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## HYDROPLUS SUBMERSIBLE FUSEGATES FOR SURFACE SPILLWAY

C. BESSIERE  
S.E.E.E. (France)

Controlling floods is one of the most important factors in dam safety and economics. It accounts directly or (allowing for the cost of gate supervision and maintenance or the lost storage capacity associated with ungated spillways) indirectly for about one-third of the cost of an average dam. In addition, the high uncertainty factor on the design flood estimated often leads, in practice, to spillway capacity being either overdesigned, which is a waste of money, or inadequate, without any certainty as to which of the two situations applies except when the catchment area is very large. Lastly, refusal of gates to open is one of the main causes of gated dam failures and has been known to occur at much less than the design flood.

These problems can be partially overcome at some sites by fuse dykes. Moderate floods are discharged by conventional gated or ungated spillways, but the, says, 100 - or 500 - year flood overtops the fuse dyke and washes it away to provide the necessary extra discharge capacity. Although cost effective in many cases, it is only feasible at a minority of sites or puts constraints on the setting out of the main dam. It does have the added advantage of preventing destruction of the main dam if the gates fail to open during a moderate flood, but on the other hand, it releases a large flash flood downstream which may be substantially greater than the incoming flood.

The HYDROPLUS system derives from the fuse dyke idea. It can be retrofitted without difficulty to most existing ungated dams and has many attractions for most new gated and ungated dams, since it has all the advantages of the fuse dyke, without its drawbacks. And it has a further key advantage of substantially increasing reservoir storage capacity at ungated projects, at little cost per cubic metre saved.

## 1 - HYDROPLUS FUSEGATE CONCEPT

The HYDROPLUS system consists of one or more contiguous but independent fusegate units sitting on the overspill sill, and held in place solely by gravity forces (fig. 1).

The fusegates are overtopped by moderate river floods, and their labyrinth crest shape is more efficient than the conventional straight weir crest.

Larger floods will cause them to overturn by rotating about an abutment at their downstream edges ; the number of units washed away is graded to suit the hydrograph of the particular expected flood.

Each unit sits freely in a precast concrete frame cemented into the crest, and consists of three parts (see fig. 2 Operating Sequence) :

- a) The sheet steel or reinforced concrete top part is usually given a zig-zag or labyrinth shape to lengthen the overspill length and so discharge moderate floods with a relatively small head on the lip.
- b) The bottom chamber is usually reinforced concrete. Pressure is admitted when the headwater level reaches a predetermined height, which is different for each fusegate.
- c) The pressure inlet to the chamber is a well which begins to fill at a precise predetermined reservoir level.

The fusegate on the spillway crest functions in one of three ways, depending on headwater level (fig. 2).

- 1 ) As part of the dam, so long as reservoir level does not exceed the fusegate top level.
- 2 ) As a weir, when headwater level is higher than the fusegate top level but lower than the predetermined level causing the fusegate to overturn.
- 3 ) As a "breaching dyke" or orthodox spillway gate when headwater reaches this predetermined level.

In the first two cases, the fusegate is designed to have an ample stability margin, even in the event of willful damage or incidents. It meets the same criteria as a well-drained gravity dam.

Fig. 1 - HYDROPLUS fusegates

GENERAL VIEW

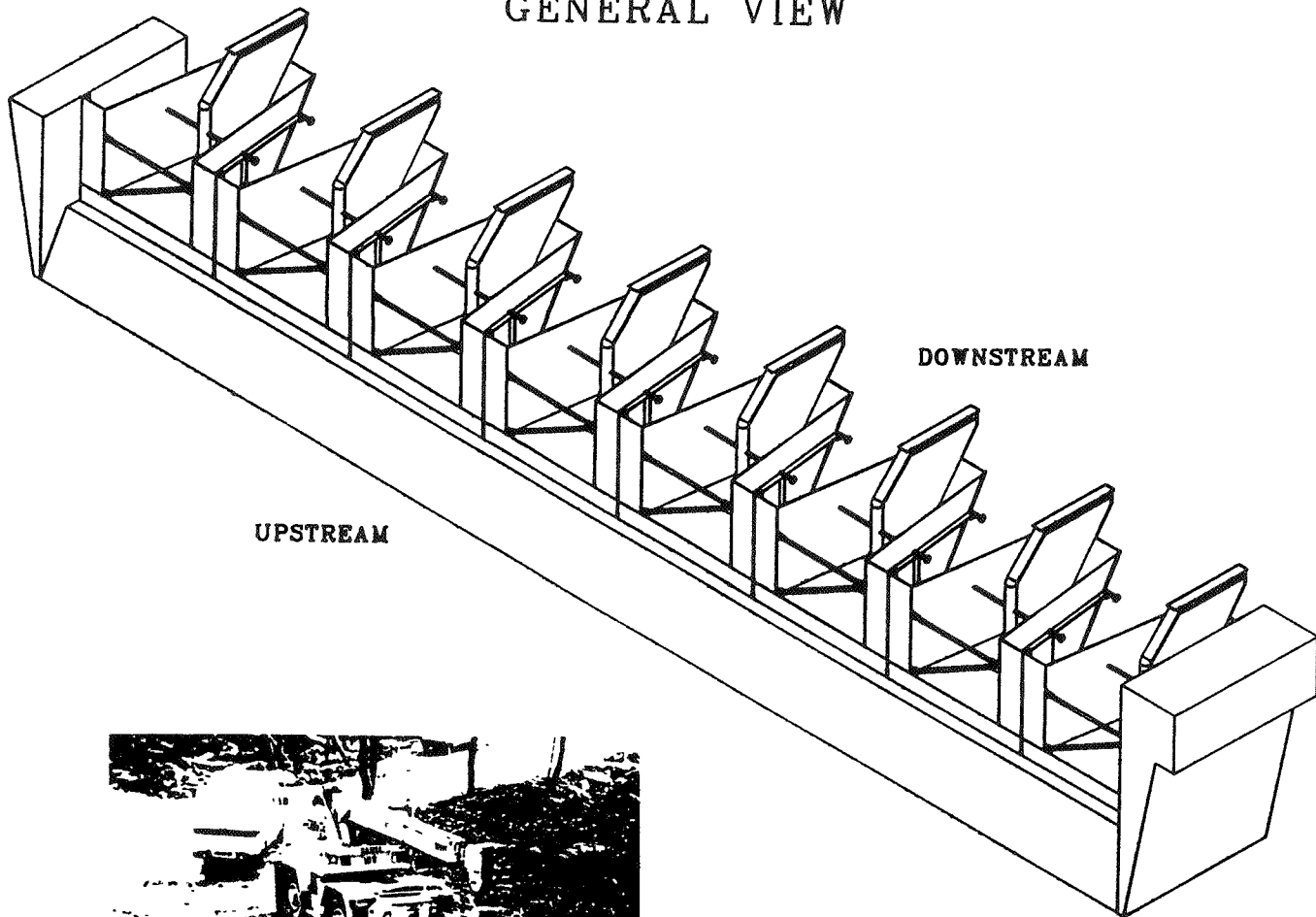
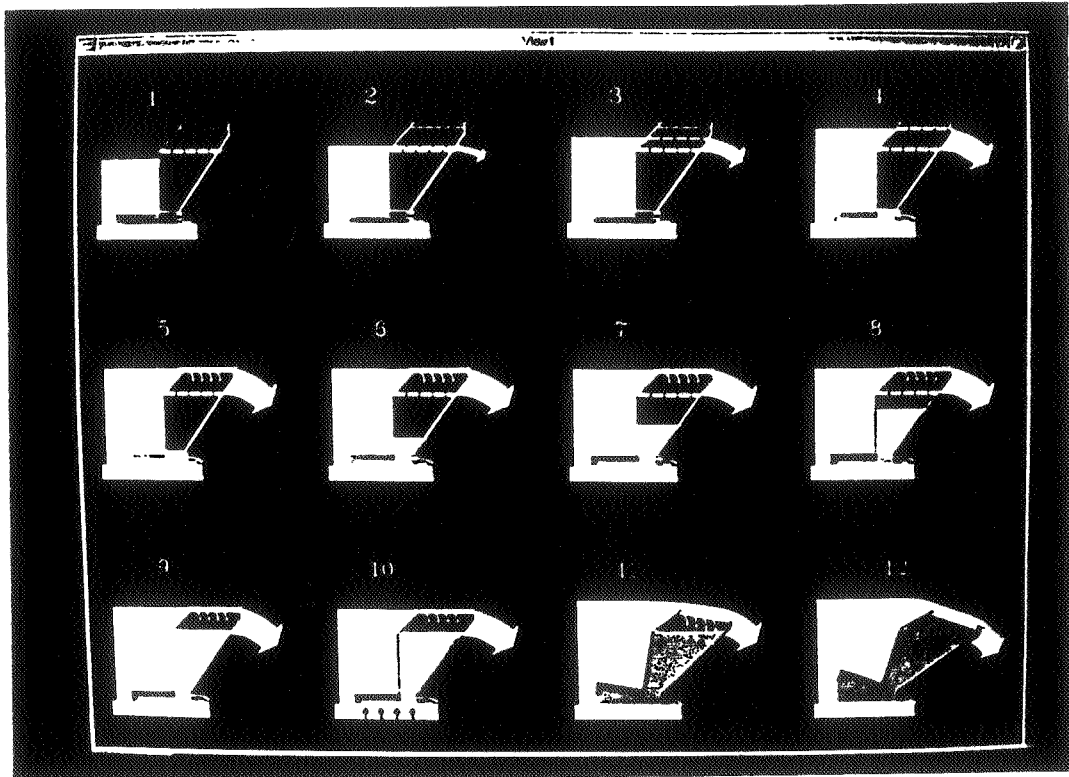


Fig. 2 - Fusegate Operating Sequence



1 - Acting as part of the dam

2 - 3 - 4 - Acting as a weir

(The vents in the downstream part of the bottom chamber evacuate the possible leakages due to waves ...)

5 to 10 - Progressive filling of the well when headwater level reaches the well top

11 and 12 - Uplift pressure in the bottom chamber is sufficient to produce the rotation of the fusegate

When headwater level reaches the desired height, the fusegate rotates about an abutment strip at its downstream edge as uplift pressure is admitted to the base chamber. The triggering system is extremely precise and accurate and leaves an ample stability margin until the reservoir rises to exactly the predetermined level.

Once a large flood has receded, the overturned fusegate(s) are simply hoisted back on the sill or replaced with identical new units if they have been seriously damaged.

Much theoretical research has been conducted on fusegate performance when spilling and rotating, and abundant model testing performed by GTM and EDF National Hydraulics Laboratory (LNH) at Chatou.

Fig. 3 shows fusegates spilling before overturning.

All the tests have demonstrated that individual fusegates can overturn without entraining their neighbours (fig. 4 = a fusegate rotation test at St Herbot dam in France the 24th of march 1992 for the S.H.E.M.A. subsidiary of Electricité de France).

Floating debris and waves have almost no effect on discharge efficiency and very little effect on rotation.

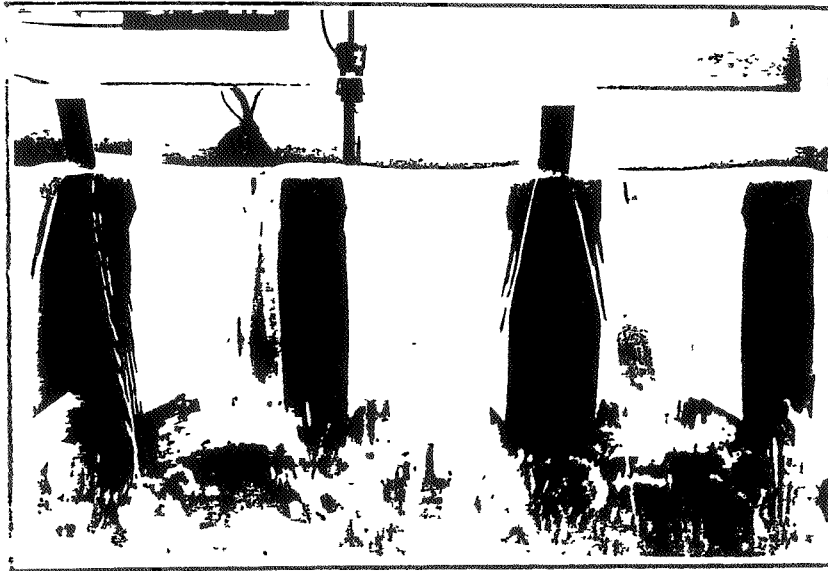
Willful damage (such as attempts to block the wells) can only cause minor inconvenience at the seals (which is quickly put right) or precision of the triggering level. Even total blockage of the well would have no impact on dam safety ; the fusegates will rotate even without uplift pressure, at a somewhat higher reservoir level, it is true, but below dam crest level. This engineered safeguard has been verified by tests at Marolles and Chatou.

Hydraulic tests have shown that there is no danger of overturned fusegates being caught on the spillway chute, since they are unstable in this position at flow velocities in excess of 2.5 m/s.

There is a step in the outflow hydrograph as each fusegate overturns, similar to the opening of an orthodox control gate, but by this time, the downstream discharge is considerable, equivalent to about one-third the maximum channel flow, so that the river level has reached about 60 % of its maximum height. Thus a step in the outflow curve will cause a jump of only about 10-20 cm in tailwater level, which quickly dies away farther downstream.

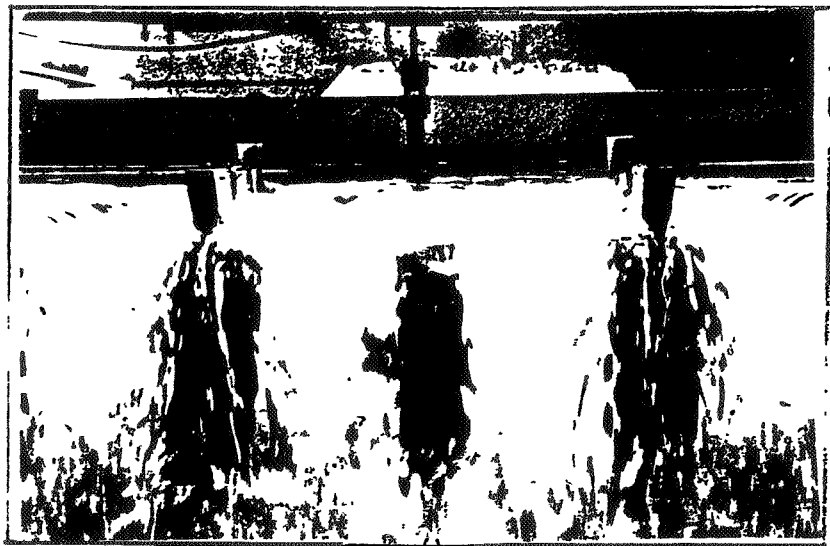
When one or more fusegates have overturned, the natural flood recession period is extended by the time needed for the extra capacity represented by fusegate height to drain away.

Fig. 3 - Fusegates spilling before overturning



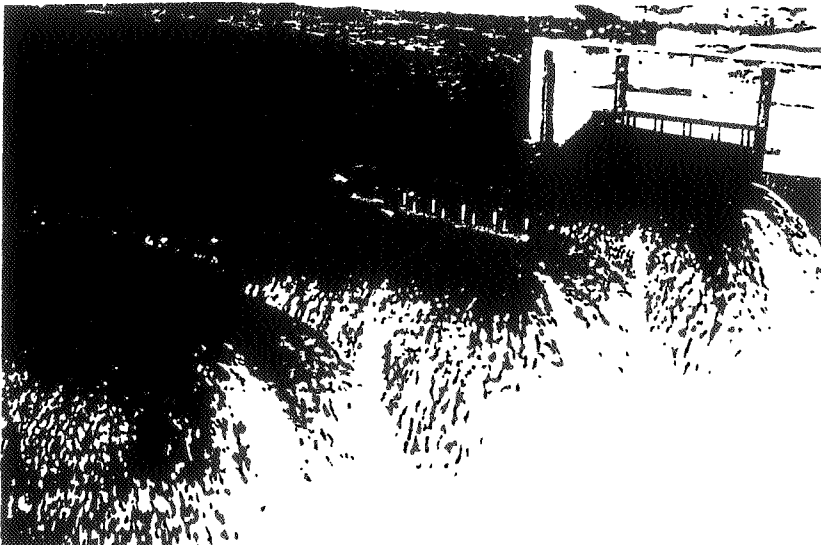
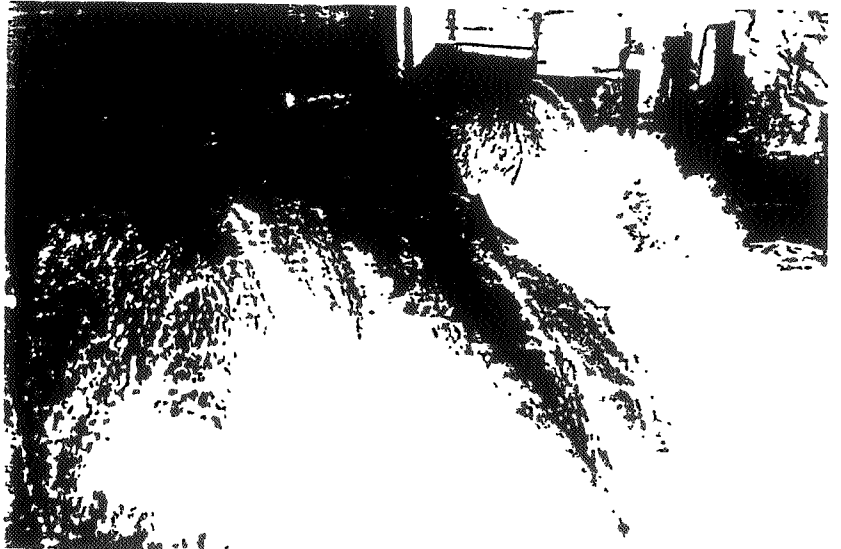
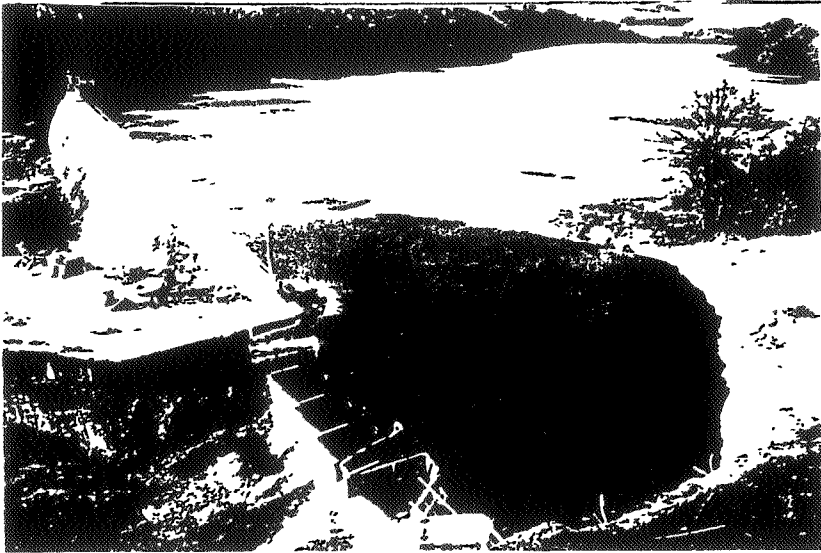
a) Small to moderate flows

b) Large flows



c) Floating debris

Fig. 4 - A fusegate rotation test at St Herbot dam in France



## 2 - APPLICATIONS TO DIFFERENT DAM TYPES

HYDROPLUS fusegates are placed on uncontrolled overspill sills to increase discharge capacity and/or storage capacity (and available head for hydroelectric plants).

They can equip existing and planned dams, small or large.

### 2.1 - Increased spillway capacity

In designing an overspill with HYDROPLUS fusegates, the designer has three parameters to play with :

- a) Elevation of sill on which the fusegates are to sit (final sill level of planned dam or lowered sill level at existing dam).
- b) Fusegate height.
- c) Reservoir level at which first fusegate is to overturn, and subsequent steps for other fusegates.

The first parameter can be used to increase the maximum spillway capacity without changing sill length or maximum reservoir level.

The other two parameters can be beneficially used to control outflow from the dam, avoiding the major problem with breaching dykes, which is that they cause a sudden, large increase in downstream flow, perhaps even substantially in excess of the flood inflow value.

On new dams, HYDROPLUS fusegates enables the spillway to be shortened, thereby making it easier to fit into the site.

Certain future very large spillways might provide an attractive opportunity to combine fusegates with orthodox gates controlling, say, 10-40 % of the design flood.

### 2.2 - Increased live storage capacity

The same three parameters enable the designer to consider increasing the live storage capacity of the reservoir.

With existing dams, such an increase depends on the benefits expected from the dam. If it is not required to afford any substantial flood control, it would be possible to raise the normal reservoir level by about 75 % of the height of the maximum head on the sill.

The sill would be lowered by about 10-15 % of this maximum head if there is no need to increase discharge capacity, and the fusegates would be slightly less than this height, giving a fusegate height of about 85-90 % of the original head on the sill.

If flood control is one of the main purposes of the dam and it also provides over-year storage, the normal reservoir level would have to be raised slightly less ; it might be of the order of 30-50 % of the maximum head on the sill in order to avoid any excessive increase in the maximum outflow from the dam, although this will always be less than the inflow peak.

In this case, the sill would be lowered by something of the order of 20-25 % of the height of the maximum head on the sill, and the fusegates would represent the equivalent of 50-75 % of this height.

In many cases, it might be attractive in both cost and political terms to increase spillway capacity as well as live storage.

### 3 - OPERATING DAMS AND PROSPECTS

The HYDROPLUS system was fully developed and model-tested by 1990. The first practical application was to equip Lussas dam in France between march and may 1991. The recent rains have meant that they spilled in early november 1991 (fig. 5).

A second dam in France, Le Gouyre, was equipped with HYDROPLUS fusegates in september 1991.

A third one "St Herbot" was equipped in march 1992 and at Electricité de France request a full scale overturning test was performed the 24th of march 1992 (see fig. 4) and reproduced the 22nd of april.

A fourth one "Le Tordre" will be equipped in the next weeks.

Five or six further applications are in the design stage or scheduled for implementation by end of 1992 early 1993, in France and abroad (Morocco - India).

It is estimated that it would be possible to equip 50 to 100 large dams in France with fusegates, plus about as many smaller dams. This would, in total, increase reservoir storage capacity by about 200 hm<sup>3</sup>.

Yet the discharge capacity of these spillways is generally less than 500 m<sup>3</sup>/s and the potential increase in the storage capacity in France represents less than 1 % of the feasible extra capacity in the world as a whole. The first applications to very large spillways is therefore planned abroad from 1992 onwards.

Standardisation and quick construction of fusegates should open up opportunities for many applications in many countries, both at existing dams and others as yet unbuilt, which justifies the research and development investment of the order of 10 million french francs.

Fig. 5 - Fusegates spilling at Lussas Dam, november 1991

