

Calibration and validation of 3D numerical models of a straight channel with leaky barriers

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HR EXCELLENCE IN RESEARCH

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Objective and Scope

Under the statement:

"We do not need to stop building; we need to build different"

It highlights a shift in thinking about construction and development. It suggests that rather than halting building projects, there's a need for innovation and change in how we design and construct buildings, focusing on sustainable, efficient, and community-focused approaches.

It also concerns new alternatives and approaches to consider modern and **more green infrastructure** against flooding at all planning scales.

Case study

Leaky barriers, as a new method of flood defence, are gradually used in flood management especially in small rivers due to functions of the engineering in ecological and connecting rivers and regulating floods. Understanding the hydraulic effects and especially the backwater rise caused by leaky barriers is necessary to assess its impact and optimize the design.

Figs. beside:

- A) Leaky dams in Ruislip woods (London);
- B) Experimental model at Brunel UL and
- C) Experimental model at the Wrocław UST (Poland).



Contents

As the calibration and validation procedures were achieved as described in this contribution, the simulation of different scenarios is to be carried out. Thanks to this model, different schemes for three-logs leaky barriers are to be analyzed and it can contribute to a better understanding of them. As stated in Table 1, the RMSE are small enough to consider the model as reliable.

Situation (simulation ID)	Purpose	RMSE (-)
Brunel no-logs (1)	Determination of roughness	0.40
Brunel smooth (2)	Calibration of roughness	0.50
WrUST Q ₁ (3)	Roughness calibration (PL)	0.49
WrUST Q ₂ (4)	Velocity profile calibration	0.42
WrUST Q ₃ (5)	Velocity profile validation	0.20

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Abstract: In this contribution, two 3D numerical models are tested using laboratory records to properly calibrate and validate these models. 1D numerical techniques are also used for this purpose. Mesh sensitivity analyses, different roughness coefficients, and Acoustic Doppler Velocimetry (ADV) records were applied to increase the reliability of the 3D model results.



FIGS. 1, 2 & 3. Above: Man-made leaky dams (on site and at the laboratory). Right: pilot project site at the Ruislip Woods area in North London.

Motivations: Natural Flood Management (NFM) is the phrase given to the measures and techniques used to reduce flood risk. Leaky woody barriers/dams (LWD), which is one of those techniques, occur naturally in river channels with the help from beavers, man-made with the usage of trees, branches or logs fall into the river channel. The blockages slow the flow of water at flood conditions and temporarily hold large volumes releasing it at a steadier rate over a longer period of time.

Scientific interest: The design of man-made LWD is still complex to understand from a hydraulic point of view. It is because many parameters can control the flow through these kind of structures. For a two-log dam (see Fig. 2), it has its bottom at height a above the streambed and its top at height D . Thus, three basic flow modes can be identified (neglecting the downstream value of h_0):

- $h < a$ — corresponding to the water level being below the bottom and the LWD does nothing;
- $D > h > a$ — corresponding to the situation when the dam is operating normally and
- $h > D$ — when the dam is overspilling.



FIG. 4. Flow basic modes for the case of leaky barriers (modified from Hanson et al., 2020)

To enhance our understanding on the hydraulic behavior of these kind of structures is the main motivation of this research. Moreover, thanks to the usage of numerical modelling, plenty of design scenarios can be analyzed. Thus, a reliable numerical model shall be set-up for this purpose.

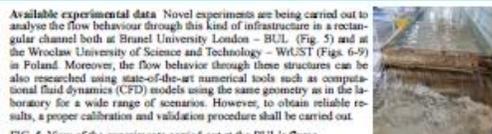


FIG. 5. View of the experiments carried out at the Brunel's flume.

Data from two experimental flumes were available for this research: a) the data from the experiments carried out at the Brunel University London (Martín-Moreta et al., 2025) and the data available from the experimental research at the Wrocław University of Science and Technology - WUUST. For both cases a three-log leaky barrier was analyzed. For the case of the experiments that were carried out in London, the general purpose was to establish the flume's roughness coefficient as well as the weir coefficient of the LWD, which will assure the accurate approximation of the velocity field using 3D modeling (and for calibration using the records registered at WUUST).

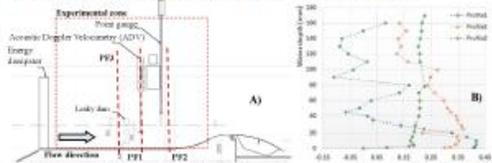
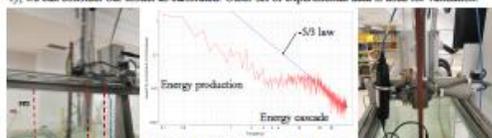


FIG. 6. Experimental set-up in Poland: A) Scheme of the experimental set-up and location of the record measurements, B) Records for Q1 at PFI, PF2 (downstream) and PFS (upstream).

The data that was obtained from the experiments in Poland was used to compare the hydrodynamic parameters recorded with an Acoustic Doppler Velocimetry (ADV) with the simulated values of the 3D numerical model. Once the model will reach the same values that those obtained at the laboratory, we can consider our model as calibrated. Other set of experimental data is used for validation.



FIGS. 7, 8 & 9. Left: location of the registered profiles at the WUUST. Above: measured filtration process and Left: ADV instrumentation mounted in the flume.

Numerical model set-up: To set-up the numerical models, the five step procedure depicted in Fig. 10 was followed for both 1D and 3D numerical analyses using the geometry of the experimental flumes.

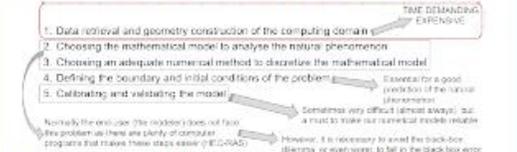


FIG. 10. Five steps to set-up and run a reliable numerical model (Herrera-Granados, 2022).

For 3-Dimensional modeling, the Reynolds' Average Navier Stokes (RANS) equations represent an adequate technique (step two of the depicted in Fig. 10) to analyze 3D flows for engineering because not all the turbulent scales are resolved (Herrera-Granados, 2021) and provided time averaged reliable results (such as the time-averaged profile of the velocity). Therefore, the $k-\epsilon$ and $k-\omega$ approaches were used for this part of the analysis and its correspondent calibration and validation procedures.

1D numerical model: For the case of the experiments carried out in London, the general purpose was to establish the flume's roughness coefficient (not LWD equivalent) that will assure the accurate approximation of the velocity field using 3D modeling. Nine experimental flows were registered at i) at the beginning of the flume; ii) at the location of the leaky barriers (without them) and iii) at the outlet.

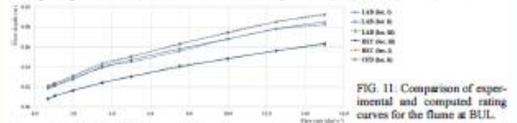


FIG. 11. Comparison of experimental and computed rating curves for the flume at BUL. As appreciated in Fig. 11, the records from the experiments best fit the 1D and 3D numerical results with the roughness value equal to $k_s = 0.0013$ mm. As stated in Tab. 1, the results of the models in comparison with the measured rating curves present good agreement.

CFD output: Once the geometrical data (WUUST flume and a three-log LWD) was input into the Flow3D software, several simulations were run for both $k-\epsilon$ and $k-\omega$ mathematical approaches. For this contribution, three flow rates are analyzed: $Q_1 = 0.0203$ m³/s, $Q_2 = 0.0361$ m³/s & $Q_3 = 0.0275$ m³/s.

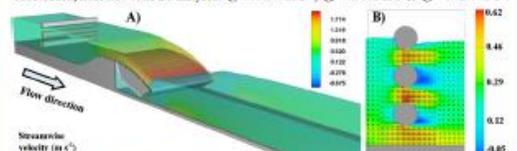


FIG. 12. A) Axonometric & B) XZ plane (close to the LWD) views of the streamwise velocity field correspondent to the experimental flow rate Q₃.

Output, calibration and validation of the models: The most widely used calibration procedure is optimization of the model performance. This has been done using a trial-error procedure or changing the parameters that are introduced as data in the model (Herrera-Granados, 2022). The velocity profiles (streamwise) registered at the lab were compared with the output of the simulated values of the two CFD (see Fig. 13), which were very similar using both mathematical approaches. However, after doing a mesh sensitivity analysis, the $k-\epsilon$ provided a slightly smaller error.

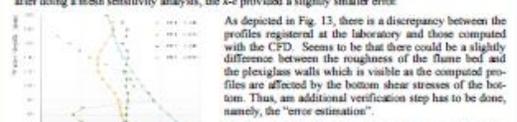


FIG. 13. Comparison between the experimental and computed profiles for Q₃. As depicted in Fig. 13, there is a discrepancy between the profiles registered at the laboratory and those computed with the CFD. Seems to be that there could be a slightly difference between the roughness of the flume bed and the Plexiglas walls which is visible as the computed profiles are affected by the bottom shear stresses of the bottom. Thus, an additional verification step has to be done, namely, the "error estimation".

Final remarks: After several runs and error estimation, the final comparison and summary is depicted in Table 1. The Root Mean Square Error (RMSE) for all the models were calculated. Once the authors achieved a good agreement for the velocity profiles for Q₃, the validation procedure was carried out for Q₂.

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TABLE 1: Comparison of the numerical models output with the experimental results.

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Thank you very much for your attention

Let's discuss during the poster session



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