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ARROWROCK DAM MID-LEVEL OUTLET WORKS REHABILITATION 48-INCH CLAMSHELL GATE CONCEPT

1:10.67 SCALE PHYSICAL MODEL STUDY

July 2001

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation Water Resources Research Laboratory in Denver, Colorado, conducted a 1:10.67 Froude-scale physical model study of the Arrowrock Dam outlet works clamshell gate concept . Hydrostatic and hydrodynamic loading on the proposed gate-house structure during submerged operating conditions was determined. The maximum static pressure differential across any part of the structure did not exceed 2.5 feet of water (1.2 lb/in^2). The peak external dynamic pressure differential did not exceed 1.0 foot of water (0.44 lb/in^2). Thus, a minimum total pressure differential of 3.5 feet of water (2.0-lb/in^2) represents an adequate design value for the gate-house structure. Internal pressure differentials were also determined. The maximum internal static pressure did not exceed 0.75 foot of water (0.32 lb/in^2) and the peak internal dynamic pressure differential did not exceed 1.0 foot of water (0.44 lb/in^2.) Thus, the total internal load across the top of the gate-house structure is not expected to exceed 1.75 feet of water (0.75 lb/in^2). Surface vortices were observed during model operation submergences of prototypes below tailwater elevation 3035 feet. Although undesirable, such conditions are not expected to influence prototype performance of the clamshell gates.

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July 2001

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Mission Statements

U.S. Department of the Interior

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 tribes.

Bureau of Reclamation

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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PURPOSE

This report documents the results of physical model investigations associated with the Arrowrock Dam mid-level outlet works rehabilitation concept. The concept consists of replacing the existing 10 mid-level ensign valves with 7 48-in and 3 66-in clamshell gates to be located on the downstream face of Arrowrock Dam. The results of this study establish proof-of-concept.

APPLICATION

The information included in this report is intended for site-specific application to Arrowrock Dam. Hydrostatic and hydrodynamic loading on the proposed clamshell-gate house structure under submerged operating conditions was determined specifically for the proposed configuration and associated operating conditions.

INTRODUCTION

BACKGROUND

Arrowrock Dam is a 350-foot-high concrete gravity-arch dam with a crest length of 1,150 feet. Figure 1 is a general location map of the project. The dam is located on the Boise River, approximately 42 miles downstream from Anderson Ranch Dam and at the upstream end of Lucky Peak Reservoir. The appurtenances include a concrete side-channel spillway, 20 outlet conduits through the dam, and 5 sluice outlets. Figure 2 is a general plan and section layout. The spillway has a maximum capacity of 40,000 ft^3/s and is regulated by six 62-foot-long by 6-foot-high drum gates. Of the 20 outlet conduits, 10 are located in an adjacent arrangement at elevation 3018 feet (mid-level). The remaining, outlets are located at elevation 3105 feet (upper-level). Each of the existing outlets is independently regulated by 58-inch ensign valves, each having a maximum capacity of 960 ft^3/s. The five sluice outlets are located at elevation 2967 feet and are independently regulated using 5-foot-wide by 5-foot-high pressure gates.

PROTOTYPE OPERATION

Arrowrock Dam is one in a series of three storage reservoirs on the Boise River, including Anderson Ranch and Lucky Peak Dams. Figure 3 is a photograph of Arrowrock dam during operation of the upper-level outlets. Each of these structures provides both storage and flood control and is operated in accordance with seasonal

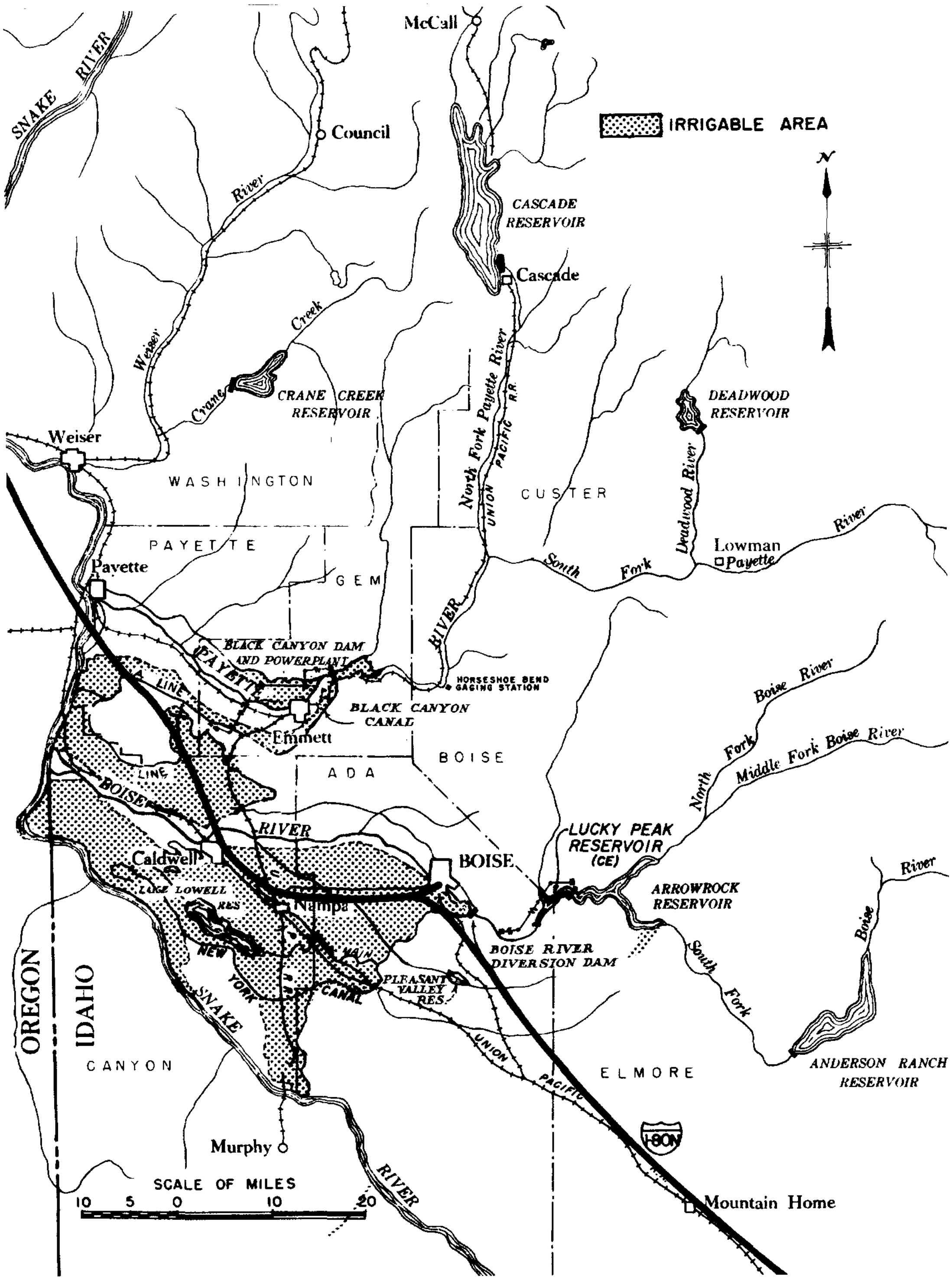


Figure 1. – Boise Project general location map showing location of Arrowrock Dam and Reservoir.

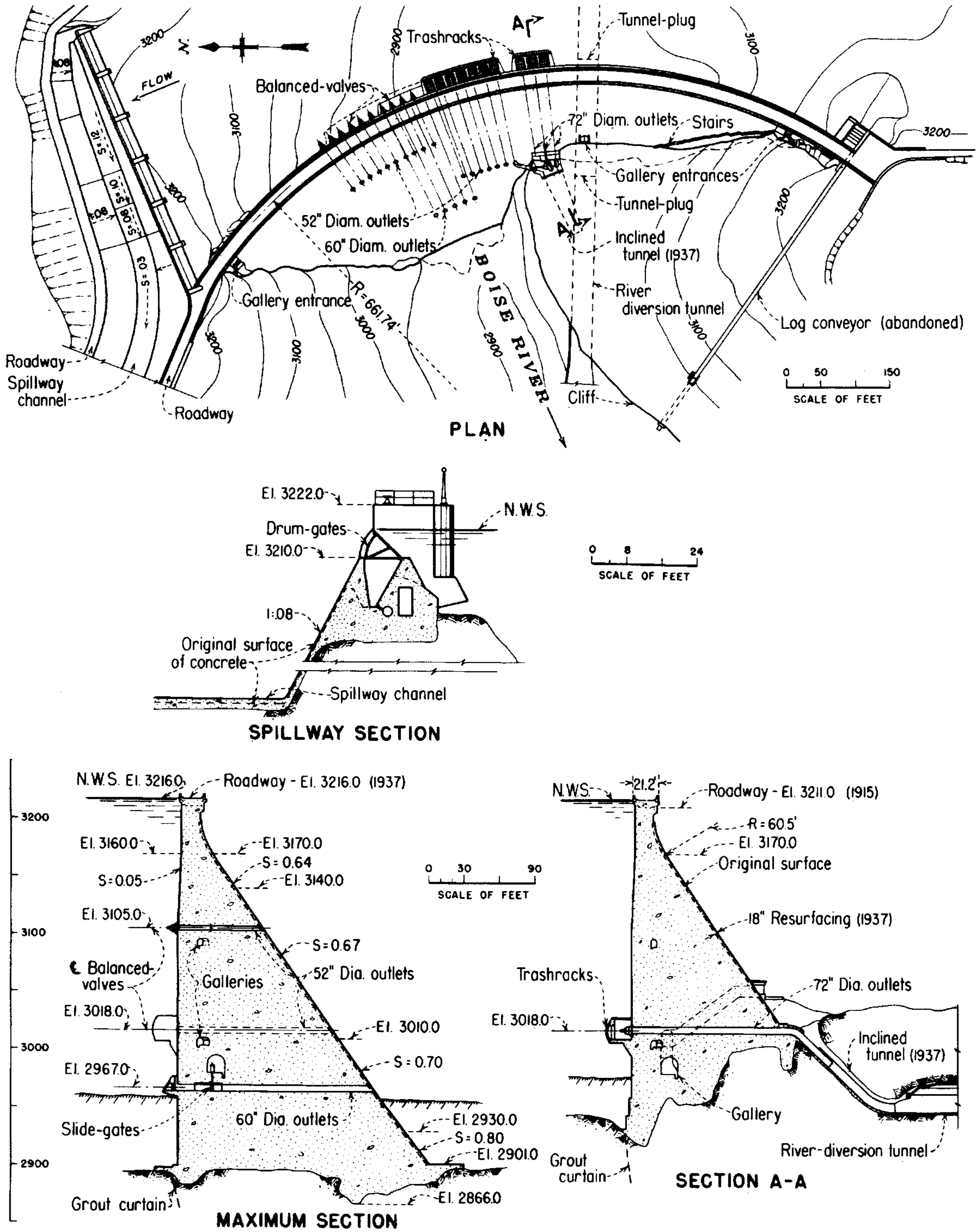


Figure 2. – General plan and section details for Arrowrock Dam.

Figure 3. – Photograph of Arrowrock Dam illustrating proposed mid-level outlet works modifications.

needs in those respects. During a normal irrigation season, each reservoir is filled to its typical operating water surface elevation and releases are made from Anderson Ranch and Arrowrock Reservoirs to meet irrigation demand at Lucky Peak Reservoir. The normal operating water surface elevation at Lucky Peak Reservoir is between elevations 3050-3055 feet, which is above the existing Arrowrock Dam mid-level outlets elevation of 3018 feet.

Currently, all the outlets except outlets 1, 2, and 3 are operational. These outlets were locked out of service in 1990 because of extensive cavitation damage in the conduits downstream from the ensign valves. All the conduits have experienced cavitation damage throughout their service. Various concepts have been identified for improving the cavitation problems inherent to ensign valves and the operating conditions at Arrowrock Dam. Mefford [2] conducted physical model investigations of submerged jet flow gates to assess application potential at Arrowrock Dam. However, the clamshell gate modification alternative was selected. This concept moves the release control for these outlets to the downstream end of the outlet conduits and, by doing so, eliminates the cavitation potential associated with the existing upstream control configuration using ensign valves. A complete description of the various conceptual alternatives and the selected clamshell concept has been documented during the feasibility phase of this project as "Arrowrock Dam Outlet Works Rehabilitation Final Conceptual Design," March 2000 [3]. Although the clamshell gate concept is relatively new, it has been used before. One example of such use is Grassy Lake, for which physical model investigations were conducted by Fitzwater and Frizell [2]. However, the clamshell gate concept has yet to be used under submerged operating conditions, and hence this physical model study was recommended to demonstrate proof of concept.

CLAMSHELL GATE CONCEPT DESCRIPTION

The clamshell gate concept consists of replacing the existing 10 mid-level outlet ensign valves located upstream of the outlet conduits with 7 48-in and 3 66-in clamshell gates located downstream from the outlet conduit. In addition, the existing outlet conduits will be reinforced with steel liners of the same size, and bulkhead gates will be installed at the upstream end of the conduits. A gate-house structure will be constructed on the downstream face of the dam to support and house the new clamshell gates. The gate-house will consist of a concrete enclosure and access structure. The clamshell gates themselves consist of a cylindrical valve body and two radial-gate leafs. The gate leafs are actuated using hydraulic cylinders and can be positioned from fully closed to 100-percent open. Figures 4 and 5 show the conceptual profile and plan view layout for the proposed outlet works modification at Arrowrock Dam. The primary advantages of these gates include increased flow capacity and reduced cavitation potential. Furthermore, the location of the gates affords improved accessibility for inspection and maintenance.

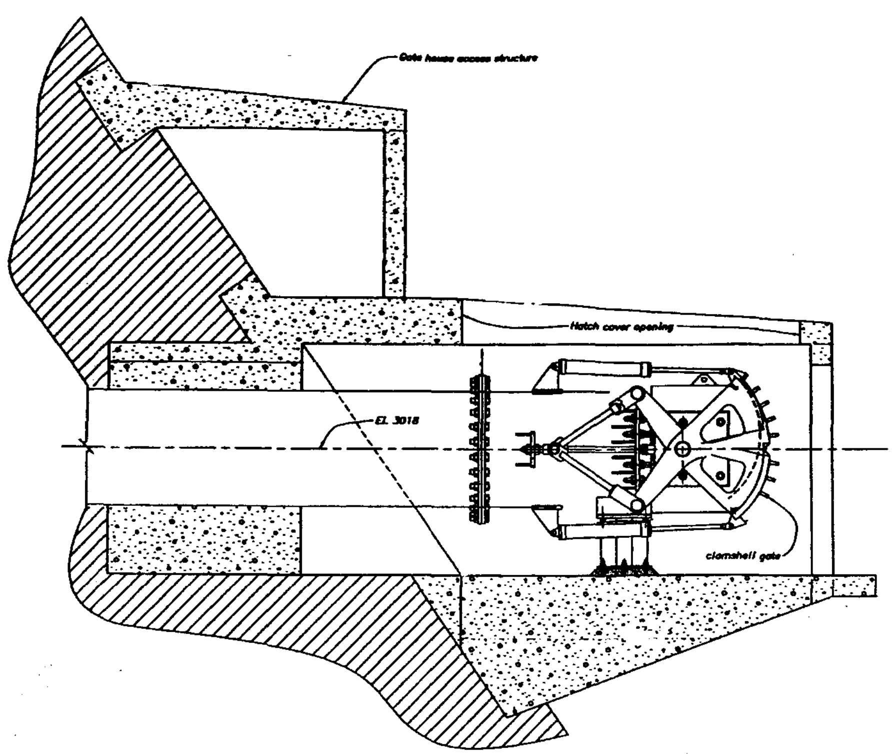


Figure 4. – Elevation view of clamshell gate concept.

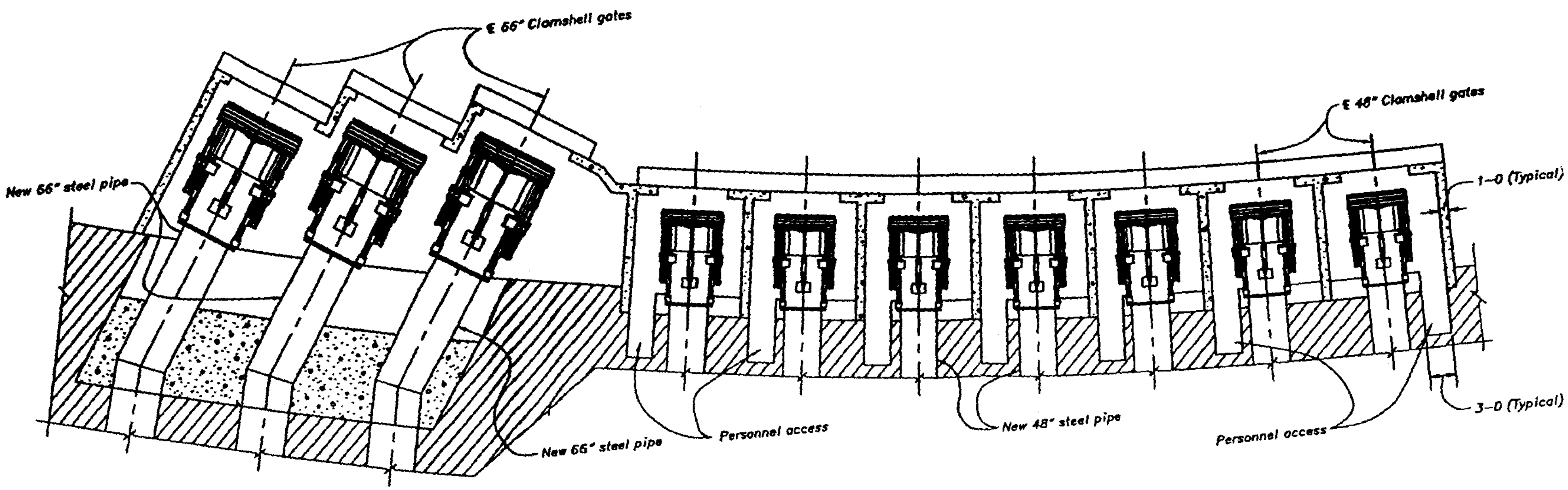


Figure 5. – Plan view layout of outlet works modifications.

CONCLUSIONS

- In general, all three configurations tested appear to perform adequately. However, locating the clamshell gates in each gate-house such that the issuing jet is entirely outside of the structure (configuration 3) appears to produce the lowest static and dynamic pressure differentials across the structure as well as reduced surface vortex action. Thus, a configuration similar to configuration 3 is recommended for the final design.

- Static and dynamic pressure differentials may be internal or external depending on which gates are operated and in what manner. Although the maximum static pressure differential observed was 2.5 feet of water (1.2 lb/in^2) in all cases tested, the results of the dynamic testing indicate that a larger design value of 3.5 feet of water (2.0-lb/in^2) total differential loading is required because the dynamic loading will be superimposed on the static loading.

- Internal pressure differentials were also determined for design of the access hatches located above each gate bay on top of the gate-house structure. The results indicate that the maximum internal static pressure across the top of the gate-house structure did not exceed 0.75 foot of water (0.32 lb/in^2), and the measured peak dynamic pressure differential did not exceed 1.0 foot of water (0.44 lb/in^2.) Thus, the total internal differential across the access hatches is not expected to exceed 1.75 feet of water (0.75 lb/in^2) during submerged operation.

- Submergences below tailwater elevation 3035 feet produced significant surface vortex action that was air entraining, in some cases. Such operating conditions are not expected to influence clamshell performance, but are generally considered undesirable.

- Tailrace flow patterns, in all cases tested, were observed to be upwelling from below and in front of the gate-house structure. Surface recirculation was observed to be directed laterally along the gate-house structure, toward the operating gates. In both cases, this feature resulted from recirculation to the shear zone produced by the issuing jet. The recirculation strength will probably diminish in the prototype because there is a much larger tailrace extent than was modeled for this study.

- Submergence produced by tailwater elevations at the outlet centerline elevation 3018 feet resulted in unsteady slugflow and large "roostertails" downstream from the gate-house for all cases tested. During free release (nonsubmerged) conditions, no jet impingement on the gate-house structure was observed for configuration 3. Configurations 1 and 2 produced some jet impingement on the gate-house caused by the lateral spray created by the jet.

PHYSICAL MODEL

DESCRIPTION

A 1:10.67 Froude-scale physical model of three adjacent, mid-level, 48-in clamshell gates was constructed at Reclamation's Water Resources Research Laboratory in Denver, Colorado. Figure 6 is a photograph of the model as constructed in the laboratory. The scale was chosen such that a standard diameter pipe could be used and to achieve sufficiently large Reynolds numbers (i.e. $Re_d > 5 \times 10^5$) such that scaling effects with respect to viscosity are negligible. The modeling of three adjacent gates was selected as the minimum spatial extent to determine adjacent gate interaction for multiple outlet operation (e.g. this allowed for operation of a single gate, operation of two adjacent gates, operation of two gates separated by a non-operating gate, and operation of three adjacent gates). The tailrace was modeled using a 10-foot-deep by 10-foot-wide by 30-foot-long tail box. This approach allowed for adequate spatial extent to achieve desired submergence while minimizing lateral effects of the model boundaries. No tailrace topography was modeled during this study.

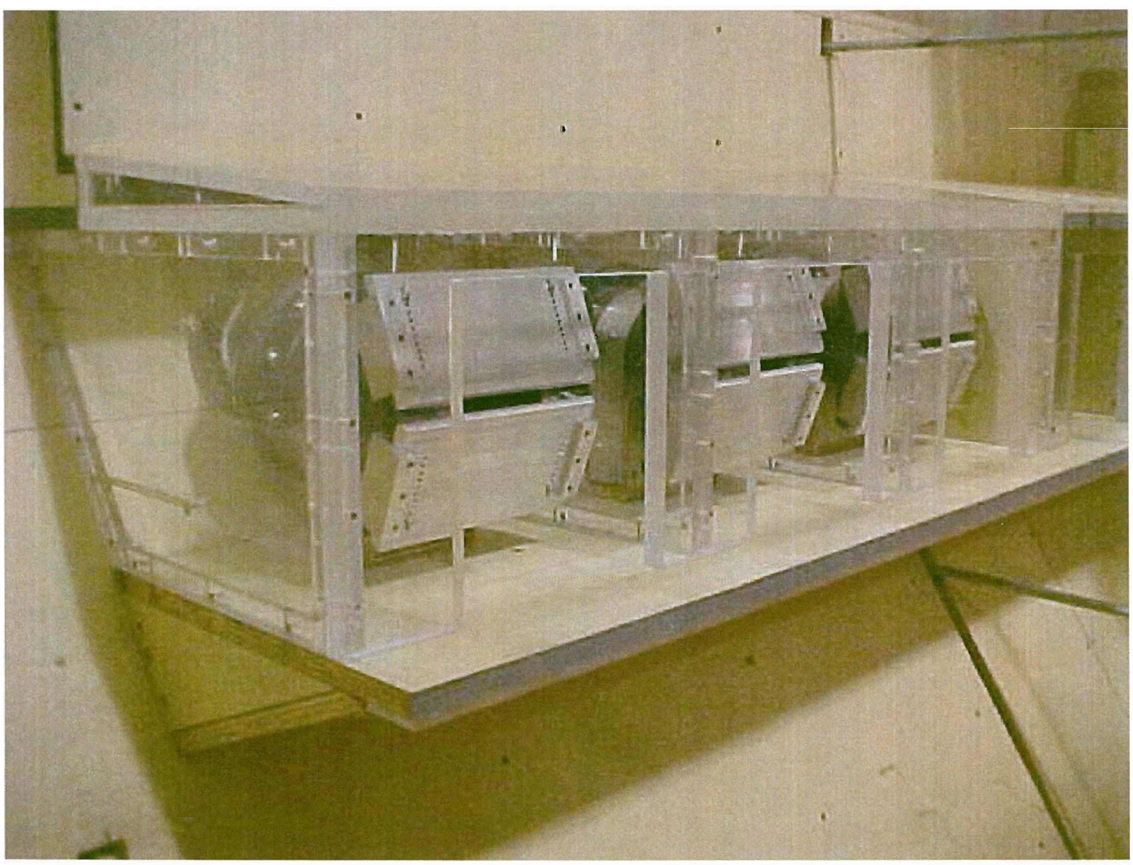


Figure 6. – 1:10.67 scale physical model of three adjacent 48-inch clamshell gates and corresponding gate-house structure.

The clamshell gates were modeled using a simplified angled-slide gate arrangement to facilitate model construction and operation while representing similar jet geometry and hydrodynamics of the prototype clamshell gates (i.e., prototype gate performance was represented without the design complexity of the prototype gates). Figure 7 is a photograph of the slide gate configuration used to represent the clamshell gates. The three gates modeled represent prototype gates 8, 9, and 10. The discharge coefficient (C_d) for the slide-gate configuration was compared with those for the clamshell gates and found to be within 2.0-percent for the full range of gate settings (10- to100-percent open). The slide gate configuration was found to have slightly higher discharge coefficients over this range as compared with the clamshell gate. This result was determined to be because of gate geometry that produced slightly larger gate openings at each 10-percent incremental gate setting, shifting the discharge coefficient curve slightly to the left.

Figure 7. – Slide gate arrangement used to model the 48-in clamshell gates at 1:10.67 scale.

SIMILITUDE

To adequately represent prototype performance, the physical model must achieve geometric and kinematic similarity to the prototype. Geometric similarity is achieved with the ratios of all geometric lengths between the model and the prototype being equal, thus producing similarity in form. Kinematic similarity is achieved with the ratios of all velocities at geometrically similar points being equal. This approach presumes that gravitational forces predominate; hence kinematic similitude is achieved solely by maintaining equal Froude numbers between model and prototype. The Froude number is defined as:

$$\mathrm{Fr} \equiv \frac{\text{Inertial Forces}}{\text{Gravitational Forces}} \equiv \frac{U}{\sqrt{gL}} \tag{1}$$

where:
$U \equiv$ characteristic velocity
$L \equiv$ characteristic length
$g \equiv$ gravitational acceleration

Based on this approach, the geometric and kinematic scale relationships are determined as

Geometric
L_r = length ratio = L_p/L_m = 10.67
A_r = area ratio = $(L_r)^2$ = 113.78
V_r = volume ratio = $(L_r)^3$ = 1,213.63

Kinematic
T_r = time ratio = $(L_r)^{1/2}$ = 3.27
U_r = velocity ratio = $(L_r)^{1/2}$ = 3.27
a_r = acceleration ratio = 1.0
Q_r = discharge ratio = $(L_r)^{5/2}$ = 371.60

Dynamic
F_r = force ratio = $(L_r)^3$ = 1,213.63
P_r = pressure ratio = L_r = 10.67
E_r = energy ratio = $(L_r)^4$ = 12,945.38

Because viscous forces are also expected to have some influence in the physical model for this application, it is necessary to define the relationship between inertial forces and viscous forces to ascertain the degree of influence of viscous effects. The Reynolds number based on pipe diameter provides this indication and is defined as:

$$Re_d \equiv \frac{inertial\ forces}{viscous\ forces} \equiv \frac{UL}{\nu} \tag{2}$$

where
$U \equiv$ characteristic velocity (pipe average velocity in this case)
$L \equiv$ characteristic length (pipe diameter in this case)
$\nu \equiv$ kinematic viscosity of water (1.217×10^{-5} ft^2/s @ 60°F)

It is important to note that the Reynolds number based on pipe diameter was found to be on the order of 8.4×10^4 for the smallest gate opening (i.e., 10 percent) and 8.8×10^5 for the largest gate opening (i.e., 100 percent). A Reynolds number of 5×10^5 is generally considered to be sufficient to neglect viscous effects in scaling between model and prototype. Thus, at lower gate settings (e.g., 10-50 percent openings), some viscous effects are inherent to this model. Such effects are manifest in how vortex formation and downstream jet diffusion characteristics scale between model and prototype. Thus, prototype surface vortices in the tailrace will be stronger and jet diffusion will be reduced as compared with model observations. However, model observations for larger gate openings (e.g., 60-100 percent) are expected to correspond closely with prototype characteristics.

METHODS

Static and dynamic pressures were measured during submerged operating conditions. Static pressures were acquired in and around the gate-house structure at 38 locations using piezometer taps attached to a single-end manometer board from which differential pressures were calculated at corresponding locations. Figure 8 is a schematic of the gate-house structure. The schematic identifies static pressure measurement locations. Following static pressure testing for all three configurations, dynamic pressures were measured for configuration 3 that represented the lowest static pressure differentials. The largest static pressure fluctuations were used to determine locations for dynamic pressure measurements. Three Kistler 30-psi 606A high-impedance dynamic pressure transducers were flush-mount installed at those selected locations; one was internal and one external to the gate bay for gate 9, and the remaining transducer external to the gate bay for gate 8. The sensors have 0.436-inch-diameter heads and measure the fluctuating pressure component about the mean or static pressure. An IOTech® 1-MHz, 16-bit data acquisition system was used to simultaneously sample dynamic pressures at a rate of 20 Hz over a period of 5 minutes.

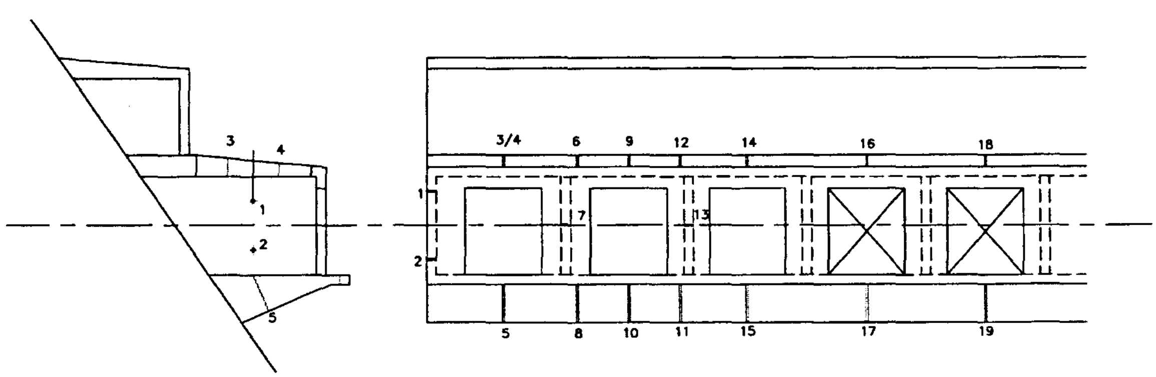


Figure 8. - Piezometer tap locations where static pressure differentials were measured. Gate 10 is located in the far-left gate bay, and gates 9 and 8 are located in the respective adjacent bays.

A total of three gate configurations were evaluated. Each configuration is distinguished by gate position in the gate-house structure. Configuration 1 represents clamshell gates set back from the face of the gate-house structure opening as illustrated in figure 10. Configuration 2 represents clamshell gates located such that the gate lips were flush with the inside face of the end of the gate-house structure as illustrated in figure 11. And, configuration 3 represents clamshell gates located such that the gate lips protrude outside of the gate-house structure as illustrated in figure 12. For all three configurations, three gate settings (10, 50, and 100-percent gate openings) were tested under two submergence conditions representing tailwater elevations 3025.5 feet (top of gate-house structure) and 3035 feet (top of access structure). Gate settings of 10, 50, and 100 percent open were deemed adequate to span the range of possible prototype operations. Furthermore, gate operations were tested in various combinations of single, 2-gate, and 3-gate operation. The required prototype clamshell gate discharges were established for each gate opening from the results of a numerical analysis (Appendix A: Head-Discharge Curves for Outlet Works, HDCOW) completed during the model design phase of this study. For that analysis, the Arrowrock Dam operating reservoir elevation was chosen as elevation 3210 feet and corresponds with the spillway crest elevation. This reservoir elevation represents the maximum discharge conditions expected for the prototype. The head-discharge results are plotted as figure 13 for the full range of reservoir elevations 3050-3210 feet.

The influence of submergence on performance was also evaluated. Submergence, in this case, is defined as the depth of tailwater above the outlet conduit centerline (elevation 3018 feet). For all tests, submergence conditions were evaluated in the range of tailwater elevations 7.25 –10 feet (model) that corresponds to tailwater elevation 3025.25 – 3055 feet (prototype). Elevation 3025.25 feet is the top elevation of the gate-house (figures 10, 11, and 12) and, therefore, was used as a lower limit of submergence for these tests. Similarly, elevation 3055 feet is the normal reservoir elevation for Lucky Peak and typical tailwater elevation for Arrowrock Dam and, therefore, was taken as the upper limit of submergence.

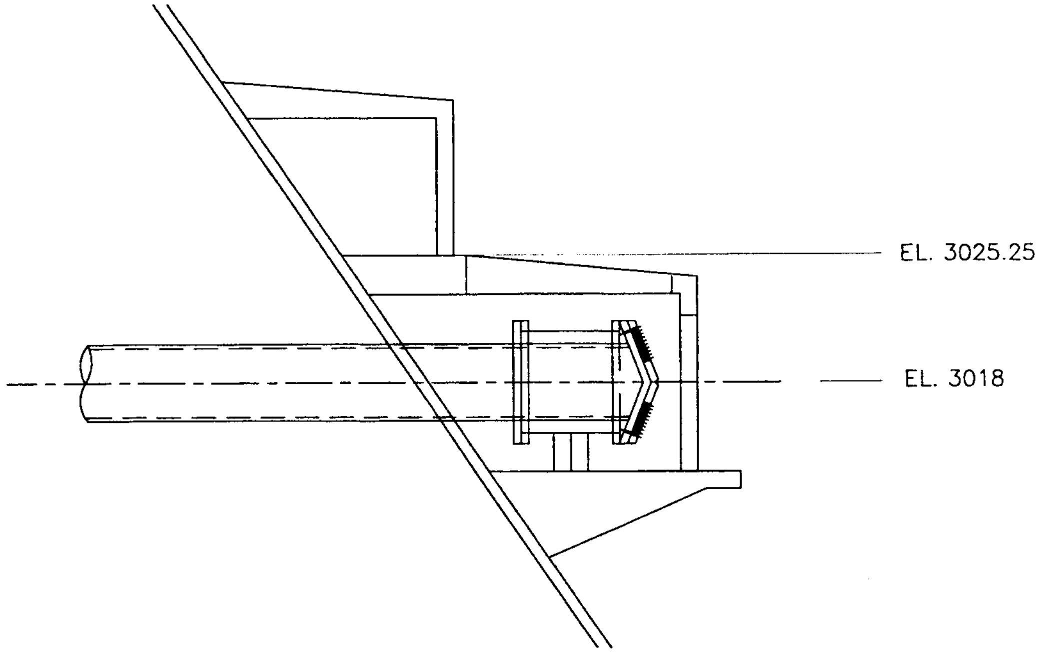


Figure 9. - Configuration 1: Gates located back from end of gate house-structure such that gate lips are inside the structure.

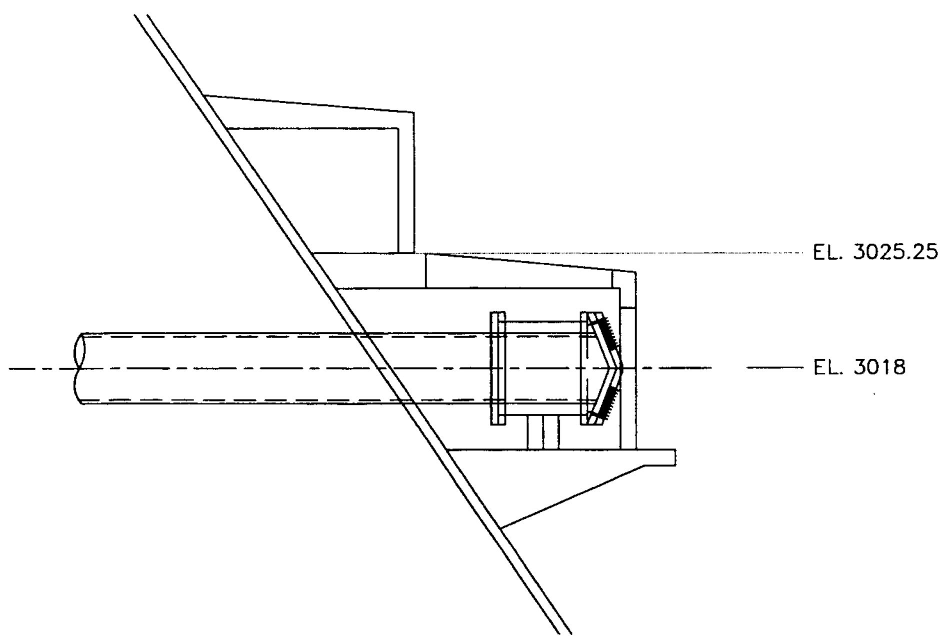


Figure 10. - Configuration 2: Gates located forward in gate house-structure such that gate lips are flush with inside of end wall.

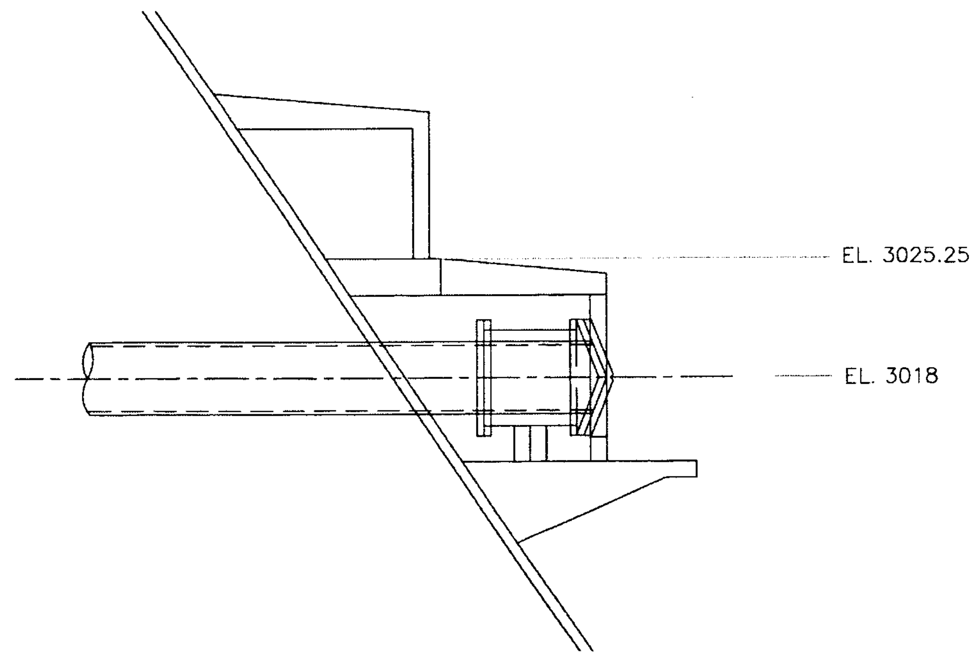


Figure 11. - Configuration 3: Gate house-structure shortened and gates set back such that gate lips protrude from structure.

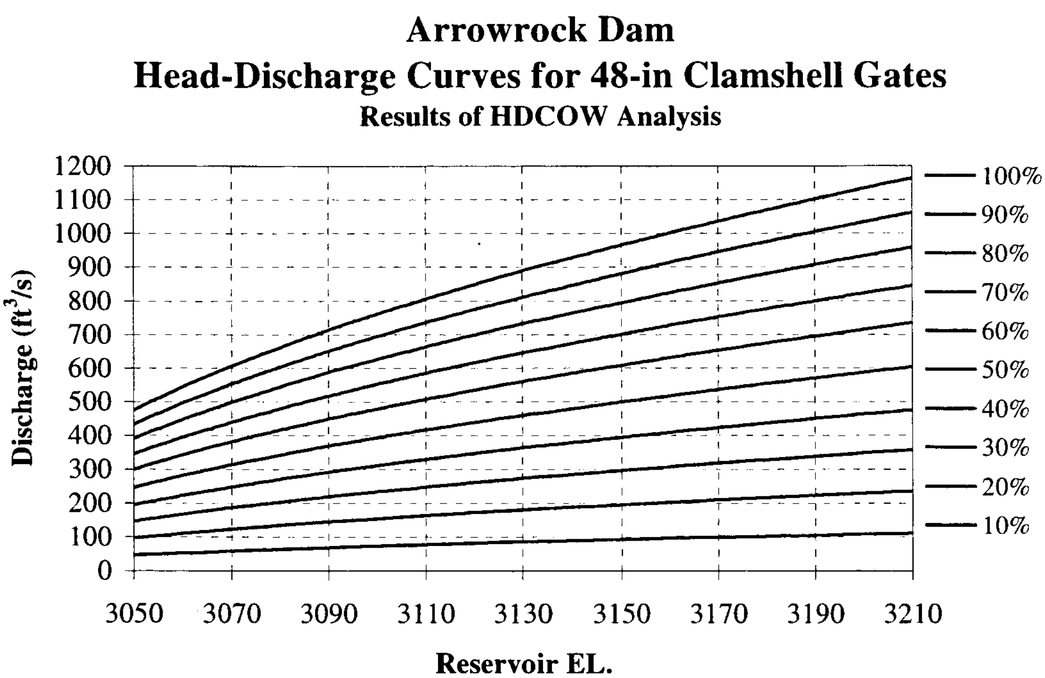


Figure 12.—HDCOW results for 48-in clamshell gates under various Arrowrock reservoir elevations.

RESULTS

STATIC PRESSURE RESULTS

The results indicate that a gate location inside the gate-house has a slight influence on static pressure differentials at certain locations. In all cases tested, the maximum static pressure differential across any part of the gate-house structure was 2.5 ± 0.3 feet of water for configuration 1. Configuration 2 produced a maximum static differential of 1.5 ± 0.2 feet of water, and configuration 3 produced the lowest maximum static differential of 1.0 ± 0.2 foot of water. All measured differentials approaching these upper limits were observed for 2- and 3-gate simultaneous operation. Single-gate operation produced the lowest static pressure differentials.

The results of the static testing are plotted for each test as static pressure differentials at each of the measurement locations. The heading indicates the configuration identification and the number of gates operated. The respective measurement locations correspond with those identified in figure 4. Static pressure differentials along the end wall are given by measurement locations 1 and 2, and the pressure differentials along the divider walls between gate bays 10 and 9 and 9 and 8 are given by measurement locations 7 and 14, respectively. Positive pressure differentials at locations 7 and 14 represent loading across the divider walls in the direction from bay 10 and 9 and bay 9 and 8, respectively. Negative differentials represent loading in the opposite direction. Positive differentials at all other locations represent external loading, and negative differentials represent internal loading. In general, the results indicate:

- Different operating configurations influence the maximum static pressure locations. For example, under single-gate operation, the measured differentials are higher in and around a particular bay in which the gate is operating. Figures 13 and 14 represent a comparison of pressure differentials for configuration 1 during single gate operation at 10- and 50-percent gate openings. These results demonstrate that the localized effect of gate operation manifests as higher static pressure differentials around the gate that is operating. Similarly, figures 15 and 16 represent the comparison of results at 50- and 100-percent gate openings for configuration 2. It can be seen that the local effect of gate operation on static pressure differentials is reduced with increased gate openings.

- For all cases tested, 50-percent gate openings generally represented the largest static pressure differentials. This is most likely a result of increased strength of the shear zone immediately above the issuing jet of rectangular geometry produced by 50-percent gate openings as compared with the circular geometry of the jet produced by 100-percent gate openings. This increased shear produces increased recirculation strengths and patterns around the gate-house structure and thereby alters the corresponding static pressure field.

- Operation of three gates tended to produce the largest overall static pressure differentials. Figures 17 through 19 represent the comparison of results for all three configurations under operation of three gates at 10-, 50-, and 100-percent gate openings, respectively. Furthermore, comparison of figures 17 through 19 shows that configuration 3 represents generally lower static pressure differentials under the same operating conditions as compared with configurations 1 and 2.

- At lower submergence conditions, recirculation appears to produce a local drawdown above the gate-house structure. This drawdown produces elevated internal static pressures in nonoperating gate bays and results in occasional negative pressure differentials.

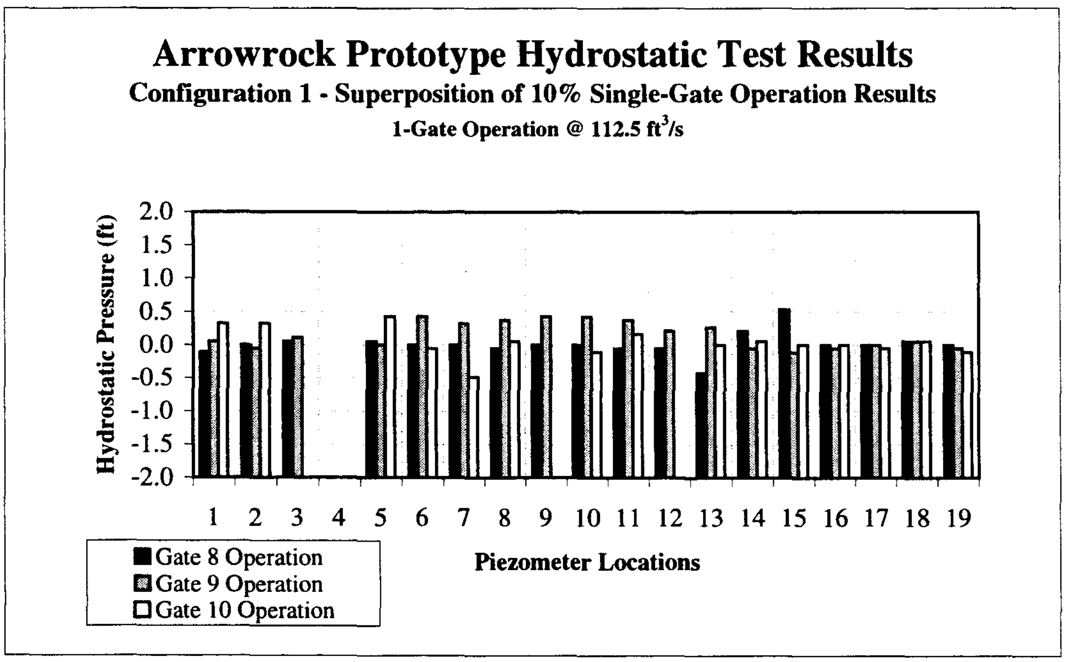


Figure 13. - Comparison of 10-percent single-gate operation results for configuration 1 demonstrating the local influence of gate operation on static pressure differentials.

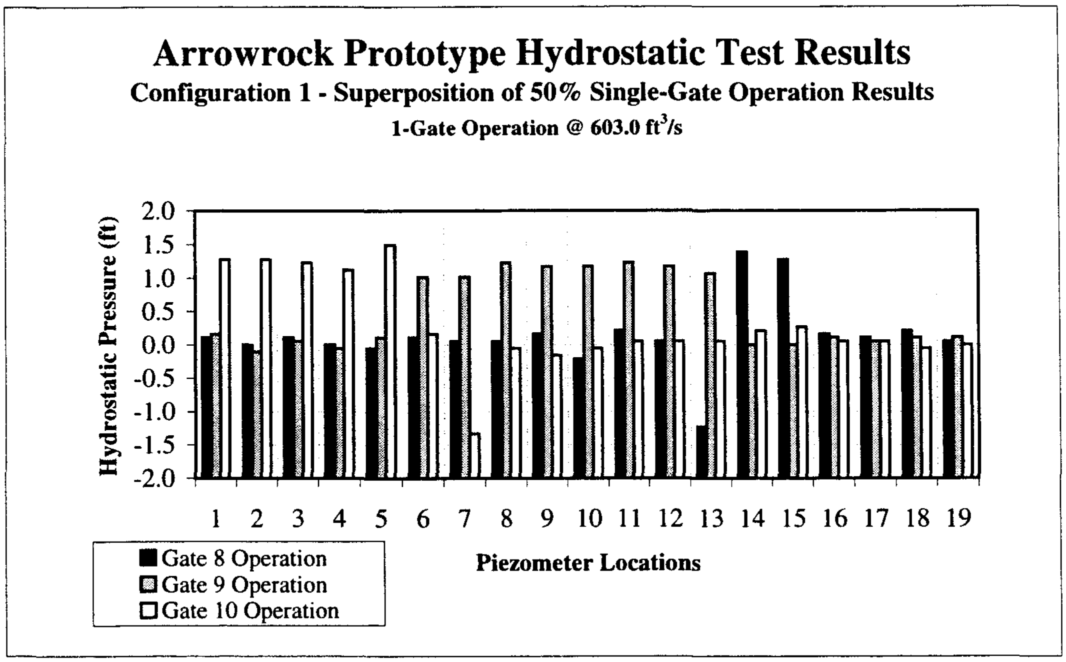


Figure 14. - Comparison of 50-percent single-gate operation results for configuration 1 also showing local influence of gate operation on static pressure differentials.

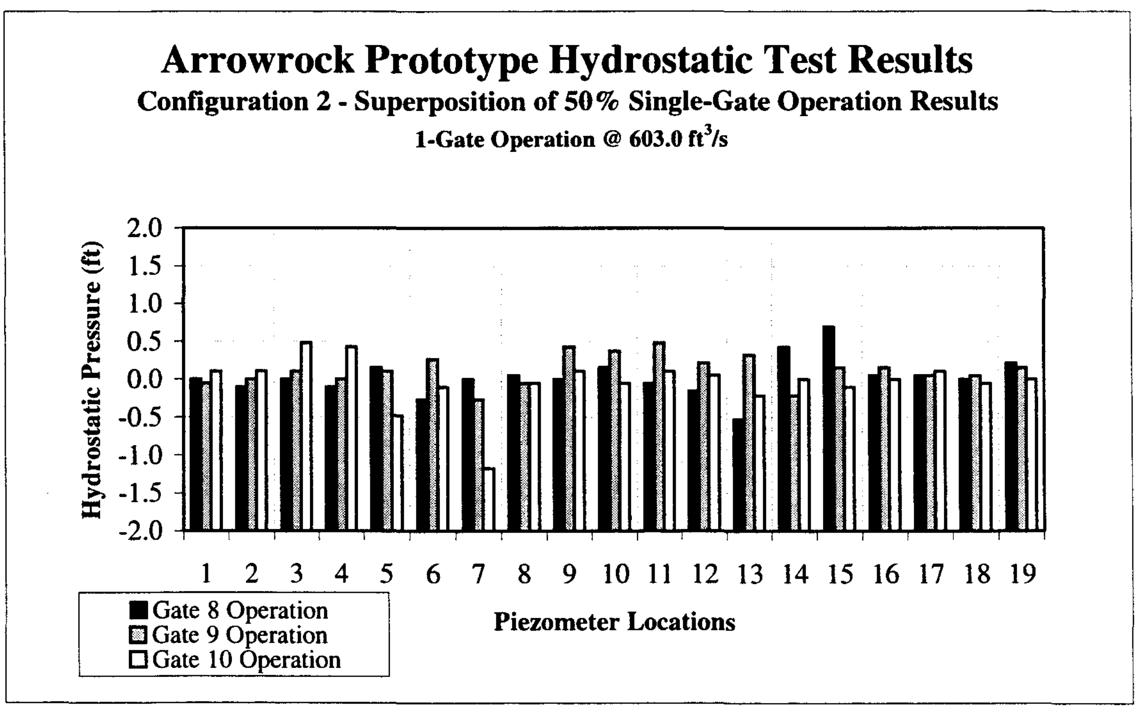


Figure 15. - Comparison of 50-percent single-gate operation results for configuration 2 illustrating lower overall pressure differentials in comparison with configuration 1, but similar local increased pressure differentials caused by gate operation.

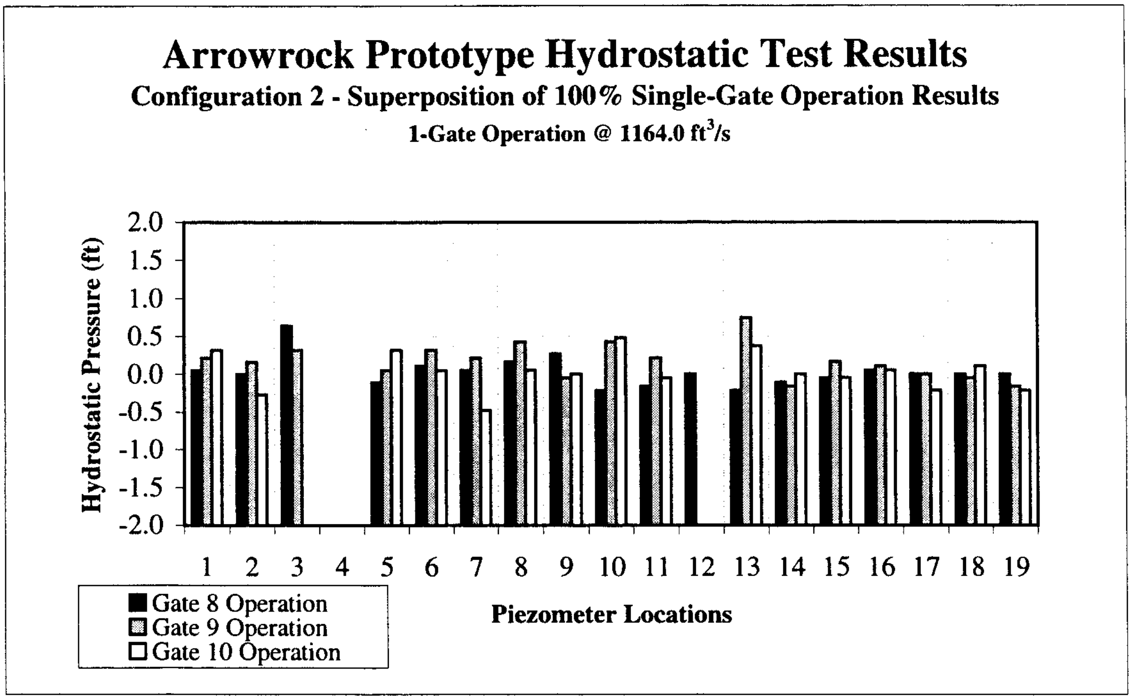


Figure 16. - Comparison of 100-percent single-gate operation results for configuration 2 showing diminished local pressure increase effect.

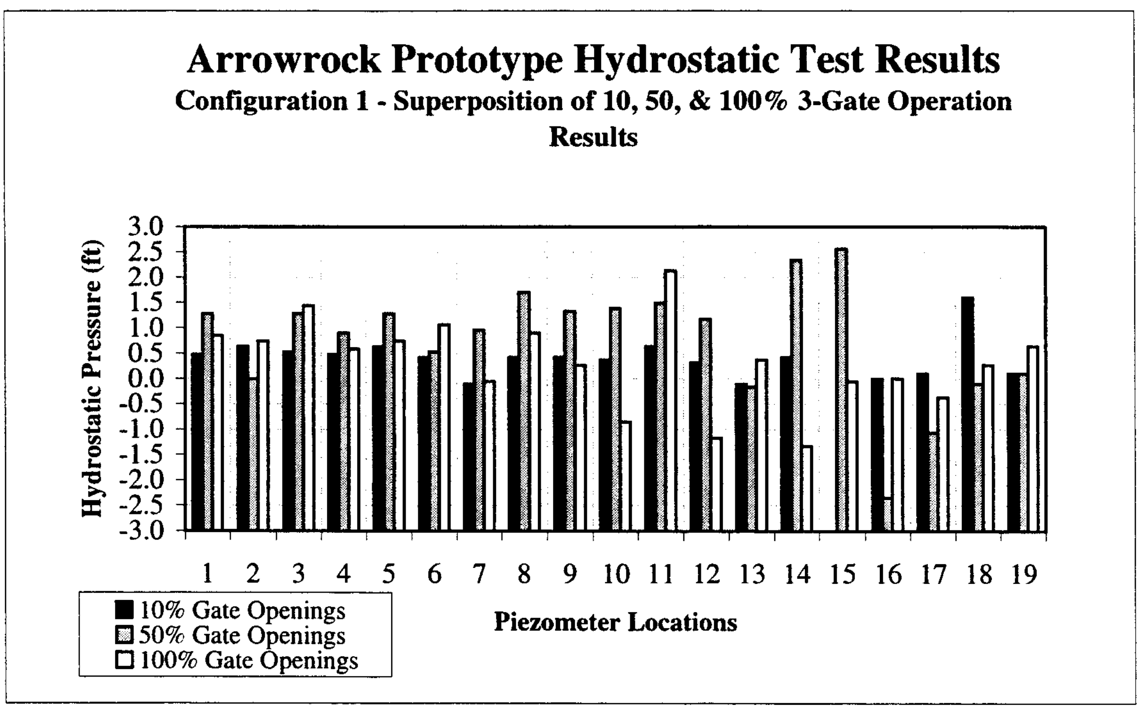


Figure 17. – Results comparison plot for configuration 1, three-gate simultaneous operation at 10-, 50-, and 100-percent gate openings.

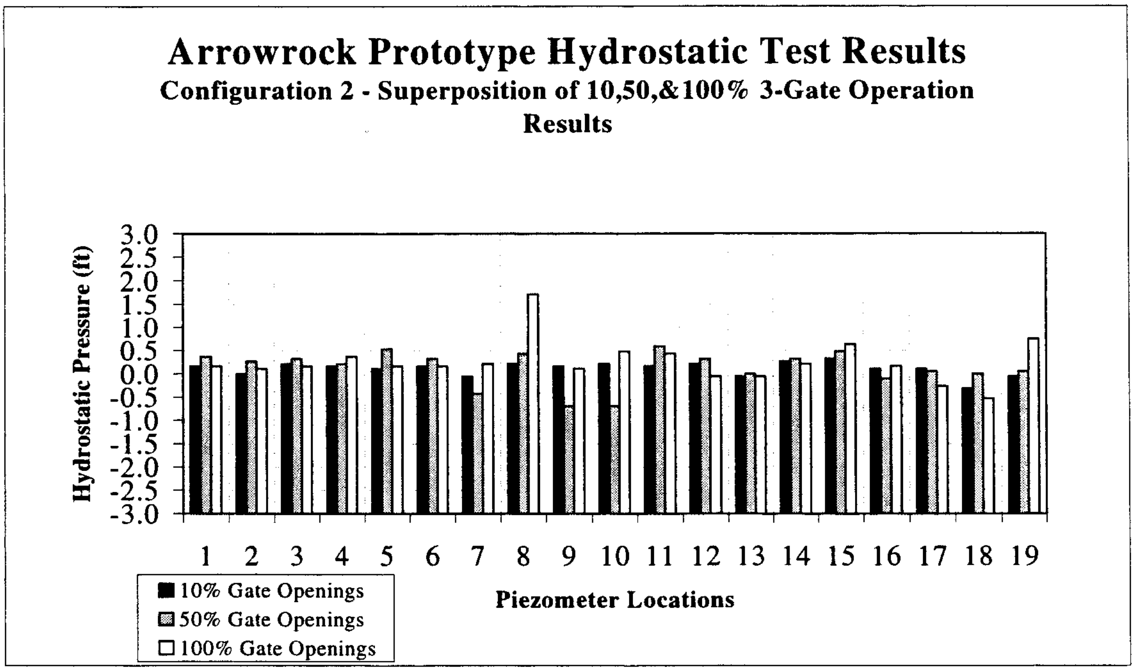


Figure 18. – Results comparison plot for configuration 2, three-gate simultaneous operation at 10-, 50-, and 100-percent gate openings.

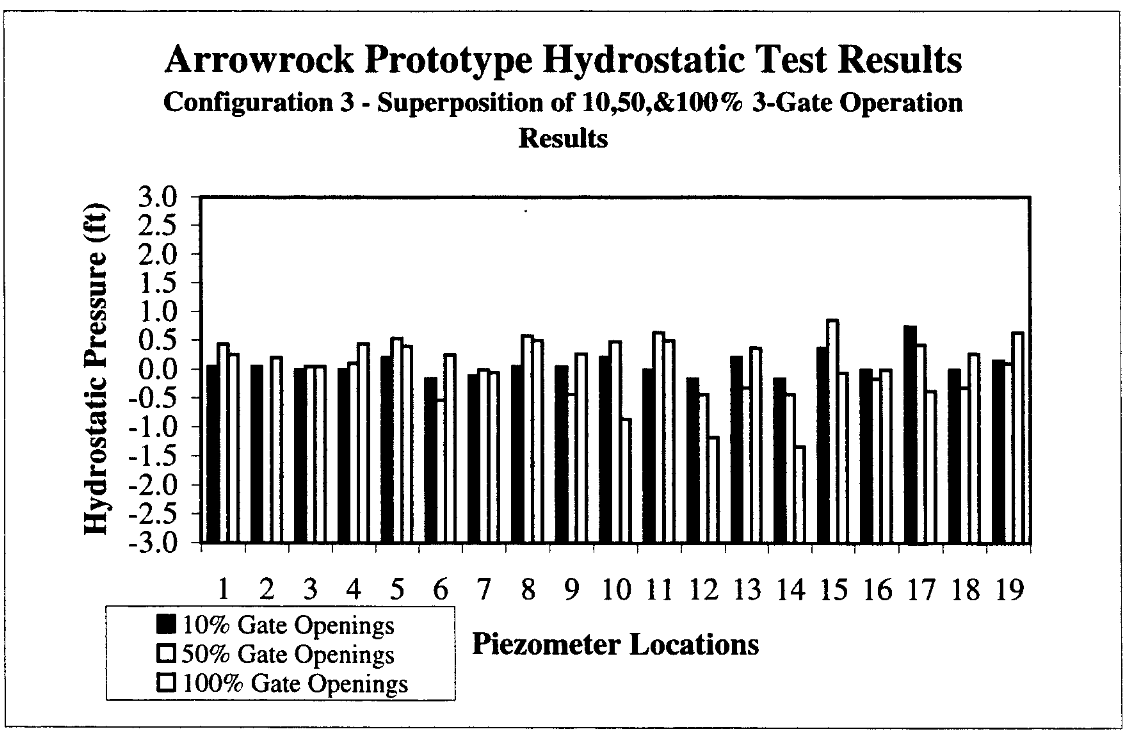


Figure 19. – Results comparison plot for configuration 3, three-gate simultaneous operation at 10-, 50-, and 100-percent gate openings.

DYNAMIC PRESSURE RESULTS

Peak dynamic pressures were observed to increase with reduced tailwater elevations. The maximum measured external dynamic pressure differential across the top of the gate-house structure was 0.9 foot of water (0.38 lb/in^2). This result occurred for single-gate operation of Gate 9 at 50-percent open under tailwater elevation 3025.5 feet (top of gate-house structure). It is interesting to note that, in general, single-gate operation produced the largest peak dynamic pressure differentials. Furthermore, as was the case for the static pressure differentials, the 50-percent gate openings produced the largest dynamic pressure differentials. The maximum measured internal dynamic pressure differential 1.0 foot of water (0.44 lb/in^2) and occurred for single gate operation of Gate 9 under tailwater elevation 3035 feet.

Table 1 summarizes the results obtained from 100-percent gate settings under single and multiple gate operation at tailwater elevations 3025.5 feet and 3035 feet. Table 2 summarizes the results obtained from 50-percent open gate settings under single and multiple gate operation at tailwater elevations of 3025.5 general peak dynamic pressures internal and external to the gate-house structure were in phase (i.e., minimum and maximum internal and external pressure fluctuations occurred at the same instant in time). It appears from these results that dynamic pressures will probably peak in and around the gate that is operating, and dynamic pressure differentials across the top of the gate-house structure above those gates that are not operating will probably diminish. Also, similar to the static pressure results, peak dynamic pressures generally diminish with increased tailwater elevation.

Table 1. – Peak dynamic pressure differentials for 100-percent gate openings and various combinations of gate operation. Data acquired across top of the gate-house structure above Gate 9.

100-percent gate settings

Tailwater Elevation = 3025.5 feet	**MAX**	**MIN**	**SDEV**
Differential (Simultaneous External-Internal)	[lb/in^2]	[lb/in^2]	[lb/in^2]
Gate 8	0.26	-0.27	0.05
Gate 9	**0.28**	**-0.23**	0.05
Gate 10	0.24	-0.22	0.05
Gates 8, 9, and 10	0.22	-0.22	0.06
Tailwater Elevation = 3035.0 feet	**MAX**	**MIN**	**SDEV**
Differential (Simultaneous External-Internal)	[lb/in^2]	[lb/in^2]	[lb/in^2]
Gate 8	0.27	-0.24	0.07
Gate 9	**0.27**	**-0.30**	0.07
Gate 10	0.23	0.22	0.05
Gates 8, 9, and 10	0.27	-0.23	0.06

Table 2. – Peak dynamic pressure differentials for 50-percent gate openings and various combinations of gate operation. Data acquired across top of the gate-house structure above Gate 9.

50-percent Gate settings			
Tailwater Elevation = 3025.5 feet	**MAX**	**MIN**	**SDEV**
Differential (Simultaneous External-Internal)	[lb/in²]	[lb/in²]	[lb/in²]
Gate 8	0.21	-0.19	0.05
Gate 9	**0.44**	**-0.36**	0.09
Gate 10	0.22	-0.23	0.06
Gates 8, 9, and 10	0.32	-0.30	0.08
Tailwater Elevation = 3035.0 feet	**MAX**	**MIN**	**SDEV**
Differential (Simultaneous External-Internal)	[lb/in²]	[lb/in²]	[lb/in²]
Gate 8	0.32	-0.35	0.05
Gate 9	**0.35**	**-0.43**	0.09
Gate 10	0.25	-0.33	0.05
Gates 8, 9, and 10	0.31	-0.33	0.08

Figure 20 represents a typical time-series plot of the dynamic pressure measurements for operation of Gate 9 under tailwater elevation 3035 feet. Figure 21 is the same data plotted as a histogram illustrating the distribution of occurrences for the measured dynamic pressure differentials. And figure 22 shows the power spectrum of the time series data. Apparently, based on figures 21 and 22, the dynamic pressure fluctuations are essentially random and, therefore, the occurrence of the peak dynamic pressure is likely captured in the time series obtained. This, too, may be interpreted to indicate that long-time scale, large-magnitude peak pressure events are not likely. Although this analysis provides no indication of the eddy size responsible for generating pressure fluctuations, it does increase the level of confidence that the peak measured dynamic pressures represent a conservative design value.

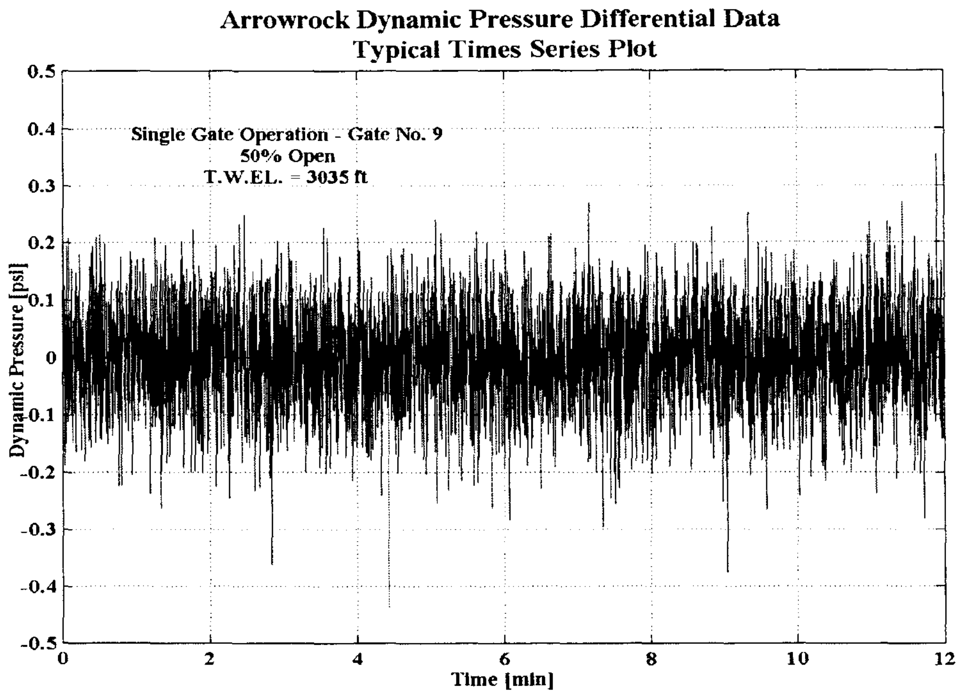


Figure 20. – Typical time series plot of dynamic pressure data.

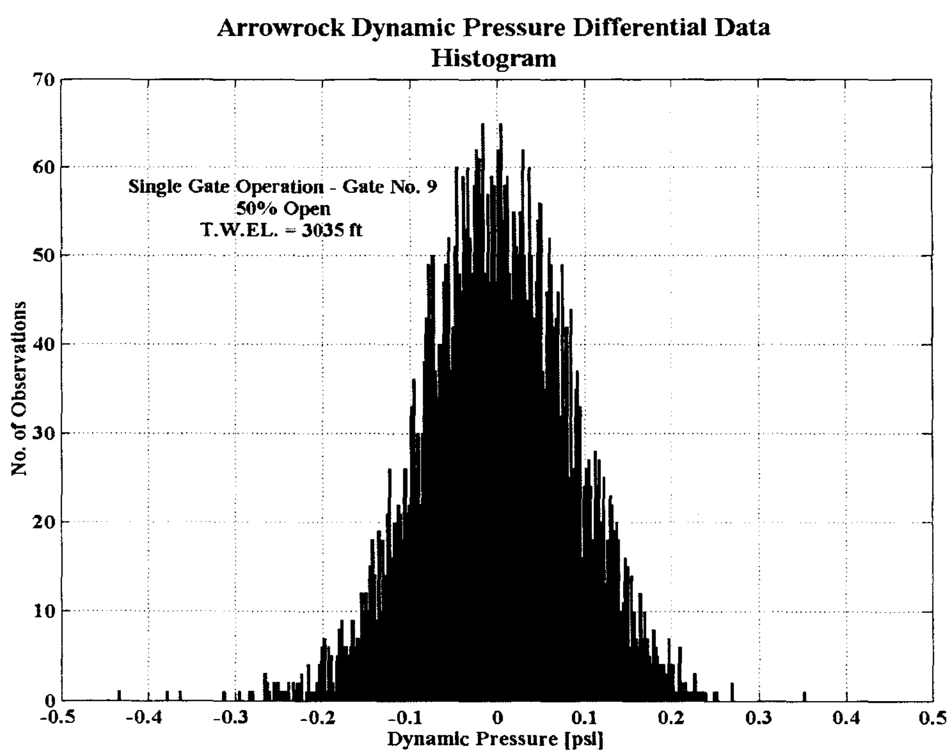


Figure 21. – Typical histogram plot of dynamic pressure differential data.

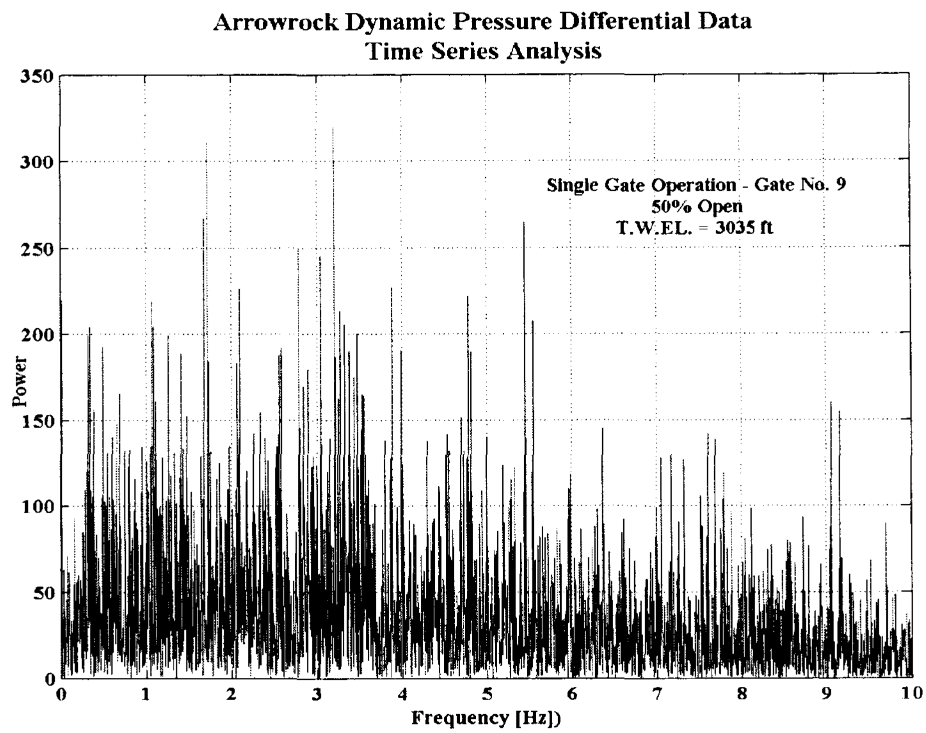


Figure 22. – Power verses Frequency plot of time series data.

SURFACE VORTEX FORMATION

Qualitative observations during testing indicated a slight difference in the degree of surface vortex action between the three configurations. Configurations 2 and 3 (figures 6 and 7) appear to produce reduced vortex action as compared with configuration 1 (figure 5). This is probably a result of moving the issuing jet outside the gate-house structure, thereby reducing the near-field recirculation velocities along the shear zone and consequently reducing vortex strength. In all cases, the vortices were air entraining up to elevation 3035 feet. However, these observations are qualitative and caused by scaling relationships between model and prototype; vortex action (extent and strength) will probably increase for the prototype, and air entrainment will probably result at greater depths of submergence. These conditions will not affect prototype gate performance, but they are generally considered to be undesirable.

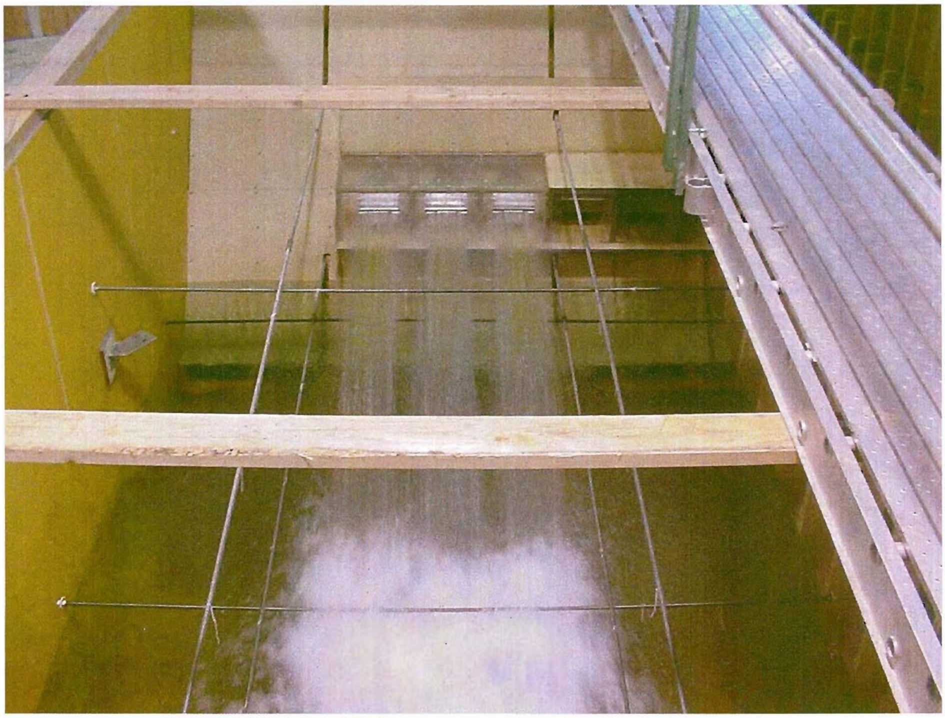
REFRENCES

[1] Fitzwater, J. R. and K. W. Frizell. 1990. *Laboratory Tests on the 30-inch Clamshell Gate for Grassy Lake.* U.S. Department of the Interior, Bureau of Reclamation Report No. R-90-16.

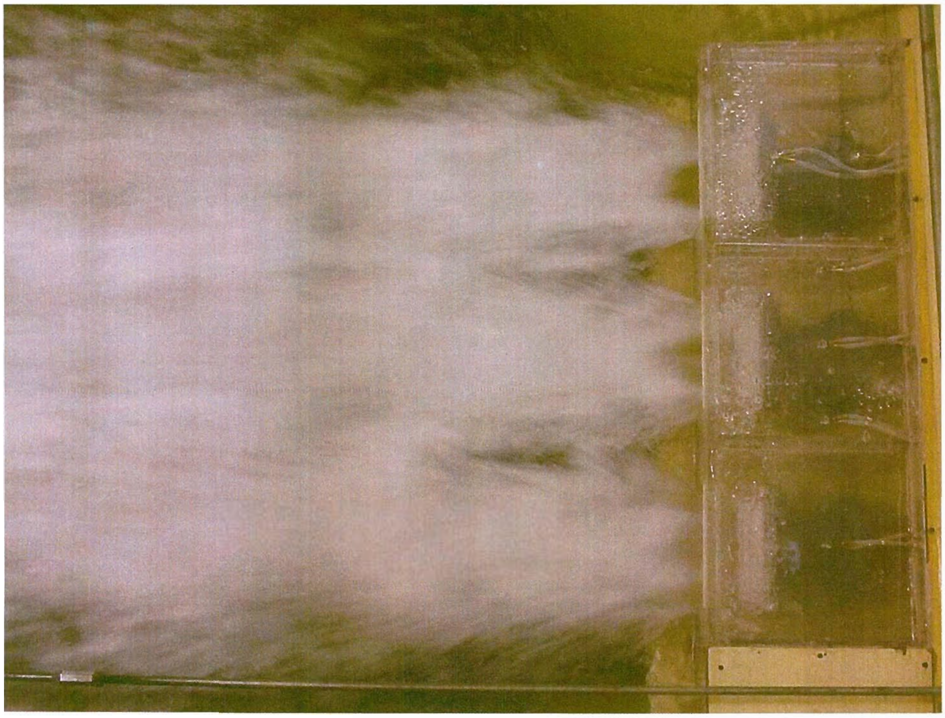
[2] Mefford, B.W. 1987. *Hydraulic Model Study of Submerged Jet Flow Gates for Arrowrock Dam Outlet Works Modification.* Bureau of Reclamation Report No. PAP-511.

[3] U.S. Bureau of Reclamation, Technical Service Center. March 2000. *Arrowrock Dam Outlet Works Rehabilitation Final Conceptual Design.*

APPENDIX A: Photographs of 1:10.67 Scale Physical Model



Three gates operated at 10-percent open in free-discharge mode.

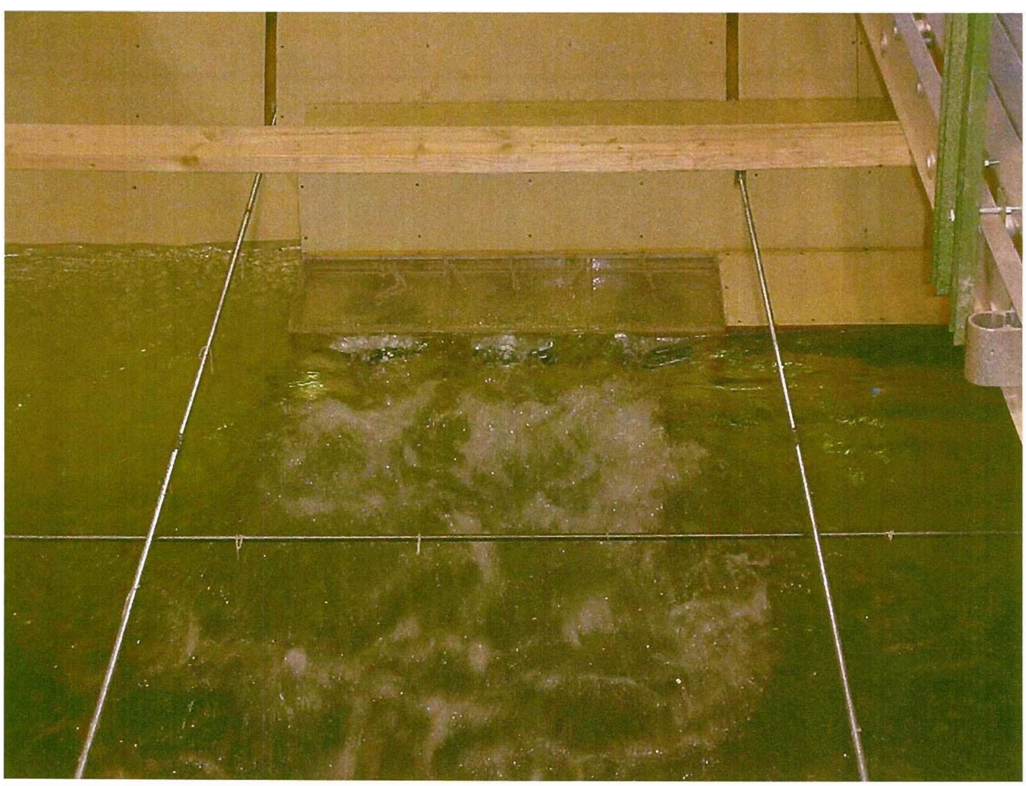


Three gates operated at 10-percent open under partial submergence.

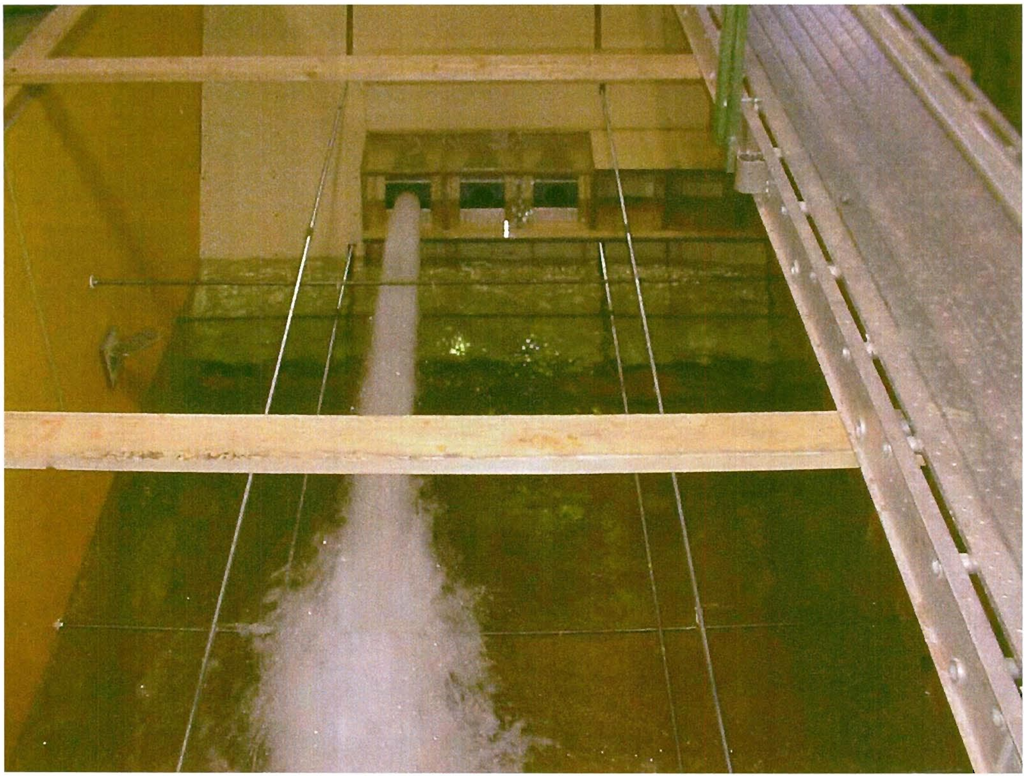
Three gates operated at 10-percent open under partial submergence.

Three gates operated at 50-percent open in free-discharge mode.

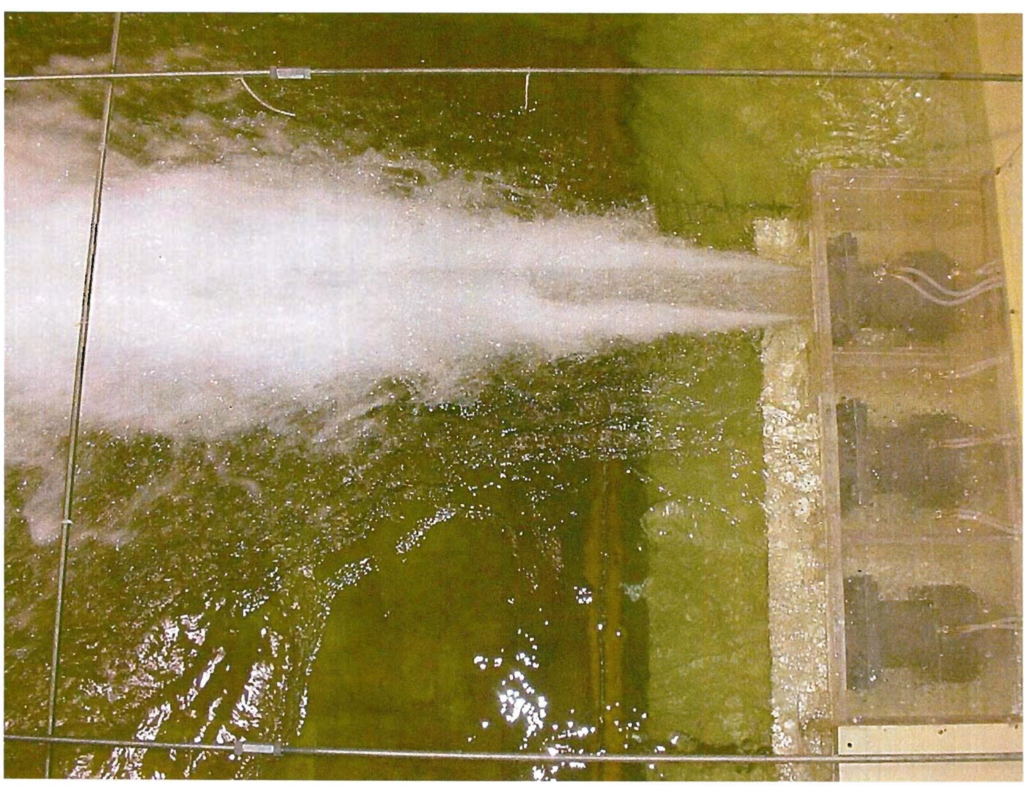
Three gates operated at 50-percent open under partial submergence.



Three gates operated at 50-percent open under full submergence.



Single gate operated at 100-percent open in free-discharge mode.



Single gate operated at 100-percent open under partial submergence.

APPENDIX B: HEAD-DISCHARGE CURVES FOR OUTLET WORKS (HDCOW) RESULTS

ARROWROCK 48-in CLAMSHELL GATE MODIFICATION
Single Outlet Rating
J. Kubitschek
01/12/2000
fn = arrock48.xls
Head-discharge curves for outlet works (HDCOW)
English Units
Colebrook-White Formula used with friction factor, f = 0.01

Max. Res. El. = 3220.0 feet
Min. Res. El. = 3050.0 feet (assumed 30-foot minimum submergence)
Outlet El. = 3018.0 feet

Input Data File
(fn = arrowrck.dat):

#	J	I	K	Structure Name			Parameters		
1	1	5	0	Intake Structure		Trashrack	0.55	144.00	
2	1	6	1	Intake Structure	Circular Bellmouth	Entrance	5.67	4.00	0.10
3	2	4	1	Conveyance Structure	Circular	Conduit	4.00	135.00	0.01
4	3	6	8	48-inch Clamshell Gate			12.57	12.57	

Note: See user manual for description of input file format (Wittler, 1990)

SINGLE OUTLET DISCHARGE RATING (CFS):

	% GATE OPENING									
RES. EL. (feet)	**10%** Cd = 0.08	**20%** Cd = 0.17	**30%** Cd = 0.26	**40%** Cd = 0.35	**50%** Cd = 0.45	**60%** Cd = 0.56	**70%** Cd = 0.66	**80%** Cd = 0.77	**90%** Cd = 0.88	**100%** Cd = 1.00
3050.0	46	96	146	195	246	299	345	391	433	475
3050.5	46	97	147	196	248	302	348	394	437	479
3051.0	46	98	148	198	250	304	350	397	440	483
3051.5	47	99	150	199	252	306	353	400	443	486
3052.0	47	99	151	201	254	309	355	403	447	490
3052.5	47	100	152	202	255	311	358	406	450	493
3053.0	48	101	153	203	257	313	361	409	453	497
3053.5	48	102	154	205	259	315	363	412	457	501
3054.0	48	102	155	206	261	318	366	415	460	504
3054.5	49	103	156	208	263	320	368	418	463	508
3055.0	49	104	157	209	265	322	371	421	466	511
3055.5	49	104	158	211	266	324	373	423	469	514
3056.0	50	105	159	212	268	326	376	426	472	518
3056.5	50	106	160	213	270	328	378	429	475	521
3057.0	50	106	161	215	272	331	381	432	478	525
3057.5	51	107	162	216	273	333	383	435	482	528
3058.0	51	108	163	217	275	335	386	437	485	531
3058.5	51	108	164	219	277	337	388	440	488	535
3059.0	52	109	165	220	278	339	390	443	491	538
3059.5	52	110	166	222	280	341	393	445	494	541

SINGLE OUTLET DISCHARGE RATING (CFS):

					% GATE OPENING					
RES. EL. (feet)	**10%** Cd = 0.08	**20%** Cd = 0.17	**30%** Cd = 0.26	**40%** Cd = 0.35	**50%** Cd = 0.45	**60%** Cd = 0.56	**70%** Cd = 0.66	**80%** Cd = 0.77	**90%** Cd = 0.88	**100%** Cd = 1.00
3060.0	52	110	167	223	282	343	395	448	497	544
3060.5	53	111	168	224	284	345	397	451	500	548
3061.0	53	112	169	225	285	347	400	453	502	551
3061.5	53	112	170	227	287	349	402	456	505	554
3062.0	53	113	171	228	288	351	404	459	508	557
3062.5	54	114	172	229	290	353	407	461	511	560
3063.0	54	114	173	231	292	355	409	464	514	564
3063.5	54	115	174	232	293	357	411	466	517	567
3064.0	55	116	175	233	295	359	413	469	520	570
3064.5	55	116	176	234	297	361	416	471	522	573
3065.0	55	117	177	236	298	363	418	474	525	576
3065.5	56	117	178	237	300	365	420	477	528	579
3066.0	56	118	179	238	301	367	422	479	531	582
3066.5	56	119	180	239	303	369	425	482	534	585
3067.0	56	119	181	241	304	371	427	484	536	588
3067.5	57	120	182	242	306	372	429	486	539	591
3068.0	57	120	183	243	308	374	431	489	542	594
3068.5	57	121	184	244	309	376	433	491	544	597
3069.0	58	122	185	246	311	378	435	494	547	600
3069.5	58	122	185	247	312	380	438	496	550	603
3070.0	58	123	186	248	314	382	440	499	553	606
3070.5	58	123	187	249	315	384	442	501	555	609
3071.0	59	124	188	250	317	385	444	503	558	612
3071.5	59	125	189	252	318	387	446	506	560	614
3072.0	59	125	190	253	320	389	448	508	563	617
3072.5	59	126	191	254	321	391	450	510	566	620
3073.0	60	126	192	255	323	393	452	513	568	623
3073.5	60	127	193	256	324	394	454	515	571	626
3074.0	60	128	193	257	325	396	456	517	573	629
3074.5	61	128	194	258	327	398	458	520	576	631
3075.0	61	129	195	260	328	400	460	522	578	634
3075.5	61	129	196	261	330	401	462	524	581	637
3076.0	61	130	197	262	331	403	464	527	584	640
3076.5	62	130	198	263	333	405	466	529	586	643
3077.0	62	131	199	264	334	407	468	531	589	645
3077.5	62	131	199	265	335	408	470	533	591	648
3078.0	62	132	200	266	337	410	472	536	593	651
3078.5	63	133	201	267	338	412	474	538	596	653
3079.0	63	133	202	269	340	413	476	540	598	656
3079.5	63	134	203	270	341	415	478	542	601	659
3080.0	63	134	203	271	342	417	480	544	603	661
3080.5	64	135	204	272	344	419	482	547	606	664
3081.0	64	135	205	273	345	420	484	549	608	667
3081.5	64	136	206	274	347	422	486	551	611	669
3082.0	64	136	207	275	348	424	488	553	613	672
3082.5	65	137	208	276	349	425	490	555	615	675
3083.0	65	137	208	277	351	427	492	557	618	677
3083.5	65	138	209	278	352	428	493	560	620	680
3084.0	65	138	210	279	353	430	495	562	622	682
3084.5	66	139	211	280	355	432	497	564	625	685

SINGLE OUTLET DISCHARGE RATING (CFS):

RES. EL. (feet)	% GATE OPENING 10% Cd = 0.08	20% Cd = 0.17	30% Cd = 0.26	40% Cd = 0.35	50% Cd = 0.45	60% Cd = 0.56	70% Cd = 0.66	80% Cd = 0.77	90% Cd = 0.88	100% Cd = 1.00
3085.0	66	139	212	281	356	433	499	566	627	688
3085.5	66	140	212	283	357	435	501	568	630	690
3086.0	66	141	213	284	359	437	503	570	632	693
3086.5	67	141	214	285	360	438	505	572	634	695
3087.0	67	142	215	286	361	440	506	574	636	698
3087.5	67	142	215	287	363	441	508	576	639	700
3088.0	67	143	216	288	364	443	510	578	641	703
3088.5	68	143	217	289	365	445	512	581	643	705
3089.0	68	144	218	290	366	446	514	583	646	708
3089.5	68	144	219	291	368	448	516	585	648	710
3090.0	68	145	219	292	369	449	517	587	650	713
3090.5	69	145	220	293	370	451	519	589	652	715
3091.0	69	146	221	294	372	452	521	591	655	718
3091.5	69	146	222	295	373	454	523	593	657	720
3092.0	69	147	222	296	374	455	524	595	659	723
3092.5	70	147	223	297	375	457	526	597	661	725
3093.0	70	148	224	298	377	458	528	599	664	728
3093.5	70	148	225	299	378	460	530	601	666	730
3094.0	70	149	225	300	379	462	531	603	668	732
3094.5	70	149	226	301	380	463	533	605	670	735
3095.0	71	150	227	302	382	465	535	607	672	737
3095.5	71	150	228	303	383	466	537	609	675	740
3096.0	71	150	228	304	384	468	538	611	677	742
3096.5	71	151	229	305	385	469	540	613	679	744
3097.0	72	151	230	306	387	471	542	615	681	747
3097.5	72	152	230	307	388	472	544	616	683	749
3098.0	72	152	231	308	389	474	545	618	685	751
3098.5	72	153	232	309	390	475	547	620	687	754
3099.0	73	153	233	309	391	476	549	622	690	756
3099.5	73	154	233	310	393	478	550	624	692	758
3100.0	73	154	234	311	394	479	552	626	694	761
3100.5	73	155	235	312	395	481	554	628	696	763
3101.0	73	155	235	313	396	482	555	630	698	765
3101.5	74	156	236	314	397	484	557	632	700	768
3102.0	74	156	237	315	399	485	559	634	702	770
3102.5	74	157	238	316	400	487	560	636	704	772
3103.0	74	157	238	317	401	488	562	637	706	774
3103.5	75	158	239	318	402	490	564	639	708	777
3104.0	75	158	240	319	403	491	565	641	711	779
3104.5	75	158	240	320	404	492	567	643	713	781
3105.0	75	159	241	321	406	494	569	645	715	784
3105.5	75	159	242	322	407	495	570	647	717	786
3106.0	76	160	242	323	408	497	572	649	719	788
3106.5	76	160	243	323	409	498	574	650	721	790
3107.0	76	161	244	324	410	499	575	652	723	792
3107.5	76	161	244	325	411	501	577	654	725	795
3108.0	76	162	245	326	413	502	578	656	727	797
3108.5	77	162	246	327	414	504	580	658	729	799
3109.0	77	163	247	328	415	505	582	660	731	801
3109.5	77	163	247	329	416	506	583	661	733	804

SINGLE OUTLET DISCHARGE RATING (CFS):

RES. EL. (feet)	% GATE OPENING 10% Cd = 0.08	20% Cd = 0.17	30% Cd = 0.26	40% Cd = 0.35	50% Cd = 0.45	60% Cd = 0.56	70% Cd = 0.66	80% Cd = 0.77	90% Cd = 0.88	100% Cd = 1.00
3110.0	77	163	248	330	417	508	585	663	735	806
3110.5	78	164	249	331	418	509	586	665	737	808
3111.0	78	164	249	332	419	511	588	667	739	810
3111.5	78	165	250	333	421	512	590	669	741	812
3112.0	78	165	251	333	422	513	591	670	743	814
3112.5	78	166	251	334	423	515	593	672	745	817
3113.0	79	166	252	335	424	516	594	674	747	819
3113.5	79	167	253	336	425	517	596	676	749	821
3114.0	79	167	253	337	426	519	597	677	751	823
3114.5	79	167	254	338	427	520	599	679	753	825
3115.0	79	168	255	339	428	521	600	681	755	827
3115.5	80	168	255	340	429	523	602	683	757	829
3116.0	80	169	256	340	431	524	604	684	759	832
3116.5	80	169	256	341	432	525	605	686	760	834
3117.0	80	170	257	342	433	527	607	688	762	836
3117.5	80	170	258	343	434	528	608	690	764	838
3118.0	81	170	258	344	435	529	610	691	766	840
3118.5	81	171	259	345	436	531	611	693	768	842
3119.0	81	171	260	346	437	532	613	695	770	844
3119.5	81	172	260	346	438	533	614	697	772	846
3120.0	81	172	261	347	439	535	616	698	774	848
3120.5	82	173	262	348	440	536	617	700	776	850
3121.0	82	173	262	349	441	537	619	702	778	853
3121.5	82	173	263	350	442	539	620	703	779	855
3122.0	82	174	264	351	444	540	622	705	781	857
3122.5	82	174	264	352	445	541	623	707	783	859
3123.0	83	175	265	352	446	542	625	708	785	861
3123.5	83	175	265	353	447	544	626	710	787	863
3124.0	83	175	266	354	448	545	628	712	789	865
3124.5	83	176	267	355	449	546	629	714	791	867
3125.0	83	176	267	356	450	548	631	715	793	869
3125.5	84	177	268	357	451	549	632	717	794	871
3126.0	84	177	269	357	452	550	634	719	796	873
3126.5	84	177	269	358	453	551	635	720	798	875
3127.0	84	178	270	359	454	553	637	722	800	877
3127.5	84	178	270	360	455	554	638	724	802	879
3128.0	85	179	271	361	456	555	639	725	804	881
3128.5	85	179	272	361	457	556	641	727	805	883
3129.0	85	180	272	362	458	558	642	728	807	885
3129.5	85	180	273	363	459	559	644	730	809	887
3130.0	85	180	274	364	460	560	645	732	811	889
3130.5	85	181	274	365	461	562	647	733	813	891
3131.0	86	181	275	366	462	563	648	735	814	893
3131.5	86	182	275	366	463	564	650	737	816	895
3132.0	86	182	276	367	464	565	651	738	818	897
3132.5	86	182	277	368	465	566	652	740	820	899
3133.0	86	183	277	369	466	568	654	741	822	901
3133.5	87	183	278	370	467	569	655	743	823	903
3134.0	87	184	278	370	468	570	657	745	825	905
3134.5	87	184	279	371	469	571	658	746	827	907

SINGLE OUTLET DISCHARGE RATING (CFS):

RES. EL. (feet)	% GATE OPENING 10% Cd = 0.08	20% Cd = 0.17	30% Cd = 0.26	40% Cd = 0.35	50% Cd = 0.45	60% Cd = 0.56	70% Cd = 0.66	80% Cd = 0.77	90% Cd = 0.88	100% Cd = 1.00
3135.0	87	184	280	372	470	573	659	748	829	909
3135.5	87	185	280	373	471	574	661	749	831	911
3136.0	88	185	281	374	472	575	662	751	832	913
3136.5	88	185	281	374	473	576	664	753	834	914
3137.0	88	186	282	375	474	578	665	754	836	916
3137.5	88	186	283	376	475	579	666	756	838	918
3138.0	88	187	283	377	476	580	668	757	839	920
3138.5	88	187	284	377	477	581	669	759	841	922
3139.0	89	187	284	378	478	582	671	761	843	924
3139.5	89	188	285	379	479	584	672	762	845	926
3140.0	89	188	285	380	480	585	673	764	846	928
3140.5	89	189	286	381	481	586	675	765	848	930
3141.0	89	189	287	381	482	587	676	767	850	932
3141.5	90	189	287	382	483	588	678	768	851	934
3142.0	90	190	288	383	484	590	679	770	853	935
3142.5	90	190	288	384	485	591	680	771	855	937
3143.0	90	191	289	384	486	592	682	773	857	939
3143.5	90	191	290	385	487	593	683	775	858	941
3144.0	90	191	290	386	488	594	684	776	860	943
3144.5	91	192	291	387	489	595	686	778	862	945
3145.0	91	192	291	388	490	597	687	779	863	947
3145.5	91	192	292	388	491	598	688	781	865	949
3146.0	91	193	292	389	492	599	690	782	867	950
3146.5	91	193	293	390	493	600	691	784	869	952
3147.0	92	194	294	391	494	601	692	785	870	954
3147.5	92	194	294	391	495	602	694	787	872	956
3148.0	92	194	295	392	496	604	695	788	874	958
3148.5	92	195	295	393	497	605	696	790	875	960
3149.0	92	195	296	394	498	606	698	791	877	961
3149.5	92	195	296	394	499	607	699	793	879	963
3150.0	93	196	297	395	500	608	700	794	880	965
3150.5	93	196	297	396	501	609	702	796	882	967
3151.0	93	197	298	397	502	611	703	797	884	969
3151.5	93	197	299	397	502	612	704	799	885	971
3152.0	93	197	299	398	503	613	706	800	887	972
3152.5	93	198	300	399	504	614	707	802	889	974
3153.0	94	198	300	400	505	615	708	803	890	976
3153.5	94	198	301	400	506	616	710	805	892	978
3154.0	94	199	301	401	507	617	711	806	894	980
3154.5	94	199	302	402	508	619	712	808	895	981
3155.0	94	199	302	402	509	620	714	809	897	983
3155.5	94	200	303	403	510	621	715	811	898	985
3156.0	95	200	304	404	511	622	716	812	900	987
3156.5	95	201	304	405	512	623	717	814	902	989
3157.0	95	201	305	405	513	624	719	815	903	990
3157.5	95	201	305	406	514	625	720	817	905	992
3158.0	95	202	306	407	515	626	721	818	907	994
3158.5	96	202	306	408	515	628	723	820	908	996
3159.0	96	202	307	408	516	629	724	821	910	997
3159.5	96	203	307	409	517	630	725	822	911	999

SINGLE OUTLET DISCHARGE RATING (CFS):

RES. EL. (feet)	10% Cd = 0.08	20% Cd = 0.17	30% Cd = 0.26	40% Cd = 0.35	50% Cd = 0.45	60% Cd = 0.56	70% Cd = 0.66	80% Cd = 0.77	90% Cd = 0.88	100% Cd = 1.00
	% GATE OPENING									
3160.0	96	203	308	410	518	631	727	824	913	1001
3160.5	96	203	309	410	519	632	728	825	915	1003
3161.0	96	204	309	411	520	633	729	827	916	1005
3161.5	97	204	310	412	521	634	730	828	918	1006
3162.0	97	204	310	413	522	635	732	830	919	1008
3162.5	97	205	311	413	523	636	733	831	921	1010
3163.0	97	205	311	414	524	637	734	833	923	1012
3163.5	97	206	312	415	525	639	735	834	924	1013
3164.0	97	206	312	416	525	640	737	835	926	1015
3164.5	98	206	313	416	526	641	738	837	927	1017
3165.0	98	207	313	417	527	642	739	838	929	1019
3165.5	98	207	314	418	528	643	740	840	931	1020
3166.0	98	207	314	418	529	644	742	841	932	1022
3166.5	98	208	315	419	530	645	743	843	934	1024
3167.0	98	208	315	420	531	646	744	844	935	1025
3167.5	99	208	316	420	532	647	745	845	937	1027
3168.0	99	209	317	421	533	648	747	847	938	1029
3168.5	99	209	317	422	534	649	748	848	940	1031
3169.0	99	209	318	423	534	651	749	850	942	1032
3169.5	99	210	318	423	535	652	750	851	943	1034
3170.0	99	210	319	424	536	653	752	852	945	1036
3170.5	100	210	319	425	537	654	753	854	946	1037
3171.0	100	211	320	425	538	655	754	855	948	1039
3171.5	100	211	320	426	539	656	755	857	949	1041
3172.0	100	211	321	427	540	657	757	858	951	1042
3172.5	100	212	321	427	541	658	758	859	952	1044
3173.0	100	212	322	428	541	659	759	861	954	1046
3173.5	100	212	322	429	542	660	760	862	955	1048
3174.0	101	213	323	429	543	661	761	864	957	1049
3174.5	101	213	323	430	544	662	763	865	959	1051
3175.0	101	214	324	431	545	663	764	866	960	1053
3175.5	101	214	324	432	546	664	765	868	962	1054
3176.0	101	214	325	432	547	665	766	869	963	1056
3176.5	101	215	325	433	548	666	768	870	965	1058
3177.0	102	215	326	434	548	668	769	872	966	1059
3177.5	102	215	326	434	549	669	770	873	968	1061
3178.0	102	216	327	435	550	670	771	875	969	1063
3178.5	102	216	327	436	551	671	772	876	971	1064
3179.0	102	216	328	436	552	672	774	877	972	1066
3179.5	102	217	328	437	553	673	775	879	974	1068
3180.0	103	217	329	438	554	674	776	880	975	1069
3180.5	103	217	329	438	554	675	777	881	977	1071
3181.0	103	218	330	439	555	676	778	883	978	1072
3181.5	103	218	330	440	556	677	780	884	980	1074
3182.0	103	218	331	440	557	678	781	885	981	1076
3182.5	103	219	331	441	558	679	782	887	983	1077
3183.0	104	219	332	442	559	680	783	888	984	1079
3183.5	104	219	332	442	559	681	784	889	986	1081
3184.0	104	220	333	443	560	682	786	891	987	1082
3184.5	104	220	333	444	561	683	787	892	989	1084

SINGLE OUTLET DISCHARGE RATING (CFS):

RES. EL. (feet)	10% Cd = 0.08	20% Cd = 0.17	30% Cd = 0.26	40% Cd = 0.35	50% Cd = 0.45	60% Cd = 0.56	70% Cd = 0.66	80% Cd = 0.77	90% Cd = 0.88	100% Cd = 1.00
	% GATE OPENING									
3185.0	104	220	334	444	562	684	788	893	990	1086
3185.5	104	221	334	445	563	685	789	895	992	1087
3186.0	104	221	335	446	564	686	790	896	993	1089
3186.5	105	221	335	446	565	687	791	898	995	1090
3187.0	105	222	336	447	565	688	793	899	996	1092
3187.5	105	222	336	448	566	689	794	900	998	1094
3188.0	105	222	337	448	567	690	795	901	999	1095
3188.5	105	223	337	449	568	691	796	903	1000	1097
3189.0	105	223	338	450	569	692	797	904	1002	1099
3189.5	106	223	338	450	570	693	798	905	1003	1100
3190.0	106	223	339	451	570	694	800	907	1005	1102
3190.5	106	224	339	452	571	695	801	908	1006	1103
3191.0	106	224	340	452	572	696	802	909	1008	1105
3191.5	106	224	340	453	573	697	803	911	1009	1107
3192.0	106	225	341	454	574	698	804	912	1011	1108
3192.5	106	225	341	454	574	699	805	913	1012	1110
3193.0	107	225	342	455	575	700	807	915	1014	1111
3193.5	107	226	342	456	576	701	808	916	1015	1113
3194.0	107	226	343	456	577	702	809	917	1016	1114
3194.5	107	226	343	457	578	703	810	919	1018	1116
3195.0	107	227	344	457	579	704	811	920	1019	1118
3195.5	107	227	344	458	579	705	812	921	1021	1119
3196.0	108	227	345	459	580	706	813	922	1022	1121
3196.5	108	228	345	459	581	707	815	924	1024	1122
3197.0	108	228	346	460	582	708	816	925	1025	1124
3197.5	108	228	346	461	583	709	817	926	1027	1125
3198.0	108	229	347	461	583	710	818	928	1028	1127
3198.5	108	229	347	462	584	711	819	929	1029	1129
3199.0	108	229	348	463	585	712	820	930	1031	1130
3199.5	109	230	348	463	586	713	821	931	1032	1132
3200.0	109	230	349	464	587	714	822	933	1034	1133
3200.5	109	230	349	465	588	715	824	934	1035	1135
3201.0	109	231	350	465	588	716	825	935	1037	1136
3201.5	109	231	350	466	589	717	826	937	1038	1138
3202.0	109	231	351	466	590	718	827	938	1039	1139
3202.5	109	231	351	467	591	719	828	939	1041	1141
3203.0	110	232	352	468	592	720	829	940	1042	1143
3203.5	110	232	352	468	592	721	830	942	1044	1144
3204.0	110	232	352	469	593	722	831	943	1045	1146
3204.5	110	233	353	470	594	723	833	944	1046	1147
3205.0	110	233	353	470	595	724	834	945	1048	1149
3205.5	110	233	354	471	595	725	835	947	1049	1150
3206.0	110	234	354	471	596	726	836	948	1051	1152
3206.5	111	234	355	472	597	727	837	949	1052	1153
3207.0	111	234	355	473	598	728	838	951	1053	1155
3207.5	111	235	356	473	599	729	839	952	1055	1156
3208.0	111	235	356	474	599	730	840	953	1056	1158
3208.5	111	235	357	475	600	731	841	954	1058	1159
3209.0	111	235	357	475	601	732	843	956	1059	1161
3209.5	112	236	358	476	602	733	844	957	1060	1162

SINGLE OUTLET DISCHARGE RATING (CFS):

					% GATE OPENING					
RES. EL. (feet)	**10%** Cd = 0.08	**20%** Cd = 0.17	**30%** Cd = 0.26	**40%** Cd = 0.35	**50%** Cd = 0.45	**60%** Cd = 0.56	**70%** Cd = 0.66	**80%** Cd = 0.77	**90%** Cd = 0.88	**100%** Cd = 1.00
3210.0	**112**	**236**	**358**	**476**	**603**	**734**	**845**	**958**	**1062**	**1164**
3210.5	112	236	359	477	603	735	846	959	1063	1166
3211.0	112	237	359	478	604	735	847	961	1064	1167
3211.5	112	237	359	478	605	736	848	962	1066	1169
3212.0	112	237	360	479	606	737	849	963	1067	1170
3212.5	112	238	360	480	607	738	850	964	1069	1172
3213.0	113	238	361	480	607	739	851	966	1070	1173
3213.5	113	238	361	481	608	740	852	967	1071	1175
3214.0	113	239	362	481	609	741	854	968	1073	1176
3214.5	113	239	362	482	610	742	855	969	1074	1178
3215.0	113	239	363	483	610	743	856	970	1075	1179
3215.5	113	239	363	483	611	744	857	972	1077	1181
3216.0	113	240	364	484	612	745	858	973	1078	1182
3216.5	114	240	364	484	613	746	859	974	1080	1184
3217.0	114	240	365	485	613	747	860	975	1081	1185
3217.5	114	241	365	486	614	748	861	977	1082	1187
3218.0	114	241	365	486	615	749	862	978	1084	1188
3218.5	114	241	366	487	616	750	863	979	1085	1189
3219.0	114	242	366	488	617	751	864	980	1086	1191
3219.5	114	242	367	488	617	751	865	981	1088	1192
3220.0	115	242	367	489	618	752	867	983	1089	1194