JUIN 1996

UPGRADING SPILLWAYS FOR EXTREME FLOODS WITH GRAVITY FUSEGATES : CASE HISTORIES

UTILISATION DES HAUSSES FUSIBLES POUR AUGMENTER LA CAPACITE DES EVACUATEURS DE CRUES: EXEMPLES D'APPLICATION

Abdellah AIT ALLA , Technical manager HYDROPLUS

22-38 , Rue Michelet, 92 000 - Nanterre - France
Phone : 33 1 40976732 Fax : 33 1 40976050

Summary

Modern methods of design flood estimation frequently require re-evaluation of spillway capacity at existing dams.
The Hydroplus system enables undersized spillways to be brought up to modern standards at low cost, safely and without loss of storage capacity.

The purpose of this communication is to illustrate, through various projects typical fusegate application to increase spillway capacity.

Résumé

Les nouvelles méthodes d'estimation de la crue de projet conduisent souvent à revoir la capacité des évacuateurs de crues des barrages existants.
Le procédé Hydroplus permet de résoudre ce problème de manière sûre, économique et sans perte de stockage.

L'objet de cette communication est d'illustrer, à travers divers projets, des applications types des hausses fusibles, pour augmenter la capacité des évacuateurs de crues.

1. FUSEGATE CONCEPT

Fusegates are independent gravity units set side-by-side on the spillway sill to form a watertight barrier. Moderate floods are discharged over the crest of this barrier. When an exceptional flood occurs, the barrier is breached as an adequate number of fusegates rotate in a predetermined sequence.

Individual fusegates rotate when the reservoir level reaches the tilting level set for each one.
The overturning is caused by the combination of hydrostatic pressure on the upstream face and uplift pressure in the bottom chamber (fig. 1), into which water is admitted through an inlet well topped out at the appropriate level.
Each fusegate on the sill is set to overturn at a different reservoir level.

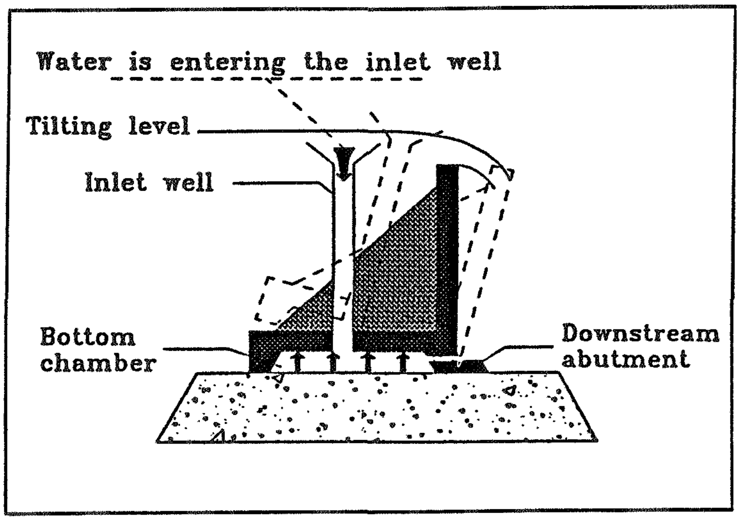

Figure 1 : Fusegate concept

Further details on how fusegates function can be found in a number of publications [1, 2, 3, 4].

Fusegates are generally used at existing dams to increase storage capacity and/or spillway capacity.
When applied to new dams, they contribute to spillway optimisation and general dam design.

Other types of use can be considered, some of which have already been implemented:

- controlling the entrance to retention areas on large rivers, as was done at a pilot project in China;
- initiating breaching and erosion of fuse plug dykes.

2. ST HERBOT DAM, FRANCE, 1992

The use of fusegates to increase spillway capacity at St Herbot dam was the first application of this type.
This pilot project helped finalise the fusegate concept.

St Herbot dam lies in Brittany, 70 km from Brest. It was built primarily for hydropower generation. This masonry gravity dam, 12.50 m high, was completed in 1932.

2.1. Design Flood Review

The total capacity of the original side channel spillway was less than 30 m^3/s.
Re-evaluation of the design flood called for a spillway capacity of approximately 80 m^3/s.

Fusegates enabled this goal to be successfully achieved while retaining the original Full Supply Level, a vital criterion for maintaining powerstation output.

2.2. Spillway Renovation Works

The spillway renovation works consisted of:

- changing the position of the spillway sill; the new sill: 20m long on the left bank, was aligned with the dam axis;
- upgrading the spillway channel, by excavating some 2200 m^3 of granite;
- installing on the sill five 1.50 m high, 2.25 m wide fusegates and a fixed labyrinth wall, 8.75 m long and the same height as the fusegates.

Upgrading the spillway channel took around two months, installing the fusegates was completed in a week.

2.3. Spillway with Fusegates

For exceptional floods, the five fusegates controlling part of the spillway rotate, one after the other, when the reservoir reaches predetermined levels. The first fusegate overturns for an inflow of around 40 m^3/s, the last rotates on arrival of the design flood.

The total capacity of the revised spillway is 80 m^3/s, i.e. 16 m^3/s over the labyrinth sill and 64 m^3/s over the part of the sill fitted with fusegates, after they have overturned.

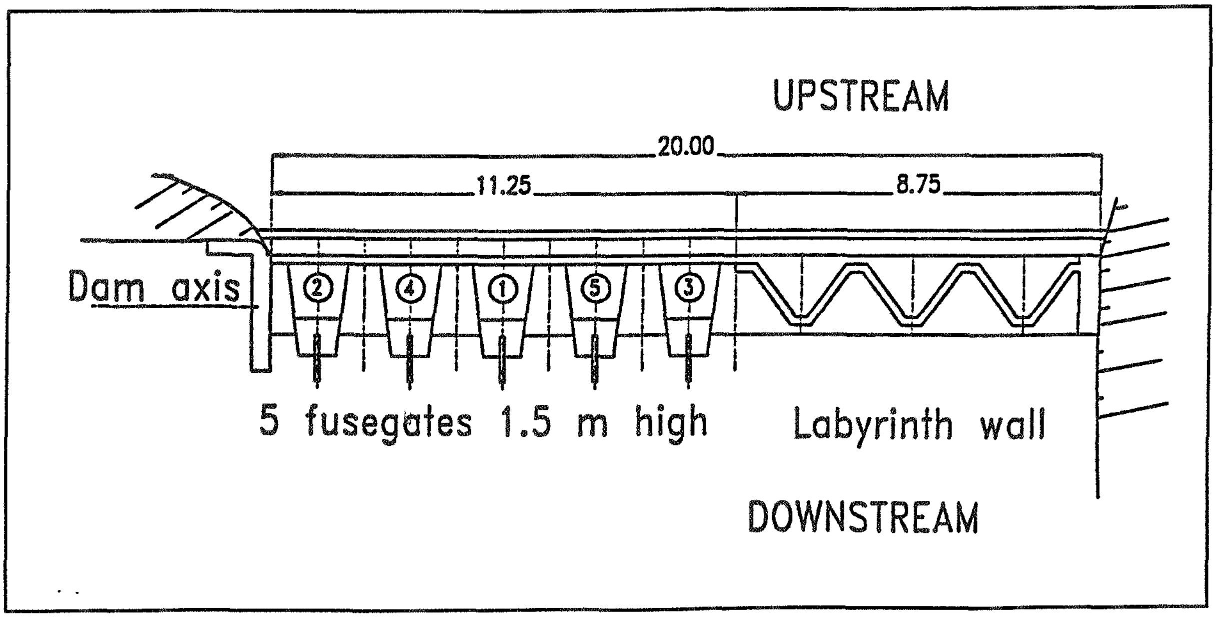

Figure 2 : Plan of spillway

On 29 December 1994, a natural flood estimated at 53 m^3/s caused the first fusegate to overturn, at the expected reservoir level. The highest reservoir level reached during this flood was only just below the level at which the second fusegate was designed to tilt. The seconde fusegate remained stable.

The fusegate that rotated was replaced by one of the pair of spares kept at the dam site for this purpose.

3. SHONGWENI DAM, SOUTH AFRICA, 1994

Shongweni dam is a gravity structure, 33 m high, on the Mlazi river, 20 km from Durban in Natal, South Africa. It was completed in 1927. The reservoir lies in a nature reserve covering some 1500 ha.
The use of fusegates for upgrading spillway at Shongweni was the largest application of this type to date.

3.1. Design Flood Review

A safety review in 1988-1989 concluded that spillway capacity should be increased from its original 1400 m^3/s to 5000 m^3/s (PMF). Modification was urgent in view of the many townships located downstream of the dam, as well as Durban airport.

It would have been possible to obtain the desired safety standard, without affecting storage capacity, by lowering the spillway sill 6.5 m over its whole 126 m length and installing fusegates of equivalent height.
However a cost analysis and architectural study (part of the dam is listed as a historic monument) prompted the owner to opt for lowering the original sill by 7.9 m over a length of around 100m (where there are no masonry piers as on the left bank end) and fitting ten labyrinthe fusegates, 6.5 m high and 9.75 m wide.
This reduced storage capacity by only 1.4 m with no significant impact given the purpose of the dam reservoir (recreation area).

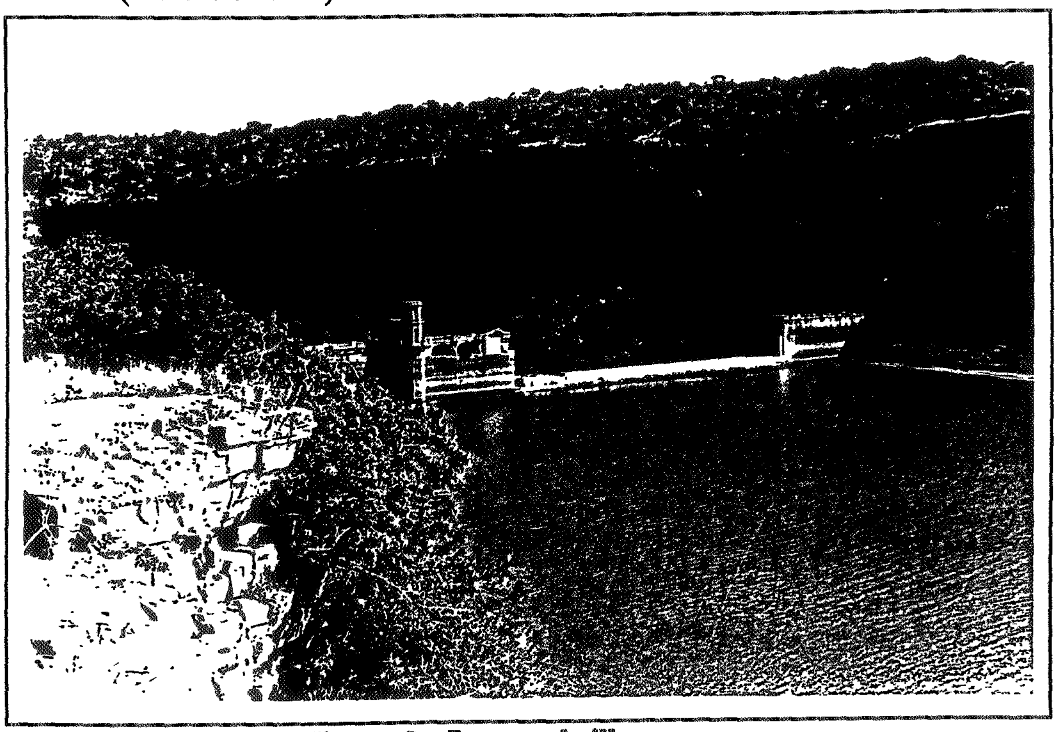

Figure 3 : Lowered sill

3.2. Spillway Renovation Works

The spillway sill was cut back 8.20 m and topped with a 30 cm reinforced concrete slab tied down in the body of the spillway. Since the dam lies in a nature reserve sheltering a rare specy of bat, controlled mini-blasting was used for the demolition of the sill.

The fusegates were made and installed by local contractors under Hydroplus supervision.
Each fusegate has a concrete base weighing 70 tonnes, a 35 tonne steel bucket incorporating the inlet well, and prefabricated concrete blocks providing the required ballast.
Ballast ranges from 15 tonnes to 40 tonnes depending on fusegate overturning level.

Difficult site access governed the choice of method for installing the fusegates, and therefore their design. The concrete base is made up of prefabricated beams keyed together on the sill. A concrete slab laid on this assembly provides the lost form for pouring an in situ slab, 60 cm thick, where the lower part of the steel bucket is rooted in.

Each steel bucket was built up from eight panels (excluding the well), each weighing 5 tonnes. The panels were transported from the left abutment by cableway and assembled on the sill. The 60 cm slab was poured after the bucket had been completely assembled in position.

Fabrication of the buckets and wells took five months. During this time, the owner set about lowering the sill and setting up the cableway. Installing the ten fusegates took around four months.

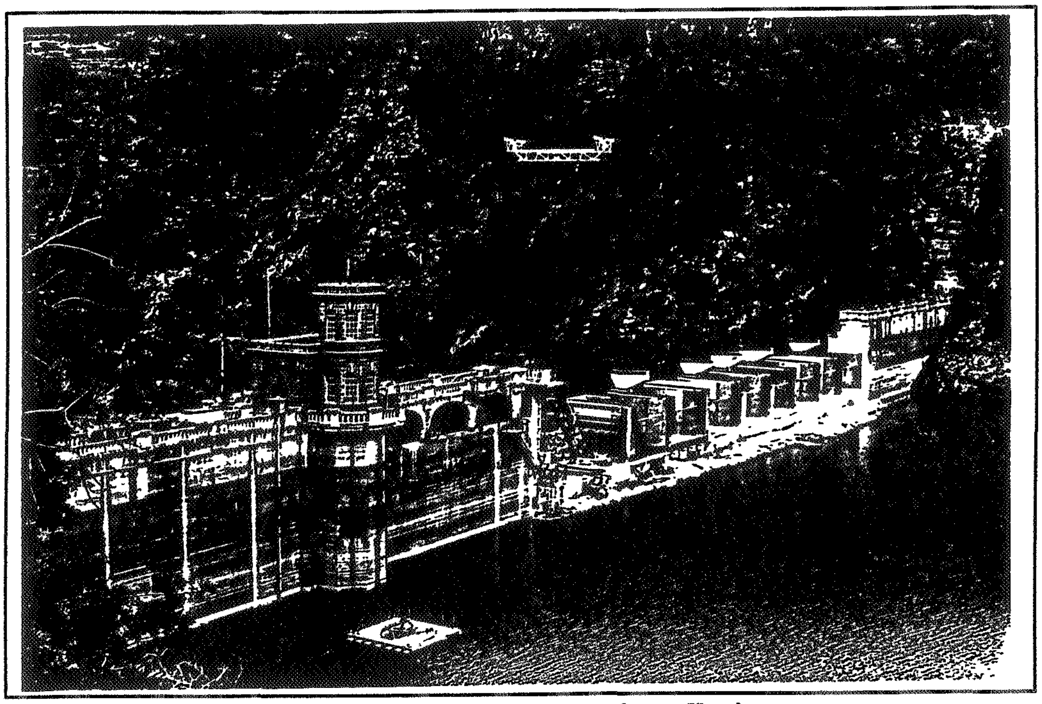

Figure 4 : Fusegate installation

At the 18th ICOLD Congress in Durban (November 1994), there were study tours to visit the site, when installation of the fusegates was in progress. The works were completed in February 1995.

3.3. Spillway with Fusegates

The new spillway sill can discharge the 5000 m^3/s PMF once all the fusegates have rotated, without the reservoir reaching the safety level determined from the dam stability analysis.
The first fusegate is set to overturn for a flood of 1500 m^3/s, representing a recurrence interval of the order of 250 years.

Filling the reservoir after installation of the fusegates took approximately four months and the Shongweni reserve has undergone considerable growth since.

In December 1995, Natal province experienced extremely heavy rainfall which caused large river floods, especially on the Mlazi river.
On 25 December 1995, Shongweni dam experienced an exceptional flood (of the order of the 100-year flood) with an estimated peak of around 1000 m^3/s (see photo below).
This flood was discharged without any fusegate tilting as expected.
The fusegates were inspected after this flood had receded and no damage was found.

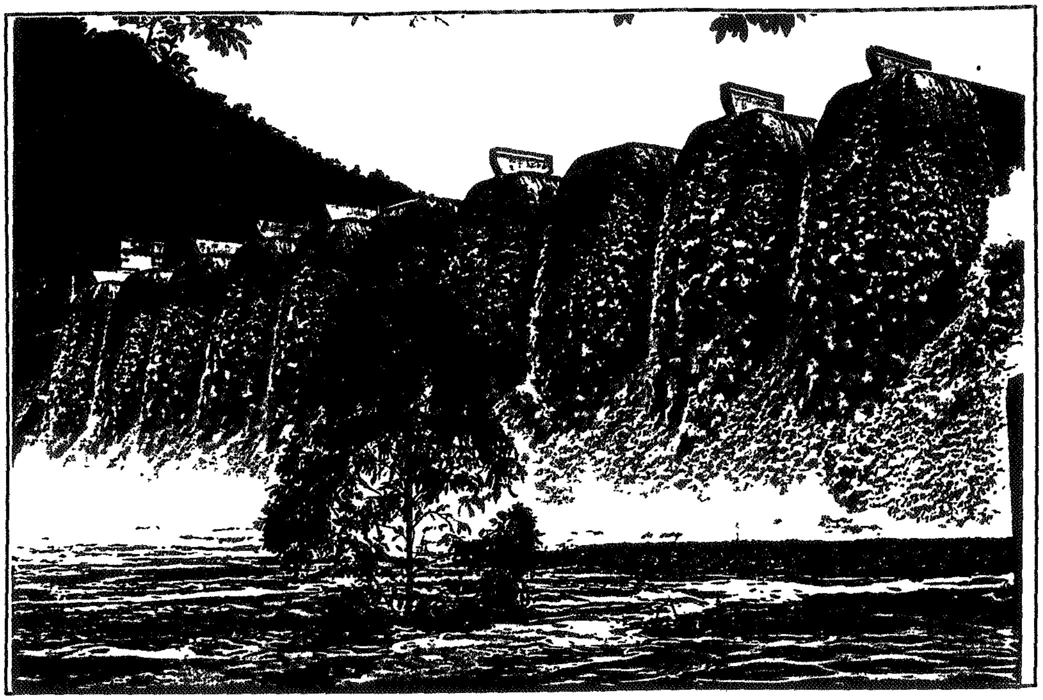

Figure 5 : 25 December 1995 flood

4. CAILLAOUAS DAM, FRANCE, 1994

Caillaouas is a masonry gravity dam at an altitude of 2710 m in the Pyrenees. It was built for hydropower generation.

Despite the small size of the project, the spillway upgrading at Caillaouas dam is very interesting because access to the site was extremely difficult and the design combined a conventional gate with fusegates designed to overturn for very small heads.
This arrangement is a promising solution for large spillways.

4.1. Design Flood Review

An analysis of extreme floods at Caillaouas dam by the Gradex method, undertaken in 1992, showed that spillway capacity would have to be increased.
The spillway was controlled by two slide gates 0.75 m high, with gate openings 3.70 m wide.
The original spillway capacity was 10 m^3/s under a head of 0.80 m. The new hydrological study estimated a peak inflow from the 1000-year flood of 37 m^3/s, requiring a spillway discharge capacity of 29 m^3/s.

4.2. Spillway Renovation Works

The spillway was modified to provide this discharge capacity as follows:

- the sill was lowered by 0.75m;
- the pier between the two gate openings was moved sideways so that the openings became 2.60m and 4.80m wide. One was fitted with a 1.50m-high flap gate controlled by reservoir level and the other, with three straight-crested fusegates 1.50m high and 1.60m wide;

Full Supply Level was maintained at its original level.

Because of the location of the site, the fusegates had to be brought in by helicopter. They consisted of a lightweight metal structure heavily weighted with reinforced concrete ballast. The metal structure of each fusegate weighed 400 kg with 90 kg concrete blocks providing the necessary ballast. The total concrete ballast for each fusegate was between 1600 kg and 1800 kg.

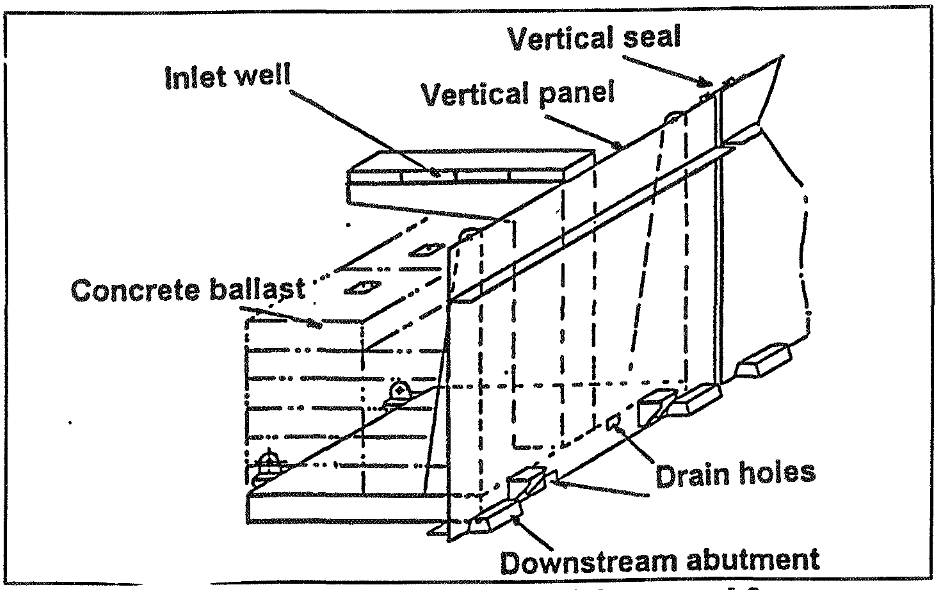

Figure 6 : Perspective view of straight-crested fusegate

Transportation of the fusegates to site from the lowland storage yard, installation, placing the concrete ballast blocks, setting up downstream abutments and seals, and other installation works took only two days in the field.

4.3. Spillway with Fusegates

The flap gate discharges floods with a peak inflows of up to 17 m^3/s (outflow discharge of 9 m^3/s) with a reservoir level slightly above FSL.

If larger floods occur or in case of gate failure, reservoir level would rise significantly above FSL and the fusegates would overturn, in sequence, when the reservoir reaches predetermined levels 8cm, 5cm and 2cm below Maximum Water Level.

Total discharge capacity of the new spillway is 29 m^3/s, practically three times the original capacity.

5. DOVESTONE DAM, UNITED KINGDOM, 1995

Dovestone dam is an earth embankment on Saddleworth moor, 8 km from Oldham in Lancashire.
The primary purpose of the dam, owned by North West Water, is water supply to several small villages. The service spillway is a bellmouth weir, 19.5m in diameter.

5.1. Design Flood Review

Calculation and 1/21 scale model tests showed that the service spillway could discharge 160 m^3/s. Capacity necessary to control PMF was 280 m^3/s. It was therefore necessary to increase the discharge capacity of the original spillway in order to meet the safety criteria for the dam.

If no extra spillway works had been provided, it would have been necessary to lower FSL by 2.3 metres, with scale model tests to check that the spillway culvert was capable of discharging this flow of 280 m^3/s.

It was possible to solve the safety problem by supplementing the service spillway with an auxiliary spillway.

5.2. Spillway Upgrading, Auxiliary Spillway

The basic solution was to build an auxiliary side channel spillway with a straight ungated sill 56m long set 0.73 m higher than the main spillway sill. Installing fusegates made it possible to shorten the new sill to 9.80 m.
The auxiliary spillway sill is fitted with three steel labyrinth fusegates 2.15 m high and 3.25 m wide. Their crests are set 0.73m above FSL, and they are designed to overturn when reservoir level rises 0.53 m, 0.58 m and 0.63 m above their crests.

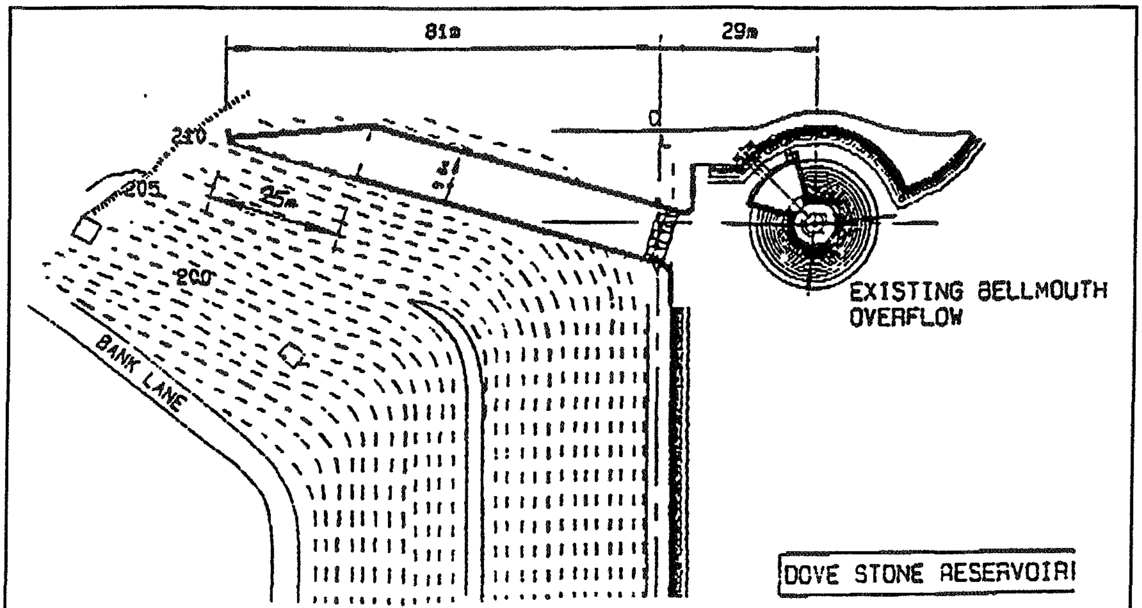

Figure7 : Plan showing the fusegate solution

Overspilling occurs only for floods larger than the 100-year flood, and the fusegates are designed to overturn for floods between the 1000-year and PMF.
The fusegate installation was completed in December 95.

6. SIMILAR PROJECTS UNDER STUDY AND OTHER FUSEGATE SAFETY APPLICATIONS

The use of fusegates for upgrading spillways represents a large proportion of Hydroplus projects, completed or under study. Of the 150 projects currently under examination, 50 cases are related to safety.
Several projects are at the design stage, and installation of some of them may start in a very near future.
The most noteworthy examples are:

- use of straight-crested fusegates (tilting for low heads) combined with conventional gates;
- increasing spillway capacity at large earth dams by installing fusegates on an emergency spillway. This function is frequently filled by fuse plugs;
- substituting fusegates for some of the gates on run-of-river dam.

Another possible application for improving auxiliary spillway safety would be to use non-overspill fusegates as reliable means of initiating breaching of fuse plug dykes.
Fusegates are set on top of the dyke. Fusegate crest level would be substantially higher than reservoir Maximum Water Level (MWL) at which the fuse plug is washed away, in order to avoid any risk of accidental spilling on the dyke (due to waves for example).
The inlet well level would be set to enable the fusegate to overturn at the desired MWL. Fusegate tilting would release a heavy discharge over the dyke (e.g. 2 to 3 m deep nappe) reliably initiating erosion of the fill.

The use of fusegates at new dams would help in optimising the spillway and the general layout of the whole dam without adversely affecting safety. At very large dams, a combination of fusegates (designed to tilt for a reservoir level below their crest level or slightly above) and gates would optimise reservoir management while having a similar level of safety as with an ungated spillway of adequate size.

Fusegates can be used to improve safety at water-retaining structures other than dams.
The pilot project at Dongfeng Lake on the Huaihe river in China controlling a flood retention area designed to fill during relatively frequent floods (5-year flood) is an extremely interesting application.
Three straight non-overspill fusegates sit on a 20 m long sill on the right river embankment which controls the entrance of the retention area. The fusegates rotate when the river reaches a predetermined level; a system of adjusting the wells makes it easy to change the tipping level.
This application should be extended to the whole Huaihe river basin after a period of observation of the pilot project. This would represent a total length of sill to be fitted with fusegates aggregating some twenty kilometres, the first phase covering a length of 4 km.

Similar applications for protecting embankments along major rivers are feasible in many other countries, especially in the southern European countries.

7. CONCLUSIONS

The two principal applications of the Hydroplus concept are increasing storage capacity and upgrading spillways.

Projects of the first type are more numerous because they help meet the demand for water for agriculture, domestic supply and hydropower and are therefore easier to justify in terms of economics.

There is however a significant increase in projects and studies arising out of concern about earlier hydrological studies based on methods that are now considered inadequate.

The simplicity of the Hydroplus concept and its great versatility e.g. in choice of materials, fusegate type, method of construction and installation, etc. facilitates adaptation to conditions in different countries, dam sites and owners' expectations. It is a safe and low-cost answer to the need to improve safety at dams and water-retaining structures in general.

In many cases, upgrading spillways can be combined with an increase in storage capacity, making dam safety improvement an economically attractive exercise.

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