# CITY OF LONGMONT
# STORM DRAINAGE CRITERIA MANUAL

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# SECTION 1100 HYDRAULIC STRUCTURES

## 1101 INTRODUCTION

Hydraulic structures for the purpose of this MANUAL, are defined as those structures which control the storm runoff during a condition of rapid directional change, or rapid acceleration or deceleration of velocity. Included in this category are channel drops (sometimes referred to as check drops or erosion control devices), energy dissipators (i.e., stilling basins) and irrigation ditch crossings. Also included in this structure category are culverts and bridges (Section 1000) and channel bends (Section 700) which are discussed in other sections of this MANUAL.

The criteria presented in this section in many cases is generalized since each structure is unique, with the possible exception of channel drops. The user is encouraged to coordinate with the City Engineer when planning and designing hydraulic structures.

## 1102 CHANNEL DROPS

The information presented for riprap channel drops was obtained from the 1982 draft revisions of the "Riprap Drop Structures" section in the USDCM. The criteria has been applied by the UD&FCD and completed structures are being monitored for performance before final adoption of the criteria. The user should contact the City Engineer for any revisions.

### 1102.1 Criteria for use of Drops

The most common use of channel drops is to control the longitudinal slope of grass lined channels to keep design velocities within acceptable limits (Section 700). Sloping and vertical riprap drop structures, Figure-1101, are two possible types of drop structures. The Urban Drainage and Flood Control District has studied riprap drop structures and has developed criteria and charts to aid in the design of these types of structures. All check drops with a unit discharge, q, of 35 cfs/ft or less shall be designed and constructed of ordinary or grouted riprap in accordance with Section 1102.2, 1102.3, and 1102.4. For unit discharges in excess of 35 cfs/ft, refer to Section 1102.4.2 and Section 1103 for discussion.

The riprap channel drop criteria are for the 100-year discharge with no factor or safety. Use of these criteria for more frequent discharges will result in more frequent failures and should be avoided.

### 1102.2 Sloping Riprap Drops

The design chart for the sloping drop structure is based upon the unit discharge (q) of the approach channel, the riprap classification and the slope of the drop structure, and is valid only for sub-critical flow in the approach channel (i.e., $Fr \leq 0.8$). The unit discharge is found by taking the average or normal channel velocity (Vn) for the 100-year discharge times the normal depth of the channel (Yn). Since the maximum for a grass lined channel in erosion resistant soils are Vn = 7 ft/sec and Yn = 5 ft. (Section 704.2), the maximum q allowed is q = VnYn = (7 ft/sec)(5 ft) = 35 cfs/ft. This q is also the practical limit for the largest riprap specified in the Section 705.

The design chart is also based upon a prismatic channel section throughout, from the upstream channel through the drop to the downstream channel. The maximum (steepest) allowable side slope for the riprap lined channel within the drop structure is 4:1. Flatter side slopes are allowable and encouraged when available right-of-way permits.

The classification of riprap chosen for the sloping portion of the structure should be used throughout the structure, including the upstream and downstream aprons, the channel bottom and side slopes. The riprap should extend up the side slopes to a depth equal to 1-foot above the normal depth projected upstream from the downstream channel, or 1-foot above the critical depth, whichever is greater. The maximum fall allowed at any one drop structure is 4-feet from the upper channel bottom to the lower channel bottom, excluding the trickle channel.

Due to the recent experience gained by the UD&FCD, the requirements for the riprap of sloping check drops has been revised. Where Class "H" or "VH" is specified (Table-1101), Class "M" grouted riprap shall be used instead in Boulder County. See Section 705 for riprap requirements.

A detailed description of the drop structure and the design procedure, proceeding from upstream to downstream is given below and shown on Figure-1102.

1. Criteria
   a. Approach Depth: The upstream and downstream channels will normally be grass lined trapezoidal sections with trickle channels to convey normal low water flows. The maximum normal depth Yn is 5-feet and the maximum normal velocity Vn is 7-feet/sec. for erosion resistant soils and 5-feet/sec. for easily eroded soils.

   b. Trickle Channel: The trickle channel shown in this case is a rectangular concrete channel. The concrete channel ends at the upstream end of the upstream riprap apron. A combination cut-off wall and foundation wall is provided to give the end of the trickle channel additional support. The water is allowed to "trickle" through the upstream apron and through the crest wall (discussed below). Riprap trickle channels would simply feather into the upstream apron.

   c. Approach Apron: A 10-foot long riprap apron is provided upstream of the cutoff wall to protect against the increasing velocities and turbulence which result as the water approaches the sloping portion of the drop structure. The same riprap and bedding design should be used as specified for the portion of the drop structure downstream of the cut-off wall.

   d. Crest Wall: The crest wall is a very important part of the drop structure, and has several purposes, one of which is to provide a level rigid boundary section and distribute the flow evenly over the entire width of the structure. This is extremely important since the selection of the riprap is based upon the unit discharge, and without the wall, flow concentrations could result which would greatly exceed the design discharge.

The trickle channel is ended at the upstream end of the upstream apron to prevent the trickle channel from concentrating additional water at a point during high flows, thus exceeding the design unit discharge. The apron and the crest wall combine to disperse the concentrated flow. The trickle flows must be allowed through the crest wall to prevent ponding. A series of notches in the wall will allow the trickle flows to do this. The size and number of notches will depend on the design discharge of the trickle channel. Note that they are offset from the trickle channel to permit flow of water through the upstream apron. The voids in the riprap below the notch inverts are expected to silt in rapidly or they can be filled at the time of construction. The crest wall can also be used to reduce or eliminate seepage and piping along with the failures which can result from these problems.

The two most common types of walls used will probably be reinforced concrete or sheet pile. The design of the wall is a structural problem which will not be addressed here. The depth of the wall should be at least to the bottom of the bedding material and could be deeper if necessary for the control of piping.

The top of the crest wall should be placed a distance P above the upstream channel bottom. This is done to create a higher water surface elevation upstream, thus reducing the drawdown effects normally caused by a drop structure. P can be determined from Table-1101 and is not considered in the total allowable vertical drop.

e. Chute Apron: The riprap chute portion of the drop structure and the downstream apron can be sized using Table-1101. The way to use the table is to compute q = VnYn, enter the table at the next highest value of q in the left-hand column, determine the allowable slopes for the three riprap classifications in the row for that q and select the best combination of riprap classification and slope using site and cost considerations. The length of the downstream apron L-sub B and the depth of the riprap D-sub R can also be obtained from Table-1101. The riprap must be placed on bedding and filter fabric as shown in Figure-1102. The 2-foot long filter fabric cutoffs help prevent piping failures. The riprap should extend up the side slopes a distance of Yn + 1' as projected from the downstream channel or the critical depth plus 1-foot whichever is greater. The side slopes for the chute and downstream apron should be the same as the crest wall and upstream channel with the exception that a riprap slope as steep as 2:1 can be used starting above the riprap lining the height required above. The thickness of the riprap immediately downstream of the crest wall should be increased to D-sub RW as shown in Table-1101. This extra thickness is necessary to protect the most critical area of the structure. The voids in the apron can be filled during construction to reduce ponding of low flows in the apron area.

f. Exit Depth: The downstream channel should be the same as the upstream channel, including a trickle channel. The trickle channel invert must be below the top of the adjacent riprap section to insure that trickle flows will drain into the trickle channel. For concrete trickle channels a foundation wall similar to the one used for the upstream trickle channel should be used. In some instances the wall may also be used to control seepage and piping.

## 2. Design Example

**Example No. 20: Sloping Riprap Channel Drop**

Given: Q = 1600 cfs

Upstream and downstream channel dimensions

bottom width = 50 ft. S = .0043 ft./ft.

side slopes = 4:1 Yc = 2.9 ft.

Yn = 4.0 ft. $V_n$ = 6.0 fps

Erosion resistant soils

Concrete trickle channel

Drop required = 3.0 ft.

Procedure:

Step 1: Determine maximum unit discharge.

q = VnYn = (6.0 fps)(4 ft) = 24 cfs/ft

Step 2: Select the best combination of riprap classification and chute slope from Table-1101 for q = 25 cfs/ft

The following options are available:

a. Type M at 10:1 or flatter; Dr=1.75';Drw=2.6'

b. Type H at 6:1 or flatter; Dr = 2.6';Drw=3.25'

c. Type VH at 4:1 or flatter; Dr=3.5'; Drw=3.5'

Substitute Type M grouted for Type H or Type VH riprap (refer to Section 1102.2).

The best combination or riprap classification and slope will depend on many factors such as availability and cost of the various riprap classifications and right-of-way limitations. Remember to consider bedding and filter cloth costs. For the sake of this example select Type M riprap grouted at a 7:1' slope.

Step 3: Select length of downstream apron $L_B$ = 20'

Step 4: Determine crest wall elevation.

Bottom width = 50', closest to 40'

Vn = 6 fps, halfway between 5 fps and 7 fps

Use P = 0.3'

### 1102.3 Vertical Riprap Drops

The design chart for the vertical channel drop is based upon the height of the drop and the normal depth and velocity of the approach and exit channels. The channel must be prismatic throughout, from the upstream channel through the drop to the downstream channel.

The maximum (steepest) allowable side slope for the riprap stilling basin is 4:1. Flatter side slopes are allowable and encouraged when available right-of-way permits. The riprap should extend up the side slopes to a depth equal to 1-foot above the normal depth projected upstream from the downstream channel. The maximum fall allowed at any one drop structure is 4-feet from the upper channel bottom to the lower channel bottom, excluding the trickle channel.

A detailed description of the drop structure and the design procedure, going from upstream to downstream is given below and shown on Figure-1103.

1. Criteria

   a. Approach Depth: The upstream and downstream channels will normally be grass lined trapezoidal channels with trickle channels to convey normal low water flows. The maximum normal depth Yn is 5-feet and the maximum normal velocity Vn is 7-feet/sec. for erosion resistant soils and 5-feet/sec. for easily eroded soils.

   b. Trickle Channel: The trickle channel shown in this case is a rectangular concrete channel. The concrete channel ends at the upstream end of the upstream riprap apron. A combination cut-off wall and foundation wall, to give the end of the trickle channel additional support, is provided. The water is allowed to "trickle" through the upstream apron and through the vertical wall. Riprap trickle channels would simply feather into the upstream apron.

   c. Approach Apron: A 10-foot long apron is provided upstream of the cutoff wall to protect against the increasing velocities and turbulence which result as the water approaches the vertical drop. Type M riprap can be used for this apron.

   d. Crest Wall: The vertical wall should have the same trapezoidal shape as the approach channel. The wall distributes the flow evenly over the entire width of the drop structure. This is important to prevent flow concentrations which would adversely affect the riprap basin.

      The trickle channel is ended at the upstream end of the upstream apron to prevent the trickle channel from concentrating additional water at a point during high flows, thus exceeding the design assumptions. The apron and the vertical wall combine to disperse the flow concentrated in the trickle channel. The trickle flows are allowed through the wall through a series of notches in order to prevent ponding. The voids in the riprap below the notch inverts are expected to silt in rapidly, or they can be filled at the time of construction.

The wall must be designed as a structural retaining wall. The top of the wall should be placed a distance P above the upstream channel bottom. This is done to create a higher water surface elevation upstream, thus reducing the drawdown effects normally caused by a sudden drop. P can be determined from Table-1102.

e. Chute Apron: The riprap stilling basin is designed to force the hydraulic jump to occur within the basin, and is designed for essentially zero scour. The floor of the basin is depressed an amount B below the downstream channel bottom, excluding the trickle channel. This is done to create a deeper downstream sequent depth which helps keep the hydraulic jump in the basin. This arrangement will cause ponding in the basin. The trickle channel can, depending on the depth, relieve all or some of the ponding. The riprap can also be buried and vegetated to reduce the ponded area to a smaller size.

The riprap basin can be sized using Table-1102. The way to use the table is to determine the required height of the drop C, the normal velocity of the approach channel Vn, and the upstream and downstream normal depths Yn and Y-sub 2. Both channels must have the same geometry and Y-sub 2 must be equal to Yn in order to use the table. Enter the row which contains the correct C, Vn and Yn and Y-sub 2 and select the riprap classification and all necessary dimensions from that row.

The riprap must be placed on bedding and filter fabric as shown in Figure-1103. The riprap should extend up the channel side slopes a distance of Y-sub 2 + 1' as projected from the downstream channel. The basin side slopes should be the same as those in the downstream channel (4:1 or flatter) up to the Y-sub 2 + 1' location, above which riprap slopes as steep as 2:1 are allowable.

f. Exit Depth: The downstream channel should be the same as the upstream channel, including a trickle channel. For concrete trickle channels a foundation wall similar to the one used for the upstream trickle channel should be used. In some instances the wall may also be used to control seepage and piping.

2. Design

Example No. 21: Vertical Riprap Channel Drop

Given: Q = 1600 cfs

Upstream and downstream channel dimensions

| | |
|---|---|
| bottom width = 50 ft. | S = .0043 ft./ft. |
| side slopes = 4:1 | Yc = 2.9 ft. |
| Yn = 4.0 ft. | Vn = 6.0 fps |

Erosion resistant soils

Concrete trickle channel

Drop required = 3.0 ft.

Procedure:

Step 1: From Table-1102, for C = 3.0', Vn = 6.0 fps and Yn and Y sub-2 = 4.0'.

Select the riprap designation and the riprap basin dimensions.

Riprap - Type H

B = 1.0'

A = 2.5'

$L_B$ = 20'

D = 5.0'

E = 4.0'

Step 2: Determine P = 0.1 from Table-1102

Step 3: Design retaining wall and finalize dimension

## 1102.4 Other Channel Drops

The criteria in Sections 1102.2 and 1102.3 are for ordinary riprap (not grouted), and trapezoidal sections only. For other type of channel drops, additional analysis or special care during construction will be required.

1. Grouted Riprap

When riprap is grouted, the tendency is for the concrete to completely cover the rock, resulting in a wavy but smooth surface. This smooth surface would require a larger basin than specified in Tables-1101 or -1102. If the grout is placed in strict accordance with the specifications of Section 705.1.2, then the dimensions in Tables-1101 and -1102 can be used for grouted riprap channel drops. The rock size requirement can be reduced by one size from that specified in Tables-1101 and -1102 (i.e., from Type H to Type M) except Type M shall be the smallest size allowed for channel drops and Type M shall be substituted for Type VH in Table-1101.

2. Concrete

When the unit discharge in the channel exceeds 35 cfs/ft (see Section 1101.1), riprap drop structures will not be permitted. A different type of channel drop and extensive channel transitioning will be required. The trapezoidal section must first be transitioned into a vertical concrete channel. The flows are then accelerated by a sloping concrete chute and a concrete stilling basin is constructed to dissipate the energy. The channel is then transitioned back into the trapezoidal grass lined section.

The detailed hydraulic evaluation of the channel transitions, chute, and energy dissipators are beyond the scope of this MANUAL. The user is referred to References-7 and -50 for this information. A general discussion and design examples for energy dissipators are presented in Section 1103.

## 1103 ENERGY DISSIPATORS

### 1103.1 Criteria for use of Structures

Energy dissipators will be required at channel drops when the unit discharge exceeds 35 cfs/ft and at the outlet of culverts or storm sewers when the velocity exceeds 16 fps (Section 1002). The dissipators shall be constructed of concrete and shall be one of the types of structures presented in this section.

### 1103.2 Types of Energy Dissipators

Many stilling basins and energy-dissipating devices have been designed in conjunction with spillways, outlet works, and canal structures, utilizing blocks, sills, or other roughness elements to impose exaggerated resistance to the flow. The type of stilling basin selected is based upon hydraulic requirements, available space and cost. The hydraulic jump which occurs in a stilling basin has distinctive characteristics depending on the energy of flow which must be dissipated in relation to the depth of the flow. A comprehensive series of tests have been performed by the Bureau of Reclamation for determining the most efficient energy dissipator (Reference-50).

1. Short Stilling Basin (USBR Type III)

The most effective way to shorten a stilling basin is to modify the jump by the addition of appurtenances in the basin. However, the appurtenances should be self-cleaning or nonclogging. The recommended design for Type III stilling basin is shown in Figure-1104 (Reference-50). The chute blocks at the upstream end of a basin tend to corrugate the jet, lifting a portion of it from the floor to create a greater number of energy dissipating eddies. These eddies result in a shorter length of jump than would be possible without them, and tend to stabilize the jump. The baffle piers act as an impact dissipation device and the end still is for scour control. The end still has little or no effect on the jump. The only purpose of the end still in a stilling basin is to direct the remaining bottom currents upward and away from the channel bed.

This type of basin is recommended at the outlet of a sloping channel drop when there is adequate tailwater. For insufficient tailwater, USBR Type IX basin is recommended.

2. Baffled Apron Stilling Basin (USBR Type IX)
Baffled aprons are used to dissipate the energy in the flow at a drop. They require no initial tailwater to be effective although channel bed scour is not as deep and is less extensive when the tailwater forms a pool into which the flow discharges. The chutes are constructed on an excavated slope, 2:1 or flatter, extending to below the channel bottom. Backfill is placed over one or more rows of baffles to restore the original streambed elevation. When scour or downstream channel degradation occurs, successive rows of baffle piers are exposed to prevent excessive acceleration of the flow entering the channel. If degradation does not occur the scour creates a stilling pool at the downstream end of the chute, stabilizing the scour pattern. The simplified hydraulic design of the baffled apron is shown on Figure-1105.

This type of basin is recommended for a channel drop where insufficient tailwater prevents the use of a Type III stilling basin. The basin can also be used for channel drops when adequate tailwater is available.

3. Impact Stilling Basin (USBR Type VI)
This stilling basin is an impact-type energy dissipator, contained in a relatively small box-like structure, and requiring little or no tailwater for successful performance. The general arrangement of the basin for various discharges are shown on Figure-1106. This type of basin is subjected to large dynamic forces and turbulences which must be considered in the structural design. The structure should be made sufficiently stable to resist sliding against the impact load on the baffle wall and must resist the severe vibrations. Riprapping should also be provided along the bottom and sides adjacent to the structure to avoid the tendency for scour of the outlet channel downstream from the end still when shallow tailwater exists. This type of stilling basin is very effective at the outlet of storm drains or culverts where there is little or no tailwater.

## 1103.3 Hydraulic Design

1. Channel Type Basin
The three different stilling basin configurations can be divided into two categories, basins for spillways or channels (Type III or IX) and basins for pipe outlets (Type VI). A summary of the design data for Type III and IX basins is presented in Figure-1107. The reader is referred to Reference-50 for a detailed discussion of the design requirements. However, the data in Figure-1107 is sufficient for hydraulic design purposes.

2. <u>Pipe Outlet Basins</u>
The requirement for a stilling basin for a culvert or storm sewer outlet is dependent upon the velocity of the flow. For velocities less than 7 fps a grassed channel with a small amount of riprap for protection against eddy current erosion is sufficient. For velocities less than 16 fps, a formal riprap lining is required (see Section 705.6). For velocities greater than 16 fps, a Type VI stilling basin is recommended. The design procedure is illustrated by the following example:

<u>Example No. 22</u>: <u>Impact Stilling Basin (USBR Type VI)</u>

<u>Given</u>: Pipe Dia = 48" RCP

$Q = 214$ cfs

$V = 17$ fps $< 30$ fps (upper limit)

Tailwater depth = 2.5-feet

Channel slope = 1.0 percent

<u>Solution</u>:

Step 1: Using the discharge (Q = 214 cfs) enter the DISCHARGE LIMITS portion of Figure-1107 and read the maximum and minimum basin width.

$W_{min} = 12.5$ ft

$W_{max} = 15.0$ ft

Step 2: From the BASIC DIMENSION portion of Figure-1107 and using the discharge Q = 214 cfs, interpolate for the basin dimensions. Note that for corresponding pipe size in the table is between a 54-inch and 60-inch diameter, which is larger than the example pipe size of 48-inches. The basin will therefore provide ample room for the example pipe.

| | |
|---|---|
| W = 12' - 4" | b = 10' - 6" |
| H = 10' - 3" | c = 5 ' - 8" |
| L = 18' - 2" | d = 2 ' - 4" |
| A = 7' - 8" | g = 5 ' - 1" |

Step 3: Provide minimum riprap downstream of structure a minimum distance of 3D (or 3 times the pipe rise). Compute the velocity at the structure outlet.

3D = 3 x 4' = 12' riprap length

A = W x tailwater depth

= 12' - 4" x 2.5'

$A = 30.8\ ft^2$

$V = Q/A$

$V = 6.9$ fps

Step 4: Using the procedures outlined in Section 705.4, and Table-711, determine the riprap size required

$$VS^{0.17}/(S_s - 1)^{0.66} = 6.9\ (0.01)^{0.17}/(2.5-1)^{0.66} = 2.4$$

From Table-711, the minimum riprap size is VL, which must be buried. An alternate would be to use type M riprap.

## 1104 IRRIGATION DITCH CROSSINGS

As required by the Policy for irrigation ditches (Section 305.3), a structure shall be constructed to separate peak storm runoff from the ditch flows except where permitted (i.e., Oligarchy Ditch). Three types of structures are defined to achieve this requirement.

1. Type 1
   Complete separation of storm flow and irrigation flow. This type of control is often used for the smaller ditches, and where intermingling of the flows would cause water quality problems. Type 1 structure occurs frequently as a flume crossing of a gulch, or by a pipe under the ditch.
2. Type 2
   Discharging the storm flows into the ditch, then releasing "excess" flows into the drainageway at a point downstream utilizing a formal control structure. This type of control can be used where the ditch has water rights on the stream in question. the structure requirements for this control may be less expensive than complete flow separation (Type 1 structure) especially for the larger drainageways.
3. Type 3
   Discharging the runoff into the ditch, without returning the runoff peak into the drainageway. This type of control requires a thorough analysis of the ditch capabilities and the storm runoff peaks and volumes, and may require a detention pond to reduce the runoff to the ditch capabilities.

Each irrigation ditch crossing of a drainageway will have its own unique design and requirements and, therefore, a typical ditch crossing configuration does not exist. Where a ditch structure is required, the applicant shall meet with City Engineer and the ditch company officials to develop the specific design requirements for the structure.

# SLOPING RIPRAP CHANNEL DROP DESIGN CHART

| MAXIMUM UNIT DISCHARGE q (cfs/ft | ALLOWABLE CHUTE SLOPE - So FOR EACH RIPRAP CLASSIFICATION | | | LENGTH OF DOWNSTREAM APRON $L_B$ (Ft) |
|---|---|---|---|---|
| | M | H | VH | |
| 15 | 0 to 7:1 | 7:1 to 4:1 | N/A | 15 |
| 20 | 0 to 8:1 | 8:1 to 5:1 | 5:1 to 4:1 | 20 |
| 25 | 0 to 10:1 | 10:1 to 6:1 | 6:1 to 4:1 | 20 |
| 30 | 0 to 12:1 | 12:1 to 7:1 | 7:1 to 4.5:1 | 25 |
| 35 | 0 to 13:1 | 13:1 to 8:1 | 8:1 to 6:1 | 25 |
| DR* | 1.75' | 2.6' | 3.5' | |
| DR** | 2.0' | 3.0' | 4.0' | |
| DRW | 1.5 x DR | 1.25 x DR | 1.0 x DR | |

* For Erosion Resistant, Cohesive Soils
** For Sandy or Highly Erosive Soils

NOTES:

1. q = Unit discharge = VnYn, where Vn = average channel velocity and Yn = normal depth of the upstream channel.
2. So = Longitudinal channel slope expressed in feet horizontal per foot vertical.
3. Dr = Depth of riprap blanket in feet.
4. Drw = Depth of riprap blanket at the downstream face of the crest wall.
5. Rock size, Dr and Drw shall be the same throughout the drop structure.
6. Chute and channel side slopes shall not be steeper than 4:1.
7. Maximum allowable drop = 4.0'
8. This chart is for ordinary riprap structures only. Other types of drop structures require their own hydraulic analysis. (See Section 1102.4).
9. For "H" and "VH" riprap substitute grouted "M" riprap.

# CREST WALL ELEVATION CHART

| BOTTOM WIDTH* (ft) | P@Vn = 5 fps (ft) | P@Vn = 7 fps (ft) |
|---|---|---|
| 5 | 0.2' | 0.2' |
| 40 | 0.4' | 0.2' |
| 100 | 0.5' | 0.3' |

*Bottom Width of Approach Channel

**WRC ENG.**

**REFERENCE:** USDCM, DRCOG, 1982 Draft Revisions for Channel Drops

TABLE 1102

# VERTICAL RIPRAP CHANNEL DROP DESIGN CHART

| C (ft) | Vn (fps) | Yn&Yz (ft) | P (ft) | B (ft) | A (ft) | $L_B$ (ft) | D (ft) | E (ft) | RIPRAP CLASS. |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 5 | 4 | 0.1 | 0.6 | 2.0 | 20 | 4 | 3 | M |
| 2 | 5 | 5 | * | 0.8 | 2.5 | 25 | 5 | 4 | H |
| 2 | 5; 7 | 4 | 0.1 | 0.8 | 2.5 | 20 | 5 | 4 | H |
| 2 | 5; 7 | 5 | * | 0.8 | 2.5 | 25 | 5 | 4 | H |
| 3 | 5 | 4 | 0.1 | 1.0 | 2.5 | 20 | 5 | 4 | H |
| 3 | 5 | 5 | * | 1.0 | 2.5 | 25 | 5 | 4 | H |
| 3 | 5; 7 | 4 | 0.1 | 1.0 | 2.5 | 20 | 5 | 4 | H |
| 3 | 5; 7 | 5 | * | 1.0 | 2.5 | 25 | 5 | 4 | H |
| 4 | 5 | 4 | 0.1 | 1.2 | 3.5 | 20 | 7 | 5 | VH |
| 4 | 5 | 5 | * | 1.2 | 3.5 | 25 | 7 | 5 | VH |
| 4 | 5; 7 | 4 | 0.1 | 1.4 | 3.5 | 20 | 7 | 6 | VH |
| 4 | 5; 7 | 5 | * | 1.4 | 3.5 | 25 | 7 | 6 | VH |

*** See Table below to caculate P**

NOTES:

1. See Fig. 1103 for definition of symbols
2. See Section 705 for riprap gradation, classification and bedding requirements.
3. Maximum Allowable C = 4.0'
4. This chart is for ordinary riprap structures only. Other types of drop structures require their own hydraulic analysis. (See Section 1102.4).

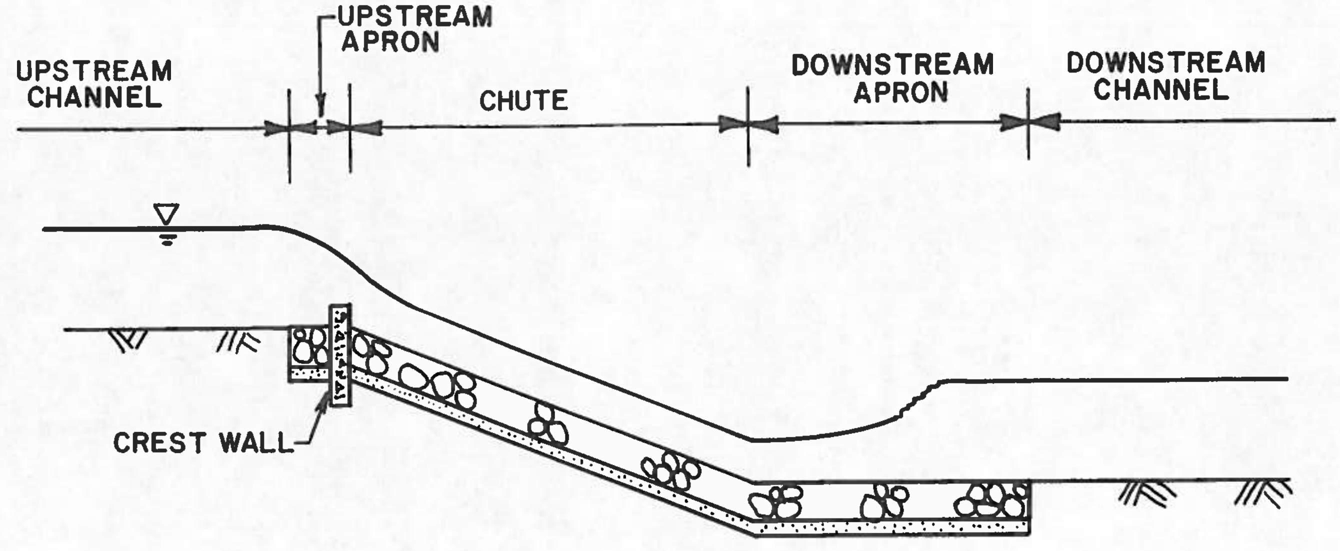
## CREST WALL ELEVATION CHART

| BOTTOM WIDTH* (ft) | P@Vn = 5 fps (ft) | P@Vn = 7 fps (ft) |
|---|---|---|
| 5 | 0.2' | 0.2' |
| 40 | 0.4' | 0.2' |
| 100 | 0.5' | 0.3' |

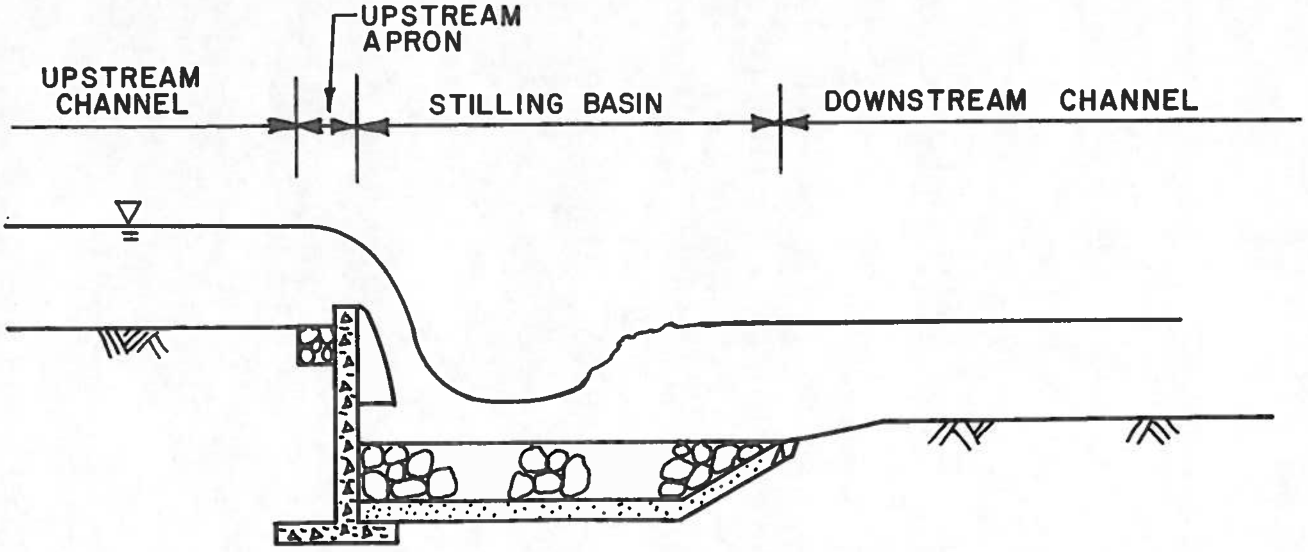
*Bottom Width of Approach Channel

**WRC ENG.**

**REFERENCE:** USDCM, DRCOG, 1982, Draft Revisions for Channel Drops



A. SLOPING CHANNEL DROP

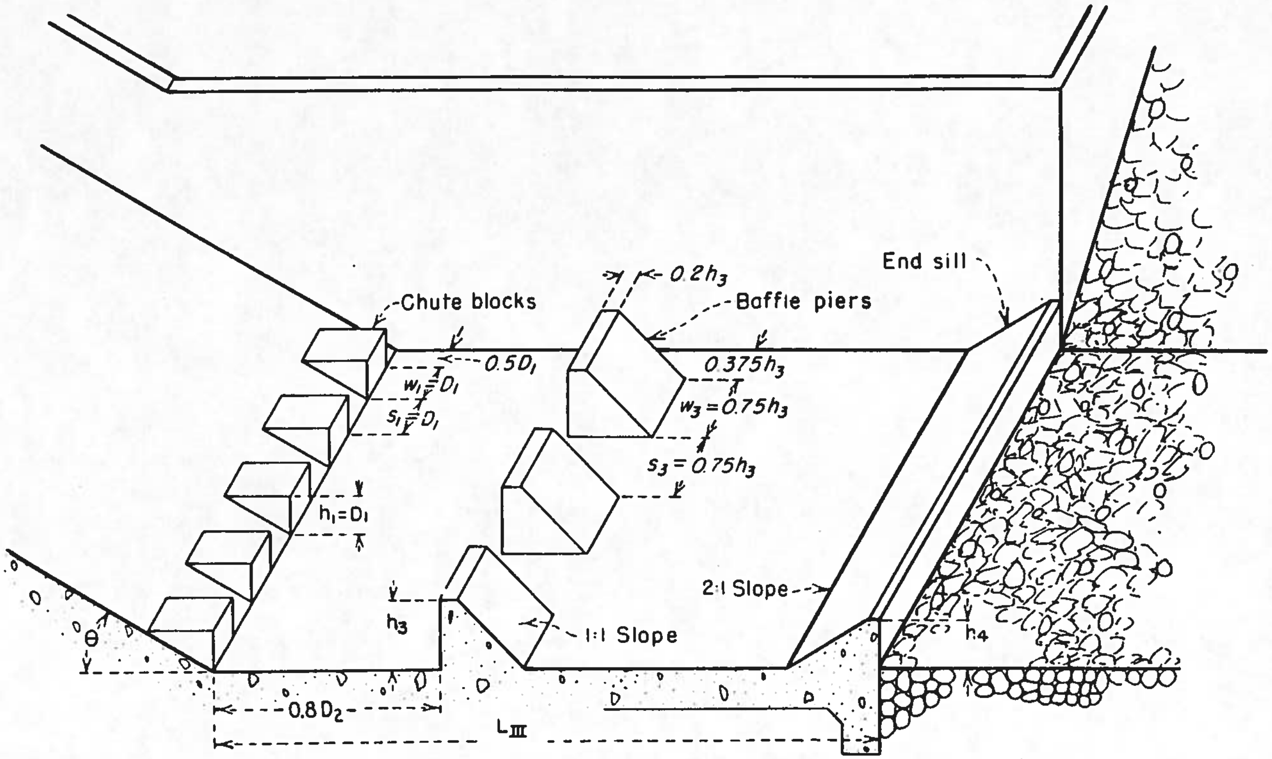


B. VERTICAL CHANNEL DROP

# GENERALIZED PROFILES OF RIPRAP DROP STRUCTURES

| WRC ENG | REFERENCE: USDCM, DRCOG, 1982 DRAFT REVISIONS FOR CHANNEL DROPS |
|---|---|

# USBR TYPE III STILLING BASIN



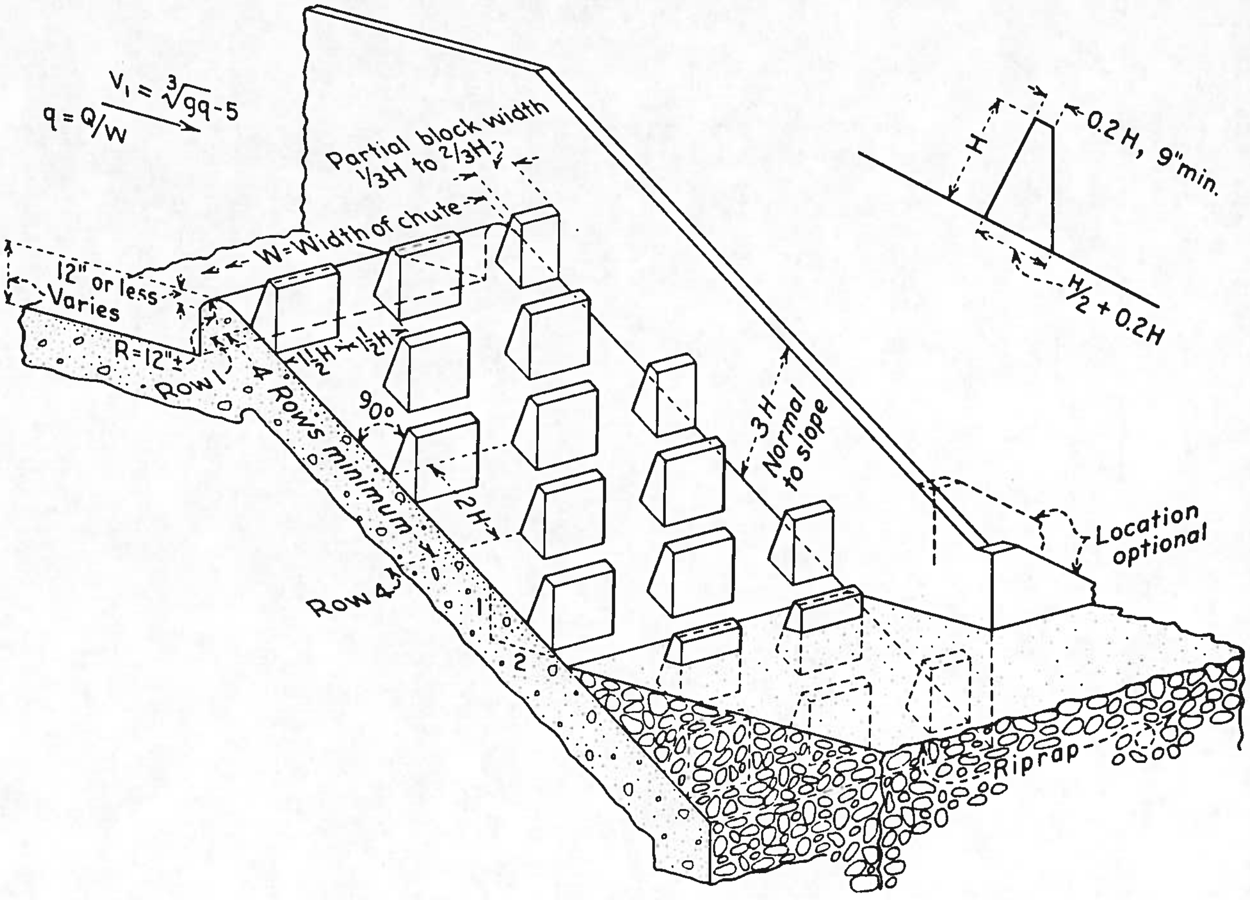
NOTE: See figure 1107 for design data

**WRC ENG.**

**REFERENCE:** "Hydraulic Design of Stilling Basins and Energy Dissipators", EM25 BR, January 1978

**FIGURE 1105**

# USBR TYPE IX
# STILLING BASIN

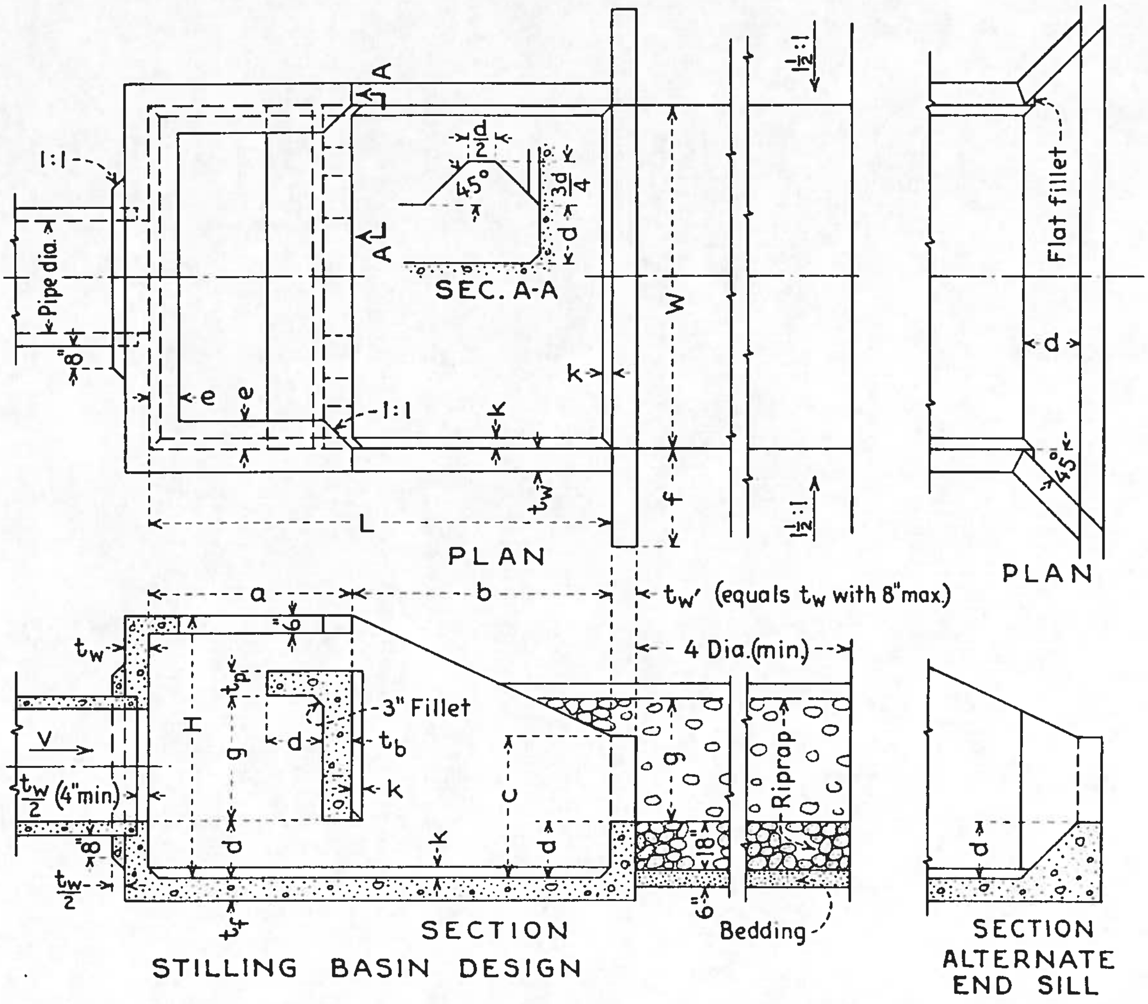


NOTE: See figure 1107 for design data

**WRC ENG.**

**REFERENCE:** "Hydraulic Design of Stilling Basins and Energy Dissipators", EM25 BR, January 1978

# USBR TYPE VI STILLING BASIN



NOTE: 1. See figure 1107 for design data

2. Refer to reference for structural details

**WRC ENG.**

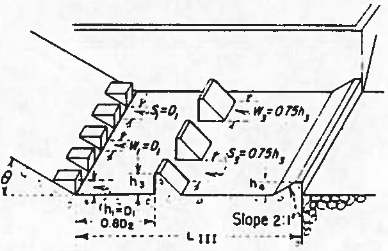
**REFERENCE:** "Design of Small Canal Structures",
USDI, BR, Denver 1974

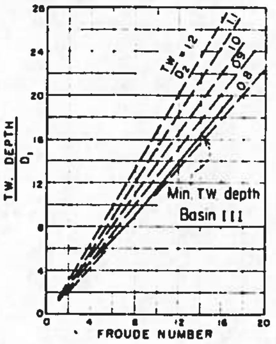
# DESIGN DATA - USBR TYPE STILLING BASINS

## SHORT STILLING BASINS FOR CANAL STRUCTURES, SMALL OUTLET WORKS AND SMALL SPILLWAYS (BASIN III)

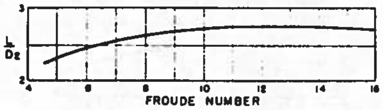
Jump and basin length reduced about 60 percent with chute blocks, baffle piers, and solid end sill.

For use on small spillways, outlet works, small canal structures where $V_1$ does not exceed 50-60 feet per second and Froude number is above 4.5.

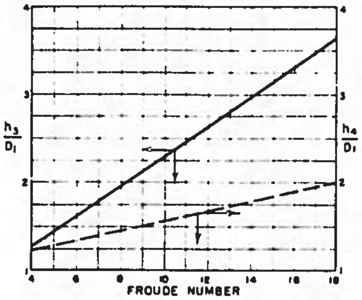




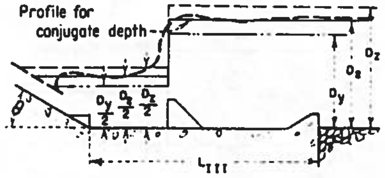
MINIMUM TW DEPTHS (SWEEPOUT)



LENGTH OF JUMP



HEIGHT OF BAFFLE BLOCKS AND END SILLS



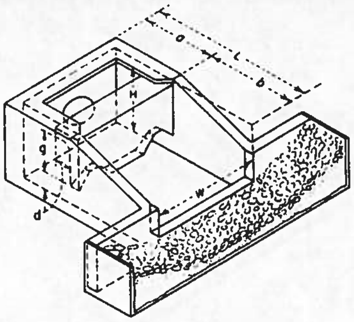
WATER SURFACE AND PRESSURE PROFILES

## STILLING BASIN FOR PIPE ON OPEN CHANNEL OUTLET (BASIN VI)

For use on pipe or open channel outlets. Sizes and discharges from table. $V_1$ should not exceed 30 feet per second. No tailwater required. Froude number usually 1.5 to 7 but not important.

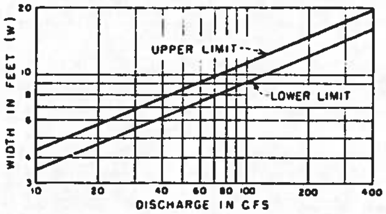
May substitute for Basin IV.

Energy loss greater than in comparable jump, figure 44.

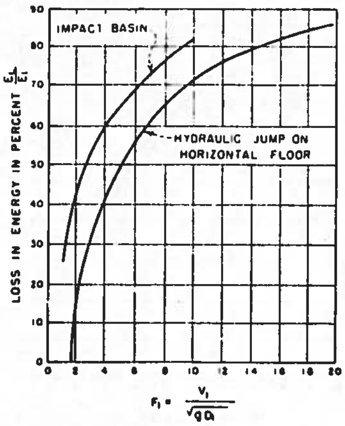


| PIPE | | Q | FEET AND INCHES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DIA IN | AREA SQ FT | | W | H | L | a | b | c | d | g |
| 18 | 1.77 | 21 | 5-6 | 4-3 | 7-4 | 3-3 | 4-1 | 2-4 | 0-11 | 2-1 |
| 24 | 3.14 | 38 | 6-9 | 5-3 | 9-0 | 3-11 | 5-1 | 2-10 | 1-2 | 2-6 |
| 30 | 4.91 | 59 | 8-0 | 6-3 | 10-8 | 4-7 | 6-1 | 3-4 | 1-4 | 3-0 |
| 36 | 7.07 | 85 | 9-3 | 7-3 | 12-4 | 5-3 | 7-1 | 3-10 | 1-7 | 3-6 |
| 42 | 9.62 | 115 | 10-6 | 8-0 | 14-0 | 6-0 | 8-0 | 4-5 | 1-9 | 3-11 |
| 48 | 12.57 | 151 | 11-9 | 9-0 | 15-8 | 6-9 | 8-11 | 4-11 | 2-0 | 4-5 |
| 54 | 15.90 | 191 | 13-0 | 9-9 | 17-4 | 7-4 | 10-0 | 5-5 | 2-2 | 4-11 |
| 60 | 19.63 | 236 | 14-3 | 10-9 | 19-0 | 8-0 | 11-0 | 5-11 | 2-5 | 5-4 |
| 72 | 28.27 | 339 | 16-6 | 12-3 | 22-0 | 9-3 | 12-9 | 6-11 | 2-9 | 6-2 |

BASIC DIMENSIONS



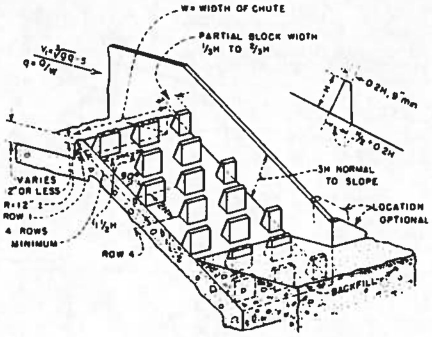
DISCHARGE LIMITS

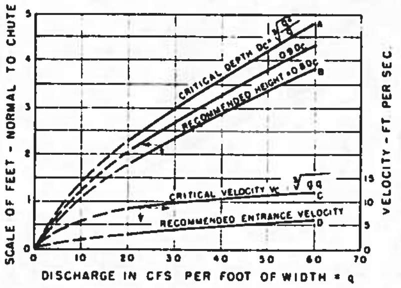


COMPARISON OF ENERGY LOSSES

## BAFFLED APRON FOR CANAL OR SPILLWAY DROPS (BASIN IX)

For use in flow ways where water is to be lowered from one level to another. The baffle piers prevent undue acceleration of the flow as it passes down the chute. Since the flow velocities entering the downstream channel are relatively low, no stilling basin is required. The chute may be designed to discharge up to 60 cubic feet per second per foot of width, and the drop may be as high as structurally feasible.





BAFFLE PIER HEIGHTS AND ALLOWABLE VELOCITIES

### SIMPLIFIED DESIGN PROCEDURE

The baffled apron should be designed for the maximum expected discharge, Q, up to 60 c.f.s. per foot of width.

Entrance velocity $V_1$, should be as low as practical or $V_1 = \sqrt[3]{gq}$

See Figures 103, 105, 107 and 109 for sample approach pools.

Baffle pier height, H, should be about $0.8D_c$ to $0.9D_c$, Curve B above.

Baffle pier widths and spaces should be equal, up to 3/2 H, but not less than H.

The slope distance between rows of baffle piers should be 2H, twice the baffle height H. See text for increase in row spacing on flat chutes.

Four rows of baffle piers are required to establish full control of the flow, although fewer rows have operated successfully. At least one row of baffles should be buried in the backfill.

The chute training walls should be three times as high as the baffle piers.

Riprap consisting of 6-to 12-inch stones should be placed at the downstream ends of training walls to prevent eddies from undermining the walls.

**WRC ENG.** **REFERENCE:** "Hydraulic Design of Stilling Basins and Energy Dissipators", EM25 BR, January 1978