Gondo Throttled Surge Tank
Numerical Modeling and Design Review

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Introduction

Swiss energy strategy 2050 aims to phase out nuclear energy by the year 2050 and completely rely on renewable energy sources. The production of the new renewables (wind, solar) is often intermittent, hence the need to increase the hydropower production in order to control the grid stability. This increase could be done by either constructing new hydropower plants or refurbishing existing ones, a large part of which consists of high-head power plants (hydraulic head >200 m).

This study focuses on Gondo high-head power plant (HPP) in Switzerland. To increase the installed capacity, the refurbishment of this plant required a modification to the existing inclined surge tank by installing a throttle at its entrance. In a previous study, the geometry of this throttle was optimized by physical modeling to achieve the target loss coefficients as identified by a transient 1D numerical analysis. The goal is to complement previous analyses by: (i) investigating the performance of the designed rack throttle of Gondo HPP by combined 1D and 3D numerical modeling tools; and (ii) establishing a consolidated design methodology of throttled surge tanks.

Methodology

Procedure: A new 1D numerical model is constructed on Hytran (387.5.17). It is then calibrated and validated with on-site measurements. Results can serve as an input for transient CFD analysis. Model also serves as a tool to investigate the effect of CFD findings on 1D transient analysis results.
Then, two geometries are created on ANSYS CFX (2019 R1): **G01** (without a throttle) and **G02** (with a throttle).

Main **goals of the CFD software** are to:
1. Validate physical model results
2. Investigate the impact of the connecting gallery on the head loss coefficients of a surge tank
3. Investigate the effect of flow sharing on the throttle's head loss coefficient

Geometry limits of the 3D model: confined penstock (B) and pressure tunnel (C) stretches (Fig.1)
Mesh type: Tetrahedral + edge sizing at throttle's narrow spacings
✓ Mesh sensitivity analysis (different edge sizes) to get a grid-independent solution
Pre-Processing: steady-state simulations (single-phase fluid); boundary conditions (pressure inlet + velocity outlet); Shear Stress Transport turbulence model

Tested flow directions:
- A-C (surge tank outflow during mass oscillation)
- C-A (surge tank inflow during mass oscillation)
- A-B (surge tank outflow during turbine opening)
- C-B (steady flow during turbine generation)

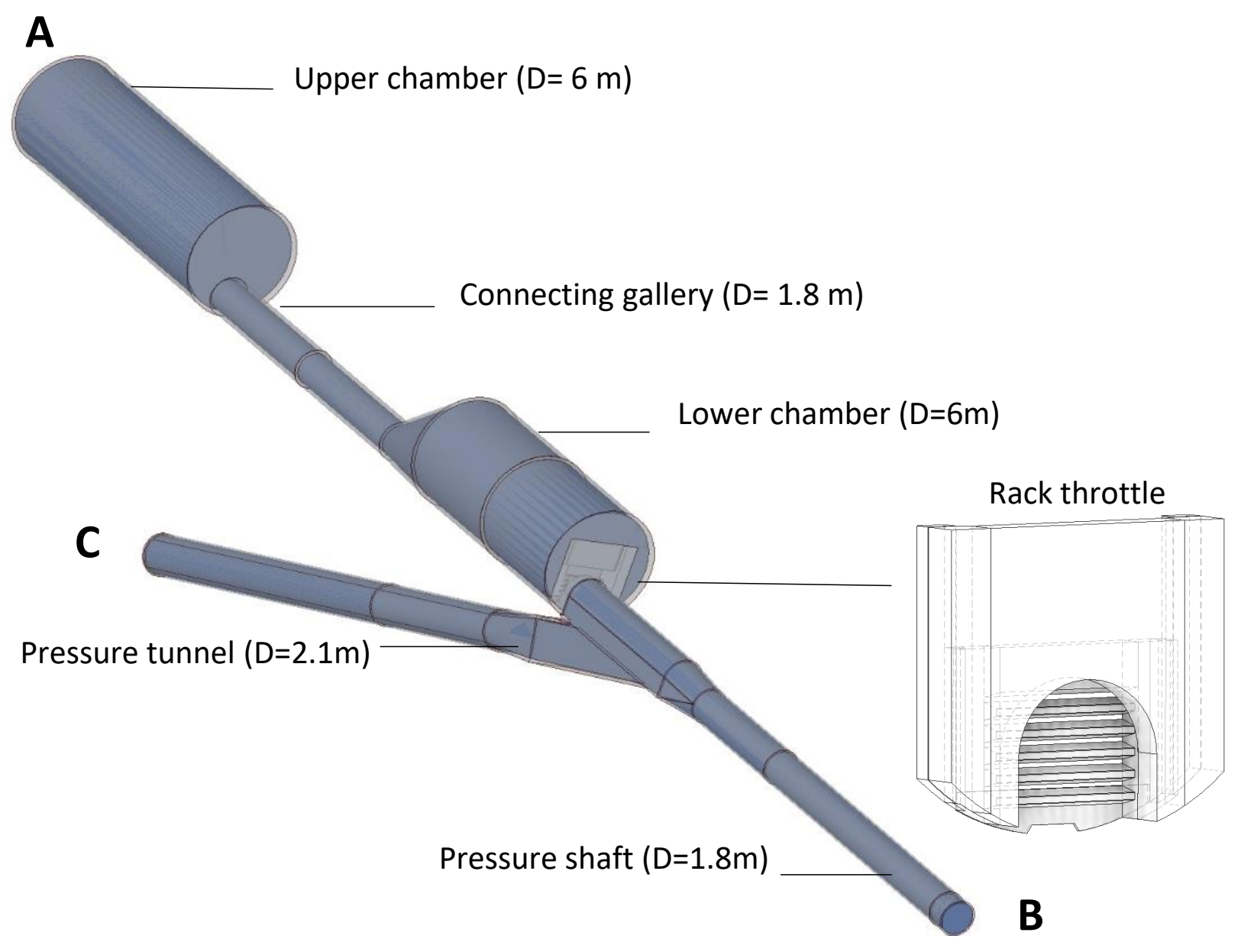


Figure 1. *3D model of the system consisting of the pressure tunnel, pressure shaft, surge tank and a throttle installed at its entrance.*

Results and Discussion

Validation with the physical model

The mesh accuracy as well as the numerical assumptions used in the pre-processing phase were all verified thanks to the availability of the physical model results.
- ➢ Pressure measurement sections chosen similarly to the physical model
- ➢ Calculations of k based on the same reference section (bottom of surge tank) as the physical model

Good agreement between the two methods especially for directions involving the throttle (Table 1).

✓ $K_{CB} < K_{AC} < K_{AB} < K_{CA}$

valid numerically & experimentally for *G01*

✓ $K_{CB} < K_{CA} < K_{AB} < K_{AC}$

valid numerically & experimentally for *G02*

Table 1. *Summary of experimental and numerical (ANSYS CFX) head loss coefficients*

Geometry	Investigated flow direction	Experimental value of k	Numerical value of k	Relative difference [%]
G01	A-C	3.9 ± 0.07	3.3 ± 0.004	16.73
	A-B	4.13 ± 0.05	3.5 ± 0.02	16.49
	C-A	5.7 ± 0.12	5.5 ± 0.10	3.59
	C-B	1.06 ± 0.01	0.81 ± 0.01	23.86
G02	A-C	45.9 ± 0.70	45.2 ± 0.12	1.42
	A-B	39.8 ± 0.35	42.1 ± 0.32	6.05
	C-A	29.6 ± 0.54	28.2 ± 0.013	4.93
	C-B	0.98 ± 0.02	0.86 ± 0.004	16.22

Differences between the results of a direction compared to the other one are evident just by observing the streamlines and comparing them under the same simulated discharge (Fig. 2 and 3).

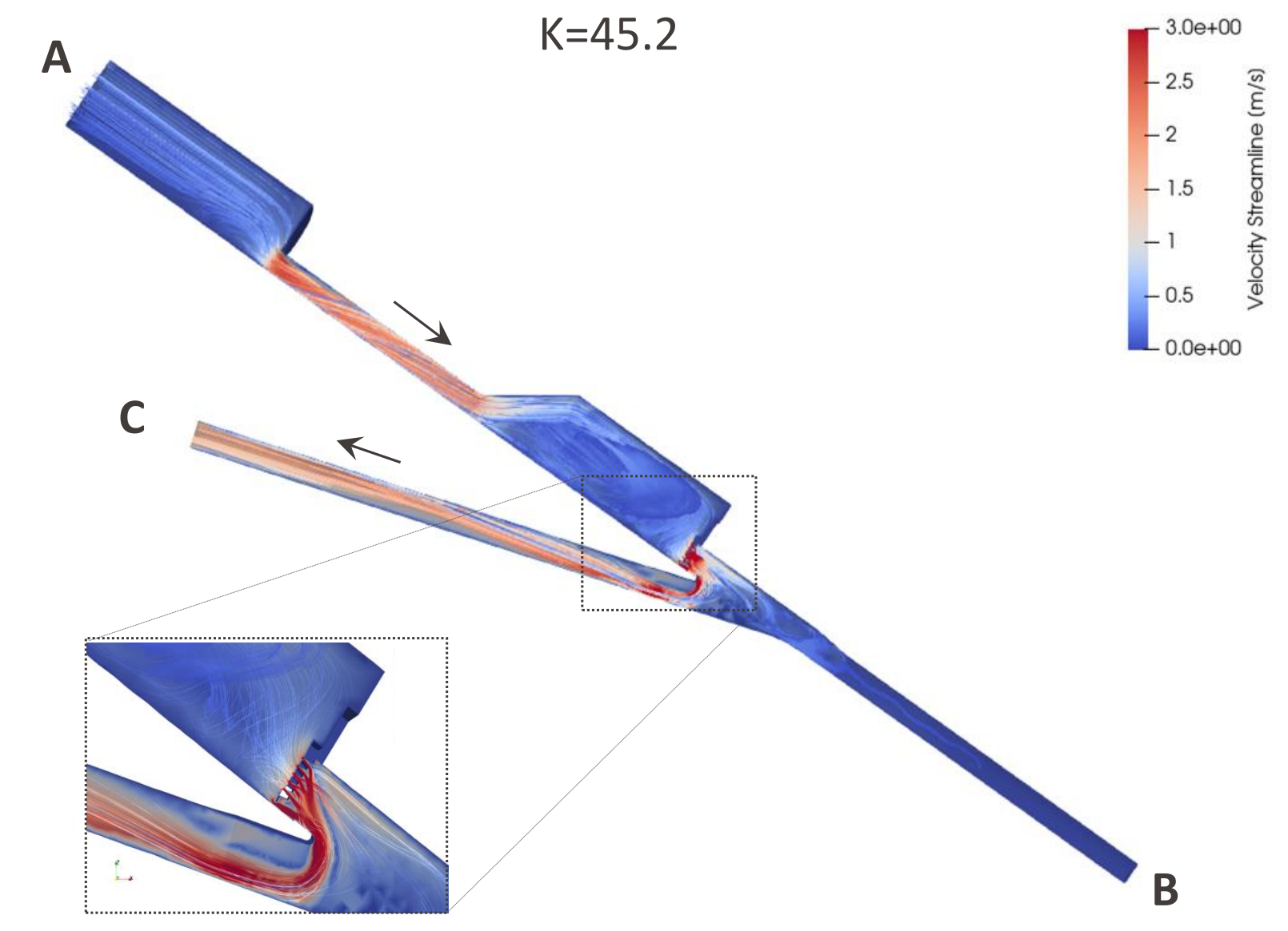


Figure 2. *Velocity streamlines for a 5 m^3/s flow going from A to C*

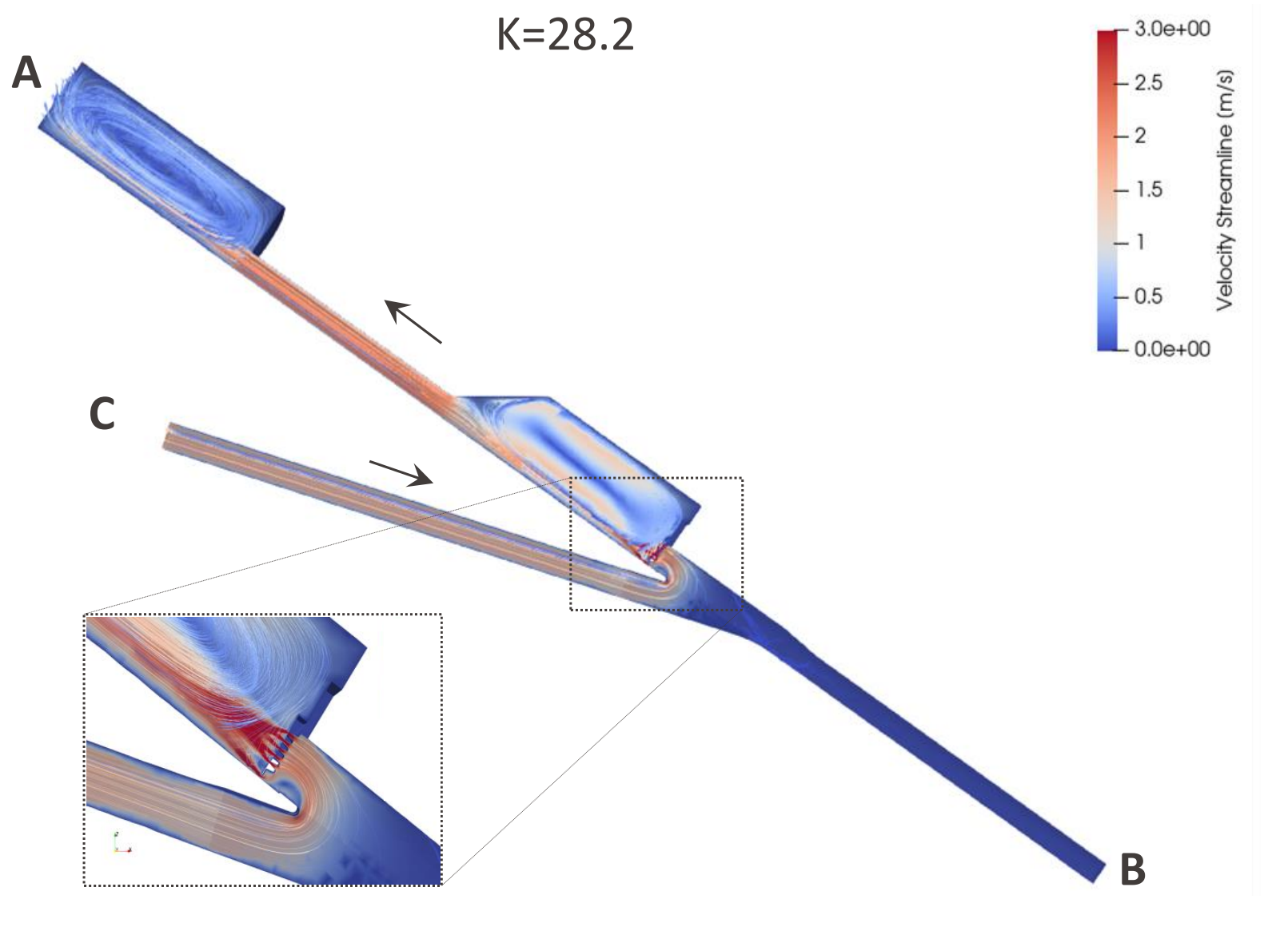


Figure 3. *Velocity streamlines for a 5 m^3/s flow going from C to A*

Impact of the connecting gallery

The connecting gallery introduces local losses (contractions and expansions) which are also obvious by observing the streamlines. For a throttled surge tank, as is the case of the refurbished Gondo power plant, local losses caused by section variations in the surge tank are very negligible when compared to the ones induced by the throttle; their effect can be disregarded in the 1D analysis.
On the contrary, these losses should not be ignored in the instance of a standard surge tank at low head loss coefficients. They should be included in the 1D software algorithm that varies the loss coefficients with the water level in the surge tank. Although it proved to be safer, a design approach ignoring the additional losses of the connecting gallery may result in oversized structures.

Impact of the flow share

ANSYS CFX investigations of variable surge tank flow shares showed that the head loss coefficient of a throttle varies for a share <20% of the total flow in the waterway under combining (Fig.4) or dividing (Fig.5) flow conditions. The variation of k was implemented in the 1D Hytran model for a controlled and uncontrolled operation scenarios.

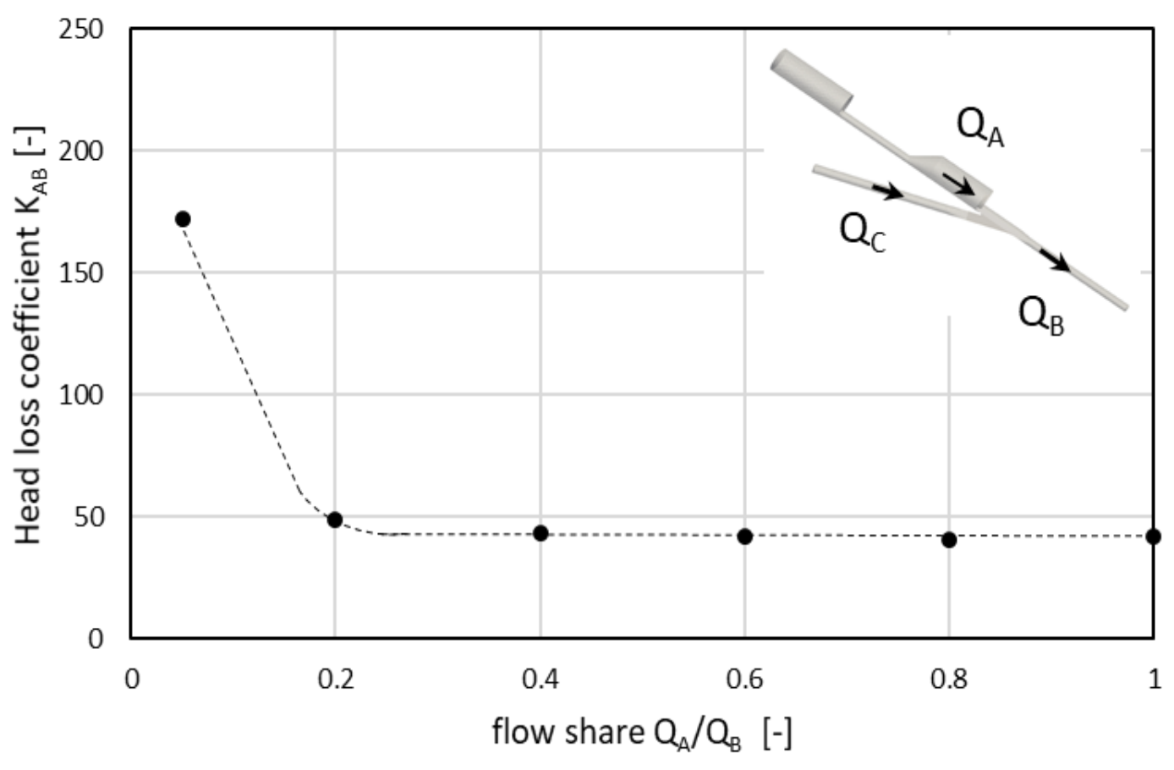


Figure 4. *Variation of K_{AB} with the flow share (combining flow conditions in the case of startup)*

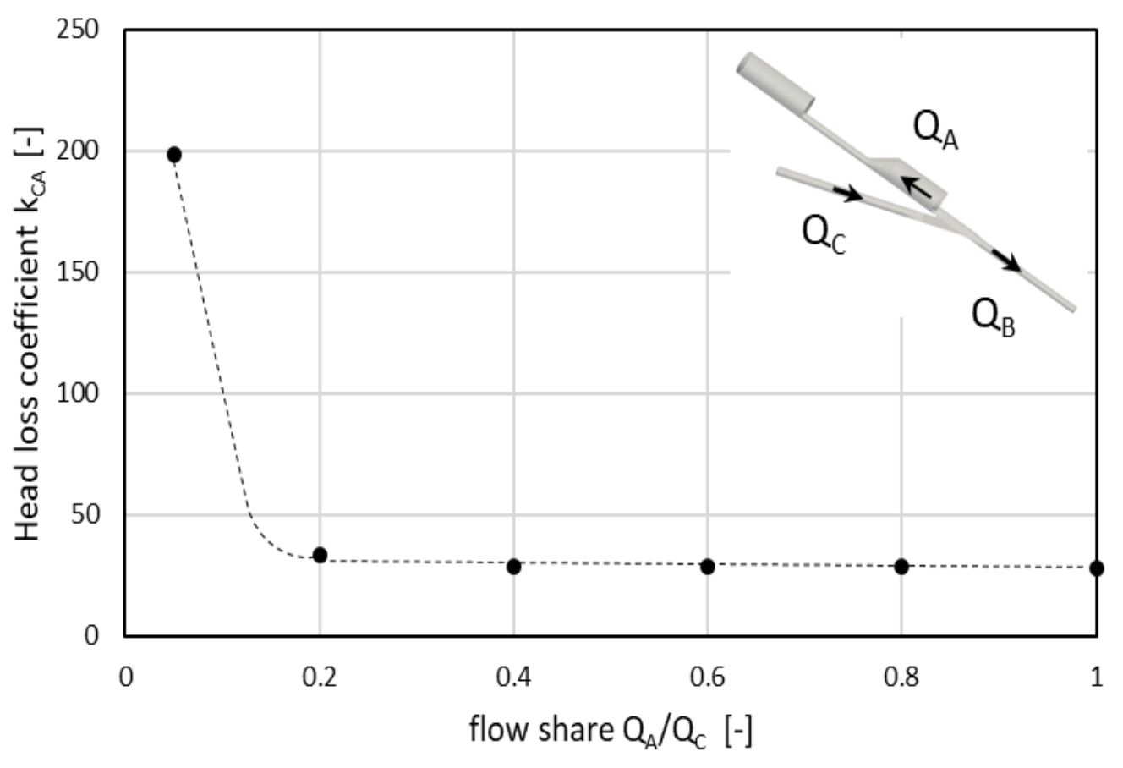
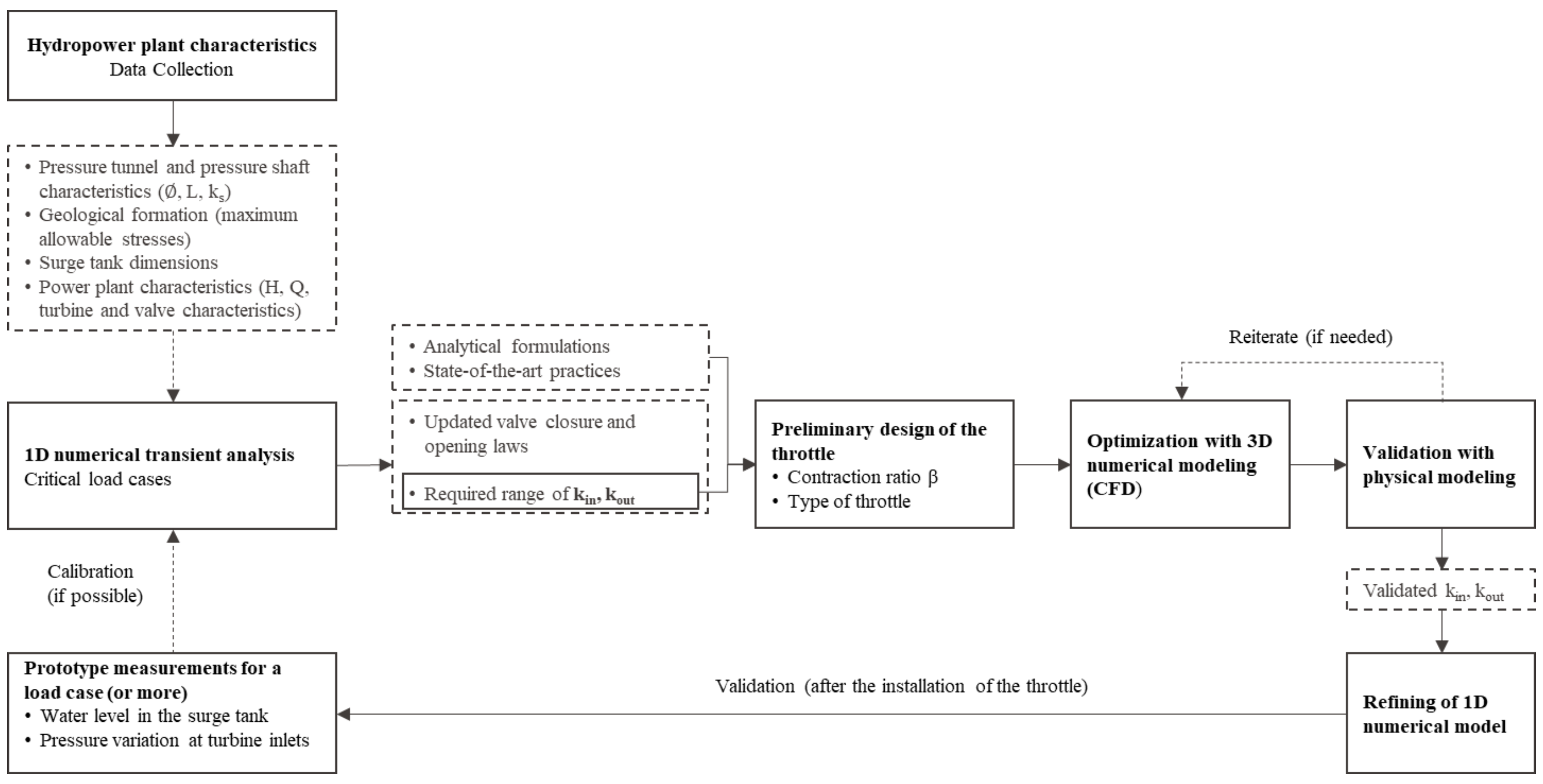


Figure 5. *Variation of K_{CA} with the flow share (dividing flow conditions in the case of closure)*

The conclusions of the 1D transient analysis in terms of water levels/pressure fluctuations were not altered. This could be due to the fact that the transition from 0 to 20% flow share or vice versa is relatively fast.

Hybrid Modeling as a Necessity

A clear interaction between the 3 modeling strategies was observed and deemed necessary in this project. Adopting a hybrid modeling approach backed by calibration and validation results in a more comprehensive design of throttled surge tanks. Below is a suggested design approach for a HPP subjected to a moderate increase of installed capacity.



Hydropower plant characteristics
Data Collection

- Pressure tunnel and pressure shaft characteristics (Ø, L, k_s)
- Geological formation (maximum allowable stresses)
- Surge tank dimensions
- Power plant characteristics (H, Q, turbine and valve characteristics)

1D numerical transient analysis
Critical load cases

- Analytical formulations
- State-of-the-art practices

- Updated valve closure and opening laws
- Required range of k_{in}, k_{out}

Preliminary design of the throttle
- Contraction ratio β
- Type of throttle

Optimization with 3D numerical modeling (CFD)

Validation with physical modeling

Reiterate (if needed)

Validated k_{in}, k_{out}

Refining of 1D numerical model

Validation (after the installation of the throttle)

Prototype measurements for a load case (or more)
- Water level in the surge tank
- Pressure variation at turbine inlets

Calibration
(if possible)

Figure 6. *Holistic approach to design throttled surge tanks (during a refurbishment of high-head power plant)*

Conclusion and Outlook

3D numerical modeling can provide preliminary convenient conclusions prior to passing into validation on a physical scale thereby decreasing the number of likely costly modifications to the latter. It is very important to examine the characteristics of a waterway from a holistic approach (hybrid modeling + calibration/validation with in-situ measurements). Ultimately, transient CFD investigations could be performed to explore the aptitudes of CFD models to predict the same fluctuations of pressures and water levels as a 1D numerical model. Furthermore, other CFD tools could be tested for the sake of more evaluation and comparison.

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