CERIS Civil Engineering Research and Innovation for Sustainability

Stilling basin performance downstream of stepped spillways

PhD student
Ivan Stojnic

PhD program
Civil Engineering (IST, University of Lisbon)

Supervisor
Jorge Saldanha Matos (CERIS, IST, University of Lisbon)

Co-supervisor
Eugen Brühwiler (EPFL)

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Summary

Advances in dam construction techniques have significantly increased the number of implemented stepped spillways worldwide. A key hydraulic feature of a stepped chute, compared to a smooth chute, is the enhanced energy dissipation resulting in a reduced residual energy at the chute end. Nevertheless, stepped chutes provide only a partial energy dissipation, so that an adequate dissipation structure may be still required at the chute end. Stepped chute hydraulics was extensively investigated in the past decades. However, only a few studies focused on the hydraulics of stilling basins downstream of stepped chutes. As a result, design guidelines developed for stilling basins downstream of smooth chutes are still considered for stilling basins preceded by stepped chutes. As a stepped surface alters the flow structure of the approaching flow, such practice is questionable. The present experimental research work aimed to examine the effect of stepped chute approach flows on the performance of a plain stilling basin. Physical modeling was conducted using a relatively large-scale experimental facility of a smooth or stepped chute with adjustable slope, terminating in a plain stilling basin. The experimental campaign included both smooth and stepped chute approaches, allowing direct comparison of the basin performance.

The measuring campaign included collection of flow conditions at the chute end, dynamic bottom-pressure and flow depths along the basin, and internal air-water flow properties of the hydraulic jump. The results show a significant effect of stepped chute approach flows on the hydraulic characteristics of the stilling basin for the tested range of relative critical depths ($2.70 \leq h_c/s \leq 7.94$) and chute angles ($30° \leq \varphi \leq 50°$). Using a novel analysis technique of acquired flow depths and bottom pressures along the basin, the present study demonstrates that normalized hydraulic jump lengths are up to 17% longer downstream of stepped chutes as compared to tested smooth chutes, and relative to values reported in the literature for smooth chute spillways. Consequently, the present results suggest that longer normalized stilling basin lengths are required downstream of stepped chutes. Considering some safety margin, a basin length of 7 times the tailwater depth is recommended. The analysis of bottom pressures shows that the stepped chute approach flow pronounce extreme and fluctuating pressure coefficients within about one tailwater depth downstream of the chute end, as compared to smooth chute approach flows. The coefficients increase with increasing chute slope and extreme positive and negative pressure coefficients can reach up to 125% and 60% of the approach flow kinetic energy, respectively. These magnitudes are up to 3 times higher compared to observed magnitudes for smooth chute approach flows or relative to magnitudes reported in the literature for smooth chute spillways. However, this zone should not be endangered by cavitation damage as the measured bottom air concentration values are well above the recommended limits to avoid cavitation damage. In conclusion, the present thesis demonstrates that stilling basin design guidelines developed for smooth chute approach flows are not applicable for stepped chute approach flows. Empirical formulae for predicting flow properties along the basin downstream of smooth and stepped chute approach flows, which can be used for the design of plain stilling basins, are proposed.

Keywords

Stepped spillway, hydraulic jump, stilling basin, flow depths, fluctuating bottom pressures, air-water flow properties, jump length, roller length, stilling basin length.

Photo of the physical model with the inclined chute in the background and the stilling basin at the front.