HYDRAULIC MODELING OF TOM MILLER DAM

Abstract

Tom Miller Dam has a unique and interesting history with three failures and two major reconstructions. The present dam is a composite structure combining structural elements from the original construction and each reconstruction. Located on the Colorado River in Austin, Texas, the Dam is owned by the City of Austin and operated by the Lower Colorado River Authority (LCRA). Although the dam is only 1440 feet long and ranges in height from 60 to 100 feet, the dam was reported to be the largest dam in the world built across a major flowing river when originally constructed in 1890. Although it is no longer the largest dam, it is still an important resource providing primary drinking water supply for the City and hydro-electric power generation for the LCRA.

During the LCRA Dam Modernization Program, the extreme flood events were re-evaluated. The Probable Maximum Flood (PMF) for Tom Miller Dam is 834,000 cfs. Stability analyses showed that the structure was subject to a more severe loading condition than that of the original design. As a result, improvements to the dam were required to bring the dam in compliance with modern design criteria. In conjunction with the Utah Water Research Laboratory, a physical hydraulic modeling program was completed.

The modeling program included three separate models of the dam including a full-width model, a sectional model of the gated spillway, and a sectional model of the uncontrolled overflow spillway. This paper presents a detailed discussion of the modeling program. The models provided dynamic and static loading, identified potential areas of downstream scour, and allowed the designers to determine the effects of structural and gate modifications on overall performance of the dam. The findings of the model study not only allowed the designers to analyze this unique hydraulic structure with confidence, but also have reduced estimated construction costs by approximately $13 million.
History of Tom Miller Dam

Austin Dam (Tom Miller Dam’s original name) was constructed from 1890 to 1893. The original dam was an overflow spillway constructed of limestone masonry faced with granite blocks. Figure 1 shows the dam near the end of construction in 1893.

![Figure 1: Original Dam Construction (1893)]

In 1900, severe undermining of the foundation lead to a tragic failure of the dam. A 500 foot section of the dam slid downstream approximately 200 feet. The failed portions of the dam split into two sections and then were engulfed by the floodwater. Figure 2 shows the dam following the failure.

![Figure 2: Failure of Original Dam (1900)]

The City of Austin contracted to reconstruct the dam in 1912. The new dam was a thin slab and buttress dam that mimicked similar designs of the time by the Ambursen Dam Company. The new dam was built on top of the remaining
portions of the masonry spillway. Figure 3 shows the first reconstruction of the dam.

Figure 3: First Reconstruction (1914)

Before construction could be completed, severe flooding destroyed portions of the new dam and the reconstruction project was abandoned. The dam remained in an abandoned, partially failed state until the 1930s. In 1935, a substantial flood, nearly 60% of the current PMF, flooded Central Texas and severely destroyed what was remaining of the dam. Figure 4 shows the undermining below the dam and the damage to the downstream deck slabs and buttresses following the flood of 1935.
In 1937, the LCRA leased the dam from the City of Austin and began an extensive program to rehabilitate the dam. The project was completed in 1939 and has operated successfully since that time. Figure 5 shows an aerial view of Tom Miller Dam as is presently appears. Figure 6 provides a plan view.
Development of PMF Computer Models

Central Texas is known to be the center of concentration for some of the largest flood-producing storms in the continental United States. The largest rainfall event ever recorded in the continental United States fell in Thrall, Texas in 1921. The Lower Colorado River Authority (LCRA) owns and operates a series of six dams and reservoirs on the lower Colorado River in Central Texas, known as the Highland Lakes Dams. The LCRA Highland Lakes Dams were not designed to accommodate floods as large as the PMF. Recognizing the potential for extreme flooding, the LCRA undertook a Dam Modernization Program for all six dams in 1991. The first step was a preliminary re-evaluation of the Probable Maximum Flood (PMF). More detailed modeling was completed in 1992. The numerical PMF studies began by obtaining the Probable Maximum Precipitation (PMP) in accordance with Hydrometeorological Report No. 51 (HMR 51), developing the storm pattern according to Hydrometeorological Report No. 52 (HMR 52), and calculating the PMF. Revised analyses optimized the storm center location in the drainage basin and determined storage volumes for the reservoirs. The PMF for Tom Miller Dam is approximately 834,000 cfs with a corresponding reservoir elevation of 522.2 ft-msl (equivalent to approximately 29 feet above the crest of the uncontrolled overflow spillway).

The PMF studies were used to determine the need for modernization improvements to meet current design standards at four of the six dams. The LCRA established a $50 million modernization program and scheduled the repairs to each dam based on prioritized need for improvements. As of the end of 2001, three dams (Wirtz Dam, Inks Dam, and Buchanan Dam) were modernized to safely pass the PMF with a remaining budget of approximately $15 million.
Physical Hydraulic Models

Throughout the modernization program, LCRA and Freese and Nichols have teamed with the Utah Water Research Laboratory (UWRL) to conduct physical hydraulic model studies of the four dams being rehabilitated. The UWRL facility was selected because of their unique ability to model storms of the magnitude seen in Central Texas at a reasonable scale. Based on data from past projects, physical models improve confidence in design and reduce construction costs. The physical models provided $12 in savings for each dollar spent on modeling (12:1 savings) on previous LCRA projects and an overall 17:1 savings ratio over the last 25 years of Freese and Nichols projects with UWRL.

Modeling for Tom Miller Dam consisted of three models: two sectional models and one full-width model. The following sections describe the details of these models.

Sectional Models

Sectional models were constructed for the uncontrolled and gated sections of the dam. Larger scale sectional models allow a detailed evaluation of unit discharge capacity, determination of discharge coefficients, and accurate measurement of flow depths, velocities, and hydrodynamic pressures on the dam. The sectional models were constructed out of molded acrylic (Plexiglas) and were run in a test flume that measures six feet wide, 50 feet long and four feet deep. Figure 7 shows the test flume that was used for the sectional models.

Figure 7: Test Flume used for Sectional Hydraulic Models
**Uncontrolled Spillway**

The model of the uncontrolled spillway was built at a scale of 1:30 and a width of six feet corresponding to 180 feet of the prototype spillway. Figure 8 shows the sectional model during a test run with PMF flow over the spillway. Figure 9 shows the profile of the uncontrolled spillway model. As shown in the figure, pressure taps were installed along the crest and down the face of the spillway. Data collected from these pressure taps was used to develop pressure profiles for flows from the 100-year event up to a discharge equivalent to 900,000 cfs (greater than the PMF).

![Figure 8: Uncontrolled Sectional Model](image)

![Figure 9: Model Profile](image)
The Tom Miller Dam spillway was designed and constructed before the USACE had published its standards for ogee spillways. The crest of the spillway is sharper and steeper than a modern ogee design. The sharper crest results in high negative pressures at the crest of the dam. The resulting high velocity jet produces higher loading on the lower portion of the section than indicated by the USACE WES curves. Use of the model data lowered the required stabilization forces that would be required if the design was based on the USACE WES nomographs. As such, this reduced the overall number of anchors and reduced the estimated construction cost for stabilization of the uncontrolled spillway section by $1 million.

**Gated, Slab and Buttress Spillway**

The model of the gated spillway was built at a scale of 1:36 and a width of six feet corresponding to 216 feet of the prototype spillway (two full gate widths and two partial gates). Figure 11 shows the sectional model during a test run with PMF flow over the spillway. Figure 12 shows the profile of the gated spillway model. As shown in the figures, pressure taps were installed along the crest and down the face of the spillway. Data collected from these pressure taps was
again used to develop pressure profiles for flows from the 100-year event up to a discharge equivalent to 900,000 cfs.

Figure 11: Gated Sectional Model

Figure 12: Model Profile
In addition to modeling unit discharge capacity, determining discharge coefficients and measuring flow depths, velocities, and hydrodynamic pressures on the dam, this model was used to determine pressures and water levels inside the hollow portion of the dam. This information was used in the external stability analysis and internal stress analysis. A three dimensional finite element model indicated that significant overstressing of the downstream deck slabs and internal buttresses may occur at flood events greater than the 500-year event based on the conventional design nomographs. Use of the model data lowered the internal stresses in the lightly reinforced structural concrete members. As such, the model findings eliminated the need to strengthen the interior buttress of the dam and reduced the estimated construction cost for strengthening the gated section by approximately $12 million.

**Full Width Model**

A full-width model of the dam was built at a scale of 1:50 and incorporated the topography upstream and downstream of the dam, corresponding to an area approximately 1600 feet by 1600 feet. The model of the structure was fabricated from Plexiglas. However, the foundation, river overbanks, and stream bed were modeled using mortar that was contoured to match recent survey cross sections. Figure 13 shows an overview of the model. Figure 14 shows the operation of the model at discharges approximating the PMF.

![Figure 13: Overview of Full-Width Model](image-url)
Figure 14: Full-Width Model at PMF

The full width model was used to develop the composite discharge-rating curve for the dam and to determine the composite discharge coefficient. Because high velocity jets were observed in the sectional models, the design team was concerned about the scour potential downstream of the dam during significant flood events. The full-width model provided data that was used to map three-dimensional velocities and flow patterns and helped characterize scour potential. The model was modified to include several options for minimizing scour downstream of the dam. These included several flip bucket configurations and sizes, energy dissipaters, and training walls. In addition to physical improvements, gates sequencing was also studied to develop an improved spillway operation plan to minimize scour potential. Figure 15 shows the measured velocity and flow directions during the PMF event.
During significant flood events (above 75% of the PMF) the dam's embankment section is overtopped by approximately four feet of water. The model was again modified to examine several overtopping protection scenarios, including the construction of a parapet wall atop the embankment and various embankment plating solutions.

Another area of concern for the design team was anticipated debris loading during the significant flood events. The full-width model runs at PMF showed a significant build-up and trapping of large debris due to the discharge impinging on the gates, thus submerging the gates and creating a stagnant pool of water in front of the spillway. During the model testing, it was observed that the gates could clear the full PMF discharge if the gates were opened two feet above their current maximum gate opening. Subsequent testing showed that this lowered the PMF reservoir elevation by nearly two feet and provided for passage of large trees and other flood debris.
Conclusions

The old saying, “Everything is bigger in Texas,” is certainly true when it comes to flood events. Extreme rainfall events were developed to determine the PMF for Tom Miller Dam. The PMF flood event for Tom Miller Dam is greater than 834,000 cfs. Physical hydraulic models were tested to collect data on the loading of the dam and passage of floodwaters during storm conditions. The modeling data were used to refine the analyses for design of modernization improvements. The models were then modified to determine the effect of various proposed improvements on the performance of the dam. The physical hydraulic modeling program resulted in a construction costs savings of over $13 million; approximately a $40 saving in construction cost for each dollar spent on modeling. As a result of the PMF models, the physical hydraulic modeling, and the construction scheduled for 2003, Tom Miller Dam will safely pass the worst anticipated flood events of Central Texas.