THE FUSEGATE SYSTEM REACHES NEW HEIGHTS IN CALIFORNIA

Hasan T. Kocahan, *Business Development Manager, Hydroplus, Inc.*

PO Box 1731

Falls Church, VA 22041, USA

Phone : 703-575-9075, Fax: 703-575-9193

Norbert F. Suter, *Project Manager, USACE, Sacramento District*

1325 J. Street

Sacramento, CA 95814

Phone : 916-557-6978, Fax: 916-557-7848

ABSTRACT:

An unusual solution to increasing reservoir capacity without raising the dam embankment was investigated by the US Army Corps of Engineers (USCOE), Sacramento District. The so called Fusegate system was considered as the most cost-effective and appropriate solution among the various alternatives studied to provide additional flood control protection and water supply for the Terminus Dam (California).

Terminus Dam is located on the Kaweah River, south of Fresno, California and is operated for flood control and agricultural water supply by the USCOE. The purpose of

the rehabilitation at Terminus Dam was to increase flood protection from a 46-year event to 70-year event by increasing the existing reservoir storage from 142,600 acre-ft to 185,000 acre-ft, whilst providing an incidental water supply for irrigation.

Model tests were also performed at the Utah State University in Logan, Utah in order to optimize the Fusegate solution. For the proposed arrangement, a total of six Fusegates made of reinforced concrete were built, each 38.4 feet-wide, 21.33 ft-high, and 42.6 ft in length at the crest. It appeared that the Fusegate System offers a reliable engineering solution to raise the gross pool level of Terminus Dam. Only the third North American installation, and the largest in the world, the 450-ton Fusegates provide savings of more than $15 million compared to conventional methods.

1. BACKGROUND:

Terminus Dam, built in 1961 on the Kaweah River, is the first line of flood protection defense for the town of Visalia and other highly vulnerable natural lands in California, US. It has a drainage area of 560 square miles and is operated for flood control and agricultural water supply by the US Army Corps of Engineers, Sacramento District. It consists of a 260 ft high and 2,395 ft long main earthfill embankment, and an ungated spillway, having a 307 ft wide concrete sill with a notched center section of 135 ft width.

The purpose of the rehabilitation at Terminus Dam is to increase flood protection by increasing the existing reservoir storage from 142,600 acre-feet to 185,000 acre-feet, whilst providing an incidental water supply for irrigation.

During feasibility studies, a 21 ft high ogee spillway was designed to accomplish the increase in storage. This required a widening of the existing spillway to 455 ft in order to pass the Probable Maximum Flood (PMF).

During feature design, alternatives that would reduce the spillway costs were investigated. A Fusegate design was selected as the preferred alternative. The Fusegates fit within the existing spillway footprint.

Fig.1 Existing Spillway weir and channel

Fig. 2 Upstream view of Terminus Dam

2. ALTERNATIVES INVESTIGATED:

At the end of a preliminary evaluation process, only three design options for rehabilitation were retained from among various alternatives. In addition, a value engineering study identified a fourth alternative consisting of a curved ogee spillway. An evaluation matrix was then applied, which considered a range of technical, environmental, social and economical issues.

2.1 Widening the Spillway:

This design option involved the replacement of the original spillway by a 21 ft high ogee spillway, 128 ft wider than the original spillway. This option required extensive excavations through the native rock of the approach channel, and major modifications to the access bridge over the spillway. A broad crested spillway and a labyrinth weir spillway were also investigated, but both had no particular advantage over an ogee spillway, thus they were not included in the cost analysis.

2.2 Rubber Dam:

Several variations for this type of weir were considered and flood routing analyses were made to determine their suitability. In general, some of the rubber dam configurations could have fulfilled the requirements without extensive excavation, however, further analysis has revealed that the rubber dam would cause a sharp spike in the outflow over the spillway resulting in a rapid increase in the peak flows downstream of the reservoir during the PMF. In addition, the associated installation, operation, and maintenance costs were quite high.

2.3 Curved Spillway:

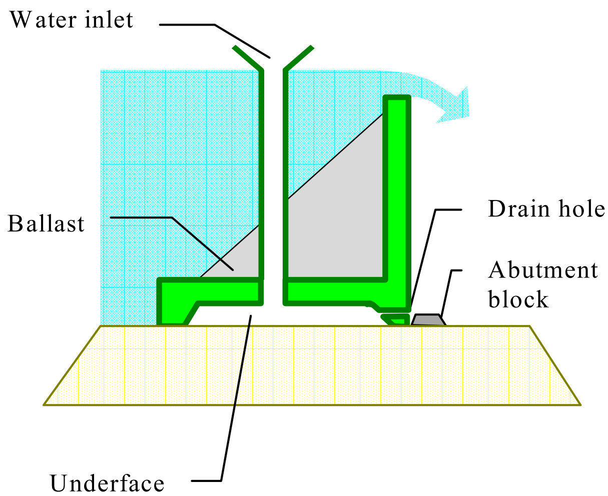
This alternative eliminated the cost of widening the spillway, since it involved a 450 ft long curved ogee spillway located upstream of the access bridge. Because of the uncertainties regarding the discharge coefficient, model tests were performed for this alternative at the Utah State University Hydraulic Laboratory in Logan, Utah, using a

1:30 scale model operating with Froude similitude. The test results suggested that the pool elevation during the PMF corresponded to an overtopping of the dam by 1 ft for this type of spillway. Thus, a freeboard parapet wall would be required on the embankment, which increased the cost significantly. In addition, the upper deck of the access bridge would be overtopped by the flow from the curved ogee spillway.

2.4 Fusegate System:

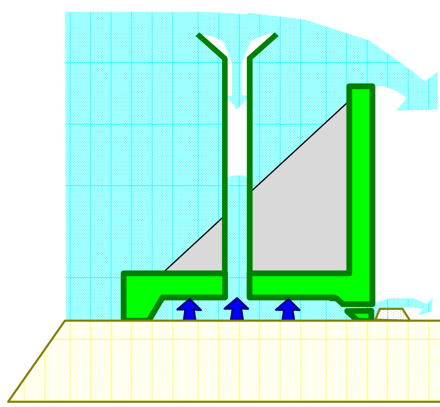
The last alternative investigated was the Fusegate System. The Fusegate System is an innovative and cost effective means of providing increased reservoir storage capacity. Fusegates are a non-mechanical spillway control system. A typical installation consists of multiple gates placed on a spillway crest. When installed, the gates operate as a labyrinth weir, in which each gate represents once cycle of the labyrinth. The gates are held in place by gravity. For a moderate range of reservoir levels, the water flows over the Fusegates as it would over a labyrinth weir. If the reservoir level exceeds some predetermined value, the Fusegate overturns by rotating about its downstream edge. Each gate is set to overturn at a progressively higher reservoir elevation. The first Fusegate is usually designed to tip off for a very low probability flood; at least 100-year or 200-year floods. For the maximum design discharge, usually equivalent to the PMF, all of the Fusegates tip and the entire crest length is available to pass the flow. Below is a more detailed illustrated description of the concept (Fig 3).

The Fusegate System is based on the following concept shown below:



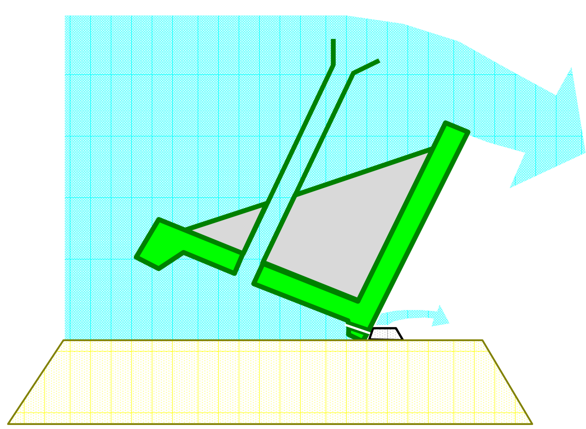
Fusegates are free-standing units installed side-by-side on a spillway sill to form a watertight barrier.

- They bear against small abutment blocks set in the sill to prevent them from sliding before they are required to rotate (under extreme flood conditions).
- There is a chamber in the base of each Fusegate, with drain holes to discharge incidental inflow (due to leaking seals for example).
- An inlet well on the upstream side of the Fusegate crest discharges water into the chamber when the headwater reaches a predetermined level. (Well lips on individual Fusegates are actually set at different levels).



During very large floods, water entering the chamber over the inlet well causes an 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, (for floods of extremely low risk of occurrence), 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 Fusegate alternative was the selected option, because there was no requirement to widen the existing spillway and the outflows for the Fusegated spillway were nearly identical to the originally planned ogee spillway.

3. HYDRAULIC CONCERNS AND PHYSICAL MODEL STUDY

3.1 Model Tests:

There were several concerns, that made it necessary to perform model tests for the Fusegate alternative, as for the ogee spillway, due to the particular characteristics of the spillway configuration. The model tests were performed at the same University by using the same methods as described for the curved spillway alternative. The concerns requiring the model tests were:

- Analysis of the existing exit channel indicated that tailwater will be above the crest of the Fusegates and may affect the tilting action of the gates. To reduce the tailwater effects it was decided to assume that the rock benches would be excavated for the entire length of the exit channel.
- Water surface profile analysis, using a Manning n-value of 0.035, indicated that the exit channel will flow at critical depth. Therefore, there is uncertainty as to what the actual tailwater at the Fusegates will be.
- Due to the presence of the drain holes on the Fusegates, the tailwater may result in uplift pressures occurring in the base chamber prior to flow entering the intake well. This may increase the uncertainty as to when the Fusegates will tilt, and if the tilting will proceed in a predicted manner.

- Once the Fusegates tilt they normally tumble downstream in the exit channel. Since the exit channel is relatively flat (1% slope), there was a concern that the Fusegates will tilt but not tumble downstream. This could cause local flow disturbances that may affect behavior of the adjacent Fusegates and possibly increase upstream pool elevations.
- The effect of debris on intake well blockage and interference with overall stability of the Fusegates is a concern.
- If the nappe over the Fusegate walls is not properly aerated there may be an undesirable vibration of the sidewalls. The resulting negative pressure will also contribute to the overturning moment of the Fusegate, which may cause the gate to tip prematurely.

3.2 Adopted Fusegate Configuration after Model Tests:

For the Terminus Dam spillway, a total of six Fusegates were required, each 38.4 ft wide, 21.33 ft high, and 42.6 ft in length at the crest. The Fusegates will fit in a 230.4 ft rectangular opening within the existing spillway. Concrete overflow sections will fill the gap between the Fusegates and the sidewall of the spillway. The overflow sections will be broad crested weirs with a crest width of 41.6 ft, a crest length (parallel to flow) of 14.5 ft, and a downstream slope of 1V on 0.54H. The Fusegates and overflow section will sit on a 33 ft wide concrete base, with an additional concrete apron extending downstream 45 ft for invert protection. Figure 4 illustrates the proposed Fusegate spillway.

Spillway Raise Pertinent Features

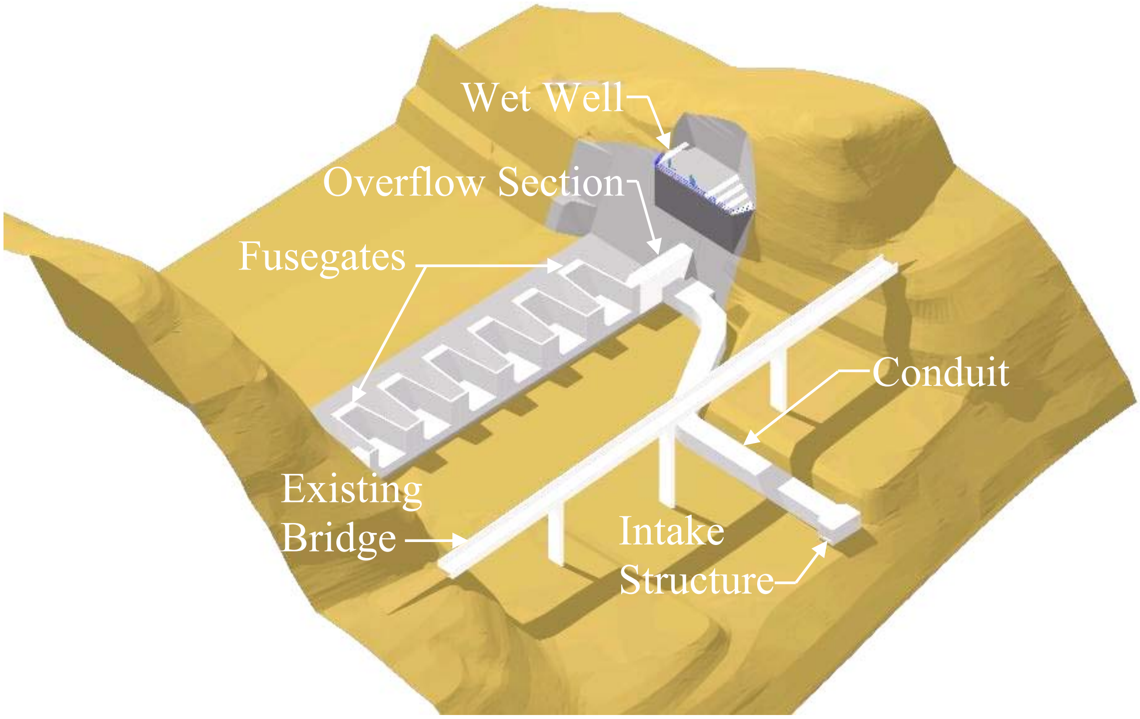


Fig. 4 Adopted Fusegated Spillway arrangement

The intake wells are normally constructed as part of the Fusegate. Since Terminus Dam is located on a catchment with giant sequoias trees, some concerns about possible adverse effects of floating trunks arose. This debris could impact and damage the intake wells during floods. Therefore, the intake wells at Terminus are gathered within a protective enclosure, called a wet well tower located on the right abutment just upstream of the spillway and equipped with a bottom port to allow flow to enter. Pipes embedded in the concrete sill would connect the intake wells to the base chambers of the Fusegates.

The Fusegates can be constructed from either steel or concrete. Concrete was selected to reduce maintenance during the life of the project. Small drain holes are provided at the base of the Fusegates to drain the base chamber of any leakage that occurs from the upstream seals so that uplift pressures do not occur until flow enters the intake wells.

4. CONSTRUCTION STAGE:

The construction works at Terminus Dam began in early 2001 within the first contract to modify the spillway. The Prime Contractor was AFA of Santa Rosa, CA. To start with, the benches that ran down both sides of the spillway were blasted and removed to increase the width of the bottom to about 315 ft. About 100,000 cubic yards of rock was removed from the spillway and hauled off-site. The spillway materials range from hard marble, through quartzite (the most common material), to soft material that can be gouged out by hand and sifted through the fingers. Sidewalls in the spillway were maintained at the original 400 to 500 percent slopes.

The excavated areas on the sides of the spillway were supported by 600 ea. one-and-three eights-inch rock anchor bolts with anchor heads 26 feet deep in the rock. Set at a downward slope of 10 degrees from horizontal, each bolt was pretensioned after testing and locked off at a 55 dip. 62 ea.

The first contract was completed in Spring 2002, ahead of schedule and at less than the award obligation.

The contract for the Fusegate construction was awarded in the middle of 2002. The Prime Contractor was Whitaker Contractors from Santa Margarita, CA. The construction works within this contract included the removal of the existing broad crested weir and excavation of the Fusegate foundation.

Figure 5. Excavation for Fusegate Foundation

Figure 6. Removal of Benches at the spillway

Sixty-two additional two-inch rock bolts were also tied into the Fusegate foundations and set at a 45 degree dip for stabilization.

The construction of the intake structure and the conduit was started simultaneously while the excavation and stabilization works were in progress.

Figure 7. Construction of Intake Structure and the conduit

After the preparation of the foundation, the embedded materials such as the downstream toe abutments as well as the pipes stretching from the intake tower to the chambers of each Fusegate were installed.

The construction of the Fusegates then started at the completed sections of the foundation and the new spillway sill. With summer heat a major problem, and limited availability of materials, mass concrete placements were started in the early morning hours, and mix designs included chilled aggregate, chilled water and ice. Each completed Fusegate had to be jacked and weighed upon completion in order to make sure there is no bonding between the Fusegate and the spillway sill, and to determine the center of gravity of the Fusegates. The determination of center of gravity is essential to find out whether any of the Fusegates will need any additional ballast to maintain the projected weight and stability moment.

Figure 8. Installation of Fusegate formwork for lateral walls and the pipes in the foundation

The above picture shows the installation of the pipes in the foundation of the sill, that will connect the Fusegates' chambers and the steel inlet wells. The inlet wells will be collected inside a Wet Well constructed on the berm, which is on the upper right corner of the picture.

Figure 9. View of a finished Fusegate

Figure 10. View of Fusegates under construction

The construction of the intake tower was also performed at the same time with the Fusegates, as soon as all of the pipes were installed inside the spillway sill.

Figure 11. Concreting works for the Intake Tower at the right abutment

The contract related to the Fusegate construction was completed by early February 2004. Unlike most Fusegates designs, the gates at Terminus are designed to be submerged to about twice their own height before they tip over, which corresponds to a flood twice the recorded highest 1955 flood. The return period event for the tipping of the first Fusegate is a 1,000-year flood.

Figure 12: Upstream View

Figure 13: View of Fusegates from the left abutment

While they are the pivotal point of the enlargement, the Fusegates are not the full extent of the Terminus Enlargement Project. In three locations, Highway 198 that goes halfway around Lake Kaweah had to be raised. A bridge at Horse Creek also had to be raised. Six residences were purchased and removed, and a dike was built to protect a hotel at the head of the lake.

5. CONCLUSION

The Fusegate System offers a reliable engineering solution to raise the gross pool level of Terminus Dam by 21 ft, which in particular provided millions of dollars of savings when compared to the next least expensive alternative. Model tests also established the Fusegate system as the best, and feasible engineering alternative, and it was possible to optimize the design according to the project requirements thanks to the versatility of the system. Besides the savings, the San Joaquin Valley will enjoy the improved flood damage protection, and better use of precious water resources.