UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PROGRESS REPORT VII--RESEARCH STUDY ON STILLING BASINS, ENERGY DISSIPATORS, AND ASSOCIATED APPURTENANCES--SECTION 13 STILLING BASINS FOR HIGH HEAD OUTLET WORKS WITH SLIDE-GATE CONTROL (PRELIMINARY STUDIES)

Report No. Hyd-544

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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FOREWORD

Progress Report VII includes Section 13, Stilling Basins for High Head Outlet Works with Slide-gate Control, in the continuing study of stilling basins, energy dissipators, and associated appurtenances. Contents of the first six progress reports are listed below, and also a guide to the completed sections of the study. Sections 1 through 11 have been published in a revised edition of Engineering Monograph No. 25.

Progress Report I--Report No. Hyd-380--Research Study on Stilling Basins, Energy Dissipators, and Associated Appurtenances.

Progress Report II--Report No. Hyd-399--Supersedes Progress Report I.

Progress Report III--Report No. Hyd-415--Section 7, Slotted and Solid Buckets for High, Medium, and Low Dam Spillways (Basin VII).

Progress Report IV--Report No. Hyd-446--Section 8, Stilling Basin for High Head Outlet Works Utilizing Hollow-jet Valve Control (Basin VIII).

Progress Report V--Report No. Hyd-445--Section 9, Baffled Apron on 2:1 Slope for Canal or Spillway Drops (Basin IX).

Progress Report VI--Report No. Hyd-514--Section 12, Stilling Basin Chute Block Pressures (Basin II).

Section 1--General Investigation of the Hydraulic Jump on a Horizontal Apron (Basin I)

Section 2--Stilling Basin for High Dam and Earth Dam Spillways and Large Canal Structures (Basin II)

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ABSTRACT

The purpose of these studies was to develop an efficient, economical stilling basin for use with slide gate control for high-head outlet works. Design curves were developed for a rectangular plunge basin to determine basin depth and length, height of the gate above the basin floor, and magnitude of impact heads on the basin floor. Comparisons were made with corresponding basins of the hydraulic jump type designed according to Engineering Monograph 25. Tentative design curves were obtained for the hydraulic jump basin based on data derived from general model studies of four particular stilling basins. Recommendations for continuing work in this study are presented.

DESCRIPTORS-- *slide gates/ *outlet works/ *stilling basins/ *hydraulic jumps/ *model tests/ hydraulic models/ research and development/ design criteria/ hydraulic structures/ high pressure gates/ closed conduits/ control structures/ Froude number/ jets/ turbulent flow/ pressure measuring equip/ piezometers/ water pressures/ appurtenances/ vibrations
IDENTIFIERS-- plunge basin/ impact head/ jump basins/ dividing walls/ jet spreading/ impact pressure

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PROGRESS REPORT VII--RESEARCH STUDY ON STILLING BASINS, ENERGY DISSIPATORS, AND ASSOCIATED APPURTENANCES--SECTION 13, STILLING BASINS FOR HIGH HEAD OUTLET WORKS WITH SLIDE-GATE CONTROL (PRELIMINARY STUDIES)

PURPOSE

The purpose of these studies was to develop an efficient, economical hydraulic jump stilling basin or, where practicable, a simple plunge-type energy dissipating pool.

CONCLUSIONS

1. The plunge basin indicates an advantage over the hydraulic jump basin in the necessary length to contain the hydraulic jump. Approximately the same tailwater depth is necessary to keep the jump from sweeping from either type of basin. Data are presented in Figures 12, 13, and 14.

2. Dividing walls are necessary for satisfactory operation of a plunge basin when more than one outlet gate discharges into the same basin. Baffle piers and chute blocks were not considered, in order to maintain simplicity of design.

3. The studies indicated that impact forces on the floor of the plunge pool may be a controlling factor in the design. An increase in tailwater depth might be necessary to relieve scour or prevent excessive loading of the concrete floor in a lined pool. Curves for the determination of the magnitude of these forces are included in Figure 15.

4. Qualitative measurements of the vibration characteristics of the plunge basin were inconclusive. Similar measurements will be made in future tests on hydraulic jump basins to properly evaluate the findings and a correlation with pressure data will be made.

5. Data on the configuration of the jump obtained for four hydraulic jump basins, Figure 4, during project model studies of these basins,

were analyzed. Tentative design curves were obtained, Figures 5, 6, 7, and 8, but should be verified by generalization tests in a glass-sided flume.

6. Future work should include (in addition to the proposals listed in the preceding paragraphs) determination of pressures on the training walls for both basin types, determination of optimum basin width, a study of the hydraulic characteristics of plunge basins with other than rectangular shapes, and refinement of the design curves for both basin types. Data presented in this report are preliminary. Final designs based on the data should be verified by hydraulic model studies of the particular installation being designed.

ACKNOWLEDGMENT

These studies are being conducted in the hydraulic laboratory of the Bureau of Reclamation in Denver, Colorado. Much of the early work is credited to T. J. Rhone, Supervising Hydraulic Engineer, T. M. Kopp, an Australian engineer formerly in training in the Hydraulics Branch, and D. K. Gill, who at that time was a rotation engineer in the laboratory.

INTRODUCTION

The slide gate was developed as a relatively inexpensive device for controlling high-head outlet works discharges. Studies of a stilling basin for slide gate controlled outlets were initiated to obtain information on spreading characteristics of efflux jets on sloping aprons or vertically curved chutes which discharge into hydraulic jump stilling basins. These tests led to the idea to develop a simple plunge-type stilling pool.

Although this report is slanted toward development of a plunge-type stilling basin, it also contains data concerned with the design of the conventional hydraulic jump basin.

A discussion of the initial tests of the hydraulic jump stilling basin appears first, followed by a treatment of the plunge basin.

THE HYDRAULIC JUMP STILLING BASIN

The tests of the hydraulic jump stilling basin will be considered a separate study. The initial work was prompted by the request for development of criteria for use in the design of stilling basins for slide gate controlled outlet works.

The Model

The first model, Figure 1, consisted of twin Palisades-type slide gates mounted on a 2:1 slope (26° - 34' below horizontal) and discharging onto a floor with the same slope. The basin consisted of a 32-3/8-inch-wide glass-walled flume to facilitate observation of the hydraulic jump. The flume width was based on an estimated spreading angle of 8° on each side of the jet in a distance of 38.9 inches and allowance for a 1-inch-thick center dividing wall. Water was supplied to the model through a recirculating system by a centrifugal pump, and discharges were measured with volumetrically calibrated Venturi meters. Tailwater depths were set with an adjustable tailgate at the downstream end of the model.

The Investigation

Jet spreading characteristics.--Initial tests of the stilling basin were concerned primarily with the spreading charactertistics of the jets on the sloping apron. The purpose of these tests was to determine the configuration of diverging walls that would guide the jet smoothly into the stilling basin. The spreading characteristics of the efflux from one gate were measured for gate openings of 25 and 50 percent with varying heads and discharges. Figure 2 shows the outer boundaries of the jet on the sloping apron, and Figure 3 shows the cross-sectional shape of the jet at various stations. These data clearly indicate that if wall divergence and basin width are designed for one gate opening, they may not be suitable for a different gate opening. For specific ranges of low heads and relatively large gate openings, the flow spreads quite rapidly upon leaving the gate. For high heads and relatively small gate openings, the jet tends to remain concentrated. This condition was also observed in model studies of Norton Dam Outlet Works.1/ At this point in the model study it was apparent that departure from the conventional design of a hydraulic jump stilling basin would be advantageous and that a more practical approach to the problem would be to develop a design for a plunge-pool-type stilling basin.

Data from project model studies of hydraulic jump stilling basins.--During the course of model studies of hydraulic jump stilling basins for several slide gate controlled outlet works, general data were obtained to aid in future designs of basins of this type. The structures studied were Bully Creek Dam Outlet Works, Bully Creek Dam Canal Outlet Works, Causey Dam Outlet Works, and Norton Dam Outlet Works. These studies are described in Hydraulics Branch Reports Hyd-494, -495, -496, and -497, respectively. The basin configurations are shown in Figure 4.

1/"Hydraulic Model Studies of Norton Dam Outlet Works," by D. L. King, Report No. Hyd-497, October 1963.

The dimensions of the hydraulic jump were measured for heads and discharges within and beyond the range of normal operation. The data in Figures 5 through 8 do not provide a sufficient basis for generalization and should be used with discretion. The general model studies, from which the data were obtained, did not facilitate adequate observation of the hydraulic jump. More precise design data will be developed by tests in a glass-sided flume.

All curves are based on 100 percent gate opening. The Froude number, F (at the toe of the jump), is equal to the term $\frac{V}{\sqrt{gd_1}}$. V is the computed velocity through the gate and d_1 is the flow depth obtained by assuming uniform flow distribution and by using the gate flow velocity at the bottom of the chute, assuming no losses. D_2, D_s, and L are the optimum tailwater depth, sweepout tailwater depth, and jump length, respectively. W is the designed width of the stilling basin in each case. Optimum tailwater depth is defined as the lowest depth at which the hydraulic jump appears to be stable and free from excessive surging and splashing. After determination of the sweepout depth, the tailwater was raised slowly until the optimum condition was exhibited.

Figure 5 shows that the data for Bully Creek Outlet Works for optimum tailwater depth lie considerably below those for the other three studies. This basin was designed to operate with tailwater depths less than optimum for the maximum discharge, because operation at maximum discharge is only remotely possible. The Bully Creek Outlet Works curve should not be used in designing a basin. Figure 8 also reflects this conclusions.

Example Application

Gate dimensions: 3 feet square
Design discharge for 100 percent gate opening: 400 cubic feet per second
Assumed basin width: 10 feet
Gate area, A = 9 square feet

$$V = \frac{Q}{A} = \frac{400}{9} = 44.4 \text{ feet per second}$$

At entrance to stilling basin, $d_1 = \frac{A}{W} = \frac{9}{10} = 0.9$ feet.

$$F = \frac{V}{\sqrt{gd_1}} = 8.25$$

From Figure 5, $\frac{D_2}{d_1} = 12.75$, $D_2 = 12.75\ (0.9) = 11.5$ feet.

From Figure 6, $\frac{D_s}{d_1} = 10.1$, $D_s = (10.1)\ (0.9) = 9.1$ feet.

Thus, the safety margin against sweepout is 2.4 feet. If additional safety margin is required, the tailwater depth may be increased.

From Figure 7, $\frac{L}{D_2} = 4.05$, $L = 4.05 (11.5) = 46.6$ feet.

From Figure 8, $\frac{W}{D_2} = 0.91$, $W = 0.91 (11.5) = 10.5$ feet.

D_2 is the depth determined from Figure 5.

Using the new basin width, $d_1 = \frac{9}{10.5} = 0.86$ and $F = 8.44$.

Recaluation on basis of new Froude number will not greatly alter the basin dimensions. Thus, a basin 10.5 feet wide and 47 feet long with a tailwater depth of 9 feet is required.

THE PLUNGE BASIN

The Model

The sloping apron was removed from the glass-sided flume, leaving a rectangular box as the stilling basin. Piezometers were installed in the floor of the model to determine the magnitude of pressures due to impact of the jets. Other features of the model remained the same as previously described.

The Investigation

Basin performance with and without appurtenances. --In general, the plunge basin operation was very similar to that observed with the conventional hydraulic jump basin. The toe of the jump appeared to be more stable against sweepout because flow circulated behind the jets. Upon striking the floor, the jets traveled downstream along the floor and turned upward, as in flow from a sloping apron in a conventional jump basin. A turbulent boil appeared on the surface at approximately the same location at which the jets turned upward from the floor. The surface turbulence rapidly decreased downstream from the turbulent boil and surface flow conditions were relatively calm except for occasional surges. There was no turbulence along the basin floor downstream from where the jets turned upward.

Dimensions of the hydraulic jump, or turbulent zone, were measured to determine if appurtenances such as a center dividing wall or a short sloping apron downstream from the gates would improve the performance. Both minimum tailwater depth and jump length were found to be unaffected by the addition of a 3-foot-long center dividing wall, Figures 9 and 10. Figure 10 indicates a trend toward a reduction in the jump length without the dividing wall at larger gate openings; however, the limited data do not warrant this conclusion.

The minimum tailwater depth was also apparently unchanged by addition of a short sloping apron immediately downstream from the gates (with the center dividing wall in place), Figure 11. However, the apron caused the flow to spread rapidly and climb the walls of the stilling basin, resulting in excessive splashing. The use of a sloping apron was therefore abandoned for this particular basin width. However, operation with the apron might be satisfactory in a wider basin. Use of a short apron of this type would reduce excavation under and immediately downstream from the gate and reduce the height of the walls at the upstream end of the basin. This appurtenance will be investigated further in future tests in a variable width flume.

A dividing wall is recommended for inclusion in the design of a plunge basin with more than one gate to improve stilling basin performance during single-gate operation and to eliminate the possibility of resonant transverse surging. The length of the wall should be one-half to three-fourths of the basin length, as determined in the hollow-jet valve basin studies.[2] The designer might also wish to include an end sill to reduce the possibility of stream bed material moving upstream into the basin. This appurtenance was not investigated and its use should be contingent upon a hydraulic model study of the particular installation being designed.

Design data.--Data were taken to construct preliminary design curves concerning the configuration of the hydraulic jump in the plunge-type basin. No appurtenances were included. The curves, Figures 12, 13, and 14, contain information on the jump length (L), optimum tailwater depth (D_2), sweepout tailwater depth (D_s), and depth of water under the gate (D') as functions of the Froude number at the gate (F_G). The length of the hydraulic jump was very difficult to measure; thus the data points are scattered. For purposes of this study the projected horizontal jump length was measured from the jet impact point on the floor to the top of the turbulent boil. The basin width remained as described previously for the hydraulic jump basin, jet spreading tests. One-half basin width was about 3.4 times the width of one gate.

The impact of the jets on the basin floor caused a lateral spreading of the jets and excessive splashing along the basin walls. A wider or deeper basin would probably alleviate this condition. A tentative basin

2/Progress Report IV, Section 8, Report Hyd-446, by G. L. Beichley and A. J. Peterka, April 1960.

width of 3.5 times the gate width (7.0 times the gate width plus dividing wall width for a two-gate basin) is recommended for design. These criteria will be finalized in future tests.

Jet impact pressures.--Because of the configuration of the basin, the magnitude of impact pressures occurring on the floor and walls of the basin might be a controlling factor in designing a plunge basin. The primary problem appears to be determination of the allowable value of maximum impact on the basin floor to avoid structural failure or erosion of the concrete lining. If impact pressures are excessive for the given conditions, the tailwater depth should be increased to reduce the magnitude of the impact pressures. As mentioned previously, piezometers were installed in the floor of the stilling basin to determine the magnitude and degree of fluctuation of the pressures due to the impact of the jets.

The pressure distribution on the basin floor was determined for gate openings of 25, 50, 75, and 100 percent and was used to estimate the maximum instantaneous pressure occurring on the floor for various percentages of the ideal tailwater depth. Data were obtained with electronic pressure transducers connected to a direct-writing oscillograph. To determine the reduction in maximum impact with an increase in tailwater, a dimensionless ratio of impact head (H_I) over tailwater depth (TW) was plotted against the ratio of tailwater depth to optimum tailwater depth (D_2), Figure 15. The optimum tailwater was determined from Figure 12. A curve is included for each of three values of the Froude number of the gate flow. Theoretically, the curves approach an H_I/TW value of 1.0, which corresponds to the head due to the tailwater depth alone, with no additional head due to impact. The oscillograph data showed that the maximum impact occurred at a distance downstream from the gate equivalent to between 1.1 and 1.5 times the height of the bottom of the gate frame above the floor, for the particular gate angle tested. The material presented by the curves is intended as a guide for the designer to determine the magnitude of impact pressures to be expected under various operating conditions.

Guide to the use of the data.--To use these data to design a plunge basin, first compute the Froude number of the gate efflux:

$$F_G = \frac{V}{\sqrt{g\ d}}$$

$$V = \frac{Q}{A}$$

Q = discharge through one gate
A = area of gate opening
g = acceleration of gravity
d = gate opening

These computations apply to symmetrical operation of two gates or to one gate operating alone, at full or partial openings, with a center dividing wall included in the basin. The contraction of the jet is not included in determination of the area.

From Figure 12, determine the values of D_2 and D_s (or compute according to the equations of the lines). D_2 = optimum tailwater depth for best jump appearance and energy dissipation; D_s = tailwater depth at which the jump is on the verge of being swept downstream. If $D_2 - D_s$ does not give the desired margin of safety against sweepout, increase the tailwater depth.

L, D', and H_I are determined from Figures 13, 14, and 15, respectively.

The center dividing wall for a two-gate basin, and an end sill, may be added if desired.

<u>Example</u>:

Gate dimension: 3 feet square
Design discharge for 100 percent gate opening: 400 cubic feet per second
A = 9 square feet
d = 3 feet

$$V = \frac{Q}{A} = \frac{400}{9} = 44.4 \text{ feet per second}$$

$$F_G = \frac{V}{\sqrt{g\,d}} = \frac{44.4}{9.8} = 4.53 \text{ (Froude number at the gate)}$$

From Figure 12, for $F_G = 4.5$, $\frac{D_2}{d} = 3.25$, $D_2 = 9.75$ feet; $\frac{D_s}{d} = 2.95$, $D_s = 8.85$ feet. To provide more safety against sweepout, increase D_2 to 12 feet. This revised tailwater depth (TW) gives 3.15 feet safety margin against sweepout.

From Figure 13, $\frac{L}{D_2} = 2.85$, L = 2.85 (9.75) = 27.8. The length is based on the optimum tailwater depth determined from Figure 12, exclusive of the additional tailwater for safety against sweepout.

From Figure 14, $\frac{D'}{TW} = 0.6$, for $F_G = 4.5$ and $\frac{TW}{d} = 4.0$, where TW is the revised tailwater depth. D' = 0.6 (12) = 7.2 feet. The bottom of the gate should be placed about 7 feet above the basin floor to avoid submergence during operation. However, a greater height might be necessary to avoid submergence when the outlet works is not operating. As described earlier, the basin width for each gate should be 3.5 times the gate width. W = 3.5 (3) = 10.5 feet.

$$\text{From Figure 15, } \frac{H_I}{TW} = 3.0, \text{ for } \frac{TW}{D_2} = 1.23 \text{ and } F_G = 4.5$$

$$H_I = 3.0\ (12) = 36 \text{ feet of water}$$

Thus, a plunge basin 28 feet long and 10.5 feet wide with a tailwater depth of 12 feet is required.

Figures 16 through 19 show the profile of the hydraulic jump for varying gate Froude numbers, at the optimum tailwater depth (D_2) (determined from Figure 12) and at the maximum tailwater possible without submerging the gates (D_2 max). Figure 19B approximates the stilling basin flow conditions for the above example.

Vibration tests.--Preliminary tests were performed to determine the feasibility of measuring vibration characteristics of the plunge stilling basin. Dissimilarity between the material of the model (glass and wood) and the prototype (concrete and steel) walls made a quantitative prediction of prototype vibration impracticable. However, the model yielded qualitative information on the variation of vibration amplitude with location on the wall, Froude number, and tailwater depth.

A miniature linear accelerometer (1-inch diameter) was mounted at several positions on the right wall of the model. Minute deflections of the wall result in movement of a mass in a magnetic field within the accelerometer and generation of voltages which are recorded on an oscillograph. The data indicated that the greatest amplitude of vibration occurred near the point of impact of the jets and decreased steadily in a downstream direction. The amplitude increased as the Froude number of the gate flow increased and decreased as the tailwater depth increased. These findings only substantiate what might be predicted in a basin of this type and are very general in nature. The frequency of vibration was in all cases very high and could not be accurately recorded; however, the trend of the frequency was the same as that observed for the amplitude. Future work will include a more comprehensive measurement of vibration characteristics, comparison of these characteristics with those of the hydraulic-jump stilling basin, and correlation with pressure fluctuations.

Comparison of the plunge basin with existing hydraulic-jump stilling basins.--To further determine the acceptability of a plunge basin, computations were made to compare design dimensions (without regard to impact pressures) with dimensions of existing stilling basins for slide gate controlled outlet works which had been designed as Type II hydraulic-jump basins through the use of Engineering Monograph No. 25.3/ It is

3/ "Hydraulic Design of Stilling Basins and Energy Dissipators" by A. J. Peterka, Engineering Monograph No. 25, Revised Printing, July 1963.

important to note that these comparisons in no way reflect upon the design of the existing structures. The plunge basin is a relatively new concept for use with slide gates and has not been proved in the field. In many cases topography or other factors will not permit the use of a plunge basin. Comparative dimensions of the various structures are shown in Table 1. The hydraulic jump basins were equipped with chute blocks and dentated end sills.

Table 1

COMPARISON OF PLUNGE BASIN DIMENSIONS
WITH DIMENSIONS OF EXISTING HYDRAULIC JUMP BASINS

Project	Percent gate opening	Discharge cfs	Hydraulic jump basin			Plunge-type basin			
			D_2	D_s	L	D_2	D_s	L	D'
Causey4/	100 (one gate)	554	18	14	54	15	14	46	6
	100 (two gates)	784	18	11	54	11	10	29	4
Norton5/	100	385	11	9	34	11	10	30	4
Bully Creek6/	100	283	14	10	45	11	10	32	4
Bully Creek7/	100	288	11	--	40	8	7	22	4

The close similarity between sweepout tailwater depths for any project is noteworthy, considering that the data were obtained from two different models. This similarity verifies the accuracy of the plunge basin design curves for the D_s dimension. The design curves give an optimum tailwater depth which does not allow an adequate safety margin against sweepout. D_2 would therefore be increased and would approach the values shown for the hydraulic jump basin. The plunge basin shows no advantage with regard to tailwater depth.

The table indicates a reduction in the necessary basin length for the plunge basin. The impact of the jet on the basin floor causes the jet to turn upward

4/"Hydraulic Model Studies of Causey Dam Outlet Works," Report No. Hyd-496, April 5, 1963.
5/"Hydraulic Model Studies of Norton Dam Outlet Works," Report No. Hyd-497, October 21, 1963.
6/"Hydraulic Model Studies of Bully Creek Dam, Bully Creek Outlet Works," Report No. Hyd-494, January 11, 1963.
7/"Hydraulic Model Studies of Bully Creek Dam, Canal Outlet Works," Report No. Hyd-495, January 9, 1963.

from the floor in less distance than in the hydraulic jump basin. An apparent reduction in length of 8 feet (15 percent) could be made for Causey Outlet Works (the design of the hydraulic jump basin was based on one gate operation); Norton Outlet Works and Bully Creek Outlet Works show a possible reduction of 4 feet (12 percent) and 13 feet (20 percent), respectively. Bully Creek Canal Outlet Works indicates a reduction of 18 feet; however, the model studies indicated that approximately half the length of the hydraulic jump basin was occupied by the jump. It should be noted that the Norton Outlet Works included a sloping apron downstream from the end sill. It is concluded that the four basins indicated a possible basin length reduction of 10 to 20 percent with the use of a plunge basin.

Recommendations for future work.--The following investigations are recommended for continuing studies of stilling basins for high-head slide gates. Some have been mentioned earlier in the report.

1. Generalization tests of the hydraulic jump basin in a glass-sided flume, including an investigation of jet spreading characteristics for varying degrees of jet impingement on a sloping apron.

2. Comparison of vibration characteristics of the hydraulic jump basin with the corresponding plunge basin and correlation with pressure fluctuations.

3. Training wall pressures for both basin types.

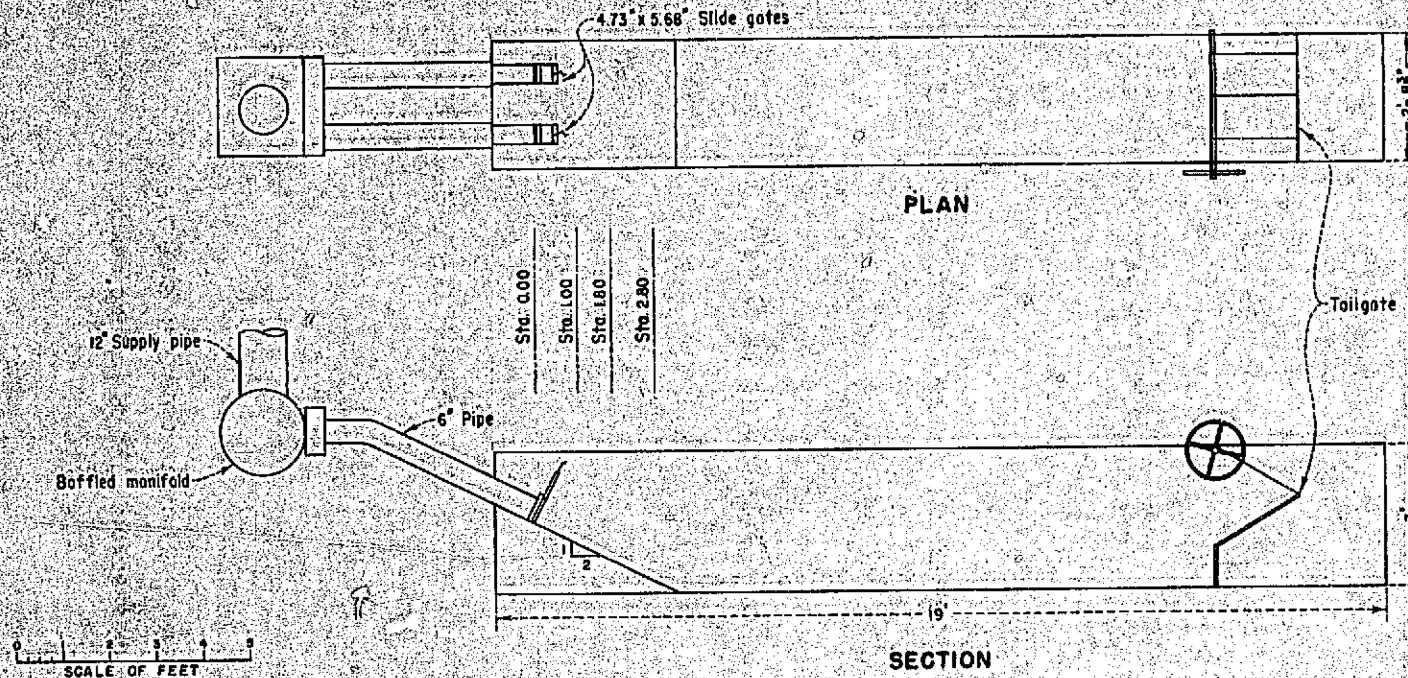
4. Determination of optimum basin width for both types.

5. Refinement of design curves for both basin types.

6. Development of specific design criteria for appurtenances such as a sloping apron, dividing wall, and end sill.

7. Study of hydraulic characteristics of plunge basins with shapes other than rectangular for use in connection with unlined basins.

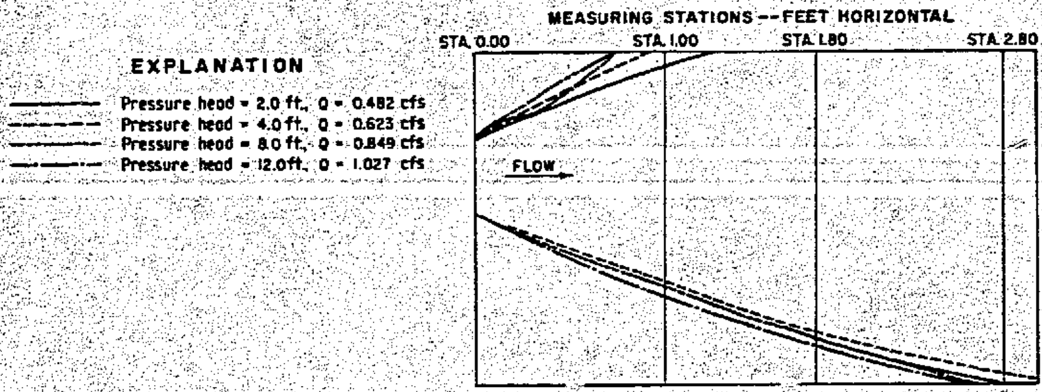
FIGURE 1
REPORT-HYD-544



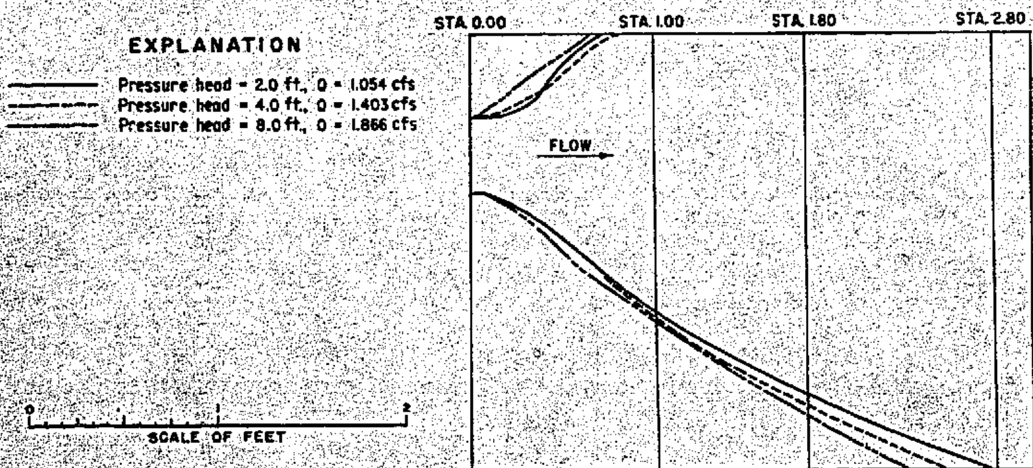
SLIDE GATE STILLING BASIN STUDIES

MODEL CONFIGURATION

FIGURE 2
REPORT HYD-344



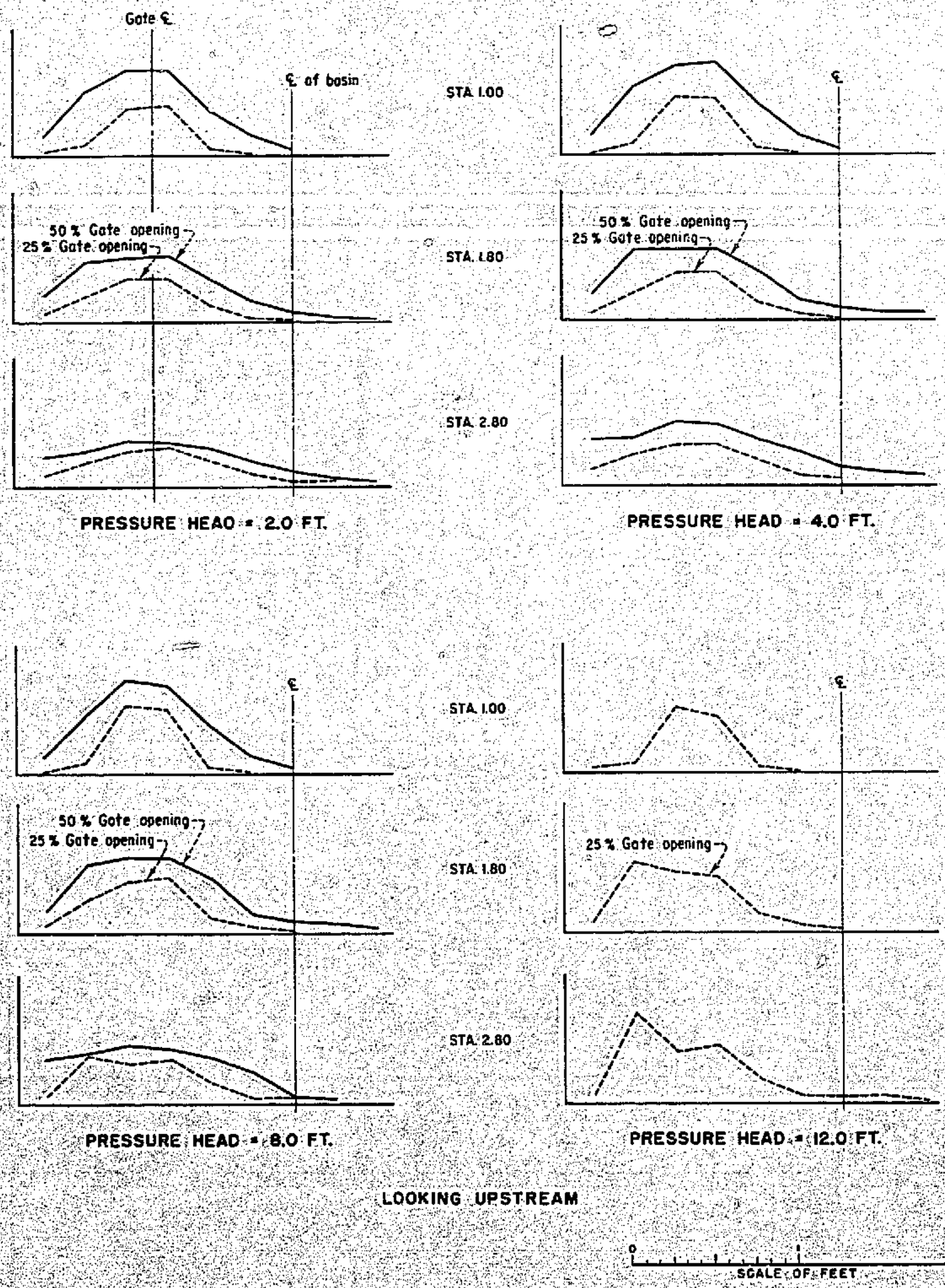
25 PERCENT GATE OPENING



50 PERCENT GATE OPENING

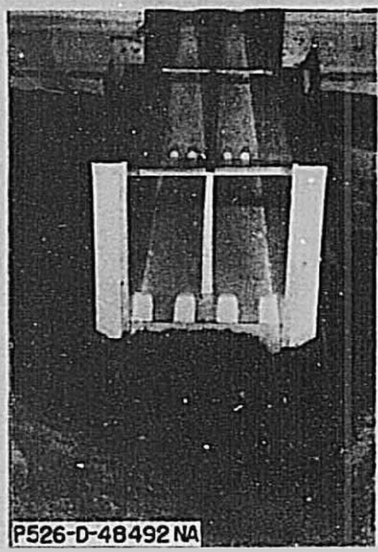
SLIDE GATE STILLING BASIN STUDIES

PLAN OF SPREADING JET ON SLOPING APRON

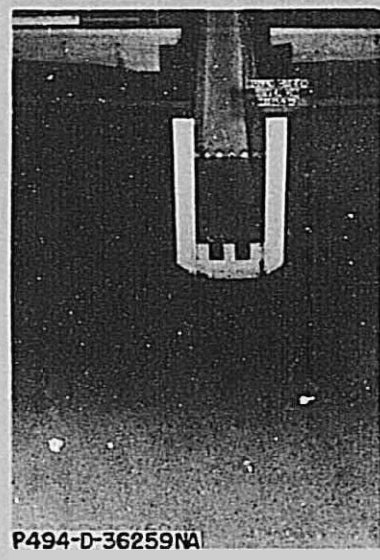


SLIDE GATE STILLING BASIN STUDIES

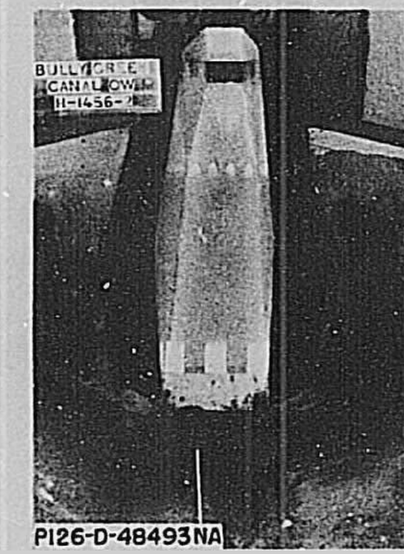
SECTIONS OF SPREADING JET ON SLOPING APRON



CAUSEY OUTLET WORKS
1:11 Scale Model



BULLY CREEK
OUTLET WORKS
1:6.75 Scale Model



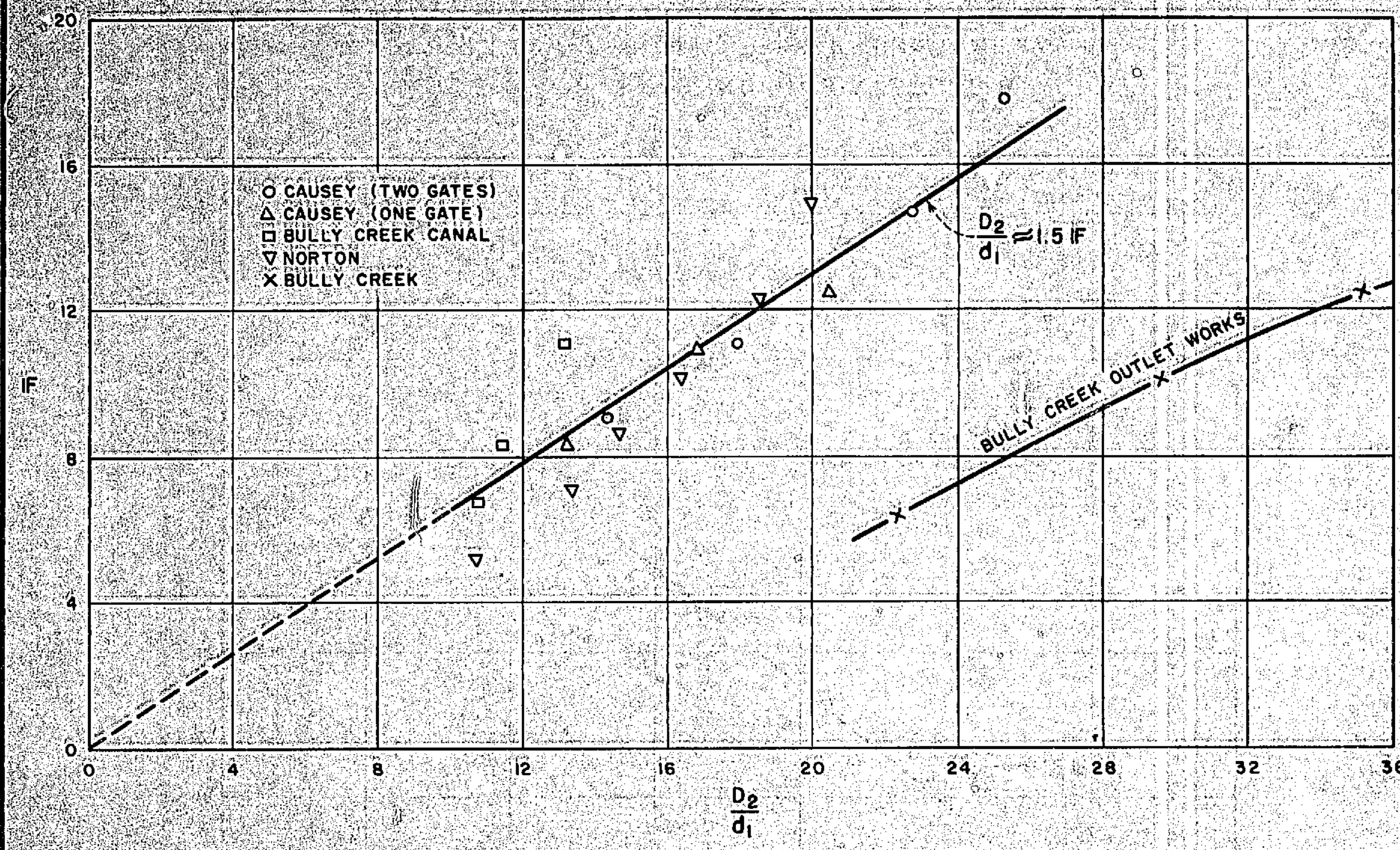
BULLY CREEK
CANAL OUTLET WORKS
1:9.75 Scale Model

NORTON OUTLET WORKS
1:8.25 Scale Model

SLIDE GATE STILLING BASIN STUDIES
HYDRAULIC JUMP BASIN

Models Used to Obtain Data in
Figures 5 through 8

Figure 4
Report Hyd-544

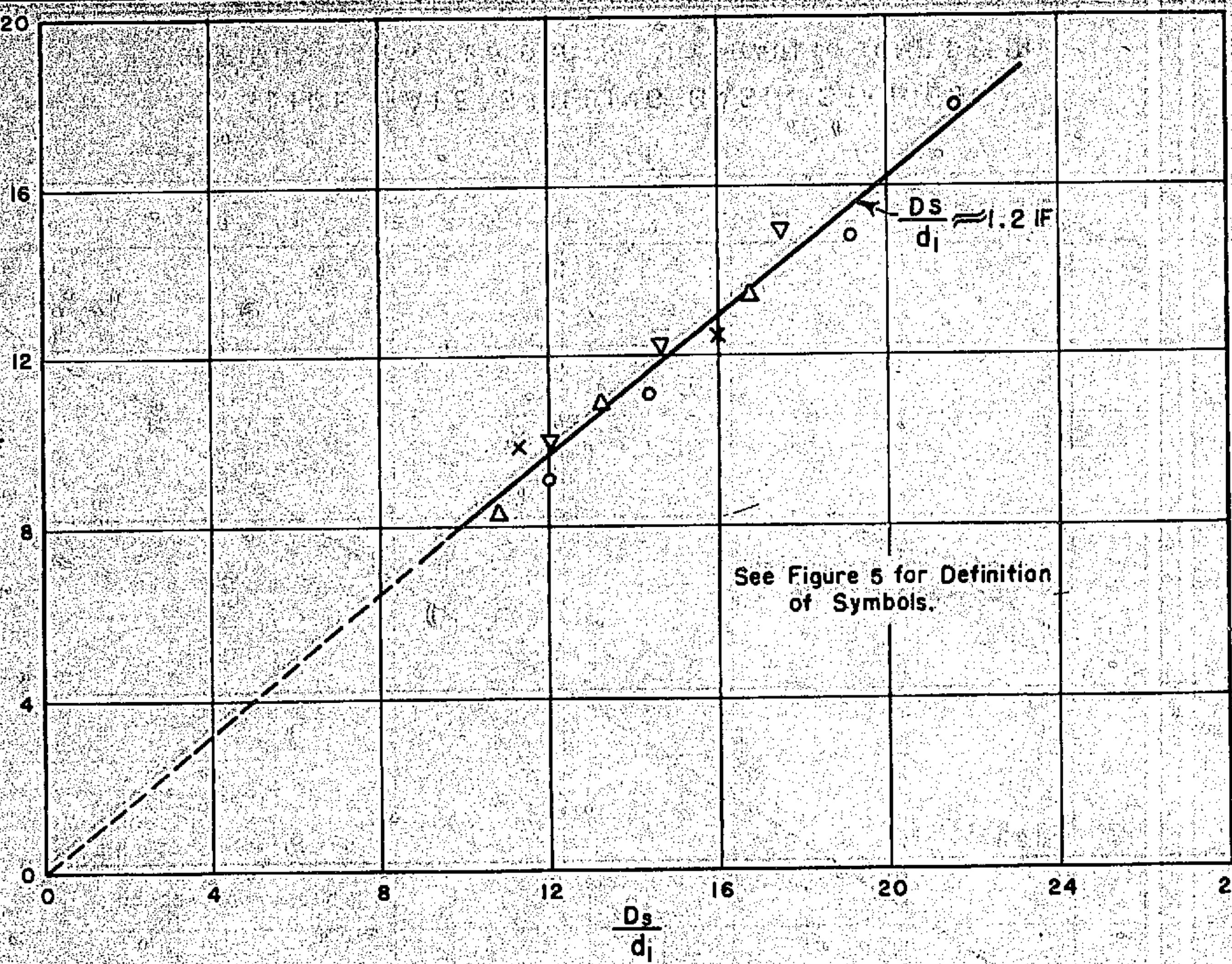


SLIDE GATE STILLING BASIN STUDIES

OPTIMUM TAILWATER DEPTH--HYDRAULIC JUMP BASIN

691

FIGURE 6
REPORT HYD-544



SLIDE GATE STILLING BASIN STUDIES

SWEEPOUT TAILWATER DEPTH--HYDRAULIC JUMP BASIN

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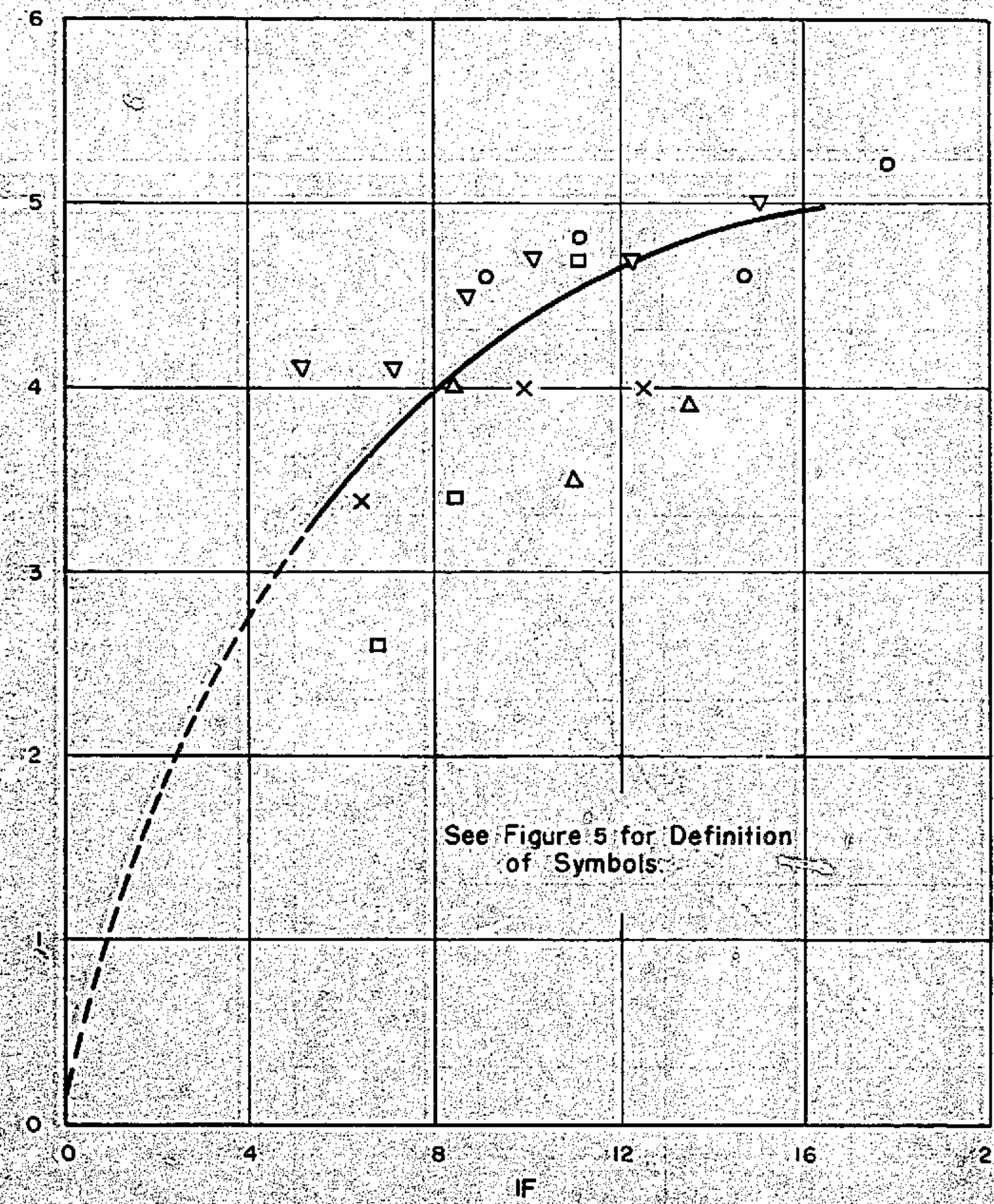
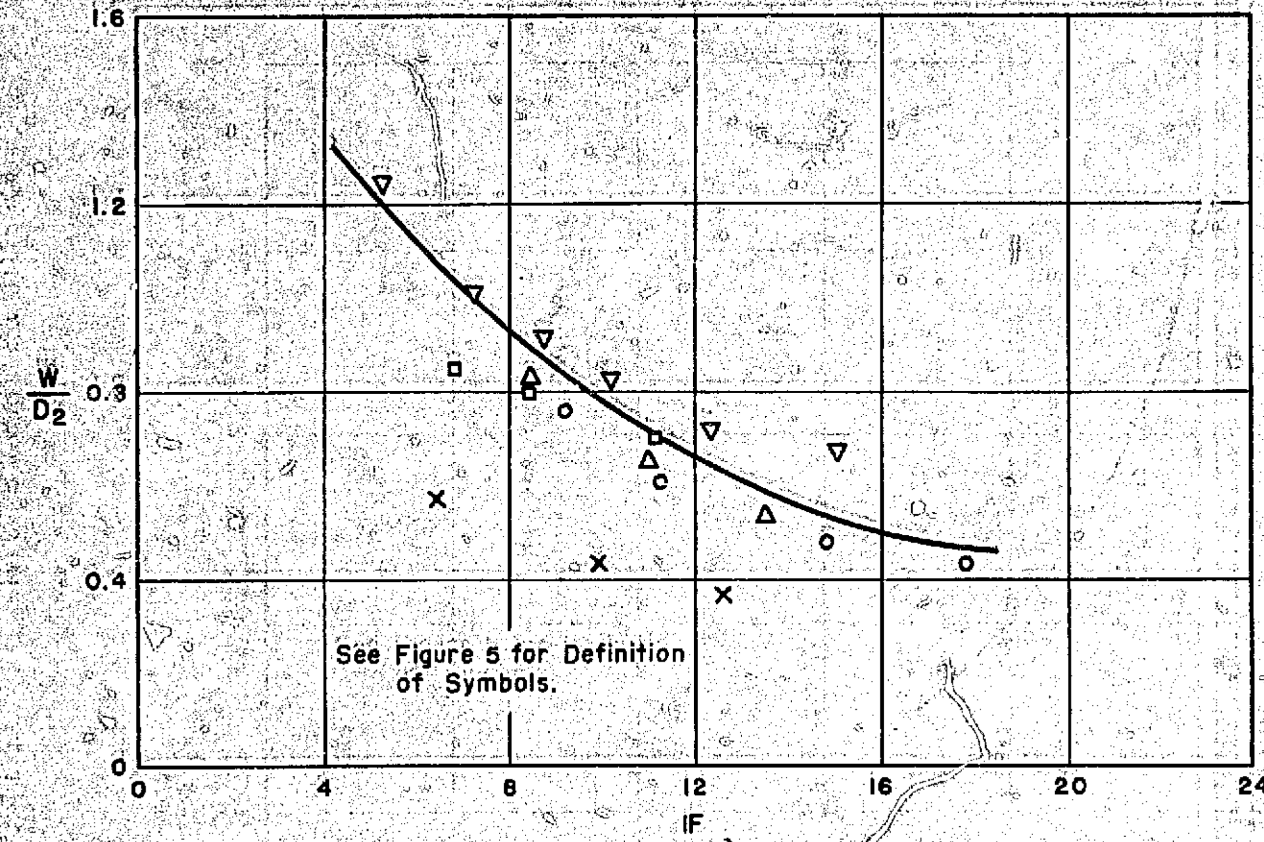


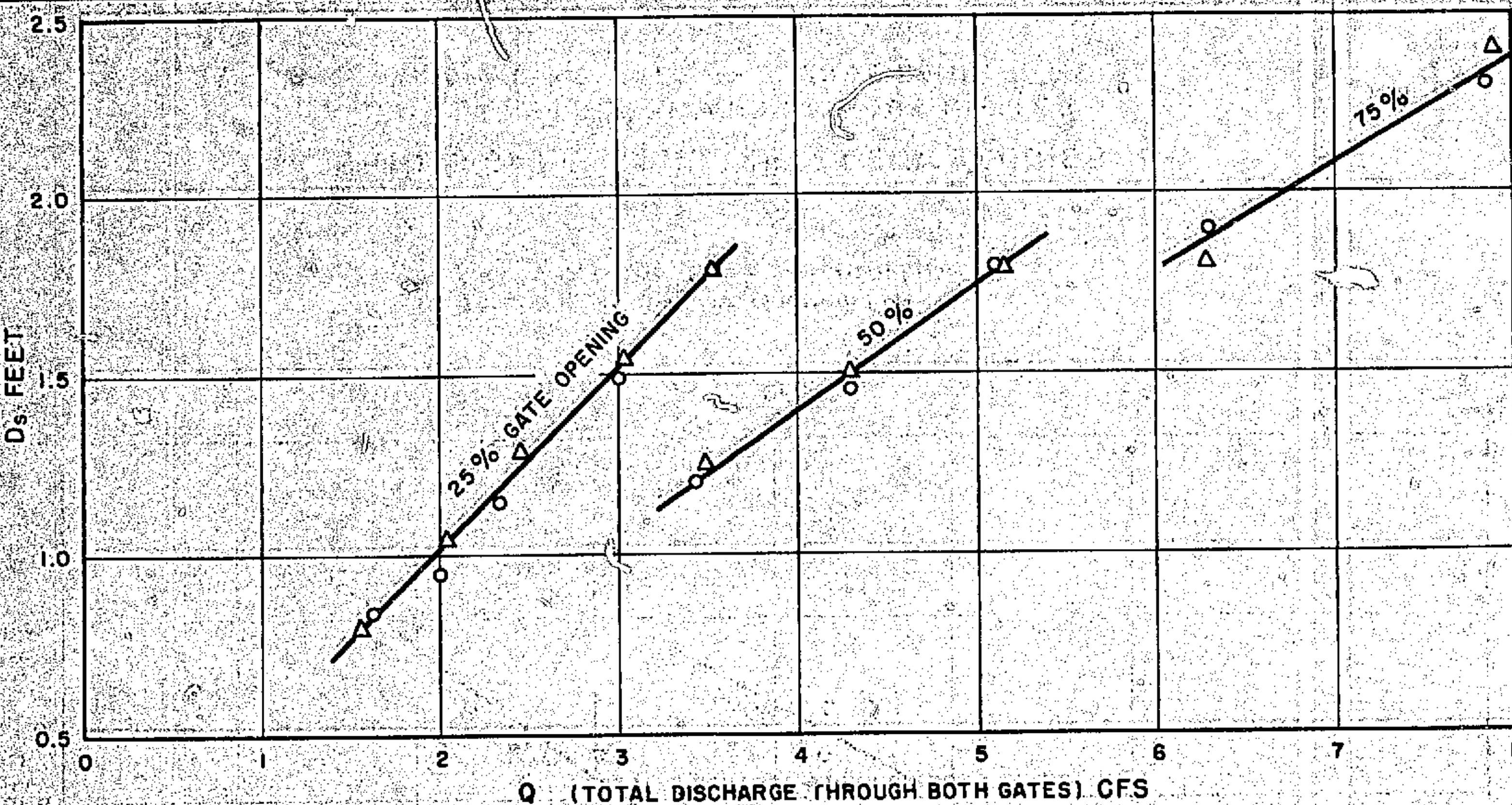
SLIDE GATE STILLING BASIN STUDIES

LENGTH OF HYDRAULIC JUMP--HYDRAULIC JUMP BASIN



SLIDE GATE STILLING BASIN STUDIES

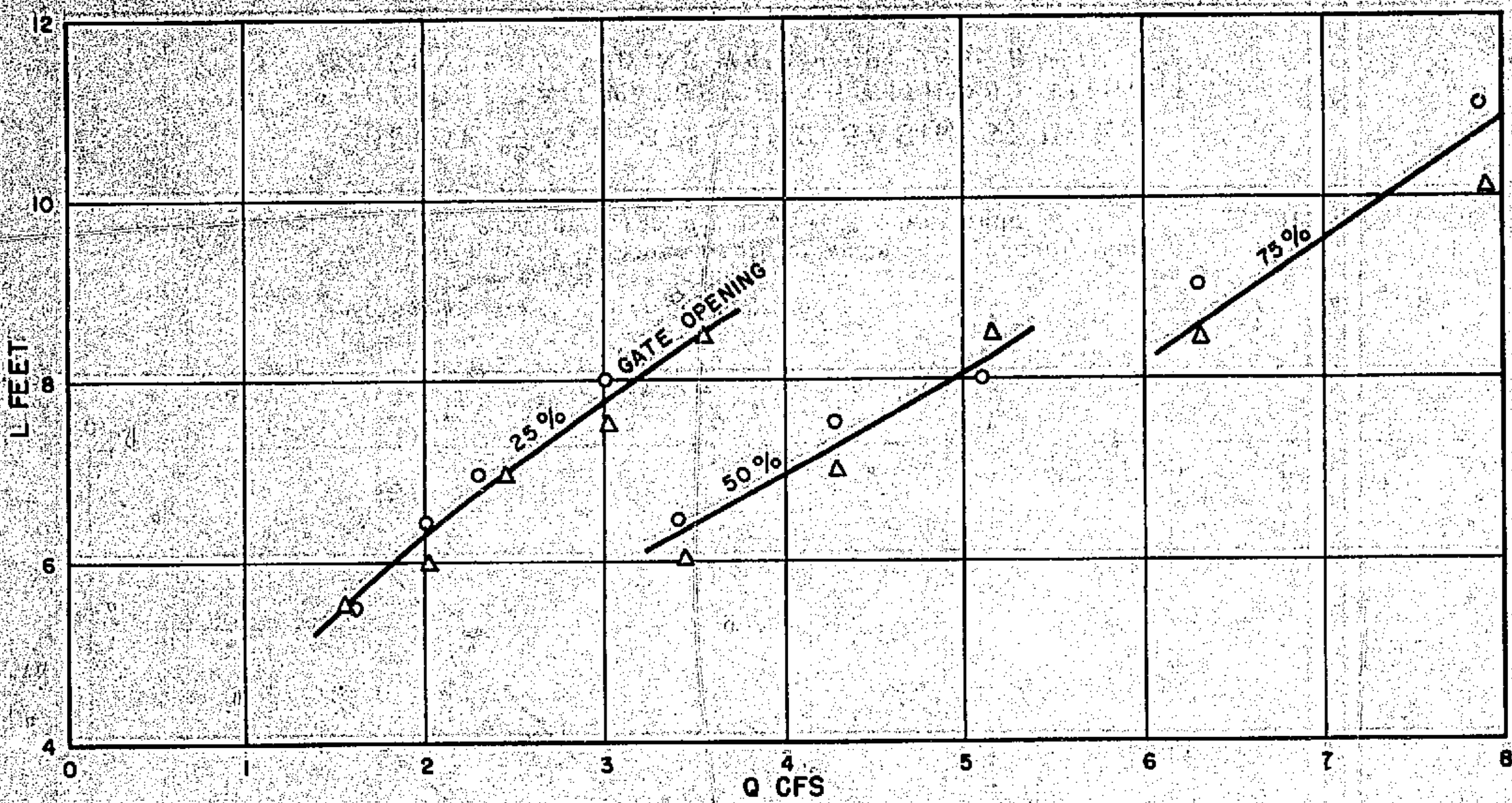
BASIN WIDTH -- HYDRAULIC JUMP BASIN



Note: o is with center dividing wall.
Δ is without center dividing wall.
D_s is the tailwater depth at which the hydraulic jump is on the verge of being swept downstream.

SLIDE GATE STILLING BASIN STUDIES

SWEEPOUT TAILWATER DEPTH WITH AND WITHOUT CENTER DIVIDING WALL--PLUNGE BASIN

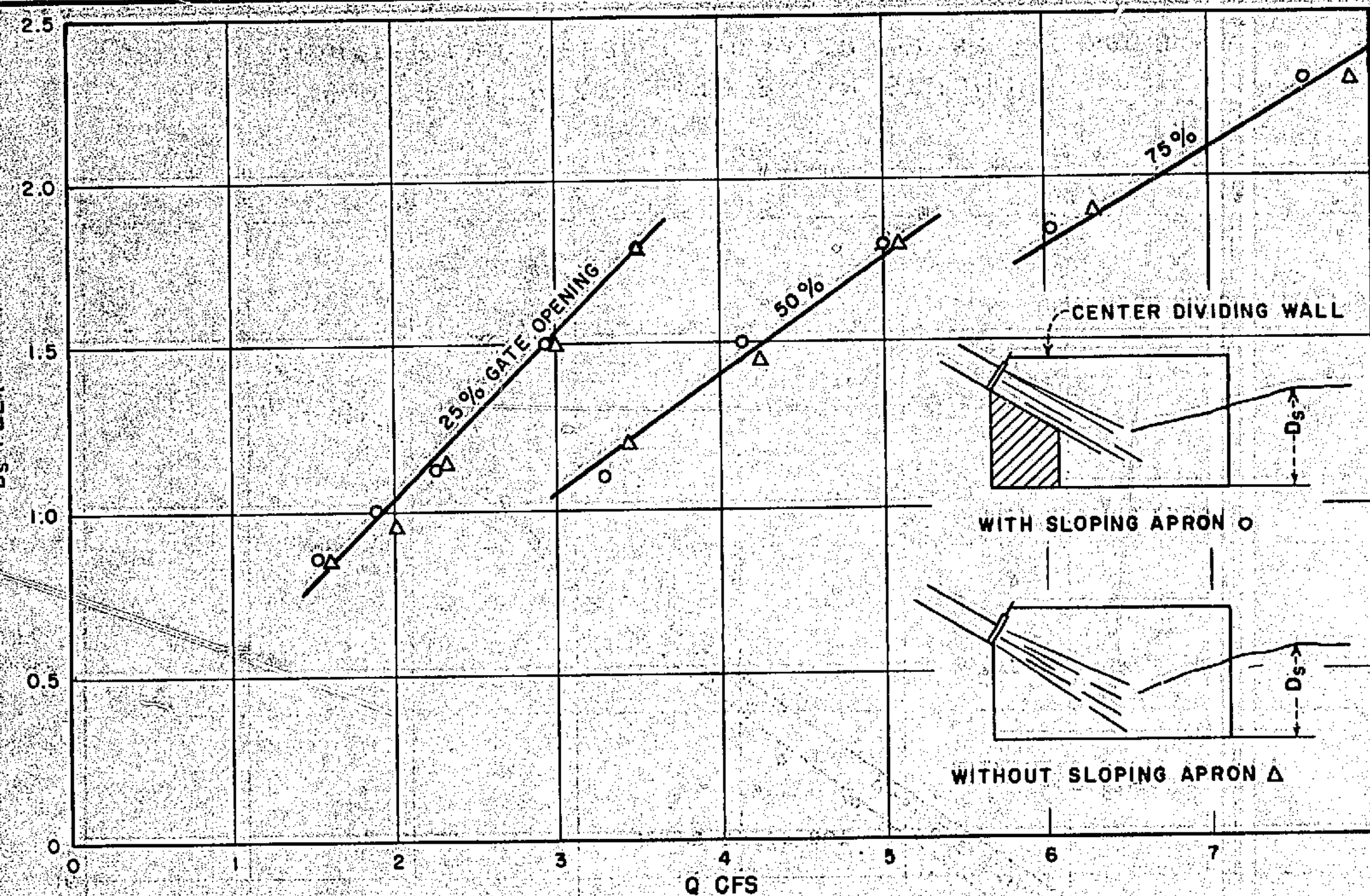


Note: L is the jump length in feet.
Q, o and Δ are defined in Figure 9

SLIDE GATE STILLING BASIN STUDIES

JUMP LENGTH WITH AND WITHOUT CENTER DIVIDING WALL -- PLUNGE BASIN

691

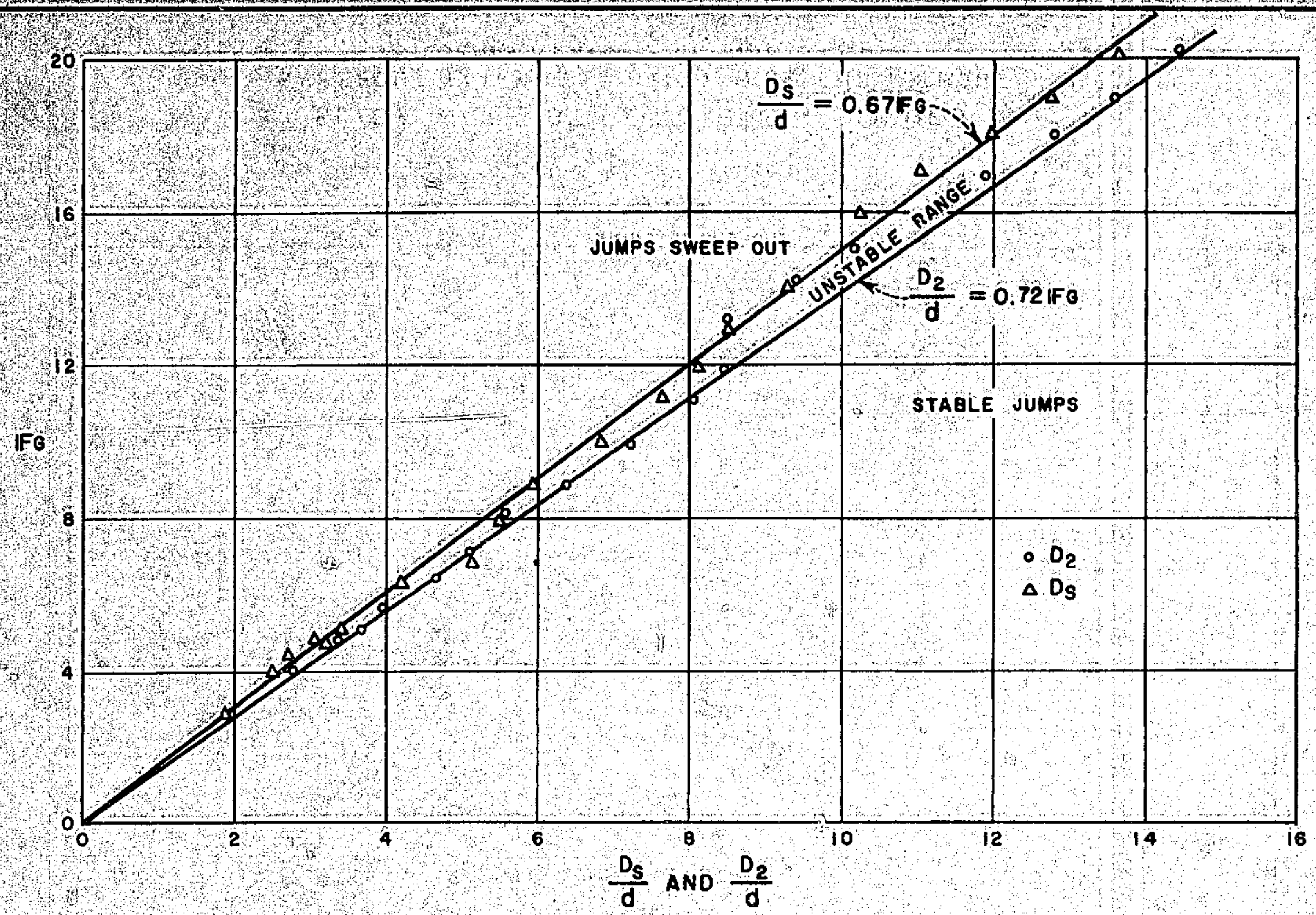


Q is defined in Figure 9

SLIDE GATE STILLING BASIN STUDIES

SWEEPOUT TAILWATER DEPTH WITH AND WITHOUT SLOPING APRON -- PLUNGE BASIN

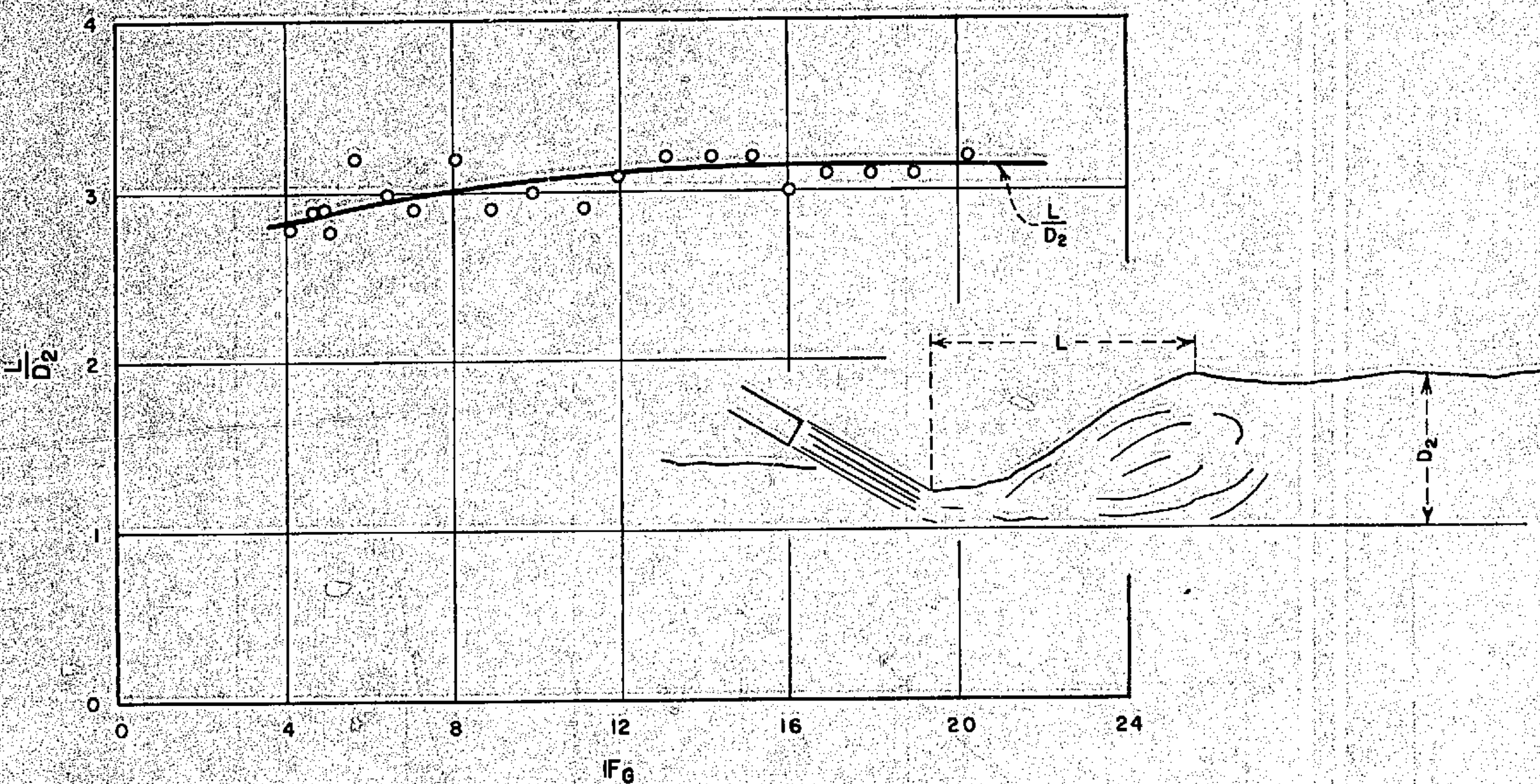
691



SLIDE GATE STILLING BASIN STUDIES

OPTIMUM TAILWATER AND SWEEPOUT TAILWATER DEPTHS--PLUNGE BASIN

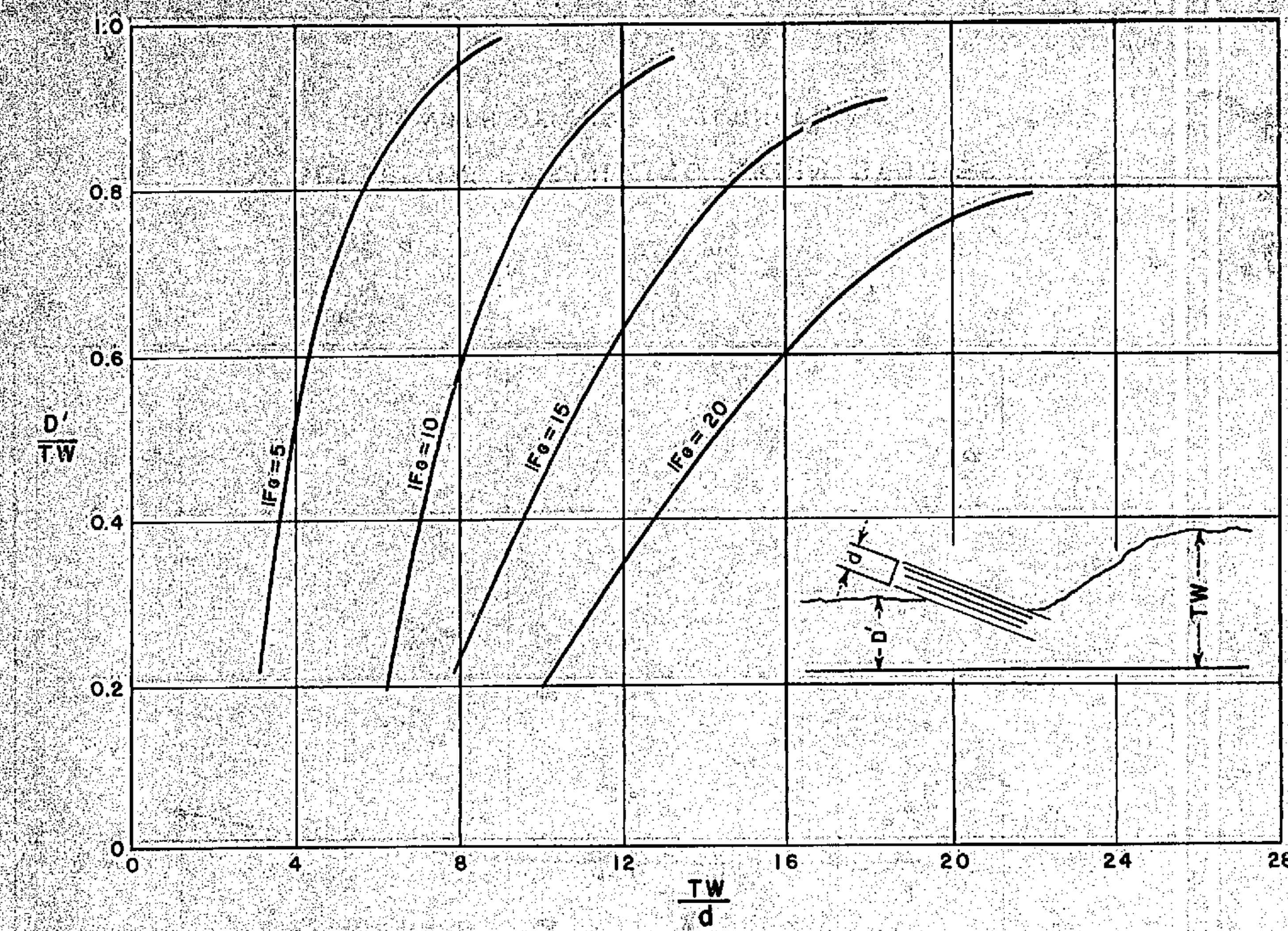
691



SLIDE GATE STILLING BASIN STUDIES

LENGTH OF JUMP--PLUNGE BASIN

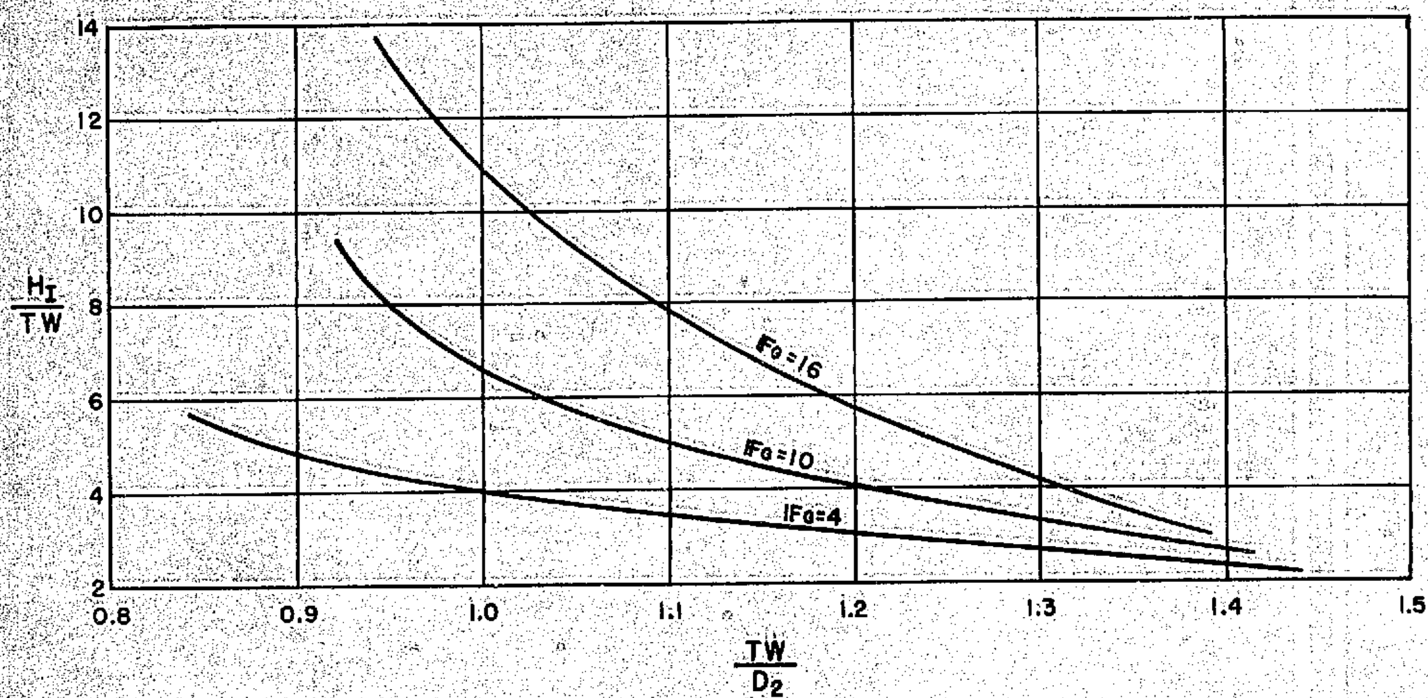
691



SLIDE GATE STILLING BASIN STUDIES

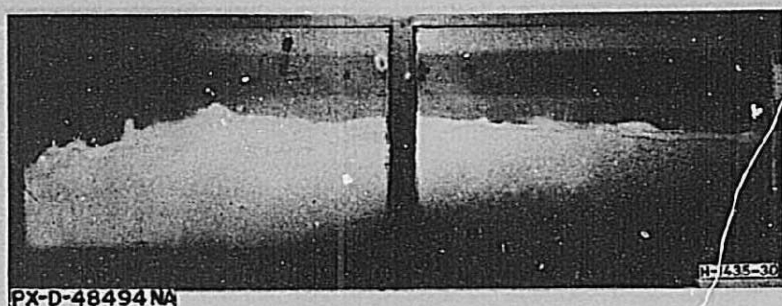
WATER DEPTH BELOW GATE -- PLUNGE BASIN

6917

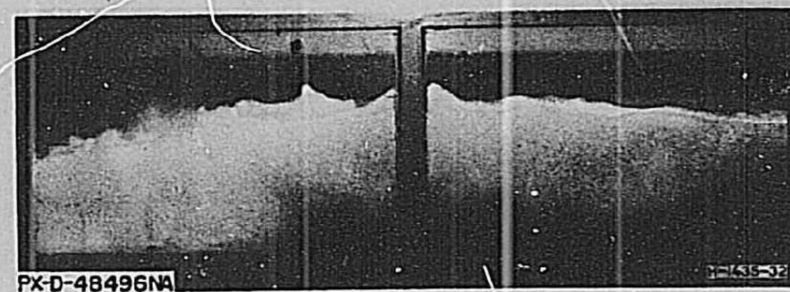


SLIDE GATE STILLING BASIN STUDIES

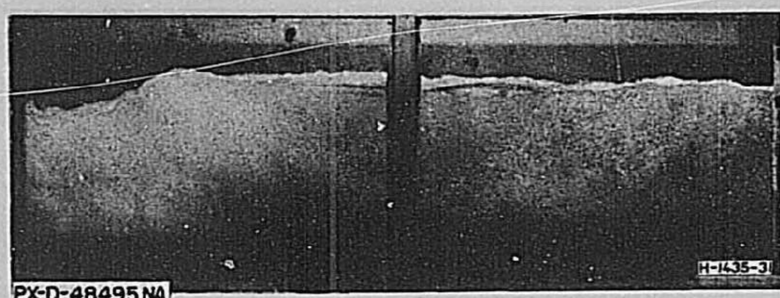
VARIATION OF MAXIMUM IMPACT HEAD -- PLUNGE BASIN



A. $\frac{D_2}{d} = 10.2$

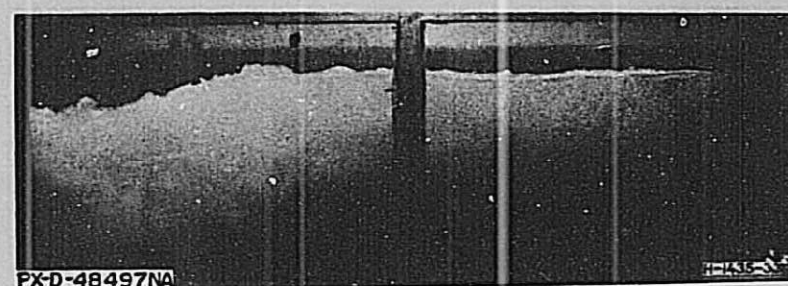


C. $\frac{D_2}{d} = 11.5$



B. $\frac{D_2 \max}{d} = 13.8$

25 percent gate opening
FG = 14

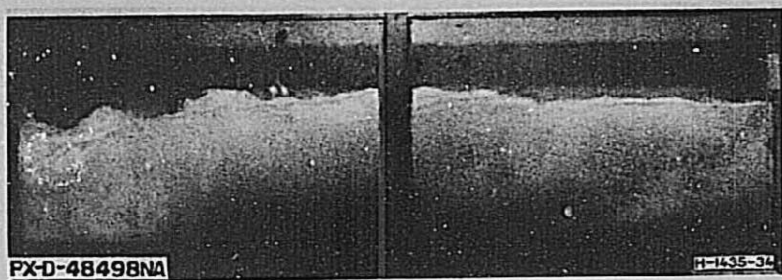


D. $\frac{D_2 \max}{d} = 14.8$

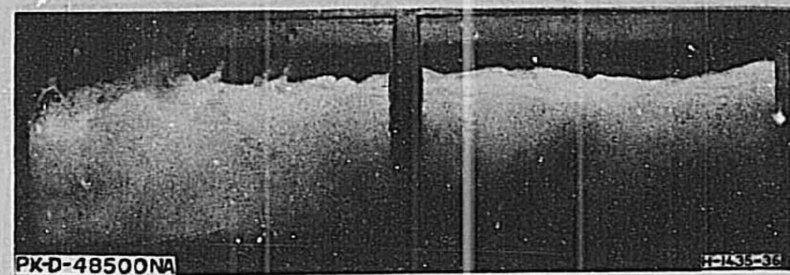
25 percent gate opening
FG = 16

SLIDEGATE STILLING BASIN STUDIES
JUMP PROFILE
PLUNGE BASIN

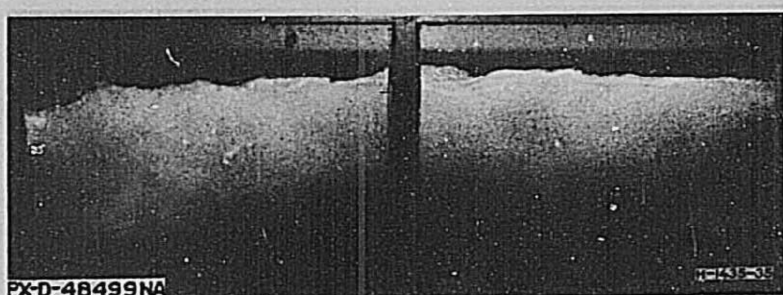
Figure 17
Report Hyd-544



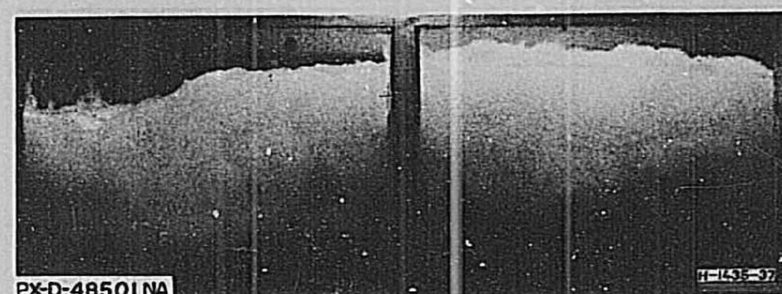
A. $\frac{D_2}{d} = 5.7$



C. $\frac{D_2}{d} = 7.1$

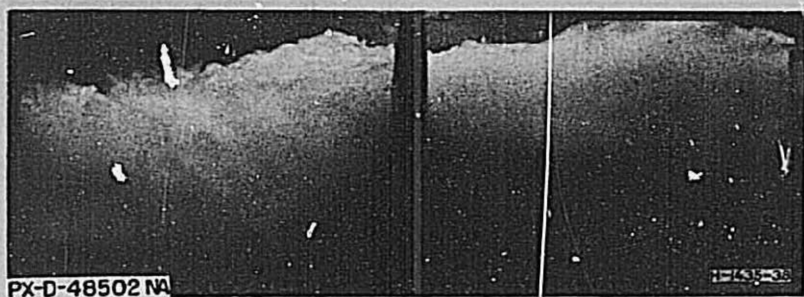


B. $\frac{D_2 \text{ max}}{d} = 7.4$
50 percent gate opening
FG = 8



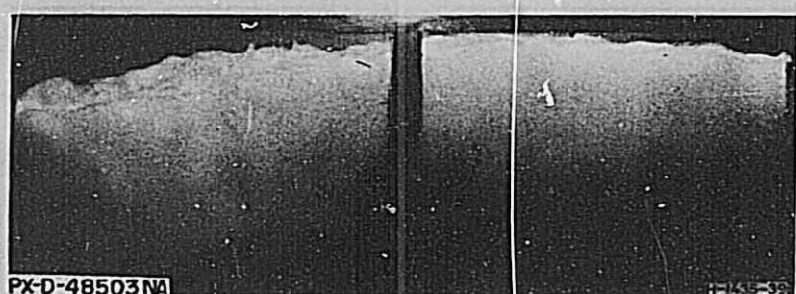
D. $\frac{D_2 \text{ max}}{d} = 8.1$
50 percent gate opening
FG = 10

SLIDE GATE STILLING BASIN STUDIES
JUMP PROFILE
PLUNGE BASIN

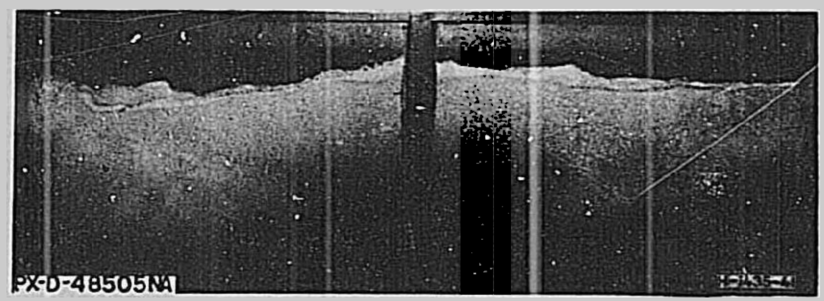


A. $\frac{D_2}{d} = 8.6$

C. $\frac{D_2}{d} = 4.3$

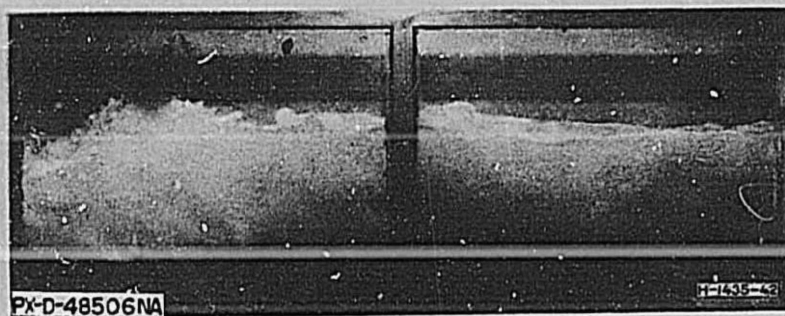


B. $\frac{D_2 \max}{d} = 9.5$
50 percent gate opening
FG = 12

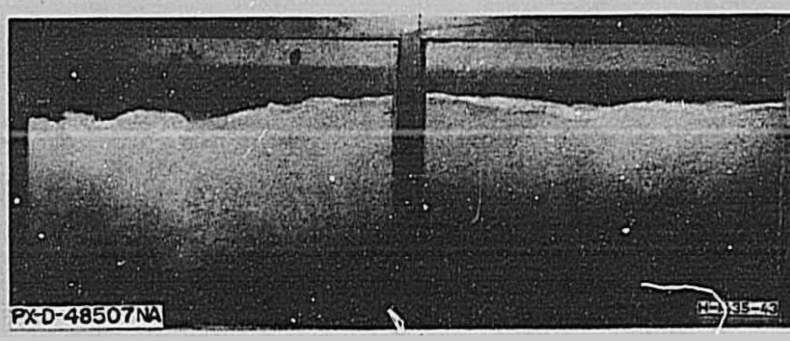


D. $\frac{D_2 \max}{d} = 5.2$
75 percent gate opening
FG = 6

SLIDE GATE STILLING BASIN STUDIES
JUMP PROFILE
PLUNGE BASIN



A. $\frac{D_2}{d} = 2.9$



B. $\frac{D_2 \text{ max}}{\quad} = 3.7$

100 percent gate opening
FG = 4

SLIDE GATE STILLING BASIN STUDIES
JUMP PROFILE
PLUNGE BASIN

7-1750
(10-64)

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.798 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second²	0.3048*	Meters per second²
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft² deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft² deg F	1.4880*	Kg cal m/hr m² deg C
Btu/hr ft² deg F (C, thermal conductance)	0.568	Milliwatts/cm² deg C
	4.882	Kg cal/hr m² deg C
Deg F hr ft²/Btu (R, thermal resistance)	1.761	Deg C cm²/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft²/hr (thermal diffusivity)	0.2581	Cm²/sec
	0.09290*	M²/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft² (water vapor transmission)	16.7	Grams/24 hr m²
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 845-237

ABSTRACT

The purpose of these studies was to develop an efficient, economical stilling basin for use with slide gate control for high-head outlet works. Design curves were developed for a rectangular plunge basin to determine basin depth and length, height of the gate above the basin floor, and magnitude of impact heads on the basin floor. Comparisons were made with corresponding basins of the hydraulic jump type designed according to Engineering Monograph 25. Tentative design curves were obtained for the hydraulic jump basin based on data derived from general model studies of four particular stilling basins. Recommendations for continuing work in this study are presented.

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Hyd-544
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PROGRESS REPORT VII--RESEARCH STUDY ON STILLING BASINS, ENERGY DISSIPATORS, AND ASSOCIATED APPURTENANCES--SECTION 13, STILLING BASINS FOR HIGH HEAD OUTLET WORKS WITH SLIDE-GATE CONTROL (PRELIMINARY STUDIES)
Laboratory Report, Bureau of Reclamation, Denver, 11 p, 19 fig, 1 tab, 6 ref, 1965

DESCRIPTORS-- *slide gates/ *outlet works/ *stilling basins/ *hydraulic jumps/ *model tests/ hydraulic models/ research and development/ design criteria/ hydraulic structures/ high pressure gates/ closed conduits/ control structures/ Froude number/ jets/ turbulent flow/ pressure measuring equip/ piezometers/ water pressures/ appurtenances/ vibrations
IDENTIFIERS-- plunge basin/ impact head/ jump basins/ dividing walls/ jet spreading/ impact pressure

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