Orifices as throttle for surge tank adaptations during a refurbishment by increase of installed capacity

Dr. Nicolas Adam, SHSC, Alpiq SA (previous LCH EPFL)

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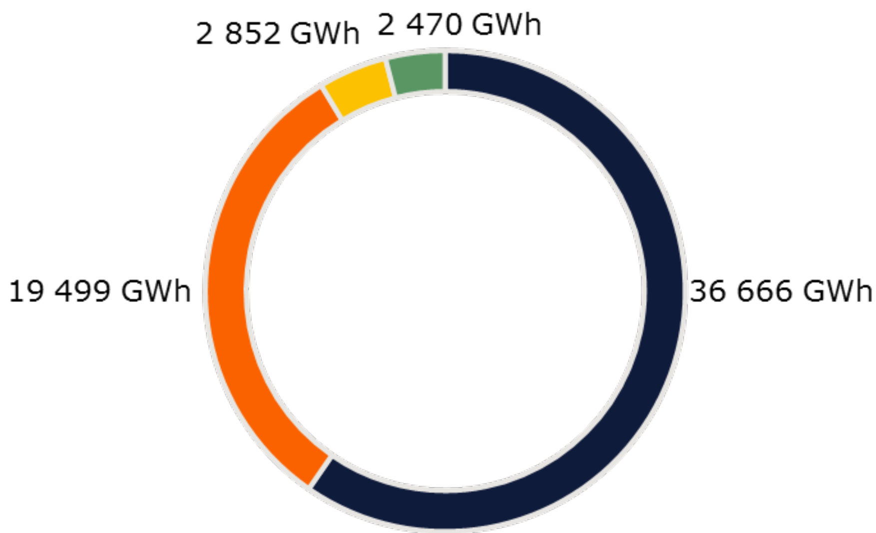
Introduction

Swiss electricity generation (2017)



- Hydro 59.6 % (run-of-river 25.9 % and storage 33.7%)
- Nuclear 31.7 %
- Thermal plant 4.6 %
- Small hydro, wind, photovoltaic, etc. 4 %

Source: BFE, Statistique globale suisse de l'énergie 217

Energy strategy 2050

- Energy efficiency
- Phase out nuclear energy
- Reduction of CO_2 emission

For hydroelectricity:

36 666 GWh/y. (now)

↓

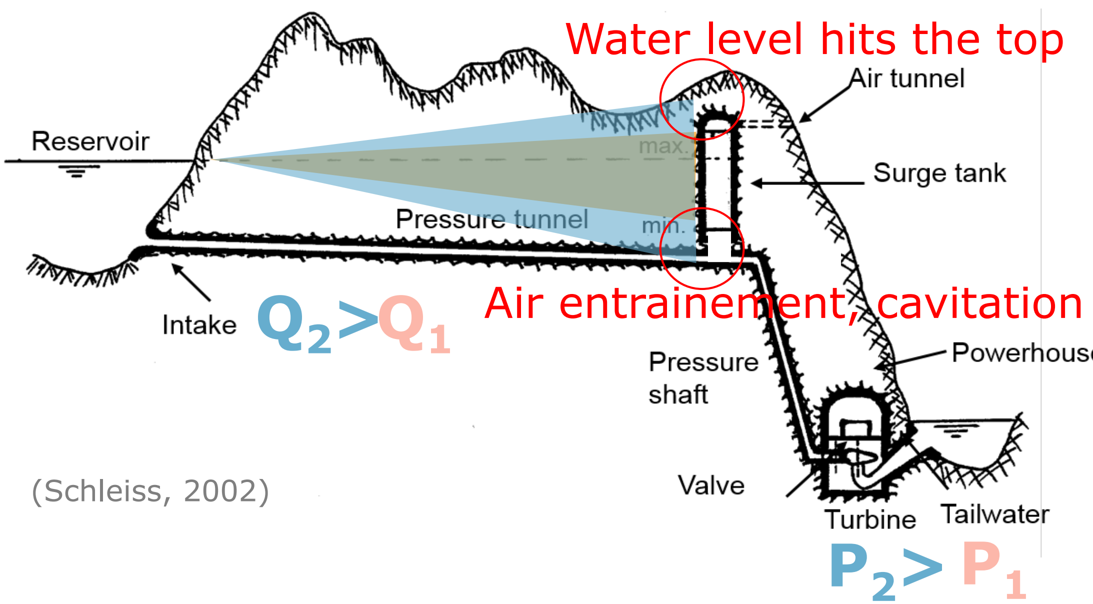
37 400 GWh/y. (2035)

↓

38 600 GWh/y. (2050)

→ Building new plants AND Refurbishing existing plants

Refurbishment



(Schleiss, 2002)

Role of a surge tank (Schleiss,2002 ; Chaudry, 1987)

- Reduce, i.e. eliminate, the water hammer in the pressure tunnel
- Damp of the acceleration and deceleration of flow in the pressure tunnel
- Improve the regulation of turbines

Main function principle and consequence

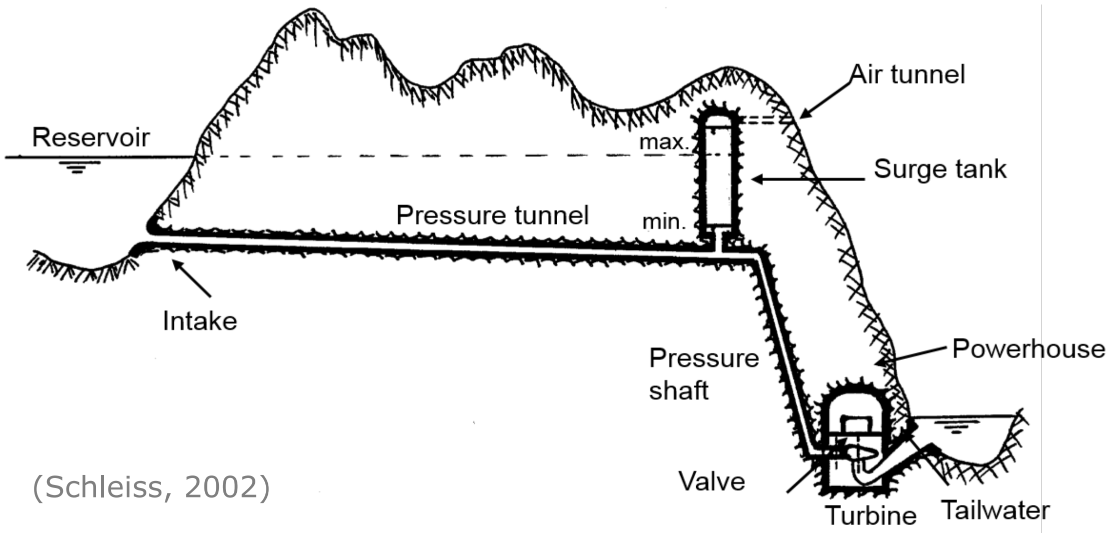
- Mass oscillation
  → Limit oscillations with extreme upsurge and downsurge

Current situation

Decision of a refurbishment: Heightening of dam (more head) or increase of installed generation capacity (more MW)

Usually, a refurbishment of the hydraulic machinery induces an increase of discharge. This increase leads to increase (resp. decrease) maximum (resp. minimum) water level in the surge tank.

Introduction
Efficient solution



(Schleiss, 2002)

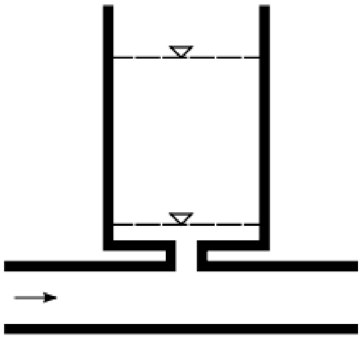
- For a reasonable increase of discharge (power capacity), the placement of a throttle is often an appropriate and economical solution
- This small modification influences the transient behavior of the whole waterway system.
- Throttles in surge tank are critical structural elements from which depend the good functioning of the whole power plant.

For a closure:

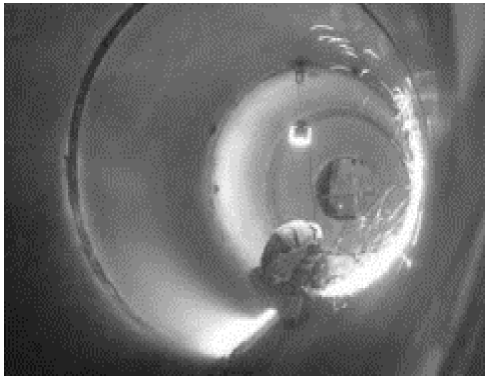
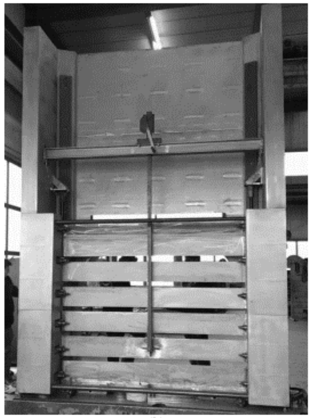
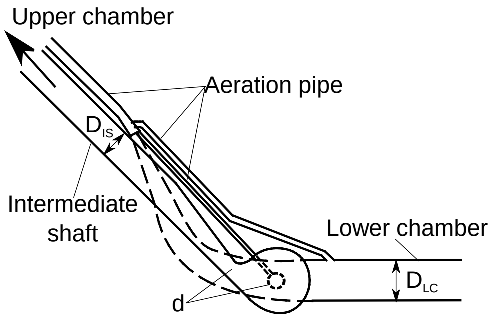
- The excess discharge flowing in the pressure tunnel goes in the surge tank

- The pressure (head) under the ST is equal to the water level in the ST ***+ the head losses produced by the orifice***

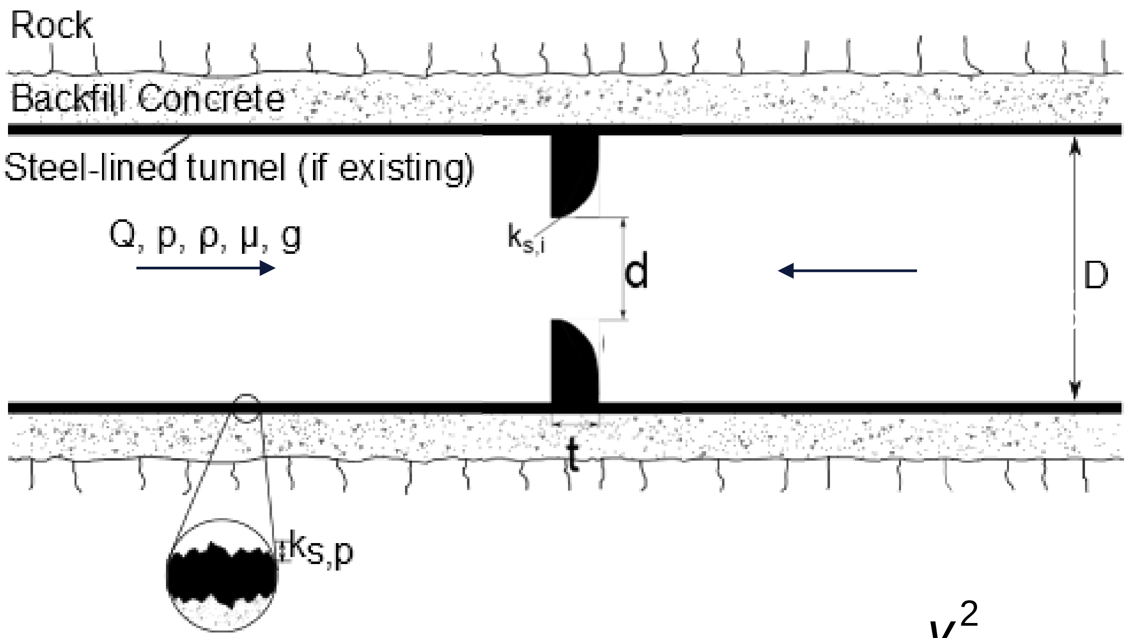
Throttled surge tank



Different types of throttle

Orifice	Racks / Bar screen	Vortex throttle
 *FMHL +* (Hachem et al., 2013)	 *Gondo* (Adam et al., 2018)	 (Steyrer, 1999)

Introduction
Orifice



Contraction parameter $\beta = \frac{d}{D}$

Thickness parameter $\alpha = \frac{t}{D}$

Inner thickness parameter $\alpha_i = \frac{t_i}{D}$

Chamfer angle θ

$$\Delta H = k \frac{v^2}{2g}$$

Comments

- k and v are related to a reference area.
- k is the head loss coefficient containing all boundary conditions (i.e. the upstream and downstream conditions), recirculation, flow contraction or expansion, etc.

Modeling

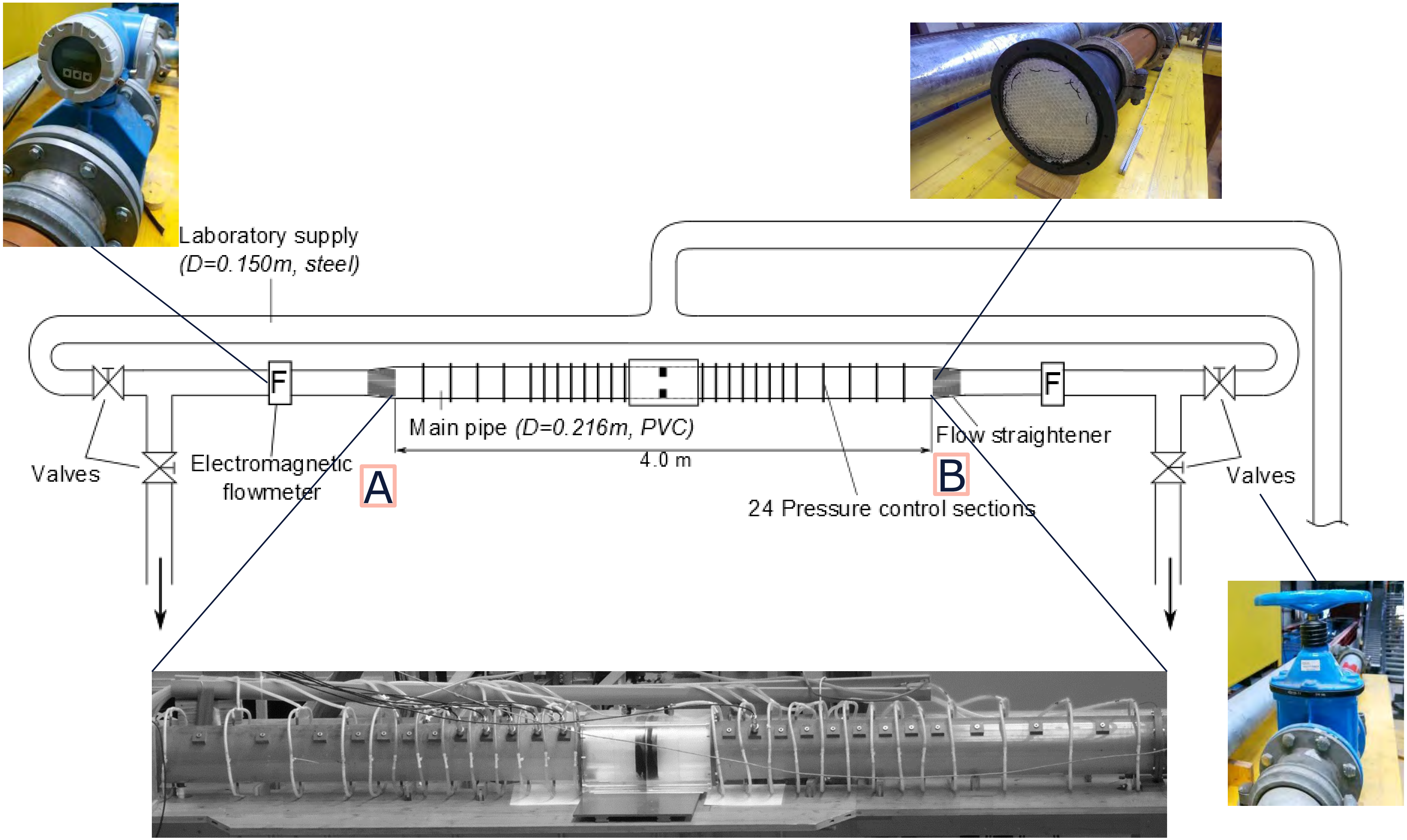
Two different approaches: Experimental and numerical

	Experimental	Numerical
Head loss evaluation	S T	S
Influence length	S	S
Reattachment length		S
Cavitation risk		S

S Steady discharge

T Transient discharge

Modeling
Experimental facility



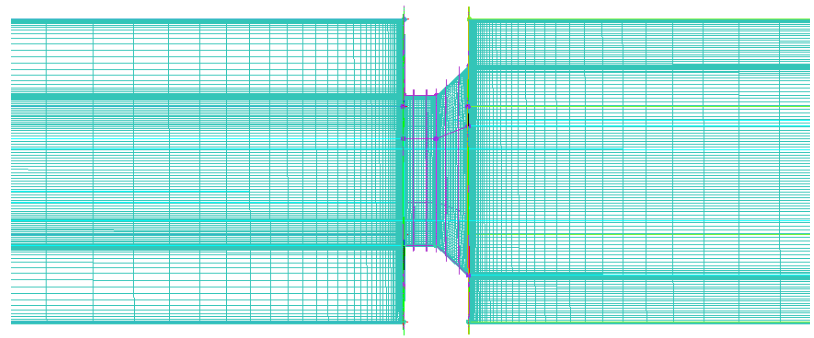
Numerical geometry

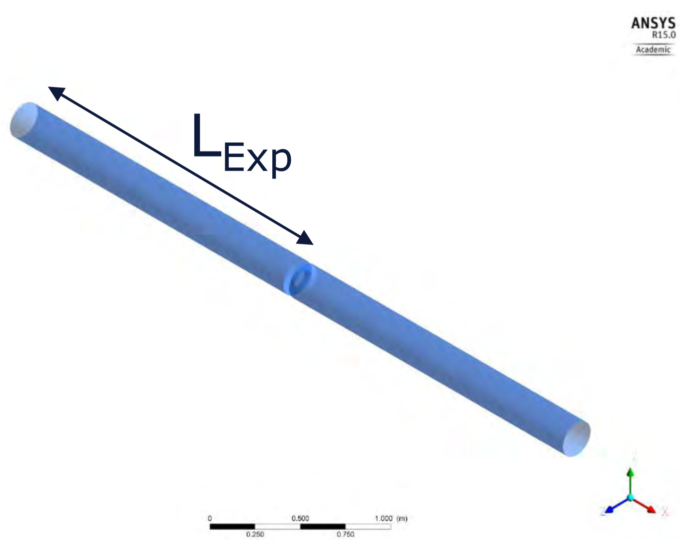
Numerical model Ansys CFX Version 17.1 or Version 15.0

Validation experimental results

Goal

- Extend to other geometries
- More detail inside view
- Reattachment length
- Cavitation risk





Mesh

- Hexahedrons
- ca. 1.2 million elements

Turbulence model

- SST model

Boundary conditions

- Inlet: Velocity
- Outlet: Pressure

Head loss evaluation

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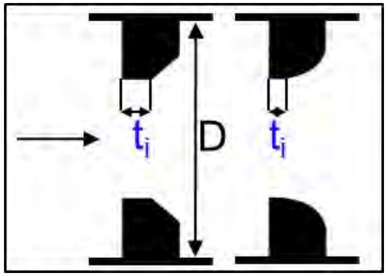
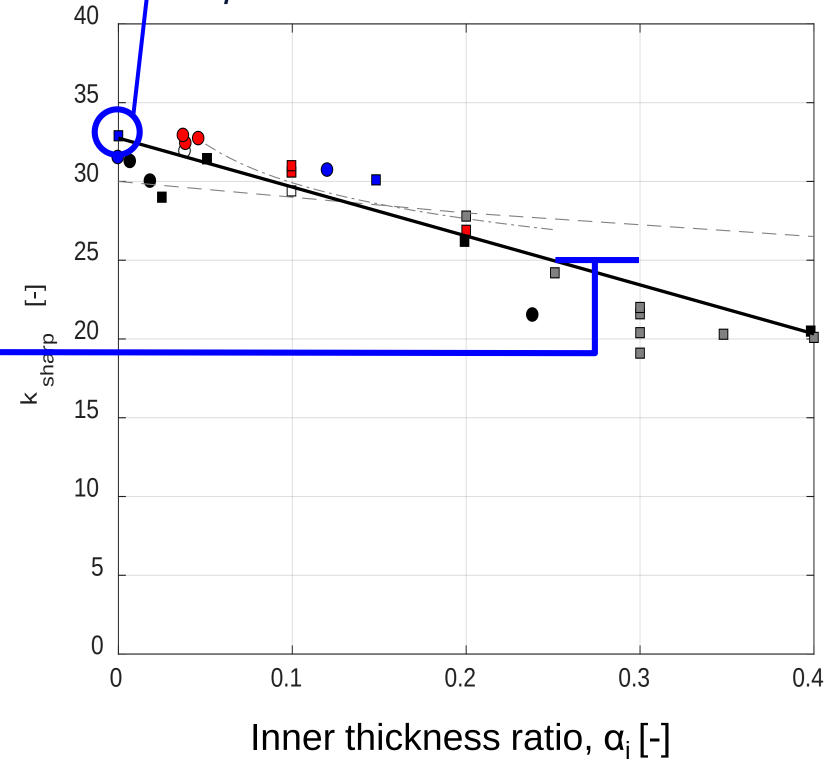
Materials Experimental and numerical results



Empirical equations

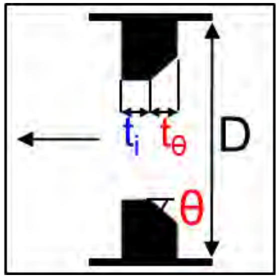
$$k = \lambda_k \cdot \Gamma_{\alpha i} \frac{\left(1 + \tau\sqrt{1-\beta^2} - \beta^2\right)^2}{\beta^4}$$

- Sharp approach flow
  - $\lambda_k = 1$
  - $\Gamma_{\alpha i} = 1 - 0.947\ \alpha_i$



Head loss evaluation

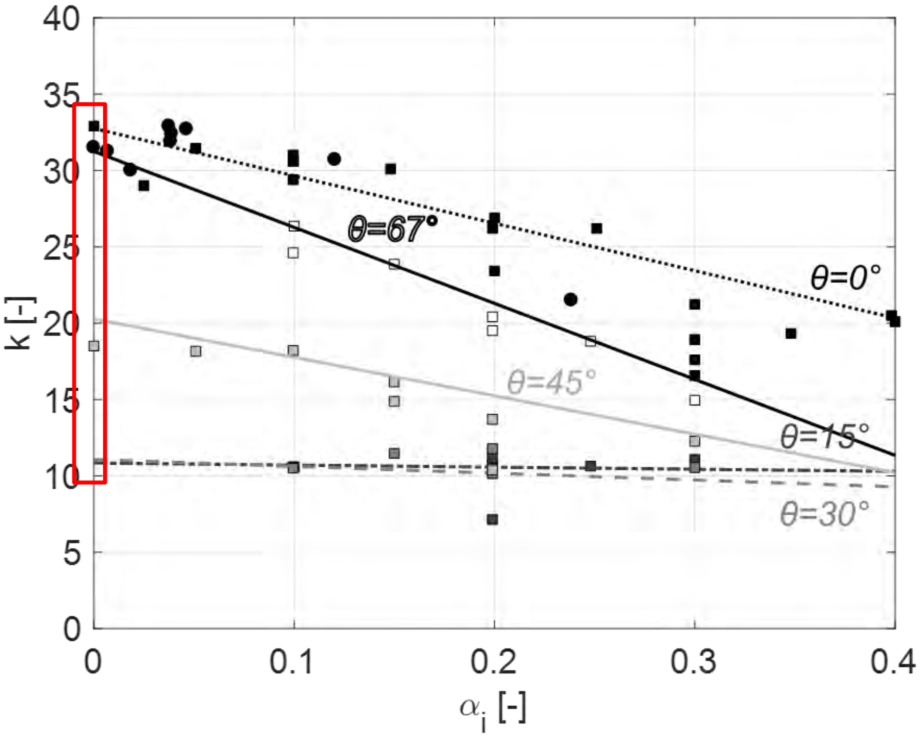
Materials Experimental and numerical results



Empirical equations

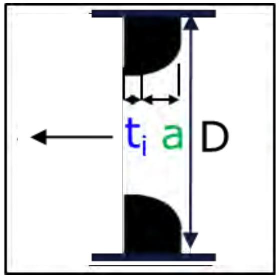
$$k = \lambda_k \cdot \Gamma_{\alpha i} \frac{\left(1 + \tau\sqrt{1-\beta^2} - \beta^2\right)^2}{\beta^4}$$

- Chamfer approach flow
  - $\lambda_k = \frac{\lambda_k^0(\theta)\alpha_\theta + 0.0125}{\alpha_\theta + 0.0125}$
  - $\Gamma_{\alpha i}(\theta, \alpha_\theta) = 1 - \kappa(\theta, \alpha_\theta)\, \alpha_i$



Head loss evaluation

Materials Experimental and numerical results



Empirical equations

$$k = \lambda_k \cdot \Gamma_{\alpha i} \frac{\left(1 + \tau\sqrt{1-\beta^2} - \beta^2\right)^2}{\beta^4}$$

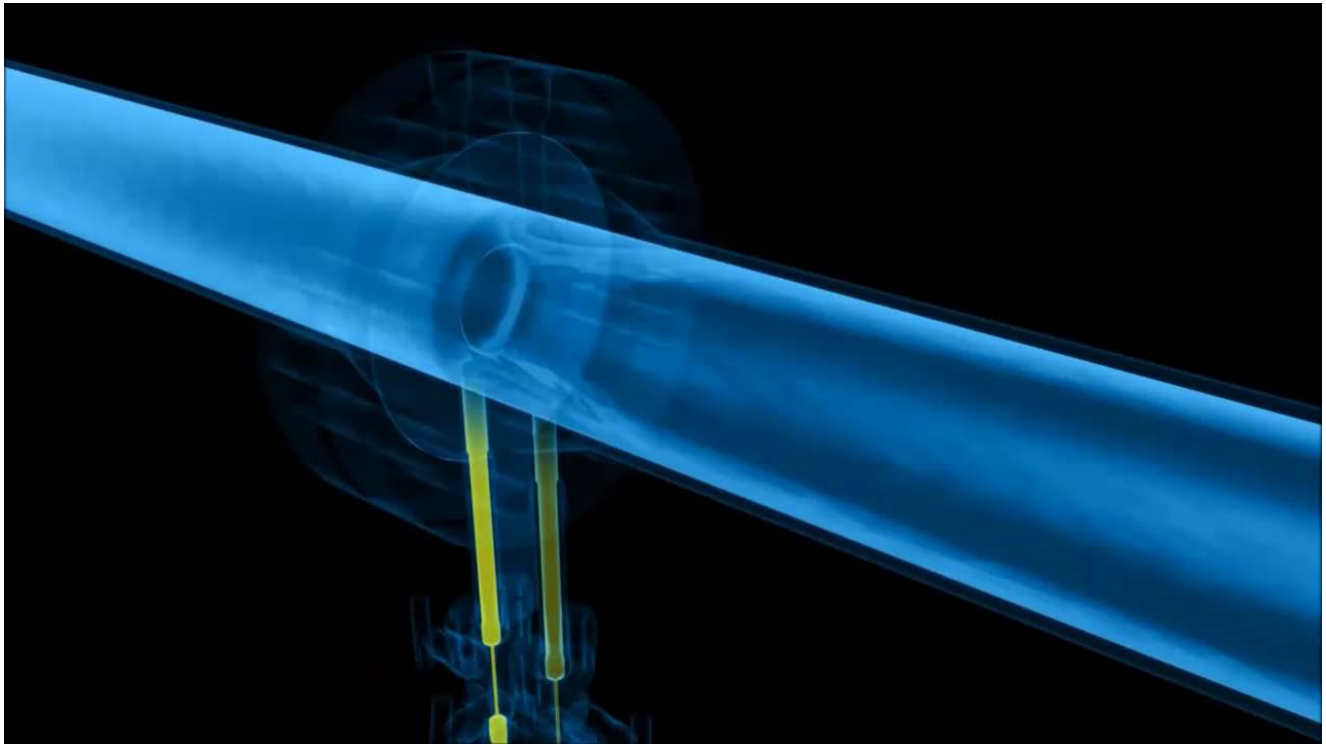
- Rounded approach flow
  - $\lambda_k = \frac{0.271\alpha_a + 0.0125}{\alpha_a + 0.0125}$
  - $\Gamma_{\alpha i}(a) = 1 - \kappa(a)\,\alpha_i$

!!! The head loss coefficient does not depend on the rounded shape !!!

Characterizing lengths

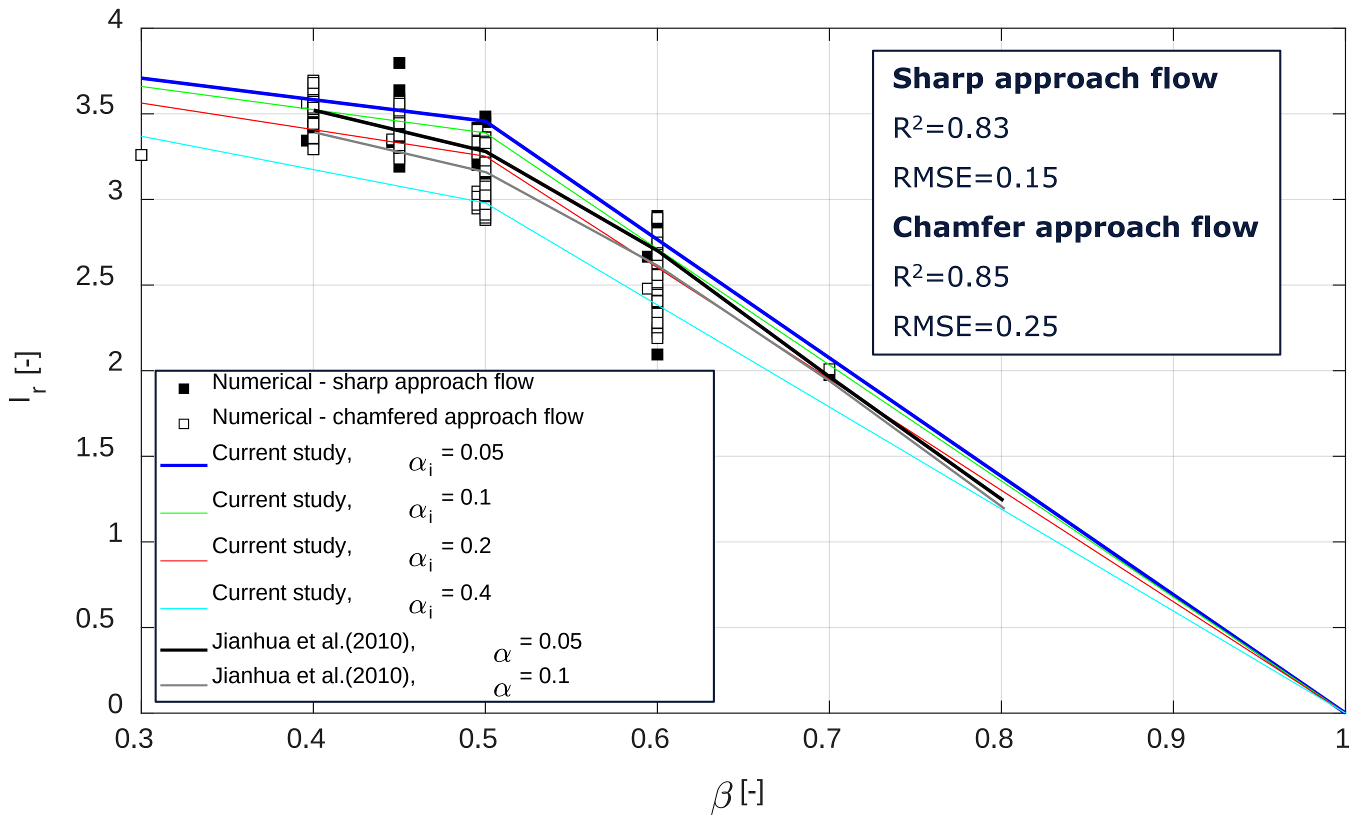
Materials Numerical results

Definition Reattachment and influence length



Endress+Hauser, The Differential Pressure Flow Measuring Principle (Orifice-Nozzle-Venturi).
YouTube video : https://www.youtube.com/watch?v=oUd4WxjoHKY

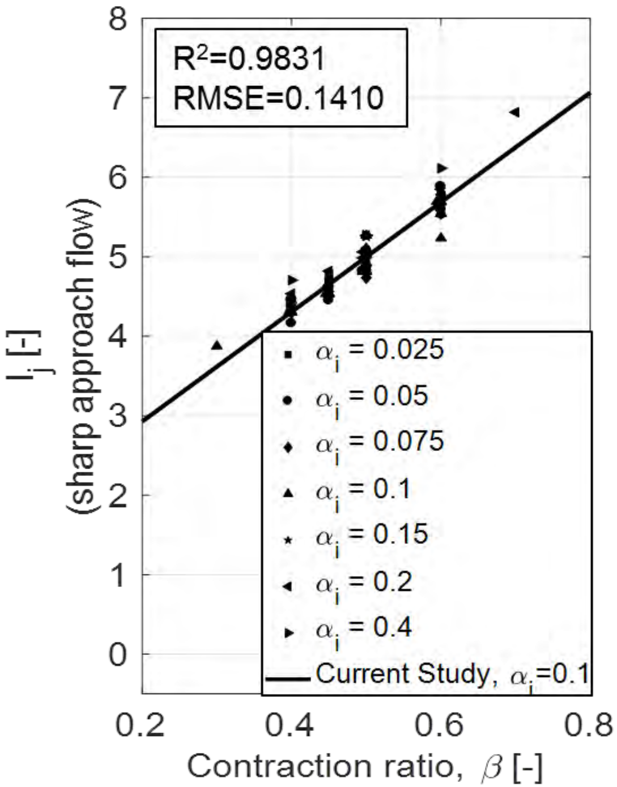
Reattachment length

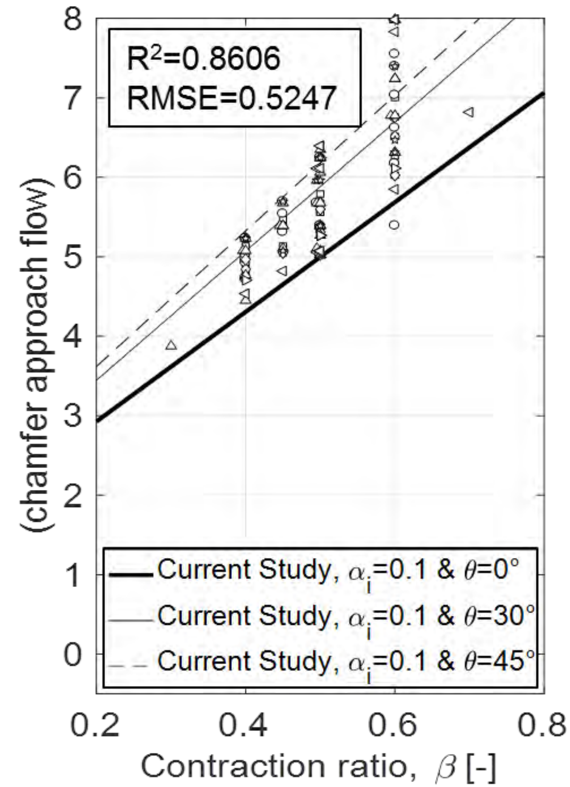


$$\begin{cases} l_r = (-5.46\alpha_i + 14.1)\cdot\gamma_o & \text{for} \quad \beta \geq 0.5 \\ l_r = (3.95\alpha_i + 2.32)\cdot\gamma_o + (-2.35\alpha_i + 2.95) & \text{for} \quad \beta < 0.5 \end{cases}$$

L_r does not depend on the approach flow. L_r depends on β and α_i.

Influence length





$$l_{j,sharp} = 1.47 + 6.90\beta + 0.77\alpha_i$$

$$l_{j,chamfer} = \left(1.47 + 6.90\beta + 0.77\alpha_i\right) \cdot \lambda_j$$

$$\text{with } \lambda_j = \left[1 + \left(0.97\alpha_i + 0.14\right)\sin^2\left(2\theta\right)\right]$$

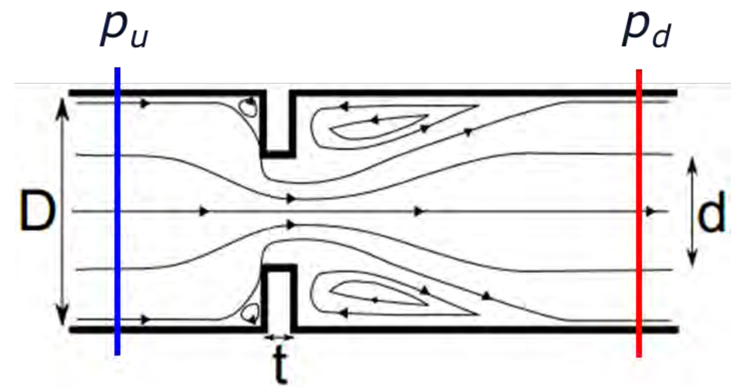
L_j depends on the sharp or chamfer approach flow. For the sharp approach, L_j depends mainly on β and α_i, while it depends also on θ for chamfer approach.

Cavitation risk

Cavitation number

$$\sigma = \frac{p_u - p_{min}}{p_u - p_d}$$

p_{min} is the minimum pressure in the pipe



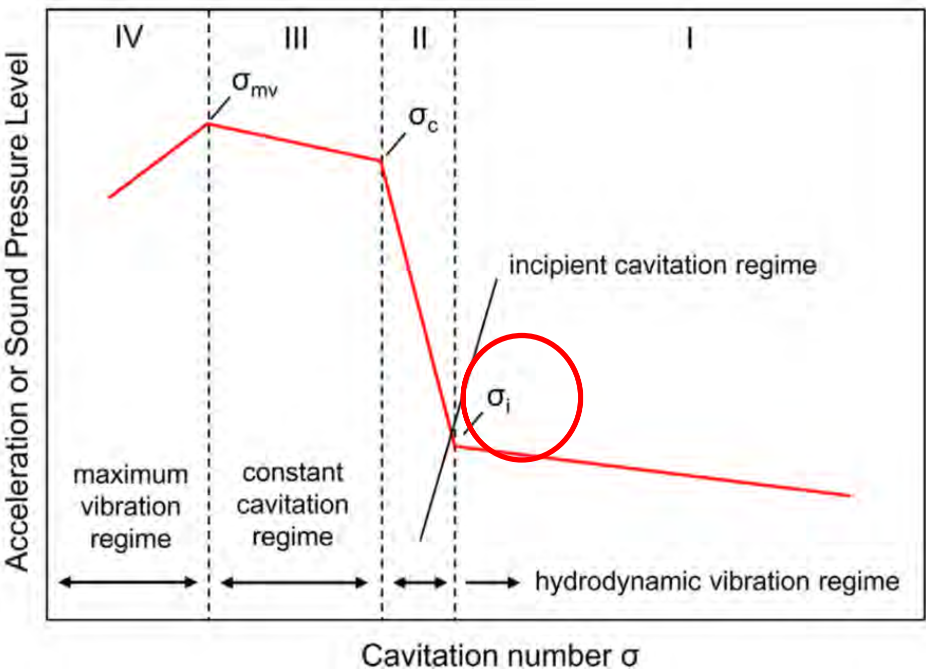
Data Incipient cavitation number

$$\sigma_i = \frac{p_u - p_{vg}}{p_u - p_d}$$

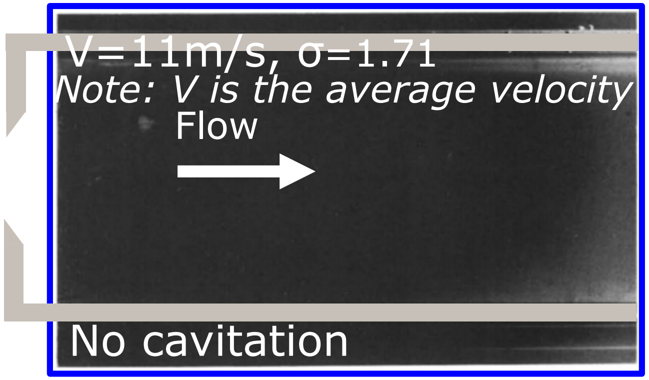
Where p_{vg} is the vapor pressure

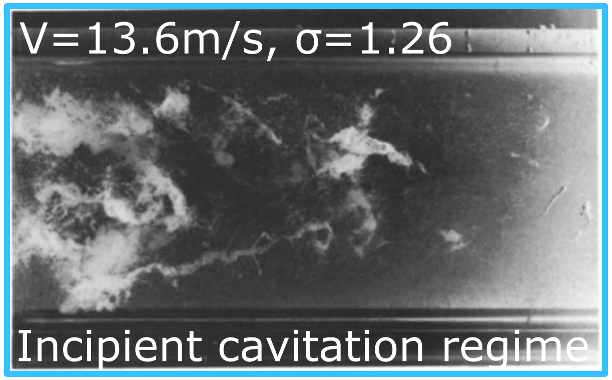
Method Single phase numerical simulations *(Ferrarese et al., 2015)*

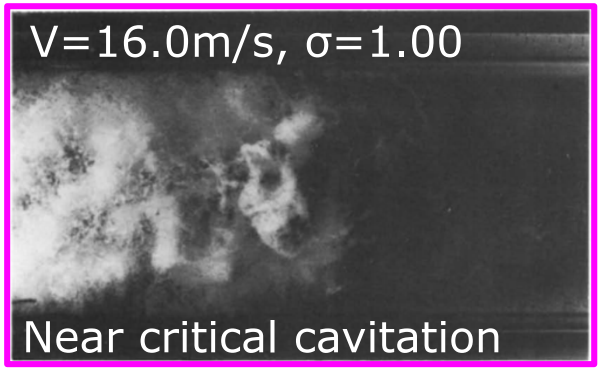
$$\sigma_i = \frac{p_u^* - p_m^*}{p_u^* - p_d^*}$$



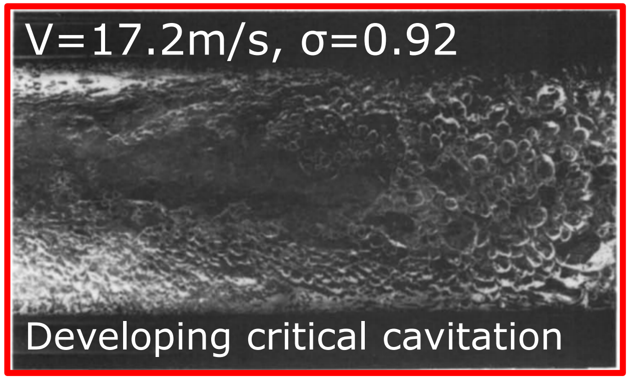
Cavitation risk

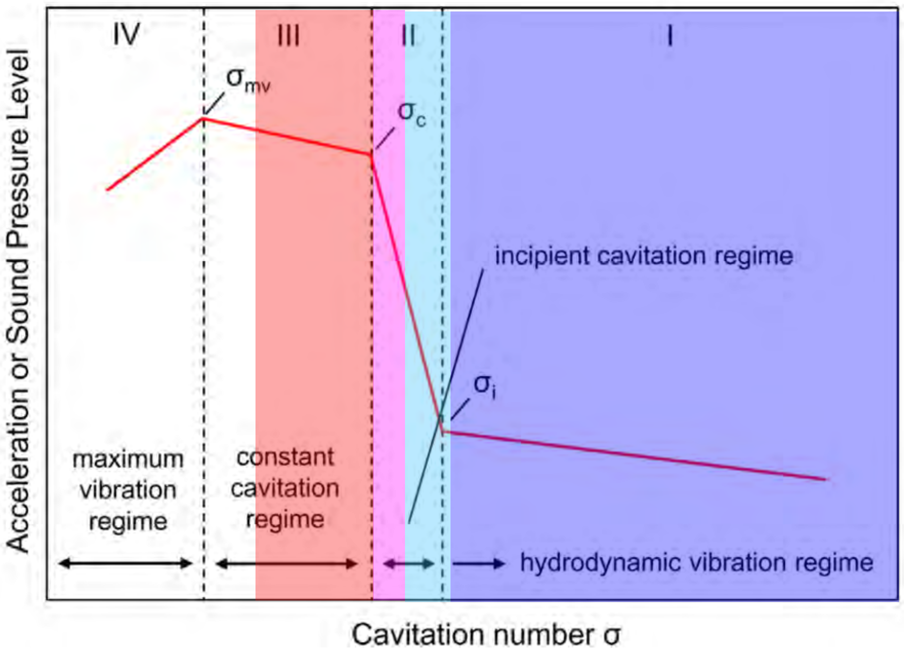






Yan & Thorpe (1990)





Incipient cavitation number remains conservative in comparison with the critical cavitation

Cavitation risk

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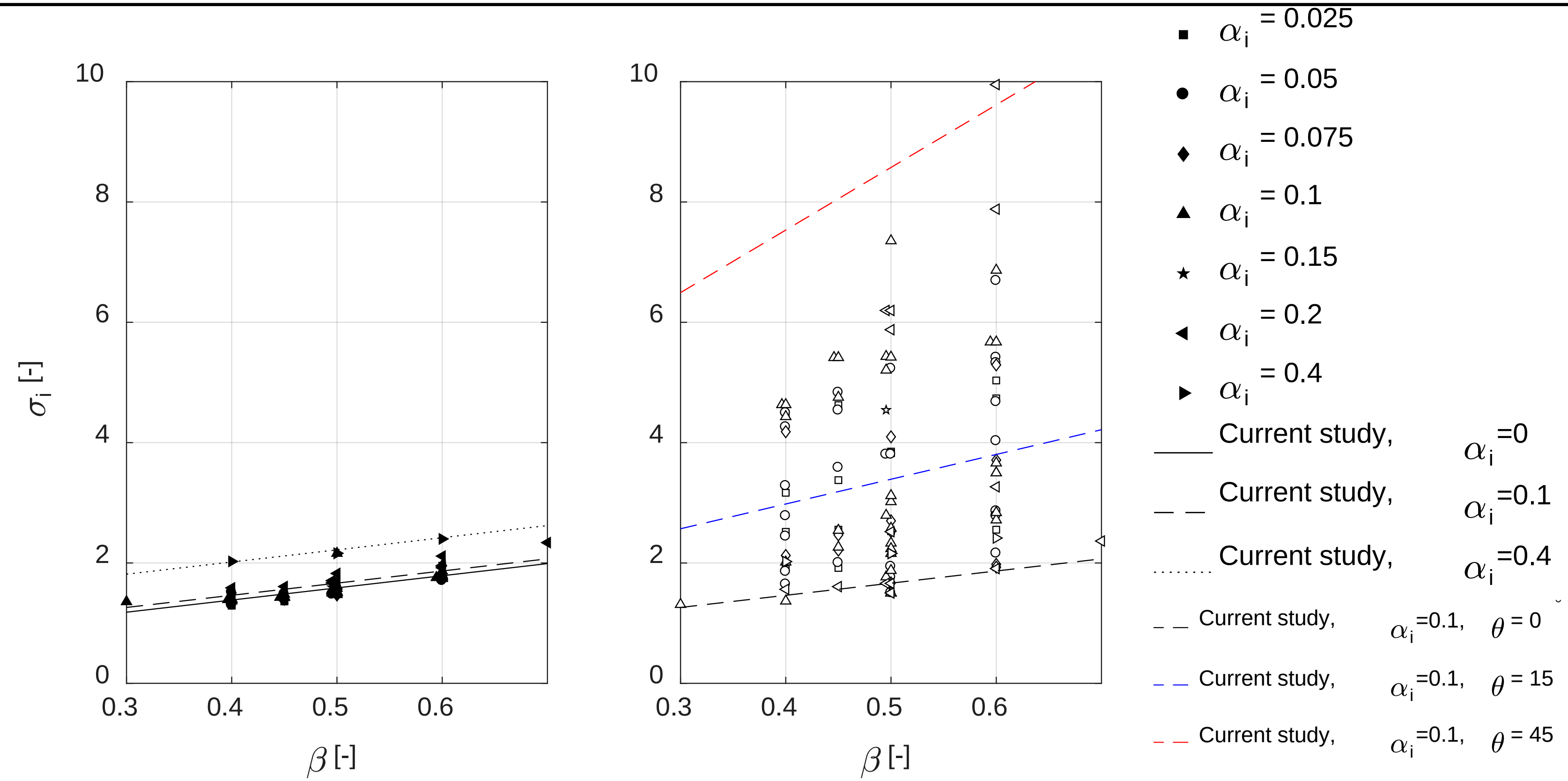

$$\sigma_i = 1 + 2.02\beta^2 + 2.50\alpha_i^{1.5}$$

$$\sigma_i = \left(1 + 2.02\beta^2 + 2.50\alpha_i^{1.5}\right)\cdot\lambda_{\sigma i}$$

with $\lambda_{\sigma i} = 1 + 4.15\sin^2(2\theta)$

→ *Conservative hypothesis, envelope curve*

Cavitation risk

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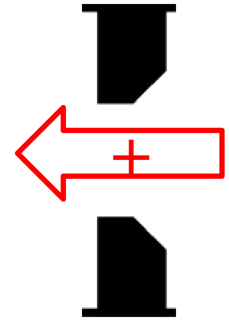
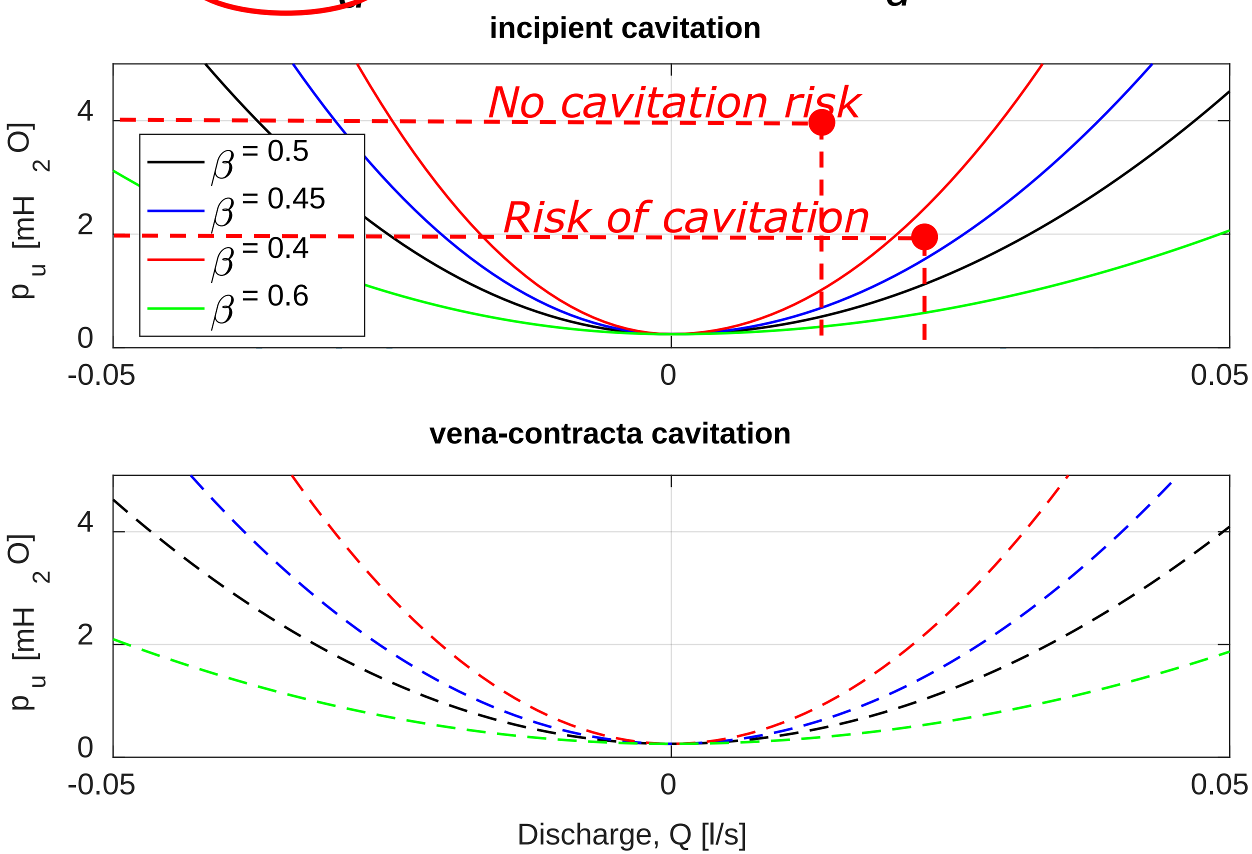
Application to a straight pipe (conduit)

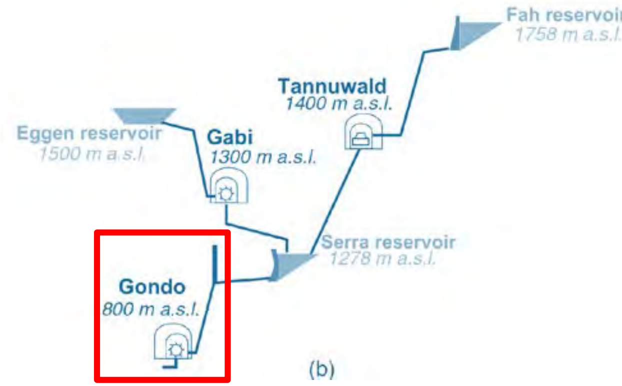
$$\sigma_i = \frac{p_u - p_{vg}}{p_u - p_d} \Rightarrow p_u = \sigma_i \cdot \frac{8}{gA_d^2} k Q^2 + p_{vg}$$



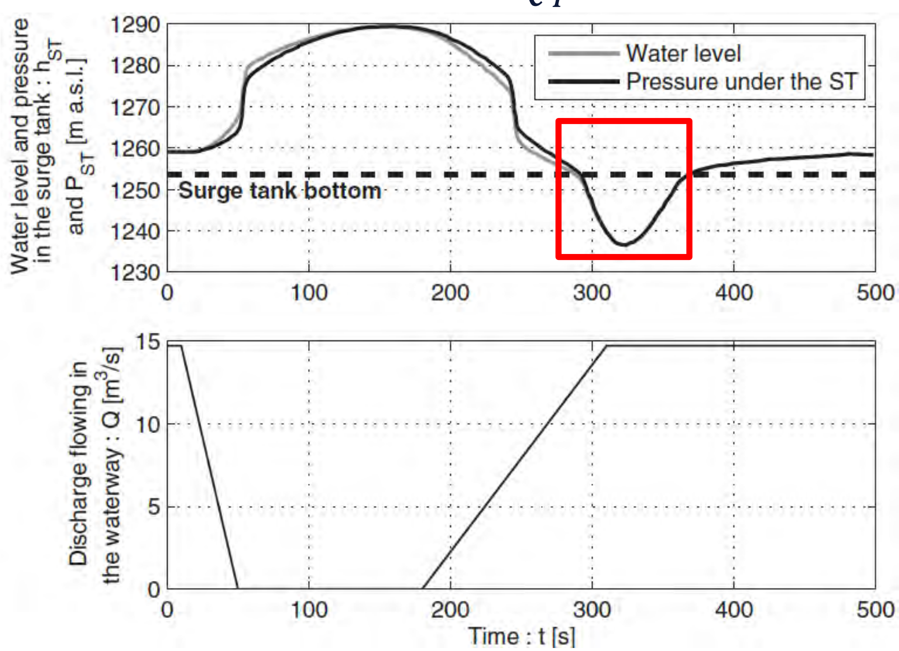


- Evaluate the maximum discharge for a given upstream pressure
- Evaluate the cavitation risk for a given orifice with a given flow characteristics

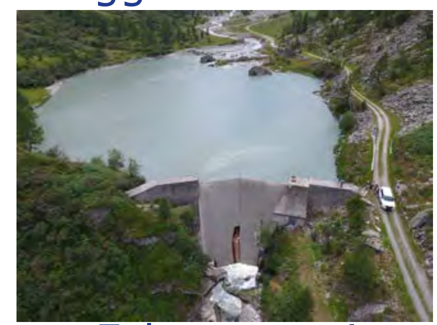
Case study
Increase of the installed turbine discharge



Renewal of the 3rd turbine $Q_T = 12.0 \ \rightarrow 14.7m^3/s$



Eggen reservoir



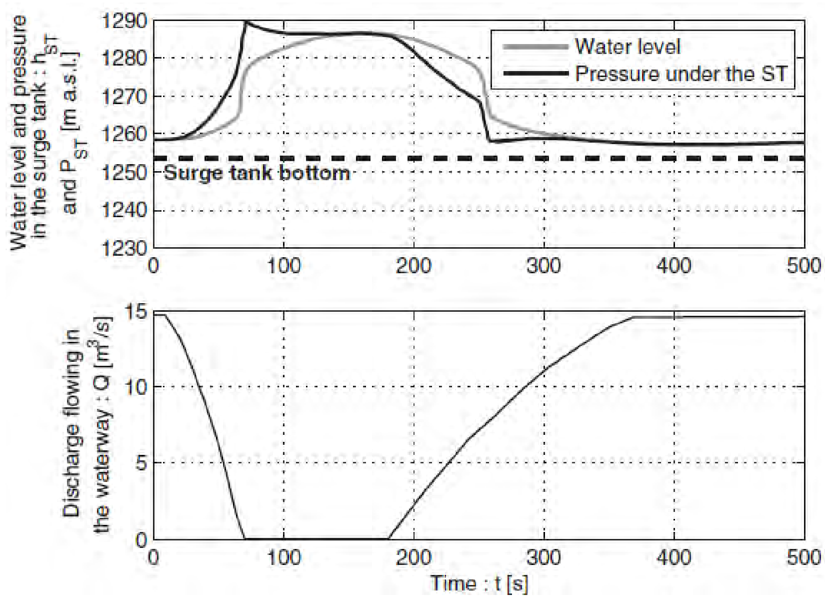
Fah reservoir

Sera reservoir

Case study
Increase of the installed turbine discharge

Placement of a throttle

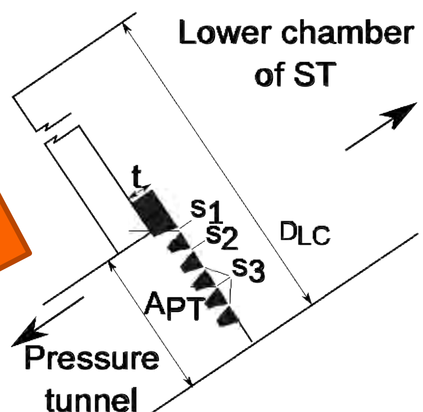
+ 13 iterations to link head losses to a geometry



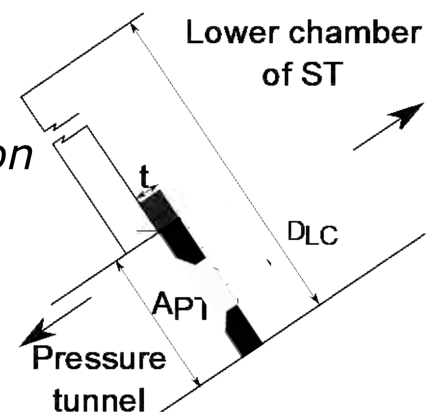
Head losses work…

BUT no information about the cavitation risk!

Throttle Geometry ≠ orifice



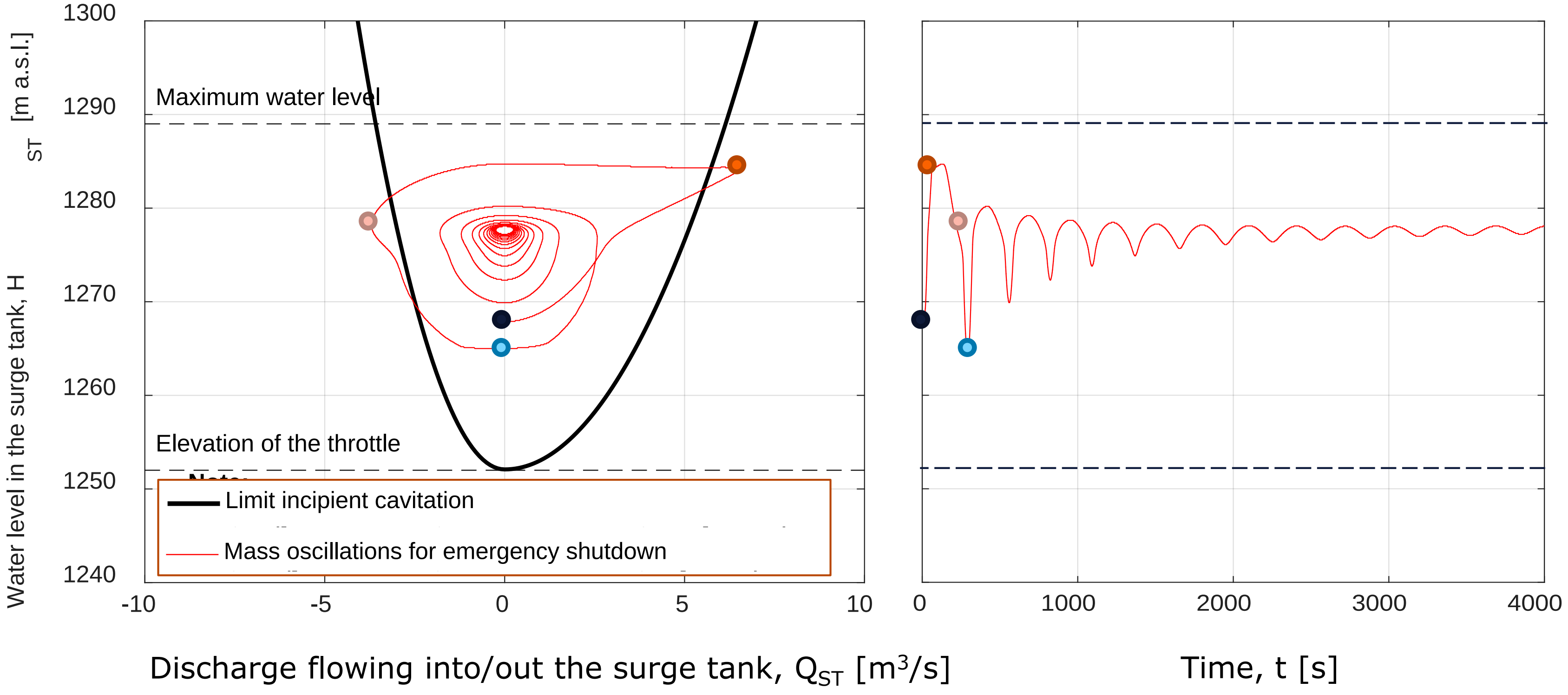
idealization



predicting

σ_i

Case study
Increase of the installed turbine discharge



Conclusions

- Based on systematic tests, different orifice geometries were characterized and help to design new surge tank orifices.

  → Head loss evaluation with empirical relations and a online catalog

  → Undisturbed flow conditions in order to use the empirical relations

  → Particular definition of incipient cavitation numbers which characterize each orifice geometry and allow comparing their behavior regarding cavitation.

Published in the next Wasser Energie Luft (3/2018)

- New method is suggested in order to evaluate the risk of cavitation at throttles of surge tanks during mass oscillations → Give new information about the throttle behaviors.

+ Exhaustive review of the throttle in the surge tank of Gondo in JHE.

Adam, N. J., De Cesare, G., Nicolet, C., Billeter, P., Angermayr, A., Valluy, B. & Schleiss, A. (2018). Design of a Throttled Surge Tank for Refurbishment by Increase of Installed Capacity at a High-Head Power Plant. Journal of Hydraulic Engineering 144(2).

Acknowledgments

Project Chopin S2C (Hydraulic characterization of surge tank orifices for high head power plants, parametrization and influence on the waterway stability) in collaboration with the HES-SO VS (Prof. Cécile Muench-Allighé)

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Confederazione Svizzera
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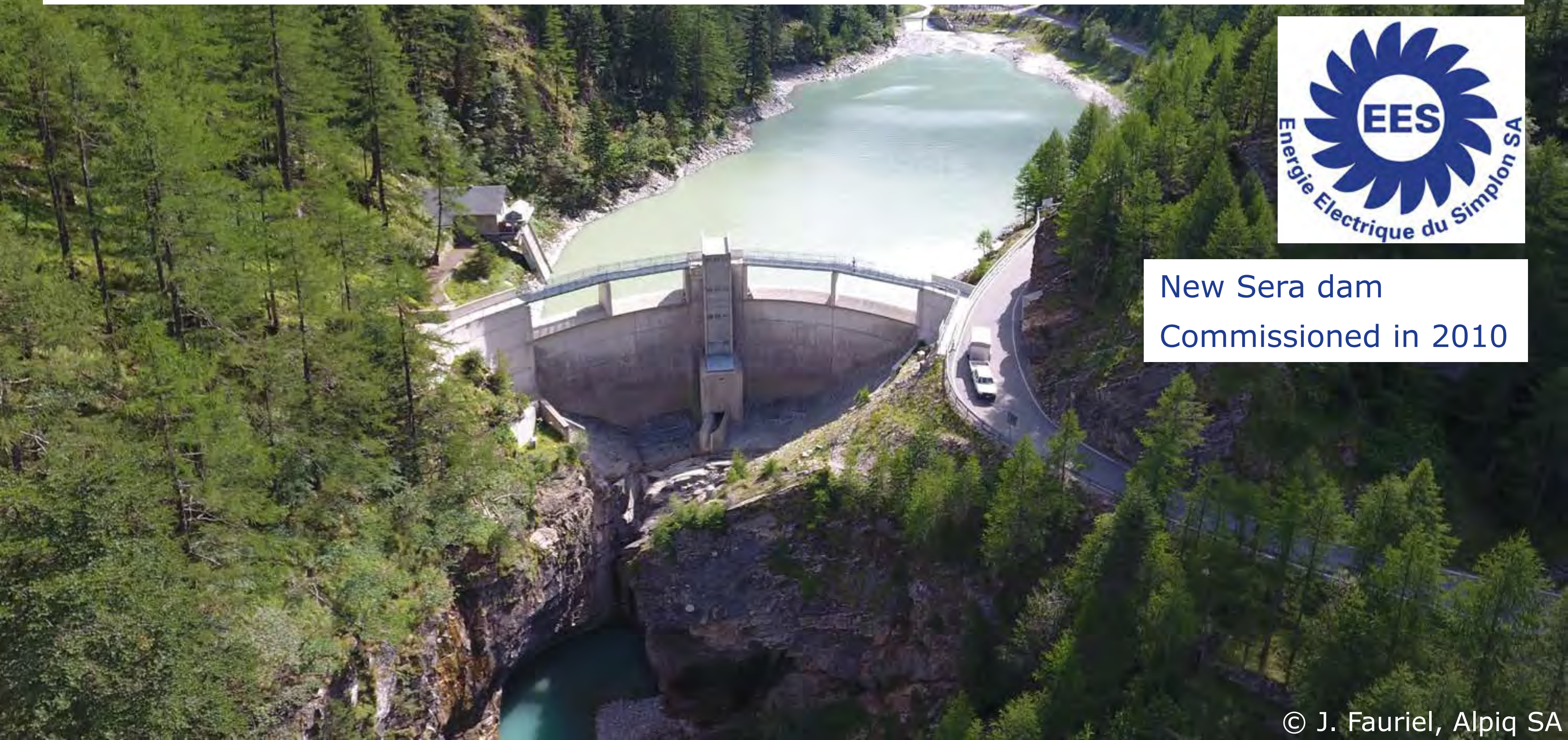
Département fédéral de l'environnement, des transports, de l'énergie et de la communication DETEC

Office fédéral de l'énergie OFEN
Section Force hydraulique

Thank for your attention

Nicolas Adam, nicolas.adam@alpiq.com
+41 21 341 25 57



New Sera dam
Commissioned in 2010