Designing Dredging Equipment
OE4671/ WB3408

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Section Dredging engineering
Purpose of the lecture

• To design a particular type of dredger on basis of (simple) dredging processes.

• Such a method can be used for many design problems!
Course development

• Introduction lecture in the 5th quarter

• Assignment for one or two persons can be done the whole year around.

• Total 4 credits (ECT)
Assignments for hydraulic dredgers

- Trailing Suction Hopper Dredger (TSHD) for large reclamation works
- Multi Purpose TSHD for maintenance and beach nourishments
- Gravel Trailing Suction Hopper Dredgers
- Cutter Suction Dredger
- Environmental Dredger
- Plain Suction Dredger
- Dustpan Dredger
Assignments for mechanical dredgers

• The backhoe dredger
• The grab dredger
• Bucket ladder dredger
Trailing Suction Hopper Dredger
Plain Suction Dredger
Plain Suction Dredger

DSC Dredge During Construction Phase for FRI Virginia-Based Facility
Dustpan Dredger
The Environmental Dredger
The Backhoe Dredger
The Grab or Clamshell Dredger
Bucket Ladder Dredger
Work Load

The assignment for

- the TSHD, CSD are for 2 students
- The other ones are for 1 student
Designing Dredging Equipment

Productions

Dredging installation

Propulsion (optional)

Prime movers (main engines)

General layout
Design basis = yearly output in m³ (production)

- To be translated to the significant design parameters.
- Depends on the scale (or cycle) of the process.
- Large scales
  - Hopper dredger ⇒ volume and load per trip
  - Barge unloader dredger ⇒ Barge volume
  - Backhoe dredger ⇒ the volume per cycle
- Continuous operating dredgers or equipment m³/week or m³/month
Design Basis (2)

• Small scale:
  • “Wall” speed of a breach mm/s
  • Pump output in m³/s
  • Cutter head Excavated output in m³/s
  • Bucket ladder dredger Buckets/min
  • Backhoe dredger Bucket volume/cycle
  • Grab dredger Grab volume/cycle
Problems during translation

- Change of volumes
- In many cases the contractor is paid in volumes removed, but many processes are based on mass.
- Working hours per week (168 or 84 or 40)
- Down time
- Overhaul & Maintenance
- Bunkering, crew changes, etc
- Delays due to weather conditions
Concentration (1/3)

• By volume
  \[ C_v = \frac{\text{Volume sand}}{\text{Mixture volume}} = \frac{U_s}{U_m} \]

• By weight
  \[ C_w = \frac{\text{Sand mass}}{\text{Mixture mass}} = \frac{\rho_s U_s}{\rho_m U_m} = \frac{\rho_s}{\rho_m} C_v \]

• Delivered
  \[ C_{vd} = \frac{U_s / \text{time}}{U_m / \text{time}} = \frac{Q_s}{Q_m} \]
Concentrations (2/3)

- Ratio between $C_{vd}$ & $C_v$ follows from:

$$C_{vd} = \frac{Q_s}{Q_m} = \frac{v_s A C_v}{v_m A} \Rightarrow \frac{C_{vd}}{C_v} = \frac{v_s}{v_m}$$

- Ratio between $C_w$ & $C_v$

$$C_w = \frac{\rho_s}{\rho_m} C_v \Rightarrow \frac{C_w}{C_v} = \frac{\rho_s}{\rho_m}$$
Concentrations (2/3)

\[
\frac{C_{vd}}{C_v} = \frac{v_s}{v_m}
\]

• In horizontal transport \( v_s < v_m \rightarrow \) slip
• In vertical transport \( v_s \approx v_m \) the difference is the settling velocity
Mixture Densities ⇔ Volumetric Concentration

• \( \text{Mass}_{\text{mixture}} = \text{mass}_{\text{liquid}} + \text{mass}_{\text{solids}} \)

\[
\rho_m U_m = \rho_f U_f + \rho_s U_s \quad \text{with} \quad C_v = \frac{U_s}{U_m}
\]

\[
\rho_m = \rho_f (1 - C_v) + \rho_s C_v
\]

\[
C_v = \frac{\rho_m - \rho_f}{\rho_s - \rho_f}
\]

"Note U is volume"
Volume changes

- When removing soil the in situ density will change; mostly from a dense to a loose state
  - Increase in porosity; f.i. From 40 to 50%
  - Porosity n is ratio pore volume over total volume
  - Condition: \( V_1(1-n_1)=V_2(1-n_2) \)

Examples:
  - Sand; \( n_1=0.4 \) and \( n_2=0.5 \) gives \( V_2/V_1=0.6/0.5=1.2 \)
  - Rock; \( n_1=0 \) and \( n_2=0.4 \) gives \( V_2/V_1=1/0.6=1.7 \)
Every dredging process can have losses, called spillage
- More excavated than picked up by the flow or bucket
- Non removed loads in TSHD’s, particular when the loads is pumped ashore or rainbowed.
- Unstable slopes after dredging (plain suction dredgers)
- In accurate placing of material
- Losses due to current and waves
Excavating production

- Mechanically
- Hydraulically
Mechanical excavation
Specific Energy Concept (SPE)

Energy required to excavated 1m$^3$ of soil

Dimension is Joule/m$^3$

or per unit of time J/s/m$^3$/s=W/m$^3$/s,

That equals a power over production

$$SPE = \frac{power}{production} \Rightarrow power = SPE \times production$$
Mechanical Excavating
Mechanical Excavating
Hydraulic excavation
Momentum of flow

A reasonable assumption is that the jet-production is linear with the total momentum flux of the jet system independent of the trail speed.

\[ Q_{sand} = (1-n)Q_{dredged} \]

\[ M_{sand} = Q_{sand} \rho_{sand} = (1-n)Q_{dredged} \rho_{sand} \]

\[ M_{sand} = \alpha \cdot I = \alpha \rho_{w} \cdot Qu = \alpha \rho_{w} \cdot Q \sqrt{\frac{2p}{\rho_{w}}} = \alpha \sqrt{2\rho_{w}} \frac{P_{power}}{\sqrt{p_{pressure}}} \]
Excavation by dragheads is hydraulically
Water injection dredger
Transport production

- Mechanically
  - ship/barge conveyor
- Hydraulically
  - pipeline
Mechanical transport

- Trailing suction hopper dredger
- Barges

- Be aware of the effective load, because the unloading is not always 100%
Transport by barges
By Trailing Suction Hopper Dredgers
Hydraulic transport
Pump-pipeline system

Pressure [kPa]

Flow [m3/s]

mixture

water

mixture

water

1

2

3

4

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Hydraulic transport
Methods of deposing (1/2)
Methods of deposing (2/2)
disposing
Rainbowing
Mechanical Assistance
Design examples
Example 1

Design a Trailing Suction Hopper Dredger that can dredge yearly 5 Mm$^3$ coarse sand & gravel at 75 nautical miles from a port.

The dredger works 5 days at 24 hours
Bunkers will be taken in the weekend
Overhaul 2 weeks
Weather delays 3 weeks
Workability 95%
Christmas 1 week
Designing TSHD

Main dimensions

Dredging installation

Propulsion

General layout
Cycle time

First estimate of dredge cycle:
Sailing to the dredging area: \( \frac{75}{15} = 3.0 \) hr
Loading \( = 1.5 \)
Sailing to the unloading area: \( = 3.0 \)
Unloading \( = 1.5 \)
Total \( = 9.0 \) hr
Required load/ trip

Available hours: \((52-6) \times 5 \times 24=5520\)

Effective hours: \(0.95 \times 5520=5244\)

Number of trips per year: \(5244/9=582\)

Required volume per trip: \(5,000,000/582=8591\ m^3\)

In coarse sand & gravel max. filling hopper is 90%

Required hopper volume: \(8591/.9=9546 \Rightarrow 10000\ m^3\)

Density of sand & gravel in hopper 2000 kg/m^3

PayLoad is: \(8600 \times 2=17200\ ton\)

Hopper density: load/volume = 1.72 t/m^3.
Deadweight & lightweight

Crew and their possessions, consumer goods, spare parts, and ballast water and payload.

Deadweight = 1.05 x payload

Light weight as function of deadweight

\[ y = -3 \times 10^{-6}x^2 + 0.5586x \]

\[ R^2 = 0.9607 \]
Displacement

\[ y = 0.6827x \quad \text{with } R^2 = 0.9929 \]

\[ y = 0.3173x \quad \text{with } R^2 = 0.9622 \]
Block coefficient

\[ C_b = \frac{\nabla}{LBT} \]
Ship Numbers

Ships Numbers

Year of Construction

L/B, B/H, B/T

L/B
B/H
B/T


0 1 2 3 4 5 6 7 8

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Dredging installation

Required pump capacity

Overflow losses

Overflow losses equal as assumed?

No

Main Dimensions

Yes

Pumps and pipelines
Pump capacities

• 10000 m³ in 90 min = 1.85 m³/s including pores or 1.85 x 0.6 = 1.11 m³/s excluding pores
• Assume $C_{vd} = 0.2 \rightarrow$ capacity $Q = \frac{1.11}{0.25} = 5.55$ m³/s or per suction tube 2.8 m³/s
• Critical velocity for course sand is 5 m/s, so pipe diameter is 0.85 m → 0.85 m

• In coarse sand and gravel there are no overflow losses to account for.
Excavation process
Calculated the required jet pressure

- Sand mass follows from production

\[ Q_{sand} = (1 - n) Q_{dredged} \]
\[ M_{sand} = Q_{sand} \rho_{sand} = (1 - n) Q_{dredged} \rho_{sand} \]

- Momentum follows from:

With \( \alpha = 0.1 \)

\[ M_{sand} = \alpha \cdot I \]

\[ \alpha \cdot I = \alpha \rho_w \cdot Q_{jet} u = \alpha \rho_w \cdot Q \sqrt{\frac{2p}{\rho_w}} = \alpha \sqrt{2\rho_w} \frac{P_{power}}{\sqrt{P_{pressure}}} \]
Relation between $Q_{\text{mix}}$, $Q_{\text{jet}}$ and $Q_{\text{erosion}}$
Pumps and pipelines

Determine jet capacity and pressure

Submerged pump required?

No

Yes

Depth of submerged pump

Determine headlosses and power(s)

Choose pump(s)
Submerged pump required?

\[ \rho_{\text{water}} gH + Vac = \rho_{\text{mixture}} gh_z + \xi \frac{1}{2} \rho_{\text{mixture}} v^2 = \rho_{\text{mixture}} g(H-k) + \xi \frac{1}{2} \rho_{\text{mixture}} v^2 \]
Hydraulic transport

- From seabed into the hopper
- From hopper to the shore
  - Mostly empirical relations (Matousek)

- For gravel dredgers this is mostly be mechanically
Pump characteristics
Propulsion

For dredging & sailing

Bow trust power

Total Installed

Power balance

General layout
Propulsion power

\[ y = 0.4641x - 510.11 \]

\[ R^2 = 0.8741 \]
Bow trust power

Bow trust power

\[ y = 0.1758x - 19.495 \]

\[ R^2 = 0.8036 \]

Propulsion power during trailing [kW]
General Arrangement
General Arrangement of gravel dredger
Simple general arrangement

L_{ship} = 165 m
H_{ship} = 14.7 m
T_{ship} = 13.2 m

L_{hopper} = 62 m
B_{hopper} = 2.5 m

See figure B7.1
The Cutter Suction Dredger
Example 2

Design a cutter dredger that can dredge yearly 5 Mm$^3$ rock with a unconfined compressive strength of 5 MPa. The tensile strength is 1 Mpa.

The dredgers have to work 168 hrs a week.
Yearly overhaul 4 weeks
Christmas leave 1 week
General delays 10%
Dredging delays 20
SPE~qu
Required cut production

Available hours \( (52-5) \times 168 = 7896 \)
Non dredging hours: \( 0.3 \times 7896 = 2369 \)
Dredging hours \( 7896 - 2369 = 5527 \)
Estimated spillage 25%
Required hourly output: \( 1.25 \times \frac{5000000}{5527} = \pm 1130 \text{ m}^3 \)
\( Q_{\text{dredged}} = \frac{1130}{3600} = 0.314 \text{ m}^3/s \)
Time losses due to stepping, spud changes 15%
\( Q_{\text{cut}} = \frac{0.31}{0.85} = 0.37 \text{ m}^3/s \)
SPE = 5MJ/m\(^3\).
Required mean cutter power \( 0.37 \times 5 = 1.85 \text{ MW} \)
Cutter head productions c.q. Spillage

• The rotational speed of the cutter head causes spillage.

• The productivity c.q. spillage depends on the ratio:

• For sand the productivity is:

\[ P_r \approx 2.5 \frac{Q_{\text{pump}}}{\omega R_{\text{cutter}}^3} \]

• For rock the productivity is much lower
Cutter head productions c.q. Spillage

![Graph showing relative production with different symbols for gravel 10 mm, gravel 15 mm, ladder 25 deg., and sand.](image-url)
Cutter head production process in rock or gravel
Cutter head dimensions for rock with 25 % spillage

Cutter head speeds
Capsules
Cutter head speed [rpm]
Pump capacity [m^3/s]
Cutter diameter [m]
Pump capacity and concentrations

\[ Q_{\text{dredged}} = 0.314 \text{ m}^3/\text{s} \]
\[ Q_{\text{mixture}} = 3.5 \text{ m}^3/\text{s} \]

\[ C_{vd} = \frac{Q_{\text{sand}}}{Q_{\text{mixture}}} = \frac{Q_{\text{dredged}}}{Q_{\text{mixture}}} (1 - n) \]
Pumping distances and installed pump power

- Knowledge of hydraulic losses can be found in the lecture notes of Matousek c.q. Talmon
- Knowledge of dredge pump can be found on our website and is downloadable.
Lightweight of pontoon

\[ y = 0.3485x \]

\[ R^2 = 0.925 \]
Pontoon dimensions (1/2)

Light weight [t]

L/B & B/T

L/B  B/T
Pontoon dimensions (2/2)

\[ y = 0.4664x \]
\[ R^2 = 0.9597 \]
Simple Plan
Backhoe dredger
Example 3

• A backhoe dredger have to dredge 500 m$^3$/in fine sand with a SPE of .7MJ/m$^3$.
• Calculated the Bucket size and cylinder forces
## Fill Degree & Bulk factor

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Filling degree</th>
<th>Bulking factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft clay</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Hard clay</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Sand &amp; Gravel</td>
<td>1</td>
<td>1.05</td>
</tr>
<tr>
<td>Rock; well blasted</td>
<td>0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Rock, unblasted</td>
<td>0.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Dredge Cycle

• Cycle times of the bucket depends on the dredging depth and soil type, but are in the order between 20 and 40 seconds.
• The cycle consists of:
  • Digging
  • Lifting and swinging
  • Dumping
  • Swinging and lowering
  • Positioning.
Crane weight versus bucket size for soft soil

\[ y = -7 \times 10^{-6} x^2 + 0.0494 x + 1.5486 \]

\[ R^2 = 0.9778 \]
Required power

Liebherr Excavators

\[ y = 4.4679x \]

\[ R^2 = 0.9936 \]
Relation for existing dredgers
Light weight pontoon

![Graph showing the relationship between total installed power and light weight](image)
Pontoon volume

\[ y = 0.4713x \]

\[ R^2 = 0.6122 \]
Ships numbers for BHD

![Graph showing light weight (t) vs. L/B & B/t]
Newer ideas can be discussed
The shallow draught TSHD