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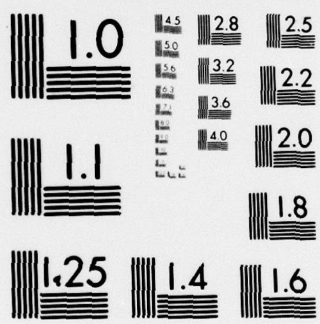

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MISCELLANEOUS PAPER HL-79-8

STILLING BASINS FOR OUTLET WORKS

by

Thomas E. Murphy

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October 1979

Final Report

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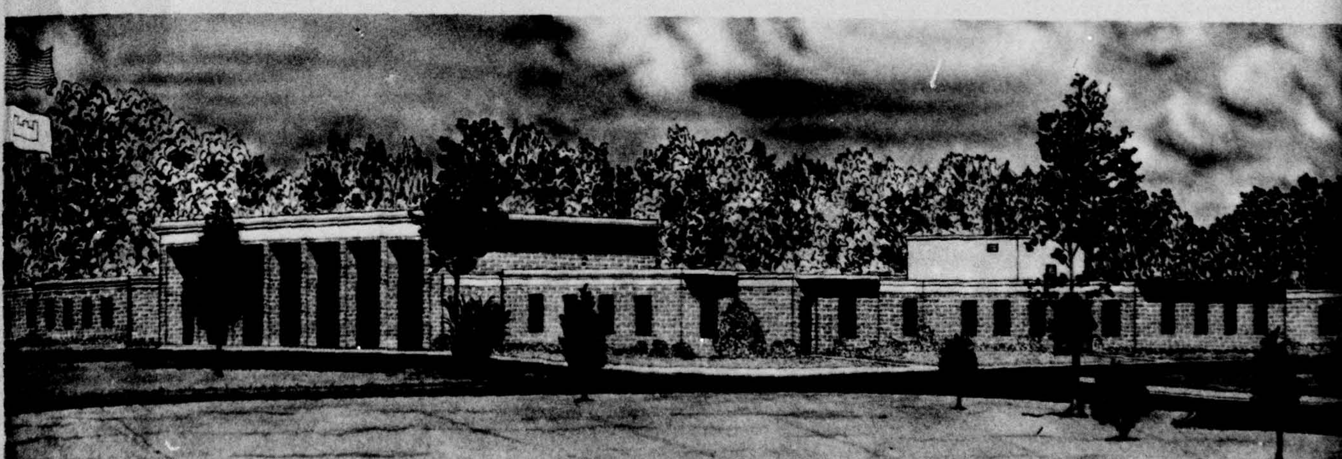

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Miscellaneous Paper HL-79-8

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 STILLING BASINS FOR OUTLET WORKS.

5. TYPE OF REPORT & PERIOD COVERED
9 Final report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Thomas E./Murphy

8. CONTRACT OR GRANT NUMBER(s)
14 WES/HL-MP-79-8

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Hydraulics Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

12. REPORT DATE
11 Oct [redacted]979

13. NUMBER OF PAGES
12

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
12 15

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Outlet works
Stilling basins

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Low and intermediate flows in a stilling basin for a single conduit outlet may form an eddy in the basin. This eddy may entrap rocks and debris and result in abrasion and impact damage to the basin. This problem occurs where the invert of the conduit outlet portal is "low" with respect to tailwater. The invert of the outlet portal of a conduit is "low" with respect to tailwater, and eddy problems can be expected, if for any operating discharge the d_2 curve intersects the tailwater for that discharge in the transition between the conduit and the stilling basin proper at a section where the slope of the apron is flatter than 1V on 6H.

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Preface

This report was prepared by Mr. Thomas E. Murphy, Consultant to the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), under the supervision of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory. It defines conditions under which eddy action is likely to form in outlet works stilling basins. This action can trap debris and result in damage to the basin. The report was reviewed and approved for publication by the Office, Chief of Engineers, U. S. Army.

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

Contents

STILLING BASINS FOR OUTLET WORKS

The Problem

1. This progress report is concerned with eddy action at low and intermediate flows in a stilling basin for a single outlet conduit. At several Corps installations, such stilling basins perform adequately throughout the higher range of discharges; but at low and intermediate flows, an eddy forms in the basin and downstream flow is confined to a narrow section along one of the sidewalls. Rocks and debris are trapped in the eddy and are moved upstream to the point at which they meet the efflux from the conduit; here they are agitated and some are bounced violently against the apron as they are picked up by the issuing jet and moved to the downstream portion of the basin where they again are trapped in the eddy. This action of the rocks results in impact and abrasion damage to the concrete apron, baffles, and sidewalls.

2. It is well known that the above problem occurs only at those projects where the invert of the conduit outlet portal is "low" with respect to tailwater. "Low" is defined in paragraph 12.

Past Observations

3. Bakhmeteff and Matzke[1] (references are listed in table 1) state:

> Observations indicate, that for steep slopes the forms of the phenomena are substantially modified. A jump in a horizontal or mildly sloped channel is marked by a steep roller front. Further, the live streaming commences to expand under the roller rather brusquely right near the toe, the upper surface of the live jet being directed upward. Both these features are absent in case of a steep slope. Instead of following an outline as indicated in Fig. 22a, the pattern unfolds as shown in Fig. 22b. The live jet "plunges" into the tailwater and within the steep section follows the slope downward with comparatively slow expansion and obviously relatively small losses.

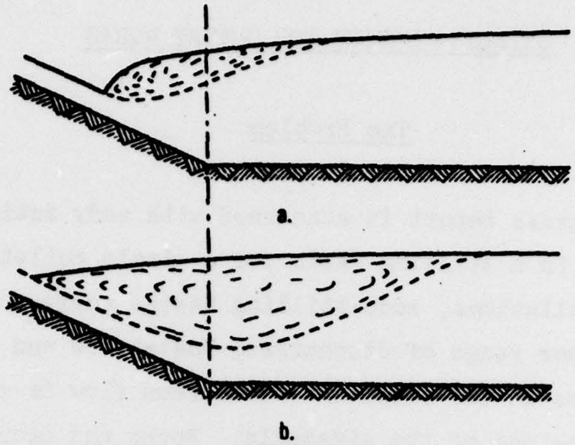


Fig. 22

4. Stevens[2] states:

> From the foregoing analysis, it would appear that what have been called hydraulic jumps on inclined beds of 1 on 6 or steeper, projecting into tailwater, are not hydraulic jumps at all but a mere plunging of water into a pool.

5. In model tests of outlet stilling basins, the writer has observed that at low and intermediate discharges, even though stilling action commences in the transition between the conduit and stilling basin proper, conditions are stable and stilling action is considered satisfactory when the jet plunges into the tailwater. In the structure, dimensioned for a much greater discharge, the jet moves along the surface of the apron until it loses its energy by gradual expansion or is deflected upward by baffles or the end sill. Rocks and debris are moved to the downstream portion of the basin where they remain until the discharge is increased. Stable conditions in the stilling basin under this type of action are not affected by the normal inequalities in energy distribution across the efflux which are inherent with the usual outlet transitions and varying flow conditions.

6. Also, in tests of outlet stilling basins, the writer has observed that at low and intermediate discharges stable hydraulic jumps occurring on the upper and flat portion of the transition between the conduit and stilling basin proper are difficult to establish or maintain. The slightest imbalance of flow, which again is inherent with the

usual outlet transitions and varying flow conditions, causes the jump to be drowned and flow is forced to one side of the basin with an eddy in the opposite side. Once this condition is established, the jump does not re-form. This eddy action produces the damage discussed in paragraph 1.

Data Analyses

7. In some recent studies, model operators have observed for each of several discharges the tailwater elevations at which eddy action occurred and those at which stilling action was satisfactory. Subsequent analyses have revealed a remarkable conformity between the observed tailwater elevation separating satisfactory basin action from eddy action and the tailwater elevation at which the theoretical depth of tailwater, d_2, required for a hydraulic jump occurs at the section of the stilling basin transition where the slope of the apron is 1V on 6H. The observed maximum tailwater for satisfactory basin action (at higher tailwater elevations, eddy action developed) and computed tailwater elevations for jumps at the section of the stilling basin transition where the apron slope is 1V on 6H are shown in table 2 for five different basin designs studied in the Clinton Dam model tests.[3] Data from one test are plotted in plate 1. Note that the observed tailwater separating eddy action from satisfactory stilling action intersects the computed d_2 curve very near the section of the stilling basin transition where the apron slope is 1V on 6H. At tailwater elevations higher than those observed, action starts at sections where the apron slope is flatter than 1V on 6H; a true jump attempts to form, but inequalities in flow distribution cause the jump to be drowned and the undesirable eddy action develops. Once developed, eddy action persists. At tailwater elevations lower than those observed, the jet plunges into the tailwater; and stable, satisfactory stilling action occurs in spite of the inherent inequalities in flow distribution across the entering jet.

8. Based on the writer's observations that slight inequalities in flow distribution make it difficult to maintain a hydraulic jump in the transition section of the stilling basin but allow satisfactory

basin action with plunging jets, the data presented in paragraph 7 provide excellent confirmation of Mr. Stevens' statement that a true hydraulic jump will not form on a slope steeper than 1V on 6H.

9. A study also was made of basins in which a hump at the outlet portal was used to obtain satisfactory basin action. It has been assumed that this hump improves basin action by spreading and creating a better distribution of energy in the flow entering the tailwater. This may have some merit, but it is significant that humps have proved effective only in those cases in which the hump has resulted in the computed d_2 for each operating discharge intersecting the tailwater for that discharge at a position in the basin transition where the apron slope is as steep or steeper than 1V on 6H. Plate 2 is a drawing of a humped basin, type 10 design, studied for the Tallahala Dam outlet works.[4] Plate 3 shows tailwater curves for the Tallahala project on which have been added for discharges of 500, 750, and 1000 cfs computed tailwater elevations for the jump to form at the section of the type 10 design where the slope is 1V on 6H. It is stated in the final report of the Tallahala study that: "The type 10 design eliminated the eddy for flows of 750 cfs and greater; however, mild eddies remained at flows of 500 cfs or less." When action commenced in the transition from the conduit to the basin proper on a slope flatter than 1V on 6H, eddies again developed; but satisfactory stilling resulted when the action commenced on a slope steeper than 1V on 6H.

10. In model tests of the existing Pomona Dam outlet basin,[5] where extensive damage in the prototype has resulted from eddy action at low and intermediate flows, humps at the outlet were not effective unless they were at least 9.7 ft high. Subsequent computations have indicated that a hump of this height is required to cause action to commence at sections of the transition where the slope of the apron is as steep as 1V on 6H.

11. Review of reports (data for detail analyses are not readily available) of model tests conducted during 1934 and 1935 at Case School of Applied Science[6] again indicates that humps at the outlet portal are

effective only when they cause action to commence at a position where the apron slope is steeper than 1V on 6H.

Conclusion

12. The invert of the outlet portal of a conduit is "low" with respect to tailwater, and eddy problems can be expected, if for any operating discharge the d_2 curve intersects the tailwater for that discharge in the transition between the conduit and the stilling basin proper at a section where the slope of the apron is flatter than 1V on 6H.

Discussion

13. Eddy problems are not likely in an outlet stilling basin developed in accord with usual procedures, if it is determined that d_2 for each operating discharge intersects tailwater for that discharge in the transition between the conduit and basin proper at a section where the slope of the apron is steeper than 1V on 6H. Of course, the designer must not make the apron of the transition section steeper than the trajectory of a free jet with initial velocity equal to 1.25 times the average velocity at the design discharge, or the design discharge will not spread adequately for a jump in the basin proper. However, the designer can influence to some degree the position at which action commences for low and intermediate discharges by decreasing the flare of the sidewalls. Also, a hump in the floor essentially will have the same effect as raising the invert of the outlet portal by an amount equal to the height of the hump.

14. If, for any reason, a conduit must be placed so low that eddy problems are likely, then a hydraulic model study is imperative to assist in development of a satisfactory stilling basin. Also, the designer should be aware that such a basin probably will require very mild flares and thus very long transitions.

Table 1

List of References

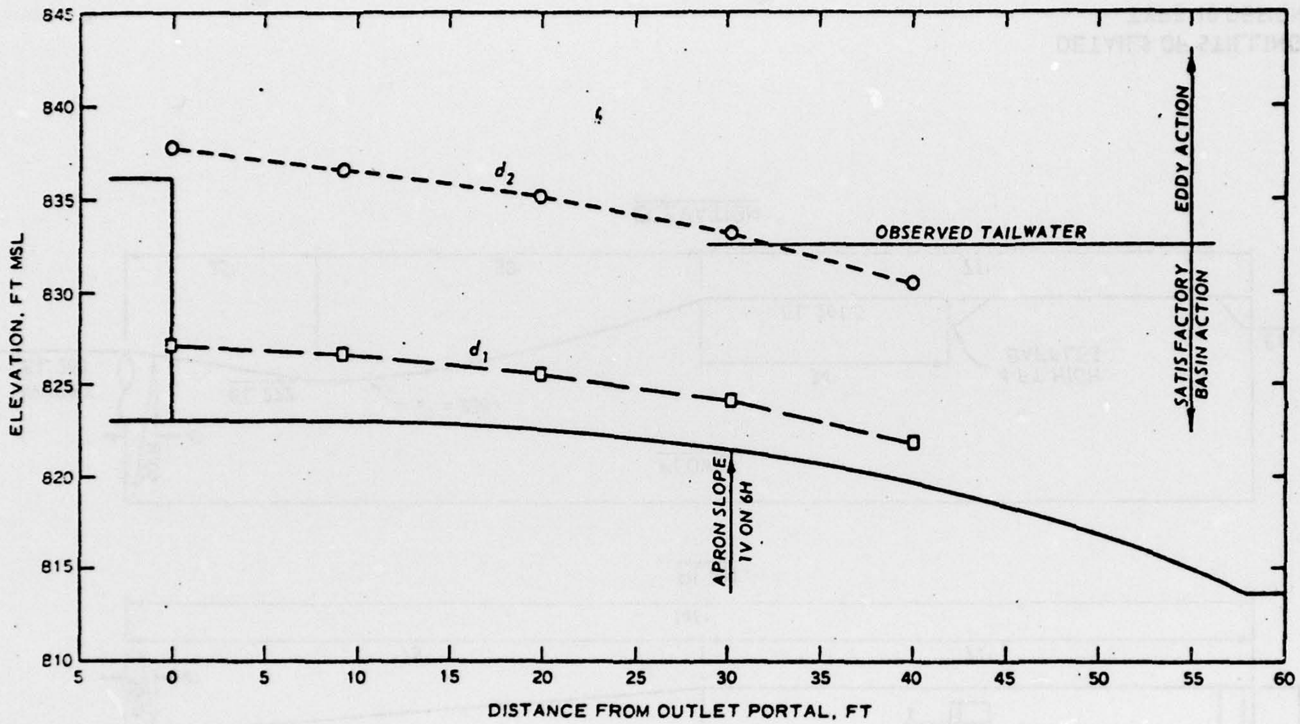
No.	Item
1	Bakhmeteff, B. A. and Matzke, A. E., "The Hydraulic Jump in Sloped Channels," Transactions, American Society of Mechanical Engineers, Vol 60, No. 2, HYD-60-1, Feb 1938, pp 111-118.
2	Stevens, J. C., Discussion of "The Hydraulic Jump in Sloping Channels," Transactions, American Society of Civil Engineers, Vol 109, 1944, pp 1125-1135.
3	Melsheimer, E. S., "Outlet Works Stilling Basins, Clinton and Fort Scott Dams, Wakarusa and Marmaton Rivers, Kansas; Hydraulic Model Investigation," Technical Report H-73-6, Jun 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
4	Oswalt, N. R., "Outlet Works Stilling Basin for Tallahala Dam, Tallahala Creek, Mississippi; Hydraulic Model Investigation," Technical Report H-73-5, Apr 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
5	__________, "Pomona Dam Outlet Stilling Basin Modifications," Memorandum Report, 31 Mar 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
6	Barnes, G. E., "A Report on Hydraulic Model Studies for the Outlet Works of the Tappan Dam on Little Stillwater Creek, Ohio," Mar 1935; and "A Report on Hydraulic Model Studies for the Outlet Works of the Clendening Dam, Brushy Fork, Little Stillwater Creek, Ohio," Mar 1935, Case School of Applied Science, Cleveland, Ohio.

Table 2

Clinton Dam Outlet Stilling Basin*

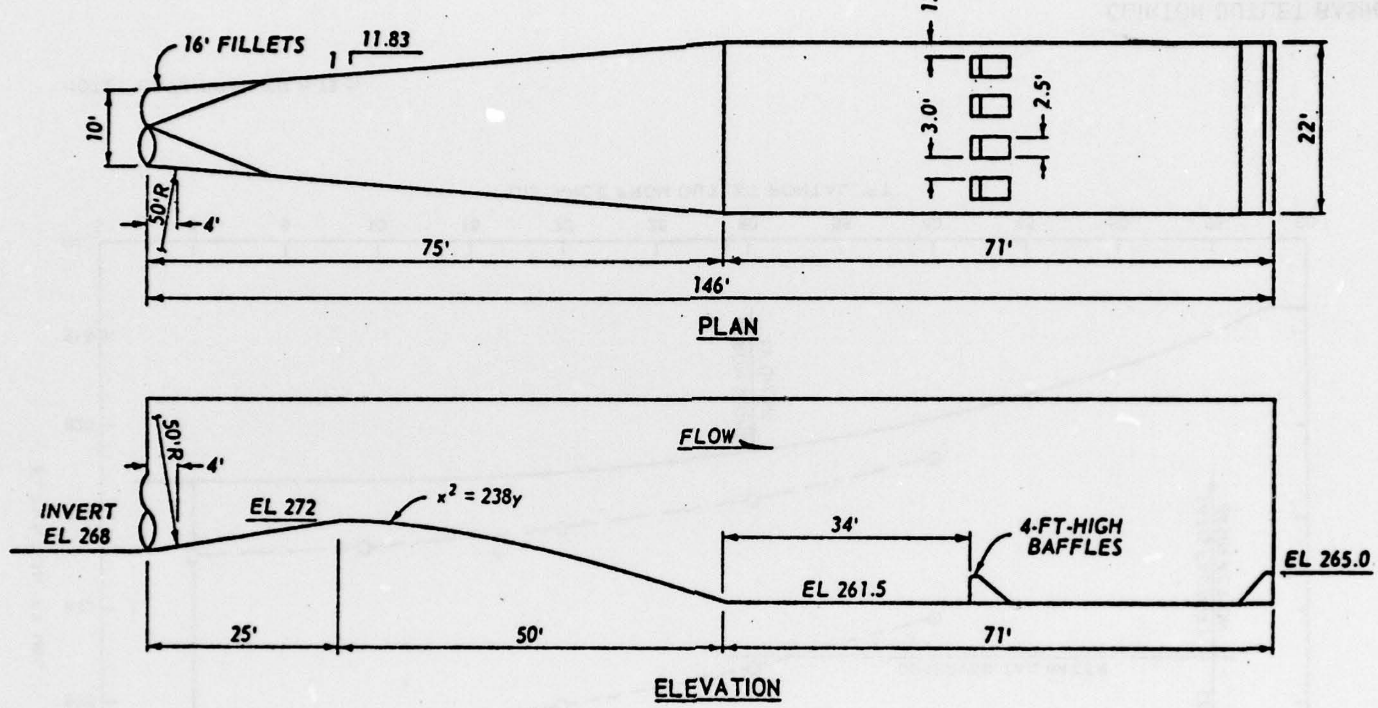
Basin Type	Discharge cfs	Section at Which Apron Slope Is 1V on 6H: Distance from Outlet Portal ft	Width ft	Elevation ft msl	Tailwater for Computed d_2 ft msl	Observed Maximum Tailwater for Satisfactory Basin Action ft msl
1	1000	30.1	24.2	821.3	828.7	826.6
	1700				832.1	832.5
	2500				835.2	834.6
3	1000	30.1	20.0	821.3	829.4	829.1
	1700**				833.1	832.4
	2500				836.5	834.9
4	1000	54.4	28.1	818.5	825.4	825.5
	1700				828.6	828.5
	2500				831.5	832.6
15	1000	48.7	26.7	821.3	828.4	827.0
	1700				831.7	831.0
	2500				834.6	835.2
16	1000	59.8	26.7	821.3	828.4	827.5
	1700				831.7	831.7
	2500				834.6	835.6

* From WES TR H-73-6.[3]
** See plot in Plate 1.

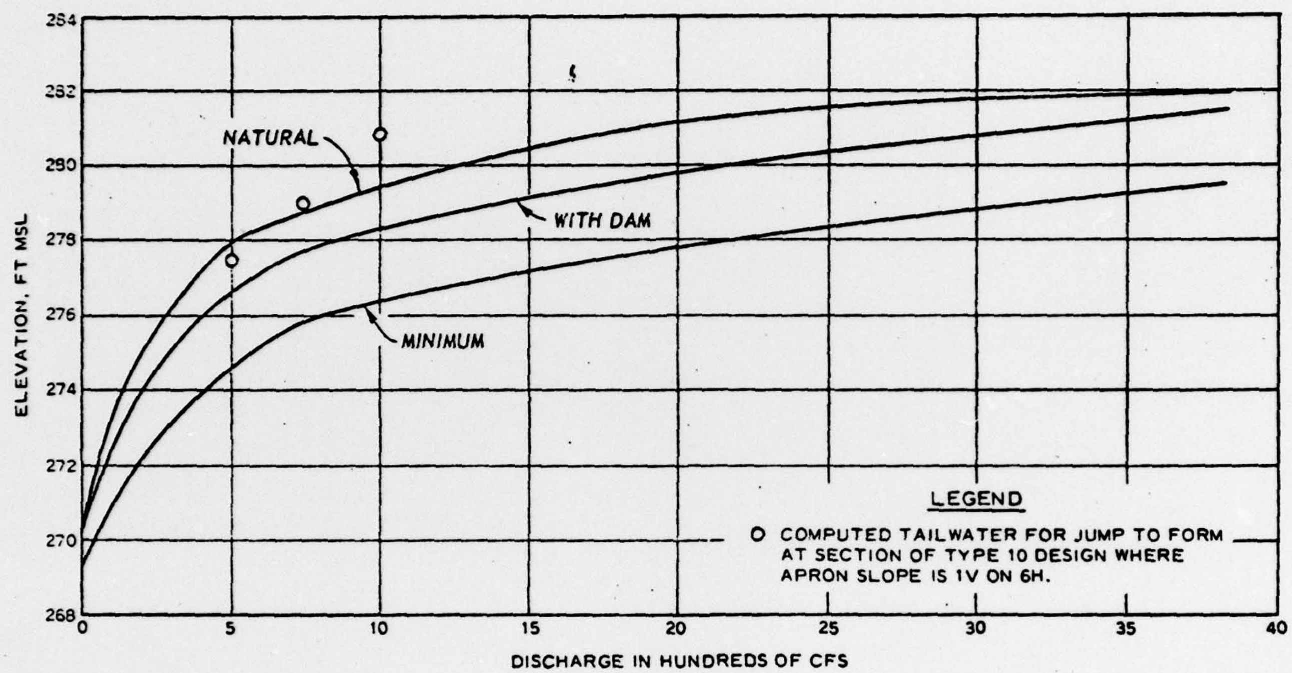


NOTE: DATA FROM TR H-73-6.

CLINTON OUTLET BASIN
TYPE 3
DISCHARGE 1700 CFS



DETAILS OF STILLING BASIN
TYPE 10 DESIGN



NOTE: WITH DAM – (IMPROVED DOWNSTREAM CHANNEL)
MINIMUM – (BASED ON MOBILE FIELD DATA)

TAILWATER RATING CURVES

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Murphy, Thomas E
Stilling basins for outlet works / by Thomas E. Murphy. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
iii, 5, [2] p., 3 leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; HL-79-8)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.
Includes bibliography.

1. Outlet works. 2. Stilling basins. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; HL-79-8.
TA7.W34m no.HL-79-8