

Searching for conventional spillway control system alternatives

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The US Army Corps of Engineers investigated various options for raising the height of the Terminus dam spillway in California, USA, by 6.4 m. This article describes why, following a detailed study period, the fusegate system was chosen because of its reliability and its cost efficiency.

Choosing between various spillway control systems frequently appears to be a challenge for engineers and dam owners when taking into account financial and technical considerations. This paper describes the process which led to the selection of the fusegate system, within the scope of a particular project (raising the height of the Lake Kaweah spillway at Terminus dam in California). The model tests are described which were undertaken to ensure the suitability of the fusegates for the particular spillway configuration.

The Terminus project

Terminus dam consists of an 80 m-high and 730 m-long main earthfill embankment across the Kaweah river, and an auxiliary embankment extending across a saddle upstream of the city of Visalia in California, USA.

The lake is operated for flood control and agricultural water supply by the Sacramento District of the US Army Corps of Engineers.

The purpose of the project to increase the height of the spillway at Terminus is to improve flood protection by increasing the existing reservoir storage volume by $52 \times 10^6 \text{ m}^3$ to $226 \times 10^6 \text{ m}^3$, while providing additional water supply for irrigation.

During the feasibility stage, a 6.4 m-high ogee spillway was designed for the storage increase. This would have required widening the existing spillway to 134 m to pass the revised Probable Maximum Flood (PMF). It was found, however, that the increased cost of environmental mitigation measures and spillway excavation would have resulted in a project with only marginal economic feasibility. To improve net benefits, Sacramento District investigated alternative spillway types.

Various options investigated

A preliminary selection process led to the retention of only three design options of the various schemes which had previously been envisaged. A value engineering study identified a fourth option, which consisted of a curved ogee spillway. An evaluation matrix was then applied which considered a range of technical, environmental, social and economic issues.

Widening the spillway

This design option would have necessitated replacing the original spillway by a 6.4 m-high ogee spillway 39 m wider. This would have required extensive excavations through the native rock of the approach chan-

nel. Furthermore, the access road bridge over the spillway would have required lengthening and relocation of the left column supports.

A broadcrested spillway and a labyrinth weir spillway were also investigated, but neither had any particular advantage over an ogee spillway, and therefore they were not included in the cost analysis.

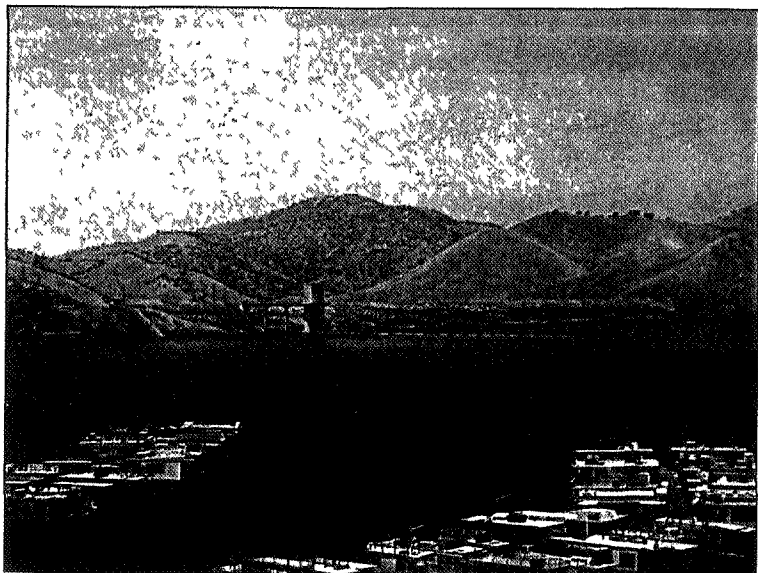
Rubber dam

Several variations for this type of weir were considered, and flood routings were made to determine their suitability. In general, some of the rubber dam configurations could have fulfilled the conditions for passing the PMF flow within the maximum pool elevation restraint, without requiring extensive excavation.

However, the analysis highlighted some operational problems, since the rubber dam would have actually increased downstream flooding compared with the original ogee weir design. When the height of flow reached the maximum allowable for the rubber dam, the device would have to be deflated. The time for deflation was short (one hour or less) relative to the time period for the PMF. This sudden deflation would have created a sharp spike in the outflow over the spillway, resulting in a rapid increase in the peak flows downstream of the reservoir.

For a 5.5 m-high rubber dam, deflation at the maximum height would have resulted in a surge of outflow during the PMF routing from approximately $764 \text{ m}^3/\text{s}$ to $3115 \text{ m}^3/\text{s}$ within less than an hour.

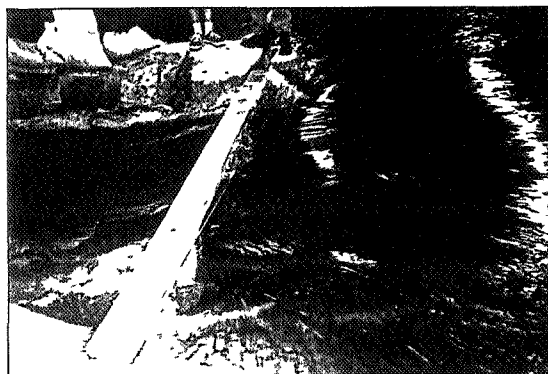
Upstream view of the dam and spillway located under the bridge



Modelling of ogee spillway heightening, showing the start of flow



Flow impacting on the upper deck of the bridge



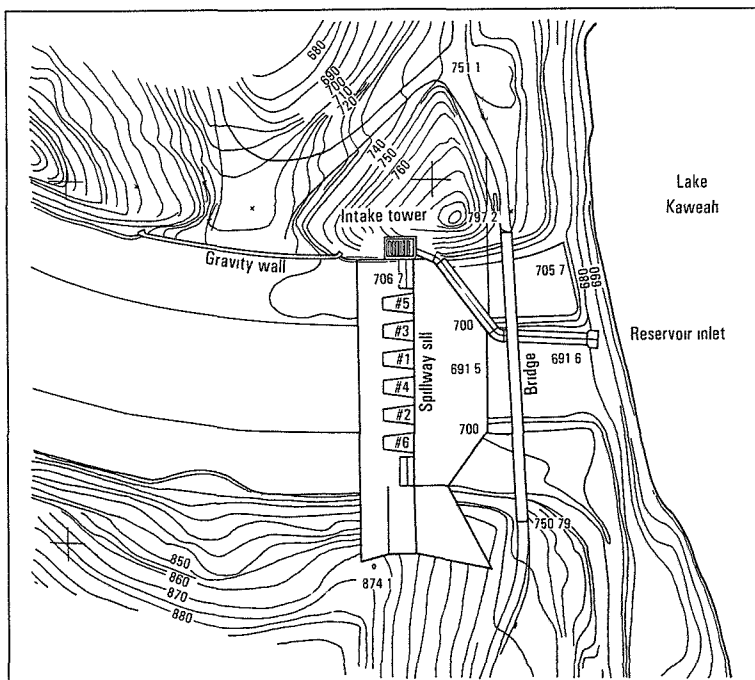
Furthermore, discussion with the manufacturers indicated that operation, maintenance and periodic replacement of the rubber dam (the useful life span of the dam is estimated to be 25 to 30 years) would be a major expense.

Curved spillway

This possibility would have eliminated the cost of widening by providing for a 137 m-long curved ogee spillway upstream of the access bridge at the entrance to the existing spillway channel. Because of the uncertainties regarding the discharge coefficient, the curved ogee was tested on a physical model.

The results indicated that the maximum PMF pool

Plan view of the spillway channel with fusegates



elevation was within 0.3 m of overtopping the dam. Thus a freeboard parapet wall would have been required, which would have increased the cost of this scheme. Furthermore, the highway bridge would have been affected significantly by the flow from the curved ogee crest. PMF routing would have caused flow to impact on the upper deck of the bridge and to wash over the bridge.

Fusegates

The design option consists of installing fusegates, which form a watertight barrier at the existing spillway sill. Major floods pass over the fusegates until a pre-determined tilting point is reached. Above this point, water entering the intake well will develop sudden uplift pressure at the interface between the spillway sill and the fusegate base chamber, thus triggering the fusegate to tip over. To restore operations, any lost fusegates must be replaced with a new fusegate structure; however, tilting of the first fusegate will be in excess of a 1 in 1000 year flood event.

The proposed fusegate superstructures would be made of concrete which minimizes the associated maintenance and maximizes the useful life span of the system compared with any other conventional spillway control system.

The fusegates come in a range of standard gate heights. The 6.5 m-high fusegate was initially selected because its height is comparable with the proposed rise in the gross pool elevation (6.4 m) and it provides an almost identical level of flood protection as the originally authorized ogee design.

Main selection points

The major inconvenience which would have been experienced with the rubber dam option was the increase in outflows downstream as highlighted by the flood simulation. The ogee option required an excessive amount of rock excavation, which would have made the scheme significantly more expensive. The curved ogee option required an undesirable parapet wall which would have increased costs. For these reasons the three options were discarded.

The fusegate option was the one selected because the existing spillway would not require widening, making this option cost effective. Also, the outflows from the fusegate design were nearly identical to those from the originally planned ogee spillway heightening.

Proposed fusegated spillway arrangement

The existing spillway is a 94 m-wide concrete sill at el. 215.9 m, with a notched centre section 41 m-wide, and a crest elevation of 211.5 m. The increase in storage will be accomplished by raising the spillway crest elevation to 217.9 m.

The selected arrangement comprises a total of six labyrinth crested fusegates, each 11.7 m-wide and 6.5 m-high, the superstructure of which will be fabricated in concrete. The fusegate height of 6.5 m would require the sill elevation for the gate to be set at el. 211.4 m to achieve a crest elevation of 217.9 m. The existing notched spillway section will be widened to accommodate the additional width of the fusegates by excavating the bench of the approach channel.

The gap between the fusegates and the existing spillway abutments will be filled with concrete overflow sections. The fusegates and overflow sections will form a watertight barrier, thus avoiding any spillage

over the spillway until the water level in the reservoir reaches el. 217.9 m. As the reservoir full supply level will usually be maintained below the crest of the fusegates, flow over the fusegates will only occur when floods exceed the 80-year event.

The fusegates are designed to overturn in a range of pool elevations from $1.1H$ to $1.3H$ above the fusegate crests (H being the fusegate height from invert to the crest). Thus, the first fusegate tips at a pool elevation of 225.1 m (7.2 m above the crest, corresponding to the 1000-year flood) and the last fusegate at a pool elevation of 226.36 m (8.4 m above the crest). The PMF can be passed with all fusegates tipped, with the pool elevation reaching 227.7 m, that is, 0.9 m freeboard below the top of the dam elevation of 228.6 m.

Instead of the conventional arrangement with wells set in the fusegate superstructure, the wells were initially located at each abutment of the spillway, and were connected individually to the fusegates, using pipes embedded in the spillway sill. Because the high velocity approach channel causes fluctuations in the water level of the intake well towers, which could affect fusegate performance, all the intake wells were relocated to the right abutment, and a conduit extending into the reservoir was used to transport water into the intake tower. Locating the intake wells at the abutment allows the water to discharge unencumbered along the complete fusegate crest length.

It was determined that a physical model study was required to address the concerns involved by the hydraulics and by the spillway arrangement. The fusegates proposed for Terminus are located in a long approach channel with a relatively flat exit channel, and overtopped by approximately $5660 \text{ m}^3/\text{s}$ at 7.6 m of head before reaching the first tipping level.

The model study was unique in that the model fusegates were completely functional and operated in the same manner as the prototype.

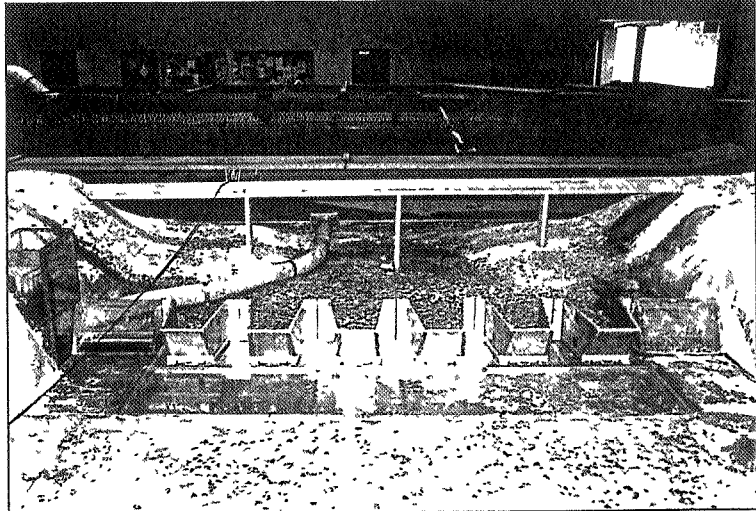
Tests

The physical model was constructed at Utah State University hydraulic laboratory (in Logan, Utah, USA) using a 1:30 scale and operating with Froude similitude. The installations at Utah State University enabled simulation of the maximum prototype flow of $8500 \text{ m}^3/\text{s}$ (model: $1.72 \text{ m}^3/\text{s}$) corresponding to the PMF.

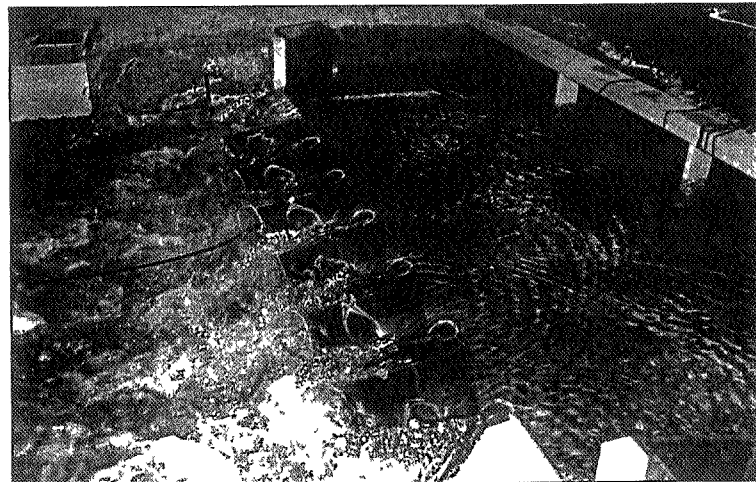
The resulting upstream reservoir area was large enough so that tipping of model fusegates did not significantly decrease the water levels. The overall model represented prototype dimensions of approximately 488 m length and 232 m width (model: 16.1 m by 7.6 m).

The specific design concerns that were addressed by the model study included:

- the effect of the tailwater on the stability and aeration of the fusegates;
- the mechanics and path of the tilting and tumbling of the fusegates;
- the effect of debris on the intake wells and fusegate operation, and the effects of partially plugging the screens of the inlet to the conduit leading from the reservoir to the intake tower;
- aeration of the nappe over the fusegates and possible vibration of the fusegates if aeration were not to occur;
- the effect of increased roughness on the downstream exit channel;
- the blockage of drainage holes and leakage of the fusegate seals;



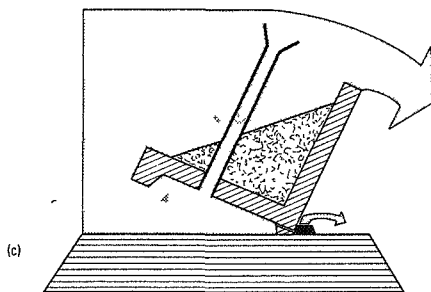
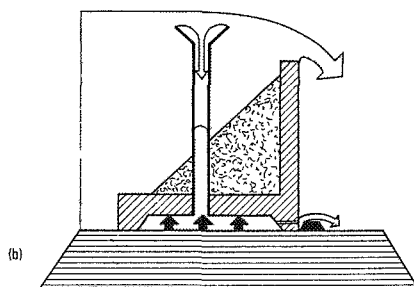
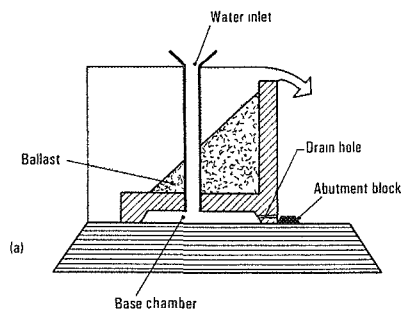
Downstream view of the spillway equipped with fusegates.



View of overtopping fusegates



View of the intake tower and inlet wall



The Hydroplus system is based on the following concept:

- Fusegates are free-standing units installed side-by-side on a spillway sill to form a watertight barrier.
- They bear against small abutment blocks set in the sill to prevent them sliding before they are required to rotate (in extreme flood conditions).
- There is a chamber in the base of each fusegate, with drain holes to discharge incidental inflow (caused by leaking seals, for example).
- An inlet well on the upstream side of the first fusegate crest discharges into the chamber when the headwater reaches a predetermined level. (Well lips on individual fusegates are set at increasingly higher levels).

During very large floods, water entering the chamber over the inlet well causes uplift pressure to develop in the chamber.

The uplift pressure, combined with the hydrostatic pressure (acting from left to right on the adjacent diagram) is sufficient to overcome the restraining forces, and the imbalance causes rotation of the unit off the spillway. The fusegate is then washed away clear of the spillway by the flood.

If the water level continues to rise after the first breach, more fusegates can rotate, all according to pre-determined upstream water levels, until eventually there are no more units remaining and the spillway is free to pass the original maximum design flood. Until rotation of the first fusegate, (normally for floods in excess of the 1:100 year event), the user has the benefit of the additional storage.

Each fusegate has a different overturning level, precisely determined by the height of the water inlet and its own unique stability.

- the stability and operation of the fusegates for the extreme conditions of missing gate seals, blocked drain holes, and an increased gap between the spillway sill and the base chamber beams of the fusegates; and,
- the range of ballast permitted for stable and correct operation of the fusegates for normal joint sealing conditions.

The model tests undertaken demonstrated that the fusegates operate satisfactorily in all the above mentioned cases, that is, even in the most extreme conditions with a very high tailwater level, and under downgraded operating conditions such as drainage holes being blocked, the upstream seal destroyed or the presence of floating debris.

Furthermore, the model tests have shown that even though the fusegates are totally submerged, the discharge capacity over their labyrinth crest is not reduced, at least as long as the downstream tailwater level does not exceed the fusegate crest by more than 20 per cent of the fusegate height.

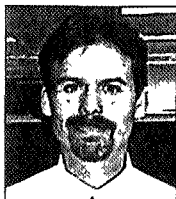
The model tests also enabled improvements to be made to the original configuration of the system, by replacing the previously envisaged two separate intake towers by a single tower with an inlet at the entrance of the spillway channel.

Conclusion

It is considered that the Hydroplus system represents a reliable engineering solution for increasing the

reservoir capacity at Terminus dam. The system will provide a saving of several million dollars compared with the originally envisaged project cost for heightening the existing spillway. The US Army Corps of Engineers intends to complete construction of the project by 2003. ◇

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