Can we use hydraulic handbooks in blind trust? Two examples from a real-world complex hydraulic system

Vasilis BELLOS[1,2], Panagiotis KOSSIERIS[3], Andreas EFSTRATIADIS[4], Ilias PAPAKONSTANTIS[5], Panos PAPANICOLAOU[6], Panagiotis DIMAS[7], Christos MAKROPOULOS[8]

[1] Democritus University of Thrace, Greece
email: vbellos@env.duth.gr

[2,3,4,5,6,7,8] National Technical University of Athens
email: vmpellos@mail.ntua.gr; pkossier@mail.ntua.gr; andreas@hydro.ntua.gr; ipapak@mail.ntua.gr; panospap@hydro.ntua.gr; pdimas@mail.ntua.gr; cmakro@mail.ntua.gr

ABSTRACT

In this work, we investigate whether the parameters of physics-based hydraulic models, omnipresent in every relevant engineering handbook, can be used in blind trust in a real-world complex system. Here, we focus on the discharge coefficient for flows through a sluice gate and the Manning's coefficient for steady flows, and we compare their typical literature values (experimentally derived) against the ones obtained via a "grey-box" calibration approach using real flow data from the complex raw-water conveyance system of Athens, Greece.

1. Introduction

In the design and control of hydraulic works, modelling approaches are bounded by two extreme cases: the pure "white-box" and pure "black-box" approach. In the first case, the system is described via physically-based equations, whose parameters are obtained on the basis of hydraulic handbooks. In the second case, data-driven models (such as Machine Learning algorithms) are calibrated against field data, without any prerequisite to obey physical laws and provide physically meaningful parameters. In between these two approaches lies the "grey-box" approach (Bellos et al., 2018) that combines the advantages of these two extreme cases to develop more robust and scientifically sound models. Here, we adopt this approach to investigate the question posed in the title for two widely known hydraulic coefficients: a) the discharge coefficient of sluice gates; b) the Manning's coefficient of a channel. The motivation behind this work is the development of an operational tool to provide advice on the optimal flow control of the complex raw-water conveyance system of Athens, Greece. The control in the lower part of the system, which is our study area, is performed via a series of Λ-type regulation structures, which include a sluice gate and a broad crest weir.

2. Real world examples

2.1. Sluice gate discharge coefficient

The tool is based on a model that simulates the current situation regarding the flow characteristics in every Λ-type structure and predicts the required opening of the sluice gates for a new desirable discharge. For this reason, the relationships proposed by Wu and Rajaratnam (2015) are used, in which the discharge Q is calculated by:

$$Q = C_d\, a\, B\, \sqrt{2g(H_1 - H_2)} \tag{1}$$

where C_d is the discharge coefficient of the sluice gate, a is the gate opening, B is the width of the channel, H_1 is the water depth upstream of the Λ-type structure and H_2 is the water depth just downstream of the structure. The latter can be calculated in respect to y_t, which is the water depth at some distance downstream of the structure, as follows:

$$H_2 = C_d\, a \left[2\left(1 - \frac{C_d\, a}{y_t}\right) + \sqrt{4\left(1 - \frac{C_d\, a}{y_t}\right)^2 + \left(\frac{y_t}{C_d\, a}\right)^2 - 4\left(\frac{H_1}{C_d\, a}\right)\left(1 - \frac{C_d\, a}{y_t}\right)}\right] \tag{2}$$

Due to the discrepancy between the desired accuracy of the flow regulation and the current accuracy of the monitoring system, we adopt a "grey-box" modelling approach, where the discharge coefficient is calibrated in real time. Yet, when these values are not reasonable, we apply a global discharge coefficient, as a safety net, which was found using historical data. In Fig. 1, we give the results of the calibration (in respect to the ratio a/H_1) and we compare them with the corresponding theoretical results proposed by Wu and Rajaratnam (2015).

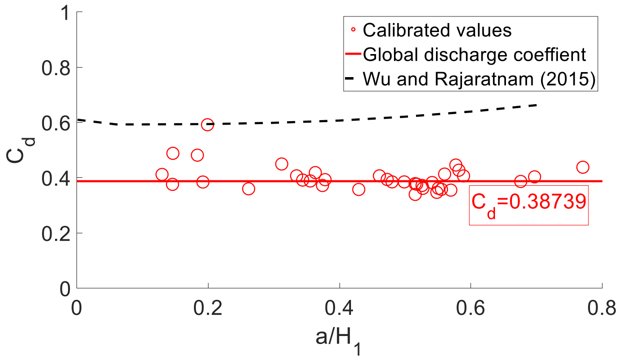

Fig. 1. Comparison of the discharge coefficient in respect to the ratio a/H_1, as was calibrated using historical data, against the theoretical values given by Wu and Rajaratnam (2015).

2.2. *Manning coefficient*

Furthermore, to indicate the time response between the time instant which a sluice gate is moved (either opening or closing) and the time instant which the latter move is captured by the flow meter, we calibrated a global Manning coefficient of the channel *n*, assuming that flow is steady and uniform. In Fig. 2 we compare this global Manning coefficient against values reported in classic hydraulic handbooks, such as Chanson (2004) and Chaudhry (2008), for several categories of a channel made up with concrete.

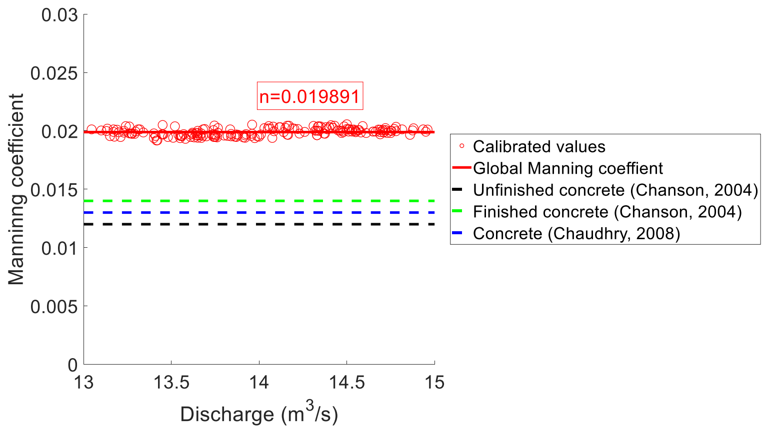

Fig. 2. Comparison of the Manning coefficient for several discharges, as was calibrated using historical data, against values reported by Chanson (2004) and Chaudhry (2008).

3. Discussion and concluding remarks

In this work, we performed a blind test, assuming that two physical parameters have no physical meaning and are calibrated with no prior knowledge, in a real-world case study. According to our findings, it seems that the calibrated values are quite different from the corresponding values proposed in the literature, which are derived from theory or ideal laboratory conditions. In this respect, this difference should be attributed to the complex reality of field conditions, and lies within the expected range of uncertainty. Therefore, although we live in the era of big data and artificial intelligence it seems that physics still works. On the other hand, moving from theory to practice should be performed carefully, by adopting more “grey-box” modelling approaches that account both for physics and real-world data.

Acknowledgements

This work was carried out in the framework of Fiware4Water project (2019-2022), receiving funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 821036.

References

Bellos V, Nalbantis I, Tsakiris G (2018). Friction modeling of flood flow simulations, Journal of Hydraulic Engineering, 144(12), 04018073.

Chaudhry, MH (2008) Open channel flow, Second edition, Springer, 528 pp.

Chanson H (2004) The hydraulics of open channel flow: an introduction, Second edition, Elsevier, 585 pp.

Wu S and Rajaratnam N (2015) Solutions to rectangular sluice gate flow problems, Journal of Irrigation and Drainage Engineering, 118(1), 1113, 56-60.