Increase in storage capacity at Xyliatos dam, Cyprus

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The storage capacity of the Xyliatos dam in Cyprus has recently been increased using fusegate technology. The dam is in an environmentally sensitive area, within the boundaries of a forest. Application of this system was found to offer the optimum solution with respect to cost and environmental impact.

Xyliatos dam is one of the key elements of the Pitsilia Integrated Ruler Development Project, which was implemented in Cyprus in the early 1980s. This is a multipurpose project, aimed at stimulating the economically depressed mountainous region of Pitsilia, in the Central Troodos Massive, thus raising the standard of living of some 21 000 inhabitants in 50 local villages, and reducing urban migration. The water development element of the project consists of small irrigation (850 ha) and domestic supply schemes which are supplied with water from boreholes or off-stream ponds. The project includes only one dam, Xyliatos, which was completed in 1983; its purpose is to store water for irrigating some 300 ha of land in the villages of Ayia Marina and Xyliatos.

The dam is within the boundaries of a forest at an elevation of approximately 500 m. It is a rockfill structure with a central clay core, and a height of 48 m above the lowest foundation level. The reservoir capacity is 1220×10^3 m^3. The spillway is on the left abutment within the rock mass, and is of the free overflow type with an ogee-crested weir 15 m wide. It has a concrete-lined chute of varying width, which ends in a flip bucket and a low flow chute.

Since its construction, the dam has been overspilling frequently during the wet winter seasons and in 1997 a decision was taken to increase its storage capacity by about 210 000 m^3 using the Hydroplus fusegate system. The increase in capacity is sufficient to supply the water needs for three village communities downstream of the dam.

The fusegates were installed in February 1998 and increased the storage capacity of the dam to 1430×10^3 m^3. Water was impounded behind the fusegates, during the 1998-99 and 2000-2001 winter seasons and the system overspilled for the first time in January this year.

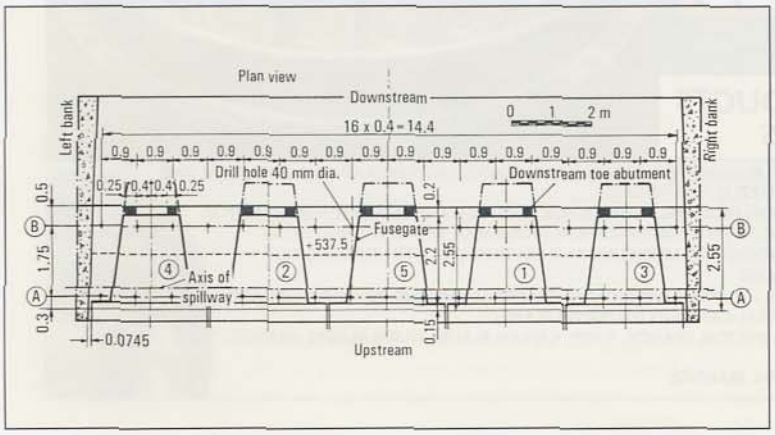

Fig. 1. Plan of the fusegate arrangement at Xyliatos.

The fusegate system adopted was found to offer the most cost-effective and environmentally favourable solution. It also allowed for a fast installation time.

Hydrology

The climate of Cyprus is semi-arid with long, hot, dry summers and relatively wet winter months. The average annual precipitation for the past century has been about 500 mm, but records show that the average precipitation of the last 30 years of the century was approximately 15 per cent lower than the average precipitation of the first 70 years. The catchment of Xyliatos dam (about 20 km^2) is above el. 500 m, where precipitation is well above the average value for the whole of the island. The maximum inflow values of the 50-year, spillway design and freeboard floods, as calculated at the dam *design stage, are 57, 130 and 243 m^3/s respectively.*

The fusegate system

The fusegate system has been used successfully in the last decade for optimizing storage behind dams or increasing the capacity of spillways to improve safety. It has been applied to existing and new dams, as well as river flood management schemes. The design of the system and its method of operation have been described by Falvey and Treille [1995[1]] and the cost benefits from adopting it in achieving extra storage and improving dam safety have been analysed by Lempérière [1995[2]] and Ait Alla [1997[3]].

The system comprises a set of independent gravity units, called fusegates, which are placed on the dam spillway sill to form a watertight barrier. The fusegates are usually built of concrete or steel or of a combination of both. Each unit consists of three different parts: the main body, which forms the water-retaining structure, the pressure chamber on the underside, and the water inlet which can admit water to the underside in cases of high floods. The fusegates bear against small abutment blocks specially built on the downstream edge of the spillway concrete sill. Stability against overturning is achieved with ballast blocks (usually made of concrete) which are placed on the main body of the gates. Specially manufactured rubber seals are used to prevent leakage between the individual units and also between the units and the concrete sill and spillway walls. The fusegates remain stable when overtopped by water, as long as the level of the overflowing water is below that of the water inlet. In the case of high floods, water is admitted through the inlet well to the underside of the fusegate and the resulting uplift pressure causes overturning of the unit.

In the case of high floods, the tilting sequence can be controlled very accurately by adjusting the level of each water inlet. Tilting of each fusegate progressively increases the spillway discharge in a calculated

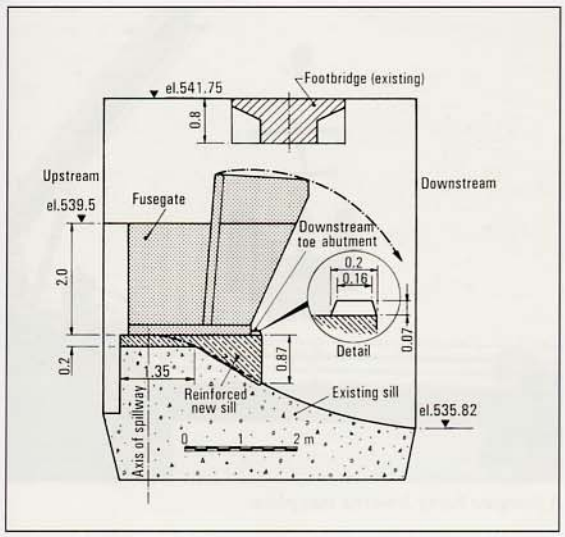

Fig. 2. Typical cross section through a fusegate.

manner, thus accommodating the maximum possible floods without risk of overtopping of the dam crest.

Unlike other spillway control systems, no electrical or mechanical power is needed at the time of operation during major floods. Inspection and maintenance requirements are therefore minimal.

Furthermore, unlike the classical raising of a spillway and embankment which is a traditional alternative solution for increasing the storage capacity of an existing dam, the fusegate system does not involve any disturbance to the environment, as the modifications are accomplished within the limits of the existing spillway.

There are therefore significant environmental benefits from such an application which is achieved without the necessity for major civil works.

The Xyliatos fusegate system

The fusegate system adopted at Xyliatos consists of five 3 m-wide labyrinth-shaped units placed on a new concrete sill constructed at spillway level. The height of the fusegates was chosen to be 2 m, as this was considered to offer the optimum solution, taking into consideration the water storage requirements, the construction cost and hydraulic performance.

In addition, this height ensures that the new full supply level remains below the top of the clay core, to ensure safe performance of the embankment. It also allows sufficient space for tilting of the fusegates in view of the presence of the spillway footbridge a few metres downstream of the spillway.

The arrangement of the fusegates in plan is shown in Fig. 1, and a typical cross-section through a fusegate in Fig. 2.

The installation of the fusegates results in an additional storage volume of 210 000 m^3, which represents 17 per cent of the original gross storage capacity.

Hydraulic design

The hydraulic performance of the fusegate system has been examined with flood routing calculations based on the assumption that at the beginning of the flood the reservoir level is at the fusegate crest level. A summary of these calculations is shown in Table 1.

The calculations show that for the 50-year flood there will be no tilting. The first tilt occurs with a hydrograph corresponding to a maximum inflow of 78 m^3/s.

Table 1: Summary of the flood routing calculations

Flood	Max. inflow (m^3/s)	Max. outflow (m^3/s)	MWL (el.)	Number of tips
Highest flood without a tip	78	58	540.63	0
Spillway design flood	130	123	540.76	3
Freeboard flood	243	213	541.40	5
50 year flood	57	42	540.34	0

Table 2: Sequence of fusegate tipping at Xyliatos

Tipping sequence	Fusegate No.	Upstream tip level (el.)
1	1	540.64
2	2	540.69
3	3	540.74
4	4	540.79
5	5	540.84

When routing the spillway design flood with a maximum inflow value of 130 m^3/s, there will be three tiltings and for the freeboard flood with a maximum inflow value of 243 m^3/s there will be five. The fusegates are designed to tilt in a progressive manner by adjusting the inlet level of each well, as shown in Table 2.

The sequential overturning of the fusegates is designed to avoid any sudden increase in outflow. Furthermore, the flood recurrence interval for the first fusegate rotation is significantly higher than the 50-year flood. Therefore it is expected that the benefit from the system over a sufficiently long period of operation will greatly outweigh the inconvenience from loss of the first unit and the corresponding loss of water.

The routed freeboard flood for Xyliatos dam is shown in Fig. 3. The tilting of each fusegate is clearly indicated by the steps in the outflow discharge.

Other design considerations

The design of the fusegate system included stability analyses of the units under normal overflow conditions, but it also examined their performance in exceptional loading conditions, such as seismic action, dynamic wave effects and wind set up. Calculations were also carried out to examine several types of malfunctioning such as wells blocked, drains blocked and leakage through the rubber seals. On all occasions the safety factors produced were acceptable.

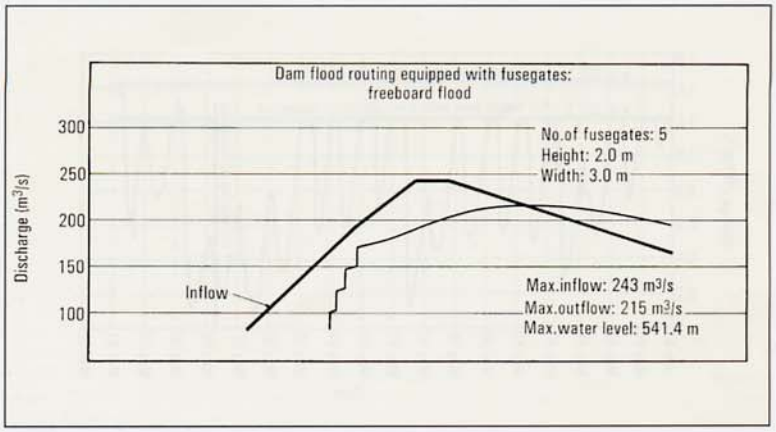

Fig. 3. The routed freeboard flood for the Xyliatos dam.

Installation of the fusegates at Xyliatos dam. Each fusegate weighs about 2 t.

Installation of the fusegate system

The contract for manufacture and installation of the fusegates was awarded in October 1997. The design of the fusegates was done in six weeks, and construction of the units was done in France, within two months.

The Water Development Department of Cyprus undertook the modifications of the original spillway itself. Installation of the fusegates and the horizontal and vertical seals took about five days. By the end of February 1998 the system was fully operational.

The overall duration of the project was thus five months.

Performance of the fusegate system

The total investment cost was approximately US$ 0.78/m^3 of stored water.

This cost is substantially lower than that of any other impounding works. The environmental benefits from adopting this solution were also significant, as major civil works and interference with the environment were avoided. The system has been fully operational during the past three winter periods, impounding 130 000 m^3 in 1998-99 and 210 000 m^3 in 2000-2001 (see the time/storage curves in Fig. 4).

From the records shown in this Figure, it can be noted that over the last 18 years the extra storage provided by the fusegates could have been used 13 times. The probability of filling the extra storage capacity is therefore about 70 per cent.

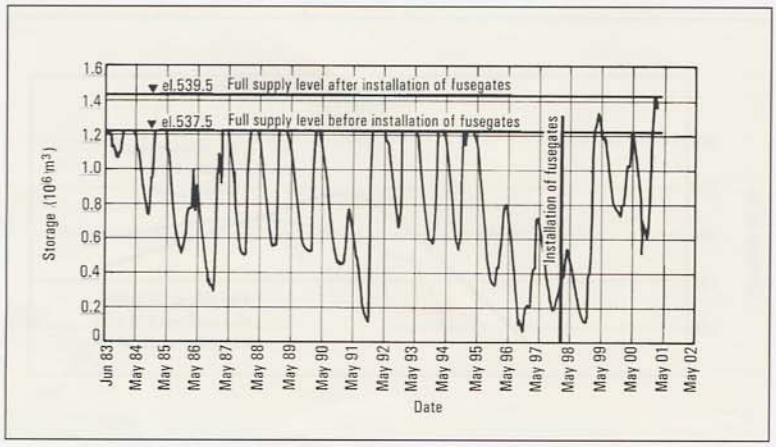

Fig. 4. Time/storage curves for the Xyliatos dam.

A fusegate being lowered into place.

Considering a 30 year operation period with 1 per cent maintenance cost per year and a financing loan at 8 per cent interest rate over 30 years, with an initial investment cost of C£ 0.5/m^3 (US$ 0.78/m^3), the net cost per cubic metre of water provided by the fusegate system is C¢ 7 (US$ 0.11/m^3).

Compared with the marginal cost of developing new sources of water in Cyprus such as desalination, which costs more than C£ 0.5 per m^3 (US$ 0.78/m^3), it may be concluded that even within the small period of operation of the fusegate system at Xyliatos dam, the returns have already balanced the costs.

Conclusion

The safety of the dam has not been affected in any way by the installation of the system, and the freeboard flood can be passed safely without risk of overflow over the embankment.

Since the establishment of the Republic of Cyprus in 1960, the Government has implemented a major programme for the development of surface water resources. As a result, a large number of dams have been built and Cyprus is today ranked first in the ICOLD (International Commission on Large Dams) register, in the area of Europe, with a ratio of 50 large dams for every 10 000 km^2.

Considering the high marginal cost of developing new sources of water, the application of the fusegate system may have a significant role to play in increasing the yield of those dams which overspill even if overspilling is not a frequent event. Furthermore, such a solution does not have any negative impact on the environment.◊

General view of the Xyliatos spillway.

The fusegates overspilling.

Acknowledgement

The authors would like to thank the Director of the Water Development Department, Cyprus, for his permission to publish this paper.

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