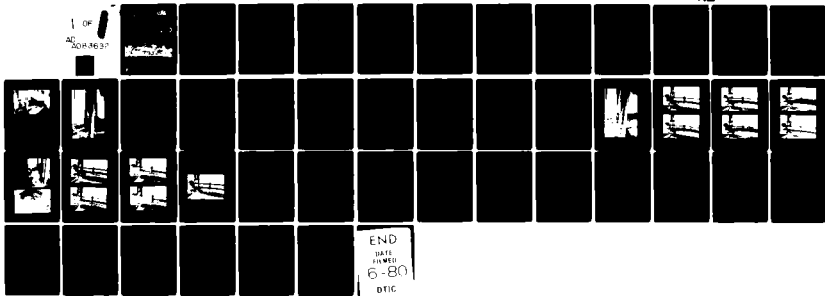
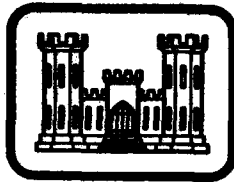


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SELECTIVE WITHDRAWAL RISER FOR SUTTON DAM, WEST VIRGINIA

Hydraulic Model Investigation

by

John F. George, Mark S. Dortch, Charles H. Tate, Jr.

Hydraulics Laboratory

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March 1980

Final Report

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20. ABSTRACT (Continued).

intake gate, and the flip bucket downstream of the sluice.

With the initial riser tested in this model, the top of the riser was set at el 910 and the invert at el 810. Very unstable flow conditions were observed for all discharges greater than 800 cfs. Vortices and vapor cavities, sufficient for severe cavitation damage, were observed immediately upstream of the sluice intake and resulted in significant fluctuations of pressures in the bell-mouthed intake for the majority of flow conditions.

Recommended modifications (type 5 design) incorporated into the original design included raising the riser invert to el 825 and placing a 2V-on-1H fillet on the riser invert. These modifications streamlined flow conditions into the sluice which eliminated the vortices and vapor cavities that formed upstream of the sluice intake with the original design and reduced pressure fluctuations in the bell-mouthed intake to a minimum.

A 1:40-scale model of the type 5 riser, sluice intake, and a 44-ft-long section of the sluice was used to determine the selective withdrawal characteristics of the proposed structural modification to provide a selective withdrawal outlet. Results from this study were used to modify an existing numerical selective withdrawal predictive technique that forms part of a lake temperature and turbidity simulation model that will be used by the Ohio River Division to determine the best plan of operating the project with the withdrawal structure to control in-lake and downstream temperature and turbidity.

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PREFACE

The hydraulic model investigations reported herein were authorized by the U. S. Army Engineer Division, Ohio River (ORD), on 27 July 1977 and by the Office, Chief of Engineers, U. S. Army, on 7 March 1978, respectively, at the request of the U. S. Army Engineer District, Huntington (ORH). The studies were conducted by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), during the period 12 August 1977 to 20 October 1978. All studies were conducted under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. The hydraulics model study was conducted by Mr. J. F. George under the supervision of Mr. G. A. Pickering, Chief of the Locks and Conduits Branch. Mr. George was assisted by Messrs. James Riley and Henry Allen. The selective withdrawal model study was conducted by Messrs. Charles H. Tate, Jr., Mark S. Dortch, and David H. Merritt with assistance from Ms. Nancy Allen, under the supervision of Mr. Darrell G. Fontane, Acting Chief of the Reservoir Water Quality Branch (Physical). This report was written by Messrs. George, Dortch, and Tate.

Messrs. Glenn Drummond and Laszlo Varga of ORD and Bo Copley, Randy Spurlock, and James Lynch of ORH visited WES during the studies to observe model performance, discuss test results, and correlate these results with concurrent design work.

Commanders and Directors of WES during the study and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres

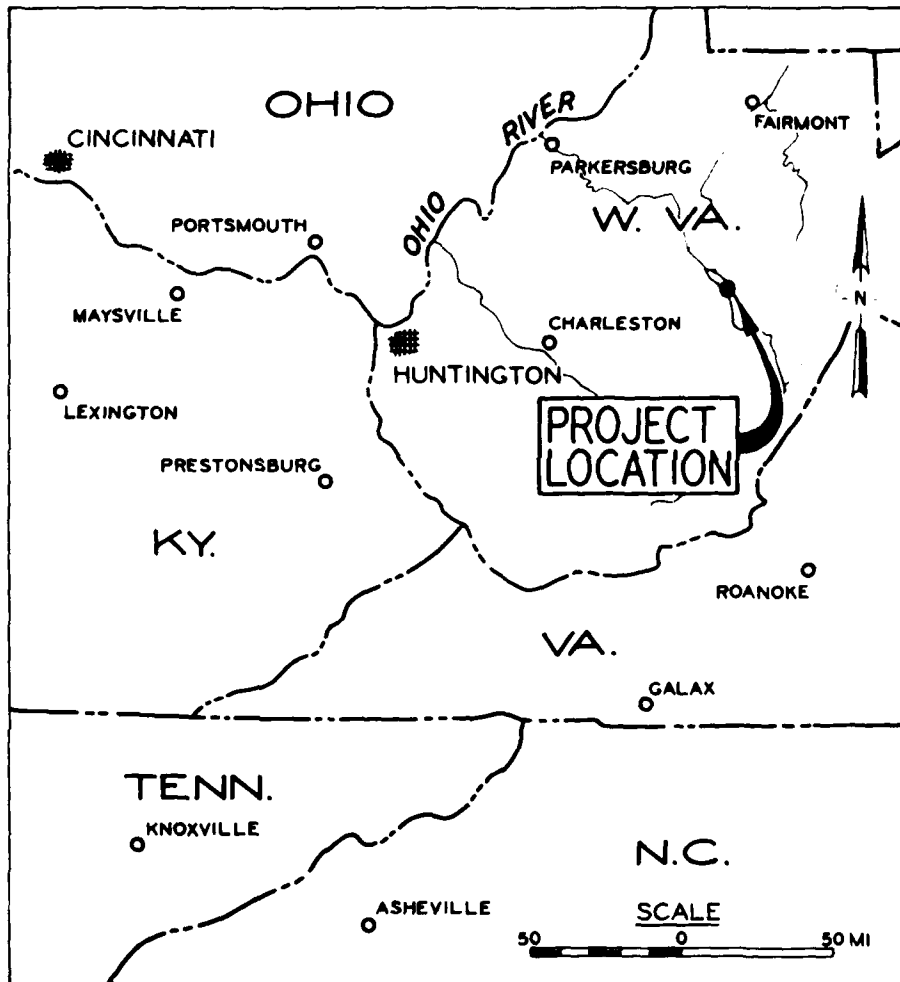


Figure 1. Location map

SELECTIVE WITHDRAWAL RISER FOR
SUTTON DAM, WEST VIRGINIA
Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Sutton Dam project is located in Braxton County, West Virginia (Figure 1) on the Elk River, a tributary of the Kanawha River. The project, located approximately 100 miles* above the mouth of the Elk River and 159 miles above the mouth of the Kanawha River, serves the surrounding area by providing flood-control protection, pollution abatement, a habitat for fish and wildlife, and an area for general recreation.

2. Sutton Dam, a concrete gravity structure with a maximum height of 210 ft and a length of 1178 ft, consists of a 280-ft-long spillway, six 40-ft-wide tainter gates, 5 gated sluices, and a 50-ft-radius flip bucket. The structure is designed to handle discharges up to 222,200 cfs.

Existing Problems

3. Two significant water quality problems associated with withdrawal from the hypolimnion have existed since completion of Sutton Dam in June 1960. These problems involved cooler than desired tailwater temperature throughout late spring, summer, and early fall and increased duration of excessive turbidity in the outflow following summer storms.

4. The proposed plan of improvements to Sutton Dam consisted of placing a semicircular riser on the upstream side of the center sluice. The semicircular riser would enable flow that is released through the sluice to be drawn from a higher elevation (the epilimnion) or warmer

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

layer near the surface of the impoundment.

Purpose and Scope of Model Investigations

5. Initially, a 1:40-scale model was considered necessary to define selective withdrawal characteristics of the proposed semicircular riser. During preliminary tests with a 10-ft-radius semicircular riser (type 1), air-entrained vortices were observed in the model at the sluice intake, indicating unsatisfactory flow conditions in the riser and sluice. The 1:40-scale model was not adequate to fully evaluate the unstable flow conditions; therefore it was determined that a second model, which reproduced additional details at a larger scale, was required to properly evaluate the hydraulic performance of the proposed selective withdrawal riser.

6. The second model, a 1:20-scale hydraulic model, was used to determine the hydraulic adequacy of a proposed new design. The design modifications resulting from tests conducted with the 1:20-scale model were incorporated into the 1:40-scale model prior to conducting selective withdrawal tests.

7. The 1:40-scale model was then used to define selective withdrawal characteristics of the recommended riser so that the effect of the riser on the temperature and turbidity regimes within and downstream of the lake could be properly evaluated. Results of the selective withdrawal analysis were incorporated into the existing withdrawal subroutine of the thermal and turbidity mathematical simulation model that is used by the U. S. Army Engineer Division, Ohio River (ORD), for Sutton Lake. The hydraulic models are described in detail in PARTS II and III of this report.

Scale Relations

8. The accepted equations of hydraulic similitude, based on Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the models and prototype.

General relations for transference of model data to prototype equivalents are as follows:

Dimensions	Ratio	Scale Relations	
		Hydraulics Model	Selective Withdrawal Model
Length	$L_r = L$	1:20	1:40
Area	$A_r = L_r^2$	1:400	1:1,600
Velocity	$V_r = L_r^{1/2}$	1:4.47	1:6.32
Time	$T_r = L_r^{1/2}$	1:4.47	1:6.32
Discharge	$Q_r = L_r^{5/2}$	1:1,789	1:10,119

9. The water density gradient obtained with fresh and saline water in the selective withdrawal model forebay reproduced that experienced in the prototype lake. Model measurements of discharge, water-surface elevations, and pressures can be transferred quantitatively to prototype equivalents by means of the preceding scale relations.

PART II: HYDRAULICS MODEL

Description

10. The 1:20-scale model reproduced the semicircular riser with trashrack, a 120-ft-wide section of the dam, the entire length of one sluice including its bell-mouthed intake, the intake gate, and the flip bucket downstream of the sluice (Figure 2, Plates 1-3). The riser, upstream side of the dam, sluice, intake gate, and flip bucket were constructed of transparent plastic so that flow conditions could be observed; the trashrack was constructed of copper tubing.

Model Appurtenances

11. Water used in the operation of the model was supplied by a recirculation system. Discharges, measured by means of an orifice meter installed in the flow lines, were baffled after entering the model. Water-surface elevations were measured with a graduated scale and pressures were measured with piezometers. Different designs, along with various flow conditions, were recorded photographically.

Tests and Results

12. Flow conditions were initially observed without the semicircular riser installed (Photo 1) for discharges ranging from 200 cfs to 3,650 cfs with various heads and gate openings. Calibration data recorded for a 4-ft and full (10-ft) gate opening (Plate 4) correlated closely with the prototype rating curve. Tailwater elevations used during all tests are shown in Plate 5.

Type 2 riser

13. The type 1 riser design which was initially tested in the 1:40-scale model had a radius of 10 ft and was determined to be too small. It permitted flow to be controlled by the riser rather than the sluice and negative pressures sufficient for cavitation were present. Thus, it was necessary to enlarge the cross-sectional area of the proposed riser.

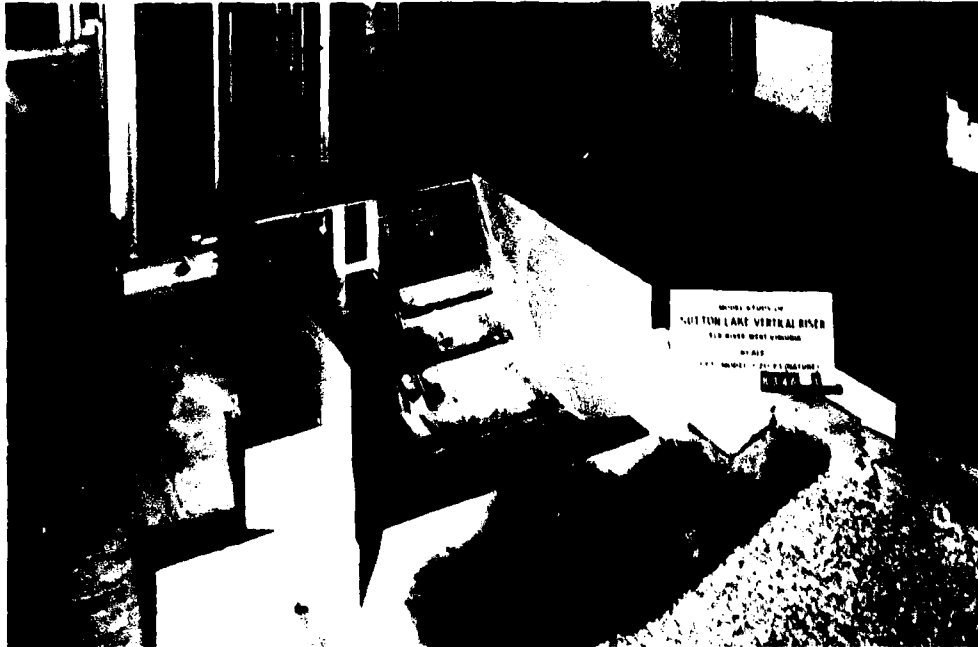


Figure 2. General view of model

The type 2 riser design (Figure 3) consisted of a 16-ft-radius semicircular riser positioned on the upstream side of the center sluice. This design was based on providing an average velocity of 5 fps in the riser when passing the design discharge of 2,000 cfs which is sufficient for maintaining any entrained air in suspension until it is absorbed within the riser. This would prevent slug flow of air and water through the sluice should an air-entraining vortex develop in the prototype riser and would increase the dissolved oxygen content of releases should a deficit exist. The invert of the type 2 riser was initially set at el 810⁶ with the top of the riser at el 910. Details of the type 2 riser and trashrack are shown in Plates 2 and 3.

14. Flow conditions were observed and documented with the type 2

⁶ All elevations (el) cited herein are in feet referred to mean sea level.



Figure 3. Type 2 riser

riser for discharges ranging from 100 cfs to 3,200 cfs with various gate openings and upper pool elevations. Vortices and vapor cavities formed at the intake (Photo 2c-2e) with discharges as small as 800 cfs (3-ft gate opening) and increased in size and strength with increased gate openings and discharges.

15. With partial sluice flow conditions, vortices and vapor cavities would initially form at the intake gate and very rapidly extend upstream into the bell-mouthed intake and riser. As this occurred a turbulent condition in the sluice flow downstream of the intake gate would develop, often causing the flow to come in contact with the roof of the sluice (Photo 2e). With full conduit flow (Photo 2f), small vortices and vapor cavities intermittently developed in the riser and bell-mouthed intake. Pressures were not measured in the center of the intake where the vortices formed; however, the presence of the vapor cavities indicated severe low pressures sufficient to induce cavitation, and severe damage of the riser and sluice would probably occur. The majority of pressures measured along the sides of the bell-mouthed intake were positive; however, significant fluctuations of pressures were measured with large discharges during fully open gate operations. These pressure data are presented in Table 1. Locations of the piezometers used in measuring pressures are shown in Plate 6.

16. Calibration data obtained with the type 2 riser with various gate openings are shown in Plate 7. The discharge capacity of this riser with the gate fully opened was 3,100 cfs with normal upper pool el 925 and 3,200 cfs with upper pool el 935. A 7-ft gate opening was required to pass the 2,000-cfs design discharge (equaled or exceeded about 5 percent of time during the period 16 May-15 September) through the sluice with upper pool el 925.

Type 3 riser

17. Results of a previous model study* with a similar vortex

* P. H. Burgi and S. Fujimoto. 1973 (Dec). "Hydraulic Model Studies of Crystal Dam Spillway and Outlet Works, Colorado River Storage Project," REC-ERC-73-22, Engineering and Research Center, U. S. Bureau of Reclamation, Denver, Colo.

problem indicated that raising the riser invert improved flow conditions. Therefore, in the type 3 design (Plate 8, Photo 3), the riser invert was raised to el 821.75 in an effort to improve flow conditions just upstream of the sluice intake. Flow conditions were considerably more stable throughout the sluice for the range of discharges previously observed. This resulted in a significant reduction of vortices and vapor cavities in the sluice and reduced the pressure fluctuations that were present with the type 2 design. These pressure data are also presented in Table 1.

Type 4 riser

18. The invert of the riser was raised to el 825 (the same elevation as the sluice invert) in an effort to further improve flow conditions upstream of the intake. This was designated the type 4 riser shown in Plate 8. Vortices and vapor cavities did not form as frequently as they did with earlier designs tested. A further reduction of pressure fluctuations in the bell-mouthed intake was also noted, and these data are also included in Table 1.

Type 5 (recommended design) riser

19. In the type 5 design a 2V-on-1H slope fillet was installed on the riser invert (el 825) in an attempt to streamline entrance conditions into the sluice as shown in Photo 4 and Plate 9. This modification eliminated the vortices and vapor cavities for the full range of discharges observed. A further reduction in pressure fluctuations (Table 1) relative to those observed with previous designs was noted which indicated better flow conditions, as shown in Photo 5. The discharge capacity of the sluice with upper pool el 925 and the gate fully opened was 3,500 cfs. A gate opening of 6.5 ft was required to pass 2,000 cfs through the sluice with upper pool el 925. The type 5, 16-ft radius, semicircular riser is the recommended design, since flow conditions were stable throughout the sluice for the full range of discharges observed and only minor pressure fluctuations were observed in the sluice intake. Calibration data are presented in Plate 10.

PART III: SELECTIVE WITHDRAWAL MODELS

20. The selective withdrawal model was used to determine the selective withdrawal characteristics of the recommended type 5 riser (see paragraph 19). These results then provided the basis for modifying and applying the withdrawal subroutine of the reservoir temperature and turbidity mathematical simulation model used by ORD. The withdrawal subroutine was formulated from the U. S. Army Engineer Waterways Experiment Station (WES) generalized selective withdrawal predictive technique* which also exists as a computer code entitled SELECT.

Physical Model Description

21. The 1:40-scale selective withdrawal model (Plate 11) reproduced a single sluice entrance, the upstream sloping dam face, a 44-ft-long section of the sluice, and the riser attached to the face of the dam. Flow was controlled by hand valves since the service gates were not reproduced in the model. The 44-ft (prototype) section of the sluice was transitioned to a 3-in. (model) plastic pipe. The pipe was branched and one leg contained a rotometer capable of measuring flows up to 900 cfs prototype (Plate 11). The other branch was used to measure higher flow rates with a 90-deg V-notch weir and a volumetric tank. The model was constructed of transparent plastic for the purpose of flow observation.

22. A transparent plastic tank, 40 ft long by 16 ft wide, served as a model forebay. Density profiles, typical of those found in the prototype lake due to temperature stratification (Plate 12), were reproduced in the forebay using fresh and saline water. Vertical profiles of the resulting stratification were measured using a conductivity probe and a temperature probe. The same probes were used to measure the

* J. P. Bohan and J. L. Grace, Jr. 1973 (Mar). "Selective Withdrawal from Man-Made Lakes; Hydraulic Laboratory Investigation," Technical Report H-73-4, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

conductivity and temperature of the release through the structure. From the conductivity and temperature measurements and calibration with solutions of known density, the densities of the forebay profile and of the release could be determined. From video recordings of dye streak displacement in the model, it was possible to determine the vertical extent of the in-lake withdrawal zones and velocity distributions upstream of the riser for various operational and stratification conditions.

Test Procedure

23. After setting up the density stratification in the model forebay and allowing time for transient currents to damp out, a steady-state release flow was established. Data collection was started about 5 min after initiating the release to allow time for the withdrawal profile to develop. Data collection consisted of obtaining a forebay density profile, recording dye streak displacement for in-lake velocity profiles, and measuring release density. The stratification and flow conditions for the test were input to SELECT and predictions were made with SELECT. The predicted velocity distribution and outflow density were then compared with that observed. This same procedure was used for each test. Approximately 20 selective withdrawal tests were used to compare with SELECT predictions that were obtained for various computational assumptions or modifications. Through these comparisons it was possible to determine how SELECT should be modified and applied to provide reliable predictions. The conditions tested by the selective withdrawal model covered a range of pool and flow conditions of el 914 to el 935 and 100 to 2,689 cfs, respectively.

Test Results

24. To apply SELECT, the hydraulic structure must first be classified as either a weir or an orifice. The computations depend on which classification is input to SELECT. It was initially thought that the riser could be treated as a submerged weir for SELECT application.

However, the observed elevation of the lower limit of withdrawal was significantly different from that predicted by SELECT. The upper limit of the withdrawal zone extended to the surface for all tests. The riser was simulated as a submerged weir with crest el 910 and an effective crest length of 50 ft. Most of the predicted lower limits were lower in the pool than the observed lower limits as shown by Plate 13. The submerged weir simulations did predict the correct elevation of the maximum in-lake velocity most of the time.

25. Next, the riser was considered as an orifice extending from the water surface to the crest of the riser with an effective center line midway between the water surface and the crest. Using the orifice classification as input to SELECT, the predicted and observed lower limits were in good agreement for most cases (Plate 14). However, when the predicted and observed velocity distributions were compared, it was found that the observed elevation of the maximum velocity was lower in most cases than that predicted by SELECT.

26. SELECT uses a different equation to compute the elevation of the maximum velocity, depending on whether an orifice or weir outlet is simulated. Treating the riser as an orifice resulted in better predictions of the lower limit of withdrawal but did not do well predicting the location of maximum velocity. The drawdown over the crest of the riser appeared to affect the location of the maximum velocity in a manner similar to flow over a weir. As a result of the drawdown effect, the riser was treated as an orifice but the weir equation was used to predict the elevation of the maximum velocity. Results of these predictions are shown in Plate 15 as predicted versus observed average release density.

PART IV: SUMMARY AND DISCUSSION

27. A 1:40-scale model was initially constructed to define selective withdrawal characteristics of the proposed 10-ft-radius semicircular riser. During preliminary tests with this model, vortices were observed at the sluice intake, indicating unstable flow conditions. A 1:20-scale model was recommended to determine the hydraulic adequacy of the riser, including discharge characteristics, pressure conditions, trashrack details, and essential operational guidance. After the vortices were observed with the 10-ft-radius riser in the 1:40-scale model, it was concluded that a larger riser was needed which should be subjected to tests in a larger scale model to define hydraulic conditions. Thus, a 16-ft-radius riser was built in the 1:20-scale model. Design of this riser was based on providing an average velocity in the riser of at least 5 fps for a discharge of 2,000 cfs which would keep any entrained air in suspension until it is absorbed within the riser. This would prevent slug flow of air and water through the sluice should an air entraining vortex develop in the prototype riser and would increase the dissolved oxygen content of releases should a deficit exist.

28. Flow conditions were initially observed without the riser installed with various heads, gate openings, and discharges. Calibration data obtained without the riser correlated closely with the prototype rating curves (Plate 4).

29. With the 16-ft-radius riser installed on the dam, very unstable flow conditions were observed for all discharges with gate openings of 3 ft or greater. Severe vortices and vapor cavities formed immediately upstream from the sluice inlet resulting in significant fluctuations of pressure in the bell-mouthed intake. These unstable flow conditions were attributed to the abrupt change in direction of flow near the intake because the riser invert was at el 810, 15 ft lower than the sluice invert. Thus, the riser invert was raised first to el 821.75, and later to el 825, the elevation of the sluice invert. This modification greatly reduced pressure fluctuations at the intake and fewer vortices

were observed. However, vortices and vapor cavities still formed for some of the larger discharges.

30. A 2V-on-1H fillet, placed on the riser invert at el 825 (type 5 design), further streamlined flow conditions into the sluice. This design eliminated the vortices and vapor cavities at the sluice intake and reduced pressure fluctuations to satisfactory levels for the full range of discharges. The discharge capacity of the sluice was 3,500 cfs with a normal upper pool elevation of 925. The type 5 semicircular riser design is recommended for prototype construction based on the results of these tests.

31. From the selective withdrawal model study, it was determined that the withdrawal characteristics of the riser predicted by the mathematical model, SELECT, for the condition of an orifice with center line elevation midway between the water surface and the riser crest el 910 were very similar to those observed in the physical model. It was necessary to modify SELECT so that the equation to predict the elevation of in-lake maximum velocity for weir flow conditions would be used rather than a similar equation normally used for orifice flow conditions. Applying the mathematical model in this way provided reasonably accurate predictions of observed data. Results of the selective withdrawal study were incorporated into the withdrawal subroutine of the reservoir temperature and turbidity mathematical simulation model used by ORD. ORD will apply the mathematical model to determine the best plan of operating the project with the withdrawal structure to control in-lake and downstream temperature and turbidity.

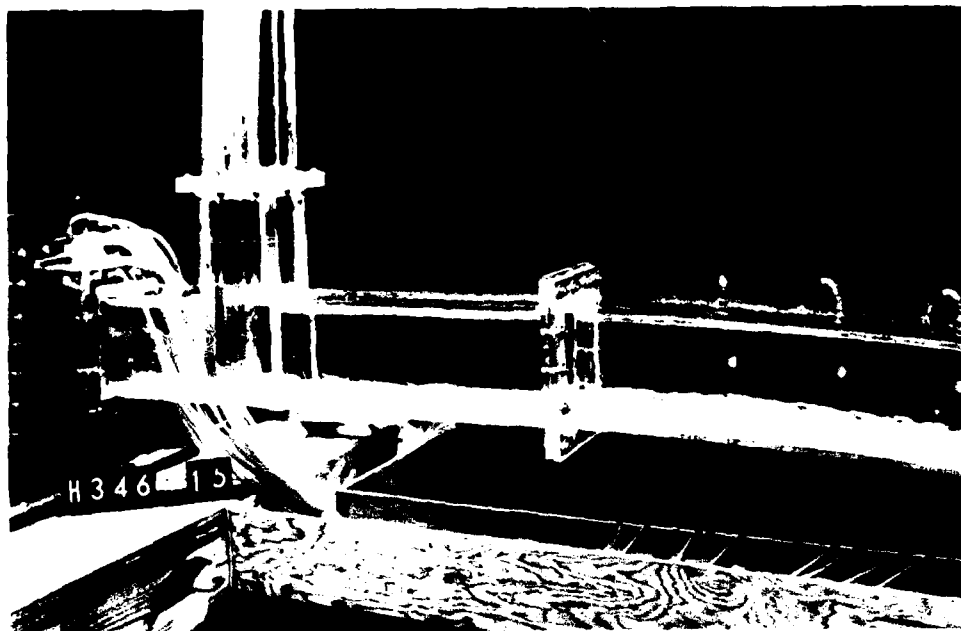
Table 1
Maximum and Minimum Pressures in Bell-Mouthed Sluice Intake

Piezometer No.	Piezometer Elevation	Type 2 (Riser Invert = El 810)			Type 3 (Riser Invert = El 821.75)			Type 4 (Riser Invert = El 825)			Type 5 (Riser Invert = El 825 with 2V-on-LH Slope Insert)		
		Full Gate Opening			Full Gate Opening			Full Gate Opening			Full Gate Opening		
		Q = 3100 cfs, H.P. = El 924.5	Maximum	Minimum	Q = 3480 cfs, H.P. = El 925	Maximum	Minimum	Q = 3500 cfs, H.P. = El 925.8	Maximum	Minimum	Q = 3590 cfs, H.P. = El 925.4	Maximum	Minimum
		Pres- sure	Difference	Pres- sure	Difference	Pres- sure	Difference	Pres- sure	Difference	Pres- sure	Difference	Pres- sure	Difference
1	837.83	+67.2	25	+42.2	5.5	+36.7	4	+32.7	4	+37.2	4.5	+32.7	4.5
2	837.83	+74.2	23	+61.2	12.5	+48.7	7.5	+46.7	7.5	+50.2	5	+45.2	5
3	837.17	+61.8	24	+41.3	4	+37.3	2.5	+32.8	2.5	+35.3	3	+32.3	3
4	837.17	+66.8	29	+50.8	9.5	+41.3	5.5	+34.3	5.5	+37.8	4	+33.8	4
5	836.55	+52.4	21	+35	3	+32	2.4	+26.0	2.4	+28	3	+25	3
6	836.55	+50.4	24	+42	13	+29	9.4	+31.4	9.4	+23	3.6	+19.4	3.6
7	836.15	+46.8	23	+29.8	4	+25.8	3	+21.4	3	+19.8	2	+17.8	2
8	836.15	+47.8	30	+31.8	17	+14.8	8.4	+16.8	8.4	+10.8	4	+6.8	4
9	835.77	+36.2	23	+18.2	4.5	+13.7	3	+9.7	3	+7.7	1.5	+6.2	1.5
10	835.77	+33.2	30.5	+17.7	16	+1.7	8.5	+1.2	8.5	-1.3	5.5	-6.8	5.5
11	835.42	+25.6	34	+8.1	6	+2.1	2.5	+0.6	2.5	-1.4	1.5	-2.9	1.5
12	835.42	+30.6	24.5	+25.1	19.5	+5.6	5	+5.1	5	+4.6	6.5	-1.9	6.5
13	835.16	+21.8	40	+4.3	14	-9.7	4	-1.2	4	-3.7	1.5	-5.2	1.5
14	835.16	+22.8	18	+18.8	13.5	+5.3	5.5	+4.8	5.5	+1.3	3.5	-2.2	3.5
15	830.0	+80	58	+86	26.5	+59.5	11	+62	11	+58	6	+52	6
16	830.0	+60	27	+73	18	+55.5	6	+49.5	6	+54	3.5	+50.5	3.5
17	830.0	+57	27	+59	10	+49	3.5	+46.5	3.5	+46	2.5	+43.5	2.5
18	830.0	+49	33	+58	21.5	+36.5	5	+34.5	5	+38	2	+36	2
19	830.0	+48	48	+42.5	8.5	+34	4.5	+32.5	4.5	+31	1.5	+29.5	1.5
20	830.0	+42	38	+35.5	8	+27.5	3.5	+25.5	3.5	+25	2.5	+22.5	2.5
21	830.0	+37	29	+32	5.5	+26.5	5	+23.5	5	+27	2.5	+24.5	2.5
22	830.0	+30	33	+26.5	6	+25	3.5	+21.5	3.5	+24.5	3	+21.5	3
23	830.0	+29	23	+25.5	6.5	+19	4.5	+23.5	4.5	+23	2	+21	2

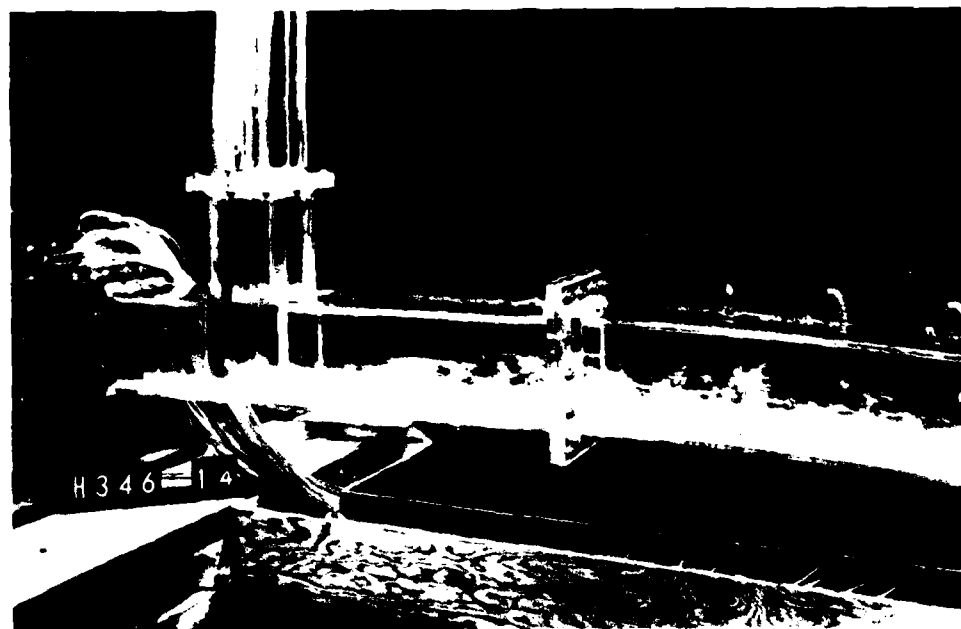
Note: Q - discharge, H.P. - head pool. All pressures are in prototype feet of water.



Photo 1. Side view showing existing conditions upstream of sluice
before installation of riser

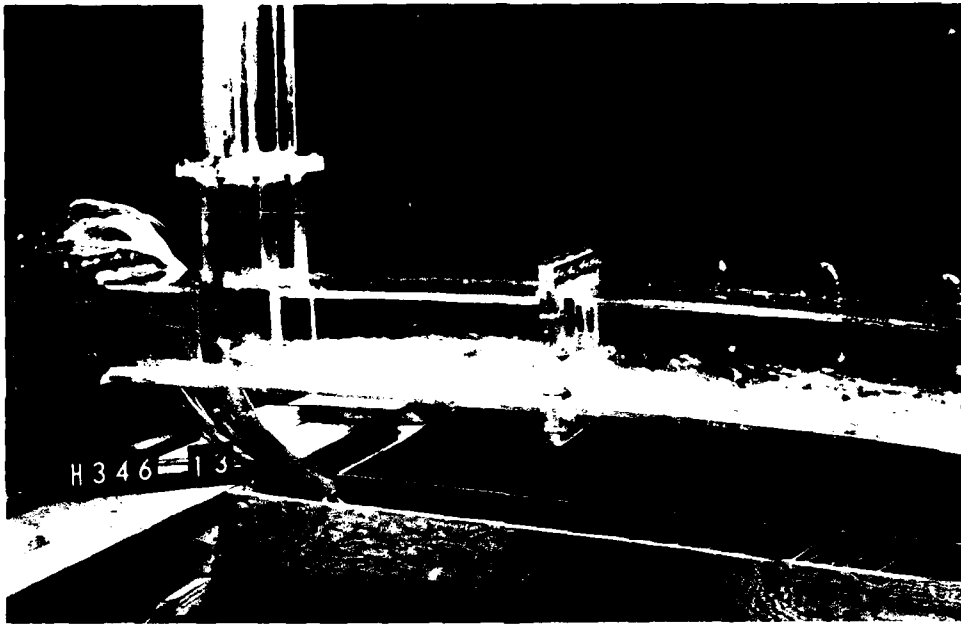


a. Discharge 300 cfs, gate opening 1 ft

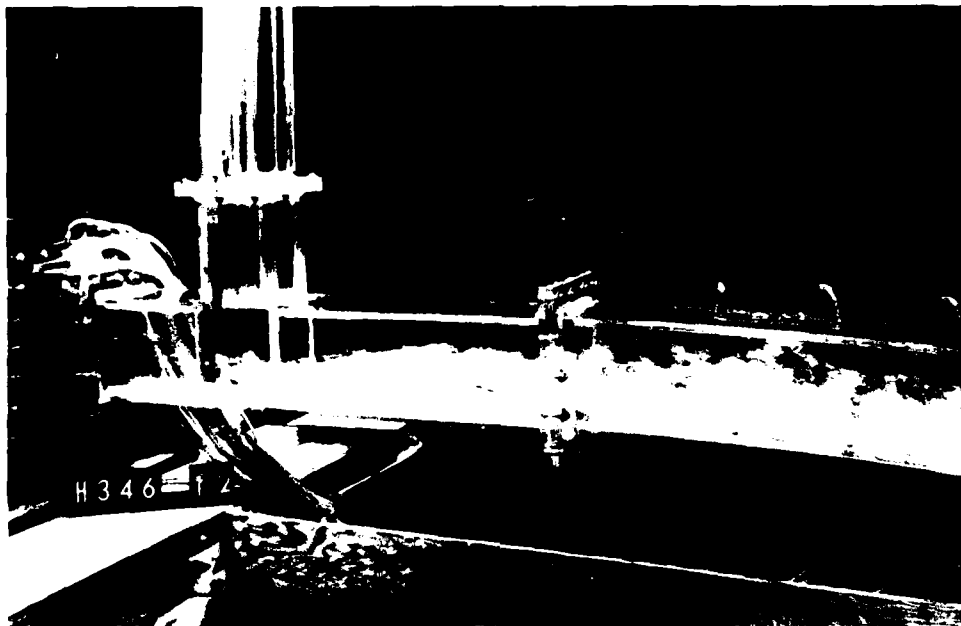


b. Discharge 600 cfs, gate opening 2 ft

Photo 2. Side view of flow conditions in sluice with type 2 riser design and head pool el 925 (Sheet 1 of 3)

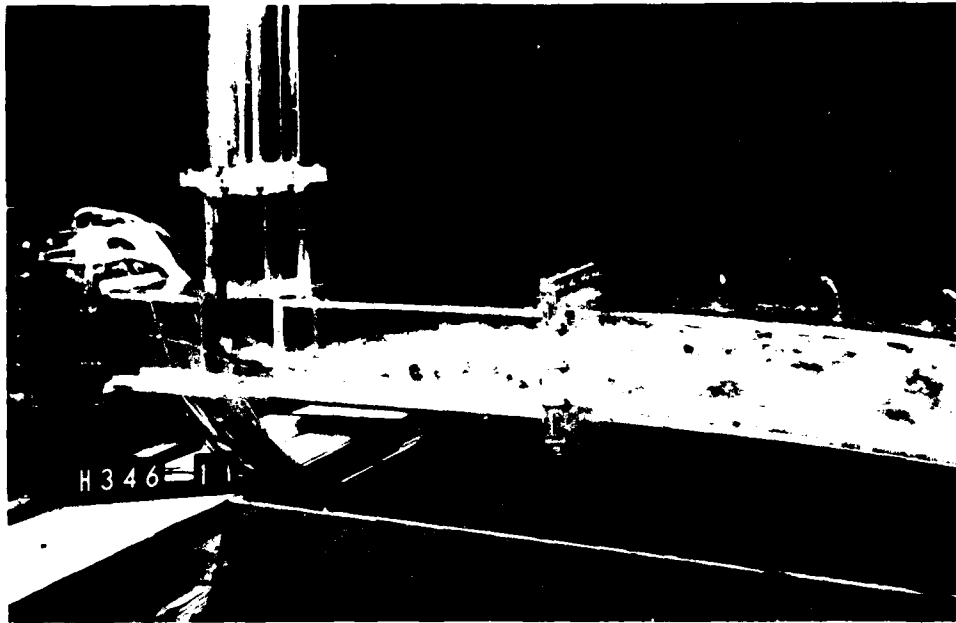


c. Discharge 900 cfs, gate opening 3 ft



d. Discharge 1,000 cfs, gate opening 3.3 ft

Photo 2. (Sheet 2 of 3)



e. Discharge 1,200 cfs, gate opening 4 ft



f. Discharge 3,100 cfs, gate opening 10 ft (full gate opening)

Photo 2. (Sheet 3 of 3)

Photo 3. Type 3 riser design

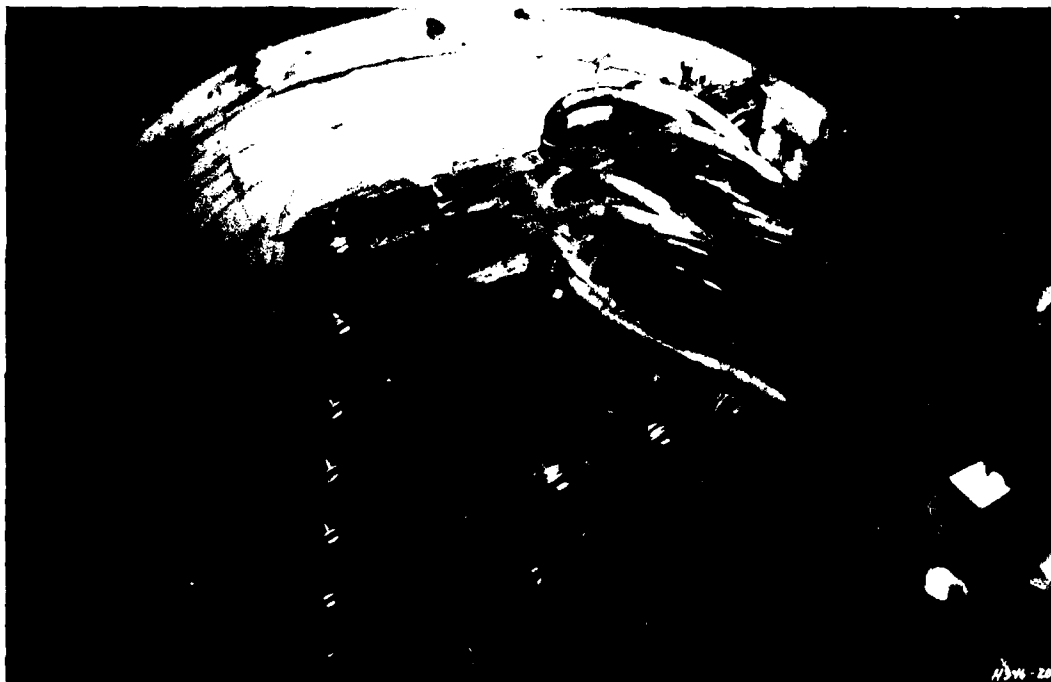
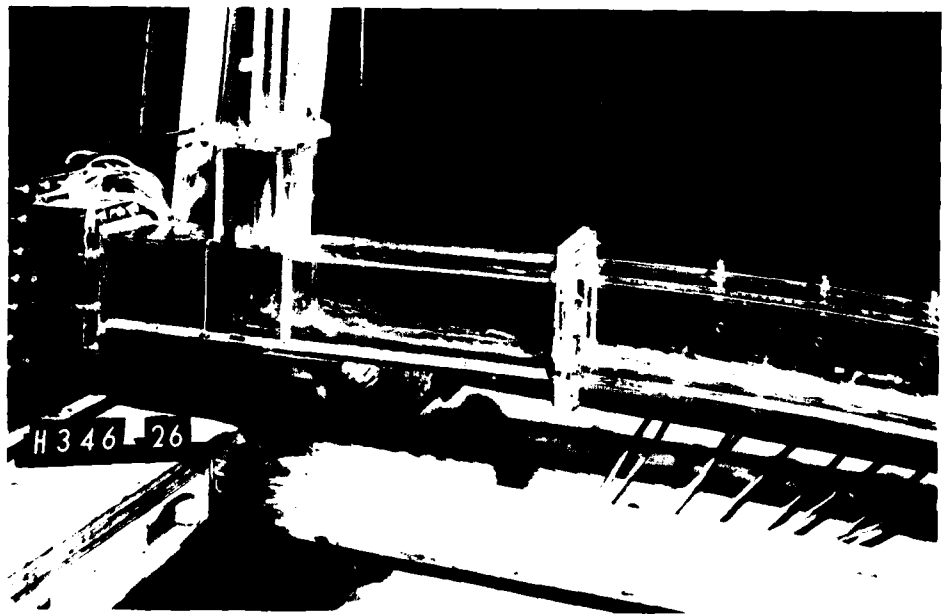


Photo 4. Type 5 riser design

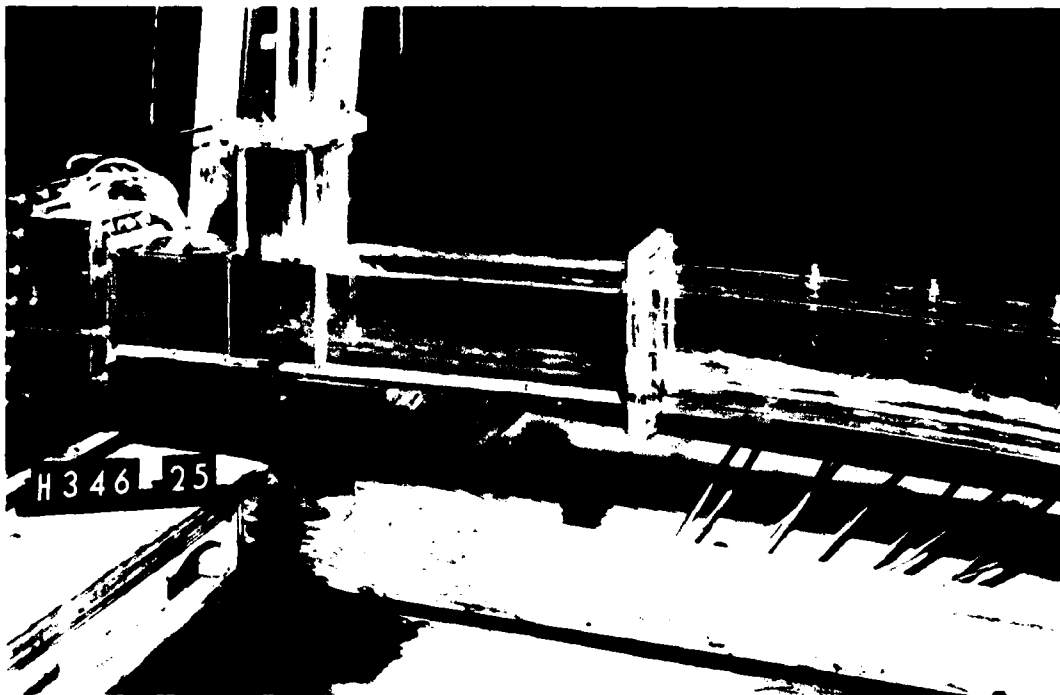


a. Discharge 300 cfs, gate opening 1 ft

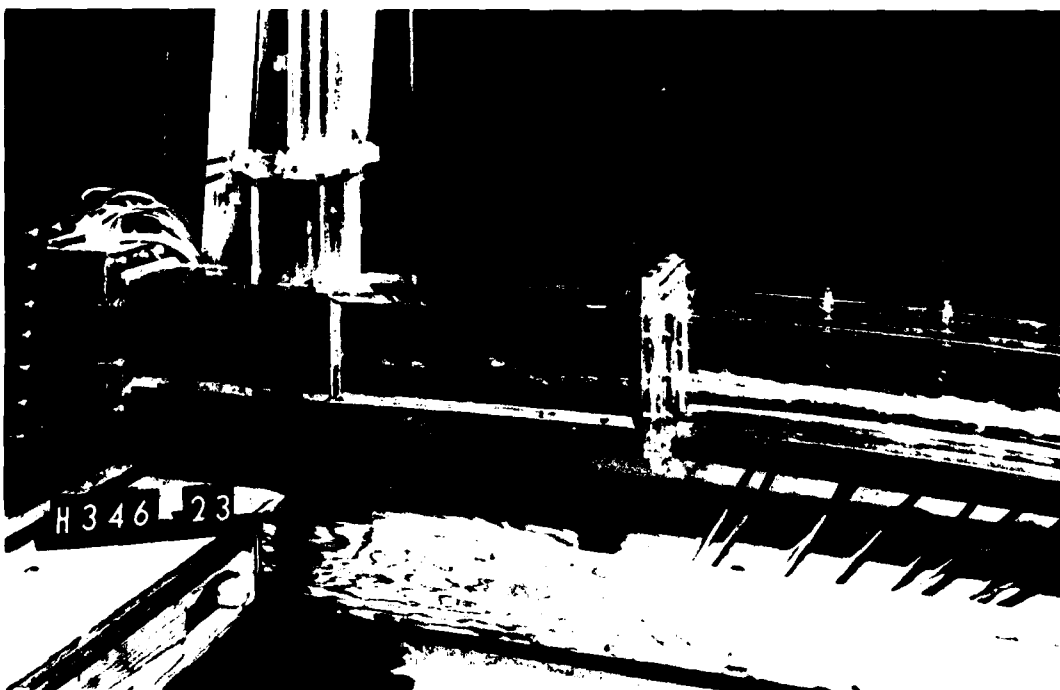


b. Discharge 600 cfs, gate opening 2 ft

Photo 5. Side view of flow conditions in sluice with type 5 riser design and a head pool el 925 (Sheet 1 of 3)

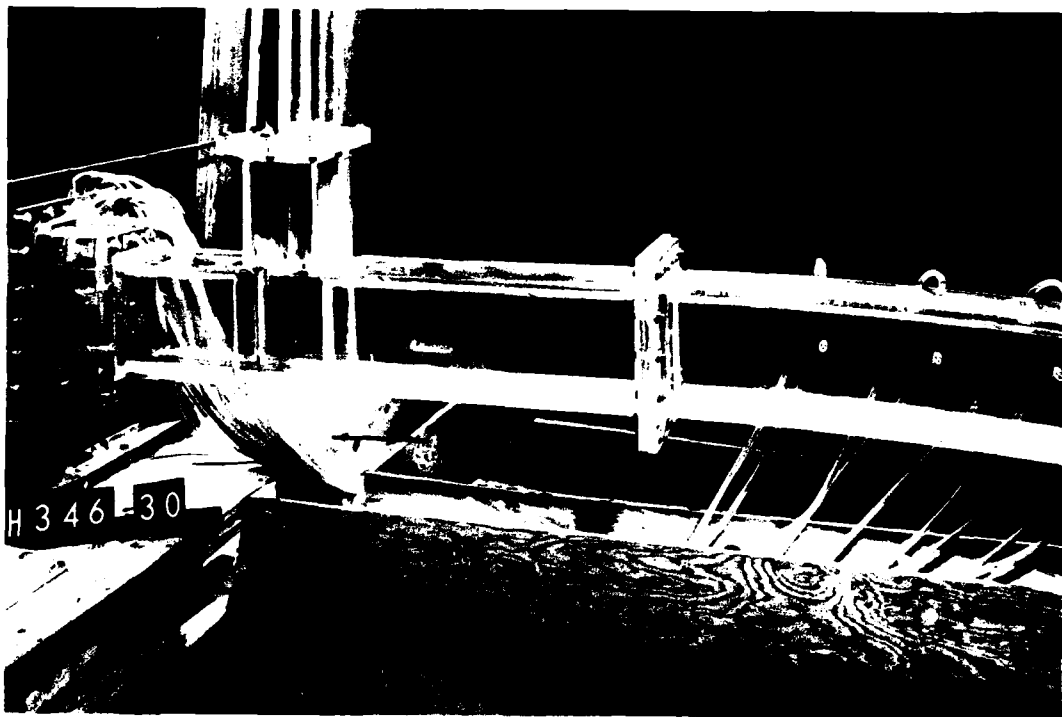


c. Discharge 900 cfs, gate opening 3 ft



d. Discharge 1,200 cfs, gate opening 4 ft

Photo 5. (Sheet 2 of 3)



e. Discharge 3,500 cfs, gate opening 10 ft (full gate opening)

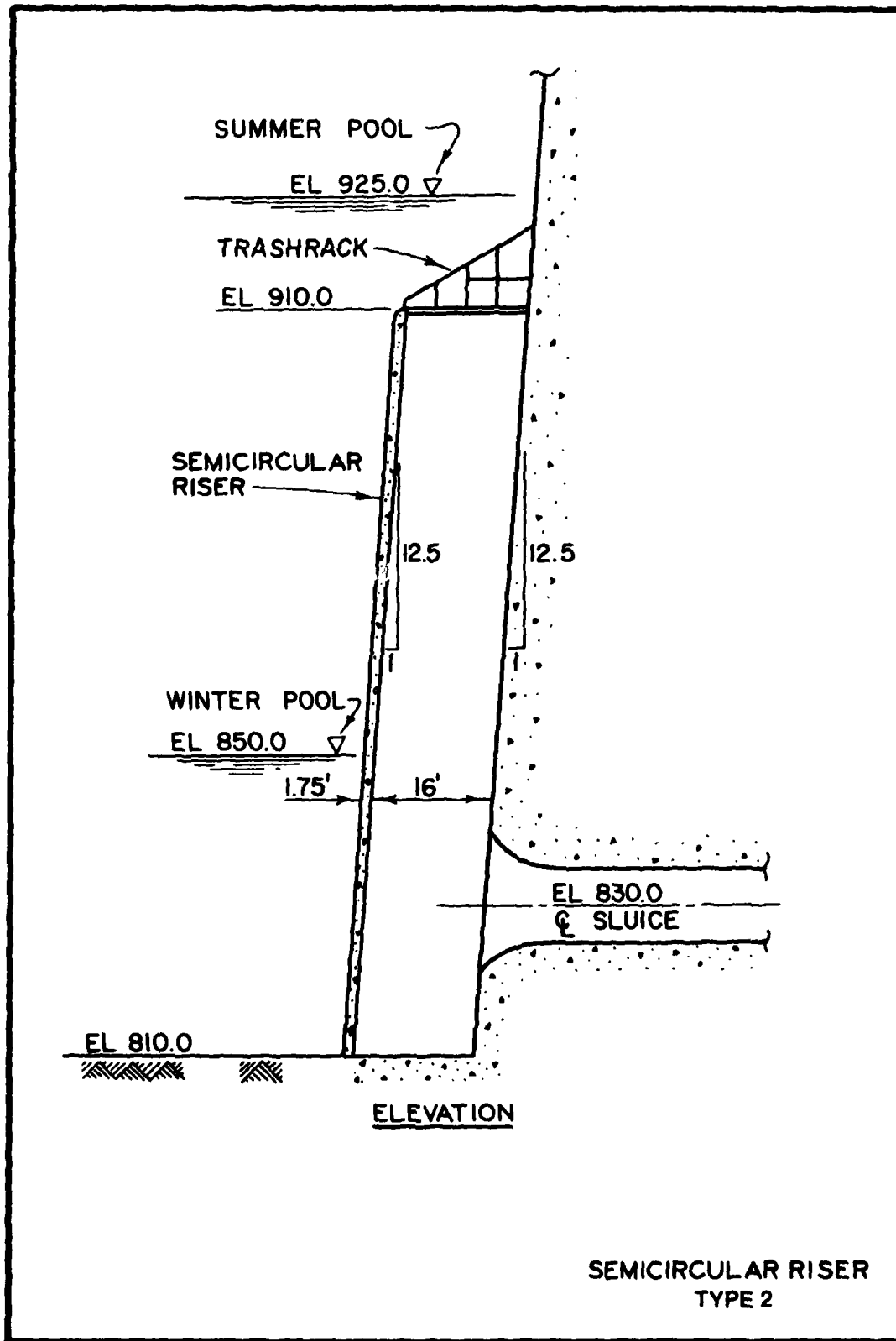
Photo 5. (Sheet 3 of 3)

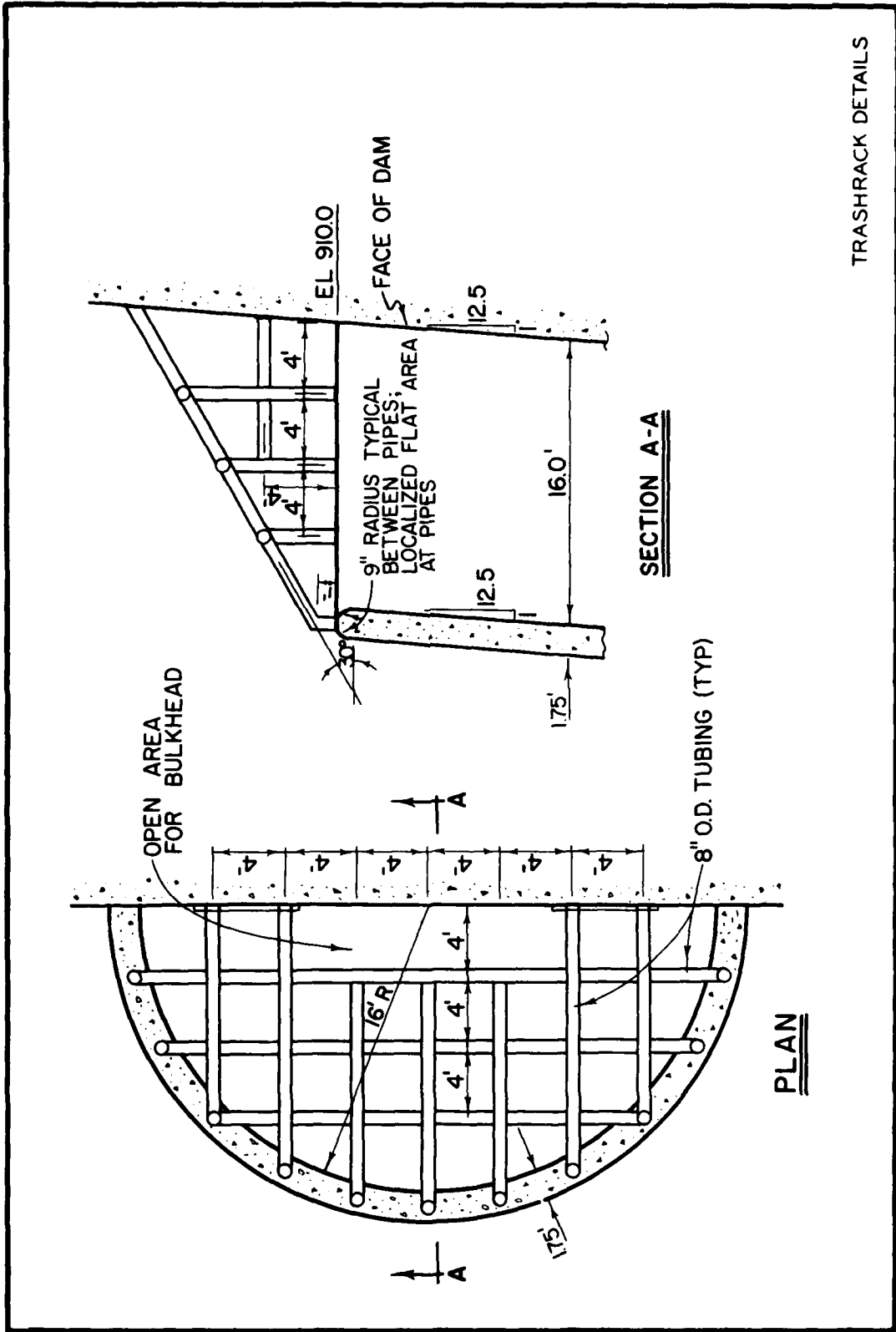
COORDINATES FOR SLUICE ENTRANCE

EQUATION

SECTION B

NO.	ELEVATION	TABLE NO.	SECTION B
1	0.00	333	0.00
2	1.00	337	1.00
3	2.00	341	2.00
4	3.00	345	3.00
5	4.00	349	4.00
6	5.00	353	5.00
7	6.00	357	6.00
8	7.00	361	7.00
9	8.00	365	8.00
10	9.00	369	9.00
11	10.00	373	10.00
12	11.00	377	11.00
13	12.00	381	12.00
14	13.00	385	13.00
15	14.00	389	14.00
16	15.00	393	15.00
17	16.00	397	16.00
18	17.00	401	17.00
19	18.00	405	18.00
20	19.00	409	19.00
21	20.00	413	20.00
22	21.00	417	21.00
23	22.00	421	22.00
24	23.00	425	23.00
25	24.00	429	24.00
26	25.00	433	25.00
27	26.00	437	26.00
28	27.00	441	27.00
29	28.00	445	28.00
30	29.00	449	29.00
31	30.00	453	30.00
32	31.00	457	31.00
33	32.00	461	32.00
34	33.00	465	33.00
35	34.00	469	34.00
36	35.00	473	35.00
37	36.00	477	36.00
38	37.00	481	37.00
39	38.00	485	38.00
40	39.00	489	39.00
41	40.00	493	40.00
42	41.00	497	41.00
43	42.00	501	42.00
44	43.00	505	43.00
45	44.00	509	44.00
46	45.00	513	45.00
47	46.00	517	46.00
48	47.00	521	47.00
49	48.00	525	48.00
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53	52.00	541	52.00
54	53.00	545	53.00
55	54.00	549	54.00
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63	62.00	581	62.00
64	63.00	585	63.00
65	64.00	589	64.00
66	65.00	593	65.00
67	66.00	597	66.00
68	67.00	601	67.00
69	68.00	605	68.00
70	69.00	609	69.00
71	70.00	613	70.00
72	71.00	617	71.00
73	72.00	621	72.00
74	73.00	625	73.00
75	74.00	629	74.00
76	75.00	633	75.00
77	76.00	637	76.00
78	77.00	641	77.00
79	78.00	645	78.00
80	79.00	649	79.00
81	80.00	653	80.00
82	81.00	657	81.00
83	82.00	661	82.00
84	83.00	665	83.00
85	84.00	669	84.00
86	85.00	673	85.00
87	86.00	677	86.00
88	87.00	681	87.00
89	88.00	685	88.00
90	89.00	689	89.00
91	90.00	693	90.00
92	91.00	697	91.00
93	92.00	701	92.00
94	93.00	705	93.00
95	94.00	709	94.00
96	95.00	713	95.00
97	96.00	717	96.00
98	97.00	721	97.00
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100	99.00	729	99.00
101	100.00	733	100.00
102	101.00	737	101.00
103	102.00	741	102.00
104	103.00	745	103.00
105	104.00	749	104.00
106	105.00	753	105.00
107	106.00	757	106.00
108	107.00	761	107.00
109	108.00	765	108.00
110	109.00	769	109.00
111	110.00	773	110.00
112	111.00	777	111.00
113	112.00	781	112.00
114	113.00	785	113.00
115	114.00	789	114.00
116	115.00	793	115.00
117	116.00	797	116.00
118	117.00	801	117.00
119	118.00	805	118.00
120	119.00	809	119.00
121	120.00	813	120.00
122	121.00	817	121.00
123	122.00	821	122.00
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127	126.00	837	126.00
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131	130.00	853	130.00
132	131.00	857	131.00
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134	133.00	865	133.00
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137	136.00	877	136.00
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140	139.00	889	139.00
141	140.00	893	140.00
142	141.00	897	141.00
143	142.00	901	142.00
144	143.00	905	143.00
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148	147.00	921	147.00
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156	155.00	953	155.00
157	156.00	957	156.00
158	157.00	961	157.00
159	158.00	965	158.00
160	159.00	969	159.00
161	160.00	973	160.00
162	161.00	977	161.00
163	162.00	981	162.00
164	163.00	985	163.00
165	164.00	989	164.00
166	165.00	993	165.00
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187	186.00	1077	186.00
188	187.00	1081	187.00
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190	189.00	1089	189.00
191	190.00	1093	190.00
192	191.00	1097	191.00
193	192.00	1101	192.00
194	193.00	1105	193.00
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202	201.00	1137	201.00
203	202.00	1141	202.00
204	203.00	1145	203.00
205	204.00	1149	204.00
206	205.00	1153	205.00
207	206.00	1157	206.00
208	207.00	1161	207.00
209	208.00	1165	208.00
210	209.00	1169	209.00
211	210.00	1173	210.00
212	211.00	1177	211.00
213	212.00	1181	212.00
214	213.00	1185	213.00
215	214.00	1189	214.00
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217	216.00	1197	216.00
218	217.00	1201	217.00
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220	219.00	1209	219.00
221	220.00	1213	220.00
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230	229.00	1249	229.00
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245	244.00	1309	244.00
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247	246.00	1317	246.00
248	247.00	1321	247.00
249	248.00	1325	248.00
250	249.00	1329	249.00
251	250.00	1333	250.00
252	251.00	1337	251.00
253	252.00	1341	252.00
254	253.00	1345	253.00
255	254.00	1349	254.00
256	255.00	1353	255.00
257	256.00	1357	256.00
258	257.00	1361	257.00
259	258.00	1365	258.00
260	259.00	1369	259.00
261	260.00	1373	260.00
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263	262.00	1381	262.00
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267	266.00	1397	266.00
268	267.00	1401	267.00
269	268.00	1405	268.00
270	269.00	1409	269.00
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272	271.00	1417	271.00
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275	274.00	1429	274.00
276	275.00	1433	275.00
277	276.00	1437	276.00
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279	278.00	1445	278.00
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281	280.00	1453	280.00
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283	282.00	1461	282.00
284	283.00	1465	283.00
285	284.00	1469	284.00
286	285.00	1473	285.00
287	286.00	1477	286.00
288	287.00	1481	287.00
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TRASHRACK DETAILS

PLAN

SECTION A-A

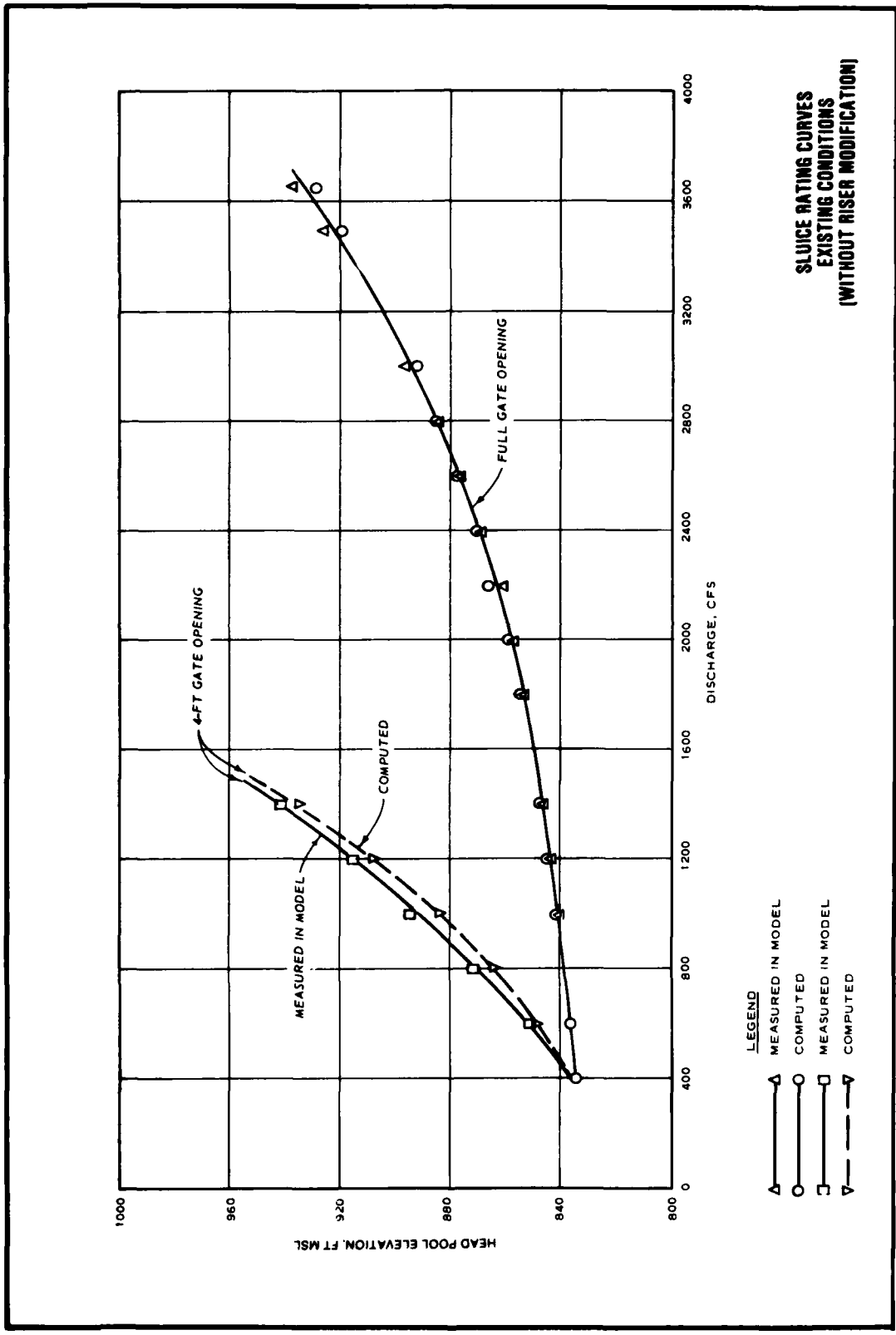
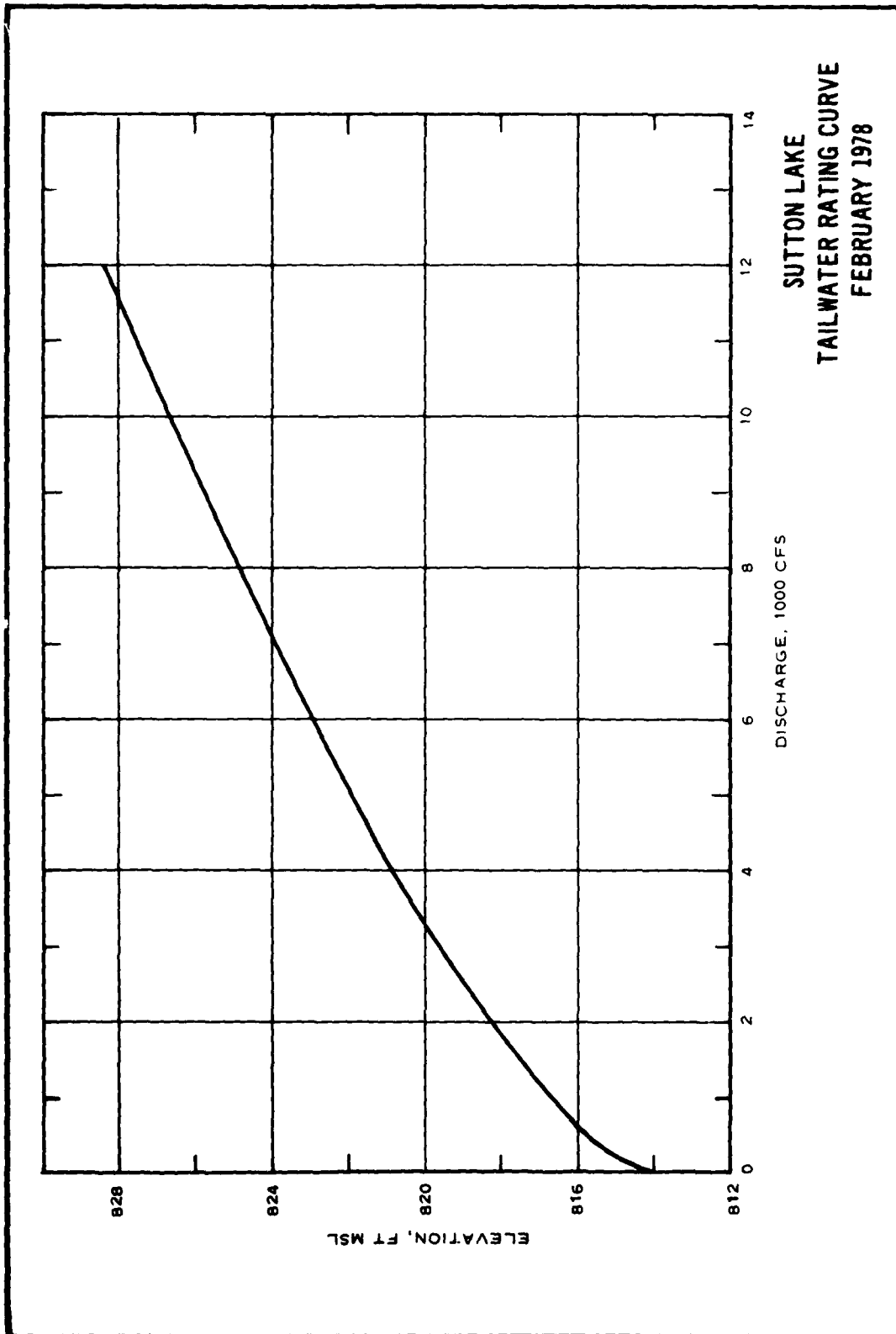


PLATE 4



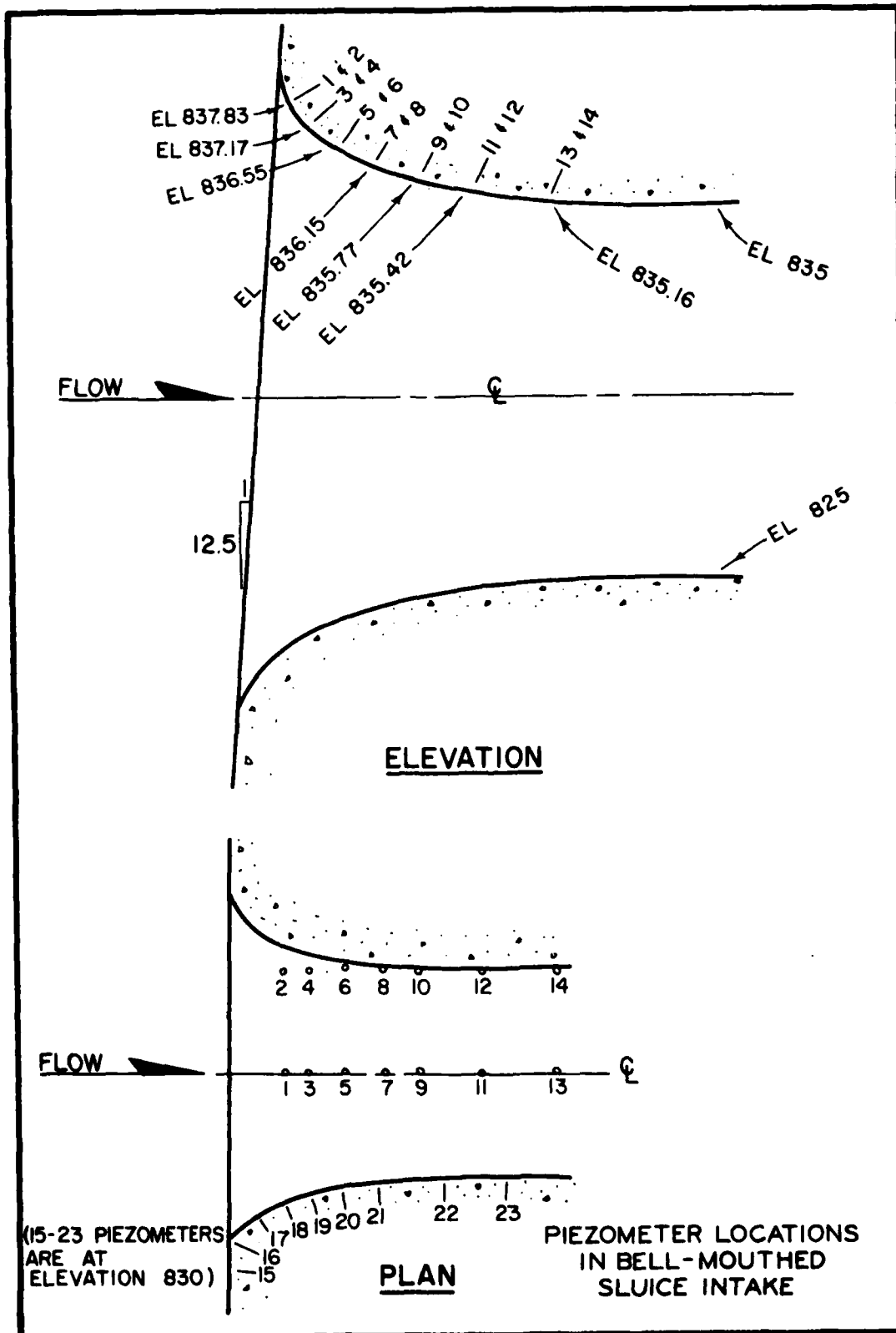
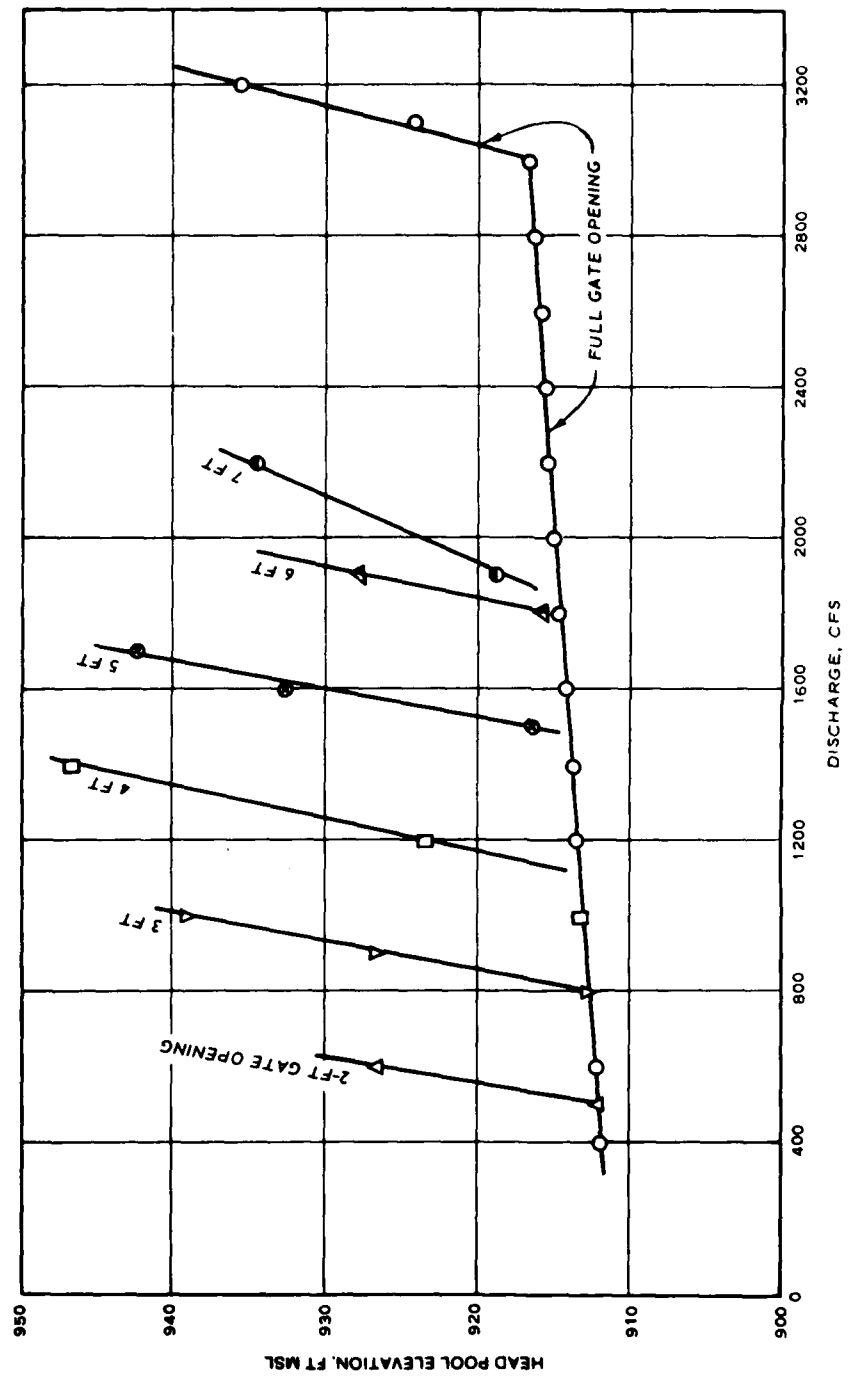


PLATE 6

SLUICE RATING CURVES
TYPE 2



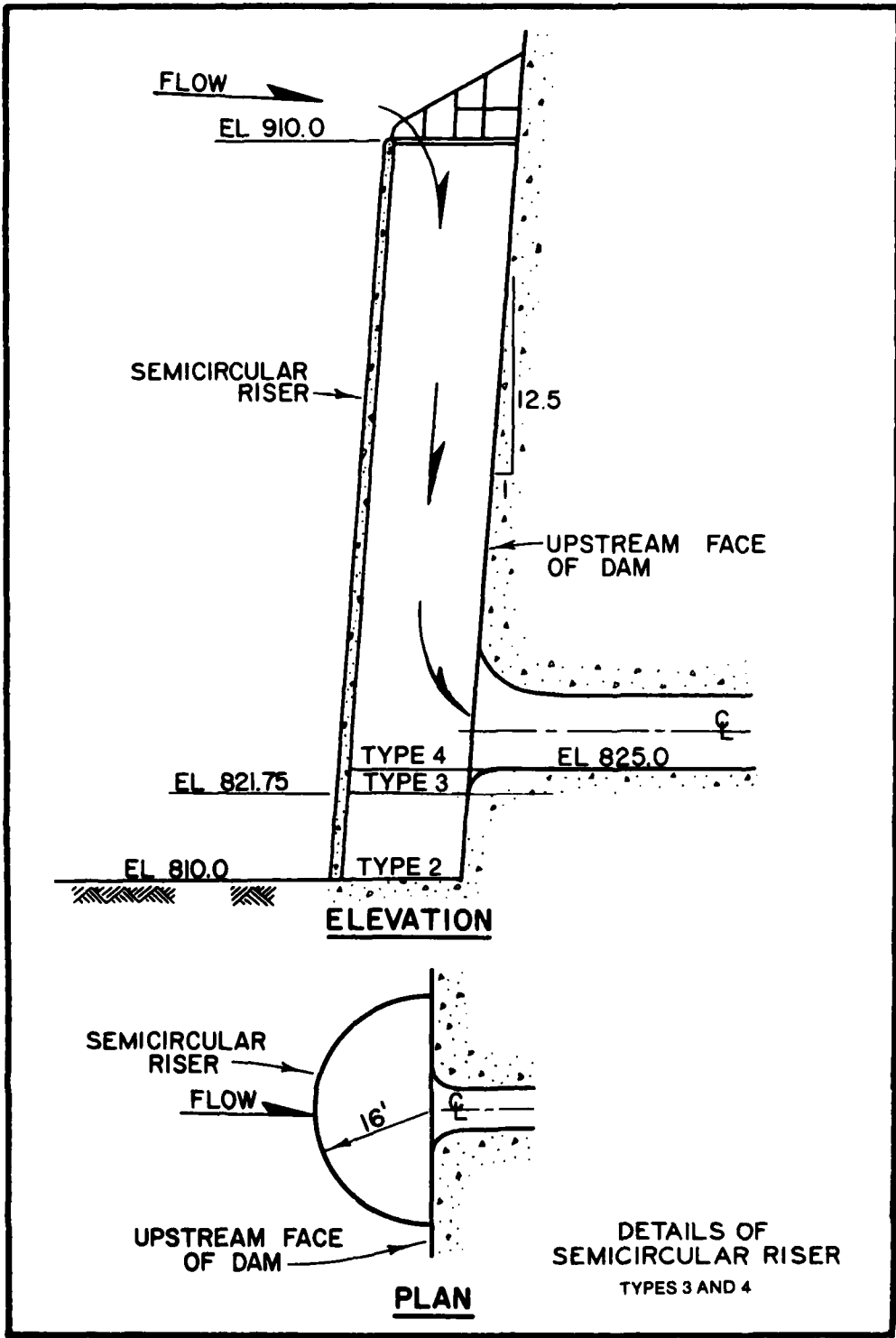
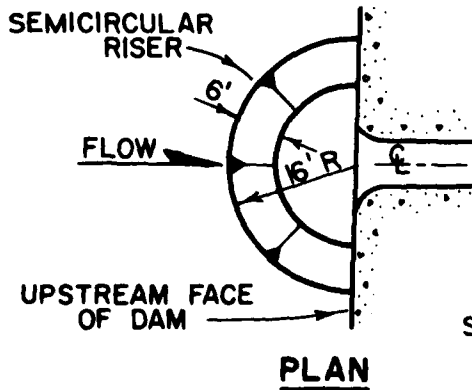
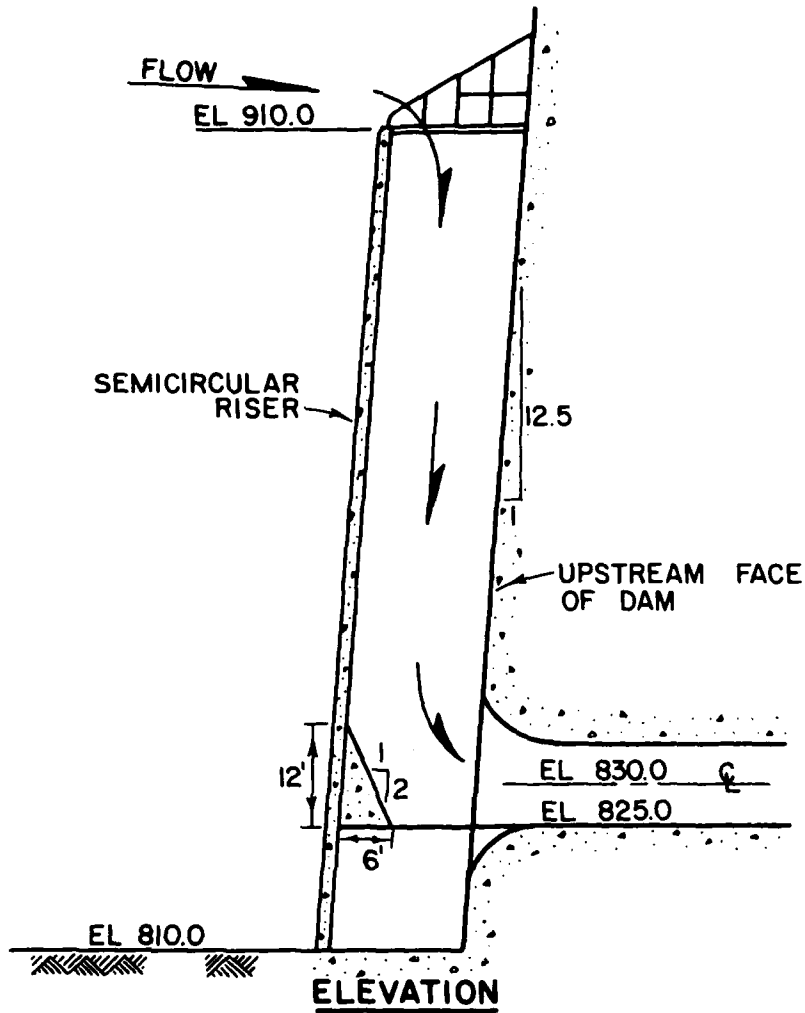


PLATE 8



DETAILS OF
 RECOMMENDED
 SEMICIRCULAR RISER
 TYPE 5

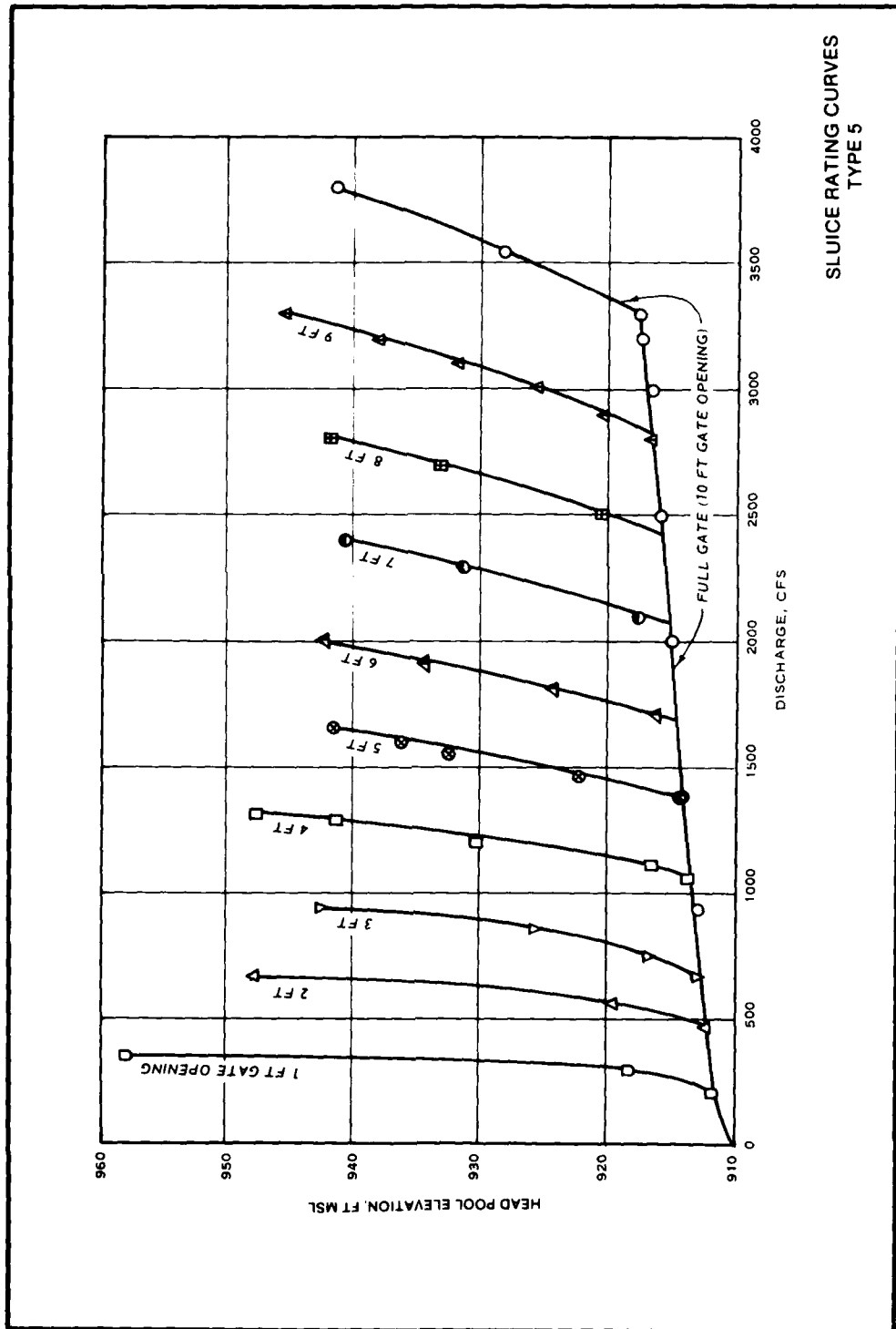
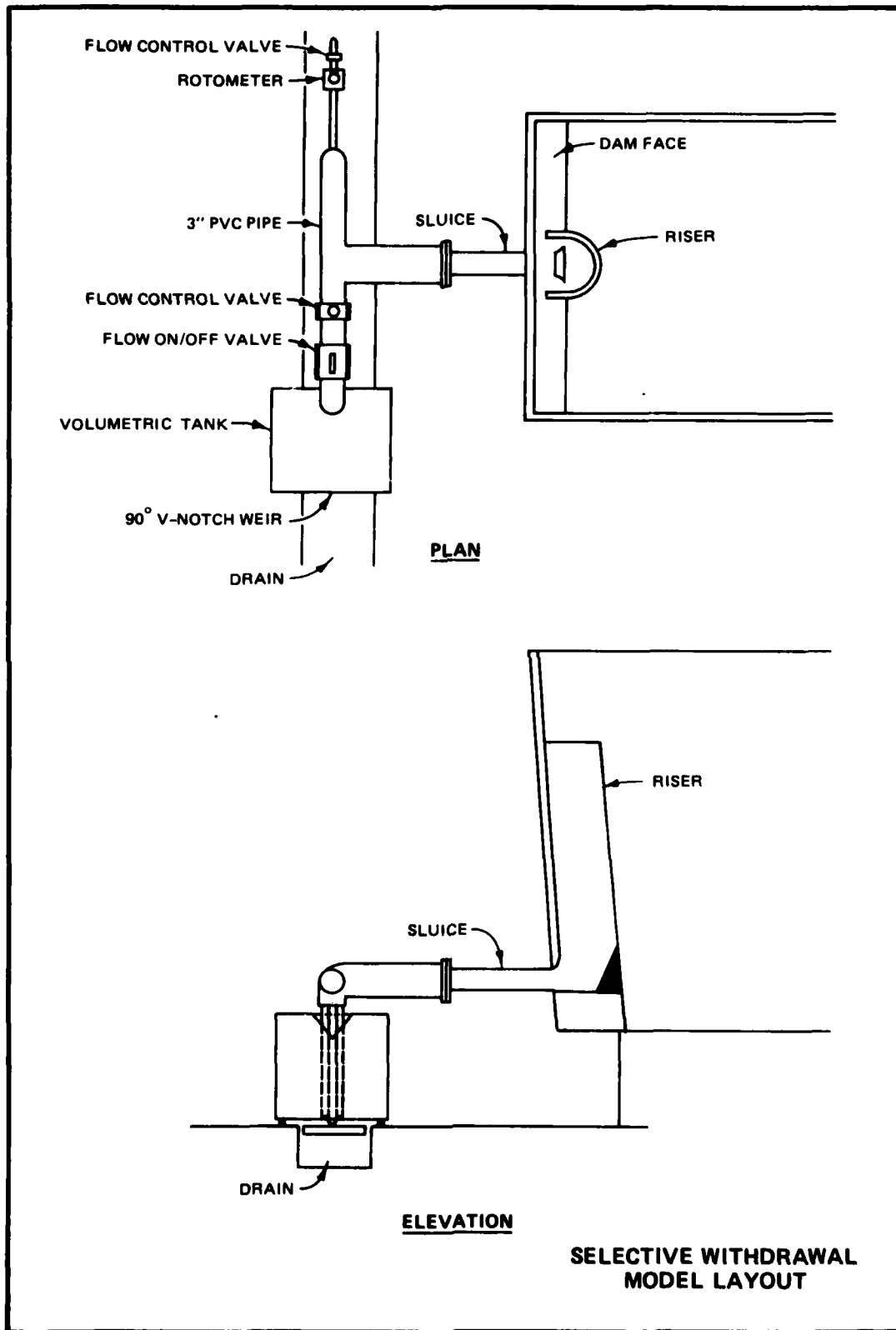
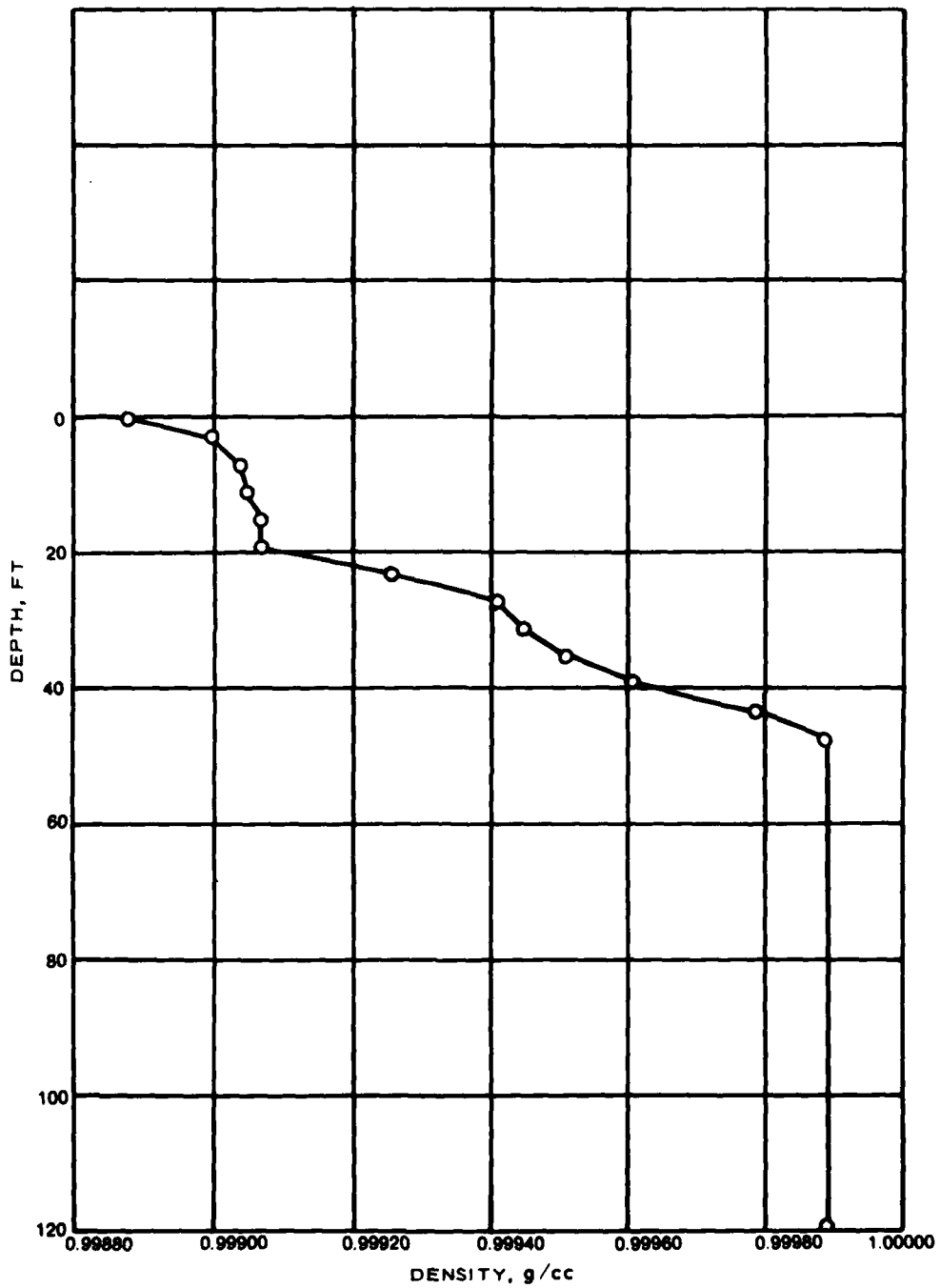
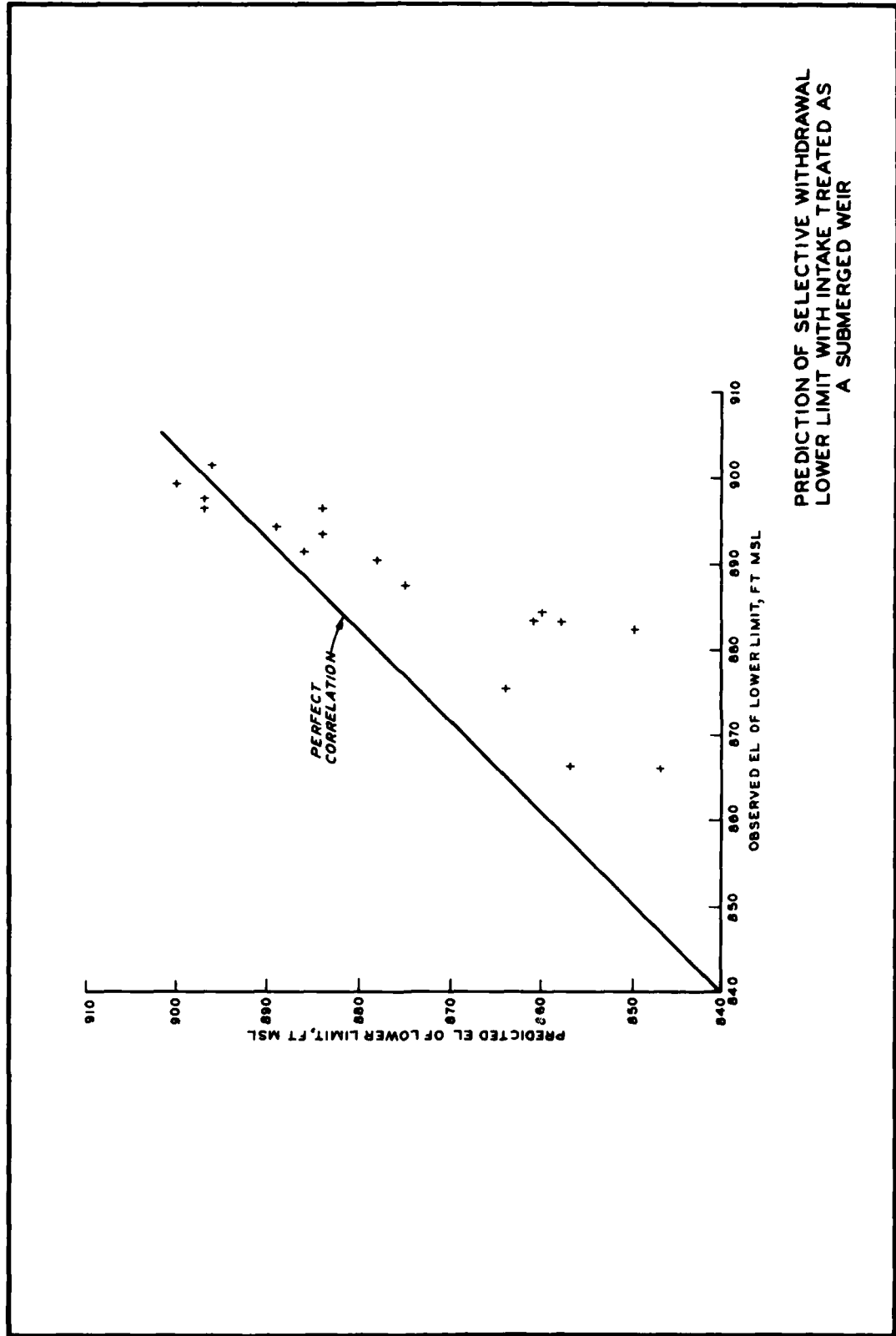


PLATE 10





EXAMPLE DENSITY/
PROFILE



PREDICTION OF SELECTIVE WITHDRAWAL
 LOWER LIMIT WITH INTAKE TREATED AS
 A SUBMERGED WEIR

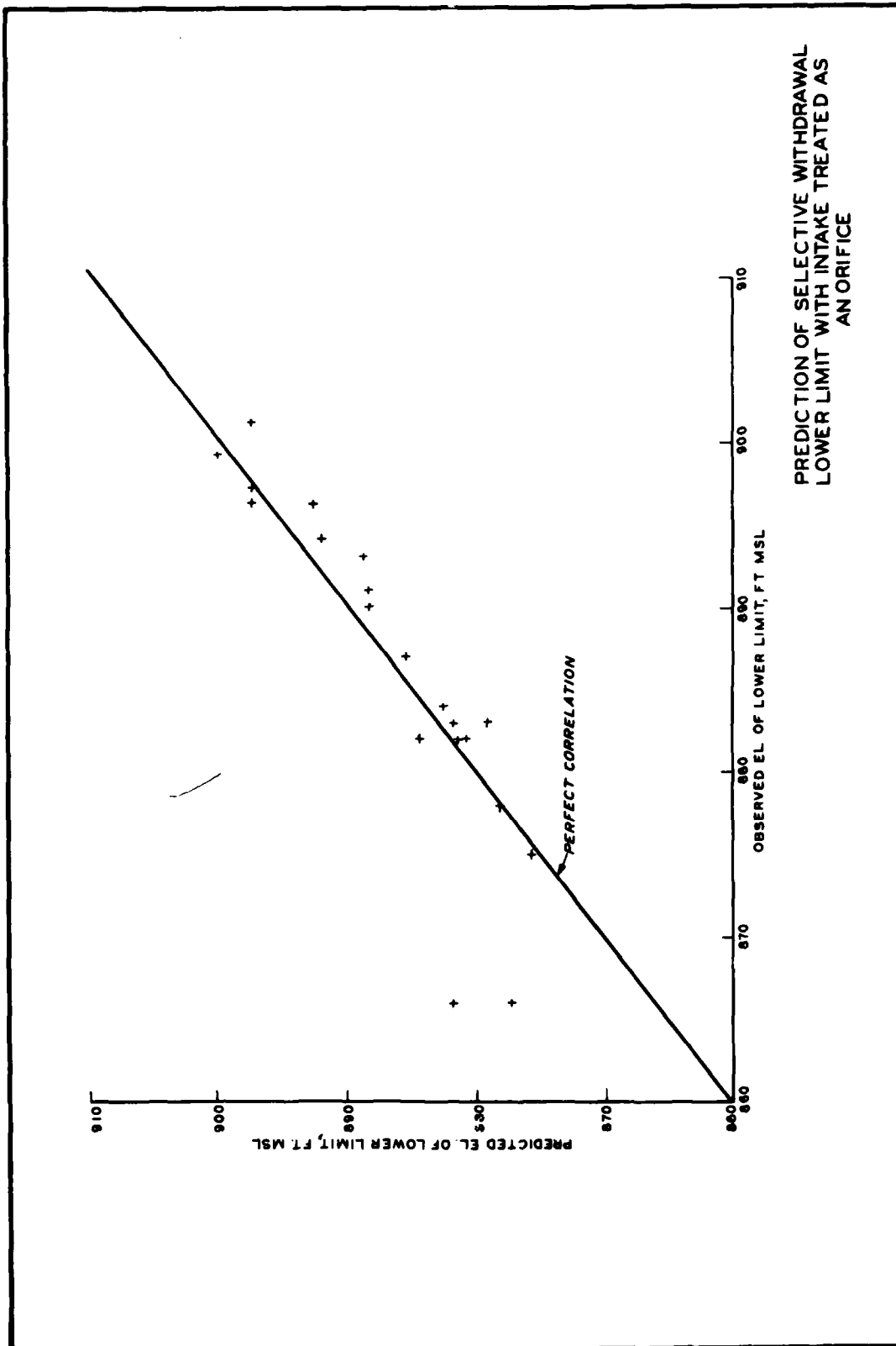
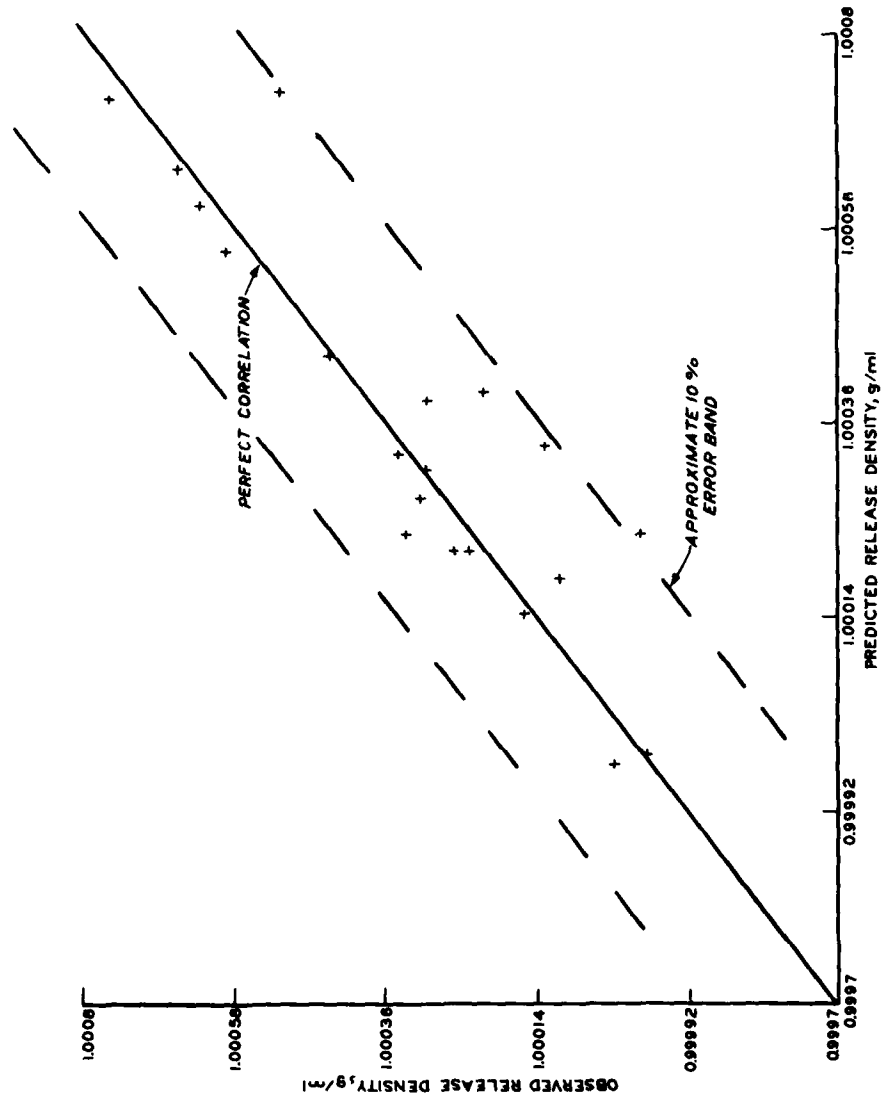


PLATE 14



PREDICTED VS OBSERVED AVERAGE
RELEASE DENSITY

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

George, John F

Selective withdrawal riser for Sutton Dam, West Virginia; hydraulic model investigation / by John F. George, Mark S. Dortch, Charles H. Tate, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.

17, [9] p., [8] leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-80-4)

Prepared for U. S. Army Engineer District, Huntington, Huntington, West Virginia.

1. Hydraulic models. 2. Risers. 3. Selective withdrawal. 4. Sutton Dam. I. Dortch, Mark S., joint author. II. Tate, Charles H., joint author. III. United States Army Corps of Engineers. Huntington District. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-80-4.
TA7.W34 no.HL-80-4