NTNU

Master thesis

Candidate: NN

Title: Physical and numerical modeling of closed conduit spillway, case study Storlivatn

1. Background

All dams must have a spillway to ensure that flood discharges can pass the facility without damage to the facility itself and the surrounding property and environment. In Norway, spillways are designed in accordance with NVE's Guidelines for spillways, but in some spillways there are conditions that are not covered by the calculation methods in the guidelines. This applies in particular to the flow conditions in spillways with side channels and closed conduit, which we often find in connection with embankment dams in narrow valleys. NVE is now working on a revision of the guidelines, and therefore has initiated a research and development project to investigate which calculation methods and models are best suited for designing closed conduit spillways. Multiconsult is engaged by NVE to do a literature study, and case studies in connection with the research project. The master's thesis is therefore done in collaboration with Multiconsult.

One can make calculations on side channel and closed conduit spillways with hand calculations, numerical models or physical models. Traditionally, physical model studies have been the preferred way to document the capacity of complex closed conduit systems. However, such studies are expensive and time-consuming, and with the development that has taken place in numerical methods in recent years, these can appear as attractive alternatives. Both 1- and 2-dimensional models that solve St. Venant's equations (1D and 2D hydraulic models), and 3-dimensional models that solve Navier-Stokes equations in combination with advanced turbulence models (CFD models) can potentially be used to calculate the capacity of such systems. However, both physical and numerical models have limitations and it is therefore very important to map the benefits and limitations of different models.

CFD simulations have previously been performed on at least 3 closed conduit spillways in Norway, Sysendammen, Innerdalen and Svartevassdammen. The calculations have generally shown to give very good agreement with physical experiments as long as the capacity is limited by the overflow, while the results have varied when it comes to modeling the capacity of the shaft inlet and tunnel. Among other things, this may be due to problems with modelling air entrainment, that the roughness of the tunnel is uncertain and that sufficient mesh resolution have not been used. In 2015, NTNU conducted a literature study on closed floodplains on behalf of NVE and subsequently an addendum was written to guidelines for floodplains which conclude that we have too little basis to be able to use CFD modeling on closed floodplains as of today. NVE encourages the use of CFD modeling in parallel with physical experiments. The last of the mentioned experiments was made in 2010, and CFD modeling has developed greatly since then, at the same time as available calculation resources have increased considerably. Recent attempts at CFDs in other areas have yielded promising results.

2. Main tasks of thesis

In recent years, several physical model studies of closed conduit spillways have been carried out at the hydrotechnical laboratory at NTNU, and there is currently an operational model of a new spillway at Storlivatn (see picture below) which is suitable for making physical experiments on closed conduits.

Figure 2-1: Physical model of closed conduit spillway at Storlivatn (photo taken from Baard Aasmund Utvik Gjerde's master thesis)

In connection with the research project on closed conduit spillways, it is of special interest to investigate how well numerical models can reproduce the conditions when the inlet is drowned. This can in principle happen in two ways:

- The capacity is limited by the tunnel and the shaft and the inlet is drowned from downstream, so that there is pressure flow in the tunnel system.
- The capacity is limited by the inlet to the shaft, so that the inlet is submerged.

In order to investigate these conditions effectively, it will be necessary to narrow the tunnel and the inlet, so that the system closes at lower discharges than today.

In both cases, the capacity will be limited so that a large change in head will lead to only a small change in discharge through the system. An example of the capacity curve for a closed conduit spillway (Sysendammen) is shown in the figure below.

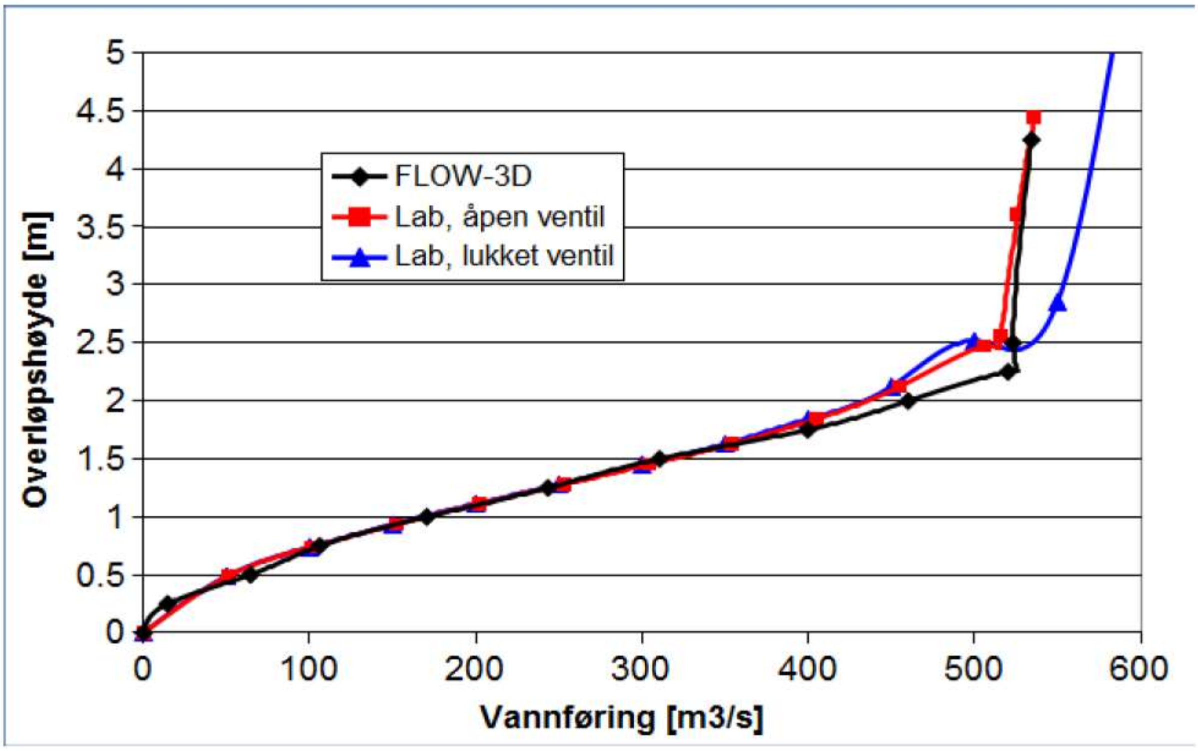

Figure 2-2: Figure 2 2: Comparison between capacity curves from simulation and physical experiment at Sysendammen (N.R.B Olsen, 2015)

The thesis should cover physical experiments on the already existing model of Storlivatn and numerical modeling with CFD model to try to reproduce the results from physical modeling. The this work should focus on reproducing the point where the system closes, and to calculate the capacity after closing the system. The work must include experiments with free surface flow in the system, the transition to the system closing, and calculation of the capacity after closing. The study must include sensitivity tests on relevant model parameters. It is expected that a fine-resolution model will have to be used, and it will be an advantage if the models can be run on a HPC-cluster. The thesis will contribute to our knowledge about the capability of physical and CFD models for modeling closed conduit systems.

Adjacent topics that may be of interest to investigate in connection with the project are the possibility of modeling air entrainment and the effect of roughness in the tunnel.

Multiconsult is currently working on CFD modeling in the program ANSYS CFX in connection with the research project, and it is therefore recommended that ANSYS is also used for the master's thesis. One can then use much of the numerical setup from Multiconsult's model, including the layout of model parameters and boundary conditions as a starting point for further modeling. Alternatively, other models can also be used. A good alternative may be the open source software OpenFOAM, but this might be more demanding from a model-technical perspective. A third option might be to use the Flow-3D software. This program has built-in air entertainment algorithms that can be interesting to test in connection with the project.

The assignment can also be divided into a physical and a numerical part, where one student does physical experiments and another student performs numerical modeling.

The thesis work should cover:

NTNU

1 Literature review
2 Planning of model experiments In collaboration with project group and supervisors
3 Physical model experiments and / or numerical modeling of a closed conduit spillway system
4 Analysis of model results
5 Conclusions and recommendations on modeling of closed conduit spillways
6 Reporting

3 Guidance, data and information

Professor Nils Rüther will be the main supervisor and will, together with co-supervisors Professor Leif Lia and Dr. Øyvind Pedersen (Multiconsult), supervise the thesis work.

Discussion with and contributions from colleagues and employees at NTNU, NVE, power companies, Multiconsult and other consulting engineering companies are recommended. The candidate will be part of the project group in the research project.

4 Report format, references and delivery

The thesis must be written in a word processing program so that figures, tables, photos, etc. have good report quality. The report shall contain summaries, table of contents, bibliography and information on other relevant references and sources. The thesis must be submitted in B5 format as .pdf in Blackboard and printed in three copies which are sent directly from the printing press of the department. The summary shall not exceed 450 words and shall be suitable for electronic reporting.

The master thesis must be submitted by XX June 2021

Trondheim, XX. January 20XX

____

NN
Professor
Department of Civil and Environmental Engineering
NTNU