Erosion

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Erosion – Current & Waves

- Introduction
- Theory
- Shields – model
- International Erosion Models
- Dutch Erosion Model
- Mirtskhoulava Model
- Modelling (wave) loads
- Discussion

Introduction

- Wave overflow
- Wave overtopping
- Wave impact
- Wave run-up

Theory

- Newton 2nd law:

$$\tau = \rho g R S < \tau_c$$

- turbulence-theory:

$$\tau = 0.7\rho\left(r_0 U_0\right)^2 < \tau_c$$

- Shields theory:

$$\tau = \left(\rho_s - \rho\right) g d_{50} \Psi < \tau_c$$

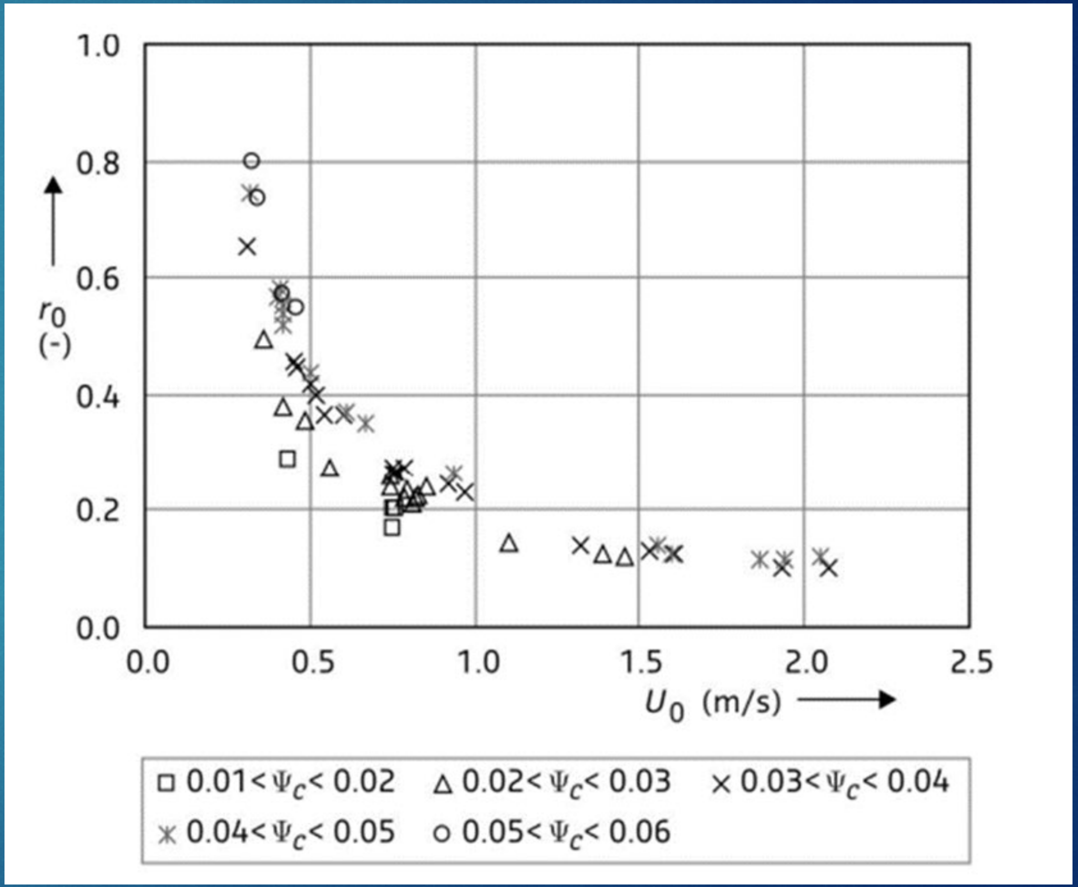
- d_{50} = particle size (m)
- g = gravity (m s^{-2})
- r_0 = turbulence intensity (-)
- R = hydraulic radius (m)
- S = hydraulic gradient (-)
- U_0 = flow velocity (m s^{-1})

- ρ = water density (kg m^{-3})
- ρ_s = sediment density (kg m^{-3})
- τ = bed shear stress (N m^{-2})
- Ψ = Shields parameter (-)

Theory

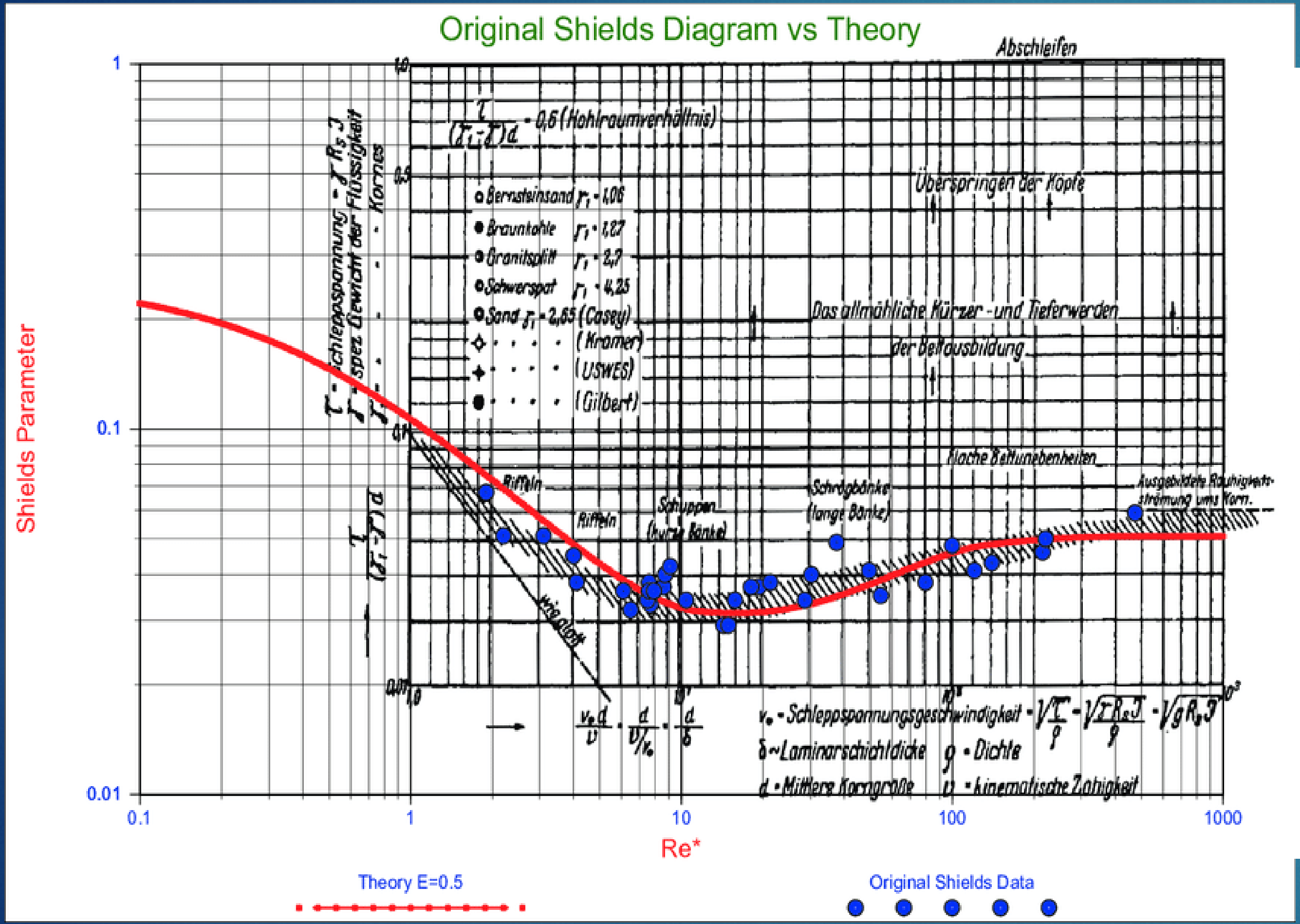
- Can you express the erosion rate by only the flow velocity?

turbulence intensity	
0.08 – 0.15	normal turbulence in rivers
0.15 – 0.25	high turbulence at outer slope of sea dike
0.25 – 0.40	very high turbulence (non-uniform flow)
0.40 – 0.60	extreme high turbulence

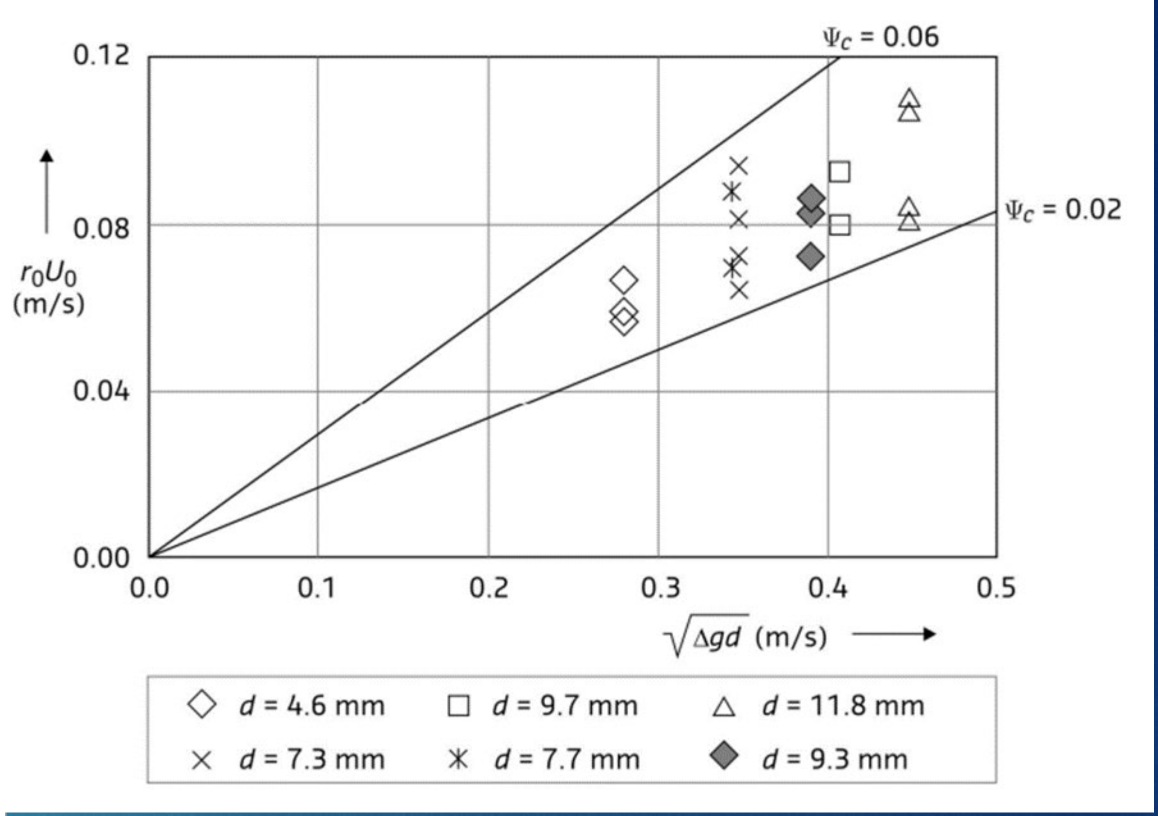


r_0 as function of U_0 for sand with d = 5 cm (uniform flow conditions)

Shields - model

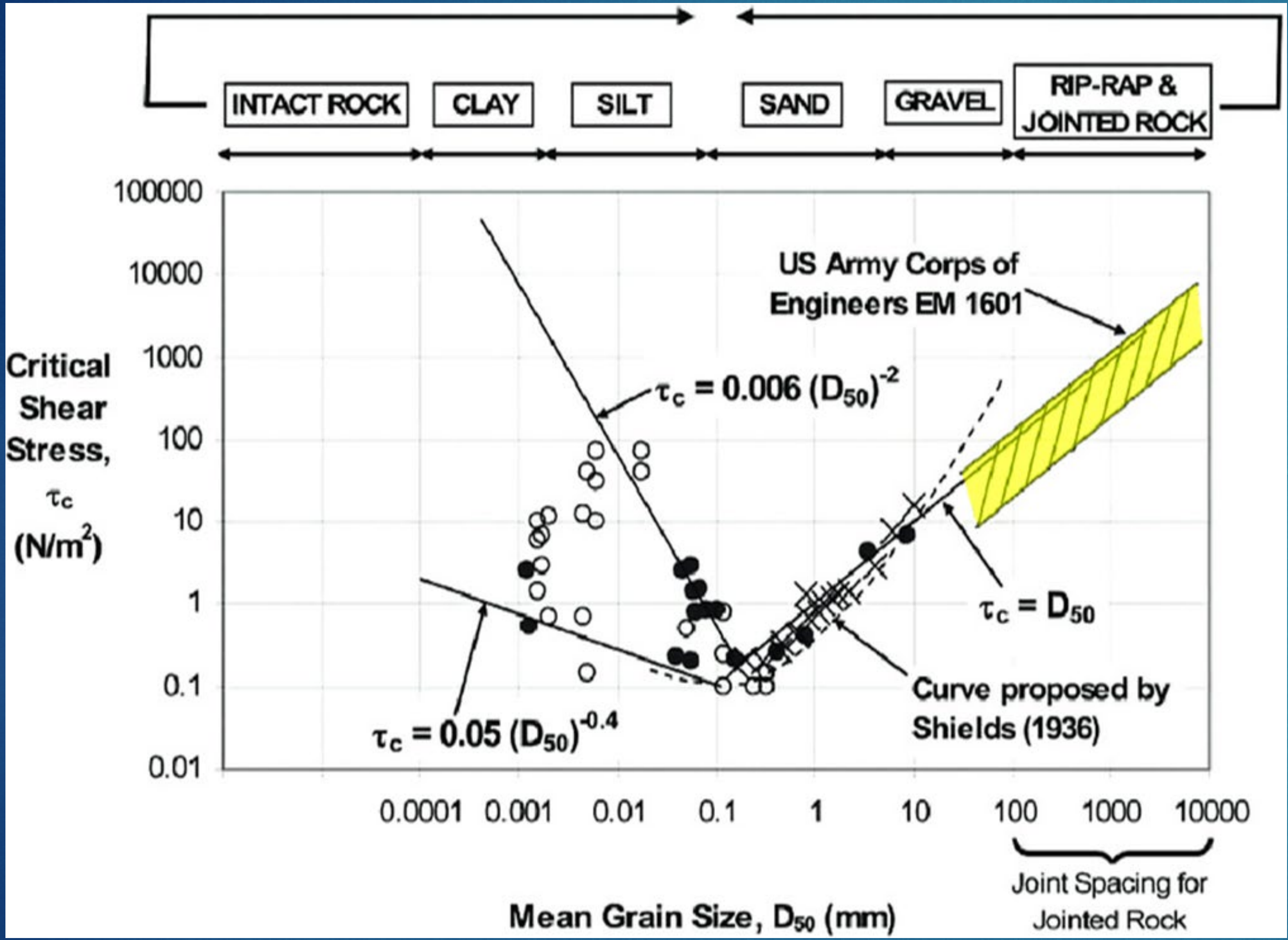


- Shields diagram (1936)

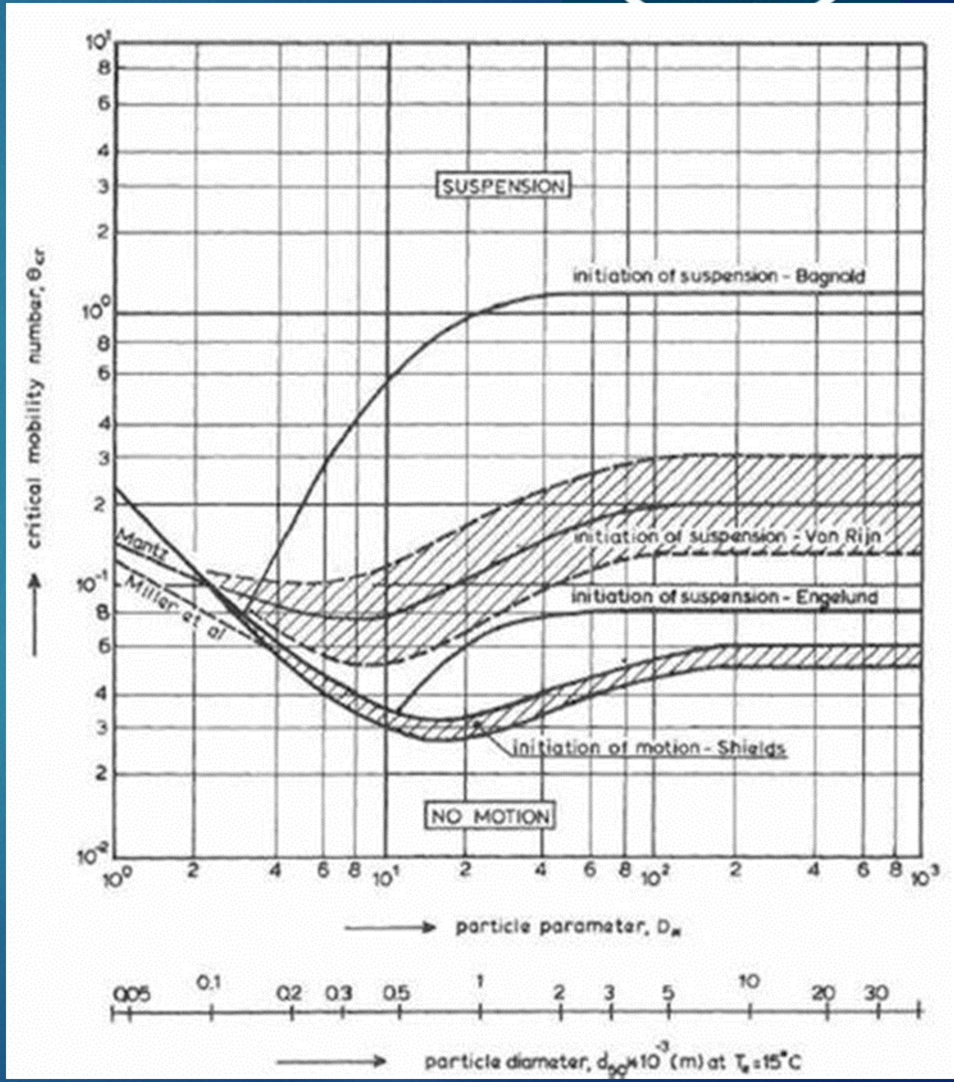


Modern load – strength diagram

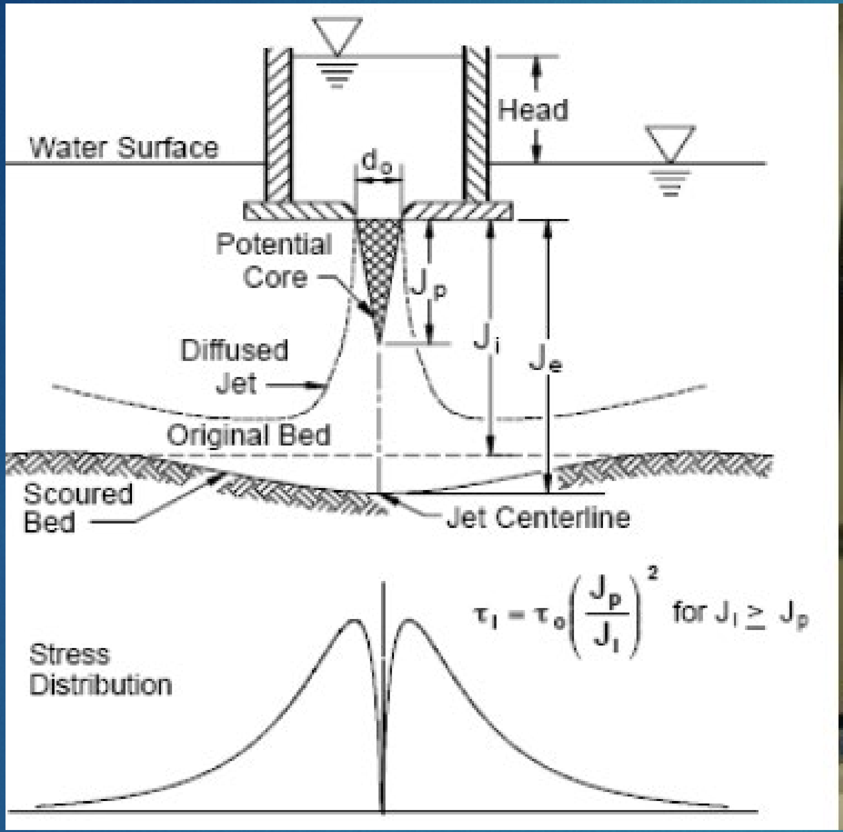
Shields model

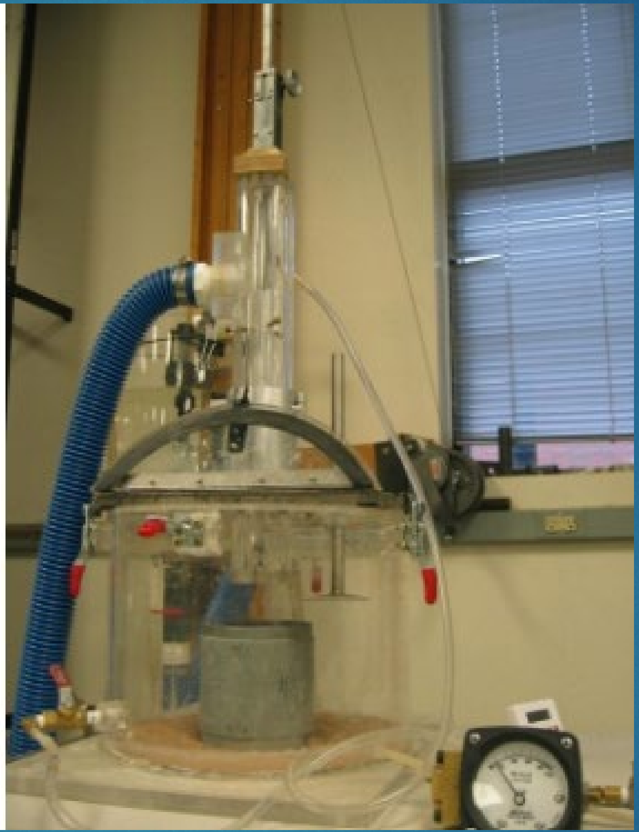


Extended Shields diagram (cohesive soils)



International Erosion Models

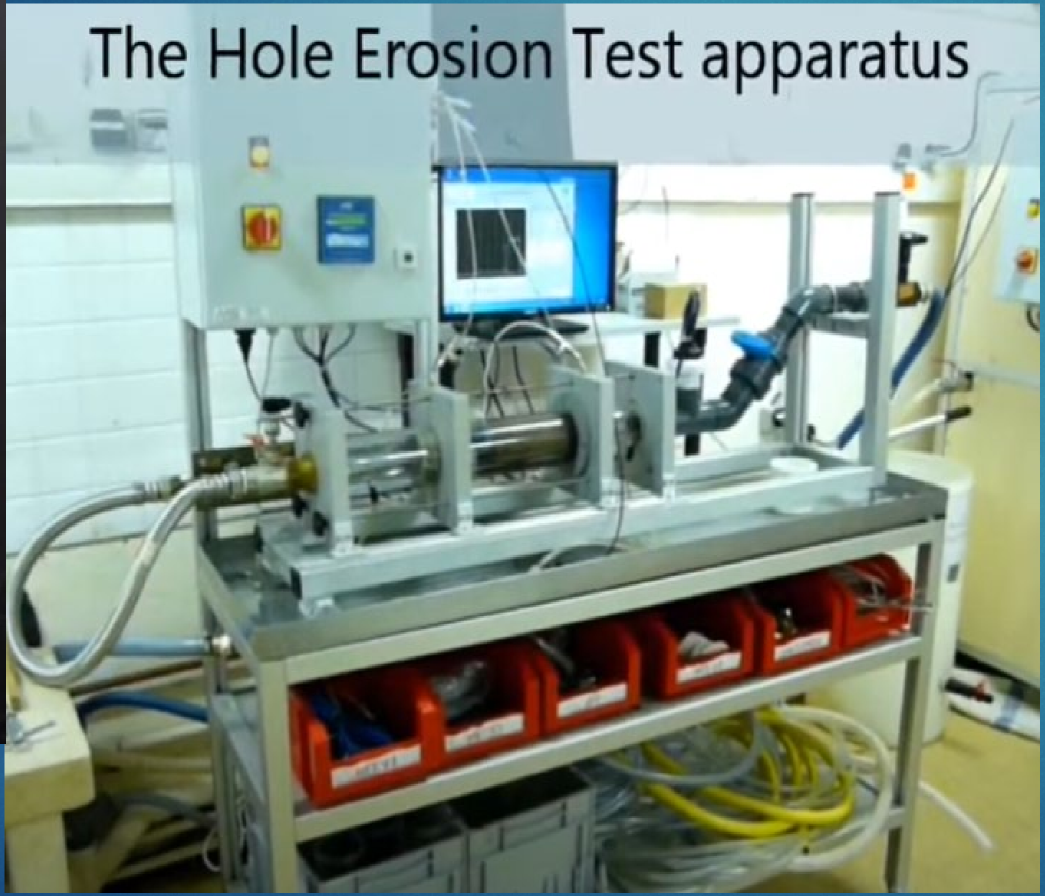


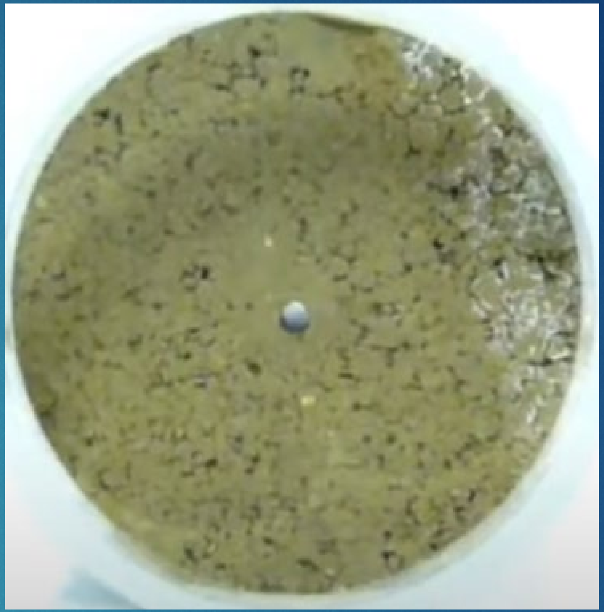


Jet erosion test

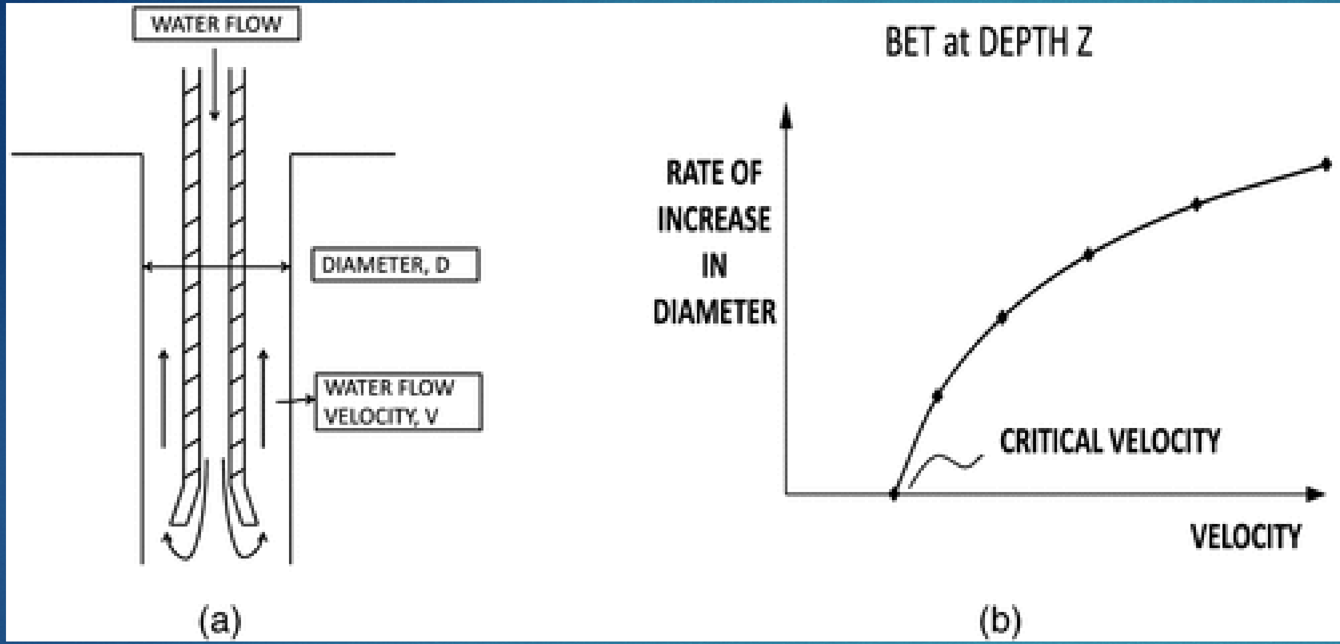
International Erosion Models

The Hole Erosion Test: a laboratory geotechnical test to characterize concentrated leak erosion



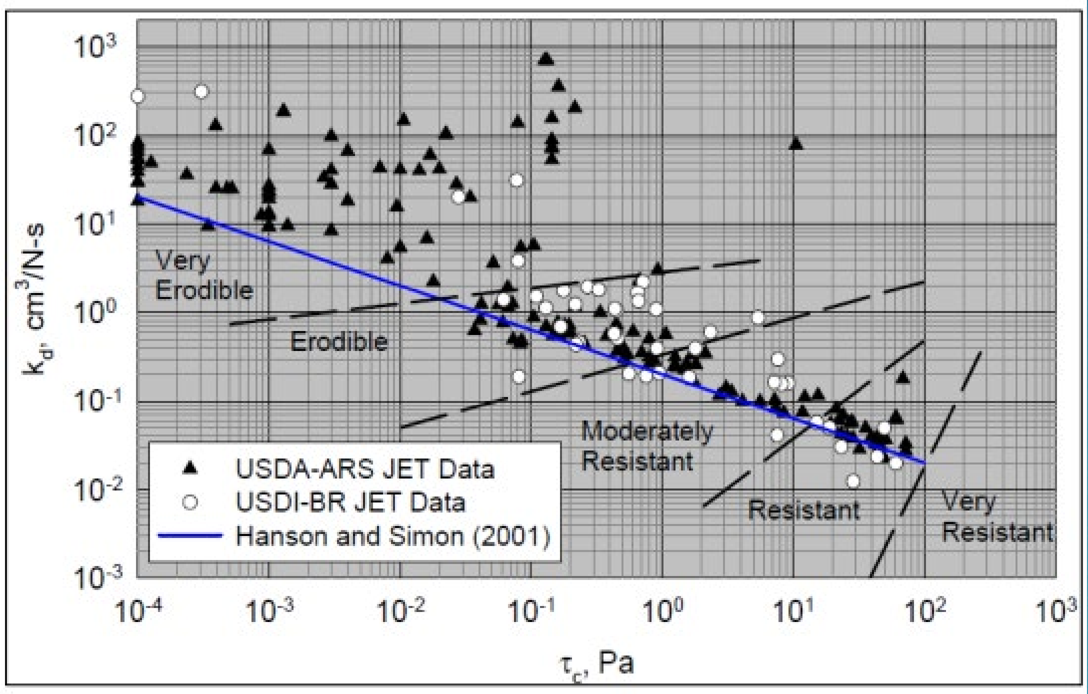


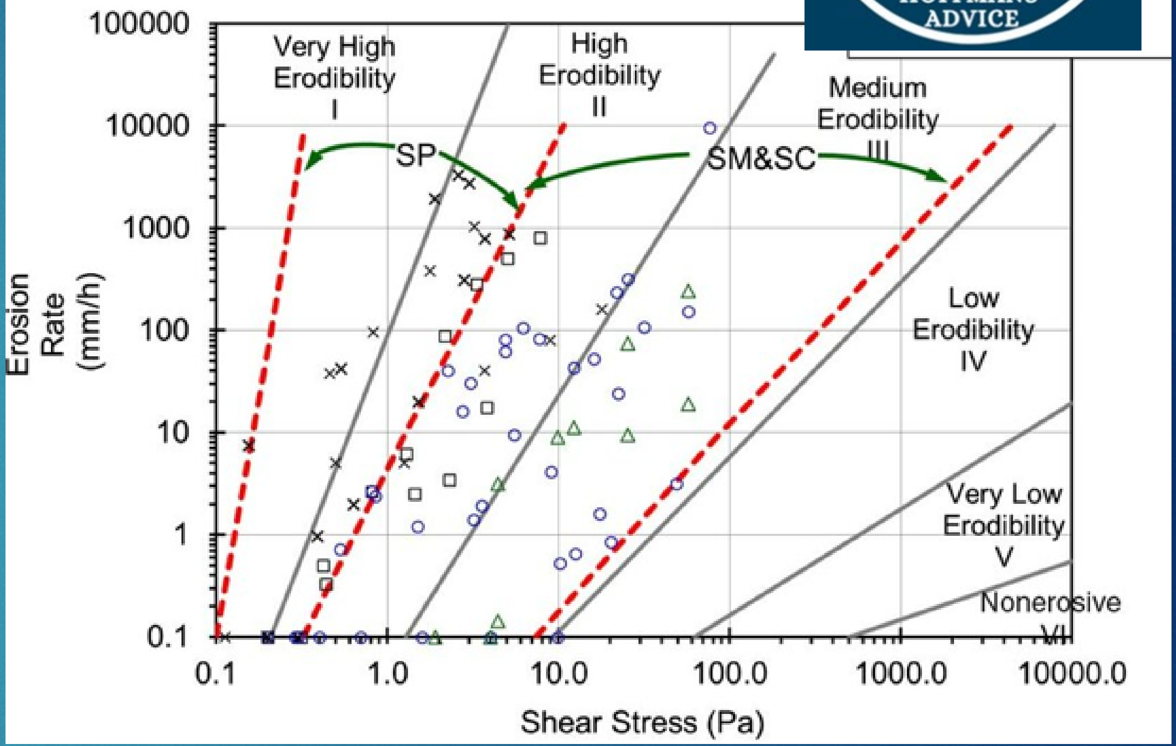
International Erosion Models



Bore Erosion Test

International Erosion Models





Erodibility	k_d (cm^3/N-s)
Very Erodible	1 to 5 (or more)
Erodible	0.05 to 2
Moderately Resistant	0.01 to 0.5
Resistant	0.001 to 0.4
Very Resistant	0.0005 (or less) to 0.1

$$\text{Erosion rate} = k_d\left(\tau - \tau_c\right)$$

Dutch Erosion Model

Force balance: $$\sum_{i=1}^{N}\left(U_i^2 - U_c^2\right) = D \quad \text{for} \quad U_i > U_c$$

initial damage $D = 1000\ \text{m}^2/\text{s}^2$

damage at various locations $D = 4000\ \text{m}^2/\text{s}^2$

failure of dike slope $D = 7000\ \text{m}^2/\text{s}^2$

Dutch Erosion Model

Turf-element model

$$U_c = 2r_0^{-1}\sqrt{\Psi_c\left(\sigma_{grass,c}(0) - p_w\right)/\rho}$$

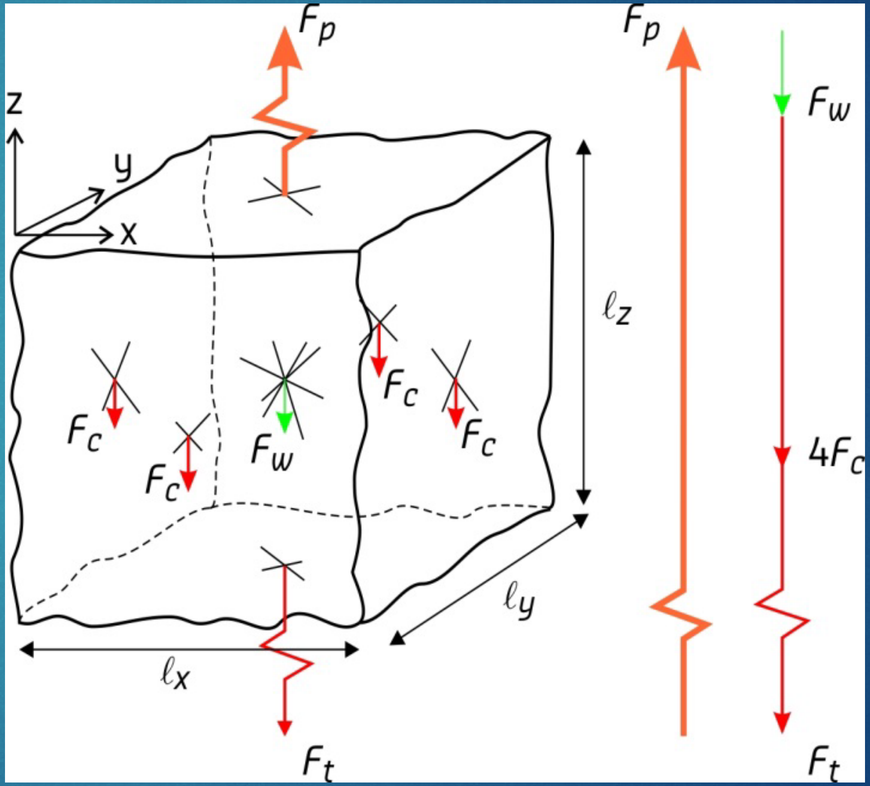
$\sigma_{grass,c}(0)$ is strength and depends on

root area ratio (or root intensity)

critical root tensile strength

root diameter

p_w is suction pressure



Mirtskhoulava - model

Definition:

$$U_c = r_0^{-1}\sqrt{\frac{\tau_c}{0.7\rho}}$$

Mirtskhoulava

$$U_c = \log\left(\frac{8.8h}{d_a}\right)\sqrt{\frac{0.4}{\rho}\left(\left(\rho_s-\rho\right)gd_a + 0.6C_f\right)}$$

← turb. →← critical bed shear stress →

Parameter C_f depends on:

1) cohesion (30 kPa – 80 kPa)
2) liquidity index (0 – 0.75)
3) void ratio (0.45 – 1.05)
4) angle of internal friction (10^0 – 30^0)

Erosion of dike slopes – what are the loads?

(plans for the indoor overtopping simulator)

Large scale physical models

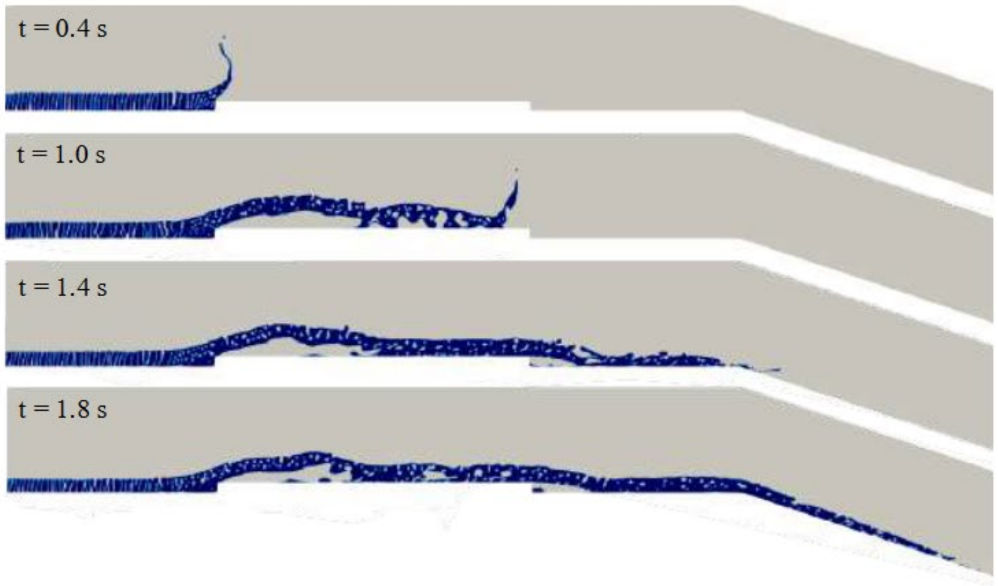
- Complex flows cause loads on dikes
- Details (e.g. turbulence) are not understood

Wave attack outer slope, Delta Flume

Overtopping flow inner slope, overtopping simulator

Computational Fluid Dynamics

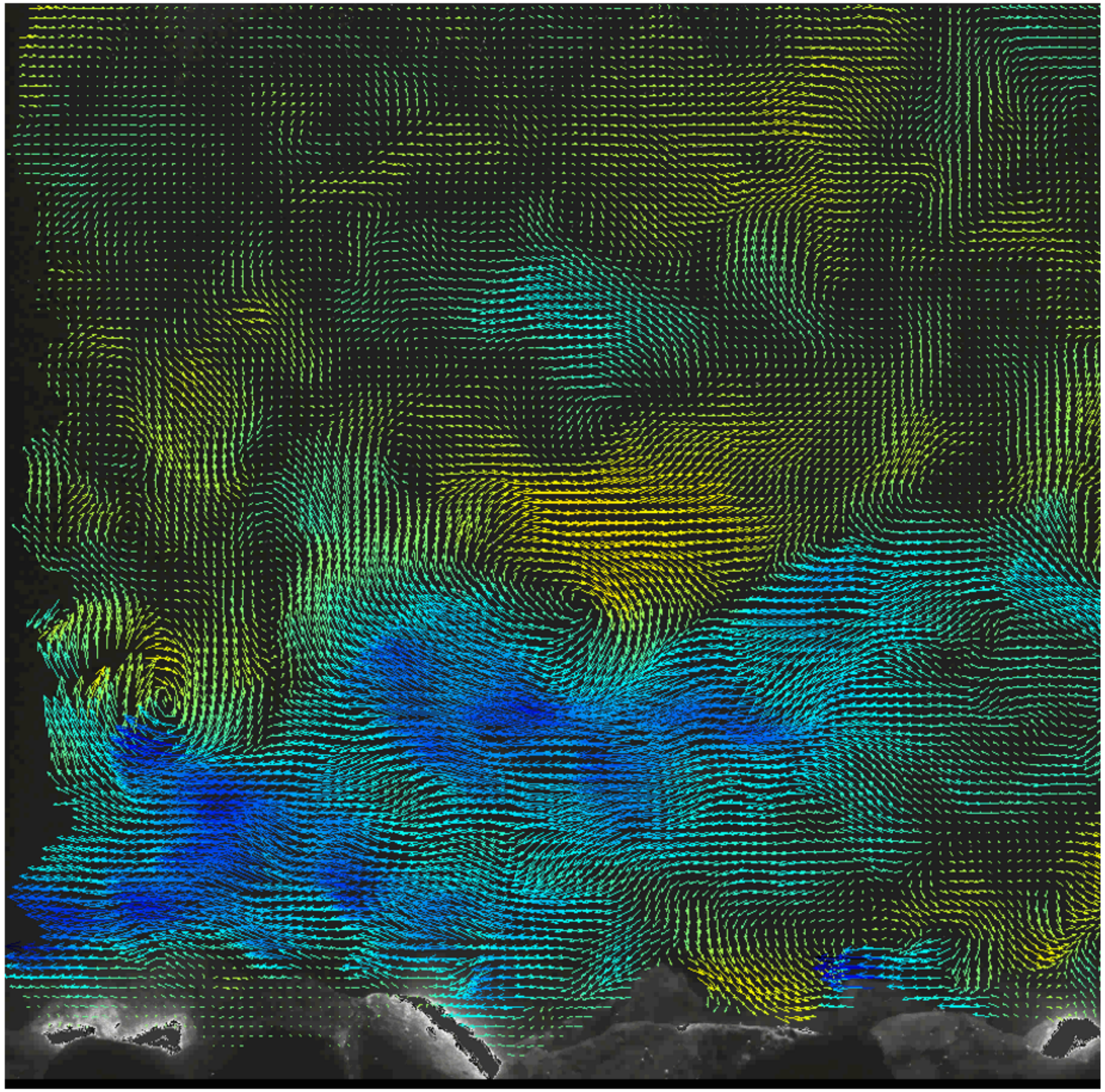
- CFD models are becoming better
- Impact pressures and global velocities are well simulated
- Shear stresses, aeration, and turbulence are not well simulated



Van Bergeijk (2022)

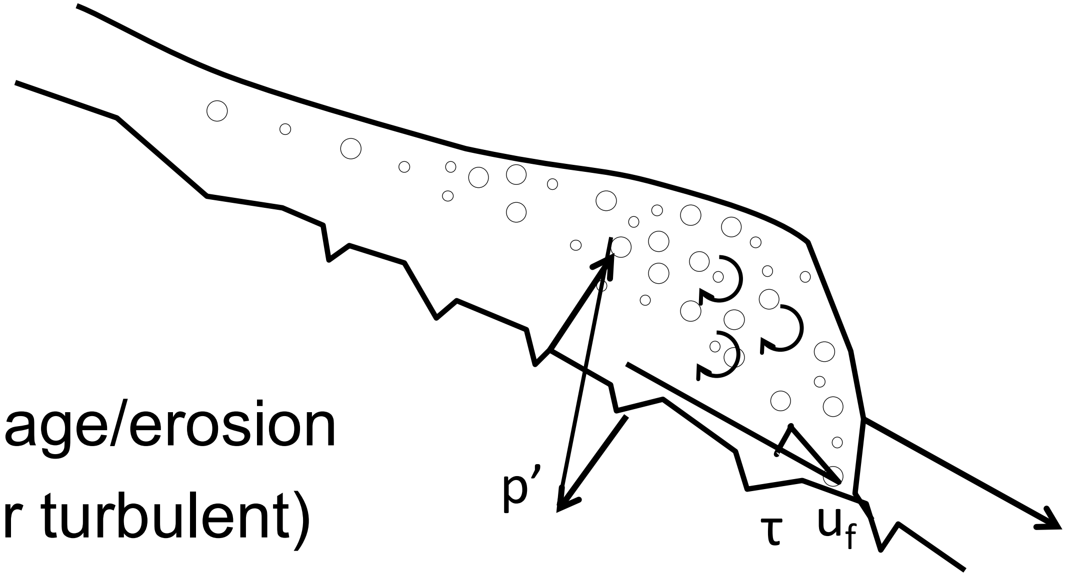
Figure 5.9
Screenshots of the overtopping flow at time t for height transitions with a height of 10 cm above the crest height ($H8$).

Detailed flow measurements



Hofland (2005)

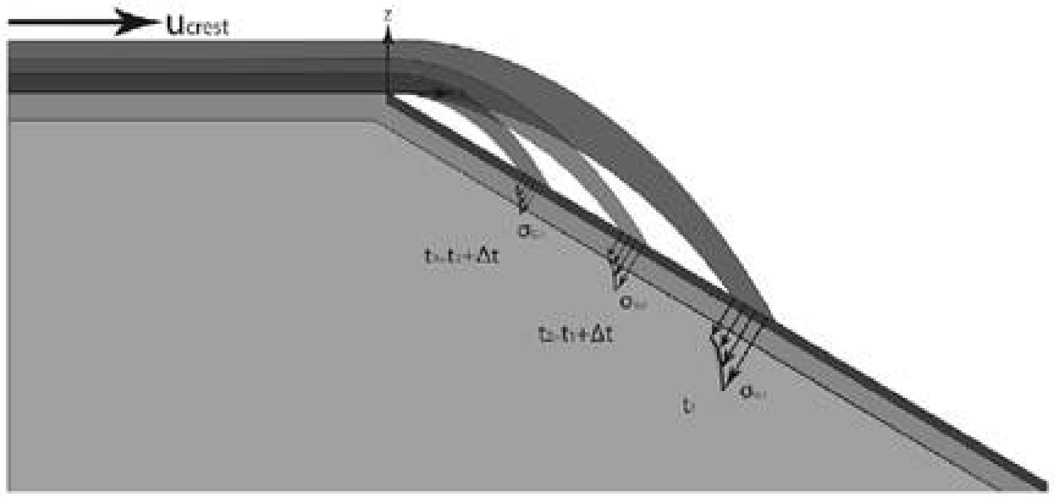
Flow field on slope



- What aspect of load causes damage/erosion
  - Shear stress (quasi-steady or turbulent)
  - Drag forces on sods (quasi-steady and/or turbulent)
  - Pressure (quasi-steady and/or turbulent)
- Are flow characteristics the same as normal uniform flow
  - High Froude numbers (instabilities of surface)
  - Aerated flow (changes turbulence)
  - Transient flow (boundary layer is still developing)

Do we know everything?

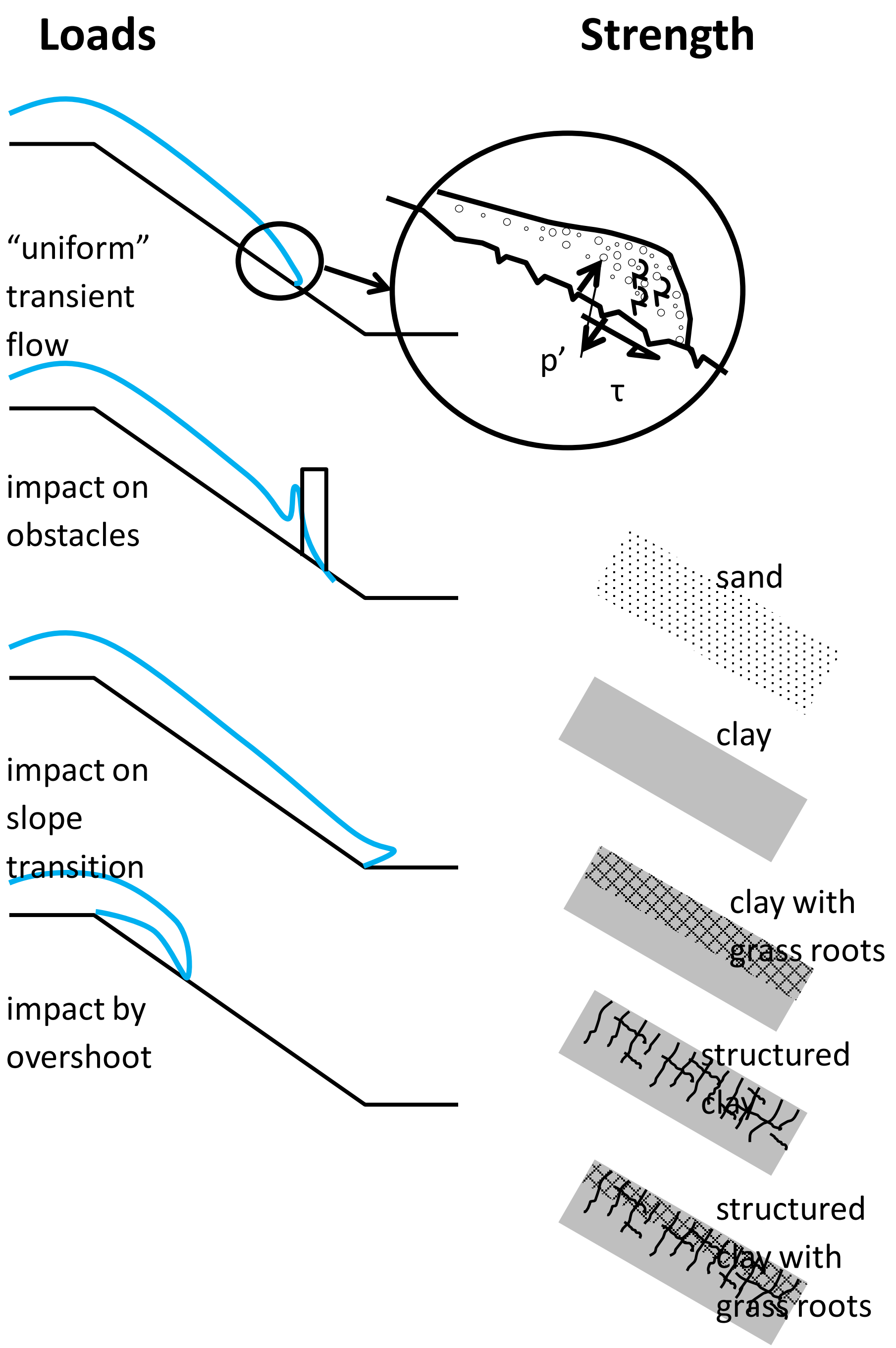
- Example:
  undamaged rear slope clearly clearly attacked by flow.



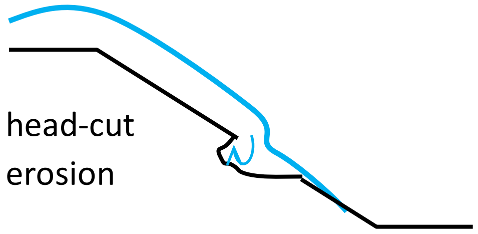
- Overtopping loads: clearly velocities/shear stresses
- Impact loads (pressures) due to overtopping flows (Ponsioen et al. 2019)

Configurations

- Load and effect of load will vary for different configurations



Progressive loads



caption

Indoor overtopping simulator

- PhD with Twente under future FRM-tech programme
- To be built in HElab (TU Delft)
- Scale ≈1:2
- Total height: ~8 m
- Slope: ~5 m high, 1:3
- Simulator: ~2 m high

Previous indoor full scale test (erosion under crack in asphalt) at Deltares

- How can we use this?

TU Delft

Discussion (shared slide)

Which erosion model should we choose to determine the erodibility of clay/grass?
(JET, HET, BET tests or CU model)

Are different parts of the dike loaded by the same, or by fundamentally different load mechanisms (and which)?

How can we use the indoor overtopping simulator?