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

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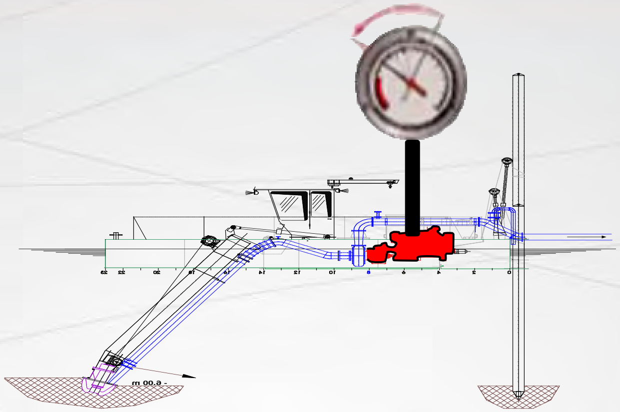
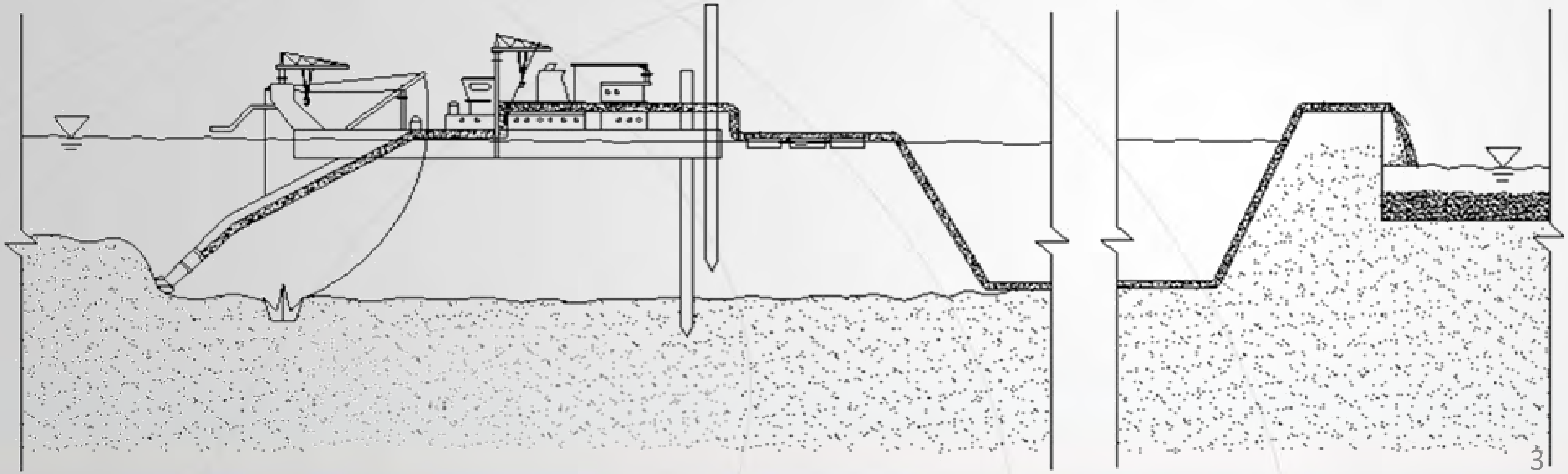
Contents

Introduction

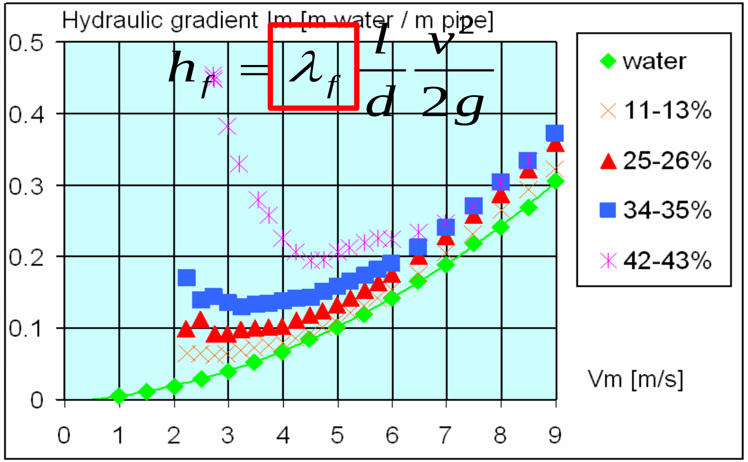
- Slurry transport consumes most of the installed power of CSD
- Accurate calculation of the hydraulic loss is important for forecasting dredger production and corresponding project progress





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

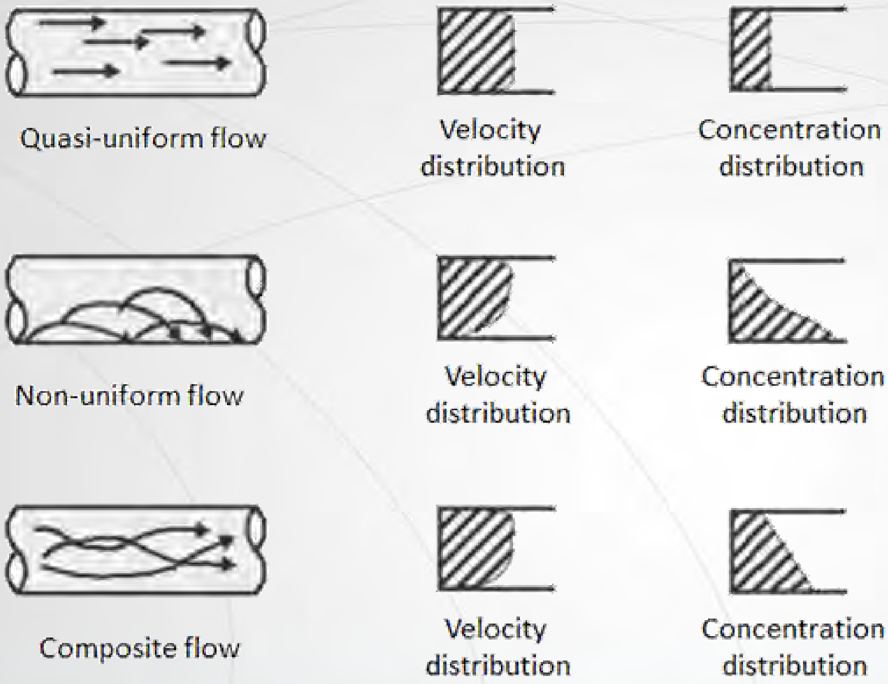
- There are a lot of formulas for calculating hydraulic loss during slurry transport process. Every formula has its own applicable conditions.
- To master the basic theories and applicable conditions of different calculation formulas will help to improve the estimation accuracy of the dredger production.

Contents

Particle motion patterns and hydraulic loss characteristics

Particle motion patterns

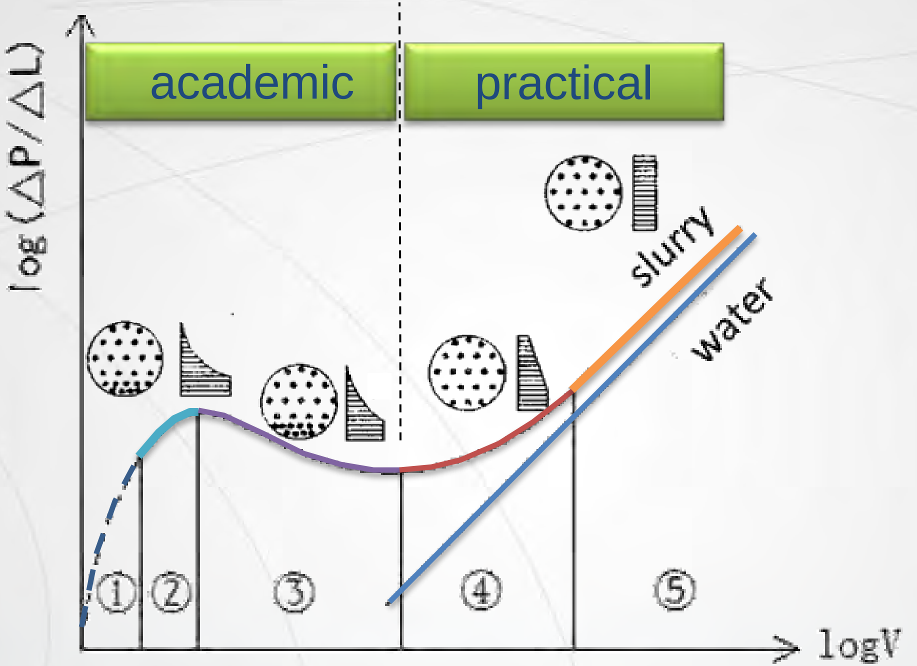
- Quasi-uniform flow
- Non-uniform flow
- Composite flow



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.



Contents

● Resistance formula and basic theory

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- 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.

Resistance formula and basic theory

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

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Characteristic formulas

Jufin-Lopatin model

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

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

- 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

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

Characteristic formulas

Wilson Model

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

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

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

- 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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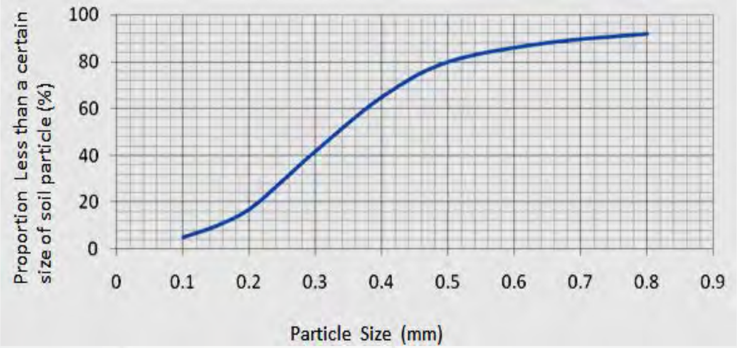
Practical Calculation and Formula Evaluation

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

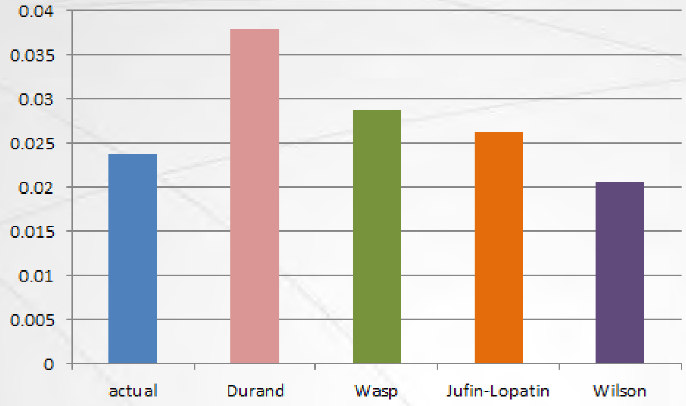
$\lambda_m = 0.0238$

Practical Calculation and Formula Evaluation

Calculation result

- The results of loss coefficient calculated by different formulas:

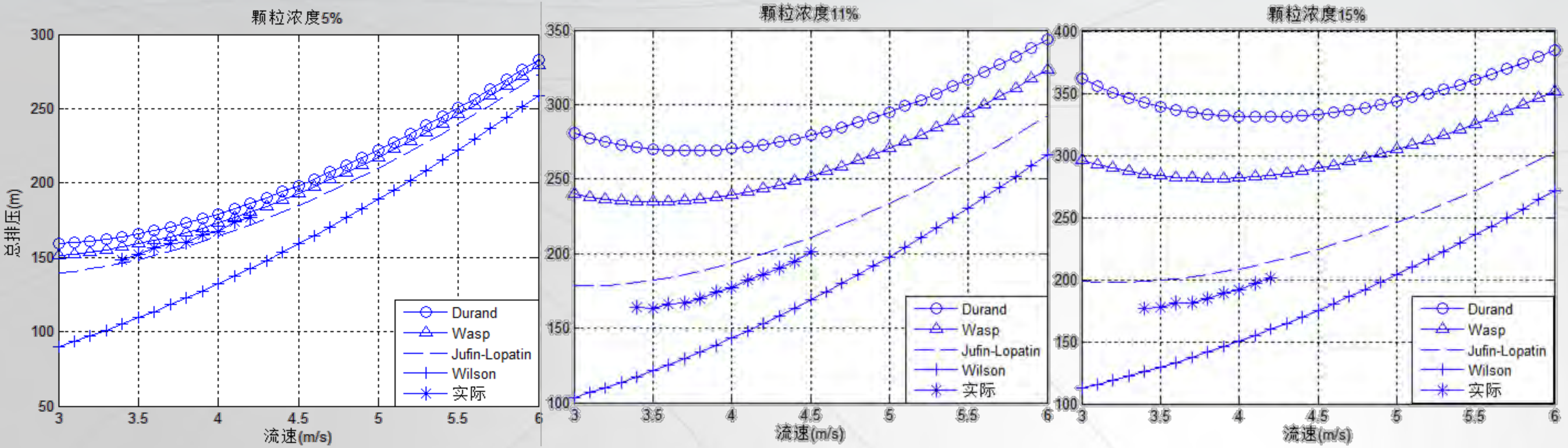
Formula	λ_m
Durand	0.0380
Wasp	0.0288
Jufin-Lopatin	0.0263
Wilson	0.0206



- 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

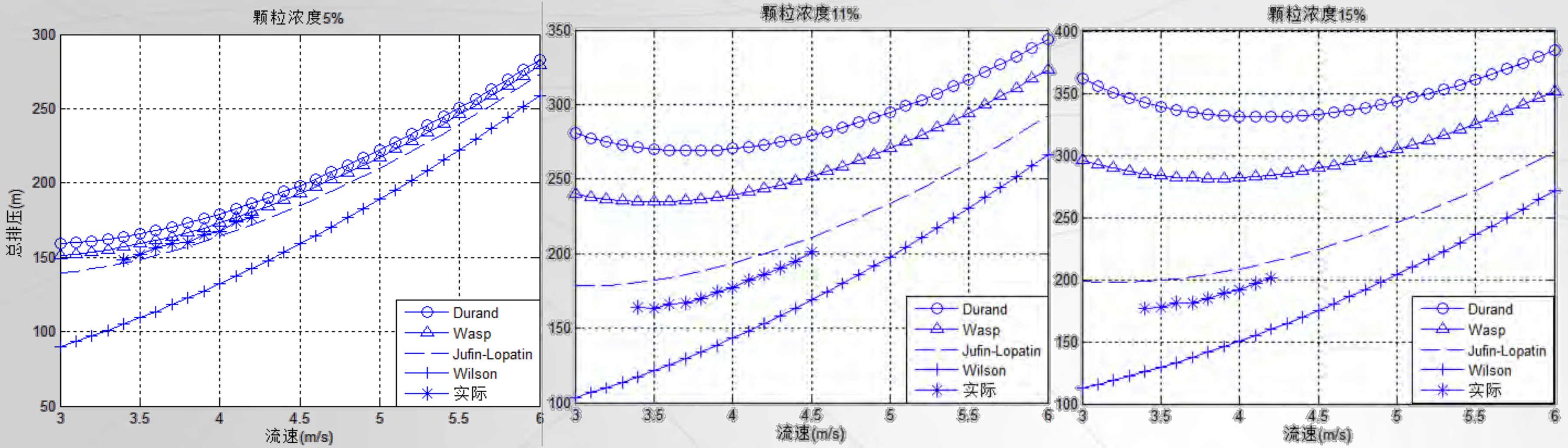
Calculation result



- 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 relatively, when the concentration is high.
- Wilson model has a high sensibility for the value of characteristic particle size in particle size distribution curve

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Thank you for attentions!