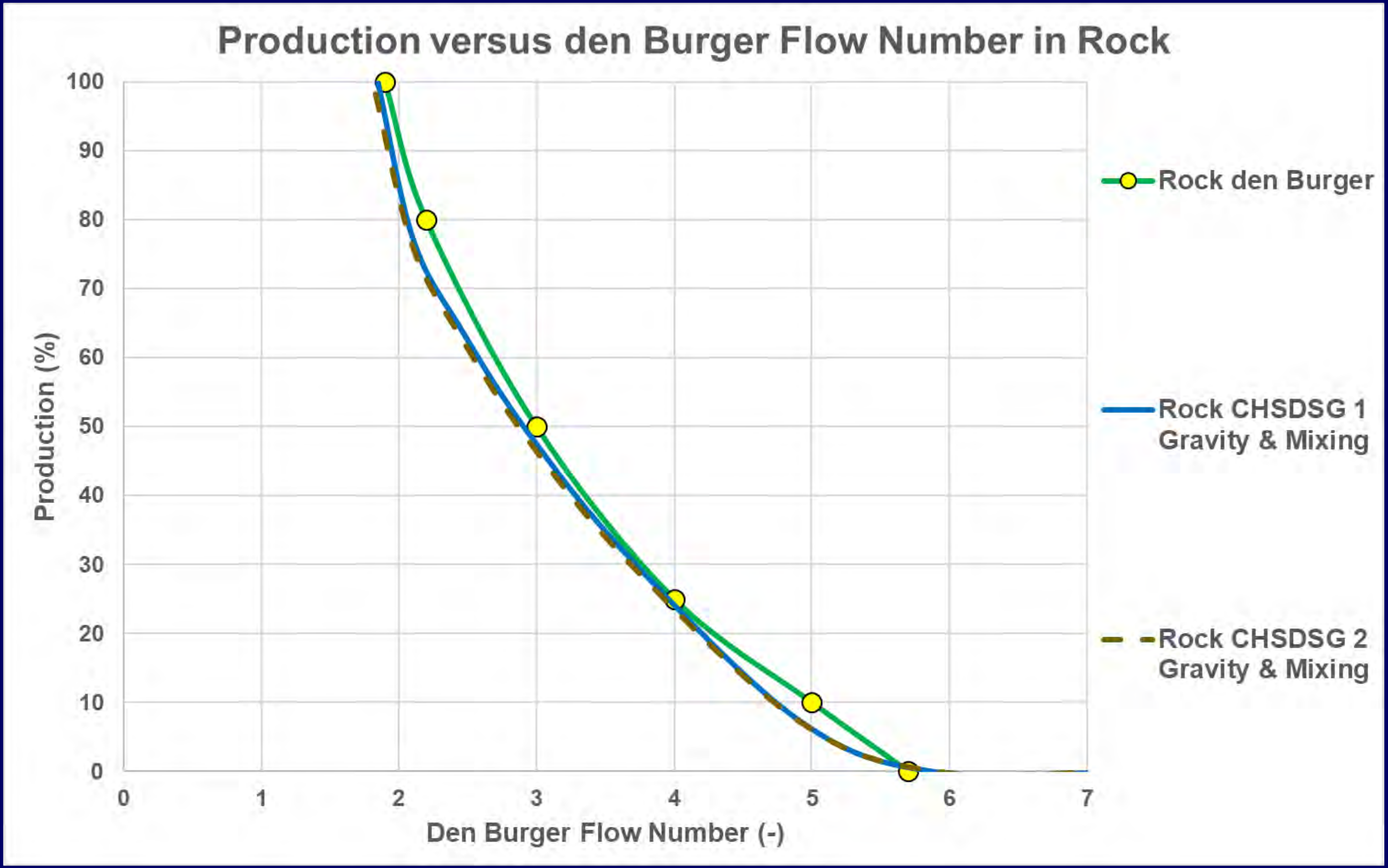


Figure 6.7: Production percentage vs. inverse of the flow number in the under-cut situation for cutting of gravel (left plot) and the results of the sand and plastic particles (right plot)

Model versus Experiments in Sand



Model versus Experiments in Rock



Filling Degree

Filling Degree

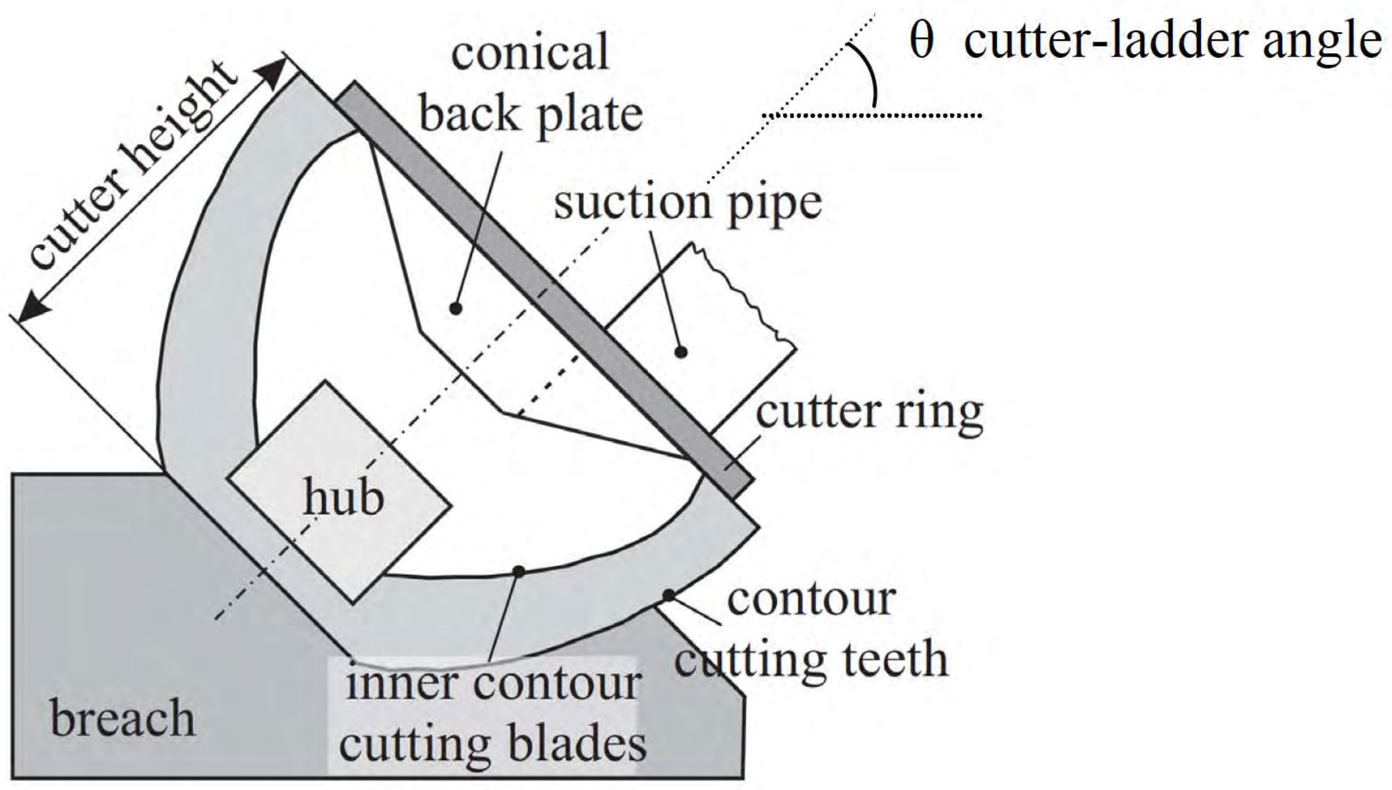


Figure 2. Model cutter positioned in breach.

Filling Degree

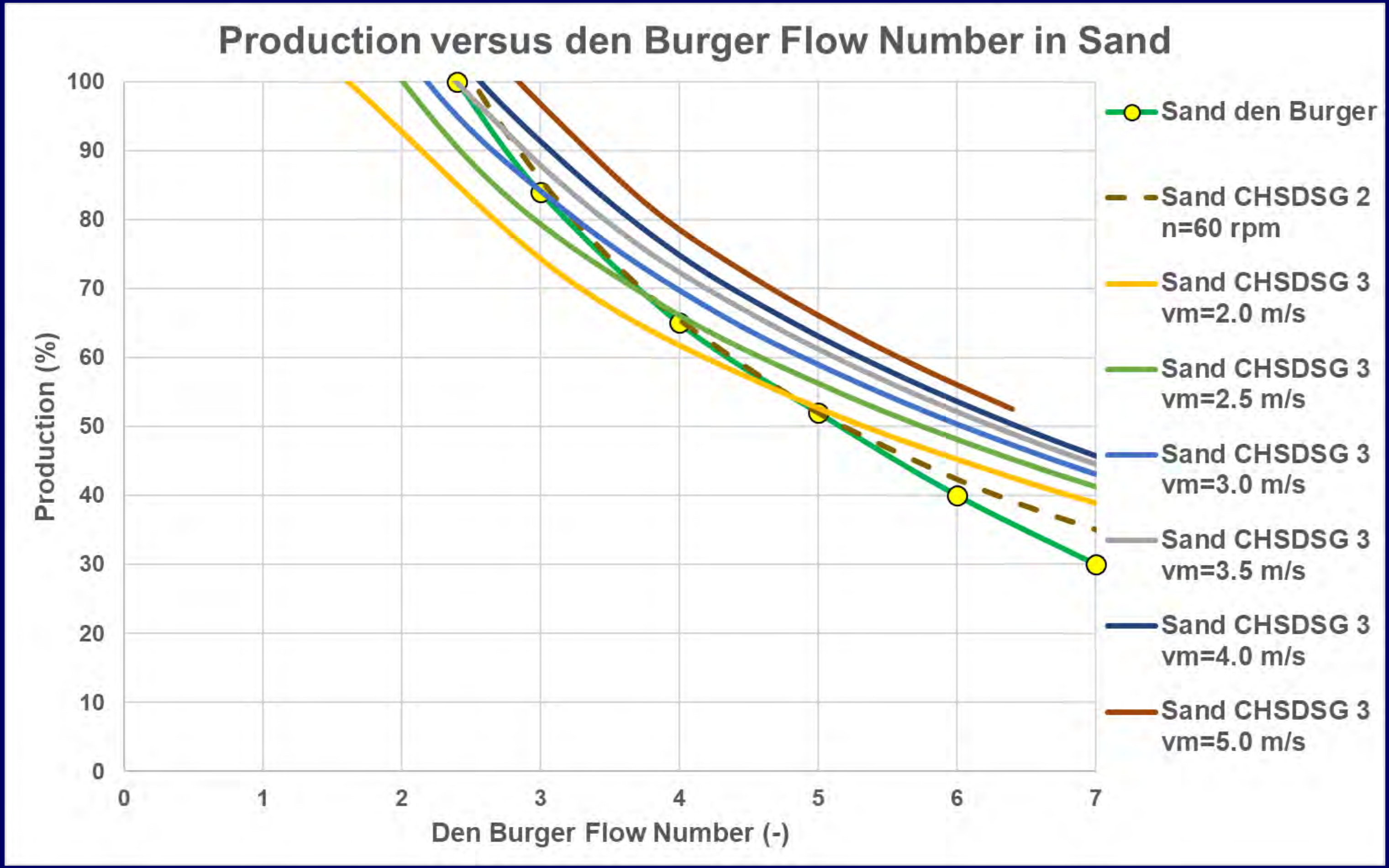
$$\text{FillingDegree} = \xi \cdot \left(\frac{\frac{D_r \cdot 2 \cdot \pi \cdot n}{2 \cdot 60} \cdot \cos(\theta)}{v_t} \right)^2$$

and

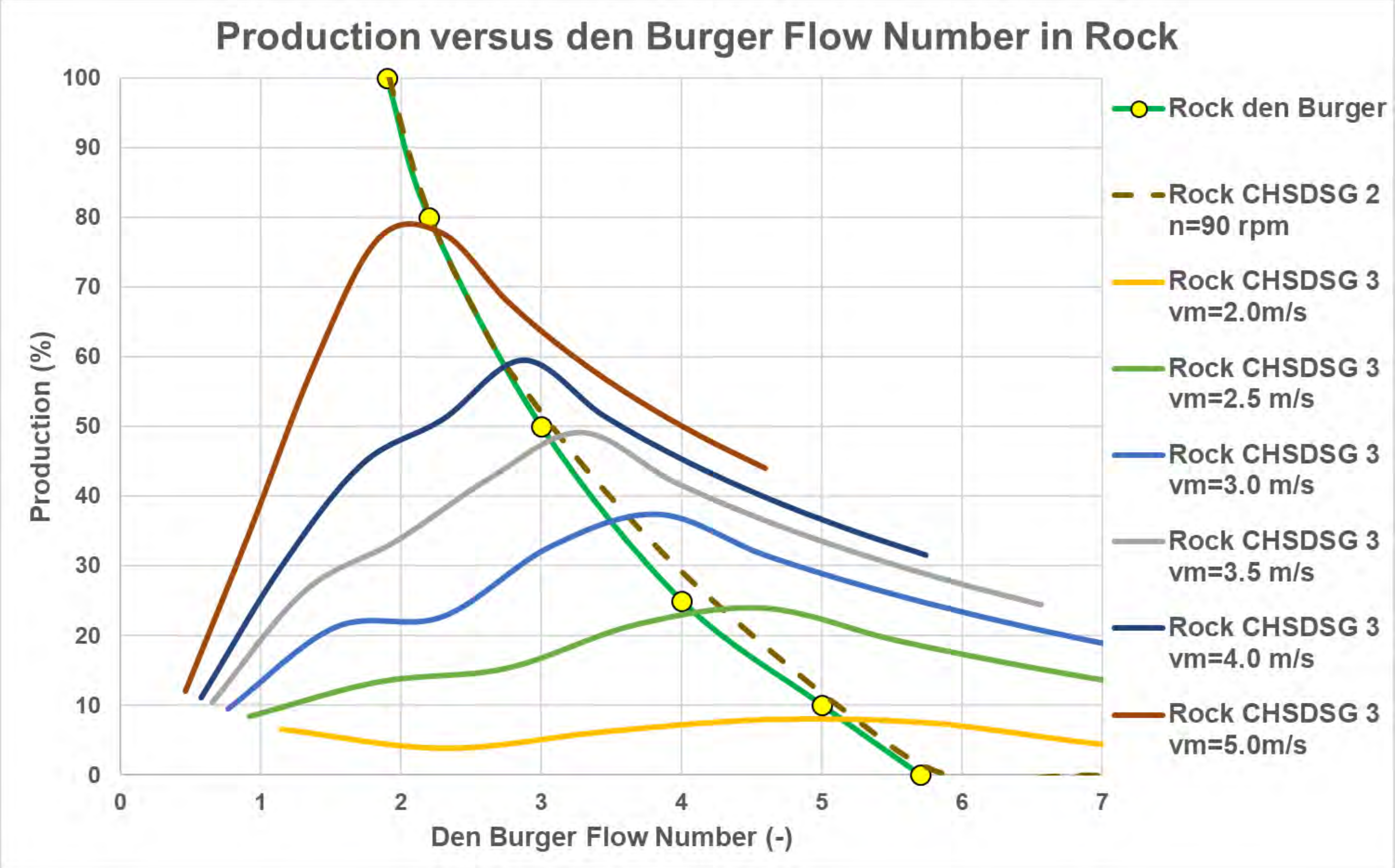
$$\text{FillingDegree} \leq 1$$

$$\text{FinalSpillage} = \text{Spillage} \cdot \text{FillingDegree} + (1 - \text{FillingDegree})$$

Filling Ratio in Sand



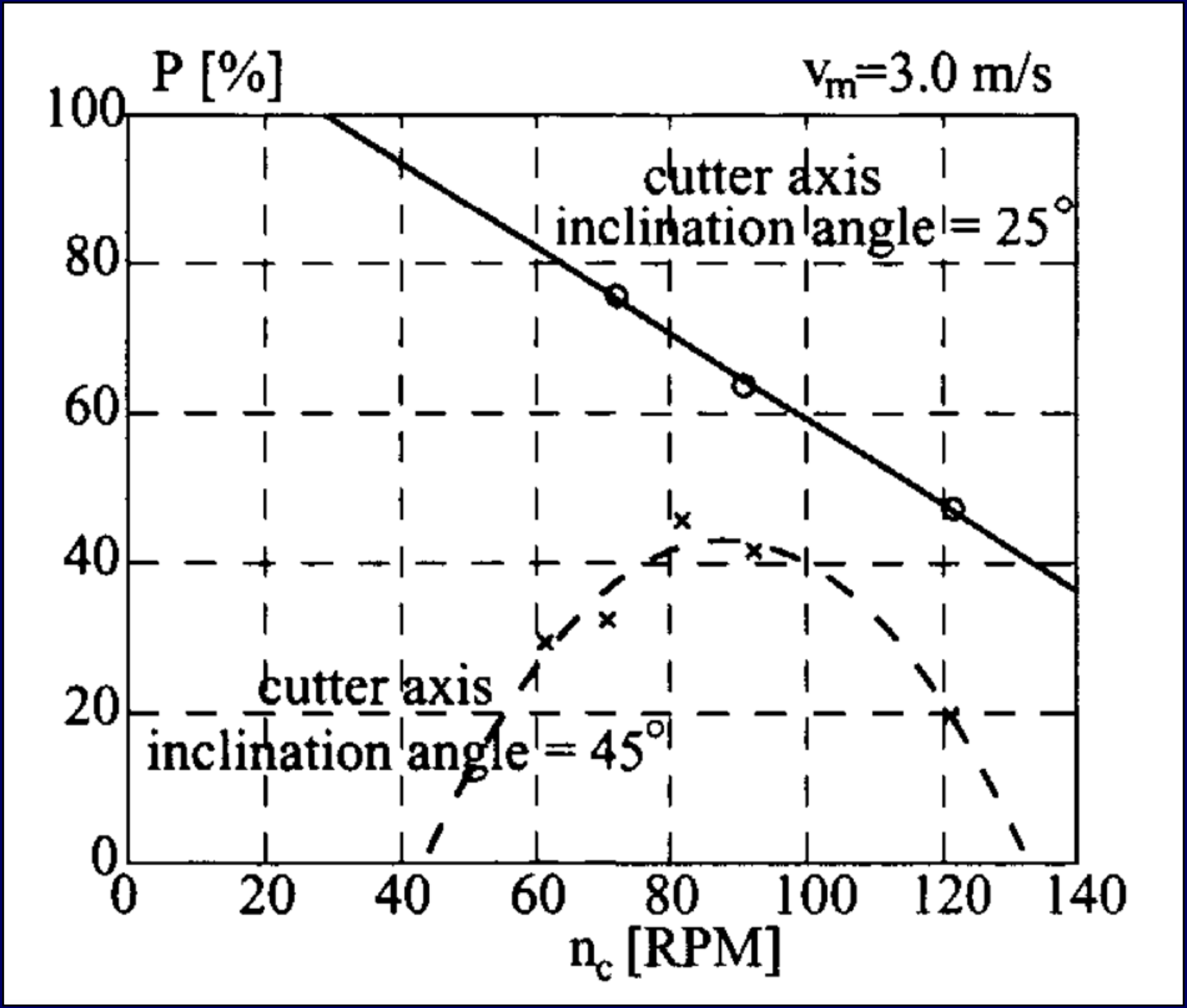
Filling Ratio in Rock



Delft University of Technology
Offshore & Dredging Engineering

Ladder Angle

Ladder Angle



Delft University of Technology
Offshore & Dredging Engineering

Ladder Angle Influence

$$\text{Spillage} = \frac{Q_{1,out} \cdot \left(C_{vs} + \left(C_{vs,max} - C_{vs} \right) \cdot \left(\left(0.1 \cdot \left(\frac{v_t \cdot \sin(\theta) \cdot \pi \cdot r_r^2}{Q_m} \right) \right)^2 + \left(\frac{Bu}{10.8} \right)^3 \right) \right)}{Q_s}$$

$$\text{FillingDegree} = \xi \cdot \left(\frac{\frac{D_r \cdot 2 \cdot \pi \cdot n}{2 \cdot 60} \cdot \cos(\theta)}{v_t} \right)^2$$

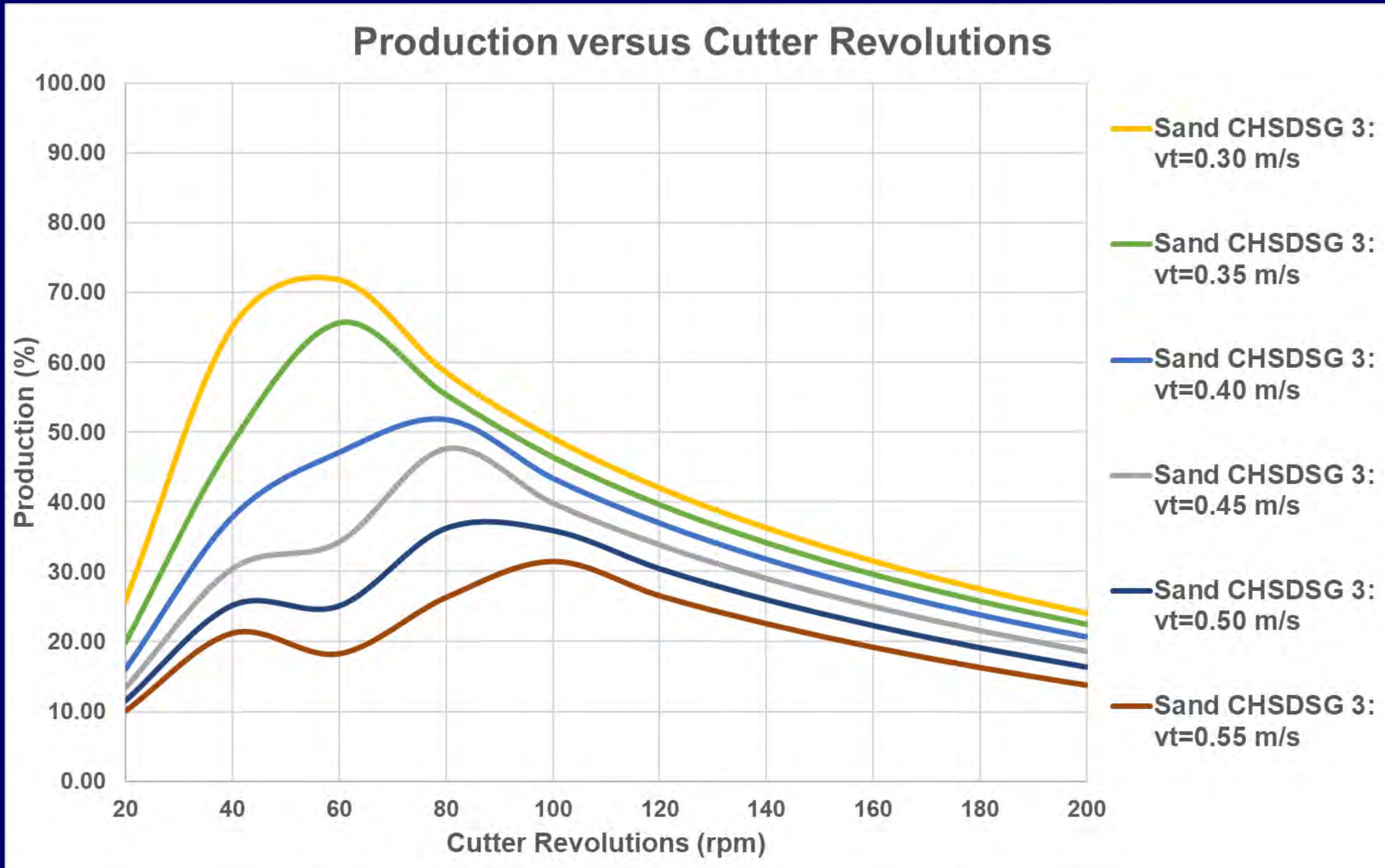
and

$$\text{FillingDegree} \leq 1$$

$$\text{FinalSpillage} = \text{Spillage} \cdot \text{FillingDegree} + \left(1 - \text{FillingDegree} \right)$$

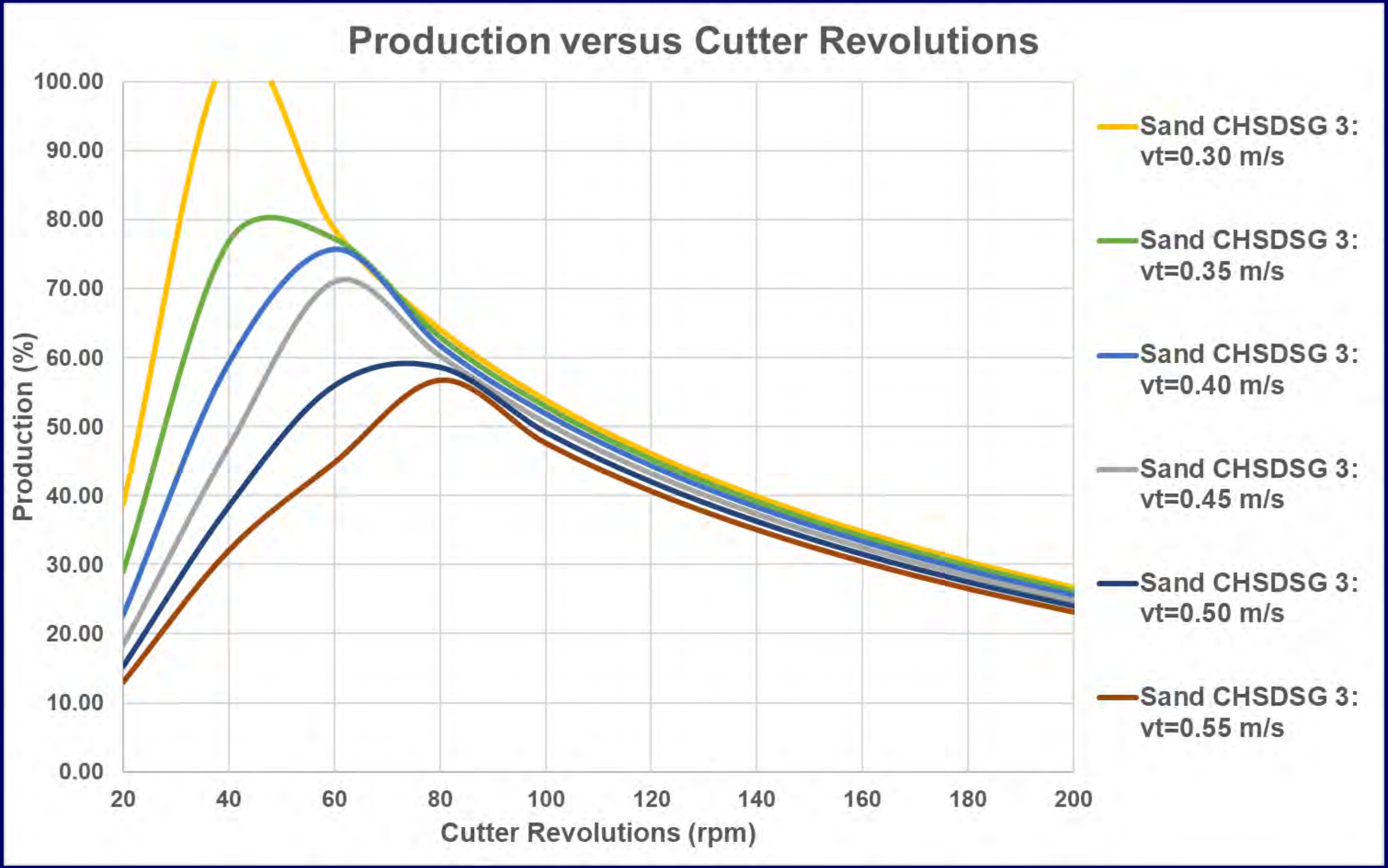
TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Ladder Angle 45°



Delft University of Technology
Offshore & Dredging Engineering

Ladder Angle 25°



Validation Miltenburg 1983

The 40 cm Model Cutter Head for Rock

Configurations

Miltenburg (1982) used 6 different configurations of the crown cutter head and of course carried out the experiments overcutting and undercutting. The 6 configurations are:

- No skirts, short cone, suction mouth at 0°.
- No skirts, long cone, suction mouth at 0°.
- No skirts, long cone, suction mouth at +30°.
- No skirts, long cone, suction mouth at -30°.
- Skirts, long cone, suction mouth at 0°.
- Skirts, long cone, suction mouth at +30°.

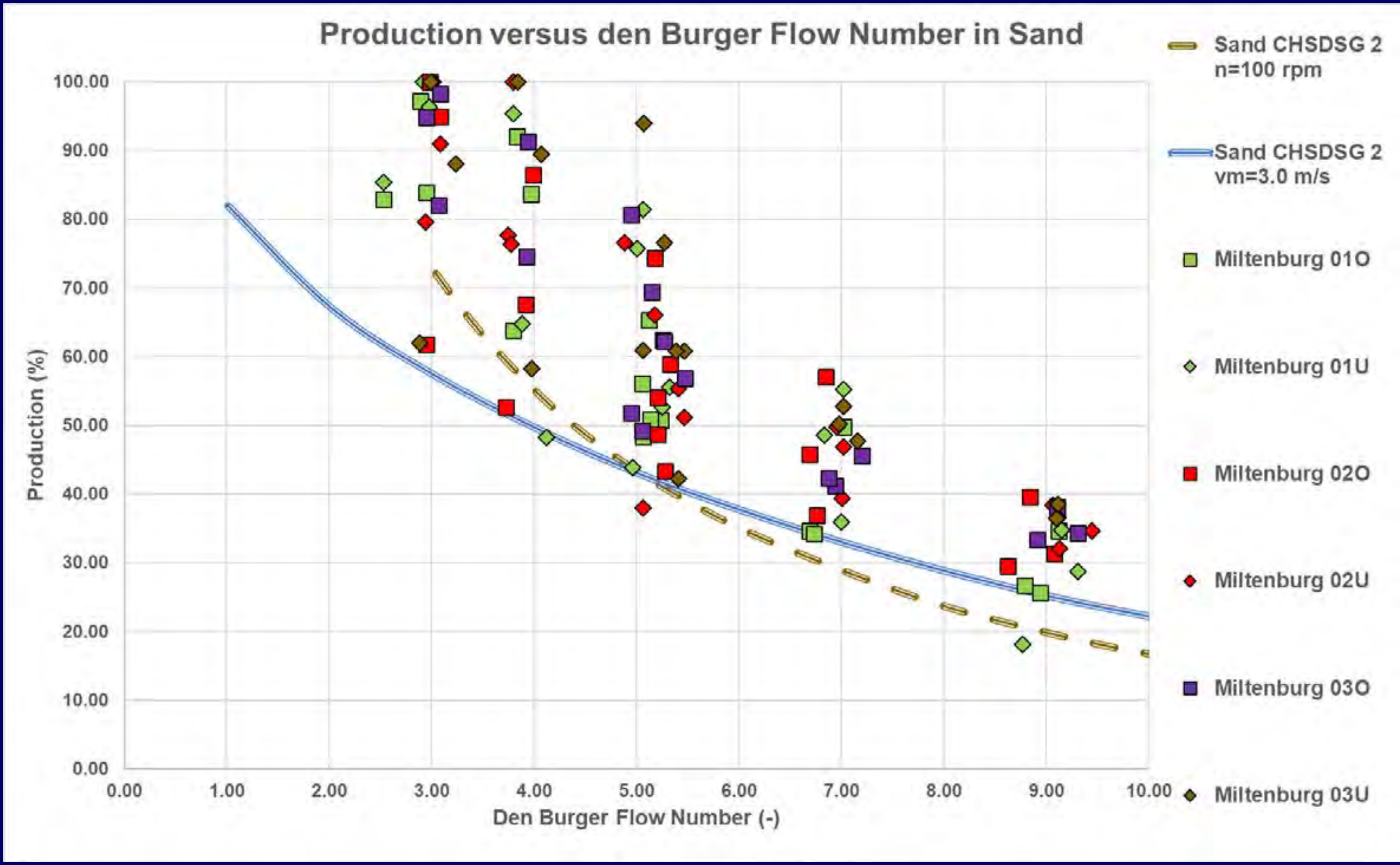
Besides the 6 configurations, each test has been carried out overcutting and undercutting. So, many subsets of experiments can be made.

Delft University of Technology – Offshore & Dredging Engineering

The Cone and the Short Cone

Skirts Inside the Cutter Head

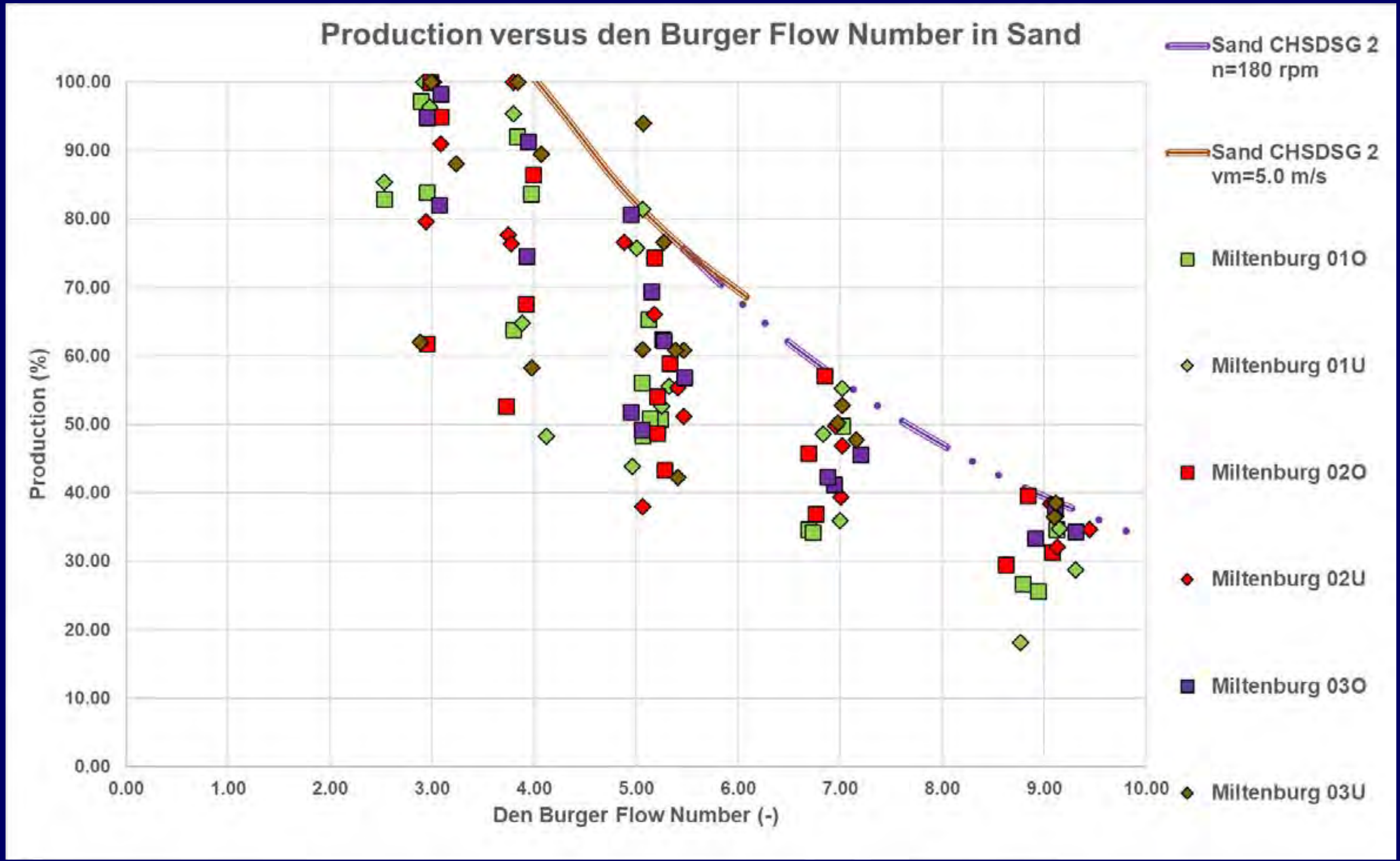
Data Miltenburg with Lower Limit



The lower limit is determined from n=100 rpm and v_m=3 m/s. No skirts, suction mouth normal.

Delft University of Technology
Offshore & Dredging Engineering

Data Miltenburg with Upper Limit



The upper limit is determined from n=180 rpm and v_m=5 m/s. No skirts, suction mouth normal.

Delft University of Technology
Offshore & Dredging Engineering

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Conclusions

- An analytical model has been derived and validated.
- The ratio of the rotating volume flow inside the cutter head to the mixture flow gives a usefull dimensionless number named the Burger number.
- Below a certain Burger number there is no spillage, so the total flow into the cutter head equals the mixture flow into the suction mouth.
- Above this Burger number, the spillage increases non-linear. The higher the Burger number the smaller the increase of the spillage.
- The Miltenburg data indicate the spillage does not reach 100% at very high Burger numbers.
- Terminal settling velocity of the particles and ladder angle play an important role in the spillage model.

TU Delft
Delft University of Technology
Offshore & Dredging Engineering

Conclusions Final Equation

$$\text{Spillage} = \frac{Q_{1,out}}{Q_m + Q_{1,out}} = \frac{Q_{1,out} \cdot C_{vs}}{Q_s}$$

$$\text{Spillage} = \frac{Q_{1,out} \cdot \left(C_{vs} + \left(C_{vs,max} - C_{vs}\right) \cdot \text{Factor}\right)}{Q_s}$$

$$\text{With:} \quad C_{vs,max} = \frac{Q_s}{Q_{1,out}} \quad \text{and} \quad C_{vs,max} < 0.5$$

$$\text{Factor} = 0.1 \cdot \left(\frac{v_t \cdot \sin(\theta) \cdot \pi \cdot r_r^2}{Q_m}\right)^2 + \left(\frac{Bu}{10.8}\right)^3 - \left(\frac{Bu}{12}\right)^4$$

$$\text{Factor} \le 1$$

Questions?