GR-81-10

HYDRAULIC MODEL STUDIES OF THEODORE ROOSEVELT DAM – SOUTH SPILLWAY

May 1981

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16. ABSTRACT

During a spillway discharge to Theodore Roosevelt Dam near Phoenix, Ariz., in February 1980, water overtopped the right wall of the south spillway causing extensive damage to the powerhouse and destroying a downstream protective wall. A 1:36 scale model was used to develop protective measures for this powerplant, the highly jointed downstream canyon wall, and other structures. Also determined from the model study were spillway and radial gate discharge capacity curves. The model showed that a 15-ft (4.57-m) high extension to the right training wall would provide full protection for the powerhouse. A 200-ft (61.0-m) long wall was found necessary to provide adequate protection for the lower canyon wall. An extension to this wall, angled toward the river channel, was also recommended to protect a downstream warehouse. Dynamic pressure measurements were obtained to aid in the structural design of the walls.

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by
M. F. Young
for
Salt River Project
Phoenix, Arizona

Hydraulics Branch
Division of Research
Engineering and Research Center
Denver, Colorado
May 1981

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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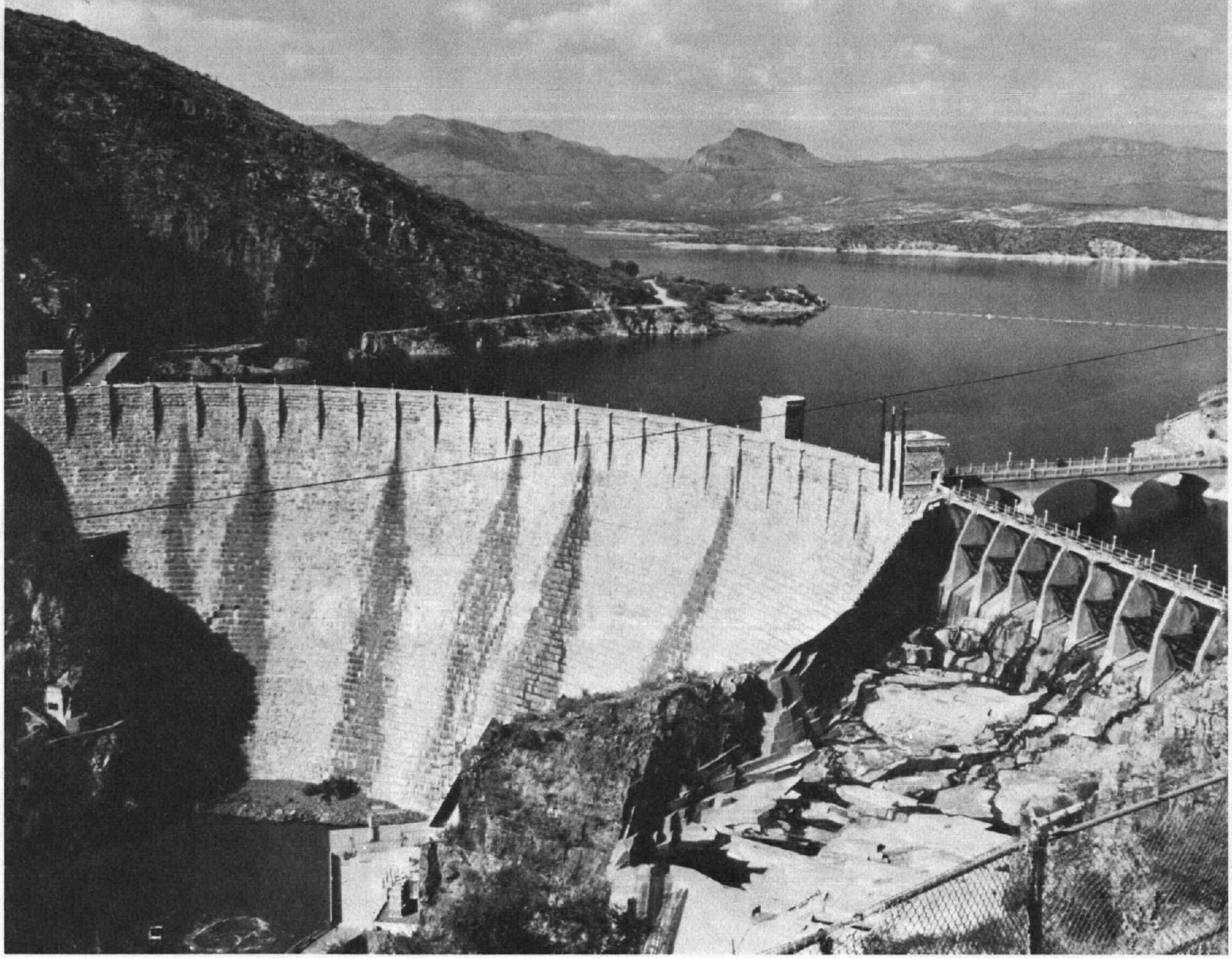
The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

In May of 1981, the Secretary of the Interior approved changing the Water and Power Resources Service back to its former name, the Bureau of Reclamation.



Frontispiece.–Theodore Roosevelt Dam near Phoenix, Arizona. P801-D-79556

ACKNOWLEDGMENTS

The studies were reviewed by T. J. Rhone, Hydraulic Structures Section Head, whose considerable help was greatly appreciated. The final designs were developed through the cooperation of the Salt River Project and the Hydraulics Branch, Division of Research, Engineering and Research Center.

CONTENTS

FIGURES

CONTENTS– Continued

TABLES IN APPENDIX

PURPOSE

These studies were made to determine a spillway rating curve for the south spillway of Theodore Roosevelt Dam, and to test different wall configurations to provide protection from flooding for various structures located downstream of the dam.

INTRODUCTION

Theodore Roosevelt Dam was the first major structure built by the Reclamation Service (now the Bureau of Reclamation) after its formation in 1902 by the Reclamation Act. Construction of the dam began in 1903 and was completed in 1911. Located 80 mi (129 km) northeast of Phoenix, Ariz., on the Salt River (fig. 1), the dam is part of the multipurpose Salt River Project that controls floods, generates power, and stores irrigation water.

Roosevelt Dam is a 280-ft (85.3-m) high, rubble-masonry, thick-arch structure that is 723 ft (220.4 m) long and impounds a reservoir of 1 382 000 acre-ft (1.7×10^9 m^3). The dam originally had two uncontrolled overflow spillways. During the 1930's, radial gates were installed on both spillways to provide extra reservoir storage. The general plan and sections of the dam and spillways are shown on figure 2. The spillways were cut into each abutment with each spillway crest oriented to continue the arch shape of the dam. This alinement creates many problems because the south spillway channels its flow directly toward the upper right training wall instead of downstream (fig. 3).

During a flood in February 1980, the spillways operated with a combined discharge of approximately 73 500 ft^3/s (2080 m^3/s). The south spillway, with a flow of about 35 000 ft^3/s (990 m^3/s), overtopped the upper right training wall, cascaded down the slope, and entered the powerhouse. Approximately $1 million in damage resulted. During this same flood, a downstream training wall that protected the highly jointed canyon walls from erosion was damaged when water overtopped the wall and eroded rock from behind it. This caused a large section of the wall to be lifted out and deposited downstream.

Directly downsteam, approximately 300 ft (91 m) from the toe of the south spillway, a converted warehouse was also damaged by mud and water entering the lower floors. A wall to protect this structure was included in these studies.

CONCLUSIONS

1. The maximum discharge capacity of the south spillway is 65 777 ft^3/s (1862 m^3/s) with the dam access bridge in place and 66 314 ft^3/s (1878 m^3/s) with the bridge deck removed.

2. The most economical design for the upper right training wall would be to increase the height by 15 ft (4.57 m). Pressures on this wall ranged up to 11.88 ft (3.621 m) of water.

3. To provide maximum protection, the lower left training wall should be 200 ft (61.0 m) in length with a top elevation of 1975 ft (602.0 m). The minimum wall length that would direct the spillway flow away from the canyon wall and minimize danger of undercutting is 125 ft (38.1 m). Instantaneous pressure readings to 1965.20 ft (598.993 m) were measured.

4. Warehouse protection could be accomplished by a 90-ft (27.4-m) long addition to the lower training wall, with the top elevation at 1975 ft (602.0 m) and sloping constantly to the maximum tailwater elevation of 1940 ft (591.3 m). The wall extension should make an angle of 154° with the end of the lower wall and extend out toward the river channel.

MODEL

A 1:36 scale for the model was selected as the best ratio to provide the most accurate test results and also have a model of manageable dimension. The overall model box was 16 ft (4.9 m) wide by 42 ft (12.8 m) long. The spillway crest width of 208.58 ft (63.575 m) had a model width of 5.79 ft (1.765 m). The 15.75-ft (4.801-m) high by 19-ft (5.8-m) wide radial gates had model dimensions of 5.25 by 6.33 in (133 by 161 mm). The total drop in elevation from the maximum reservoir water surface elevation of 2146 ft (654.1 m) to the downstream river channel elevation of 1905 ft (580.6 m) was 241 ft (73.5 m). This gave a model change in elevation of 6.69 ft (2.039 m). The maximum discharge of 65 777 ft^3/s (1862 m^3/s) was represented by a flow of 8.46 ft^3/s (0.239 m^3/s) in the model. Photographs of the model under construction and of the completed model are shown on figures 4 through 7.

Reservoir elevation was measured by a pressure tap installed 38 in (965 mm) from the centerline of the dam access bridge along the dam face in the model, 114 ft (34.7 m) in the prototype, and connected to a stilling well containing a hook gage mounted on the outside of the headbox. Even though reservoir water surface elevations in the model were not measured at the same locations as in the prototype, they were both measured in areas where no drawdown occurs when the spillways are discharging. Therefore, the model will reflect the same water surface elevations as the prototype. After calibration of the spillway crest and gates using the permanent laboratory Venturi meters, the hook gage readings were used to set spillway discharges for additional testing.

The dam access bridge (fig. 8), powerhouse, and warehouse were constructed of wood; spillway crest and piers of polyurethane foam and acrylic plastic; radial gates of sheet metal; spillway chute (fig. 6) of layered Styrofoam to achieve desired blocky effect; and the remaining topography of wire mesh was overlaid with 0.75 in (19 mm) of concrete mortar.

All elevations that appear in this report are based on sea level. The spillway crest and upper right training wall, designed in 1935, are based on a gage elevation and are changed to sea level elevations by adding 1901.37 ft (579.538 m) to each gage elevation. The elevations shown on figure 3, the bridge elevations on figure 8, and the spillway crest and gate elevations on figure 2 were correctly placed in the model to accurately represent the prototype. Because of the critical nature of correctly measuring the south spillway discharge, these elevations were verified as accurate by using a surveyor's level.

INVESTIGATION

Because the upper right training wall modification was to be accomplished before any additional spillway operation, the design had to be completed by the fall of 1980. For this reason, the model construction and testing were divided into two phases. The first phase consisted of determining the discharge capacity of the spillway crest and gates and testing preliminary designs of the upper right training wall modification. The reservoir topography, access bridge, spillway crest, piers and gates, spillway chute, existing upper training wall, and powerhouse were then constructed for this phase (figs. 9 and 10). The model was operated in this mode until the spillway calibration was accomplished and the final design for the upper training wall was completed. Upon completion of the first phase of testing, craftsmen placed the downstream topography, and testing of the lower training wall began.

Spillway Discharge Capacity

In determining the maximum discharge capacity of the spillway crest, all spillway radial gates were opened to the maximum gate opening of 21 ft (6.40 m), and two capacity curves were developed. The dam access bridge was left in place while the first discharge-elevation curve was developed. With a maximum reservoir elevation of 2145.37 ft (653.909 m), which is the top of the dam parapet wall, the discharge through the south spillway was 65 777 ft³/s (1862 m³/s). Figure 11 shows a discharge of 40 700 ft³/s (1152 m³/s), where the bridge starts to restrict the flow. At the maximum discharge of 65 777 ft³/s, the water backed up behind the bridge railing and a drawdown occurred on the downstream side of the bridge (fig. 12). However, when the bridge deck was removed for the development of the second discharge-elevation curve, this discharge only increased 537 ft³/s (15 m³/s) to 66 314 ft³/s (1878 m³/s). Also tested were gate openings of 5, 10, and 15 ft (1.52, 3.05, and 4.57 m). The discharge capacity curves developed for each gate opening appear in figure 13, and the raw data for the curves are given in table A-1 of the appendix.

An additional test was run to determine the capacity of the three inner (right) gates, the four middle gates, and the three outer (left) gates operating as separate units. When referring to left and right gates, these directions are looking downstream. Discharges for this test were measured at a water surface elevation of 2136 ft (651.0 m), the top of closed gates. The following tabulation shows the different gate openings and resulting discharges for the test:

No. of gates fully opened	Discharge	
	ft^3/s	m^3/s
All 10	31 000	877
Right 3	11 000	312
Middle 4	14 500	411
Left 3	10 000	283
Left 7	22 000	623
Right 7	24 500	694
Left 3 and right 3	20 000	566

The data indicate that although the right three gates appear to be flowing only partially full, the increased velocity makes the flow approximately the same as the other groups of gates.

Upper Training Wall

The approach conditions to the south spillway are not ideal because the flow must make an abrupt turn to the right to pass over the spillway crest, see figure 11. Because of this direction change, severe contractions form on the right side of gate bays 8, 9, and 10, while water backs up onto the left side of the gates as shown on figure 14. These gate bays flowed only approximately 40 percent full while the remaining bays were near their capacity. On the right side of gate bay 10, the surface of the spillway crest was visible.

After passing over the spillway crest, the water entered the spillway chute. The water emerging from bays 8, 9, and 10 flowed directly toward the concrete-covered outcropping on the right side of the chute located just below the upper right training wall. As the water traveled up this outcropping, the flow fell back onto itself and a hydraulic jump was formed. This water was then directed back across the spillway over the top of the flow from bays 1 through 7. Because of this hydraulic jump action, at discharges of 40 000 ft^3/s

(1133 m^3/s) or greater, water reached the top of the training wall intermittently and cascaded down the slope beyond the wall into the powerhouse. Instead of redirecting the flow down the chute by using pier extensions and guide walls, it was decided that a height addition to the upper training wall would be less expensive. Two different designs were developed and tested in the hydraulic model.

The first design was a straight 15-ft (4.57-m) high wall with a top elevation of 2126.57 ft (648.178 m). The wall addition began where the existing wall had this elevation, and extended 141 ft (43.0 m) (fig. 15). This wall design did not follow the existing angled wall, instead it extended straight down the side of the chute. This wall design protected the slope and powerhouse from the spillway flow; however, the 141-ft length was required because water flowed along the entire length of the wall footing and over the unprotected slope into the channel below. It was decided that another wall configuration might provide the same protection while being shorter and less expensive to build.

The second wall design was also 15 ft (4.57 m) in height but followed the existing 63-ft (19.2-m) straight wall and 21-ft (6.4-m) angled end section (fig. 16). This design deflected the flow back into the spillway chute and protected the hillside and powerhouse below it. Because this design provided the same protection as the first, it was recommended because of the cost savings involved.

Pressure measurements were taken on both the existing training wall and the preferred angled wall extension using water manometers. The highest pressure, measured at piezometer 3, was 11.88 ft (3.621 m) which is equivalent to a water column rising to elevation 2122.14 ft (646.828 m) at the maximum discharge. Appendix table A-2 lists the complete water manometer pressure data from piezometers 1 through 6, and figure 17 shows the upper training wall orientation and the piezometer locations.

Lower Training Wall

After completing pressure measurements on the upper training wall, the topography downstream of the dam was installed and the second phase of testing began.

The preliminary design and location of the lower training wall was supplied by the Salt River Project. The upstream end of this 200-ft (61.0-m) long wall was located near the toe of the slope between the spillway chute and the lower channel, and generally followed the canyon wall. For the first 100 ft (30.5 m), the top of the wall was at elevation 1975 ft (602.0 m) and was approximately 80 ft (24.4 m) high. The wall then sloped down for 50 ft (15.2 m) to elevation 1935 ft (589.8 m) and retained this elevation for the remaining 50 ft. The model for this wall (fig. 18) was constructed of Styrofoam sheets for ease of installation and removal.

Initial tests indicated the 1935-ft (589.8-m) elevation was too low and that an elevation of 1975 ft (602.0 m) was required along the full 200-ft (61.0-m) long wall. As the spillway flow fell into the basin in the downstream channel, the flow impinged on the lower training wall approximately 75 ft (23 m) from the start of the wall and churned along the remaining 125 ft (38 m) of the wall.

Another wall, constructed of wood, was then placed in the model with a top elevation of 1975 ft (602.0 m) along its entire length, and 19 piezometers were installed at critical locations to determine impact pressures (fig. 19). The piezometers were connected to water manometers and pressures were measured for discharges of 15 000, 30 000, 45 000, and 65 777 ft^3/s (425, 850, 1275, and 1862 m^3/s), see appendix table A-3. The seven most actively fluctuating piezometers were then attached to pressure transducers and the dynamic pressures were recorded electronically, see appendix table A-4. The transducers allowed the pressure fluctuations to be permanently recorded so the pressure peaks could be seen readily. The maximum pressure measured was located at piezometer 14 with a pressure elevation of 1965.20 ft (598.993 m), which is equivalent to 52.37 ft (15.962 m) of water. This wall design, with the dimensions as shown on figure 19 and located as shown on figure 3, contained all spillway discharges (figs. 20, 21, and 22).

After completion of the model testing, the Salt River Project began excavation for the lower training wall footing. Hazardous working conditions were encountered because of a highly fractured rock overhang over approximately 100 ft (30 m) of the downstream portion of the lower training wall.

To miminize this problem, additional tests were performed to determine the shortest length of wall that would contain the spillway flow. After viewing the model at the maximum discharge, it was decided that 125 ft (38.1 m) was the minimum wall length that would direct the spillway flow away from the canyon wall and minimize danger of undercutting.

An extension to the lower training wall was also tested to determine its effectiveness in protecting the warehouse downstream of the south spillway from spillway releases. The test configuration had an interior angle of approximately 154°, was 90 ft (27.4 m) long, and had a top elevation of 1975 ft (602.0 m) for the full length. Model operation showed this elevation was required to contain the flow at the beginning of the extension, but that the water surface dropped off sharply into the river channel and it would be satisfactory to slope the top of the wall downward to the maximum tailwater elevation of 1940 ft (591.3 m). Figures 23 and 24 show how the wall extension deflects the flow away from the warehouse.

Piezometer 19 was installed in the impingement area of the wall addition. The highest resulting pressure measurement reached an elevation of 1958.36 ft (596.908 m), see appendix table A-4.

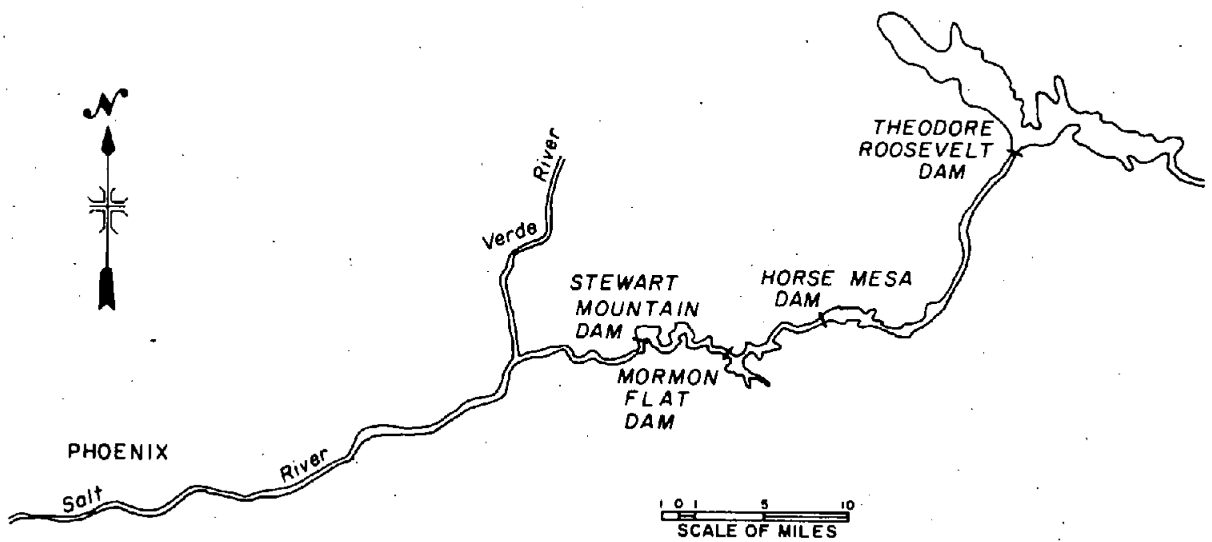


Figure 1.–Location map.

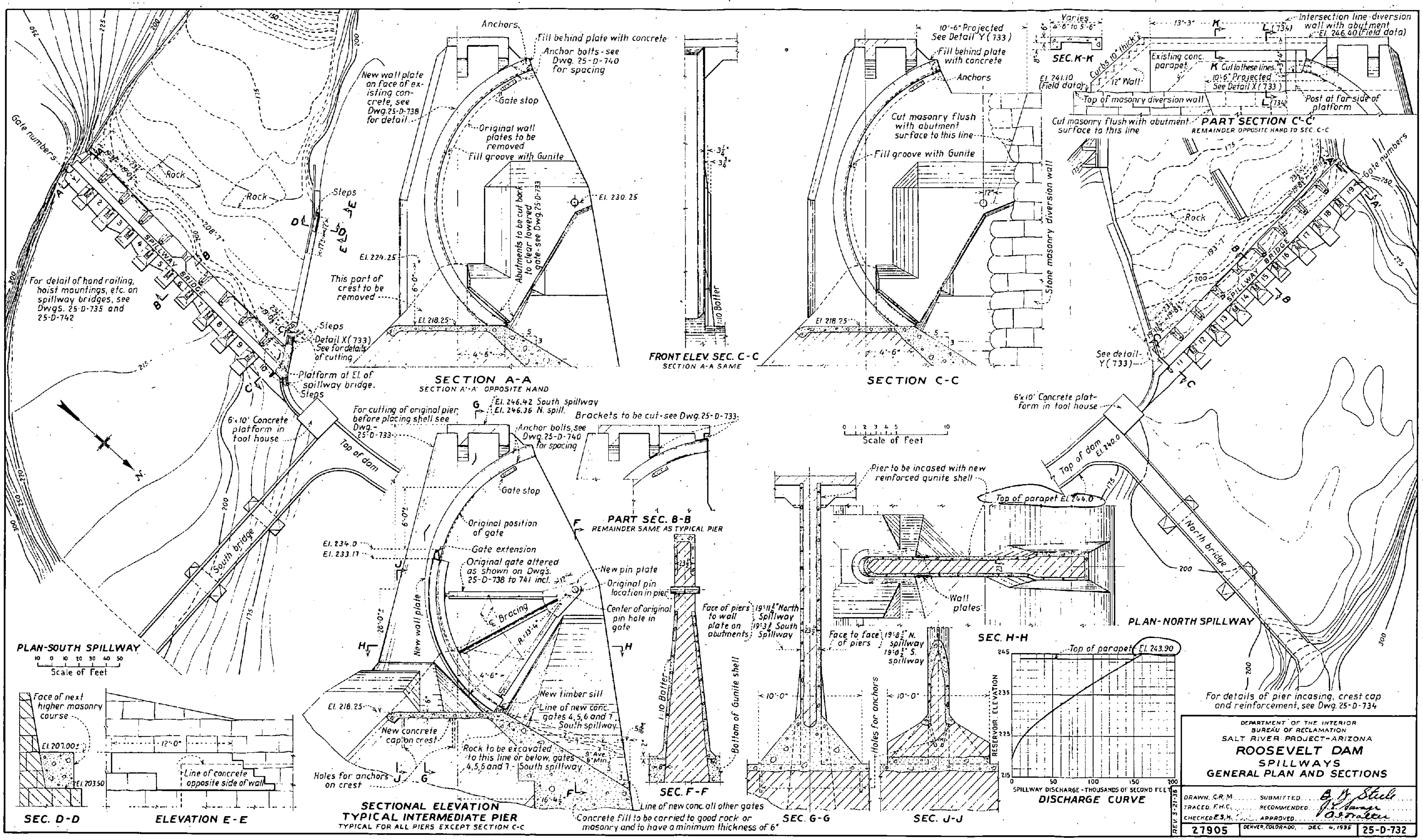


Figure 2.–General plan and sections.

Figure 3.–Topographic map and model layout.

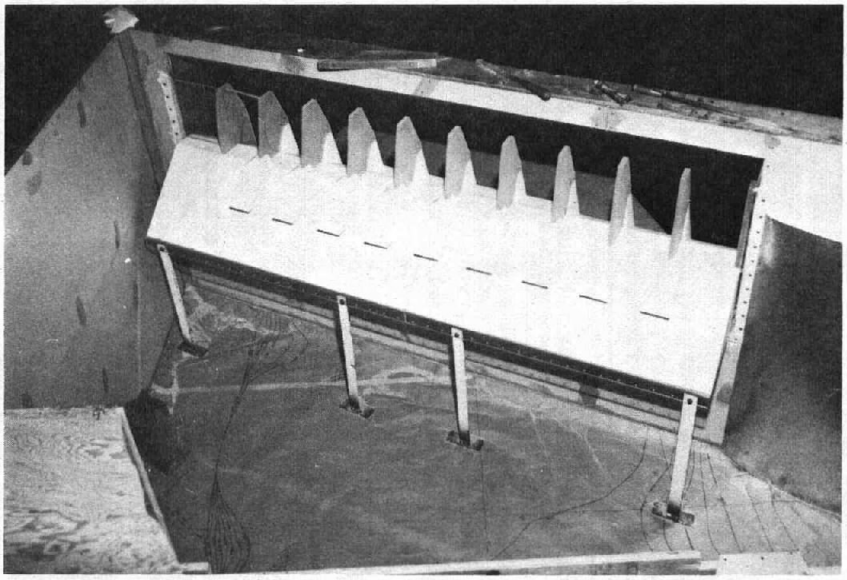


Figure 4.–Spillway crest and piers installed in model before topography was placed. P801-D-79557

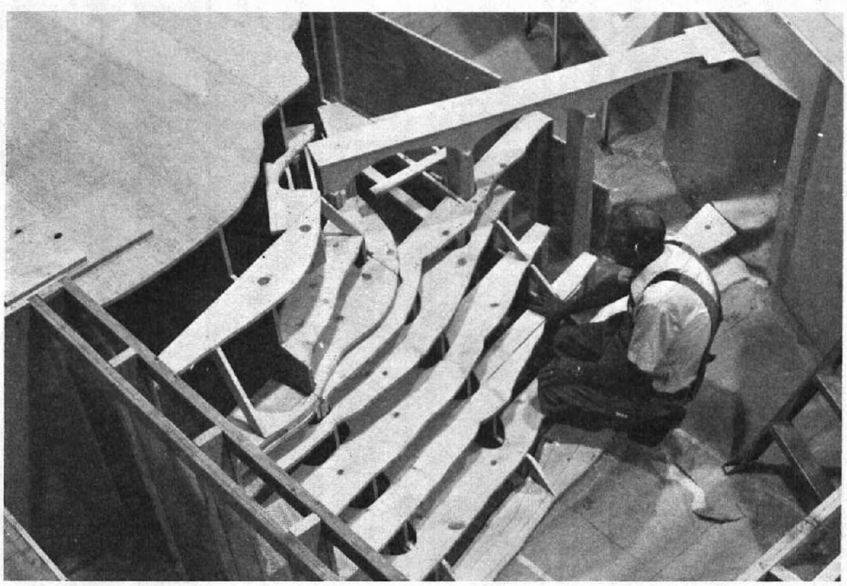


Figure 5.–Reservoir topography supports in model. P801-D-79558

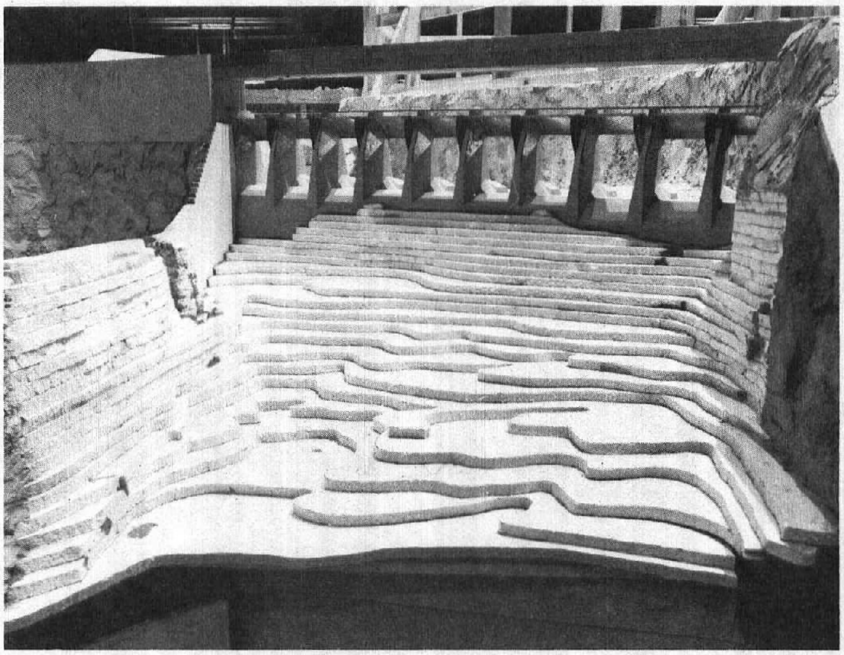


Figure 6.–Spillway cut from Styrofoam to achieve blocky effect of prototype chute. P801-D-79559

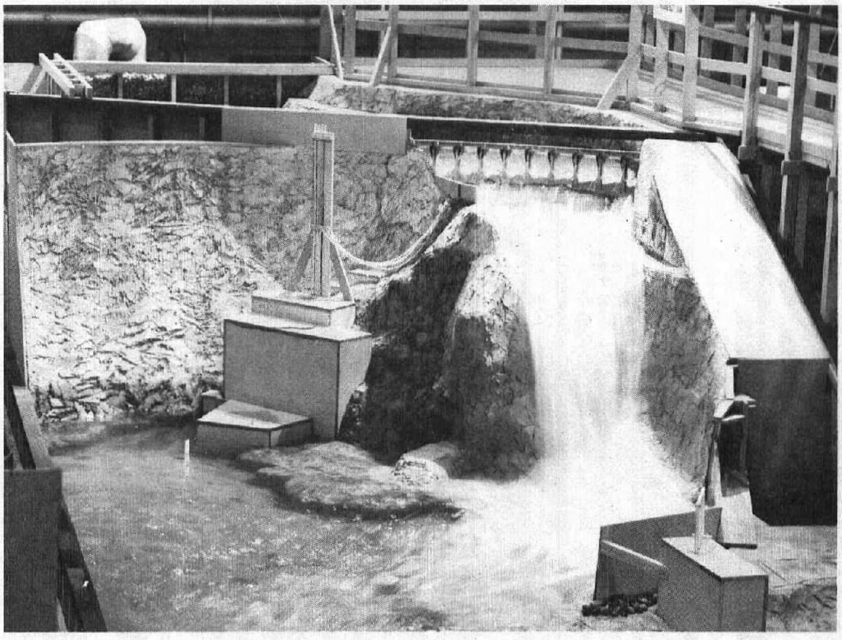


Figure 7.–Completed hydraulic model in operation. P801-D-79560

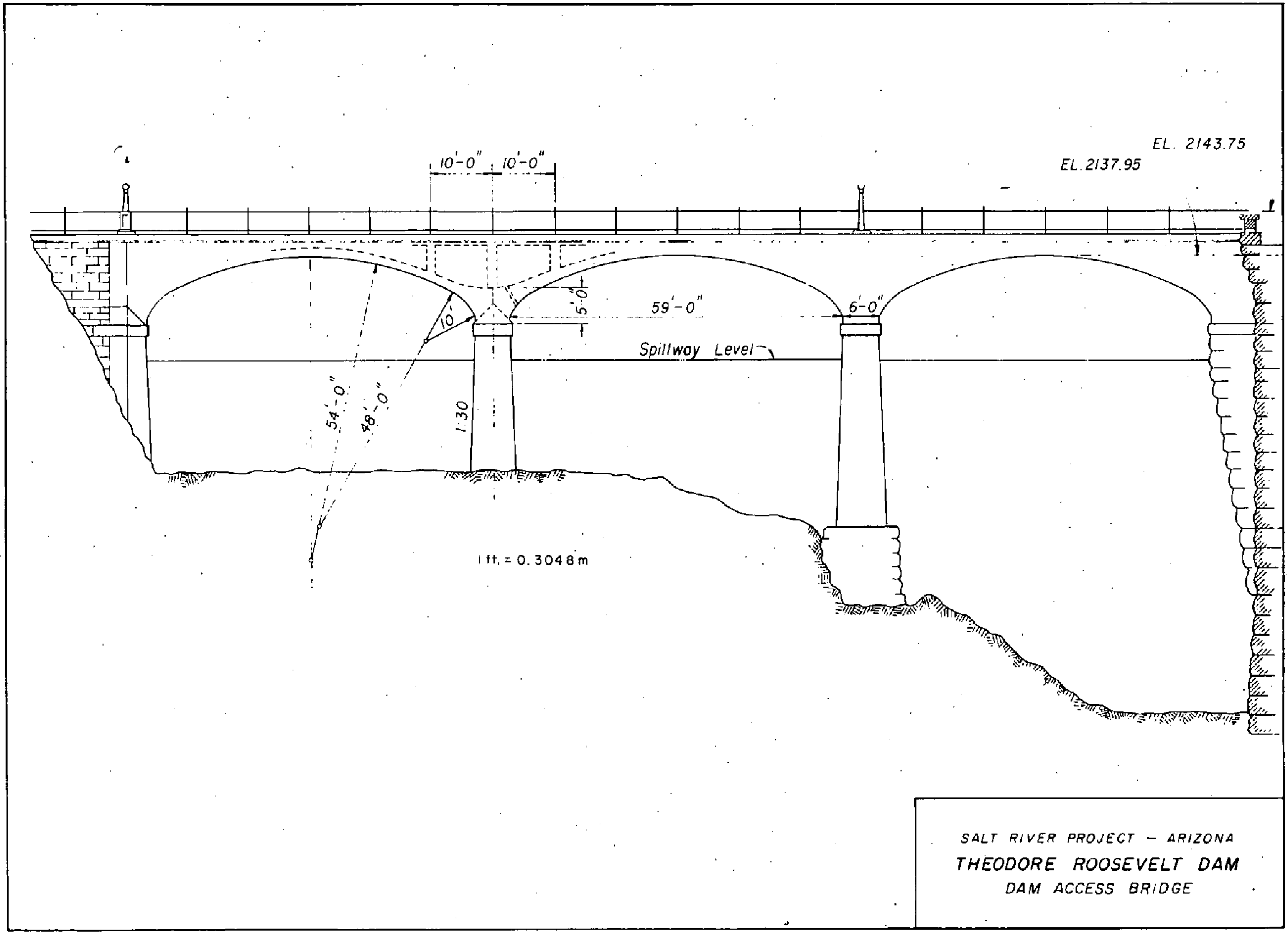


Figure 8.–Dam access bridge over south spillway approach channel.

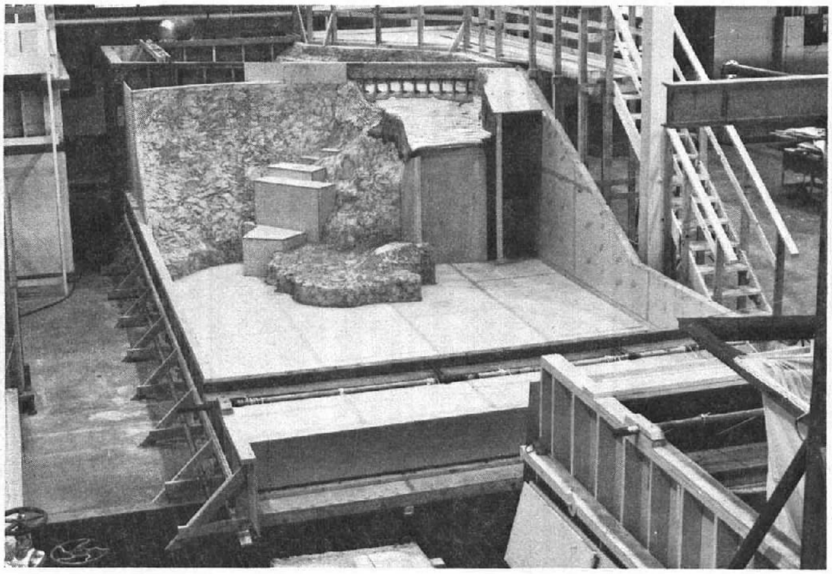


Figure 9.–First phase hydraulic model. P801-D-79561

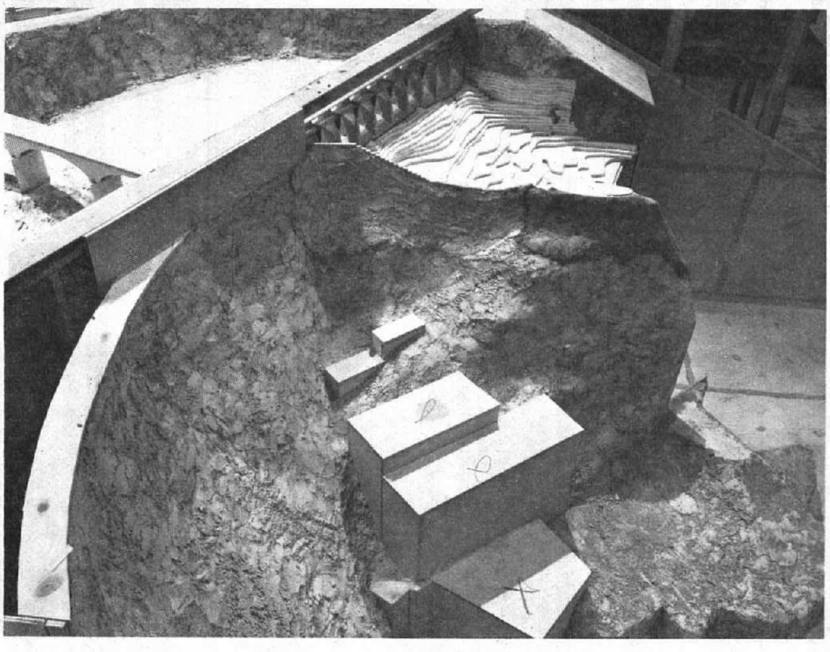


Figure 10.–Spillway chute, reservoir topography, and powerhouse – first phase. P801-D-79562

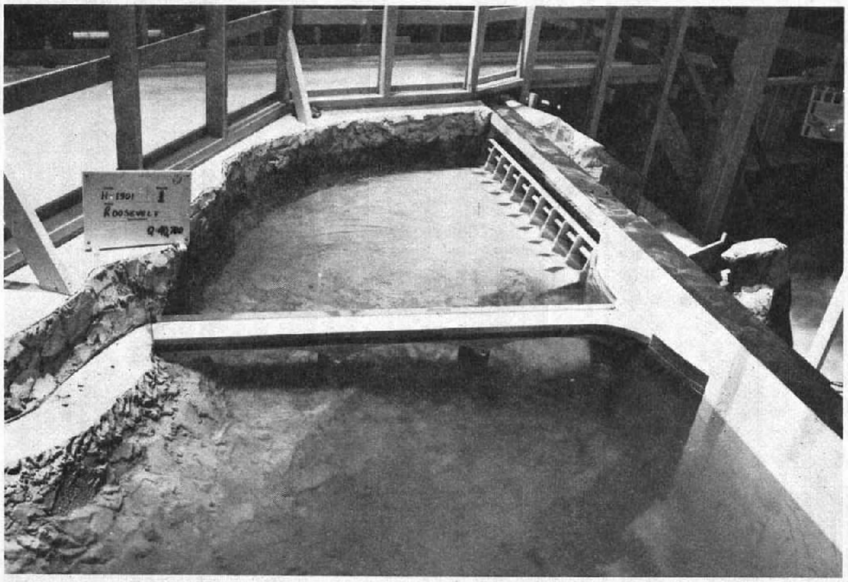
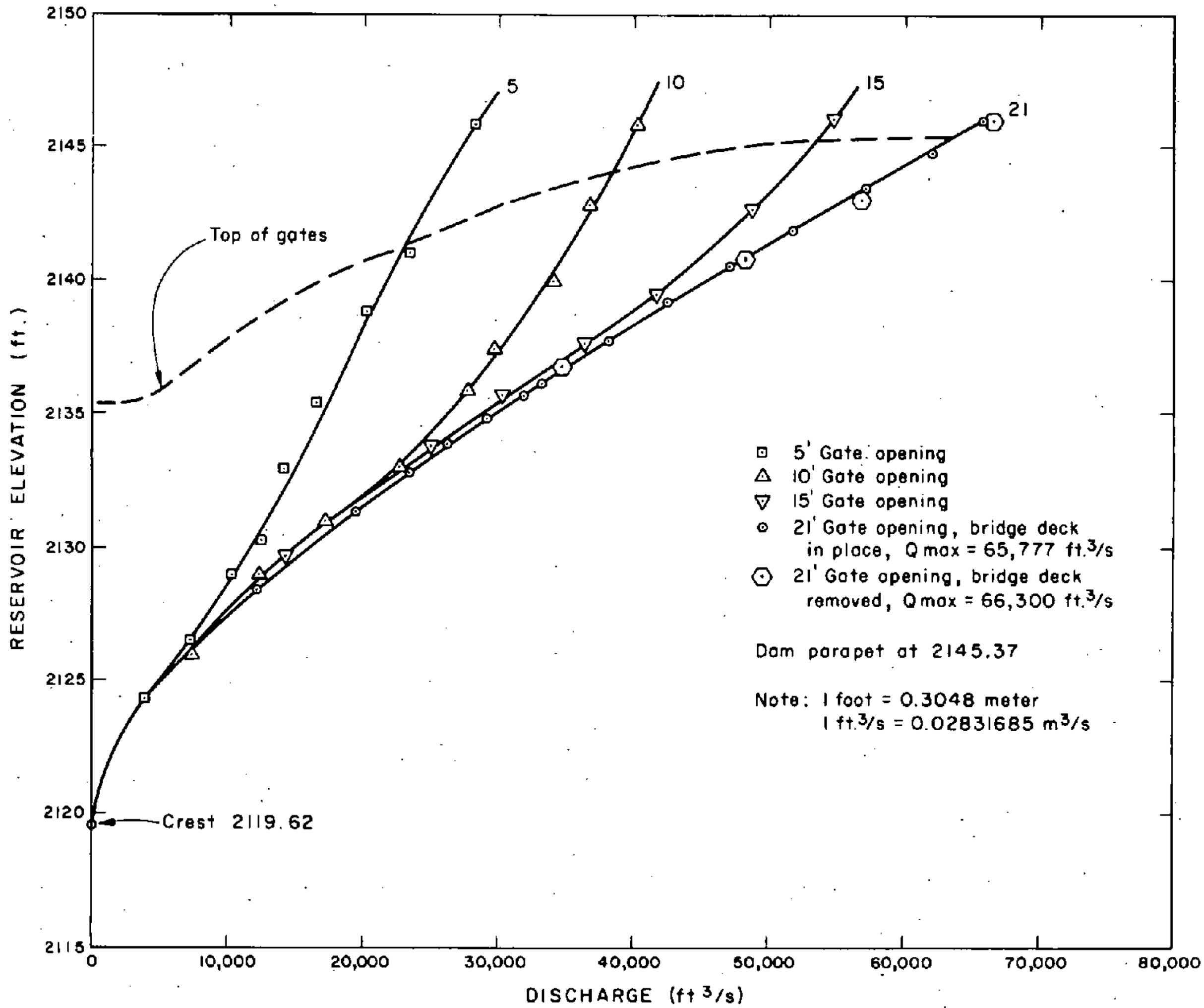


Figure 11.–View looking toward south spillway crest during first phase testing. Q = 40 700 ft^3/s (1152 m^3/s) free flow. P801-D-79563

Figure 12.–View from spillway crest looking at dam access bridge. Q = 65 777 ft^3/s (1862 m^3/s) maximum discharge. P801-D-79564



SPILLWAY CAPACITY CURVES FOR SOUTH SPILLWAY ONLY

Figure 13.–South spillway capacity curves.

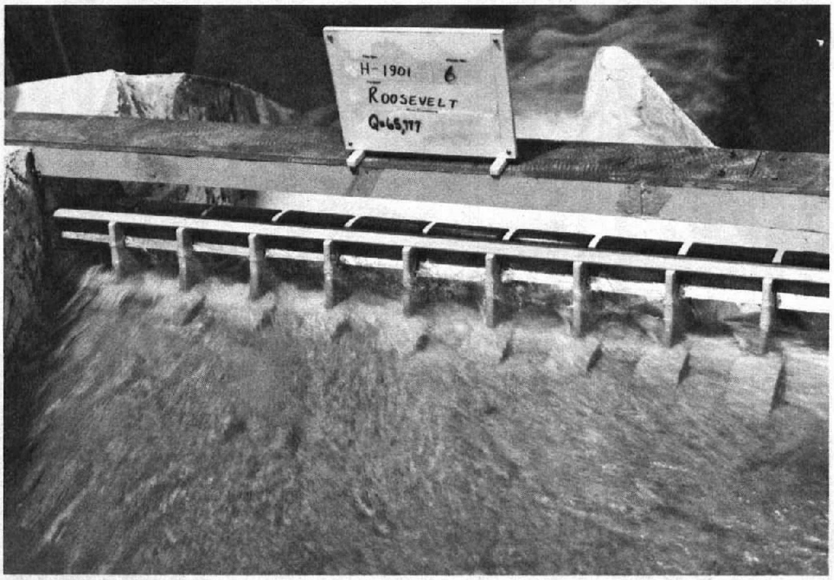


Figure 14.–View of model spillway gates in operation. Q = 65 777 ft^3/s (1862 m^3/s). Note severe contractions in bays 8, 9, and 10. **P801-D-79565**

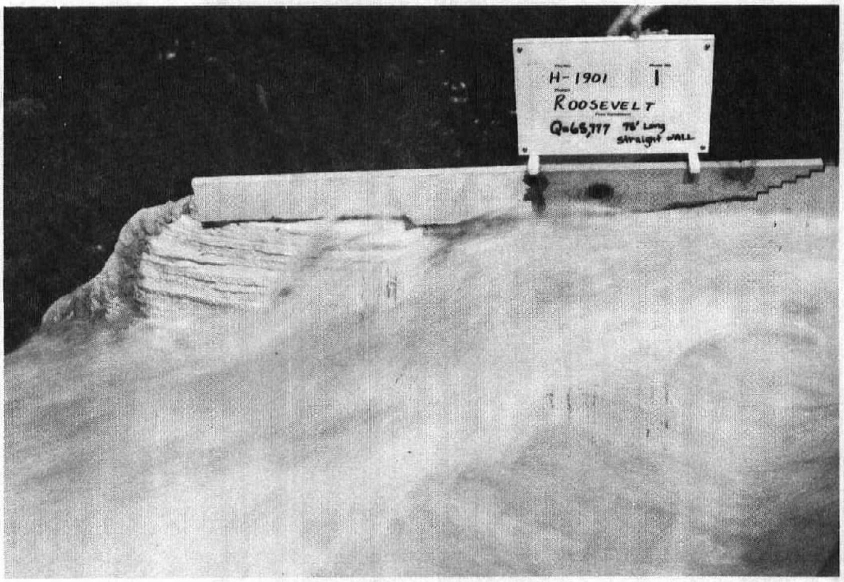


Figure 15.–Straight upper training wall addition. P801-D-79566

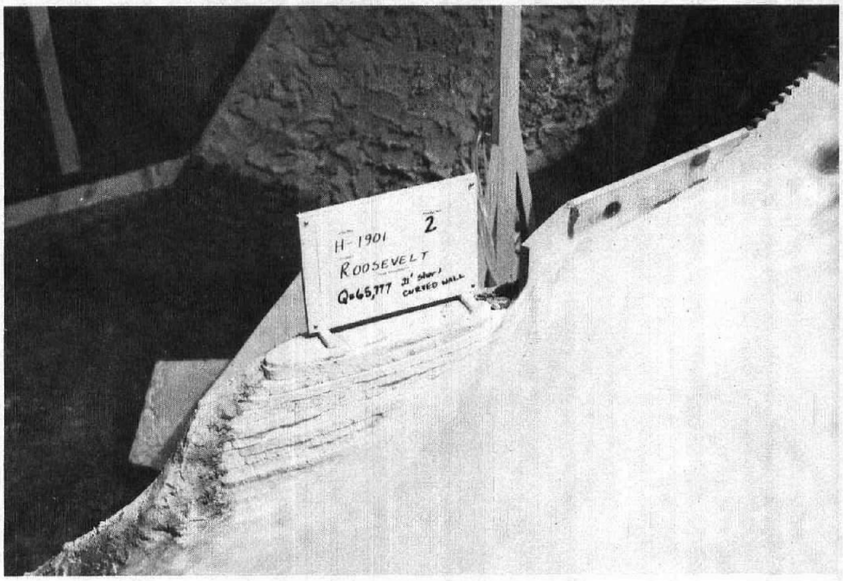
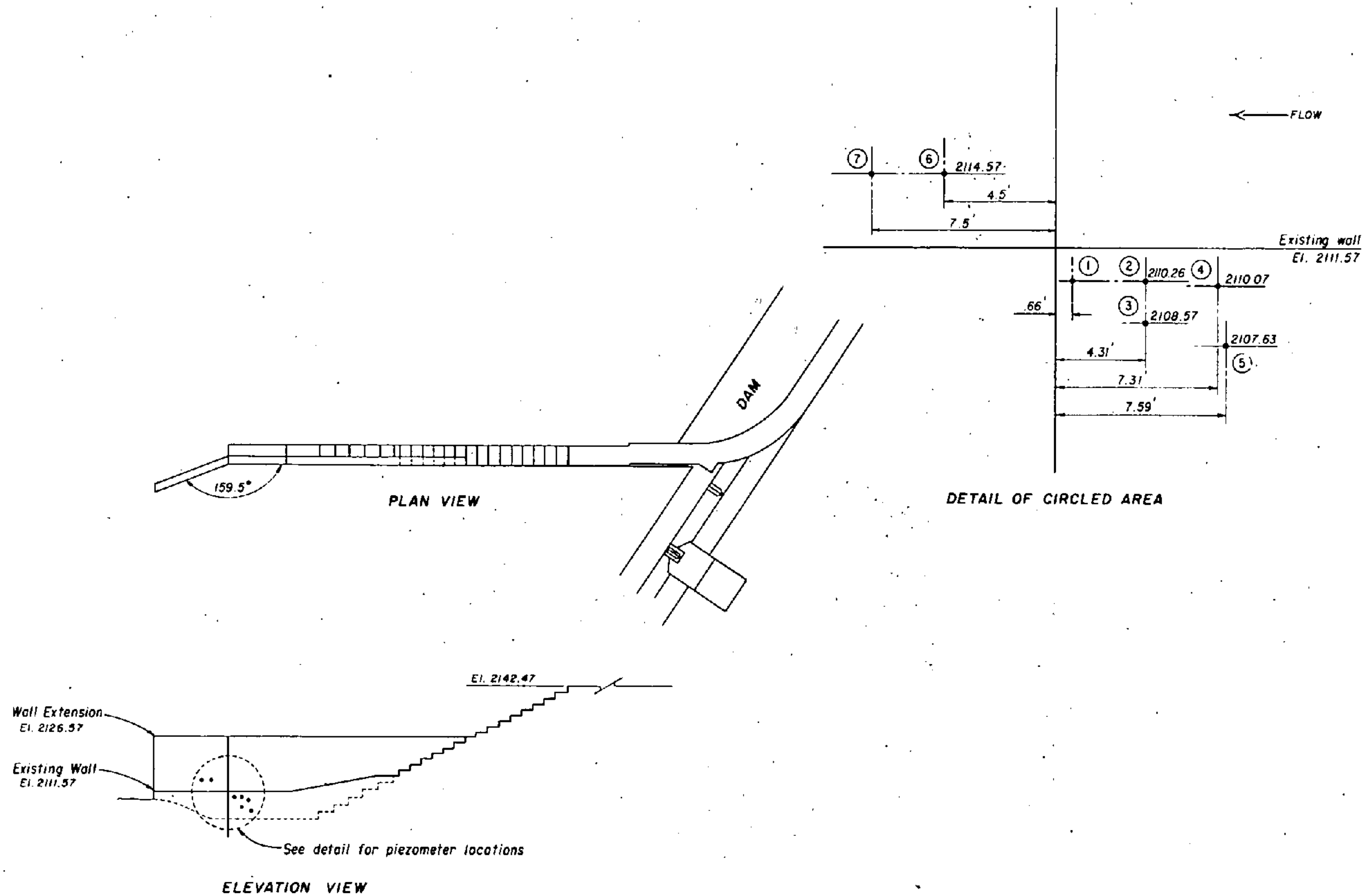


Figure 16.–Angled upper training wall addition – preferred design. P801-D-79567



UPPER TRAINING WALL AND PIEZOMETER LOCATIONS

Figure 17.–Preferred design of upper training wall, orientation, and piezometer locations.

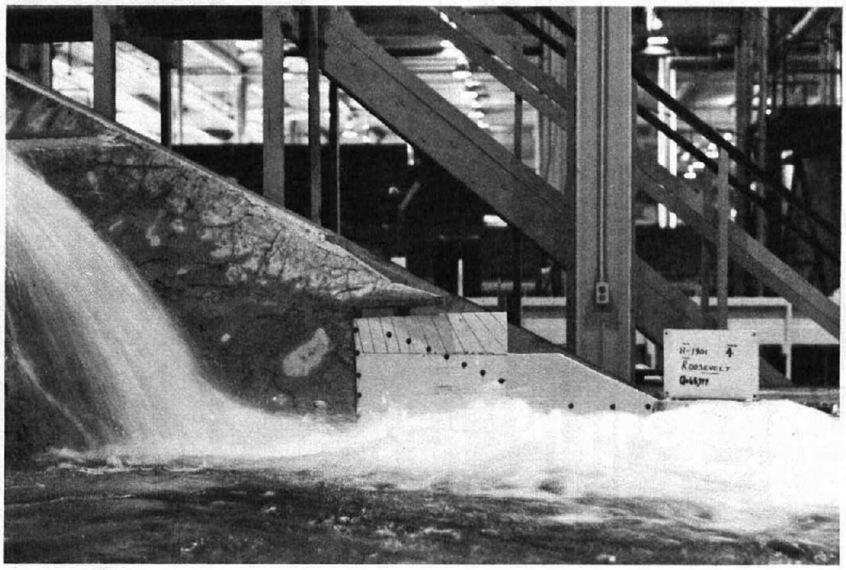


Figure 18.–Original lower training wall design. P801-D-79568

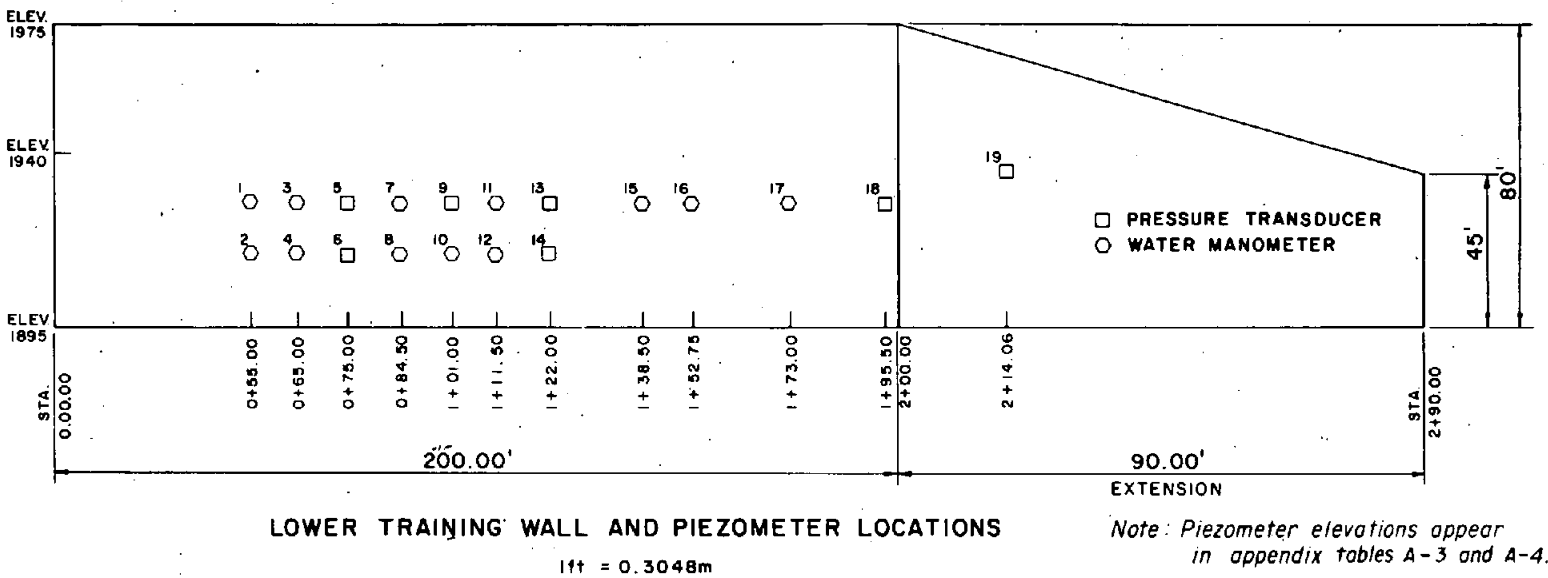


Figure 19.–Preferred design of lower training wall and piezometer locations.

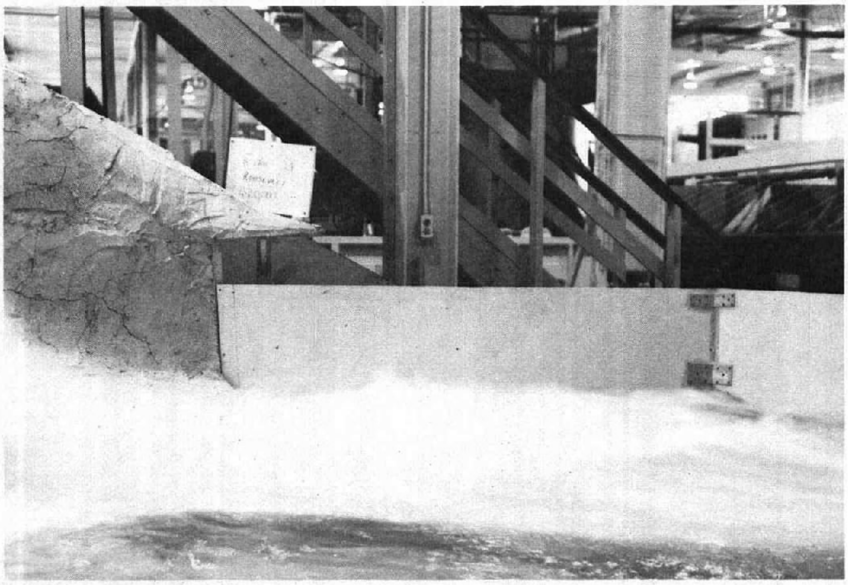


Figure 20.–Preferred design of lower training wall operating at 20 000 ft^3/s (566 m^3/s). P801-D-79569

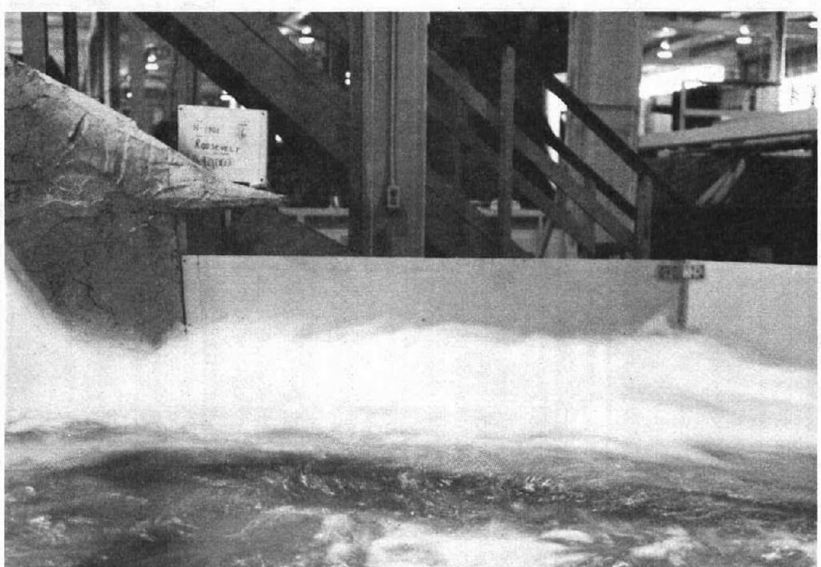


Figure 21.–Preferred design of lower training wall operating at 40 000 ft^3/s (1133 m^3/s). P801-D-79570

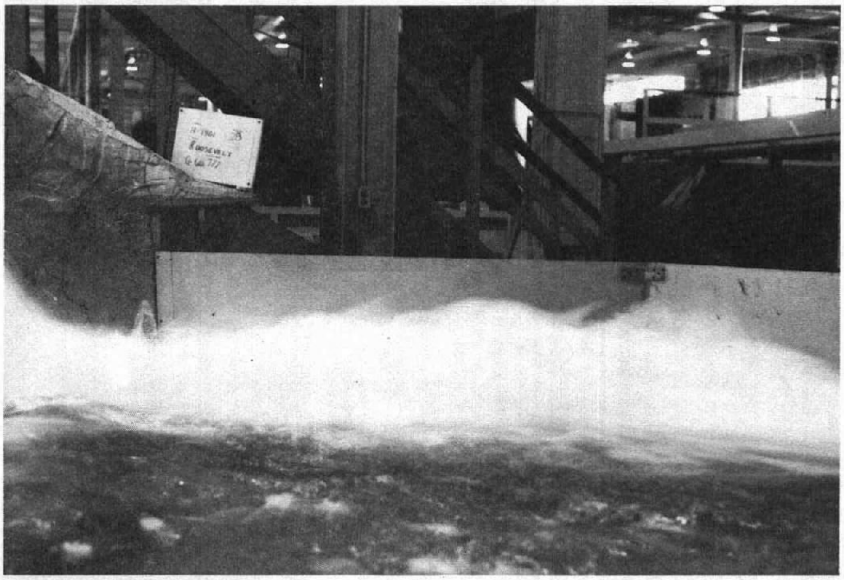


Figure 22.–Preferred design of lower training wall operating at 65 777 ft³/s (1862 m³/s). P801-D-79571

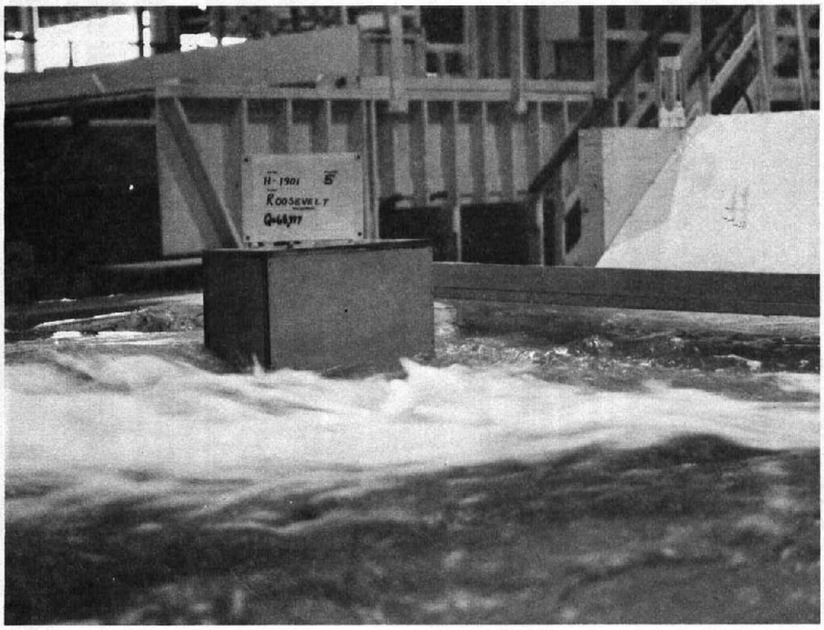


Figure 23.–Warehouse without spillway protection. Q = 65 777 ft³/s (1862 m³/s). P801-D-79572

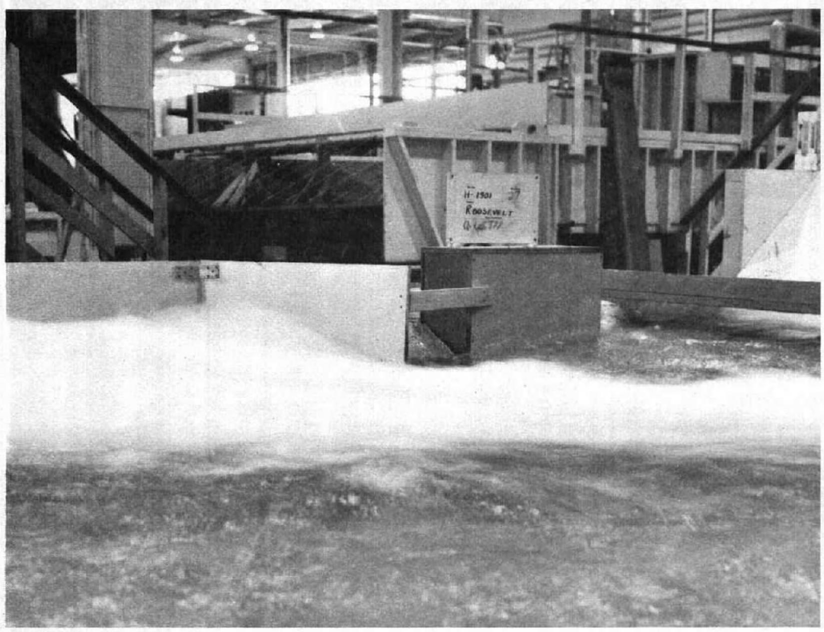


Figure 24.–Warehouse with spillway protection. Q = 65 777 ft³/s (1862 m³/s). P801-D-79573

APPENDIX[1]

[1] As requested by the Salt River Project, the data collected directly from the model appear in this appendix and are converted to prototype values in inch-pound units.

Table A-1.–*Model data obtained for south spillway capacity curves (fig. 13) and converted to inch-pound units*

Measured model discharge, ft³/s	Prototype discharge, ft³/s	Measured model reservoir elevation,[1] ft	Prototype reservoir elevation, ft	Comments
		5-ft (1.52-m) gate opening, bridge in place		
0.482	3 748	0.132	2124.37	
0.942	7 325	.191	2126.50	
1.613	12 543	.294	2130.20	
2.121	16 493	.441	2135.50	
3.009	23 398	.605	2141.40	
3.702	28 787	.734	2146.04	Gates overtopped
2.618	20 358	.534	2138.84	
1.826	14 199	.373	2133.05	
1.340	10 420	.260	2128.98	
		10-ft (3.05-m) gate opening, bridge in place		
1.578	12 270	0.260	2128.98	
2.197	17 084	.321	2131.18	
2.924	22 737	.376	2133.16	
3.565	27 721	.455	2136.00	
4.309	33 507	.572	2140.21	
5.188	40 342	.730	2145.90	Gates overtopped
4.718	36 687	.643	2142.78	
3.848	29 922	.503	2137.73	
0.935	7 271	.187	2126.35	
		15-ft (4.57-m) gate opening, bridge in place		
1.857	14 440	0.287	2129.95	
3.218	25 023	.392	2133.73	
5.378	41 819	.552	2139.49	
6.243	48 546	.640	2142.66	
7.052	54 836	.736	2146.11	Gates overtopped
3.900	30 326	.446	2135.68	
4.681	36 400	.505	2137.80	

Table A-1.–*Model data obtained for south spillway capacity curves (fig. 13) and converted to inch-pound units* – Continued

Measured model discharge, ft^3/s	Prototype discharge, ft^3/s	Measured model reservoir elevation,[1] ft	Prototype reservoir elevation, ft	Comments
		21-ft (6.40-m) gate opening, bridge in place		
4.388	34 121	0.479	2136.86	
5.897	45 855	.579	2140.46	
8.459	65 777	.719	2145.50	
7.894	61 384	.698	2144.75	
7.351	57 161	.664	2143.52	
6.658	51 773	.618	2141.87	
6.062	47 138	.584	2140.64	
5.457	42 434	.544	2139.20	
4.889	38 017	.503	2137.73	
4.264	33 157	.461	2136.22	
4.085	31 765	.448	2135.75	
3.748	29 144	.422	2134.81	
3.377	26 260	.397	2133.91	
3.007	23 382	.367	2132.83	
2.495	19 401	.326	2131.36	
1.553	12 076	.245	2128.44	
		21-ft (6.40-m) gate opening, bridge removed		
8.525	66 290	0.718	2145.47	
7.347	57 130	.648	2142.95	
6.285	48 872	.594	2141.00	
4.563	35 482	.484	2137.04	

[1] Model crest elevation equals zero.

Note: 1 ft = 0.3048 m
1 ft^3/s = 0.0283 m^3/s

Table A-2.–*Pressure data for upper training wall – manometer measurements*

Piezometer No.	Elevation, ft	South spillway discharge, ft^3/s	Pressure, ft	Pressure elevation, ft
1	2110.26	30 620	0.036	2110.30
		35 850	0.864	2111.12
		41 330	1.764	2112.02
		45 725	3.276	2113.54
		50 170	4.320	2114.58
		53 640	5.148	2115.41
		57 450	5.760	2116.02
		60 810	6.336	2116.60
		65 777	9.830	2120.09
2	2110.26	30 620	0.072	2110.33
		35 850	0.216	2110.48
		41 330	1.116	2111.38
		45 725	2.196	2112.46
		50 170	2.988	2113.25
		53 640	3.564	2113.82
		57 450	3.996	2114.26
		60 810	4.356	2114.62
		65 777	7.056	2117.32
3	2108.57	30 620	1.080	2111.34
		35 850	3.240	2113.50
		41 330	5.180	2115.44
		45 725	6.732	2116.99
		50 170	7.884	2118.14
		53 640	8.496	2118.76
		57 450	9.360	2119.62
		60 810	9.972	2120.23
		65 777	11.880	2122.14
4	2110.07	30 620	0.576	2110.65
		35 850	0.864	2110.93
		41 330	1.116	2111.19
		45 725	1.944	2112.01
		50 170	2.664	2112.73
		53 640	3.132	2113.20
		57 450	3.492	2113.56
		60 810	3.672	2113.74
		65 777	5.364	2115.43

Table A-2.–*Pressure data for upper training wall – manometer measurements* – Continued

Piezometer No.	Elevation, ft	South spillway discharge, ft^3/s	Pressure, ft	Pressure elevation, ft
5	2107.63	30 620	1.332	2108.96
		35 850	2.340	2109.97
		41 330	3.168	2110.80
		45 725	4.104	2111.73
		50 170	4.644	2112.27
		53 640	4.860	2112.49
		57 450	5.400	2113.03
		60 810	5.508	2113.14
		65 777	6.876	2114.51
6	2114.57	45 000	0.360	2114.93
		55 000	0.610	2115.18
		60 000	1.440	2116.01
		65 777	3.420	2117.99
7	2114.57	45 000	0.430	2115.00
		55 000	0.830	2115.40
		60 000	1.550	2116.12
		65 777	3.600	2118.17

Note: 1 ft = 0.3048 m
1 ft^3/s = 0.0283 m^3/s

Table A-3.–*Pressure data for lower training wall – manometer measurements*

Piezometer No.	South spillway discharge, ft³/s	Piezometer elevation, ft	Average pressure elevation, ft	Pressure, ft
1	15 000	1919.01	1924.41	5.40
	30 000		1929.09	10.08
	45 000		1930.89	11.88
	65 777		1934.13	15.12
2	15 000	1911.71	1917.47	5.76
	30 000		1922.15	10.44
	45 000		1933.31	21.60
	65 777		1936.19	24.48
3	15 000	1918.46	1922.78	4.32
	30 000		1928.90	10.44
	45 000		1928.90	10.44
	65 777		1931.42	12.96
4	15 000	1911.89	1924.13	12.24
	30 000		1928.45	16.56
	45 000		1938.53	26.64
	65 777		1942.85	30.96
7	15 000	1921.08	1923.96	2.88
	30 000		1930.08	9.00
	45 000		1932.24	11.16
	65 777		1939.44	18.36
8	15 000	1912.26	1922.70	10.44
	30 000		1927.74	15.48
	45 000		1929.18	16.92
	65 777		1936.02	23.76
10	15 000	1912.83	1923.27	10.44
	30 000		1930.83	18.00
	45 000		1932.99	20.16
	65 777		1941.27	28.44

Table A-3.–*Pressure data for lower training wall – manometer measurements* – Continued

Piezometer No.	South spillway discharge, ft^3/s	Piezometer elevation, ft	Average pressure elevation, ft	Pressure, ft
11	15 000	1921.64	1923.80	2.16
	30 000		1933.88	12.24
	45 000		1937.84	16.20
	65 777		1943.24	21.60
12	15 000	1913.39	1924.55	11.16
	30 000		1934.27	20.88
	45 000		1937.15	23.76
	65 777		1943.27	29.88
15	15 000	1920.33	1923.93	3.60
	30 000		1935.45	15.12
	45 000		1937.97	17.64
	65 777		1941.93	21.60
16	15 000	1921.08	1927.56	6.48
	30 000		1937.28	16.20
	45 000		1940.88	19.80
	65 777		1946.64	25.56
17	15 000	1920.89	1920.89	0.00
	30 000		1934.57	13.68
	45 000		1940.69	19.80
	65 777		1947.89	27.00

Note: 1 ft = 0.3048 m
1 ft^3/s = 0.0283 m^3/s

Table A-4.–*Pressure data for lower training wall – pressure transducer measurements*

Piezometer No.	Piezometer elevation, ft	South spillway prototype discharge, ft³/s	Pressure elevation, ft Min.	Avg.	Max.	Maximum pressure, ft
5	1921.83	15 000	1921.83	1921.83	1925.24	3.41
		30 000	1921.83	1925.60	1932.44	10.61
		45 000	1922.00	1929.20	1934.60	12.77
		65 777	1925.24	1934.60	1951.16	29.33
6	1912.83	15 000	1914.80	1919.48	1922.00	9.17
		30 000	1914.44	1923.80	1929.20	16.37
		45 000	1914.60	1925.60	1938.20	25.37
		65 777	1914.80	1932.44	1950.44	37.61
9	1921.83	15 000	1921.83	1921.83	1925.96	4.13
		30 000	1927.04	1932.08	1940.72	18.89
		45 000	1929.56	1934.60	1958.00	36.17
		65 777	1924.88	1940.00	1957.70	35.87
13	1921.83	15 000	1921.83	1921.83	1924.88	3.05
		30 000	1931.00	1936.40	1941.80	19.97
		45 000	1931.20	1938.20	1948.64	26.81
		65 777	1934.16	1947.20	1959.80	37.97
14	1921.83	15 000	1918.40	1923.08	1925.60	12.77
		30 000	1929.20	1933.52	1943.96	31.13
		45 000	1927.40	1936.40	1947.20	34.37
		65 777	1927.76	1943.60	1965.20	52.37
18	1912.83	15 000	1921.83	1923.80	1925.60	3.77
		30 000	1932.44	1935.68	1938.92	17.09
		45 000	1934.56	1940.00	1947.56	25.73
		65 777	1936.40	1950.80	1959.80	37.97
19	1940.31	15 000		Atmospheric Pressure		0
		30 000				0
(warehouse		45 000	1936.76	1945.76	1950.44	10.13
protection)		65 777	1940.00	1952.60	1958.36	18.05

Note: 1 ft = 0.3048 m
1 ft³/s = 0.0283 m³/s.

GPO 833-433

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