Increasing the discharge capacity of free-flow spillways fivefold

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A drawback associated with traditional free-flow spillways is their low specific discharge. This paper shows how a concept which could be termed 'combining innovative spillways' (CIS) could increase the discharge fivefold, at low cost. The idea is to combine two spillways: PK weirs and concrete fuseplugs.

The solution to adopt a labyrinth shape for a spillway has now been implemented in many countries, both for increasing the capacity of existing spillways and for new dams.

1. Piano Key weirs (PK weirs)

PK Weirs have been used for discharges as low as 100 m^3/s, and also as high as 5000 m^3/s and there are designs for tens of thousands of m^3/s.

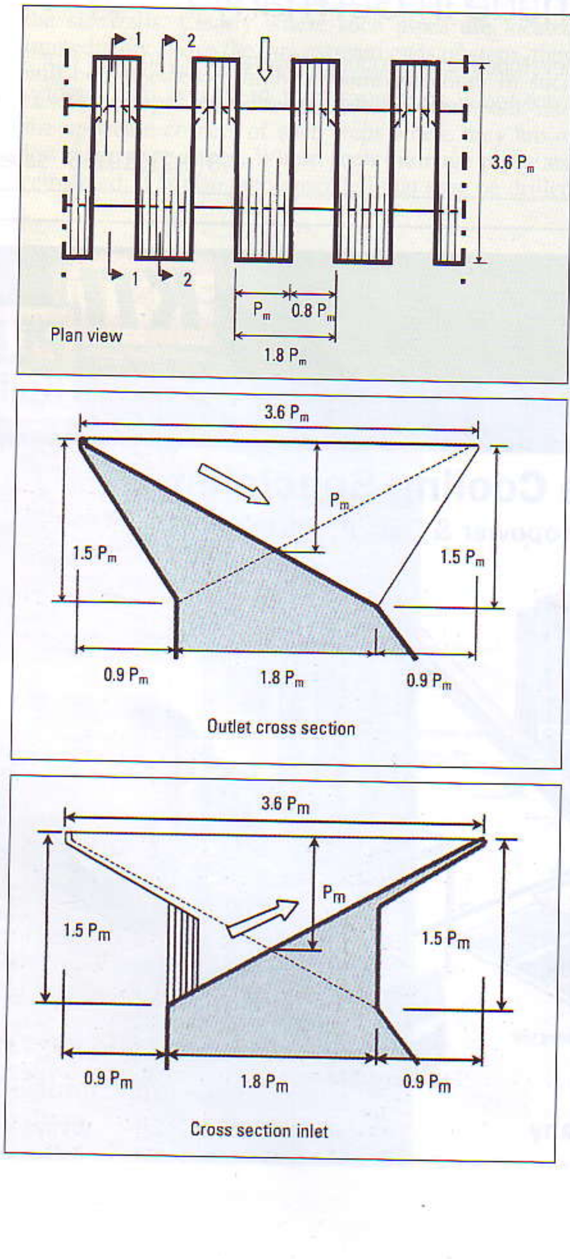


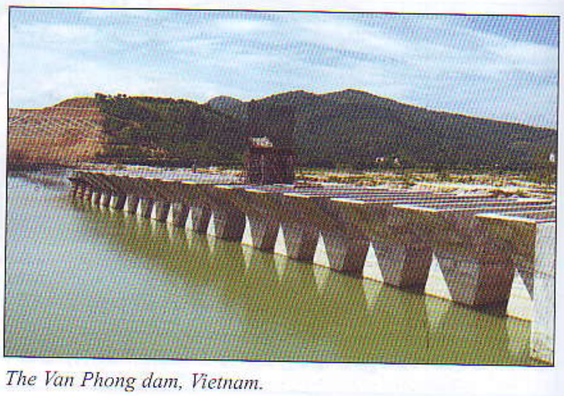
Fig. 1. Examples of designs of Piano Key Weirs.

Flow discharge on the model.

The layout of the walls has a rectangular shape; part of the walls overhang and the walls along the flow path are inclined. This is hydraulically favourable, and enables the base width of the structure to be reduced, thus allowing it to be used on most spillways or at gravity dams. Fig. 1 shows a typical design for a symmetrical PK Weir with proportions based on P_m, which is the maximum height of the labyrinth walls. Other configurations can be used on a case-by-case basis, according to local conditions; for example, having only one upstream overhang, or only one downstream overhang, or no overhangs.

For an upstream head over the weir crest of between 0.4 P_m and 2 P_m and a ratio between the length of wall and the overall spillway length close to 5, the discharge (m^3/s per metre of spillway), for the model above, is close to $4.3\ h\sqrt{P_m}$, compared with $2.15\ h\sqrt{h}$ for a Creager weir. More details are given in ICOLD Bulletin No. 144.

For a reasonable height of the PK Weir walls: P_m = 2 h or 3 h, the discharge is 6 to 7.4 $h^{1.5}$, that is, about three times the Creager weir discharge.



The Van Phong dam, Vietnam.

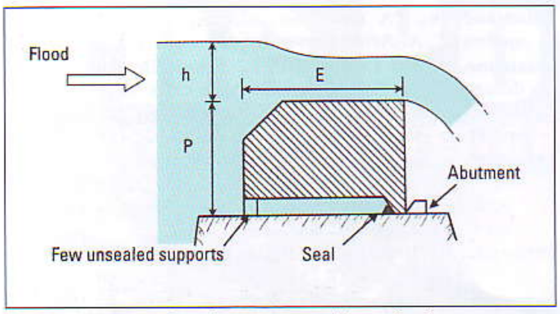


Fig. 2. A concrete fuseplug overtopped by a flood.

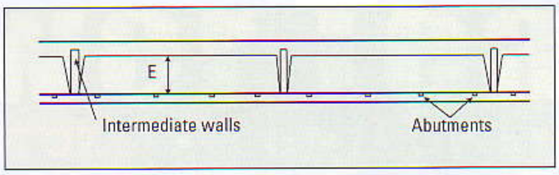


Fig. 3. Plan view of concrete fuseplugs.

2. Concrete fuseplugs

Tests have been carried out on fuseplugs in France, Algeria and Vietnam, and spillways incorporating them have been constructed in Burkina Faso and Vietnam.

Concrete fuseplugs are simple massive blocks placed side by side on a spillway sill. They are free standing and stable, until the water level in the reservoir reaches a certain elevation and they start tilting when this elevation is exceeded.

To ensure that the magnitude of uplift pressure under each block develops as required, a hollow area is provided under each block which is wide open at the upstream side and completely closed and watertight on the downstream side. Blocks placed on the same sill may have the same height but a different width, so that they tilt at different water elevations according to the increase of flood discharge.

Concrete fuseplugs can be used at new dams. In such cases, it is possible, using about the same quantity of concrete and with around the same cost as for Creager weirs, to double the flow of the extreme flood discharged through the spillway, or to increase the storage providing the same level of safety. They can also be used to improve existing free overflow spillways, by increasing the maximum spillage, after lowering the sill, or by increasing reservoir storage or by combining both.

More details are given in Appendix 3 of ICOLD Bulletin No. 144.

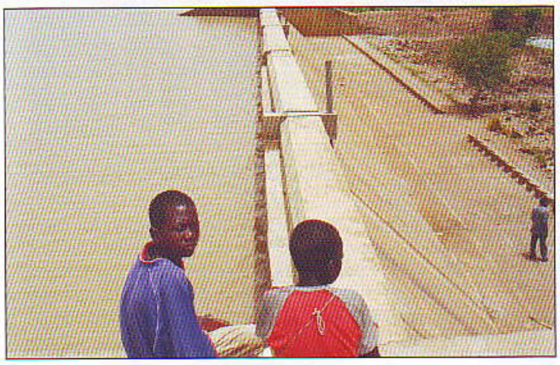
The plug width corresponding to the nappe depth causing tilting varies with the exact shape and density of the plug and void under the plug; a specific study and test is thus advisable in each case. Approximate values are given for the case shown in Figs. 2 and 3.

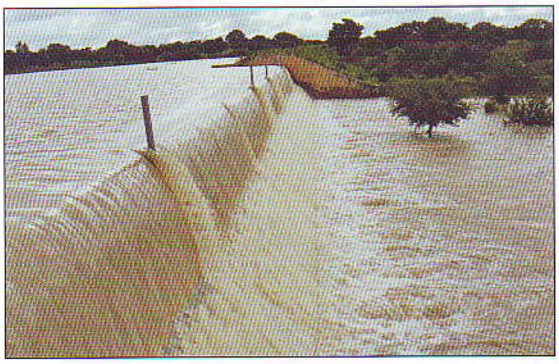
For an upstream nappe depth (h) equal to the plug height, the plug width E is about 1.3 h.

Its discharge after tilting would be $2.15 \times (2h)^{1.5}$, that is, about three times the discharge before tilting. This is the logical use of fuseplugs with a discharge before tilting of one third of the extreme flood, that is, tilting and loss of plugs for a flood with an annual probability of 1/100.

It would be more interesting to have a plug height equal to 3 h and a discharge after tilting of $2.15 \times h^{1.5} \times (3 + 1)^{1.5}$, eight times the discharge before tilting: but tilting would occur for the annual flood, which would be unacceptable.

However, this option could be used in association with PK Weirs.





Concrete fuseplugs at the Wedbila dam in Burkina Faso.

3. Combining innovative spillways (CIS)

Devoting part of the spillway length to PK Weirs and part to a fuseplug makes it possible to benefit from the specific advantages of both systems: the higher flow of the PK Weirs before tilting of the fuseplugs and the higher flow of the fuseplugs after tilting.

An example is given below for a 50 m-long spillway, with a maximum nappe depth of 1 m.

- If used as a traditional Creager spillway, its discharge will be $50 \times 2.15 = 107$ m^3/s.
- If used as a fully PK Weir spillway with a wall height of 2 m, its discharge is $50 \times 4.3 \times \sqrt{2} = 307$ m^3/s.
- If used with fuseplugs 3 m high, its discharge would be: $50 \times 2.15 \times (3+1)^{1.5} = 860$ m^3/s.
- If used as a CIS with 25 m of PK Weirs and 25 m of fuseplugs, its discharge is:

$$\frac{307 + 860}{2} = 585 \text{ m}^3/\text{s}$$

about 5.5 times the discharge of a Creager weir and double that of the PK Weir. And its discharge for the first tilting of the plug, designed, for instance, at 0.85 m, will be:

$25 \times 0.85 \times 4.3\sqrt{2} + 25 \times 2.15 \times 0.85^{1.5} = 175$ m^3/s, or 30 per cent of the extreme flood, usually a flood with a probability of around 1/100.

Devoting 30 m to PK Weirs and 20 m to fuseplugs would reduce the discharge after tilting to 530 m^3/s, or five times the Creager discharge, but the discharge before first tilting should be increased from 175 to 195 m^3/s, that is, close to 40 per cent of the extreme flood 530 m^3/s, perhaps the flood of annual probability 1/1000.

For h greater than 1 or 2 m, the weight of simple fuseplugs becomes very important. It may be better to

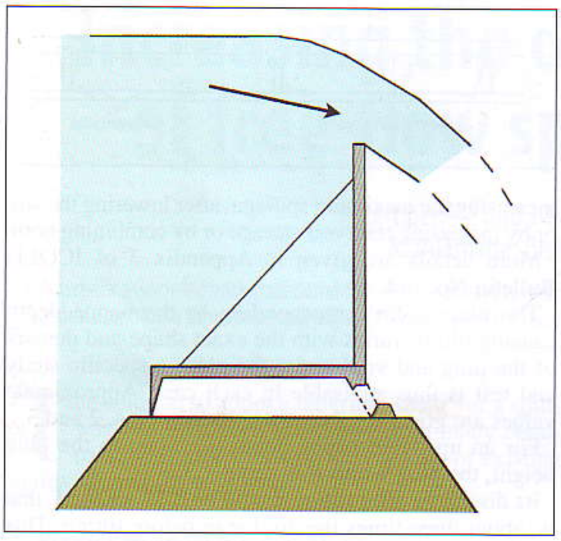


Fig. 4. Cross section to demonstrate the CIS concept.

use reinforced concrete structures as shown in Fig. 4, or similar to straight fusegates with or without a tilting system by uplift; 10 m high fuseplugs may then be possible operating with a 3 or 4 m nappe depth, that is, a possible discharge per m of $2.15 \times (10 + 4)^{1.5}$, or, up to 100 $m^3/s/m$ associated with PK Weirs discharging 40 $m^3/s/m$, or about 70 $m^3/s/m$ on average.

About 50 spillways of various sizes are successfully using Hydroplus labyrinth fusegates which may have performances close to the CIS concept. Their design is more complex than CIS, but their cost may be in the same range, especially in cases of upgrading large existing spillways.

4. Other spillway combinations

Gates may be necessary for managing reservoir operation or to mitigate floods or siltation, but their necessary capacity is not more than 20 or 30 per cent of the extreme flood. It can thus be interesting for large dams to combine three spillways of similar capacities: low or high gates, PK weirs, and fuseplugs. Gate operators need not be permanent and this combination can be very safe and cost effective.

5. Regulations

The solution above significantly reduces the necessary gap between the top of the PK weirs top and the dam crest.

Reducing the freeboard is very cost effective, and increases by 20 or 30 per cent the storage volume of most dams devoted to water supply and irrigation, in other words, the great majority of dams.

It is only necessary to adapt the dam crest to the possible impact of exceptional waves; concrete dams can withstand overtopping by large waves. It may be advisable to line the crest of embankment dams, or to increase their height with parapets, or alternatively to make the crest steeper.

The principles of the traditional design flood may prevent the adoption of CIS because it imposes an unnecessarily high freeboard. The check flood criterion is therefore considered preferable. ◊

Bibliography

Lempérière, F. and Ouamane, A., "Piano Key Weirs: a new cost-effective solution for spillways", *Hydropower & Dams*, Issue Four, 2003.

Ouamane, A., "A new cost effective solution for most spillways", Al-Azhar University, Algeria; 2005.

Ouamane, A. and Lempérière, F., "Nouvelle conception de déversoir pour l'accroissement de la capacité des retenues des barrages", International Symposium on the Protection and Preservation of Water Resources, Blida, Algeria; 2006.

Ouamane, A. and Lempérière, F., "Design of a new economic shape of weir" International Symposium on Dams in the Societies of the XXI Century. Barcelona, Spain. Published by Taylor & Francis, UK; 2006.

Ouamane, A., "Hydraulic and Costs data for various Labyrinth Weirs" Q84, 22nd ICOLD Congress, Barcelona, Spain; 2006.

Ouamane, A. and Lempérière, F., "Amélioration du rendement des évacuateurs de crues en labyrinthe", Second International Symposium on Water and the Environment, ENSH, Blida, Algeria; 2007.

Ouamane, A. and Lempérière, F., "Increase of the safety of existing dams - Rehabilitation of weirs", Symposium on Dam Safety Management: Role of State, Private Companies and Public in Designing, Constructing and Operating of Large Dams", 75th Annual Meeting of ICOLD, Saint Petersburg, Russia; 2007.

Ouamane, A. and Lempérière, F., "Nouvelles solutions économiques permettant l'accroissement de la capacité des retenues des barrages existants", National Seminar on Water and the Environment (SNEE), Blida, Algeria; 2008.

Ouamane, A. and Lempérière, F., "The Piano Key Weir is the solution to increase the capacity of the existing spillways" HYDRO 2008: Progressing World Hydro Development, Aqua-Media International Ltd, Ljubljana, Slovenia; 2008.

Ouamane, A. and Ben Said, M., "Economic conceptions of the labyrinth weir allowing the improvement of the management of floods and the increase of the useful capacity of the reservoir" Rheinisch-Westfälische Technische Hochschule, Aachen, Germany. Published by Shaker Verlag, Germany; 2010.

Ouamane, A. and Lempérière, F., "Study of various alternatives of shape of piano key weirs" HYDRO 2010 - Meeting Demands in a Changing World, Aqua-Media International Ltd, Lisbon, Portugal; 2010.

Lemperière, F., Ouamane, A. and Vigny, J-P., "General comments on labyrinths and P.K. Weirs: The past and present", Labyrinth and Piano Key Weirs, published by Taylor & Francis, UK; 2011.

Ouamane, A., "Nine years of study of the Piano Key Weir in the university laboratory of Biskra - Lessons and reflections". In: Labyrinth and Piano Key Weirs, published by Taylor & Francis, UK; 2011.

Lemperière, F., Ouamane, A. and Vigny J-P., "Promising future for PK Weirs" *Hydropower & Dams*, Issue Two, 2012.

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