Dredging Processes

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6. Rock Cutting
Dredging A Way Of Life

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Offshore A Way Of Life
Offshore & Dredging Engineering

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Rock Cutting
Rock Cutterheads

NORMAL HELIX CUTTER

REVERSE HELIX CUTTER

WIDE CHISEL

CL FLARED

BELOW CL FLARED TYPE A

BELOW CL FLARED TYPE B (CLAY FLARE)

"DEVIL TEETH" (FLORIDA)
Brittle versus Ductile

Brittle & Ductile Cutting

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Brittle versus Ductile
Rock Cutting

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\[ F_c = \sigma_T \cdot h_i \cdot w \cdot \frac{2 \cdot \sin(\alpha + \delta)}{1 - \sin(\alpha + \delta)} \]

\[ F_{ch} = F_c \]

\[ F_{cv} = 0 \]

\[ E_{sp} = \frac{F_{ch} \cdot v_c}{h_i \cdot w \cdot v_c} = \sigma_T \cdot \frac{2 \cdot \sin(\alpha + \delta)}{1 - \sin(\alpha + \delta)} \]
Evans Brittle Horizontal Force Coefficient

Evans Brittle Horizontal Force Coefficient $\lambda_{HT}$ vs Blade Angle $\alpha$

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Evans under an Angle
Evans under an Angle

\[ F_c = \sigma_T \cdot h \cdot w \cdot \frac{2 \cdot \sin(\alpha + \delta)}{1 - \sin(\alpha + \delta + \varepsilon)} \]

\[ F_{ch} = F_c \cdot \cos(\varepsilon) \]

\[ F_{cv} = F_c \cdot \sin(\varepsilon) \]

\[ E_{sp} = \frac{F_{ch} \cdot v_c}{h_i \cdot w \cdot v_c} = \sigma_T \cdot \frac{2 \cdot \sin(\alpha + \delta)}{1 - \sin(\alpha + \delta + \varepsilon)} \cdot \cos(\varepsilon) \]
Evans Pick Point

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Evans Pick Point

\[ F_c = \sigma_T \cdot h \cdot w \cdot \frac{2 \cdot \sin(\alpha + \delta)}{1 - \sin(2 \cdot \alpha + \delta)} \]

\[ F_{ch} = F_c \cdot \cos(\alpha) \]

\[ F_{cv} = F_c \cdot \sin(\alpha) \]

\[ E_{sp} = \frac{F_{ch} \cdot v_c}{h_i \cdot w \cdot v_c} = \sigma_T \cdot \frac{2 \cdot \sin(\alpha + \delta)}{1 - \sin(2 \cdot \alpha + \delta)} \cdot \cos(\alpha) \]
\[ F_h = \frac{1}{(n+1)} \cdot \frac{2 \cdot c \cdot h_i \cdot w \cdot \cos(\varphi) \cdot \sin(\alpha + \delta)}{1 + \cos(\alpha + \delta + \varphi)} = \frac{1}{(n+1)} \cdot \lambda_{HF} \cdot c \cdot h_i \cdot w \]

\[ F_v = \frac{1}{(n+1)} \cdot \frac{2 \cdot c \cdot h_i \cdot w \cdot \cos(\varphi) \cdot \cos(\alpha + \delta)}{1 + \cos(\alpha + \delta + \varphi)} = \frac{1}{(n+1)} \cdot \lambda_{VF} \cdot c \cdot h_i \cdot w \]

**Stress Distribution Nishimatsu**

- Distance along the shear plane
- Values for different parameters:
  - \( n = 0.00 \)
  - \( n = 0.25 \)
  - \( n = 0.50 \)
  - \( n = 1.00 \)
  - \( n = 2.00 \)
  - \( n = 4.00 \)
  - \( n = 8.00 \)
The Ductile Horizontal Coefficient

Ductile Horizontal Force Coefficient $\lambda_{HF}$ vs Blade Angle $\alpha$

- $\Phi = 0$ degrees
- $\Phi = 5$ degrees
- $\Phi = 10$ degrees
- $\Phi = 15$ degrees
- $\Phi = 20$ degrees
- $\Phi = 25$ degrees
- $\Phi = 30$ degrees
- $\Phi = 35$ degrees
- $\Phi = 40$ degrees
- $\Phi = 45$ degrees

Blade Angle $\alpha$ (Degrees) vs Ductile Horizontal Force Coefficient $\lambda_{HF}$ (°)
The Ductile Vertical Coefficient

Ductile Vertical Force Coefficient $\lambda_{VF}$ vs Blade Angle $\alpha$

- $\Phi = 0$ degrees
- $\Phi = 5$ degrees
- $\Phi = 10$ degrees
- $\Phi = 15$ degrees
- $\Phi = 20$ degrees
- $\Phi = 25$ degrees
- $\Phi = 30$ degrees
- $\Phi = 35$ degrees
- $\Phi = 40$ degrees
- $\Phi = 45$ degrees

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Forces on the Layer Cut

\[ \text{Diagram showing forces and variables such as } F_h, F_v, v_c, h_b, N_1, N_2, S_1, S_2, \alpha, \delta, \varphi, \beta, h_i. \]
Forces on the Blade

\[ v_c \]

\[ v_c \]

\[ F_h \]

\[ F_v \]

\[ h_b \]

\[ h_i \]

\[ \alpha \]

\[ \beta \]

\[ \delta \]

\[ K_2 \]

\[ S_2 \]

\[ N_2 \]

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Moments

\[ F_h \]
\[ F_v \]
\[ v_c \]
\[ h_b \]
\[ \alpha \]
\[ R_1 \]
\[ N_1 \]
\[ h_i \]
\[ R_2 \]
\[ N_2 \]

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Resulting Equations

\[ K_2 = \frac{C \cdot \cos(\varphi)}{\sin(\alpha + \beta + \delta + \varphi)} \]

\[ F_h = K_2 \cdot \sin(\alpha + \delta) \]

\[ F_v = K_2 \cdot \cos(\alpha + \delta) \]
Mohr Circle
Brittle Cutting

The Tear Type

\[ v_c \]
\[ F_h \]
\[ F_v \]
\[ h_b \]
\[ \alpha \]
\[ \beta \]
\[ h_i \]
Transition Tensile Failure – Shear Failure

Tensile Failure vs Shear Failure

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Transition Tensile Failure – Shear Failure

Tensile Failure vs Shear Failure

Ratio UCS/BS

Blade Angle $\alpha$ (Degrees)

- $\Phi=0$ degrees
- $\Phi=5$ degrees
- $\Phi=10$ degrees
- $\Phi=15$ degrees
- $\Phi=20$ degrees
- $\Phi=25$ degrees
- $\Phi=30$ degrees
- $\Phi=35$ degrees
- $\Phi=40$ degrees
- $\Phi=45$ degrees

Ductile limit
Brittle limit

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The Brittle Horizontal Coefficients

Brittle Horizontal Force Coefficient $\lambda_{HT}$ vs Blade Angle $\alpha$

Blade Angle $\alpha$ (Degrees)

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The Brittle Vertical Coefficients

Brittle Vertical Force Coefficient $\lambda_{VT}$ vs Blade Angle $\alpha$

- $\Phi=0$ degrees
- $\Phi=5$ degrees
- $\Phi=10$ degrees
- $\Phi=15$ degrees
- $\Phi=20$ degrees
- $\Phi=25$ degrees
- $\Phi=30$ degrees
- $\Phi=35$ degrees
- $\Phi=40$ degrees
- $\Phi=45$ degrees

Blade Angle (Degrees)
Hyperbaric Rock Cutting
Measurements in Carthage Marble by Rafatian

Specific Energy as a Function of Pressure in Carthage Marble

Esp (MPa)

Pressure (MPa)

Measurements

Brittle

Ductile

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Measurements in Indiana Limestone by Rafatian

Specific Energy as a Function of Pressure in Indiana Limestone

Esp (MPa) vs Pressure (MPa)

- Measurements
- Brittle
- Ductile

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Measurements of Kaitkai & Lei

Cutting Forces in Carthage Marble

Pressure (MPa)

Fh, Fv (N)


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Forces on the Layer Cut

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Forces on the Blade
Resulting Equations

\[ K_2 = \frac{W_2 \cdot \sin(\alpha + \beta + \varphi) + W_1 \cdot \sin(\varphi)}{\sin(\alpha + \beta + \delta + \varphi)} + \frac{C \cdot \cos(\varphi)}{\sin(\alpha + \beta + \delta + \varphi)} \]

\[ F_h = -W_2 \cdot \sin(\alpha) + K_2 \cdot \sin(\alpha + \delta) \]

\[ F_v = -W_2 \cdot \cos(\alpha) + K_2 \cdot \cos(\alpha + \delta) \]
Curling/Balling Type

The Curling Type

- $v_c$
- $F_h$
- $F_v$
- $h_b$
- $\alpha$
- $h_i$
- $\beta$
Moments

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Equilibrium of Moments

\[
\left( W_2 \cdot \sin(\delta) + W_1 \cdot \sin(\alpha + \beta + \delta) - C \cdot \cos(\alpha + \beta + \delta) + A \cdot \cos(\delta) \cdot \cos(\phi) - W_1 \right) \cdot \frac{\lambda_1 \cdot h_i}{\sin(\beta)} \\
= \left( W_2 \cdot \sin(\alpha + \beta + \varphi) + W_1 \cdot \sin(\phi) + C \cdot \cos(\phi) - A \cdot \cos(\alpha + \beta + \varphi) \cdot \cos(\delta) - W_2 \right) \cdot \frac{\lambda_2 \cdot h_b}{\sin(\alpha)}
\]

\[
A \cdot x^2 + B \cdot x + C = 0
\]

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

\[
A = \frac{\lambda_2 \cdot p_{2m} \cdot \sin(\alpha + \beta + \delta + \varphi) - \lambda_2 \cdot p_{2m} \cdot \sin(\alpha + \beta + \varphi) \cdot \cos(\delta) + a \cdot \lambda_2 \cdot \cos(\alpha + \beta + \varphi) \cdot \cos(\delta)}{\sin(\alpha) \cdot \sin(\alpha)}
\]

\[
B = \frac{\lambda_1 \cdot p_{1m} \cdot \sin(\delta) \cdot \cos(\phi) - \lambda_2 \cdot p_{1m} \cdot \cos(\delta) \cdot \sin(\phi) - c \cdot \lambda_2 \cdot \cos(\delta) \cdot \cos(\phi) + a \cdot \lambda_1 \cdot \cos(\phi) \cdot \cos(\delta)}{\sin(\alpha) \cdot \sin(\beta)}
\]

\[
C = \frac{\lambda_1 \cdot p_{1m} \cdot \sin(\alpha + \beta + \delta) \cdot \cos(\phi) - \lambda_1 \cdot p_{1m} \cdot \sin(\alpha + \beta + \delta + \varphi) - c \cdot \lambda_1 \cdot \cos(\alpha + \beta + \delta) \cdot \cos(\phi)}{\sin(\beta) \cdot \sin(\beta)}
\]
Forces measured by Zijssling

![Graph showing forces measured by Zijssling against bottomhole pressure. The graph is labeled with various data points for different pressures and hole sizes.](image-url)

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Specific Energy measured by Zijsling

![Graph showing the relationship between Specific Energy (Esp) and Bottomhole Pressure (MPa). The graph includes data points for different conditions, such as various hole sizes and pressures.]
Specific Energy 60 Degrees
Specific Energy 110 Degrees

The specific energy $E_{sp}$ as a function of the compressive strength of rock, for different ratios between the compressive strength and the tensile strength. For a 110 degree blade.
Specific Energy

Rock Cutting

Esp in kPa

Compressive strength in kPa

Ductile

Brittle
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
4. Different rock cutterheads, source: unknown.