CEDA DREDGING TECHNOLOGY WEBINARS

#4

WELCOME
The sedimentation process in a TSHD

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Hopper Sedimentation

Contents Hopper Sedimentation

- Global process overview
- Settling velocity of sediments
  - Settling velocity of a single particle
  - Influence of the concentration
- Modelling of the sedimentation process
- Camp based models
  - 1DV Model
  - 2DV Model
- Optimal loading
TSHD Process Description

Sailing loaded

Discharge

Sailing empty
TSHD Process Discription

Suction

Excavation
Vertical transport

Loading
Hopper sedimentation
Loading (overflow)

Overflow phase

Overflow level
Initial water level
Settled sediment
Settled sediment

Phase 1

Phase 2
Loading & Overflow system

- Loading system
  - Distribution of sediment
    - Influence on overflow losses
    - Influence on hopper load
    - Influence on trim of the hopper
  - Overflow system
    - Adjustable in height

Overflow system
Overflow Losses

- Important to know:
  - Quantity of losses
  - Which part of the particle size distribution is lost
- Why:
  - Production
  - Sand Quality
  - Environment

Factors influencing overflow losses

- Sediment characteristics
  - Particle size distribution  ) Settling
  - Shape factor  ) velocity
- Equipment
  - Hopper dimensions (L,H,B)
  - Loading and overflow system
- Operational
  - Discharge
  - Concentration
  - Loading time
  - Loading procedure
  - Water temperature

Most important?
Definition Overflow losses

\[
O_{\text{v,ex}} = \frac{\text{sand flux out}}{\text{sand flux in}} = \frac{\rho_v Q_{\text{v,ex}} c_{\text{ex}}}{\rho_v Q_v c_v}
\]

\[
O_{\text{v,ex}} = \frac{c_{\text{ex}}}{c_v} \quad \text{if} \quad Q_{\text{ex}} = Q_v
\]

\[
O_{\text{v,ex}} = \frac{\int \rho_v Q_{\text{v,ex}} c_{\text{ex}} \, dt}{\int \rho_v Q_v c_v \, dt}
\]

Flow Pattern

- Inflow
- Overflow

Settling velocity

- Influenced by
  - particle size, shape, density
  - concentration
  - Viscosity
    - Water temperature
    - Silt / clay
Settling Velocity

\[ F_s = \frac{\pi}{6} D^3 C_w \left( \frac{\rho_s - \rho_w}{\rho_s} \right) w_s^2 \]
\[ G = F_s \]

\[ G = \frac{4}{3} D^3 g (\rho_s - \rho_w) \]
\[ w_s = \sqrt{\frac{4}{3} (\rho_s - \rho_w) g D^3}{3 \rho_s C_w} \]

Small particles: Stokes equation

\[ w_s = \sqrt{\frac{4}{3} (\rho_s - \rho_w) g D^3}{3 \rho_s C_w} \]
\[ C_w = f \left( \frac{w_s D}{v} \right) \]
\[ \frac{w_s D}{v} = Re_p \]

Shape factor
\[ \psi = \frac{V}{\frac{4}{3} D^3} \]

\[ w_0 = \frac{\psi \Delta g D^2}{18 v} \]
\[ \Delta = \frac{\rho_s - \rho_w}{\rho_w} \]
Coarse particles: Turbulent regime

\[ w_g = \sqrt{\frac{4(\rho_i - \rho_w)gD\nu}{3\rho_w C_D}} \]

\[ w_0 = 1.8 \sqrt{\Delta g D\nu} \]

\[ \Delta = \frac{\rho_g - \rho_w}{\rho_w} \]

\[ C_D = 0.4 \]

Intermediate Regime

- Iteration of \( C_D \)
- Or use empirical equations

\[ w_g = \frac{10\nu}{D} \left( \sqrt{1 + \frac{\Delta g D^3}{100\nu^2}} - 1 \right) \]

Influence of the concentration

Return flow
Hindered settling

Not one particle is settling:
- Mutual influence
- Return flow
- Particle – particle interaction

This effect is called hindered settling
- Settling velocity of single grain is reduced with a factor $f$

$$w_s = w_0 \cdot f(c)$$

$$f(c) = (1 - c)^n$$

Hindered settling function

$$w_s = w_0 \cdot f(c)$$

$$f(c) = (1 - c)^n = f(Re_p)$$

Richardson & Zaki

$$Re_p < 0.2 \quad n = 4.65$$

$$0.2 \leq Re_p \leq 1 \quad n = 4.35 Re_p^{-0.03}$$

$$1 \leq Re_p \leq 200 \quad n = 4.45 Re_p^{-0.1}$$

$$Re_p > 200 \quad n = 2.39$$
Influence concentration on settling velocity

- Settling velocity decreases with concentration
- And therefore loading velocity decreases also ???
- NO
- Settling flux = product of concentration and settling velocity is important

Settling flux = $W_s \times C$

Optimal Loading Concentration ??
**Sedimentation velocity**

\[ T_{\text{load}} = \frac{H}{v_{\text{sed}}} \]

\( v_{\text{sed}} \) is the vertical velocity of the settled bed.

![Diagram of sedimentation velocity](image)

\[ v_{\text{sed}} = \frac{c(1-c)^n}{1-n_0 - c} \]

Small concentration:

\[ v_{\text{sed}} = \frac{1}{1-n_0} c \]

**Settling velocity influence temp**

Diagram showing settling velocity influence on temperature.
Modelling Overflow losses

Camp based models

- 'Ideal' settling basin
- Originates from clarifiers
- First published by Camp (1946)

- Extended and applied for dredging by Vlasblom & Miedema

Ideal settling basin
Particles with settling velocity $w_s$ starting between $bc$ will settle

This is $r_s = \frac{bc}{ac}$ from the total number of particles.

Influence Particle Size Distribution

$$r_s dp = \frac{w_s(p)}{v_0} dp$$

$$r_s = 1 - p_0 + \frac{1}{v_0} \int_0^{p_0} w_s dp$$
example

- TSHD:
  - L = 79.2 m
  - B = 22.5 m
  - Q = 14 m$^3$/s

- PSD

![Diagram]

Camp no turbulence, including hindered settling

\[ L = 79.2 \text{ m} \]
\[ B = 22.5 \text{ m} \]
\[ Q = 14 \text{ m}^3/\text{s} \]
\[ v_0 = 7.856341 \text{ mm/s} \]

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<th>p</th>
<th>D [mm]</th>
<th>we [mm]</th>
<th>wp/\text{w}</th>
<th>r_p</th>
<th>r_f</th>
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<td>2.61</td>
<td>26.817</td>
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Total: 0.731776
Ov$_{cum}$: 27%

![Diagram]
Conclusion Camp model

- Shortcomings Camp approach:
  - Flowfield prescribed
    - In reality density currents
  - Influence bed shear stress on sedimentation
  - Inflow and outflow zone not modeled
  - Variation in location not possible
  - But gives a good estimate for overflow loss for optimal loading situation

1 D numerical modelling

1 DV Model

- 1 D in Vertical direction
  - no horizontal transport (possible erosion)
  - Vertical Sediment Transport
    - Advection - Diffusion Equation for n fractions
    - Coupling of different fractions (hindered settling)
    - Movable Bed (sedimentation)
  - Numerical solution (Finite Volume/Difference Method)
Simulation Test 5

- 100 micron, 0.1 m³/s, 1300 kg/m³

Simulation Test 6

- 100 micron, 0.137 m³/s, 1420 kg/m³

2 DV model

- In Camp model (with Turbulence) the sediment transport equations were solved using a prescribed velocity field
- Separate equations have to be solved to determine the flow field:
  - 2DV Reynolds Averaged Navier-Stokes
  - mixture model (no multi-phase flow)
  - Hydrodynamic (non-hydrostatic)
  - Coupling momentum - sediment transport equations
  - Buoyancy (density currents)
  - k-eps turbulence modelling
2 DV model (continued)

- Moving bed
  - Erosion - Sedimentation boundary condition
- Moving Water surface
  - filling of hopper, variation overflow level
  - influence PSD by n fractions mutually coupled
- Loading and Discharge location
  - variation of position and quantity (in time)
  - Inlet conditions (velocity, turbulence intensity)

Overview 2DV Model

Computed hor. Velocity in hopper
Cycle production

\[ P_{\text{cycle}} = \frac{m^3 \text{ unloaded}}{\text{cycle time}} \quad \left[ m^3/s \right] \]

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<th>Item</th>
<th>Description</th>
<th>Time (min)</th>
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<tr>
<td>Hopper load</td>
<td>20,000 m³</td>
<td>300</td>
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<tr>
<td>Sailing empty</td>
<td>330 min</td>
<td>330</td>
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<tr>
<td>Loading</td>
<td>70 min</td>
<td>70</td>
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<tr>
<td>Unloading</td>
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<tr>
<td>Turning etc.</td>
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<tr>
<td>Cycle Prod</td>
<td>27.39 m³/min</td>
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An overview of the slurry transport model

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