UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

JUNE 1969

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values. A table of conversion factors--BRITISH TO METRIC UNITS OF MEASUREMENT--is provided at the end of this report.

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by

G. L. Beichley

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ACKNOWLEDGMENTS

The study was conducted by the writer and reviewed by Mr. T. J. Rhone under the supervision of the Applied Hydraulics Section Head, Mr. W. E. Wagner, and the direction of the Hydraulics Branch Chief, Mr. H. M. Martin.

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ABSTRACT

Model studies on 1.6- and 2.4-ft-wide (48.76 and 73.15 cm) Type VI stilling basins were conducted to modify existing standard design procedures. Investigations were concerned with: basin entrance flow conditions including type of entrance, slope, velocity, and Froude number; basin dimensions in relation to the basin width; basin width in relation to Froude number; and riprap size and location. Performance was evaluated in terms of energy dissipation and prototype operation. An optimum tailwater, an alternate end sill design, methods of preventing clogging of the basin, and means for automatic removal of sediment from the basin were suggested.

DESCRIPTORS--/ *stilling basins/ entrances/ *riprap/ erosion/ *hydraulic models/ hydraulic structures/ discharges/ *energy dissipation/ velocity/ pipes/ open channels/ debris barriers/ *laboratory tests/ baffles/ model tests/ sediment concentration/ trash racks/ impact
IDENTIFIERS--/ deflectors/ Franklin Canal, Tex/ *energy dissipators/ progress reports

PURPOSE

This study was conducted to standardize and modify existing procedures used in the design of the impact, Type VI stilling basin.

DESIGN RECOMMENDATIONS

The following procedures and rules are recommended in the design of the Type VI basin:

1. Given a design discharge "Q" determine the velocity "V" and Froude number "F" of the incoming flow. If the Froude number is less than 1 or more than 10, use of this basin is not practicable.

2. In computing the Froude number assume the depth "D" to be square root of the cross sectional area of the flow at the entrance "Q/V." The flow is usually from a pipe. If the pipe flows partially full, it should be vented at the upstream end.

3. If the entrance pipe slopes downward, the outlet end of the pipe should be turned horizontal, or the invert filled to form a horizontal surface, for at least one pipe diameter upstream from the portal. For slopes 15° or greater, the horizontal length of pipe or fillet should be two or more diameters.

4. If the flow enters the basin from a rectangular open channel, the channel walls should be as high as the basin walls and the invert should be horizontal for a minimum of two channel widths upstream from the basin.

5. Having determined the Froude number, enter Figure 8 to find the minimum required width of basin.

6. Figure 8 shows data points above the recommended width that provide satisfactory operation for basins larger than the design limit; however, if the basin is too large, the incoming jet will pass under the hanging baffle to reduce the effectiveness of the basin. Since the basin will be larger than need be for less than design flows, the basin should not be oversized for the design flow.

7. Relate the basin dimensions to the basin width in accordance with Figure 1. The dimension "t" is a suggested minimum thickness for the hanging baffle and is not related to the hydraulic performance of the structure.

8. To prevent the possibility of cavitation or impact damage to the basin, it is believed that an entrance velocity of 50 feet (15.24 meters) per second should not be exceeded.

9. Riprap with a well-graded mixture of stones, most of which have diameters equal to one-twentieth of the basin width, should be placed to a depth equal to the height of end sill for a distance equivalent to one basin width downstream from the end sill. The riprap on the side slopes should extend to the same height as the training walls.

If the elevation of the channel bed is below the end sill, the velocity of flow entering the channel will be increased and the riprap stone size should be increased as determined using Figure 14. The drop in elevation from sill to bed must be added to the velocity head of the flow at the end sill, as determined from Figure 13, to obtain the average velocity of flow entering the tailwater channel. This velocity can be used in Figure 14 to determine the size of stones required.

10. Tailwater depth other than that created by the natural slope of the channel is not required. However, a smoother water surface will be obtained and smaller riprap stones can be used by increasing the tailwater depth in the channel to a depth of d + b/2 (see Figure 1 for definition of "d" and "b") above the basin floor. Compare Figures 4 and 6 with Figures 15 and 16.

11. This basin is more effective in the dissipation of energy than the hydraulic jump, Figure 14. Prototype basins have operated successfully with entrance velocities up to 38 feet per second (Table 1 and Figure 17) and the recommended riprap size requirement has been verified by the performance of these basins.

12. The alternate end sill design (Figure 1) utilizing the 45° wingwall is not required but will reduce the drop in water surface elevation from end sill to channel (Figure 13) and reduce channel erosion.

13. No practical method of making the basin self-cleaning of debris such as Russian thistles was found. Where debris is a problem, screening devices are recommended at the entrance to and over the top of the structure. If thistles are allowed to enter the basin, they will not wash out.

14. During periods of nonoperation, sediment may accumulate in the basin. Notches in the baffle (Figure 1) are recommended to provide two jets that will start the erosion of the sediment which will eventually be washed from the basin. However, the basin is capable of satisfactorily discharging the entire design flow over the top of the baffle for short periods of time.

INTRODUCTION

Stilling Basin VI as referred to in Section 6 of Report No. Hyd-399 1/ and in Engineering Monograph No. 25 2/ was originally developed for use as an energy dissipator at several locations on the Franklin Canal. Many of these basins are in use on other Bureau projects and generally they have been designed in accordance with the procedures outlined in these two publications. However, operation of the various prototype structures has revealed the need for revision of these design standards. Unforeseen operating conditions in the field and the over generalization of the present design rules have caused operating problems at some of the prototype structures.

Four principal operating problems that have occurred at various installations are: (1) The basin tends to clog with debris upstream of the hanging baffle. Russian thistles and similar weeds are the main source of the debris which is not generally a problem in cultivated areas. (2) Excessive splash overtopping the compartment walls upstream of the baffle, usually resulting from too small a basin for the quantity and velocity of flow involved, has eroded the fill outside the basin walls. (3) The discharge from the entrance pipe passes under the baffle, resulting in very little energy dissipation in the basin and excessive erosion of the downstream channel. This has occurred with a sloping entrance pipe or with an oversized basin having a horizontal entrance pipe discharging at less than the design flow. (4) Channel erosion at the end of the basin where the size of riprap was not adequate.

THE MODELS

Two model basins, 1.6 and 2.4 feet (48.76 and 73.15 cm) wide, were constructed. The other dimensions were related to the width of the basin as shown in Figure 1.

1/Hyd-399 - "Progress Report II - Research Study on Stilling Basins, Energy Dissipators, and Associated Appurtenances" - by J. N. Bradley and A. J. Peterka

2/July 1963 printing of Engineering Monograph 25 - "Hydraulic Design of Stilling Basins and Energy Dissipators" by A. J. Peterka

An 8-inch (20.32-cm) inside-diameter pipe was used at the entrance to each of the basins. Deflectors of various sizes were installed on the crown of this pipe upstream of the portal to vary the velocity of flow entering the basins. One-fourth, one-half, three-fourths, and full pipe flows were used in the tests as well as flow from an 8-inch (20.32-cm) rectangular open channel.

exit ?

Each of the two basins discharged into a canal section lined with 1-1/2-inch (38.10-mm) gravel. Tailwater elevations were controlled by stoplogs at the end of the canal section. The bottoms of the canal sections were at the same elevation of the basin end sill and were as wide and as long as the basin width. The side slopes were 1-1/2 to 1 for the 2.4-foot (73.15-cm) wide basin and vertical for the smaller basin.

THE INVESTIGATION

The investigation was primarily concerned with relating the basin size to the discharge and velocity and in relating the downstream channel and riprap requirements to the basin size. It was also concerned with special situations involving debris, silt, tailwater, sloping entrance pipe, and rectangular open channel entrances not usually encountered in the standard design of the Type VI basin.

Standardization of the Basin Dimensions in Terms of Basin Width

Initially, a test basin was constructed with dimensions related to the basin width in accordance with average relationship of the dimensions given in Table 11 of Reference 2. To test the adequacy of this 2.4-foot (73.15-cm) wide model basin, tests were conducted over a range of flows that had been determined in the earlier tests (Reference 2) to be the limits of exceptionally mild operation and of satisfactory maximum flow for a given basin width, providing the entrance flow velocity did not exceed 30 feet (9.14 m) per second (prototype).

These test discharges were related to the basin width in accordance with the equation:

$$Q = (W/C)^{2.5}$$

where "Q" is the discharge in cubic feet per second, "W" is the inside width of basin in feet, and "C" is a coefficient that varies for the maximum, minimum, and intermediate flows. The coefficient in English units is 1.46 for the maximum flow, 1.80 for the minimum flow, and 1.60 for the intermediate flow. (To obtain the discharge in cubic meters per second, the width must be in meters and the coefficient must be multiplied by 1.27.) Each test discharge was run at approximately half

full and full pipe to obtain high- and low-entrance velocity conditions and with controlled and uncontrolled tailwater depths (Figures 2 and 3). Particular attention was given to the intermediate discharge which represented the flows tabulated in Table 11 of Reference 2.

The larger flows with the higher velocities intermittently surged and splashed high on the basin walls immediately downstream from the hanging baffle and overtopped the sidewalls at the downstream end of the basin (Figures 2 and 3). To improve these flow conditions, the width of the notches in the baffle was reduced and the notches moved a short distance away from the sidewalls. Also, the slope of the top of the basin sidewalls was reduced to increase the height of the wall at the downstream end of the basin. The modification to the notches reduced the splashing and the height of the water surface rise on the sidewalls. Increasing the height of the sidewalls provided additional freeboard at the downstream end of the basin. These modifications are incorporated into the standard design dimensions shown in Figure 1.

Standardization of the Basin Flow Entrance

The flow usually enters the basin from a circular pipe but may enter from a rectangular open channel. The pipe may flow full or partially full. If it flows partially full and the upstream entrance to the pipe is submerged, the pipe should be vented to the atmosphere. The vent should be located near the upstream end of the pipe and have a diameter of about one-sixth the pipe diameter.

Although the entrance pipe or channel is usually horizontal or on a very slight downward grade, some installations may require an entrance pipe on a relatively steep slope. The hydraulic performance of the 2.4-foot (73.15-cm) wide model basin was determined with the entrance pipe sloped downward about 12°. Both high- and low-velocity test flows partially impinged on the hanging baffle and the bottom of the baffle was only partially submerged resulting in incomplete energy dissipation.

The model tests showed that a horizontal fillet on the invert of the pipe for a distance of one pipe diameter upstream from the portal caused greater jet impingement on the baffle, deeper submergence of the bottom of the baffle, and consequently better energy dissipation. The same improvement could be obtained by placing the entrance pipe horizontally for a distance of one or more pipe diameters upstream from the basin entrance. Either of these two methods may be used for entrance pipe slopes up to 15°. Entrance pipes having a downward grade exceeding 15° should be horizontal for at least two diameters upstream from the basin entrance.

Replacing the sloping entrance pipe in the model with an 8-inch-wide rectangular channel on a similar slope did not change the hydraulic performance of the basin. However, flow from the basin backed up into the open channel, making it necessary to raise the channel walls to the same height as the basin walls. To further contain the flow, the invert of the channel should be horizontal for a distance equivalent to at least two channel widths upstream from the basin entrance.

Standardization of the Basin Width

With the basin dimensions standardized in relation to the basin width, the next step was to standardize the width in relation to the quantity and velocity of the flow entering the basin. The test flows (Figures 2 and 3) used in verifying the standard dimensions of the basin in Reference 2 were repeated in the 2.4-foot (73.15-cm) wide model basin but with a riprapped channel simulated at the downstream end of the basin. Water surface roughness and erosion together with the ability of the basin to contain the flow were used as guidelines in evaluating the hydraulic performance test flows (Figures 4 through 7). Each of the test flows was judged to be satisfactory or unsatisfactory and plotted in dimensionless terms (Froude number of the incoming flow "F" versus the ratio of basin width to the incoming depth of the flow "W/D") in Figure 8.

It was believed that the shape of the incoming jet was relatively unimportant in evaluating the adequacy of a Type VI basin. Therefore, to standardize the method of computing the Froude number of the incoming flow, it was assumed that the cross sectional area of the jet in the circular pipe or rectangular channel had the shape of a square; thus, the depth of the incoming flow "D" was considered to be the square root of its cross sectional area.

To increase the range of data to be evaluated for Figure 8, the cross sectional area of the incoming flow was reduced to one-fourth the area of the 8-inch (20.32-cm) pipe, and the velocity of the flow entering the 2.4-foot (73.15-cm) wide model basin was increased (Figure 9). Thus both the Froude number and the width/depth ratio increased. The width/depth ratio for these tests was 8.15 at which the Froude number of a theoretical square jet at the entrance was 6.70 for the minimum satisfactory operation. Because the size of the jet was becoming very small in relation to the width of basin, the design curve in Figure 8 was not extended beyond a width to depth ratio of 10 which corresponded to capacity flow having a Froude number of about 9.

To increase the range of data in the other direction, the cross sectional area of the incoming flow was increased in relation to the basin width by switching to the 1.6-foot

(48.76-cm) wide model while maintaining the 8-inch (20.32-cm) entrance pipe (Figure 10). The tests were evaluated and plotted in Figure 8 at a W/D ratio of 3.08. The side slopes of the downstream discharge channel were vertical and the same distance apart as the basin side walls. Although this was not typical of the usual prototype installation and is not recommended, it was not considered to be critical in evaluating the performance of the basin. For these tests the Froude number was in the vicinity of 1.0 and the depth of the incoming flow was near the top of the baffle. Therefore, it did not appear practical to design this basin for W/D ratios smaller than 3.

Additional tests were run in this smaller model (Figures 11 and 12) to confirm the findings found in the larger model basin. The results of these tests are plotted in Figure 8 at W/D ratios of 3.8 and 6.1. The two models showed very good agreement in what was considered satisfactory and unsatisfactory performance as seen by comparing Figures 4 and 6 with 11 and 12.

In Figure 8 the straight line drawn through the data points with the highest Froude numbers for which satisfactory operation existed indicates the minimum width of basin that can be used for a given Froude number. Data points above the line indicate that it should be permissible to increase the size of the basin approximately 25 percent; however, this should not be done as these points represent the condition when the basin is operating at less than the design discharge. If the basin is too large, the incoming jet will pass under the baffle as has occurred at some installations and effective energy dissipation will not occur. For best results the basin should be designed for the minimum width indicated in Figure 8.

Standardization of the Entrance Velocity

In previous studies (Reference 2) the design criteria for this type of structure was based on discharge alone. The maximum incoming velocity was arbitrarily limited to 30 feet (9.14 meters) per second. However, some prototype structures have been designed and operated at velocities exceeding this limit. The Type VI stilling basins for the outlet works of Picacho South and North Dams were designed for velocities up to 39 and 48 feet (11.90 and 14.63 meters) per second, respectively, for flows of 210 and 275 cubic feet (5.94 and 7.78 cubic meters) per second, respectively. They have operated satisfactorily at 80 percent capacity at velocities of 32 and 37 feet (9.75 and 11.28 meters) per second (Figure 17).

To prevent the possibility of cavitation or impact damage to the basin, it is believed that an entrance velocity of 50 feet (15.24 meters) per second should not be exceeded.

The maximum Froude number, 8.82, for which the basin is recommended will occur at this entrance velocity when the design flow is 50 cubic feet (1.41 cubic meters) per second with the maximum recommended "W/D" ratio of 10.

Standardization of the Discharge Channel Riprap

No channel bed erosion tests were conducted to prove the required size of stones in the riprap. Instead, a reasonable riprap size was chosen to fit the size of basin. Having predetermined the basin size and relative size of stones in the riprap, the discharge capacity and entrance velocity limitations were determined as already described.

A model riprap was chosen that approximated a basin width-to-stone diameter ratio of 20 to 1. This size appeared to be reasonable and was confirmed by the tests described in the preceding section on standardization of basin width. These tests showed that slight erosion of the riprap began at about the same time as excessive water surface roughness showed up within and downstream of the basin.

The model riprap consisted of rounded gravel that was retained on a 3/4-inch (19.05-mm) sieve and passing a 1-1/2-inch (38.10-mm) sieve; 50 percent or more of the stones were the larger size which is approximately 1/20 of the basin width. The gravel was placed on the channel bottom at end sill elevation and on the 1-1/2 to 1 side slopes for a distance equal to the basin width beyond the end sill, and to a depth equal to the height of the end sill (Figure 1). The recommended nominal stone size was W/20 for the majority of the riprap. Fifty percent of the riprap mixture may be graded down from this size. The model stones were rounded, although angular ones would be preferred in the prototype.

In some instances, the discharge channel bed may be several inches (centimeters) or a few feet (meters) below the end sill elevation. This will considerably increase the riprap stone size requirement.

The following data was plotted to determine the increased riprap stone size requirement. The ratio of the average flow velocity at the end sill to the average entrance velocity was plotted versus Froude number in Figure 13, and the end sill velocity was plotted versus the stone size requirement, W/20, in Figure 14.

The additional head as provided by the lower channel bed should be added to the velocity head at the sill to determine the velocity of flow entering the channel. Having determined the increased velocity, Figure 14 can be entered to determine the riprap stone size requirement.

The stone size requirement for end sill velocities is compared in Figure 14 with the stone size requirement for bottom velocities in channels downstream of stilling basin, Reference 2. - mono 25 1963 printing The comparison indicates that the stone size recommendation here is conservative; however, the flow from the sill is in a downward direction as there is a drop in water surface from end sill to channel (Figure 13). Also, the average velocity plotted in Figure 13 is not as high as the velocity of flow from the center of the sill.

Tailwater Recommendations

The effect of tailwater on the basin efficiency was determined by repeating the above tests using a maximum tailwater controlled to a depth of d + b/2 above the basin floor as suggested in Reference 2. (See Figure 1 for definitions). A comparison of these flow conditions (Figures 15 and 16) with the uncontrolled tailwater flow conditions (Figures 4 and 6) shows that the water surface roughness and bed erosion are reduced by the higher tailwater but not sufficient to allow a reduction in the basin size. The riprap stone size could be reduced slightly as determined by the reduced velocity using Figure 14.

Performance Evaluation

Energy dissipation is initiated by flow striking the vertical hanging baffle and being turned upstream by the horizontal portion of the baffle and by the floor, in vertical eddies. Its effectiveness is best illustrated by plotting the percent of energy loss between the entrance portal and the end sill for a range of operating conditions as represented by the Froude number (Figure 13). Comparing the energy loss with the losses in a hydraulic jump shows the impact basin to be more efficient.

Prototype structures previously designed using Reference 2 but meeting the standards here have operated successfully. The outlet basins at Picacho South and North Dams, discharging at 80-percent capacity, are examples (Figure 17). The following table shows the design requirements for the 80-percent capacity which occurred August 20, 1954, and for the 100-percent design capacity.

For operation at 80-percent capacity, the table shows the width of basin and, therefore, the size of basins to be adequate. The actual performance on August 20, 1954, proved this to be true, Figure 17. However, for 100-percent design capacity, the table shows the basins to be about 13 percent undersized based on the design standards presented herein, Figure 8. The photographs in Figure 17 seem to indicate that the basins are operating at or very near their desired capacities.

Table 1

DESIGN SPECIFICATIONS FOR THE OUTLET WORKS STRUCTURE AT PICACHO NORTH AND SOUTH DAMS

	Flood of August 20, 1954		Maximum designed flood	
	South Dam	North Dam	South Dam	North Dam
Discharge cfs "Q"	130	210	165	275
Estimated entrance velocity, "V_1", feet per second	31.8	37	39	48
Cross sectional area of flow, "A", square feet	4.09	5.67	4.23	5.73
Depth, "D", in feet	2.02	2.38	2.06	2.39
Froude number, "F"	3.94	4.23	4.77	5.46
Width to depth ratio from Figure 8, "W/D"	6.21	6.50	6.95	7.50
Width recommended, "W", feet	12.54	15.47	14.31	17.93
Actual width used, feet	12.50	15.50	12.50	15.50
Percent undersized	1	0	13	13
Ratio of end sill velocity to entrance velocity, "V_2/V_1" (Figure 13)	0.18	0.17	0.158	0.149
End sill velocity in recommended width basin, "V_2" feet per second	5.72	6.29	6.16	6.77
Velocity head at end sill, feet	0.50	0.61	0.58	0.71
Drop from end sill to channel, feet (y)	0.75	1.33	0.75	1.33
Velocity head in channel, feet	1.25	1.94	1.33	2.04
Velocity in channel, feet per second	8.98	11.17	9.26	11.47

Table 1 - Continued

	Flood of August 20, 1954		Maximum designed flood	
	South Dam	North Dam	South Dam	North Dam
Riprap stone diameter for recommended basin above channel, Figure 14, inches	~~18~~ 12"	~~28~~ 18"	~~20~~ 12"	~~30~~ 19"
Riprap stone diameter for channel at end sill elevation, Figure 14, inches	8.0	9.8	9.3	11.0
Stone diameter specification (both dams), inches	18 to 5-1/2			

where did this come from

The prototype structures at Picacho South and North Dams can also be used to verify the recommended size of riprap. Table 1 shows the computations for the recommended stone size to be used in the riprap for the design flow conditions and for the estimated flow conditions that occurred on August 20, 1954.

According to construction specifications for both dams, the riprap below the outlets was to "* * * consist of durable rock fragments reasonably graded in size * * *" from 1/8 cubic yard (95 cubic centimeters) to 1/10 cubic foot (28 cubic centimeters). The individual rocks, therefore, would vary from about 18- to 5-1/2-inch (46- to 14-centimeter) cubes or in weight 500 to 15 pounds (22.7 to 6.8 kilograms). Although it is impossible from the photograph of the outlet at North Dam (Figure 17) to determine the size of stones in the channel riprap at the start of the run, the bank riprap indicates that there were very few pieces of the 500-pound size. The few remaining pieces near the man at the right seem to be in the upper range of sizes and are not washed out. It is also difficult to determine the elevation of the channel bed at the beginning of the run; but, here again, the bank riprap and the water-fall effect of the flow over the end sill in Figure 17 indicate that the riprap was placed no higher than the design elevations shown in the table. Therefore, the majority of the stones in the riprap should be 28 inches (71 centimeters) in diameter as recommended here. Since the specified stones were smaller than this size, the riprap would be expected to fail and did.

At South Dam the photographs of the outlet discharging do not show a waterfall effect from the end sill. Therfore, the riprap was probably nearer to end sill elevation than specified in the above table. This would reduce the required stone diameter to something less than 18 inches (46 centimeters) but greater than 8 inches (20 centimeters). Since this range is within that specified, the riprap would be expected to remain in place and did.

An Alternate End Sill Design

The alternate end sill design (Figure 1) having 45° wingwalls was not tested in this study. Examination of the data and photographic results of the earlier studies (Reference 2), however, indicated that height of boil and drop in water surface elevation to the channel (Figure 13) will be reduced by using the 45° wingwalls and a longer end sill. The use of this sill would allow the flow to spread more uniformly over a wider channel and, thereby, reduce erosion tendencies and wave heights.

Debris Barrier and Trashrack

At some prototype installations, weeds and debris such as Russian thistles have been trapped in the basin between the pipe portal and the baffle. This debris has compacted to the extent of blocking the portal, thus reducing the capacity of the structure. The compacted weeds will not wash out and are very difficult to remove. The only satisfactory field method of removing the debris has been to destroy portions of the baffle.

This condition was tested in the two models using Russian thistle branches. The model demonstrated that the thistles would not wash out and no satisfactory method of making the basin self-cleaning of weeds and debris was developed.

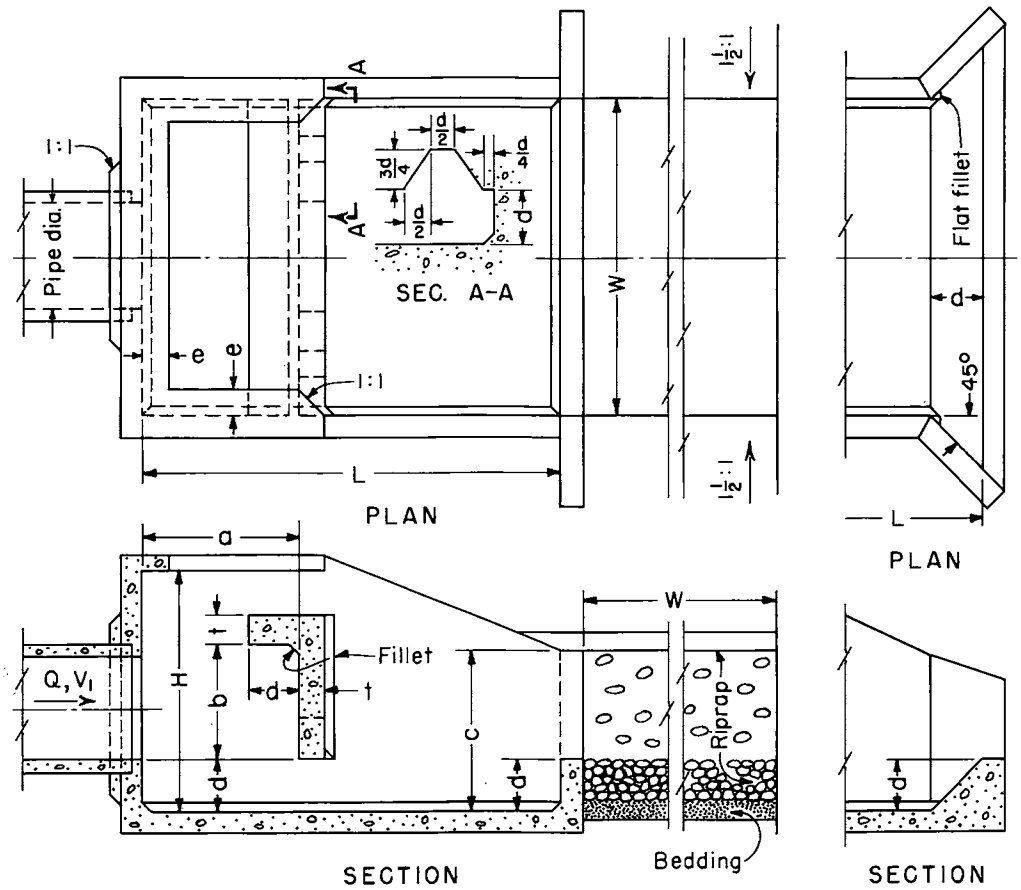
At structures where thistles or other debris are likely to be a problem, it is suggested that screening be used to cover the upstream portion of the basin and that a screen or trashrack device be used where the flow enters the pipe to the basin.

Self-cleaning Feature

Sediment may accumulate in the basin below the hanging baffle during periods of non-use. The notches were installed in the baffles to provide an opening through which a jet would discharge to begin erosion and removal of the sediment from the basin.

The 2.4-foot (73.15-cm) wide basin was operated with the portion of the basin below the hanging baffle blocked to simulate a sediment-filled basin. It was determined from this test that

the design discharges could be passed over the top of the baffle with very little splashing outside the basin and, in general, only minor erosion in the riprapped area. This type of operation could be tolerated for a limited time while sediment is being washed from the basin. If it is anticipated that the basin beneath the baffle will remain relatively free of sediment, the notches may be omitted.



STILLING BASIN DESIGN

ALTERNATE END SILL & WING WALL

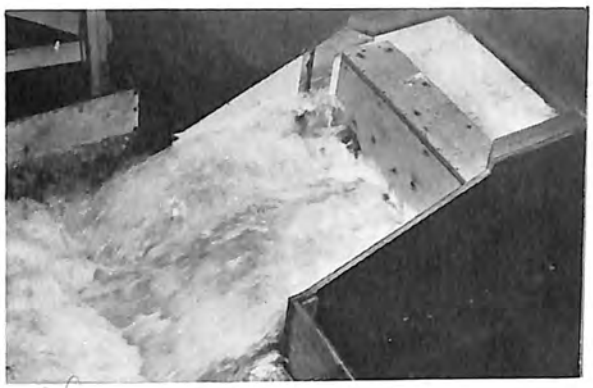
H = 3/4 (W)	d = 1/6 (W)
L = 4/3 (W)	e = 1/12 (W)
a = 1/2 (W)	t = 1/12 (W), suggested minimum
b = 3/8 (W)	Riprap stone size diameter = 1/20 (W)
c = 1/2 (W)	

IMPACT STILLING BASIN

TYPE VI

GENERAL DESIGN

Figure 2
Report Hyd-572

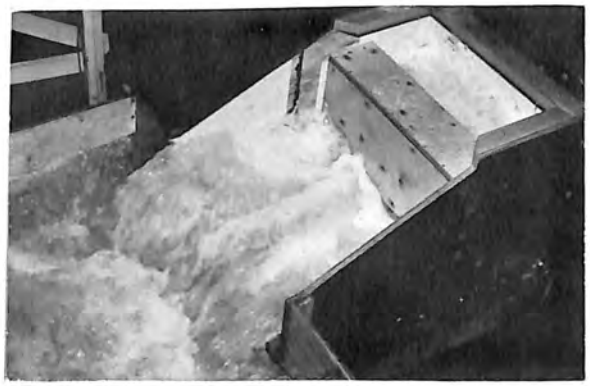


full

V = 9.9 ft/sec (3.02 m/sec) V = 21.58 ft/sec (6.58 m/sec)
Photo PX-D-64315 C = 1.46 (1.855) Photo PX-D-64316
Q = 3.47 cfs (0.098 cms)

full

V = 7.89 ft/sec (2.40 m/sec) V = 17.15 ft/sec (5.23 m/sec)
Photo PX-D-64308 C = 1.60 (2.04) Photo PX-D-64307
Q = 2.76 cfs (0.078 cms)



full

V = 5.84 ft/sec (1.78 m/sec) V = 12.69 ft/sec (3.87 m/sec)
Photo PX-D-64314 C = 1.80 (2.29) Photo PX-D-64317
Q = 2.04 cfs (0.058 cms)

$Q = (w/c)^{5/2}$ where w = basin width of 2.4 feet (73.15 cm)
V = velocity of flow at entrance
Tailwater elevation in tailbox is below basin end sill

IMPACT STILLING BASIN
TYPE VI
Test Flows with Uncontrolled Tailwater

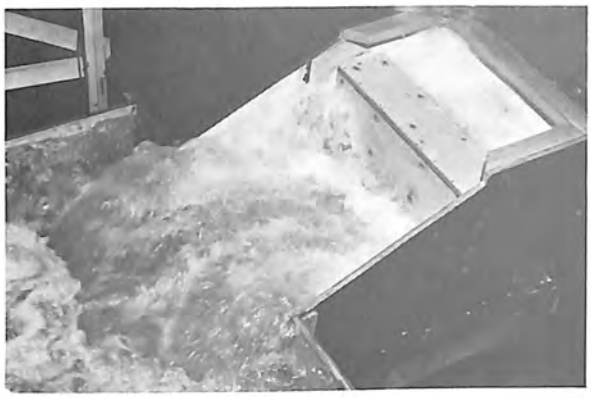


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Photo PX-D-64311 C = 1.46 (1.855) Photo PX-D-64310
Q = 3.47 cfs (0.098 cms)

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V = 5.84 ft/sec (1.78 m/sec) V = 12.69 ft/sec (3.87 m/sec)
Photo PX-D-64312 C = 1.80 (2.29) Photo PX-D-64313
Q = 2.04 cfs (0.058 cms)

$Q = (w/c)^{5/2}$ where w = basin width of 2.4 feet (73.15 cm)
V = velocity of flow at entrance. Tailwater elevation in the tailbox at d + b/2 (see Figure 1)

IMPACT STILLING BASIN
TYPE VI

Test Flows with Controlled Tailwater

Figure 4
Report Hyd-572

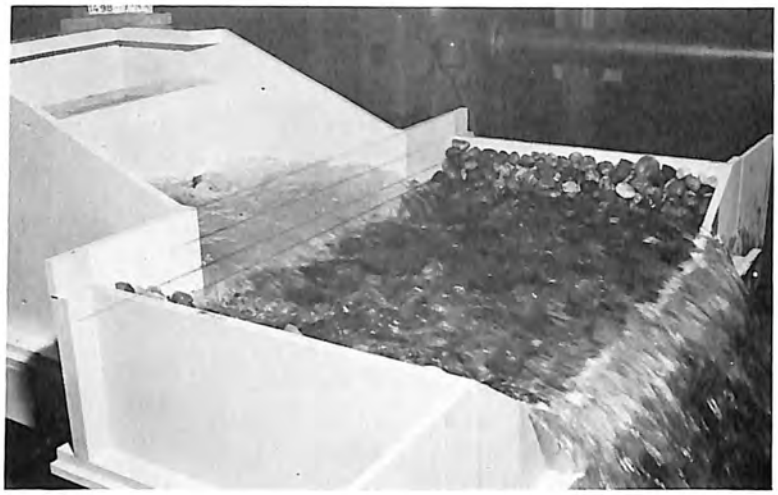
F = 1.34
W/D = 4.06
Satisfactory
PX-D-64318

D = .59
W = 2.40
A = .35

$F = \frac{V}{\sqrt{gD}}$

$1.34 = \frac{V}{\sqrt{32.2(.59)}}$

V = 5.84
Q = 2.04



F = 1.81
W/D = 4.06
Satisfactory
PX-D-64320

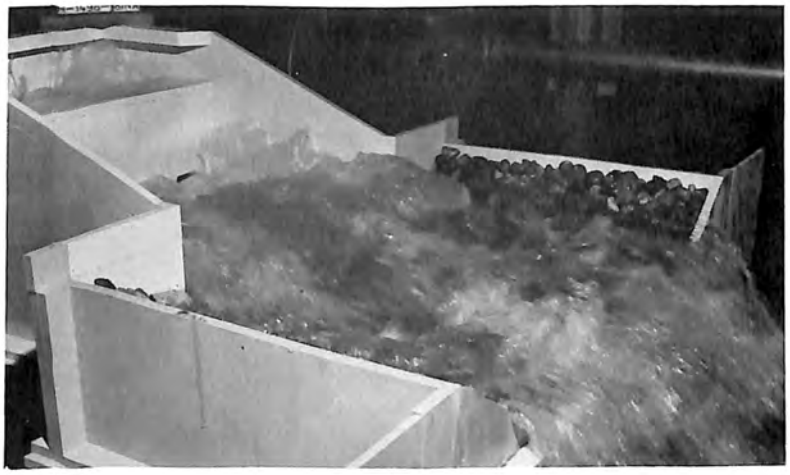
4.35

V = 7.89
Q = 2.76

F = 2.27
W/D - 4.06
Unsatisfactory
PX-D-64322

Note: For erosion results see Figure 5; for plot of these operating conditions see Figure 8.

V = 9.87
Q = 3.45



IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing Full with Uncontrolled Tailwater
in 2.4-foot-wide Basin

F = 1.34
W/D = 4.06
No erosion
Satisfactory
PX-D-64319

V = 5.84

F = 1.81
W/D = 4.06
Erosion
Satisfactory
PX-D-64321

V = 7.69

F = 2.27
W/D = 4.06
Excessive erosion
Unsatisfactory
PX-D-64323

Note: For plot of these operating conditions see Figure 8.

V. 9.69

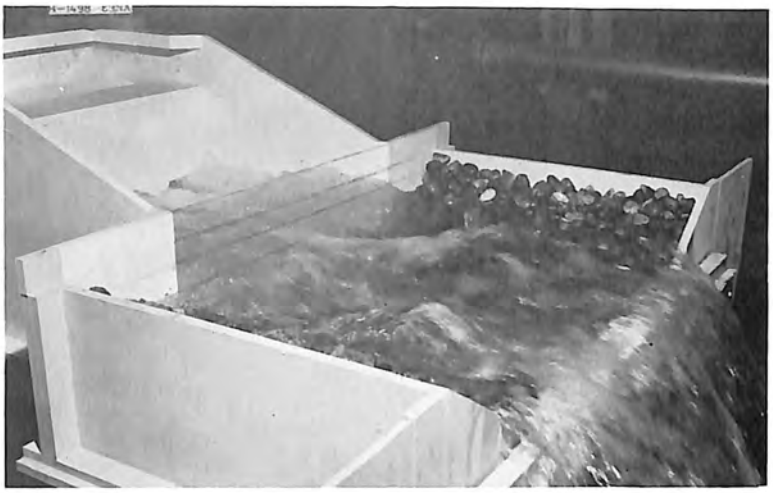
IMPACT STILLING BASIN
TYPE VI

Erosion for Uncontrolled Tailwater with Entrance Pipe Flowing Full in 2.4-foot-wide Basin

Figure 6
Report Hyd-572

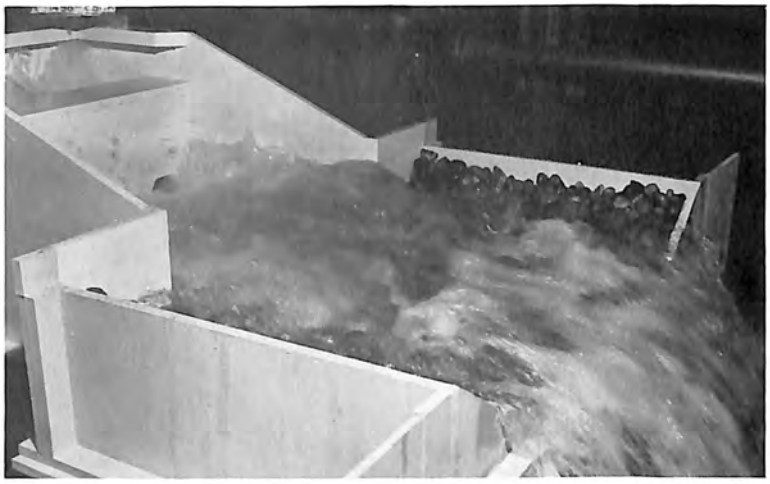
F = 3.53
W/D = 5.98
Satisfactory
PX-D-64324

V = 12.68



F = 4.77
W/D = 5.98
Unsatisfactory
PX-D-64326

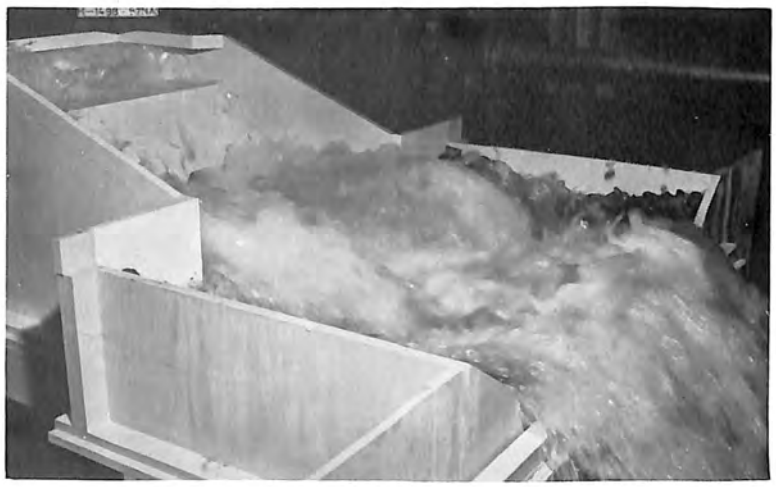
V = 17.12



F = 6.01
W/D = 5.98
Unsatisfactory
PX-D-64328

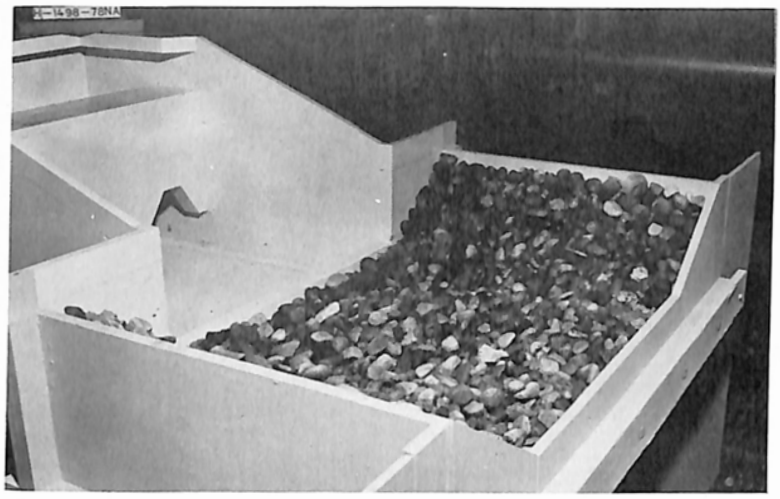
Note: For erosion results see Figure 7; for plot of these operating conditions see Figure 8.

V = 21.57



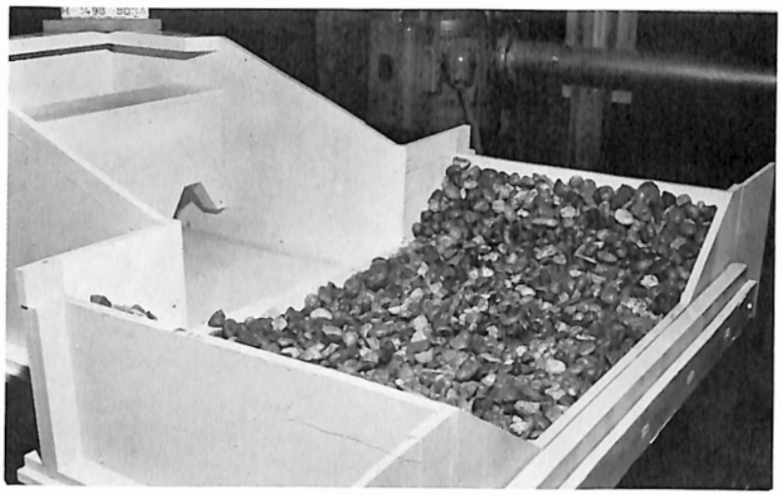
IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing Half Full with Uncontrolled Tailwater in 2.4-foot-wide Basin



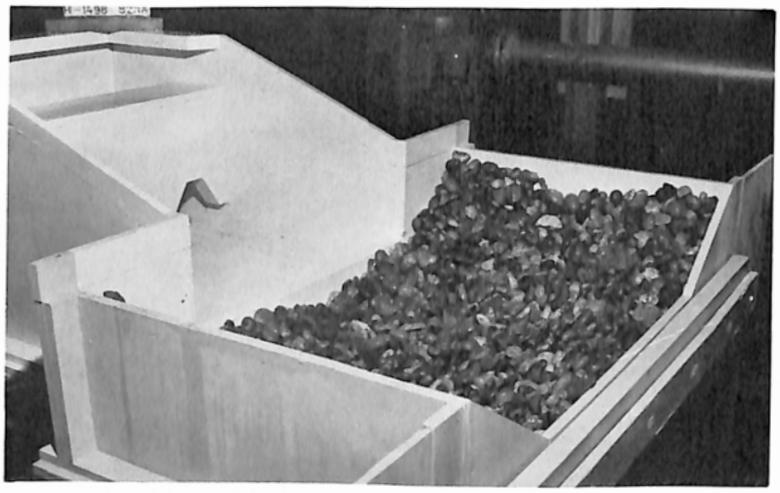
F = 3.53
W/D = 5.98
Minor erosion
Satisfactory
PX-D-64325

V = 12.68



F = 4.77
W/D = 5.98
Excessive Erosion
Unsatisfactory
PX-D-64327

V = 17.12



F = 6.01
W/D = 5.98
Excessive Erosion
Unsatisfactory
PX-D-64329

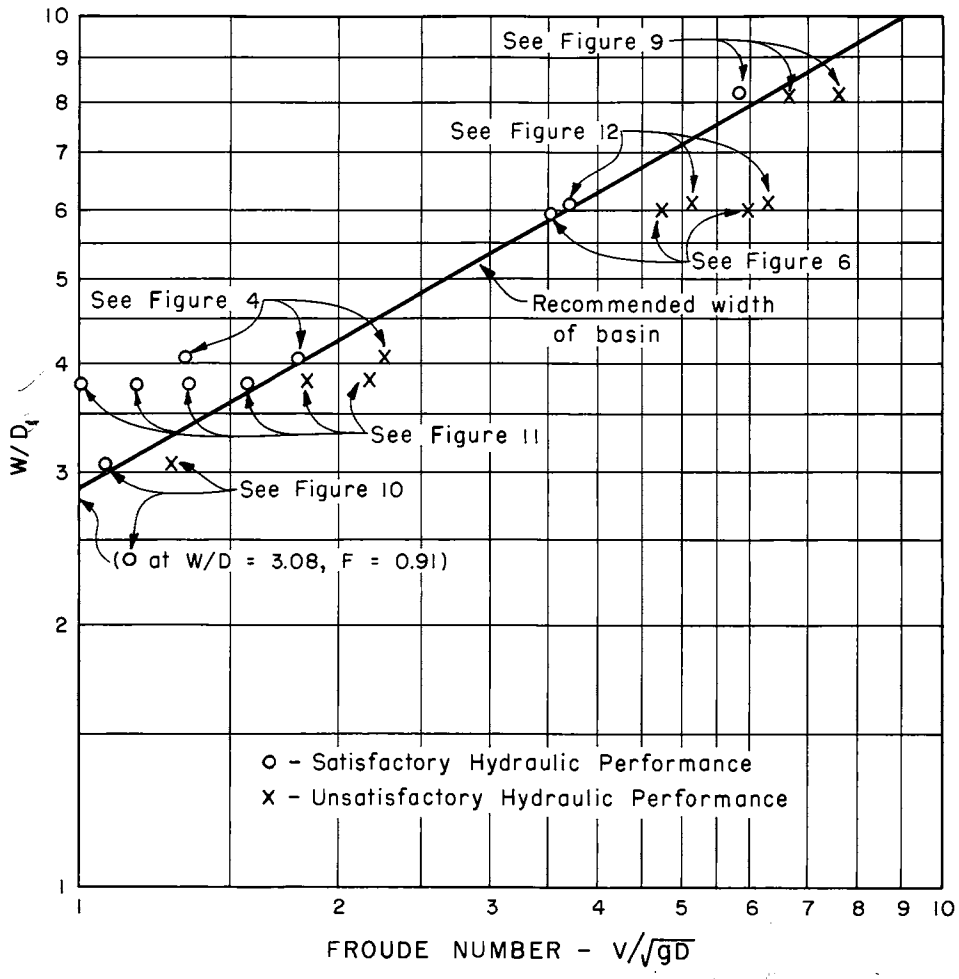
Note: For plot of these operating conditions see Figure 8.

V = 21.57

IMPACT STILLING BASIN
TYPE VI

Erosion for Uncontrolled Tailwater with Entrance Pipe Flowing Half Full in 2.4-foot-wide Basin

FIGURE 8
REPORT HYD-572

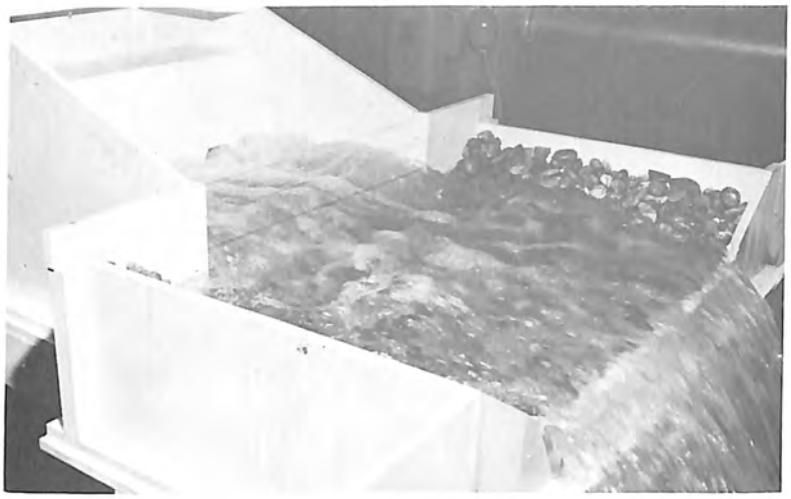


NOTES

"W" is the inside width of the basin.
"D" represents the depth of flow entering the basin and is the square root of the flow area.
"V" is the velocity of the incoming flow.
The tailwater depth is uncontrolled.

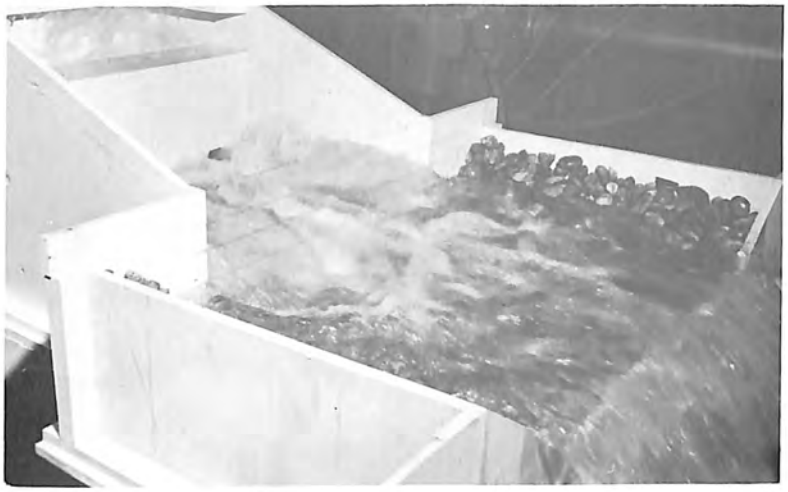
IMPACT STILLING BASIN

TYPE VI
DESIGN WIDTH OF BASIN VS FROUDE NUMBER



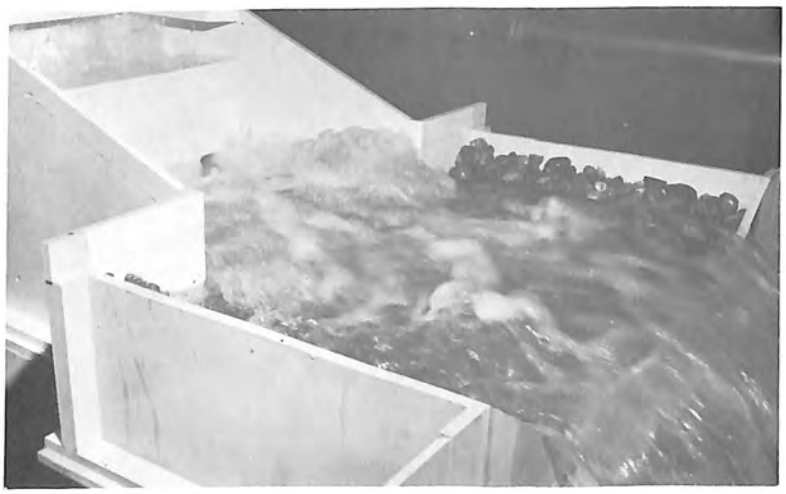
F = 5.87
W/D = 8.15
No erosion
Satisfactory
PX-D-64339

V = 17.94
Q = 1.56



F = 6.67
W/D = 8.15
No erosion
Satisfactory
PX-D-64340

V = 20.4
Q = 1.77



F = 7.59
W/D = 8.15
Minor erosion
Unsatisfactory
PX-D-64341

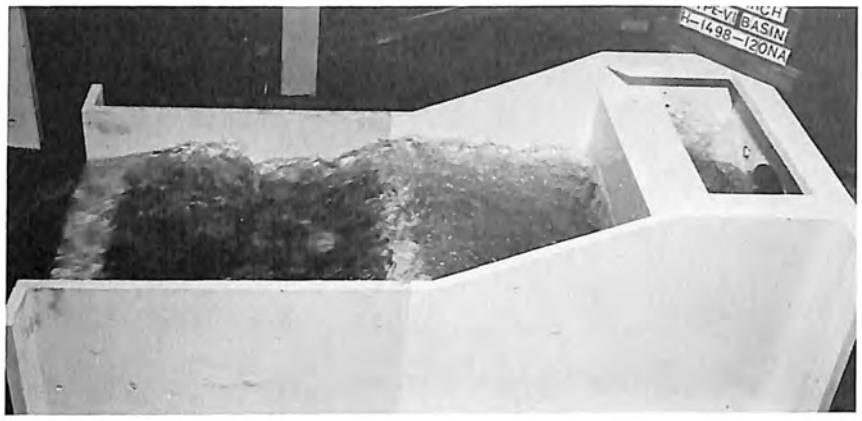
Note: For plot of these operating conditions see Figure 8.

V = 23.22
Q = 2.01

IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing One-fourth Full with Uncontrolled Tailwater in 2.4-foot-wide Basin

Figure 10
Report Hyd-572



F = 0.91
W/D = 3.08
No erosion
Satisfactory
PX-D-64346

V = 3.72
Q = 1.00

F = 1.07
W/D = 3.08
No erosion
Satisfactory
PX-D-64347

V = 4.38
Q = 1.18

F = 1.27
W/D = 3.08
Minor erosion
Unsatisfactory
PX-D-64348

Note: For plot of these operating conditions see Figure 8.

V = 5.20
Q = 1.40

IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing Three-fourths Full with Uncontrolled Tailwater in 1.6-foot-wide Basin

F = 1.01
W/D = 3.81
No erosion
Satisfactory
PX-D-64342

V = 3.71
Q = .65

F = 1.56
W/D = 3.81
No erosion
Satisfactory
PX-D-64343

V = 5.72
Q = 1.00

F = 1.83
W/D = 3.81
Minor erosion
Unsatisfactory
PX-D-64344

V = 6.72
Q = 1.18

F = 2.17
W/D = 3.81
Excessive erosion
Unsatisfactory
PX-D-64345

Note: For plot of these operating conditions see Figure 8.

V = 7.96
Q = 1.40

IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing Half Full with Uncontrolled Tailwater in 1.6-foot-wide Basin

GPO 852-552

Figure 12
Report Hyd-572

F = 3.72
W/D = 6.14
No erosion
Satisfactory
PX-D-64336

V = 10.78
Q = .73

F = 5.11
W/D = 6.14
Excessive erosion
Unsatisfactory
PX-D-64337

V = 14.82
Q = 1.01

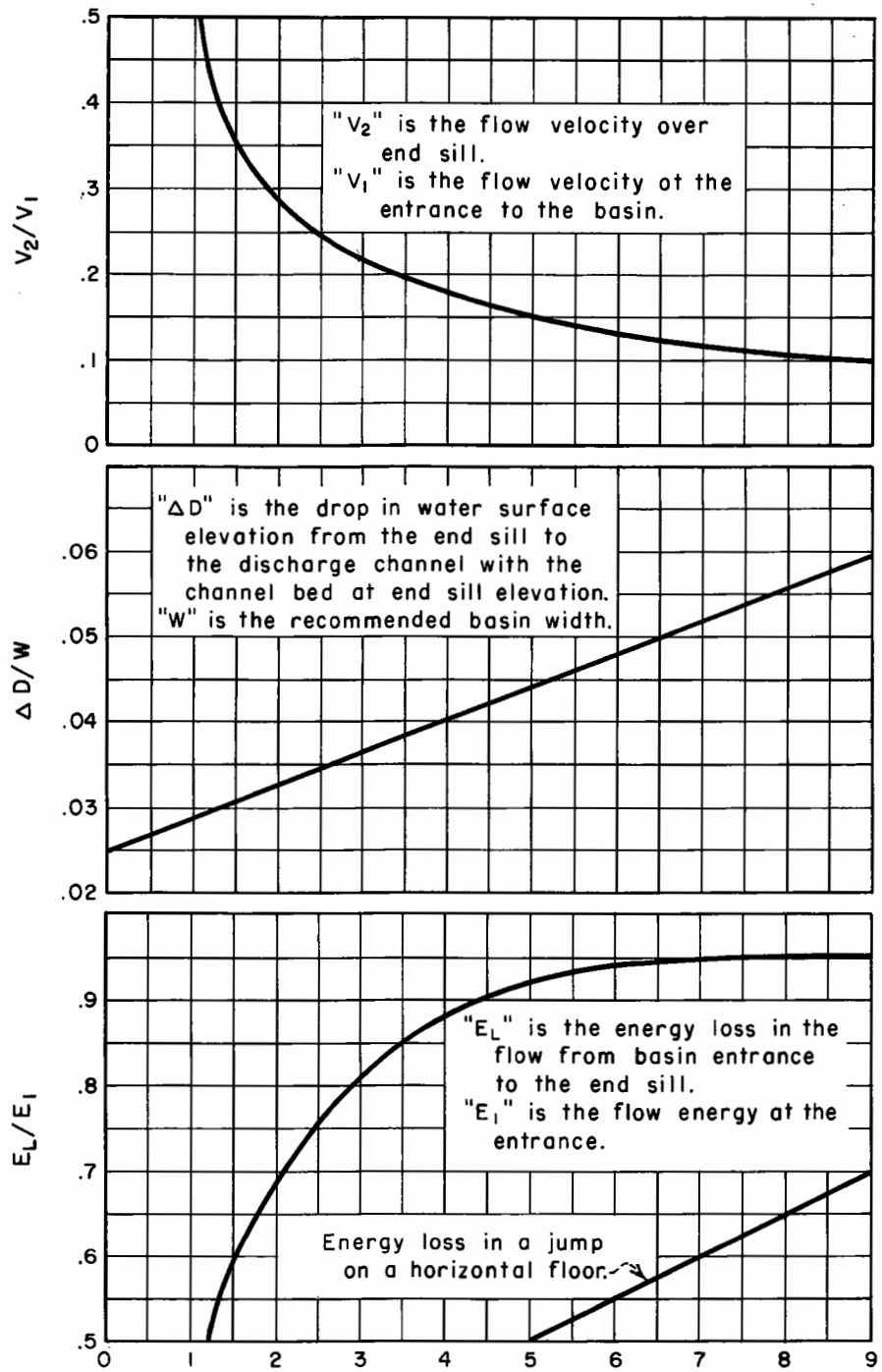
F = 6.28
W/D = 6.14
Excessive erosion
Unsatisfactory
PX-D-64338

Note: For plot of these operating conditions see Figure 8.

V = 18.24
Q = 1.24

IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing One-fourth Full with Uncontrolled Tailwater in 1.6-foot-wide Basin



FROUDE NUMBER "F" = $V_1/\sqrt{gD_1}$

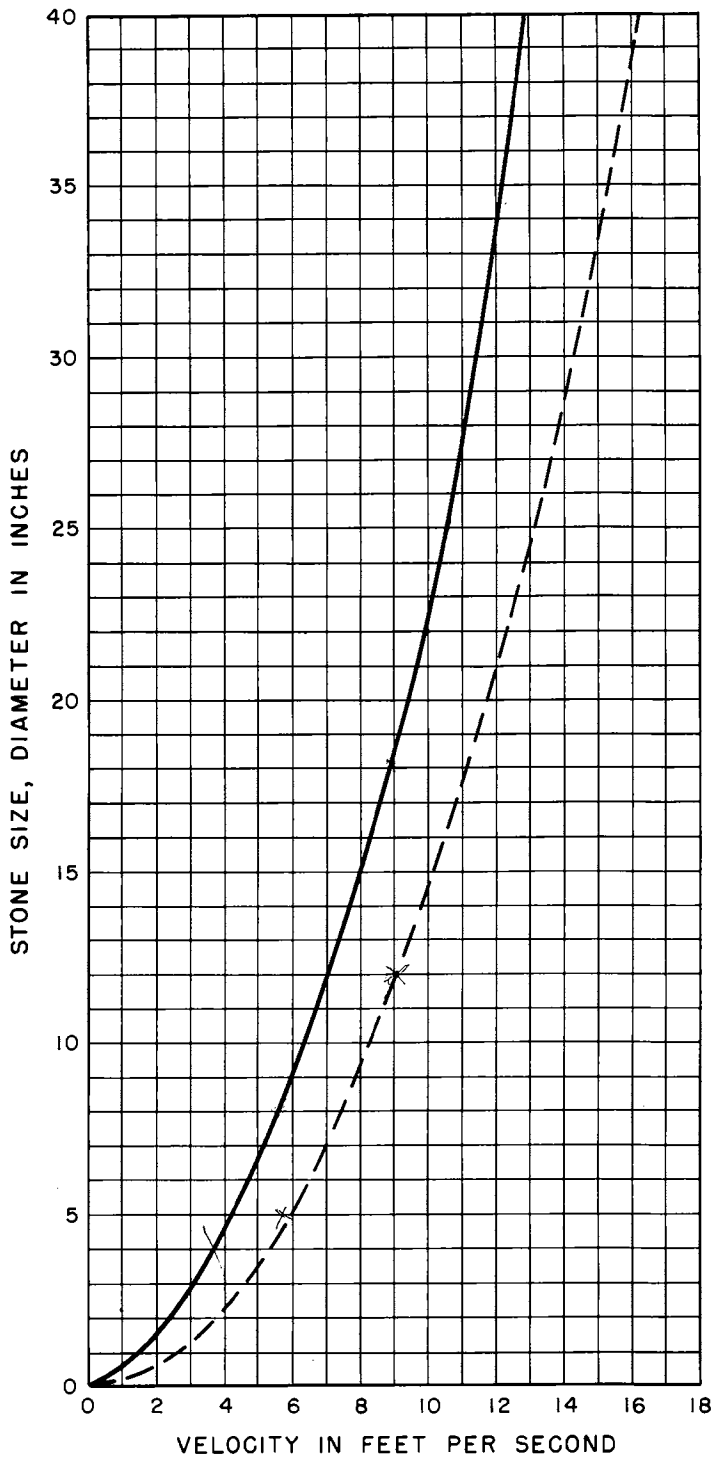
(Where "D_1" is the square root of the cross-sectional area of the entrance flow area.)

IMPACT STILLING BASIN

TYPE VI

END SILL VELOCITY, WATER SURFACE DROP FROM END SILL, AND ENERGY LOSS THROUGH BASIN (STANDARD BASIN AND CHANNEL WITH UNCONTROLLED TAILWATER)

FIGURE 14
REPORT HYD-572



NOTE

The riprap should be composed of a well graded mixture but most of the stones should be of the size indicated by the curve.

——— End sill velocity in Type VI Basin VS stone size required in riprap.

— — — Bottom velocity in a channel VS stone size required in riprap. (See Figure 165 in reference 2)

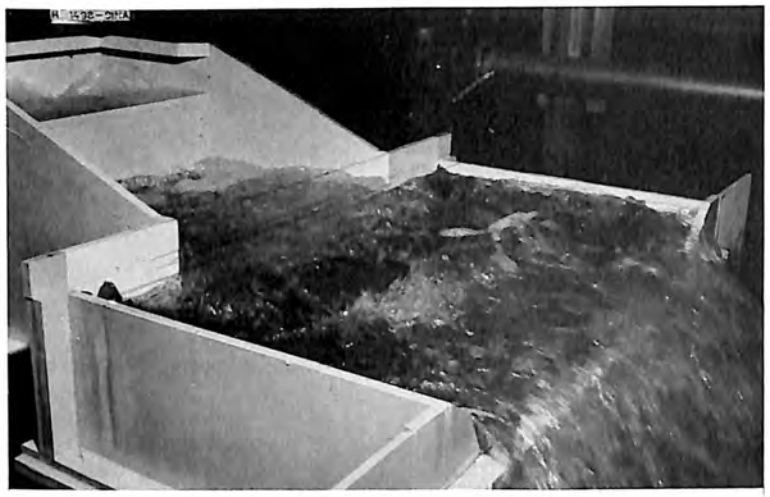
IMPACT STILLING BASIN

TYPE VI

RECOMMENDED RIPRAP STONE SIZE

F = 1.34
W/D = 4.06
No erosion
Satisfactory
PX-D-64332

V = 5.84
Q = 2.04



F = 1.81
W/D = 4.06
No erosion
Satisfactory
PX-D-64331

V = 7.89
Q = 2.76

F = 2.27
W/D = 4.06
Excessive erosion
PX-D-64330

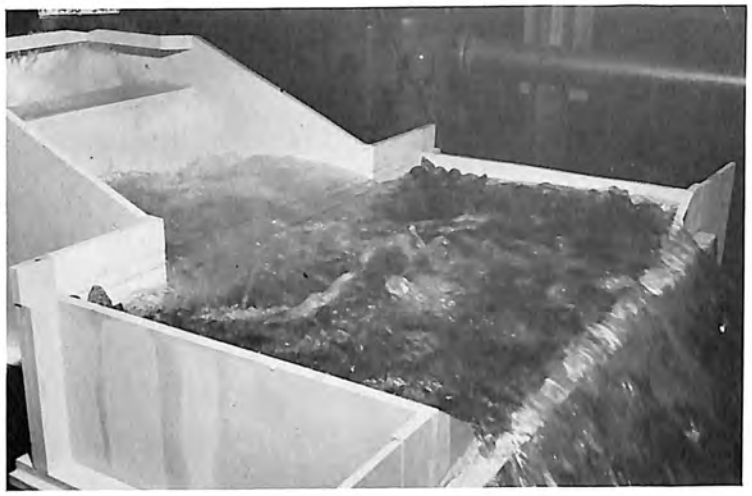
Note: Tailwater = d + b/2; see Figure 1 for definitions

V = 9.90
Q = 3.46

IMPACT STILLING BASIN
TYPE VI

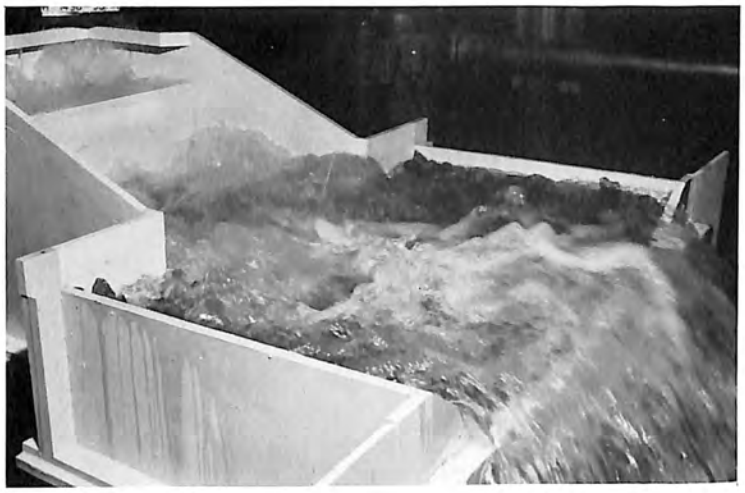
Entrance Pipe Flowing Full with Controlled Tailwater
in 2.4-foot-wide Basin

Figure 16
Report Hyd-572



F = 3.53
W/D = 5.98
No erosion
Satisfactory
PX-D-64333

V = 12.67
Q = 2.02



F = 4.77
W/D = 5.98
Minor erosion
Unsatisfactory
PX-D-64334

V = 17.12
Q = 2.74

F = 6.01
W/D = 5.98
Excessive erosion
Unsatisfactory
PX-D-64335

Note: Tailwater = d + b/2; see Figure 1 for definitions

V = 21.58
Q = 3.45

IMPACT STILLING BASIN
TYPE VI

Entrance Pipe Flowing Half Full with Controlled Tailwater in 2.4-foot-wide Basin

South Dam outlet works structure discharging 130 cfs (80 percent of maximum). Photo PX-D-31830.

Picacho North Dam outlet works structure discharging 210 cfs (80 percent of maximum capacity). Photo PX-D-64350.

Scour below Picacho North Dam outlet works following flood of August 20, 1954. Evidence points to undersized riprap. Photo PX-D-64351.

Note: At full capacity the basins are approximately 13 percent undersized based on present design standards.

IMPACT STILLING BASIN
TYPE VI
Prototype Operation

7-1750
(2-67)
Bureau of Reclamation

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 I

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*	Square centimeters
	0.092903	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.)	946.358*	Cubic centimeters
	0.946331*	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)	64.79891 (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 second^2	0.3048*	Meters per second^2
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

Multiply	By	To obtain
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 ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
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)	0.092903*	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 835-159

ABSTRACT

Model studies on 1.6- and 2.4-ft-wide (48.76 and 73.15 cm) Type VI stilling basins were conducted to modify existing standard design procedures. Investigations were concerned with: basin entrance flow conditions including type of entrance, slope, velocity, and Froude number; basin dimensions in relation to the basin width; basin width in relation to Froude number; and riprap size and location. Performance was evaluated in terms of energy dissipation and prototype operation. An optimum tailwater, an alternate end sill design, methods of preventing clogging of the basin, and means for automatic removal of sediment from the basin were suggested.

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Model studies on 1.6- and 2.4-ft-wide (48.76 and 73.15 cm) Type VI stilling basins were conducted to modify existing standard design procedures. Investigations were concerned with: basin entrance flow conditions including type of entrance, slope, velocity, and Froude number; basin dimensions in relation to the basin width; basin width in relation to Froude number; and riprap size and location. Performance was evaluated in terms of energy dissipation and prototype operation. An optimum tailwater, an alternate end sill design, methods of preventing clogging of the basin, and means for automatic removal of sediment from the basin were suggested.

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DESCRIPTORS--/ *stilling basins/ entrances/ *riprap/ erosion/ *hydraulic models/ hydraulic structures/ discharges/ *energy dissipation/ velocity/ pipes/ open channels/ debris barriers/ *laboratory tests/ baffles/ model tests/ sediment concentration/ trash racks/ impact
IDENTIFIERS--/ deflectors/ Franklin Canal, Tex/ *energy dissipators/ progress reports

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