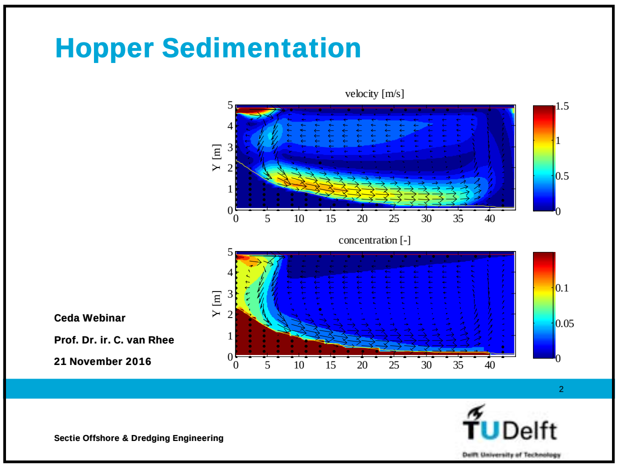
CEDA DREDGING TECHNOLOGY WEBINARS #4

WELCOME

The sedimentation process in a TSHD

Prof. dr. ir. Cees van Rhee

Delft University of Technology



Hopper Sedimentation

Ceda Webinar

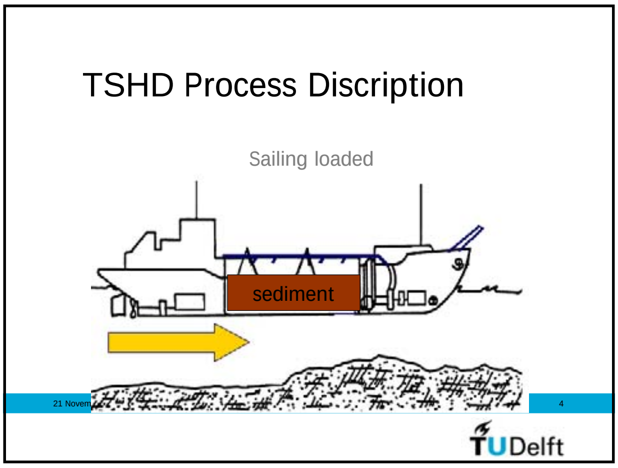
Prof. Dr. ir. C. van Rhee

21 November 2016

Sectie Offshore & Dredging Engineering

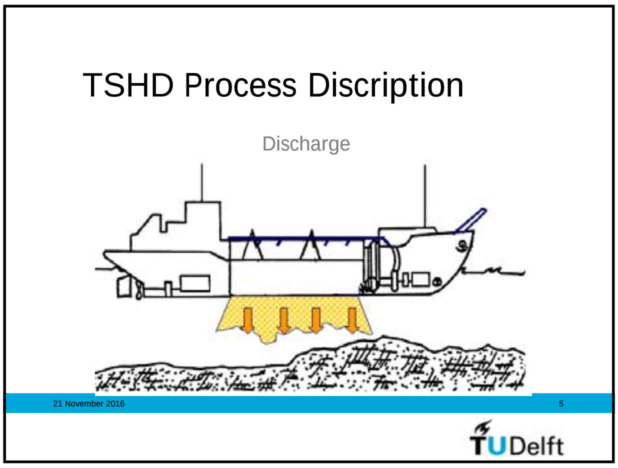
Contents Hopper Sedimentation

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
2 DV Model
Optimal loading



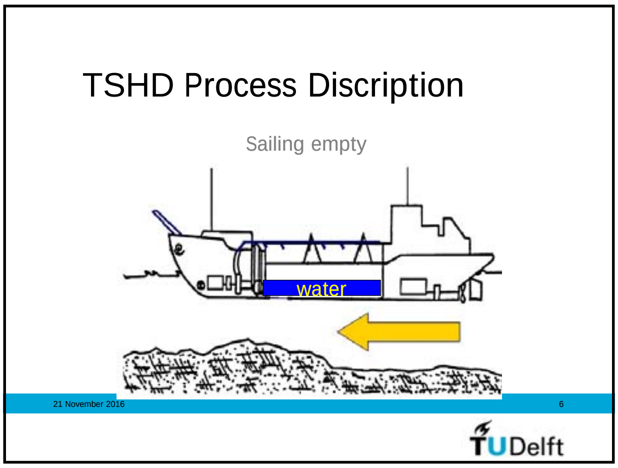
TSHD Process Discription

Sailing loaded



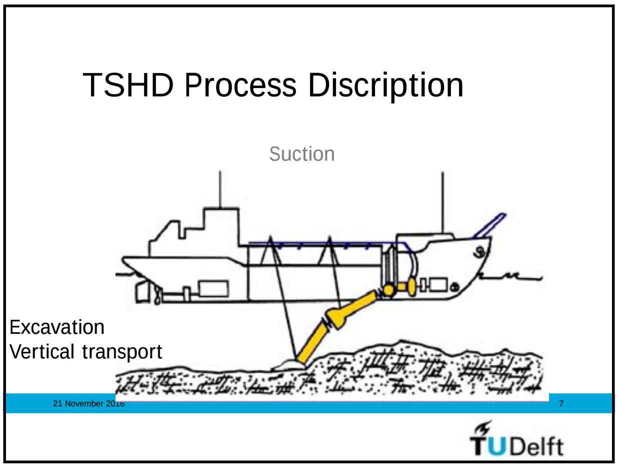
TSHD Process Discription

Discharge



TSHD Process Discription

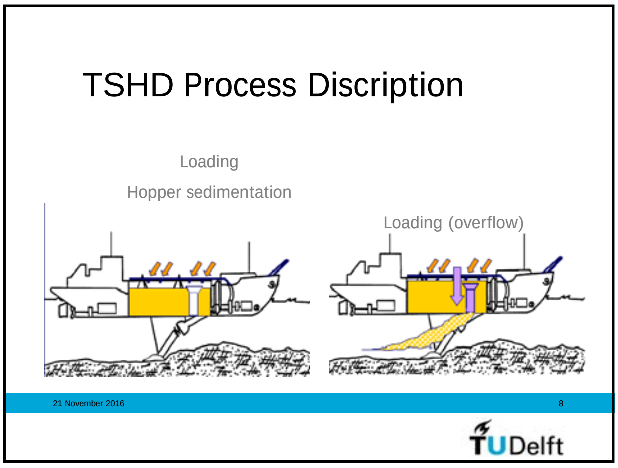
Sailing empty



TSHD Process Discription

Suction

Excavation
Vertical transport

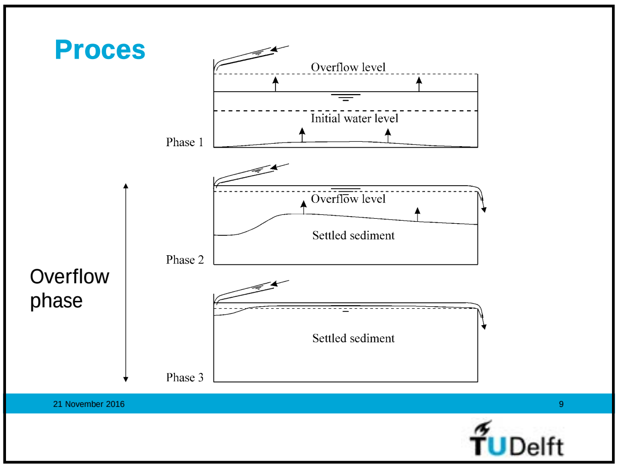


TSHD Process Discription

Loading

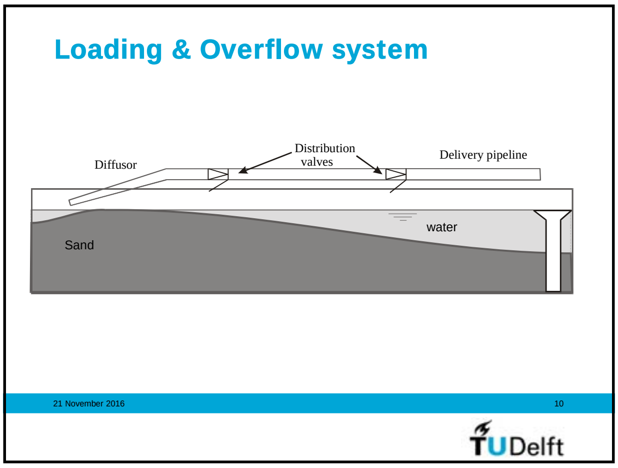
Hopper sedimentation

Loading (overflow)

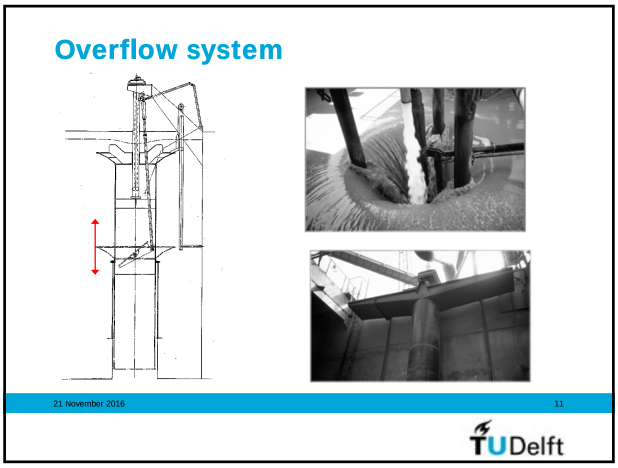


Proces

Overflow phase



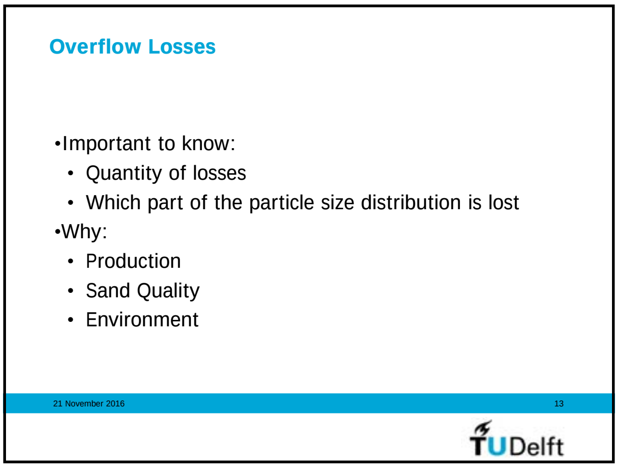
Loading & Overflow system



Overflow system

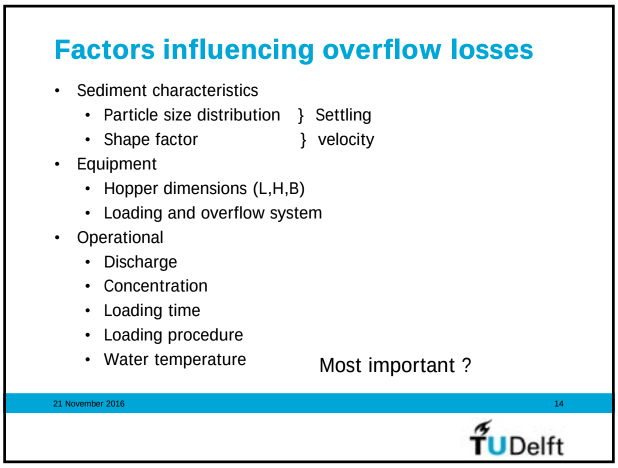
Loading & Overflow system

- 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 Losses

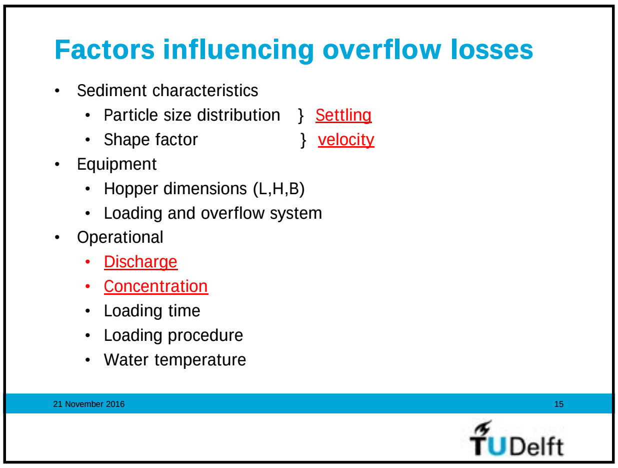
- Important to know:
  - Quantity of losses
  - Which part of the particle size distribution is lost
- Why:
  - Production
  - Sand Quality
  - Environment



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 ?



Factors influencing overflow losses

- Sediment characteristics
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- Operational
  - Discharge
  - Concentration
  - Loading time
  - Loading procedure
  - Water temperature

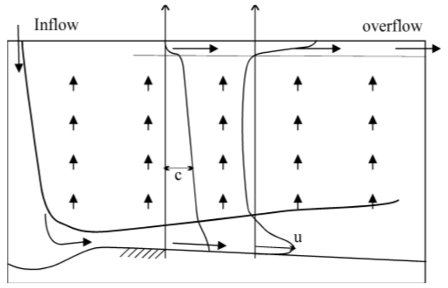
Definition Overflow losses

$$Ov_{mom} = \frac{sandflux\ out}{sandflux\ in} = \frac{\rho_s Q_{out} c_{out}}{\rho_s Q_{in} c_{in}} =$$

$$Ov_{mom} = \frac{c_{out}}{c_{in}} \qquad if\ \ Q_{in} = Q_{out}$$

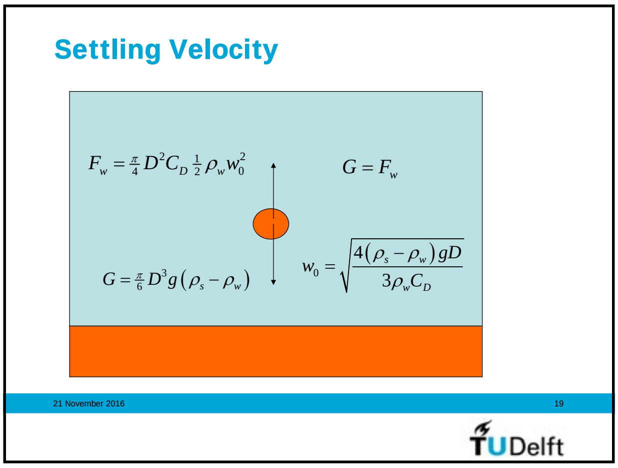
$$Ov_{cum} = \frac{cum\ sandflux\ out}{cum\ sandflux\ in} = \frac{\int_0^t \rho_s Q_{out} c_{out}\, dt}{\int_0^t \rho_s Q_{in} c_{in}\, dt}$$

Flow Pattern



Settling velocity

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



Settling Velocity

$$F_w = \tfrac{\pi}{4} D^2 C_D \tfrac{1}{2} \rho_w w_0^2$$

$$G = F_w$$

$$G = \tfrac{\pi}{6} D^3 g \left(\rho_s - \rho_w\right)$$

$$w_0 = \sqrt{\frac{4\left(\rho_s - \rho_w\right) gD}{3\rho_w C_D}}$$

$$w_0 = \sqrt{\frac{4\left(\rho_s - \rho_w\right) gD\psi}{3\rho_w C_D}} \qquad C_D = f\left(\frac{w_0 D}{\nu}\right) \qquad \frac{w_0 D}{\nu} = Re_p$$

Shape factor $\psi = \dfrac{V}{\tfrac{\pi}{6} D^3}$

Small particles : Stokes equation

$$w_0 = \sqrt{\frac{4\left(\rho_s - \rho_w\right) gD\psi}{3\rho_w C_D}} \qquad C_D = \frac{24}{Re_p} = \frac{24\nu}{w_0 D}$$

$$w_0 = \frac{\psi \Delta g D^2}{18\nu} \qquad \Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

Coarse particles : Turbulent regime

$$w_0 = \sqrt{\frac{4(\rho_s - \rho_w)gD\psi}{3\rho_w C_D}}$$

$$C_D = 0.4$$

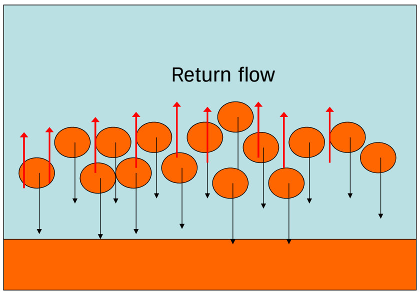
$$w_0 = 1.8\sqrt{\Delta g D \psi} \qquad \Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

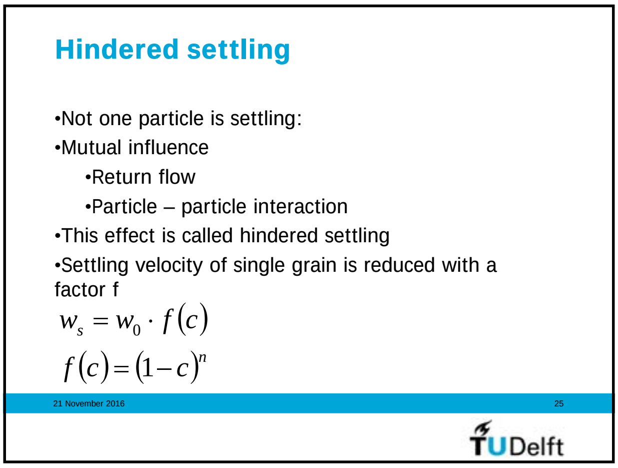
Intermediate Regime

- Iteration of Cd
- Or use empirical equations

$$w_0 = \frac{10\nu}{D}\left(\sqrt{1+\frac{\Delta g D^3}{100\nu^2}} - 1\right)$$

Influence of the concentration



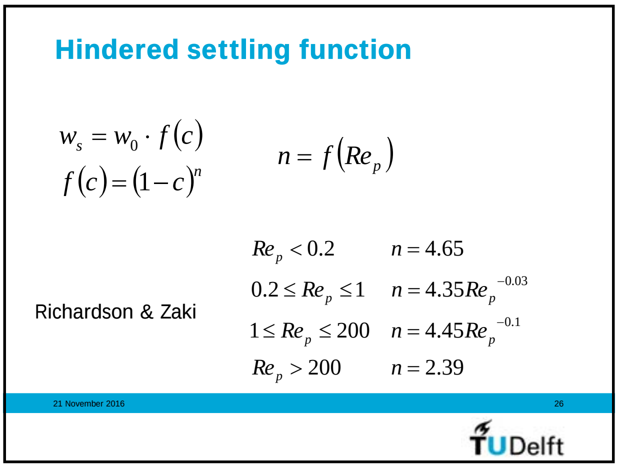


Hindered settling

- 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

$$w_s = w_0 \cdot f(c) \qquad n = f(Re_p)$$

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

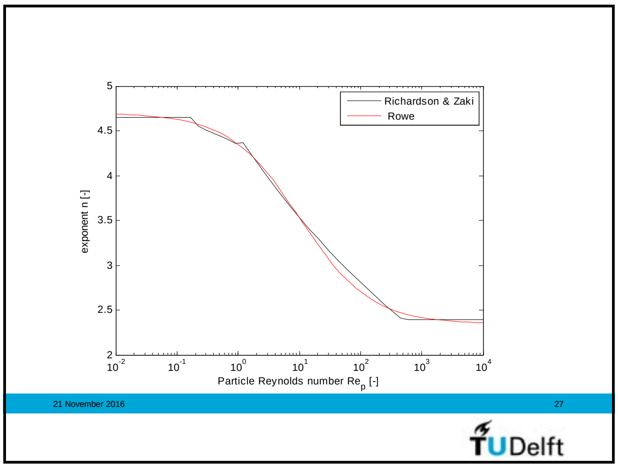
Richardson & Zaki

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

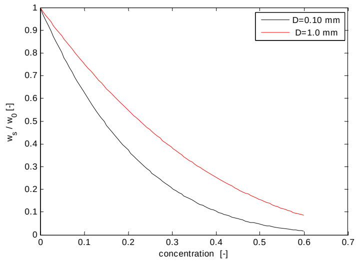
$$0.2 \le Re_p \le 1 \qquad n = 4.35 Re_p^{-0.03}$$

$$1 \le Re_p \le 200 \qquad n = 4.45 Re_p^{-0.1}$$

$$Re_p > 200 \qquad n = 2.39$$



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

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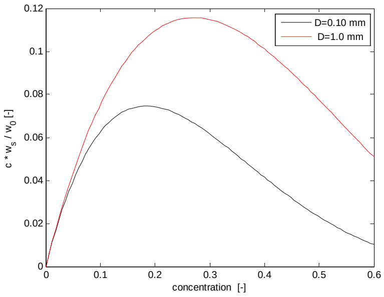
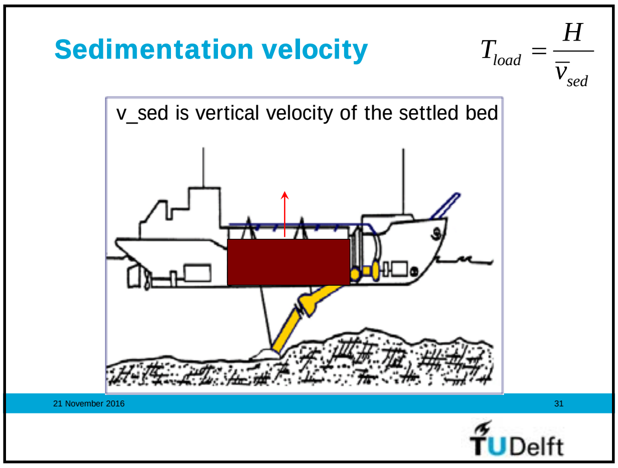
Settling flux = $w_s * c$



Optimal Loading Concentration ??

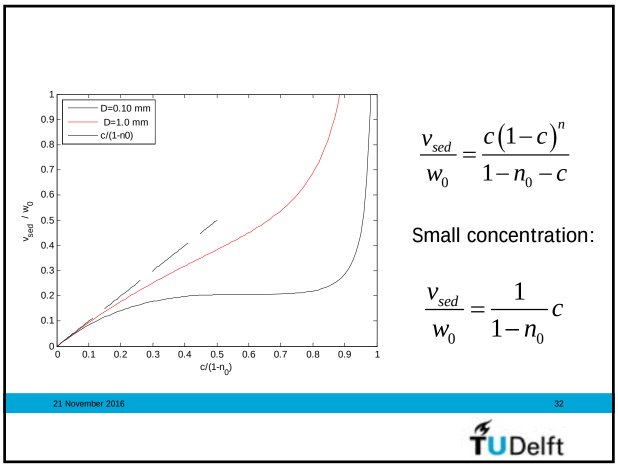


Sedimentation velocity

$$T_{load} = \frac{H}{\bar{v}_{sed}}$$

v_sed is vertical velocity of the settled bed

TU Delft

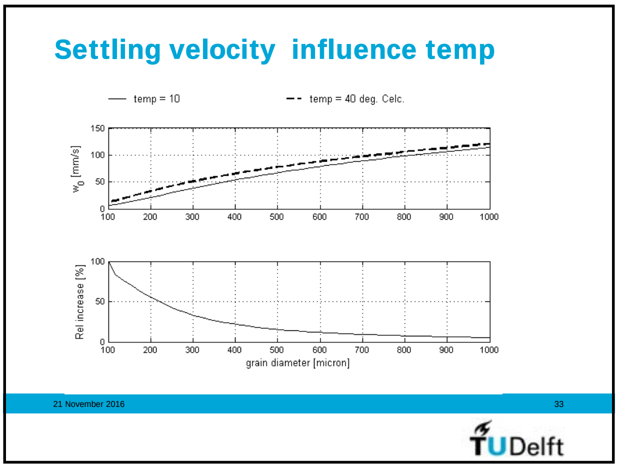


$$\frac{v_{sed}}{w_0} = \frac{c\left(1-c\right)^n}{1-n_0-c}$$

Small concentration:

$$\frac{v_{sed}}{w_0} = \frac{1}{1-n_0}c$$

TU Delft



Settling velocity influence temp

TU Delft

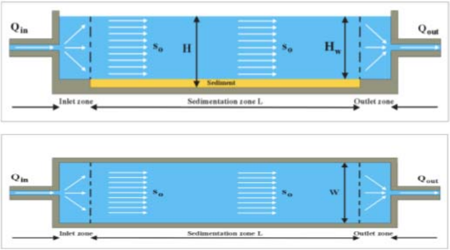
Modelling Overflow losses

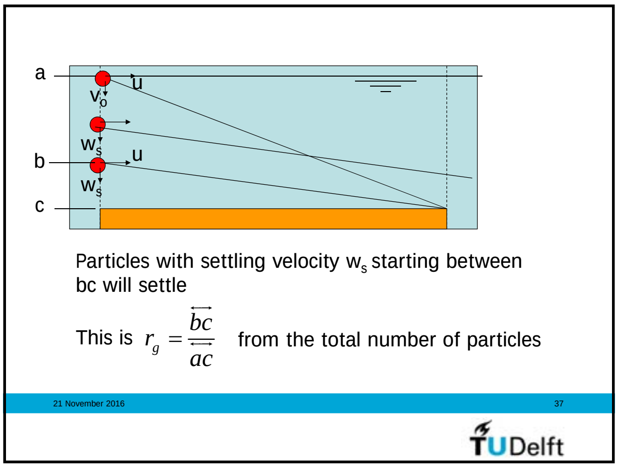
Camp based models

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

- Extended and applied for dredging by Vlasblom & Miedema

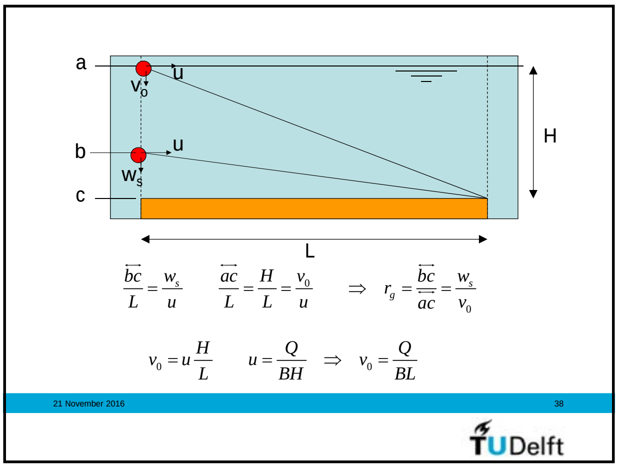
Ideal settling basin





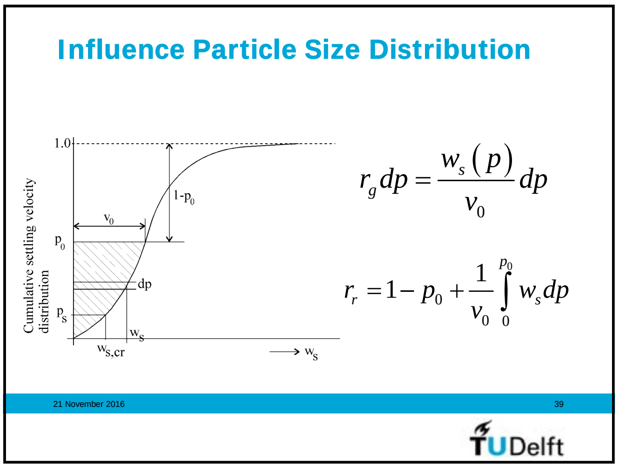
Particles with settling velocity w_s starting between bc will settle

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



$$\frac{\overleftrightarrow{bc}}{L} = \frac{w_s}{u} \qquad \frac{\overleftrightarrow{ac}}{L} = \frac{H}{L} = \frac{v_0}{u} \qquad \Rightarrow \quad r_g = \frac{\overleftrightarrow{bc}}{\overleftrightarrow{ac}} = \frac{w_s}{v_0}$$

$$v_0 = u\frac{H}{L} \qquad u = \frac{Q}{BH} \qquad \Rightarrow \quad v_0 = \frac{Q}{BL}$$



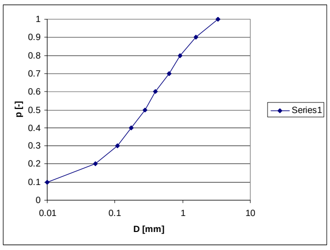
Influence Particle Size Distribution

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

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

example

- TSHD :
- L= 79.2 B = 22.5
- Q= 14 m³/s
- PSD →

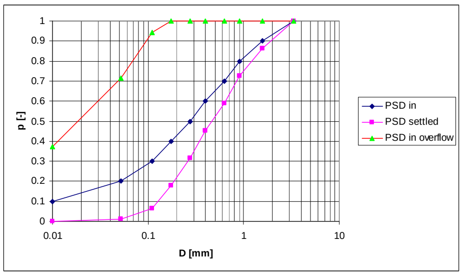


Camp no turbulence , including hindered settling

L= 79.2 m
B= 22.5 m
Q= 14 m
c_in 0.17 [-]
v0 7.856341 mm/s

fraction	p [-]	D [mm]	ws mm/s	ws/v0 [-]	r_g	r_r
1	0.1	0.01	0.02	0.003	0.003004	0.0003
2	0.1	0.052	0.65	0.082	0.082367	0.008237
3	0.1	0.11	3.03	0.385	0.385345	0.038534
4	0.1	0.174	6.65	0.847	0.847048	0.084705
5	0.1	0.275	15.29	1.946	1	0.1
6	0.1	0.398	27.58	3.510	1	0.1
7	0.1	0.631	50.84	6.471	1	0.1
8	0.1	0.912	75.84	9.653	1	0.1
9	0.1	1.585	124.25	15.815	1	0.1
10	0.1	3.311	210.61	26.807	1	0.1
					total:	0.731776
					Ov_cum=	27%

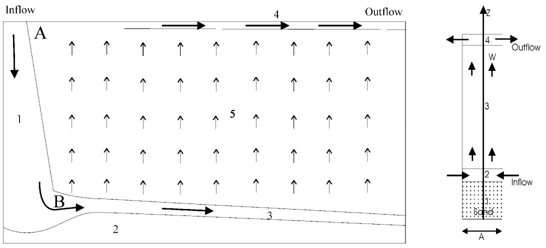
PSD’s



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

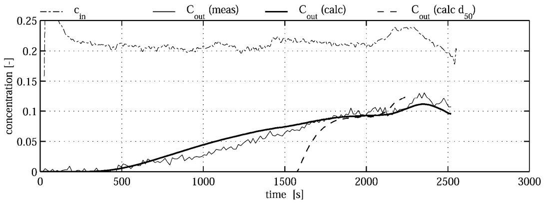


1 DV Model

- 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)

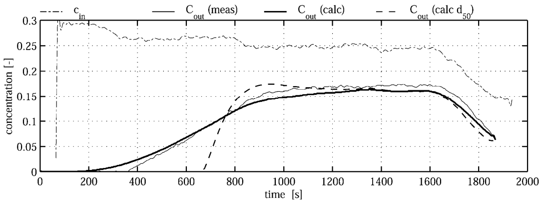
Simulation Test 5

- 100 micron, 0.1 m³/s, 1300 kg/m³



Simulation Test 6

- 100 micron, 0.137 m³/s, 1420 kg/m³



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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 **R**eynolds **A**veraged **N**avier-**S**tokes

  - mixture model (no multi-phase flow)

•Hydrodynamic (non-hydrostatic)

•Coupling momentum - sediment transport equations

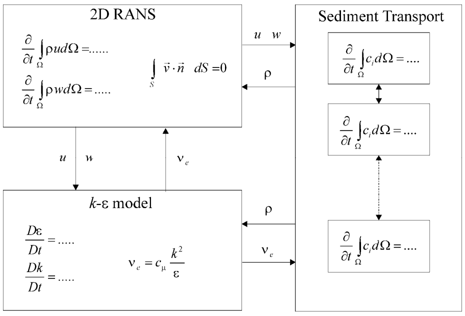
  - Buoyancy (density currents)

•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



2D RANS

$$\frac{\partial}{\partial t}\int_{\Omega}\rho u d\Omega = \ldots\ldots$$

$$\frac{\partial}{\partial t}\int_{\Omega}\rho w d\Omega = \ldots\ldots$$

$$\int_{S}\vec{v}\cdot\vec{n}\ \ dS = 0$$

k-ε model

$$\frac{D\varepsilon}{Dt} = \ldots\ldots$$

$$\frac{Dk}{Dt} = \ldots\ldots$$

$$\nu_e = c_\mu \frac{k^2}{\varepsilon}$$

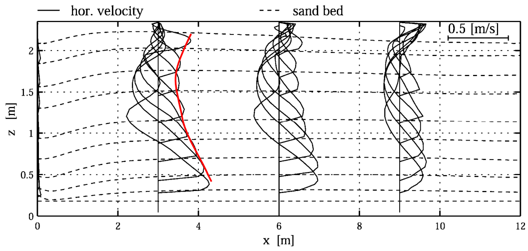
Sediment Transport

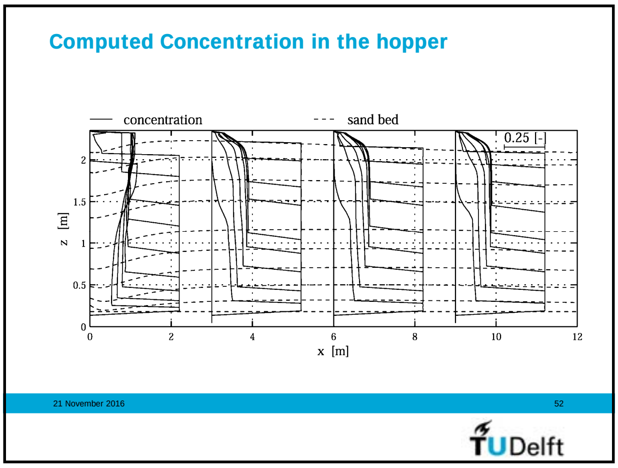
$$\frac{\partial}{\partial t}\int_{\Omega} c_i d\Omega = \ldots.$$

$$\frac{\partial}{\partial t}\int_{\Omega} c_i d\Omega = \ldots.$$

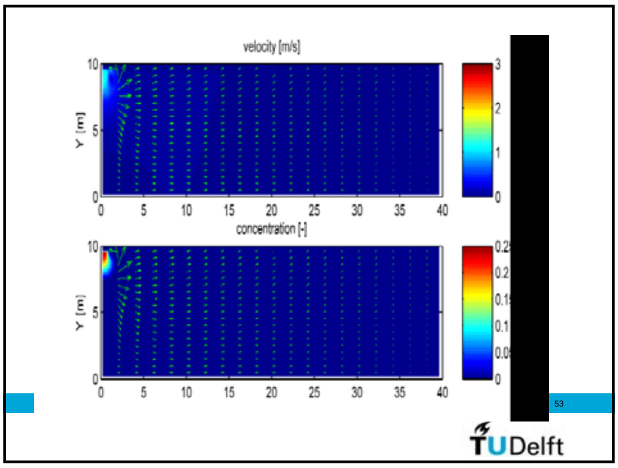
$$\frac{\partial}{\partial t}\int_{\Omega} c_i d\Omega = \ldots.$$

Computed hor. Velocity in hopper





Computed Concentration in the hopper



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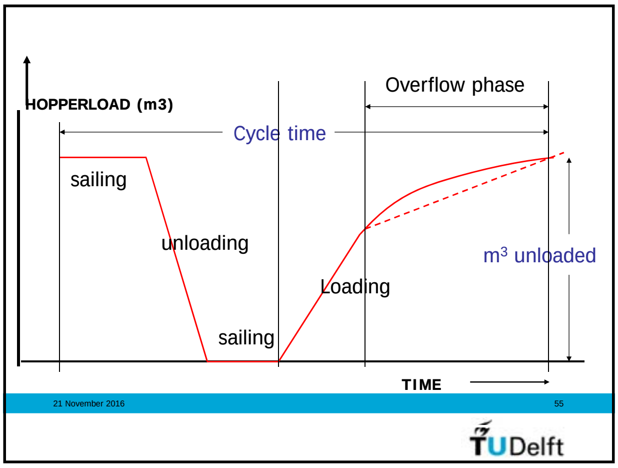
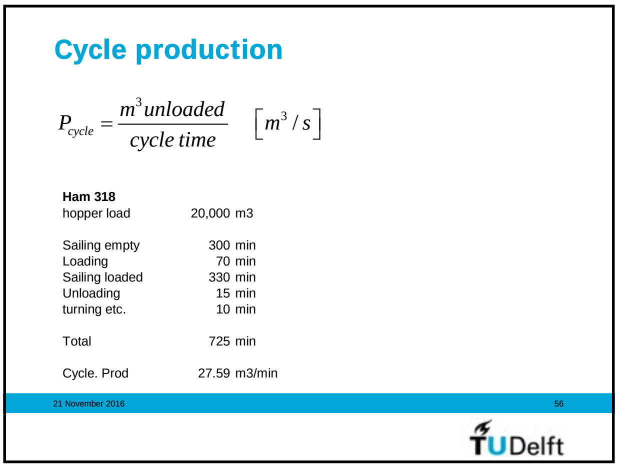
Optimal loading time

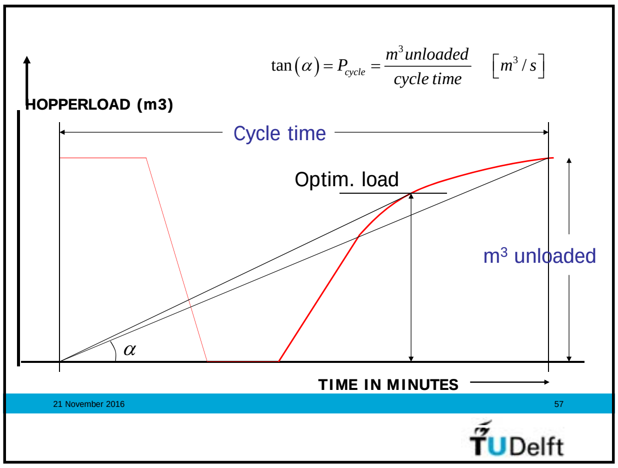




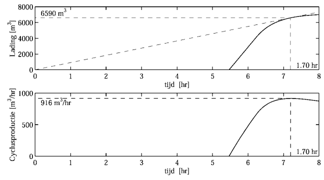
Cycle production

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

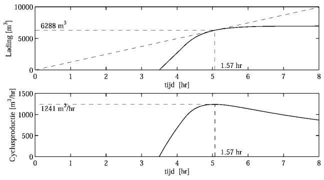
Ham 318	
hopper load	20,000 m3
Sailing empty	300 min
Loading	70 min
Sailing loaded	330 min
Unloading	15 min
turning etc.	10 min
Total	725 min
Cycle. Prod	27.59 m3/min



$$\tan(\alpha) = P_{cycle} = \frac{m^3 unloaded}{cycle\ time} \quad \left[m^3/s\right]$$



Long sailing distance



Short sailing distance

Questions?

CEDA DREDGING TECHNOLOGY WEBINARS: NEXT EVENTS

22 November 2016, 14:00-15:00 hrs (CET)
An overview of the slurry transport model

6 December 2016, 14:00-15:00 hrs (CET)
Flow regimes diagrams in slurry transport

by dr.ir. Sape Miedema

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