HYDRAULIC MODEL STUDY
ROBERT LEE DAM SPILLWAY

COLORADO RIVER MUNICIPAL
WATER DISTRICT

Big Springs, Texas

CIVIL ENGINEERING DEPARTMENT

Engineering Research Center
Colorado State University
Fort Collins, Colorado

June 1966

CER66JFR30

FINAL REPORT

OF

HYDRAULIC MODEL STUDY

OF

ROBERT LEE DAM SPILLWAY

Prepared for

Colorado River Municipal
Water District
Big Springs, Texas

by

J. F. Ruff

Colorado State University
Engineering Research Center
Civil Engineering Department
Fort Collins, Colorado
June 1966

PREFACE

The Engineering Research Center at Colorado State University is located between two lakes, Horsetooth Reservoir of the Colorado Big Thompson Project, and College Lake. The laboratories of the Center were strategically placed to utilize the high head, 250 feet, available from the reservoir and the storage capacity of the lake. The Center is the focal point for research and graduate education.

There are four principal parts to the Center; the offices for staff and graduate students, the hydraulics laboratory, the fluid dynamics laboratory, and the outdoor hydraulics - hydrology laboratory. The research activities of the Center are fluid mechanics, hydraulics, hydrology, ground-water, soil mechanics, hydro-biology, geomorphology and environmental engineering.

The hydraulics laboratory includes 50, 000 square feet of floor space in which basic and applied research activities are undertaken. The floor of the laboratory is constructed over a large sump system, having one-acre foot capacity, which permits recirculation of water through the various research facilities. Generally, pumps are used for recirculation but the high head and large flow capacity from the reservoir can also be utilized.

The Center includes well equipped machine and woodwork shops. All research facilities of the Center are constructed on site and in the case of this model study, necessary metal work, carpentry, and nearly all the plastic work was done by personnel in the shops. The shop personnel are particularly well experienced in the art and skill of model construction.

Grateful acknowledgement is hereby expressed by the writers to Mr. W. L. Eeds of Freese, Nichols and Endress for his cooperation during the conduct of this study, to personnel of the machine shops for their ingeneous contributions in solving model construction problems, particularly in the plastic works and to others contributing to the model study and the preparation of this report.

CONTENTS

FIGURES

SUMMARY

This report describes a hydraulic model study of the morning glory spillway for Robert Lee Dam. Specific studies of the morning glory spillway, vertical bend and conduit and stilling basin indicated that modifications to the basic design were required to give satisfactory performance and to save costs of construction. Increasing the crest diameter of the morning glory provided satisfactory operation. An air vent and deflector were installed at the P C of the vertical bend to eliminate detrimental negative pressures along the inside radius of the bend.

The basic stilling basin was modified by raising the basin floor, reducing the total length and providing 3 feet of additional freeboard. Immediately downstream from the conduit portal, fillets were included to provide a smoother transition from a circular to a rectangular cross section.

Graded rip rap with maximum sized stones of 42 inches should be provided for a distance of 300 feet downstream of the basin to prevent scouring of the earth channel. An earth channel 300 feet wide with sufficient freeboard to accommodate maximum flows of 39,500 cfs should be provided.

The model construction, tests, conclusions and recommendations are described in this report. Discharge rating curves for the spillway are included.

INTRODUCTION

General Description of the Project

Robert Lee Dam is a proposed earth-fill dam to be constructed across the Colorado River by the Colorado River Municipal Water District at a site approximately two miles west of the town of Robert Lee, Texas. The length of the dam crest is about 20,000 ft. The crest elevation is at 1928.0 ft[1]. The upstream face of the dam is sloped at 3:1 (horizontal to vertical) from the base to elevation 1898.0 ft where the slope changes to $2\frac{1}{2}$:1 and continues to the crest. The width of the dam crest is 20 ft. The downstream slope is $2\frac{1}{2}$:1 from the crest to elevation 1898.0 ft. A 3:1 slope continues from elevation 1898.0 ft to a 120 ft wide berm at elevation 1842.0 ft. The slope from the berm to the base of the dam is 5:1. A general plan of the dam and appurtenant works is shown in Fig. 1.

The project is conceived as a water supply for member cities of the District. The reservoir capacity will be 488,800 acre-feet. The proposed reservoir spillway is a morning glory type capable of passing floods up to 39,000 cfs. The crest of the morning glory is at elevation 1878.0 ft and is 59.07 ft in diameter. It will be gated with 12 vertical fixed wheel gates to permit controlled outflow through the spillway.

Description of the Spillway

The location of the spillway relative to the dam is shown in Fig. 1. Detail plan and profile of the spillway are given in Fig. 2. The spillway consists of three principal features: the morning glory crest structure, the circular conduit and the hydraulic jump stilling basin. Details of these features are shown in Fig. 3.

The morning glory spillway crest is at elevation 1878.0 ft where the diameter is 59.07 ft. The diameter reduces to 28 ft at elevation 1832.5 ft, 45.5 ft below the crest where the 28 ft diameter conduit enters a 90-degree vertical bend with a radius of 56 ft to the centerline of the conduit. Twelve equally spaced piers are located around the circumference of the spillway crest.

A circular conduit 28 ft in diameter extends from the end of the vertical bend 600 ft downstream to the stilling basin. About 400 ft of the initial length is inclined upward at a slope of 0.085 ft/ft which levels out at an invert elevation of 1803.0 ft. The purpose of the inclination is to keep the portal of the conduit above the influence of the backwater in the channel downstream.

The stilling basin consists of a flared chute approach to the basin 152.1 ft long and a hydraulic jump basin 223.5 ft long. Chute and floor blocks are provided to assist formation and stabilization of the jump. The basin is 65 ft wide and the floor elevation is 1761.0 ft. The stepped end sill is 11 ft in height. Downstream from the basin, a rip rapped transition section will be required to join structure and channel.

Scope of the Model Study

The specific objectives sought in the model study are listed below:

1. Determine through visual observation, photographs and pressure data the flow characteristics through the morning glory spillway, the vertical bend, the conduit and the stilling basin for all expected discharges.

2. Observe flow through the spillway and pressures on the crest for various numbers and combinations of open gates; 1, 2, 3, 4, 6 and 12, at several reservoir levels. The bottom of the gate in all instances is to be above the water surface.

3. Determine the existence and magnitude of negative pressures on the boundaries and the necessity of aeration to relieve the negative pressures.

4. Study the performance of the stilling basin for the full range of discharges with the tailwater at the level determined from the backwater curve shown in Fig. 4.

5. Recommend rip rap sizes in the transition from the stilling basin to the channel and recommend a channel size downstream from the stilling basin.

---

[1]All elevations on levels expressed in numbers will be understood to have dimensions of feet whether or not it is explicitly stated.

FIGURE 1 GENERAL PLAN OF DAM AND APPURTENANT WORKS

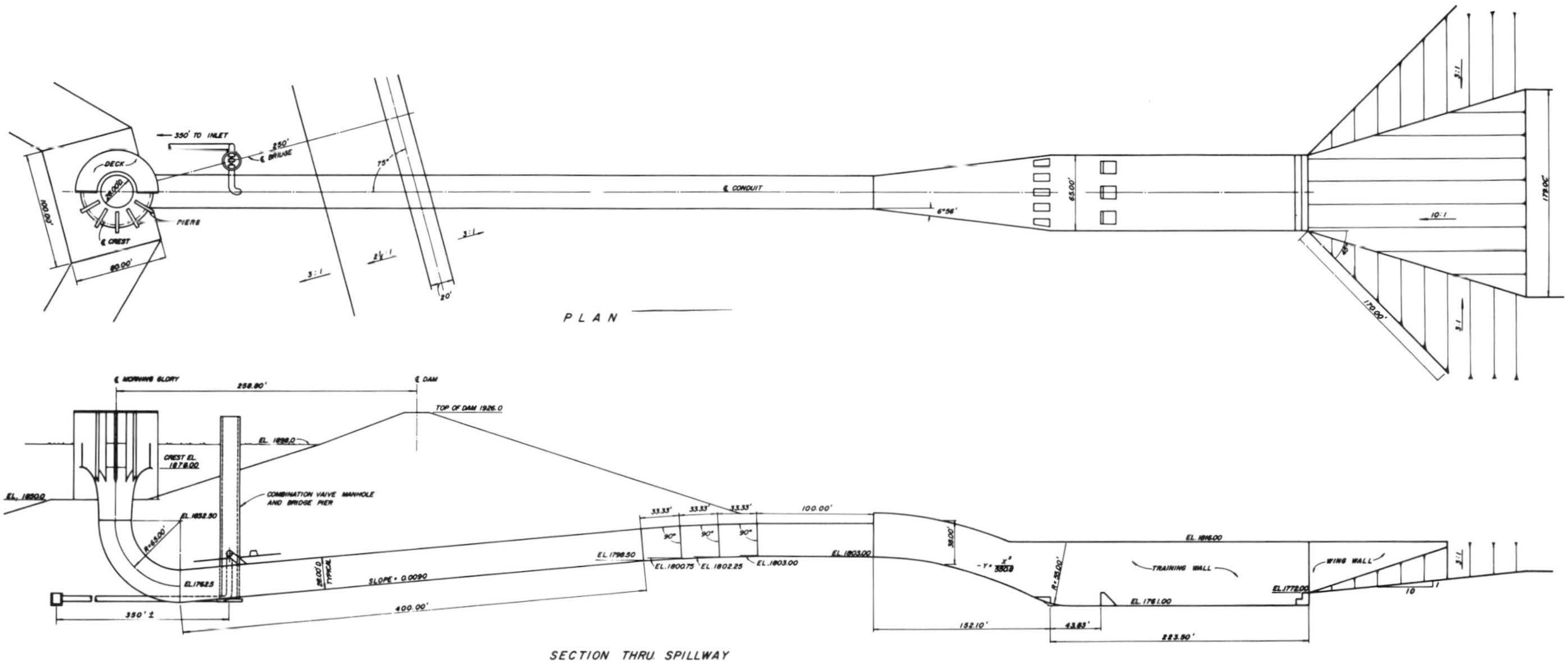


FIGURE 2 ROBERT LEE DAM SPILLWAY

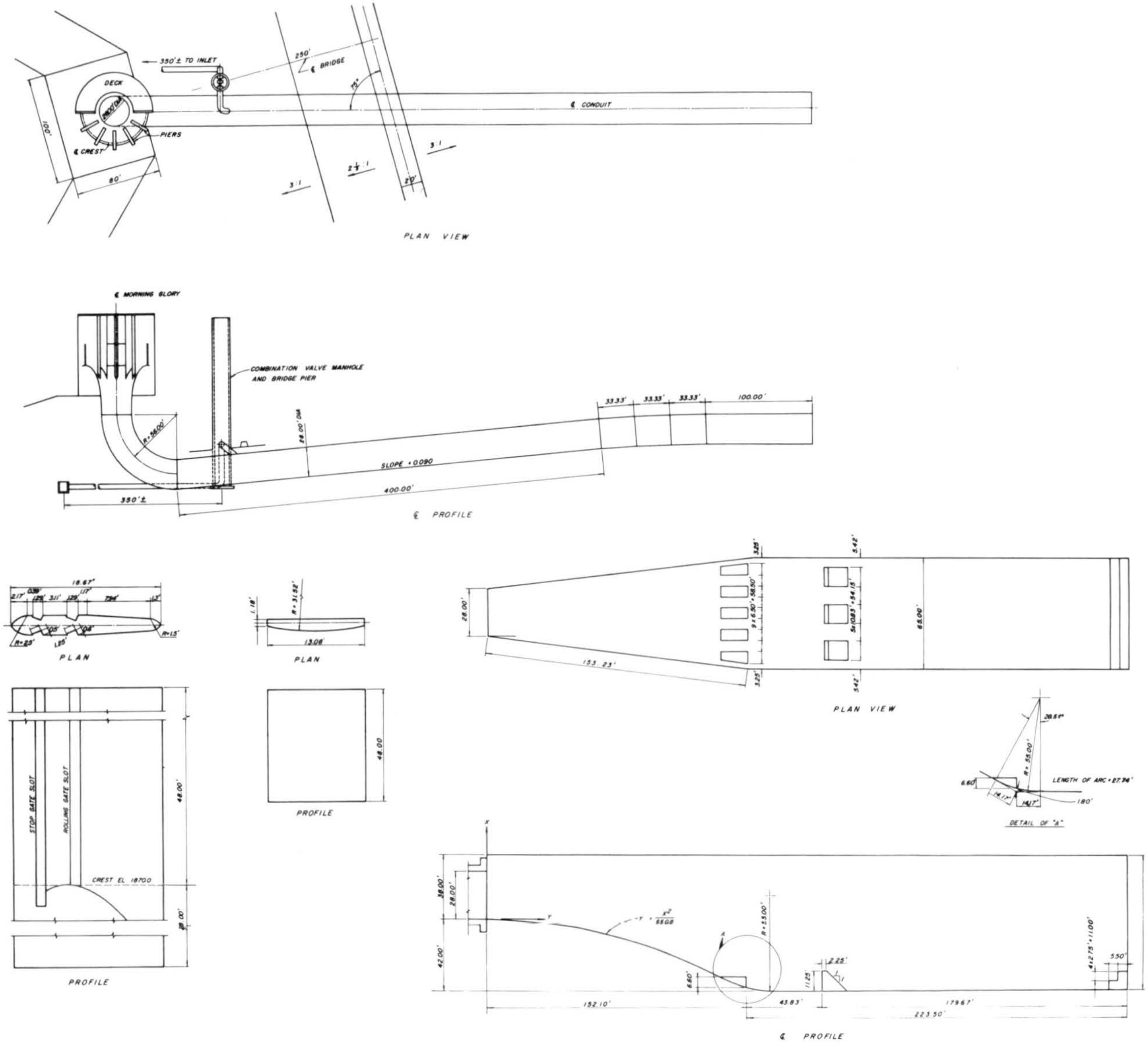


FIGURE 3 DETAILS OF STRUCTURE

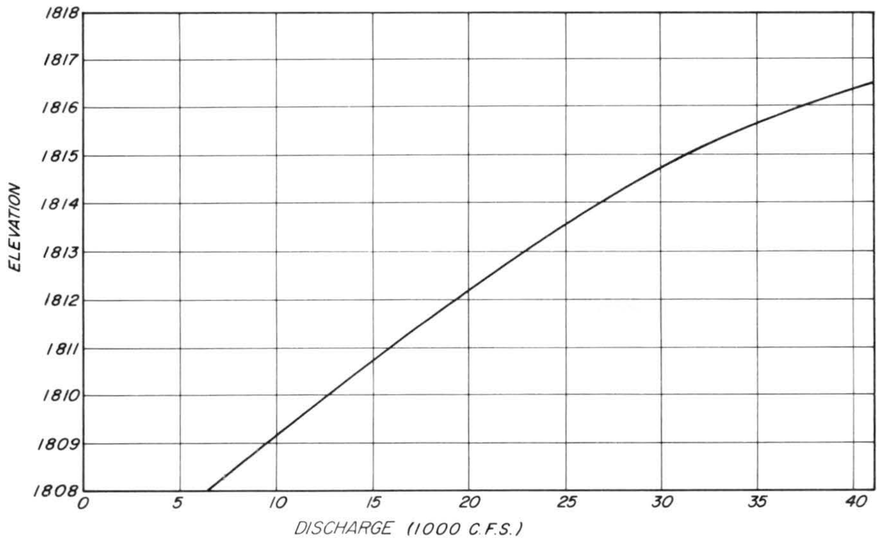


FIGURE 4 BACKWATER CURVE FOR SPILLWAY CHANNEL

Selection of Model Scale and Model Criteria

The objective of a hydraulic model is to develop dynamically and kinematically similar flows in the model prototype. This requires geometrical similitude. Dimensional analysis indicated that both the Froude and Reynolds numbers were important for the objectives of this study. For instance, the free overflow into the morning glory spillway, the hydraulic jump in the stilling basin and the open channel flow are dependent upon gravity predominantly; hence, the Froude criterion is important, whereas, for the closed conduit flow viscous effects are dominant and the Reynolds criterion is involved. Because in this study the open channel flow aspects dominate, the Froude criterion was chosen to determine the geometric scale.

A model-prototype relationship of about 1:40 was determined to be most feasible from an analysis of scale ratios based upon model size required for accurate measurements, flow conditions, available laboratory space, facilities and economy. The actual geometric scale used was 1:37.333 which was determined by the available sizes of commercially manufactured cast acrylic resin tubes used to construct the model conduit. Table I contains a list of some of the characteristic model-prototype ratios based upon the selected scale.

TABLE I

MODEL PROTOTYPE SCALE RATIOS

Parameter	Scale Ratio		Absolute Magnitude	
	Function of the length	Numerical Ratio	Prototype	Model
Length	L_r	1:37.333	1 ft	0.321 in.
Area	L_r^2	1:1393.75	1000 ft^2	0.717 ft^2
Velocity	$L_r^{1/2}$	1:6.1101	1 fps	0.164 fps
Discharge	$L_r^{5/2}$	1:8516.0	10,000 cfs	1.174 cfs
Time	$L_r^{1/2}$	1:6.1101	1 min	9.820 sec

THE MODEL

Model Construction

The general limits of the model are shown in Fig. 5. Dimensions of the model facilities and actual arrangement are given in Fig. 6 with a photograph of the completed model shown in Fig. 7.

The head box and tail box were constructed of plywood and waterproofed with a fiberglass lining. The inside dimensions of the head box were 10 ft wide by 12 ft long by 3 ft deep. The tail box was constructed to the size indicated in Fig. 6. The areal extent of the tail box was considered sufficient to provide control of the tailwater level by a hinged gate at the downstream end of the tail box.

Water to the head box was supplied by a 14-inch turbine pump. The discharge was regulated by control valve in the pipe line near the head box. A rock baffle was used to distribute the flow uniformly in the approach to the spillway. The approach velocity in the head box was designed to be small enough to assure that model effects would not influence the results of the study. The topography of the upstream face of the dam was included in the model to represent the approach conditions in the prototype. Discharge measurements were made with a calibrated orifice in the supply line.

The basic morning glory spillway (hereinafter referred to as spillway A) was constructed by forming a wooden mold in the lathe to the exact inside dimensions of the model spillway and then covering the mold with fiberglass as shown in Fig. 8. Four lines of piezometers were installed in the spillway to measure pressures on the face of the crest. The position and orientation of the piezometers, with respect to the conduit, are given in Fig. 9. To provide a continuous line of piezometers along the crest of the spillway, the vertical bend and the crown and invert of the conduit, the piers in the model were rotated 7.5^0 with respect to those of the prototype. This rotation of the piers did not affect the performance or flow conditions of the spillway nor the results of the tests.

The piers were constructed from wood and coated with fiberglass. Orientation of the piers on the spillway was as noted above. The fixed wheel roller gates were also made from wood and coated with fiberglass. A rubber seal was glued to the edge of the gates. The morning glory spillway and piers, during final stages of construction, are shown in Fig. 10.

The 90^0 vertical bend was molded with epoxy resin. Four lines of piezometers were installed in the bend to measure pressures at the boundaries. The piezometer locations in the bend are given in Fig. 9.

A 9-inch inside diameter cast acrylic resin tube was used to model the 28-ft diameter conduit. Piezometers were located along the crown and invert of the conduit at the position given in Fig. 11.

The stilling basin was constructed from plexiglass and fiberglass coated plywood. Plywood formed the chute, basin floor and left[2] wall. Plexiglass was used for the right wall to facilitate visual observations of the flow conditions and water surface profile within the stilling basin. Piezometers were located in the basic stilling basin (hereinafter referred to as stilling basin I) as shown in Fig. 12. Piezometers were located in the center chute block as shown in Fig. 13. The center baffle block also had piezometers located as shown in Fig. 13. The chute and baffle blocks containing the piezometers were made from blocks of plexiglass. The other chute and baffle blocks were wooden with a coating of fiberglass.

All piezometers were attached to manometer boards with flexible polyethylene tubing. Where negative pressures were observed, measurements were made with a U-tube manometer.

[2]Left and right as used in this report refer to the observer's left and right looking downstream.

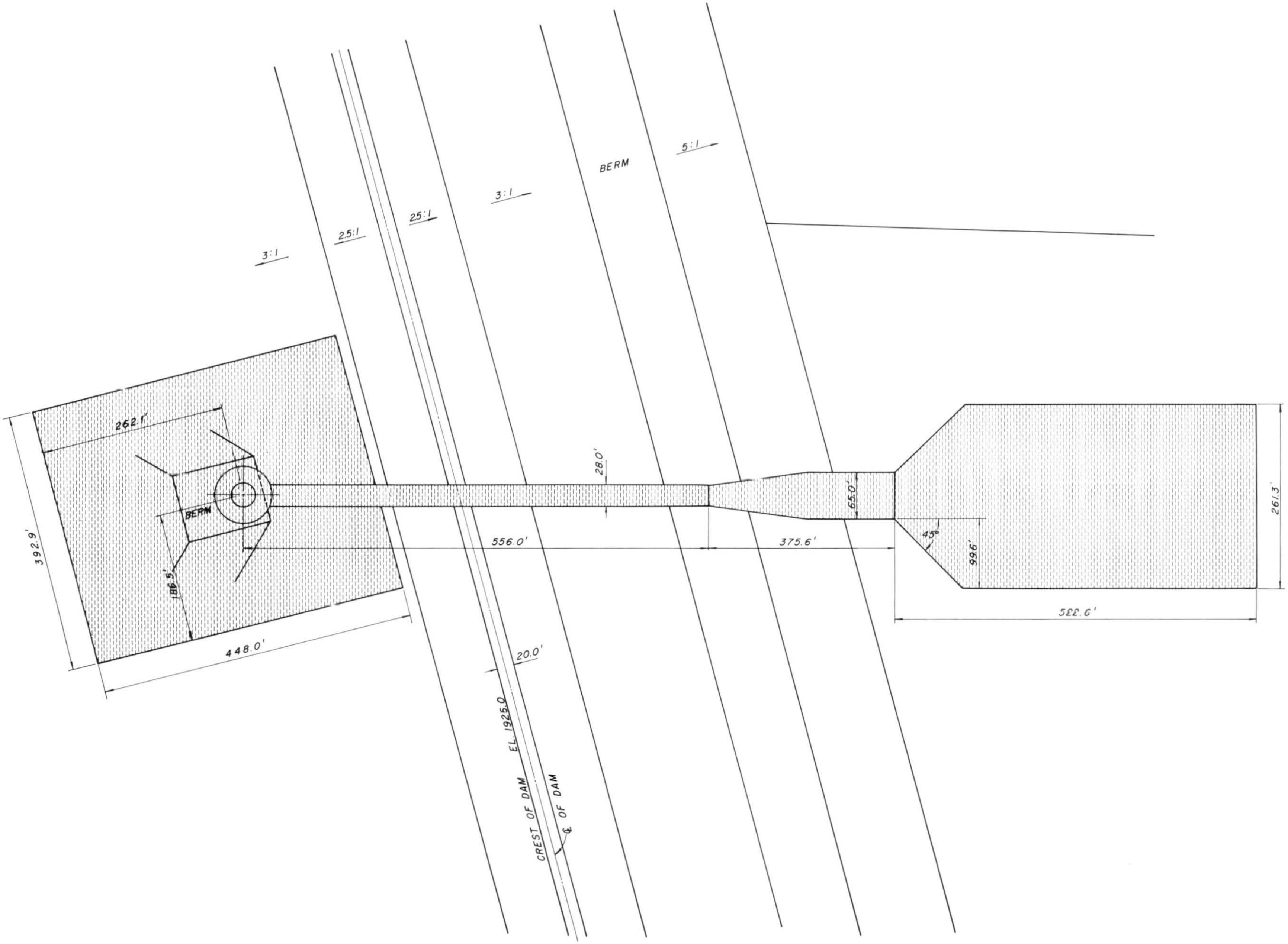


FIGURE 5 GENERAL LIMITS OF MODEL

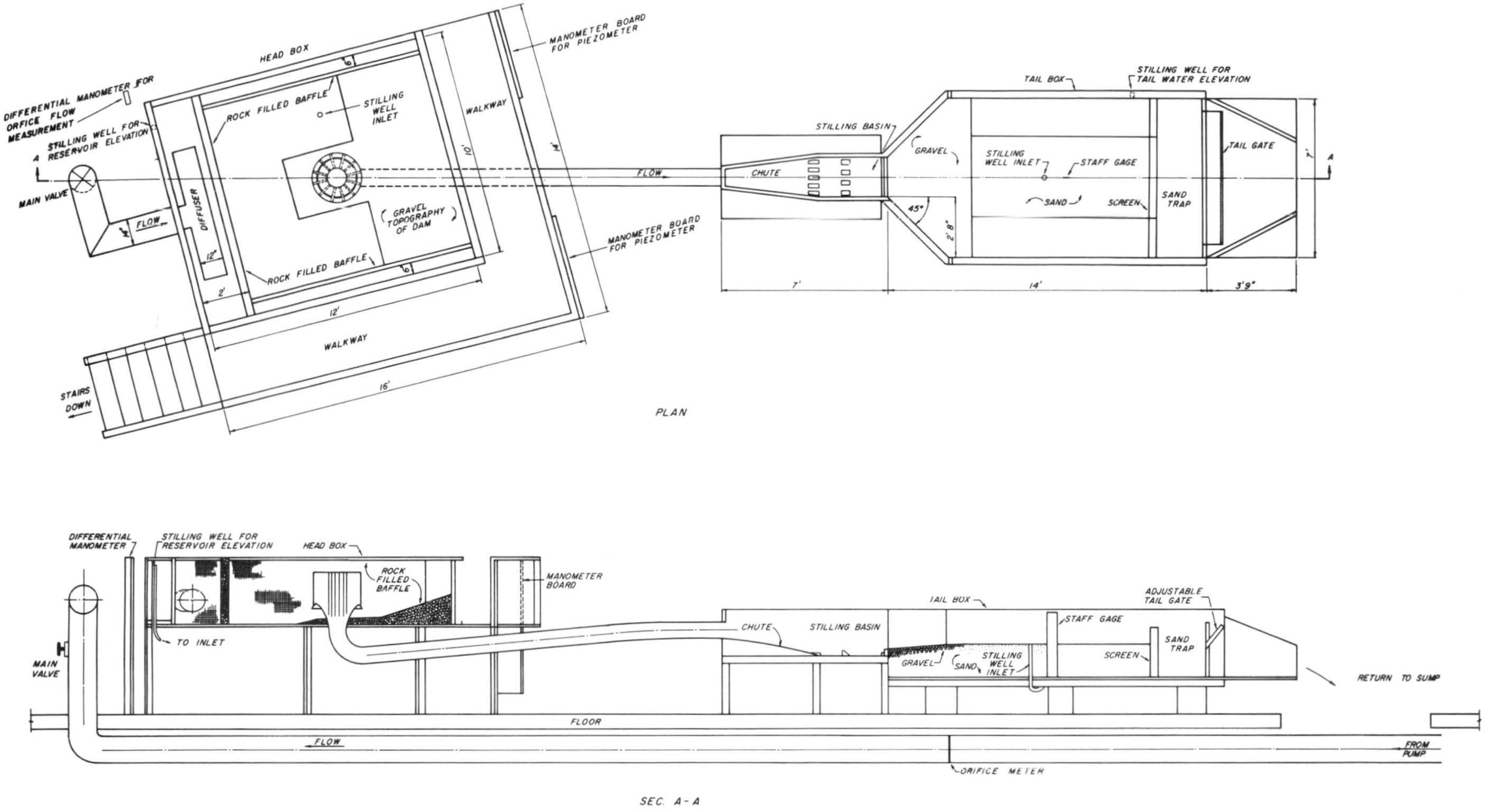


FIGURE 6 SCHEMATIC DRAWING OF MODEL

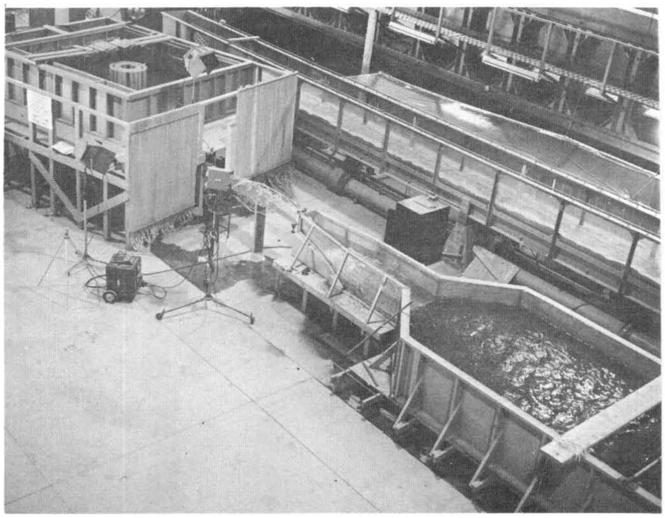
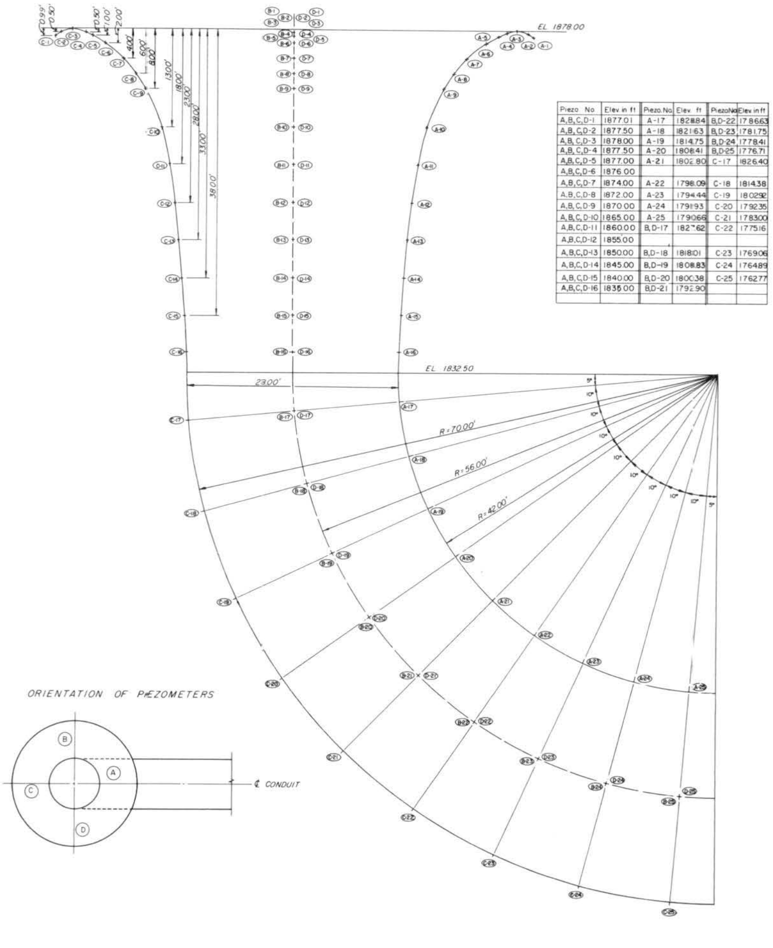


Figure 7. Photograph of completed model

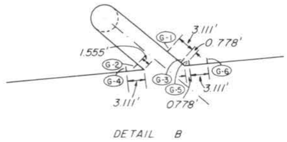
Figure. 8. Morning glory mold being covered with fiberglass



Piezo No	Elev in ft	Piezo. No	Elev ft	Piezo No	Elev in ft
A,B,C,D-1	1877.01	A-17	1828.84	B,D-22	1786.63
A,B,C,D-2	1877.50	A-18	1821.63	B,D-23	1781.75
A,B,C,D-3	1878.00	A-19	1814.75	B,D-24	1778.41
A,B,C,D-4	1877.50	A-20	1808.41	B,D-25	1776.71
A,B,C,D-5	1877.00	A-21	1802.80	C-17	1826.40
A,B,C,D-6	1876.00				
A,B,C,D-7	1874.00	A-22	1798.09	C-18	1814.38
A,B,C,D-8	1872.00	A-23	1794.44	C-19	1802.92
A,B,C,D-9	1870.00	A-24	1791.93	C-20	1792.35
A,B,C,D-10	1865.00	A-25	1790.66	C-21	1783.00
A,B,C,D-11	1860.00	B,D-17	182[illegible].62	C-22	1775.16
A,B,C,D-12	1855.00				
A,B,C,D-13	1850.00	B,D-18	1818.01	C-23	1769.06
A,B,C,D-14	1845.00	B,D-19	1808.83	C-24	1764.89
A,B,C,D-15	1840.00	B,D-20	1800.38	C-25	1762.77
A,B,C,D-16	1835.00	B,D-21	1792.90		

FIGURE 9 MORNING GLORY SPILLWAY AND VERTICAL BEND PIEZOMETER LOCATIONS

Figure 10. Morning glory spillway during construction



Piezo. No.	Elev. (ft)	Piezo. No.	Elev. (ft)	Piezo. No.	Elev. (ft)	Piezo. No.	Elev. (ft)
A-26	1792.89	A-34	1829.47	C-29	1780.00	C-37	1803.00
A-27	1797.89	A-35	1830.50	C-30	1785.00	C-38	1803.00
A-28	1802.89	A-36	1831.00	C 31	1790.00		
A-29	1807.89	A-37	1831.00	C-32	1795.00	G-1	1798.19
		A-38	1831.00			G-2	1795.99
A-30	1812.89			C-33	1799.50	G-3	1796.19
A-31	1817.89	C-26	1764.00	C-34	1801.50	G-4	1794.72
A-32	1822.89	C-27	1770.00	C-35	1802.50	G-5	1795.77
A-33	1827.55	C-28	1775.00	C-36	1803.00	G-6	1796.05

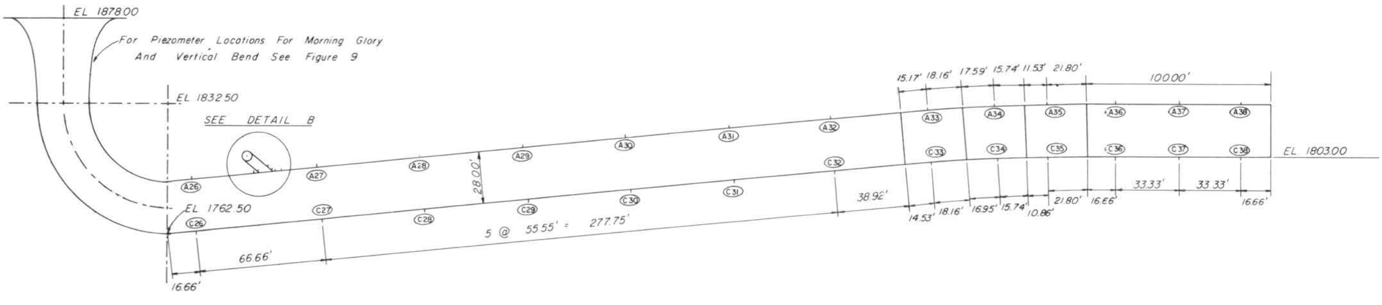
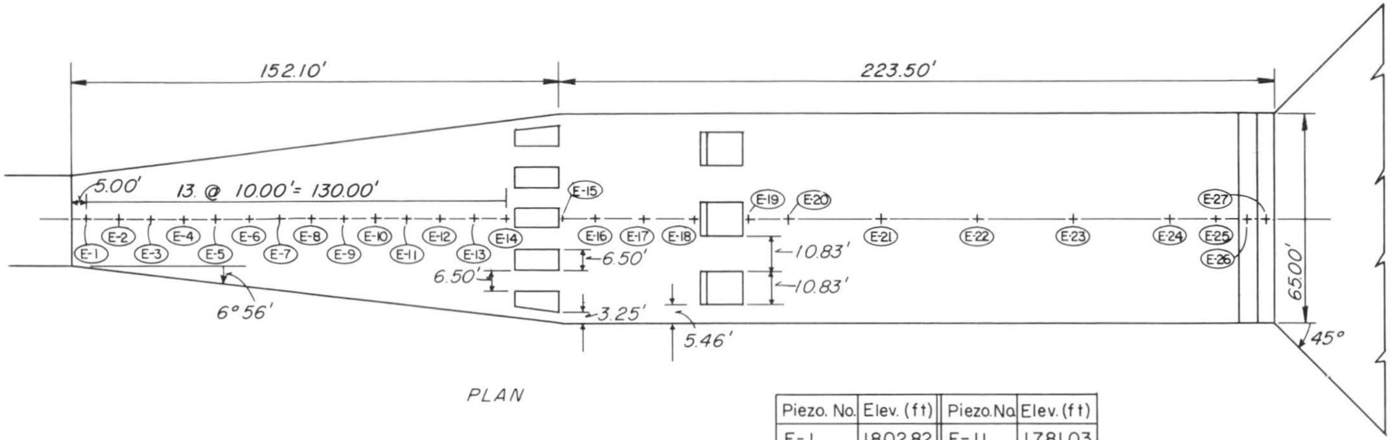


FIGURE 11 CONDUIT PIEZOMETER LOCATIONS



Piezo. No.	Elev. (ft)	Piezo. No.	Elev. (ft)
E-1	1802.82	E-11	1781.03
E-2	1802.27	E-12	1776.86
E-3	1801.37	E-13	1772.32
E-4	1800.10	E-14	1767.42
E-5	1798.46	E-15 to	1761.00
E-6	1796.47	E-25	
E-7	1794.11	E-26	1763.75
E-8	1791.38	E-27	1769.25
E-9	1788.29		
E-10	1784.85		

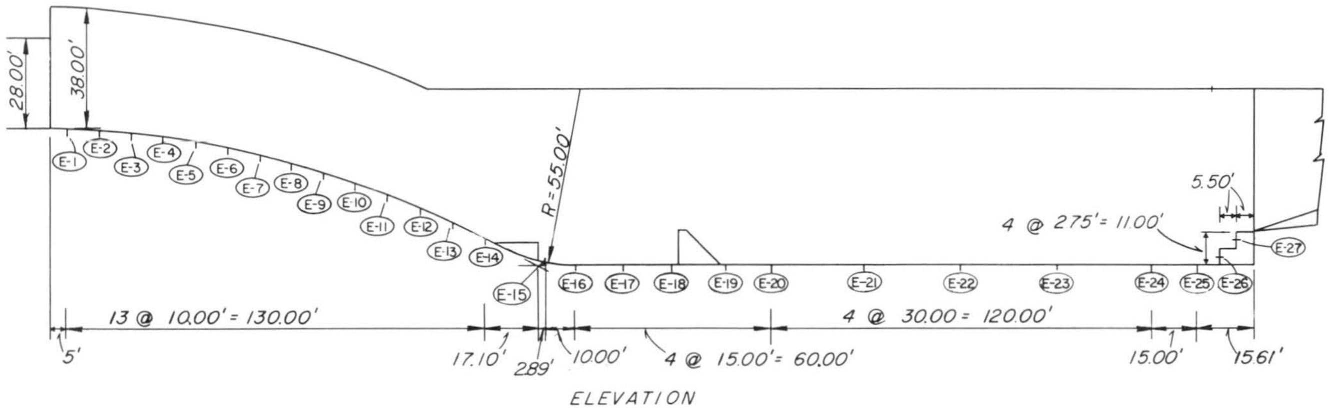
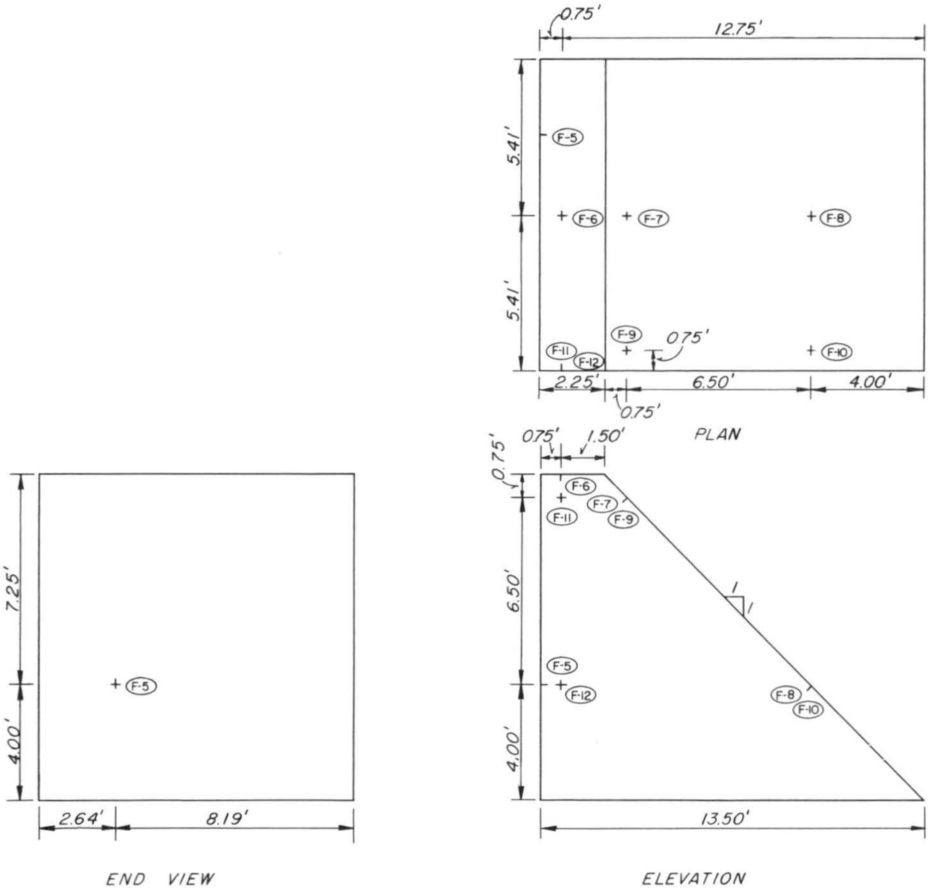


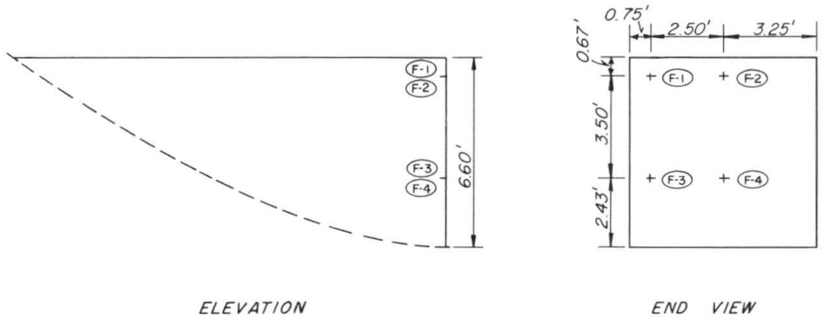
FIGURE 12 STILLING BASIN I PIEZOMETER LOCATIONS



BAFFLE BLOCK

Piezo. No.	Elev. (ft)
F-1, F-2	1768.50
F-3, F-4 F-5, F-8 F-10, F-12	1765.00
F-7, F-9 F-11	1771.50
F-6	1772.25

CHUTE AND BAFFLE BLOCK PIEZOMETER LOCATIONS



CHUTE BLOCK

FIGURE 13 CHUTE AND BAFFLE BLOCK PIEZOMETER LOCATIONS

Morning Glory Spillway I

Initial tests of spillway I were made to determine the location and magnitude of negative pressures on the spillway crest with all gates open. The discharge rating curve for spillway I with all gates open is given in Fig. 14. The curve is included here so that the reader may relate discharge to reservoir elevation or vice versa when only one quantity is mentioned.

For reservoir levels above 1891.0 ft, spillway I was submerged. All pressure observed on spillway I were positive. These pressure data are given in Table A-1 of Appendix A.

Generally, for reservoir levels below 1891.0 ft, free overflow occurred and negative pressures with magnitudes on the order of -2.0 to -10.5 ft of water were observed at piezometers 6 through 12 located on the crest and in the throat of the morning glory. For a reservoir elevation of 1891.0 ft, negative pressures of -10.5, -9.0, -9.5 and -8.5 ft of water were observed at piezometers A8, B8, C8 and D8, respectively. Pressures observed on this basic morning glory crest are given in Table A-1 of Appendix A.

The low pressure of -10.5 ft of water observed at piezometer A8 was considered to be excessive. Cavitation could result if this magnitude of negative pressure persisted. Therefore, spillway I was modified. The modification, tests and results are described in the following section.

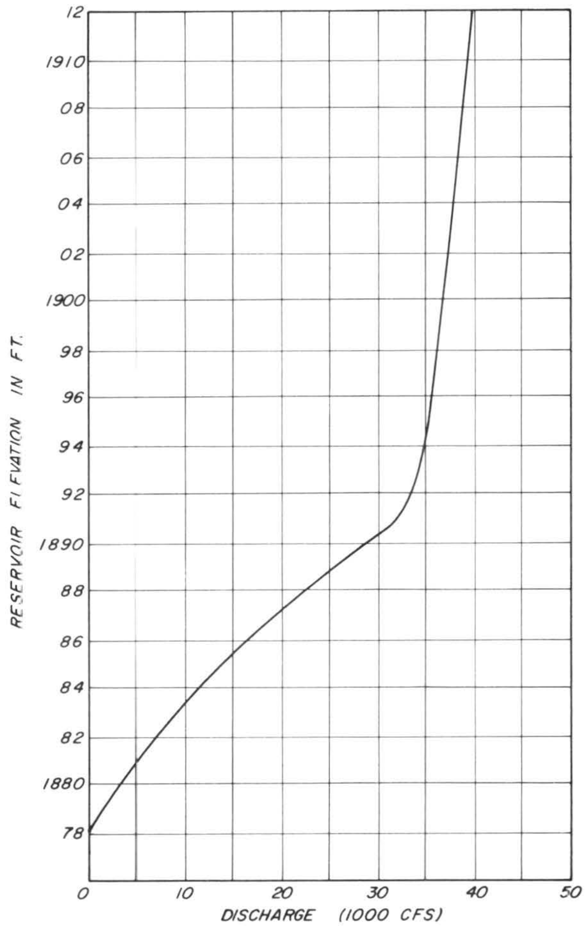


FIGURE 14 SPILLWAY I DISCHARGE RATING CURVE

Morning Glory Spillway II

The morning glory crest was reshaped to reduce the magnitude of the negative pressures observed on spillway I. The crest diameter was increased from 59.07 ft to 66.62 ft. The width of the piers was increased to 3 ft. Details of the modified morning glory, hereinafter referred to as spillway II, are given in Fig. 15. Piezometers were located at the same elevations as piezometers for spillway I and were given identical numbers. The piezometer locations are shown in Fig. 16.

The discharge rating curve for spillway II with all gates open is given in Fig. 17. The curve shown is for the model when all modifications, described hereinafter, were completed. Any reference to reservoir elevation or discharge made in the following discussion may be related by this curve.

Increasing the crest diameter increased the curvature of the crest. This curvature reduced the tendency of the water to separate from the boundary and thus the magnitudes of the negative pressures were reduced. The minimum pressure observed on the crest of spillway II with all gates open was -7.0 ft of water at piezometer C9 at a discharge of 31,600 cfs. A pressure of -7.0 ft of water was satisfactory. Pressure data for spillway II are given in Table A-2 of Appendix A.

After the adverse pressures on the morning glory crest were eliminated, a study was made of the approach conditions to the spillway, the pressures on the crest and the discharge rating of the morning glory spillway for combinations of open gates. Photographs of the approach flow lines to the morning glory spillway from the reservoir are shown in Fig. 18 for discharges of 27,500 cfs and 37,500 cfs at reservoir elevations of 1890.0 ft and 1910.0 ft. The magnitude and orientation of the surface velocities for the same two reservoir elevations are given in Fig. 19. As the reservoir rises, the surface velocities of the approaching flow increase until they reach a maximum at a reservoir level of about 1891.0 ft. As the reservoir level rises above 1891.0 ft, the spillway becomes submerged and the surface velocities decrease. This is because the throat or conduit controls the discharge above 30,000 cfs and the rate of change of discharge with head becomes less than for free overflow. Therefore, the discharge per unit area of approach decreases and lower surface velocities result.

Uniform discharge through each bay for all reservoir levels was evident from the uniformity of the pressure readings of the four lines of piezometers located in the spillway crest. Flow conditions through the bays were satisfactory. There was drawdown of the water surface on the order of 1 to 2 ft near the piers when the spillway was not submerged. Standing waves about 0.5 ft high were also observed between the piers for discharges of about 20,000 cfs to 30,000 cfs. Neither the drawdown or standing waves were objectionable since they did not interfere with the flow.

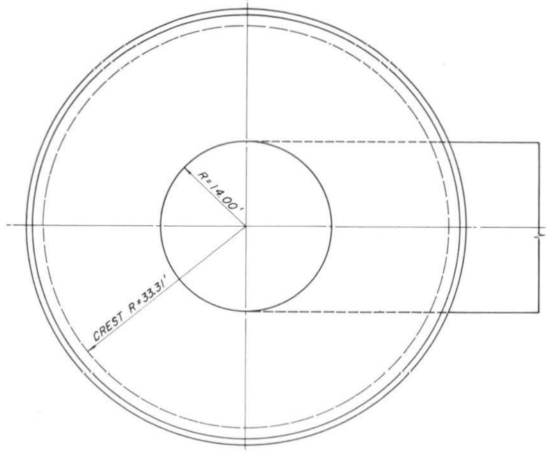
When the reservoir level was near 1891.0 ft, an oscillation of the water surface in the throat of the morning glory was noted. The frequency of the oscillation was quite uniform. The "boil" of water in the throat rose to submerge the morning glory and then dropped and completely swept out of the throat. This oscillation is due to the characteristics of the morning glory spillway. As long as a free overfall exists, the discharge is directly proportional to the head on the crest to the three halves power ($Q = CLH^{3/2}$). When the morning glory becomes submerged, the throat diameter controls, and in effect it becomes an orifice with the discharge proportional to the one-half power of the head above the orifice ($Q = KH^{1/2}$). By referring to the discharge rating curve of spillway II (Fig. 17), the two regions of operation, free overall and orifice flow, are clearly distinguished. In the region where the two curves intersect, at about 1891.0 ft, instability of the discharge occurs and the result is an oscillation of the water surface in the throat as previously described. A considerable amount of turbulence and alternate entrainment and release of air at the throat accompanied the oscillation. Detrimental vibrations of the prototype could result from oscillation of the water surface in the throat when the reservoir level remained near 1891.0 ft with all gates open. Discharge at this reservoir level with all gates open should be avoided.

The discharge rating curve for combinations of open gates is given in Fig. 20. The gates when opened were above the surface of the water and with the exception of one gate were symmetrically oriented about the periphery of the morning glory.

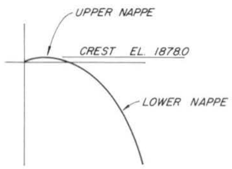
The oscillatory condition did not occur when 6 or fewer gates were open. The tranisition zone between free overfall and orifice flow was "smoothed out" as can be seen from the rating curves.

Pressures on the surface of the spillway crest were satisfactorily positive for combinations of 3, 4, 6 and 12 open gates at all reservoir levels. Pressure data for these tests are given in Table B-1 of Appendix B.

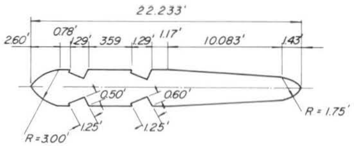
When only one or two gates were operated, the morning glory never became submerged and the flow was controlled by the size of the bay at reservoir levels above about 1892.0 ft. The piers in effect created a vertical orifice. The contraction of the water due to the jet caused the flow to attempt



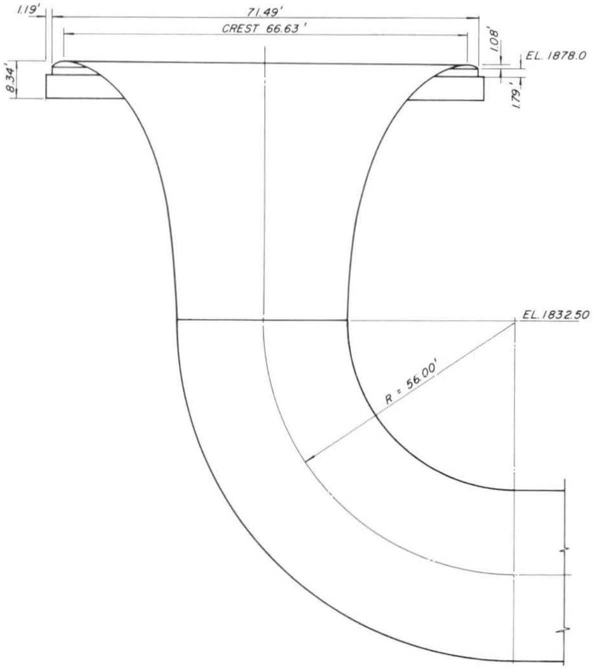
PLAN VIEW



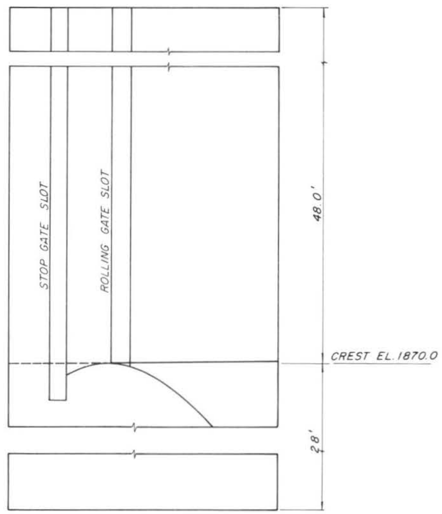
X_{ft}	Y_{ft}	X_{ft}	$-Y_{ft}$
0.000	0.000	6.277	0.000
0.152	0.186	6.882	0.304
0.304	0.342	7.401	0.608
0.458	0.468	7.887	0.911
0.607	0.573	8.344	1.215
0.760	0.662	8.769	1.520
0.911	0.743	9.741	2.279
0.957	0.816	10.609	3.039
1.215	0.878	11.399	3.799
1.368	0.932	12.112	4.559
1.520	0.976	13.374	6.078
1.824	1.037	14.453	7.599
2.128	1.071	15.381	9.119
2.452	1.079	16.901	12.159
2.735	1.071	18.071	15.198
3.039	1.046	18.967	18.283
3.799	0.905	19.652	21.277
4.559	0.678	20.213	24.318
5.320	0.425	20.640	27.357
6.079	0.092	20.989	30.397
		21.282	32.277
		21.671	38.234
		21.744	41.809



PLAN VIEW



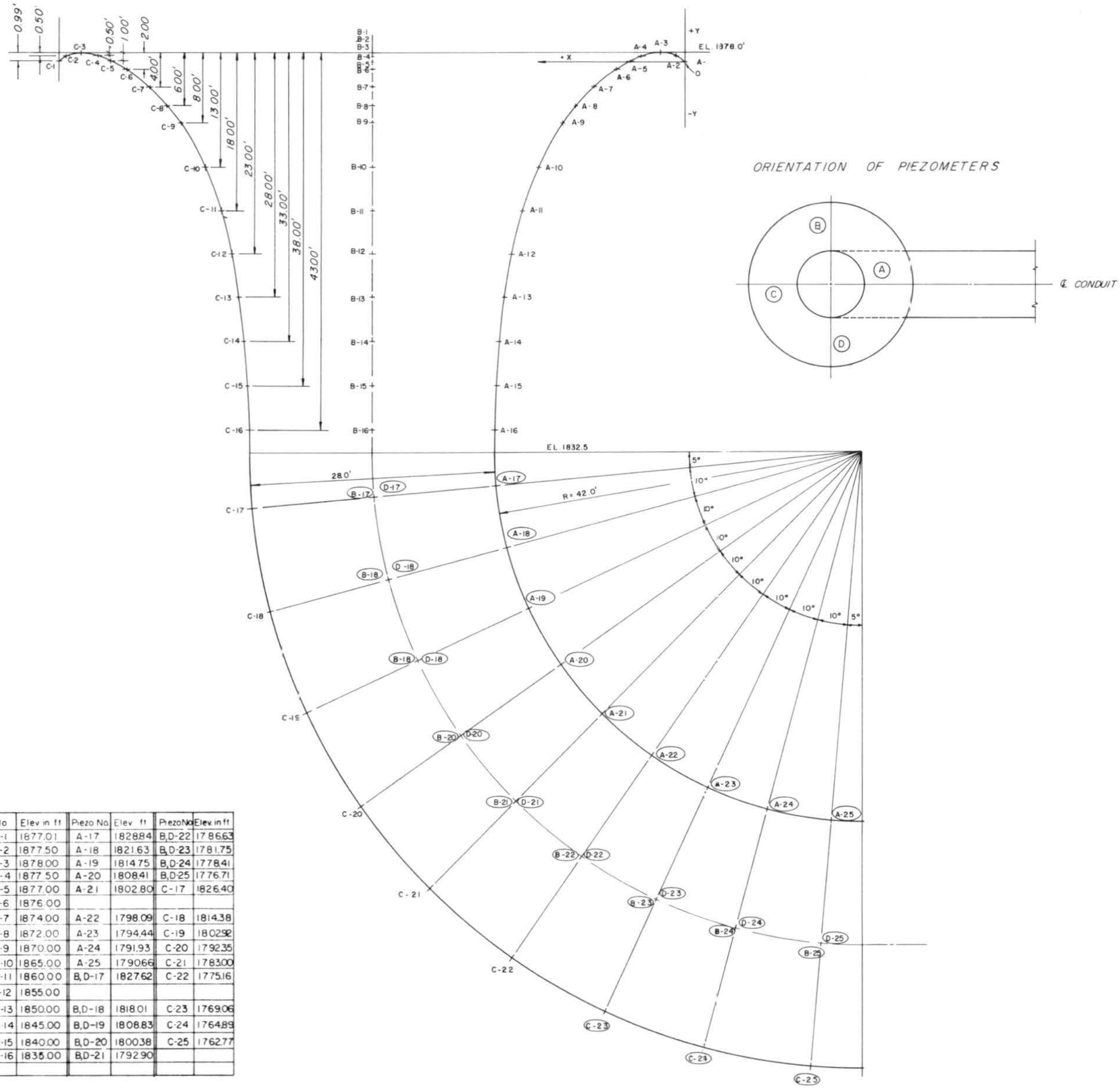
℄ PROFILE



PROFILE

PIER DETAIL

FIGURE 15 DETAILS OF SPILLWAY II



Piezo No	Elev in ft	Piezo No.	Elev ft	Piezo No.	Elev. in ft
A,B,C,D-1	1877.01	A-17	1828.84	B,D-22	1786.63
A,B,C,D-2	1877.50	A-18	1821.63	B,D-23	1781.75
A,B,C,D-3	1878.00	A-19	1814.75	B,D-24	1778.41
A,B,C,D-4	1877.50	A-20	1808.41	B,D-25	1776.71
A,B,C,D-5	1877.00	A-21	1802.80	C-17	1826.40
A,B,C,D-6	1876.00				
A,B,C,D-7	1874.00	A-22	1798.09	C-18	1814.38
A,B,C,D-8	1872.00	A-23	1794.44	C-19	1802.92
A,B,C,D-9	1870.00	A-24	1791.93	C-20	1792.35
A,B,C,D-10	1865.00	A-25	1790.66	C-21	1783.00
A,B,C,D-11	1860.00	B,D-17	1827.62	C-22	1775.16
A,B,C,D-12	1855.00				
A,B,C,D-13	1850.00	B,D-18	1818.01	C-23	1769.06
A,B,C,D-14	1845.00	B,D-19	1808.83	C-24	1764.89
A,B,C,D-15	1840.00	B,D-20	1800.38	C-25	1762.77
A,B,C,D-16	1835.00	B,D-21	1792.90		

FIGURE 16 MORNING GLORY SPILLWAY II PIEZOMETER LOCATIONS

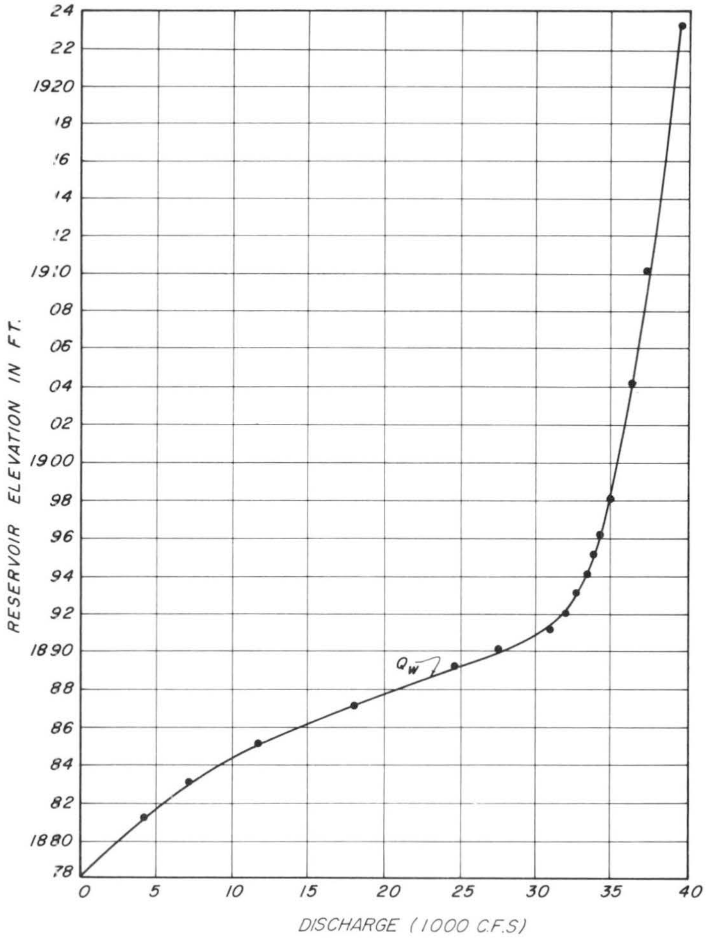


FIGURE 17 SPILLWAY II DISCHARGE RATING CURVE

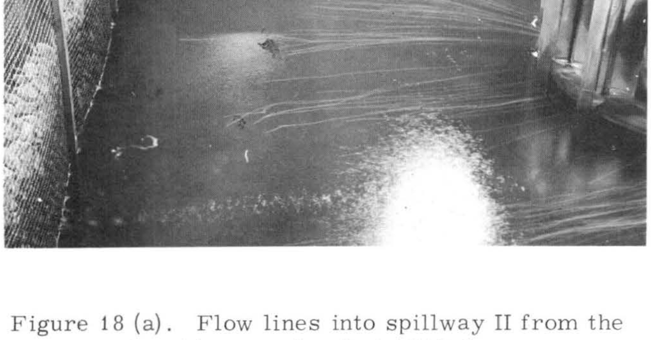


Figure 18 (a). Flow lines into spillway II from the reservoir with water level at 1890. 0

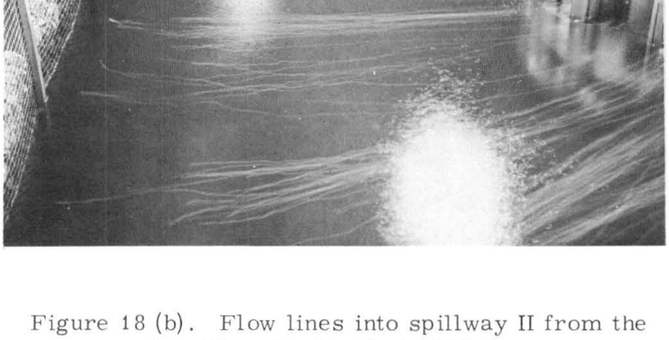


Figure 18 (b). Flow lines into spillway II from the reservoir with water level at 1910. 0

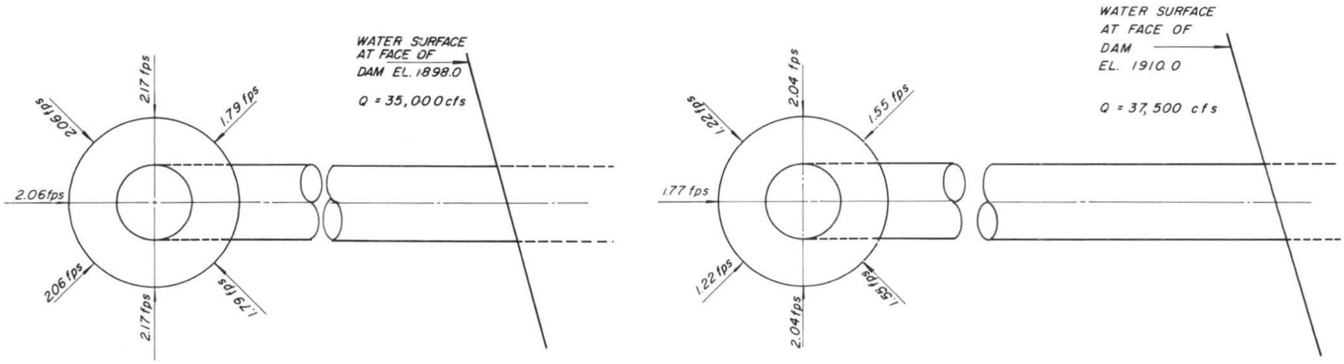


FIGURE 19 SURFACE VELOCITIES OF APPROACH TO THE SPILLWAY

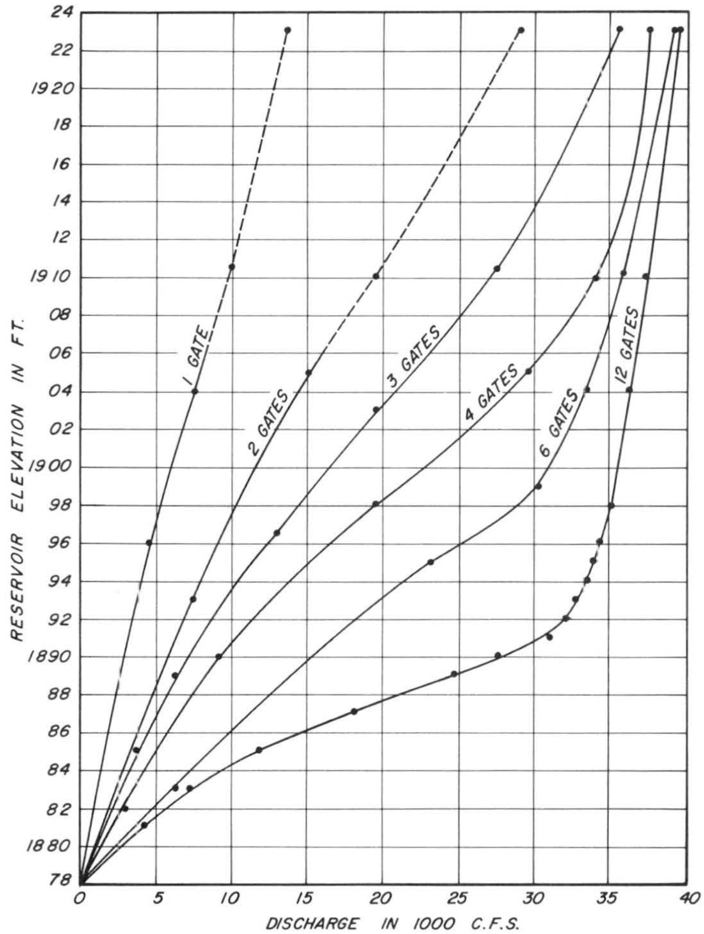


FIGURE 20 SPILLWAY II DISCHARGE RATING CURVE FOR COMBINATIONS OF OPEN GATES

to separate from the surface of the crest. Negative pressures of -11.0, -11.5 and -11.0 ft of water were observed at piezometers A6, A7 and A8, respectively, when two gates were open with the reservoir level at 1910.0 ft. With one gate open, piezometers A6, A7 and A8 read -11.0, -11.5 and -11.5 ft of water, respectively, for a reservoir level of 1910.5 ft. Pressure data for the above conditions are given in Table B-1 of Appendix B. Also, when one gate was open at reservoir levels above 1907.0 ft, the jet impacted on the opposite side of the morning glory. Therefore, operation of the morning glory with one or two gates open should be restricted to reservoir elevations of 1907.0 ft or less. The curves of Fig. 20 show all allowable range of operation of one or two gates as a solid line and the dashed line indicates the adverse operating region.

The Vertical Bend and Conduit

Pressures recorded at piezometers A18 and A19, located along the inside radius of the vertical bend, were -11.6 and -12.8 ft of water, respectively, with the reservoir at 1911.5 ft. Pressure data are given in Table A-1 of Appendix A. This magnitude of negative pressure was considered to be excessive. Therefore, aeration of the conduit at this point is necessary to reduce the magnitudes of the negative pressures to an acceptable level. An air vent was installed near the point of curvature of the bend to allow air to be drawn into the zone of negative pressures. A wedge shaped deflector was placed directly above the vent to create a separation of the flow from the boundary and to prevent the flow of water from impacting on the downstream lip of the air vent and causing erosion of the concrete. Details of the air vent and deflector are shown in Fig. 21. Aeration of the conduit reduced the discharge by approximately 5 percent from the non-aeratedconduit for reservoir levels above 1890.0 ft. A discharge of 30,000 cfs at a reservoir level of 1891.0 ft was considered satisfactory. The aeration increased the pressures at piezometers A18 and A19 from -11.6 and -12.8 to -4.0 and -4.0 ft of water, respectively, at a reservoir level of 1910.5 ft. Pressures of -4.0 ft of water were satisfactory. For pressure data resulting from aeration of the vertical bend, see Table A-2 of Appendix A. Flow through the vertical bend is illustrated in Fig. 22.

The air demand required to give satisfactory pressures is given in Fig. 23. The air flow in the model was measured with a calibrated Venturi meter. The maximum air demand on the model was about 200 cfs (prototype). The Corps of Engineers[3] suggest that air vent pipes be sized so that air velocities of not more than 150 ft per sec occur in the pipe. Using this as a guide, the total area of the air vent should be 2.0 ft^2, assuming a maximum air velocity of 100 ft per sec. A nominal 20" standard pipe provides approximately this area and should be adequate for an air vent. The vent must be shaped to permit self draining. If a water lock should form in the vent pipe, there is the possibility that some damage could occur before the water plug is "blown out". An arrangement suggested by the consulting engineers for the air vent is shown in Fig. 21.

Flow conditions through the conduit were satisfactory for all discharges. Some low pressures were measured along the crown of the conduit near the portal. All other piezometers in the conduit downstream from the vertical bend indicated positive pressure heads. Pressure data for the conduit are given in Appendix A.

The air entrained by the "boil" at the throat of the morning glory or from the air intakes passed through the conduit without difficulty. At low discharges the air separated from the water and passed through the conduit as slugs of air as shown in Fig. 24. For discharges above about 25,000 to 30,000 cfs, the entrained air passed through the conduit in small bubbles that tended to rise and flow near the crown as shown in Fig. 25.

The junction of the 60-inch service outlet pipe and the 28-ft conduit is shown in Fig. 2. Piezometer locations are given in Fig. 11. Pressures were satisfactorily positive with magnitudes on the order of feet of water for all discharges at all piezometer locations. Pressure data are given in Appendix B. The photographs of Fig. 26 illustrate flow conditions at the junction for two discharges.

Horizontal and vertical velocity traverses were made near the portal. The velocities were measured with a pitot tube. The velocity distributions recorded for two discharges are shown in Fig. 27. From the velocity profiles, it can be seen that no unusual conditions prevailed at the portal.

Stilling Basin I

The basic design of stilling basin I is shown in Fig. 3. The hydraulic jump is the principal energy dissipator for this type of structure. The purpose of the chute and floor blocks is to reduce the length of the basin from that which would be required for a natural hydraulic jump. The blocks aid in the formation and stabilization of the jump.

[3] Corps of Engineers, Hydraulic Design Criteria, sheet 050-1, "Air Demand - Regulated Outlet Works", Revised 1-64.

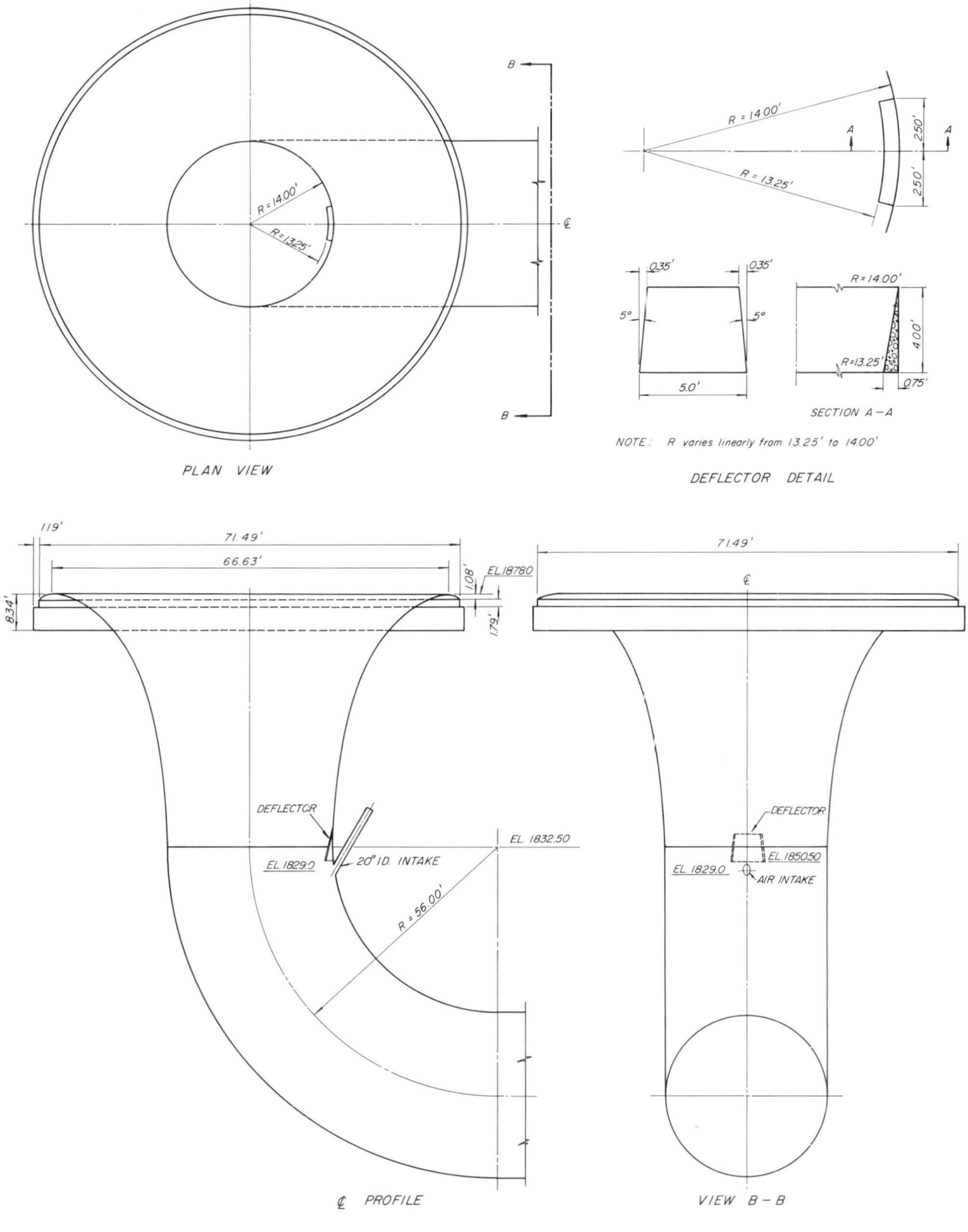


FIGURE 21 AIR VENT AND DEFLECTOR

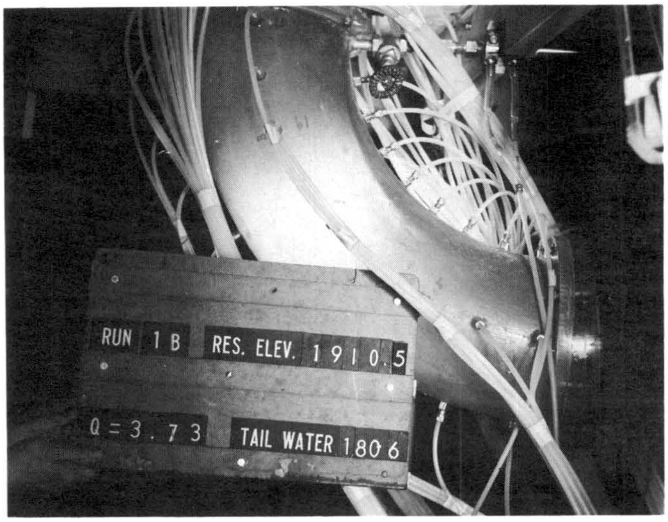


Figure 22. Flow through the vertical bend Q = 37,300 cfs

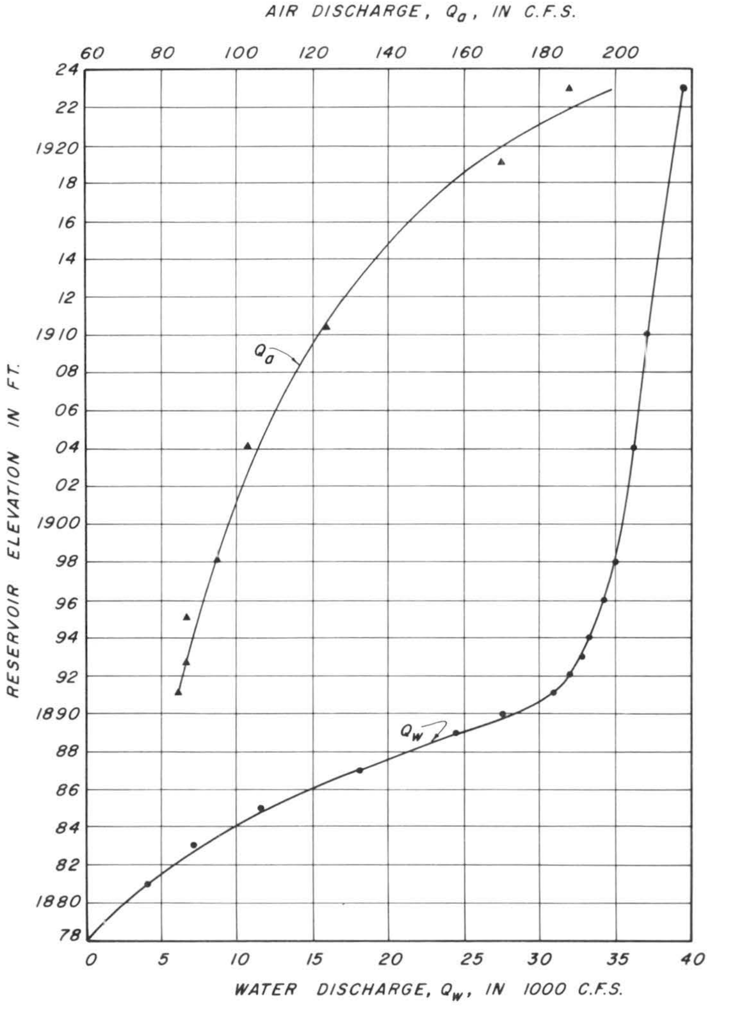


FIGURE 23 AIR DEMAND FOR RECOMMENDED WATER DISCHARGE

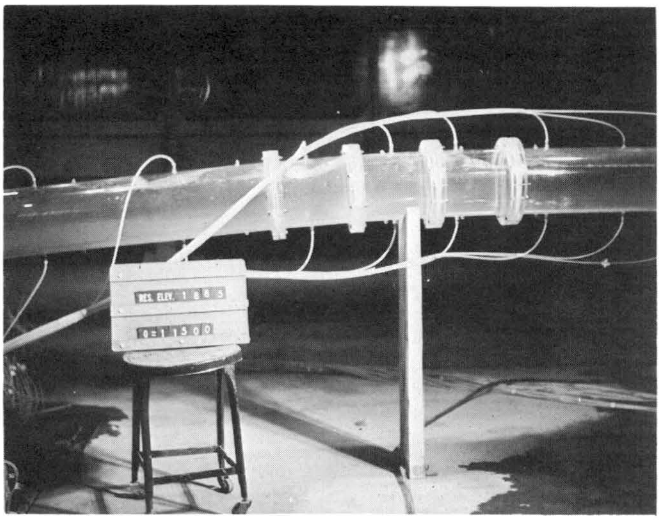


Figure 24. Air slugs in the conduit Q = 11,500 cfs

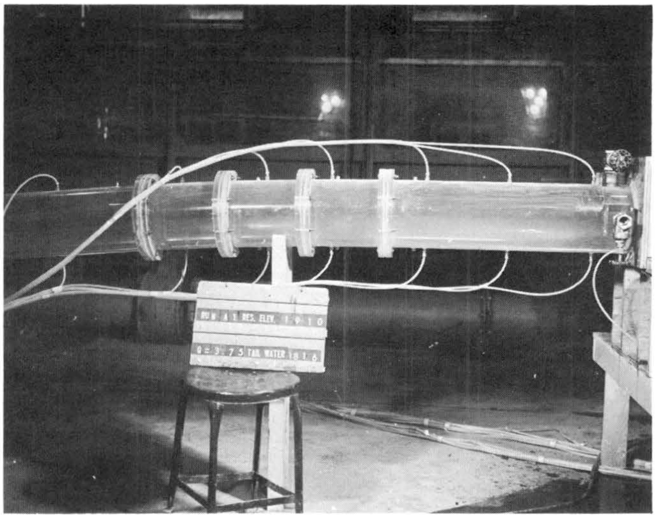


Figure 25. Air engrained flow in the conduit Q = 37,500 cfs

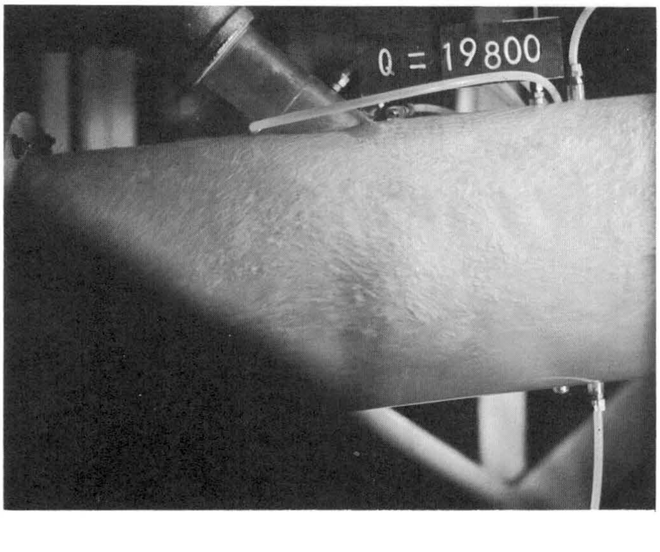


Figure 26 (a). Flow at the junction of the 60-inch pipe and 28-foot conduit, Q = 19,800 cfs

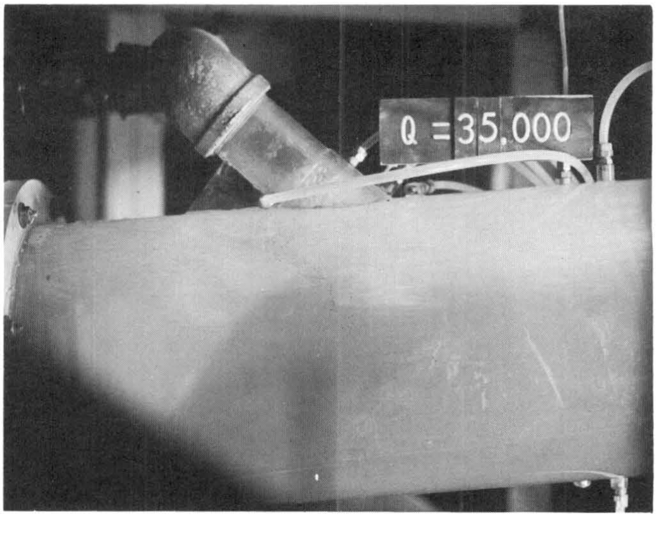


Figure 26 (b). Flow at the junction of the 60-inch pipe and 28-foot conduit, Q = 35,000 cfs

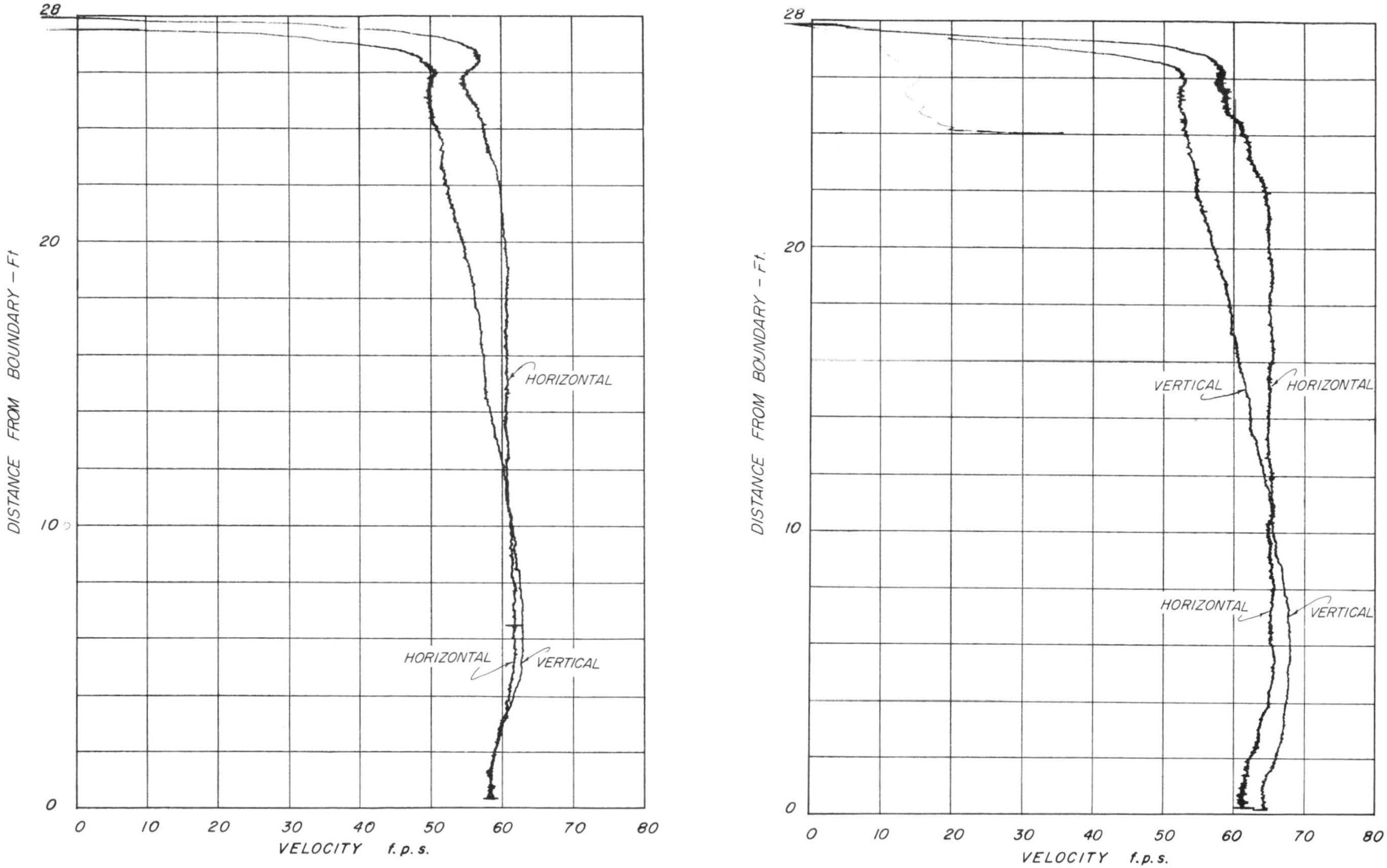


FIGURE 27 VELOCITY PROFILE AT PORTAL
(a) Q = 35,000 cfs Res 1898
(b) Q = 37,500 cfs Res 1910

Pressures on the chute and basin floor were positive for all discharges tested at different tail-water levels corresponding to the backwater curve shown in Fig. 4. Tailwater levels less than those suggested by the curve were also tested. The pressures on the chute and basin floor remained positive with magnitudes varying from 8.0 to 40.0 ft of water. Pressure data are given in Table C-1 of Appendix C. Pressures below vapor pressure were recorded because of the scale.

The spreading jet of water at supercritical velocities in the chute created fins at the walls. These fins did not overtop the walls and did not interfere with the flow, hence, aside from spray, did not create any problems.

Stilling basin I satisfactorily dissipated the kinetic energy of the flow. However, due to the turbulence and undulations of the hydraulic jump at near maximum discharges, the water overtopped the basin walls as shown in the photograph of Fig. 28. To confine the jump within the walls, it would have been necessary to increase the height of the walls approximately 10 ft. To reduce the cost of the structure, tests were made with the basin raised 8 ft. The results are described in the following section.

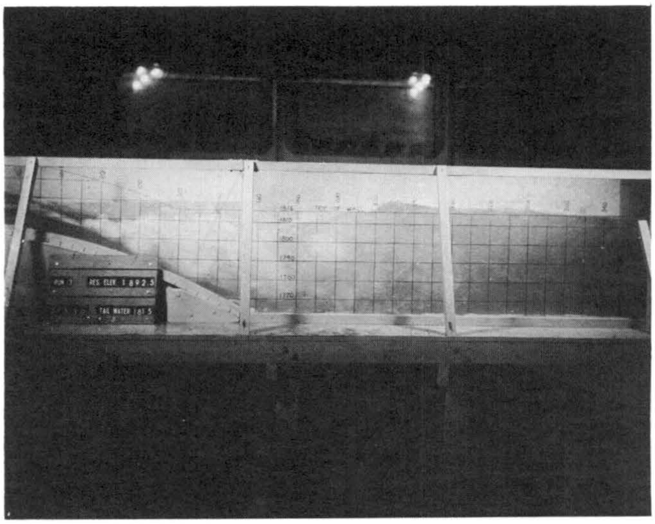


Figure 28. Hydraulic jump profile in stilling basin I, Q = 33,000 cfs, tailwater level at 1815.0

Stilling Basin II

For stilling basin II, the basin was raised 8 ft in elevation and shifted upstream to intersect the chute. The walls remained the same height as for stilling basin I. The overall length of the basin was reduced 15.3 ft. Details of stilling basin II with the piezometer locations shown are given in Fig. 29.

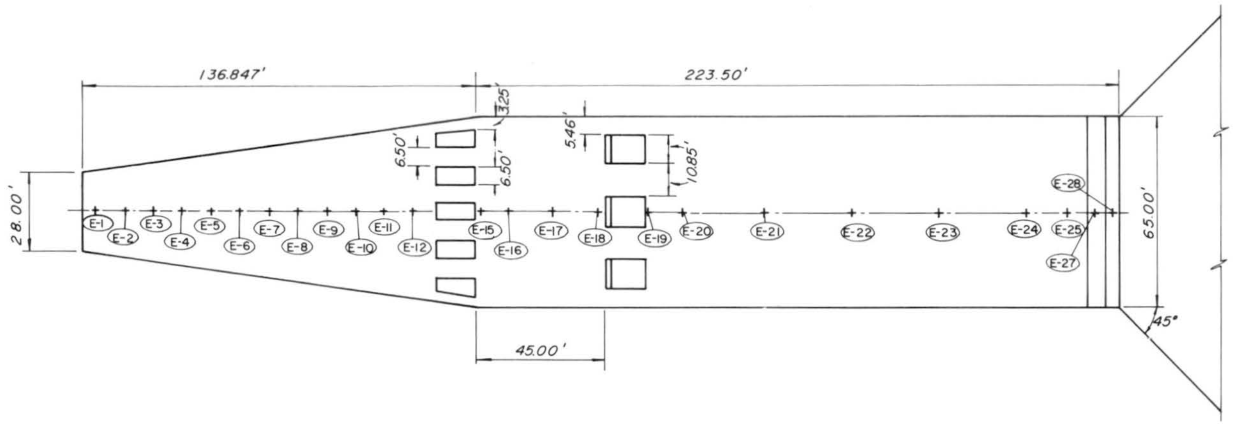
Generally, flow conditions in stilling basin II were satisfactory. Pressures were positive on the chute and basin floor. Negative pressures were recorded at piezometers F11 and F12, located on the baffle block. (See Fig. 13 for piezometer locations.) The minimum pressure was -15.5 ft of water for a discharge of 37,500 cfs and was recorded at piezometer F11. Some erosion of the concrete baffle blocks can be anticipated because of the possibility of cavitation on the blocks, but this type of block has been used in many existing structures without serious deterioration or maintenance difficulty. Cavitation of these blocks was not considered a problem.

The water overtopped the basin walls in the area of the baffle blocks due to the undulations of the hydraulic jump. Increasing the freeboard of the basin walls by 3 ft eliminated almost all of the "splash". A photograph of the jump profile is shown in Fig. 30. Pressure data are given in Table C-2 of Appendix C.

To further reduce the cost of the structure, the basin length was reduced. The end sill was moved upstream in increments of 10 ft and the jump profile was observed to insure that adverse conditions were not initiated by the change. Reduction of stilling basin II by 75.60 ft did not appear to affect the jump characteristics. Pressure data for these tests are given in Table C-3 of Appendix C. Therefore, the basin was modified and piezometers were located as shown in Fig. 31.

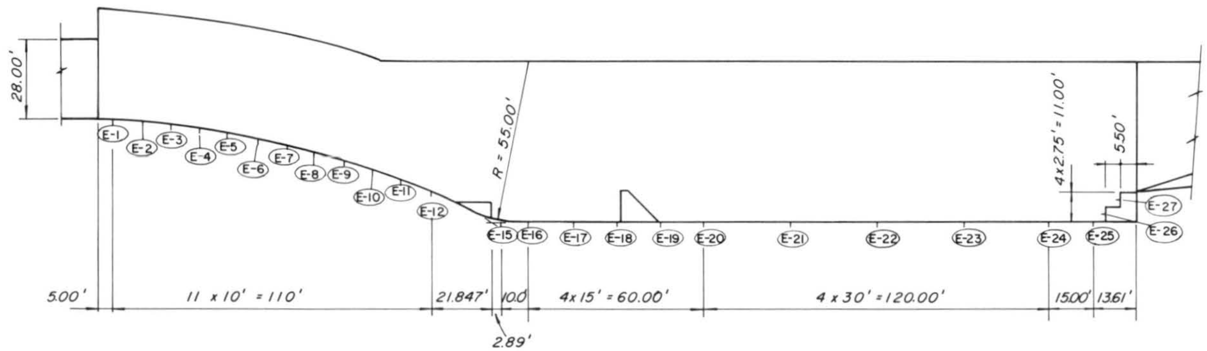
Pressures for the modified stilling basin II, hereinafter referred to as the recommended stilling basin, were positive on the chute and basin floor for all discharges. Some negative pressures were registered at the piezometers located in the chute and baffle blocks. However, these pressures cause no concern since these types of blocks have been used successfully in many similar existing structures as previously discussed. Pressure data for the recommended stilling basin are given in Table C-4 of Appendix C. The photographs of Fig. 32 show the jump profile in the basin for two tailwater levels and a discharge of 37,500 cfs. Test runs made at a tailwater depth of about 1806.0 ft, 10 ft lower than the tailwater rating curve, indicated that the jump would not sweep out of the basin.

To insure that negative pressures along the boundary immediately downstream from the tunnel



PLAN VIEW

Piezo No.	Elev. - ft.	Piezo No.	Elev. - ft.
E - 1	1802.82	E - 9	1788.29
E - 2	1802.27	E - 10	1784.85
E - 3	1801.37	E - 11	1781.03
E - 4	1800.10	E - 12	1776.86
E - 5	1798.46	E - 15 to E - 25	1769.00
E - 6	1796.47		
E - 7	1794.11	E - 26	1771.75
E - 8	1791.38	E - 27	1777.25



ELEVATION

FIGURE 29 STILLING BASIN II PIEZOMETER LOCATIONS

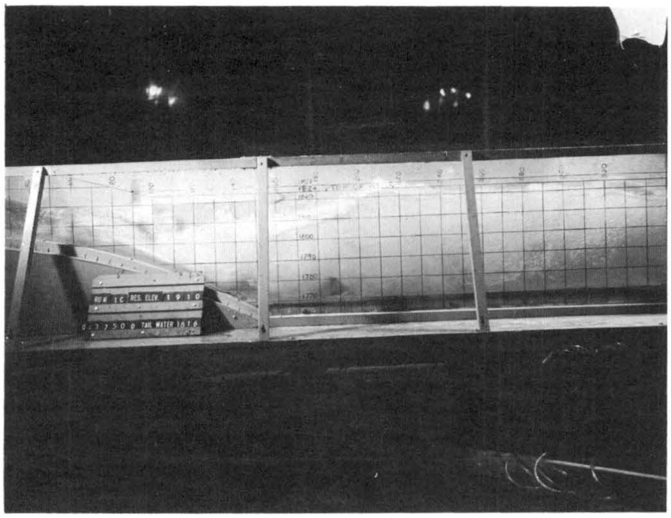


Figure 30. Stilling basin II jump profile Q = 37, 500 cfs

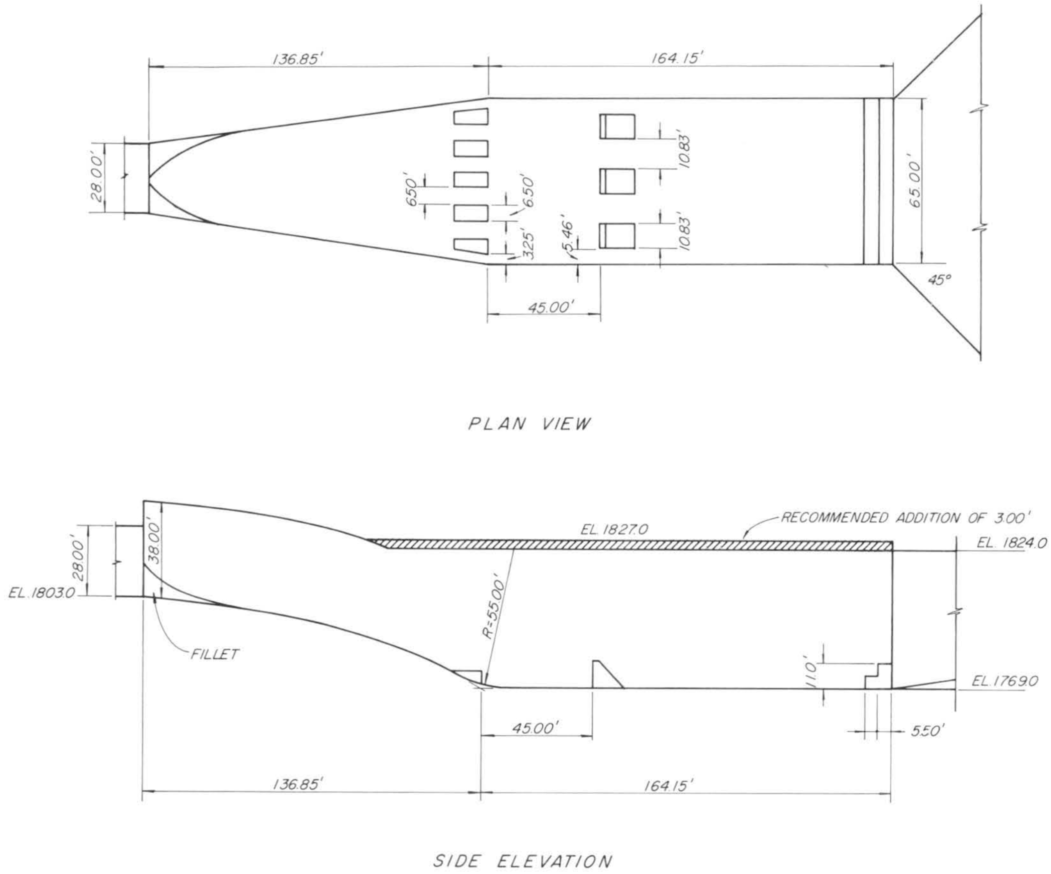


FIGURE 31 RECOMMENDED STILLING BASIN

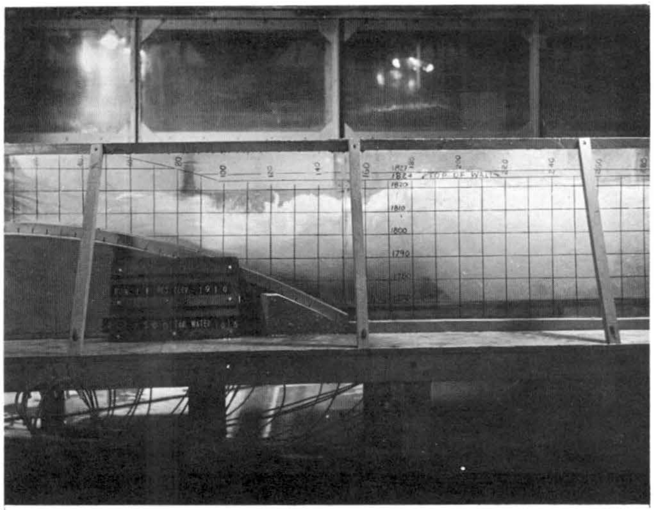


Figure 32 (a). Jump profile in recommended stilling basin, Q = 37, 500 cfs, tailwater level 1816. 0

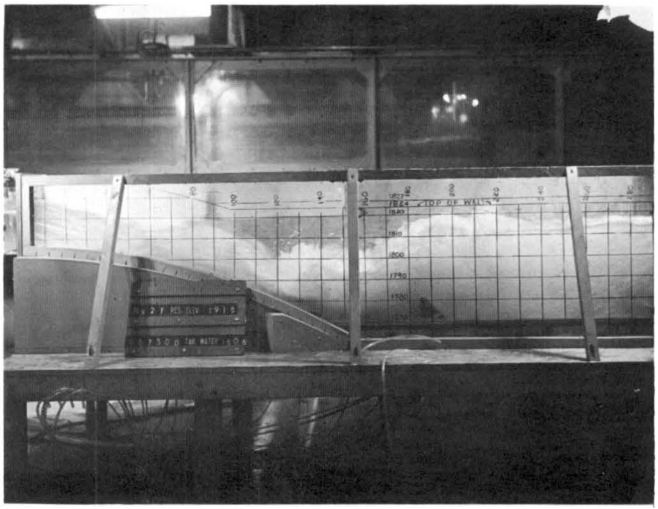


Figure 32 (b). Jump profile in recommended stilling basin, Q = 37, 500 cfs, tailwater level 1806. 0

portal did not occur because of the sudden change in geometry from a circular to rectangular section, fillets were placed in the corners as shown in Fig. 33. Details of the fillets are given in Fig. 33. These fillets also assisted in reducing the height of the fins at the chute walls created by the spreading jet.

It is suggested that 3 ft additional freeboard be added to the walls. The top of the walls would then be set at 1827. 0 ft. This additional freeboard is shown in Fig. 31.

Scour Control

Sand was placed in the channel downstream from the stilling basin. Tests were made to determine the depth and pattern of scour for different discharges and tailwater levels. Scour patterns and depths for two tailwater levels at a discharge of 37, 500 cfs are shown in Fig. 34. The maximum depth of scour was 19 ft, just downstream from the end sill.

A layer of 3/4-inch mean diameter (model) gravel was placed in a layer over the sand to simulate rip rap and scour tests were again made. The scour patterns for a discharge of 37, 500 cfs and two tailwater levels are shown in Fig. 35. This maximum depth of scour for the normal tailwater level (1816. 0) was 3 ft. When the tailwater level was dropped 10 ft to 1806. 0 ft, the maximum depth increased to only 5 ft. Relatively little movement of the gravel was evident.

The size of rip rap required for an average velocity of about 17 fps, which would occur at a maximum discharge of 39, 500 cfs and a normal tailwater level of 1816. 0 ft, would be 42-inch diameter stones. This size of stone is based upon data developed by the Bureau of Reclamation.[4] The 42-inch diameter stones should be placed on a graded layer of gravel and stones at least 63 inches thick. It is recommended that for the channel downstream from the spillway, graded rip rap ranging in sizes from 10 to 42 inches in diameter be placed in a layer five feet thick including a gravel bed, for a distance of at least 300 ft downstream from the end sill of the stilling basin.

Channel Downstream from Stilling Basin

The channel downstream from the stilling basin was designed to convey all of the discharge within its banks. The channel should have a bottom width of 300 ft at an elevation near 1791. 0 ft.

The depth at a discharge of 39, 500 cfs would be 25 ft. A side slope of 3:1 is suggested. The longitudinal slope should be 0. 0001 ft/ft. The channel bed will coincide with the existing river bed. The flow will spread at the existing river channel onto its natural flood plain. Alignment and suggested cross section of the channel are shown in Fig. 36.

[4] Peterka, A. J., Hydraulic Design of Stilling Basins and Energy Dissipators. Engineering Monograph No. 25, U. S. Bureau of Reclamation, revised July 1963, pp. 207-217.

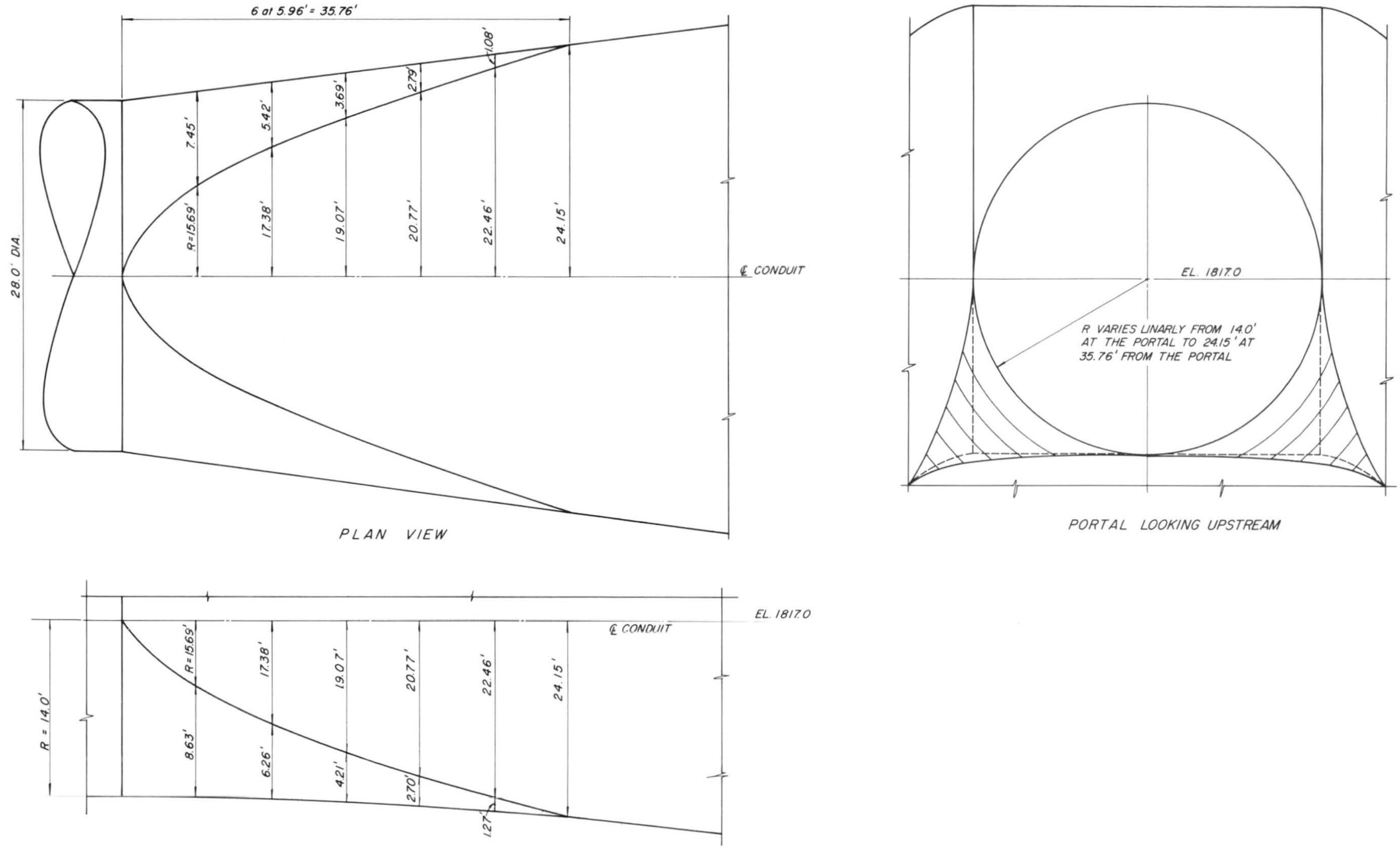


FIGURE 33 DETAIL OF FILLET DOWNSTREAM OF PORTAL

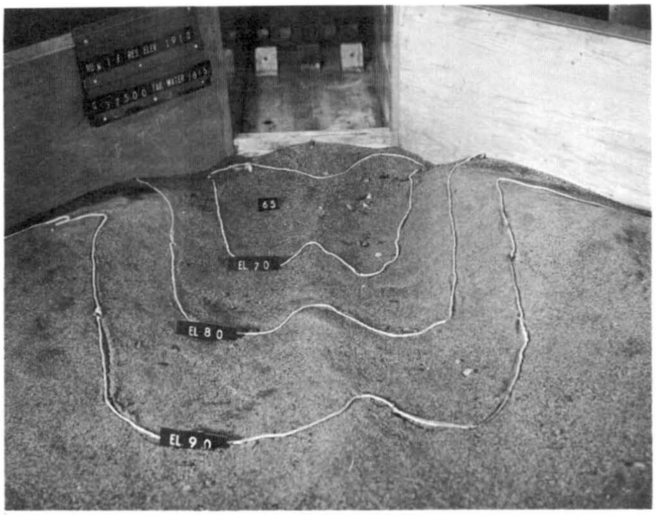


Figure 34 (a). Scour downstream from the recommended stilling basin, Q = 37,500 cfs, tailwater level 1816.0

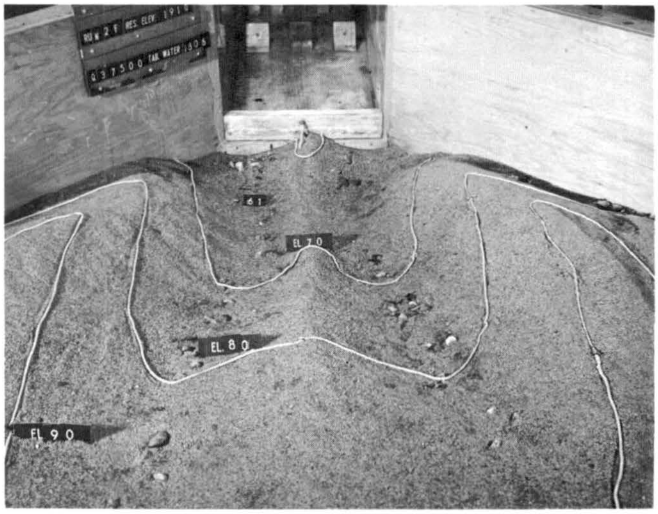


Figure 34 (b). Scour downstream from the recommended stilling basin, Q = 37,500 cfs, tailwater level 1806.0

Figure 35 (a). Scour downstream from the recommended stilling basin, Q = 37,500 cfs, tailwater level 1816.0

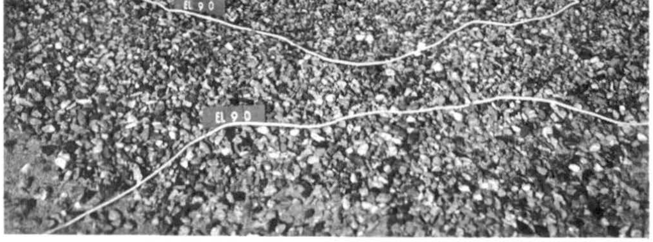


Figure 35 (b). Scour downstream from the recommended stilling basin, Q = 37,500 cfs, tailwater level 1806.0

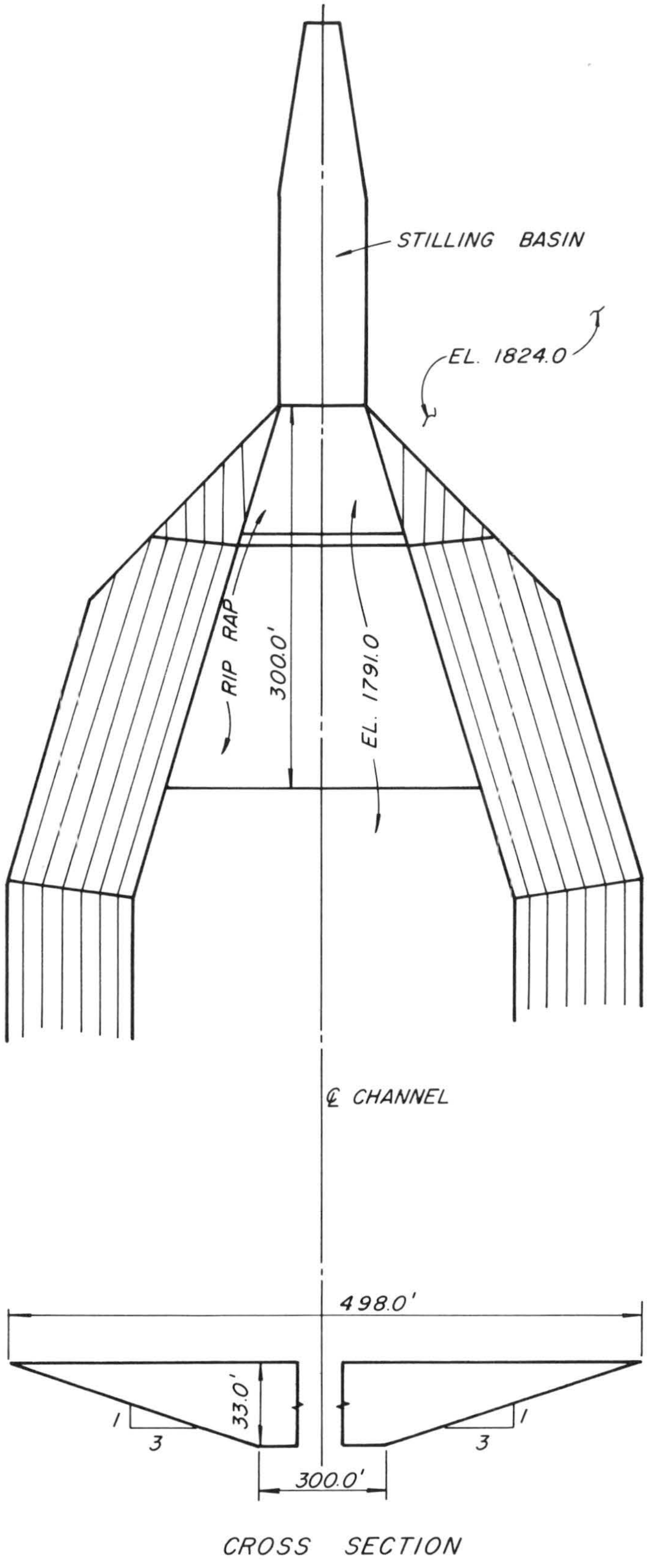


FIGURE 36 CHANNEL PLAN AND CROSS SECTION

CONCLUSIONS AND RECOMMENDATIONS

Morning Glory Crest

The morning glory was modified by increasing the diameter of the crest to 66.62 ft. The modified spillway performed satisfactorily with 3, 4, 6 and 12 gates open for all discharges. When 1 or 2 gates were opened, the morning glory performed satisfactorily for reservoir elevations up to 1907.0 ft. For reservoir elevations above 1907.0 ft, the morning glory should not be operated with only 1 or 2 gates open because of the possibility of cavitation indicated by the low pressures registered on the model. The discharge rating curve for the recommended spillway is given in Fig. 20.

Operation of the morning glory at reservoir elevation 1892.0 ft with all gates open created an oscillitory condition in the throat that could set up detrimental vibrations in the structure. Operation of the morning glory with 6 or less gates open at reservoir elevation 1892.0 ft, eliminated the oscillation. Therefore, it is recommended that when the reservoir elevation is 1892.0 ft, 12 gates not be used to regulate the flow.

Vertical Bend and Conduit

Flow conditions in the vertical bend were made satisfactory by the addition of an air vent and deflector near the P.C. of the bend. The maximum air demand was 200 cfs (prototype). It is suggested that the air vent be a 20" pipe centered at elevation 1829.0 ft. The size and oscillation of the deflector and vent are shown in Fig. 21.

Flow conditions in the pipe were satisfactory at all discharges. The entrained air was trapped by the 60-inch service pipe and formed a fluid flow ceiling at the junction of the service pipe and 28-foot conduit. Flow conditions and pressures were satisfactory at the junction.

Stilling Basin

The stilling basin was modified by raising the floor 8 ft and reducing the overall length of the chute and basin by 75.6 ft. To provide additional freeboard, 3 ft should be added to the wall. The top of the wall would then be at elevation 1827.0 ft.

No modification to the chute, chute blocks, baffle blocks or end sill was required excepting a reduction in the chute length resulting from the raised basin. Pressures were positive for all discharges at all locations in the stilling basin with the exception of the chute and baffle blocks. Negative pressures indicated possibility of cavitation on the sides of the baffle blocks, but based upon other existing basins, maintenance of the blocks should not be a serious problem.

Downstream Channel

A channel to convey all of the discharge is recommended. The channel should be 300 ft wide with 3:1 side slopes. The depth of water for discharge of 39,500 cfs would be about 25 ft. Graded rip rap with maximum sized stones of 42-inch diameter should be placed on a graded layer 63 inches thick of sand and gravel. The rip rap should extend for about 300 ft downstream from the end sill and should be placed on both the bed and banks of the channel. The suggested channel is shown in Fig. 36.

APPENDICES

TABLE A-1

PRESSURE HEADS ON BASIC MORNING GLORY SPILLWAY, VERTICAL BEND AND CONDUIT

Pressure Heads in Feet of Water

Run No.	2	3	4	6	7	8	9	10
Reservoir Elevation	1911.5	1905.5	1899.0	1893.0	1891.0	1889.0	1886.0	1882.0
Discharge cfs	39,500	38,000	36,000	34,000	32,000	25,500	16,000	7,000
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
A 1	32.0	26.0	19.0	11.0	9.5	8.0	6.5	4.0
2	29.0	22.5	15.0	5.0	2.5	3.0	3.0	2.5
3	25.5	19.0	11.0	0	-5.0	-3.0	-1.0	0.5
4	24.5	18 5	11.5	1.0	-5.5	-3.5	-0.5	-1.0
5	24.0	18.0	11.0	0.5	-7.0	-4.5	-2.0	-1.0
6	23.0	17.0	10.5	0.5	-8.0	-6.0	-3.0	-1.0
7	21.0	15.5	9.5	1.0	-9.0	-7.0	-4.0	-2.0
8	20.0	14.5	9.0	1.5	-10.5	-8.5	-4.5	-2.0
9	19.0	13.5	9.0	2.0	-8.5	-8.0	-4.5	-2.0
10	16.0	11.5	8.0	3.5	-5.0	-7.0	-4.0	-2.0
11	13.0	9.5	6.5	3.0	-2.0	-5.0	-4.5	-2.0
12	12.5	9.5	7.0	4.0	-0.5	-3.0	-2.0	-1.0
13	10.0	7.0	5.0	3.5	0	-3.5	-2.5	-2.0
14	9.0	6.5	4.5	4.0	2.0			
15	5.0	3.5	2.0	2.5	2.0	-3.0	-2.0	-1.5
16	1.5	0.5	0	1.0	0	-3.0	-1.5	0
17	1.2	-8.8	-8.3	-4.8	-5.8	-4.0	-3.8	-2.0
18	-11.6	-9.1	-9.6	-5.6	-5.6	-4.6	-2.6	-1.6
19	-12.8	-8.8	-9.8	-5.8	-3.3	-1.8	-0.3	3.7
20	-3.4	-2.4	-0.4	3.6	6.6	7.6	9.1	3.1
21	-0.8	3.7	3.2	8.2	13.7	22.2	19.2	0.2
22	7.9	8.9	10.9	15.9	20.9	29.9	25.4	24.9
23	13.6	14.6	16.6	21.1	26.6	33.6	28.1	29.6
24	15.1	19.1	21.1	26.1	30.1	34.1	33.1	33.6
25	27.3	27.8	28.3	31.8	33.3	36.3	34.8	34.3
26	48.6	47.6	46.1	46.6	41.6	42.1	33.1	33.6
27	37.1	36.1	36.1	37.1	38.6	35.1	34.1	34.1
28	31.1	29.6	29.1	30.6	32.6	30.6	27.6	21.6
29	21.1	20.6	20.1	22.1	27.6	28.1	29.1	20.1
30	19.6	19.1	18.1	20.1	22.6	22.1	20.1	12.6
31	11.1	10.1	10.1	12.1	18.6	16.6	16.1	15.1
32	4.6	4.1	3.6	5.6	13.1	10.1	10.1	8.6
33	-1.1	-1.6	-1.6	0.9	6.4	4.4	4.4	3.9
34	-4.5	-4.5	-5.0	-2.5	4.0	5.5	4.5	4.5
35	-6.0	-6.0	-6.5	-4.0	4.0	6.5	5.5	5.5
36	-9.0	-9.0	-9.0	-6.0	0	-1.0	-0.5	0
37	-10.0	-10.0	-10.0	-7.0	0.5	2.5	2.0	2.5
38	-9.5	-9.5	-9.5	-5.0	4.0	11.0	11.0	11.0
B 1	32.0	24.5	19.5	12.5	10.5	10.0	7.0	4.0
2	28.0	20.5	14.0	4.5	2.5	3.0	3.0	2.5
3	24.5	18.0	10.5	0	-5.0	-3.0	0	1.0
4	24.5	18.0	11.5	0.5	-5.0	-3.5	-1.0	0
5	24.0	17.0	11.0	0	-6.5	-4.0	-2.0	0
6	22.5	17.0	10.0	-0.5	-8.0	-5.0	-9.0	-7.0
7	21.5	16.0	10.0	0	-9.5	-7.0	-4.0	-1.0
8	19.5	14.5	9.0	1.0	-9.0	-8.0	-5.0	-2.0
9	18.5	14.0	9.0	2.0	-7.5	-8.0	-12.5	-10.0
10	16.5	12.0	8.0	3.0	-4.0	-6.0	-4.0	-2.0
11	19.0	10.0	7.0	3.5	-2.0	-5.0	-4.5	-2.0
12	13.5	10.0	7.0	4.5	0.5	-3.0	-2.5	-1.0
13	12.0	9.5	7.0	5.0	3.0	-2.0	-2.0	-1.0
14	11.5	9.0	6.5	6.0	5.0	-2.0	-2.0	-1.5
15	12.0	10.0	7.5	7.0	6.5	-1.0	-1.0	0
16	13.5	12.0	10.0	10.0	9.5	-2.0	-0.5	4.0
17	19.9	13.4	16.4	16.4	16.4	-0.6	-1.6	-1.1
18	24.0	22.0	22.0	23.0	32.5	7.0	-2.0	-1.0
19	38.2	37.2	35.2	35.2	34.7	19.2	8.7	5.7
20	45.6	44.1	42.6	42.6	41.6	28.6	22.1	19.6
21	56.1	54.1	52.1	52.1	51.1	39.1	23.6	24.1
22	59.9	53.4	56.4	57.4	55.4	45.4	29.9	30.4
23	66.2	64.7	62.7	62.7	61.7	53.2	37.2	34.7
24	68.1	65.1	64.1	64.6	62.1	53.6	40.6	38.6
25	69.8	67.8	65.8	66.3	63.3	55.3	42.8	41.3

TABLE A-1 (continued)

Run No.	2	3	4	6	7	8	9	10
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
C 1	33.0	26.5	19.0	13.0	11.0	7.0	7.0	4.5
2	28.0	22.0	14.0	4.5	1.5	2.5	3.0	2.5
3	25.0	18.0	10.0	-0.5	-5.0	-5.0	3.5	-1.5
4								
5	24.0	17.0	11.0	-0.5	-6.5	-6.0	-2.5	-1.5
6	23.0	16.5	11.0	-0.5	-8.0	-6.0	-2.5	-1.0
7	21.0	15.5	10.0	0	-9.0	-8.0	-4.0	-2.0
8	19.0	14.0	9.0	1.0	-9.5	-11.0	-6.5	-4.0
9	19.0	14.0	9.0	3.5	-8.0	-8.5	-5.5	-3.5
10	16.0	5.0	8.0	3.0	-5.0	-8.0	-5.5	-4.0
11	15.0	17.0	7.0	2.0	-2.0	-9.0	-7.0	-5.0
12	13.5	10.0	8.0	4.0	2.0	-3.0	-1.5	0
13	14.0	10.0	7.0	4.0	2.5	-3.0	-2.0	-1.5
14	13.5	11.0	9.0	6.0	6.0	-3.5	-1.0	-1.5
15	15.5	13.0	11.0	8.0	9.0	-2.0	-1.5	-1.0
16	21.0	19.0	16.5	14.0	14.0	-1.0	-1.0	-1.0
17	40.6	37.6	34.6	31.1	31.1	-8.6	3.6	0.6
18	56.1	52.6	49.1	44.6	46.1	34.6	11.6	9.6
19	67.6	64.1	62.1	59.1	57.6	47.1	38.1	25.1
20	78.1	74.6	72.6	67.6	68.2	58.6	50.1	36.1
21	87.5	84.0	81.0	77.5	77.5	68.0	55.0	41.0
22	93.3	89.8	86.8	83.8	83.3	73.8	55.3	44.8
23	100.9	97.4	94.4	91.4	90.4	80.9	61.4	51.4
24	103.6	100.1	97.6	95.6	93.1	84.1	65.6	55.1
25	104.2	101.2	98.2	95.2	93.7	85.2	69.2	58.7
26	80.0	78.5	77.0	77.0	74.0	66.0	56.0	54.5
27	65.5	64.5	64.0	65.0	65.5	60.0	55.5	52.5
28	60.5	59.5	59.0	60.0	61.0	57.0	53.0	48.0
29	52.0	51.0	51.0	52.0	54.0	51.5	48.5	43.0
30	45.0	44.5	44.0	45.0	48.0	46.5	44.0	38.0
31	38.0	37.5	37.5	39.5	42.0	41.5	39.0	33.0
32	32.0	32.0	31.5	33.5	35.0	35.0	34.0	28.5
33	25.5	25.0	25.0	27.5	30.0	30.5	29.0	23.0
34	22.5	22.5	22.5	24.5	27.0	28.5	27.0	20.5
35	20.0	20.5	20.0	22.5	25.5	25.5	26.0	18.0
36	18.5	19.0	19.0	21.0	23.5	25.0	25.0	16.5
37	18.0	18.5	18.5	20.5	23.0	25.0	24.0	15.5
38	15.5	16.0	16.0	18.0	19.5	21.0	20.5	14.0
D 1	32.5	26.5	20.0	13.0	12.0	11.0	8.0	5.0
2	28.0	21.0	12.5	1.5	2.5	3.0	3.5	3.0
3	24.5	18.0	14.0	5.0	-4.0	-2.0	0	1.5
4	24.5	18.5	13.5	2.5	-3.5	-2.0	-0.5	0.5
5	23.5	17.5	11.0	0.5	-5.0	-3.0	-1.0	0.5
6	22.5	17.5	11.0	1.0	-7.0	-4.0	-2.0	0
7	21.5	16.5	10.5	1.0	-8.0	-6.0	-3.0	-1.0
8	20.0	15.5	10.0	1.0	-8.5	-6.0	-3.5	-1.0
9	18.5	14.5	10.0	1.5	-8.5	-6.0	-4.0	-2.0
10	16.5	12.5	8.0	2.5	-6.0	-6.0	-3.5	-2.0
11	14.5	11.0	8.0	3.0	-2.5	-4.5	-2.5	-1.5
12	14.5	11.0	5.0	4.0	0.5	-2.0	-2.5	-1.0
13								
14	11.5	10.0	7.5	5.0	5.5	-2.0	-1.0	0
15	12.5	10.0	8.0	6.0	6.5	-2.0	-1.0	0
16	14.0	13.5	10.5	9.0	10.5	-1.0	-0.5	0
17	20.4	17.9	16.4	14.4	16.9	-5.1	-7.1	-6.1
18	32.0	30.0	28.0	26.0	27.5	8.5	0.5	13.0
19	37.2	35.2	34.2	33.2	35.2	15.2	4.2	13.2
20	44.6	44.1	42.6	40.6	42.6	28.6	20.6	21.1
21	53.1	52.1	51.1	49.1	50.6	39.1	28.6	25.6
22	60.9	59.9	58.4	56.4	57.4	46.4	29.9	30.9
23	64.2	63.2	61.2	61.2	60.2	50.2	34.7	36.2
24	67.6	67.1	64.6	64.6	63.6	53.6	38.6	40.1
25	69.8	68.3	66.3	66.8	65.3	56.3	41.3	42.3
G 1	44.8	43.8	41.8	43.3	44.3	34.8	28.0	23.8
2	53.0	51.0	49.0	50.0	42.0	38.0	30.5	26.0
3	27.3	27.8	27.8	30.8	48.8	33.8	28.8	24.8
4	51.8	50.3	48.3	49.3	43.8	40.3	33.8	30.3
5	10.2	11.2	12.2	18.2	38.7	32.2	31.2	29.2
6	34.9	33.9	32.9	35.9	41.4	34.9	32.4	26.9

TABLE A-2

PRESSURE HEADS ON RECOMMENDED MORNING GLORY, SPILLWAY, VERTICAL BEND AND CONDUIT WITH RECOMMENDED AIR INTAKE AND DEFLECTOR INSTALLED

Pressure Heads in Feet of Water

Run No.	7-G	1-C	2-C	3-C	28-C	4-C	31-C	5-C	6-C
Reservoir Elevation	1923.0	1910.5	1898.0	1895.0	1893.0	1891.0	1890.0	1887.0	1883.3
Discharge cfs	40,000	37,500	35,000	33,600	32,700	31,600	27,500	19,800	8,000
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
A 1	44.0	31.0	17.5	12.5	8.0	7.0	7.0	6.0	4.0
2	42.5	29.5	16.0	11.0	6.5	4.5	4.5	5.5	3.5
3	40.0	28.0	13.5	8.0	2.0	0	0	1.0	1.0
4	40.5	28.0	14.5	9.0	3.0	-0.5	0.5	1.0	0.5
5									
6	40.0	28.0	15.0	9.5	3.5	-2.0	-1.0	0	1.0
7	40.0	28.0	15.5	10.5	4.5	-3.5	-2.5	-1.0	0
8	39.0	27.5	15.5	11.0	5.0	-4.0	-4.0	-2.0	-0.5
9	38.0	26.0	15.0	11.0	6.0	-5.5	-5.0	-4.0	-1.0
10	33.5	25.0	15.0	12.0	8.0	-5.0	-5.0	-3.0	-1.0
11	30.0	21.5	13.0	10.5	8.0	-4.0	-5.0	-3.0	-2.0
12	26.0	18.5	11.0	9.0	7.5	-1.0	-5.0	-2.0	-1.0
13	23.0	16.5	10.0	8.0	6.5	-3.0	-4.0	-1.0	-1.0
14		6.0							
15	13.5		6.0	5.0	4.0	2.0		-1.0	-1.0
16									
17									
18	-4.0	-4.0		0		-1.0		-1.0	
19	-4.0	-4.0		-2.5		-2.0		0	
20	-3.0	-4.0		-1.0		-2.0			
21		-4.0		0					
22		-3.0	-2.1	0.4					
23		0	17.6	23.1					
24		2.0	32.1	32.1					
25			32.8	34.3					
26			42.1	42.1					
27			29.6	49.6					
28			33.6	33.1					
29			25.1	34.6					
30			19.1	20.1					
31			14.6	14.6					
32			8.6	8.6					
33			3.4	2.9					
34									
35									
36									
37									
38									
B 1	43.0	30.5	17.0	11.5	8.0	5.0	6.0	5.5	4.0
2	42.5	29.5	14.5	8.5	4.0	1.5	5.5	3.5	2.5
3	41.0	29.5	16.0	10.0	6.5	5.0	1.5	4.0	3.0
4	40.5	28.0	14.5	8.5	3.5	0.0	0.5	1.0	1.5
5	40.0	28.0	14.5	9.0	4.0	-1.5	0	0.5	1.0
6	38.5	26.0	15.0	9.5	4.5	-1.0	-1.0	0	1.0
7	40.0	28.0	15.5	10.5	5.5	-3.5	-2.5	-1.0	0
8	39.0	27.5	15.5	11.0	6.5	-5.0	-4.0	-3.5	-0.5
9	38.0	26.0	15.0	11.5	7.0	-5.0	-5.0	-4.0	-1.0
10	36.0	25.0	12.5	9.0	9.0	-3.0	-5.0	-4.0	-2.0
11	32.0	22.0	13.5	11.0	8.5	-5.0	-5.0	-3.0	-1.0
12	26.5	19.0	11.5	9.5	7.5	-1.0	-4.5	-3.0	-1.0
13	23.0	17.0	10.5	8.0	7.0	2.0	-4.0	-2.0	0
14	11.0	8.0			1.0		-10.0		
15			8.0	7.0		2.0		-2.5	-1.0
16									
17	27.4	23.9	18.9	18.4	16.4	18.4	4.4	0.4	-0.6
18	34.0	31.0	36.0	25.0	24.0	26.0	20.0	1.0	0
19	40.2	37.2	32.2	31.2	30.2	34.2	26.2	28.2	12.2
20	44.6	42.6	36.6	36.1	36.6	41.6	28.6	21.6	15.6
21	53.1	51.1	44.6	45.6	45.1	51.1	15.1	20.1	21.1
22	55.4	55.4	47.9	50.4	51.4	68.4	38.4	29.9	26.4
23	65.2	64.2	47.7	68.7	55.2	64.2	46.2	23.7	31.2
24	69.6	68.6	62.6	62.6	58.1	65.6	52.6	30.6	35.6
25	73.3	71.3	65.3	65.3	60.3	68.3	54.3	36.3	38.3

TABLE A-2 (continued)

Run No.	7-G	1-C	2-C	3-C	28-C	4-C	31-C	5-C	6-C
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
C 1	44.0	30.0	16.5	12.0	10.0	7.0	6.5	6.0	4.5
2	42.5	28.0	14.5	9.5	5.5	1.5	4.5	2.5	2.5
3	41.0	28.0	14.0	9.0	7.0	3.5	1.5	4.0	3.0
4	40.5	27.5	14.5	9.0	6.5	0.0	0.5	1.0	1.5
5	40.0	28.5	14.5	9.5	7.0	-0.5	0	0.5	1.0
6	40.0	28.0	15.0	10.0	7.5	-1.5	-1.0	0	1.0
7	40.0	28.0	15.0	11.0	9.0	-3.5	-3.0	-1.0	0
8	39.0	27.0	15.0	11.0	9.0	-5.5	-4.5	-3.5	-1.0
9	37.5	26.0	15.5	11.5	9.5	-7.0	-6.0	-4.0	-1.0
10	36.0	25.0	14.0	12.0	11.0	-4.0	-5.0	-4.0	-2.0
11	37.0		14.0	11.5	10.0	-2.0	-5.0	-3.0	-1.0
12	27.0	19.0	12.0	10.0	9.0	1.0	-5.0	-2.5	-1.0
13	10.0	18.0	11.0	9.5	9.0	3.0	-3.5	-2.0	0
14		11.0			3.0		-9.0		
15			10.5	9.0		8.0		-3.0	-1.0
16									
17	48.6	40.6	34.6	33.1	32.6	32.6	15.6	6.0	1.6
18	62.6	54.6	47.6	56.1	45.1	35.6	38.6	24.6	9.1
19	73.1	64.6	58.1	56.6	55.1	57.6	50.1	43.1	30.1
20	82.6	73.1	67.1	66.6	65.6	67.6	57.6	48.6	36.6
21	91.0	81.0	75.0	74.5	74.5	77.0	65.0	53.0	41.0
22	97.8	79.3	82.3	81.8	81.8	84.3	71.8	55.8	44.8
23	105.4	94.4	90.4	99.4	89.9	91.4	78.9	62.4	50.9
24	109.1	99.1	95.6	94.1	93.6	95.1	84.1	66.1	54.1
25	110.2	100.2	96.7	94.7	94.2	96.2	85.7	68.2	57.2
26	86.0	80.0	38.0	78.0	78.0	80.0	70.0	56.0	52.5
27	71.0	69.0	17.0	67.5	67.5	67.0	64.0	62.5	51.0
28	64.0	63.0	11.0	61.5	62.0	62.0	59.5	59.0	49.8
29	56.5	55.5	4.0	54.0	54.5	54.0	53.5	55.0	44.5
30	50.0	49.0	-2.0	48.0	49.0	48.5	48.5	50.5	39.5
31	43.5	43.0	25.0	42.0	42.0	43.0	43.5	45.5	34.5
32	37.0	36.5	86.0	36.0	36.0	37.0	38.0	40.5	29.5
33	31.5	29.5	89.5	30.0	29.5	30.5	33.0	35.5	24.5
34	27.0	26.5	76.5	27.5	27.0	27.5	29.5	33.5	22.0
35		24.5	74.5	25.0	25.5	26.5	27.5	32.0	19.5
36	23.0	23.0	73.0	23.5	24.0	25.0	26.5	31.0	18.0
37	22.0	22.5	73.0	23.0	23.0	24.0	28.0	30.0	17.0
38	19.0	19.0	69.0	19.0	20.0	20.0	21.0	21.5	15.0
D 1	44.0	31.5	17.5	12.0	11.5	7.0	7.0	6.0	5.0
2	42.5	29.5	14.5	9.5	7.5	1.5	5.0	2.5	2.5
3	41.0	30.0	15.0	11.0	10.0	4.0	2.0	4.0	3.0
4	41.5	28.5	14.5	10.0	8.0	0	0.5	2.0	1.5
5	41.0	28.5	15.0	10.5	9.0	0	0.5	1.0	-3.0
6	40.5	26.0	15.0	11.0	9.0	-1.5	-1.0	0	-3.5
7	40.0	28.5	15.5	12.0	10.0	3.5	-2.5	-1.0	-5.0
8	39.0	28.0	16.0	12.5	11.0	-5.0	-4.0	-2.0	-5.0
9									
10	36.0	24.5	15.5	13.0	12.0	-5.0	-5.5	-3.5	-1.0
11	31.5	22.0	14.0	12.0	11.0	-5.0	-5.0	-3.0	-1.0
12	27.0	19.0	12.0	10.0	9.5	-1.0	-5.0	-2.0	0
13	24.0				9.0		-3.0		
14	11.0	5.5			9.5		-9.0		
15			6.5	6.0		4.0		-3.0	-1.0
16									
17	26.4	21.9	17.4	18.4	16.9	18.4	1.4	-1.1	-0.6
18	36.0	30.0	26.5	36.0	25.5	27.0	19.0	2.0	0.5
19	42.2	33.2	30.2	30.2	29.2	34.2	26.2	17.2	12.2
20	43.5	36.6	35.1	34.6	34.1	40.6	28.6	17.6	17.1
21	50.1	42.6	41.6	41.6	42.1	51.1	32.1	17.1	21.1
22	58.4	49.9	50.4	50.9	51.9	69.4	39.4	21.4	26.4
23	63.2	54.2	56.7	56.7	58.2	63.2	43.2	25.2	31.7
24	70.6	61.6	62.6	63.1	63.6	66.6	51.6	31.6	36.1
25	76.3	68.3	67.3	68.3	66.8	69.3	58.3	38.3	38.3
G 1	29.8					44.8		27.8	33.8
2	36.0					50.0		30.0	26.0
3	33.8					33.8		26.8	33.8
4	38.3					50.3		23.3	30.3
5	31.2					32.8		28.2	27.2
6	28.9					38.1		28.9	26.9

TABLE B-1

PRESSURE HEADS ON RECOMMENDED MORNING GLORY SPILLWAY CREST FOR VARIOUS NUMBERS OF OPEN GATES

Pressure Heads in Feet of Water

Run No.	7-G	1-C	2-C	4-C	6-C	8-G	37-C	8-C	10-C	11-C
Reservoir Elevation	1923.0	1910.5	1898.0	1891.0	1883.3	1923.0	1910.3	1899.0	1890.0	1883.0
Discharge cfs	40,000	37,500	35,000	31,600	8,000	39,200	35,800	30,200	15,000	62,000
Number of Gates Open	12	12	12	12	12	6	6	6	6	6
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
A 1	44.0	31.0	17.5	7.0	4.0	38.0	26.0	9.5	7.0	4.5
2	42.5	29.5	16.0	4.5	3.5	35.5	23.5	5.0	4.5	3.5
3	40.0	28.0	13.5	0	1.0	42.0	18.0	-3.5	0.5	1.5
4	40.5	28.0	14.5	-0.5	0.5	33.5	19.0	3.0	0.5	1.5
5								5.0		
6	40.0	28.0	15.0	-2.0	1.0	34.0	19.0		-1.0	1.0
7	40.0	28.0	15.5	-3.5	0	34.0	20.0	-5.5	-2.0	0
8	39.0	27.5	15.5	-4.0	-0.5	35.0	21.0	-6.0	-3.0	0
9	38.0	26.0	15.0	-5.5	-1.0	34.0	22.0	-5.5	-4.0	1.0
10	33.5	25.0	15.0	-5.0	-1.0	34.0	23.0	-5.0	-2.0	-1.5
11	30.0	21.5	13.0	-4.0	-2.0	31.0	21.0	12.5	0	-1.5
12	26.0	18.5	11.0	-1.0	-1.0	25.0	18.0	13.0	0.5	-1.0
13	23.0	16.5	10.0	-3.0	-1.0	22.0	16.0	13.0	0.5	0.5
14		6.0								
15	13.5		6.0	2.0	-1.0	11.0		10.5	0.5	0.5
16										
B 1	43.0	30.5	17.0	5.0	4.0			21.5	12.5	6.5
2	42.5	29.5	14.5	1.5	2.5			21.0	12.0	6.0
3	41.0	29.5	16.0	5.0	3.0			20.5	11.5	5.5
4	40.5	28.0	14.5	0	1.5			-0.5	-0.5	-0.5
5	40.0	28.0	14.5	-1.5	1.0			0.5	0	0
6	38.5	26.0	15.0	-1.0	1.0			0	-1.0	-1.0
7	40.0	28.0	15.5	-3.5	0			0	0	0
8	39.0	27.5	15.5	-5.0	-0.5			1.0	0	0
9	38.0	26.0	15.0	-5.0	-1.0			1.0	0.5	0
10	36.0	25.0	12.5	-3.0	-2.0			10.0	0	0
11	32.0	22.0	13.5	-3.0	-1.0			21.5	0.5	0
12	26.5	19.0	11.5	-1.0	-1.0			19.5	0.5	0.5
13	23.0	17.0	10.5	2.0	0			16.0	0.5	0
14	11.0	8.0								
15			8.0	2.0	-1.0			8.0	0.5	0.5
16										
C 1	44.0	30.0	16.5	7.0	4.5	39.0	25.0	7.0	12.0	6.5
2	42.5	28.0	14.5	1.5	2.5	37.5	21.5	-1.0	2.5	2.5
3	41.0	28.0	14.0	3.5	3.0	34.0	18.0	-3.0	-1.0	3.0
4	40.5	27.5	14.5	0	1.5	33.5	19.0	-1.5	1.0	1.5
5	40.0	28.5	14.5	-0.5	1.0	33.0	19.0	-3.0	0	1.0
6	40.0	28.0	15.0	-1.5	1.0	33.0	19.0	-4.0	-1.0	0.5
7	40.0	28.0	15.0	-3.5	0	34.0	20.0	-5.0	-2.0	0
8	39.0	27.0	15.0	-5.5	-1.0	34.0	20.5	-5.5	-4.0	-0.5
9	37.5	26.0	15.5	-7.0	-1.0	34.0	21.5	-4.5	-4.0	0
10	36.0	25.0	14.0	-4.0	-2.0	34.0	23.5	4.5	-1.5	-1.5
11	37.0		14.0	-2.0	-1.0	31.0	21.5	12.0	0.5	-1.0
12	27.0	19.0	12.0	1.0	-1.0	26.0	19.0	14.0	1.0	-1.0
13	10.0	18.0	11.0	3.0	0	22.0	17.5	13.0	0	0
14		11.0				13.0	10.0			
15			10.5	8.0	-1.0			13.5	0.5	0
16										
D 1	44.0	31.5	17.5	7.0	5.0			22.0	12.5	6.5
2	42.5	29.5	14.5	1.5	2.5			21.5	12.0	6.0
3	41.0	30.0	15.0	4.0	3.0			21.0	11.5	5.5
4	41.5	28.5	14.5	0	1.5			0.5	0	0
5	41.0	28.5	15.0	0	-3.0			0	0	0
6	40.5	26.0	15.0	-1.5	-3.5			0.5	1.0	-1.0
7	40.0	28.5	15.5	3.5	-5.0			0.5	0	-1.0
8	39.0	28.0	16.0	-5.0	-5.0			1.0	0.5	0.5
9										
10	36.0	24.5	15.5	-5.0	-1.0			11.0	0	0
11	31.5	22.0	14.0	-5.0	-1.0			22.5	0.5	0.5
12	27.0	19.0	12.0	-1.0	0			20.0	1.0	6.0
13	24.0								23.0	
14	11.0	5.5								4.5
15			6.5	4.0	-1.0			8.5	1.0	
16										

TABLE B-1 (continued)

Run No.	11-G	17-C	19-C	20-C	21-C	12-G	26-C	39-C	27-C
Reservoir Elevation	1923.0	1910.0	1898.0	1893.0	1885.0	1923.0	1910.5	1904.0	1896.0
Discharge cfs	29,000	19,500	10,000	7,500	3,700	13,600	10,000	7,500	4,500
Number of Gates Open	2	2	2	2	2	1	1	1	1
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
A 1	13.0	11.0	8.5	8.0	5.5	11.0	12.0	10.0	9.0
2	4.5	4.5	4.5	5.0	4.5	0.5	3.5	4.5	4.5
3	-14.0	-10.5	-3.0	-1.0	1.5	-20.0	-11.0	-14.0	-2.0
4	-9.5	-8.5	-2.5	-0.5	1.5	-20.5	-9.5	-5.5	-1.5
5									
6	-7.0	-11.0	-5.0	-2.0	0.5	-20.0	-11.0	-7.5	-3.0
7	-3.0	-11.5	-6.0	-3.5	0	-19.0	-11.5	-8.0	-4.5
8	1.0	-11.0	-6.5	-4.5	-1.0	-17.0	-11.5	-8.5	-5.5
9	6.0	-9.0	-6.0	-5.0	-2.0	-14.0	-10.0	-8.0	-6.0
10	17.0	3.0	-2.5	-2.0	-2.0	-3.0	-3.0	-2.0	-2.5
11	23.0	11.0	0	0	-2.0	7.0	1.0	1.0	0
12	23.0	11.5	1.0	0.5	-1.0	11.0	3.0	0	1.0
13	23.0	11.5	0	0	0	15.0	3.0		0
14									
15	15.0								
16									
B 1	10.0					5.0			
2	7.5					2.5			
3	-10.0					-17.0			
4	-6.5					-13.5			
5	-7.0					-17.0			
6	-4.0					-15.0			
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
C 1	14.0	6.0	12.0	7.5	5.5	7.5	34.0		18.0
2	5.5	2.5	8.5	1.0	2.5	-1.5	33.5		17.5
3	-6.0	0	3.0	3.5	3.5	-15.0	33.0		17.0
4	-5.5	-8.0	-2.0	-0.5	1.5	-15.0	0.5		-0.5
5	-7.0	-9.5	-3.5	-1.5	1.0	-23.0	0.5		0
6	-6.0	-11.0	-4.5	-2.5	0.5	-20.0	1.0		0
7	-3.0	-11.5	-6.0	-4.0	0		1.5		0
8	0	-11.0	-7.0	-5.0	-1.5		2.0		0
9	6.0	-8.0	-6.0	-5.0	-2.0		1.0		0
10	18.0	2.0	-2.0	-2.0	-2.5		-1.0		0
11	22.0	9.0	0	0	-1.5		27.0		0
12	24.0	11.5	1.0	0	-1.0		39.0		0
13	24.0	13.0	0	0	0		24.0		0
14	12.0	8.0	1.0	-5.0	-5.5		6.0		0.5
15									
16									
D 1	13.0					10.0			
2	5.5					-2.5			
3	-5.0					-15.0			
4	-8.5					-19.5			
5	-7.0					-19.0			
6	-8.0					-20.0			
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									

TABLE B-1 (continued)

Run No.	9-G	12-C	14-C	15-C	16-C	10-G	22-C	23-C	24-C	25-C
Reservoir Elevation	1923.0	1910.0	1898.0	1890.0	1882.0	1923.0	1910.5	1903.0	1896.5	1889.0
Discharge cfs	37,500	34,000	19,600	8,900	3,100	35,500	27,500	19,500	13,000	6,200
Number of Gates Open	4	4	4	4	4	3	3	3	3	3
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
A 1	33.0	17.5	9.5	7.0	4.5	26.0	13.5	11.5	8.5	7.0
2	29.5	12.5	4.5	4.5	2.5	20.5	5.5	4.5	4.5	4.5
3	22.0	2.0	-3.5	0.5	1.5	14.0	-9.0	-6.5	-3.0	1.0
4	25.5	5.0	-3.0	0.5	1.5	16.5	-6.0	-5.0	-2.5	1.0
5										
6	28.0	5.5	-4.5	-1.0	1.0	19.0	-7.0	-7.0	-4.0	-0.5
7	28.0	7.5	-5.5	-2.0	0	21.0	-6.0	-8.0	-5.0	-2.0
8	29.5	10.5	-6.0	-3.0	0	24.0	-3.0	-8.5	-6.0	-3.0
9	30.5	13.0	-6.5	-4.0	-1.0	27.0	1.5	-7.5	-6.0	-4.0
10	33.0	20.0	-2.0	-2.0	-1.5	30.0	15.0	-2.0	-2.0	-2.0
11	30.0	22.0	1.0	0	-1.5	28.0	21.0	2.0	1.0	0
12	25.0	20.5	0.5	0.5	-1.0	30.0	21.0	4.0	2.0	1.0
13	22.0	18.5	0.5	0	-1.0	22.0	21.0	4.0	0	0
14										
15	12.0	13.0	2.5	0	-0.5					
16										
B 1	32.0	16.5	7.5	6.5	4.5					
2	31.0	5.5	6.5	2.0	2.5					
3	24.0	14.0	-2.0	5.5	3.5					
4	24.5	6.0	-2.5	0.5	1.5					
5	25.0	5.5	-3.0	0	1.0					
6	26.0	7.0	-3.5	-0.5	1.0					
7	26.0	8.0	-6.0	-2.0	0					
8	28.0	16.5	-6.2	-3.0	0					
9	29.5	19.5	-6.0	-4.0	-1.0					
10	33.0	25.5	-3.0	-2.0	-1.0					
11	29.0	22.0	1.0	0	-1.0					
12	25.0	25.5	1.0	1.0	-0.5					
13	22.0	9.5	1.5	0.5	0					
14	8.0									
15		16.5	2.5	0.5	0					
16										
C 1	33.0	14.0	8.0	7.0	5.0		33.0	26.0	19.0	11.5
2	30.5	4.5	4.0	2.0	2.5		32.5	25.5	18.5	11.0
3	26.0	10.5	-1.5	4.0	3.0		32.0	25.0	18.0	10.5
4	26.5	6.0	-2.0	0.5	1.5		12.5	-0.5	-0.5	-0.5
5	26.0	5.5	-3.5	0	1.0		12.0	0	0	0
6	27.0	6.5	-4.0	-1.0	0.5		9.0	0	0	0
7	28.0	8.5	-5.5	-2.0	0		13.0	0	0	0
8	29.5	11.5	-6.0	-3.5	0		21.5	0	0	0
9	30.0	14.0	-6.0	-4.0	-1.0		31.0	0	0	0
10	32.0	11.0	-1.5	-2.0	-1.5		32.5	2.5	0	0
11	30.0	12.0	1.0	0.5	-1.0		30.0	11.5	0	0
12	25.0	22.0	1.0	1.0	-0.5		26.0	11.0	1.0	0.5
13	23.0	21.5	1.5	5.5	0		22.5	14.0	1.0	0
14	13.0						8.5	5.0	0	-2.0
15		19.0	2.0	1.0	0					
16										
D 1	34.0	17.0	9.0	7.5	5.0					
2	30.5	4.5	5.0	1.5	3.0					
3	26.0	11.0	-2.5	4.5	3.5					
4	25.5	4.5	-3.0	0.5	2.0					
5	26.0	5.5	-3.5	0.5	1.5					
6	27.0	6.0	-3.5	0	1.5					
7	28.0	8.0	-5.0	-2.0	1.0					
8	30.0	12.0	-5.5	-3.0	1.0					
9										
10	32.0	21.0	-2.0	-2.0	-1.0					
11	30.0	22.0	1.0	0.5	-0.5					
12	25.0	21.0	1.5	1.5	0					
13	23.0	20.0	1.0	1.0	0.5					
14	9.0	10.5	-2.5	-5.0	-5.5					
15										
16										

TABLE C-1

PRESSURE HEADS ON THE BASIC STILLING BASIN

Pressure Heads in Feet of Water

Run No.	2	5	7	8	13	24	19	10
Tailwater Elevation	1816.0	1815.5	1814.5	1814.0	1812.0	1811.0	1812.0	1808.0
Discharge cfs	39,500	35,500	32,000	25,500	18,500	15,200	18,500	7,000
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
E 1	6.2	7.2	9.7	11.2	13.7	10.2	10.7	11.2
2	9.7	11.7	14.2	14.7	15.7	12.7	13.2	9.7
3	10.6	14.1	15.6	15.6	14.1	11.6	12.1	8.1
4	12.9	15.9	14.9	13.4	12.4	9.9	10.9	6.4
5	15.0	16.0	14.0	12.5	11.0	9.5	10.0	6.0
6	13.5	13.5	11.5	10.5	9.5	8.5	8.5	5.5
7	11.9	10.9	9.9	8.9	8.4	7.9	8.9	5.9
8	5.1	8.6	7.6	8.6	9.6	10.6	10.1	9.6
9	11.7	11.7	10.7	12.2	15.7	16.7	16.2	14.2
10	11.6	14.1	13.1	15.6	19.6	21.0	20.1	18.1
11	14.0	19.0	17.5	21.0	24.0	24.0	24.0	22.5
12	21.1	25.1	24.1	27.1	28.6	29.1	28.6	27.1
13	28.7	32.2	31.2	32.7	34.7	34.7	33.7	32.2
14	59.1	54.6	51.6	45.6	44.1	43.6	44.6	37.6
15		31.0	27.0	36.0	42.5	44.0	43.0	43.5
16	56.0	55.5	54.0	51.0	50.5	49.0	50.0	44.0
17	51.5	53.0	52.5	51.0	50.0	50.0	50.5	44.0
18	86.0	69.0	76.0	64.0	55.5	53.0	45.0	45.0
19	38.5	43.0	42.0	46.0	48.0	49.0	49.0	44.0
20	47.5	51.0	50.0	50.0	50.0	50.5	50.5	44.0
21	51.5	53.5	52.0	51.5	50.5	50.5	51.0	44.0
22	52.0	54.0	52.5	52.0	50.5	50.5	51.0	44.0
23	53.0	54.5	53.0	52.0	50.5	50.5	51.0	44.0
24	55.5	55.0	53.0	43.0	50.5	50.5	51.0	43.0
25	53.5	55.0	53.5	52.0	50.5	50.5	51.0	44.5
26	50.7	52.2	50.7	49.2	47.7	33.7	48.2	41.7
27	44.7	46.2	44.7	43.7	42.2	42.2	42.7	36.2
28								
F 1	16.0	25.0	22.5	29.5	35.5	36.5	35.5	35.5
2	15.0	24.5	21.5	28.5	35.5	36.5	35.5	35.5
3	19.0	27.0	26.0	32.5	38.5	42.0	36.5	37.5
4		27.5	24.0	30.0	38.5	46.0	39.0	37.0
5	82.5	73.0	72.0	23.0	52.0	49.0	50.5	40.5
6	18.7	26.7	24.7	31.7	35.2	36.7	36.7	32.7
7	19.0	27.5	25.0	32.5	36.5	37.5	37.5	33.5
8	31.0	36.0	35.0	40.0	43.5	44.0	44.0	40.0
9	17.0	25.5	23.5	30.5	36.0	36.5	36.5	33.5
10	28.5	36.0	33.0	40.0	43.0	44.0	44.0	40.0
11	-1.5	9.5	5.5	23.5	33.5	35.5	34.5	33.5
12	4.0	13.0	11.0	27.0	39.0	42.0	40.0	40.5

TABLE C-2

PRESSURE HEADS ON STILLING BASIN I
BASIN FLOOR RAISED 8'

Pressure Heads in Feet of Water

Run No.	7-G	1-C	2-C	8-C	9-C	5-C	10-C	19-C	16-C
Tailwater Elevation	1816.0	1816.0	1817.0	1815.5	1813.5	1812.0	1811.0	1809.0	1807.0
Discharge cfs	40,000	37,500	35,000	30,200	23,200	19,800	15,000	10,000	3,100
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
E 1	8.2	8.2	8.7	9.7	13.2	15.2	13.2	10.2	7.7
2	8.7	11.2	13.7	14.7	16.7	16.7	14.7	10.7	5.7
3	8.1	11.1	14.6	14.6	15.1	16.6	13.6	9.6	6.1
4	8.9	12.9	14.9	14.4	13.9	12.9	10.4	0	3.9
5	12.0	14.5	13.0	12.5	12.5	11.5	9.0	8.0	3.5
6	11.5	11.5	11.5	10.5	10.5	9.5	8.0	7.0	3.0
7	9.4	9.4	9.4	8.9	8.9	8.9	7.4	7.4	2.9
8	8.6	7.1	7.6	8.6	8.6	9.6	6.7	10.6	3.6
9	11.7	9.7	11.7	11.2	13.2	15.7	15.2	14.7	3.7
10	10.1	-3.9	14.1	13.6	16.6	19.1	18.6	17.6	7.6
11	16.0	15.0	20.0	19.0	22.5	23.0	24.0	23.5	12.0
12	27.1	25.6	29.1	27.6	18.1	30.1	29.1	28.1	16.6
13	23.7								
14									
15									
16	46.0	43.5		42.5	50.0	41.0	39.0	39.0	25.5
17	46.0	46.5		45.0	51.0	42.5	40.0	39.5	25.5
18	98.0	87.0	79.0	73.0	57.0	53.0	43.5	38.0	26.0
19	35.0	33.5	36.0	37.0	39.0	40.0	40.0	39.0	25.5
20	45.0	43.5	45.5	44.0	43.5	43.0	41.0	39.5	25.5
21	49.0	47.0	47.5	46.0	44.0	43.5	41.0	40.0	25.5
22		47.5	48.0	46.5	44.0	43.5	41.0	40.0	25.5
23		47.5	48.0	46.5	44.5	44.0	41.0	40.0	25.5
24		48.0	49.0	46.5	44.5	44.0	41.0	40.0	25.5
25		51.0		47.0	44.5	44.0	36.0		27.0
26	43.3	45.7	45.3	44.3	41.8	40.8	38.3	37.3	22.8
27	41.7	43.2			35.7	34.7	32.7	31.7	17.2
28									
F 1	12.1	11.1	19.1	17.6	14.1	36.1	30.1	30.1	20.6
2	11.1	-16.9	17.4	17.6	14.1	26.6	30.1	30.6	18.6
3	14.6	14.6	21.6	22.1	22.1	30.1	34.1	33.6	23.1
4	14.6	13.6	22.6	22.1	22.1	30.6	34.1	34.6	22.1
5	93.0	82.0	74.0	66.0	53.0	47.0	40.0	37.0	22.0
6	16.7	15.2	20.2	22.7	25.7	26.7	27.2	27.7	13.7
7	16.5	14.5	20.5	22.5	24.5	27.5	27.5	28.0	14.5
8	23.0	28.0	30.0	32.0	34.0	35.0	35.0	35.0	21.0
9	13.5	13.5	17.5	19.5	25.0	36.5	28.0	28.5	14.5
10	24.0	24.5	28.0	29.0	34.0	34.5	35.0	25.0	21.0
11	-12.5	-15.5	-4.5	1.5	17.5	21.5	27.0	8.0	14.5
12	-8.0	-11.0	0	4.0	22.0	27.0	33.0	34.5	20.5

TABLE C-3

PRESSURE HEADS ON STILLING BASIN II WITH LENGTH REDUCED

Pressure Heads in Feet of Water

Run No.	1-D	1-E	2-D	2-E	3-D	3-E	4-D	4-E	6-D	6-E	7-D	7-E
Tailwater Elevation	1816.0	1806.0	1816.0	1806.0	1816.0	1806.0	1816.0	1806.0	1816.0	1806.0	1816.0	1806.0
Discharge cfs	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500
Distance of End Sill from Portal ft	330	330	320	320	310	310	300	300	280	280	260	260
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
E 1	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.7	8.2	8.2	8.2
2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.7	11.2	11.2	11.2
3	11.6	11.6	12.1	12.1	12.6	12.1	12.1	12.1	14.6	13.1	13.6	12.6
4	13.9	13.9	13.4	13.4	13.4	13.4	13.4	13.4	13.9	13.9	13.9	13.4
5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
6	12.5	12.5	12.0	12.0	12.0	12.0	12.0	11.5	12.5	12.5	12.5	12.5
7	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
8	7.6	7.6	7.6	7.6	7.6	7.6	8.1	7.6	7.6	7.6	7.6	7.6
9	9.7	9.2	10.7	8.7	9.7	8.7	11.2	8.7	10.7	9.7	11.2	9.7
10	9.1	7.1	13.1	7.1	12.1	7.6	13.1	7.6	11.1	7.6	11.1	7.6
11	14.0	9.0	19.0	9.0	19.0	9.0	19.5	8.5	17.0	9.0	18.0	9.0
12	25.1	15.1	28.1	16.1	28.1	15.6	28.1	14.1	26.6	14.6	28.1	14.1
13									41.7		42.7	31.2
14												
15												
16	43.0	37.0	46.0	38.0	46.0	38.0	46.0	36.0	44.5	35.5	45.0	35.5
17	45.0	38.5	46.0	39.5	48.0	40.0	48.5	37.5	46.0	36.0	46.5	36.5
18	87.0	85.0	84.0	87.5	86.0	88.0	85.0	85.0	85.0	85.0	85.0	86.0
19	34.0	23.0	45.5	26.0	36.0	25.0	36.0	23.0	34.0	21.0	36.5	21.0
20	43.5	38.0	49.0	39.0	46.0	39.0	46.0	37.0	44.0	37.0	45.0	37.0
21	46.5	41.0	49.5	38.0	49.0	42.0	49.0	40.0	44.0	40.0	49.0	40.0
22	47.0	41.5	49.5	42.5	49.5	43.5	50.0	41.0	49.0	41.5	46.0	32.0
23	47.0	41.5	49.5	43.0	50.0	43.1	47.0	34.0	45.0	33.5	46.0	34.0
24	43.5	34.0	49.5	35.0	47.0	36.5	47.0	34.0	46.0	36.0	47.0	36.0
25												
26	45.3	40.3	37.8	41.8	47.8	31.3	47.8	40.8	46.3	38.8	51.3	42.8
27	37.7	32.7	40.7	34.7	41.7	34.2	41.7	32.7	39.7	21.7	40.7	32.7
F 1	11.1	0.1	16.1	2.1	15.1	2.1	17.1	-0.9	14.1	-1.4	15.1	-0.9
2	10.1	-0.9	15.6	1.1	15.1	1.1	17.1	-0.9	13.1	-1.9	14.1	-0.9
3	13.6	1.6	18.1	4.1	19.1	3.6	20.6	0.6	-17.4	-17.4	-4.4	-13.4
4	13.6	1.1	19.6	3.6	18.6	3.1	19.6	-0.4	16.6	-1.4	17.6	-1.4
5	72.5	86.0	80.0	34.0	80.0	85.0	80.0	84.0	81.0	85.0	80.0	-15.0
6	15.7	3.7	17.7	8.7	18.7	5.7	19.7	2.7	17.7	2.7	19.7	2.7
7	16.5	5.5	17.5	9.5	18.5	7.0	20.5	4.5	18.5	4.0	20.5	-3.5
8	28.0	17.0	29.0	20.0	28.0	18.0	29.5	15.5	28.0	15.0	30.5	15.0
9	18.5	3.5	16.5	6.5	14.5	2.5	18.5	1.5	16.5	0.5	18.5	0.5
10	24.0	16.0	26.0	19.0	25.0	17.0	27.0	15.0	26.0	14.0	27.0	14.0
11	-17.5	-37.5*	-11.5	-4.5	12.5	-34.5*	-9.5	35.5	12.5	38.5	-10.5	-35.5*
12	-13.0	-34.0*	-6.0	-20.0	-6.0	-28.0	-6.0	35.0	-8.0	38.0	-5.0	-38.0*

* Negative pressures reading below about -30.0 feet of water have no physical meaning in the prototype except to indicate possible cavitation.

TABLE C-4

PRESSURE HEADS ON THE RECOMMENDED STILLING BASIN

Pressure Heads in Feet of Water

Run No.	1-F	2-F	3-F	4-F	6-G	7-G
Tailwater Elevation	1816.0	1806.0	1817.0	1805.5	1807.0	1816.0
Discharge cfs	37,500	37,500	35,000	35,000	39,500	40,000
Piezometer Number	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head	Pressure Head
E 1	9.2	8.2	9.2	9.7	7.2	8.2
2	11.7	11.2	12.7	13.2	7.7	8.7
3	12.1	11.6	14.6	20.6	8.6	8.1
4	12.9	12.9	14.4	13.9	9.4	8.9
5	15.5	14.5	14.0	14.5	12.5	12.0
6	13.0	12.5	11.5	12.0	11.5	11.5
7	9.9	9.9	9.9	9.4	10.4	9.4
8	8.6	6.6	7.6	7.1	8.6	8.6
9	11.7	9.7	11.7	9.7	11.7	11.7
10	13.1	7.6	14.1	7.6	8.1	10.1
11	19.0	9.5	21.5	9.0	10.0	16.0
12	28.1	16.1	28.6	13.1	17.1	27.1
13	44.2	34.7			33.7	23.7
14						
15						
16	46.0	39.0	46.0	30.5	36.0	46.0
17	48.0	40.0	47.5	31.0	35.0	46.0
18	84.7	89.0	81.0	78.0	93.0	98.0
19	36.8	29.0	37.5	19.0	16.0	35.0
20	46.3	38.0	46.0	33.0	36.0	45.0
21	48.5	42.0	48.0	35.0	40.0	49.0
22						
23						
24						
25						
26	47.8	40.0	46.8	34.8	34.3	43.3
27	41.2	32.7	40.7	28.2	32.7	41.7
28						
F 1	17.6	1.1	19.1	-5.9	-4.9	12.1
2	13.0	2.1	19.1	-5.9	-4.9	11.1
3	15.9	4.6	23.1	-6.4	-5.4	14.6
4	15.4	3.6	22.6	-12.9	-6.4	14.6
5	30.5	87.0	76.0	64.5	103.0	93.0
6	19.3	9.7	20.7	0.2	-2.3	16.7
7	21.7	8.5	22.0	2.0	-0.5	16.5
8	30.5	19.0	30.5	12.5	11.0	23.0
9	17.5	4.5	17.5	-0.5	-3.5	13.5
10	28.5	18.0	28.0	12.0	8.0	24.0
11	-7.2	-26.5*	-4.5	-37.0*	-35.5*	-12.5
12	-5.0	-20.0*	0	-38.0*	-39.0*	-8.0

* Negative pressures reading below about -30.0 feet of water have no physical meaning in the prototype except to indicate possible cavitation.