FROM LABYRINTH TO PIANO KEY WEIRS: THE STORY

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Labyrinth weirs are an efficient solution for free surface flow whose development has been initially favored by a close collaboration between research and industry in the United States. Piano Key weirs improve the traditional Labyrinth concept and have been developed with the same collaborative spirit at an international level. Both structures have a huge potential of development and application worldwide, which has been exploited yet only in a few countries.

Figure 1. Hope Mills dam spillway with a 4.6 m high Labyrinth weir in North Carolina, USA (commissioned 2018). Photo courtesy of Schnabel Engineering.

Figure 2. Charmines dam spillway in France with a 23 m wide type-A piano key weir section on both sides of the crest gates (PKW commissioned in 2015). Photo courtesy of EDF.

Spillways are key dam safety structures releasing excess water from reservoirs, in particular during floods. Weirs control the discharge through free flow spillways and corresponding reservoir levels. A high discharge capacity spillway allows for more reservoir water storage while keeping dam overtopping and other upstream flood related risks at acceptable levels. Since the discharge capacity of a weir is proportional to its crest length, engineers and scientists early on developed solutions to maximize this crest length [5] while responding to projects goals or sites limitations (restricted spillway width, project economics, etc.). In this respect, Labyrinth weirs, firstly formally studied in 1941 by Gentilini, place the crest of a thin vertical wall along a triangular, trapezoidal or rectangular path (in plan view) to maximize the crest length within a limited footprint (Figure 1). The number of Labyrinth weir projects increased exponentially after the publication of key research by the US Bureau of Reclamation and the American Society of Civil Engineers (ASCE) in the eighties and the construction of Ute Dam (USA). Additional noteworthy studies that have advanced the state-of-practice regarding Labyrinth weirs have been conducted at the Laboratório Nacional de Engenharia Civil (Portugal) and at the Utah Water Research Laboratory at Utah State University (USA). More than one hundred structures have been built to date [1] and Labyrinth weirs remains an active research topic today.

From 1999, the NGO Hydrocoop began investigations to improve the traditional Labyrinth concept, in close collaboration with the Electricité de France - Laboratoire National d'Hydraulique (EDF-LNH) in France and then the Indian Institute of Technology Roorkee in India and the Biskra University in Algeria [3]. Their objective was to develop a new type of labyrinth weir with an even smaller footprint while maintaining a structurally simple and economical structure that could readily be constructed. Such a weir could be placed atop gravity dams in addition to the various applications common to Labyrinth weirs (embankment dams, run-of-river, etc.). In 2003, based on the results of many tests with selected shapes at University of Biskra and some experiments at EDF-LNH, Lempérière and Ouamane proposed for the first time the Piano Key weir [2].

A Piano Key weir is a rectangular Labyrinth weir featuring inclined aprons with cantilevered apexes, increasing crest length while reducing footprint size. This arrangement is also structurally advantageous as the cantilevered walls are shorter and steel reinforcement reduced, relative to a Labyrinth weir. The name "Piano Key weir" refers to the rectangular crest pattern and was proposed by Claude Bessière, who was involved in the development of Fusegates, a fuse system placed on a spillway crest that operates as a Labyrinth weir for a moderate range of reservoir levels and overturns at high reservoir elevation to free the supporting crest. Several types of Piano Key weirs have been defined based upon the geometry of the overhangs with the types A and B (as described by Lempérière and Ouamane in

2003) being the primary types constructed. It is interesting to note that the dams of Beni Bahdel and Bakhada, built during the 1930s in Algeria, are equipped with a weir having an inclined upstream apron similar to the type B Piano Key weir.

Following 2003, developments continued at the University of Biskra, where a specific experimental platform was built by Professor Ouamane [4]. Additional advancements at LNH were provided by Mr Cicero but also at IIT Roorkee, IWHR Laboratory (China) and at Ho Chi Minh and Hanoi Hydraulic Laboratories (Vietnam). Subsequent research contributions and design advancements were provided by Ecole Polytechnique Fédérale de Lausanne (Switzerland), University of Liege (Belgium) and Utah State University (USA). The next crucial step in Piano Key weir development was reached with the design and construction of the first prototype structures. Electricité de France with Mr Laugier applied the concept to increase the discharge capacity of existing dams in France (Figure 2), while it has been used by the Vietnamese National Committee on Large Dams with the advices of Mr Ho Ta Khanh to avoid more expensive and less safe surface gates on new structures in Vietnam (Figure 3). As for traditional Labyrinths, the collaboration between research, consultancy and industry was a key element in the Piano Key weirs development success. Of particular note is the early organization of several specific international workshops and conferences that facilitated the connection of all these actors, forming an international nonlinear weir community. At these special events, an open and friendly environment was established where knowledge from practice and research was freely exchanged; these events also resulted in the publication of multiple reference books on these two weir types (https://www.pkw.uliege.be).

Since the 2006 Goulours dam Piano Key weir commissioning in France, more than 35 Piano Key weirs have been build worldwide, consistent with the number of traditional Labyrinth weirs built during that same period [1]. Research continues throughout the globe, with an average of 15 contributions in scientific journals every year since 2010. This prompt and fast development shows that the Piano Key weir solution fills a gap in hydraulic structures engineering, in particular in the current period of climate evolution, limited resources and continually increasing water related issues.

Labyrinth and Piano Key weirs, both very efficient free surface flow weir solutions, have a huge potential of development and application worldwide. This potential has been well used for the first type in the US, while for the latter it has mainly been exploited for existing dams in France and new structures in Vietnam. It is the authors' belief that the fast development of these nonlinear weir solutions will continue into the future, with a wish that the same level of enthusiasm, collaborative spirit and competency with which it began persists. ■

References

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Figure 3. Van Phong dam spillway with a 5 m high type-A Piano Key weir in Vietnam (commissioned in April 2015). Photo courtesy of VNCOLD.

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