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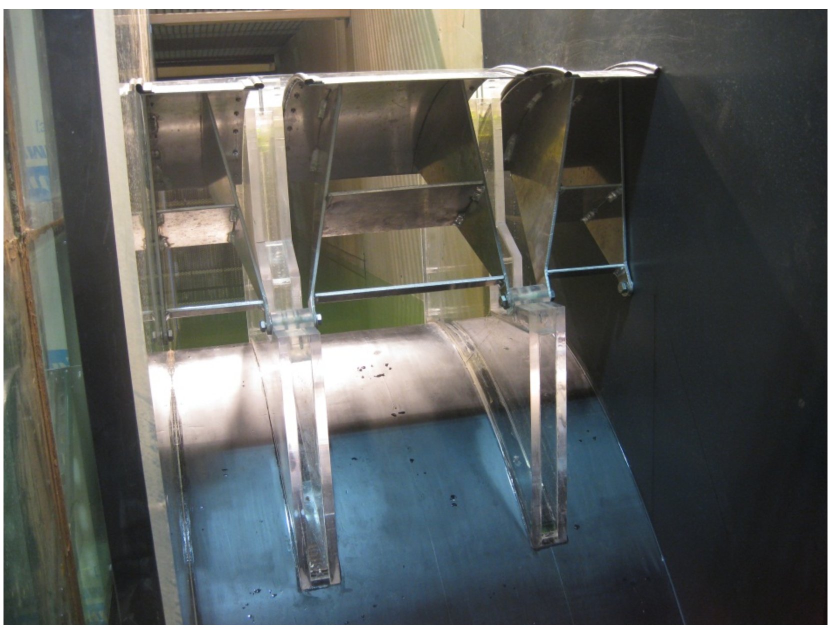
Hydraulic Laboratory Report HL-2014-01S Supplement

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

Supplement: Dynamic Pressure Measurements and Discharge Rating Curves



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14. ABSTRACT
This report is a supplement to the "Physical Hydraulic Model Study of Folsom Dam Emergency Spillway Tainter Gate Alternatives" (Svoboda, 2014). Additional tasks completed in this supplement include collecting discharge rating data for 5-, 10-, 15-, 20-, and 25-ft vertical gate openings with a top seal installed on the gates. Also, dynamic pressure data near the gate seat were collected at 1- to 6-ft vertical gate openings to determine if fluctuating down pull or uplift forces may exist for higher reservoir levels and modified release operations expected with the proposed Folsom Dam Raise Project. In summary, there was no measurable difference between discharge rating data collected with and without top seals and dynamic pressure results indicated that there will be no significant force fluctuations at the gate lip.

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hydraulic modeling, hydraulic structure, Folsom Dam, dam raise, tainter gates, spillways gates, top seal, dynamic pressure measurements

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Supplement: Dynamic Pressure Measurements and Discharge Rating Curves

Joshua D. Mortensen
Connie D. Svoboda

Prepared: Joshua D. Mortensen, P.E.
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services Group, 85-846000

Prepared: Connie D. Svoboda, P.E.
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services Group, 85-846000

Technical Approval: Robert F. Einhellig, P.E.
Manager, Hydraulic Investigations and Laboratory Services Group, 85-846000

Peer Review: K. Warren Frizell — Date: 5/14/14
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services Group, 85-846000

U.S. Department of the Interior
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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.

Acknowledgments

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Disclaimer

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Introduction

This document is a supplement to the report “Physical Hydraulic Model Study of Folsom Dam Emergency Spillway Tainter Gate Alternatives” (Svoboda, 2014). The key purpose of the original 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. These modifications were designed to prevent overtopping under higher water surface elevations and modified release operations expected with the proposed Folsom Dam Raise Project.

A 1:36-Froude scale physical hydraulic model of a section of the Folsom Dam emergency spillway was constructed at the Bureau of Reclamation’s (Reclamation) hydraulics laboratory in Denver, Colorado in 2013. The model contains a section of the emergency spillway including one full width radial gate and a half-width radial gate on each side of the full bay. The top section of the spillway crest is constructed from EL 264 to EL 418 NGVD29. The model also contains major features of the bridge including parapet, deck, and girders, seismic beams between piers with diagonal and horizontal bracing, stoplog slots on the upstream side of the piers, vertical pier extensions on the piers, and top seals along the tops of the emergency radial gates.

The additional tasks described in this supplement utilize the same physical hydraulic model. A discussion of model scale, model features, and drawings are presented in Svoboda (2014). Any modifications to the model are described separately in this report. The main model report contains a detailed description of project background and recent projects and improvements at Folsom Dam.

All data presented in this report are in prototype units unless otherwise noted. All elevations in this document are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29) as used in the original project design documents and drawings. A velocity head correction is applied to all reservoir water surface elevations to account for sectional model effects, as described in Svoboda (2014). Two-gate discharge data from the model is converted to 5-gate discharge data by using correction factors from a computational fluid dynamics model (Frizell et al., 2009). This process is described in more detail in the main report (Svoboda, 2014).

Model Objectives

In December 2013, the U.S. Army Corps of Engineers asked Reclamation to expand the scope of work for the original model study. The first objective of the expanded scope was to provide additional discharge rating data at lower gate openings with the top seal in place for comparison to previous rating data. The second objective was to determine if fluctuating down pull or uplift forces will exist near the gate seat for low gate openings. New tasks were accomplished with the dam modeled in its existing configuration, meaning that seismic beams were installed in the model. The following tasks were requested:

1.) Collect discharge rating data at 5-, 10-, 15-, 20-, and 25-ft vertical gate openings with the top seal and vertical pier extensions installed.

2.) Measure dynamic pressures on the ogee crest at the gate seat centerline without the top seal and vertical pier extensions installed. Measure static pressures at 8 taps along the centerline of the ogee crest in line with dynamic pressure measurement.
    - Vertical gate opening of 1 ft with pool EL 471.0
    - Vertical gate opening of 2 ft with pool EL 472.0
    - Vertical gate opening of 3 ft with pool EL 473.0
    - Vertical gate opening of 4 ft with pool EL 474.0
    - Vertical gate opening of 5 ft with pool EL 475.0
    - Vertical gate opening of 6 ft with pool EL 476.0

3.) Measure dynamic pressures on the ogee crest at the gate seat centerline with the top seal and vertical pier extensions installed. Measure static pressures at 8 taps along the centerline of the ogee crest in line with dynamic pressure measurement.
    - Vertical gate opening of 1 ft with pool EL 475.0
    - Vertical gate opening of 2 ft with pool EL 476.0
    - Vertical gate opening of 3 ft with pool EL 477.0
    - Vertical gate opening of 4 ft with pool EL 478.0
    - Vertical gate opening of 5 ft with pool EL 479.0
    - Vertical gate opening of 6 ft with pool EL 480.0

In the original test plan, discharge rating data were collected at 30-, 35-, 38-, 40-, and 42-ft vertical gate openings and compared to various physical and numerical model data collected over the years. Additional discharge rating data at lower gate openings (5-, 10-, 15-, 20-, and 25-ft) were requested for the current study.

Dynamic pressure measurements and observations of flow interactions with the gate lip will be used to determine if fluctuating down pull or uplift forces may exist on the emergency gates under higher water surface elevations and modified release operations. If down pull force fluctuations exist, they will originate from low pressures caused by flow clinging or reattaching to the gate lip. Direct force measurements of down pull and uplift could not be made because the physical hydraulic model was not designed to properly scale hydrodynamic interactions with the gate. Gate weight, material properties, and supports were not represented in the model and the hoist mechanism was omitted. However, pressure fluctuations on the crest near the gate lip may indicate if there are flow interactions that could cause fluctuating forces at the gate lip resulting in a negative impact on gate operation and the hoist system.

Instrumentation

A detailed discussion of flow and reservoir water surface elevation measurements is provided in Svoboda, 2014.

Static Pressure Measurements

Piezometer taps were used to measure static pressures and hence water surface elevations at 8 locations along the ogee crest. Taps were located at the centerline of the center bay, numbered 1 to 8 from upstream to downstream (Figure 1). 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. The water level measurement uncertainty of ± 0.005 ft model corresponds to ± 0.18 ft prototype.

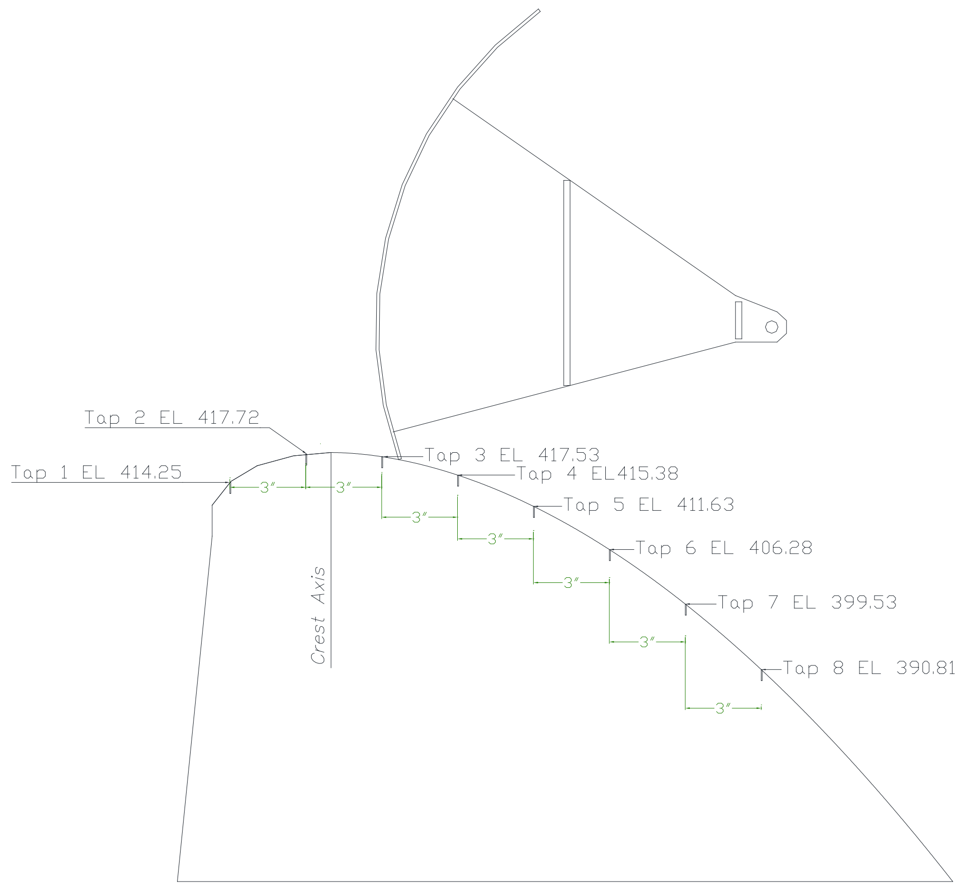

Figure 1. Ogee crest pressure taps (numbered 1-8 upstream to downstream).

Dynamic Pressure Measurements

A single Kistler piezoelectric pressure transducer (type 211B5) was used to measure dynamic pressure fluctuations at the gate seat. It has a pressure range of 0 – 100 psig, and a resolution of 0.001 psig. A sampling rate of 5 kHz was used, and the data were collected with a Measurement Computing 1616HS-4 Data Acquisition device connected to a lap top computer. The face of the pressure transducer (0.218 model-inch diameter) was mounted flush with the spillway crest at the gate seat (EL 417.16-ft, Figure 2). Transducer wiring was brought out the side of the spillway section then over the flume wall where it was connected to the power supply and data acquisition system.

Proper operation of the pressure transducer was confirmed by three separate methods for each test run. After the signal was zeroed with no flow over the spillway, the signal was tested by tapping on the transducer in the dry, recording the initial pressure spike as the crest became submerged, and then artificially inducing a pressure fluctuation from vortex shedding off of a 1-inch cylindrical rod upstream. In each case a correct transducer signal was verified.

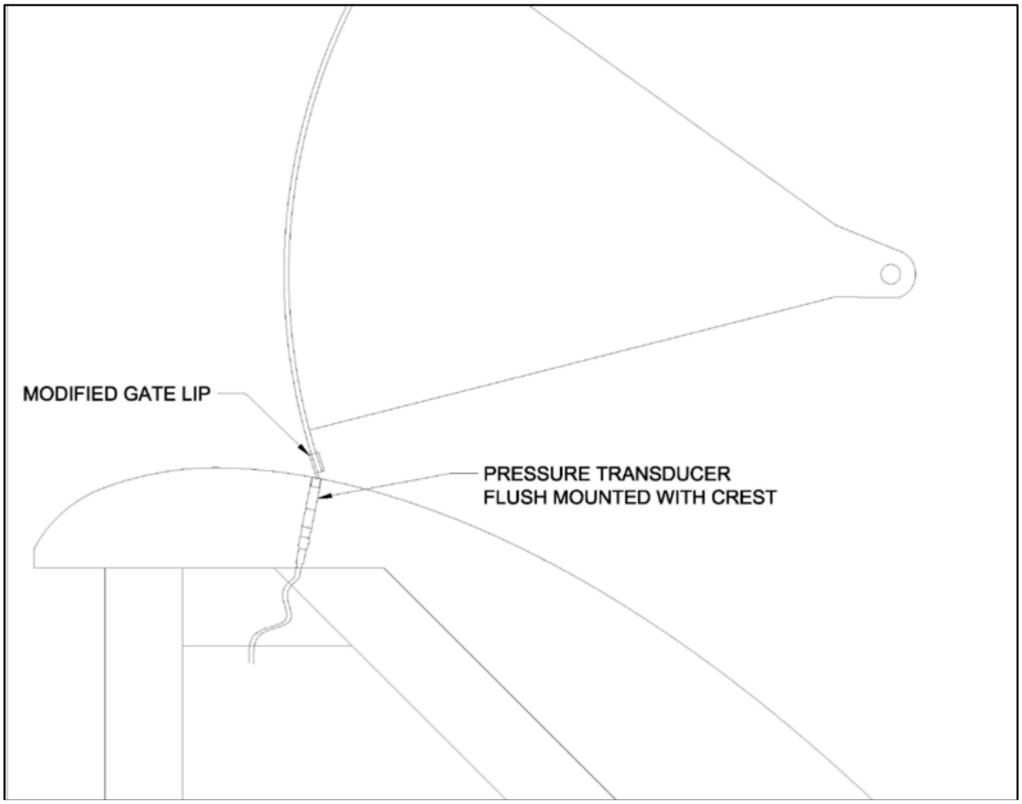

Figure 2. Installation of Kistler dynamic pressure transducer in model crest at gate seat.

The model gate lip was modified to match the geometry of the prototype gate for portion of the test plan involving pressure measurements. This was necessary to accurately represent flow interactions with the gate lip geometry. The schematic in Figure 3 shows the shape and dimensions of the modified gate lip which matches the prototype geometry provided in the bottom seal installation detail from Reclamation drawing number 485-D-2232 (Appendix C). The photograph in Figure 4 shows the modified gate lip in the model and the pressure transducer on the spillway crest.

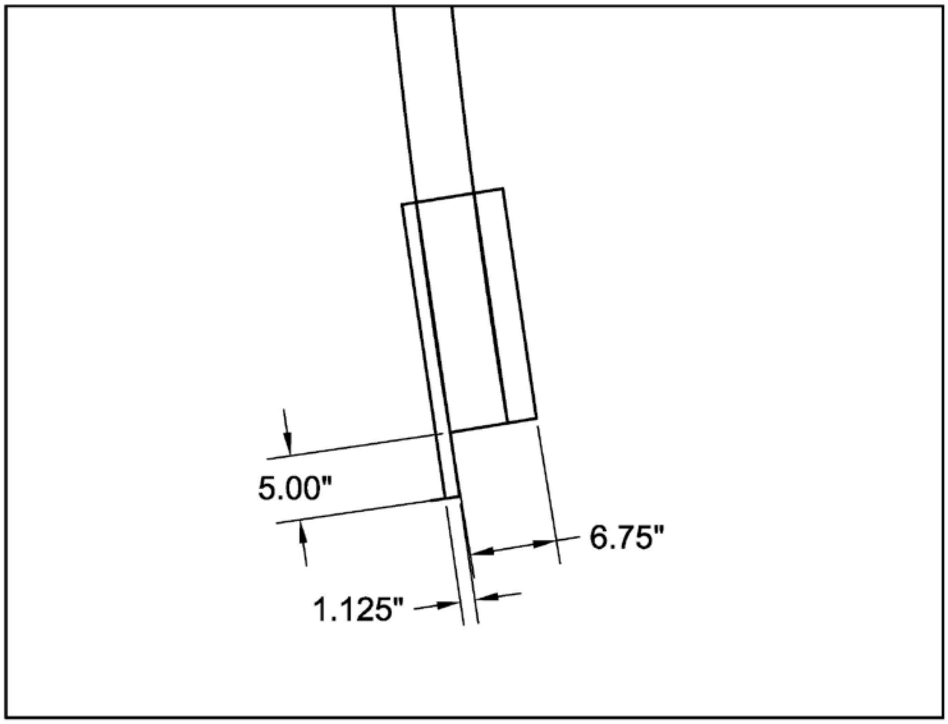

Figure 3. Modifications to gate lip to match bottom seal detail in drawing 485-D-2232 (dimensions are in prototype inches).

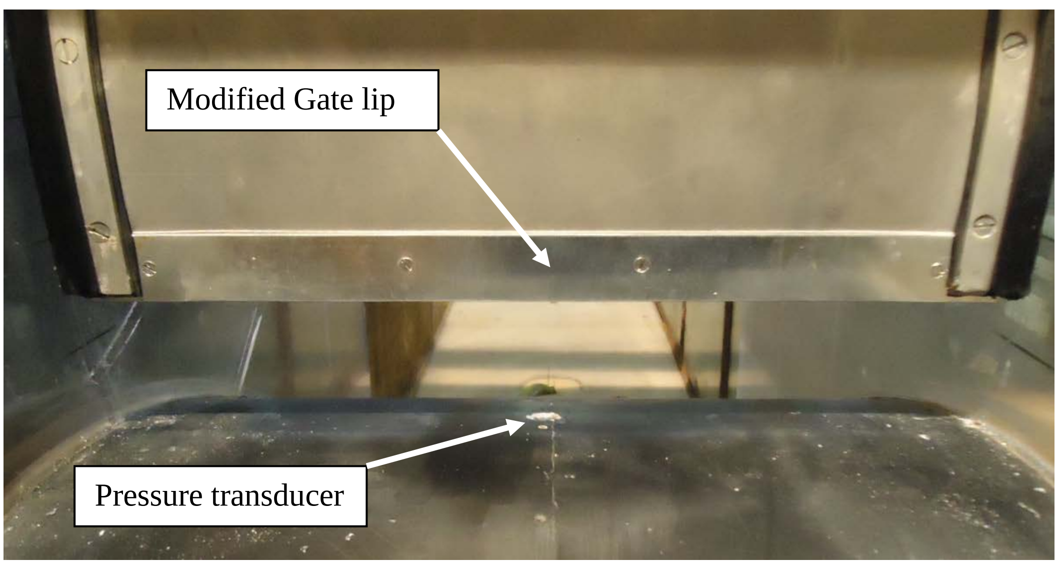

Figure 4. Modified gate lip geometry and flush mounted pressure transducer installed at the center line of the crest at the gate seat (looking downstream).

Results and Discussion

Discharge Rating Curves

Discharge rating data were collected at 5-, 10-, 15-, 20-, and 25-ft vertical gate openings with top seal, pier extensions, and seismic beams installed. The gate lip was not modified during these tests in order to directly compare discharge rating data to previous data collected at 30-, 35-, 38-, 40-, and 42-ft gate openings.

Without the top seal, water may overtop the piers at high reservoir water surface elevations. In the original test plan, overtopping occurred from EL 477-481 at a 30-ft gate opening, EL 479-481 at a 35-ft gate opening, and EL 480-481 at a 38-ft gate opening. Pier overtopping did not occur for 40- and 42-ft vertical gate openings due to strong drawdown under the gate.

The top seal prevents most overtopping from occurring. With the top seal installed, there may be some minor overtopping due to leakage through the seal. When enough leakage occurred in the model, water flowed either between the gate and the pier or over the top of the gate. Although this phenomenon was observed in the model using different model materials and a simplified top seal design, it is likely that some leakage will also occur in the prototype.

During the original test plan, data were collected at 35, 38, and 40 ft with and without top seals (Svoboda, 2014). In the current test plan, several discharge rating points were collected for 20- and 25-ft gate openings with and without top seals. The amount of flow passing over the piers or gates without the top seal is a small percentage of the overall flow past the gate. Therefore, there is no measurable difference between the discharge rating data.

Because there is no measurable difference between rating data collected with and without a top seal, data for vertical gates openings of 5, 10, 15, 20, 25, 30, 35, 38, 40 and 42 ft are plotted on the same figure (Figure 5). Simplified best fit curves for gated discharge ratings and uncontrolled flow are shown on Figure 5.

Data collected in the current 1:36-scale sectional Folsom Dam Raise model are compared to discharge rating data collected in the 1:50-scale Folsom Dam spillway model (1999) and the corresponding curve fits (Hall and Einhellig, 1997) in Figure 6. Discrepancies between model data likely occur for two reasons.

1. The 1:50-scale model included 5 spillway gates with a reservoir upstream of the spillway and the 1:36-scale sectional dam raise model included 2 spillway gates with no reservoir upstream of the spillway.

2. The 1:50-scale spillway model did not include the dam bridge or seismic beams and the 1:36-scale sectional dam raise model included both the dam bridge and the seismic beams.

The first major difference is the model layout. In the 1:50-scale spillway model, 5 gates on the service spillway were modeled and the emergency spillway was not modeled. With the reservoir modeled upstream of the service spillway, significant flow contraction occurred at gates 1 and 5 with straight approach flow for gate 3 only. In the 1:36-scale sectional dam raise model, only 2 gates were modeled and approach flow toward both gates was straight. The measured 2-gate discharge was converted to 5 gates using the 8 gate discharge correction factors obtained from numerical modeling (Frizell et al., 2009). During 8 gate operation, approach flow conditions produce increased contraction at the end piers, resulting in reduced effective area and additional energy losses at gates 1 and 8. Straighter approach flow conditions occur for the center gates 4 and 5. Application of the 8-gate discharge correction factors to the sectional model produced a higher overall value for the 5-gate discharge and the discharge curve shifts to the right of the 1:50-scale spillway model data.

The 1:36-scale discharge rating data most closely matches the 1:50-scale model at the lowest gate openings. At lower approach velocities, contraction off of the piers is not significant, so the layout of the models does not greatly affect discharge data. At higher approach velocities, flow contraction becomes significant. Flow contraction off of the piers is represented in the full-width model, but not well represented in the sectional model.

The second major difference between the models is the presence of the dam bridge and seismic beams. The 1:50-scale spillway model did not include the dam bridge or seismic beams and the 1:36-scale sectional dam raise model included the dam bridge and seismic beams. Both the seismic beams and bridge influence approach flow conditions to the gate, thereby affecting the discharge rating. The influence of the bridge is most apparent when water is on the bridge during high water reservoir elevations. The influence of the seismic beams is most apparent at larger gate openings when flow in the vicinity of the seismic beams is highly turbulent.

The transition zone curve is estimated on Figure 6. 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. 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. More discussion of the transition curve can be found in Svoboda, 2014.

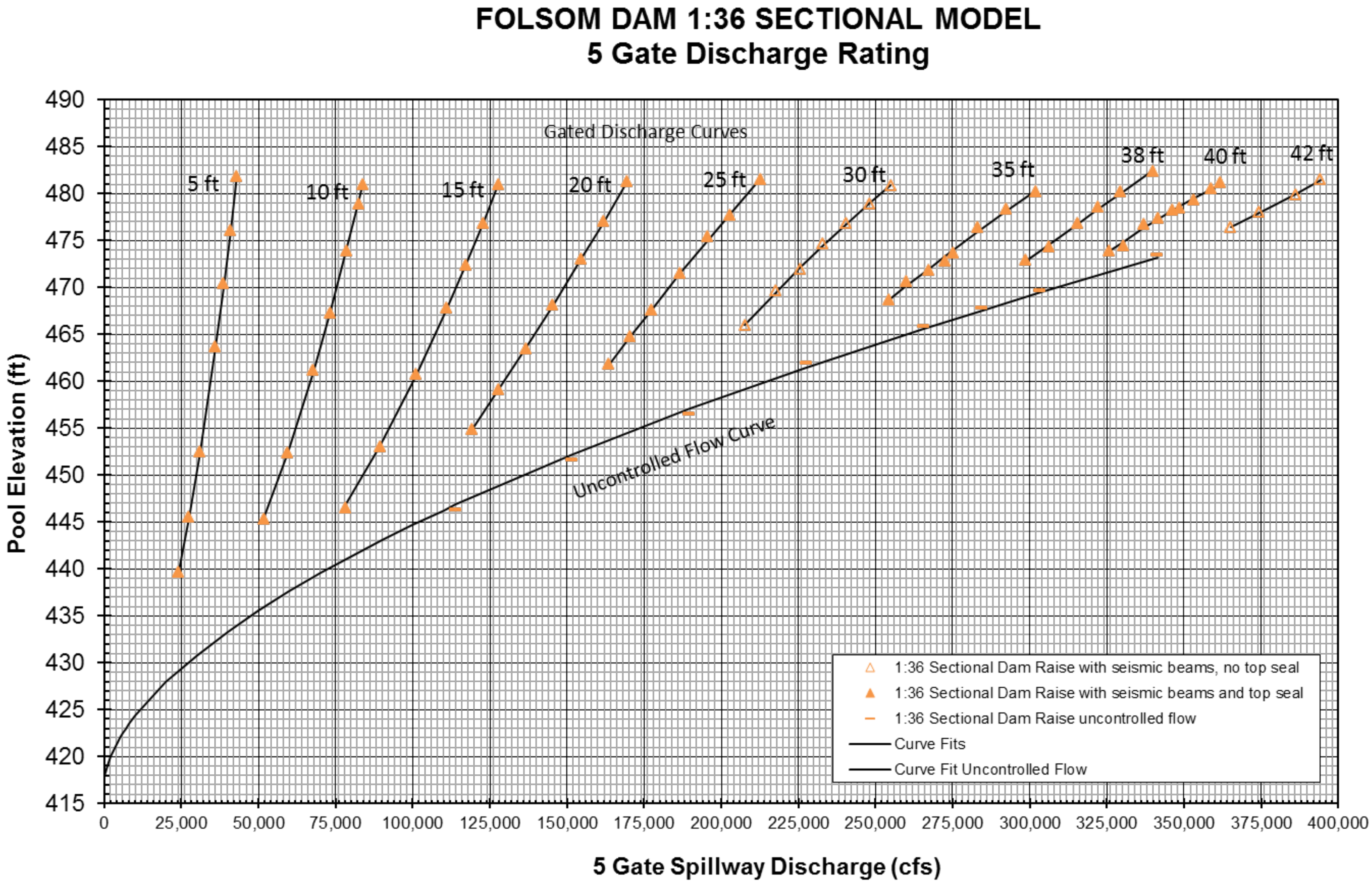

Figure 5. Discharge rating curves for 5-, 10-, 15-, 20-, 25-, 30-, 35-, 38-, 40-, and 42-ft gate openings.

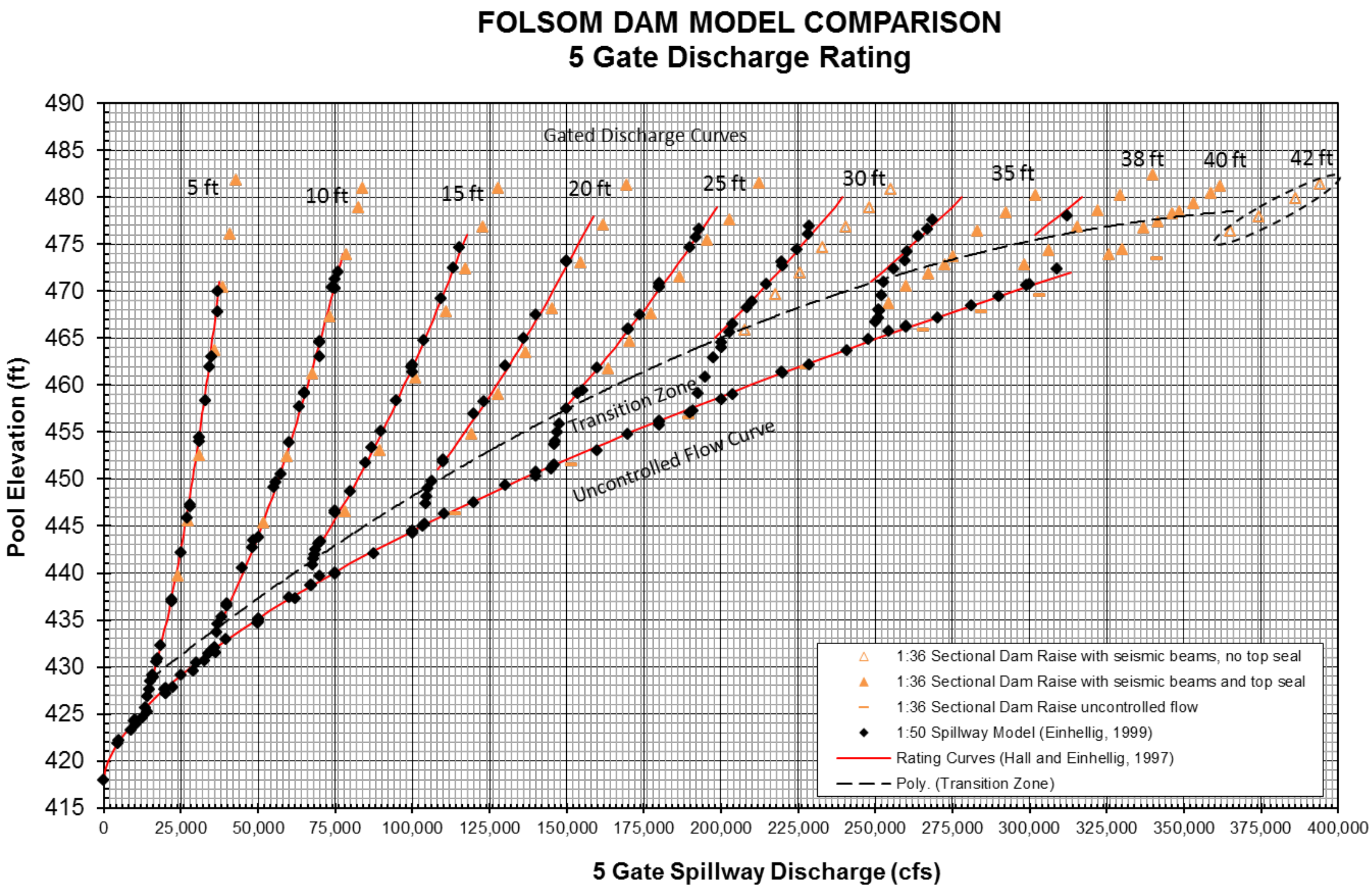

Figure 6. Comparison of 1:36-scale sectional Folsom Dam Raise model data (Svoboda, 2014) to 1:50-scale Folsom Dam spillway model data (Einhellig, 1999). The estimated transition zone is indicated on the graph.

Dynamic Pressure Measurements

Pressure fluctuations were measured at the gate seat to determine if dynamic down pull forces may exist due to flow reattachment or clinging at the gate lip. Video and photographs were also used to investigate how the flow interacts with the lip at lower gate openings. In general, both dynamic pressure data and video show that there are no significant fluctuations or reattachment present at the gate lip.

Laboratory Measurements and Analysis

Dynamic pressure data were analyzed to determine the magnitude and frequency of fluctuations at the gate seat. Overall, fluctuations were not significant for conditions both with and without a top seal at all tested gate openings. Since fluctuations in pressure were not apparent in the preliminary data, measurements were compared to a condition with no flow over the spillway. Figures 7 and 8 show the maximum and root-mean-square (RMS) pressure fluctuations measured in comparison with no flow over the transducer. In all cases, pressures fluctuated about a mean of approximately zero psi.

Time series data for each gate opening are displayed in Figures 9 and 10. These plots show that data at each gate opening are very similar to the no flow condition. There is a slight fluctuation apparent at a gate opening of 6-ft both with and without a top seal. However, the magnitude is too low (always less than ±5 psi) to cause any concern for down pull forces.

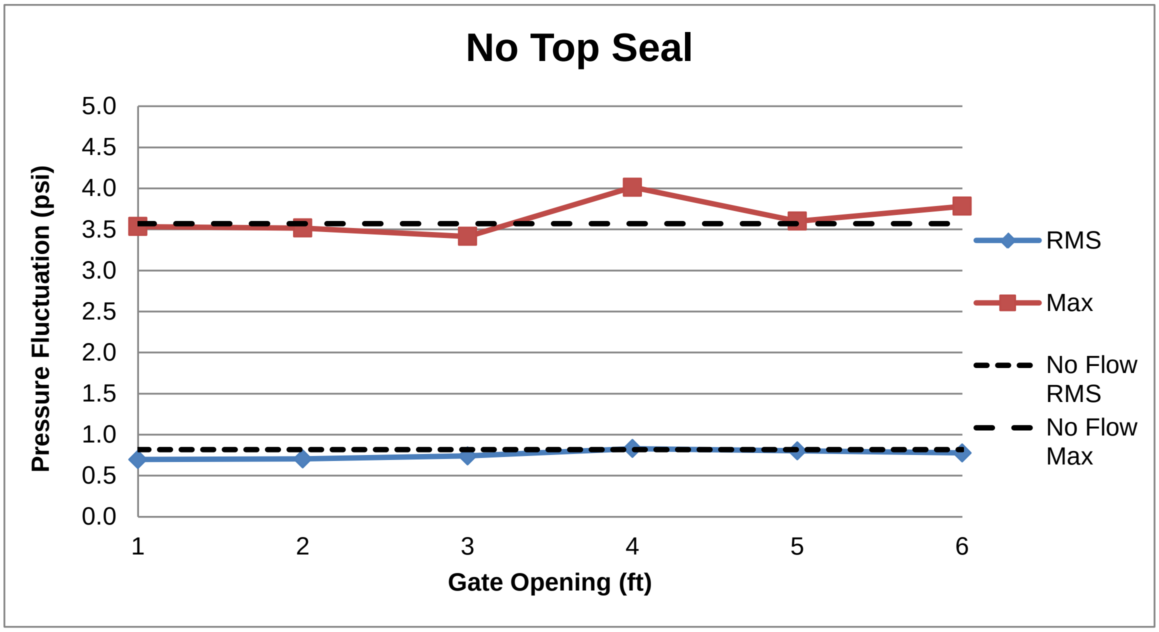

Figure 7. Maximum and RMS pressure fluctuations compared to the no flow condition recorded at the gate seat for test runs with no top seal.

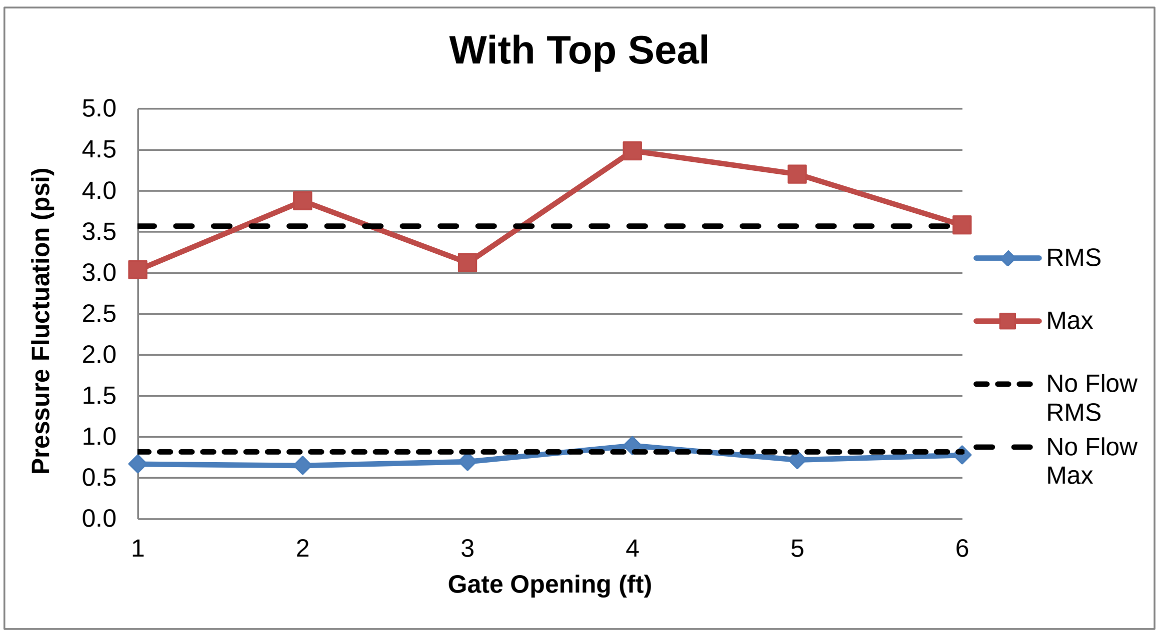

Figure 8. Maximum and RMS pressure fluctuations compared to the no flow condition recorded at the gate seat for test runs with a top seal.

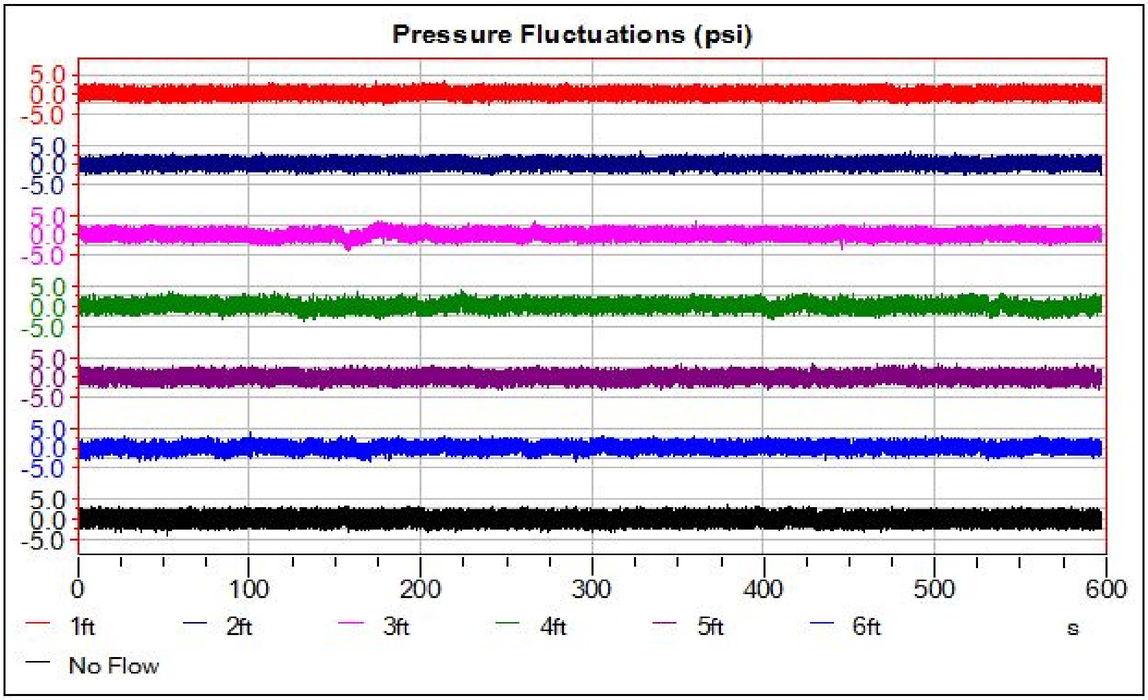

Figure 9. Time series dynamic pressure data for all gate openings with no top seal.

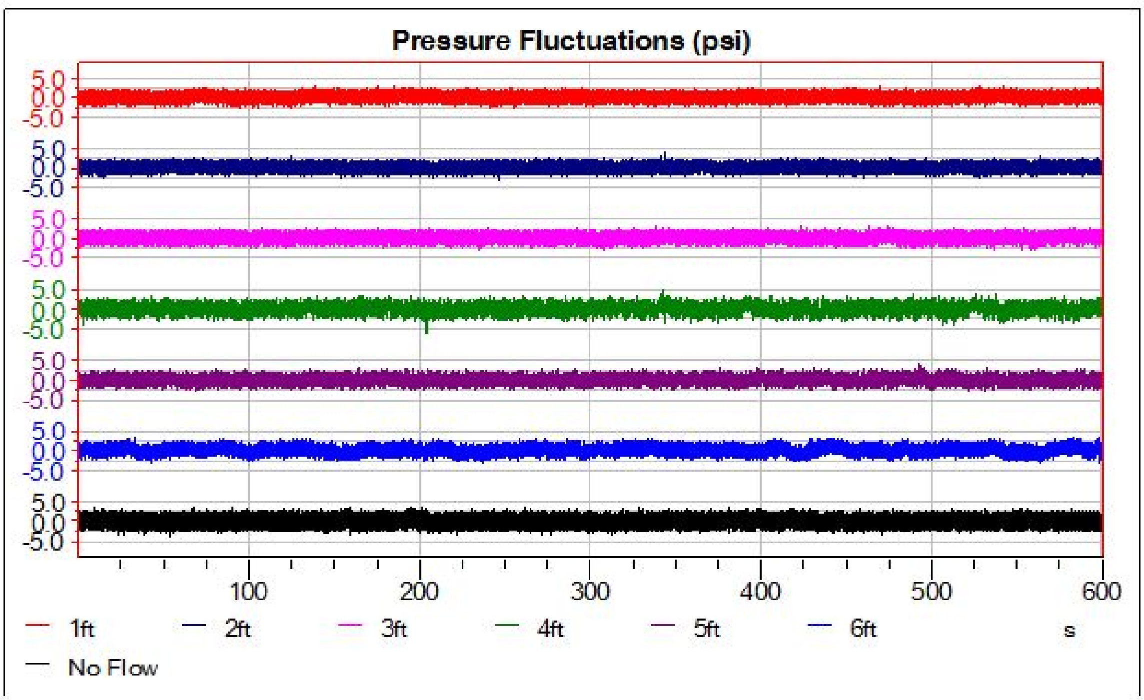

Figure 10. Time series dynamic pressure data for all gate openings with a top seal.

A frequency analysis was performed using the power density spectrum to identify any dominating fluctuation frequencies that might indicate the presence of a repetitive flow interaction with the gate lip. With a top seal, the only dominant frequency was at 0.03 Hz for the 6-ft gate opening (Figure 12). This corresponds to the slight fluctuation seen in the time series data in Figure 10. The fact that this frequency is so low (much less than 1 Hz) suggests that it was caused by some other flow interaction on the transducer that is not related to down pull on the gate. Fluctuations due to flow reattachment at the gate lip would likely occur at frequencies much higher than 1 Hz.

Frequency results for the condition without a top seal were quite similar (Figure 11). Again, a dominant frequency of about 0.03 Hz was seen at gate openings of 4- and 6-ft. The cause for this frequency is unknown, but may have been due to flow clinging to the back side of the gate leaf that joined the spillway flow near the transducer location. This clinging flow originated from leaks through the top seal and gate over topping without the top seal, and was visually observed in the model. While this condition is possible in the prototype, it is not likely to affect down pull forces on the gate.

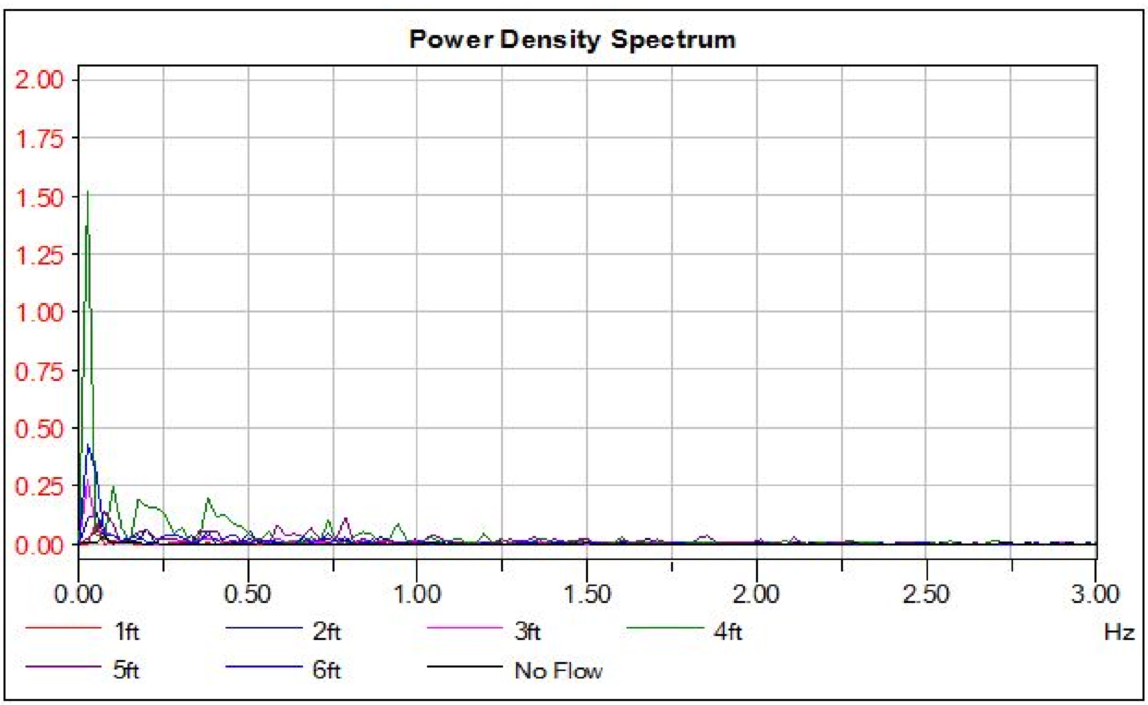

Figure 11. Power density spectrum showing frequencies for each gate opening with no top seal.

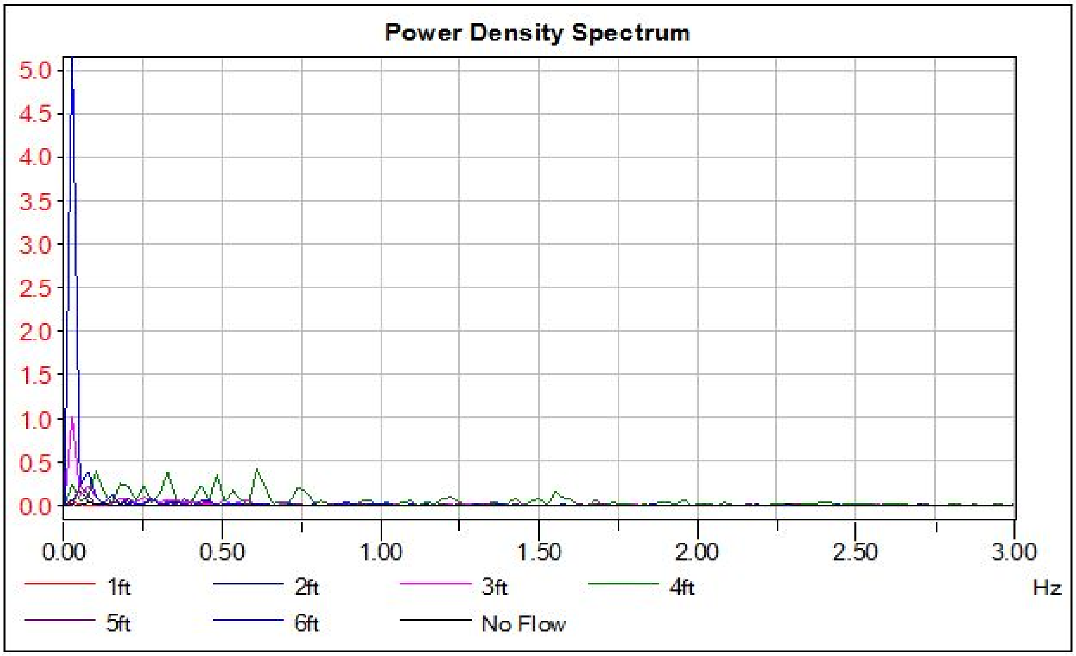

Figure 12. Power density spectrum showing frequencies for each gate opening with a top seal.

Visual Observations

Observations of the flow interaction with the gate lip were made for each gate opening. In every case the flow appeared to cleanly separate from the lip with no reattachment, clinging, or any other irregularity that would be a cause for concern (Figure 13).

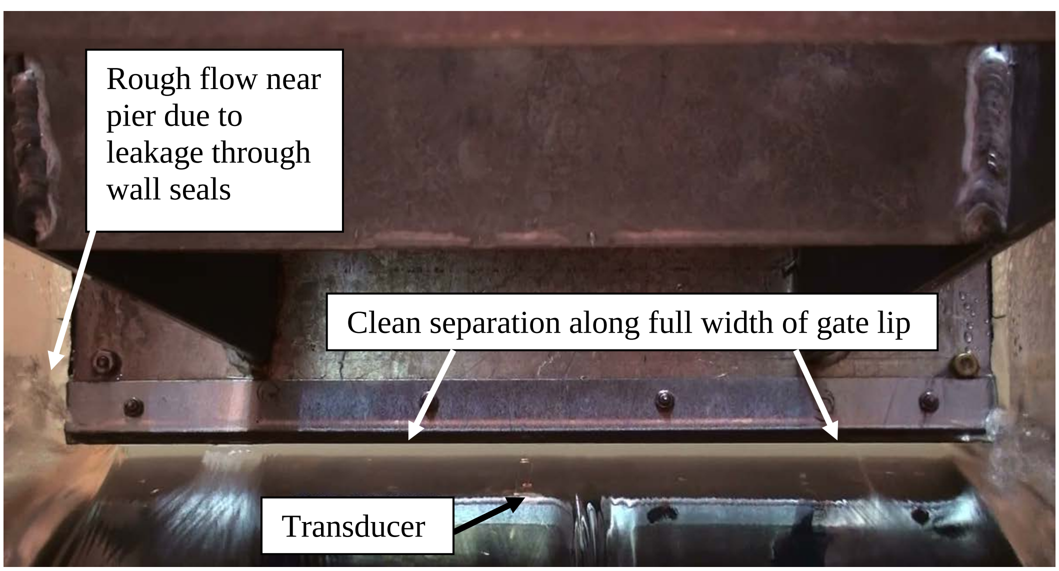

Figure 13. Photograph of spillway flow as it separates from the lip of the gate (directly behind the gate looking upstream).

Static Pressure Measurements

Measurements from the piezometer taps along the crest were collected at every test run using a manometer board. Readings appeared very steady with little to no variation on the manometer board, including those from taps near the gate lip. Again, results were very similar with and without a top seal (Figures 14 and 15). Tabular static pressure results are presented in Appendix B.

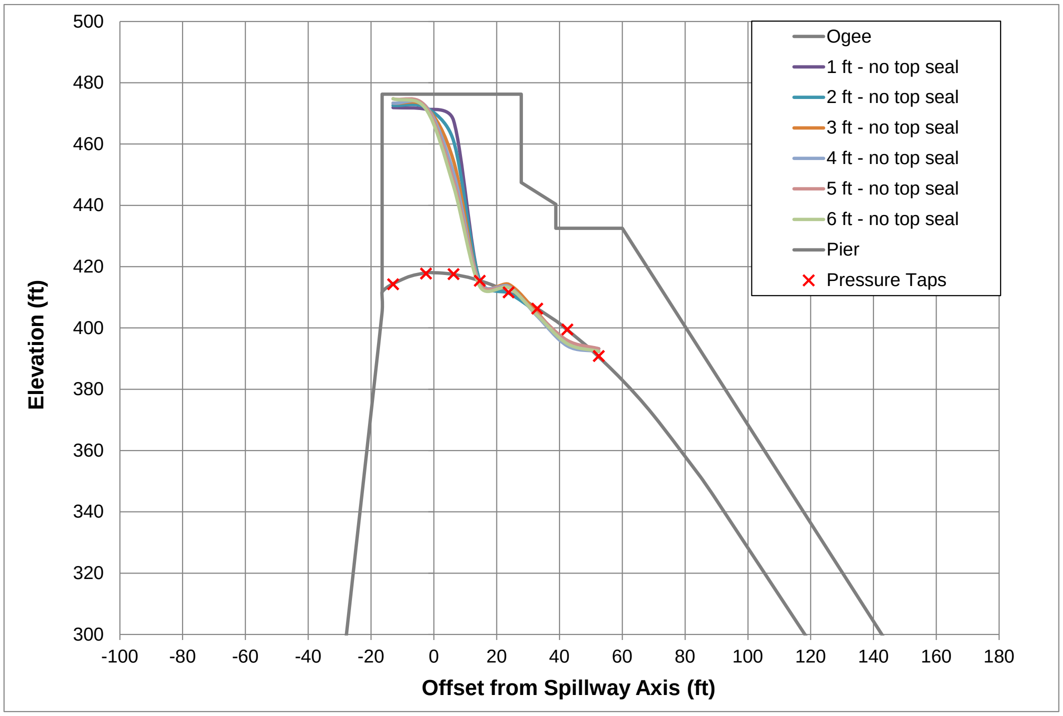

Figure 14. Static pressure data from spillway taps for test runs with no top seal.

Pressures at the first 3 upstream taps were much higher for the current testing (Figure 15) compared to those reported in Svoboda (2014) at higher gate openings. To verify pressure readings at these locations, additional measurements were taken at gate openings of 15-ft and 25-ft with a reservoir elevation near 477-ft. These are plotted in Figure 15 along with pressures at a 35-ft gate opening from Svoboda (2014) for a similar condition. The trend shown suggests that pressures decrease at these upstream locations for higher gate openings as there is more velocity head and the horizontal position of the gate lip moves further upstream as the gate opens.

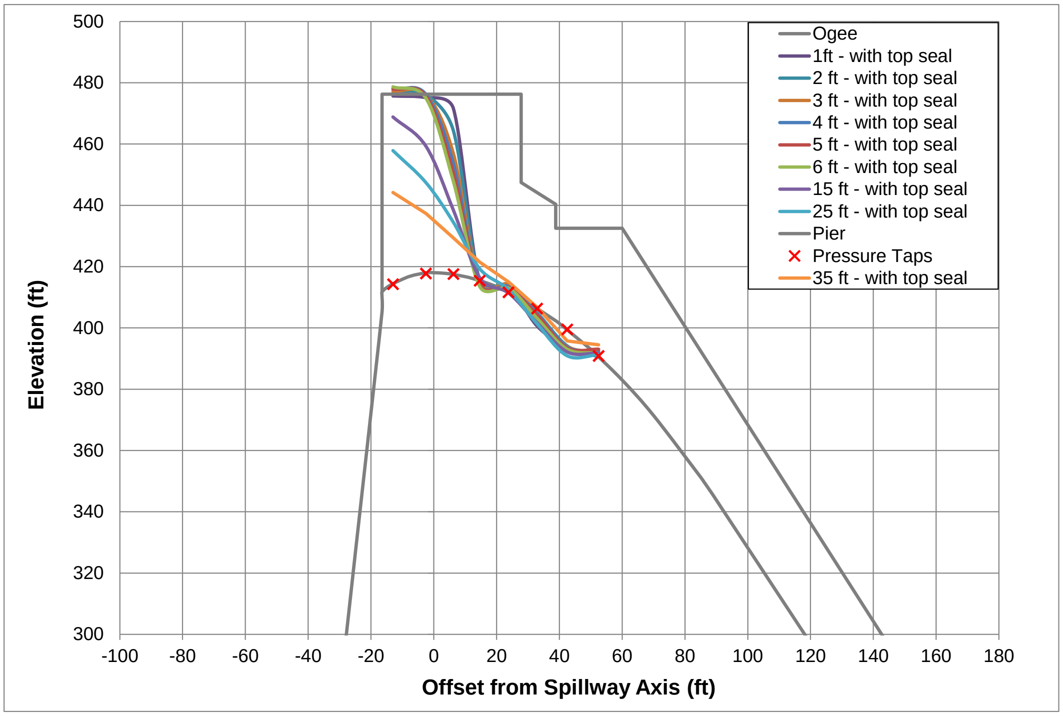

Figure 15. Static pressure data from spillway taps for test runs with a top seal.

Conclusions

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

- Discharge rating data were collected at 5-, 10-, 15-, 20-, and 25-ft vertical gate openings with top seal, pier extensions, and seismic beams installed. There was no measurable difference between rating data collected with and without a top seal.

- Dynamic pressure data were collected at 1-, 2-, 3-, 4-, 5-, and 6-ft vertical gate openings with and without a top seal. Measurements showed there were no significant pressure fluctuations at any gate opening. Video documentation showed that there was no reattachment or clinging of the flow to the gate lip. These results indicate that no significant down pull or uplift forces are expected at the gate lip with increased reservoir levels and modified release operations.

- Static pressure data collected at 1-, 2-, 3-, 4-, 5-, and 6-ft vertical gate openings with and without a top seal showed there were no significant fluctuations or negative pressures along the crest.

References

Einhellig, Robert F. (1999). “Hydraulic Model Folsom Dam Spillway Performance and Stilling Basin Abrasion”. Bureau of Reclamation, Technical Service Center, Water Resources Research Laboratory Report R-99-08, Denver, Colorado.

Frizell, K. W., J. P. Kubitschek, and R. F. Einhellig (2009). “Folsom Dam Joint Federal Project Existing Spillway Modeling - Discharge Capacity Studies.” Bureau of Reclamation, Hydraulic Laboratory Report HL-2008-03, Denver, Colorado.

Hall, Ernest and Robert Einhellig. (1997). “Recommended Flood Operations for Folsom Dam”. Technical Memorandum No. FD-8130-FD-TM-97-3, Bureau of Reclamation, Denver, Colorado.

Svoboda, Connie D. (2014). “Physical Hydraulic Model Study of Folsom Dam Emergency Spillway Tainter Gate Alternatives”. Bureau of Reclamation, Technical Service Center, Hydraulic Laboratory Report HL-2014-01, Denver, Colorado.

APPENDIX A

Summary of Observations for 5-, 10-, 15-, 20-, and 25-ft Vertical Gate Openings

Table 1. Model observations with top seal and seismic beams installed. WSEL = water surface elevation.

	Corrected Data*		
Gate Opening	**Reservoir Water Level (ft)**	**Discharge 5 Gate (cfs)**	**Key Observations**
5 ft with Top Seal and Seismic Beams	439.69	24,110	WSEL below bridge and beams. No vortices. No pier overtopping.
	445.56	27,389	WSEL below bridge and beams. No vortices. No pier overtopping.
	452.47	31,054	WSEL below bridge and beams. No vortices. No pier overtopping.
	463.67	36,069	WSEL below bridge and beams. No vortices. No pier overtopping.
	470.40	38,577	WSEL below bridge, but submerging beams. Water on top seal. No turbulence. No vortices. No pier overtopping.
	476.09	40,891	WSEL above bridge and beams. No air pocket under bridge. Water on top seal. Water leaking through seal overtops across top of gate.
	481.85	43,013	WSEL above bridge and beams. No air pocket under bridge. Water on top seal. Water leaking through seal overtops across top of gate.
10 ft with Top Seal and Seismic Beams	445.28	51,693	WSEL below bridge and beams. No vortices. No pier overtopping.
	452.42	59,408	WSEL below bridge and beams. No vortices. No pier overtopping.
	461.13	67,702	WSEL below bridge and beams. No vortices. No pier overtopping.
	467.26	73,103	WSEL below bridge and beams. No vortices. No pier overtopping.
	473.85	78,504	WSEL above bridge and beams. No air pocket under bridge. Water on top seal. No turbulence. No vortices. Water on top seal. No pier overtopping.
	478.92	82,361	Water on top seal. Water leaking through seal overtops across top of gate.
	480.98	83,712	Water on top seal. Water leaking through seal overtops across top of gate.

	Corrected Data*		
Gate Opening	Reservoir Water Level (ft)	Discharge 5 Gate (cfs)	Key Observations
15 ft with Top Seal and Seismic Beams	446.53	78,118	WSEL below bridge and beams. 2 continuous, small weak vortices at edges of gate. No pier overtopping.
	453.06	89,305	WSEL below bridge and beams. 2 continuous, small weak vortices at edges of gate. No pier overtopping.
	460.70	100,878	WSEL below bridge and beams. 1 intermittent weak vortex. No pier overtopping
	467.84	110,908	WSEL below bridge and just below beams. 1 intermittent weak vortex. No pier overtopping.
	472.34	117,080	WSEL just below bridge, submerging beams. No vortices. Water on top seal. No pier overtopping.
	476.85	122,867	WSEL above bridge and beams. No air pocket under bridge. Water on top seal. No turbulence. No vortices. Water on top seal. No pier overtopping.
	480.99	127,882	Water on top seal. Water leaking through seal overtops along gate edges.
20 ft with Top Seal and Seismic Beams	454.83	119,202	WSEL below bridge and beams. 2 continuous, small vortices at edges of gate.
	459.05	127,689	WSEL below bridge and beams. 1 continuous, small vortices at center of gate.
	463.45	136,562	WSEL below bridge and beams. 1 intermittent, small vortex at center of gate.
	468.14	145,434	WSEL below bridge and at very bottom of beams. 1 intermittent, weak vortex.
	472.94	153,921	WSEL above bridge and beams. Air pocket under bridge. No vortices. No pier overtopping.
	477.59	162,601	WSEL above bridge and beams. Water filled under bridge. Pier overtopping.
	480.09	168,966	WSEL above bridge and beams. Water filled under bridge. Gate & pier overtopping.
20 ft without Top Seal and with Seismic Beams	472.98	154,500	Water on top seal. No overtopping.
	477.09	161,829	Water on top seal. No overtopping.
	481.27	169,545	Water on top seal. Water leaking through seal overtops along gate edges.

	Corrected Data*		
Gate Opening	**Reservoir Water Level (ft)**	**Discharge 5 Gate (cfs)**	**Key Observations**
25 ft with Top Seal and Seismic Beams	461.78	163,565	WSEL below bridge and beams. Continuous vortices.
	464.70	170,509	WSEL below bridge and beams. Continuous vortices.
	467.63	177,453	WSEL below bridge & just below beams. Small, intermittent vortices.
	471.46	186,519	WSEL below bridge. WSEL interacting with beams, moving above/between beams. No vortices.
	475.39	195,584	WSEL above bridge & beams. Air pocket under bridge deck. No spill over piers.
	477.96	202,335	WSEL on bridge. Water fills space under bridge. Some spill over piers.
	480.96	211,593	WSEL on bridge. Water fills space under bridge. Significant spill over piers.
25 ft without Top Seal and with Seismic Beams	477.64	202,914	WSEL on bridge. Water fills space under bridge. Water on top seal. No overtopping from leakage.
	481.50	212,558	WSEL on bridge. Water fills space under bridge. Water leaking through seal overtops along gate edges.

* Velocity head correction applied and discharge measurement converted to 5 gate operation. Modifications to reservoir water surface elevation and discharge are described in detail in Svoboda (2014).

APPENDIX B

Dynamic and Static Pressure Data for 1-, 2-, 3-, 4-, 5-, and 6-ft Vertical Gate Openings

Table 2. Maximum and root-mean-square (RMS) dynamic pressure data measured with no top seal and with seismic beams installed, measured relative to the spillway elevation at the gate seat (EL = 417.16 ft).

	Corrected Data*			Dynamic Pressure on Gate Seat	
Gate Opening No Top Seal	Reservoir Water Surface Elevation (ft)	Prototype Discharge 5 gate (cfs)		RMS	Max
1	471.00	8,942	Pressure (psi)	0.70	3.54
			Pressure (ft)	1.61	8.17
2	472.12	16,135	Pressure (psi)	0.71	3.52
			Pressure (ft)	1.63	8.12
3	472.95	27,410	Pressure (psi)	0.74	3.41
			Pressure (ft)	1.71	7.89
4	474.03	34,603	Pressure (psi)	0.83	4.01
			Pressure (ft)	1.92	9.27
5	475.08	42,962	Pressure (psi)	0.80	3.60
			Pressure (ft)	1.85	8.32
6	476.10	55,598	Pressure (psi)	0.78	3.78
			Pressure (ft)	1.80	8.74
No Flow	N/A	N/A	Pressure (psi)	0.82	3.57
			Pressure (ft)	1.89	8.25

* Velocity head correction applied and discharge measurement converted to 5 gate operation. Modifications to reservoir water surface elevation and discharge are described in detail in Svoboda (2014).

Table 3. Maximum and root-mean-square (RMS) dynamic pressure data measured with a top seal and seismic beams installed, measured relative to the spillway elevation at the gate seat (EL = 417.16 ft).

	Corrected Data*			Dynamic Pressure on Gate Seat	
Gate Opening with Top Seal	**Reservoir Water Surface Elevation (ft)**	**Prototype Discharge 5 gate (cfs)**		**RMS**	**Max**
1	474.89	9,331	Pressure (psi)	0.67	3.04
			Pressure (ft)	1.55	7.01
2	475.97	17,302	Pressure (psi)	0.65	3.88
			Pressure (ft)	1.50	8.95
3	477.34	28,188	Pressure (psi)	0.70	3.12
			Pressure (ft)	1.61	7.22
4	478.32	34,992	Pressure (psi)	0.89	4.49
			Pressure (ft)	2.07	10.36
5	478.93	44,712	Pressure (psi)	0.72	4.20
			Pressure (ft)	1.67	9.71
6	480.05	54,821	Pressure (psi)	0.78	3.58
			Pressure (ft)	1.80	8.27
No Flow	N/A	N/A	Pressure (psi)	0.82	3.57
			Pressure (ft)	1.89	8.25

* Velocity head correction applied and discharge measurement converted to 5 gate operation. Modifications to reservoir water surface elevation and discharge are described in detail in Svoboda (2014).

Table 4. Static spillway pressure measurements on crest with no top seal and with seismic beams installed.

Gate Opening No Top Seal	Corrected Data* Reservoir Water Surface Elevation (ft)	Corrected Data* Prototype 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
1	471.00	8,942	Elevation	471.89	471.35	467.75	415.01	413.21	404.75	394.85	392.33
			Pressure (ft)	57.6	53.6	50.2	-0.4	1.6	-1.5	-4.7	1.5
2	472.12	16,135	Elevation	472.61	471.89	461.09	415.55	411.41	404.75	394.49	393.23
			Pressure (ft)	58.4	54.2	43.6	0.2	-0.2	-1.5	-5.0	2.4
3	472.95	27,410	Elevation	473.33	472.04	454.54	414.40	414.26	405.00	394.49	392.48
			Pressure (ft)	59.1	54.3	37.0	-1.0	2.6	-1.3	-5.0	1.7
4	474.03	34,603	Elevation	473.87	472.07	450.65	411.41	418.61	405.29	394.49	393.23
			Pressure (ft)	59.6	54.4	33.1	-4.0	7.0	-1.0	-5.0	2.4
5	475.08	42,962	Elevation	474.77	472.07	448.13	414.47	413.21	404.57	395.93	393.23
			Pressure (ft)	60.5	54.4	30.6	-0.9	1.6	-1.7	-3.6	2.4
6	476.10	55,598	Elevation	474.77	471.35	446.33	413.61	413.18	404.18	394.85	392.37
			Pressure (ft)	60.5	53.6	28.8	-1.8	1.6	-2.1	-4.7	1.6

* Velocity head correction applied and discharge measurement converted to 5 gate operation. Modifications to reservoir water surface elevation and discharge are described in detail in Svoboda (2014).

Table 5. Static spillway pressure measurements from taps on crest with a top seal and seismic beams installed.

	Corrected Data*			**Spillway Pressure on Ogee Crest**							
Gate Opening with Top Seal	**Reservoir Water Surface Elevation (ft)**	**Prototype Discharge 5 gate (cfs)**		**Tap 1**	**Tap 2**	**Tap 3**	**Tap 4**	**Tap 5**	**Tap 6**	**Tap 7**	**Tap 8**
1	474.89	9,331	Elevation	475.67	475.13	471.57	415.41	413.82	400.61	393.77	390.89
			Pressure (ft)	61.4	57.4	54.0	0.0	2.2	-5.7	-5.8	0.1
2	475.97	17,302	Elevation	476.57	476.03	464.33	415.37	414.29	404.93	394.13	390.53
			Pressure (ft)	62.3	58.3	46.8	0.0	2.7	-1.3	-5.4	-0.3
3	477.34	28,188	Elevation	477.29	476.18	456.84	414.47	414.29	403.96	393.95	392.30
			Pressure (ft)	63.0	58.5	39.3	-0.9	2.7	-2.3	-5.6	1.5
4	478.32	34,992	Elevation	477.98	476.21	453.53	414.29	413.57	404.57	393.77	392.51
			Pressure (ft)	63.7	58.5	36.0	-1.1	1.9	-1.7	-5.8	1.7
5	478.93	44,712	Elevation	478.01	475.67	450.47	414.11	413.21	404.21	393.41	393.05
			Pressure (ft)	63.8	58.0	32.9	-1.3	1.6	-2.1	-6.1	2.2
6	480.05	54,821	Elevation	478.66	474.95	447.77	413.57	413.03	403.13	393.05	391.79
			Pressure (ft)	64.4	57.2	30.2	-1.8	1.4	-3.1	-6.5	1.0
15	476.81	123,060	Elevation	468.83	459.29	438.41	416.45	411.41	401.69	392.15	391.79
			Pressure (ft)	54.6	41.6	20.9	1.1	-0.2	-4.6	-7.4	1.0
25	476.88	202,914	Elevation	457.85	447.41	434.45	419.33	412.49	401.33	390.89	391.25
			Pressure (ft)	43.6	29.7	16.9	4.0	0.9	-4.9	-8.6	0.4
35**	476.35	283,061	Elevation	444.17	437.33	429.41	421.49	415.01	406.73	395.75	394.49
			Pressure (ft)	29.9	19.6	11.9	6.1	3.4	0.5	-3.8	3.7

* Velocity head correction applied and discharge measurement converted to 5 gate operation. Modifications to reservoir water surface elevation and discharge are described in detail in Svoboda (2014).
** Data for 35-ft gate opening reported in Svoboda (2014).

APPENDIX C

Drawing 485-D-2232 used for gate lip geometry

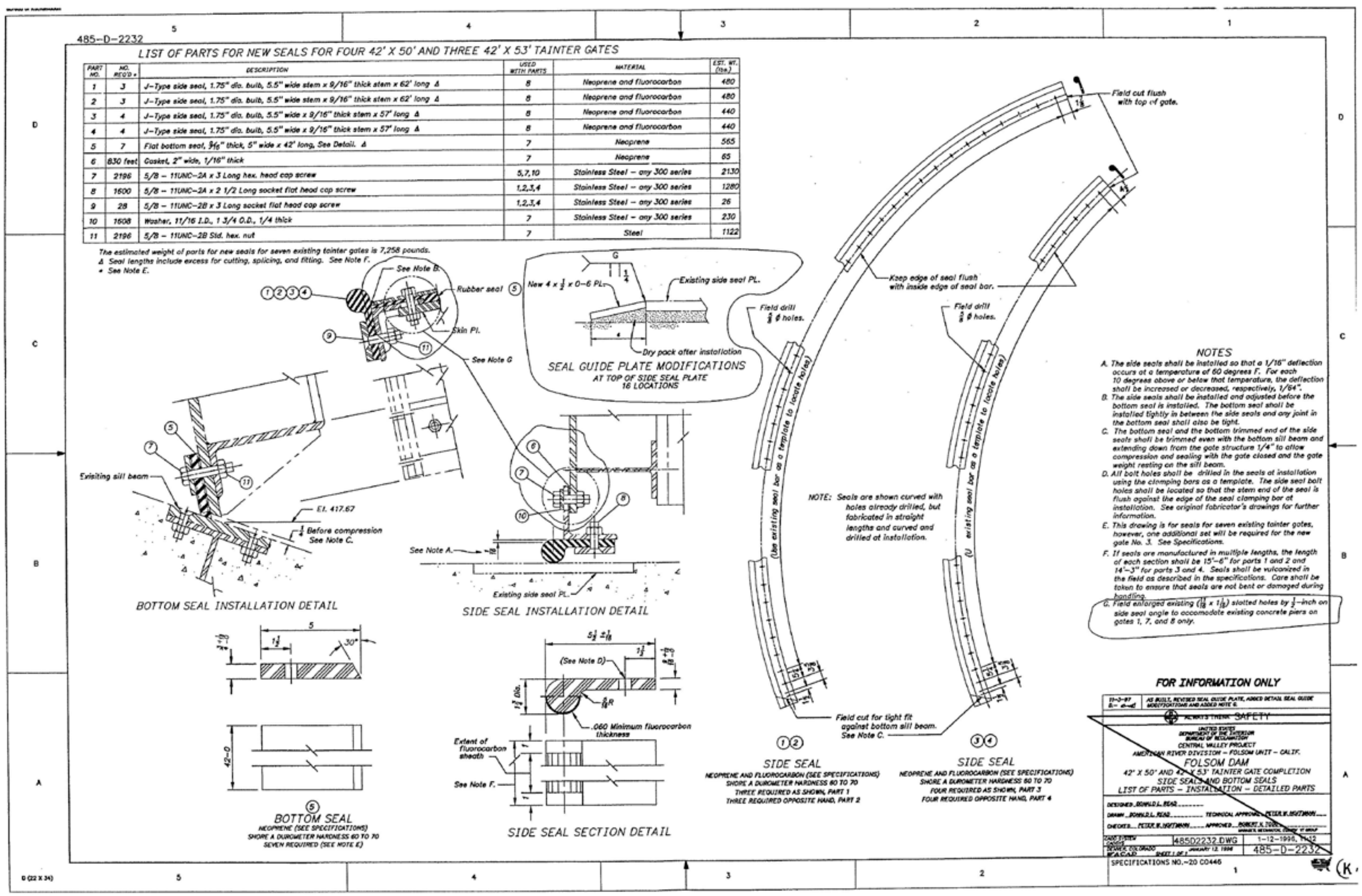

Figure 16. Reclamation drawing 485-D-2232 used for gate lip geometry shown in the Bottom Seal Installation Detail.