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Calibration and Validation of 3D Numerical Models of a Straight Channel with Leaky Barriers

Oscar HERRERA-GRANADOS[1] and Pedro MARTIN-MORETA[2]

[1]Wrocław University of Science and Technology, Wrocław, Poland
🖂 Oscar.Herrera-Granados@pwr.edu.pl

[2]Brunel University London, London, United Kingdom
🖂 Pedro.Martin-Moreta@brunel.ac.uk

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. Thanks to these analyses, the output of the models can be used for design purposes to properly assign the geometry of leaky barriers in real world cases to enhance flood resilience above all in urban areas.

1. INTRODUCTION

Natural Flood Management (NFM) is a concept that refers to the mitigation measures that use processes to restore flow regimes and help increase the attenuation of flood events in a natural way. Leaky barriers dams are one of those techniques. The purpose of this kind of structure is to allow water flow without causing backwater during normal conditions, but to attenuate the formation of higher flood waves in case of heavy rainfall. The last described situation can be achieved with a proper configuration (leaky barrier adequate dimensions) of the dam logs.

However, the design of these dams is still complex to understand from a hydraulic point of view. Novel experiments are being carried out to analyze the flow behavior through this kind of infrastructure in a rectangular channel. The flow behavior through these structures can be also researched using state-of-the-art numerical tools such as computational fluid dynamics (CFD) models using the same geometry as in the laboratory for a wide range of scenarios. Moreover, to obtain reliable results, a proper calibration and validation procedure shall be carried out. Therefore, setting up a reliable model is the main purpose of this contribution.

1.1 Available experimental data

Data from two experimental flumes were available for this research: a) the data from the experiments carried out at the Brunel University London (Martin-Moreta et al. 2025) and the data

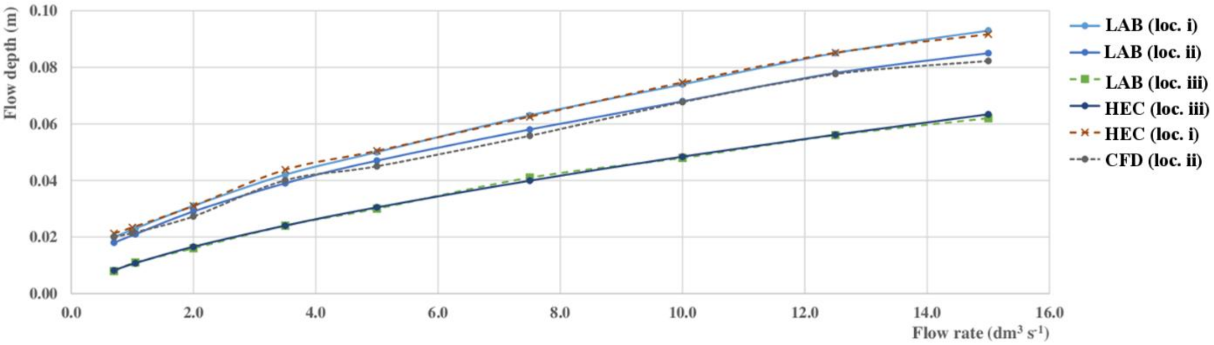

Fig. 1. Rating curves that were registered (at Brunel University London) and that were calculated using 1D and 3D modeling using HEC-RAS (1D) and Flow3D.

available from the experimental research at the Wrocław University of Science and Technology – WrUST (see Fig. 1) in South Poland. 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 that will assure the accurate approximation of the velocity field profiles using 3D modeling (and for calibration using the records registered at WrUST). For this analysis, the rating curve of the experimental flume was recorded and numerically analyzed using 1D techniques (HEC-RAS) as well as the Flow 3D RANS closure (k-ε) without the leaky dams. As depicted in Fig. 1, the rating curve was registered and calculated at four different locations: i) at the beginning of the flume; ii) at the location of the leaky barriers (without them), and iii) at the outlet.

As appreciated in Fig. 1, 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 Table 1, the results of the models in comparison with the measured rating curves present good agreement. Once the determination of the roughness was obtained, another run was compared with the leaky barriers and to validate whether the model is reliable using the well-known k-ε mathematical approach.

2. NUMERICAL MODELLING

The Reynolds' Average Navier Stokes (RANS) equations represent an adequate technique to analyse 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

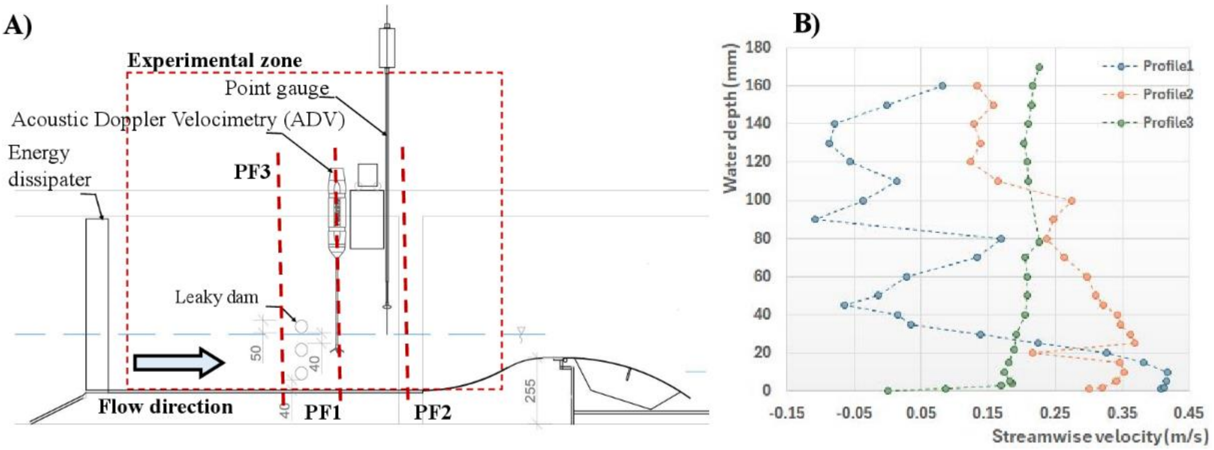

Fig. 2. Experimental set-up at the WrUST laboratory: A) scheme of the experimental set-up and location of the record measurements, B) records for Q_1 at PF1, PF2 (downstream), and PF3 (upstream).

of the velocity). Therefore, the k-ε and k-ω approaches were used for this part of the analysis. The commercial software Flow 3D (developed by Flow Science) was used for the analysis.

2.1 Numerical set-up and model run

The time averaged velocity profiles for two flow rates ($Q_1 = 0.0203\ m^3s^{-1}$ and $Q_2 = 0.0361\ m^3s^{-1}$) at three different locations (PF1, PF2, and PF3) were recorded at the Wrocław University of Science and Technology. The time averaged velocity profiles for Q_1 are depicted in Fig. 2B.

2.2 Output, calibration, and validation of the models

The most widely used calibration procedure is optimization of the model performance, which means that the model output is compared to the observed data. This can be 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. 3), which were very similar using both mathematical approaches. However, after doing a mesh sensitivity analysis, the k-ε provided a slightly smaller error. The Root Mean Square Error (RMSE) for all the models were calculated as summarized in Table 1. Once the authors archived a good agreement for the velocity profiles for Q_1, the validation procedure was carried out for Q_2.

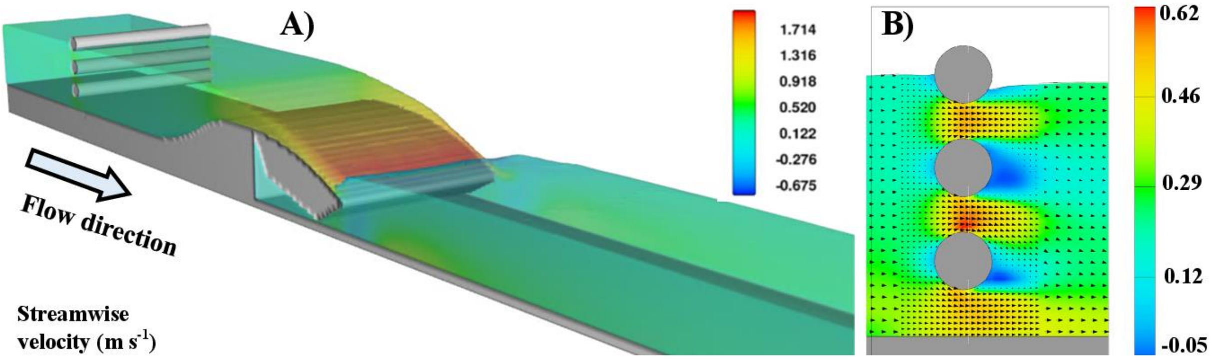

Fig. 3: A) CFD visual output for Q_2, and B) velocity field close to the leaky barriers.

Table 1

Comparison of the CFD output with the experimental results

Calibration and validation comparison between simulation results and experimental records			
Situation (simulation ID)	Purpose	Max error (%)	RMSE (–)
Brunel no-logs (1)	Determination of roughness	7.02	0.40
Brunel smooth (2)	Calibration of roughness	9.23	0.50
WrUST Q_1 (3)	Roughness calibration (PL)	8.41	0.49
WrUST Q_2 (4)	Velocity profile calibration	6.78	0.42
WrUST Q_3 (5)	Velocity profile validation	6.60	0.20

3. CONCLUSIONS AND FURTHER RESEARCH

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 3-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.

References

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