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HOW TO OPTIMISE DAM STORAGE CAPACITY WITHOUT COMPROMISING SAFETY : THE FUSEGATE CONCEPT

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SYNOPSIS

Both technical and economical parameters have to be properly evaluated during the design of a dam and it is always a dilemma for the designer to choose between the various types of hydraulic structures available.

Gated spillways offer optimum reservoir management and full utilisation of available reservoir potential. However the safety risks associated with controlled or gated spillways are well known and understood and there is much documented information describing related incidents and accidents over the years. The risks, requirements and impacts of mechanical flood gates are extremely sensitive to the circumstances of the environment.

On the other side, a solid uncontrolled spillway offers greater safety provided one accepts the loss of live storage capacity which can be about one third of the potential full capacity.

A third alternative is now available to the Designer with the non-mechanical fusegate concept, which enables to maintain the advantages of an uncontrolled spillway while maximising the storage capacity of the reservoir.

Keywords: fusegates, dam safety, storage increase, spillway

1.0 INTRODUCTION

The HYDROPLUS Fusegate system has been available for the past 10 years and to date about thirty installations located in various countries are under operation. The system has been applied for storage increase on existing dams as well as for dam safety problems to cope with undersized spillway capacity.

The system comprises a number of non-mechanical gravity units only that resemble open buckets. These units are installed across ungated spillway to create a watertight barrier.

The weight of one unit plus the weight of water within the "bucket" prevents it from tilting even when overtopped during flood events. However at a predetermined reservoir elevation, water enters an inlet well at an elevation at which the fusegate will tip. This inlet well is connected to the base chamber of each fusegate. Once the chamber fills with water the resulting uplift pressure combined with hydrostatic pressure is sufficient to tip the fusegate whereupon it is swept downstream. Since each inlet well is set at an increasingly higher elevation a sequential breaching of the system is achieved until at the Design Flood (PMF), all the units would have tipped leaving the spillway free to discharge the design flood.

2.0 CASE STUDIES

The three following case studies chosen among the HYDROPLUS most recent projects give some typical examples of application of the non-mechanical fusegate system.

2.1 Terminus Dam (USA) : How to Improve Flood Control and Storage Capacity

When the U.S. Army Corps of Engineers wanted to increase the flood protection of the 38-year old Terminus dam near Visalia, California (USA), it applied to Congress for the right to increase the height of the dam's uncontrolled spillway. In 1996, Congress approved a plan to raise the uncontrolled spillway by 6.5-m thus increasing the reservoir's capacity and flood protection from a 50-year event to a 70-year event.

The $50-million plan also called for the Corps to widen the spillway. But a value engineering analysis recommended a relatively new and less expensive system developed in France and used in Europe, Asia and Africa. The use of HYDROPLUS system would allow the Corps to increase the height of the spillway without increasing its width. The detailed evaluation undertaken by the design department of the Corps showed that the technique would also offer more control than is afforded by a strictly ungated spillway.

The Corps tested the method at Utah State University using a physical model of the dam, spillway, and fusegates that was built on a scale of 1/30. Various configurations were tested on this 23 m long and 16 m wide model able to discharge 1.7 m^3/s corresponding to the 9570 m^3/s PMF on the prototype.

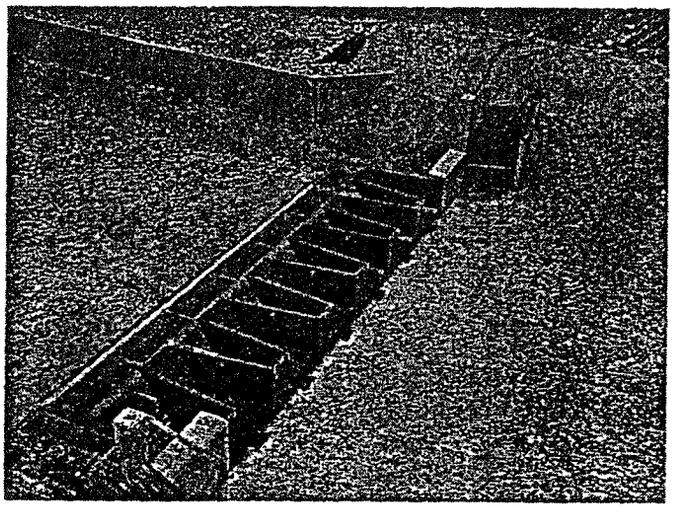
Several innovations regarding the arrangement of the fusegates were required because of the down-stream channel very shallow slope (1%) leading to high tailwater water levels.

For terminus dam, there will be six units constructed in concrete and each weighing about 405 ton. Because the Corps was concerned that large debris might get caught on the tops of the wells, the design calls for wells to be remote from the units and situated in a separate control structure near the embank-ment. This configuration offers the main advantage of being able to discharge large floating debris without any risk of them being caught.

The tumbling of the tilted fusegates and their influence on the upstream water level were also studied. The main results showed that the path of the fusegate appeared to be at random; the floods were properly discharged without any influence on the upstream water level, even with several fusegates stuck in the channel.

The first unit does not tip until a 1 in 1000 year event, so the probability of it ever happening is remote. Remaining units have their intake wells set at increasingly higher levels so that a sequential breaching of the system occurs. At the maximum design flood, all units have tipped and the spillway can pass the flood unencumbered, without increasing the maximum flood water level in the reservoir.

The tests showed that the method would do a very good alternate.



View of spillway equipped with labyrinth fusegates

The labyrinth wall crest and the fusegates crest elevations were accurately chosen and set at two different levels.

With this arrangement, the following benefits have been achieved :

- This FSL has been increased by 2 m.
- The most frequent flood up to 50 year return period at least are discharged by the labyrinth wall only.
- At the recommended design discharge, (1 in 200 years), flow in the auxiliary spillway is kept as low as practically possible, while flow down the service spillway must never exceed 220 m^3/s. This can be achieved by a proper design of the service weir which rate of increase of flow down the main chute reduces significantly due to submergence of the labyrinth spillway.
- As the water head increases, extra water is discharged above the fusegate crest in the auxiliary spillway.
- At an outflow of around 260 m^3/s, corresponding to a flood of greater than 1 in 500 year recurrence interval, the first straight crested fusegate tips off, increasing discharge down the auxiliary spillway.
- Further increase in head water level causes more fusegates to overturn down the auxiliary chute, whilst flow down the main chute is kept below the main chute carrying capacity.
- The PMF is discharged under the maximum water level kept at its original elevation.

The civil works were undertaken by a South African sub contractor under Hydroplus technical supervision. Each of the 10 tons straight fusegate was cast on the sill, then jacked up to ensure no bond had formed between their base and the sill.

The contract was completed in October 1998, which allowed the water level to rise within 0.3 m of the new FSL before the start of the irrigation season (October to April).

The Groenland Irrigation Board has increased its live water storage by 19% (from 24.4 to 29.0 million m^3). while improving the dam safety. Additional water will be available mainly for irrigation and municipal use in a region, which can be considered as the main South African orchard.

3.0 MONTSALVENS DAM (SWITZERLAND) : REHABILITATION , SAFETY AND SPILLWAYS

From May 1997 to November 1998, intensive rehabilitation works were undertaken on the Montsalvens arch dam located in the Swiss Jorge valley.

Although the behaviour of the 75 years old structure is satisfactory, these rehabilitation works become necessary to adapt the dam to actual safety requirements and mitigate the aging effect on mainly mechanical gates.

With a newly defined peak discharge of the 1000-years design flood 346 m^3/s, the total spillway capacity had to be significantly increased compared to an actual value of 150 m^3/s.

The Owner, Enterprises Electriques Fribourgeoises (EEF), appointed Lombardi SA (Minisio) as Consulting Engineer to instruct these operations.

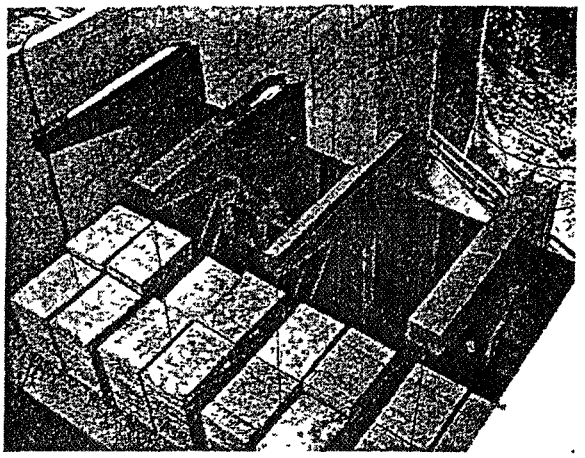
The works on the right bank spillway were limited to the replacement of the radial gate with a new gate of similar dimensions. Remote control systems were installed to operate this gate from the hydropower plant located downstream in Broc City.

The discharge capacity was kept unchanged at a value of 75 m^3/s.

As regards to the left bank spillway, major modifications were required to increase the discharge capacity by a factor of 4, while keeping the full supply level unchanged.

Four alternatives considering rubber dams, radial gates, flap gates and Hydroplus fusegates were examined; the detail assessment took in considerations both technical and economical parameters. The equipment reliability and operating requirements were also considered.

Based on the comparison of the various alternates according to these parameters, the HYDROPLUS solution involving 4 straight fusegates of 5.05 m high and 2.57 m wide located on a 10.3 m wide sill was selected.



4 Straight fusegates at Montsalvens dam

Two series of model tests were carried out to analyse the hydraulic behaviour of the left bank spillway and to verify the efficiency of the fusegates :

The first model, at a 1 to 30 scale, was constructed in the hydraulic laboratory of the "Ecole Polytechnique de Lausanne". The general behaviour of the spillway was analysed in detail.

A second model at a scale of 1 to 10 was built in the chute of the Maigrauge scheme. The reliability of the fusegate functioning in both normal and exceptional conditions was studied. The accuracy of the tilting sequence in relation with the tri-dimensional flowing condition was analysed; a special design was proposed for the inlet wells to accommodate the disturbed upstream water nape.

The design of the equipment was supervised and approved by the Swiss Federal office of Water Economy, in charge of dam safety.

The project was completed by November 1998.

The fusegate installation at the Montsalvens project, 52 m high arch dam, is considered to be innovative as, for the first time on a dam of the size, the fusegates are used to complement the operation of a radial gate and a bottom outlet. The combination provides the two-fold advantage of a good reservoir level control and improved dam safety with respect to large floods.

This arrangement could be widely used in the future to rehabilitate old dams in compliance with the directives of updated safety regulations.

4.0 CONCLUSION

The assessment of the various alternates for design of a spillway outlet structure cannot be done on economical grounds only. Other parameters such as the reliability of the equipment, operational requirement or maintenance aspects too have to be properly considered.

On a case by case basis the Designer must perform a multi criteria analysis which requires a comprehensive understanding of the project as a whole.

The Fusegate System can often provide a technically reliable alternative, quick to implement at moderate costs. This statement can generally be applied for reservoir storage increase, but even more for dam safety improvement with the increase in spillway discharge capacity.