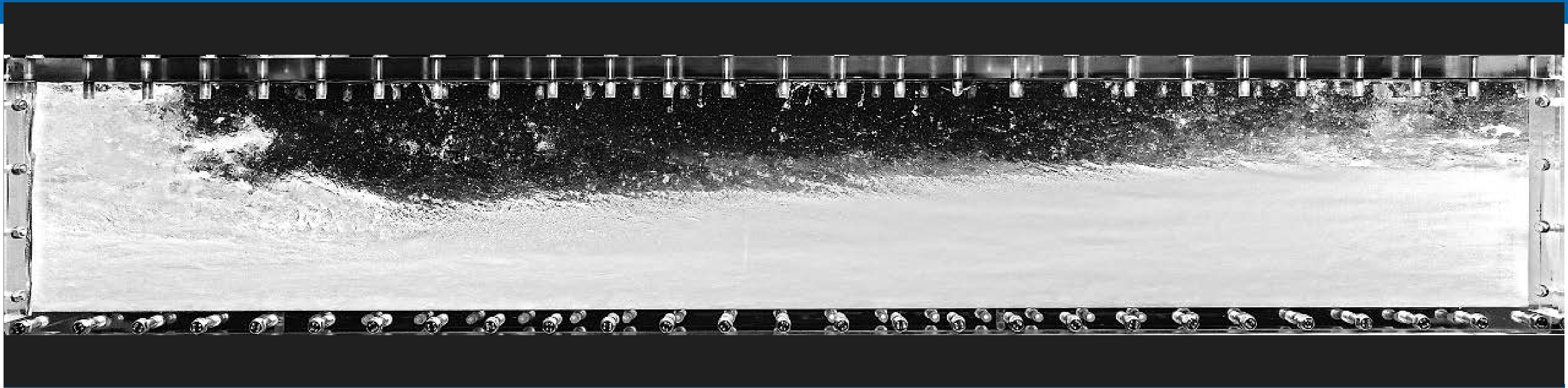
ETH zürich



Bottom Outlet Hydraulics

Benjamin Hohermuth, Lukas Schmocker, Robert Boes

SCCER-SoE Annual Conference

14th of September 2018, Horw

Laboratory of Hydraulics, Hydrology and Glaciology

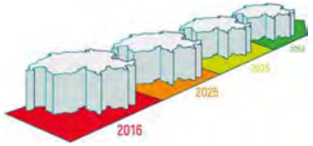
SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Motivation

Adapt hydraulic structures to meet future demands

Dam heightening at Luzzone 1998

Swiss Energy Strategy 2050



+ 3.1 TWh/a of flexible peak and winter energy in 2050

→ Dam heightening

Climate Change

Glacier/permafrost retreat exposes instable hillslopes

→ Increased risk of impulse waves

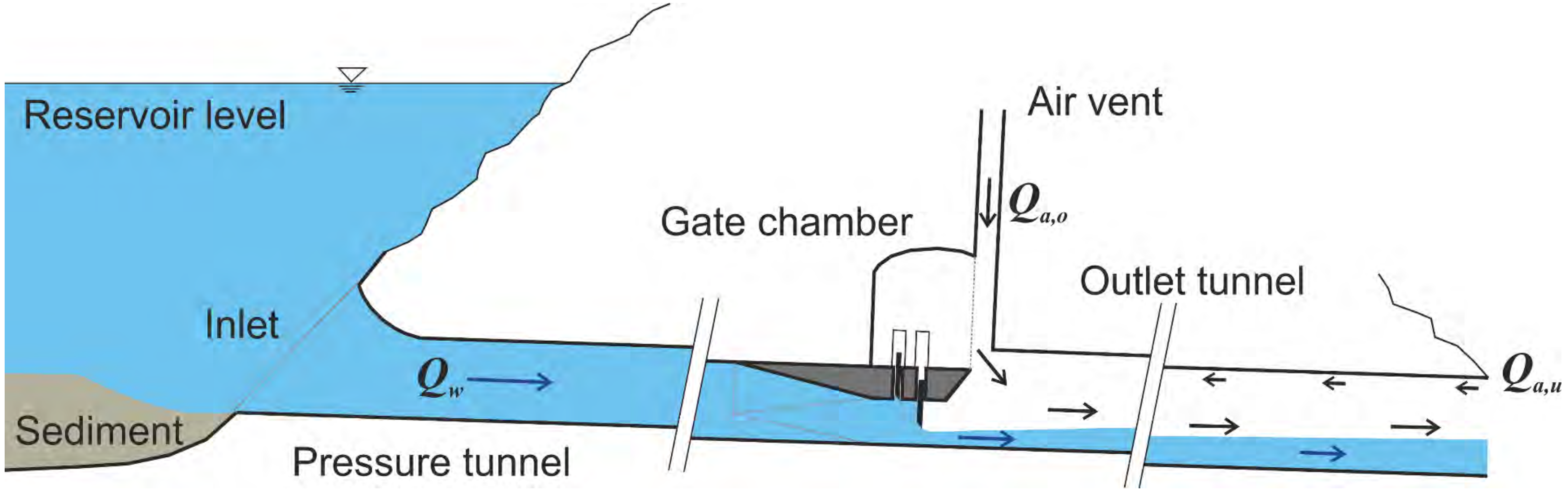
→ Increased reservoir sedimentation in periglacial environments

Reservoir sedimentation at Griessee

→ Increased load on outlet structures

Bottom Outlets: Key Safety Devices

Purposes & Challenges



Purposes:

- Control of reservoir level
- Sediment flushing
- Residual flow release
- Flood discharge

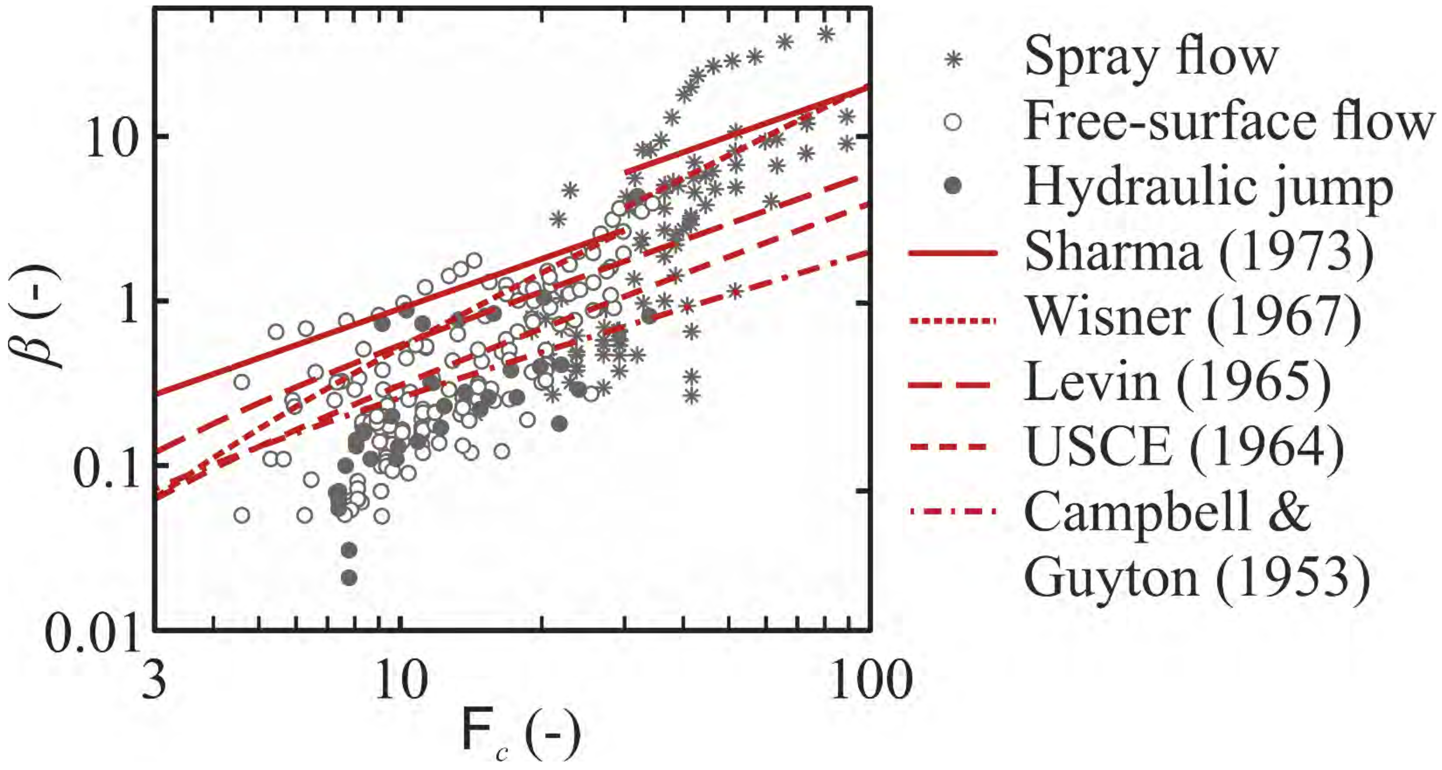
Challenges:

- Cavitation
- Gate vibration
- Flow choking / slugs

→ «sufficient» aeration is crucial for a safe operation

State of Knowledge

Air demand $\beta = Q_{a,o}/Q_w$

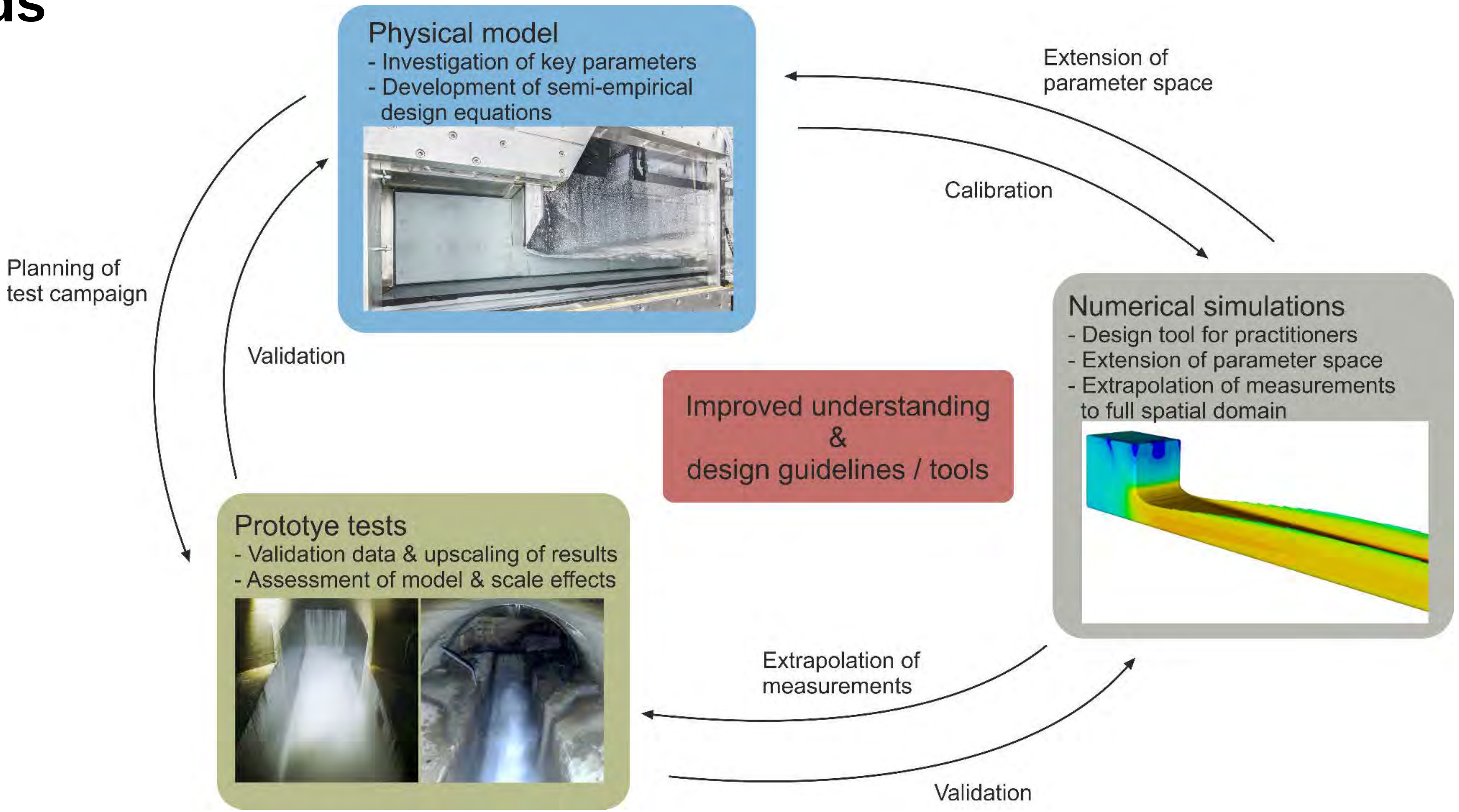


Goal

Improve design guidelines by including the effects of

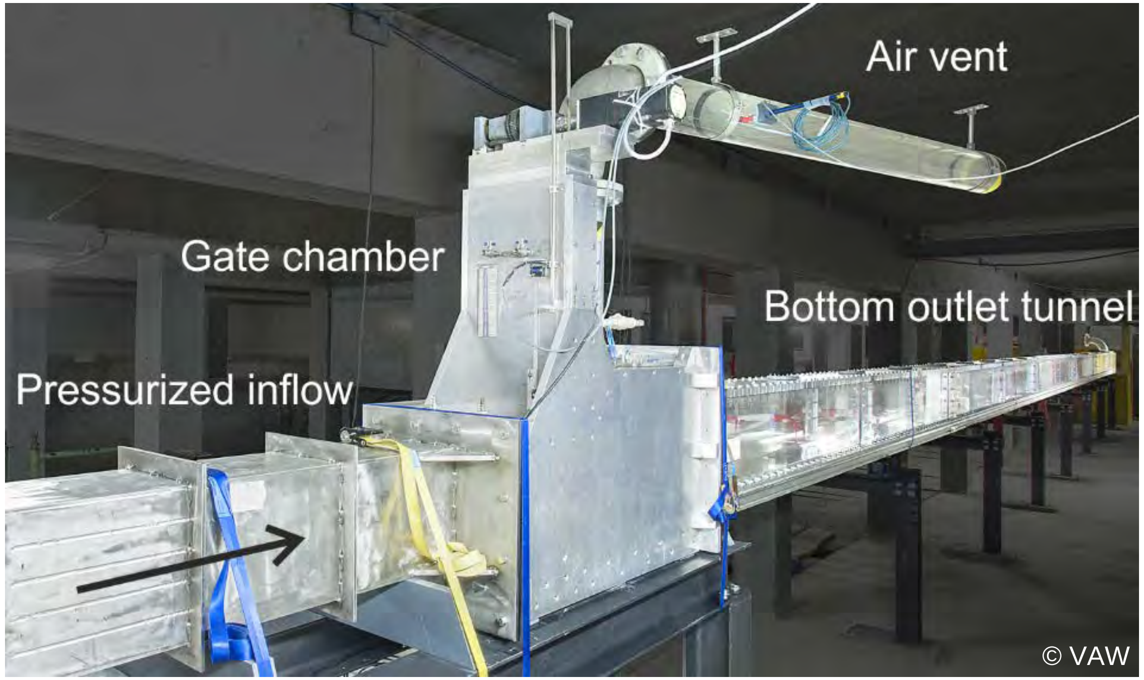
- Air vent
- Tunnel length
- Tunnel slope

Methods


Physical model
- Investigation of key parameters
- Development of semi-empirical design equations
Extension of parameter space
Calibration
Planning of test campaign
Validation
Numerical simulations
- Design tool for practitioners
- Extension of parameter space
- Extrapolation of measurements to full spatial domain
Improved understanding & design guidelines / tools
Prototye tests
- Validation data & upscaling of results
- Assessment of model & scale effects
Extrapolation of measurements
Validation

Physical Model

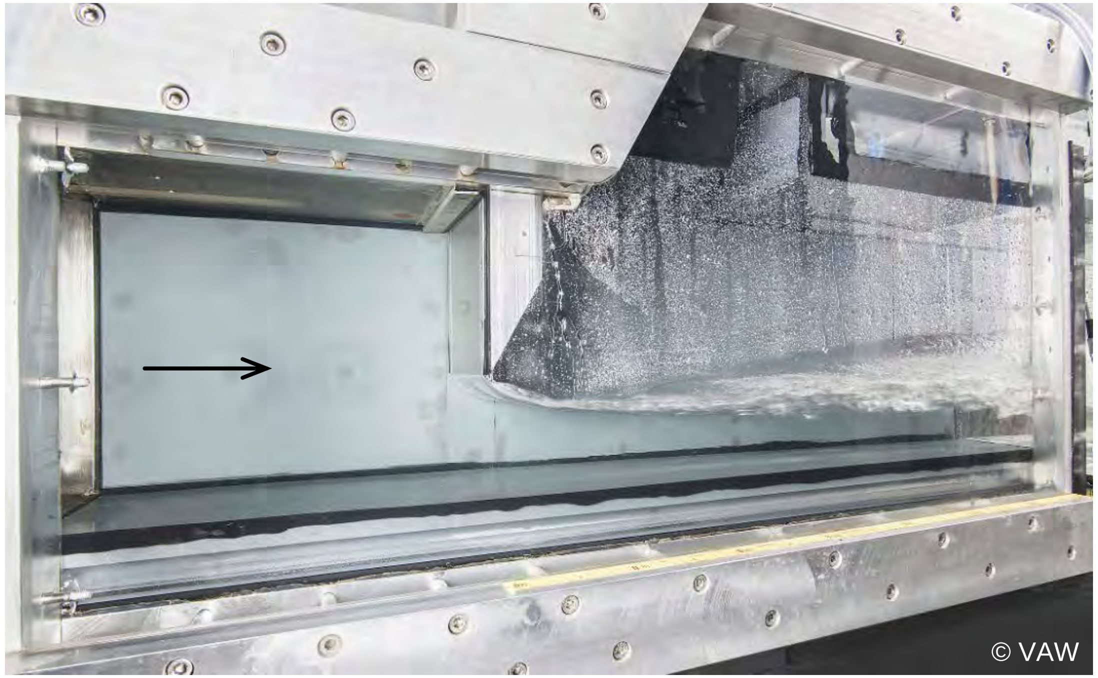
Model scale $\lambda \approx 10$



Max. length L = 20.6 m

Max. energy head H_E = 30 m w.c.

Max. discharge Q_w = 600 l/s



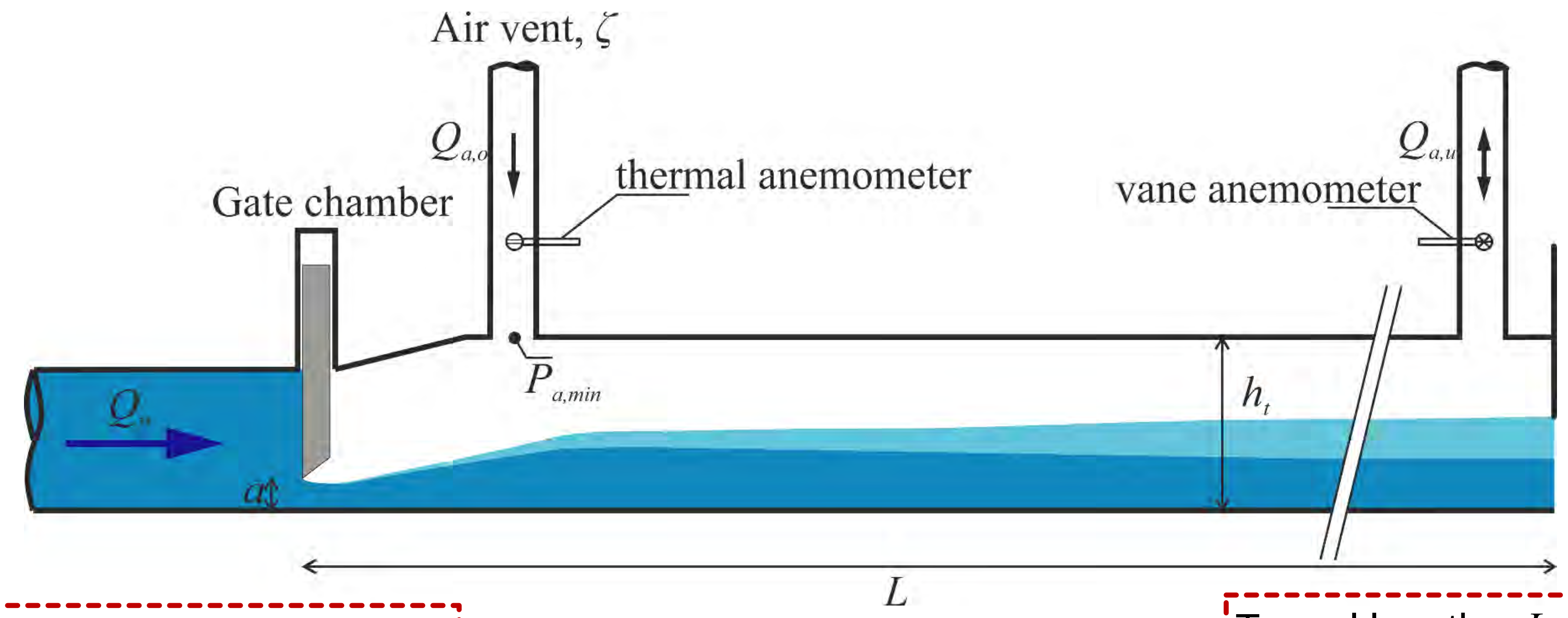
Max. flow velocity @ vena contracta ≈ 24 m/s

Max. gate opening a_{max} = 0.25 m

Tunnel width W = 0.2 m, tunnel height h_t = 0.3 m

Physical Model
General setup

Air vent loss coefficient ζ = 0.7 - 37

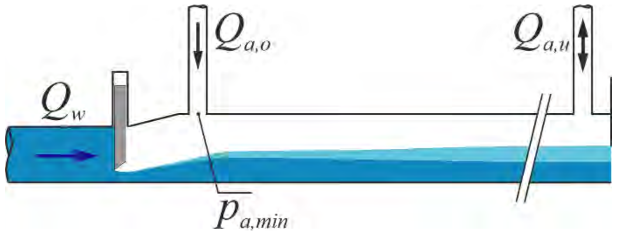


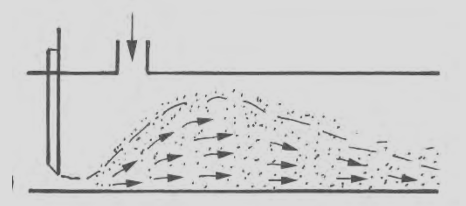
Energy head H_E = 5 - 30 m w.c.
Relative gate opening a/a_{max}= 0.1 - 0.8
Water discharge Q_w = 60 - 600 l/s

Tunnel length L = 20.6, 12.6, 6.6 m
Tunnel slope S = 0 - 0.04
Tunnel width W = 0.2 m
Tunnel height h_t = 0.3 m

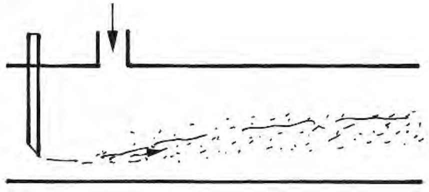
Model Tests: Air Demand

Effect of flow pattern, a/a_{max} and H_E

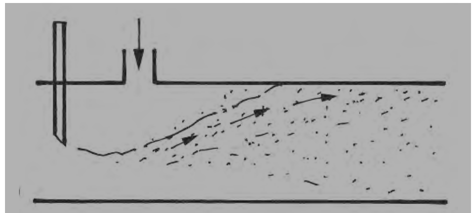




(I) spray flow



(II) free-surface flow

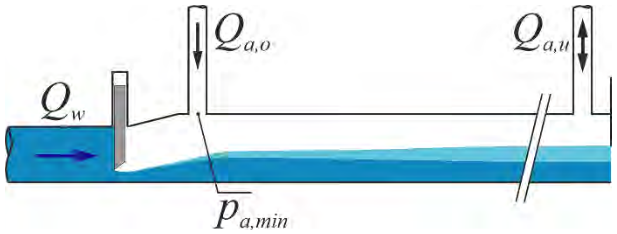


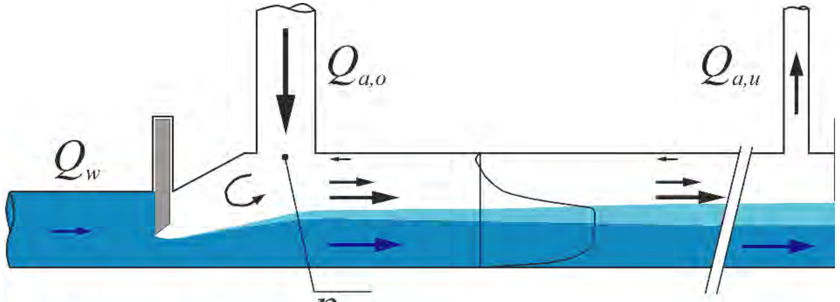
(III) foamy flow

Sharma (1973)

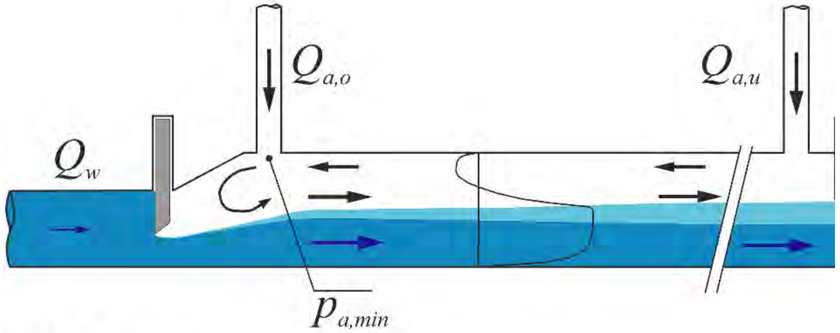
Model Tests: Air Demand

Effect of air vent loss coefficient ζ

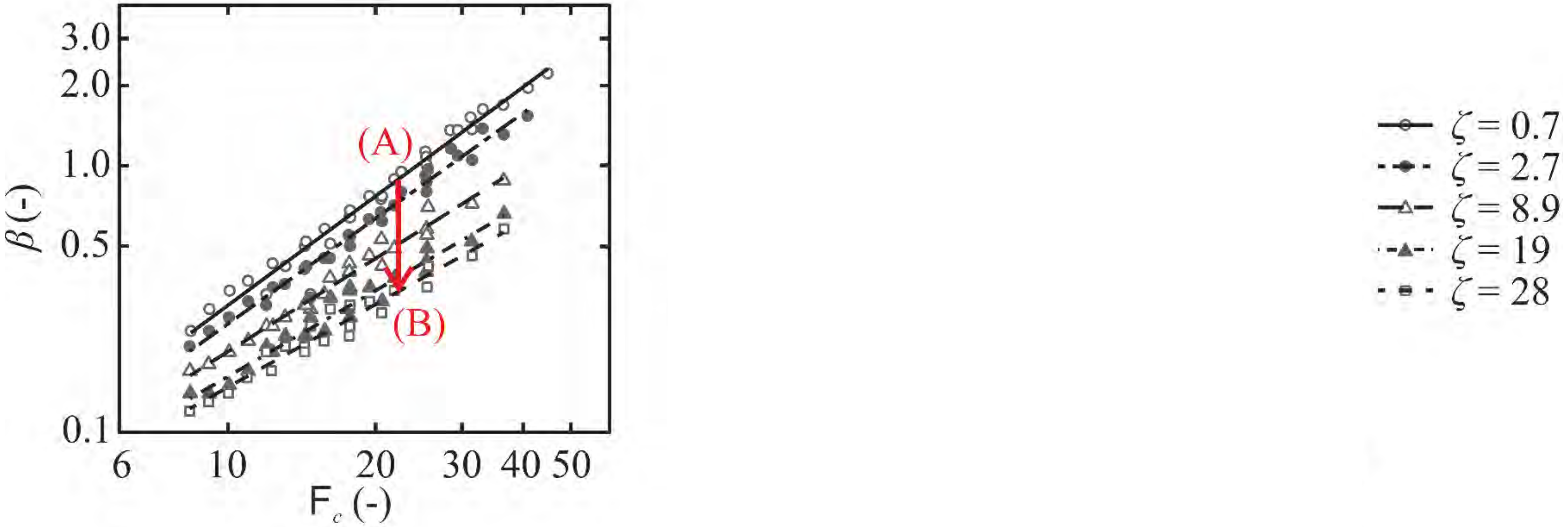




(A) Small ζ



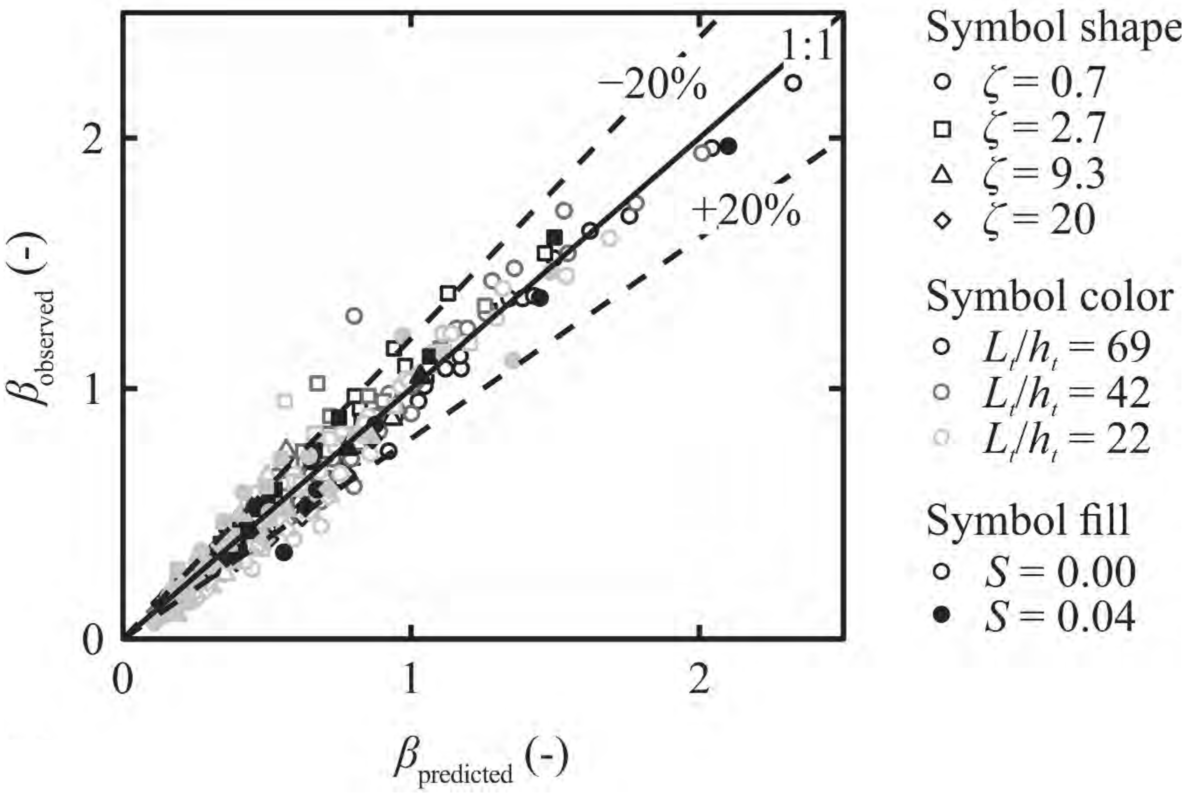
(B) Large ζ



Model Tests: Air Demand

Design Equation

$$\beta = 0.007\ \mathrm{F}_c^{1.20}\zeta^{-0.25}(L_t/h_t)^{0.26}(1+S)^{-0.92}$$



Limitations

- Free surface flow
- No profile transition
- $8 \leq \mathrm{F}_c \leq 45$
- $0.7 \leq \zeta \leq 20$
- $22 \leq L_t/h_t \leq 69$
- $0 \leq S \leq 0.04$

Air Demand

Comparison to prototype data

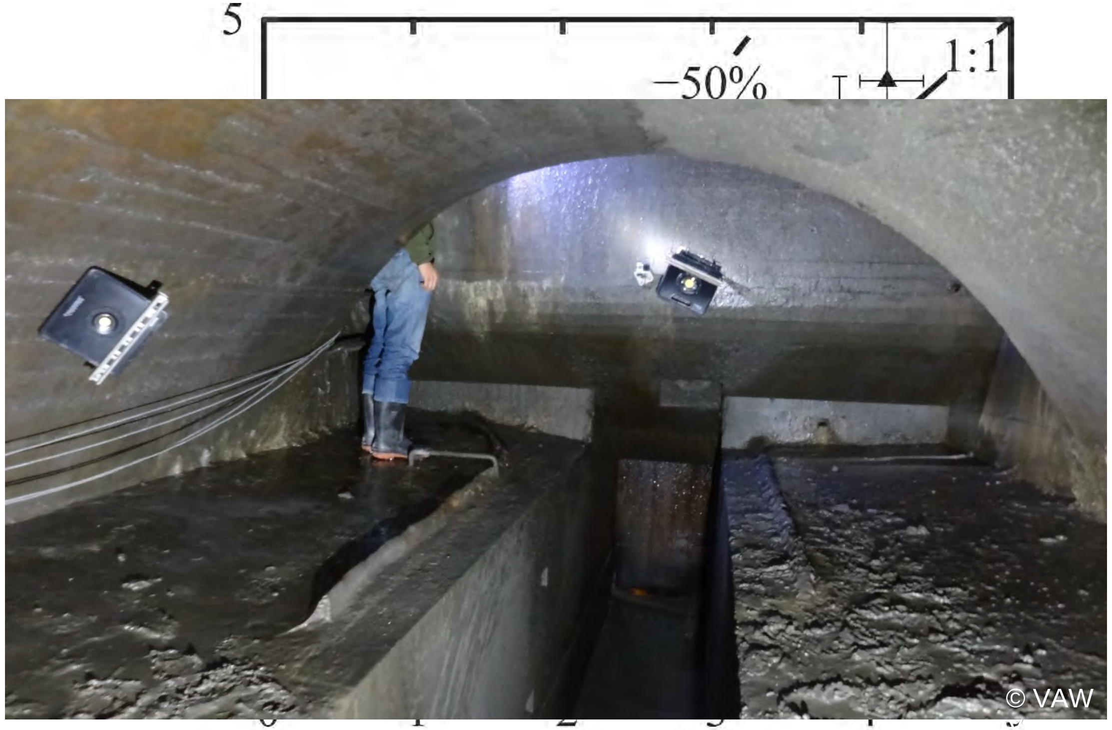
Data from literature

- Curnera (Lier & Volkart 1994) } → SF = 2
- Mauvoisin (Schilling 1963) }
- Norfork (USACE 1954) → SF = 1.2
- Panix (Volkart & Speerli 1994) → SF ~ 3

Safety factors (SF) for practical applications

- No profile transition SF = 1.2
- Smooth profile transition SF = 2
- Abrupt profile transition SF = 3 to 4

(Levin 1965, Sharma 1973)



Bottom outlet gate Luzzone

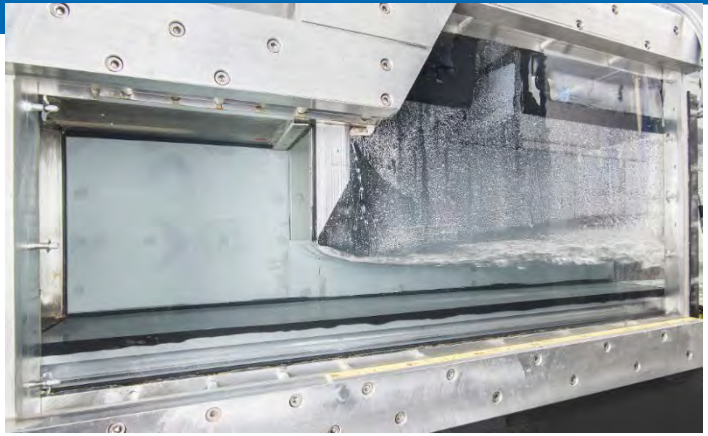
Prototype tests at Malvaglia and Luzzone

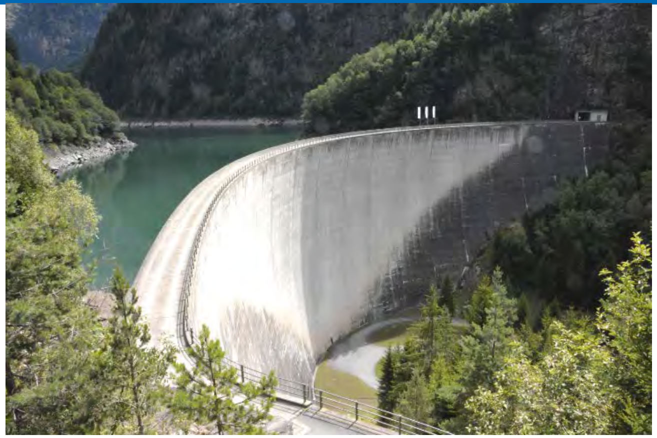
In cooperation with Ofible, financially supported by Lombardi Engineering Foundation

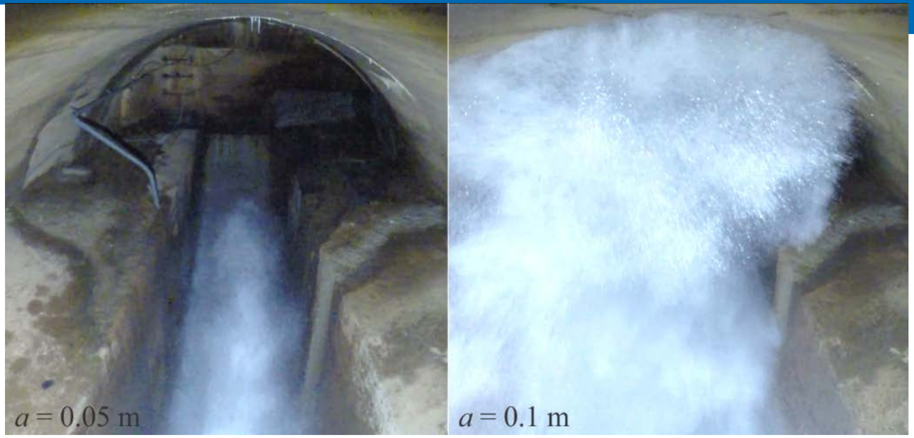
Conclusions & Outlook

- Increased process understanding from physical model tests
- Improved design equation
- First validation of model results with prototype data from literature

- More high-quality prototype data needed to further reduce uncertainty for upscaling & practical applications
- Numerical design tools require further development







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Funding: Swiss National Science Foundation, Grant 163415
Lombardi Engineering Foundation (Prototype tests)

Partner: Officine Idroelettriche di Blenio SA (Prototype tests)

Project: Swiss Competence Center for Energy Research – Supply of Electricity

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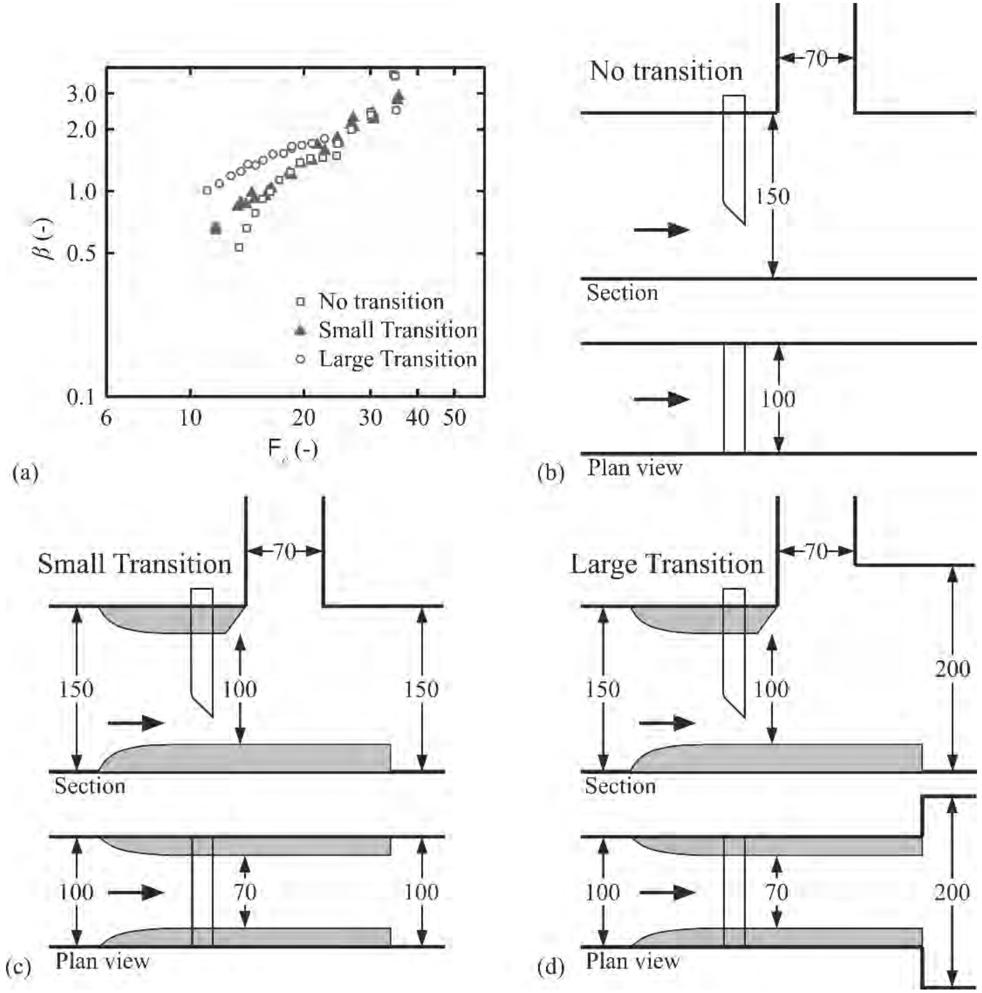
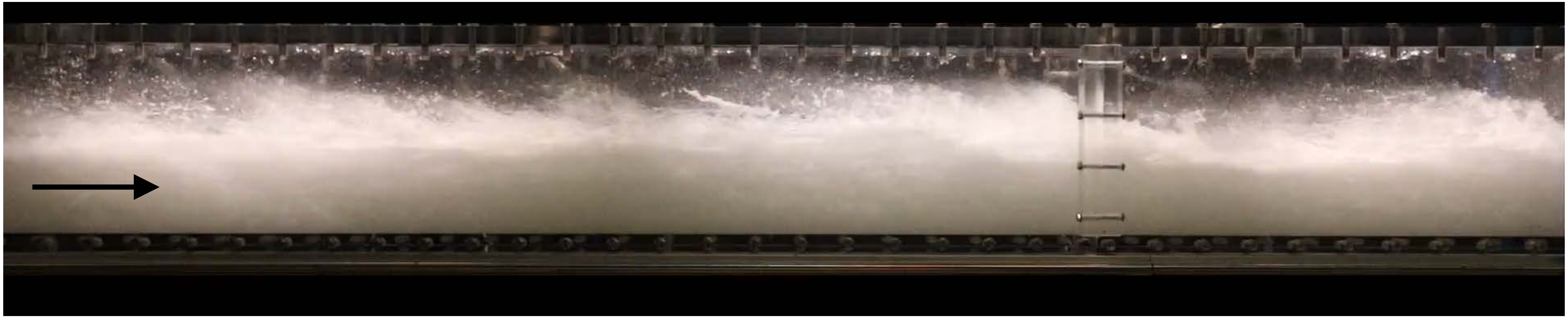
Air demand: Effect of Profile Transition

- tesg



Model Tests: Slug flow

Effect of air vent loss coefficient ζ



Physical model

Scale effects

1) Air entrainment: Limiting Weber number W > 170 (Skripalle 1994)
2) Jet break-up: Same regime

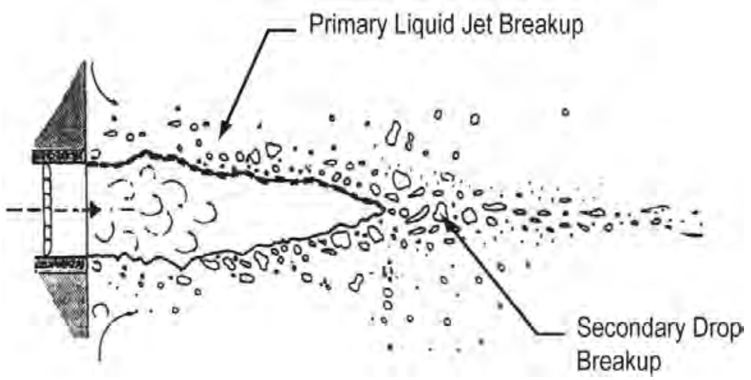
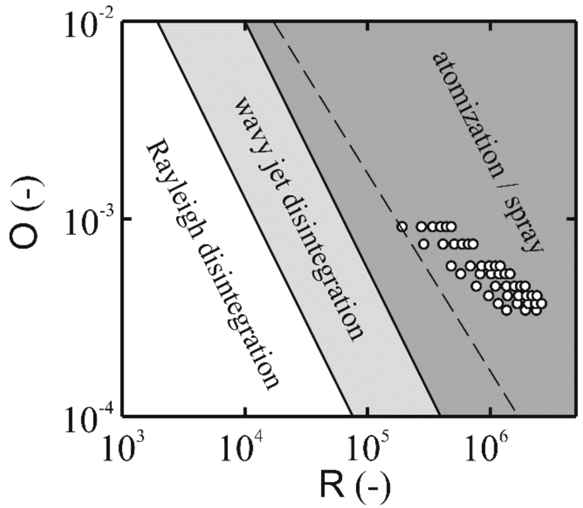
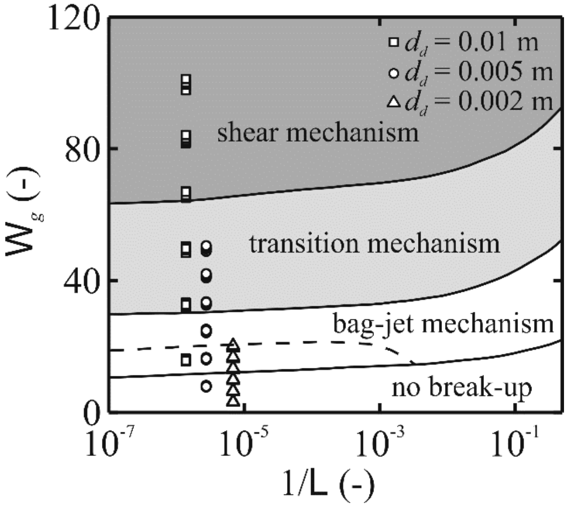


Illustration of jet break-up (Trinh 2007)





(left) Primary jet break-up (Ohnesorge 1936)
(right) Secondary jet break-up (Krezeczkowski 1980)

$W = (u^2 \rho L/\sigma)^{0.5}$
$R = uL/\nu$
$O = W/R$
$L = (\rho\sigma L)/\eta^2$

L = reference length
u = reference velocity
η = dynamic viscosity
ν = kinematic viscosity
ρ = density
σ = surface tension coeff.

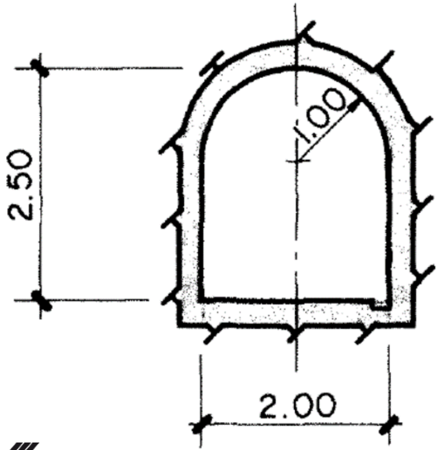
Prototype Tests HPP Blenio

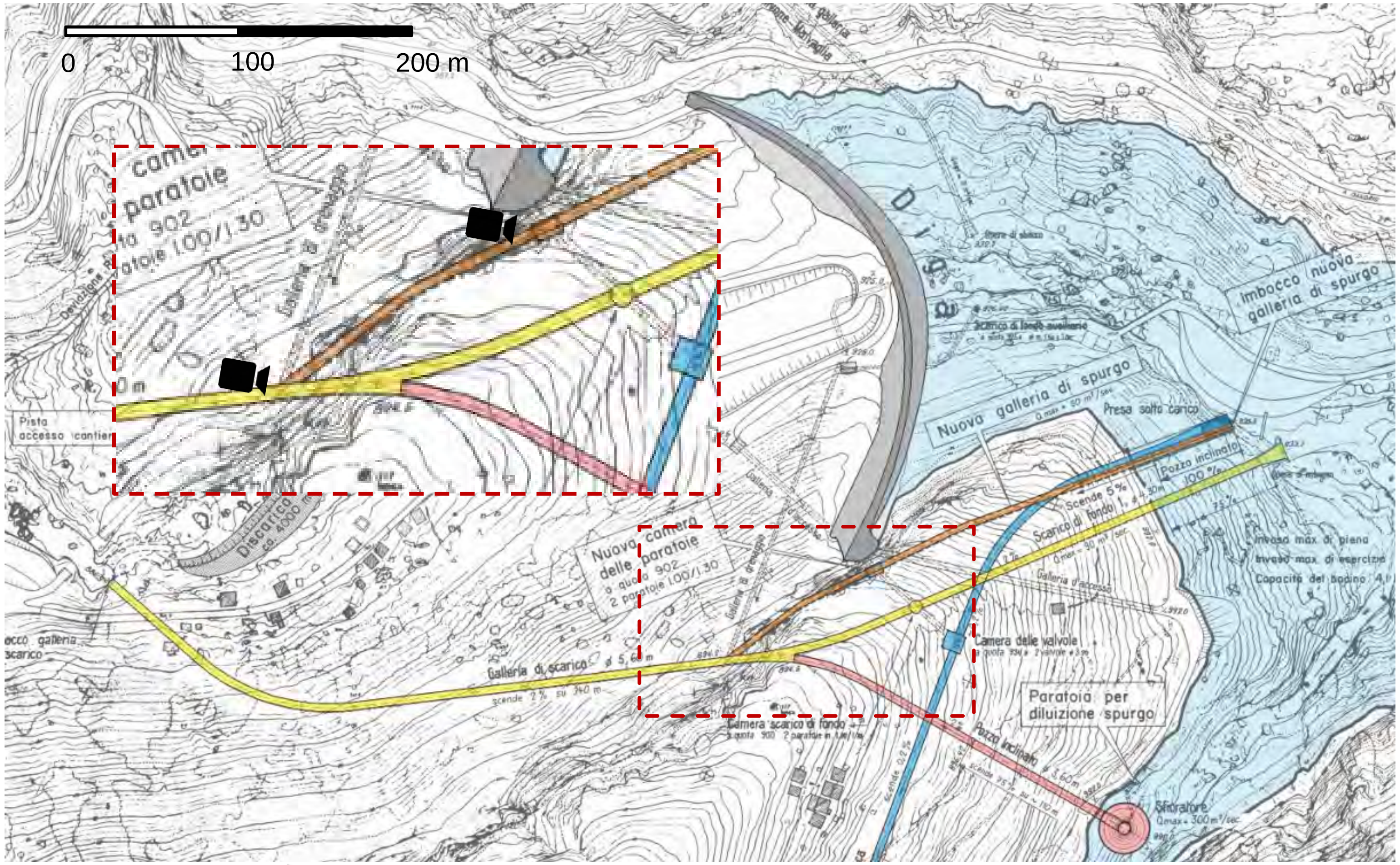
Luzzone and Malvaglia dam

New bottom outlet

- Scale compared to phys. Model $\lambda \approx 10$
- H_E = 82 m w.c.
- L = 82 m

Section A-A



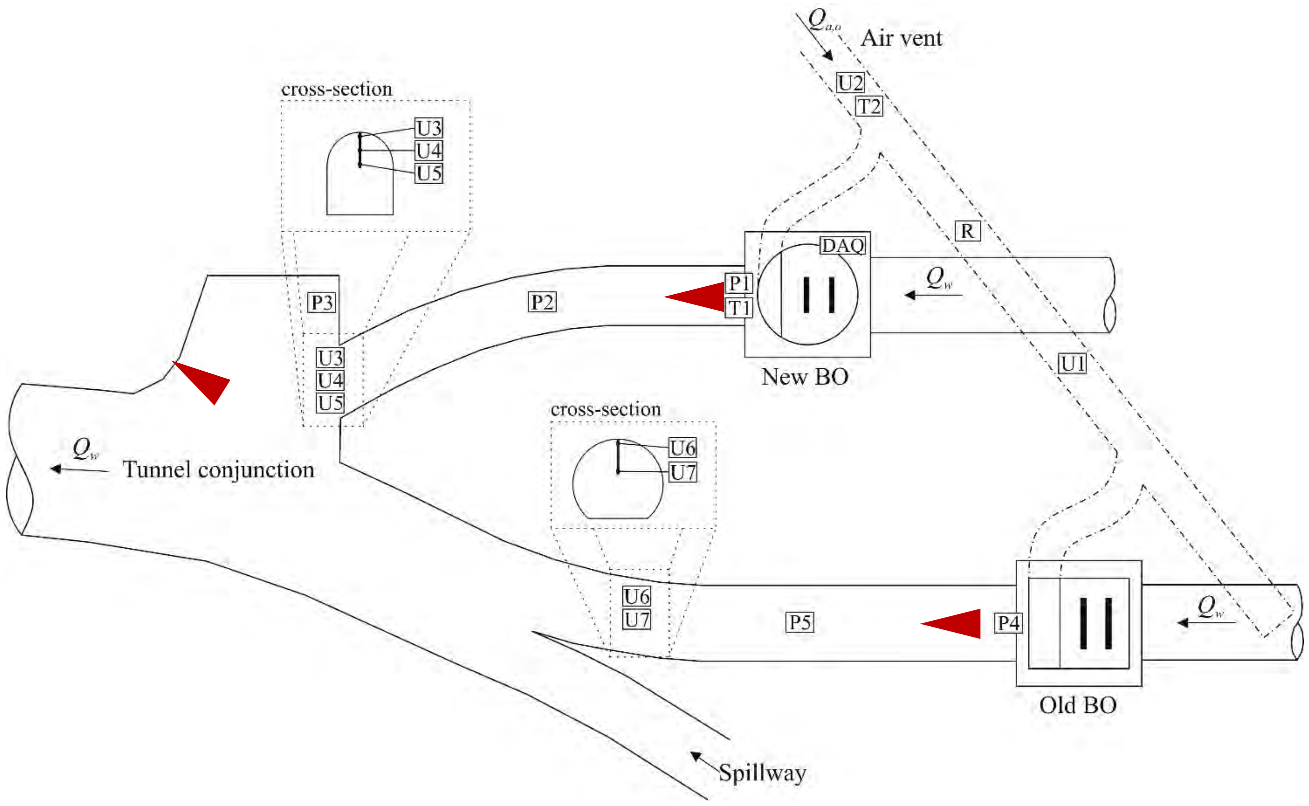


Malvaglia Test Site

Instrumentation

Measurement of:

- Air vent discharge $Q_{a,o}$
- Air flow from d/s $Q_{a,u}$
- Air vent loss coefficient ζ
  - Air pressure p_a
  - Air temperature T_a



U1-2: Vane anemometers 0-120 m/s

U3-7: Vane anemometers -60-60 m/s

P1-5: Absolute pressure sensors 700-1200 mbar

T1-2: Air temperature sensors -30-40°C

R: Flow direction sensor 0-360°

Prototype Tests: Preliminary Results

New Bottom Outlet Malvaglia

- Influence of flow pattern
- Influence of F_c
- Influence of ζ