EROSION VELOCITY OF LARGE GRAINS SUBJECTED TO AN IMPINGING MASS FLOW JET

ARNO NOBEL \ Boskalis
AXEL SMIT \ Boskalis
CEES VAN RHEE \ TU Delft

WODCON XXI

16 JUNE 2016

INDEX

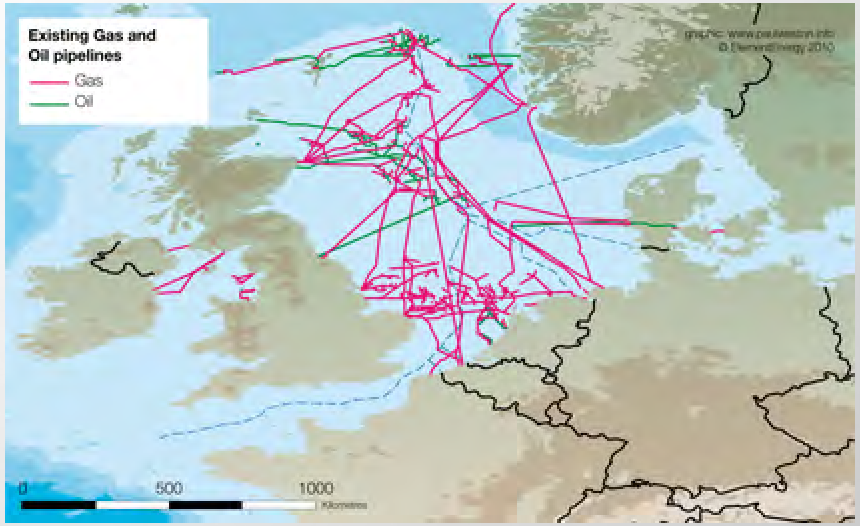
BACKGROUND

Increasing network of pipelines and cables on sea bed

- Pipelines: oil and gas
- Cables: energy / data transfer

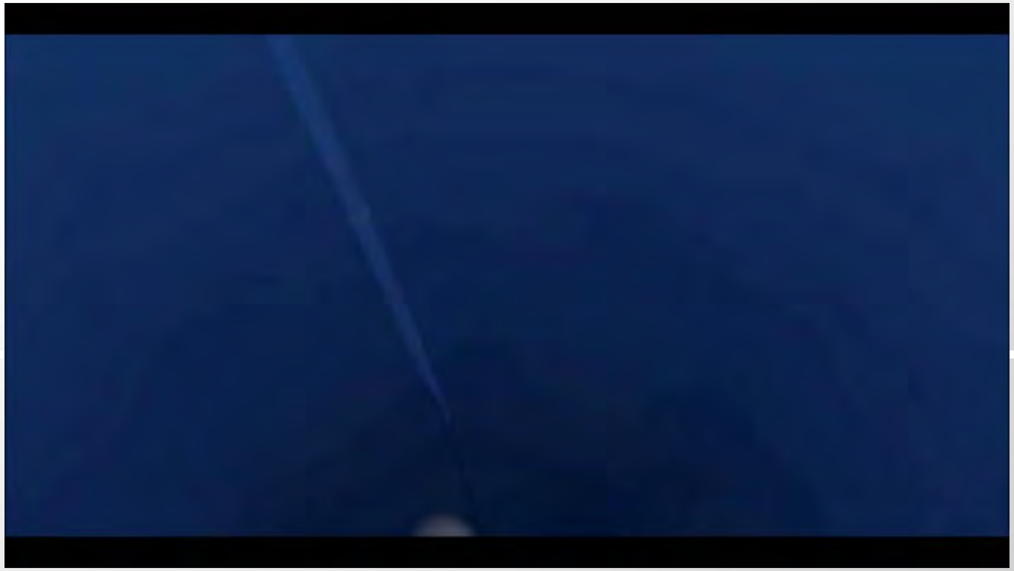
Protection

- Currents: undesired movements
- Bed erosion: uncontrolled free-spans
- Anchors & fishing trawlers: damages



BACKGROUND

Pipelines are usually protected by installing a rock berm



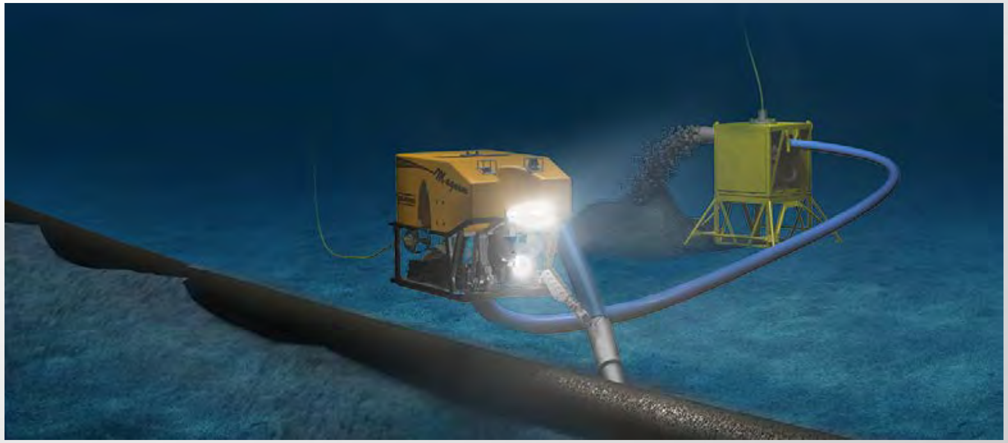
BACKGROUND

Increasing market for the removal of rock berms

- **Repair and maintenance work**
- **New flange connections**
- **Decommissioning.**

Common solution, using an ejector pump

- **Time consuming solution**



BACKGROUND

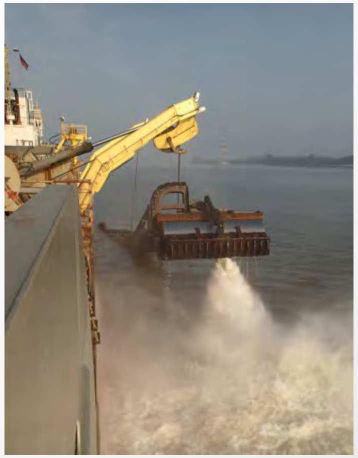
Challenge: remove rock by a mass flow jet

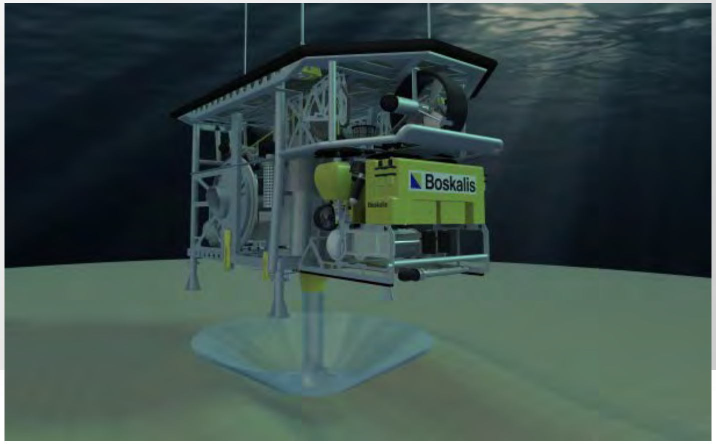
- **10.000 m³/hr @ 0.3 bars**
- **Flexible**
- **Non-contact**

- **TSHD**

  (5” stones, Assaluyeh 2008)

- **Mass flow on ROV fall pipe vessel**

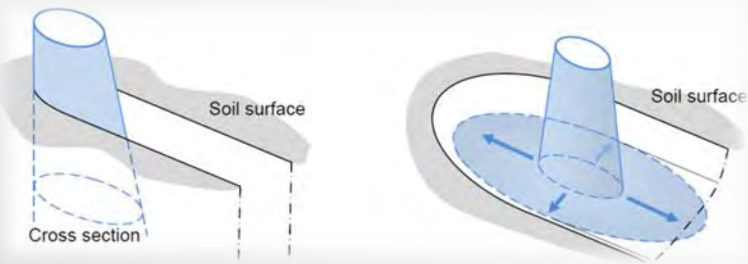


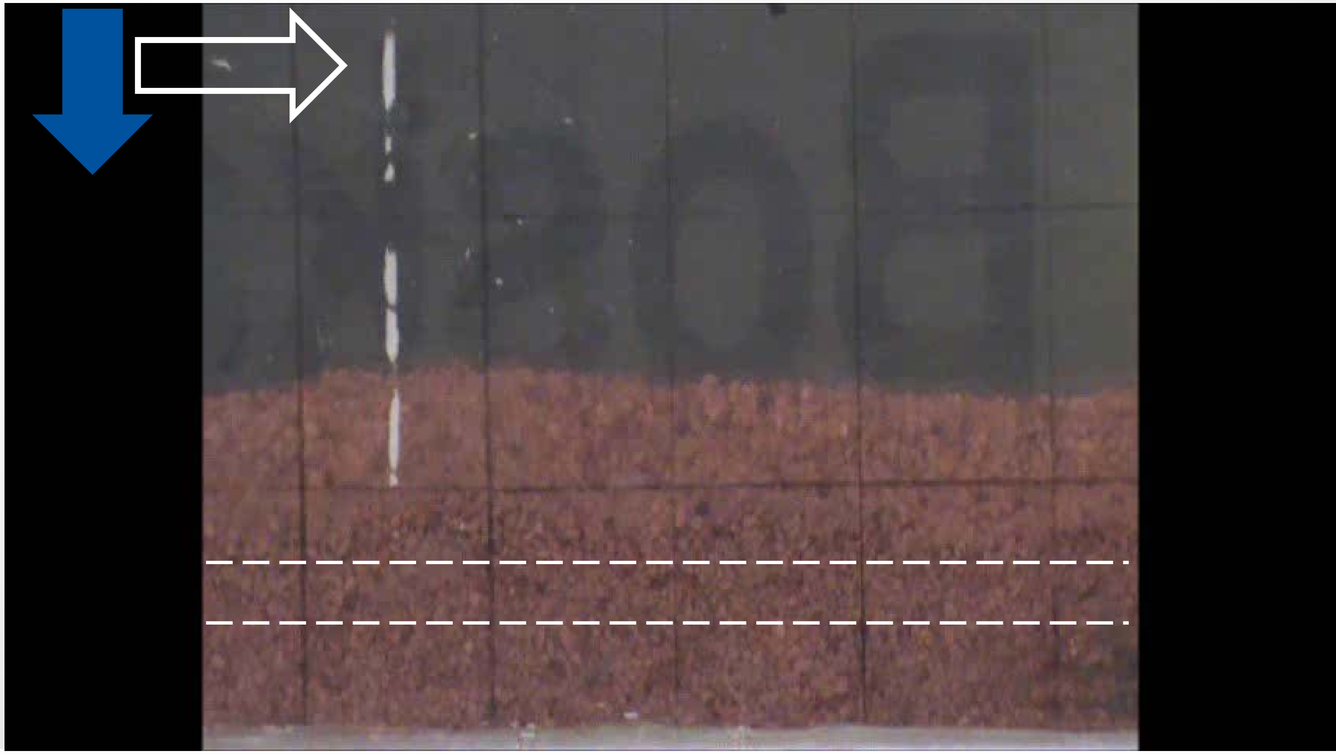


PROBLEM DEFINITION

Problem

- **No validated calculation model to predict the erosion velocity of rock**

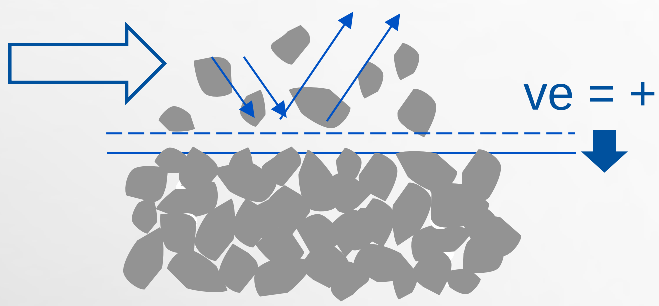




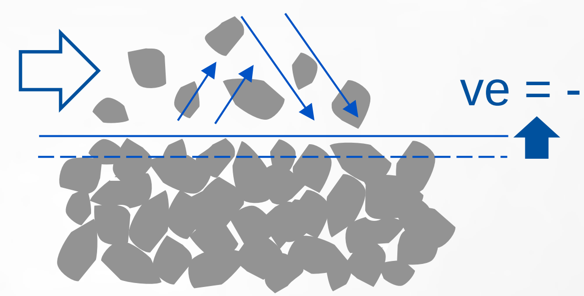
THEORY

Erosion velocity (ve) = *f* (E, S)

Erosion flux > Sedimentation flux



Erosion flux < Sedimentation flux



THEORY

Calculation models for the Erosion flux (E [kg/m²/s])

- **Fernandez Luque (1976)** $E_{FL} \sim d_{50}^{-1},\ \tau_{bed}^{1.5}$
- **Van Rijn (1984)** $E_{vanRijn} \sim d_{50}^{-0.7},\ \tau_{bed}^{1.5}$

Only validated up to *d50* = 1.5 mm

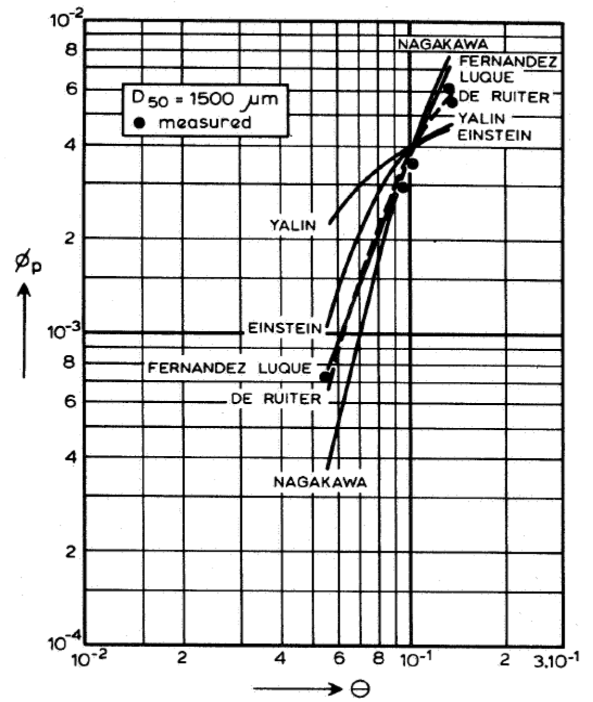


FIG. 7.—Measured and Predicted Pick-Up Rates for 1,500 μm-Sediment

THEORY

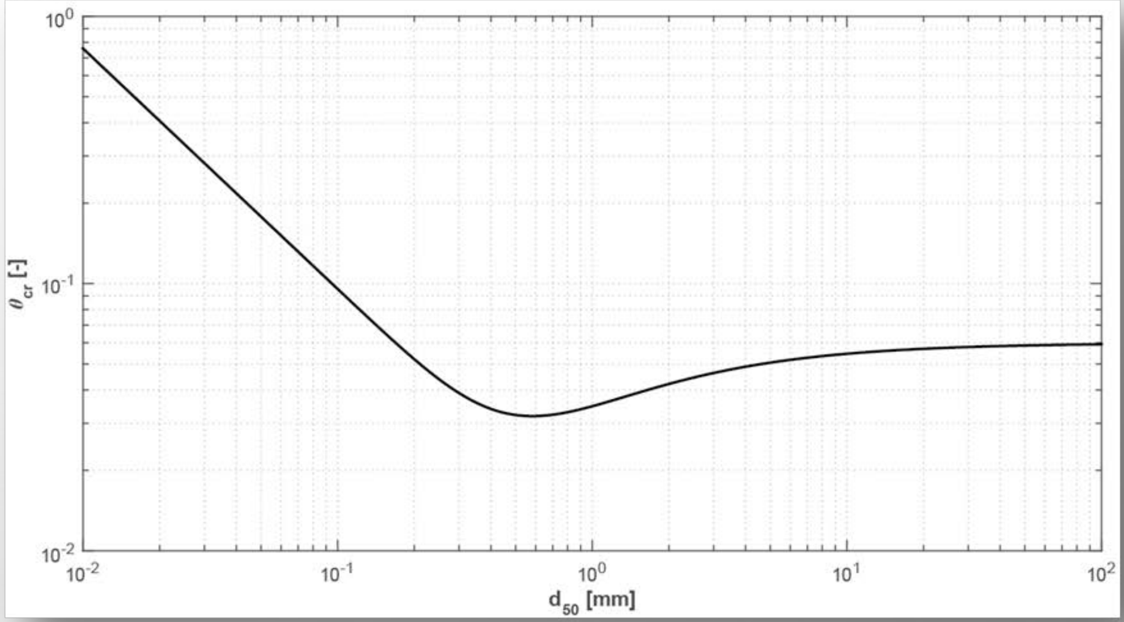
Critical Shields is constant for d_{50} > 6 mm

Froude scaling:

(inertia and gravity forces are scaled correctly)

$$n = \frac{n_{prototype}}{n_{model}}$$

$$n_u = \sqrt{n_l}$$



PROBLEM DEFINITION

Objectives

- **Develop a test setup to measure the erosion velocity.**
- **Determine the erosion velocity of large particles:**
  - Verify existing erosion models
  - Estimate the erosion velocity of rock (1-8”)

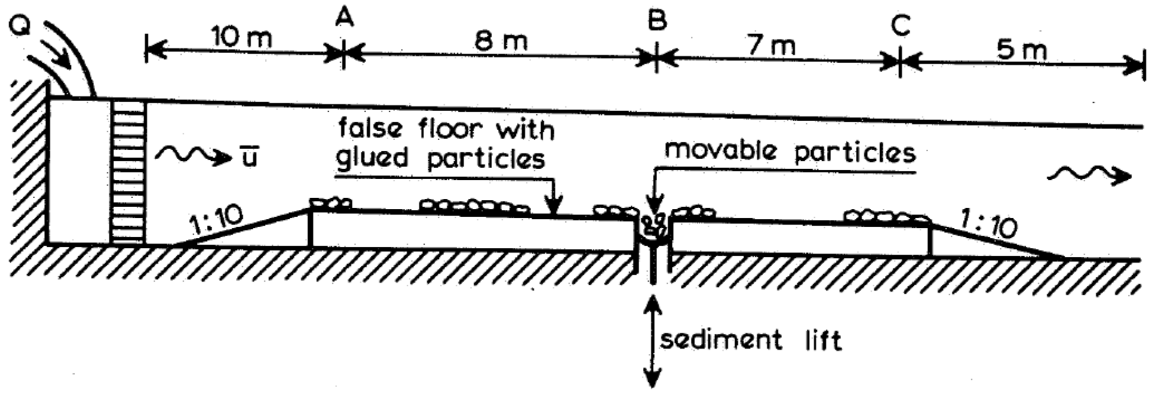
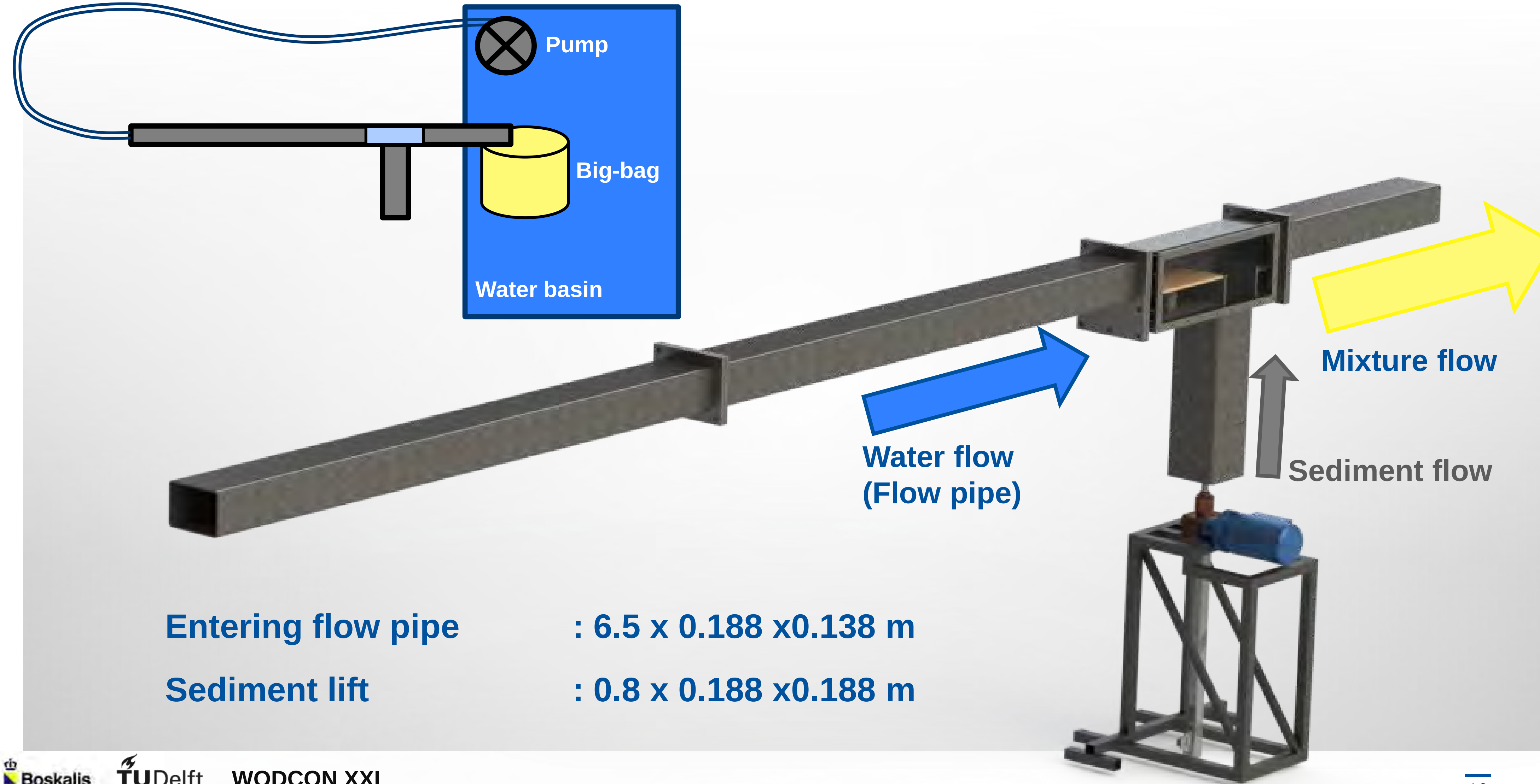


FIG. 1.—Experimental Set-Up

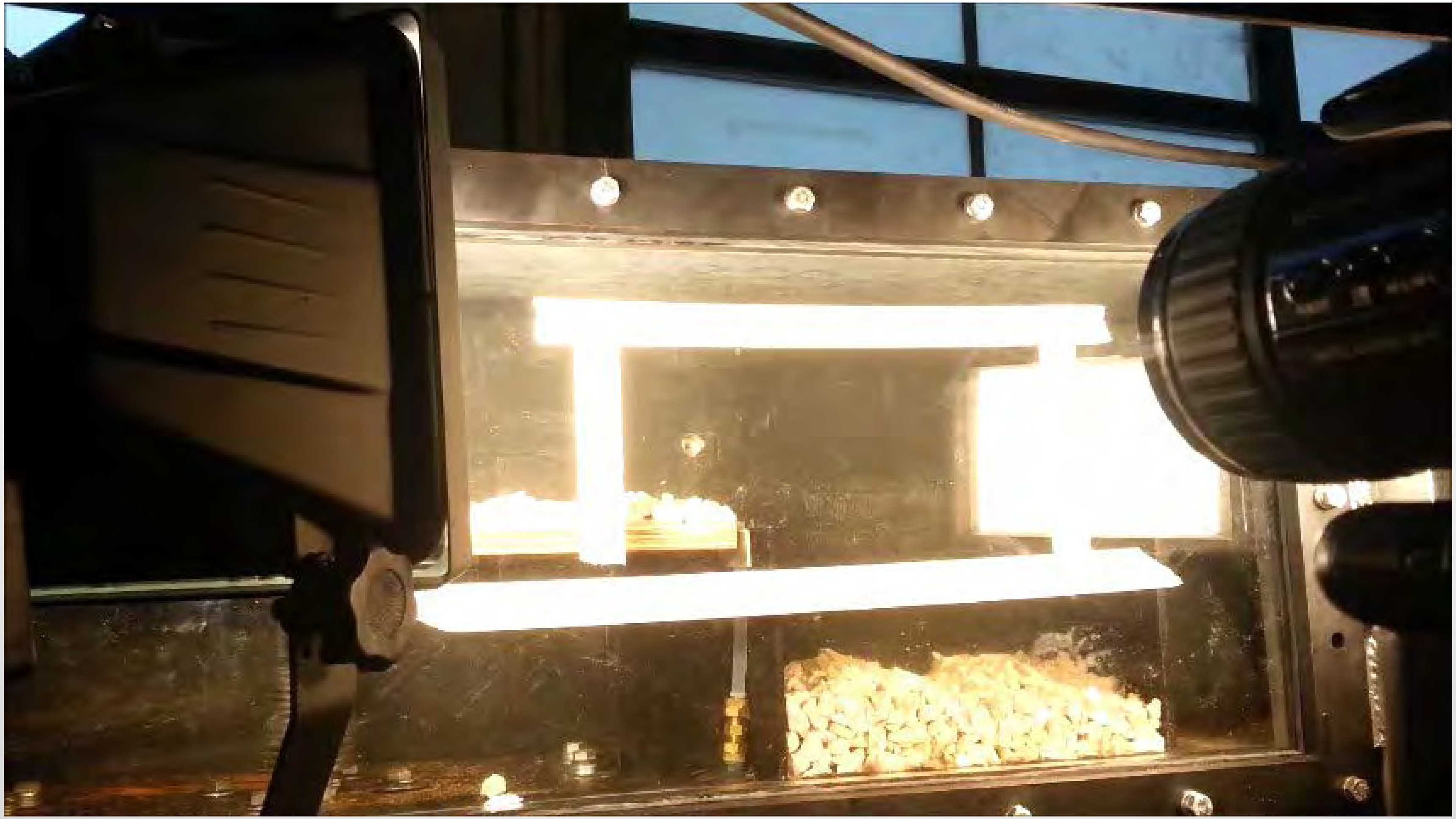
TEST SETUP



Entering flow pipe : 6.5 x 0.188 x0.138 m

Sediment lift : 0.8 x 0.188 x0.188 m

TEST SETUP



TEST SETUP

Erosion velocity based on bed shear stress

$E_{FL}, E_{van\ Rijn} \sim \tau_{bed}^{1.5}$

Separate research question:

bed shear stress development in boundary layer

- undeveloped boundary layer
- very high relative roughness (d50/flow height)
- changing flow conditions
- moving bed

Measuring bed shear stress

- Constant bed roughness
- Developed boundary layer

TEST SETUP

Measured data

- Bed shear stress
- Pressure difference
- Flow rate (flow velocity)
- Lift velocity

TEST RESULTS

u_lift too slow: ve > u_lift

u_lift = erosion velocity

u_lift = too high : ve < u_lift

TEST RESULTS

u_flow = 2.25 m/s

τ_{bed} = 63 Pa

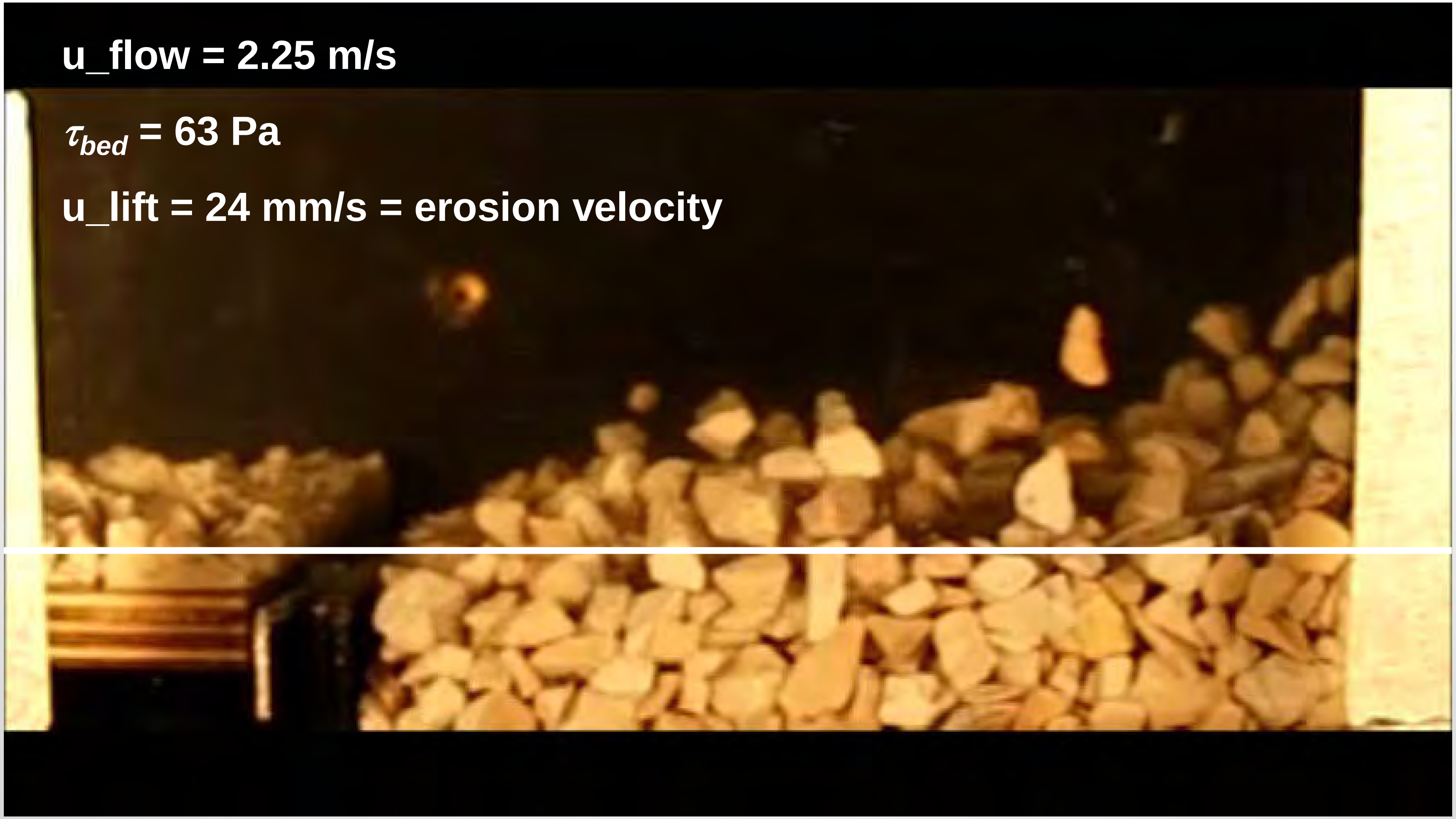
u_lift = 5 mm/s = too slow

u_flow = 2.25 m/s

τ_{bed} = 63 Pa

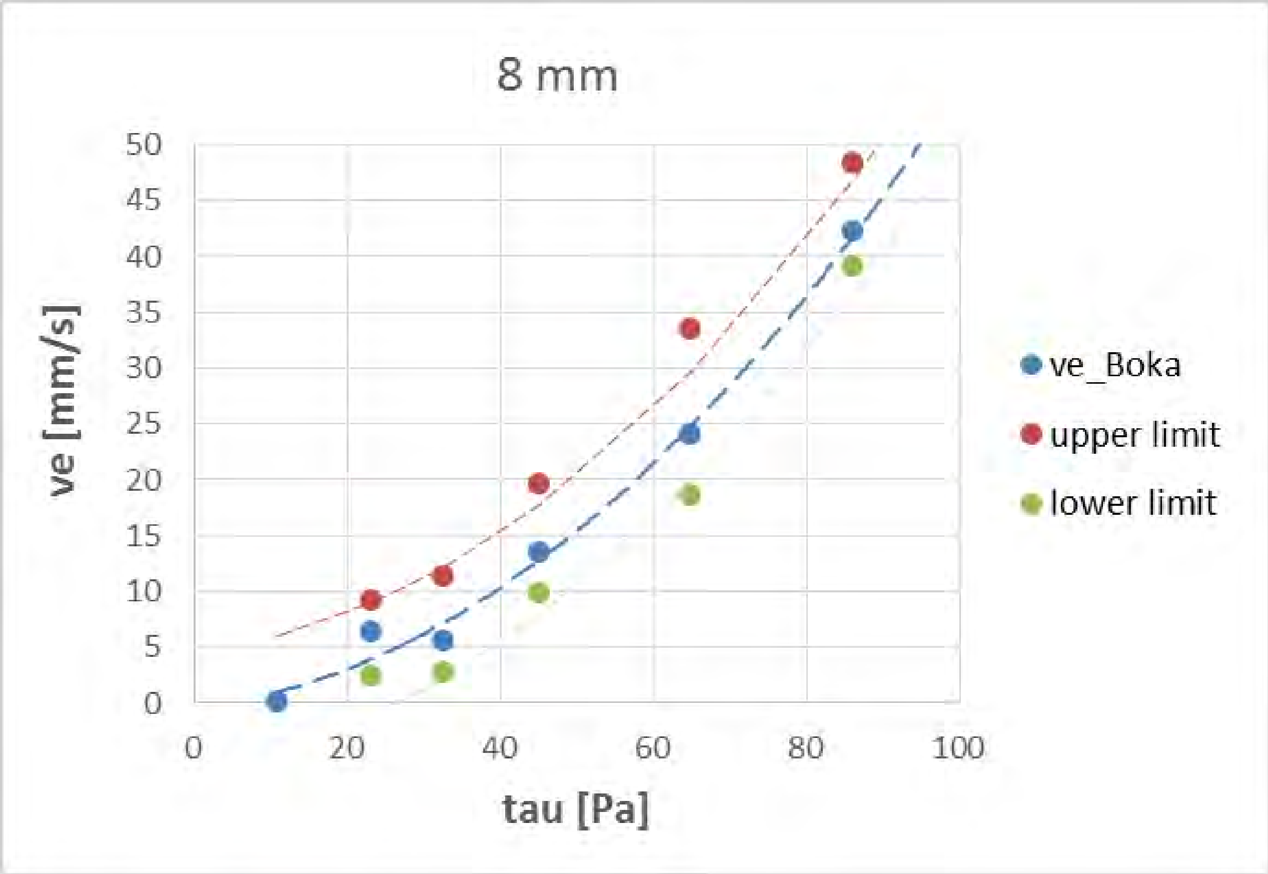
u_lift = 30 mm/s = too fast

TEST RESULTS



TEST RESULTS

accuracy: +/- 5 mm/s



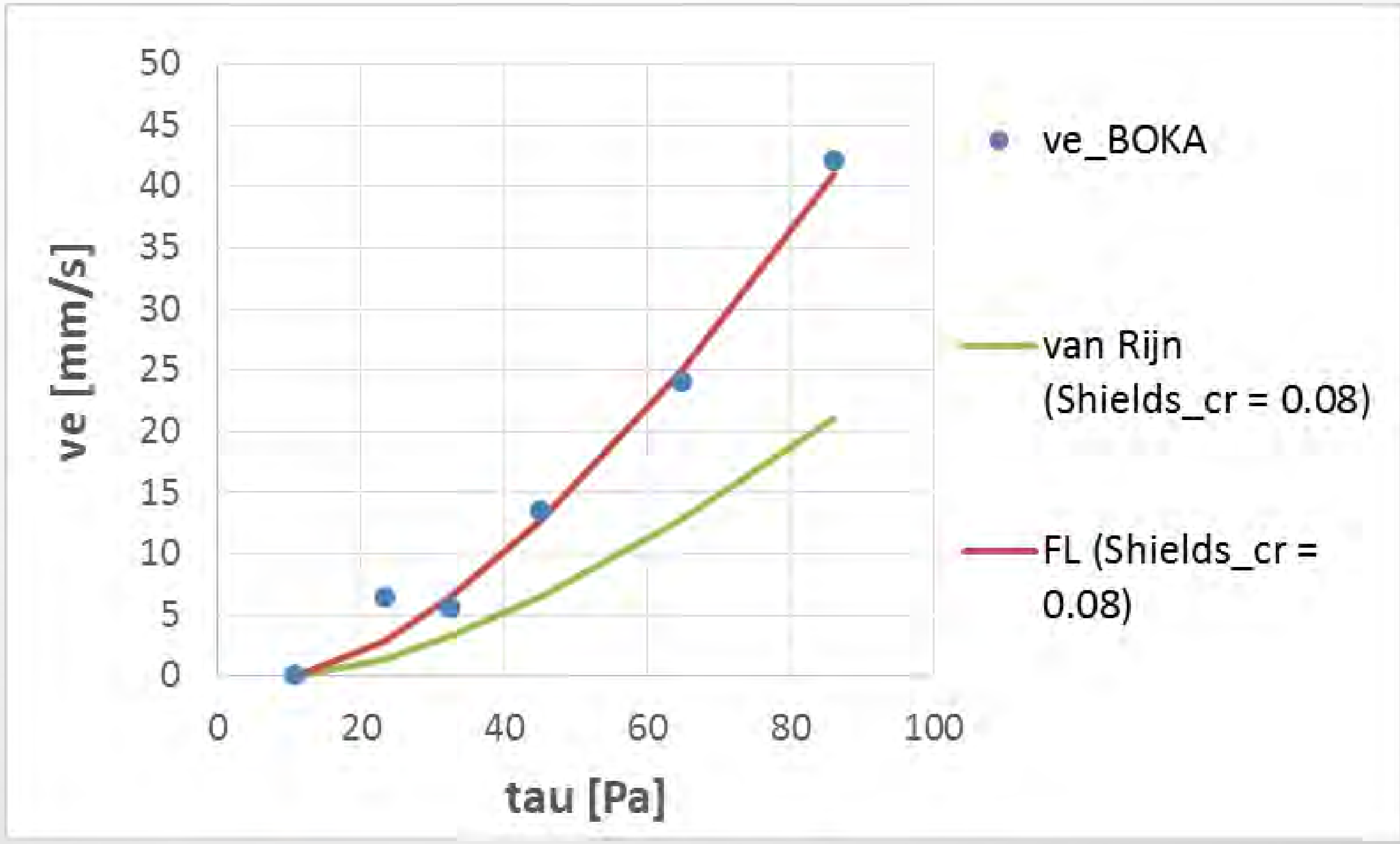
TEST RESULTS

Shields:

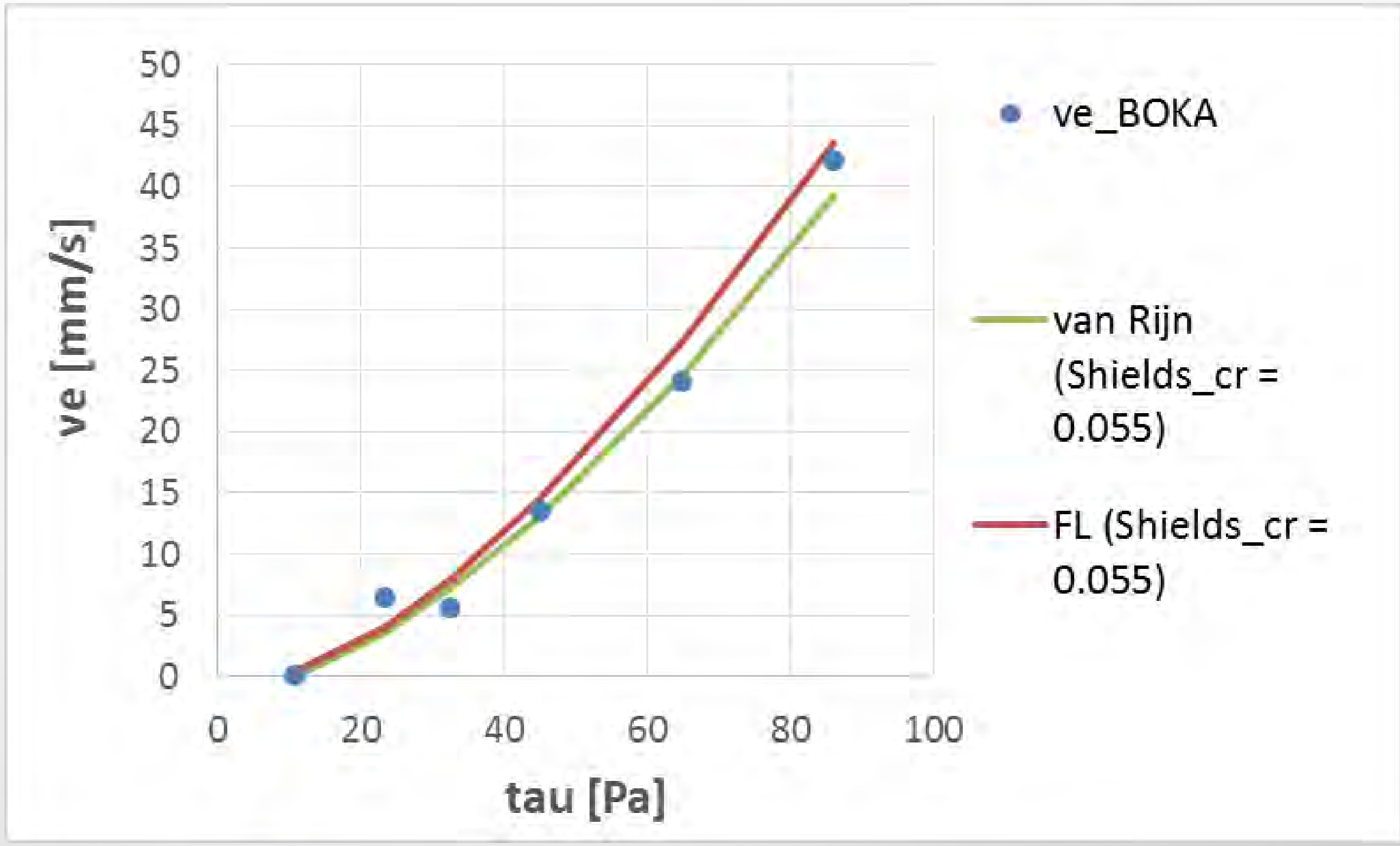
$$\theta = \frac{\tau_{bed}}{(\rho_s - \rho_w) \cdot g \cdot d50}$$

$$\theta_{cr\_measured} = 0.08$$

$$\theta_{cr\_theoretical} = 0.055$$



TEST RESULTS



PRACTICAL CASE

Hydraulic power of MF : **100 kW (Nozzle diameter = 0.5m, Jet pressure = 0.5 bar)**

Stand off distance : **3 m**

D50 : **6” → model scale = 1:20**

Maximum bed shear stress : **960 Pa → model scale 48 Pa**

[Mazurek 2005]

	Model	Prototype	FL	Van Rijn
ve [mm/s]	15	67	73	161
			+9%	+140%

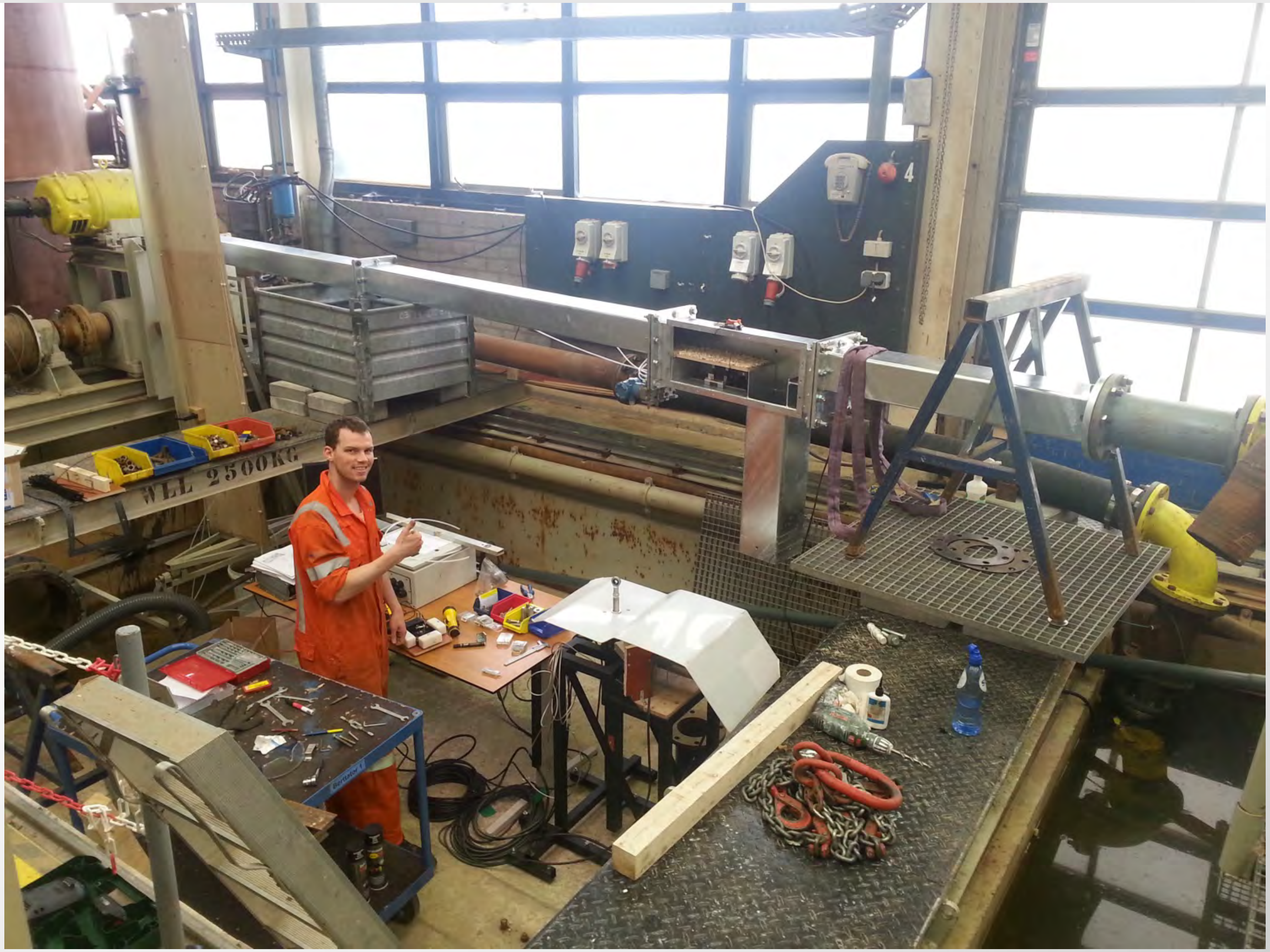
CONCLUSIONS

1. **The test setup works properly.**
2. **The test results correspond with both the erosion model of Van Rijn en Fernandez Luque**
3. **Erosion models can be used up to d50 = 8 mm.**
4. **The maximum erosion velocity on prototype scale are still uncertain: The difference between Van Rijn and Fernandez Luque in 6” rock is more than 100%.**
5. **Fernandez Luque can be used as a lower limit**

RECOMMENDATIONS

Perform additional erosion tests with a *d50* larger than 8 mm

QUESTIONS



Thanks to Axel Smit who was responsible for the tests