



Dealing with sediments at hydropower schemes: design of bypass tunnels and desanding facilities

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HYDRO 2018, Gdansk, 17 October 2018

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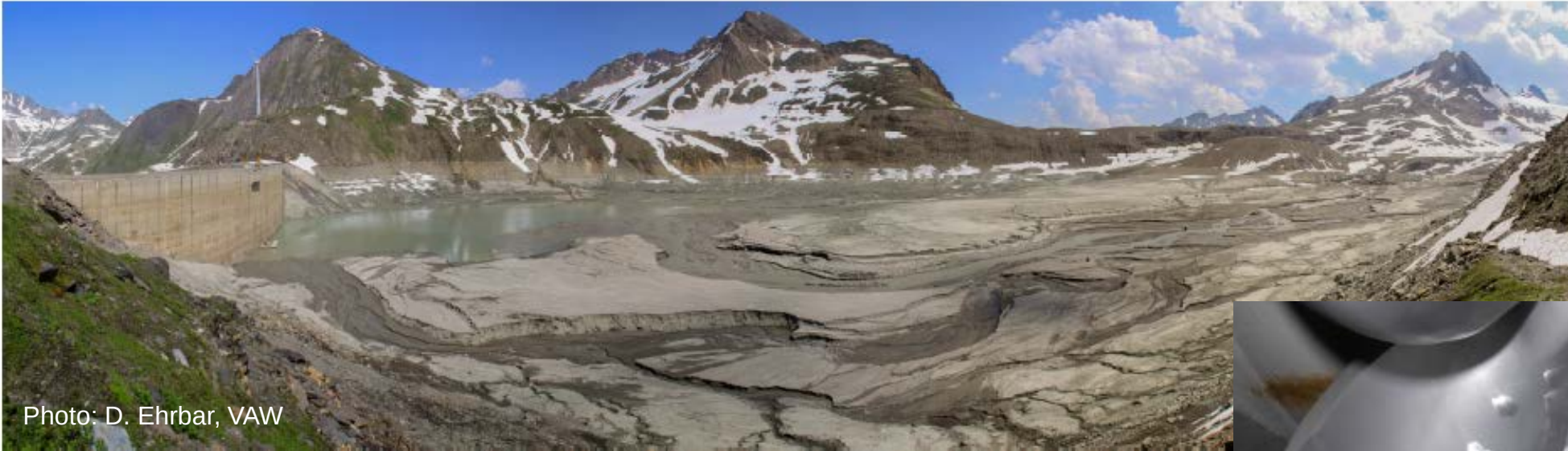
- Tunnel layout in plan view and cross section
- Invert material

3. DESANDING FACILITIES

- Classical design approach
- New, extended design approach

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1. MOTIVATION



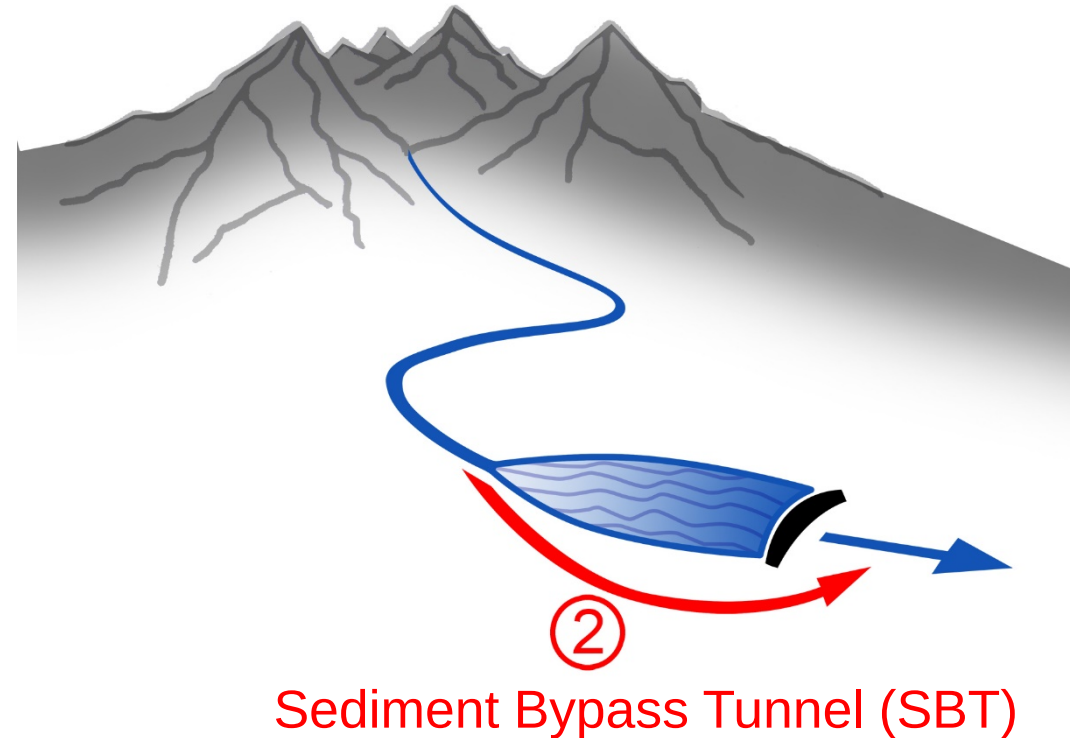
Aggradation pattern in Gries reservoir, Switzerland, with lowered reservoir level during refurbishment works at the dam on 2 July 2015

Example of a Pelton turbine with damages from hydro-abrasive erosion



Sediment management to counter reservoir sedimentation

- ① Sediment yield reduction in the catchment
- ② Sediment routing
- ③ Sediment removal
- ④ Optimized reservoir and dam layout and location



Sediment management to counter hydro-abrasive wear of turbines

Situation

Mountainous,
high-head
hydropower



Sediment-laden
turbine water

Source: Gommerkraftwerke AG (2012)

Problem

Hydro-abrasive
turbine wear



Efficiency reduction,
financial losses

Source: www.hydro-world.com (2016)

Countermeasure: **Desanding facilities**

Purpose

Continuous sediment removal
from turbine water

Functional principle

Make use of gravitational force for particle settling
under calmed flow conditions

Objective

$\min\{\text{abrasion potential}\}, \max\{\text{trapping efficiency}\}$

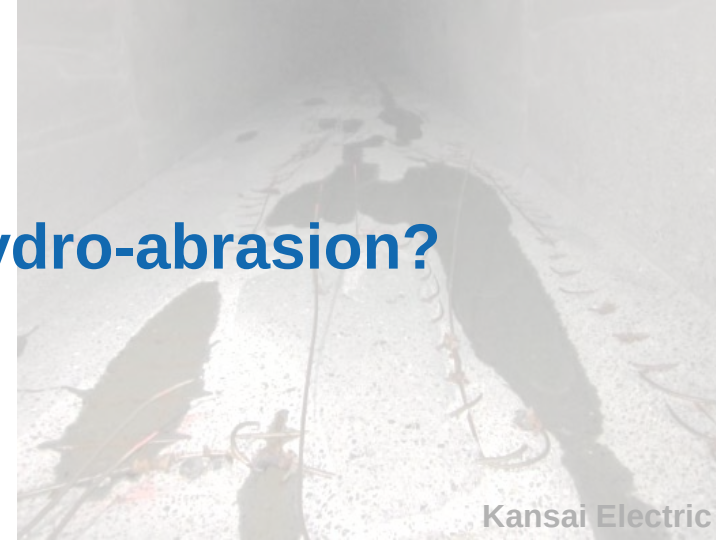
2. SEDIMENT BYPASS TUNNELS

(PhD students: Christian Auel, Michelle Müller-Hagmann, Dila Demiral)

Hydro-abrasion at Sediment Bypass Tunnels (SBTs)

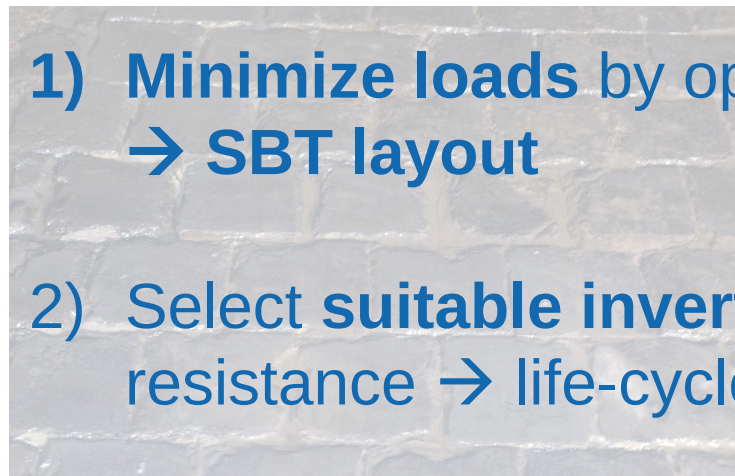


SBT Palagnedra
(Baumer and Radogna
2015)



SBT Asahi
(Kansai Electric)

- 1) Minimize loads by optimized flow conditions
→ SBT layout
- 2) Select suitable invert material to maximize
resistance → life-cycle cost approach



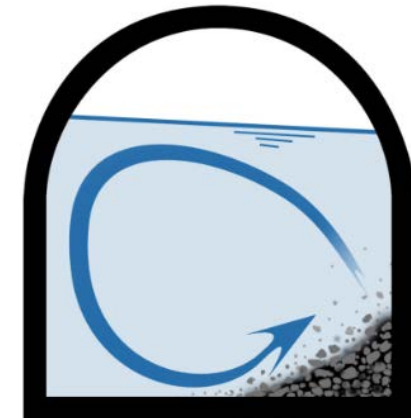
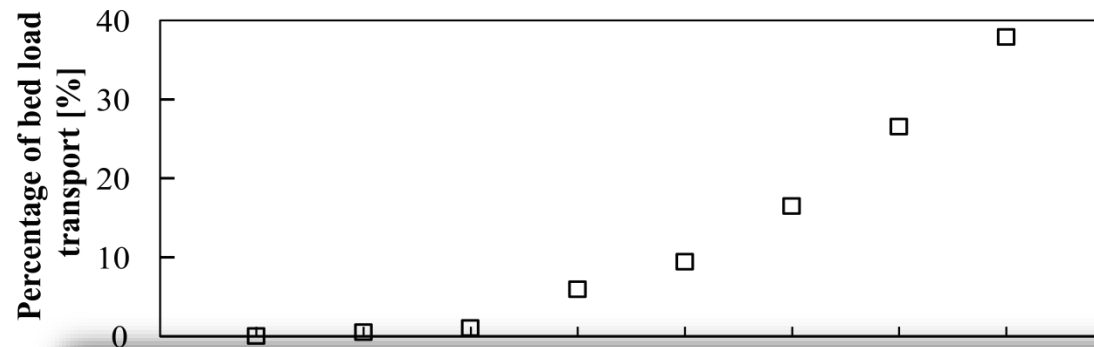
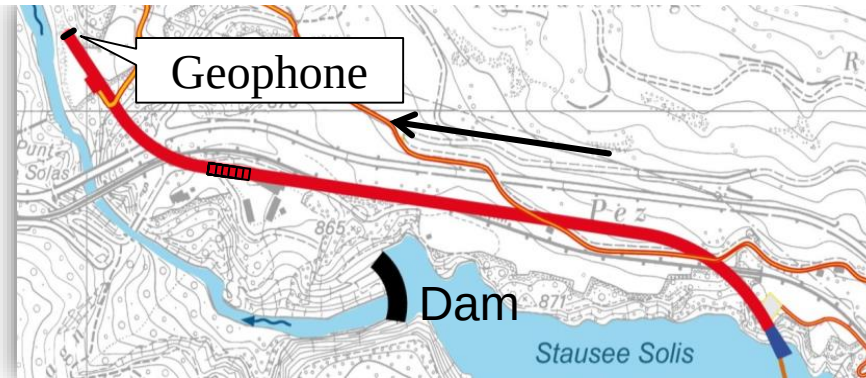
SBT Pfaffensprung
(M. Müller-Hagmann)



SBT Egschi
(sopr AG)

1) SBT design: tunnel layout in plan view

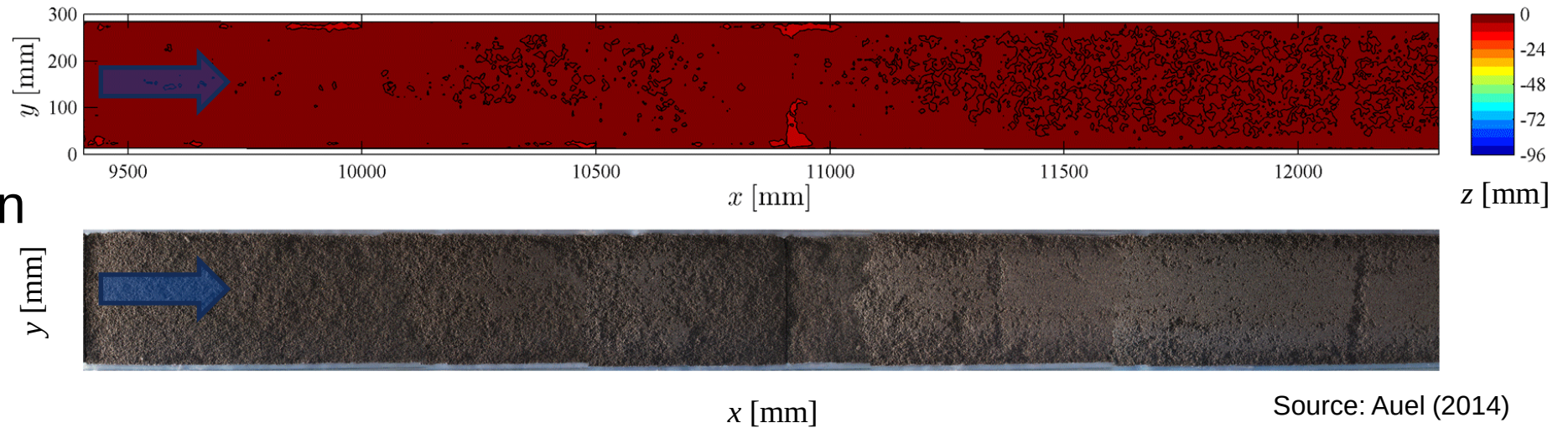
Effect of SBT alignment in plan view



1) SBT design: tunnel layout in cross section

Effect of SBT cross section – 2D vs. 3D flow

Lab study
of invert abrasion



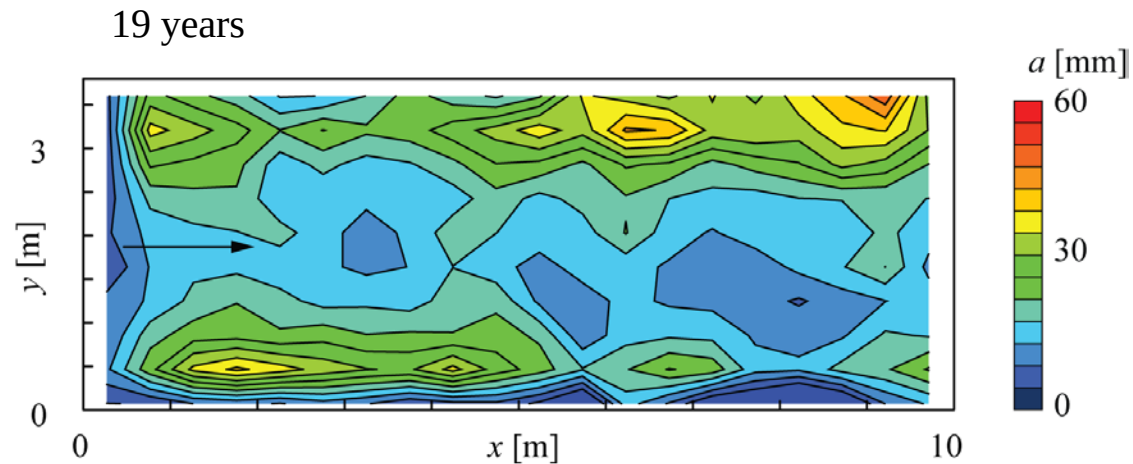
$$F = 1.8, h_o = 100 \text{ mm}, S_b = 0.01, Q_S = 0.200 \text{ kg/s}, D_b = 10.6 \text{ mm}, t = 930 \text{ min}$$

F	Froude number	S_b	Bed slope
h_o	Approach flow depth	D_b	Particle diameter
Q_S	Sediment transport rate [kg/s]	t	Test duration

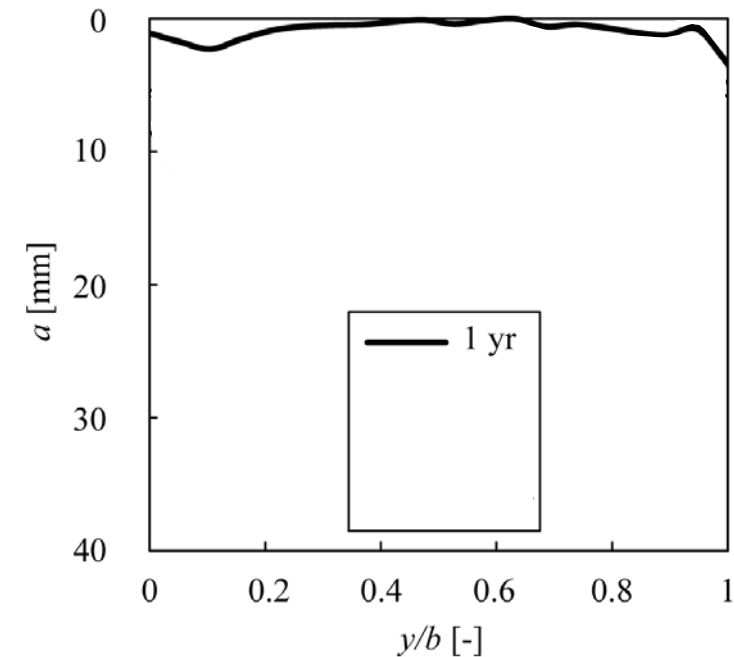
1) SBT design: tunnel layout in cross section

Effect of SBT cross section – 2D vs. 3D flow

Field study at SBT Runcahez – Invert Abrasion (1996 - 2014)



Silica fume concrete (SC)



- Incision channels along the tunnel walls
→ 3D-flow structures in narrow open channel flows

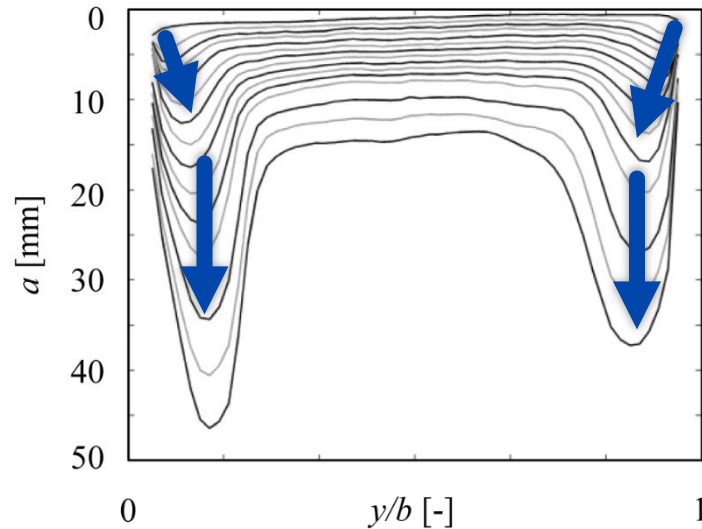
Source: Müller-Hagmann (2018)

1) SBT design: tunnel layout in cross section

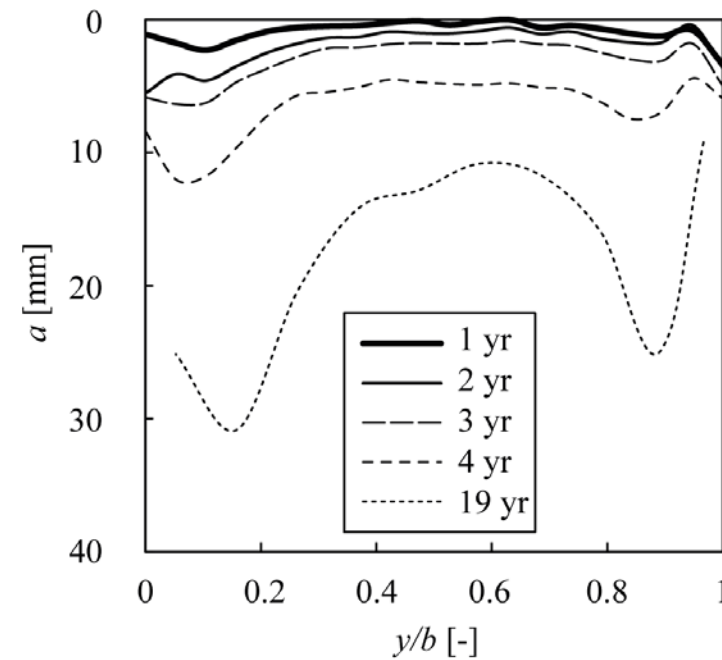
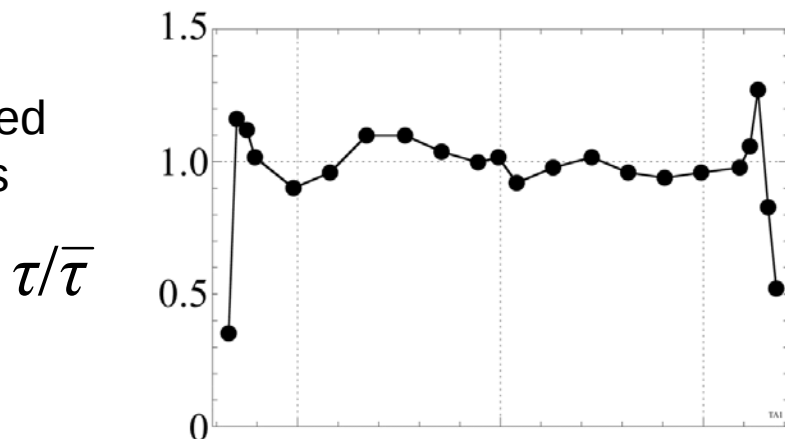
Effect of SBT cross section – 2D vs. 3D flow

lab study

- $b/h = 2.8$
- $F = 1.8$



Normalized bed
shear stress



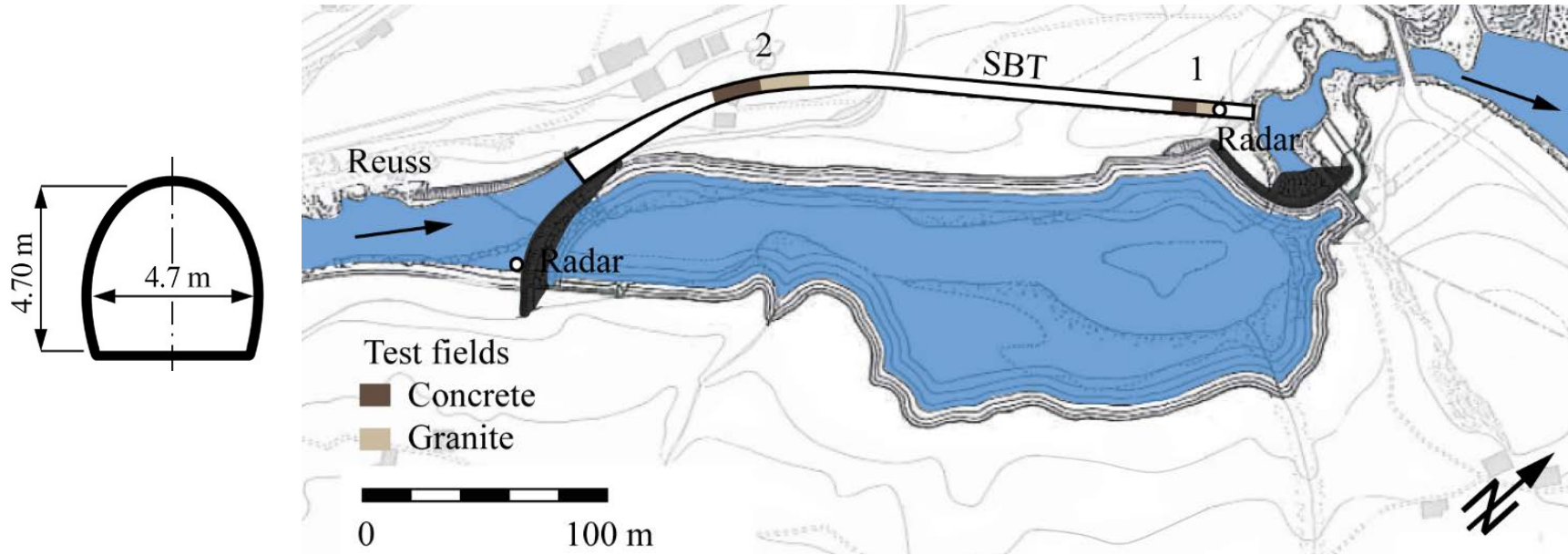
field study

- $b/h = 1.9$
- $F = 1.7$

Source: Müller-Hagmann (2018)

2) Select suitable invert material

Effect of invert lining strength - SBT Pfaffensprung field study



Source: Müller-Hagmann (2018)

■ Tested invert materials

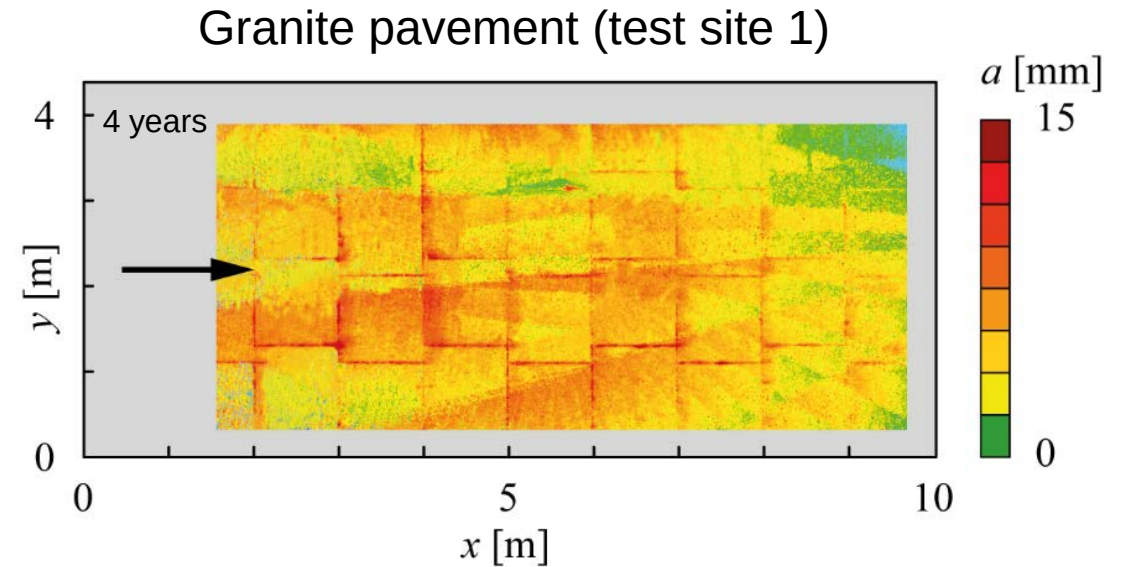
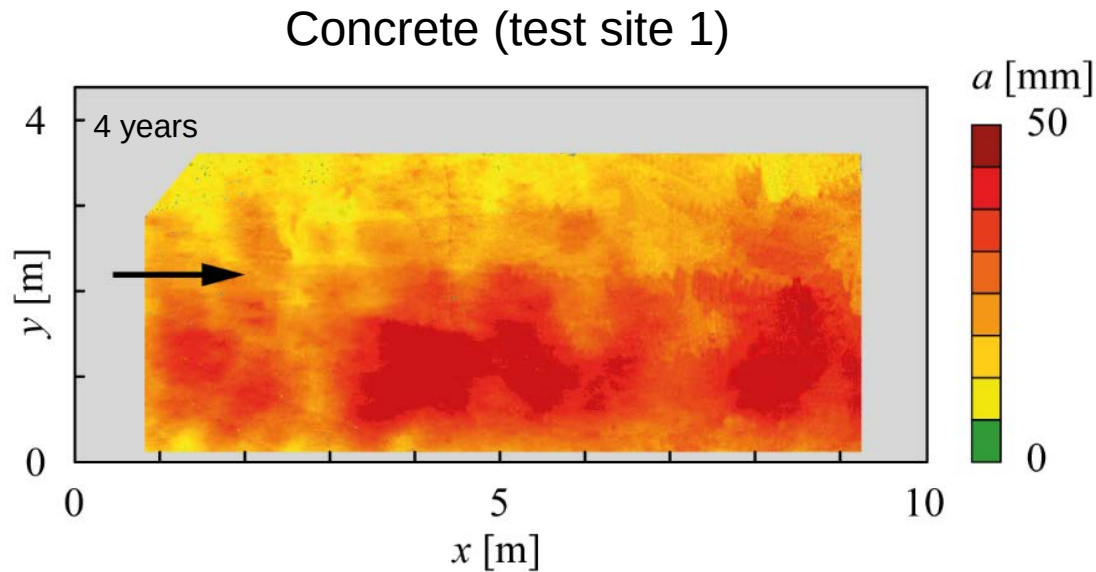
- Concrete ($f_c = 78 - 108$ MPa)
- Granite ($f_c \approx 260$ MPa)

■ Monitoring

- Hydraulic operating conditions: continuously
- Hydro-abrasion: yearly

2) Select suitable invert material

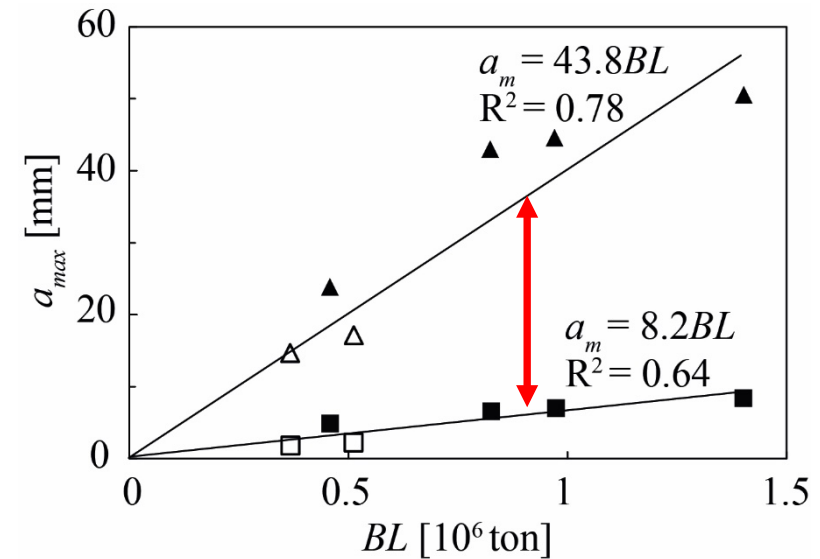
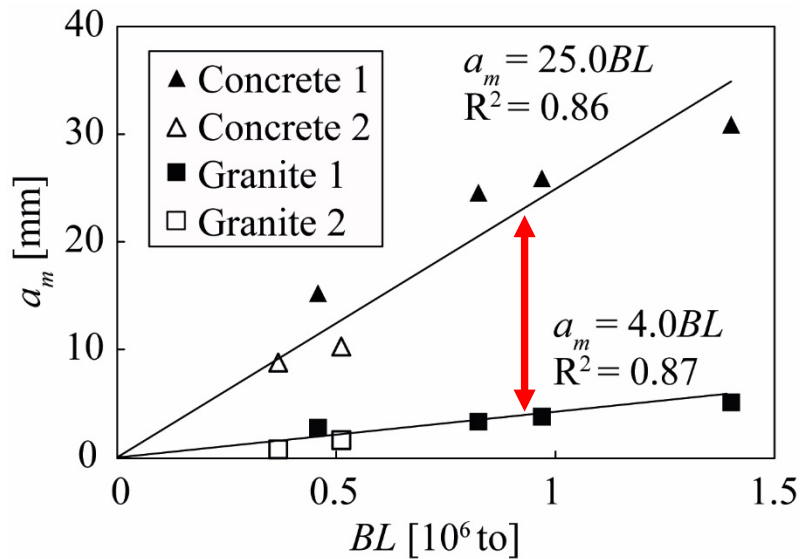
Effect of invert lining strength - SBT Pfaffensprung invert abrasion (2012-2015)



- Initial abrasion pattern amplifies
- Characteristic material-dependent abrasion pattern
- Higher abrasion on the right side → 3D-flow structures due to upstream tunnel bend

2) Select suitable invert material

Effect of invert lining strength - SBT Pfaffensprung invert abrasion (2012-2015)



- Abrasion resistance of granite ($f_c \approx 260$ MPa) about 6 times higher than of concrete C70/85
 - Abrasion triggered by discontinuities (e.g. joints) and structural weaknesses
- Optimum invert material?

2) Select suitable invert material

Cost-Effectiveness Analysis - SBT Pfaffensprung field study

Net present value (NPV):

$$NPV = \sum_{t=0}^T \frac{C_t}{(1+r)^t}$$

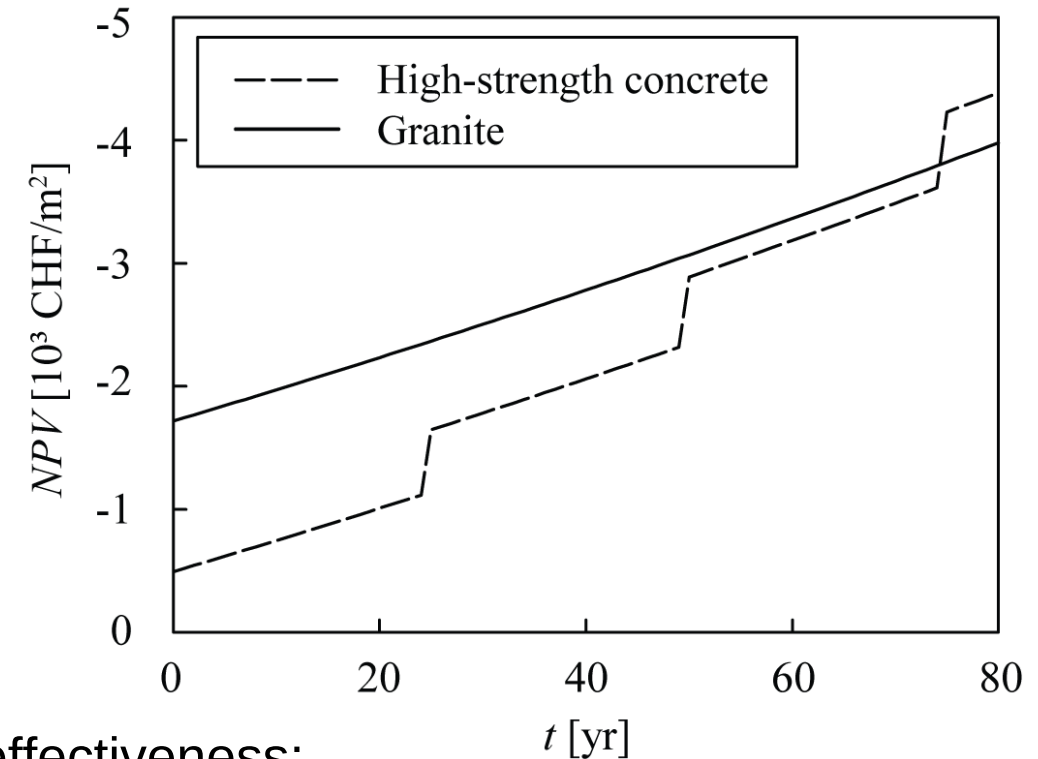
T = accounting period (here 80 yr)

C_t = net cash flow at time point t

r = interest rate (here 3%)

Input parameters / assumptions:

- Actual investment
- Maintenance costs: 25 CHF/(m²yr)
- Replacement at abrasion depth ≥ 20 cm
- Actual abrasion rates from 2012 - 2015



Cost-effectiveness:

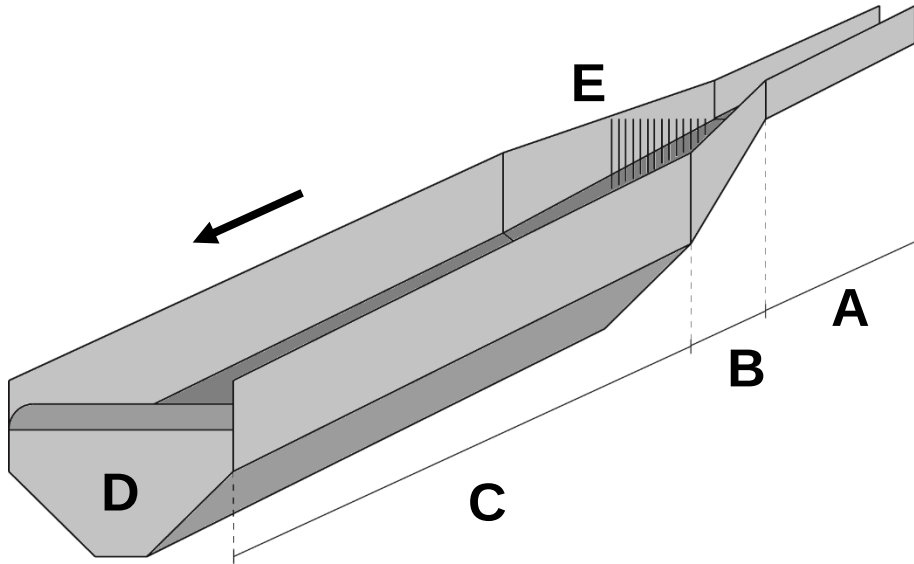
$T < 75$ yr: Concrete > granite

$T \geq 75$ yr: Concrete < granite

3. DESANDING FACILITIES (PhD student: Christopher Paschmann)



Classical desanding facility design



- A:** Inlet channel
B: Transition zone
C: Basin
D: Weir
E: Tranquilizing racks

Available design recommendations:

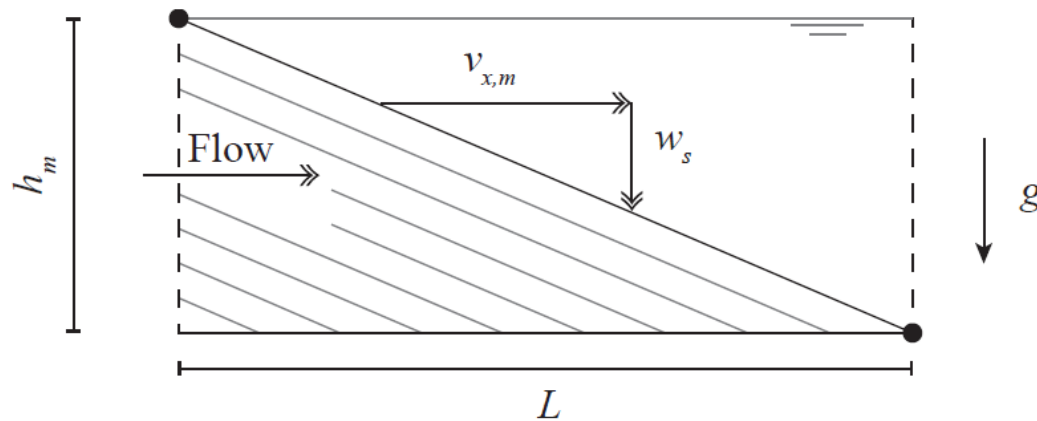
- Inlet channel: sparse
- Transition zone: sparse
- Basin: typically “classical” approach (*Camp, 1936*)

Underlying assumptions:

- Uniform and homogeneous approach flow
- No transverse and vertical flow components
- Settling effective over entire basin length

Classical desanding facility design: limitations

- **Problem:** Operational experience often indicates insufficient trapping efficiency
- Reason: “Classical” approach neglects approach flow conditions, transition zone geometry, and influence of weir



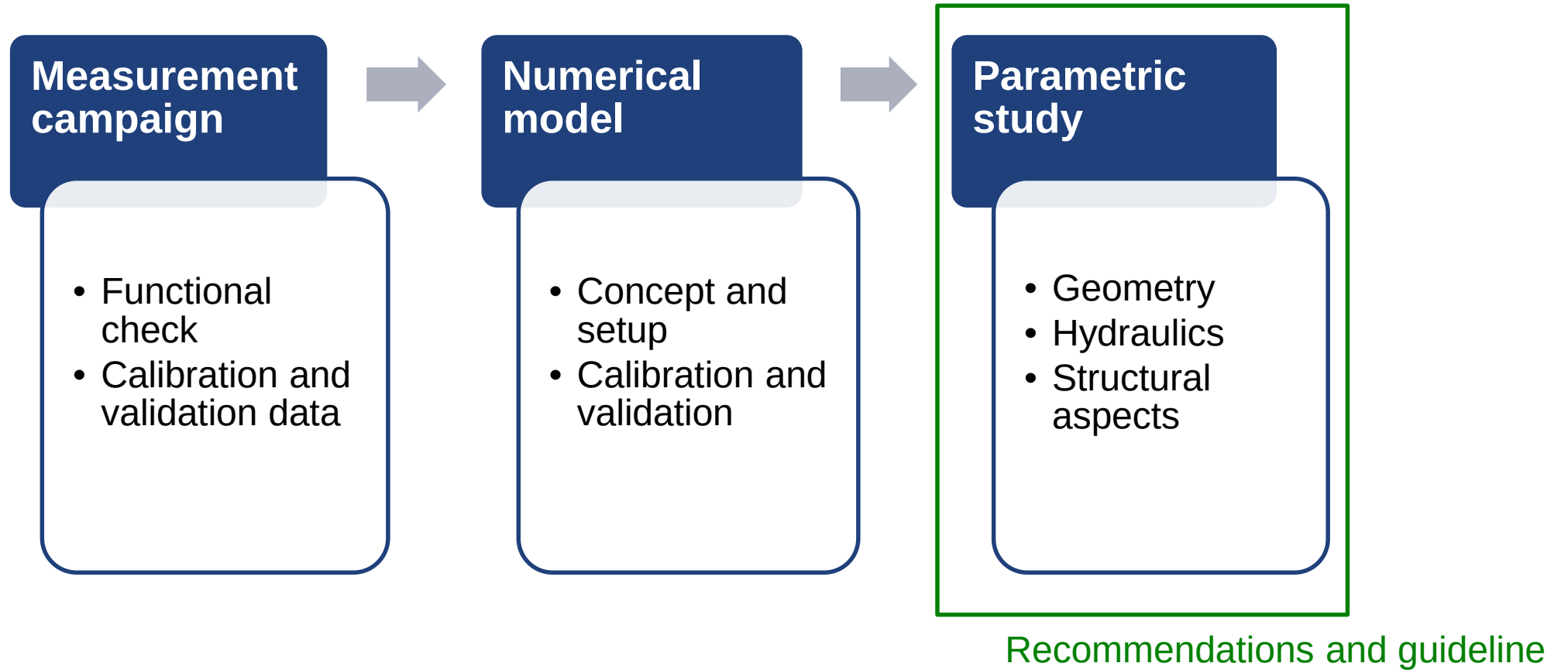
$$L = h_m \frac{v_{x,m}}{w_s} = h_m \frac{v_{x,m}}{w_{s,0} - \frac{0.132}{\sqrt{h_m}} v_{x,m}}$$

h_m = mean basin flow depth [m]

$w_{s,0}$ = settling velocity of defined critical limit particle size d_{cr} in still water [m/s]

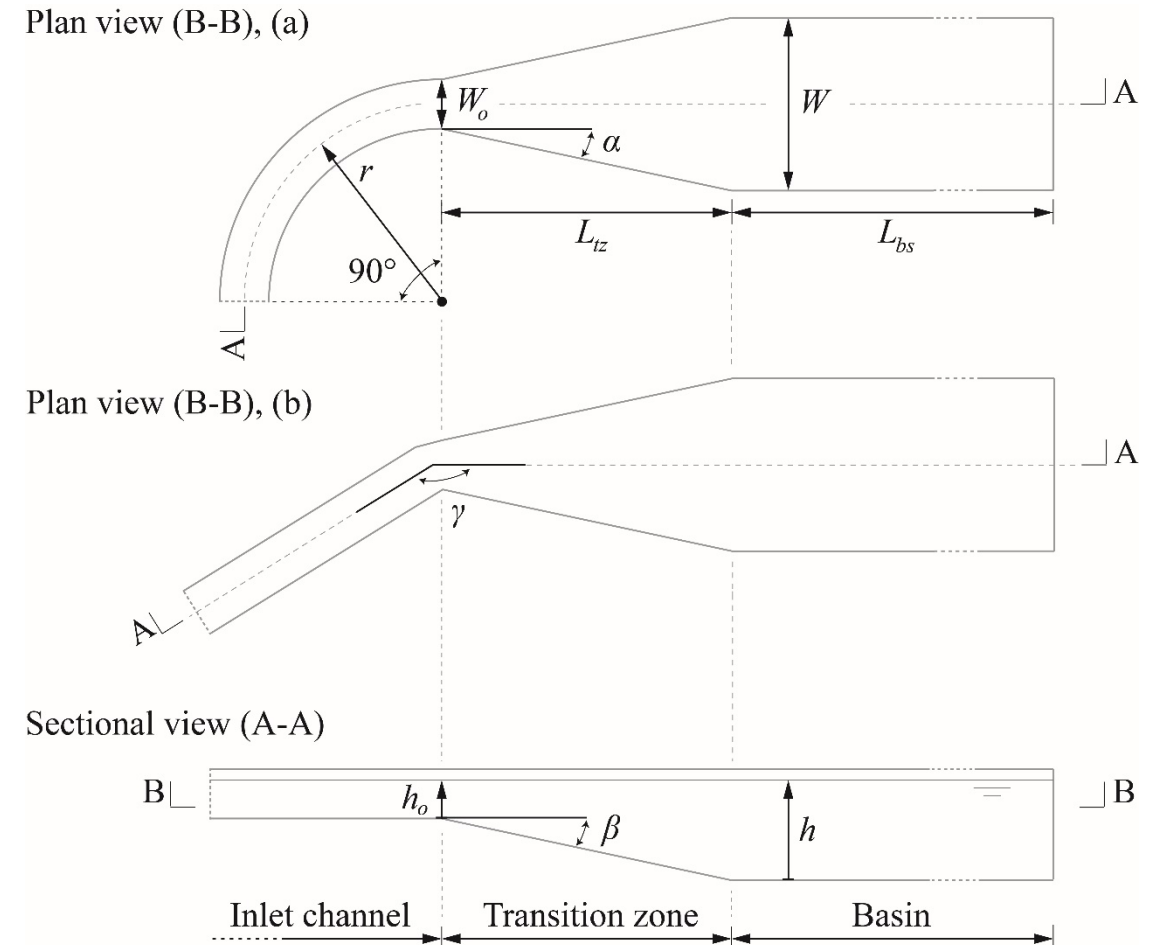
- **Research gap:** Design guideline considering desanding facility as integral system

Methodology



Systematic parametric numerical study: investigation parameters

- Inlet channel course
 - Curved (r)
 - Angled (γ)
- Transition zone geometry
 - Horizontal expansion angle (α)
 - Vertical expansion angle (β)
- Approach flow *Froude* number (F_o)
- Tranquilizing racks



New, extended design concept

- (1) Fundamental basin length L_f
(→ classical design approach)

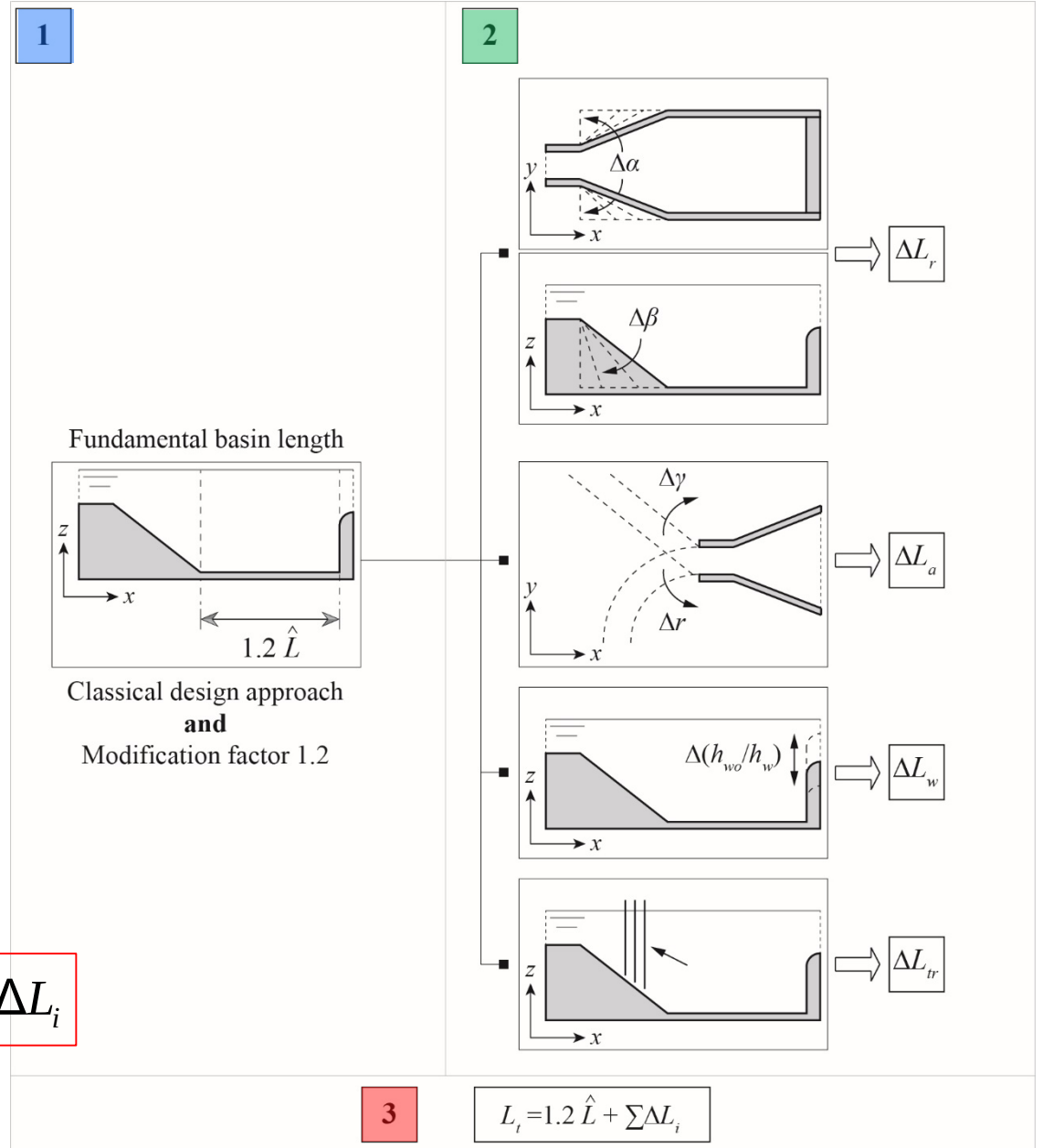
$$L_f = 1.2\hat{L} = 1.2 \cdot \max \left\{ h_m \frac{v_{x,m}}{w_s}, 8W \right\}$$

with W = basin width

- (2) Adjustment terms ΔL_i

- (i) transition zone geometry (ΔL_r)
- (ii) approach flow conditions (ΔL_a)
- (iii) weir at basin end (ΔL_w)
- (iv) tranquilizing racks in the transition zone (ΔL_{tr})

- (3) Required total basin length $L_t = 1.2\hat{L} + \sum \Delta L_i$



4. CONCLUSIONS



Conclusions

Design of bypass tunnels and desanding facilities

- Proper functioning of SBTs and desanding facilities requires an optimal hydraulic and structural design
- Optimum invert material of SBTs in terms of life-cycle cost can be selected based on abrasion predictions
- **Avoid bends** in plan view of SBTs if possible
- **Locally strengthen SBT invert** to avoid abrasion concentration induced by 3D-flow structures
- Classical design approaches underestimate required **desanding basin length**
- **New design concept** accounts for transition zone geometry incl. tranquilizing racks, approach flow conditions, and weir at basin end

THANK YOU FOR YOUR ATTENTION

