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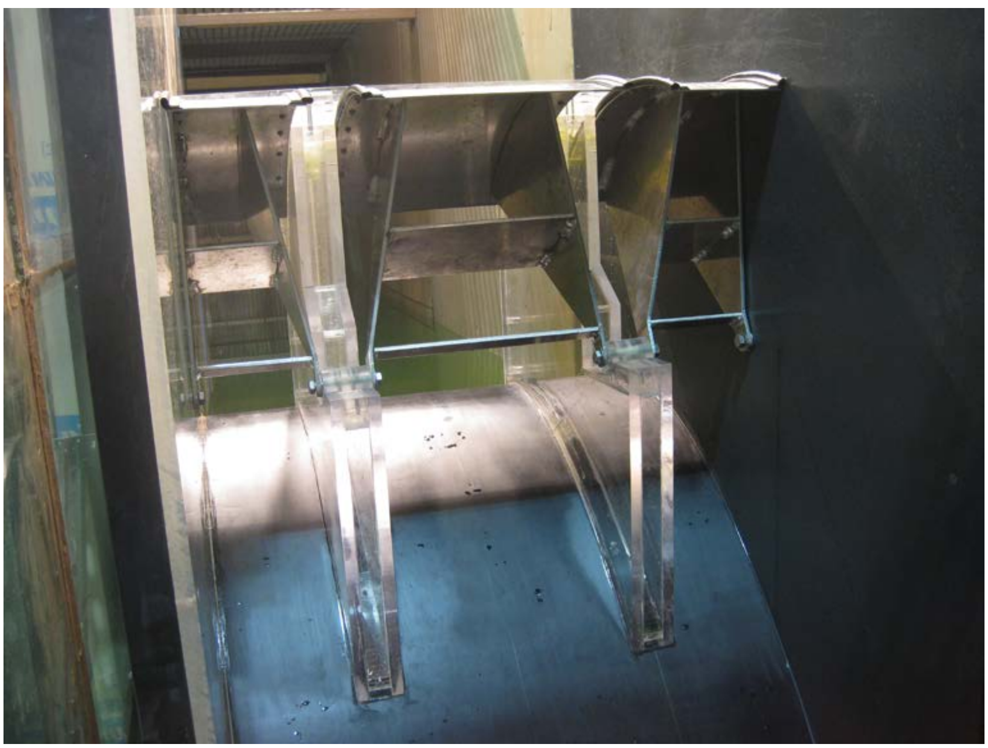
Hydraulic Laboratory Report HL-2014-01

Physical Hydraulic Model Study of Folsom Dam Emergency Spillway Tainter Gate Alternatives



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services
Denver, Colorado

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14. ABSTRACT
A 1:36-scale sectional physical hydraulic model of the Folsom Dam emergency spillway gates was constructed at the Bureau of Reclamation's Hydraulics Laboratory. Under the Folsom Dam Raise Project, higher water surface elevations and modified spillway release operations are expected. The key purpose of this study was to investigate hydraulic behavior of top seals on the emergency spillway radial gates and vertical pier extensions at the existing piers to prevent gate overtopping. Without top seals installed, discharge rating data and observations were collected for large vertical gate openings of 30, 35, 38, 40, and 42 ft with and without seismic beams. With top seals installed, discharge ratings, observations of turbulence, aeration, and vortices, static pressures on the bridge and ogee crest, and water surface profiles near the trunnions and sidewalls were collected for 35-, 38-, and 40-ft vertical gate openings with and without seismic beams.

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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LIST OF SYMBOLS AND ACRONYMS

CFD	computational fluid dynamics
cfs	cubic feet per second
USACE	U.S. Army Corps of Engineers
EL	elevation
ft	feet
ft/s	feet per second
in	inch
JFP	Joint Federal Project
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
PMF	probable maximum flood
Reclamation	Bureau of Reclamation

Executive Summary

Under the Folsom Dam Raise Project, higher water surface elevations and modified spillway release operations are expected. The key purpose of this physical model study was to investigate the performance of the gates and spillway with top seals installed on the emergency spillway radial gates and vertical pier extensions installed at the existing piers to prevent overtopping.

A 1:36-scale sectional physical hydraulic model of the Folsom Dam emergency spillway gates was constructed at Reclamation's Hydraulics Laboratory in Denver, Colorado. The effect of the top seals and pier extensions on the hydraulic behavior of the spillway was investigated both with and without seismic retrofit beams in place. Without top seals installed, discharge ratings and qualitative observations were collected for 30-, 35-, 38-, 40-, and 42-ft vertical gate openings with and without seismic beams. With top seals installed, discharge ratings, qualitative observations including turbulence, aeration, vortices, and potential shifts in control, pressures on the bridge and ogee crest, and water surface profiles near the trunnions and sidewalls were collected for 35-, 38-, and 40-ft vertical gate openings with and without seismic beams.

Discharge ratings with and without top seals installed were not measurably different. Gate control exists when the reservoir water surface reaches the gate lip. When the reservoir water surface contracts off the upstream bridge girder, approach flow conditions to the gate are modified. Seismic beams also influence approach flow conditions. When the bridge or seismic beams modify approach flow, the stage-discharge relationship becomes more efficient. Vortices were observed at lower pool levels for all of the assessed gate openings. Without seismic beams, vortices occurred with water levels up to around EL 478 with 35- and 38-ft gate openings and around EL 379 with a 40-ft gate opening. When the pool elevation is above the seismic beams, they appear to minimize or eliminate vortices by breaking up circulation and essentially acting as a vortex suppressor. When the water level rises above the seismic beams, the size and frequency of vortex formation significantly decreases. In general, vortices ceased to occur with pool elevations approximately 4 ft lower with the seismic beams than without seismic beams.

With seismic beams installed, there is minimal turbulence and air entrainment for gate openings less than 38 ft. Therefore, flow conditions appear to be acceptable except when in the transition zone between gated controlled flow and uncontrolled flow. Gate openings of 38 to 39 ft produce turbulent, aerated flow conditions in the immediate vicinity of the beams and should not be part of standard operations. However, they may be acceptable for short periods of time for extreme hydrologic conditions. Seismic beams create intense turbulence and induce significant entrainment of air into the flow in the immediate vicinity of the beams at gate openings of 40 ft, which may not be acceptable even for extreme hydrologic conditions. At a 42-ft gate opening, intense turbulence in the vicinity of the beams produces significant air-water interaction at the gate. This flow condition is “transitional” which is considered to be an adverse operating condition that should be avoided. Flow patterns observed in the model at large gate openings indicate that hydrodynamic loading will occur on the seismic beams in this highly turbulent zone. Although hydraulic conditions near the seismic beams do not look favorable under certain conditions, it is not possible to determine from model observations whether damage would be incurred in the prototype.

At gate openings of 35 ft or less, there was no impact on the trunnions from spillway flow. At a 38-ft gate opening, splashing on the trunnion pier with run-up on the trunnions occurred from water surface elevation 477-481 ft with seismic beams and 472-481 ft without seismic beams. At a 40-ft gate opening, significant splashing on the trunnion pier with frequent run-up on the trunnions was common from water surface elevation 473.5-481.0.

Static pressures along the ogee crest were typically small and remained positive at 35-, 38-, and 40-ft gate openings. Negative pressures occurred only at pressure tap 6 (32.9 ft downstream of the crest) and tap 7 (42.5 ft downstream of the crest). The maximum negative pressures measured at taps 6 and 7 were -1.35 ft and -5.04 ft, respectively. For 35- and 38-ft gate openings, uplift pressures on the underside of the bridge deck were recorded when reservoir pool elevations exceeded 478.0 ft. Typically, pressures on the upstream and downstream faces of the bridge were consistent with a hydrostatic pressure profile. Uplift pressures on the underside of the bridge were generally around 3 ft or less. For a 40-ft gate opening, so much contraction occurred around the upstream bridge girder that the water surface elevation never pressurized the underside of the bridge deck.

It does not appear that higher reservoir water levels expected with the dam raise will cause spillway sidewall overtopping. Higher reservoir water surface elevations with the Folsom Dam Raise Project will increase water surface profiles, but the difference between water surface profiles under current flood operations and with a pool increase of 3.5 ft is minimal. Water surface profiles are closer to the top of the sidewalls with larger gate openings than smaller gate openings. Water levels at the most downstream recorded locations are closest to overtopping the sidewalls. With a 35-ft gate opening, the smallest vertical distance to the top of the sidewall is 15.80 ft both with and without seismic beams. With a 38-ft gate opening, the smallest vertical distance is 11.30 ft both with and without seismic beams. With a 40-ft gate opening, the smallest vertical distance is 7.55 ft without beams and 6.05 ft with beams.

Elevation Datum

Folsom Dam was originally designed and constructed using the National Geodetic Vertical Datum of 1929 (NGVD29) as an elevation reference. Design and construction documents for the Folsom Dam Raise Project and Joint Federal Project (JFP) at Folsom Dam are being prepared using the North American Vertical Datum of 1988 (NAVD88) as an elevation reference. In the vicinity of Folsom Dam, the difference in numerical value between the two elevation references is approximately 2.34 ft (i.e., 0 ft NGVD29 equals 2.34 ft NAVD88). This difference in reference elevation between the original project drawings and the current drawings presents a significant potential for confusion. To be consistent with previous Folsom modeling efforts, all hydraulic modeling and reporting activities related to the Dam Raise and JFP are to be done using the original NGVD29 elevation reference. Thus, all elevations in this document, unless otherwise noted, are referenced to the NGVD29 as used in the original project design documents and drawings.

Introduction

Project Background

Folsom Dam is located on the American River about 20 miles upstream from Sacramento, California (Figure 1). The dam was designed and built by the USACE and transferred to the Bureau of Reclamation (Reclamation) for operation and maintenance in 1956. The existing dam and spillway are comprised of a 340-ft-high and 1,400-ft-long concrete gravity section flanked on each side by earthfill wing dams that extend from the gravity section to the abutments. In addition to the main section and wing dams, there is one auxiliary dam and eight smaller earthfill dikes that impound a reservoir of 1,010,000 acre-feet. The dam is operated for municipal and agricultural water supply purposes and to provide flood control protection for the city of Sacramento.

Figure 1. Location map of Folsom Dam and Lake upstream from Sacramento, California.

The concrete gravity section of the dam includes an ogee crest at elevation 418 ft for both the service and emergency spillways (Figures 2 and 3). Releases are controlled using five 50-ft-tall by 42-ft-wide radial gates for the service spillway and three 53-ft-tall by 42-ft-wide radial gates for the adjacent emergency spillway. The service spillway discharges into a 242-ft-wide stilling basin at invert elevation 115 ft while the emergency spillway discharges from a flip bucket into a plunge-pool energy dissipator. A hydroelectric generating facility is located along the right side of the gravity section to which flow is delivered via three 15-ft diameter penstocks. The powerstation houses 3 Francis turbines with an installed capacity of 198.7 MW. The tailrace of the powerstation is separated from the main spillway channel by a concrete gravity training wall. The dam is also equipped with eight outlet conduits through the gravity section, four outlets at elevation 280 ft (upper level) and four outlets at 210 ft (lower level), each having 5-ft by 9-ft slide gates. The downstream ends of the conduits daylight on the service spillway face, but during large floods that require spillway operation, releases through the outlets are limited.

Figure 2. Overview of Folsom Dam.

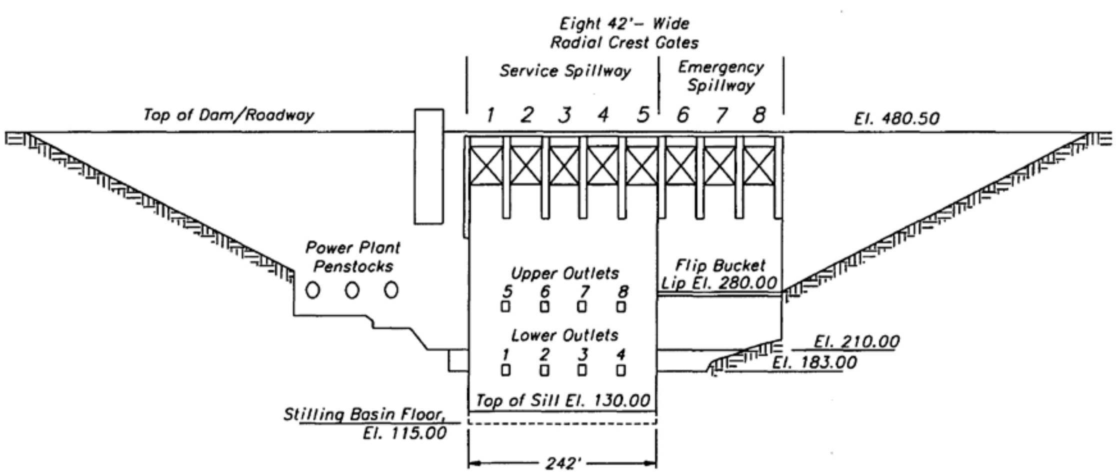

Figure 3. Concrete gravity section of Folsom Dam looking upstream.

Recent Projects and Improvements at Folsom Dam

Three major projects have been undertaken over the past decade to improve dam safety and flood protection: Folsom Dam Joint Federal Project, Folsom Dam Raise Project, and seismic protection retrofits.

Under the Folsom Dam Joint Federal Project, design and construction of a new auxiliary spillway near the left abutment of the main dam embankment is ongoing and is expected to be finished by 2017 (Figure 4). The auxiliary spillway is comprised of a control structure that houses six 23-ft-wide by 34-ft-high submerged tainter gates (top-seal radial gates) at invert elevation 368.0 ft, an approach channel from the reservoir to the control structure, a 169-ft-wide rectangular, concrete lined chute, a stilling basin, and an exit channel to return flood discharges to the American River. The downstream section of the spillway chute from Station 32+00 to Station 38+82 was designed as a stepped chute to dissipate some energy before flow enters the stilling basin. Combining the discharge capacity of the main dam and new auxiliary spillway, the probable maximum flood can be passed at a maximum pool elevation of 477.5 ft and flood protection is enhanced.

Figure 4. Artist's rendering of the new auxiliary spillway structure to the left of the main dam spillway structure.

As a result of legislation approved in 2002, the Corps of Engineers secured funding to begin studies and designs that included a raise of Folsom Dam. The objective of the Folsom Dam Raise Project is to provide flood damage reduction by increasing flood protection to the Sacramento area along the main stem of the American River. The Folsom Dam Raise Project calls for raising dam embankments 3.5 ft to elevation 484.0 and replacing or modifying the three existing emergency tainter gates. Top seals on the emergency spillway radial gates and vertical pier extensions at the existing piers are being considered to prevent overtopping with higher expected water surface elevations and modified spillway release operations (Figure 5). The maximum pool elevation during passage of the probable maximum flood (PMF) would be at elevation 481.0.

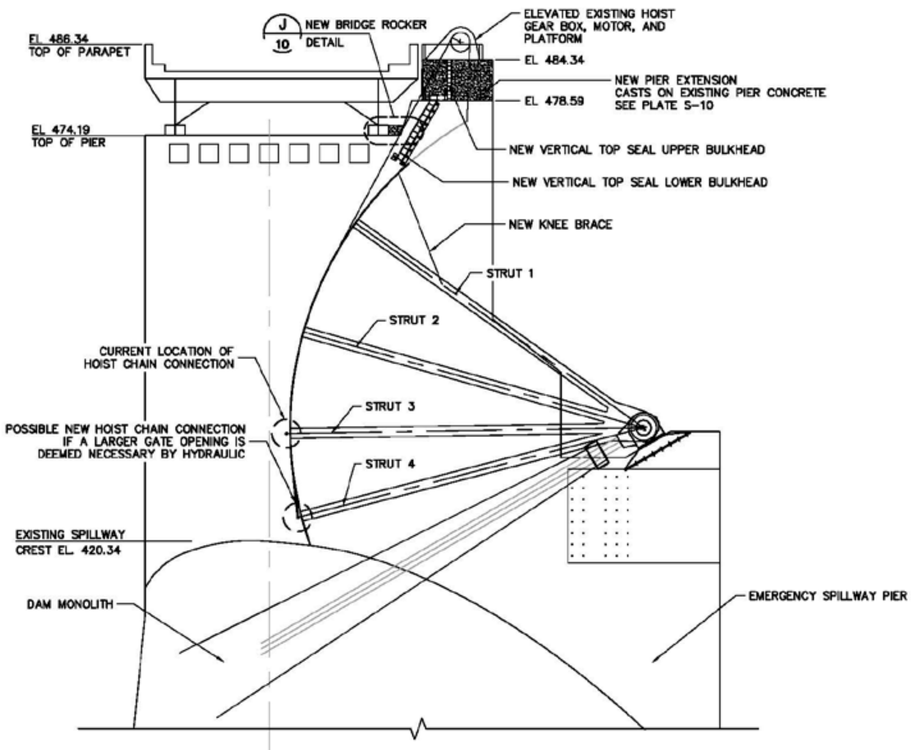

Figure 5. Preliminary drawing of emergency spillway gate top seal and vertical pier extensions (U.S. Army Corps of Engineers, January 2013). Elevations are given in NAVD88 datum.

Another project conducted during the same timeframe was a review of the seismic stability of the spillway structure. Reclamation determined that strengthening of the spillway piers and radial gates to resist cross-valley seismic motion was required. In 2012, steel trusses were installed between the spillway piers on the service spillway and emergency spillway, immediately underneath the bridge support beams. These seismic beams contain seven I-beams laced together with diagonal and horizontal bracing (Figure 6). Steel wrap-around plates were also bolted to the downstream end the concrete piers to provide additional support for the radial gate trunnions.

Figure 6. Folsom Dam prototype seismic beams underneath bridge.

Model Description

Model Objectives

In November 2012, the USACE asked Reclamation to undertake physical hydraulic modeling of a section of the Folsom Dam spillway as part of the Folsom Dam Raise Project. The key purpose of the study was to investigate the performance of the gates and spillway with top seals installed on the emergency spillway radial gates and vertical pier extensions installed at the existing piers to prevent overtopping under higher water surface elevations and modified release operations. The effect of the top seals and pier extensions on the hydraulic behavior of the spillway was investigated both with and without seismic retrofit beams in place. Since seismic beams were not previously studied in a physical hydraulic model, the USACE wanted to identify the effects of the beams on local hydraulic conditions.

The original scope of work with the top seals and pier extensions included:

- Planning and construction of the model
- Model testing both with and without seismic beams for the following aspects:
    - Discharge rating curves
    - Overall hydraulic behavior including turbulence, aeration, and vortices
    - Observations of potential shifts in hydraulic control

- Observations of water surface profiles to determine if trunnions are impacted by flow
    - Pressures on the spillway ogee crest
    - Pressures on the bridge
- Preparation of a Model Study Report, including video documentation and testing records

As modeling progressed, additional items were added to the SOW:

- Collection of water surface profiles in relation to the sidewalls.
- Evaluation of hydraulic conditions without the top seals and pier extensions. Model tests were conducted both with and without seismic beams for the following aspects:
    - Discharge rating curves
    - Overall hydraulic behavior including turbulence, aeration, and vortices
    - Observations of shifts in hydraulic control

This report includes the methodology, testing procedures, and results of the physical hydraulic modeling.

Model Scale

A 1:36 physical hydraulic model of a section of the Folsom Dam emergency spillway was constructed at Reclamation's hydraulics laboratory in Denver, Colorado in 2013. This scale was chosen to best simulate flow conditions at the spillway using one full width gate and two half-width gates in an existing hydraulic flume.

Similitude between the model and the prototype is achieved when the ratios of the major forces controlling the physical processes are kept equal in the model and prototype. Since gravitational and inertial forces dominate open channel flow, Froude-scale similitude was used to establish a kinematic relationship between the model and the prototype. The Froude number is

$$F_r = \frac{v}{\sqrt{gd}}$$

where v = velocity, g = gravitational acceleration, and d = flow depth.

When Froude-scale modeling is used, the following relationships exist between the model and prototype where the r subscript refers to the ratio of the model to the prototype and subscripts m and p are used to indicate model and prototype, respectively:

Length ratio: $L_r = L_m/L_p = 1:36$

Pressure ratio: $P_r = 1:36$

Velocity ratio: $V_r = L_r^{1/2} = (1/36)^{1/2} = 1:6$

Time ratio: $T_r = L_r^{1/2} = (1/36)^{1/2} = 1:6$

Discharge ratio: $Q_r = L_r^{5/2} = (1/36)^{5/2} = 1:7,776$

Model Design and Features

The 1:36-scale sectional model was constructed in an existing 4-ft-wide by 8-ft-high by 80-ft-long glass-walled flume. Drawings of the model are shown in Figures 7 and 8.

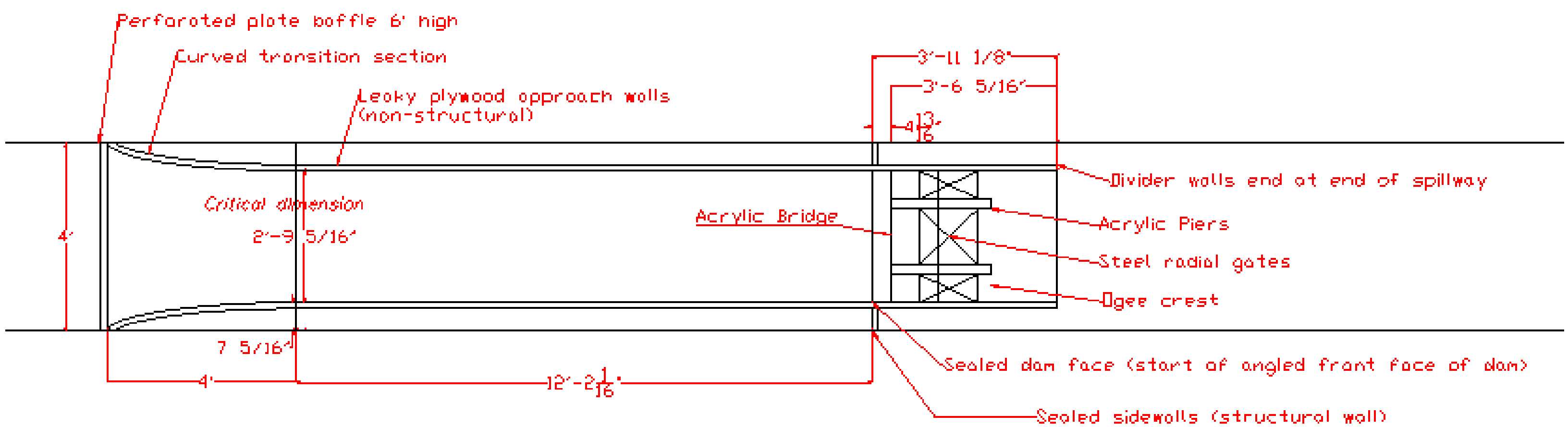

Figure 7. Plan view of 1:36-scale sectional Folsom Dam emergency spillway tainter gate physical model. Dimensions are in model scale.

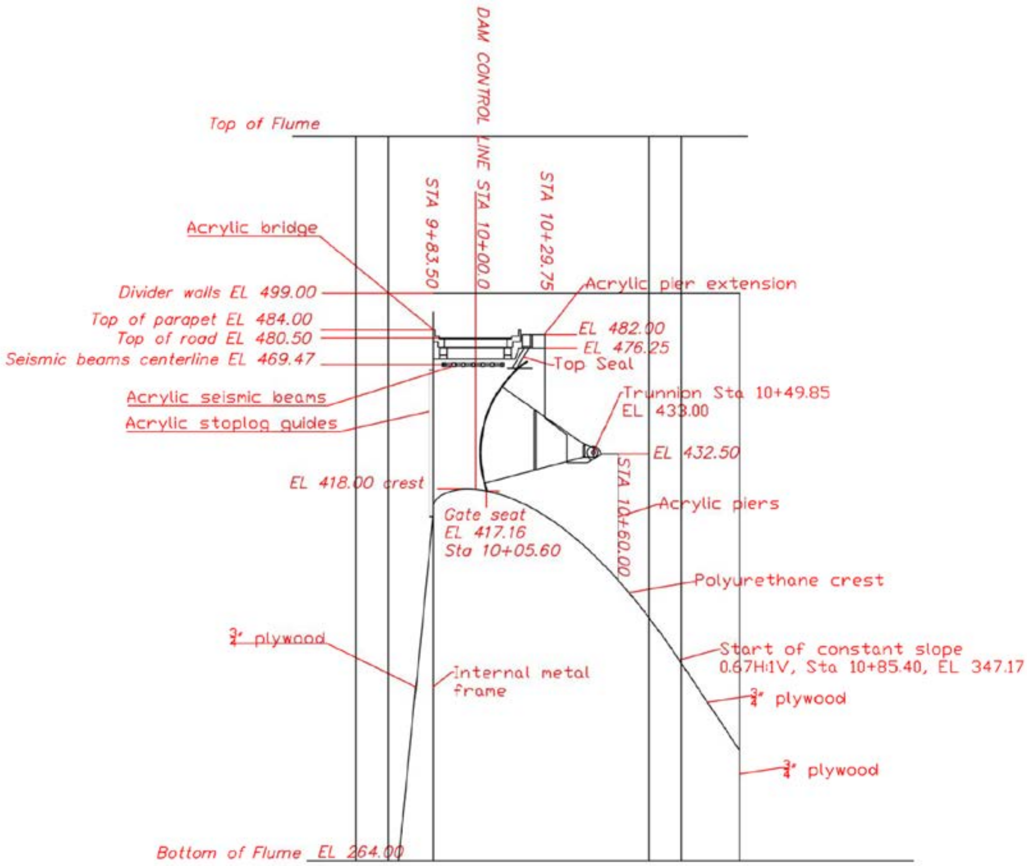

Figure 8. Profile view of 1:36-scale sectional Folsom Dam emergency spillway tainter gate physical model. Dimensions are in model scale.

Major features of the model include:

- A section of the emergency spillway, including one full spillway bay (gate 7), and half a bay on both sides of the full bay (gates 6 and 8).
- A headbox with vertical-grated diffuser approximately 31-ft upstream of the spillway model. A second, finer diffuser was located approximately 18-ft upstream of the spillway model to ensure that inflow velocities were uniform and wave induced action was dissipated.
- An elliptical transition curve to narrow flume width down to test section width
- Radial gates with trunnions (one full width gate and two half width gates)
- Major features of bridge including parapet, deck, and girders
- Seismic beams between piers with diagonal and horizontal bracing
- Stoplog slots on upstream side of piers
- Vertical pier extensions and top seal on radial gates
- Top section of spillway crest from EL 264 to EL 418

The height of the spillway crest above the invert of the flume was around 4 ft 3 in which corresponds to a prototype elevation of 264 ft. The flip bucket was not modeled downstream of the spillway crest; however tailwater levels in the downstream section of the flume were kept sufficiently low to prevent influencing the hydraulic conditions near the crest. Upstream and downstream topography were not modeled in this sectional model. Due to the scale of the model, the seismic beams with horizontal and diagonal bracing were modeled as solid rectangular beams rather than I-beams. The seismic steel wrap-around plates were not modeled because plate thickness and bolts were of insignificant size at model scale.

The spillway model included accurate representation of the spillway piers, bridges and seismic beams using molded and machined acrylic. The crest of the dam was constructed using high-density foam, painted with acrylic-based paint. The spillway gates were constructed from steel with rubber side seals to minimize leakage. Photographs of the model are shown in Figures 9 through 11.

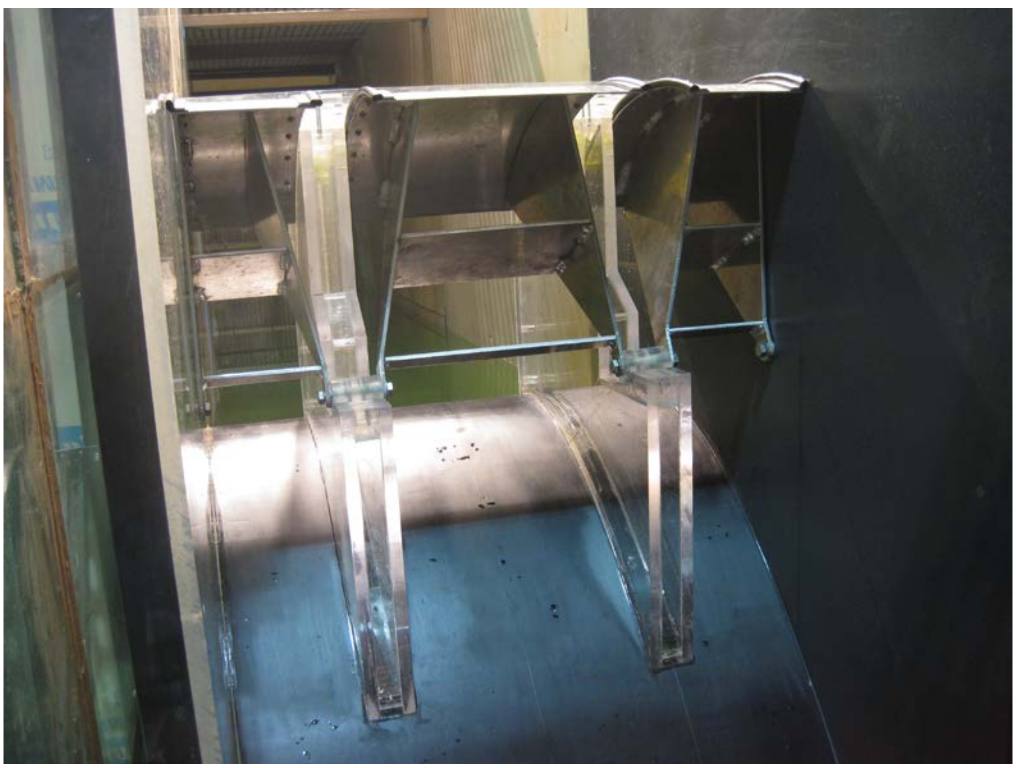

Figure 9. Overview of Folsom Dam emergency spillway sectional model looking upstream.

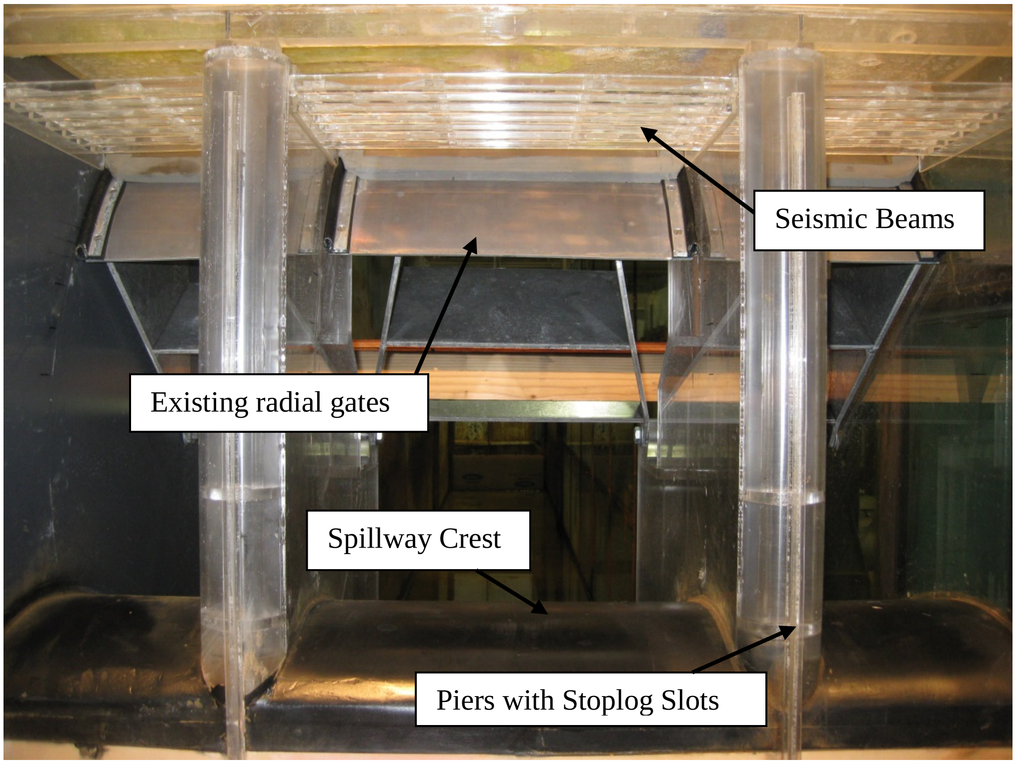

Figure 10. Folsom Dam emergency spillway sectional model looking downstream through spillway.

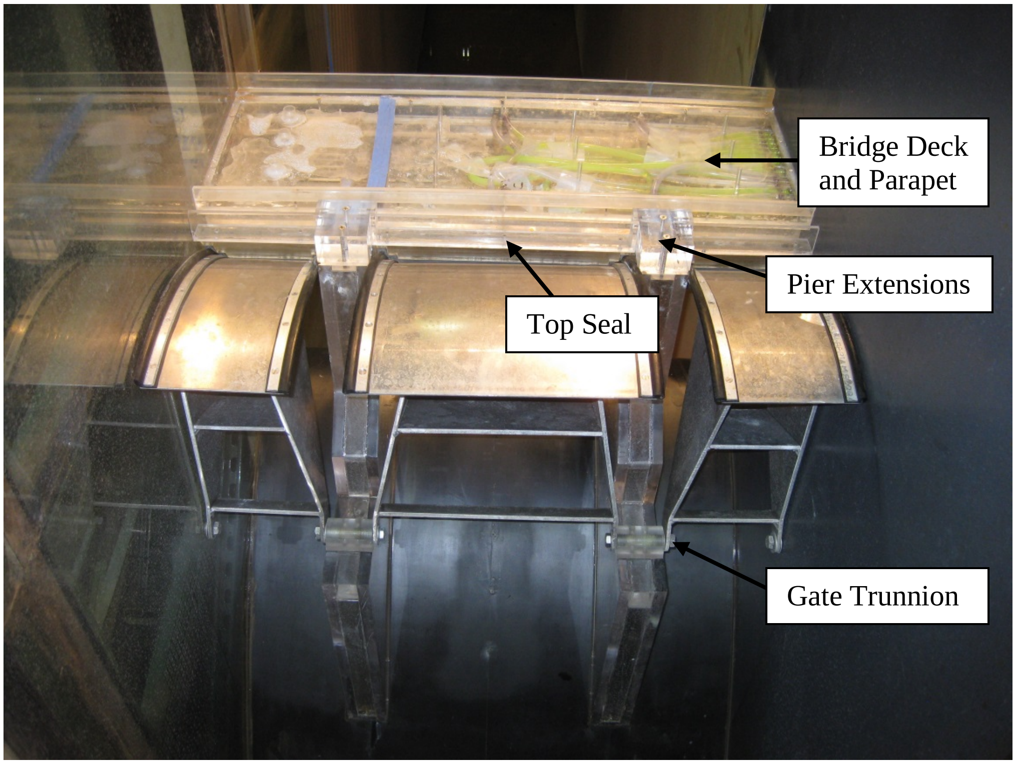

Figure 11. Folsom Dam emergency spillway sectional model looking upstream at radial gates and bridge.

The primary benefit of a sectional model is to allow a larger scale model to be constructed while passing the necessary discharge through the model. Another major benefit is visibility. Since the model was constructed in cross section, the hydraulic characteristics at various points underneath the bridge and through the gate could be easily observed.

One of the common concerns with sectional models is velocity of approach effects. At high discharges, the area upstream from the dam does not behave the same as a large reservoir due to the relatively narrow flume width. Upstream of the dam, velocities are notably higher in the model than they would be in the prototype. This does not mean that meaningful data cannot be collected; just that care must be taken in interpreting the results. Kinetic energy corrections must be applied to measured water surface elevations. In the model, the water surface elevation is measured far enough upstream of the dam to be out of the influence of localized drawdown effects near the gates. Head corrections were computed using the measured discharge entering the flume and the reservoir head measured at the upstream stilling well. A mean velocity head was calculated and added to the observed water level to determine the effective reservoir elevation. This methodology produced discharge rating curves that were generally consistent with those obtained by other methods. Although water surface elevations between the model and prototype are different at a point far upstream of the dam, these differences become less significant as flow approaches the dam and accelerates through the gated spillway. Therefore, flow interaction with the bridge deck and seismic beams can be observed with confidence.

The measured model reservoir water surface elevation was corrected for velocity head using the following formula:

$H = V^2/2g = Q^2/2gA^2$

Where H = velocity head (ft) at upstream water surface level recorder
V = velocity (ft/s)
g = acceleration due to gravity (32.2 ft/s^2)
Q = model discharge (ft^3/s)
A = cross sectional flow area (ft^2) = (measured water surface elevation – flume invert) * (model width)

Measured model discharges were representative of two gates. Some interpretation is necessary when using a two-gate discharge to estimate five- or eight-gate discharges. Lacking any additional information, what might be done is to assume equal discharge per gate and just scale up with the number of gates. However, this method for the Folsom spillway includes significant error as the two end gates would have lower discharges than a center gate due to flow contraction at the end piers.

Results of a computational fluid dynamics (CFD) model were used to estimate fractional discharges for each spillway gate (Frizell et al., 2009). The numerical model results suggested that all gates except the end gates were within about 2.5 percent of one another in discharge. The end gate variation was shown to increase with increased gate openings. Table 1 shows the corrections that were obtained from the CFD results and used to estimate 5- and 8-gate discharges. Correction factors shown below assume symmetry about the centerline for gates 4 and 5. When estimating a 5-gate discharge with the current sectional model, it is assumed that the model is representative of center gates 4 and 5 due to the approach conditions in the model. Correction factors are then applied for gates 1-3 and 6-8. For additional discussion on discharge ratings and correction factors at Folsom Dam, please refer to Frizell et al., 2009.

Table 1. Results from CFD modeling (2008) showing fractional discharges for each Folsom spillway gate at multiple gate openings.

Gate Opening (ft)	Gate 1	Gate 2	Gate 3	Gate 4
30.0 *	0.975	0.989	0.997	1.000
35.0 *	0.972	0.989	0.995	1.000
40.0 *	0.925	0.979	0.994	1.000
41.0 *	0.924	0.973	0.985	1.000
42.0 *	0.911	0.978	0.982	1.000
Free Flow **	0.905	0.977	0.995	1.000

* Reservoir elevation 477.5 ft

** Reservoir elevation 475.4 ft

Instrumentation

Flow Measurement

A 240,000-gallon storage reservoir under the laboratory floor supplied water for the hydraulic model through an automated flow delivery and measurement system. Four 100-150 hp variable-speed centrifugal pumps located in the pump pits at the north and south ends of the storage reservoir delivered water to a 12-inch supply line that runs around the perimeter of the laboratory. Laboratory venturi meters from 3 to 14 inches in diameter provide flow measurement capability for discharges ranging from 0.1 and 20 cfs. A 44,000-pound volumetric/weigh tank facility is used to calibrate the laboratory venturi meters in place at regular intervals with an estimated relative uncertainty of less than $\pm 0.50\%$ of the measured discharge. A state-of-the-art laboratory control and data acquisition system displays flow measurement data on a LCD screen.

Reservoir Water Surface Elevation

The reservoir elevation in the model was measured with a stilling well. Clear Poly-Flow tubing connected the permanent flume tap to a stilling well on the outside of the headbox. The hook gage was equipped with a vernier scale, allowing the water level to be read to the nearest 0.001 ft (Figure 12). The hook gage measurement uncertainty of ± 0.0005 ft model corresponds to ± 0.018 ft prototype. Reservoir water surface elevations were measured approximately 8 ft upstream of the dam face (288 ft prototype), so that the reading would not be measurably affected by local drawdown near the gates. The measuring station should be located at about a distance of two head measurements upstream from the overflow location (Reclamation, 2001). In this case, the maximum head on the model crest is 1.75 ft, so a permanent port location 8 ft upstream of the dam was selected. As previously discussed, reservoir elevations were corrected for velocity head to compare results with previously established prototype rating curves.

Pressure Measurements

Piezometer taps were used to measure static pressures and hence water surface elevations at 24 locations in the model. All pressures and water surface elevations are reported in prototype scale unless otherwise specified. Care was taken to ensure that the piezometer taps were flush with flow boundaries. Clear Poly-Flow tubing was run from a metal fitting at the model surface to a manometer board where water levels were visually averaged to the nearest 0.01 ft model, Figure 13. The water level measurement uncertainty of ± 0.005 ft model corresponds to ± 0.18 ft prototype.

Piezometer taps were installed in the model to record static pressure levels at various locations:

- 8 piezometer taps along the centerline of the ogee surface of the central gate bay, numbered 1 to 8 from upstream to downstream.
- 8 piezometer taps in the bridge at the centerline of the center gate bay
    - 3 taps in the upstream face of the spillway bridge parapet, deck, and girder
    - 2 taps in the underside of the bridge deck
    - 3 taps in the downstream face of the spillway bridge parapet, deck, and girder
- 8 piezometer taps in the bridge directly above the pier on the left side of the central gate bay
    - 3 taps in the upstream face of the spillway bridge parapet, deck, and girder
    - 2 taps in the underside of the bridge deck
    - 3 taps in the downstream face of the spillway bridge parapet, deck, and girder

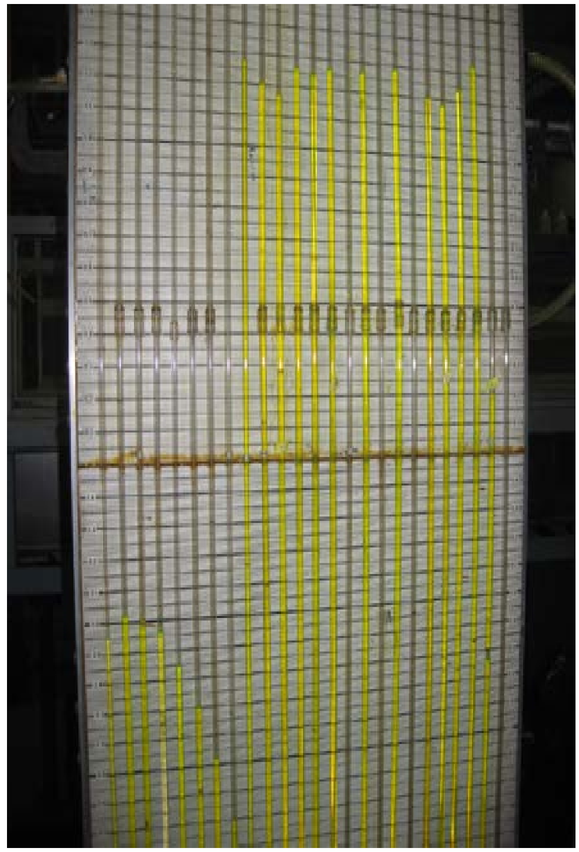

Figure 12. Reservoir water level hook gage.

Figure 13. Manometer board.

The pressure tap locations along the ogee crest are shown on Figure 14. Bridge pressure tap locations are shown in Figures 15, 16 and 17. A description of bridge pressure tap locations is provided in Table 2.

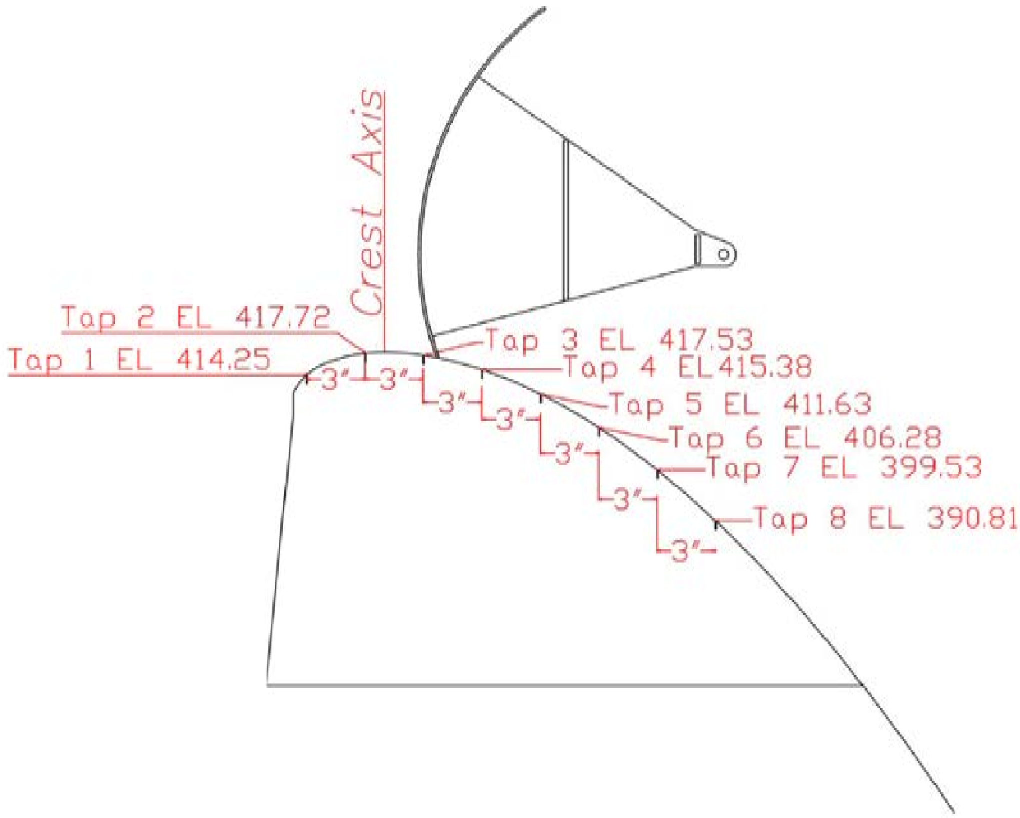

Figure 14. Ogee crest pressure taps (numbered 1-8 upstream to downstream).

Figure 15. Locations and elevations of pressures taps on bridge. Dimensions are in model scale.

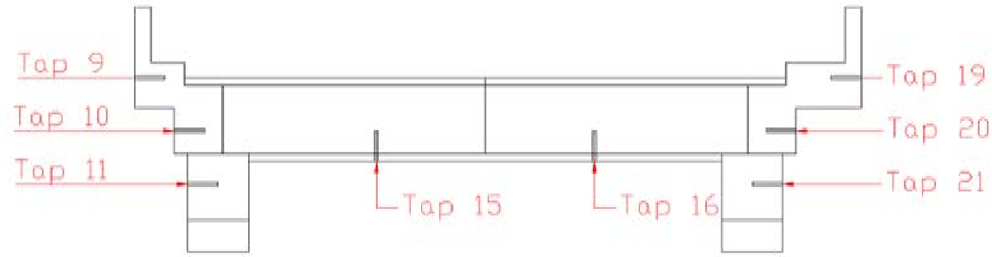

Figure 16. Pressure tap numbering for center bay.

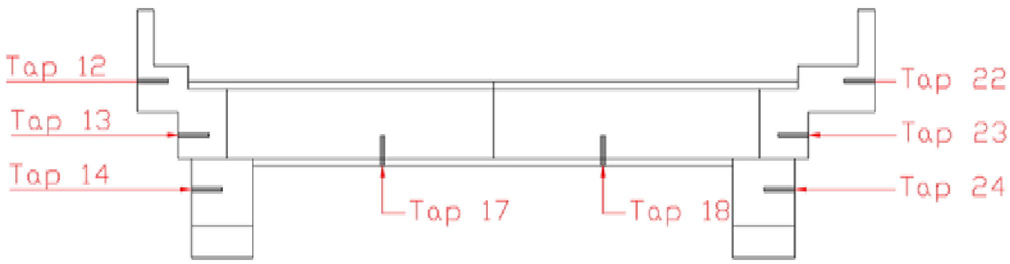

Figure 17. Pressure tap numbering above left bridge pier.

Table 2. Location and elevation of spillway and bridge pressure taps.

Pressure Tap No.	Elevation (ft)	Bay	Location
1	414.25	Center Bay	Centerline of ogee crest
2	417.72		Centerline of ogee crest
3	417.53		Centerline of ogee crest
4	415.38		Centerline of ogee crest
5	411.63		Centerline of ogee crest
6	406.28		Centerline of ogee crest
7	399.53		Centerline of ogee crest
8	390.81		Centerline of ogee crest
9	480.50	Center Bay	Upstream Bridge Parapet
10	477.86		Upstream Bridge Deck
11	475.21		Upstream Bridge Beam
12	480.50	Above Left Side Pier	Upstream Bridge Parapet
13	477.86		Upstream Bridge Deck
14	475.21		Upstream Bridge Beam
15	476.35	Center Bay	Underside of Deck toward Upstream Side
16	476.35		Underside of Deck toward Downstream Side
17	476.35	Above Left Side Pier	Underside of Deck toward Upstream Side
18	476.35		Underside of Deck toward Downstream Side
19	480.5	Center Bay	Downstream Bridge Parapet
20	477.86		Downstream Bridge Deck
21	475.21		Downstream Bridge Beam
22	480.50	Above Left Side Pier	Downstream Bridge Parapet
23	477.86		Downstream Bridge Deck
24	475.21		Downstream Bridge Beam

Water Surface Profiles along Sidewall

The elevation of the right sidewall was drawn on the acrylic model panel nearest to the observation point and a grid was drawn around the sidewall (Figure 18). The grid started 51 ft downstream of the crest axis and extended to 88.5 ft based on the downstream extent of the acrylic panel. Water surface profiles were estimated by reviewing video of flow conditions and estimating the water surface elevation in reference to the grid. Since the water surface elevation fluctuated during model operation, the maximum consistent fluctuation in the water level was chosen as the water surface. Qualitative observations of the water surface profiles were considered acceptable for these tests, so quantitative data were not collected.

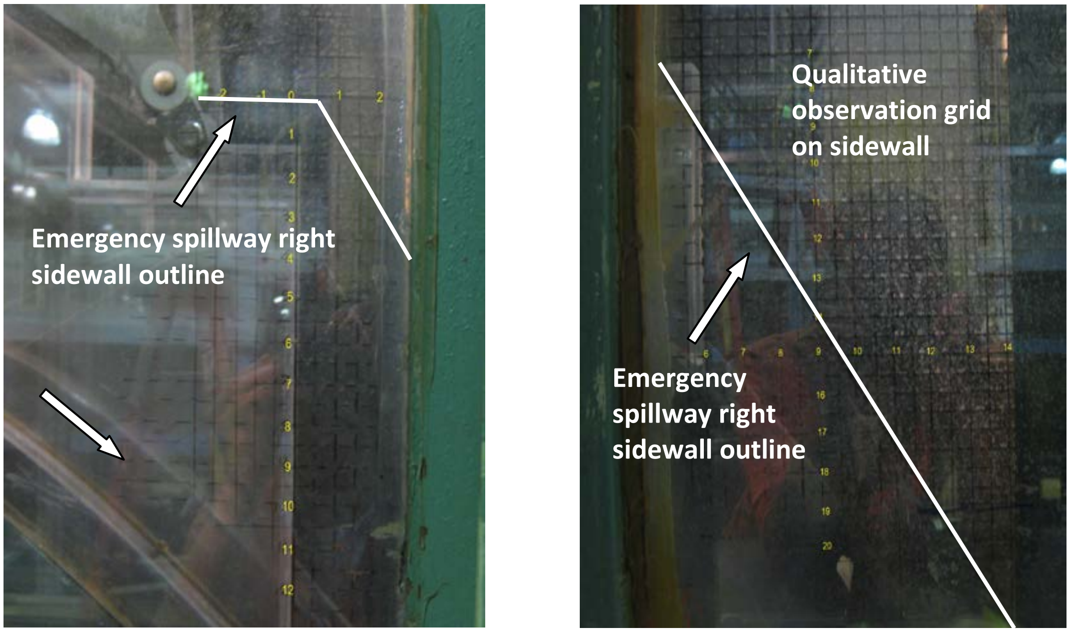

Figure 18. Right sidewall of emergency spillway with qualitative observation gridlines drawn on sidewall acrylic panel.

Results

Flow Conditions under Bridge Deck

The observed model flow conditions under the bridge deck were somewhat unexpected. In previous full-width models, it was assumed that water filled in the space beneath the bridge deck although it was difficult to make direct observations without a cross sectional view. Observations in this sectional model showed that under certain conditions flow contracts off of the upstream bridge girder, producing an air pocket beneath the bridge deck. To ensure that flow conditions under the bridge were representative of prototype conditions, several items were examined in the model.

Approach Conditions

Sectional models have greater approach velocities than would be observed during prototype operation due to the restriction in upstream channel width. Approach conditions were examined in the model to ensure that skewed approach velocities were not causing flow contraction observed in the model. In addition to a vertically-grated diffuser, a secondary finer baffle was added to ensure that inflow velocities were uniform and wave induced action was dissipated. Surface velocities were reduced using several types of temporary baffles, but flow conditions under the bridge remained the same. Therefore, it was determined that approach conditions were satisfactory in the model as long as head corrections are applied.

Testing with and without Air Holes in Bridge

The prototype bridge above the Folsom Dam spillway has grates on the deck for expansion and contraction of the bridge deck and maintenance access. The bridge deck was replicated in this sectional model using acrylic which was attached and sealed to the sidewalls, resulting in a relatively 'air tight' feature. A query was raised regarding whether such a replication of the bridge deck influences flow behavior immediately beneath the bridge.

Initial testing without the top seal did not include air holes in the model bridge. To test the concern, air holes were installed through the model bridge deck on the right-side half gate bay, closest to the observation point. With seismic beams installed, the model was run for various flows and gate openings to compare flow characteristics against the previous model runs without air holes. Pool elevations were selected to match previously collected model data.

- 35-ft Gate Opening at Pool EL 477.23, 478.94, 480.70 ft
- 38-ft Gate Opening at Pool EL 476.96, 480.34, 482.24 ft

- 40-ft Gate Opening at Pool EL 479.07 and 481.44 ft
- 42-ft Gate Opening at Pool EL 479.50 and 481.40 ft

Observations of flow conditions with and without air holes indicated that some minor differences occurred when the upstream pool level rose above 480 ft. Flow touches the underside of the bridge deck and the downstream bridge girder is submerged, eliminating the ability for air to be drawn into or expelled from this area. With pool levels less than 480 ft, flow conditions were very similar with and without air holes.

Although differences with and without air holes in the bridge were minor, air holes were drilled in the bridge above the other 2 model gates for the remainder of the tests to best represent prototype conditions. Model data collected without air holes are still considered acceptable, as observed differences were slight.

Testing Under Different Operational Scenarios

For initial tests, various flow conditions were assessed by maintaining a constant gate opening and gradually increasing the reservoir water level which is a typical approach used in laboratory modeling. However, operation of the prototype involves adjusting the gate opening to maintain a constant upstream pool level. Maintaining a constant pool level while adjusting gate openings requires precise adjustments of inflows to the model to ensure that the water level remains constant, and as such, is a more complex modeling process.

Concern was raised that the initial tests undertaken in the laboratory would produce different flow conditions underneath the bridge than what would otherwise be expected in the prototype due to the different approach in setting the gate opening (Figure 19). When the gate is set and the pool elevation is gradually raised, flow is first in free flow and then in gate control. The concern was that an air pocket underneath of the bridge was formed during low reservoir water surface elevations and then continued to exist as the higher water surface elevation was raised because air was trapped. In the other approach, the reservoir level is maintained at a constant level and the gate is raised. During small gate openings under normal operations, water fills in the space underneath of the bridge. As the gates are further opened for flood operations, it was believed that an air pocket would not form.

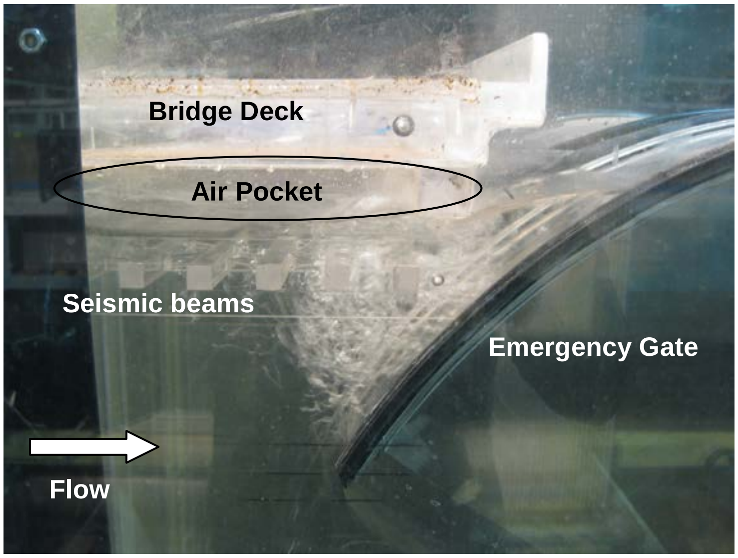

Figure 19. Description of air pocket location under the bridge deck.

Consequently, a comparison was undertaken of the two scenarios to investigate differences in flow behaviors at various gate openings and pool levels:

- Hold Gate Setting – Maintaining a constant gate opening and gradually increasing the reservoir water level.
- Hold Pool Level – Maintaining a constant reservoir water level and systematically increasing the gate opening

Flow conditions were reviewed with and without seismic beams at a reservoir level of EL 481 ft with gate openings of 30, 35, 38, 40, and 42 ft.

Without seismic beams, there was no discernible difference in flow characteristics between holding the gate opening constant and holding the pool level constant for any condition investigated.

Similarly, results with seismic beams installed showed no discernible difference between holding the gate constant and holding the reservoir pool constant. In both cases with a pool elevation of 481 ft, the air pocket underneath of the bridge formed at the same gate opening (around 38- to 40-ft gate opening). Holding the pool constant and raising the gate did not prevent the formation of the air pocket.

The results with the seismic beams in place suggest that slightly more drawdown occurs downstream of the bridge girder when the gate opening is held constant and the pool level is gradually increased. While this effect was vaguely noticeable with a gate opening of 35 ft and a pool level of 481 ft (Figures 20-21), effects are slightly more noticeable at gate openings of 38-, 40-, and 42-ft with a pool level of 481 ft (Figures 22-25). Hydraulic conditions are similar enough between the two operational scenarios that holding the gate setting constant was chosen for data collection on the model.

Figure 20. Holding pool level at 481 ft and raising gates to 35-ft gate opening. No air pocket formed under the bridge deck.

Figure 21. Holding gate opening at 35 ft and increasing pool level to 481 ft. No air pocket formed under the bridge deck.

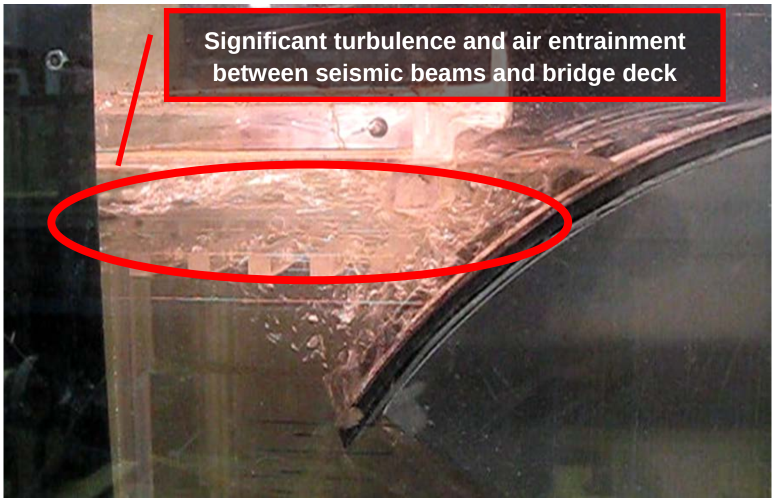

Figure 22. Holding pool level at 481 ft and raising gates to 40-ft gate opening. An air pocket formed under the bridge deck.

Figure 23. Holding gate opening at 40 ft and increasing pool level to 481 ft. A large air pocket formed under the bridge deck. Flow skims across the seismic beams.

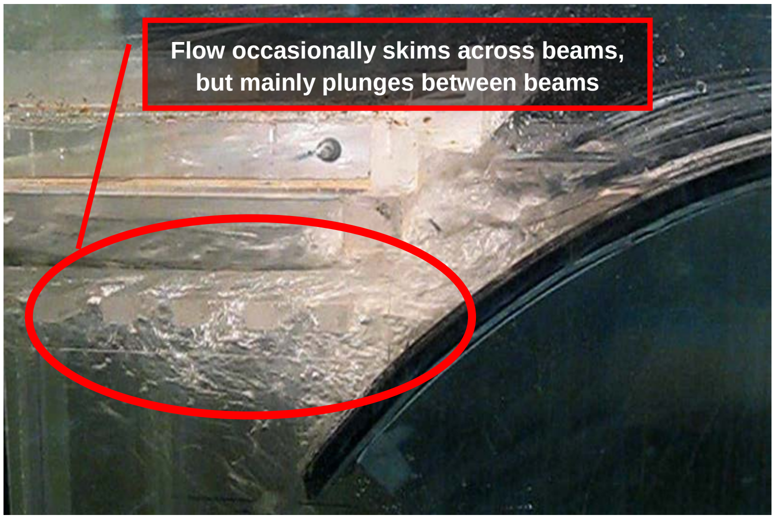

Figure 24. Holding pool level at 481 ft and raising gates to 42-ft gate opening. A large air pocket formed under the bridge deck. Flow occasionally skims across the beams as seen above, but typically plunges through the beams as seen below in Figure 21.

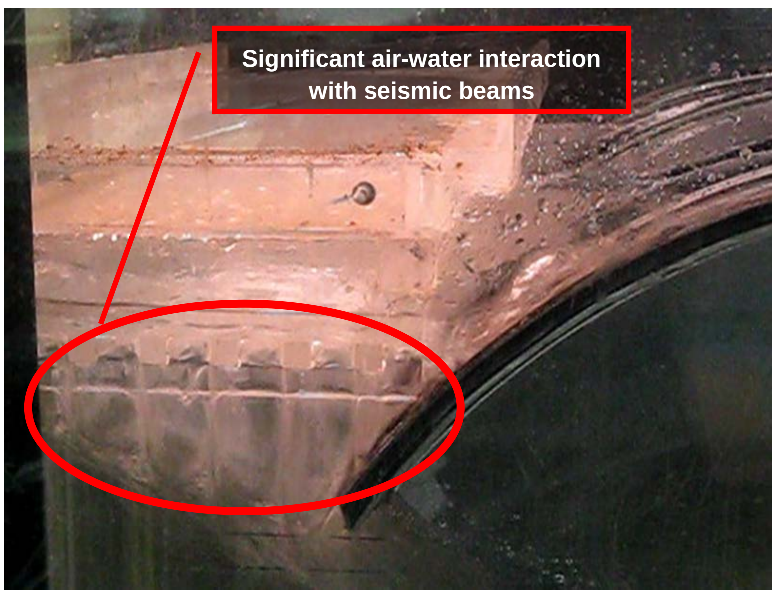

Figure 25. Holding gate opening at 42 ft and increasing pool level to 481 ft. A large air pocket formed under the bridge deck. Plunging flow through the beams is continuous. Gate is not fully in control due to air-water interaction with the seismic beams.

Model Testing Without Top Seal

Test Plan

Model data were collected without the top seal to compare model results to past physical and numerical model data. In addition, data were collected with and without seismic beams to determine the effects of the seismic beams on hydraulic performance.

The following cases were modeled without the top seal:

- 30-, 35-, 38-, 40-, and 42-ft vertical gate openings without seismic beams
- 30-, 35-, 38-, 40-, and 42-ft vertical gate openings with seismic beams
- Limited uncontrolled flow points

For gated flow conditions, the following items were recorded:

- Reservoir water level and discharge for the purpose of developing rating curves
- Overall hydraulic conditions, including potential shifts in hydraulic control and observations of turbulence and aeration in the vicinity of the seismic beams
- Video and photo documentation of model flow conditions

Tables 3-5 summarize the measured discharges and pool levels in the model with the corrected discharges and pool levels after the 2-gate discharge was converted to a 5-gate discharge with velocity head corrections. These data were used in the development of the discharge rating curve.

Table 3. Discharge rating data during uncontrolled flow.

		Measured Data		Corrected Data	
Gate Opening	**Model Features**	**Prototype Discharge 2 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**	**Prototype Discharge 5 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**
Uncontrolled flow	N/A	46,656	446.16	113,771	446.26
		62,208	451.38	151,694	451.55
		77,760	456.21	189,618	456.46
		93,312	461.53	227,541	461.88
		108,864	465.42	265,465	465.88
		116,640	467.29	284,427	467.81
		124,416	469.02	303,388	469.59
		139,968	472.77	341,312	473.46

Table 4. Discharge rating data with no top seal and no seismic beams.

		Measured Model Data		Corrected Data	
Gate Opening	**Model Features**	**Prototype Discharge 2 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**	**Prototype Discharge 5 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**
30 ft	No top seal, no seismic beams	84,292	465.96	208,700	466.23
		88,491	469.49	219,116	469.78
		91,446	472.26	226,445	472.56
		94,284	475.00	233,871	475.31
		97,200	476.98	241,105	477.30
		100,077	479.14	248,241	479.47
		103,032	481.08	255,571	481.43
35 ft	No top seal, no seismic beams	102,721	468.95	254,543	469.34
		105,831	471.36	262,250	471.77
		108,864	473.74	269,765	474.16
		111,741	475.68	276,894	476.12
		115,007	477.05	284,987	477.50
		118,351	478.49	293,273	478.96
		122,161	480.58	302,715	481.07
38 ft	No top seal, no seismic beams	118,740	473.16	292,170	473.66
		121,306	474.96	298,485	475.48
		124,416	476.51	306,138	477.04
		128,304	477.73	315,705	478.29
		134,136	479.82	330,055	480.42
		138,024	481.51	339,622	482.14
40 ft	No top seal, no seismic beams	129,035	475.86	316,007	476.44
		132,876	477.01	325,414	477.62
		137,542	478.38	336,840	479.02
		142,441	479.93	348,837	480.61
		146,943	481.62	359,864	482.33
42 ft	No top seal, no seismic beams	142,752	477.34	347,672	478.03
		146,165	478.06	355,986	478.78
		149,976	479.10	365,266	479.86
		153,708	480.15	374,356	480.93
		155,271	480.65	378,163	481.45
		158,537	481.69	386,117	482.52

Table 5. Discharge rating data with no top seal and with seismic beams.

		Measured Model Data		Corrected Data	
Gate Opening	Model Features	Prototype Discharge 2 gate (cfs)	Reservoir Water Surface Elevation (ft)	Prototype Discharge 5 gate (cfs)	Reservoir Water Surface Elevation (ft)
30 ft	No top seal, with seismic beams	83,747	465.64	207,736	465.91
		87,791	469.35	217,766	469.63
		90,901	471.65	225,481	471.95
		93,934	474.31	233,003	474.62
		96,967	476.47	240,526	476.80
		99,999	478.53	248,048	478.86
		102,799	480.54	254,992	480.89
35 ft	No top seal, with seismic beams	102,519	469.09	254,042	469.48
		104,929	470.46	260,015	470.86
		107,962	471.94	267,530	472.36
		109,984	473.16	272,540	473.59
		111,072	474.31	275,237	474.75
		114,105	476.51	282,752	476.96
		118,071	478.45	292,579	478.93
		122,037	480.43	302,407	480.93
38 ft	No top seal, with seismic beams	121,360	472.51	298,618	473.04
		124,393	473.92	306,081	474.46
		128,358	476.37	315,839	476.93
		131,057	478.09	322,478	478.68
		134,089	479.89	329,940	480.49
		138,055	481.59	339,698	482.21
40 ft	No top seal, with seismic beams	133,110	473.52	325,985	474.15
		134,976	475.14	330,556	475.78
		137,697	476.44	337,221	477.09
		139,641	477.19	341,982	477.86
		141,350	477.88	346,166	478.56
		142,277	478.31	348,438	478.99
		144,229	479.17	353,217	479.87
		146,865	480.83	359,673	481.54
42 ft	No top seal, with seismic beams	149,906	475.61	365,095	476.39
		153,716	477.16	374,375	477.97
		158,537	479.03	386,117	479.87
		161,889	480.58	394,280	481.45

Discharge Rating Curves

Discharge rating data were collected at 30-, 35-, 38-, 40-, and 42-ft vertical gate openings with and without seismic beams along with several uncontrolled flow points to compare current data to past data. Model data were plotted against data from several past hydraulic and computational models on a single graph. In general, data collected without seismic beams compared well with previous model data (Figure 26).

Data collected with seismic beams deviate from data collected without seismic beams. The Folsom Dam Service and Emergency Spillways Discharge Curves published in January 2010 (Benik, 2010) provides current rating data before the installation of seismic beams. The 2010 rating curve is conservative in that more discharge can be passed for a given water surface elevation with seismic beams installed at gate openings of 35 ft and above. An update to the official rating curve at Folsom Dam to incorporate the effects of the seismic beams may be warranted in the future.

Rating data in Figure 26 were collected without top seals installed. At 30-, 35-, and 38-ft gate openings, pier overtopping occurs at the highest measured pool elevations. There is no pier overtopping at 40- and 42-ft gate openings due to drawdown of flow under the gate. There is no measurable difference between rating data with and without top seals because the amount of flow passing over the piers is a small percentage of overall flow. More discussion on spillway performance with top seals can be found in the section “Model Testing with Top Seal”.

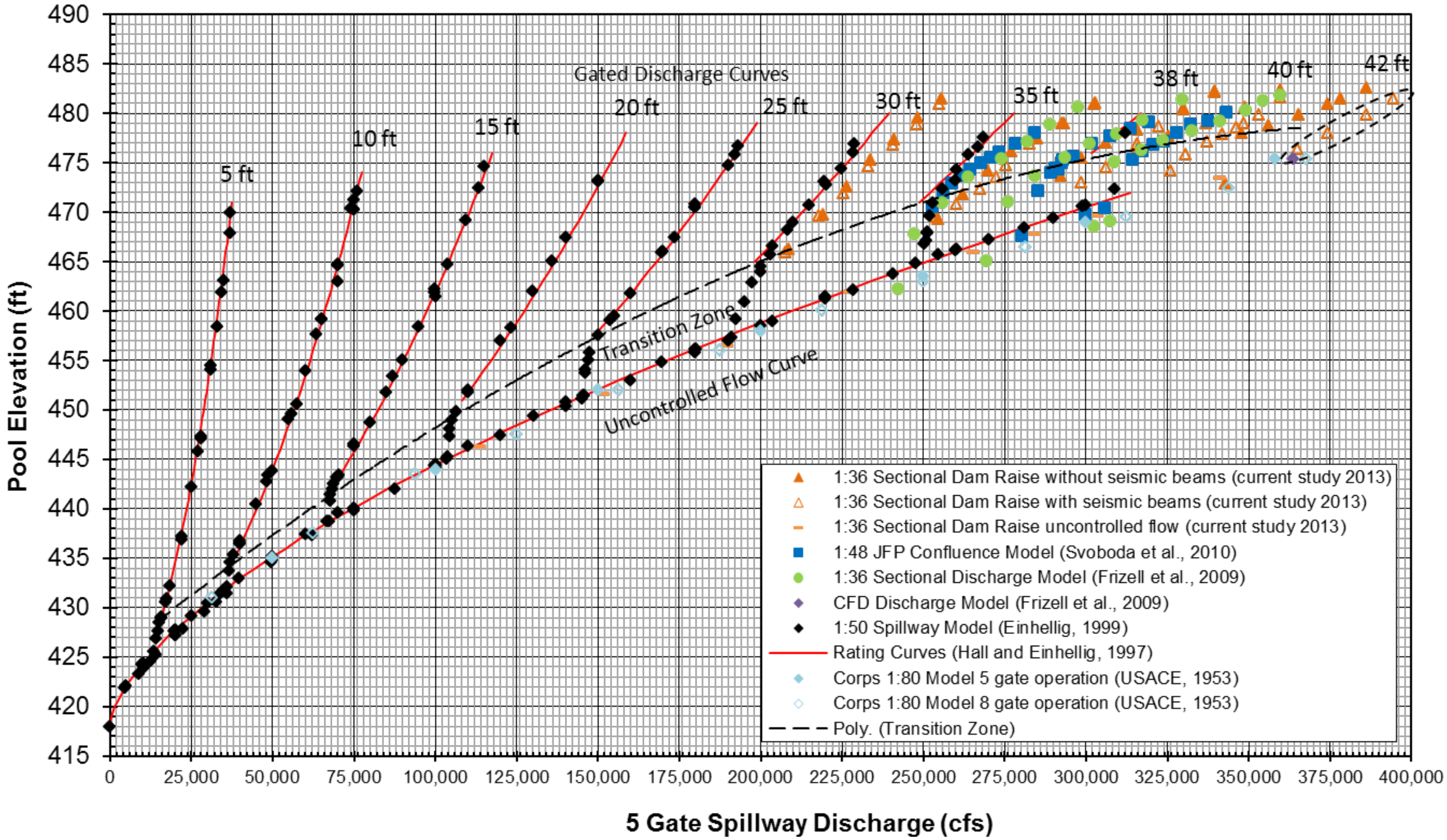

Figure 26. Comparison of current discharge rating data (1:36 Sectional Dam Raise) with various physical and numerical model data collected over the years. Model data were collected without the top seal installed. Transition zone (dashed line) designates the unstable region where flow transitions from uncontrolled flow to gated flow.

Comparison of Rating Data to Past Models

The 1:80-scale Folsom Spillway Model was tested in 1953 to study options for original construction of the spillway and energy dissipator at Folsom Dam (USACE, 1953). A 1:50-scale hydraulic model was constructed in Reclamation's hydraulics laboratory in 1997 to study the cause of stilling basin abrasion damage, to recommend modifications to minimize future damage, to develop new spillway discharge rating curves with different pier nose conditions, and to evaluate general spillway and outlet works operational criteria at Folsom Dam (Einhellig, 1999). Modified discharge rating curves and tables from the 1:50-scale model were published under separate cover (Hall and Einhellig, 1997). A 1:48-scale model of Folsom Dam Joint Federal Project Auxiliary Spillway confluence area was constructed in 2007 (Svoboda et al., 2010). The primary model objective was to evaluate the three-dimensional flow characteristics in the vicinity of the confluence between the main dam exit channel and the auxiliary spillway channel in order to assess potential design and operational issues. Several collaborative studies were undertaken in 2009 to further study the discharge capacity for the existing spillway at Folsom Dam. These studies included the existing 1:48-scale hydraulic model, a new 1:36-scale sectional model, and a computational fluid dynamics model (Frizell et al, 2009). The current 1:36-scale model (2013) was constructed in support of the Folsom Dam Raise Project to study hydraulic effects of adding top seals and vertical pier extensions to the existing emergency spillway gates.

Some discrepancies between the current study and other previous models likely occur for a couple of reasons. The 1:50-scale model and the 1:80-scale model included 5 gates on the service spillway with no emergency spillway. In this situation, significant flow contraction occurs at gates 1 and 5 with straight approach flow for gate 3 only. In the 2009 and 2013 sectional dam raise models, only 2 gates were modeled and the measured discharges were converted from 2 gates to 5 gates. This was accomplished using the 8 gate discharge correction factors obtained from numerical modeling (Frizell et al., 2009) as shown in Table 1. During 8 gate operation, approach flow conditions increase contraction at the end piers, resulting in reduced effective area and additional energy losses at gates 1 and 8. Therefore, application of the 8 gate discharge correction factors produces a higher overall value for the 5-gate discharge and the discharge curve shifts to the right. In other models such as the 1:48 scale model, 8 gates were operated and were converted to 5-gate operation by simply dividing by 8 and multiplying by 5. Because of these differences, the composite discharge rating graph is not necessarily a direct model comparison, but rather provides confidence that current model discharge data, when corrected, are consistent with past data.

Several uncontrolled flow points were collected in the 2013 model. These points fall near other data collected for either 8-gate operation or data converted to 8 gates based on the numerical modeling discharge correction factors. These data do not correspond as well with model data collected during 5-gate operation for the reasons discussed above.

All models constructed before 2013 did not include seismic beams. Models constructed before 2009 (1:50- and 1:80-scale models) did not include construction of the dam bridge. Both the seismic beams and bridge influence approach flow conditions to the gate, thereby affecting the discharge rating.

Hydraulic Control

“Hydraulic control” describes a location where there is a known relationship between water depth (or head) and discharge. For example, the control point can be a gate, weir, contraction, change in slope, or river roughness element. If the control point is removed, the stage-discharge relationship will change. The Folsom Dam spillway tainter gates are an active control point that can be varied during operation to control spillway discharge. The rating curve clearly shows when control shifts from uncontrolled flow to gate control.

Upstream features interacting with the flow can affect approach conditions or head loss upstream of the control point. When the reservoir water level impacts the bridge, flow contracts off of the upstream bridge girder. This change in approach conditions reduces head loss, which results in an increase in the discharge. This can be seen at higher reservoir elevations under gated flow in Figure 26 (note: the 1:50- scale model did not include the bridge). Seismic beams also influence approach conditions upstream of the control point. During different operational conditions, flow may skim across the beams, plunge through the beams, or contract off the upstream side of the beams and direct flow toward the gate opening. Seismic beams reduce the large recirculation zone above the gate opening. Seismic beams also minimize or eliminate vortices upstream of the gate by acting as a vortex suppressor. Figure 27 shows how data collected with seismic beams shifts to the right of data collected without seismic beams, in effect increasing discharge capacity. Figure 28 shows the location of the active control point and the locations of the two features that influence approach flow conditions upstream of the control point.

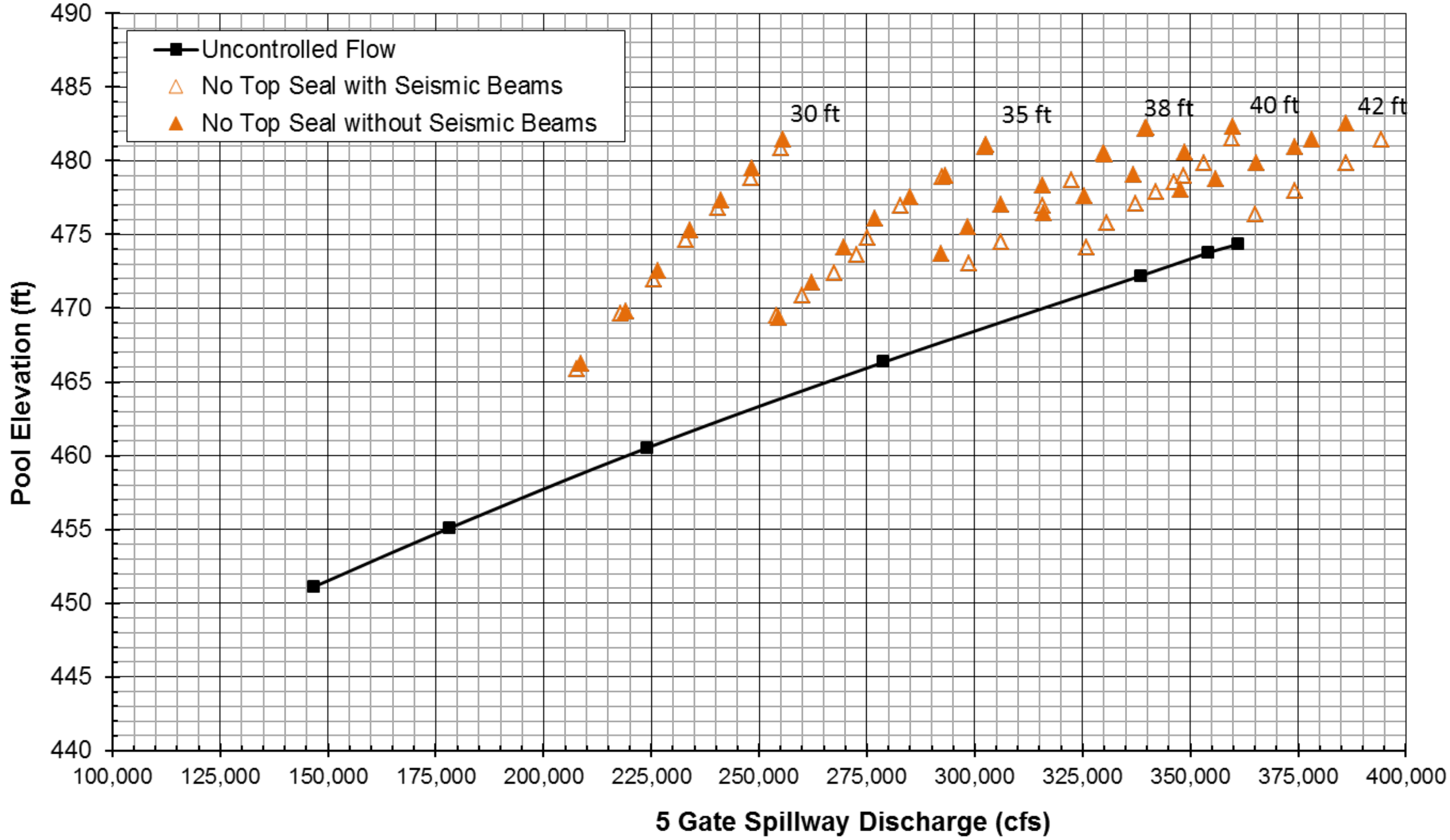

Figure 27. Direct comparison of discharge rating data with and without seismic beams for the current 1:36 Sectional Dam Raise model only. Model data was collected without the top seal installed.

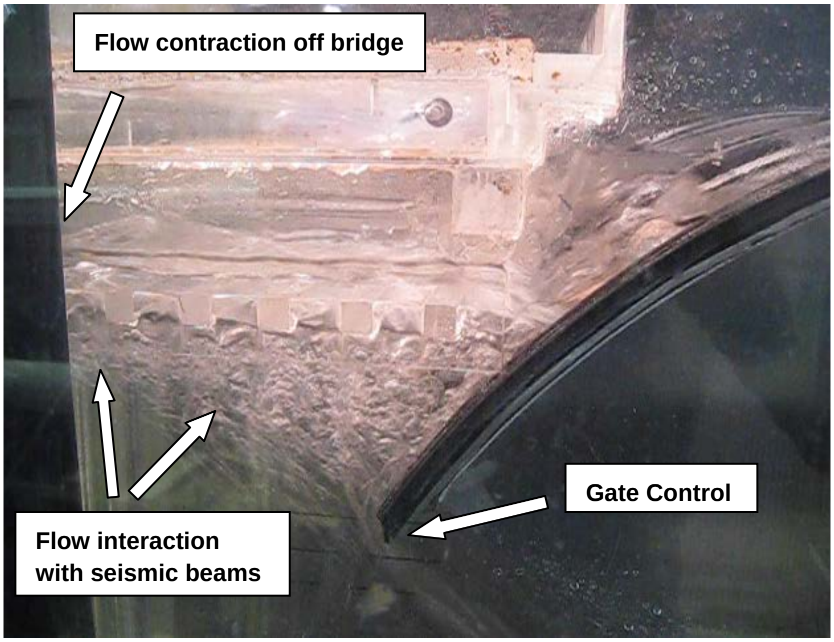

Figure 28. Location of features that affect the stage-discharge relationship.

Transition Zone

The “transition zone” is a region where flow rapidly transitions from uncontrolled flow to gated flow. Control may shift between gate control and uncontrolled flow, causing the upstream water level to fluctuate. This region can be seen on the discharge rating curve where data points drop off steeply toward the uncontrolled flow curve, indicating that it may be difficult to maintain gate control in this operating range. Operation in the “transition zone” is undesirable and should be avoided.

Since defining the transition zone was not an objective of this model study, detailed data points in the transition zone were not collected. Based on observations during data collection in the 2013 model study, the transition zone was estimated for gate openings of 35 ft and above. For gate openings less than 35 ft, data from the previous 1:50-scale model study of Folsom spillway were used since the transition zone was carefully delineated (Einhellig, 1999). The upper limit of the transition zone is identified on Figure 26 with a dotted line. Discharge measurements between the dotted line and the uncontrolled flow curve are in the transition zone. All data points collected with a 42-ft gate opening with the seismic beams in place (encircled with a dashed line) are considered transitional. The seismic beams produce air-water interaction against the gate, so the gate was not fully in control of flow at any water surface elevation (Figures 29-30).

Figure 29. Flow conditions without seismic beams with 42-ft gate opening at EL 479.86. Flow against the gate is turbulent and aerated, but gate control still exists when seismic beams are not installed.

Figure 30. Flow conditions near seismic beams with 42-ft gate opening at EL 479.87. Seismic beams produce a heavily aerated region against the gate such that the gate is not fully in gate control when seismic beams are installed.

Overall Hydraulic Conditions

Model observations are described for 30-, 35-, 38-, 40-, and 42-ft gate openings, including overall hydraulic behavior, shifts in control, turbulence and air-water interactions in the vicinity of the seismic beams, and overtopping of piers without the top seal. Photographs of hydraulic conditions during these operations are included in Appendix A.

- At a 30-ft vertical gate opening, discharge ratings with and without seismic beams are not measurably different. The seismic beams are in a somewhat stagnant, slower velocity zone, so there is little interaction between beams and flow. No turbulence or aeration was observed. Vortices occur up to EL 476 without seismic beams and EL 471 with seismic beams. When the water surface elevation is on the bridge, flow contraction off the upstream bridge girder influences approach flow to the gate. Seismic beams do not influence approach flow, as can be seen by the equivalent discharge ratings with and without beams. Occasional pier overtopping occurs in the range of EL 477-479 and significant pier overtopping occurs in the range of EL 479-481.

- At a 35-ft vertical gate opening, operations with and without seismic beams produce the same discharge rating at high pools (seismic beams in stagnant pool) and low pools (flow below seismic beams). When flow interacts with the beams at the mid-level pools the flow path through the spillway gate has a smaller hydraulic loss, so the spillway is slightly more efficient with the seismic beams. Turbulence and aeration are minimal. Vortices upstream of the gates are common without seismic beams up to EL 478 and with seismic beams up to EL 473. The beams act like a vortex suppressor, breaking up circulation and causing aeration in the flow. When the water surface elevation is on the bridge, flow contraction off the upstream bridge girder influences approach flow to the gate. Seismic beams also influence approach flow. Occasional pier overtopping occurs around EL 479 and significant pier overtopping occurs in the range of EL 480-481.

- At a 38-ft vertical gate opening, seismic beams increase discharge capacity At the very highest pools of 480-481 ft, rating curves with and without seismic beams are not measurably different. Beams are in a stagnant zone above the gate, so they have less influence over flow direction. Some turbulence and aeration occurs under the bridge. Vortices upstream of the gates are common without seismic beams up to EL 479 and with seismic beams up to EL 474. The beams act like a vortex suppressor, breaking up circulation and causing aeration in the flow. When the water surface elevation is on the bridge, flow contraction off the upstream bridge girder influences approach flow to the gate. Seismic beams also influence approach flow. Occasional pier overtopping occurs in the range of EL 480-482.

- At a 40-ft vertical gate opening, the seismic beams increase discharge capacity. Turbulence occurs under the bridge without the seismic beams.

Significant turbulence and aeration occurs with the seismic beams as flow skims across the beams and plunges between the beams. Vortices upstream of the gates are common without the seismic beams up to EL 479. Vortices were not observed with seismic beams. The beams act like a vortex suppressor, breaking up circulation and causing significant aeration in the flow. When the water surface elevation is on the bridge, flow contraction off the upstream bridge girder influences approach flow to the gate. Seismic beams also influence approach flow. There is no pier overtopping.

- At a 42-ft gate opening, flow is highly turbulent both with and without beams. Vortices upstream of the gates are common without the seismic beams up to EL 479. Vortices were not observed with seismic beams. Without beams, flow is in gate control. With beams installed, there is never true gate control due to the influence of the beams. Intense turbulence in the vicinity of the beams produces significant air-water interactionat the gate. Operation at a 42-ft gate opening with seismic beams is considered “transitional” due to flow instability and should be avoided. There is no pier overtopping.

Model Testing With Top Seal

Test Plan

The physical model was used to observe three-dimensional flow characteristics of various operational scenarios.

The following cases were modeled with the top seal installed:

- 35-, 38-, and 40-ft vertical gate openings without seismic beams
- 35-, 38-, and 40-ft vertical gate openings with seismic beams
- Limited free flow points to identify pressures on the ogee crest.

For gated flow conditions, the following items were recorded:

- Reservoir water level and discharge for the purpose of developing rating curves
- Overall hydraulic conditions, including shifts in hydraulic control, observations of turbulence and aeration in the vicinity of the seismic beams, recirculation flows, and presence of vortices.
- Pressure along the ogee crest, using pressure taps 1-8
- Pressures on the bridge, using pressure taps 9-24 (where relevant)
- Observations of water levels along the training walls
- Observations of water levels around the gate trunnion area
- Video and photo documentation of model flow conditions

Tables 6-8 summarize the measured discharges and pool levels in the model with the corrected discharges and pool levels after the 2-gate discharge was converted to a 5-gate discharge with velocity head corrections. These data were used in the development of the discharge rating curve.

Table 6. Discharge rating data during uncontrolled flow.

		Measured Data		**Corrected Data**	
Gate Opening	**Model Features**	**Prototype Discharge 2 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**	**Prototype Discharge 5 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**
Uncontrolled Flow	N/A	60,186	450.95	146,764	451.11
		73,094	454.87	178,241	455.10
		91,912	460.20	224,128	460.54
		114,385	465.85	278,928	466.35
		138,802	471.51	338,468	472.20
		145,256	473.02	354,206	473.77
		148,055	473.56	361,032	474.33

Table 7. Discharge rating data with top seal and no seismic beams.

		Measured Model Data		Corrected Data	
Gate Opening	**Model Features**	**Prototype Discharge 2 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**	**Prototype Discharge 5 gate (cfs)**	**Reservoir Water Surface Elevation (ft)**
35 ft	Top seal, no seismic beams	102,721	468.27	254,543	468.66
		104,820	470.17	259,745	470.58
		106,453	471.40	263,792	471.81
		107,698	472.37	266,875	472.79
		108,631	473.27	269,187	473.69
		112,985	475.86	279,978	476.30
		117,107	477.59	290,190	478.06
		120,917	479.53	299,632	480.02
38 ft	Top seal, no seismic beams	117,340	472.12	288,726	472.61
		118,817	473.63	292,362	474.13
		123,172	475.97	303,077	476.49
		128,537	477.77	316,279	478.33
		133,203	479.39	327,759	479.98
		139,268	481.95	342,683	482.58
40 ft	Top seal, no seismic beams	125,816	473.23	308,123	473.80
		126,049	473.88	308,694	474.44
		129,859	475.93	318,025	476.52
		132,192	476.69	323,738	477.29
		135,069	477.48	330,784	478.10
		136,469	477.88	334,212	478.51
		138,257	478.45	338,592	479.10
		142,534	479.71	349,066	480.39
		144,556	480.36	354,017	481.06

Table 8. Discharge rating data with top seal and with seismic beams.

		Measured Model Data		Corrected Data	
Gate Opening	**Model Features**	**Prototype Discharge 2 gate (cfs)**	**Reservoir Water Level (ft)**	**Prototype Discharge 5 gate (cfs)**	**Reservoir Water Level (ft)**
35 ft	Top seal, with seismic beams	102,643	468.27	254,350	468.66
		104,898	470.17	259,938	470.58
		107,853	471.40	267,260	471.82
		109,953	472.41	272,463	472.84
		111,041	473.20	275,160	473.64
		114,229	475.90	283,061	476.35
		118,040	477.88	292,502	478.35
		121,850	479.68	301,944	480.17
38 ft	Top seal, with seismic beams	121,306	472.33	298,485	472.86
		124,494	473.74	306,329	474.29
		128,226	476.22	315,513	476.79
		130,948	477.95	322,210	478.53
		133,903	479.57	329,481	480.17
		138,180	481.73	340,005	482.36
40 ft	Top seal, with seismic beams	132,970	473.27	325,643	473.90
		134,836	473.81	330,213	474.45
		137,557	476.04	336,878	476.70
		139,501	476.73	341,639	477.39
		141,368	477.55	346,209	478.23
		142,301	477.77	348,495	478.46
		144,167	478.60	353,065	479.30
		146,500	479.75	358,778	480.47
		147,744	480.43	361,825	481.16

Discharge Rating Curves

Discharge data collected at 35-, 38-, and 40-ft gate openings with and without top seals have no measurable differences (Figure 31). Pier overtopping occurs at the highest measured pool elevations without top seals. When top seals and pier extensions are installed, overtopping of piers and gates does not occur (unless there is leakage through the seal). However, installation of top seals and vertical pier extensions produces no notable difference in the rating curve because the amount of flow passing over the pier or gate is a small percentage of overall flow. The discharge rating curve displayed in Figure 26 for the current 2013 study without the top seal can be used with confidence for the top seal scenario.

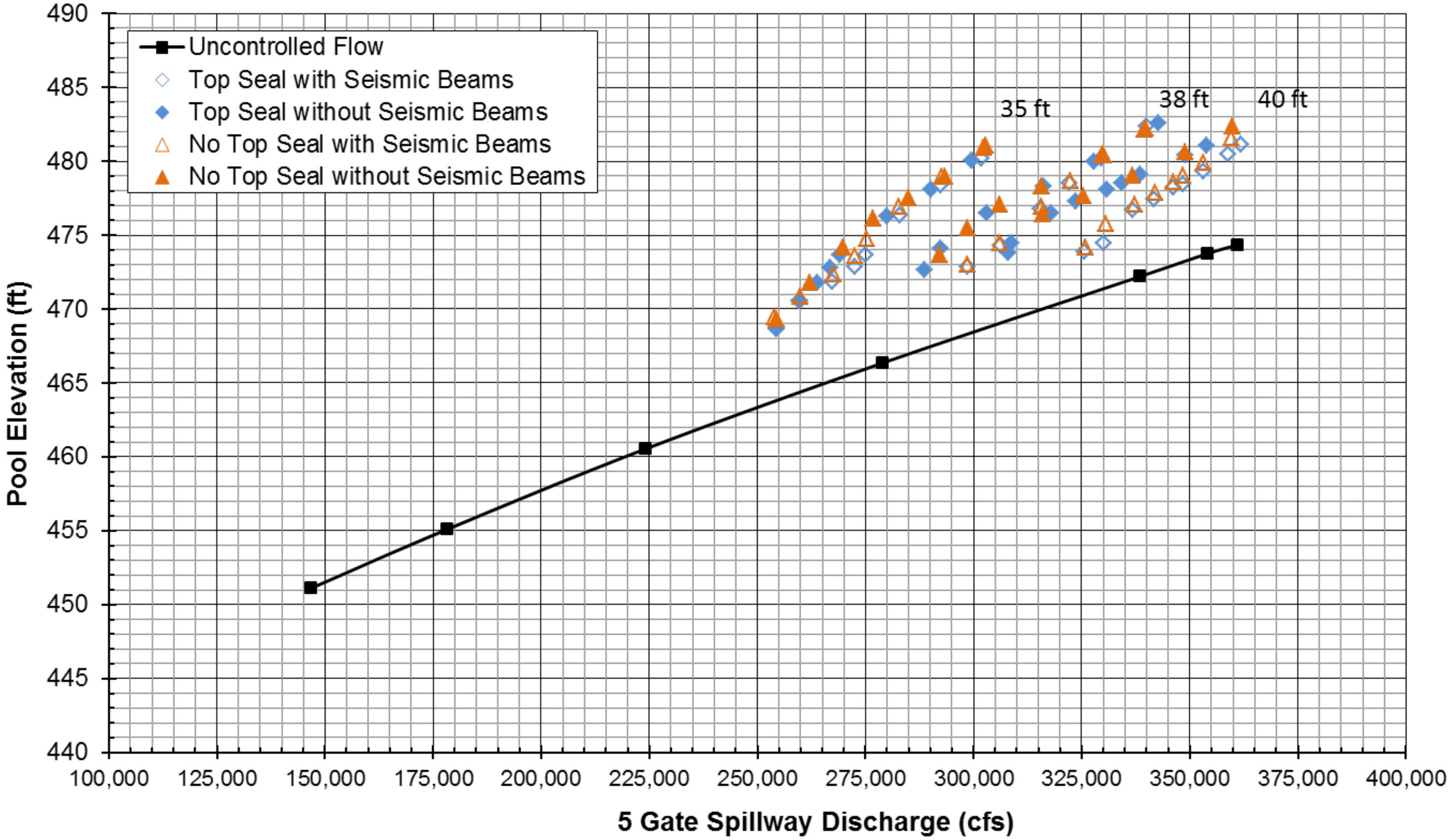

Figure 31. Direct comparison of discharge rating data with and without the top seal for the current 1:36 Sectional Dam Raise model only.

Overall Hydraulic Conditions

With the top seal installed, observations were made for hydraulic behavior under various gate openings with and without seismic beams in place. Photographs of hydraulic conditions are included in Appendix B. A summary of observations for 35-, 38-, and 40-ft gate openings are presented in Appendix C.

Shifts in hydraulic control

Spillway flow is either in free flow or gate control. The hydraulic control point depends on the gate opening and reservoir water surface elevation. When flow contracts off of the upstream bridge girder, approach flow conditions are altered and the rating curve becomes slightly more efficient. Seismic beams also influence approach flow to the gate by increasing the efficiency of the rating curve.

At a 35-ft gate opening:

- With seismic beams
    - Pool EL 468-471 ft – hydraulic control at gate (flow below seismic beams)
    - Pool EL 471-475 ft – hydraulic control at gate with approach flow influenced by seismic beams (flow below bridge)
    - Pool EL 475-481 ft – hydraulic control at gate with approach flow influenced by bridge (flow on upstream section of bridge)
- Without seismic beams
    - Pool EL 468-475 ft – hydraulic control at gate (flow below bridge)
    - Pool EL 475-481 ft – hydraulic control at gate with approach flow influenced by bridge (flow on upstream section of bridge)

At a 38-ft gate opening:

- With seismic beams
    - Pool EL 472-475 ft – hydraulic control at gate with approach flow influenced by seismic beams (flow below bridge)
    - Pool EL 475-481 ft – hydraulic control at gate with approach flow influenced by seismic beams and bridge (flow on upstream section of bridge)
- Without seismic beams
    - Pool EL 472-475 ft – hydraulic control at gate (flow below bridge)
    - Pool EL 475-481 ft – hydraulic control at gate with approach flow influenced by bridge (flow on upstream section of bridge)

At a 40-ft gate opening:

- With seismic beams
    - Pool EL 473.5-475 ft – hydraulic control at gate with approach flow influenced by seismic beams (flow below bridge)

- Pool EL 475-481 ft – hydraulic control at gate with approach flow influenced by seismic beams and bridge (flow on upstream section of bridge)

- Without seismic beams
  - Pool EL 473.5-475 ft – hydraulic control at gate (flow below bridge)
  - Pool EL 475-481 ft – hydraulic control at gate with approach flow influenced by bridge (flow on upstream section of bridge)

Vortices

Vortices were observed for all of the tested gate openings. Without seismic beams, vortices were always observed in the transition zone, but were also observed at water levels outside of the transition zone. Vortices occurred for water elevations up to approximately EL 478 with a 35-ft gate opening, approximately EL 479 with a 38-ft gate opening, and approximately EL 479 with a 40-ft gate opening. The size of vortices increased as the water level dropped below these levels.

Seismic beams along with horizontal and diagonal bracing create a lattice-like structure which acts as a vortex suppressor (Figures 32-33). As soon as the water level rises above the seismic beams, the size and frequency of vortex formation significantly decreases. In general, vortices ceased to occur at pool elevations approximately 4 ft lower with the seismic beams than without the seismic beams.

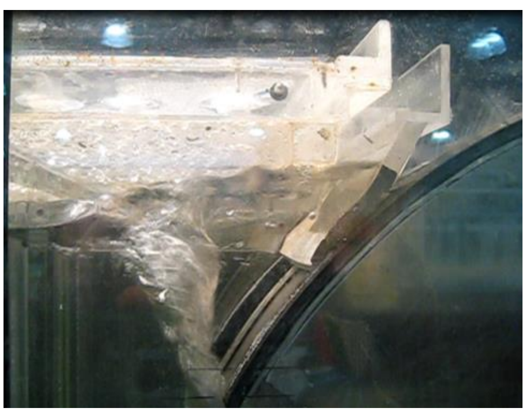

Figure 32. Significant vortices occur under lower pools without seismic beams (38-ft gate opening, EL 472.12).

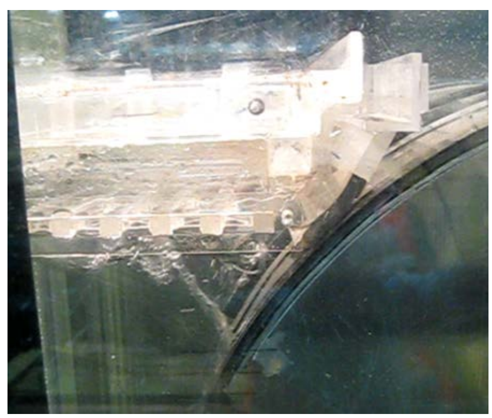

Figure 33. Vortex behavior significantly less for the same discharge with seismic beams.

In general, vortices reduce the discharge efficiency of the spillway. With the seismic beams suppressing vortex action, an increase in the discharge capacity of the spillway can be seen, particularly in the transition zone where flows are transitioning from gate control to free flow.

Vortices are typically more pronounced in the prototype than they are in a physical hydraulic model. The exception to this is when there is something in the model set-up or approach conditions that produces vortices only seen in the model. Approach conditions in this sectional model are even more uniform than they would be in the prototype; therefore, it is unlikely that model approach conditions could be inducing rotational flow. Vortex formation will likely be different for each gate due to adjacent gate interactions. The most pronounced vortices should occur at the end gates which is a condition not represented by this sectional model. It is expected that vortices in the prototype will be more pronounced than in the model.

Turbulence and aeration in the vicinity of the seismic beams

Although seismic beams have a beneficial influence on the efficiency of the spillway and the suppression of vortices, turbulence and aeration around the seismic beams must be considered. For the 35-ft gate opening, the water surface began to touch the seismic beams at a pool elevation of about 470 ft. For the 38- and 40-ft gate openings, all of the tested pool elevations and corresponding discharges were large enough that the seismic beams were impacted by the water surface for all conditions.

Without seismic beams, lower water surface elevations produce flow surging against the gate with significant wave action underneath of the bridge. As the water level rises, flow either fills in the full area underneath of the bridge (e.g. 35-ft gate opening, Figure 34) or separates off of the upstream bridge girder which produces turbulent flow that does not touch the underside of the bridge deck (e.g. 40-ft gate opening, Figure 35).

With seismic beams installed, lower water surface elevations produce flow surging against the gate with the water surface moving up and down through the beams. This can produce significant wave action across the seismic beams. As the water level rises, flow either contracts off the upstream bridge girder and fills in the full area underneath of the bridge deck (e.g. 35-ft gate opening, Figure 36) or flow skims across the top of the seismic beams, directly impacting the gate (e.g. 40-ft gate opening, Figure 37). When flow skims across the beams, a free surface exists underneath of the bridge. Flow may plunge between the beams causing turbulence and aeration in the vicinity of the beams.

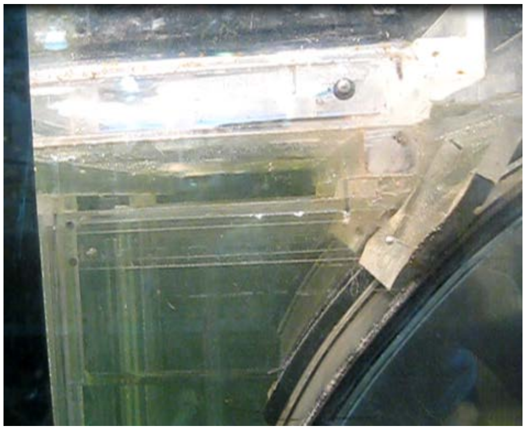

Figure 34. Water fills underside of the bridge deck with a 35-ft gate opening at EL 480.02 ft.

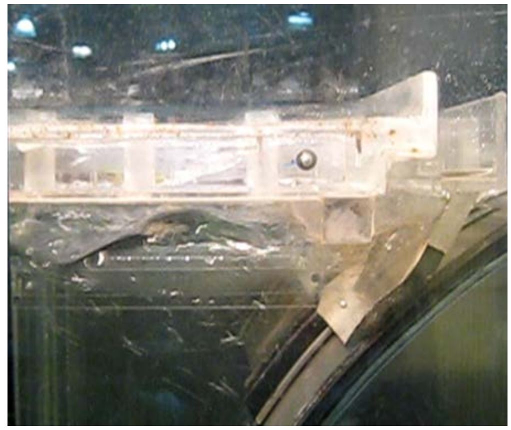

Figure 35. Water contracts off upstream bridge girder producing a free surface under the bridge deck with a 40-ft gate opening at EL 481.06 ft.

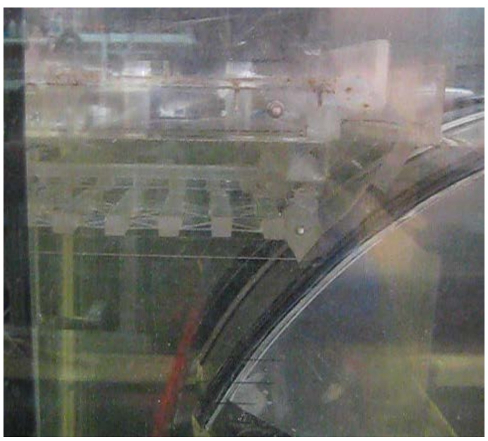

Figure 36. Water fills the underside of the bridge deck with a 35-ft gate opening at EL 480.17 ft.

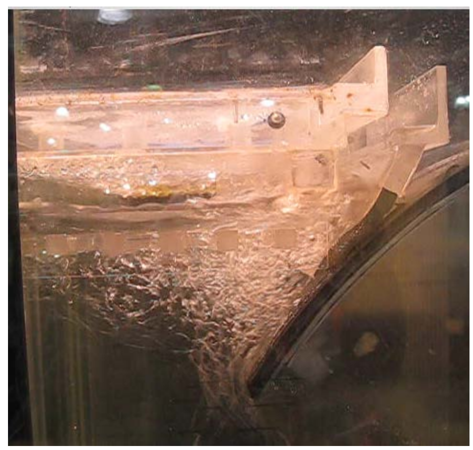

Figure 37. Water skims over seismic beams with a 40-ft gate opening at EL 481.16 ft.

Seismic beams induce significant amounts of air entrainment in the immediate vicinity of the beams. In some cases, the air bubbles are carried under the gate lip and down the spillway face. In other situations, the air bubbles enter a recirculation zone between the gate and bridge. Air entrainment will be greater in the prototype, since Weber number similitude is not achieved between model and prototype. Inertial forces are scaled in the model but surface tension is the same due to use of the same fluids (water and air).

Flow patterns observed in the model at large gate openings indicate that hydrodynamic loading will occur on the seismic beams in this highly turbulent zone. The ratio of inertial forces to viscous forces is not the same between model and prototype because the same fluid is used (water). Since viscosity is not scaled, turbulence will be greater in the prototype. Although hydraulic conditions near the seismic beams do not look favorable under certain conditions, it is not possible to determine from these model observations if damage may occur in the prototype. Since the physical model was a hydraulic model and not a structural model, it was not possible to measure vibrations or loadings on the beams that would be representative of the prototype. Engineering judgment and experience must be used to determine when unacceptable conditions may exist in the prototype.

Observations of water surface profiles in relation to trunnions

Visual observations were made during testing to determine if the trunnions experienced splashing or direct impact from spillway flow. At gate openings of 35 ft or less, there was no impact on the trunnions from spillway flow. At a 38-ft gate opening, splashing on the trunnion pier with run-up on the trunnions occurred under certain conditions. At a 40-ft gate opening, significant splashing on the trunnion pier with frequent run-up on the trunnions was common.

When vortices were present, they created a significant flow disturbance downstream of the gates. Vortices appeared to create additional wave action in the upstream section of the spillway, worsening the splashing and run-up onto the piers immediately upstream of the trunnion. Vortices were strongest without seismic beams installed; therefore, trunnion impact was more common for these cases.

At a 35-ft gate opening:

- With seismic beams
    - Pool EL 468-481 ft – trunnions not impacted
- Without seismic beams
    - Pool EL 468-481 ft – trunnions not impacted

At a 38-ft gate opening:

- With seismic beams
    - Pool EL 472-477 ft – trunnions not impacted

    - Pool EL 477-481 ft –splashing on trunnion piers with occasional run-up on trunnions
- Without seismic beams
    - Pool EL 472-477 ft – significant splashing on trunnion pier with consistent run-up on trunnions
    - Pool EL 477-481 ft – splashing on trunnion pier with occasional run-up on trunnions

At a 40-ft gate opening:

- With seismic beams
    - Pool EL 473.5-481 ft – significant splashing on trunnion pier with consistent run-up on trunnions
- Without seismic beams
    - Pool EL 473.5-477 ft – significant splashing on trunnion pier with consistent run-up that almost overtops trunnions
    - Pool EL 477-481 ft – significant splashing on trunnion pier with consistent run-up on trunnions

Static Pressure Measurements on Spillway Crest

Due to the increased reservoir water surface elevations expected with the dam raise, static pressures were measured along the spillway crest to ensure that acceptable design conditions were met to prevent cavitation. Pressures on the spillway surface were investigated using 8 pressure taps located at the centerline of the center gate.

The original design head for Folsom Dam was 50 ft with a 57.4 ft maximum head at pool EL 475.4 ft (1.15 times the design head). Under the Folsom Dam Raise Project, the new maximum head would be 63 ft at pool EL 481 ft (1.26 times the design head). Reclamation's Design of Small Dams (1960) suggests that 75% of the maximum head (or 133% of the design head) is an acceptable design limit, since small negative pressures are expected at 75% ratio during uncontrolled flow. Additional design guidance is provided by the USACE's Engineering Monograph 1110-2-1603. Paragraph 3-9 states that "A spillway crest should be designed so that the maximum expected head will result in average pressures on the crest no lower than -15 feet of water at sea level and 40 degree Fahrenheit temperature" during uncontrolled flow (USACE, 1990).

Uncontrolled Flow Pressure Measurements

Pressures were measured for ungated flow conditions to compare current model data against data from the previous 1:80-scale model and against data provided in available literature. Figure 38 shows pressure head as a percentage of design head versus the horizontal distance from the crest as a percentage of design head. The dark blue line shows pressures provided in Khatsuria, 2005 for uncontrolled flow conditions where the head is 100% of the design head. The red line shows pressures provided in Khatsuria, 2005 where the head is 133% the design head. As can be seen by the red line, negative pressures start to develop when the head is 133% of the design head. Pressures recorded in the 1953 (USACE, 1953) and current 2013 study for uncontrolled flow conditions have also been plotted for heads slightly over and under the design head (i.e. 0.95 H_d and 1.1 H_d). In general, model pressure measurements appear consistent with the literature, although the 1953 study indicates a pressure higher than expected at the upstream extent when the head is 110% the design head, and the 2013 studies indicate pressures higher than expected at the downstream extent (i.e. Pressure Tap 8).

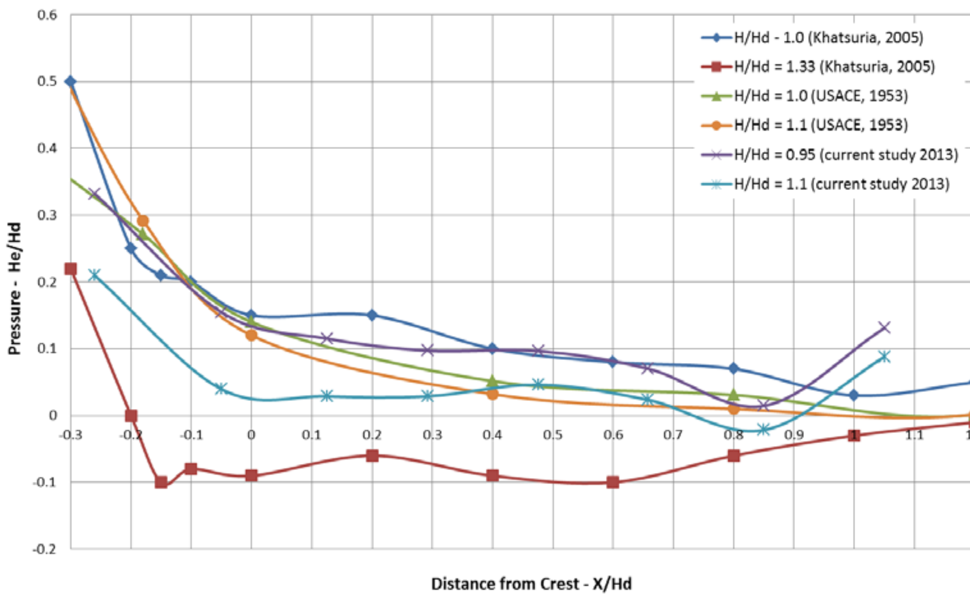

Figure 38. Comparison of pressure along spillway surface under uncontrolled flow conditions between 1953 and 2013 studies and literature (Khatsuria, 2005 and USACE, 1953).

The maximum pool level investigated in the current study under uncontrolled flow conditions was EL 474 ft, which is 1.1 times the design head. Based on available literature (Khatsuria, 2005), negative pressures would not be expected under these flow conditions and this was generally confirmed during modeling (Figure 39). A comparison of pressure results under uncontrolled flow conditions from Khatsuria, 2005, USACE, 1953, and the current 2013 model are provided in Figure 40.

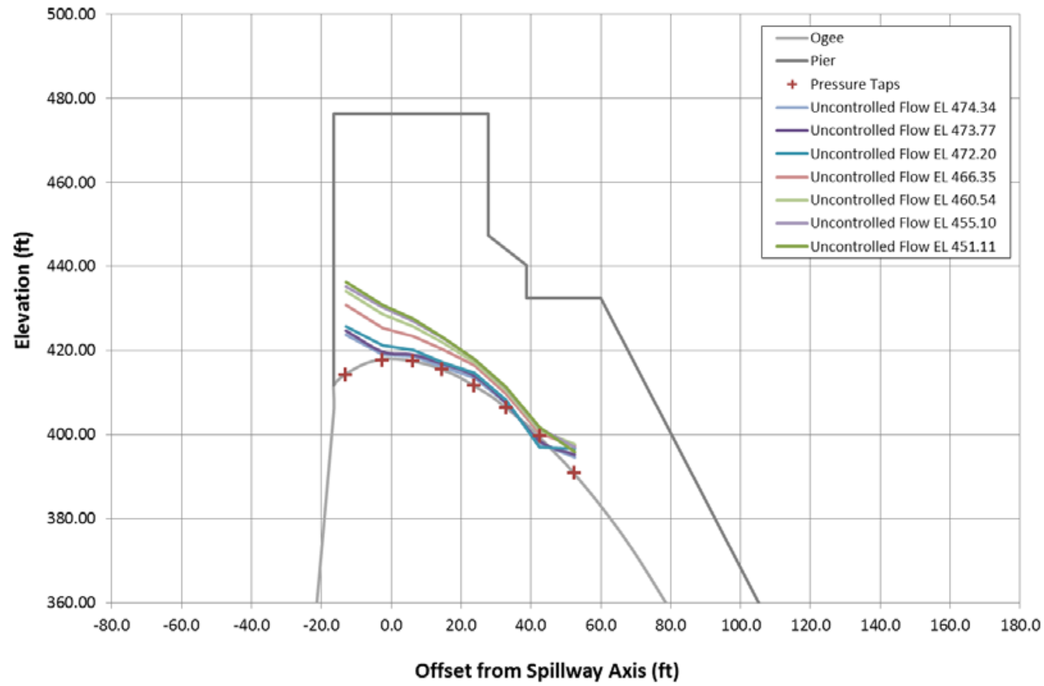

Figure 39. Pressures on ogee crest for uncontrolled flow condition in 2013 Folsom Dam sectional model. Zero offset indicates the spillway crest.

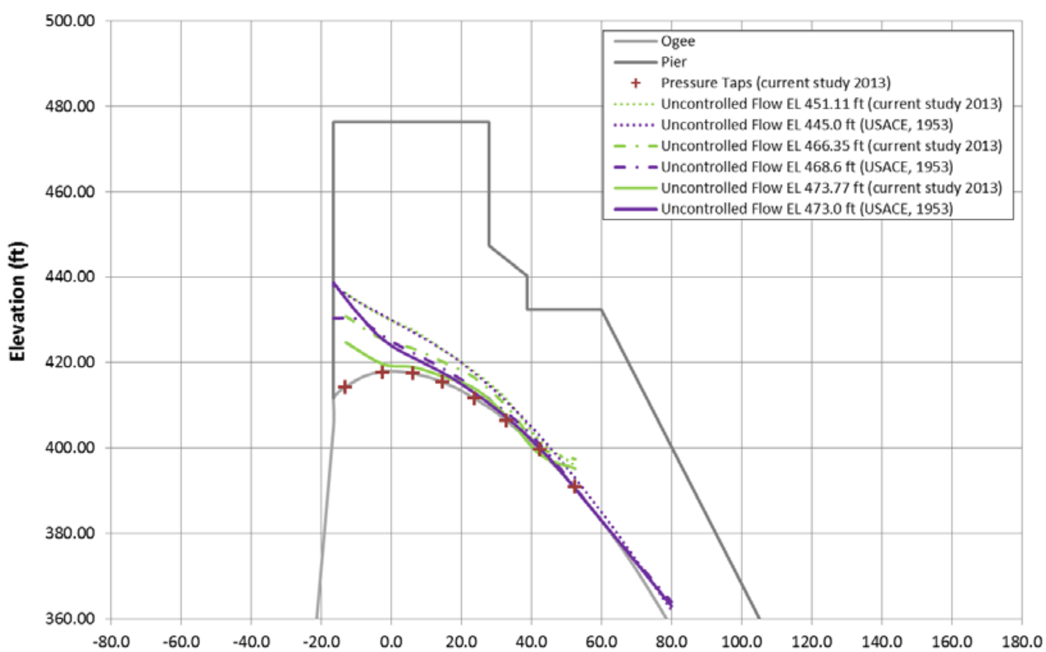

Figure 40. Comparison of pressures on ungated ogee crest spillways between 1953 and 2013 studies. Zero offset indicates the spillway crest.

Gated Flow Pressure Measurements

Pressures were measured in the model for a range of gated flow conditions. Plots of static pressure under gated discharge for the 35-, 38-, and 40-ft gate openings are provided in Figures 41-46 and tabular data is provided in Appendix D. Pressures measured in the Folsom model were typically small positive pressures. Negative pressures occurred only at Pressure Taps 6 and 7. The maximum negative pressure measured at Pressure Taps 6 and 7 were -1.35 ft and -5.04 ft, respectively. It is noted that pressures quickly increased at Pressure Tap 8. The pressure tap was checked to ensure that it was flush with the model surface. During testing, significant amounts of air were observed during the flushing of Pressure Tap 8 due to aeration in the flow. It is possible that air bubbles in the piezometer tubes were providing higher than actual readings, however the fact that the trends observed at Pressure Tap 8 were consistent for all flow cases suggests that the piezometer was giving accurate results. Regardless, the results show that pressures 20 ft downstream of the crest and beyond are close to zero.

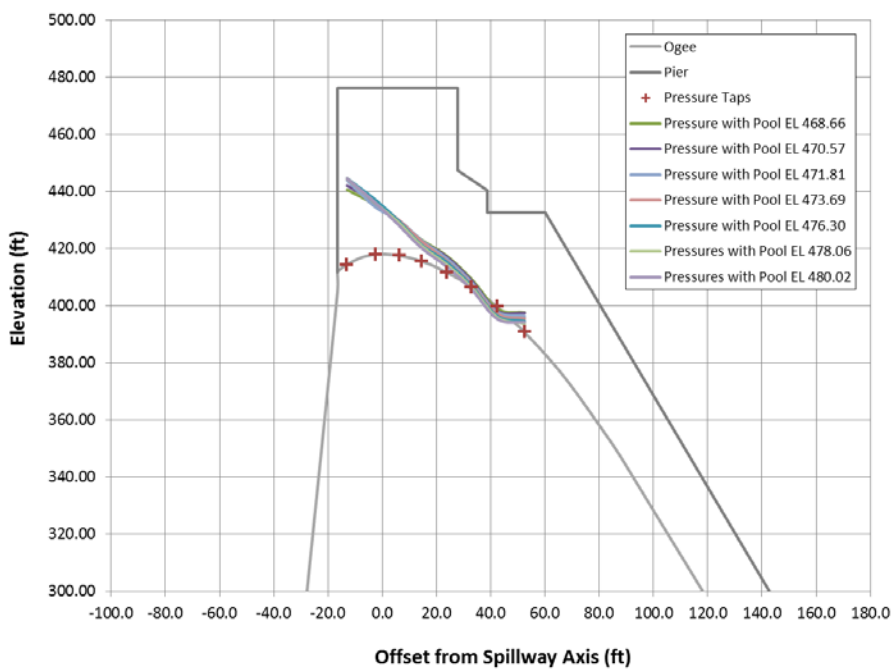

Figure 41. Pressures on ogee crest for various pool levels with 35-ft gate opening and no seismic beams.

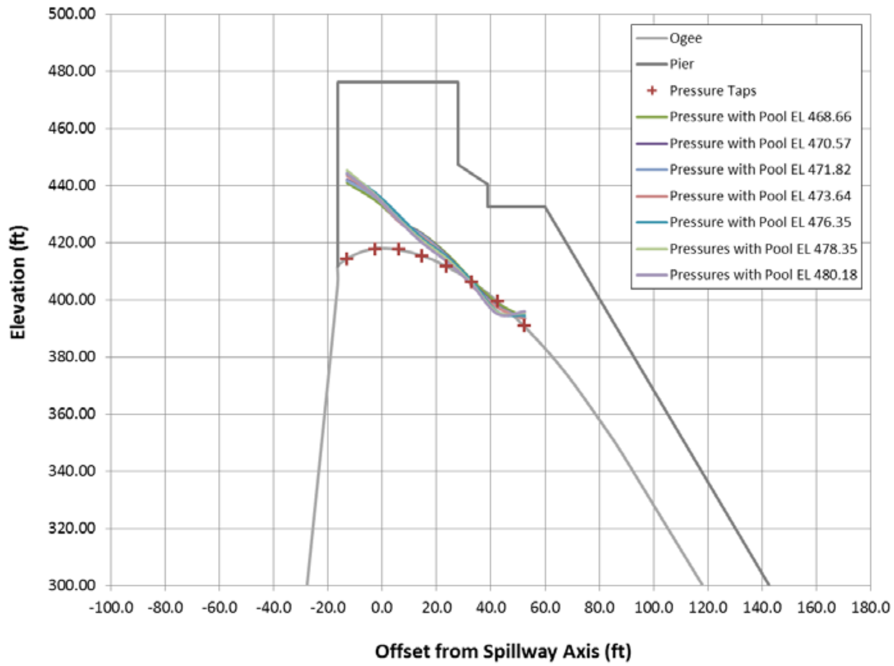

Figure 42. Pressures on ogee crest for various pool levels with 35-ft gate opening and seismic beams installed.

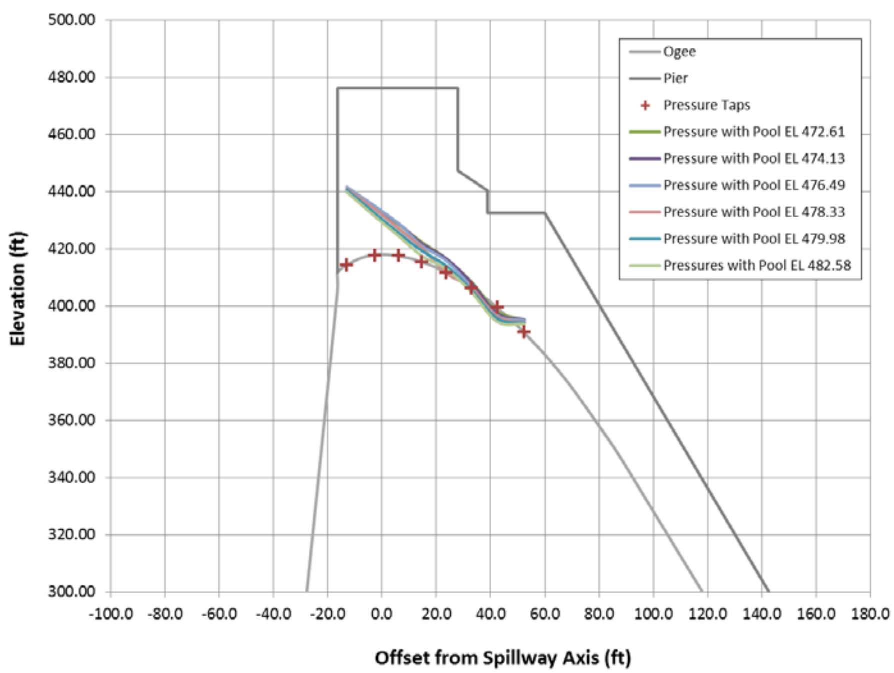

Figure 43. Pressures on ogee crest for various pool levels with 38-ft gate opening and no seismic beams.

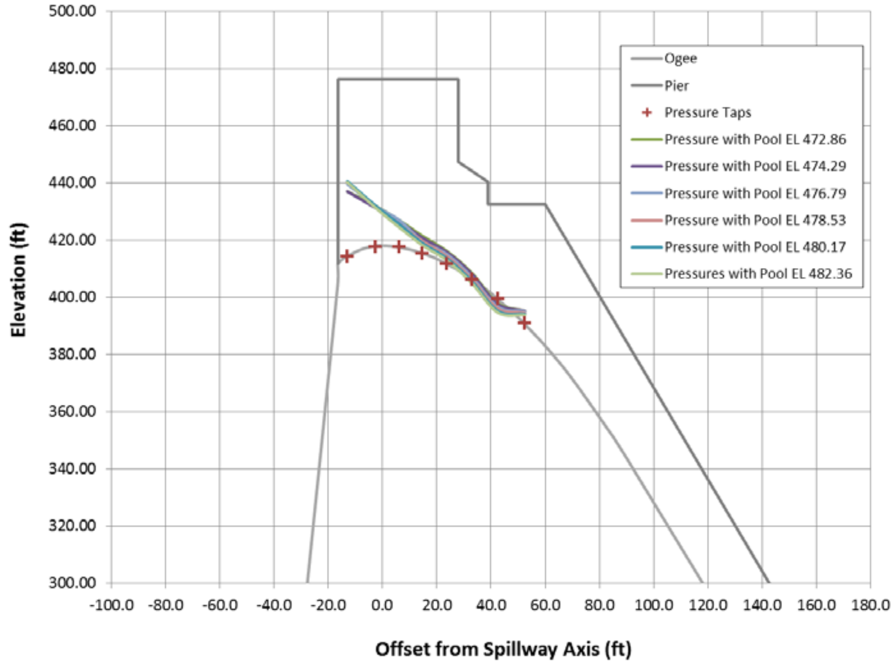

Figure 44. Pressures on ogee crest for various pool levels with 38-ft gate opening and seismic beams installed.

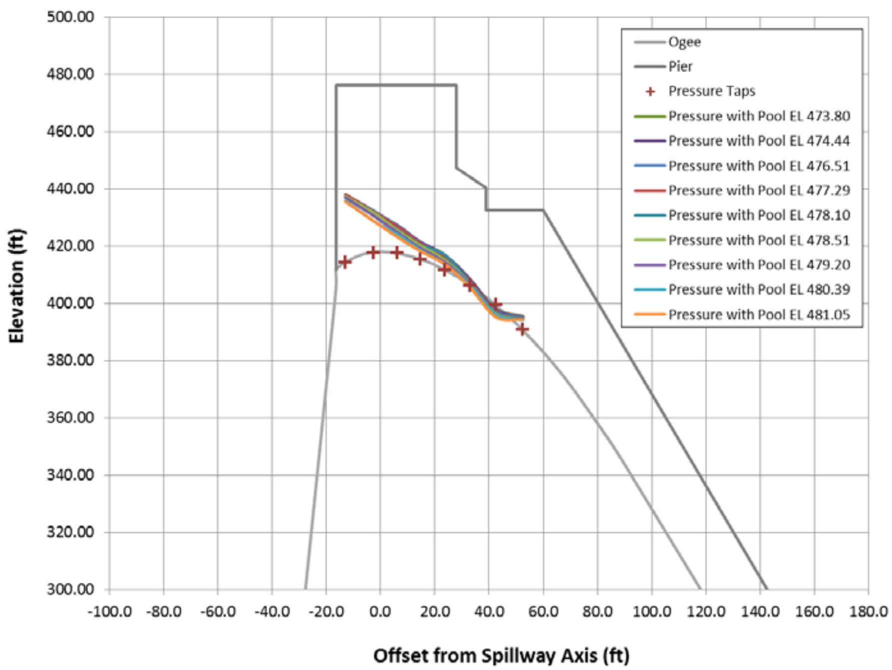

Figure 45. Pressures on ogee crest for various pool levels with 40-ft gate opening and no seismic beams.

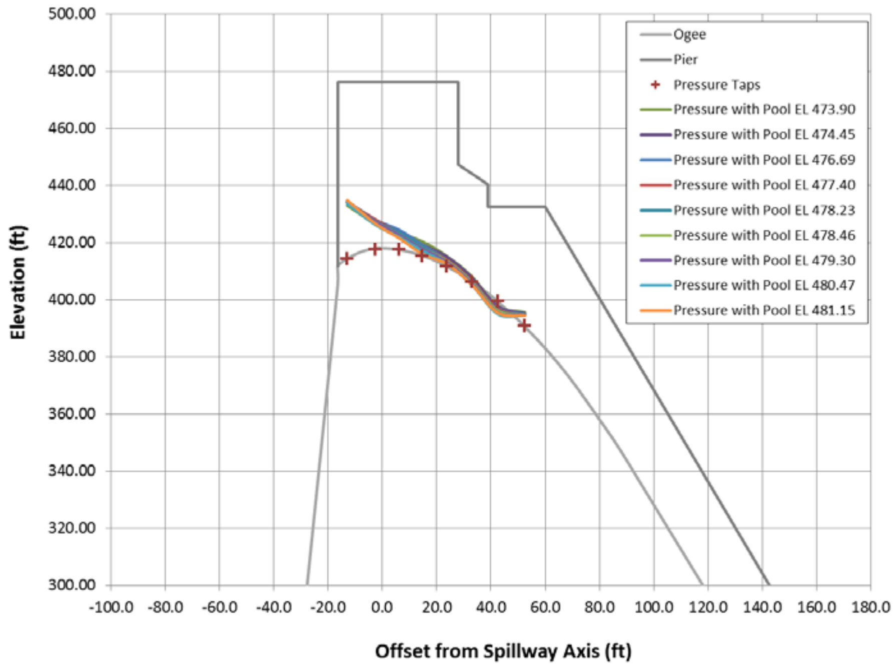

Figure 46. Pressures on ogee crest for various pool levels with 40-ft gate opening and seismic beams installed.

Measured pressure data from this study was compared to data presented in the USACE's Engineering Monograph 1110-2-1603 (USACE, 1990). Pool levels investigated under gated discharges in the model reached EL 481 ft, which is 1.26 times the design head. Figure 47, extracted from USACE (1990), shows pressures on the crest for various ratios of gate opening to design head, for heads of 1.3 times the design head. As can be seen on these plots, small negative pressures occur in many cases. The key difference between these plots and the current 2013 Folsom Dam model is that the Folsom Dam gates were tested at significantly larger gate opening ratios (i.e. 0.8 Go/Hd), whereas the largest gate opening ratio provided in the USACE literature is 0.5 Go/Hd.

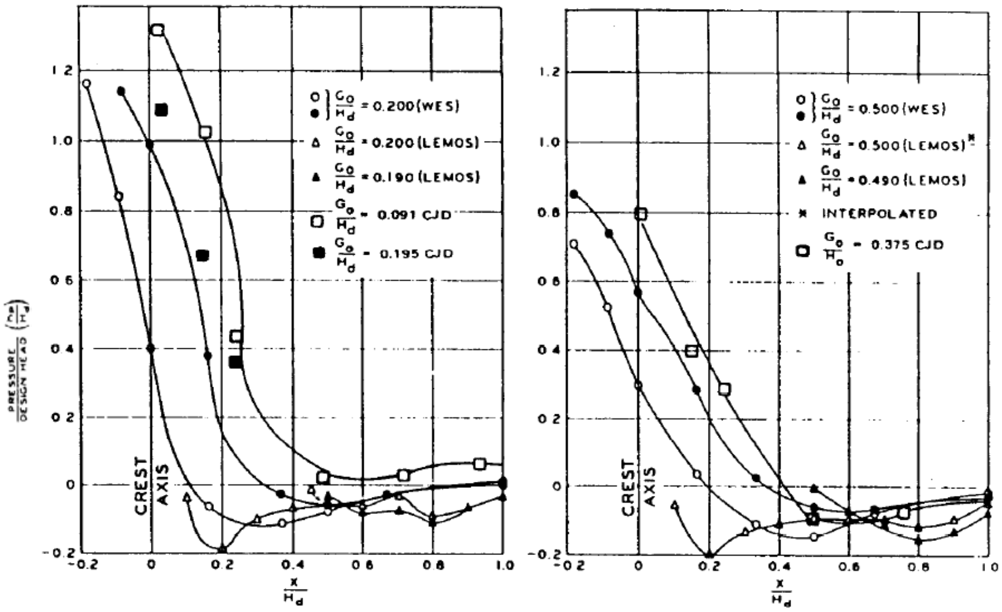

Figure 47. USACE (1990) pressure on spillway surface under gated discharges.

Pressure Measurements on Bridge

Pressures on the spillway bridge were investigated to estimate loadings on the bridge and to identify if uplift pressures exist.

For a 40-ft gate opening, contraction occurred around the upstream bridge girder, both with and without the seismic beams, such that the water surface elevation never pressurized the underside of the bridge deck and no pressure was recorded. However, flow was in contact with both the upstream and downstream sides of the bridge girders with a 40-ft gate opening under the highest discharges, so static pressures were recorded in these cases.

With 35- and 38-ft gate openings, water contacted the upstream and downstream bridge girders under higher discharges, typically with a water surface elevation of EL 478 ft or higher. Unlike the 40-ft gate opening, however, both the 35- and 38-ft gate openings experienced uplift pressures on the underside of the bridge deck for the larger discharges. Typically, pressures recorded on the upstream and downstream faces of the bridge appeared to be consistent with a hydrostatic pressure profile. Pressures on the underside of the bridge were typically less than 3 ft . The downstream pressure tap under the bridge deck often showed recordable pressure before the upstream side due to contraction off of the upstream bridge girder.

Plots of bridge pressures are provided in Figures 48-53 and are tabulated in Appendix E.

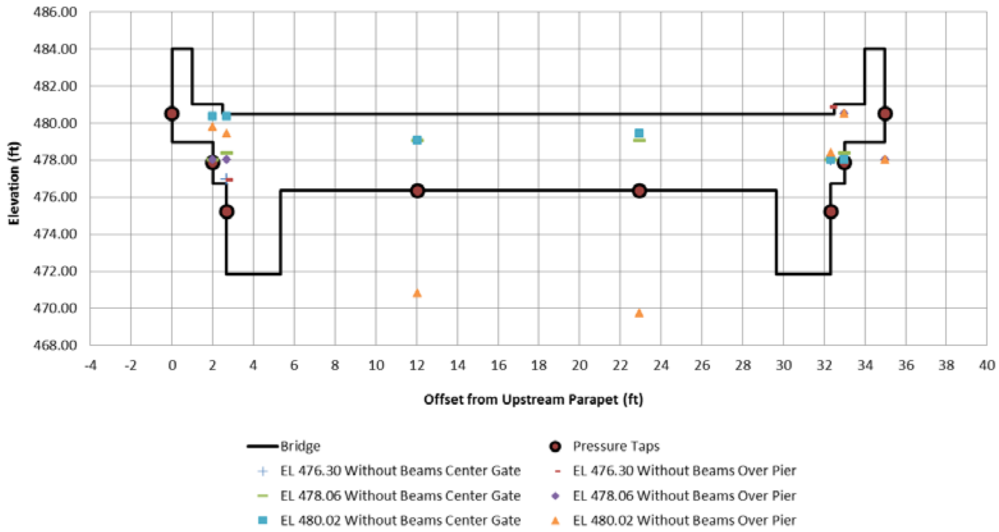

Figure 48. Pressures on spillway bridge at 35-ft gate opening and no seismic beams.

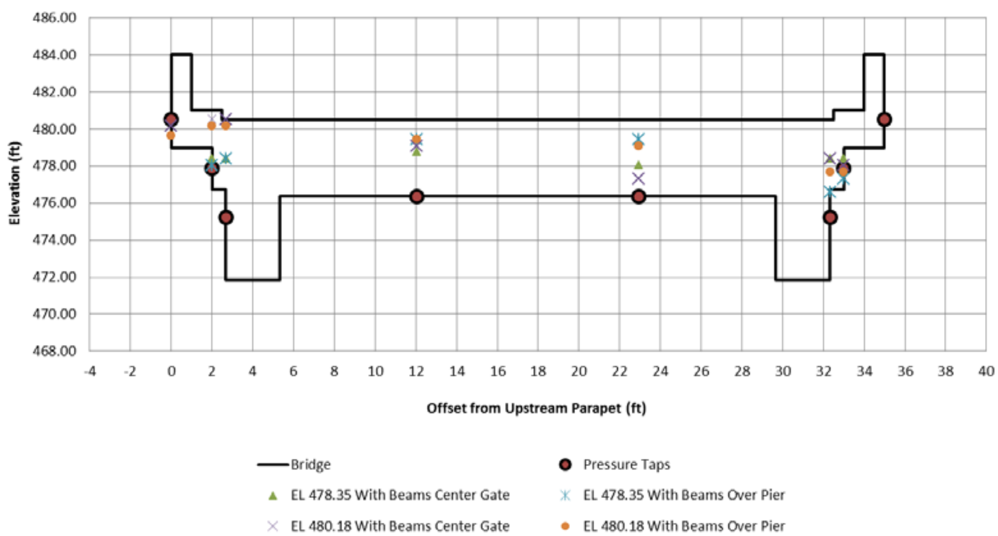

Figure 49. Pressures on spillway bridge at 35-ft gate opening and seismic beams installed.

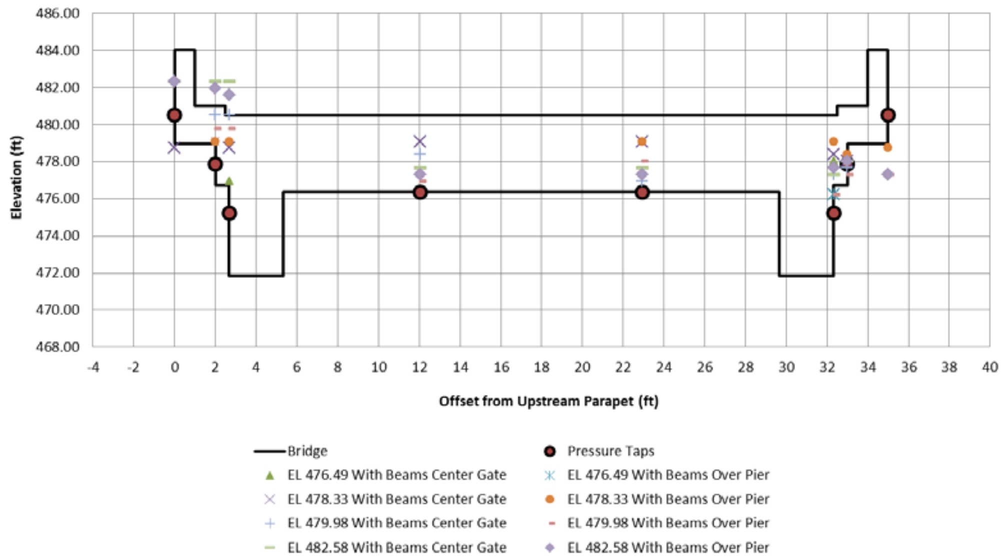

Figure 50. Pressures on spillway bridge at 38-ft gate opening and no seismic beams.

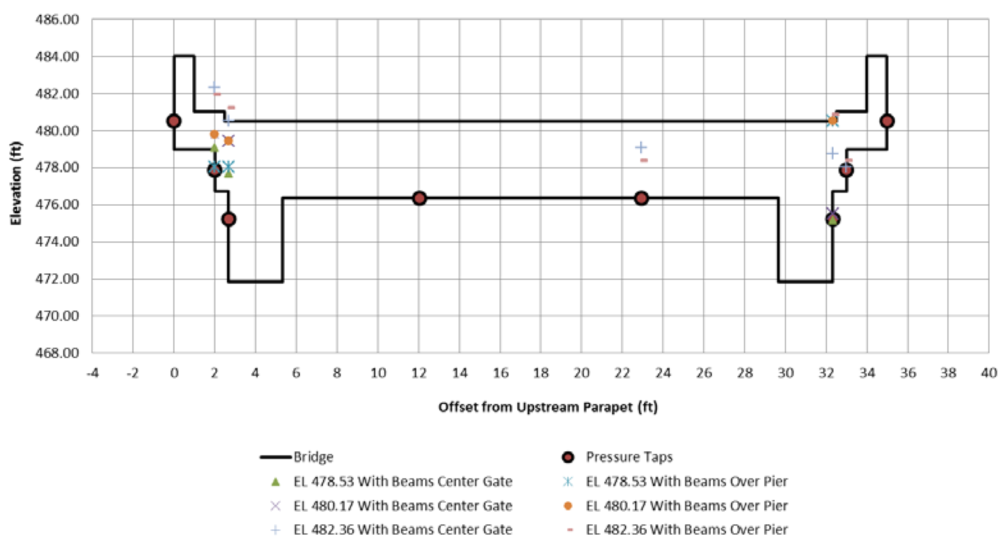

Figure 51. Pressures on spillway bridge at 38-ft gate opening and seismic beams installed.

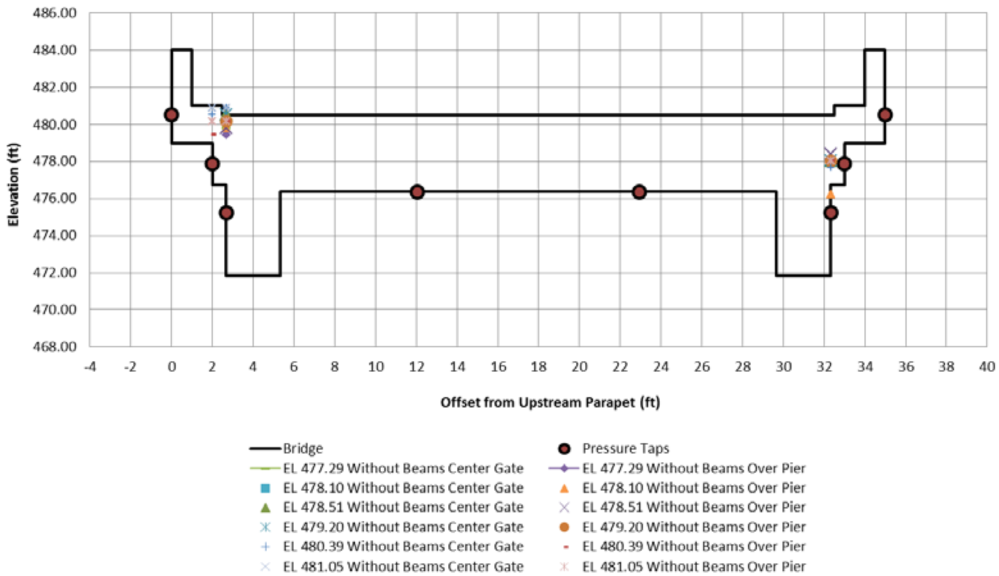

Figure 52. Pressures on spillway bridge at 40-ft gate opening and no seismic beams.

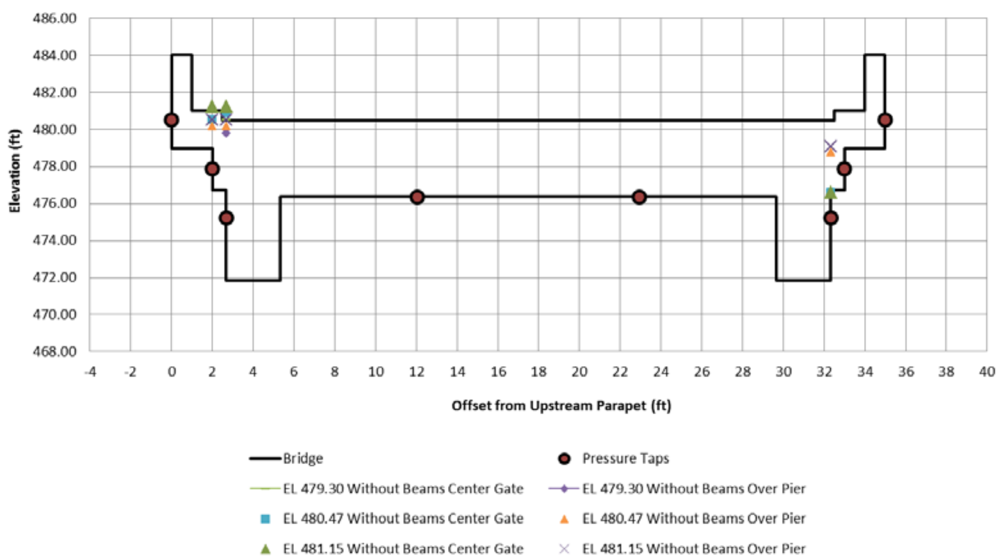

Figure 53. Pressures on spillway bridge at 40-ft gate opening and seismic beams installed.

Water Surface Profiles in Relation to Sidewalls

Estimates of water surface profiles along the right emergency spillway sidewall at gate 6 were collected in the model to determine if sidewall overtopping may occur at higher pool elevations expected with the dam raise. Water surface profiles were estimated across the extent of the acrylic side panel in the model from 51 ft downstream of the spillway axis to 88.5 ft downstream.

Air entrainment and bulked flow in model under-represents aeration in the prototype. Bulking of the flow due to air entrainment is often estimated and added to model flow depths to design chute sidewall heights. Aeration requires some development length downstream of the gate before air bulking occurs. In this model, the region where water surface profiles were estimated was not in the fully developed aerated zone. For this reason, air bulking was not added to model data.

As can be seen in Figures 54-59, water surface profiles are closer to the top of the sidewalls with larger gate openings than smaller gate openings. Water levels at the most downstream recorded locations are closest to overtopping the sidewalls. With a 35-ft gate opening, the smallest vertical distance to the top of the sidewall is 15.80 ft both with and without seismic beams. With a 38-ft gate opening, the smallest vertical distance is 11.30 ft both with and without seismic beams. With a 40-ft gate opening, the smallest vertical distance is 7.55 ft without beams and 6.05 ft with beams.

Water surface profiles are typically higher under higher reservoir water surface elevations, but the increase in water level does not cause sidewall overtopping in any observed flow condition. Higher reservoir water surface elevations with the Folsom Dam Raise Project will increase water surface profiles, but the difference between water surface profiles under current flood operations and with a pool increase of 3.5 ft is minimal.

Observations in relation to the right sidewall are detailed in Appendix F.

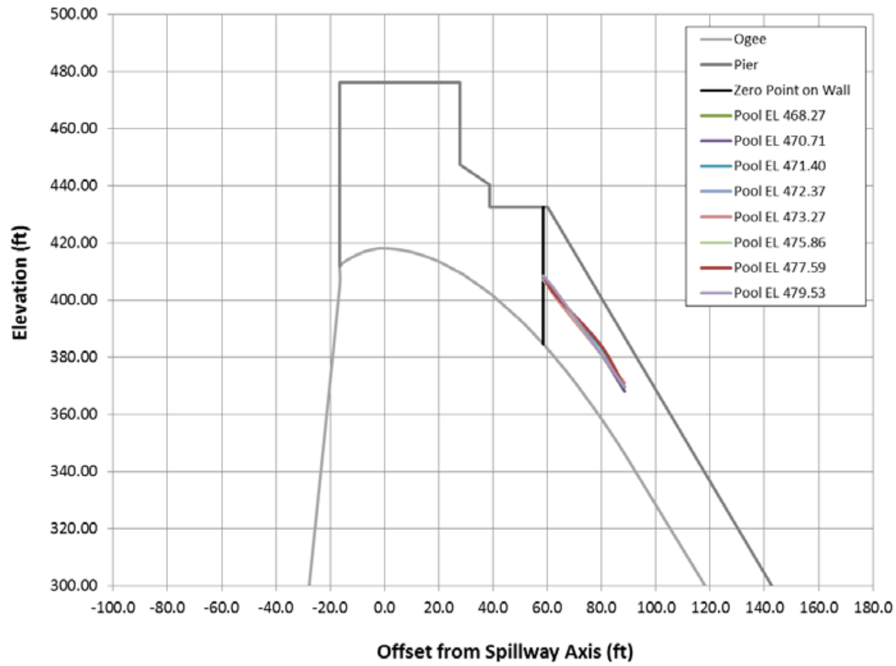

Figure 54. Water surface profile on right sidewall at 35-ft gate opening with top seal and no seismic beams.

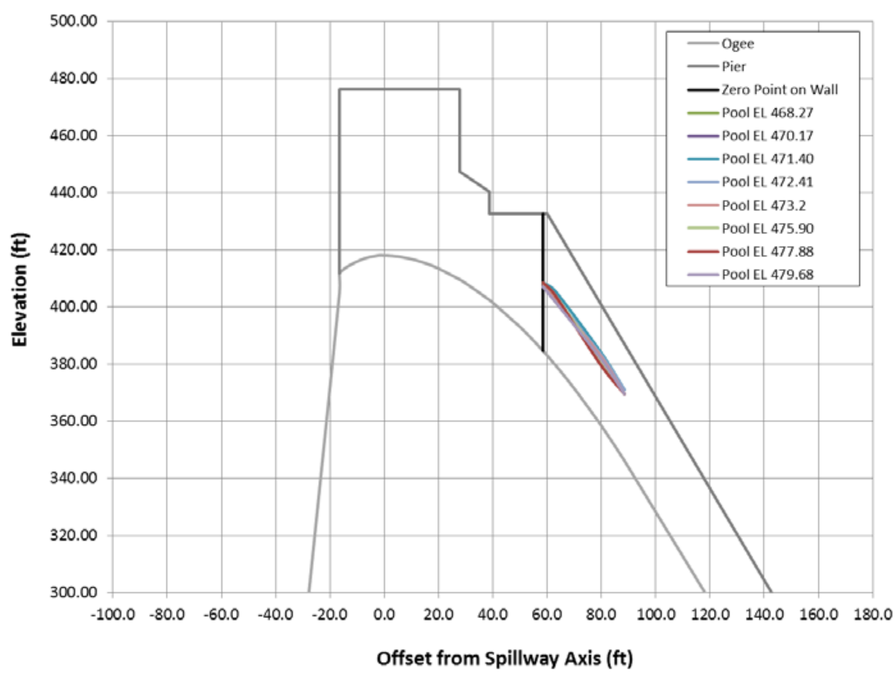

Figure 55. Water surface profile on right sidewall at 35-ft gate opening with top seal and seismic beams.

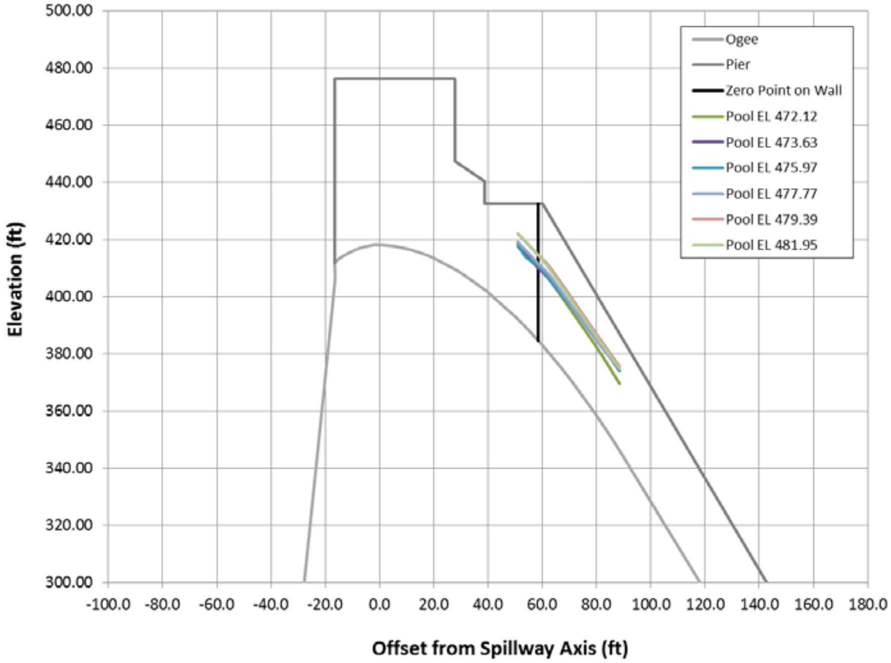

Figure 56. Water surface profile on right sidewall at 38-ft gate opening with top seal and no seismic beams.

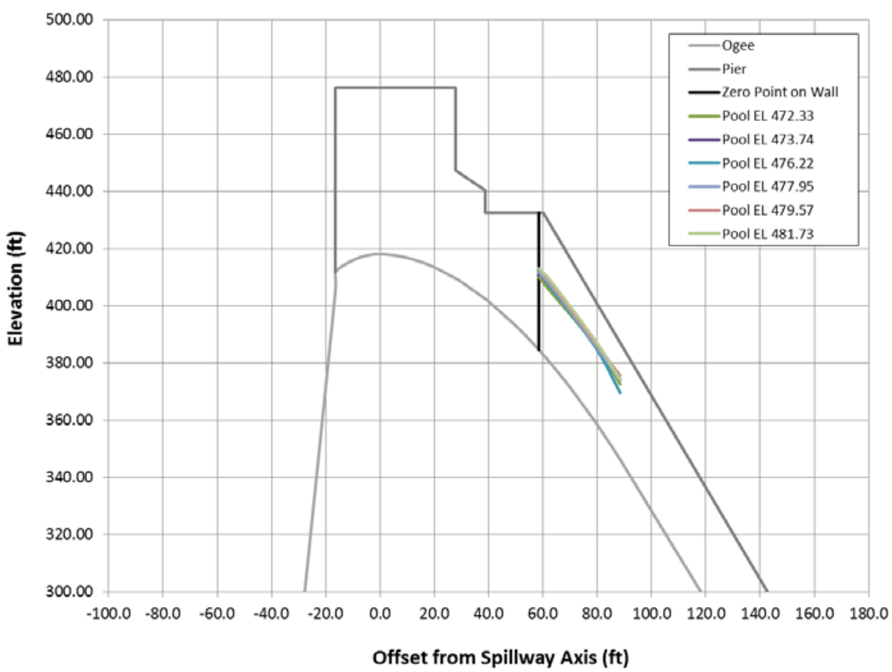

Figure 57. Water surface profile on right sidewall at 38-ft gate opening with top seal and seismic beams.

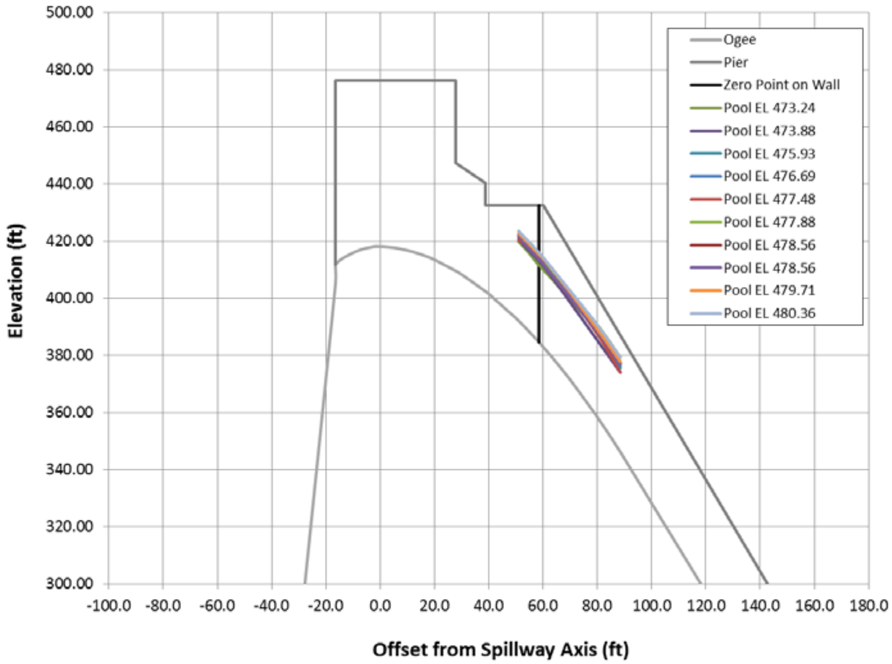

Figure 58. Water surface profile on right sidewall at 40-ft gate opening with top seal and no seismic beams.

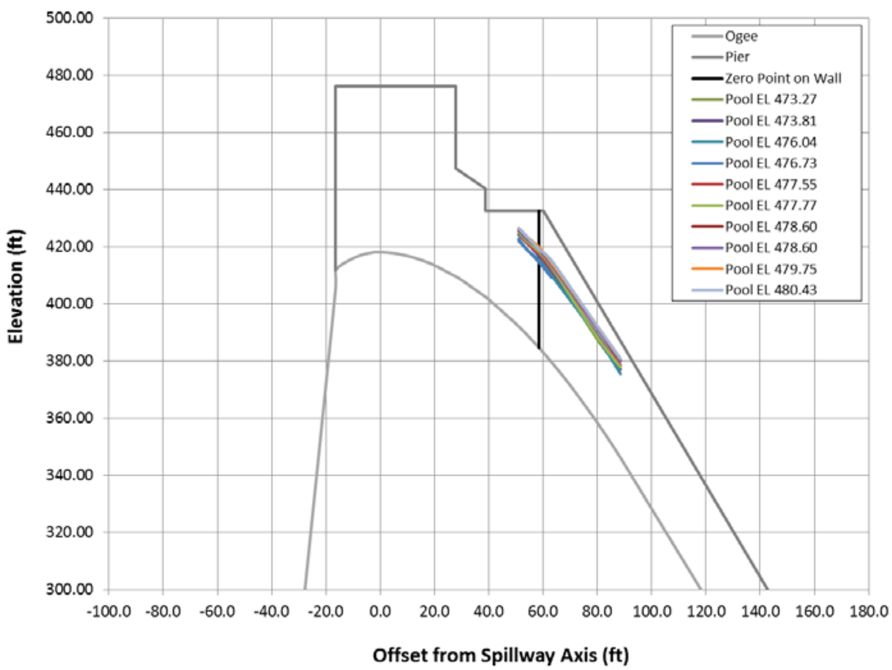

Figure 59. Water surface profile on right sidewall at 40-ft gate opening with top seal and seismic beams.

Conclusions

Conclusions based on this 1:36-scale sectional model study are as follows:

- Discharge Rating Curves
    - Discharge ratings with and without top seals installed were not measurably different.
- Shifts in Hydraulic Control
    - When the reservoir water surface contracts off the upstream bridge girder, approach flow conditions to the gate are modified.
    - Seismic beams also influence approach flow conditions. During different operational conditions, flow may skim across the beams, plunge through the beams, or contract off the upstream side of the beams and direct flow toward the gate opening. Seismic beams can reduce the large recirculation zone above the gate opening or minimize or eliminate vortices upstream of the gate by acting as a vortex suppressor.
    - When the bridge or seismic beams influence approach flow, the stage-discharge relationship becomes more efficient.
- Vortices
    - Vortices were observed at lower pool levels for all assessed gate openings. Without seismic beams, vortices occurred with water levels up to around EL 478 with 35- and 38-ft gate openings and around EL 379 with a 40-ft gate opening.
    - When the pool elevation is above the seismic beams, they appear to minimize or eliminate vortices by breaking up circulation and essentially acting as a vortex suppressor. When the water level rises above the seismic beams, the size and frequency of vortex formation significantly decreases. In general, vortices ceased to occur with pool elevations approximately 4 ft lower with seismic beams than without seismic beams.
- Turbulence and Aeration in Vicinity of Seismic Beams
    - With seismic beams installed, there is minimal turbulence and air entrainment for gate openings less than 38 ft. Therefore, flow

conditions appear to be acceptable except when in the transition zone.

- Gate openings of 38 to 39 ft produce turbulent, aerated flow conditions in the immediate vicinity of the beams and should not be part of standard operations. However, they may be acceptable for short periods of time for extreme hydrologic conditions.

- Seismic beams create intense turbulence and induce significant entrainment of air into the flow in the immediate vicinity of the beams at gate openings of 40 ft, which may not be acceptable even for extreme hydrologic conditions.

- At a 42-ft gate opening, intense turbulence in the vicinity of the beams produces significant air-water interaction at the gate. This flow condition is “transitional” which is considered to be an adverse operating condition that should be avoided. Flow patterns observed in the model at large gate openings indicate that hydrodynamic loading will occur on the seismic beams in this highly turbulent zone.

- Although hydraulic conditions near the seismic beams do not look favorable under certain conditions, it is not possible to determine from model observations whether damage would be incurred in the prototype.

- Observations of Water Surface Profiles in Relation to Trunnions

    - At gate openings of 35 ft or less, there was no impact on the trunnions from spillway flow.

    - At a 38-ft gate opening, splashing on the trunnion pier with run-up on the trunnions occurred from water surface elevation 477-481 ft with seismic beams and 472-481 ft without seismic beams.

    - At a 40-ft gate opening, significant splashing on the trunnion pier with frequent run-up on the trunnions was common from water surface elevation 473.5-481.

    - Modeling observations indicate that splashing and run-up may be able to be prevented with a relatively minor structural modification, but this was not modeled.

- Static Pressure Measurements on Spillway Crest

    - At 35-, 38-, and 40-ft gate openings, static pressures on the ogee crest were typically small positive pressures. Negative pressures occurred only at Pressure Taps 6 and 7. The maximum negative pressure measured at Pressure Taps 6 and 7 were -1.35 ft and -5.04 ft, respectively.

- Pressure Measurements on Bridge
    - For 35- and 38-ft gate openings, uplift pressures on the underside of the bridge deck were recorded when reservoir pool elevations exceeded 478.0 ft. Typically, pressures on the upstream and downstream faces of the bridge were consistent with a hydrostatic pressure profile. Uplift pressures on the underside of the bridge were generally around 3 ft or less.
    - For a 40-ft gate opening, contraction off the upstream bridge girder prevented the water surface from pressurizing the underside of the bridge deck.
- Water Surface Profiles in Relation to Sidewalls
    - It does not appear that higher reservoir water levels expected with the dam raise will cause spillway sidewall overtopping. Higher reservoir water surface elevations with the Folsom Dam Raise Project will increase water surface profiles, but the difference between water surface profiles under current flood operations and with a pool increase of 3.5 ft is minimal.
    - Water surface profiles are closer to the top of the sidewalls with larger gate openings than smaller gate openings. Water levels at the most downstream recorded locations are closest to overtopping the sidewalls. With a 35-ft gate opening, the smallest vertical distance to the top of the sidewall is 15.80 ft both with and without seismic beams. With a 38-ft gate opening, the smallest vertical distance is 11.30 ft both with and without seismic beams. With a 40-ft gate opening, the smallest vertical distance is 7.55 ft without beams and 6.05 ft with beams.

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APPENDIX A

Photographs with No Top Seal at 30-, 35-, 38-, 40-, and 42-ft Vertical Gate Openings

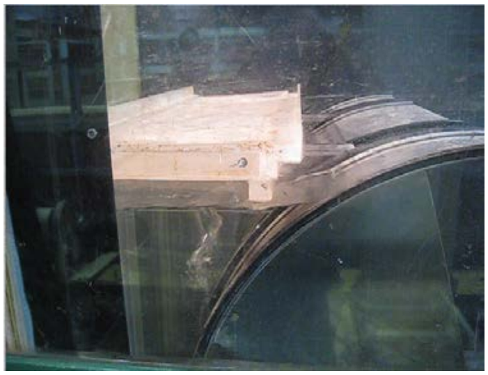

Figure 60. Flow conditions with 30-ft gate opening at EL 472.56 ft. No top seal, no seismic beams.

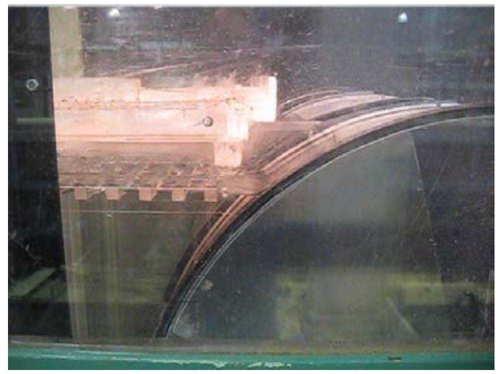

Figure 61. Flow conditions with 30-ft gate opening at EL 471.95 ft. No top seal, seismic beams installed.

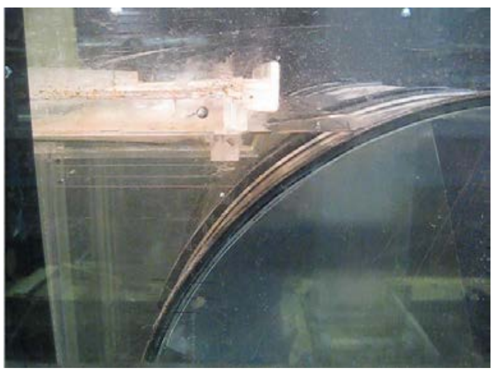

Figure 62. Flow conditions with 30-ft gate opening at EL 477.30 ft. No top seal, no seismic beams.

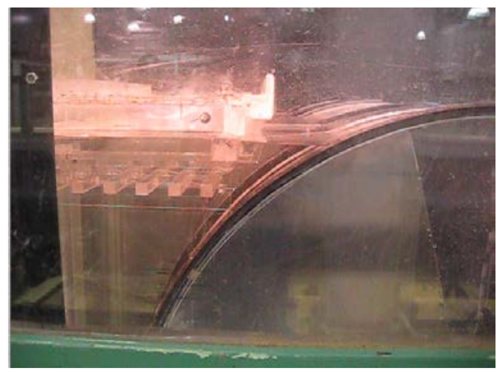

Figure 63. Flow conditions with 30-ft gate opening at EL 476.80 ft. No top seal, seismic beams installed.

Figure 64. Flow conditions with 30-ft gate opening at EL 481.43 ft. No top seal, no seismic beams.

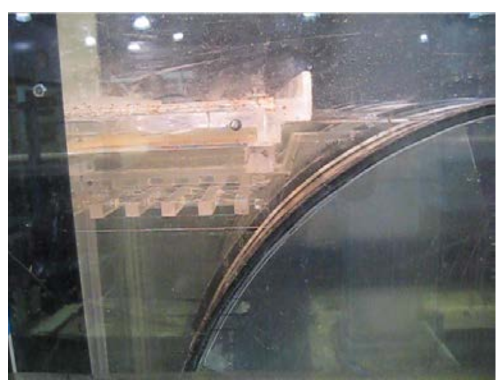

Figure 65. Flow conditions with 30-ft gate opening at EL 480.89 ft. No top seal, seismic beams installed.

Figure 66. Flow conditions with 35-ft gate opening at EL 474.16 ft. No top seal, no seismic beams.

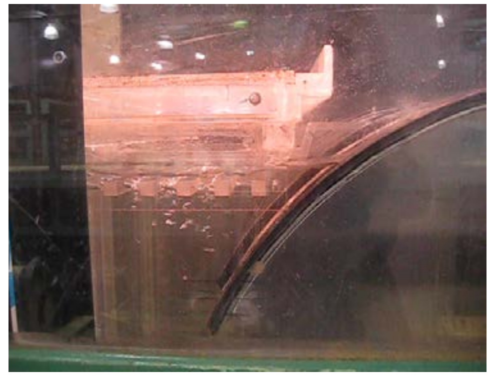

Figure 67. Flow conditions with 35-ft gate opening at EL 473.59 ft. No top seal, seismic beams installed.

Figure 68. Flow conditions with 35-ft gate opening at EL 477.50 ft. No top seal, no seismic beams.

Figure 69. Flow conditions with 35-ft gate opening at EL 476.96 ft. No top seal, seismic beams installed.

Figure 70. Flow conditions with 35-ft gate opening at EL 481.07 ft. No top seal, no seismic beams.

Figure 71. Flow conditions with 35-ft gate opening at EL 480.93 ft. No top seal, seismic beams installed.

Figure 72. Flow conditions with 38-ft gate opening at EL 477.04 ft. No top seal, no seismic beams.

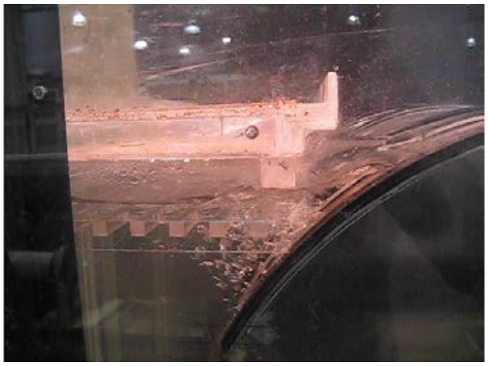

Figure 73. Flow conditions with 38-ft gate opening at EL 476.93 ft. No top seal, seismic beams installed.

Figure 74. Flow conditions with 38-ft gate opening at EL 480.42 ft. No top seal, no seismic beams.

Figure 75. Flow conditions with 38-ft gate opening at EL 480.79 ft. No top seal, seismic beams installed.

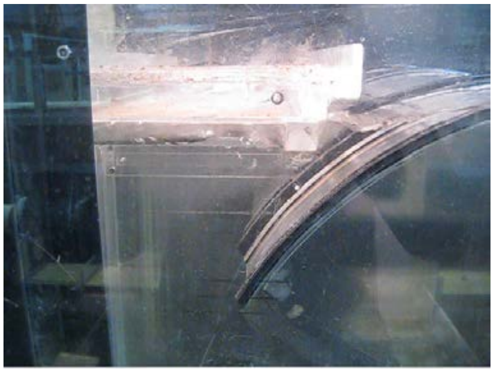

Figure 76. Flow conditions with 38-ft gate opening at EL 482.14 ft. No top seal, no seismic beams.

Figure 77. Flow conditions with 38-ft gate opening at EL 482.21 ft. No top seal, seismic beams installed.

Figure 78. Flow conditions with 40-ft gate opening at EL 477.62 ft. No top seal, no seismic beams.

Figure 79. Flow conditions with 40-ft gate opening at EL 477.86 ft. No top seal, seismic beams installed.

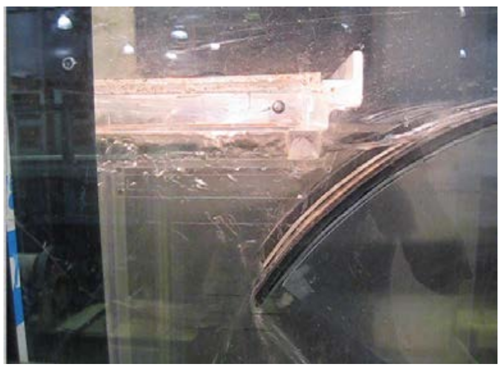

Figure 80. Flow conditions with 40-ft gate opening at EL 479.02 ft. No top seal, no seismic beams.

Figure 81. Flow conditions with 40-ft gate opening at EL 478.99 ft. No top seal, seismic beams installed.

Figure 82. Flow conditions with 40-ft gate opening at EL 480.61 ft. No top seal, no seismic beams.

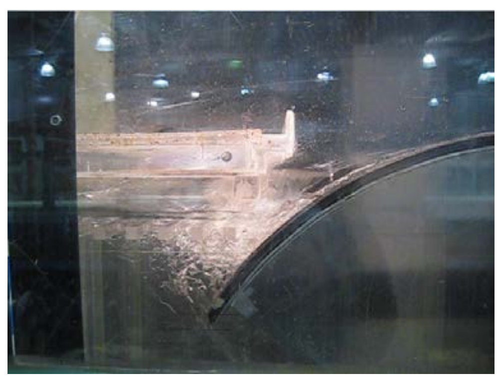

Figure 83. Flow conditions with 40-ft gate opening at EL 481.54 ft. No top seal, seismic beams installed.

Figure 84. Flow conditions with 42-ft gate opening at EL 478.03 ft. No top seal, no seismic beams.

Figure 85. Flow conditions with 42-ft gate opening at EL 477.97 ft. No top seal, seismic beams installed.

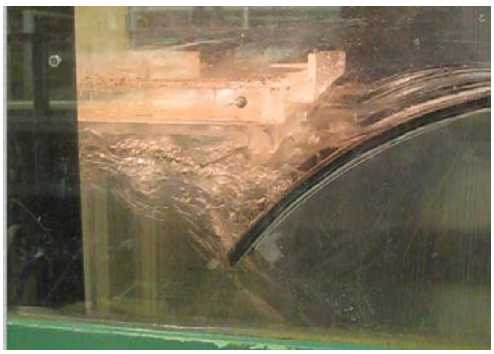

Figure 86. Flow conditions with 42-ft gate opening at EL 479.86 ft. No top seal, no seismic beams.

Figure 87. Flow conditions with 42-ft gate opening at EL 479.87 ft. No top seal, seismic beams installed.

Figure 88. Flow conditions with 42-ft gate opening at EL 480.93 ft. No top seal, no seismic beams.

Figure 89. Flow conditions with 42-ft gate opening at EL 481.45 ft. No top seal, seismic beams installed.

APPENDIX B

Photographs with Top Seal at 35-, 38-, and 40-ft Vertical Gate Openings

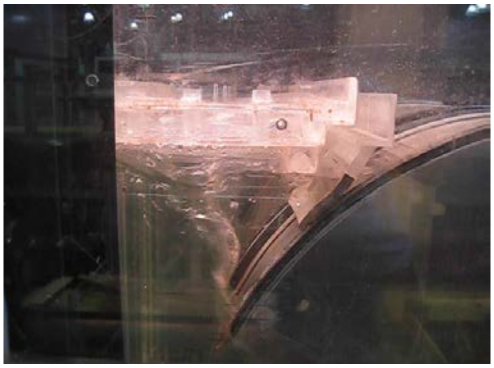

Figure 90. Flow conditions with 35-ft gate opening at EL 473.69 ft. With top seal, no seismic beams.

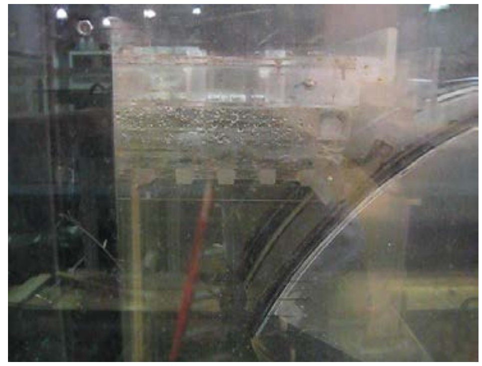

Figure 91. Flow conditions with 35-ft gate opening at EL 473.64 ft. With top seal, seismic beams installed.

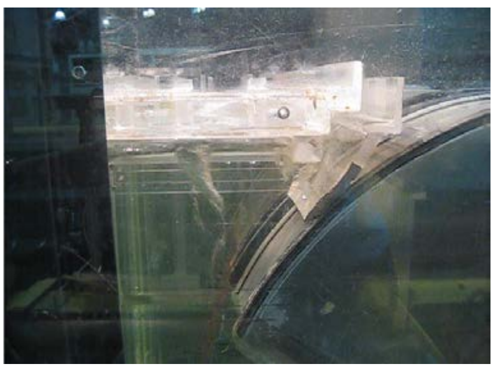

Figure 92. Flow conditions with 35-ft gate opening at EL 476.30 ft. With top seal, no seismic beams.

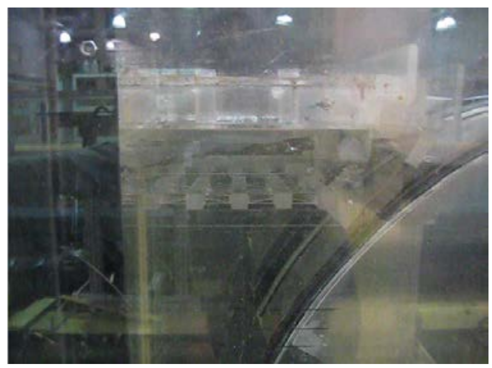

Figure 93. Flow conditions with 35-ft gate opening at EL 476.35 ft. With top seal, seismic beams installed.

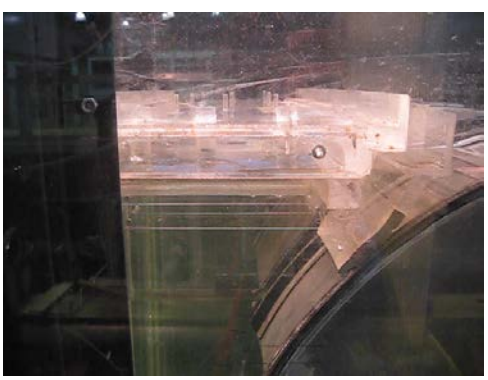

Figure 94. Flow conditions with 35-ft gate opening at EL 480.02 ft. With top seal, no seismic beams.

Figure 95. Flow conditions with 35-ft gate opening at EL 480.17 ft. With top seal, seismic beams installed.

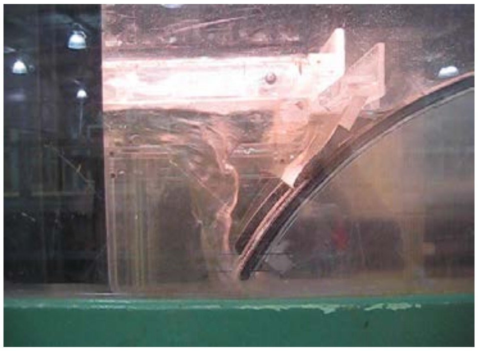

Figure 96. Flow conditions with 38-ft gate opening at EL 476.49 ft. With top seal, no seismic beams.

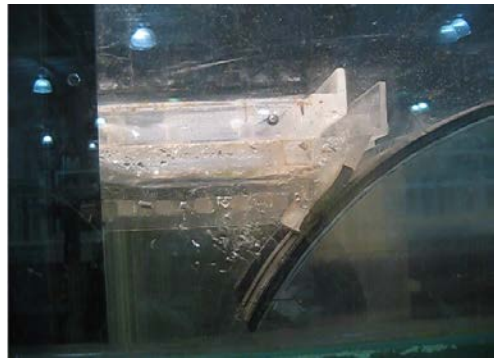

Figure 97. Flow conditions with 38-ft gate opening at EL 476.79 ft. With top seal, seismic beams installed.

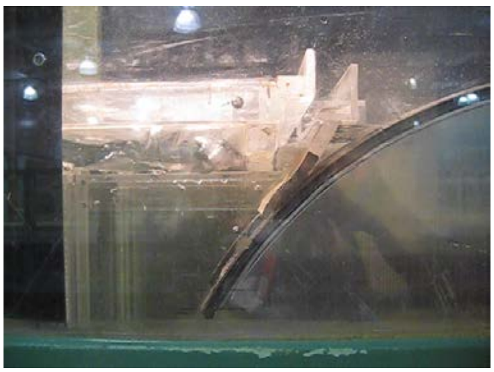

Figure 98. Flow conditions with 38-ft gate opening at EL 478.33 ft. With top seal, no seismic beams.

Figure 99. Flow conditions with 38-ft gate opening at EL 478.53 ft. With top seal, seismic beams installed.

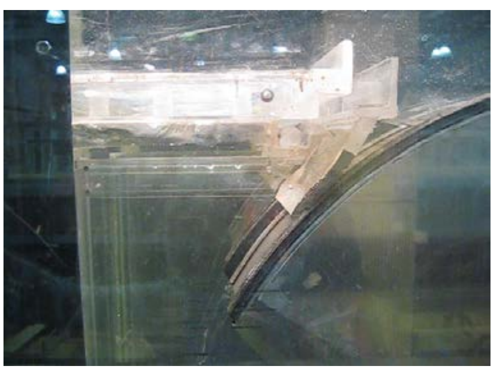

Figure 100. Flow conditions with 38-ft gate opening at EL 479.98 ft. With top seal, no seismic beams.

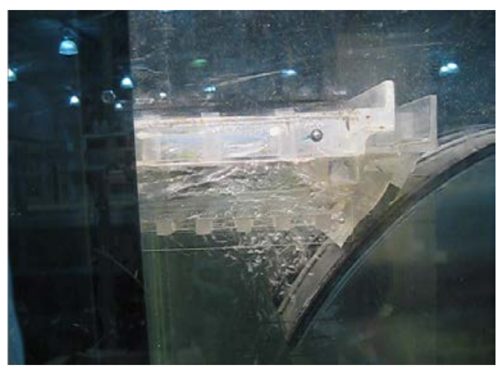

Figure 101. Flow conditions with 38-ft gate opening at EL 480.17 ft. With top seal, seismic beams installed.

Figure 102. Flow conditions with 40-ft gate opening at EL 478.10 ft. With top seal, no seismic beams.

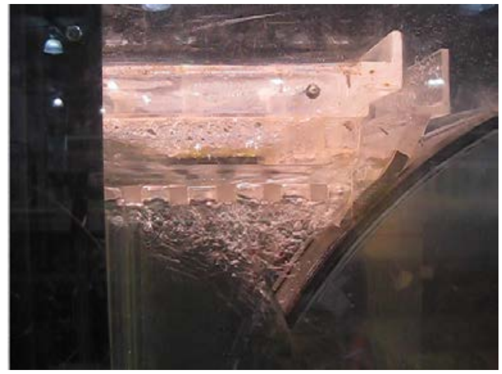

Figure 103. Flow conditions with 40-ft gate opening at EL 478.23 ft. With top seal, seismic beams installed.

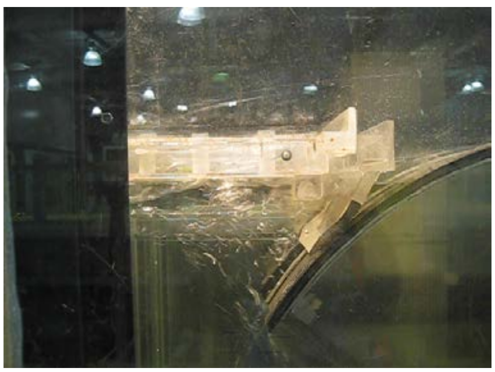

Figure 104. Flow conditions with 40-ft gate opening at EL 479.10 ft. With top seal, no seismic beams.

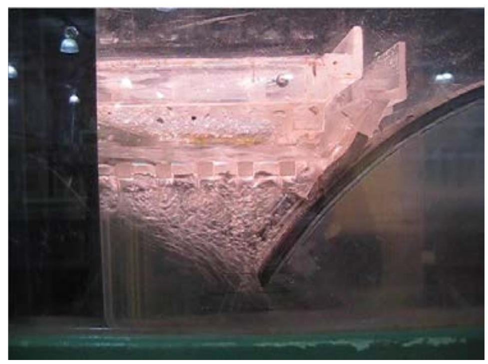

Figure 105. Flow conditions with 40-ft gate opening at EL 479.30 ft. With top seal, seismic beams installed.

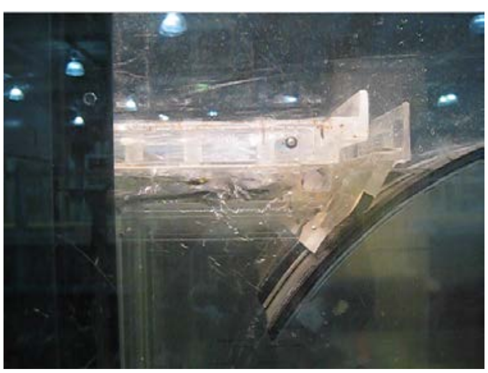

Figure 106. Flow conditions with 40-ft gate opening at EL 481.06 ft. With top seal, no seismic beams..

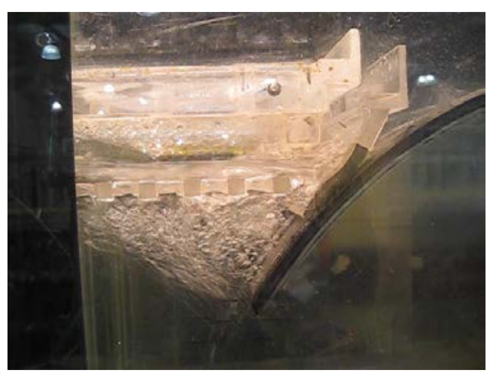

Figure 107. Flow conditions with 40-ft gate opening at EL 481.16 ft. With top seal, seismic beams installed.

APPENDIX C

Summary of Observations for 35-, 38-, and 40-ft Vertical Gate Openings

Table 9. Model observations with 35-ft gate opening with top seal and no seismic beams.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	
35 ft with Top Seal, No Seismic Beams	468.66	254,543	In transition zone. Water level below bridge. Large, regular vortices. Significant wave action at gate causing significant turbulence. Minor splashing on trunnion pier. Hydraulic control at gate. Trunnions not impacted. Training walls not overtopped.
	470.58	259,745	In transition zone. Water level below bridge. Large, regular vortices. Significant wave action at gate causing significant turbulence. Minor splashing on trunnion pier. Hydraulic control at gate. Trunnions not impacted. Training walls not overtopped.
	471.81	263,792	Just above transition zone. Water beneath upstream bridge girder and lapping against top seal. Wave action significant. Large, regular vortices. Hydraulic control at gate. Some minor splashing on trunnion pier. Trunnions not impacted. Training walls not overtopped.
	472.79	266,875	Water below upstream bridge girder with waves touching downstream girder intermittently. Wave action less than previous cases. Mid-size vortices. Hydraulic control at gate. Some minor splashing on trunnion pier. Trunnions not impacted. Training wall not overtopped.
	473.69	269,187	Waves occasionally touching upstream bridge girder and frequently touching downstream girder. Wave action is lessening. Mid-size vortices. Hydraulic control at gate. Some minor splashing on trunnion pier. Trunnions not impacted. Training wall not overtopped.
	476.30	279,978	Water contracts off upstream bridge girder. Water not touching underside of bridge deck. Air pocket underneath bridge deck. Some wave action. Minimal turbulence. Occasional, weak vortices. Hydraulic control at gate with approach flow influenced by bridge. No splashing on trunnion piers. Trunnions not impacted. Training wall not overtopped.
	478.06	290,190	Water contracts off upstream bridge girder. Water fluctuating under bridge deck. Air pocket exists at times. Some wave action. No vortices. Minimal turbulence. Hydraulic control at gate with approach flow influenced by bridge. No splashing on trunnion piers. Trunnions not impacted. Training wall not overtopped.
	480.02	299,632	Water submerging upstream and downstream bridge girders. Water level at underside of bridge deck. No air pocket. No vortices. No turbulence. Hydraulic control at gate with approach flow influenced by bridge. No splashing on trunnion piers. Trunnions not impacted. Training wall not overtopped.

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 10. Model observations with 35-ft gate opening with top seal and seismic beams.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	
35 ft with Top Seal and Seismic Beams	468.66	254,350	In transition zone. Water level below seismic beams. Large, regular vortices. Significant wave action at gate. Hydraulic control at gate. Trunnions not impacted. Training walls not overtopped.
	470.58	259,938	In transition zone. Water level just below seismic beams, but surging through beams. Large, regular vortices. Significant waves and turbulence around beams and on gate. Hydraulic control at gate. Trunnions not impacted. Training wall not overtopped.
	471.82	267,260	Just above transition zone. Water level at seismic beams with some turbulence at beams. Waves are lessening and vortices getting smaller and less frequent. Occasional, weak vortices exist. Hydraulic control at gate with approach flow influenced by seismic beams. Some minor splashing on trunnion pier. Training wall not overtopped.
	472.84	272,463	Flow above seismic beams but not touching bridge. Small air bubbles occasionally form near seismic beams. Wave action is significant. Hydraulic control at gate with approach flow influenced byseismic beams. Trunnions not impacted. Training wall not overtopped.
	473.64	275,160	Flow skims across seismic beams with wave action between beams. Some air bubbles forming. Minimal turbulence. No vortices. Hydraulic control at gate with approach flow influenced by seismic beams. Trunnions not impacted. Training wall not overtopped.
	476.35	283,061	Water contracts off upstream bridge girder. Water not touching underside of deck. Hydraulic control at gate with approach flow influenced by bridgeand seismic beams. Minimal turbulence. Some air bubbles beneath downstream bridge girder. No vortices. Trunnions not impacted. Training wall not overtopped.
	478.35	292,502	Water partially at underside of bridge deck. Air pocket exists under bridge deck. Minimal turbulence. No air bubbles or vortices. Hydraulic control at gate with approach flow influenced by bridge. Trunnions not impacted. Training wall not overtopped.
	480.17	301,944	Water at underside of bridge deck on downstream side. Small air pocket on upstream side under bridge deck due to bridge contraction. Hydraulic control at gate with approach flow influenced by bridge. No aeration. Trunnions not impacted. Training wall not overtopped.

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 11. Model observations with 38-ft gate opening with top seal and no seismic beams.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	
38 ft with Top Seal, No Seismic Beams	472.61	228,726	In transition zone. Large, consistent vortices. Wave action significant. Hydraulic control at gate. Significant splashing onto trunnion piers with consistent run-up on trunnions. Training wall not overtopped.
	474.13	292,362	In transition zone. Water surface generally below upstream and downstream bridge girders but wave action causes occasional impact. Large, consistent vortices. Hydraulic control at gate. Hydraulic control at gate. Significant splashing onto trunnion piers with consistent run-up on trunnions. Training wall not overtopped.
	476.49	303,077	Just above transition zone. Flow contracts off upstream bridge girder and touches downstream girder. Wave action has lessened, but is still significant. Large, consistent vortices. Hydraulic control at gate with approach flow influenced by bridge. Splashing onto trunnion piers with consistent run-up on trunnions. Training wall not overtopped.
	478.33	316,279	Flow contracts off upstream bridge girder. Waves intermittently touching underside of bridge deck. Air pocket under bridge. No vortices. Hydraulic control at gate with approach flow influenced by bridge. Water splashing occasionally on trunnion piers with run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	479.98	327,759	Flow contracts off upstream grider girder. Wave action lessening, but waves touch underside of bridge deck intermittently. Air pocket under bridge deck minimal. No vortices or air bubbles. Minimal turbulence. Hydraulic control at gate with approach flow influenced by bridge. Water splashing occasionally on trunnion piers with occasional run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	482.58	342,683	Water submerges upstream and downstream bridge girders. No air pocket under bridge deck. Waves are suppressed. No air bubbles or vortices. No turbulence. Hydraulic control at gate with approach flow influenced by bridge. Splashing around trunnion pier, but trunnions not impacted. Training wall not overtopped but getting close at downstream end.

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 12. Model observations with 38-ft gate opening with top seal and seismic beams.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	
38 ft with Top Seal and Seismic Beams	472.86	298,485	In transition zone. Surging in upstream water surface elevation. Water level just below seismic beams, but surging through beams. Wave action significant. Some aeration. Intermittent mid-size vortices. Hydraulic control at gate with approach flow influenced by seismic beams. Trunnions not impacted. Training wall not overtopped.
	474.29	306,329	In transition zone. Water level at seismic beams. Some aeration. No vortices. Wave action less than previous case. Wave action causes water to occasionally impact upstream bridge girder. Hydraulic control at gate with approach flow influenced by seismic beams. Minor splashing on trunnion pier. Trunnions not impacted. Training wall not overtopped.
	476.79	315,513	Just above transition zone. Flow contracts off upstream bridge girder and touches downstream girder at times. Flow skims across top of seismic beams. Some air bubbles towards downstream side of seismic beams. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water level above pier at trunnion, but not above trunnion. Some splashing on trunnion pier. Trunnions not directly impacted. Training wall not overtopped.
	478.53	322,210	Flow contracts off upstream bridge girder. Flow skims across top of seismic beams. Water level touches underside of deck at downstream end. Air pocket underneath bridge deck. Wave action and recirculation with air bubbles at downstream end near gate. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Splashing on trunnion pier with occasional run-up on trunnion. Training wall not overtopped.
	480.17	329,481	Flow contracts off upstream bridge girder. Air pocket at the upstream side of bridge deck, water touching underneath of bridge deck at the downstream side. Wave action and recirculation with air bubbles at downstream end near gate. Hydraulic control at gate with approach flow influenced by bridge. Splashing on trunnion pier with occasional run-up on trunnion. Training wall not overtopped.
	482.36	340,005	Very similar to previous case but more of underside of bridge deck is impacted by wave action with smaller air pocket. Less air and recirculation than previous case. Hydraulic control at gate with approach flow influenced by bridge. Constant slashing on trunnion pier with consistent run-up on trunnions. Training wall not overtopped.

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 13. Model observations with 40-ft gate opening with top seal and no seismic beams.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	
40 ft with Top Seal, No Seismic Beams	473.80	308,123	In transition zone. Water level below bridge girders. Water level fluctuating significantly. Heavy turbulence and significant wave action. Very large, consistent vortices. Hydraulic control at gate. Significant water splashing on trunnion piers with run-up that almost overtops trunnions. Splashing around trunnions worse than for 35 and 38 ft cases. Training wall not overtopped but getting close at downstream end.
	474.44	308,694	In transition zone. Water level below bridge girders. Water level fluctuating significantly. Heavy turbulence and significant wave action. Very large, consistent vortices. Hydraulic control at gate. Significant water splashing on trunnion piers with run-up that almost overtops trunnions. Training wall not overtopped but getting close at downstream end.
	476.52	318,025	In transition zone. Water starting to impact upstream bridge girder. Downstream bridge girder submerged most of the time. Air pocket under bridge deck. Water level fluctuating. Heavy turbulence and significant wave action. Large, consistent vortices. Hydraulic control at gate with approach flow influenced by bridge. Significant water splashing on trunnion piers with run-up that almost overtops trunnions. Training wall not overtopped but getting close at downstream end.
	477.29	323,738	Just above transition zone. Flow contracts off upstream bridge girder. Air pocket under bridge deck. Less turbulence and wave action. Mid-size vortices form occasionally. Hydraulic control at gate with approach flow influenced by bridge. Significant splashing on trunnion piers with consistent run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	478.10	330,784	Flow contracts off upstream bridge girder. Air pocket under bridge deck. Less turbulence and wave action. Mid-size vortices form occasionally. Hydraulic control at gate with approach flow influenced by bridge. Significant splashing on trunnion piers with consistent run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	478.51	334,212	Flow contracts off upstream bridge girder. Air pocket under bridge deck. Less turbulence and wave action. Mid-size vortices form occasionally. Hydraulic control at gate with approach flow influenced by bridge. Significant splashing on trunnion piers with consistent run-up on trunnions. Training wall not overtopped but getting close at downstream end.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	**Discharge 5 Gate (cfs)**	
40 ft with Top Seal, No Seismic Beams	479.10	338,592	Flow contracts off upstream bridge girder. Air pocket under bridge deck. Less turbulence and wave action. No vortices. Hydraulic control at gate with approach flow influenced by bridge. Significant splashing on trunnion piers with consistent run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	480.39	349,066	Flow contracts off upstream bridge girder. Air pocket under bridge deck. Waves occasionally impacting underside of bridge. Less turbulence and wave action. Some air bubbles in flow. No vortices. Hydraulic control at gate with approach flow influenced by bridge. Significant splashing on trunnion piers with consistent run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	481.06	354,017	Flow contracts off upstream bridge girder. Air pocket under bridge deck. Waves occasionally impacting underside of bridge. Less turbulence and wave action. Some air bubbles in flow. No vortices. Hydraulic control at gate with approach flow influenced by bridge. Significant splashing on trunnion piers with consistent run-up on trunnions. Training wall not overtopped but getting close at downstream end.

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 14. Model observations with 40-ft gate opening with top seal and seismic beams.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	**Discharge 5 Gate (cfs)**	
40 ft with Top Seal and Seismic Beams	473.90	325,643	In transition zone. Water level below seismic beams but fluctuating significantly and surging through beams. Heavy turbulence with occasional vortices. Hydraulic control at gate with approach flow influenced by seismic beams. Water splashing regularly on trunnion piers with run-up on trunnions. Splashing around trunnions worse than for 35 and 38 ft cases. Training wall not overtopped but getting close at downstream end.
	474.45	330,213	In transition zone. Water level just below seismic beams but fluctuating significantly and surging through beams. Heavy turbulence. No vortices. Hydraulic control at gate with approach flow influenced by seismic beams. Water splashing regularly on trunnion piers with run-up on trunnions. Splashing around trunnions worse than for 35 and 38 ft cases. Training wall not overtopped but getting close at downstream end.
	476.70	336,878	In transition zone, near top of transition zone. Flow contracts off upstream bridge girder. Downstream bridge girder is not submerged. Flow skims across seismic beams. Significant air bubbles. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing regularly on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	477.39	341,639	Just above transition zone. Flow contracts off upstream bridge girder, but is below downstream girder. Flow skims across seismic beams. Significant aeration. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	478.23	346,209	Flow contracts off upstream bridge girder. Water occasionally touches downstream bridge girder. Flow skims across seismic beams. Heavy aeration. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	478.46	348,495	Flow contracts off upstream bridge girder. Water occasionally touches downstream bridge girder. Flow skims across seismic beams. Heavy aeration. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.

Gate Opening	Corrected Data*		Key Observations
	Water Surface Elevation (ft)	**Discharge 5 Gate (cfs)**	
40 ft with Top Seal and Seismic Beams	479.30	353,065	Flow contracts off upstream bridge girder. Water occasionally touches downstream bridge girder. Flow skims across seismic beams. Heavy aeration. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	480.47	358,778	Large flow contraction off upstream bridge girder. Flow skims across seismic beams at high velocity. Heavy aeration. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.
	481.16	361,825	Large flow contraction off upstream bridge girder. Flow skims across seismic beams at high velocity. Underside of bridge deck no submerged. Heavy aeration. No vortices. Hydraulic control at gate with approach flow influenced by bridge and seismic beams. Water splashing on trunnion piers with significant run-up on trunnions. Training wall not overtopped but getting close at downstream end.

* Velocity head correction applied and discharge scaled up to 5 gate operation.

APPENDIX D

Static Pressure Data for Free Flow, 35-, 38-, and 40-ft Vertical Gate Openings

Table 15. Spillway pressure data on ogee crest with top seal for free flow condition.

Gate Opening	Corrected Data* Water Surface Elevation (ft)	Corrected Data* Discharge 5 Gate (cfs)		Spillway Pressure on Ogee Crest Tap 1	Tap 2	Tap 3	Tap 4	Tap 5	Tap 6	Tap 7	Tap 8
Free Flow	451.11	146,764	Elevation	436.25	430.85	427.61	423.11	417.89	411.41	401.69	395.93
			Pressure (ft)	22.00	13.13	10.08	7.74	6.27	5.13	2.16	5.12
	455.10	178,241	Elevation	435.17	430.31	427.07	422.93	417.89	411.23	401.51	397.01
			Pressure (ft)	20.92	12.59	9.54	7.56	6.27	4.95	1.98	6.2
	460.54	224,128	Elevation	434.09	428.69	425.81	421.85	417.17	410.69	400.97	397.73
			Pressure (ft)	19.84	10.97	8.28	6.48	5.55	4.41	1.44	6.92
	466.35	278,928	Elevation	430.85	425.45	423.29	420.23	416.45	409.79	400.25	397.37
			Pressure (ft)	16.60	7.73	5.76	4.86	4.83	3.51	0.72	6.56
	472.20	338,468	Elevation	425.81	421.13	420.05	417.17	414.65	408.17	397.01	396.65
			Pressure (ft)	11.56	3.41	2.52	1.80	3.03	1.89	-2.52	5.84
	473.77	354,206	Elevation	424.73	419.69	418.97	416.81	413.93	407.45	398.45	395.21
			Pressure (ft)	10.48	1.97	1.44	1.44	2.31	1.17	-1.08	4.40
	474.34	361,032	Elevation	423.65	418.97	418.61	416.09	413.57	407.45	397.91	394.67
			Pressure (ft)	9.40	1.25	1.08	0.72	1.95	1.17	-1.62	3.86

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 16. Spillway pressure data on ogee crest for 35-ft gate opening with top seal and no seismic beams.

	Corrected Data*			Spillway Pressure on Ogee Crest							
Gate Opening	**Water Surface Elevation (ft)**	**Discharge 5 gate (cfs)**		**Tap 1**	**Tap 2**	**Tap 3**	**Tap 4**	**Tap 5**	**Tap 6**	**Tap 7**	**Tap 8**
35 ft with Top Seal, No Seismic Beams	468.66	254,543	Elevation	440.57	435.17	429.05	422.93	417.35	409.25	398.81	397.55
			Pressure (ft)	26.32	17.45	11.52	7.56	5.73	2.97	-0.72	6.74
	470.57	259,745	Elevation	442.01	436.07	429.23	422.57	416.99	408.71	398.09	397.37
			Pressure (ft)	27.76	18.35	11.70	7.20	5.37	2.43	-1.44	6.56
	471.81	263,792	Elevation	443.81	434.45	429.77	422.75	416.45	408.17	397.73	396.29
			Pressure (ft)	29.56	16.73	12.24	7.38	4.83	1.89	-1.80	5.48
	472.78	266,875	Elevation	444.17	436.25	429.77	422.93	415.73	407.81	397.55	395.39
			Pressure (ft)	29.92	18.53	12.24	7.56	4.11	1.53	-1.98	4.58
	473.69	269,187	Elevation	444.35	436.25	429.77	422.39	415.55	407.45	397.01	395.39
			Pressure (ft)	30.10	18.53	12.24	7.02	3.93	1.17	-2.52	4.58
	476.30	279,978	Elevation	444.53	436.97	429.41	421.13	415.19	406.91	396.29	394.49
			Pressure (ft)	30.28	19.25	11.88	5.76	3.57	0.63	-3.24	3.68
	478.06	290,190	Elevation	444.53	435.89	428.87	420.77	414.29	406.37	395.75	393.77
			Pressure (ft)	30.28	18.17	11.34	5.40	2.67	0.09	-3.78	2.96
	480.02	299,632	Elevation	444.53	435.89	427.97	420.05	413.57	405.65	395.21	394.13
			Pressure (ft)	30.28	18.17	10.44	4.68	1.95	-0.63	-4.32	3.32

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 17. Spillway pressure data on ogee crest for 35-ft gate opening with top seal and seismic beams.

Gate Opening	Corrected Data*			Spillway Pressure on Ogee Crest							
	Water Surface Elevation (ft)	Discharge 5 gate (cfs)		Tap 1	Tap 2	Tap 3	Tap 4	Tap 5	Tap 6	Tap 7	Tap 8
35 ft with Top Seal and Seismic Beams	468.66	254,350	Elevation	440.93	434.81	427.58	423.18	416.02	407.02	398.81	393.77
			Pressure (ft)	26.68	17.09	10.04	7.81	4.39	0.74	-0.72	2.96
	470.57	259,938	Elevation	442.01	436.07	427.65	422.97	415.48	406.19	397.73	393.59
			Pressure (ft)	27.76	18.35	10.12	7.59	3.86	-0.09	-1.80	2.78
	471.82	267,260	Elevation	441.65	435.89	427.25	422.75	415.19	405.65	397.55	393.63
			Pressure (ft)	27.40	18.17	9.72	7.38	3.57	-0.63	-1.98	2.82
	472.84	272,463	Elevation	442.73	435.71	427.25	422.21	415.01	405.47	397.37	393.34
			Pressure (ft)	28.48	17.99	9.72	6.84	3.39	-0.81	-2.16	2.53
	473.64	275,160	Elevation	443.45	436.25	427.25	422.03	414.83	405.11	397.30	393.23
			Pressure (ft)	29.20	18.53	9.72	6.66	3.21	-1.17	-2.23	2.42
	476.35	283,061	Elevation	444.17	437.33	429.41	421.49	415.01	406.73	395.75	394.49
			Pressure (ft)	29.92	19.61	11.88	6.12	3.39	0.45	-3.78	3.68
	478.35	292,502	Elevation	445.25	436.61	427.97	420.77	414.29	405.83	395.57	395.39
			Pressure (ft)	31.00	18.89	10.44	5.40	2.67	-0.45	-3.96	4.58
	480.18	301,944	Elevation	444.17	436.25	427.61	420.05	413.39	405.47	395.03	395.93
			Pressure (ft)	29.92	18.53	10.08	4.68	1.77	-0.81	-4.50	5.12

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 18. Spillway pressure data on ogee crest for 38-ft gate opening with top seal and no seismic beams.

	Corrected Data*			Spillway Pressure on Ogee Crest							
Gate Opening	**Water Surface Elevation (ft)**	**Discharge 5 gate (cfs)**		**Tap 1**	**Tap 2**	**Tap 3**	**Tap 4**	**Tap 5**	**Tap 6**	**Tap 7**	**Tap 8**
38' with Top Seal, No Seismic Beams	472.61	288,726	Elevation	439.85	434.09	428.33	422.39	416.45	408.53	398.09	395.21
			Pressure (ft)	25.60	16.37	10.80	7.02	4.83	2.25	-1.44	4.40
	474.13	292,362	Elevation	440.57	434.45	428.69	421.85	416.45	408.17	397.37	395.21
			Pressure (ft)	26.32	16.73	11.16	6.48	4.83	1.89	-2.16	4.40
	476.49	303,077	Elevation	441.65	434.81	428.69	421.13	415.73	406.73	396.65	395.03
			Pressure (ft)	27.40	17.09	11.16	5.76	4.11	0.45	-2.88	4.22
	478.33	316,279	Elevation	440.93	433.73	426.89	420.41	411.41	406.37	396.29	394.31
			Pressure (ft)	26.68	16.01	9.36	5.04	-0.21	0.09	-3.24	3.50
	479.98	327,759	Elevation	440.57	432.29	425.45	419.33	413.93	405.65	395.57	394.13
			Pressure (ft)	26.32	14.57	7.92	3.96	2.31	-0.63	-3.96	3.32
	482.58	342,683	Elevation	439.85	431.21	424.37	417.53	412.85	404.93	394.49	393.77
			Pressure (ft)	25.60	13.49	6.84	2.16	1.23	-1.35	-5.04	2.96

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 19. Spillway pressure data on ogee crest for 38-ft gate opening with top seal and seismic beams.

	Corrected Data*			Spillway Pressure on Ogee Crest							
Gate Opening	**Water Surface Elevation (ft)**	**Discharge 5 gate (cfs)**		**Tap 1**	**Tap 2**	**Tap 3**	**Tap 4**	**Tap 5**	**Tap 6**	**Tap 7**	**Tap 8**
38' with Top Seal and Seismic Beams	472.86	298,485	Elevation	436.97	431.93	426.89	421.49	416.09	408.53	397.91	395.21
			Pressure (ft)	22.72	14.21	9.36	6.12	4.47	2.25	-1.62	4.40
	474.29	306,329	Elevation	436.97	431.21	426.53	420.77	415.73	408.17	397.55	395.21
			Pressure (ft)	22.72	13.49	9.00	5.40	4.11	1.89	-1.98	4.40
	476.79	315,513	Elevation	439.49	431.93	426.89	419.69	415.01	407.09	396.65	395.03
			Pressure (ft)	25.24	14.21	9.36	4.32	3.39	0.81	-2.88	4.22
	478.53	322,210	Elevation	440.21	431.93	425.45	419.69	414.29	406.37	396.11	394.49
			Pressure (ft)	25.96	14.21	7.92	4.32	2.67	0.09	-3.42	3.68
	480.17	329,481	Elevation	440.57	431.93	425.45	418.97	413.57	405.65	395.21	394.13
			Pressure (ft)	26.32	14.21	7.92	3.60	1.95	-0.63	-4.32	3.32
	482.36	340,005	Elevation	440.21	431.21	424.37	418.25	412.85	404.93	394.67	393.77
			Pressure (ft)	25.96	13.49	6.84	2.88	1.23	-1.35	-4.86	2.96

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 20. Spillway pressure data on ogee crest for 40-ft gate opening with top seal and no seismic beams.

Gate Opening	Corrected Data*: Water Surface Elevation (ft)	Corrected Data*: Discharge 5 gate (cfs)		Spillway Pressure on Ogee Crest: Tap 1	Tap 2	Tap 3	Tap 4	Tap 5	Tap 6	Tap 7	Tap 8
40 ft with Top Seal, No Seismic Beams	473.80	308,123	Elevation	436.97	431.93	426.89	421.49	416.81	408.53	398.09	395.57
			Pressure (ft)	22.72	14.21	9.36	6.12	5.19	2.25	-1.44	4.76
	474.44	308,694	Elevation	437.33	431.93	427.25	421.49	416.81	408.53	397.91	395.39
			Pressure (ft)	23.08	14.21	9.72	6.12	5.19	2.25	-1.62	4.58
	476.51	318,025	Elevation	438.05	432.29	426.89	421.13	415.73	407.81	397.19	395.21
			Pressure (ft)	23.80	14.57	9.36	5.76	4.11	1.53	-2.34	4.40
	477.29	323,738	Elevation	438.05	431.93	426.71	420.95	415.73	407.63	396.83	395.03
			Pressure (ft)	23.80	14.21	9.18	5.58	4.11	1.35	-2.70	4.22
	478.10	330,784	Elevation	437.33	430.85	425.63	420.41	416.81	407.09	396.65	394.85
			Pressure (ft)	23.08	13.13	8.10	5.04	5.19	0.81	-2.88	4.04
	478.51	334,212	Elevation	437.33	431.57	425.45	420.23	415.01	406.91	396.29	394.49
			Pressure (ft)	23.08	13.85	7.92	4.86	3.39	0.63	-3.24	3.68
	479.20	338,592	Elevation	436.97	430.49	424.73	419.33	414.29	406.73	395.93	394.49
			Pressure (ft)	22.72	12.77	7.20	3.96	2.67	0.45	-3.60	3.68
	480.39	349,066	Elevation	435.89	428.69	424.01	418.61	413.57	406.37	395.93	394.13
			Pressure (ft)	21.64	10.97	6.48	3.24	1.95	0.09	-3.60	3.32
	481.05	354,017	Elevation	435.53	428.69	423.11	418.25	413.57	405.65	395.21	394.31
			Pressure (ft)	21.28	10.97	5.58	2.88	1.95	-0.63	-4.32	3.50

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 21. Spillway pressure data on ogee crest for 40-ft gate opening with top seal and seismic beams.

Gate Opening	Corrected Data* Water Surface Elevation (ft)	Corrected Data* Discharge 5 gate (cfs)		Spillway Pressure on Ogee Crest Tap 1	Tap 2	Tap 3	Tap 4	Tap 5	Tap 6	Tap 7	Tap 8
40 ft with Top Seal and Seismic Beams	473.90	325,643	Elevation	433.01	426.53	423.29	420.41	415.19	408.17	397.73	395.57
			Pressure (ft)	18.76	8.81	5.76	5.04	3.57	1.89	-1.80	4.76
	474.45	330,213	Elevation	434.45	427.61	423.65	419.33	415.01	407.81	397.73	395.21
			Pressure (ft)	20.20	9.89	6.12	3.96	3.39	1.53	-1.80	4.40
	476.69	336,878	Elevation	434.45	427.97	424.37	419.33	413.93	406.73	397.01	395.03
			Pressure (ft)	20.20	10.25	6.84	3.96	2.31	0.45	-2.52	4.22
	477.40	341,639	Elevation	434.09	427.97	423.29	418.61	413.93	406.73	396.83	394.85
			Pressure (ft)	19.84	10.25	5.76	3.24	2.31	0.45	-2.70	4.04
	478.23	346,209	Elevation	434.09	427.43	423.29	418.61	413.57	406.37	396.29	395.03
			Pressure (ft)	19.84	9.71	5.76	3.24	1.95	0.09	-3.24	4.22
	478.46	348,495	Elevation	434.09	427.25	422.57	417.89	413.57	406.19	396.11	394.85
			Pressure (ft)	19.84	9.53	5.04	2.52	1.95	-0.09	-3.42	4.04
	479.30	353,065	Elevation	434.09	427.25	422.57	417.89	413.21	405.83	395.57	394.85
			Pressure (ft)	19.84	9.53	5.04	2.52	1.59	-0.45	-3.96	4.04
	480.47	358,778	Elevation	433.73	426.17	421.85	417.17	412.49	405.29	395.03	394.49
			Pressure (ft)	19.48	8.45	4.32	1.80	0.87	-0.99	-4.50	3.68
	481.15	361,825	Elevation	434.81	426.53	421.49	416.09	412.49	405.29	395.39	394.49
			Pressure (ft)	20.56	8.81	3.96	0.72	0.87	-0.99	-4.14	3.68

* Velocity head correction applied and discharge scaled up to 5 gate operation.

APPENDIX E

Pressure Measurements on Bridge for 35-, 38-, and 40-ft Vertical Gate Openings

Table 22. Bridge pressure data for 35-ft gate opening in center bay.

	Corrected Data*			BRIDGE PRESSURES - CENTER BAY							
				Tap 9	Tap 10	Tap 11	Tap 15	Tap 16	Tap 21	Tap 20	Tap 19
Gate Opening	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	Offset	0	2	2.67	12.06	22.93	32.33	32.99	34.99
			Tap Zero	480.50	477.86	475.21	476.35	476.35	475.21	477.86	480.50
35 ft with Top Seal, No Seismic Beams	468.66	254,543	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	470.57	259,745	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	471.81	263,792	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	472.78	266,875	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	473.69	269,187	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.30	279,978	Elevation (ft)	--	--	476.93	--	--	478.01	--	--
			Pressure (ft)	--	--	1.72	--	--	2.80	--	--
	478.06	290,190	Elevation (ft)	--	478.01	478.37	479.09	479.09	478.01	478.37	--
			Pressure (ft)	--	0.15	3.16	2.74	2.74	2.80	0.51	--
	480.02	299,632	Elevation (ft)	--	480.35	480.35	479.09	479.45	478.01	478.01	--
			Pressure (ft)	--	2.49	5.14	2.74	3.10	2.80	0.15	--
35 ft with Top Seal and Seismic Beams	468.66	254,350	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	470.57	259,938	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	471.82	267,260	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	472.84	272,463	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	473.64	275,160	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.35	283,061	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.35	292,502	Elevation (ft)	--	478.37	478.37	478.73	478.01	478.37	478.37	--
			Pressure (ft)	--	0.51	3.16	2.38	1.66	3.16	0.51	--
	480.18	301,944	Elevation (ft)	480.17	480.53	480.53	479.09	477.29	478.37	478.01	--
			Pressure (ft)	-0.14	1.16	2.31	1.19	0.41	1.37	0.07	--

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 23. Bridge pressure data for 35-ft gate opening above pier.

	Corrected Data*			BRIDGE PRESSURES - ABOVE PIER							
				Tap 12	Tap 13	Tap 14	Tap 17	Tap 18	Tap 24	Tap 23	Tap 22
Gate Opening	**Water Surface Elevation (ft)**	**Discharge 5 Gate (cfs)**	**Offset**	0	2	2.67	12.06	22.93	32.33	32.99	34.99
			Tap Zero	480.50	477.86	475.21	476.35	476.35	475.21	477.86	480.50
35 ft with Top Seal, No Seismic Beams	468.66	254,543	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	470.57	259,745	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	471.81	263,792	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	472.78	266,875	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	473.69	269,187	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.30	279,978	Elevation (ft)	--	--	476.93	--	--	480.89	--	--
			Pressure (ft)	--	--	1.72	--	--	5.68	--	--
	478.06	290,190	Elevation (ft)	--	478.01	478.01	--	--	478.01	480.53	478.01
			Pressure (ft)	--	0.15	2.80	--	--	2.80	2.67	-2.49
	480.02	299,632	Elevation (ft)	--	479.81	479.45	470.81	469.73	478.37	480.53	478.01
			Pressure (ft)	--	1.95	4.24	-5.54	-6.62	3.16	2.67	-2.49
35 ft with Top Seal and Seismic Beams	468.66	254,350	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	470.57	259,938	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	471.82	267,260	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	472.84	272,463	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	473.64	275,160	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.35	283,061	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.35	292,502	Elevation (ft)	--	478.01	478.37	479.45	479.45	476.57	477.29	--
			Pressure (ft)	--	0.15	3.16	3.10	3.10	1.36	-0.57	--
	480.18	301,944	Elevation (ft)	479.63	480.17	480.17	479.45	479.09	477.65	477.65	--
			Pressure (ft)	-0.87	2.31	4.96	3.10	2.74	2.44	-0.21	--

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 24. Bridge pressure data for 38-ft gate opening in center bay.

	Corrected Data*			BRIDGE PRESSURES - CENTER BAY							
				Tap 9	Tap 10	Tap 11	Tap 15	Tap 16	Tap 21	Tap 20	Tap 19
Gate Opening	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	Offset	0	2	2.67	12.06	22.93	32.33	32.99	34.99
			Tap Zero	480.50	477.86	475.21	476.35	476.35	475.21	477.86	480.50
38 ft with Top Seal, No Seismic Beams	472.61	288,726	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.13	292,362	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.49	303,077	Elevation (ft)	--	--	476.93	--	--	478.01	--	--
			Pressure (ft)	--	--	1.72	--	--	2.80	--	--
	478.33	316,279	Elevation (ft)	478.73	479.09	478.73	479.09	479.09	478.37	478.01	--
			Pressure (ft)	-1.77	1.23	3.52	2.74	2.74	3.16	0.15	--
	479.98	327,759	Elevation (ft)	--	480.53	480.53	478.37	476.93	477.29	477.65	--
			Pressure (ft)	--	2.67	5.32	2.02	0.58	2.08	-0.21	--
	482.58	342,683	Elevation (ft)	482.33	482.33	482.33	477.65	477.65	477.29	478.01	--
			Pressure (ft)	1.83	4.47	7.12	1.30	1.30	2.08	0.15	--
38 ft with Top Seal and Seismic Beams	472.86	298,485	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.29	306,329	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.79	315,513	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.53	322,210	Elevation (ft)	--	479.09	477.65	--	--	475.13	--	--
			Pressure (ft)	--	1.23	2.44	--	--	-0.08	--	--
	480.17	329,481	Elevation (ft)	--	479.81	479.45	--	--	475.49	--	--
			Pressure (ft)	--	1.95	4.24	--	--	0.28	--	--
	482.36	340,005	Elevation (ft)	--	482.33	480.53	--	479.09	478.73	478.01	--
			Pressure (ft)	--	4.47	5.32	--	2.74	3.52	0.15	--

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 25. Bridge pressure data for 38-ft gate opening above pier.

Gate Opening	Corrected Data* Water Surface Elevation (ft)	Corrected Data* Discharge 5 Gate (cfs)	Offset / Tap Zero	BRIDGE PRESSURES - ABOVE PIER Tap 12	Tap 13	Tap 14	Tap 17	Tap 18	Tap 24	Tap 23	Tap 22
			Offset	0	2	2.67	12.06	22.93	32.33	32.99	34.99
			Tap Zero	480.50	477.86	475.21	476.35	476.35	475.21	477.86	480.50
38 ft with Top Seal, No Seismic Beams	472.61	288,726	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft))	--	--	--	--	--	--	--	--
	474.13	292,362	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.49	303,077	Elevation (ft)	--	--	--	--	--	476.21	--	--
			Pressure (ft)	--	--	--	--	--	1.00	--	--
	478.33	316,279	Elevation (ft)	--	479.09	479.09	477.29	479.09	479.09	478.37	478.73
			Pressure (ft)	--	1.23	3.88	0.94	2.74	3.88	0.51	-1.77
	479.98	327,759	Elevation (ft)	--	479.81	479.81	476.93	478.01	476.21	477.29	477.29
			Pressure (ft)	--	1.95	4.60	0.58	1.66	1.00	-0.57	-3.21
	482.58	342,683	Elevation (ft)	482.33	481.97	481.61	477.29	477.29	477.65	478.01	477.29
			Pressure (ft)	1.83	4.11	6.40	0.94	0.94	2.44	0.15	-3.21
38 ft with Top Seal and Seismic Beams	472.86	298,485	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.29	306,329	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.79	315,513	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.53	322,210	Elevation (ft)	--	478.01	478.01	--	--	480.53	--	--
			Pressure (ft)	--	0.15	2.80	--	--	5.32	--	--
	480.17	329,481	Elevation (ft)	--	479.81	479.45	--	--	480.53	--	--
			Pressure (ft)	--	1.95	4.24	--	--	5.32	--	--
	482.36	340,005	Elevation (ft)	--	481.97	481.25	--	478.37	480.89	478.37	--
			Pressure (ft)	--	4.11	6.04	--	2.02	5.68	0.51	--

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 26. Bridge pressure data for 40-ft gate opening in center bay.

	Corrected Data*			BRIDGE PRESSURES - CENTER BAY							
				Tap 9	Tap 10	Tap 11	Tap 15	Tap 16	Tap 21	Tap 20	Tap 19
Gate Opening	Water Surface Elevation (ft)	Discharge 5 Gate (cfs)	Offset	0	2	2.67	12.06	22.93	32.33	32.99	34.99
			Tap Zero	480.50	477.86	475.21	476.35	476.35	475.21	477.86	480.50
40 ft with Top Seal, No Seismic Beams	473.80	308,123	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.44	308,694	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.51	318,025	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	477.29	323,738	Elevation (ft)	--	--	479.81	--	--	--	--	--
			Pressure (ft)	--	--	4.60	--	--	--	--	--
	478.10	330,784	Elevation (ft)	--	--	480.17	--	--	478.01	--	--
			Pressure (ft)	--	--	4.96	--	--	2.80	--	--
	478.51	334,212	Elevation (ft)	--	--	480.53	--	--	478.01	--	--
			Pressure (ft)	--	--	5.32	--	--	2.80	--	--
	479.20	338,592	Elevation (ft)	--	--	480.53	--	--	478.01	--	--
			Pressure (ft)	--	--	5.32	--	--	2.80	--	--
	480.39	349,066	Elevation (ft)	--	480.53	480.89	--	--	477.65	--	--
			Pressure (ft)	--	2.67	5.68	--	--	2.44	--	--
	481.05	354,017	Elevation (ft)	--	480.89	480.89	--	--	478.01	--	--
			Pressure (ft)	--	3.03	5.68	--	--	2.80	--	--
40 ft with Top Seal and Seismic Beams	473.90	325,643	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.45	330,213	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.69	336,878	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	477.40	341,639	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.23	346,209	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.46	348,495	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	479.30	353,065	Elevation (ft)	--	--	480.53	--	--	--	--	--
			Pressure (ft)	--	--	5.32	--	--	--	--	--
	480.47	358,778	Elevation (ft)	--	480.53	480.89	--	--	476.57	--	--
			Pressure (ft)	--	2.67	5.68	--	--	1.36	--	--
	481.15	361,825	Elevation (ft)	--	481.25	481.25	--	--	476.57	--	--
			Pressure (ft)	--	3.39	6.04	--	--	1.36	--	--

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 27. Bridge pressure data for 40-ft gate opening above pier.

Gate Opening	Corrected Data*: Water Surface Elevation (ft)	Corrected Data*: Discharge 5 Gate (cfs)		BRIDGE PRESSURES - ABOVE PIER: Tap 12	Tap 13	Tap 14	Tap 17	Tap 18	Tap 24	Tap 23	Tap 22
			Offset	0	2	2.67	12.06	22.93	32.33	32.99	34.99
			Tap Zero	480.50	477.86	475.21	476.35	476.35	475.21	477.86	480.50
40 ft with Top Seal, No Seismic Beams	473.80	308,123	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.44	308,694	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.51	318,025	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	477.29	323,738	Elevation (ft)	--	--	479.45	--	--	--	--	--
			Pressure (ft)	--	--	4.24	--	--	--	--	--
	478.10	330,784	Elevation (ft)	--	--	479.81	--	--	476.21	--	--
			Pressure (ft)	--	--	4.60	--	--	1.00	--	--
	478.51	334,212	Elevation (ft)	--	--	479.81	--	--	478.37	--	--
			Pressure (ft)	--	--	4.60	--	--	3.16	--	--
	479.20	338,592	Elevation (ft)	--	--	480.17	--	--	478.01	--	--
			Pressure (ft)	--	--	4.96	--	--	2.80	--	--
	480.39	349,066	Elevation (ft)	--	479.45	480.17	--	--	478.01	--	--
			Pressure (ft)	--	1.59	4.96	--	--	2.80	--	--
	481.05	354,017	Elevation (ft)	--	480.17	480.17	--	--	478.01	--	--
			Pressure (ft)	--	2.31	4.96	--	--	2.80	--	--
40 ft with Top Seal and Seismic Beams	473.90	325,643	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	474.45	330,213	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	476.69	336,878	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	477.40	341,639	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.23	346,209	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	478.46	348,495	Elevation (ft)	--	--	--	--	--	--	--	--
			Pressure (ft)	--	--	--	--	--	--	--	--
	479.30	353,065	Elevation (ft)	--	--	479.81	--	--	--	--	--
			Pressure (ft)	--	--	4.60	--	--	--	--	--
	480.47	358,778	Elevation (ft)	--	480.17	480.17	--	--	478.73	--	--
			Pressure (ft)	--	2.31	4.96	--	--	3.52	--	--
	481.15	361,825	Elevation (ft)	--	480.53	480.53	--	--	479.09	--	--
			Pressure (ft)	--	2.67	5.32	--	--	3.88	--	--

* Velocity head correction applied and discharge scaled up to 5 gate operation.

APPENDIX F

Water Surface Profiles in Relation to Sidewalls for 35-, 38-, and 40-ft Vertical Gate Openings

Table 28. Water surface profile model data at right sidewall for 35-ft gate opening without seismic beams.

Gate Opening	Corrected Data*			Water Levels					
	Water Level (ft)	Prototype Discharge 5 gates (cfs)	Reference	-2.5	-1.5	0	1.5	7	10
			Offset	51	54	58.5	63	79.5	88.5
			Slope Angle (from Hor.)	43.25	44.64	46.48	48.38	53.91	56.36
			Level of Ogee	392.07	389.18	384.58	379.67	359.05	346.12
			Level of Wall	432.50	432.50	432.50	427.69	401.23	386.80
35 ft with Top Seal, No Seismic Beams	468.66	254,543	Model Level	--	--	8.5	10	17	21.5
			Elevation (ft)	--	--	407	402.5	381.5	368
			Vert Dist to Top Sidewall	--	--	25.50	25.19	19.73	18.80
	470.57	259,745	Model Level	--	--	8.5	10.25	17	21.5
			Elevation (ft)	--	--	407	401.75	381.5	368
			Vert Dist to Top Sidewall	--	--	25.50	25.94	19.73	18.80
	471.81	263,792	Model Level	--	--	8.5	10.25	16.25	21
			Elevation (ft)	--	--	407	401.75	383.75	369.5
			Vert Dist to Top Sidewall	--	--	25.50	25.94	17.48	17.30
	472.78	266,875	Model Level	--	--	8.5	10.25	17	21
			Elevation (ft)	--	--	407	401.75	381.5	369.5
			Vert Dist to Top Sidewall	--	--	25.50	25.94	19.73	17.30
	473.69	269,187	Model Level	--	--	8.25	10.5	17	20.5
			Elevation (ft)	--	--	407.75	401	381.5	371
			Vert Dist to Top Sidewall	--	--	24.75	26.69	19.73	15.80
	476.30	279,978	Model Level	--	--	8	10	17	21
			Elevation (ft)	--	--	408.5	402.5	381.5	369.5
			Vert Dist to Top Sidewall	--	--	24.00	25.19	19.73	17.30
	478.06	290,190	Model Level	--	--	8	10.25	16	21
			Elevation (ft)	--	--	408.5	401.75	384.5	369.5
			Vert Dist to Top Sidewall	--	--	24.00	25.94	16.73	17.30
	480.02	299,632	Model Level	--	--	8	9.75	17	21
			Elevation (ft)	--	--	408.5	403.25	381.5	369.5
			Vert Dist to Top Sidewall	--	--	24.00	24.44	19.73	17.30

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 29. Water surface profile model data at right sidewall for 35-ft gate opening with seismic beams.

Gate Opening	Corrected Data*			Water Levels					
	Water Level (ft)	Prototype Discharge 5 gates (cfs)	Reference	-2.5	-1.5	0	1.5	7	10
			Offset	51	54	58.5	63	79.5	88.5
			Slope Angle (from Hor.)	43.25	44.64	46.48	48.38	53.91	56.36
			Level of Ogee	392.07	389.18	384.58	379.67	359.05	346.12
			Level of Wall	432.50	432.50	432.50	427.69	401.23	386.80
35 ft with Top Seal and Seismic Beams	468.66	254,350	Model Level	--	--	8.5	10	16.5	--
			Elevation (ft)	--	--	407	402.5	383	--
			Vert Dist to Top Sidewall (ft)	--	--	25.50	25.19	18.23	--
	470.57	259,938	Model Level	--	--	8.5	9.75	16.5	21
			Elevation (ft)	--	--	407	403.25	383	369.5
			Vert Dist to Top Sidewall (ft)	--	--	25.50	24.44	18.23	17.30
	471.82	267,260	Model Level	--	--	8	9	16	20.5
			Elevation (ft)	--	--	408.5	405.5	384.5	371
			Vert Dist to Top Sidewall (ft)	--	--	24.00	22.19	16.73	15.80
	472.84	272,463	Model Level	--	--	8.5	10	16.25	20.5
			Elevation (ft)	--	--	407	402.5	383.75	371
			Vert Dist to Top Sidewall (ft)	--	--	25.50	25.19	17.48	15.80
	473.64	275,160	Model Level	--	--	8.25	10	16.5	21
			Elevation (ft)	--	--	407.75	402.5	383	369.5
			Vert Dist to Top Sidewall (ft)	--	--	24.75	25.19	18.23	17.30
	476.35	283,061	Model Level	--	--	8	9.5	17	21
			Elevation (ft)	--	--	408.5	404	381.5	369.5
			Vert Dist to Top Sidewall (ft)	--	--	24.00	23.69	19.73	17.30
	478.35	292,502	Model Level	--	--	8	9.5	17.5	21
			Elevation (ft)	--	--	408.5	404	380	369.5
			Vert Dist to Top Sidewall (ft)	--	--	24.00	23.69	21.23	17.30
	480.18	301,944	Model Level	--	--	8.5	10.25	16.75	21
			Elevation (ft)	--	--	407	401.75	382.25	369.5
			Vert Dist to Top Sidewall (ft)	--	--	25.50	25.94	18.98	17.30

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 30. Water surface profile model data at right sidewall for 38-ft gate opening without seismic beams.

Gate Opening	Corrected Data*			Water Levels					
	Water Level (ft)	Prototype Discharge 5 gates (cfs)	Reference	-2.5	-1.5	0	1.5	7	10
			Offset	51	54	58.5	63	79.5	88.5
			Slope Angle (from Hor.)	43.25	44.64	46.48	48.38	53.91	56.36
			Level of Ogee	392.07	389.18	384.58	379.67	359.05	346.12
			Level of Wall	432.50	432.50	432.50	427.69	401.23	386.80
38 ft with Top Seal, No Seismic Beams	472.61	288,726	Model Level	5	6	7	9	16.5	21
			Elevation (ft)	417.5	414.5	411.5	405.5	383	369.5
			Vert Dist to Top Sidewall	15.00	18.00	21.00	22.19	18.23	17.30
	474.13	292,362	Model Level	4.5	6	7.5	9	15.5	19.5
			Elevation (ft)	419	414.5	410	405.5	386	374
			Vert Dist to Top Sidewall	13.50	18.00	22.50	22.19	15.23	12.80
	476.49	303,077	Model Level	4.75	6.25	7.25	9	15.5	19.5
			Elevation (ft)	418.25	413.75	410.75	405.5	386	374
			Vert Dist to Top Sidewall	14.25	18.75	21.75	22.19	15.23	12.80
	478.33	316,279	Model Level	4.5	5.5	7	8.5	15.75	19.25
			Elevation (ft)	419	416	411.5	407	385.25	374.75
			Vert Dist to Top Sidewall	13.50	16.50	21.00	20.69	15.98	12.05
	479.98	327,759	Model Level	3.5	4.5	6	7.5	15	19
			Elevation (ft)	422	419	414.5	410	387.5	375.5
			Vert Dist to Top Sidewall	10.50	13.50	18.00	17.69	13.73	11.30
	482.58	342,683	Model Level	3.5	4.5	6	7.75	15.25	19.25
			Elevation (ft)	422	419	414.5	409.25	386.75	374.75
			Vert Dist to Top Sidewall	10.50	13.50	18.00	18.44	14.48	12.05

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 31. Water surface profile model data at right sidewall for 38-ft gate opening with seismic beams.

Gate Opening	Corrected Data*			Water Levels					
	Water Level (ft)	Prototype Discharge 5 gates (cfs)	Reference	-2.5	-1.5	0	1.5	7	10
			Offset	51	54	58.5	63	79.5	88.5
			Slope Angle (from Hor.)	43.25	44.64	46.48	48.38	53.91	56.36
			Level of Ogee	392.07	389.18	384.58	379.67	359.05	346.12
			Level of Wall	432.50	432.50	432.50	427.69	401.23	386.80
38 ft with Top Seal and Seismic Beams	472.86	298,485	Model Level	--	--	7.5	9.25	15.5	20
			Elevation (ft)	--	--	410	404.75	386	372.5
			Vert Dist to Top Sidewall	--	--	22.50	22.94	15.23	14.30
	474.29	306,329	Model Level	--	--	7	8.75	15.25	19.5
			Elevation (ft)	--	--	411.5	406.25	386.75	374
			Vert Dist to Top Sidewall	--	--	21.00	21.44	14.48	12.80
	476.79	315,513	Model Level	--	--	6.75	8.75	15.75	21
			Elevation (ft)	--	--	412.25	406.25	385.25	369.5
			Vert Dist to Top Sidewall	--	--	20.25	21.44	15.98	17.30
	478.53	322,210	Model Level	--	--	7	8.5	15.5	19.5
			Elevation (ft)	--	--	411.5	407	386	374
			Vert Dist to Top Sidewall	--	--	21.00	20.69	15.23	12.80
	480.17	329,481	Model Level	--	--	6.5	8.25	15.25	19
			Elevation (ft)	--	--	413	407.75	386.75	375.5
			Vert Dist to Top Sidewall	--	--	19.50	19.94	14.48	11.30
	482.36	340,005	Model Level	--	--	6.5	8	15	19.5
			Elevation (ft)	--	--	413	408.5	387.5	374
			Vert Dist to Top Sidewall	--	--	19.50	19.19	13.73	12.80

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 32. Water surface profile model data at right sidewall for 40-ft gate opening without seismic beams.

Gate Opening	Corrected Data*			Water Levels					
	Water Level (ft)	Prototype Discharge 5 gates (cfs)	Reference	-2.5	-1.5	0	1.5	7	10
			Offset	51	54	58.5	63	79.5	88.5
			Slope Angle (from Hor.)	43.25	44.64	46.48	48.38	53.91	56.36
			Level of Ogee	392.07	389.18	384.58	379.67	359.05	346.12
			Level of Wall	432.50	432.50	432.50	427.69	401.23	386.80
40 ft with Top Seal, No Seismic Beams	473.80	308,123	Model Level	4.25	5.25	7	8.5	14.5	18.25
			Elevation (ft)	419.75	416.75	411.5	407	389	377.75
			Vert Dist to Top Sidewall	12.75	15.75	21.00	20.69	12.23	9.05
	474.44	308,694	Model Level	4	5	6.5	8.25	--	19.5
			Elevation (ft)	420.5	417.5	413	407.75	--	374
			Vert Dist to Top Sidewall	12.00	15.00	19.50	19.94	--	12.80
	476.51	318,025	Model Level	3.75	4.75	6.25	8	14.5	19
			Elevation (ft)	421.25	418.25	413.75	408.5	389	375.5
			Vert Dist to Top Sidewall	11.25	14.25	18.75	19.19	12.23	11.30
	477.29	323,738	Model Level	3.75	4.75	6.25	7.5	--	18.75
			Elevation (ft)	421.25	418.25	413.75	410	--	376.25
			Vert Dist to Top Sidewall	11.25	14.25	18.75	17.69	--	10.55
	478.10	330,784	Model Level	4	4.75	6.25	7.75	14.75	19.5
			Elevation (ft)	420.5	418.25	413.75	409.25	388.25	374
			Vert Dist to Top Sidewall	12.00	14.25	18.75	18.44	12.98	12.80
	478.51	334,212	Model Level	3.5	4.5	6.25	7.75	13.75	17.75
			Elevation (ft)	422	419	413.75	409.25	391.25	379.25
			Vert Dist to Top Sidewall	10.50	13.50	18.75	18.44	9.98	7.55
	479.20	338,592	Model Level	3.5	4.75	6.25	8	14.5	18.5
			Elevation (ft)	422	418.25	413.75	408.5	389	377
			Vert Dist to Top Sidewall	10.50	14.25	18.75	19.19	12.23	9.80
	480.39	349,066	Model Level	3.25	4.25	5.75	7.25	14.25	18.25
			Elevation (ft)	422.75	419.75	415.25	410.75	389.75	377.75
			Vert Dist to Top Sidewall	9.75	12.75	17.25	16.94	11.48	9.05
	481.05	354,017	Model Level	3	4	5.5	7.25	13.75	17.75
			Elevation (ft)	423.5	420.5	416	410.75	391.25	379.25
			Vert Dist to Top Sidewall	9.00	12.00	16.50	16.94	9.98	7.55

* Velocity head correction applied and discharge scaled up to 5 gate operation.

Table 33. Water surface profile model data at right sidewall for 40-ft gate opening with seismic beams.

Gate Opening	Corrected Data*			Water Levels					
	Water Level (ft)	Prototype Discharge 5 gates (cfs)	Reference	-2.5	-1.5	0	1.5	7	10
			Offset	51	54	58.5	63	79.5	88.5
			Slope Angle (from Hor.)	43.25	44.64	46.48	48.38	53.91	56.36
			Level of Ogee	392.07	389.18	384.58	379.67	359.05	346.12
			Level of Wall	432.50	432.50	432.50	427.69	401.23	386.80
40 ft with Top Seal and Seismic Beams	473.90	325,643	Model Level	2.25	3.25	4.75	6.5	14.75	18.5
			Elevation (ft)	425.75	422.75	418.25	413	388.25	377
			Vert Dist to Top Sidewall	6.75	9.75	14.25	14.69	12.98	9.80
	474.45	330,213	Model Level	2.75	3.75	5.25	7	14.25	18.5
			Elevation (ft)	424.25	421.25	416.75	411.5	389.75	377
			Vert Dist to Top Sidewall	8.25	11.25	15.75	16.19	11.48	9.80
	476.69	336,878	Model Level	3.25	4.5	5.75	7.5	14.5	19
			Elevation (ft)	422.75	419	415.25	410	389	375.5
			Vert Dist to Top Sidewall	9.75	13.50	17.25	17.69	12.23	11.30
	477.40	341,639	Model Level	3.5	4.5	6	7.75	--	--
			Elevation (ft)	422	419	414.5	409.25	--	--
			Vert Dist to Top Sidewall	10.50	13.50	18.00	18.44	--	--
	478.23	346,209	Model Level	2.5	3.75	5	6.75	13.5	18
			Elevation (ft)	425	421.25	417.5	412.25	392	378.5
			Vert Dist to Top Sidewall	7.50	11.25	15.00	15.44	9.23	8.30
	478.46	348,495	Model Level	2.5	3.5	4.75	6.5	14.5	18.25
			Elevation (ft)	425	422	418.25	413	389	377.75
			Vert Dist to Top Sidewall	7.50	10.50	14.25	14.69	12.23	9.05
	479.30	353,065	Model Level	2.25	3.25	4.5	6.25	13.5	17.5
			Elevation (ft)	425.75	422.75	419	413.75	392	380
			Vert Dist to Top Sidewall	6.75	9.75	13.50	13.94	9.23	6.80
	480.47	358,778	Model Level	2	3	4.25	6	13.25	17.25
			Elevation (ft)	426.5	423.5	419.75	414.5	392.75	380.75
			Vert Dist to Top Sidewall	6.00	9.00	12.75	13.19	8.48	6.05
	481.15	361,825	Model Level	2	3	4.5	5.75	13.25	17.25
			Elevation (ft)	426.5	423.5	419	415.25	392.75	380.75
			Vert Dist to Top Sidewall	6.00	9.00	13.50	12.44	8.48	6.05

* Velocity head correction applied and discharge scaled up to 5 gate operation.