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Analysis and Comparison of Resistance Models of Long-Distance Hydraulic Transport of Medium Sand

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About myself

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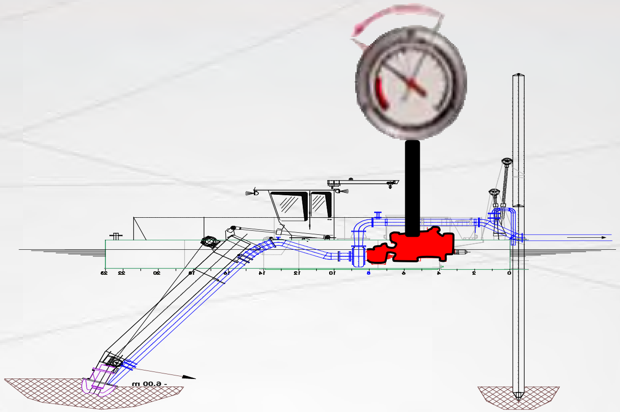
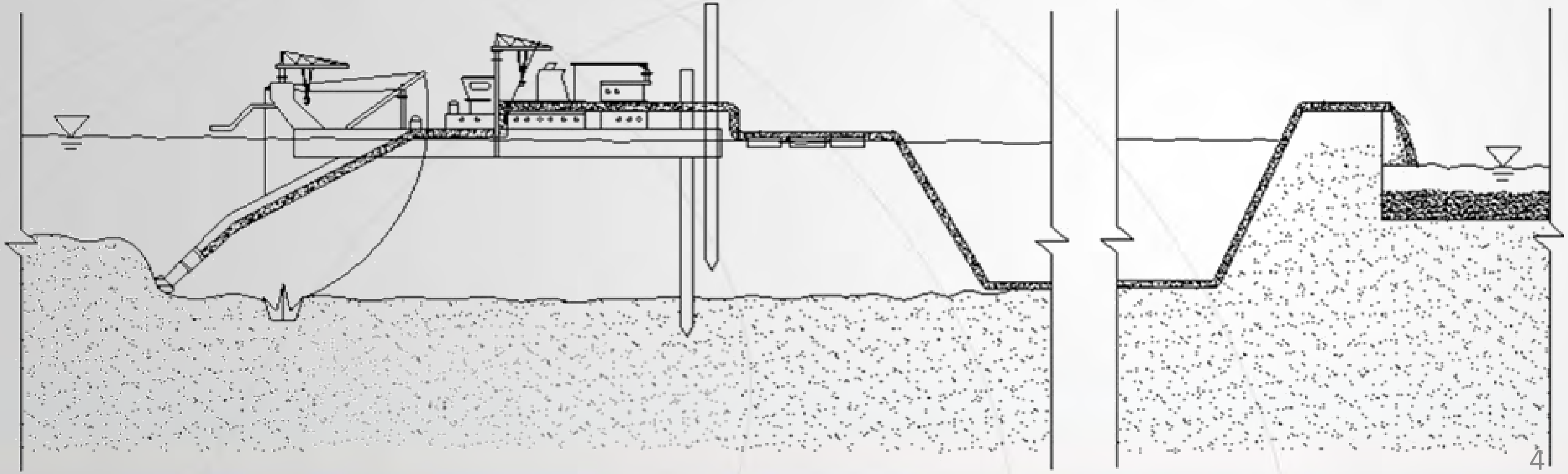
- Introduction
- Particle motion patterns and hydraulic loss characteristics
- Resistance formula and basic theory
- Practical Calculation and Formula Evaluation

● Introduction

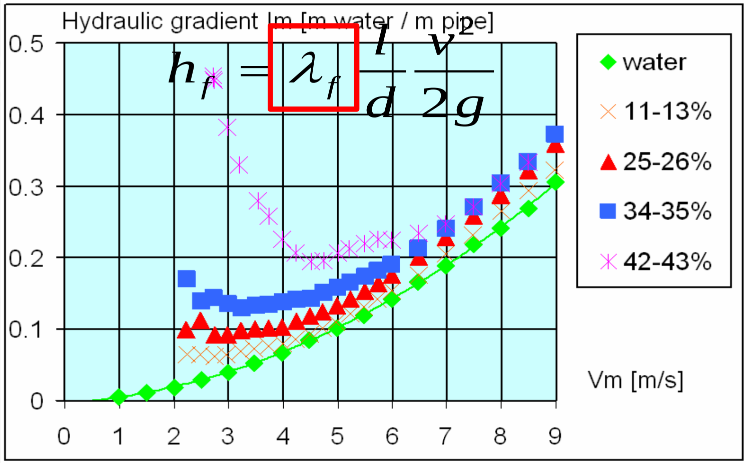
- Slurry transport consumes most of the installed power of CSD
- Accurate calculation of the hydraulic loss is important for forecasting dredger production and corresponding project progress





Introduction

- Slurry transport is affected by the physical properties of particulate, flow state, flow pattern, flow properties, viscosity, pipe diameter and other factors of the solid particulate materials;



Introduction

- There are a lot of formulas for calculating hydraulic loss during slurry transport process. Every formula has its own applicable conditions.
- To master the basic theories and applicable conditions of different calculation formulas will help to improve the estimation accuracy of the dredger production.



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Particle motion patterns and hydraulic loss characteristics

Particle motion patterns

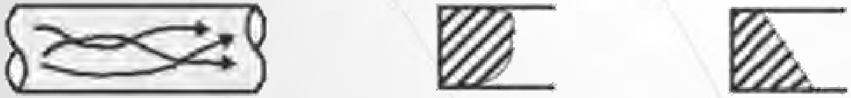
- Quasi-uniform flow

Quasi-uniform flow | Velocity distribution | Concentration distribution

- Non-uniform flow

Non-uniform flow | Velocity distribution | Concentration distribution

- Composite flow

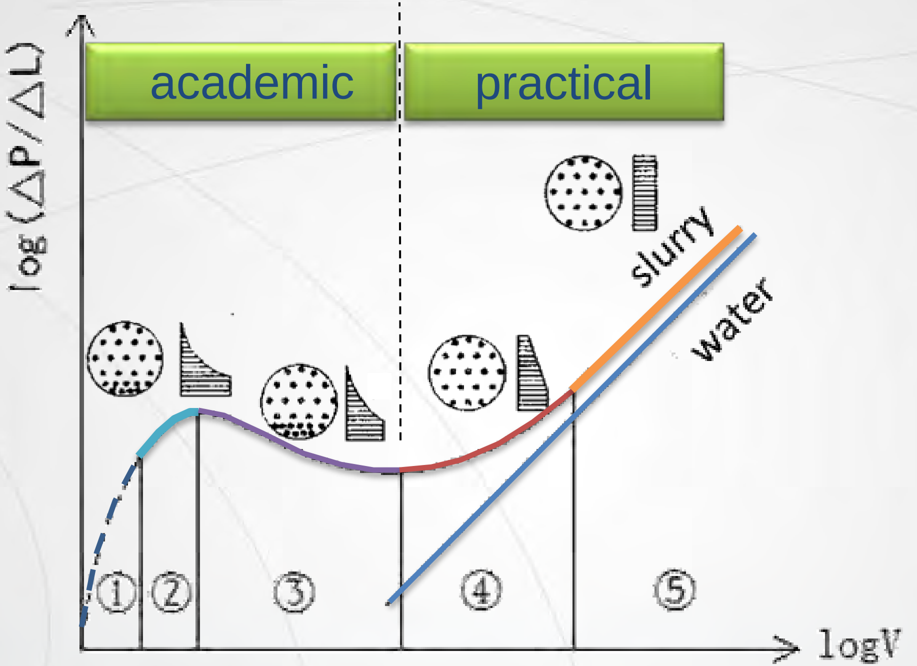


Composite flow | Velocity distribution | Concentration distribution

Particle motion patterns and hydraulic loss characteristics

hydraulic loss characteristics

- For water, the hydraulic gradient "J" is proportional to the square of the flow rate
- for slurry, it can be divided into five distinct phases.



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Resistance formula and basic theory

- The current formulas are mostly based on the combination of theory, experiment and statistics.
- A lot of trials and studies on hydraulic loss of slurry transportation have been conducted, and a number of empirical and semi-empirical formulas were proposed. These formulas can be divided into three categories:

  - Formulas based on diffusion theory: used for fine particles in low concentration
  - Formulas based on gravity theory: used for coarse particles
  - Formulas based on energy theory: combination of the above

Characteristic formulas

Durand Formula

- based on gravitational theory
- The model is based on the following experiment conditions: soil particle size 0.18 ~ 22.5mm, pipe diameter 40 ~ 700mm ,particle concentration is 22%.
- The model expresses the resistance loss I_m consist of two parts: I_0 represents pure water resistance loss ,I_s represents additional loss .
- Additional loss is related with Froude's number $\frac{V}{\sqrt{gD}}$ of pipe flow. The relations between additional loss I_s and Froude's number $\frac{V}{\sqrt{gD}}$ is determined through experiment.

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Characteristic formulas

Durand Formula

$$\frac{I_m - I_f}{I_f \cdot C_{vd}} = K_D \left[\frac{V_m^2}{gD(S_s - 1)} \frac{\sqrt{gd(S_s - 1)}}{V_t} \right]^{-\frac{3}{2}}$$

- K_D is coefficient and is set as 121
- d_{si} is the corresponding particle size of 10%, 20%, 50%, 70%, 90% respectively in particle grading curve

$$d = \frac{1}{0.2 \times \sum_{i=1}^{5} \frac{1}{d_{si}}}$$

Characteristic formulas

Wasp Formula

- Based on Durand Formula
- This formula has considered settling loss of fine particle and frictional loss caused by coarse particle moved on the pipe

$$I = I_a + I_b$$

$$I_a = \lambda_m \rho_m \frac{v^2}{2D} \qquad I_b = 82 I_0 C_v \left(\frac{V^2 \sqrt{C_x}}{gD(s-1)} \right)^{-1.5} + I_0$$

- C_x is the resistance coefficient of solid particle sedimentation, and I_0 is the resistance grade of pure water

Resistance formula and basic theory

Characteristic formulas

Jufin-Lopatin model

- Experiment condition: median particle diameter ranging from 0.25 to 11.62mm , pipe diameter ranging from 103 to 800mm.

$$I_m = I_f \cdot \left[1 + 2\left(\frac{V_{min}}{V_m}\right)^3\right] \qquad V_{min} = 5.3(C_{vd}\Psi^* D)^{\frac{1}{6}}$$

Particle Size d	ψ* Jufin & Lopatin (1966)	ψ* Jufin (1971)
0.05 - 0.10	0.0204	0.02
0.10 - 0.25	0.093	0.2
0.25 - 0.50	0.404	0.4
0.50 - 1.00	0.755	0.8
1.0 - 2.0	1.155	1.2
2.0 - 3.0	1.50	1.5
3.0 - 5.0	1.77	1.8
5 - 10	1.94	1.9
10 - 20	1.97	2.0
20 - 40	1.80	2.0
40 - 60	1.68	2.0
>60	1.68	2.0

- C_{vd} is the concentration of sand particle
- V_m is the flow velocity of slurry
- D is pipe diameter
- Ψ^*:the constant related to diameter of sand particle

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Characteristic formulas

Wilson Model

$$\frac{I_m - I_0}{s-1} = 0.5\mu_s \left(\frac{V_m}{V_{50}}\right)^{-M}$$

$$M = \left[\ln\left(\frac{d_{85}}{d_{50}}\right)\right]^{-1}$$

$$V_{50} = 3.93 d_{50}^{0.35} \left(\frac{s-1}{1.65}\right)^{0.45}$$

- considered fine particles suspension and coarse particles move at the bottom of the pipeline.
- the value of M could not exceed 1.7, and it could not less than 0.25 for fine sand.μ_s is set as 0.3

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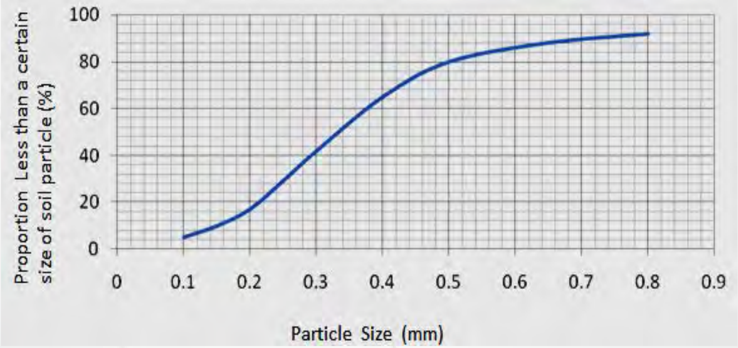
● Practical Calculation and Formula Evaluation

Practical condition

- CSD Tianniu working in long-distance reclamation of medium sand.
- diameter of discharge pipe : 800mm
- length of standard pipeline:8100m
- undisturbed soil density :1.9
- slurry concentration :18%-20%
- flow velocity :3.6-3.8m/s
- discharge pressure :16.5 bars
- grading curve of soil particle



Practical Calculation and Formula Evaluation

Calculation condition

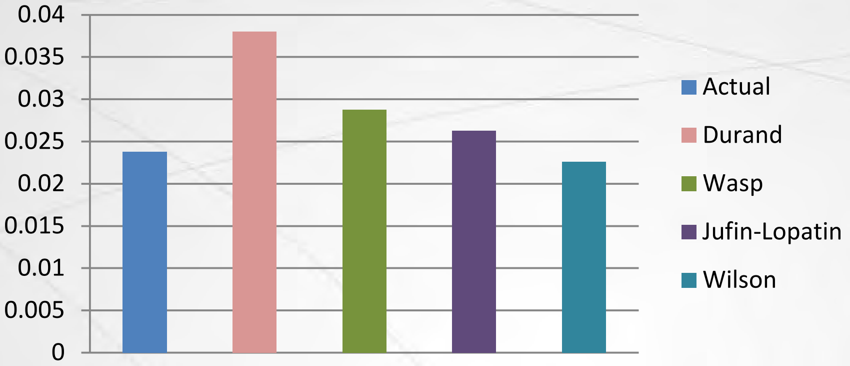
- concentration of undisturbed soil:19%
- Density:1.187
- concentration of soil particle 11%
- flow velocity 3.7m/s
- **average particle size** calculated by method of weighted mean:0.277mm
- **discharge pressure** is 16.5 bars

the actual hydraulic loss coefficient is
$\lambda_m = 0.0238$

Calculation result

- The results of loss coefficient calculated by different formulas:

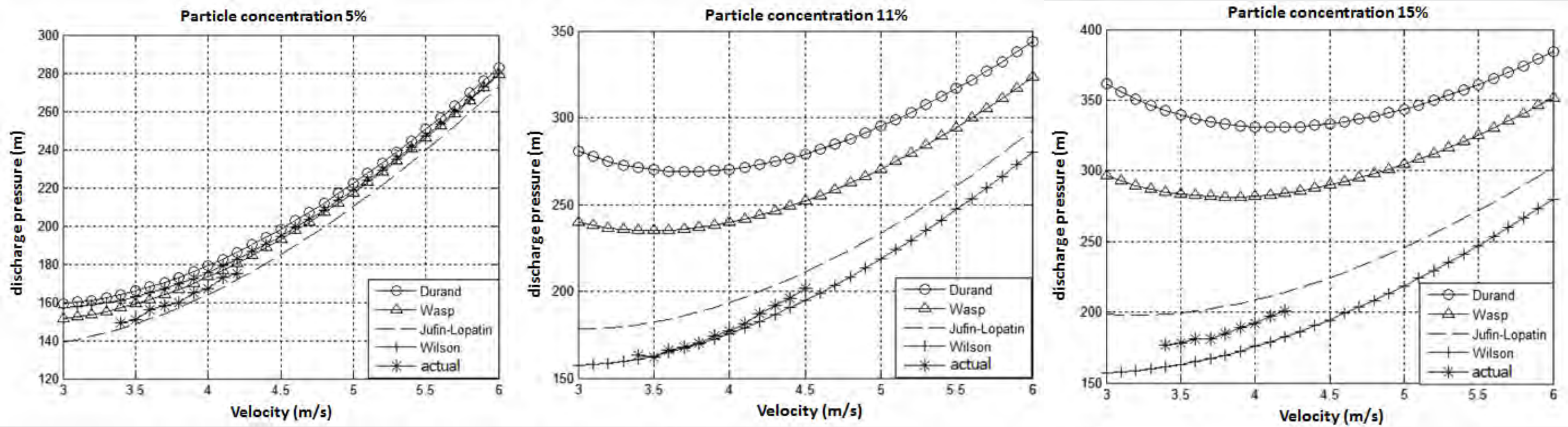
Formula	λ_m
Durand	0.0380
Wasp	0.0288
Jufin-Lopatin	0.0263
Wilson	0.0226



- Using above formulas to calculate the total discharge pressure with particle concentration of 5%, 11% and 15% separately and compare with the actual measured values

Practical Calculation and Formula Evaluation

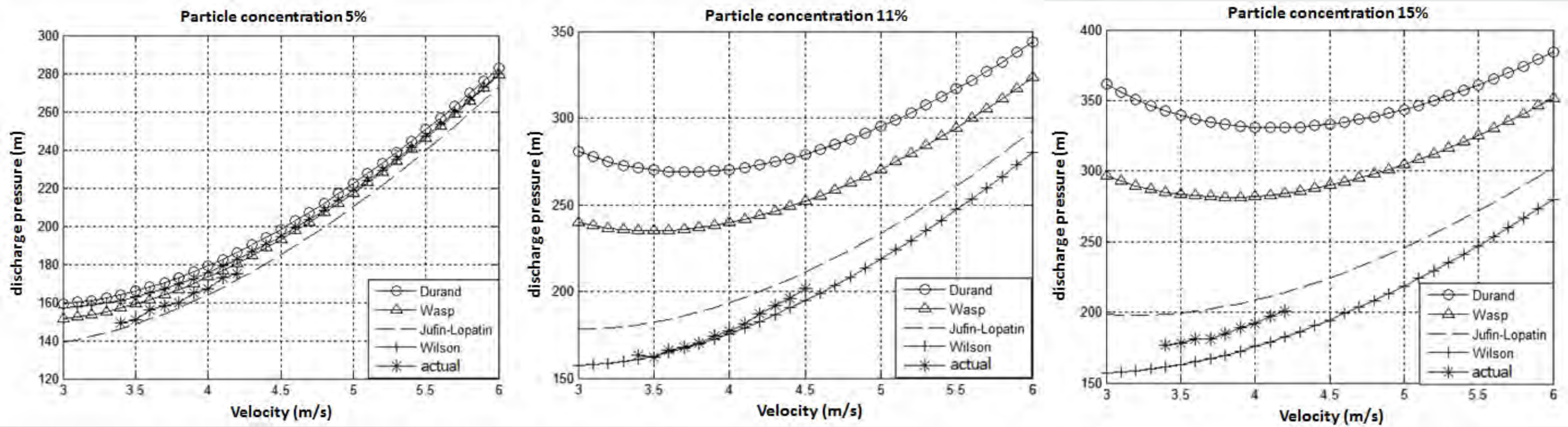
Calculation result



- Durand Formula and Wasp Formula are based on gravitational theory
- Hydraulic loss calculated by Durand Formula and Wasp Formula is significantly larger than the actual values when the flow velocity is low and the concentration is high.
- With flow velocity increasing, the results calculated by Durand Formula and Wasp Formula get closer to the actual values.

Practical Calculation and Formula Evaluation

Calculation result



- Jufin-Lopatin Model and Wilson Model have considered the influence of uneven particle on pipe resistance
- Actual values always between results calculated by Jufin-Lopatin Model and Wilson Model and are agreed well with results calculated by the two models.
- Wilson model has a high sensibility for the value of characteristic particle size in particle size distribution curve

Thank you for attentions!