



RESEARCH REPORT H-71-1

EVALUATION OF THREE ENERGY DISSIPATORS FOR STORM-DRAIN OUTLETS

Hydraulic Laboratory Investigation

by

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FOREWORD

The investigation reported herein was authorized by the Directorate of Military Construction, Office, Chief of Engineers, 29 May 1969. The study was conducted in the Hydraulics Division of the U. S. Army Engineer Waterways Experiment Station during the period June 1969 to August 1970 under the direction of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. T. E. Murphy, Chief of the Structures Branch. The tests were conducted by Messrs. G. A. Pickering, H. H. Allen, B. Perkins, and C. Dent under the direct supervision of Mr. J. L. Grace, Jr., Chief of the Spillways and Conduits Section. This report was prepared by Messrs. Grace and Pickering.

Directors of the Waterways Experiment Station during the conduct of the study and the preparation and publication of this report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

	<u>Page</u>
FOREWORD	iii
CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT	vii
SUMMARY	ix
PART I: INTRODUCTION	1
Background	1
Purpose of Study	1
PART II: MODELS AND TEST PROCEDURES	3
Test Facilities	3
Test Procedures	5
PART III: TESTS AND RESULTS	6
Stilling Well	6
USBR Type VI Basin	8
SAF Basin	10
PART IV: DISCUSSION	12
TABLE 1	
PLATES 1-6	

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
feet	0.3048	meters
feet per second	0.3048	meters per second
cubic feet per second	0.02831685	cubic meters per second
feet per second per second	0.3048	meters per second per second

SUMMARY

Model tests of three commonly used energy dissipators for storm-drain outlets were conducted to determine the limiting discharges for various sizes of stilling wells, U. S. Bureau of Reclamation type VI basins, and St. Anthony Falls stilling basins. Charts were prepared for each type of energy dissipator, showing the maximum recommended discharge that will result in good performance for given outlet diameters and structure widths in terms of the outlet diameter. With these charts and other known parameters, the designer can select the type of dissipator best suited to protect the outlet.

EVALUATION OF THREE ENERGY DISSIPATORS FOR STORM-DRAIN OUTLETS

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PART I: INTRODUCTION

Background

1. Research previously conducted at the U. S. Army Engineer Waterways Experiment Station (WES) and reported by Bohan* gives generalized results of tests for determining the extent of localized scour to be anticipated in cohesionless soils downstream of storm-drain outlets. Also presented in that report are results of tests for determining the size and extent of stone required to provide a stable horizontal blanket of riprap with top elevation the same as the outlet invert as a means of preventing localized scour. With these results the designer can estimate the expected scour and then decide upon the degree of protective works that will be required. A scour hole with an appropriate cutoff wall might be permissible; riprap placed on a stable horizontal blanket may be adequate; a compromise of depth of scour and riprap may be desirable; or an energy dissipator may be required.

2. A field performance study that permitted observation of drainage and erosion control facilities at several Army and Air Force installations throughout the United States has been conducted by WES during the past few years. One of the results of this study was the indication that there is an urgent need for practical guidance in the selection and design of energy dissipators for drainage facilities.

Purpose of Study

3. Several energy dissipators have been developed for use at

* J. P. Bohan, "Erosion and Riprap Requirements at Culvert and Storm-Drain Outlets; Hydraulic Laboratory Investigation," Research Report H-70-2, Jan 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

storm-drain outlets. The research reported herein was initiated in an effort to evaluate the applicability and limitations of three of the most commonly used energy dissipators, namely, a stilling well, the U. S. Bureau of Reclamation (USBR) type VI basin, and the St. Anthony Falls (SAF) stilling basin.

Test Facilities

4. An 0.80-ft-diam* pipe outlet was used to study the various energy dissipators in a 16-ft-wide, 5.5-ft-deep, and 40-ft-long test flume (see fig. 1). The trapezoidal channel downstream from the energy dissipators

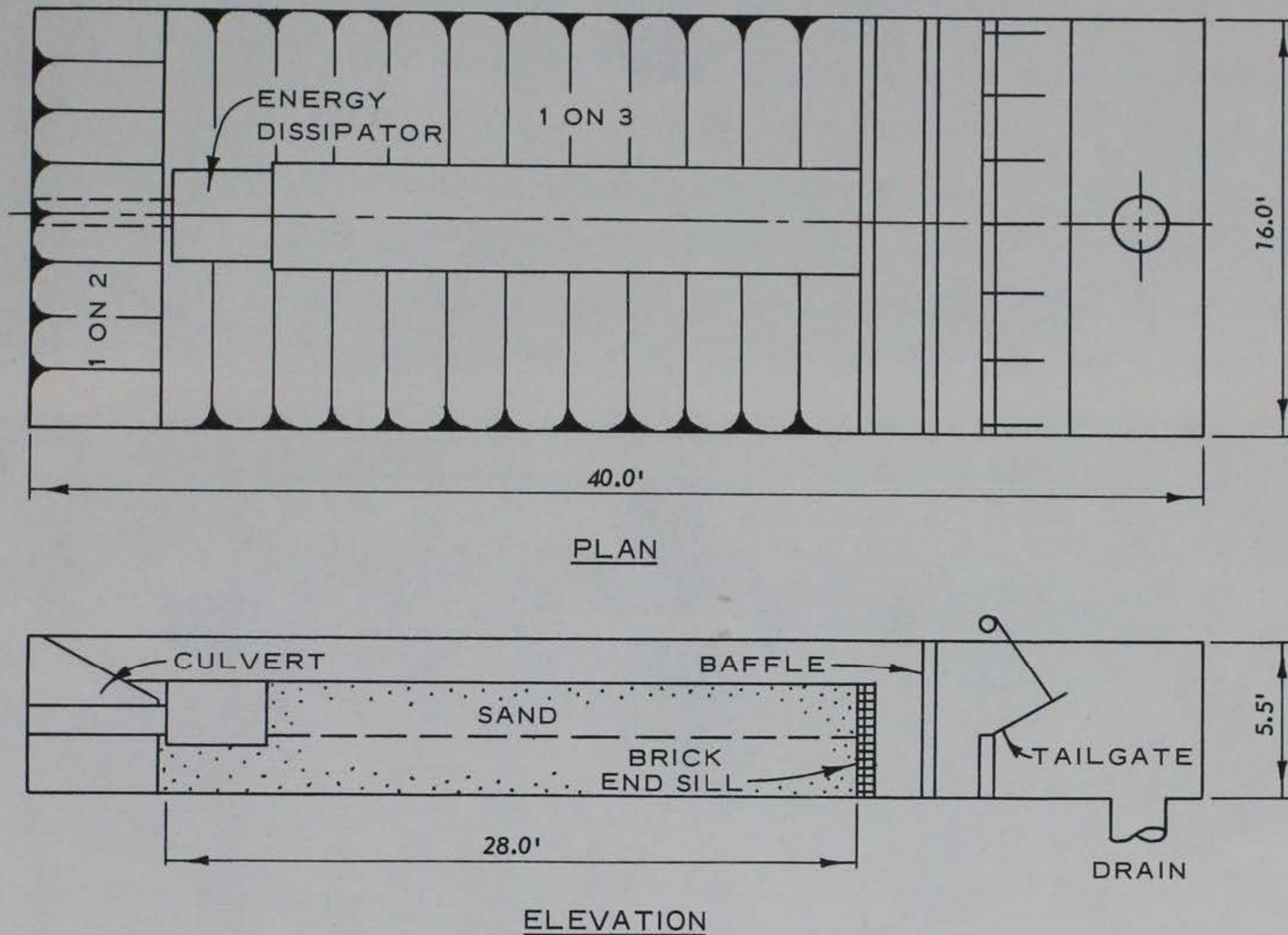


Fig. 1. Experimental facilities

was molded in sand with side slopes of 1 on 3 with the area immediately downstream from the basin outlet protected with riprap. A filter cloth was placed between the sand and riprap to prevent slumping of the riprap blanket. Models of the three energy dissipators are shown in fig. 2.

5. Water used in the operation of the models was supplied by pumps, and discharges were measured by means of calibrated venturi meters. Steel rails set to grade along the sides of the flume provided a reference plane

* A table of factors for converting British units of measurement to metric units is presented on page vii.

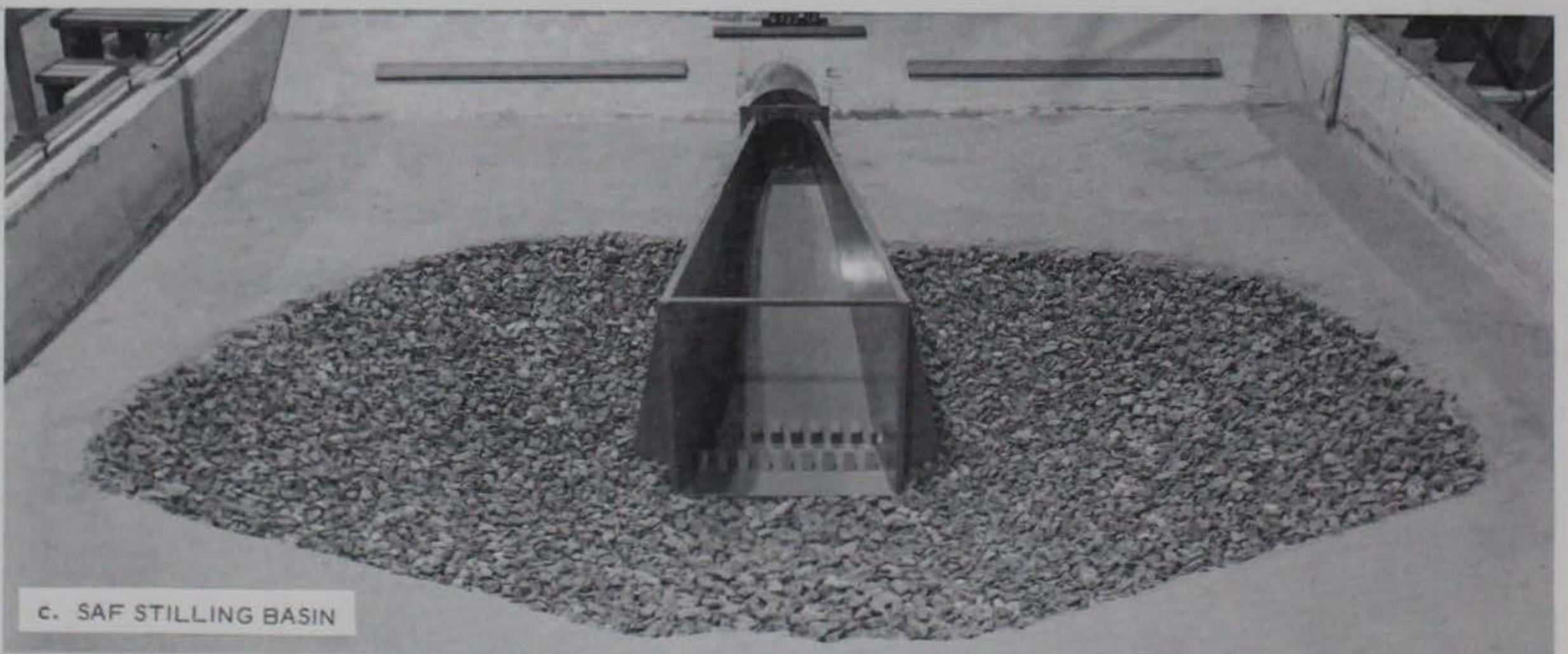
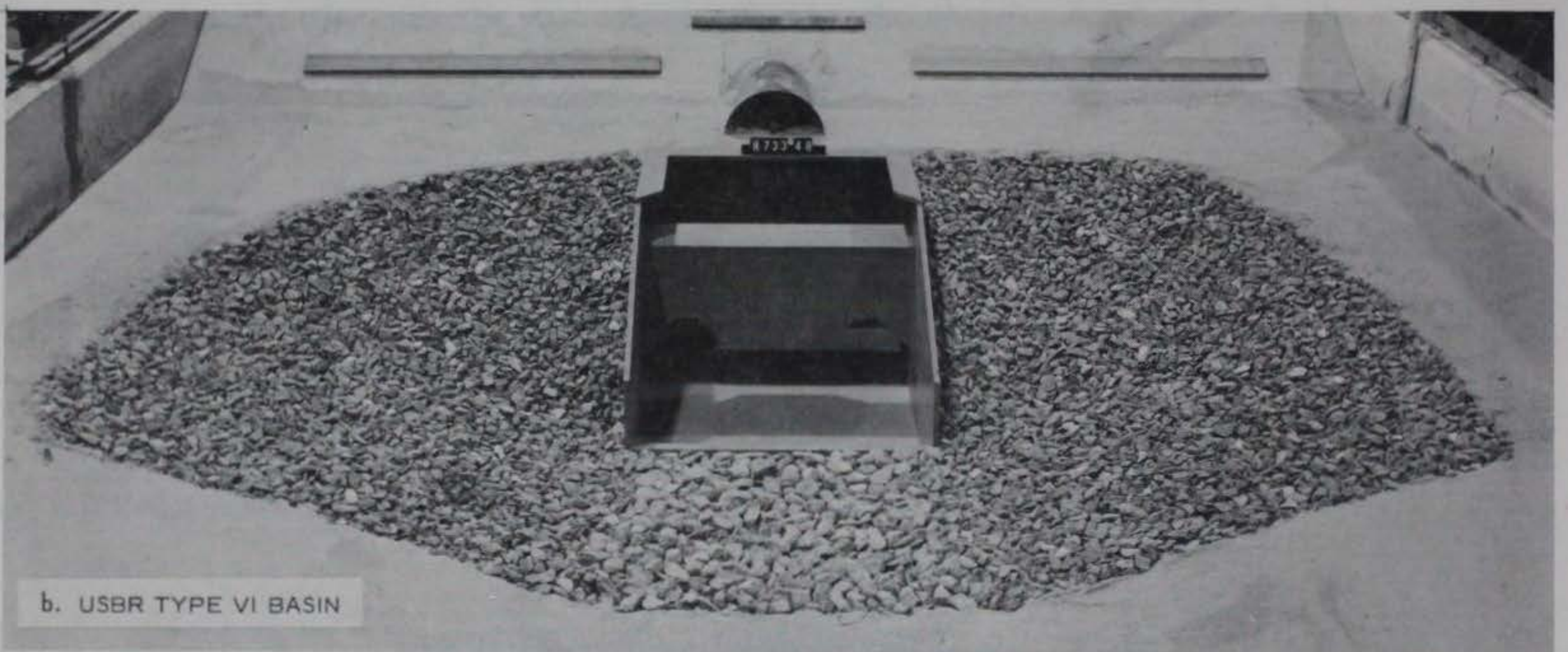
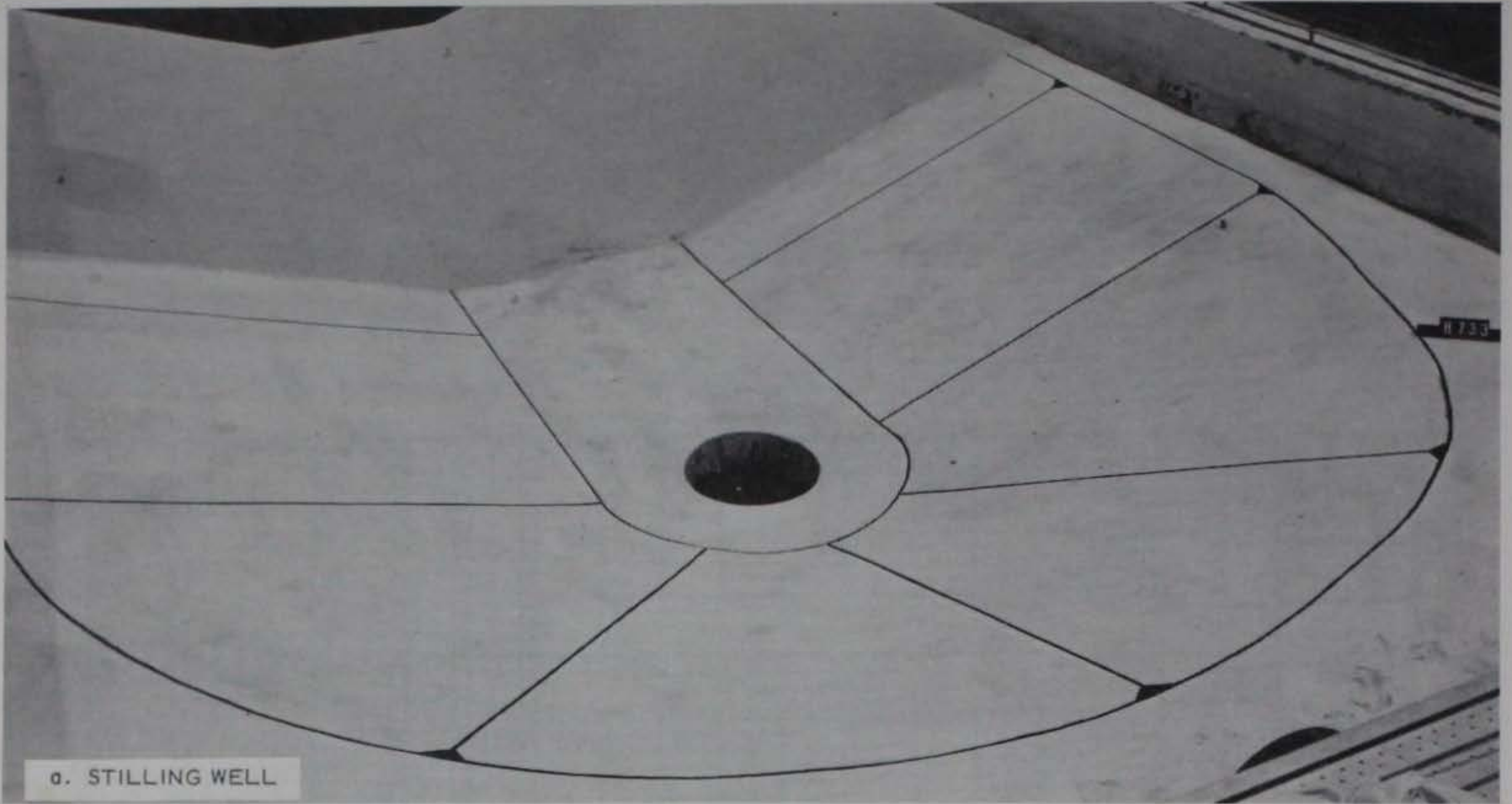


Fig. 2. Models of the three energy dissipators

for measuring devices. Water-surface elevations were measured by means of point gages, and velocities were measured with a pitot tube. Tailwater elevations were regulated by a gate at the downstream end of the flume.

Test Procedures

6. Before beginning each series of tests, the channel downstream of the energy dissipator was molded to the trapezoidal shape and flooded slowly in order to prevent erosion of the streambed. The procedures used to determine the maximum or limiting discharge with a particular energy dissipator were to set a low discharge and observe the flow conditions with various tailwater depths, then to increase the discharge and repeat until the flow conditions were considered unacceptable. The highest discharge that was considered satisfactory was reset and allowed to run for a given period of time to determine if the riprap downstream from the dissipator was sufficiently large to prevent failure. Also, in some tests velocity and wave-height measurements were made and sand scour patterns were recorded. If wave heights, velocities, and/or scour downstream from the riprap were excessive with this flow, the discharge was reduced and the procedure repeated until the flow was considered acceptable. Photographs of flow conditions, both satisfactory and unsatisfactory, were made with each design.

7. The general design practice that has developed in recent years relative to highway culverts results in the conclusion that most of these structures convey discharges up to four or five times the diameter of the culvert raised to the five-halves power. The magnitude of this quasi-dimensionless parameter will vary depending on the particular site or structure, but it is a useful, descriptive parameter for classifying the relative design capacity of such structures. It is also related to the Froude number of flow commonly used in open channel hydraulics. For example, the Froude number of full pipe flow at the outlet of a circular pipe is unity for a $Q/D_o^{5/2}$ ratio of 4.5. Thus, the main objective of this study was to determine the limiting $Q/D_o^{5/2}$ ratio for various sizes of each of the stilling devices investigated.

Stilling Well

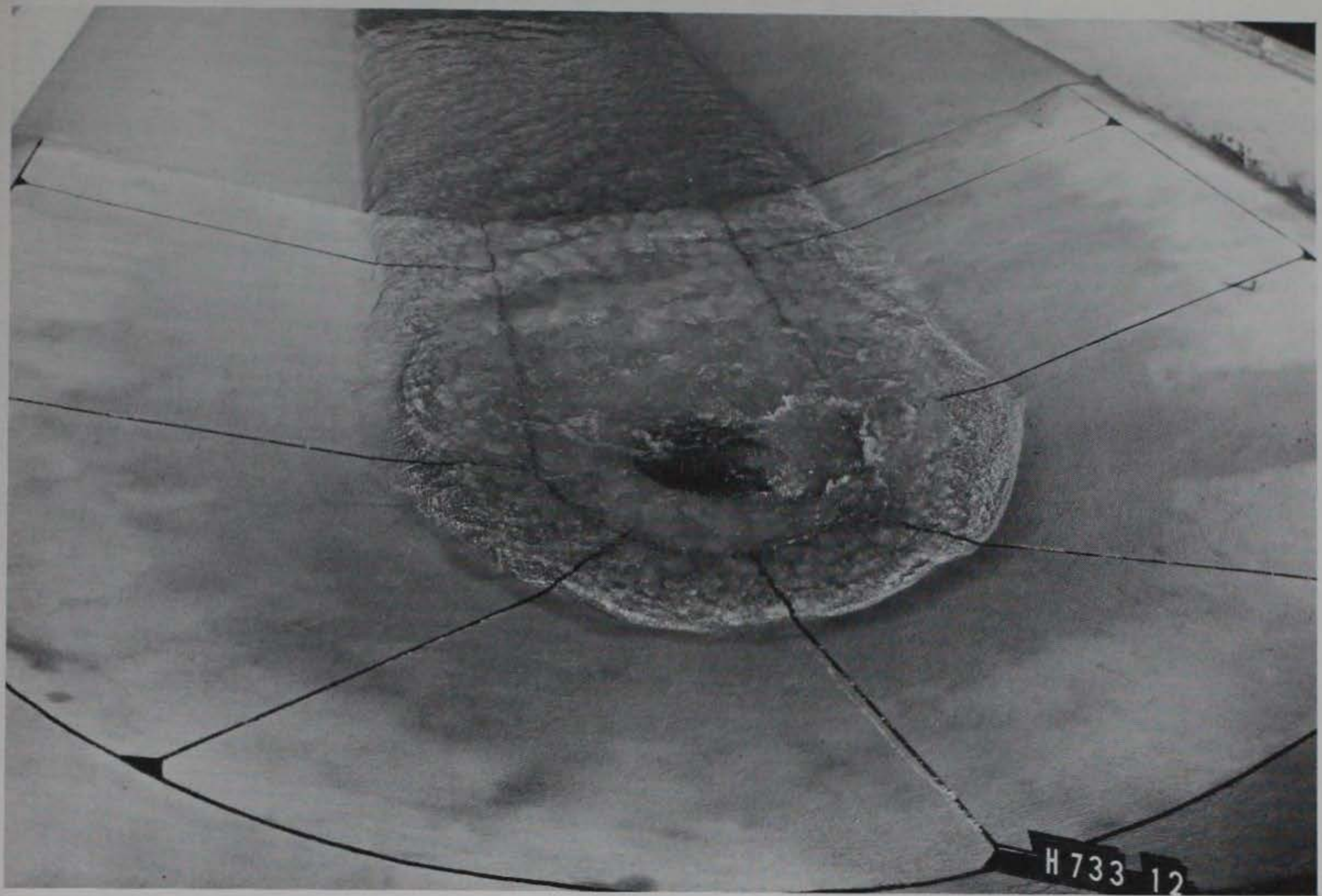
8. The stilling well consists of a vertical section of circular pipe affixed to the outlet end of a storm-drain outfall. Components of a typical stilling well are shown in plate 1. In order to be effective, the top of the well must be located at the elevation of the invert of a stable natural drainage basin or an artificial channel. The area adjacent to the top of the well, including the side slopes and outfall ditch, is usually protected by riprap or paving.

9. Energy dissipation is accomplished by the expansion of flow that occurs in the well, the impact of the fluid on the base and wall of the stilling well opposite the pipe outlet, and the change in momentum resulting from redirection of the flow. Important advantages of an energy dissipator of this type are that energy loss is accomplished without the necessity of maintaining a specified tailwater depth in the vicinity of the outlet and construction is simpler and less expensive because the concrete formwork necessary for a conventional basin is eliminated.

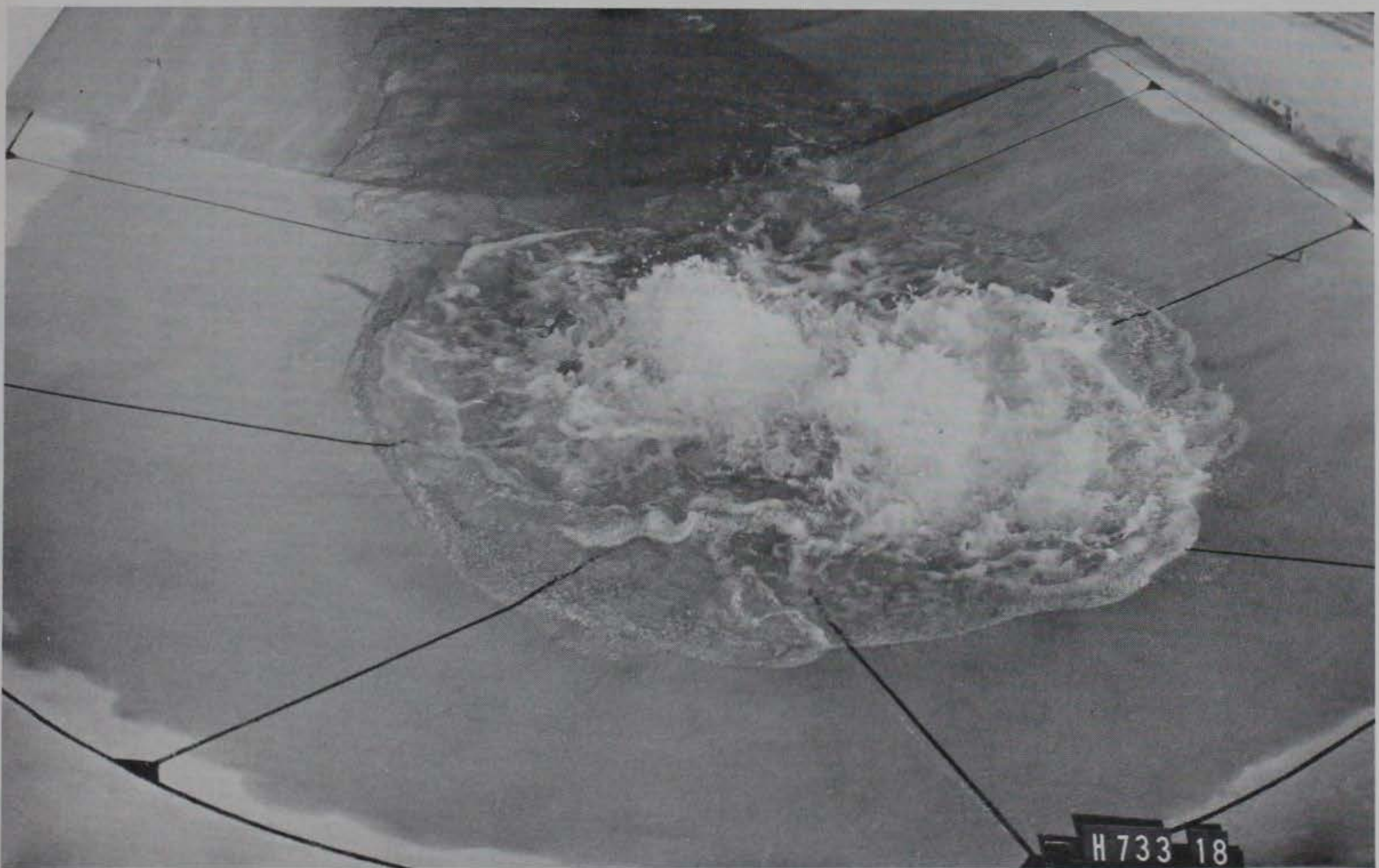
10. The stilling wells tested in this study were designed according to recommendations reported by Grace* from tests conducted on nine model stilling wells. The recommended height of stilling well above the invert of the incoming pipe is two times the diameter of the incoming pipe, D_o . The recommended depth of well below the invert of the incoming pipe is dependent on the slope of the incoming pipe and the diameter of the stilling well, D_w , and can be determined from the plot shown in plate 1.

11. Flow conditions, both satisfactory and unsatisfactory, that resulted with a stilling well diameter twice that of the incoming pipe are shown in fig. 3. The subject model investigations indicated that satisfactory performance could be maintained for $Q/D_o^{5/2}$ ratios as large as 2.0, 3.5, 5.0, and 10.0, respectively, with stilling wells with diameters one, two, three, and five times that of the incoming storm drain. These

* J. L. Grace, Jr., "Impact-Type Energy Dissipator for Storm-Drainage Outfalls, Stilling Well Design; Hydraulic Model Investigation," Technical Report 2-620, Mar 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.



a. Satisfactory; $Q/D_o^{5/2} = 3.5$



b. Unsatisfactory; $Q/D_o^{5/2} = 10$

Fig. 3. Flow conditions in stilling well

ratios were used to calculate the relations among actual storm-drain diameter, well diameter, and maximum discharge recommended for selection and design of stilling wells and shown in plate 2.

USBR Type VI Basin

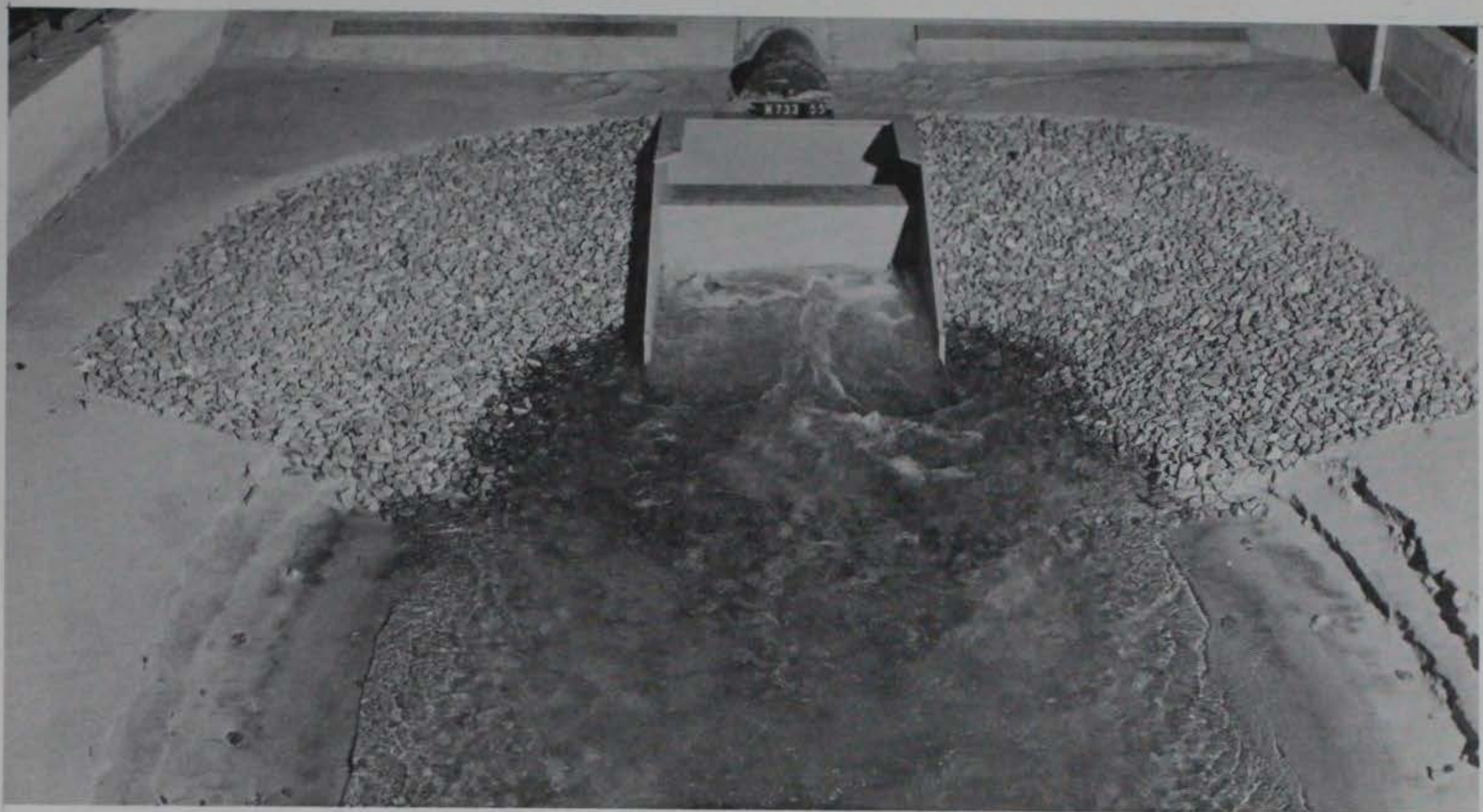
12. The USBR impact energy dissipator is an effective stilling device even with deficient tailwater. Dissipation is accomplished by the impact of the incoming jet on the vertical hanging baffle and by eddies that are formed by changing the direction of the jet after it strikes the baffle. Best hydraulic action is obtained when the tailwater elevation approaches, but does not exceed, a level halfway up the height of the baffle. Excessive tailwater, on the other hand, will cause some flow to pass over the top of the baffle; this should be avoided, if possible. With velocities less than 2 fps, the incoming jet could possibly ride underneath the hanging baffle. Thus, this basin is not recommended with velocities less than 2 fps. To prevent the possibility of cavitation or impact damage to the baffle, it is believed that an entrance velocity of 50 fps should not be exceeded with this device. The general arrangement of the type VI basin and the dimensional requirements based on the width of the structure are shown in plate 3.

13. Only one model was used to test the limitations of the type VI basin. This model was 3.3 ft wide and was designed according to recommendations reported by Beichley.* Results of tests with the subject model basin, which had a width four times the diameter of the incoming pipe, indicated that the limiting $Q/D_o^{5/2}$ was approximately 7.6. This value was slightly less than that recommended by Beichley in terms of the Froude number at the storm-drain outlet. However, the results from his study were used, with slight adjustment, to obtain conservative design criteria for other basin widths. The results of this analysis are presented in table 1.

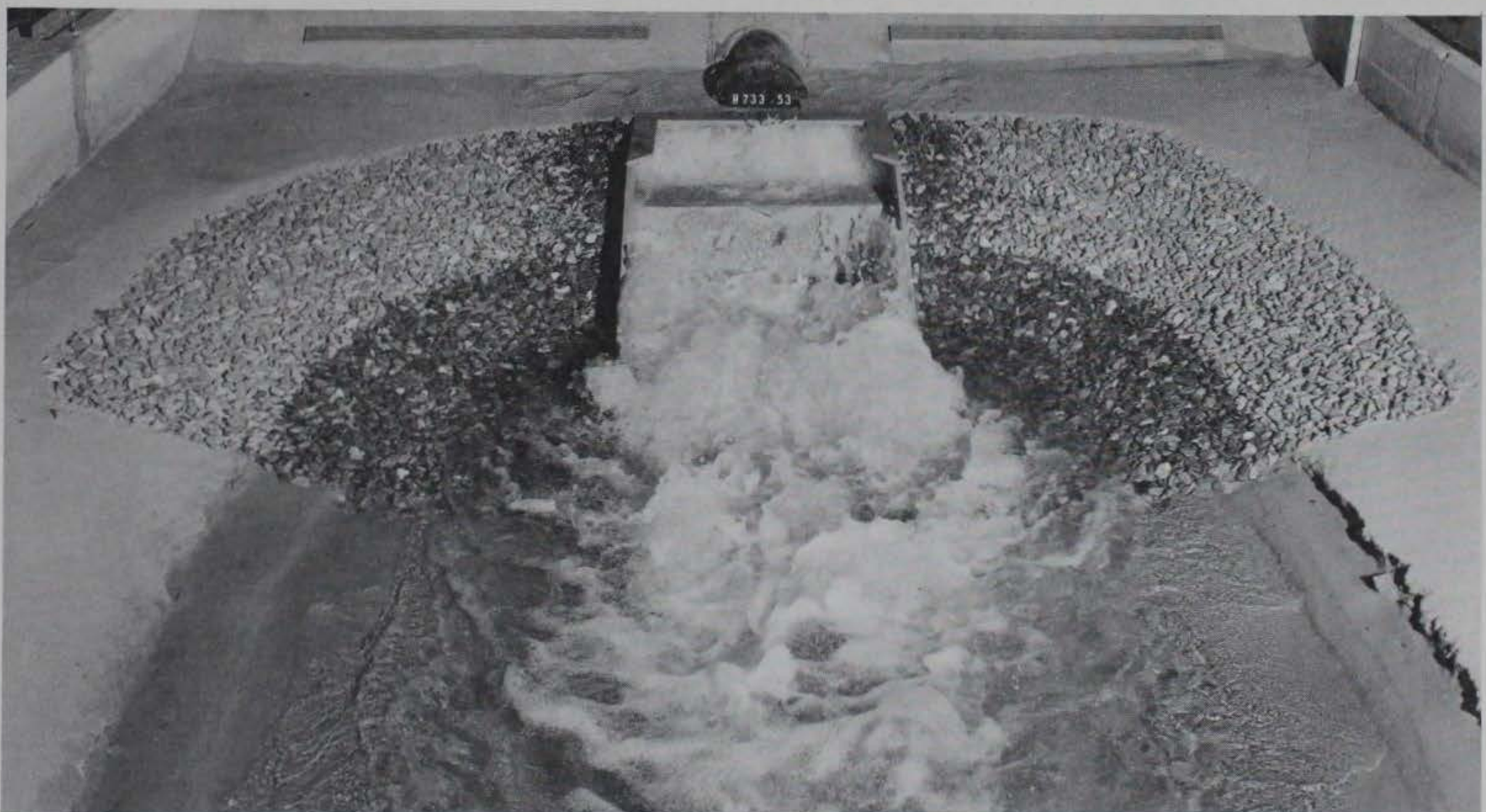
14. Photographs of flow conditions with the model basin are shown

* G. L. Beichley, "Progress Report No. XIII--Research Study on Stilling Basins, Energy Dissipators, and Associated Appurtenances--Section 14, Modification of Section 6 (Stilling Basin for Pipe or Open Channel Outlets--Basin VI)," Report No. HYD-572, June 1969, U. S. Department of the Interior, Bureau of Reclamation.

in fig. 4. The recommended relations between discharge, outlet diameters, and basin widths are shown in plate 4. With the discharge and size of the incoming pipe known, the required width of the basin can be determined from



a. Satisfactory; $Q/D_o^{5/2} = 6.9$



b. Unsatisfactory; $Q/D_o^{5/2} = 13.5$

Fig. 4. Flow conditions in USBR type VI basin

the design curves; and other dimensions of the basin can be computed from the equations in plate 3.

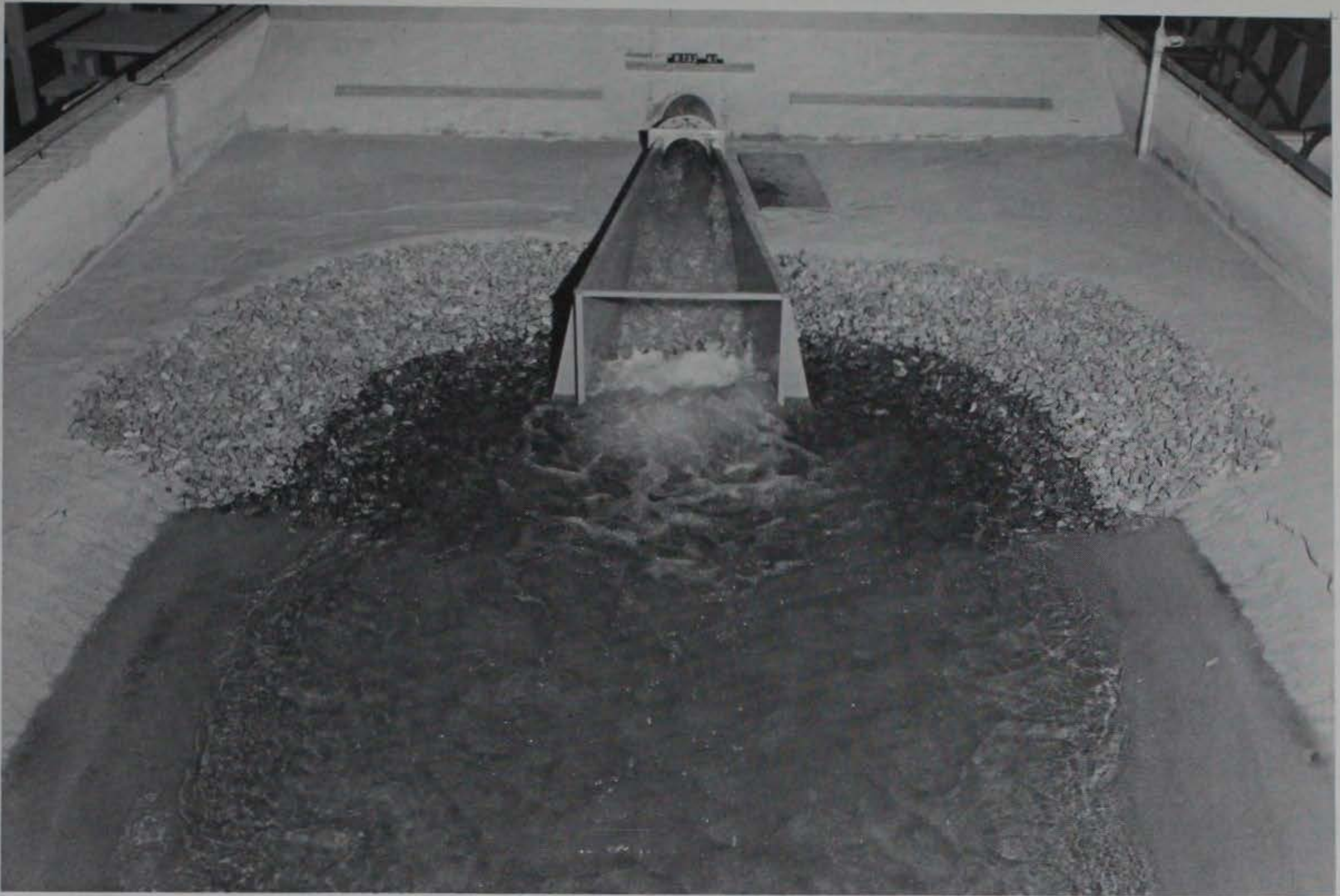
SAF Basin

15. The SAF stilling basin is a hydraulic-jump type basin. All the dimensions of this basin are related in some way to the hydraulic jump. A reduction in the basin length from that of a natural hydraulic jump is achieved through the use of appurtenances consisting of chute blocks, floor blocks or baffle piers, and an end sill. General details of the SAF basin are shown in plate 5. Dimensions of the chute blocks and floor blocks may be modified slightly to provide reasonable construction dimensions without materially affecting the efficiency of the structure.

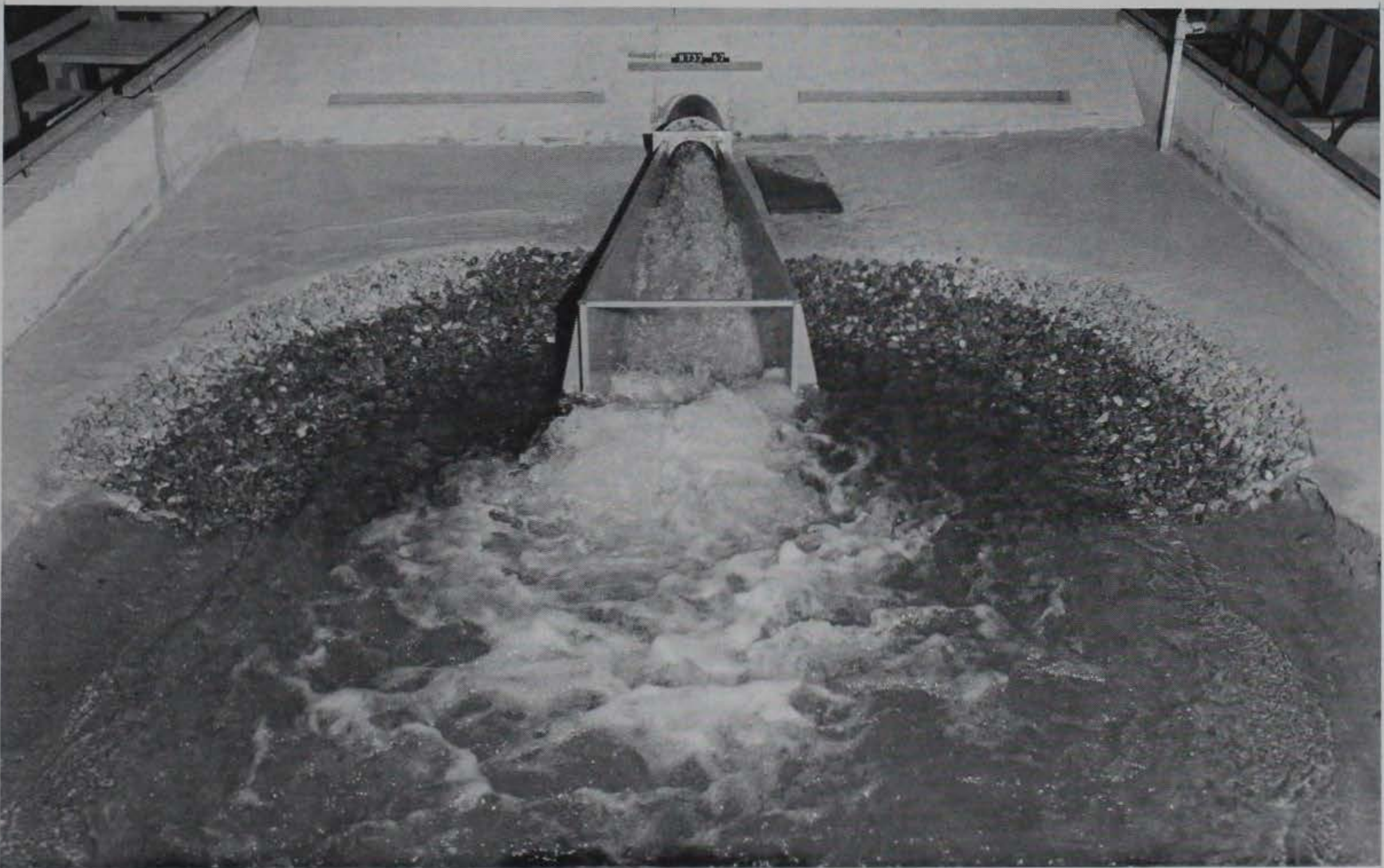
16. Models of six different SAF basins were tested. These basins were constructed according to recommendations made by Blaisdell* from model tests at the St. Anthony Falls Hydraulic Laboratory. Stilling basins one, two, and three times as wide as the outlet were tested with drops from the invert of the outlet to basin floor of one-half and two times the outlet diameter. The basins with widths of two and three times the outlet diameter were flared 1 on 8 with respect to the center line of the structure. The size of the basin elements and the basin length were adjusted for the two apron elevations according to the depth of flow entering the basin. Comparisons of flow conditions for the various discharges with each basin were made with tailwater depths that were just sufficient to produce a hydraulic jump in the basin.

17. Results of tests indicated that within the limits investigated the drop from the invert of the outlet to the basin apron had little effect on the limiting $Q/D_o^{5/2}$ ratios. Maximum values of 3.5, 7.0, and 9.5 were indicated for $1D_o$, $2D_o$, and $3D_o$ wide SAF stilling basins, respectively. These results were used to determine the relations recommended for design and shown in plate 6. Photographs of flow conditions with the SAF stilling basin are shown in fig. 5.

* F. W. Blaisdell, "The SAF Stilling Basin," Agricultural Handbook No. 156, Apr 1959, Agricultural Research Service and St. Anthony Falls Laboratory.



a. Satisfactory; $Q/D_o^{5/2} = 6.9$



b. Unsatisfactory; $Q/D_o^{5/2} = 12.0$

Fig. 5. Flow conditions in SAF stilling basin

18. The practice of siting outlets equipped with or without energy dissipators high relative to a stable downstream grade in order to reduce quantities of pipe and excavation is the primary cause of gully scour. Erosion of this type may be of considerable extent depending upon the location of the stable section relative to that of the outlet in both the vertical and downstream directions. Storm-drain outlets and energy dissipators should be located at sites where the slope of the downstream channel or drainage basin is naturally mild enough to remain stable under the anticipated conditions or else it should be controlled by ditch checks, drop structures, and/or other means to a point where a naturally stable slope and cross section exist.

19. A scour hole or localized erosion is to be expected downstream of an outlet even if the downstream channel is stable. The severity of scour depends upon the conditions existing or created at the outlet. Guidance relative to the extent of scour to be anticipated downstream of a culvert or storm-drain outlet is presented by Bohan* as well as size and extent requirements of horizontal blankets of riprap for protection of outlets. These generalized results offer considerable guidance since one can estimate the extent of localized scour to be anticipated in stable channels of cohesionless soils downstream of an outlet and then decide what degree of protection is required. For example, is it permissible to allow the anticipated scour hole to develop and provide an appropriate cutoff wall to protect the outlet? Are the size and extent of riprap required for a stable horizontal blanket practicable? Is it practicable to compromise depth of scour and size of riprap by providing a preformed and riprap-lined scour hole? Is an energy dissipator required?

20. The tests and data analyses reported herein are summarized in table 1 to indicate the range of applicability or maximum discharge capacity for various widths of three commonly used energy dissipators relative to the diameter of the incoming culvert or storm-drain outlet, D_o . Based on

* Bohan, see footnote reference on page 1.

these values of the relative maximum discharge capacity for comparable relative widths of the three energy dissipators, the stilling well is particularly suited to the lower range of discharges, the USBR type VI basin to the intermediate range of discharges, and the SAF stilling basin to the higher range of discharges. However, all three of the energy dissipators are applicable for general drainage and erosion control practice. Comparative cost analyses will indicate which of the devices is the most economical energy dissipator for a given installation.

21. With information such as that developed for each of the three energy dissipators and knowing the outlet diameter and design discharge, the designers can determine the applicability and necessary dimensions of each type of energy dissipator. In some cases, more than one type of dissipator may be applicable and in such cases local terrain, tailwater conditions, and cost analyses will determine the most practical energy dissipator for protecting the outlet. For example, with a 60-in.-diam culvert and a design discharge of 390 cfs, either a 10-ft-wide ($2D_o$) SAF stilling basin, or a 20-ft-wide ($4D_o$) USBR type VI basin, or a 20-ft-diam ($4D_o$) stilling well could be used. With a 48-in.-diam culvert and a design discharge of 110 cfs, either a 4-ft-wide ($1D_o$) SAF stilling basin or an 8-ft-diam ($2D_o$) stilling well or a 10-ft-wide ($2.5D_o$) USBR type VI basin could be used.

22. Some form of protection consisting of paved and/or riprap-lined expansions is required to prevent excessive scour downstream of energy dissipators. It is considered that an expansion in either or both the horizontal and vertical to permit dissipation of excess kinetic energy in turbulence rather than direct attack of the channel boundaries is most practical. Guidance is needed in this area as well as for selection of the size and extent of riprap required downstream of energy dissipators. In general, the unpublished results of WES investigations of riprap protection downstream of hydraulic structures indicate that the minimum average size of stone required for protection of an exit channel downstream of an energy dissipator can be described by the following empirical relation:

$$d_s = D \left(\frac{V}{\sqrt{gD}} \right)^3$$

where

d_s = minimum average size of stone, ft, usually termed d_{50} , indicating that 50 percent by weight of a graded mixture is larger than the respective diameter

D = depth of flow in channel downstream of structure, ft

V = average velocity of flow in channel, fps

g = gravitational acceleration, ft/sec^2

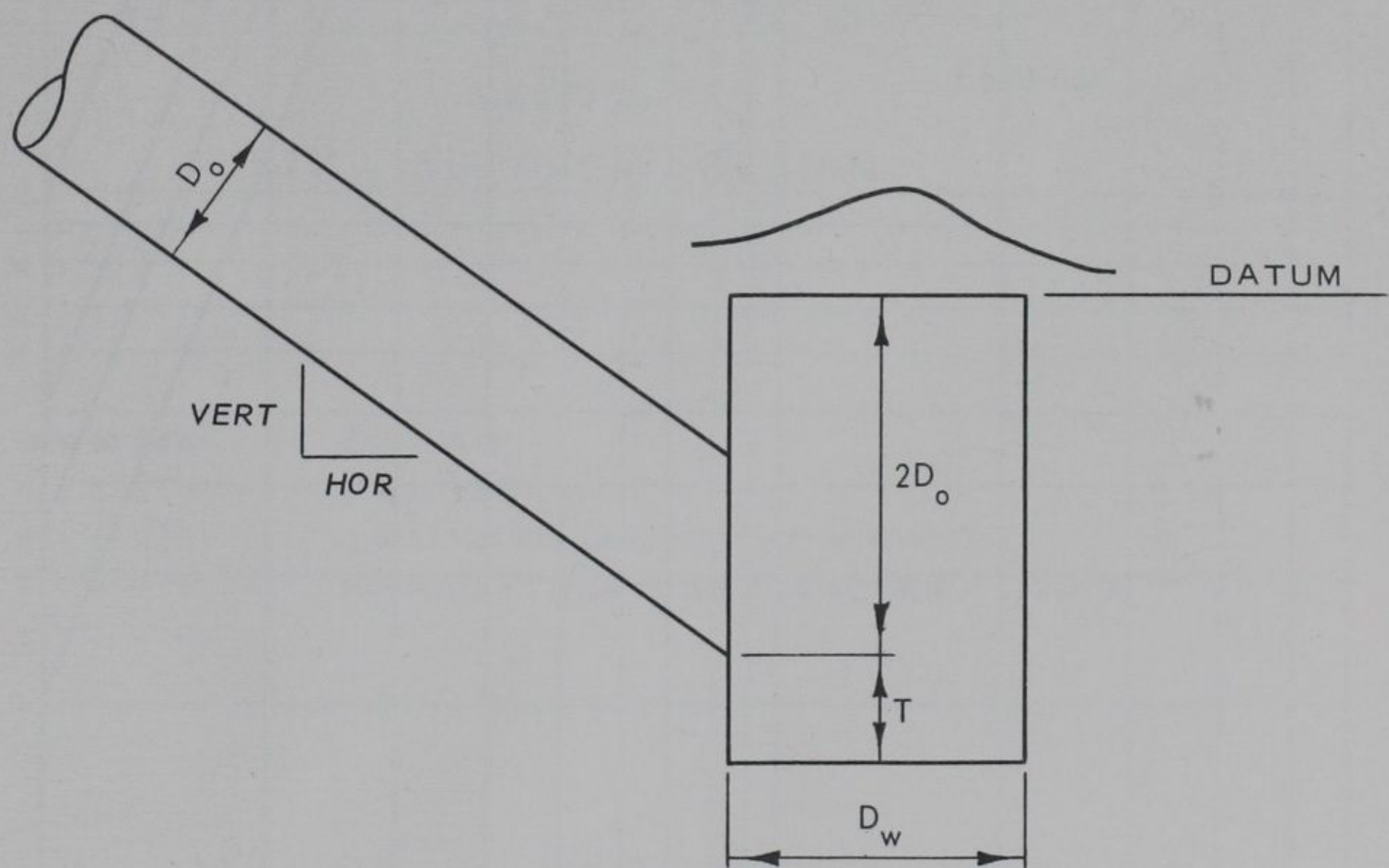
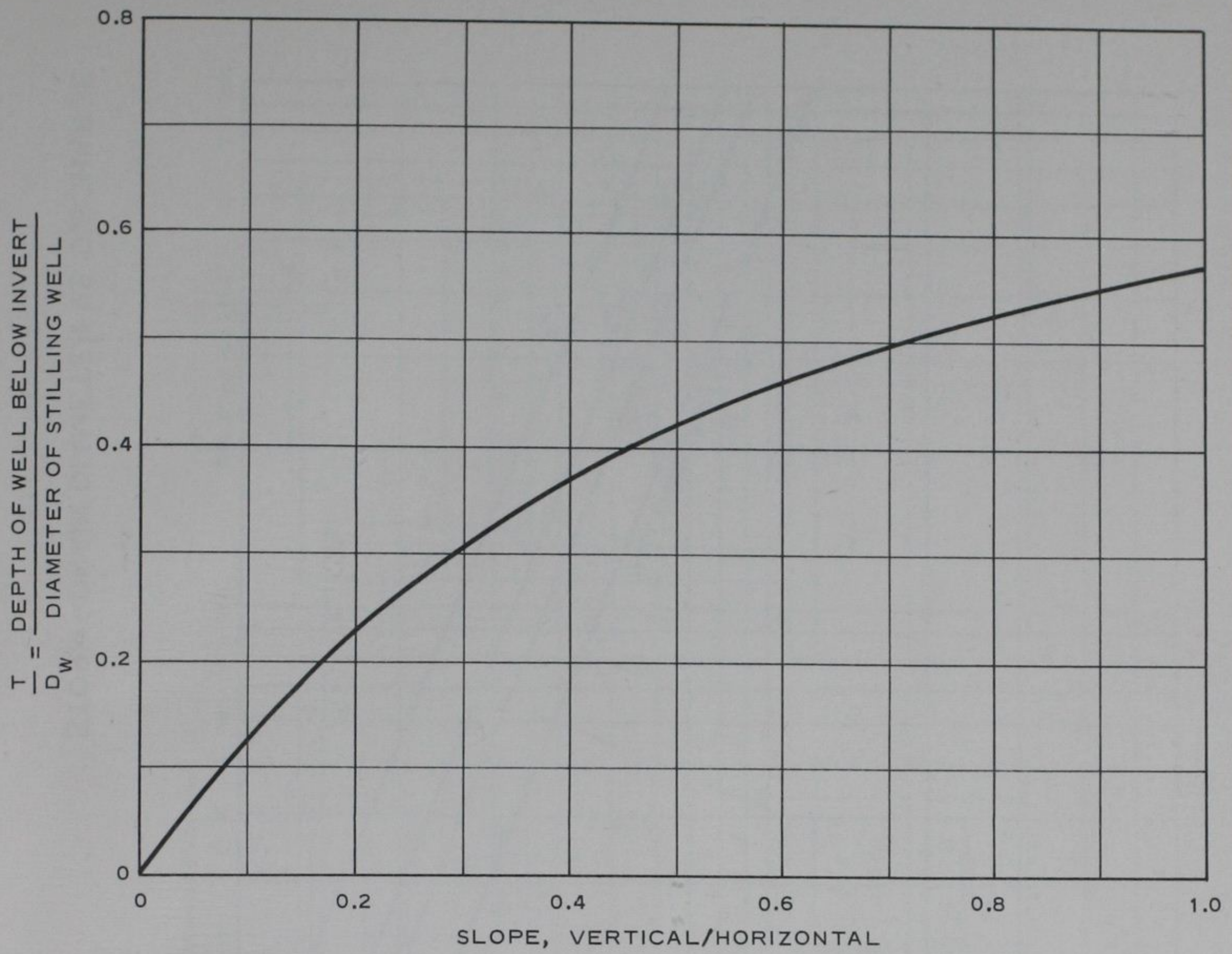
The protection should be extended downstream for a minimum distance equivalent to the width of the energy dissipator.

23. Additional options are desired that are more economical than these commonly used energy dissipators, and WES is continuing research to develop several simple stilling devices that will be more appropriate for the range of low and intermediate discharges. Efforts will be concentrated to develop practical guidance relative to preformed, riprap-lined scour holes or plunge pools, and paved aprons with and without end sills.

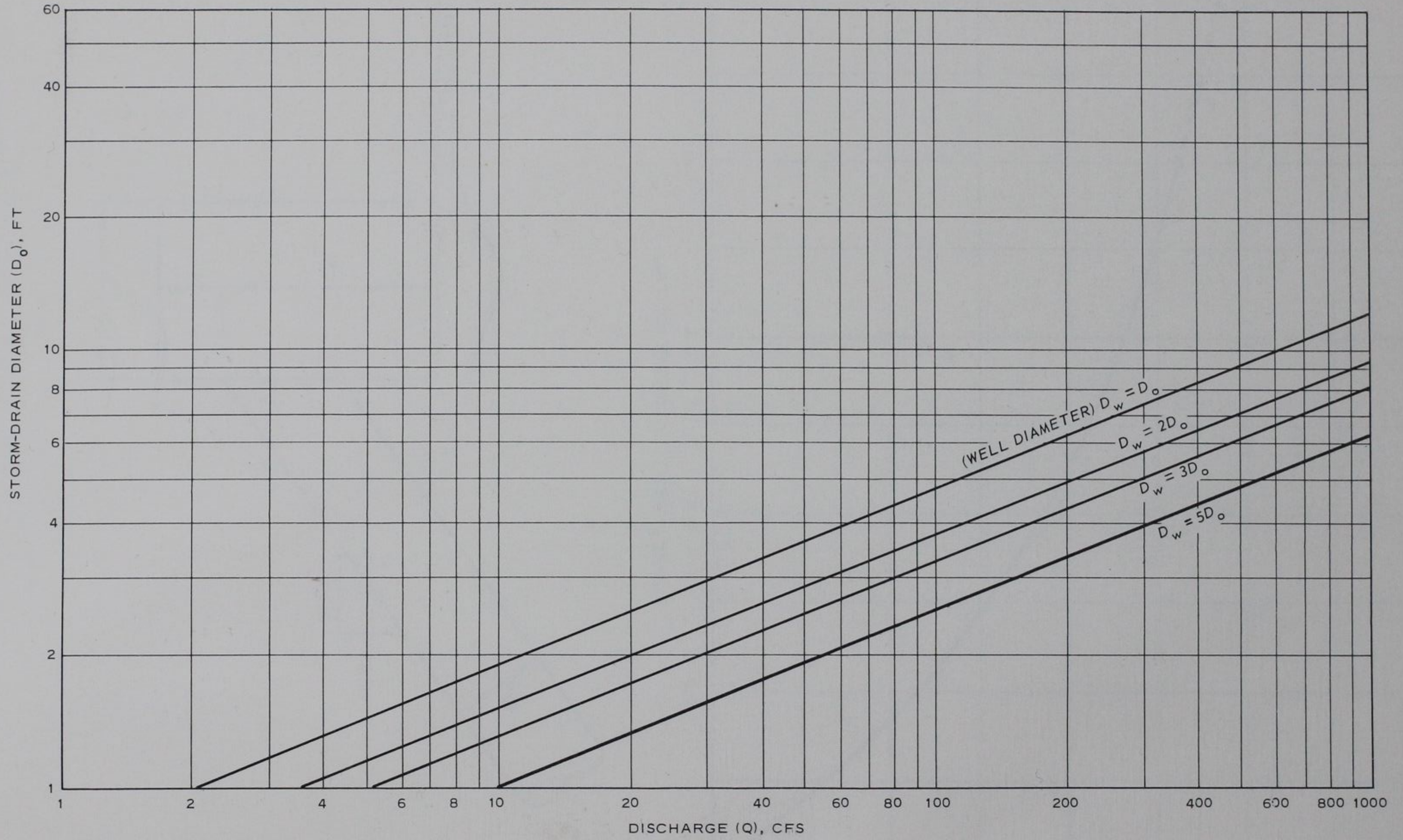
Table 1

Maximum Discharge Recommended for Various
Types and Sizes of Energy Dissipators

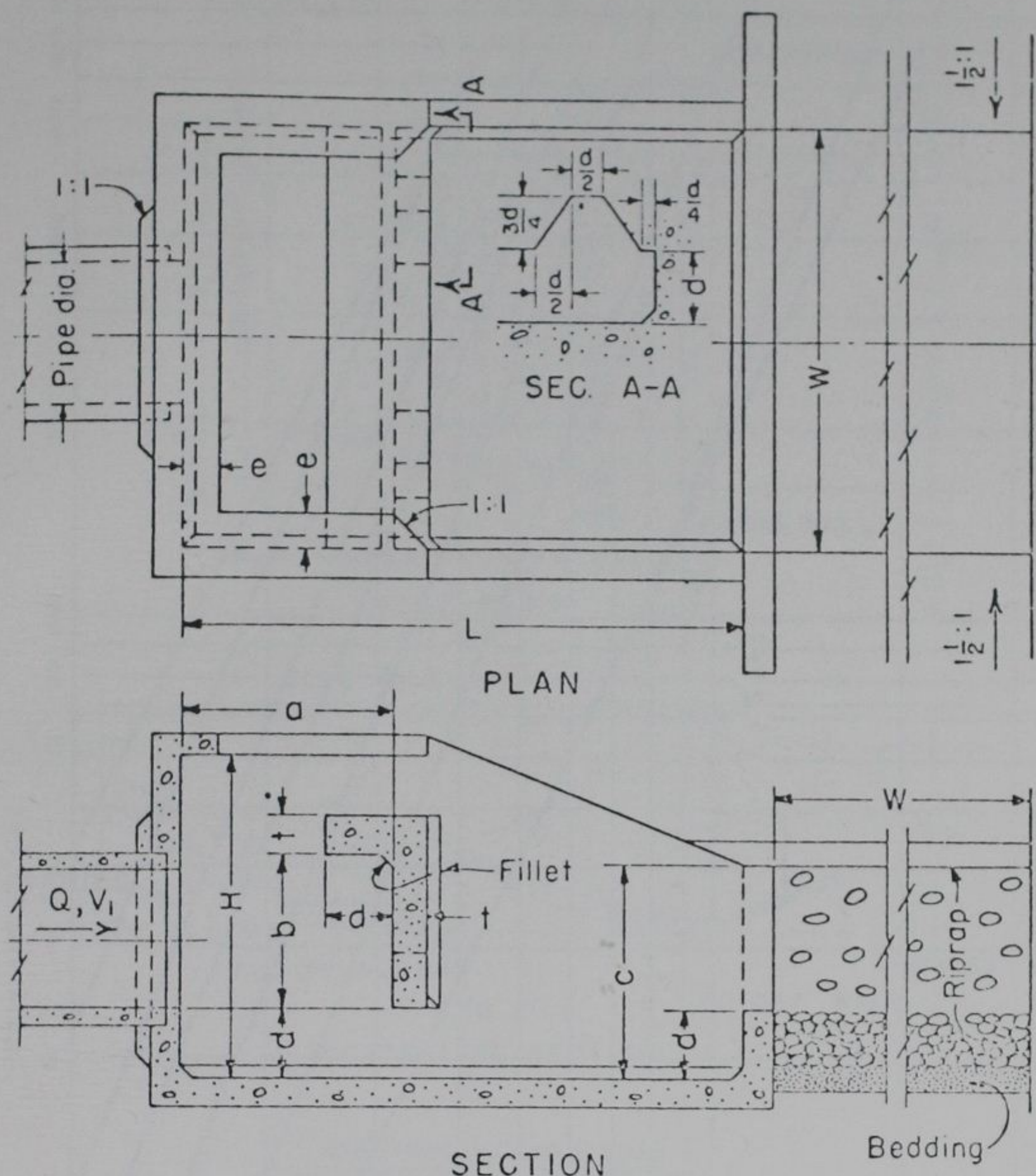
<u>Relative Width and Type of Energy Dissipator</u>	<u>Maximum $Q/D_o^{5/2}$</u>
<u>Stilling Well</u>	
1 D_o Diameter	2.0
2 D_o Diameter	3.5
3 D_o Diameter	5.0
5 D_o Diameter	10.0
<u>USBR Type VI Basin</u>	
1 D_o Wide	0.6
2 D_o Wide	2.2
3 D_o Wide	4.5
4 D_o Wide	7.6
5 D_o Wide	11.5
7 D_o Wide	21.0
<u>SAF Stilling Basin</u>	
1 D_o Wide	3.5
2 D_o Wide	7.0
3 D_o Wide	9.5



STILLING WELL



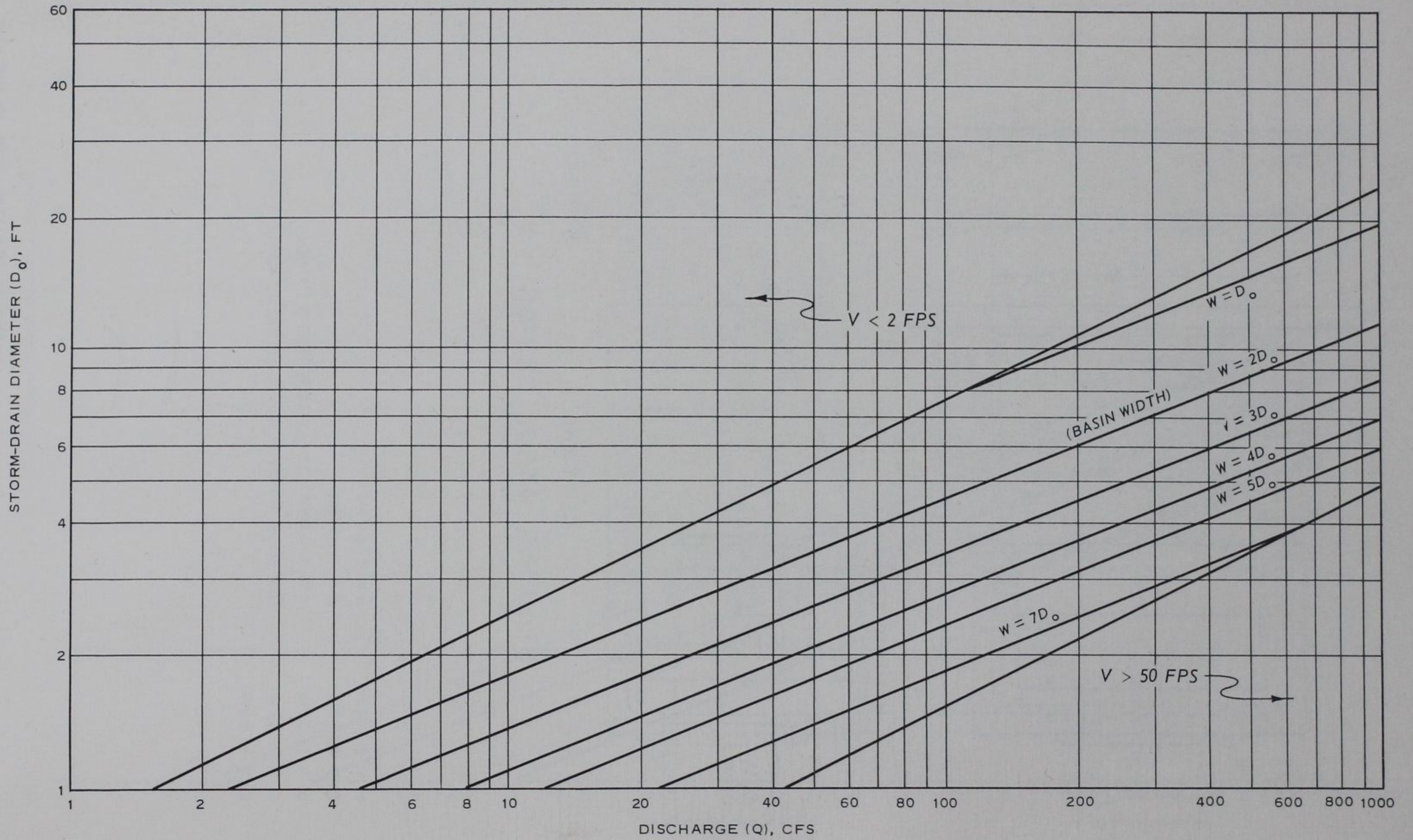
STORM-DRAIN DIAMETER VS DISCHARGE
STILLING WELL



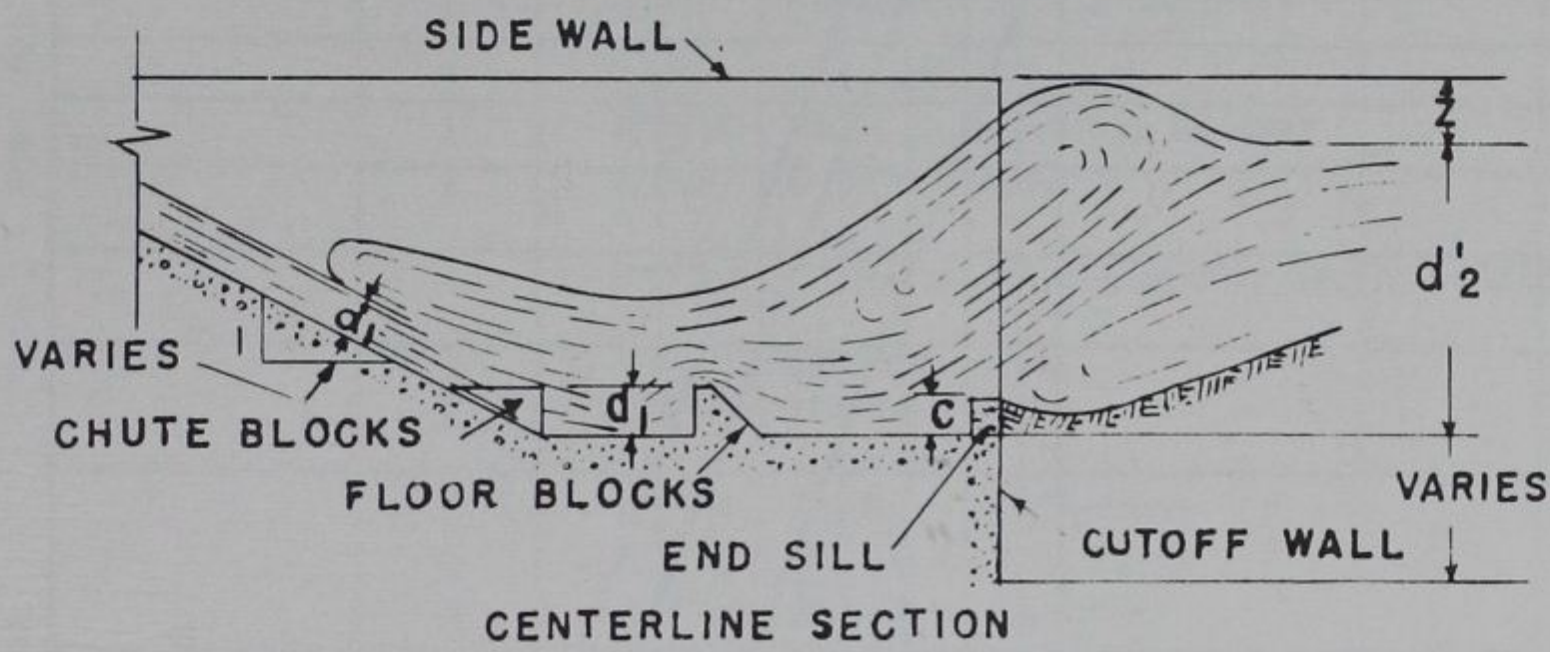
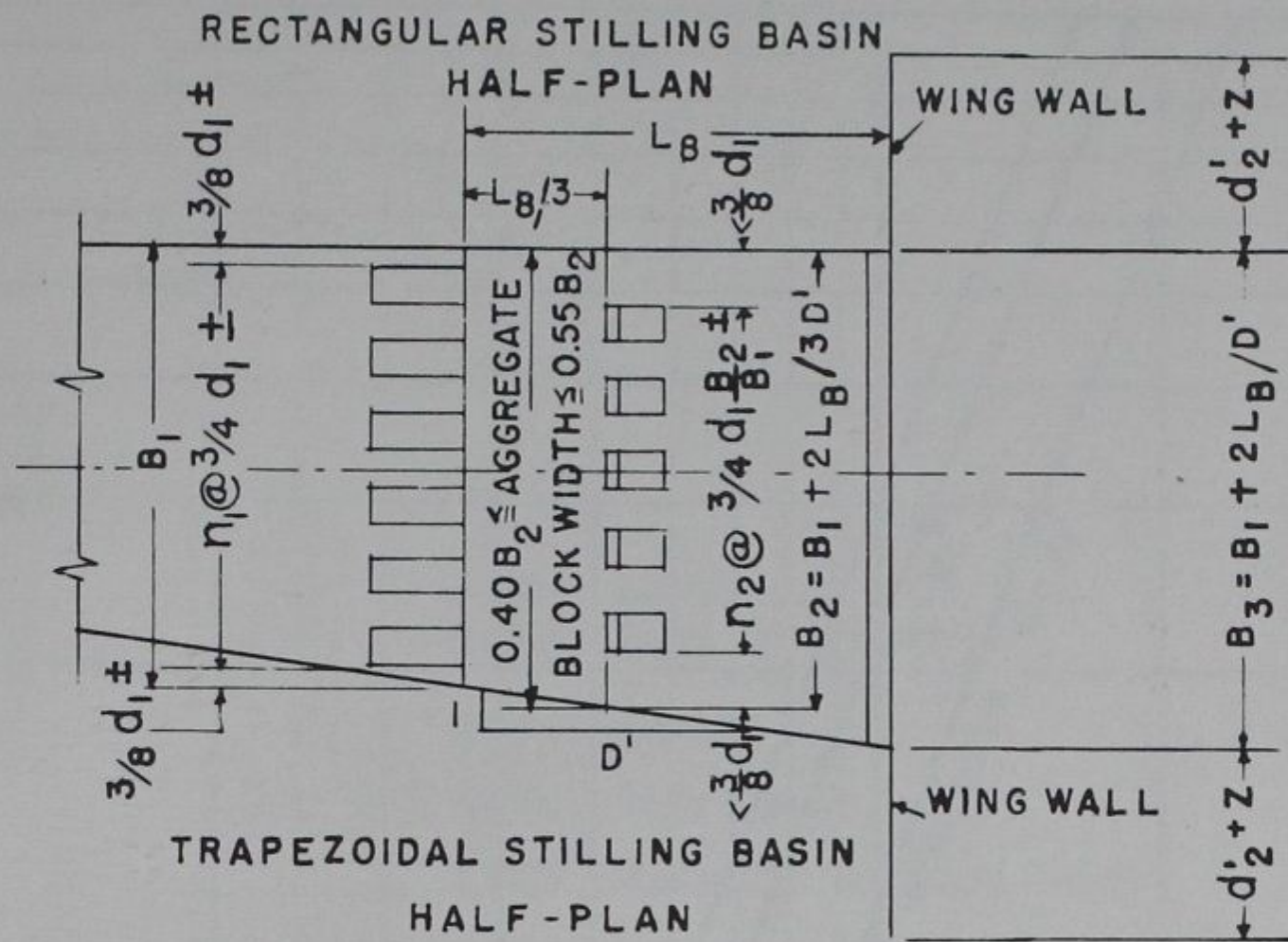
STILLING BASIN DESIGN

- | | |
|---------------|---|
| $H = 3/4 (W)$ | $d = 1/6 (W)$ |
| $L = 4/3 (W)$ | $e = 1/12 (W)$ |
| $a = 1/2 (W)$ | $t = 1/12 (W)$, SUGGESTED MINIMUM |
| $b = 3/8 (W)$ | RIPRAP STONE SIZE DIAMETER = $1/20 (W)$ |
| $c = 1/2 (W)$ | |

USBR TYPE VI BASIN



STORM-DRAIN DIAMETER VS DISCHARGE
USBR TYPE VI BASIN



DESIGN EQUATIONS

(1) $F = \frac{V_1^2}{gd_1}$ (2) $d_2 = \frac{d_1}{2} (-1 + \sqrt{8F + 1})$

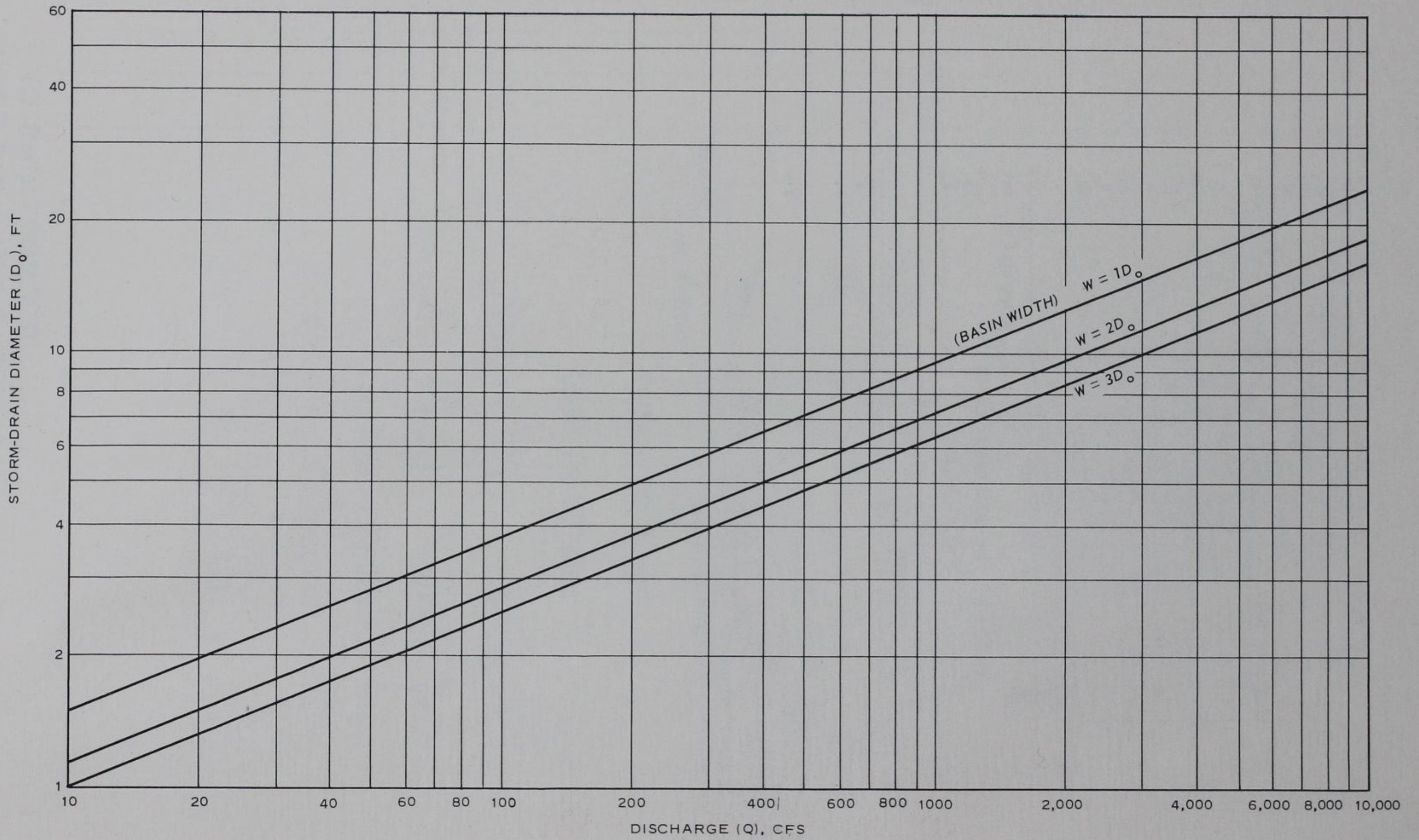
(3a) $F = 3 \text{ TO } 30$ $d'_2 = (1.10 - F/120) d_2$

(3b) $F = 30 \text{ TO } 120$ $d'_2 = 0.85 d_2$

(3c) $F = 120 \text{ TO } 300$ $d'_2 = (1.00 - F/800) d_2$

(4) $L_B = \frac{4.5d_2}{F^{0.38}}$ (5) $Z = \frac{d_2}{3}$ (6) $c = 0.07d_2$

PROPORTIONS OF SAF STILLING BASIN



STORM-DRAIN DIAMETER VS DISCHARGE
SAF STILLING BASIN

Unclassified

Security Classification

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