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THE PIANO KEYS WEIR: A NEW COST-EFFECTIVE SOLUTION FOR SPILLWAYS

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Abstract: - Free-flow spillways are simpler and safer than gated ones, but the low specific flowof their traditional shapes requires high spilling nappe depths and thus huge lossesof storage (100 x 109m3 worldwide). A new shape of free-flow spillway (the "Piano Keys weir") can increase the specific flow fourfold or more. It could substantially reduce the cost of most new dams and increase, at low cost. The safety and the storage and/or the flood control efficiency of many existing dams.Piano Key weirs are simple solutions as safe and easy to operate as traditional free flow spillways and much more efficient. It is often necessary to add emergency spillways to existing gated spillways. Instead of adding costly gated emergency spillways, which do not avoid the risk of gates jamming, it could often be very advantageous to use a Piano Key weir spilling the nappe depth corresponding to the freeboard.This solution, which has never been used, seems extremely attractive for thousands of existing dams, as the storage saving would also pay for an increase in dam safety anddownstream flood control.Safety authorities often wish to increase the spillway capacity, while dam owners mainly wish to increase the storage.

I. INTRODUCTION

The relatively recent development of Piano Key Weir spillways is taking sure steps forward for dam upgrade and new projects.A variation of traditional labyrinth weirs, the relatively recent development of Piano Key Weir (PK Weir) spillways has resulted in the first of a new generation of the new, serrated free-flow structures being installed on both existing dams and in new hydraulic structures. The development potential of the hydraulically complex, but simple, structures continues to grow for project applications and research. The main areas where they are being used so far are France and Vietnam.

Seen less as a revolutionary breakthrough in weirs and more as an evolution – albeit a major one – thePiano Key Weir is physically a self-balanced structure that can be either built from precast concrete or prefabricated steel and has no mechanical components.Geometrically, a PK Weir is configured as overhanging spilling channels alternating with receiving chutes. Each has its own leading and trailing weir edges. But the majority of the water spills over the sides of the channels onto the counter-sloping slabs of the chutes to be discharged down the spillway.

Piano Key Weir spillways are often used alone on a dam or barrage but can also be designed to work in conjunction with existing spillway provision, such as stepped structures. They can also be installed on top of existing concrete dams after some modification works

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II. THE PIANO KEY WEIR DESIGN

A totally different design has been studied for five years by Hydrocoop (a non-profitmakinginternational association), and this has been supported by more than 50 hydraulictests.

The target is a structure which:

- Can be placed on existing or new gravity dam sections.
- will allow for specific flows of up to 100 m3/s/m.
- Is structurally simple, and easy to build with the local resources of all countries.

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Preliminary model tests were done in 1999 at the LNH Laboratory in France (owned byElectricité de France) and in 2002 at Roorke University in India and Biskra University in Algeria. Some shapes were then selected, and are based on a rectangular layout somewhat similar to the shapes of piano keys which explains thename "Piano Keys weir" (thus "PK. weir"); An inclined bottom of the upstream and downstream part (the part where the flow enters is known as the inlet, and the other part the outlet).

Many detailed tests were then done in 2003 on selected shapes at Biskra University andsome tests using a very wide flume at LNH.These detailed tests provided the basis for optimizing the flow increases according to theratios between length, depth, width and shape of the elements, and particularly accordingto the ratio (length of walls/length of spillway) .The impact of various overhangs has also been studied. Particular attention has been paidto the structural design and construction facilities for selecting the most attractive solutions. Very simple longitudinal sections have at present been preferred. It is possible that refining these shapes may slightly improve the cost efficiency.Further studies are now under way in China (at IWHR in Beijing) and India (RoorkeUniversity) as there are great possibilities for using Piano Key weirs in these two countries.

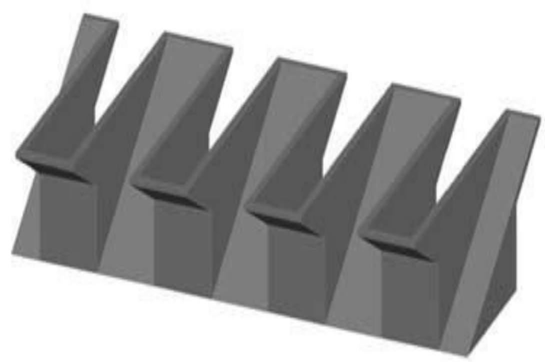

Fig.1. Three dimensional isometric view of piano key weir

III. SOLUTION FOR SPILLWAY

In many countries, the exceptional floods may be very high, and the level of safety required increases the capacity, and thus the cost, of new spillways, which may represent a large part of the total dam cost. Well adapted risk analyses and new solutions for spillways may allow substantial savings to be made.Thirty years ago, most dams were designed for a design flood with an annual probability such as 10-3Above the relevant reservoir level, a margin of safety of some meters (the freeboard) was retained below the embankment crest, but the true probability of overtopping (and failure) was not analyzed precisely.It is now usual, and advised by ICOLD Bulletins, also to consider a 'check flood' of very low annual probability (such as 10-5) or a theoretical 'probable maximum flood' and to ensure that this check flood (often about twice the design flood) may be spilled without dam failure; but it is usually accepted that the corresponding reservoir level may be close to the embankment crest, as the flood failure usually requires an overtopping of the embankment crest of some h by a nappe depth of 0.20 to 0.50 m. The freeboard is thus considerably reduced for the check flood.Two basic solutions have been used for spillways:

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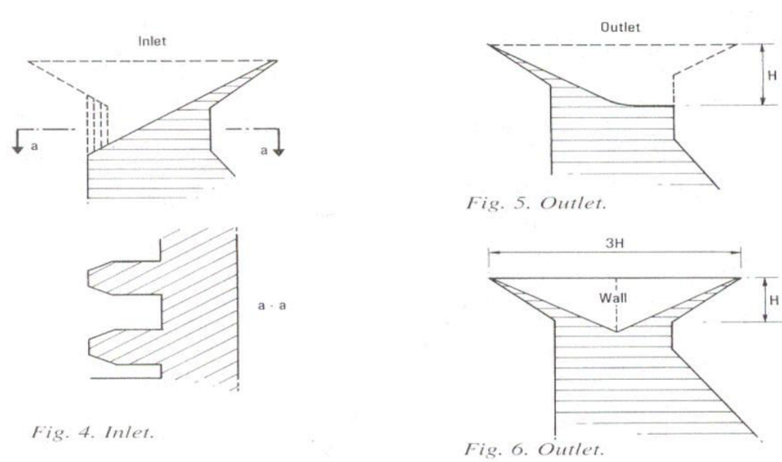
3.1 Gated Spillway

Gated spillways are most often preferred for capacities of more than 1000 m3/s, radial gates being the most usual. The reservoir may be operated at the level of the design flood,but the cost of gates is high and adapted to the check flood, that is, to about three timesthe flood of 10-2 annual probability. Consequently, for a century two-thirds of the spillway capacity will probably never be used; however, this solution is not completely safe because the gates require careful maintenance and operation and redundancy of operating devices (including power supply).To avoid the operating cost of gates, various solutions involving automatic gates have been used worldwide, but their reliability is questionable as there are two risks: unnecessary opening, or total jamming. Consequently, they should be used only for small dams, or for a part of the total spillage capacity.

3.2 Free-flow spillways

To avoid the cost or risks associated with gates, two-thirds of the world's large dams and particularly most spillways with a discharge capacity of less than 1000 m^3/s are free-flowspillways. Their operation is simple and safe, but the drawback of the usual shapes suchas the Creagershape is the rather low specific flow: the flow per metre of spillway length (in m^3/s/m) is about 2.2 h1.5 , h being the nappe depth in meters. A flow of 1000 m^3/sunder a 3 m depth thus requires 90 m of spillway length. Apart from the cost of a longspillway for embankment dams, the maximum nappe depth reduces the useful reservoirdepth; and reducing, for instance, by 3 m a reservoir depth of 30 m, in fact reduces byabout 30 per cent the live storage (or increases the dam cost by 20 per cent). Thereduction in hydropower output may also be substantial. Multiplying by 3 or 4 thespecific flow of the spillway when using thePiano Key weir solution will very often be a majorimprovement. Examples are given next for spillways of 200 m^3/s, 1000 m^3/s and 5000m^3/s discharge capacity.



Figs. 4, 5 and 6 Variations to the hydraulic shape of the inlet and outlet..

IV. INCREASING THE OPERATING LEVEL OF FREE-FLOW RESERVOIRS

If the nappe depth for the design flood is h, it will be possible to raise the operating level by 0.6 h if lowering the sill by 0.9 h and installing Piano Key weirs, of which the height H will be 1.5 h.As the value h is between 1 and 4 m for many existing dams, H will be usually between 2 and 6 m. Increasing the operating level will require 2 m^3 of reinforced concrete and 1.5 m^3 of ordinary concrete per metre of spillway length for 1 m of reservoir level increase for most spillways.

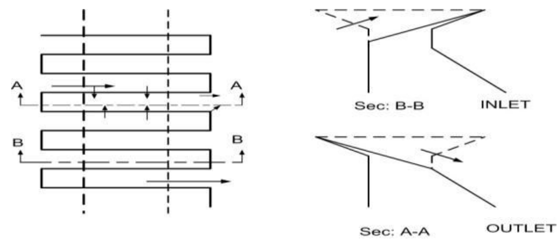


Fig.7: Inlet and outlet of Piano Key Weirwith section

The ratio between the area, of the reservoir in m² and the spillway length, L, in meters, is usually between 5000 and 50000, often between 10000 and 20000. The provision of 2 m^3 of reinforced concrete will save 10000 to 20000$m^3$of water storage. Taking into account also the cost of ordinary concrete and sill lowering, the cost per m^3 of extra water storage will be in the range of US¢5 in most developing countries (to be spent in local currencies), and possibly five times more in industrialized countries where the cost of labour is much higher.Where the area of a free-flow reservoir is more than 2 or 3 percent of the catchment area, the volume stored in the nappe depth reduces the downstream flow peak. It is necessary in this case to reduce the nappe depth saving by the Piano Key weir so as not to reduce the dam safety.It should also be underlined that using a Piano Key weir for existing dams reduces the time for floods downstream of the dam to peak, when the reservoir is not full at the beginning of the flood. Using Piano Keyweirs in conjunction with gates as suggested in Section 7 avoids these drawbacks.

V. INCREASING THE CAPACITY OF EXISTING FREE-FLOW SPILLWAYS

It is often required to increase the spilling capacity of a free-flow spillway by 50 to 100 per cent, sometimes more. Piano Key weirs can be used accordingly. For instance, if the nappe depth for the present design flood is h, lowering the sill by h and placing a Piano Key weir to keep the same operating level will increase the flow by about 70 per cent, requiring, per extra m3/s, 0.5 m^3 of reinforced concrete and 0.35 m^3 of ordinary concrete, that is, a cost of about US$ 150 in developing countries and US$ 500 in industrialized countries. It is possible to modify only a part of the spillway length according to the required flow increase.

Fig.7: Piano Key Weir

VI. INCREASING STORAGE AND FLOOD CONTROL BY EXISTING FREE-FLOW RESERVOIRS

For many existing reservoirs of area s (in m²) and a maximum nappe depth h (in m), the volume s x h is lost for storage and may represent 20 to 50 percent of the live storage anda significant part of the flood volume. It is also poorly used for reducing the flow peak offloods downstream of annual probability 10-1 to 10-2 , that is, the main usual flooddamage because the nappe depth is much less than h for these floods.

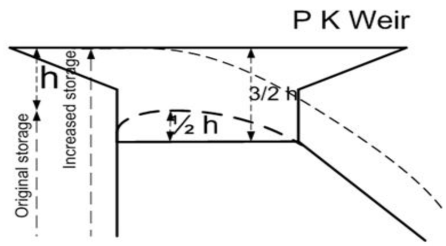


Fig.7: Piano Key Weirs for Increasing Storage

A very attractive solution may provide the advantages of a fully gated solution, without its cost and drawbacks. The sill of the existing spillway can be lowered by a depth equaltoh;Piano Key weirs 1.5 h high will be placed along two-thirds of the spillway and a flap gate1.5 h high along one-third.

The gate, which may be automatic, would be open for most of the flood season. A studyofhydrograms shows a great reduction in the flow peaks downstream for most floods.The storage will be completed at the end of the flood season, and increased by 0.5 s h.The maximum spilling capacity of the spillway is also increased. No permanent gateoperator is necessary. The consequences of gate incidents will be greatly reducedcompared with fully gated dams.This solution, which has never been used, seems extremely attractive for thousands of existing dams, as the storage saving would also pay for an increase in dam safety anddownstream flood control.

VII. CONCLUSION

Piano Key weirs are simple solutions as safe and easy to operate as traditional free flow spillway and much more efficient.

They may:

- Allow specific flows of up to 100 m^3/s/m.
- Can be placed on existing or new gravity dam sections.
- Reduce substantially the cost of most new dams and guarantee their safety.
- Improve the flood control by many existing dams and,Increase the spilling capacity of many existing dams with 0.5 m^3 of reinforced concrete per extra m^3/s.
- It's maintenance is hard to construct.
- The efficiency and cost can easily be checked within each country, and detailed designs.There are no patents, and expenses can be in local currencies.

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