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AN EXCEL PROGRAM TO DESIGN ROCK CHUTES FOR GRADE STABILIZATION

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Abstracts

Based on the research presented by Robinson, Rice, and Kadavy for the “Design of Rock Chutes”, Transactions of the ASAE Vol. 41(3):621-626, 1998, a spreadsheet program was developed to aid in rock chute design. This program is intended for use with Excel in Microsoft Office 97. For a given equivalent unit discharge and channel geometry (inlet channel, chute, and outlet channel) this program will calculate the stable median **angular** rock size D_{50} (in inches and pounds), n-value, and various chute dimensions and hydraulics. The research performed in the above mentioned reference is incorporated with general chute hydraulics to determine a stable inlet channel, chute (referring to the inlet apron, chute slope, and outlet apron), and outlet channel. This program also finds quantities of rock, bedding, and non-woven geotextile for a given cross section and gives the rock gradation envelope.

Keywords

Rock chutes, critical depth, normal depth, hydraulic jump, grade control, channel stability.

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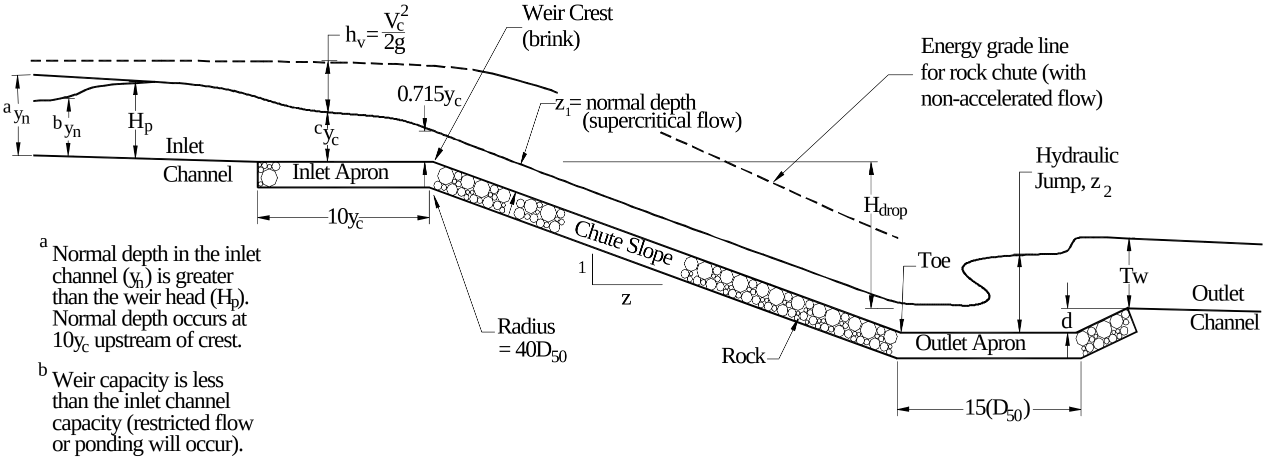
Introduction

Chutes, in general, are used to transport water from a higher elevation to a lower elevation in a non-erosive manner. Examples include flow from one waterway to another waterway, flow from a waterway to a drainage ditch, flow from a lake to a channel, etc. Chutes are composed of three parts: a level inlet apron, the chute slope, and a level outlet apron. The chute is assumed to have a uniform cross section throughout. Rock is commonly used to protect the underlying soil from erosion. Specifying the correct rock size and chute thickness are only a small portion of rock chute design. Proper design is very time consuming when several options are considered. This program will reduce design time by selecting the stable median **angular** rock size based on chute geometry and discharge. The output can be used for preparing final plans and field layout. The word angular is shown in bold in this paper and refers to rock that is 50% round and 50% cubical. The equations given in this paper are intended for use with English units. They can be used for cross sections having a trapezoidal, triangular, or rectangular shape. The equations are shown without proof and their verification is left up to the reader.

General Chute Hydraulics

Figure 1 shows a typical rock chute profile and defines various hydraulic properties of chutes in general.

d = *depth of the outlet apron below the outlet channel (1-foot suggested minimum), feet*
D_{50} = *median* ***angular*** *rock size (50% of the sample is finer by weight), inches*
g = *acceleration due to gravity,* $32.2\ ft/sec^2$
H_{drop} = *height of drop from the weir crest elevation to the outlet channel elevation, feet*
H_{ce} = *minimum specific energy head corresponding to a given discharge (at critical depth), feet*
H_p = *static head required to force the discharge through the weir (*H_{pe} *is the energy head), feet*
h_v = *velocity head associated with the critical depth, feet*
S_{ch} = *chute bed slope (1/z), ft./ft.*
Tw = *tailwater depth in the outlet channel, feet*
y_c = *critical depth in the chute, feet*
y_n = *normal depth in the inlet channel, feet*
z = *horizontal component of the chute slope (z:1)*
z_1 = *normal depth in the chute slope, feet*
z_2 = *hydraulic jump height, feet*



[a] Normal depth in the inlet channel (y_n) is greater than the weir head (H_p). Normal depth occurs at $10y_c$ upstream of crest.

[b] Weir capacity is less than the inlet channel capacity (restricted flow or ponding will occur).

[c] $H_{ce} = y_c + \frac{V_c^2}{2g}$

Figure 1 – Typical Rock Chute Profile

The most important property defining the chute is the weir head (H_p). The H_p determines the amount of flow that will go through the weir entrance (at the crest or brink) and down the chute. The shape of the weir entrance and the velocity of the approach channel affect the weir head. A method to control H_p will be discussed later in this paper. As the water approaches the inlet apron the flow accelerates. Several references define different locations upstream of the weir crest at which accelerated flow begins. The most conservative distance of $10y_c$ was used to set the inlet apron length. Critical depth occurs between $2y_c$ and $4y_c$ upstream of the weir crest. Depth at the weir crest is $0.715y_c$ (brink depth). Whenever the chute slope is steeper than critical slope, normal depth in the chute slope (z_1) is below critical depth resulting in supercritical flow. For rock chutes, the flow will reach normal depth, generally in the middle 1/3 of the slope, and continue down the slope without accelerating (roughness offsets the acceleration due to gravity). As flow reaches the outlet apron (near the toe) it will transition from supercritical flow to subcritical flow in the form of a hydraulic jump. The hydraulic jump height (z_2) varies with the chute slope (thus the velocity) and the chute cross section. The hydraulic jump height will normally be less than the weir head (H_p) for flat chute slopes. As the chute slope increases, z_2 will exceed H_p. Figure 2 illustrates a typical cross section of a rock chute.

m_{ch} = *horizontal component of the chute side slope*
Bw_{ch} = *bottom width of the chute, feet*

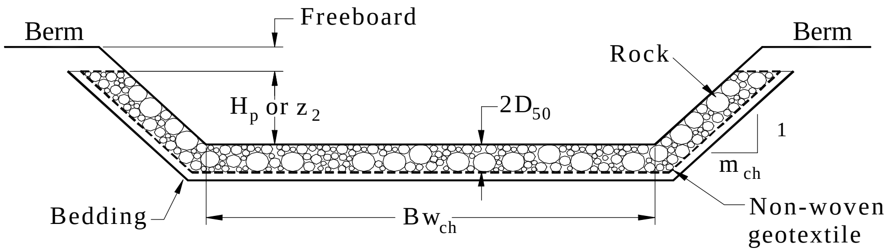


Figure 2 – Typical Rock Chute Cross Section

The height of protection along the side slope shall be the greater of H_p or z_2. The tailwater may be greater than the height of riprap along the side slope in the outlet apron. If good vegetation has been established above the riprap this is adequate to prevent erosion. Problems may occur during long duration discharges from flat watersheds or those below a watershed detention dam. Longer peak flows can be expected to have a greater potential for scouring on the side slopes. Consider placing riprap (or other types of protection) above H_p or z_2 and up to the tailwater depth (or higher) for this case. The hydraulic jump length is given as $15D_{50}$ from the research performed on rock chutes[1]. A rock thickness of $2D_{50}$[1] is recommended in addition to a non-woven geotextile over sand bedding. The geotextile acts as a filter and prevents material under the chute from being pulled up through the rocks. A non-woven geotextile is used because there is less chance of soil particle migration through this material as compared with a woven geotextile. The bedding should prevent migration of fine soil particles that may plug the non-woven geotextile. Also, the bedding provides better contact between the rock and the underlying soil and provides a cushion when the rock is placed. The cushion helps prevent damage to the non-woven geotextile.

Design Approach

The approach for designing rock chutes presented in this paper is given in sequential order (Equations 1 through 16). An example design is presented later to familiarize the reader with the design procedure and equations. The spreadsheet program output is included with this paper and shown in Appendix A. See the instructions in the spreadsheet program for further explanation of the input and output.

Channel Geometry

The Excel program (Appendix A) requires values to define the inlet channel section, the chute section, and the outlet channel section geometry. The bottom width (Bw), side slopes (m:1), Manning's roughness coefficient (n), and the bed slope (S) are used to specify each section. In this paper, the inlet channel, the chute, and the outlet channel cross sections are denoted with subscripts "i", "ch" and "o", respectively. Note the maximum values for S_{ch} and m_{ch} in the chute section (see Rock Chute Parameters). This program checks normal depth in the inlet and outlet channels (y_n and Tw, respectively) for stability of the rock chute. Tailwater depth may be determined outside the program and input to override the program calculations. This program is not intended to be a design tool for the inlet and outlet channel sections. It is assumed that the user has designed these components by some external method and are stable for the given site conditions. The n-value for the rock chute is determined by an equation presented later in this paper. The outlet apron depth (d) should have a suggested minimum value of 1 foot, and the value of d must be entered such that Tw + d will equal or exceed z_2. Freeboard refers to the height of the berm (or the embankment that directs water through the weir entrance) above the rock chute in the inlet apron. This should provide a safety factor so the berm is not overtopped unless the design storm is significantly exceeded. A base flow (or additional flow) may be entered for the outlet channel although the base flow may be small compared to the design storm. An example would be base flow in a drainage ditch prior to any storm events.

Design Storm Data

NRCS guidance for selecting the appropriate design storm is given in National Handbook of Conservation Practices, NRCS Grade Stabilization Structure Standard No. 410, Table 2. This section is used for guidance only and it is left up to the engineer to determine the chute design capacity. The selected design storm (Q_{high}) is based on the drainage area, the height of drop in the chute (from the inlet apron to the outlet channel), and the amount of rainfall for a 5-year, 24-hour storm. The 5-year, 24-hour rainfall amounts range from 0 to 3 inches, 3 to 5 inches, or greater than 5 inches. A required chute capacity (principal spillway storm) and total required capacity are given. The total required capacity is routed through the chute or in combination with an auxiliary spillway. Q_{high} and Q_{low} (both in ft^3/sec) are entered for the flow through the chute, and the corresponding tailwater elevations must be checked for both storm events. This program does not design the auxiliary spillway; however, based on the weir head, a portion of the flow can be diverted through the auxiliary spillway, thus reducing flow in the rock chute and controlling the fluctuation in H_p.

Normal Depth in the Inlet Channel

Normal depth in the inlet channel is calculated using Manning's equation for open channel flow. See Equation 1 below. Geometric properties have been substituted for a trapezoidal shaped channel. By entering the appropriate values for the inlet channel (Bw_i, m_i, n_i and S_i) the designer may solve for y_n. The normal depth in the inlet channel should be less than the weir head, i.e., the weir capacity is less than the inlet channel capacity (restricted flow). This causes the flow to "pond" upstream of the weir entrance reducing velocities and preventing erosion.

$$Q = \frac{1.49}{n_i}(Bw_i \cdot y_n + m_i \cdot y_n^2)\left[\frac{Bw_i \cdot y_n + m_i \cdot y_n^2}{Bw_i + 2y_n\sqrt{1+m_i^2}}\right]^{\frac{2}{3}} S_i^{\frac{1}{2}} \qquad \textit{(Equation 1)}$$

<u>where</u> ***n_i*** *is Manning's roughness for the inlet channel, and*
Q *is Q_{high} or Q_{low} in ft^3/sec (used in Equations 1 through 6 and 16)*

Generally, the normal depth will be less than H_p, except for flatter inlet channels. Narrowing the chute will increase H_p, but this may not be practical. Design of the inlet channel can be completed before using this program. Some programs will calculate "n" based on the type of vegetative retardance. The designer should be aware that n-values will vary based on the age of the vegetation. An initially constructed project may have low n-values, which should be used to check the initial stability of the channel.

Critical Depth in the Chute

The critical depth, based on the rock chute cross section and design discharge Q, is given by Equation 2 below. Properties for a trapezoidal shaped channel are substituted in Equation 2. By entering appropriate values for the rock chute cross section (Bw_{ch} and m_{ch}) the designer may solve for y_c.

$$\frac{Q^2}{g} = \frac{(Bw_{ch} \cdot y_c + m_{ch} \cdot y_c{}^2)^3}{Bw_{ch} + 2m_{ch} \cdot y_c} \qquad \textit{(Equation 2)}$$

As discussed previously the critical depth occurs between $2y_c$ and $4y_c$ upstream of the weir crest (brink), refer to Figure 1. Depth at the crest is $0.715y_c$ given for a free overfall. When the normal depth in the rock chute is less than y_c the flow is supercritical. Where critical depth occurs on the inlet apron the specific energy head, H_{ce}, is the minimum specific energy head corresponding to a given discharge Q. Accelerated flow exists upstream of the crest for a distance of $10y_c$, which occurs during the worst inlet channel condition, $y_n > H_p$. Protection shall extend upstream a minimum of $10y_c$.

Tailwater in the Outlet Channel

Tailwater elevation is a critical element when considering the design of rock chutes. The stability of the outlet apron is directly related to the tailwater depth (Tw). The Tw must equal or exceed the hydraulic jump height for energy to be dissipated. The loss of energy resulting from the hydraulic jump is absorbed by the rock in the outlet apron. The Tw must be checked for both high and low flow conditions (Q_{high} and Q_{low}, where Q_{high} is the design discharge and Q_{low} is a smaller discharge). Normal Tw can be calculated using Manning's equation given by Equation 3. Appropriate values for the outlet channel cross section

$$Q + BaseFlow = \frac{1.49}{n_o}(Bw_o \cdot Tw + m_o \cdot Tw^2)\left[\frac{Bw_o \cdot Tw + m_o \cdot Tw^2}{Bw_o + 2Tw\sqrt{1+m_o{}^2}}\right]^{\frac{2}{3}} S_o{}^{\frac{1}{2}} \qquad \textit{(Equation 3)}$$

*<u>where</u> **n_o** is Manning's roughness for the outlet channel*

(Bw_o, m_o, n_o, S_o and base flow) can be input by the designer to solve for Tw. If the tailwater is determined using another program, the depth can be input into the rock chute program. In some instances, the outlet channel geometry may not provide adequate tailwater for either high or low flow conditions, or both. For this case the outlet apron shall be lowered below the outlet channel elevation a distance d such that Tw + d will equal or exceed z_2. However, this alone may not insure adequate scour protection downstream of the outlet. If the hydraulic jump height is always below the tailwater, the jump will be drowned out by the tailwater but little energy may be dissipated. Submerged flow may continue at high velocity along the channel bottom for a considerable distance. As a result of this possibility, we strongly recommend lowering the outlet apron a minimum of 1 foot and forming an upturned bucket as shown in Figure 1. Also, the protection should extend a minimum of $15D_{50}$ (times a safety factor) downstream of the toe to offset submerged flow. The difference in elevation between the water surface upstream of the chute and the tailwater surface will have a considerable impact on the continuation of submerged flow downstream. For cases where the hydraulic jump is submerged during high and low flow and the difference in water surface elevation (upstream to downstream) is small, the discharge through the weir may spread out over the surface of the tailwater. A high drop (or large elevation difference) may result in continuation of submerged flow. Lowering the outlet apron and forming an upturned bucket may also prevent unraveling of the chute[1].

Head for a Trapezoidal Shaped Weir (Broad-crested)

The weir head (H_p) is determined based on the chute cross section and the velocity of the approach or inlet channel, V_i. Solving for a V_i that corresponds with H_p is a trial-and-error procedure using Equations 4, 5, and 6 below. V_i will be equal to the velocity calculated using normal depth, y_n if H_p is equal to y_n. The downstream static head, H_2 above the weir crest ($T_w - H_{drop}$) can be assumed zero if H_2 is $0.715y_c$ or less. The flow through the weir is grouped in two different categories, submerged and unsubmerged. When the tailwater elevation is at or above the weir crest elevation the weir is considered submerged. For low submergence, when Tw is at the brink depth or lower, the discharge can be considered as free flowing. Submerged flow (Q_{total}) through the trapezoidal shaped weir is equal to the sum of the free flow (Q) through the rectangular portion (with 2 end contractions)[2] and the triangular portion (v-notch)[3] of the weir multiplied by a function of the upstream and downstream heads (submergence ratio[2] shown in Equation 5). The approach velocity does not appreciably affect flow through the v-notch portion and therefore the velocity head is neglected.

$$Q = 0.385 C_d \sqrt{2g}\left(Bw_{ch} - 0.20H_p\right)\cdot\left[\left(H_p + \frac{V_i^2}{2g}\right)^{\frac{3}{2}} - \left(\frac{V_i^2}{2g}\right)^{\frac{3}{2}}\right] + \frac{8}{15}C_{nv}\sqrt{2g}\left(m_{ch}\right)H_p^{\frac{5}{2}} \qquad \textit{(Equation 4)}$$

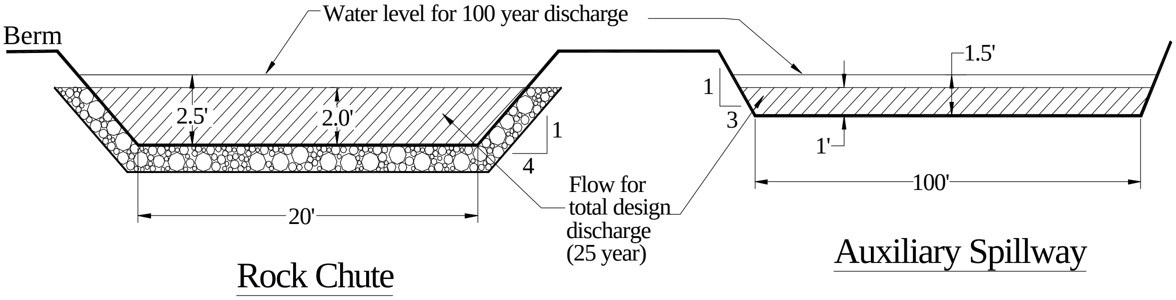
$$Q_{total} = Q\cdot\left[1 - \left(\frac{H_2}{H_p + \frac{V_i^2}{2g}}\right)^{1.44}\right]^{0.385} \qquad \textit{(Equation 5)}$$

$$Q_{total} = V_i(Bw_i \cdot H_p + m_i \cdot H_p^2) \qquad \textit{(Equation 6)}$$

<u>where</u>
C

The H_p is a critical value for design of rock chutes. To safely convey flow through the chute without exceeding the chute capacity (or the stable rock size), an auxiliary spillway may be used as shown in Figure 3. The total flow is the sum of the weir flow given by Equation 5 or 6 and the auxiliary spillway flow. The auxiliary spillway allows for greater fluctuation in discharge with a small increase in H_p. For example, in Figure 3 below a chute is designed for a 10-year, 24-hour storm (200 cfs) and the total capacity (chute plus auxiliary spillway) is a 25-year, 24-hour storm (400 cfs). When a 100-year, 24-hour storm (total of 675 cfs) flows through the chute and auxiliary spillway, H_p would increase by 0.50 feet. Without an auxiliary spillway H_p would increase by 1.40 feet.

> *Example: The use of an auxiliary spillway allows for greater fluctuation in Q without a large increase in H_p. An increase in Q of 275 cfs increases H_p by only 0.50 feet, from 2.0 feet to 2.5 feet. Without an auxiliary spillway the same increase in Q would raise H_p 1.40 feet. This increase may be accounted for by a factor of safety.*



Note: *required freeboard above this type of structure is 1 foot, therefore the 0.50-foot rise for the Q_{100} storm should be one-half the way to the top of the berm (embankment).*

Figure 3 – Auxiliary Spillway

The H_p is relatively constant for a lake or pond during most storm events. The velocity head corresponding to H_p is approximately zero. Outflow through the rock chute must equal the inflow (Q_{in}). For a given cross section, find the inlet apron elevation that gives the correct H_p, where H_p is the lake elevation minus the inlet apron elevation. A Q can then be found using Equations 4 and 5 and must be Q_{in} or greater.

Rock Chute Parameters

Several parameters must be considered when designing rock chutes. An appropriate safety factor (F_s) must be applied to the equations. The safety factor is a multiplier that increases the D_{50} size (along with rock weight), the bed thickness, and the outlet apron length. The value selected should reflect the importance of the structure, the probability of exceeding the design storm, and appropriate engineering judgement. Also, use of an auxiliary spillway may reduce the F_s as explained in the previous section. The D_{50} is selected based on the normal depth in the chute (which is a function of chute bed slope and equivalent unit discharge). When the weir crest is submerged, normal depth is never achieved on the chute slope. Normal depth may not be achieved for short chute slopes either. Therefore, the program may over estimate D_{50} for these cases and the F_s may be reduced. The user may select a F_s of 1.0 and increase the design discharge if desired (to account for under-sizing of the rock). The user <u>must not</u> round the D_{50} size down unless an appropriate safety factor has been applied ($Fs > 1.0$). The safety factor is applied to ensure that the hydraulic jump length and the continuation of submerged flow won't extend beyond the end of the chute. The flow through the mantle (q_m) or rock will be taken as zero. The rock will tend to silt in and block flow. The maximum side slope ratio is 2 horizontal to 1 vertical (m_{ch}:1 of 2.0:1 or flatter), and the maximum chute slope ratio is 2.5 horizontal to 1 vertical (S_{ch} of 0.40 ft./ft. or flatter). A uniform **angular** rock gradation is required[1]. The coefficient of uniformity (D_{60}/D_{10}) shall be 2.0 or less. The closer the sample is all to the D_{50} size (uniform), the more stable the rock chute will be for a given discharge. Although poorly graded materials (uniform) withstood higher discharge than well-graded material (non-uniform), the failure was much more sudden[4]. Well-graded materials tend to go through a process called healing where dislodged rocks are replaced by small stones from upstream[4]. Also, rounded stone failed at a unit discharge of approximately 40% less than angular shaped stones of the same median stone size[5]. Equations 7 through 11 are based on research in Reference 1 and modified slightly for use with English units. Equations 12 through 15 are the final values modified with a F_s.

$$q_t = (g)^{0.5}(y_c)^{\frac{3}{2}} \qquad \textit{(Equation 7)}$$

$$D_{50} = \left[\frac{q_t\left(S_{ch}\right)^{1.5}}{4.75(10)^{-3}}\right]^{\frac{1}{1.89}} \qquad S_{ch} < 0.10 \qquad \textit{(Equation 8)}$$

$$D_{50} = \left[\frac{q_t\left(S_{ch}\right)^{0.58}}{3.93(10)^{-2}}\right]^{\frac{1}{1.89}} \qquad S_{ch} \geq 0.10 \qquad \textit{(Equation 9)}$$

$$n_{ch} = 0.047\left(D_{50} \cdot S_{ch}\right)^{0.147} \qquad \textit{(Equation 10)}$$

$$z_1 = \left[\frac{n_{ch}\left(q_t - q_m\right)}{1.486\left(S_{ch}\right)^{0.50}}\right]^{\frac{3}{5}} \qquad \textit{(Equation 11)}$$

where S_{ch} *= chute bed slope in ft./ft.,*
q_m *= flow through the mantle, assumed zero,*
Specific gravity *= 2.65 in Equation 15,*
q_t *= equivalent unit discharge in* ft^3*/sec/ft.,*
D_{50} *= rock diameter, in.,*
W_{50} *= rock weight, lbs.*

Final rock chute calculations (use D_{50} from either Equation 8 or 9).

$$D_{50\,design} = D_{50}\,(F_s) \qquad \textit{Median angular rock size} \qquad \textit{(Equation 12)}$$

Round results from Equation 12 to the nearest even dimension and use in Equation's 13 - 15.

$$2D_{50\,design} \qquad \textit{Rock chute thickness} \qquad \textit{(Equation 13)}$$

$$\frac{15}{12}D_{50\,design} \qquad \textit{Outlet apron length} \qquad \textit{(Equation 14)}$$

$$W_{50} = 0.0275(2.65)\left(D_{50\,design}\right)^3 \qquad \textit{Rock weight} \qquad \textit{(Equation 15)}$$

The q_t in Equation 7 gives the unit discharge in ft^3/sec/ft. For a rectangular shaped channel, the unit discharge is the total discharge divided by the bottom width and is the same as Equation 7. For trapezoidal shaped channels, the total discharge divided by the bottom width will over estimate the unit discharge (conservative) and Equation 7 will give more appropriate answers. Equation 8 is used for chute slopes less than 10%, and Equation 9 is used for chute slopes 10% or greater. The normal depth determined empirically using Equation 11 matches Manning's equation very closely. The D_{50} size given by either Equation 8 or 9 will be modified by F_s as shown by Equation 12. The curve radius of $40D_{50}$ (not modified by F_s) is used to improve flow at the transition from the inlet apron to the chute slope. The rock chute program calculates the stationing and elevation for this circular curve. The chute bed slope affects Equations 8 through 11. A steeper bed slope increases the stable rock size and n-value and decreases z_1. A flatter bed slope decreases the stable rock size and n-value and increases z_1.

Hydraulic Jump Height at the Outlet Apron

Substituting properties for a trapezoidal shaped channel into the momentum equation, the hydraulic jump height (z_2) is given in Equation 16. The bottom width and side slope values correspond to the chute cross section, which assumes that the jump forms on the chute slope or outlet apron. The jump will form at the toe or slightly upstream provided that the hydraulic jump is submerged by the tailwater. Reference 1 noted that the hydraulic jump height ranges from 2-$3D_{50}$, which matches Equation 16 very closely.

$$\frac{z_1^{\,2}}{6}\left(3Bw_{ch}+2m_{ch}\cdot z_1\right)-\frac{z_2^{\,2}}{6}\left(3Bw_{ch}+2m_{ch}\cdot z_2\right)=\frac{Q^2}{g}\left[\frac{1}{\left(Bw_{ch}+m_{ch}\cdot z_2\right)z_2}-\frac{1}{\left(Bw_{ch}+m_{ch}\cdot z_1\right)z_1}\right]$$

(Equation 16)

A steeper slope increases the flow velocity and reduces the normal chute depth. As a result the hydraulic jump height will increase. Chute slopes that are not steeper than the critical slope will not have a hydraulic jump at the toe.

Rock Gradation Envelope

The rock gradation is characterized by a coefficient of uniformity (D_{60}/D_{10}) of 2.0 or less. This describes a rock sample that is poorly graded or uniform. A sample with a low coefficient of uniformity (approaching 1.0) results in less small rock and more uniform rock size. During the first large storm event, generally, the small rock is washed downstream. The riprap gradation envelope is shown on semi-log paper, with the grain size in inches plotted on the x-axis (log scale) and the percent finer by weight plotted on the y-axis (normal scale). A plot of the rock gradation envelope will be more vertical as the coefficient of uniformity approaches 1.0. A range of sizes defines the gradation envelope for different rock diameters, i.e., D_{50} refers to 50% of the sample that is finer by weight. The gradation envelope values are given below. The rock gradation envelope for a 10-inch D_{50} sample is shown in Figure 4 below. By interpolating, D_{60} can be given a range of $1.09D_{50}$ to $1.59D_{50}$. The coefficient of uniformity for the lower and upper limit line is calculated as 1.36 and 1.22, respectively. A diagonal line between the D_{60} on the upper limit line and D_{10} on the lower limit line would produce a coefficient of uniformity value of 1.99. Therefore, all gradations in this band should satisfy the requirement that the coefficient of uniformity be less than 2.0. The rock weight is determined based on research in Reference 1. The angular rocks used in research were considered 50% angular (cubical) and 50% rounded (spherical). From Minnesota Technical Release 3, *Loose Riprap Protection*, July 1989, Table 2-1, p. 17, the specific gravity of the rock is assumed to be 2.65 and Equation 15 above is used to calculate the rock weight.

$D_{100} = 1.5D_{50} - 2.0D_{50}$ - 100% of the total sample is smaller by weight

$D_{85} = 1.3D_{50} - 1.8D_{50}$ - 85% of the total sample is smaller by weight

$D_{50} = 1.0D_{50} - 1.5D_{50}$ - 50% of the total sample is smaller by weight

$D_{10} = 0.8D_{50} - 1.3D_{50}$ - 10% of the total sample is smaller by weight

Values for Rock Gradation Envelope

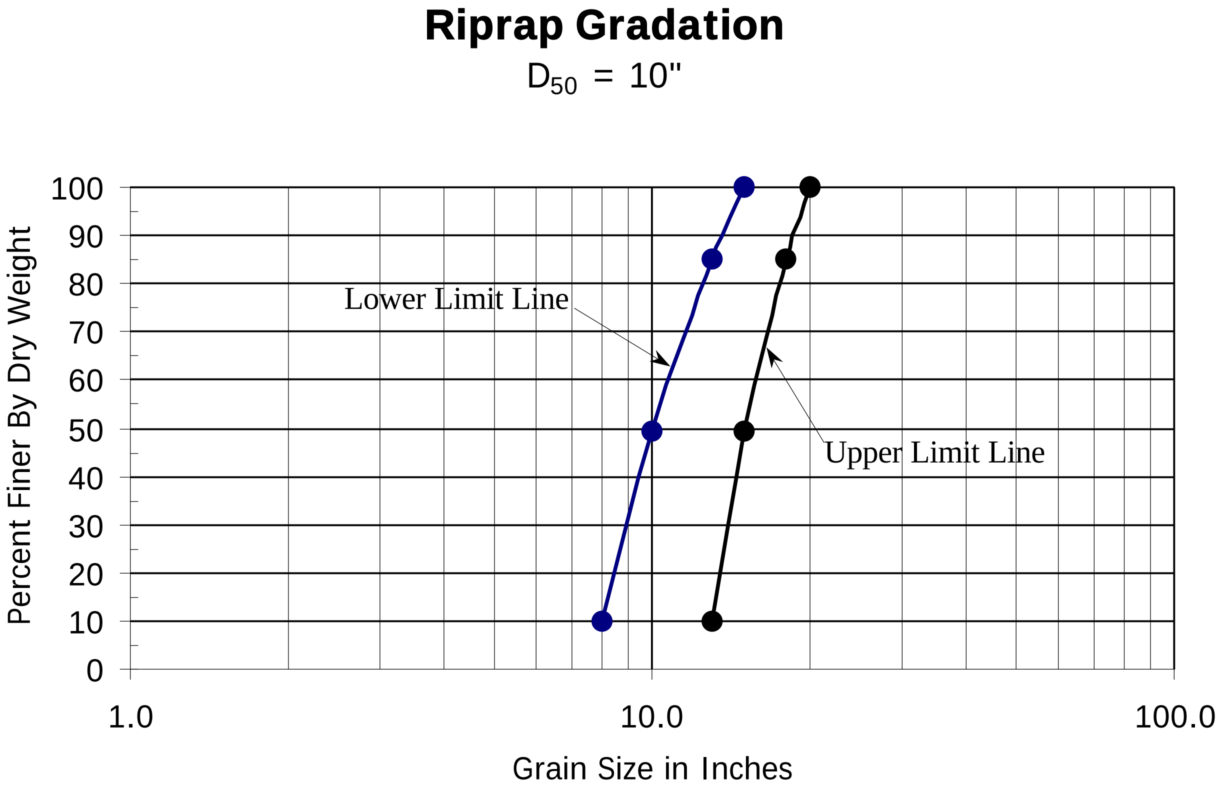


Figure 4 – Rock Gradation Envelope

Example Design

Given

A waterway with a 20-foot bottom width, 4:1 side slopes, and bed slope of 0.0060 ft./ft. was designed using an n-value of 0.035 for vegetated conditions (mowed twice per year). The waterway drops over a steep bank into a dry watercourse (5-foot drop). The watercourse was surveyed and defined by the following properties: a 40-foot bottom width, 4:1 side slopes, bed slope = 0.0050 ft./ft., n-value of 0.045, and base flow of 0.0 cfs. Total discharge = 330 cfs (10-year, 24-hour), chute discharge = 249 cfs (5-year, 24-hour), and 75 cfs was the 1-year, 24-hour storm. Assume that no auxiliary spillway will be used (total discharge through the rock chute and chute discharge is not used).

Find

The rock chute cross section, the hydraulic properties, and a corresponding stable **angular** rock size.

Solution

The hydrology has been determined and the design discharge given for the structure. Using the equations presented in this paper (1 through 16) provides a logical approach for design. Assume that the chute cross section will remain the same as the inlet channel (waterway), i.e., Bw_{ch} = 20 ft. and m_{ch} = 4. Selecting the proper rock chute slope is based on availability of space and minimizing the stable rock size (flatter slopes require a smaller stable rock size). Use a chute slope of 5:1 or 0.20 ft./ft. A safety factor of 1.20 will be appropriate for design. Calculations are shown for the high flow discharge (Q = 330 cfs). Also, the designer must check low flow discharge. A printout from the rock chute program is in Appendix A.

- *Step 1*

Determine the normal depth by substituting inlet channel geometry into Equation 1,

Bw_i = 20 ft., m_i = 4, n_i = 0.035, S_i = 0.0060 ft./ft., Q = 330 cfs

and solving, **y_n = 2.34 feet**.

- *Step 2*

Determine the critical depth in the chute by substituting the rock chute geometry into Equation 2,

Bw_{ch} = 20 feet, m_{ch} = 4, Q = 330 cfs

and solving, **y_c = 1.80 feet**.

Note: the length of the inlet apron is $10y_c$ = 18 feet, critical depth occurs between $2y_c$ and $4y_c$ (3.6 feet and 7.2 feet) upstream of the weir crest, and the depth at the weir crest is $0.715y_c$ or 1.28 feet.

- *Step 3*

Find the tailwater depth by substituting outlet channel geometry into Equation 3,

Bw_o = 40 ft., m_o = 4, n_o = 0.045, S_o = 0.0050 ft./ft., Q = 330 cfs, Base flow = 0.0 cfs

and solving, **Tw = 2.04 feet**.

Note: H_2 = 0.0 feet (use zero when Tw is at or below the weir crest) and the chute has unsubmerged flow.

- *Step 4*

Find the weir head using rock chute geometry in Equations 4 and 5 and inlet channel geometry in Equation 6 and solving simultaneously,

Bw_{ch} = 20 ft., m_{ch} = 4, Q = 330 cfs (rock chute cross section)

Bw_i = 20 ft., m_i = 4 (inlet channel cross section)

which gives, **H_p = 2.30 feet and V_i = 4.91 fps** and is approximately equal to the inlet channel velocity or 4.79 fps at normal depth (since y_n = 2.34 feet is approximately equal to H_p = 2.30 feet).

Note: the total H_{pe} including velocity head is 2.67 feet and when substituted into the rectangular broad-crested weir equation $Q_r = 3.1(Bw_{ch})H_{pe}^{1.5}$, Q_r = 271 cfs. As the weir becomes wider (or the water depth shallower), Q_r would be a better approximation for the design discharge. $Q_{trap} = 3.367(Bw_{ch})H_{pe}^{1.5}$ and Q_{trap} = 294 cfs, which agrees well with Equation 4. Also, $^2/_3(H_{pe})$ = 1.78 is equal to y_c.

- *Step 5*

Determine the rock chute parameters using Equations 7 through 11, which will give **q_t = 13.65 cfs/ft., D_{50} = 13.5 inches, n = 0.054, z_1 = 1.07 feet**, and a radius of **$40D_{50}$ = 45 feet.** Modifying the D_{50} with a safety factor of 1.20 using Equation 12 gives **$D_{50design} = D_{50}F_s$ or 16.2 inches**. Round to the nearest convenient dimension, or **$D_{50design}$ = 16 inches**. Then using Equations 13 through 15, the bed thickness is **$2D_{50design}$ = 32 inches**, the outlet apron length is **$^{15}/_{12}(D_{50design})$ = 20 feet**, and the rock weight is **298 pounds.**

Note: since a safety factor greater than 1.0 was applied, rounding down slightly is acceptable.

- *Step 6*

Find the hydraulic jump height using Equation 16 and substituting rock chute geometry,

Bw_{ch} = 20ft., m_{ch} =4, z_1 = 1.07 ft.

and solving, **z_2 = 2.76 feet**.

Note: z_2 exceeds the tailwater depth by 0.72 feet. Here the designer chooses to submerge the outlet apron 1.0 foot so that Tw + d = 3.04 feet and is greater than z_2. The outlet should function adequately for this design. A 5:1 bed slope was selected arbitrarily for this example. If a 10:1 slope was used the D_{50} size would have been reduced to 13.0 inches. For this example, z_2 exceeds H_p but is less than the tailwater. The designer should consider the possibility of erosion above the riprap protection in the outlet channel side slope. Other properties can be calculated for rock chutes, including the Froude Number and the energy lost through the jump (absorbed by the rock). These are shown in the program output in Appendix A and left up to the reader to calculate.

Conclusions

The material in this paper is presented to aid in using an Excel program for rock chute design (output is given in Appendix A). General chute hydraulics are combined with the research for selecting a stable rock size and are given in a sequential design order. The reader should refer to the Instructions (pages 1 to 3 of 3) within the Excel program for more information about its use. This paper shows steps to calculate normal depth in the inlet channel, critical depth in the chute, tailwater in the outlet channel, the head for a trapezoidal shaped weir (broad-crested), various rock chute parameters, the hydraulic jump height at the outlet apron, and the rock gradation envelope. Included with this paper is a printout of the rock chute design, which corresponds with the example design in the previous section. Refer to the Rock Chute Design Calculations pages 2 and 3 of 3 in Appendix A.

Spreadsheet Program Location

The spreadsheet program may be found in the Iowa Natural Resources Conservation Service home page under the following web address: www.ia.nrcs.usda.gov/design and link to *Engineering Programs*. It is listed under the name “Rock Chute Design Program”. Version 4.0, dated 7/10/00 is the spreadsheet program presented at the ASAE conference.

Acknowledgement

The authors wish to thank Stephen M. Becker, P.E., Area Engineer, Natural Resources Conservation Service, St. Peter, Minnesota for his assistance with rock chute design. His knowledge and review time aided greatly in the development of this paper and rock chute program.

Disclaimer

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Appendix A

(Output from the Rock Chute Design Program)

Rock Chute Design Data

(Version 4.0 - 07/10/00, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Spillway protection
Designer: Jim Villa
Date: 9/27/00

County: Woodbury
Checked by:
Date:

Input Channel Geometry

Inlet Channel	**Chute**	**Outlet Channel**
Bw = 20.0 ft.	Bw = 20.0 ft.	Bw = 40.0 ft.
Side slopes = 4.0 (m:1)	Factor of safety = 1.20 (F_s)	Side slopes = 4.0 (m:1)
n-value = 0.035	Side slopes = 4.0 (m:1) → **2.0:1 max.**	n-value = 0.045
Bed slope = 0.0060 ft./ft.	Bed slope (5:1) = 0.200 ft./ft. → **2.5:1 max.**	Bed slope = 0.0050 ft./ft.
Freeboard = 0.5 ft.	Outlet apron depth, d = 1.0 ft.	Base flow = 0.0 cfs

Design Storm Data (Table 2, NHCP, NRCS Grade Stabilization Structure No. 410)

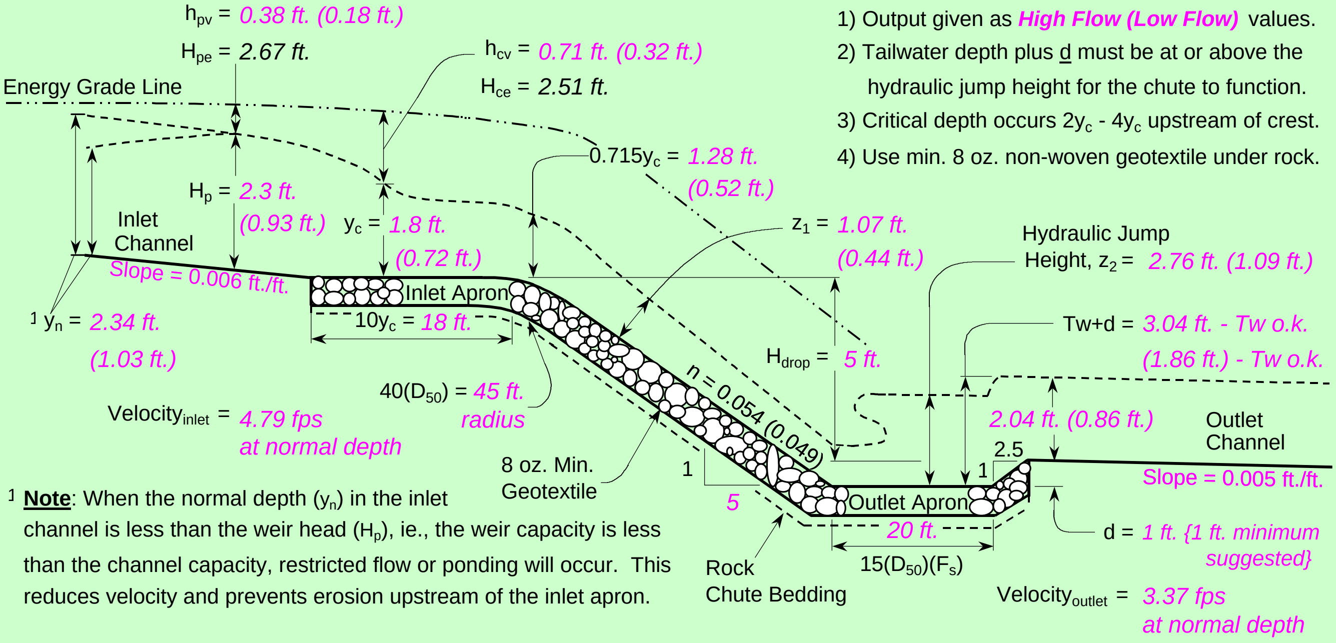
Drainage area = 450.0 acres Rainfall = ○ 0 - 3 in. ● 3 - 5 in. ○ 5+ in.
Apron elev. --- Inlet = 105.0 ft. --- Outlet = 99.0 ft. --- (H_{drop} = 5 ft.)
Chute capacity = Q5-year *Minimum capacity (based on a 5-year,*
Total capacity = Q10-year *24-hour storm with a 3 - 5 inch rainfall)*
Q_{high}= 330.0 cfs High flow storm through chute → Tw (ft.) = Program
Q_{low} = 75.0 cfs Low flow storm through chute → Tw (ft.) = Program

__Note__: The total required capacity is routed through the chute (principal spillway) or in combination with an auxiliary spillway.

***Input tailwater (Tw)*:**

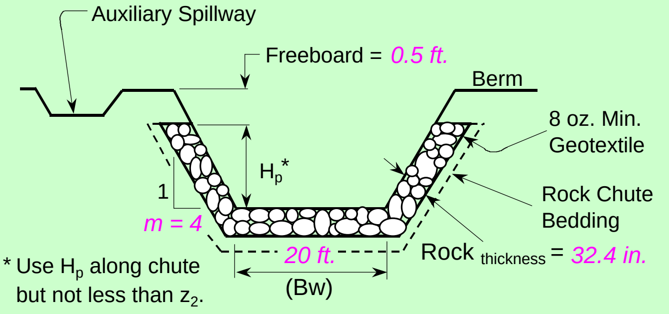
Profile and Cross Section (Output)

Notes:
1) Output given as ***High Flow (Low Flow)*** values.
2) Tailwater depth plus d must be at or above the hydraulic jump height for the chute to function.
3) Critical depth occurs $2y_c$ - $4y_c$ upstream of crest.
4) Use min. 8 oz. non-woven geotextile under rock.



[1] **Note**: When the normal depth (y_n) in the inlet channel is less than the weir head (H_p), ie., the weir capacity is less than the channel capacity, restricted flow or ponding will occur. This reduces velocity and prevents erosion upstream of the inlet apron.

Profile Along Centerline of Chute



* Use H_p along chute but not less than z_2.

Typical Cross Section

q_t =	13.65 cfs/ft.	Equivalent unit discharge
F_S =	1.20	Factor of safety (multiplier)
z_1 =	1.07 ft.	Normal depth in chute
n-value =	0.054	Manning's roughness coefficient
$D_{50}(F_S)$ =	16.2 in. (309 lbs. - 50% round / 50% angular)	
$2(D_{50})(F_S)$ =	32.4 in.	Rock chute thickness
Tw + d =	3.04 ft.	Tailwater above outlet apron
z_2 =	2.76 ft.	Hydraulic jump height
*** The outlet	will	function adequately

High Flow Storm Information

Rock Chute Design Calculations

(Version 4.0 - 07/10/00, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project:	Spillway protection	**County:**	Woodbury
Designer:	Jim Villa	**Checked by:**	
Date:	9/27/00	**Date:**	

I. Calculate the normal depth in the inlet channel.

	High Flow			***Low Flow***		
y_n =	**2.34**	**ft.**	**y_n =**	**1.03**	**ft.**	(Normal depth)
Area =	68.9	ft^2	Area =	24.9	ft^2	(Flow area in channel)
Q_{high} =	330.0	cfs	Q_{low} =	75.0	cfs	(Capacity in channel)

II. Calculate the critical depth in the chute.

	High Flow			***Low Flow***		
y_c =	**1.80**	**ft.**	**y_c =**	**0.72**	**ft.**	(Critical depth in chute)
Area =	48.8	ft^2	Area =	16.5	ft^2	(Flow area in channel)
Q_{high} =	330.0	cfs	Q_{low} =	75.0	cfs	(Capacity in channel)
H_{ce} =	2.51	ft.	H_{ce} =	1.04	ft.	(Total minimum specific energy head)
h_{cv} =	0.71	ft.	h_{cv} =	0.32	ft.	(Velocity head corresponding to y_c)
$10y_c$ =	**17.95**	**ft.**	---	---		(Required inlet apron length)
$0.715y_c$ =	**1.28**	**ft.**	**$0.715y_c$ =**	**0.52**	**ft.**	(Depth of flow over the weir crest or brink)

III. Calculate the tailwater depth in the outlet channel.

	High Flow			***Low Flow***			
Tw =	**2.04**	**ft.**	**Tw =**	**0.86**	**ft.**	(Tailwater depth)	
Area =	98.0	ft^2	Area =	37.4	ft^2	(Flow area in channel)	
Q_{high} =	330.0	cfs	Q_{low} =	75.0	cfs	(Capacity in channel)	5.00 = H_{drop}
H_2 =	0.00	ft.	H_2 =	0.00	ft.	(Downstream head above weir crest, $H_2 = 0$, if $H_2 < 0.715 * y_c$, neglect velocity head)	

IV. Calculate the head for a trapezoidal shaped broad-crested weir.

C_d = 1.00 C_{vn} = 0.581 (Discharge coefficient for rectangular & v-notch broad-crested weirs, respectively)

	High Flow				
H_p =	2.47	ft.	**2.30**	**ft.**	(Weir head)
Area =	73.9	ft^2	67.1	ft^2	(Flow area in channel)
V_i =	0.00	fps	**4.91**	**fps**	(Approach velocity)
h_{pv} =	0.00	ft.	0.38	ft.	(Velocity head corresponding to H_p)
Q_{high} =	330.0	cfs	330.0	cfs	(Capacity in channel)

Trial and error procedure solving simultaneously for velocity and head

	Low Flow				
H_p =	1.03	ft.	**0.93**	**ft.**	(Weir head)
Area =	24.9	ft^2	22.0	ft^2	(Flow area in channel)
V_i =	0.00	fps	**3.41**	**fps**	(Approach velocity)
h_{pv} =	0.00	ft.	0.18	ft.	(Velocity head corresponding to H_p)
Q_{low} =	75.0	cfs	75.0	cfs	(Capacity in channel)

Trial and error procedure solving simultaneously for velocity and head

Rock Chute Design Calculations

(Version 4.0 - 07/10/00, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project:	Spillway protection	**County:**	Woodbury
Designer:	Jim Villa	**Checked by:**	
Date:	9/27/00	**Date:**	

V. Calculate the rock chute parameters (w/o a factor of safety applied).

	High Flow		***Low Flow***	
q_t =	1.27 cms/m	q_t =	0.32 cms/m	(Equivalent unit discharge)
D_{50} (mm) =	342.66 → ***(13.49 in.)***	D_{50} =	166.21 mm	(Median ***angular*** rock size)
n =	0.054	n =	0.049	(Manning's roughness coefficient)
z_1 =	1.07 ft.	z_1 =	0.44 ft.	(Normal depth in the chute)
A_1 =	25.9 ft^2	A_1 =	9.6 ft^2	(Area associated with normal depth)
Velocity =	12.72 fps	Velocity =	7.81 fps	(Velocity in chute slope)
z_{mean} =	0.91 ft.	z_{mean} =	0.41 ft.	(Mean depth)
F_1 =	2.35	F_1 =	2.15	(Froude number)
$L_{rock\ apron}$ =	16.86 ft.	----	----	(Length of rock outlet apron = 15*D_{50})

VI. Calculate the height of hydraulic jump height (conjugate depth).

	High Flow		***Low Flow***	
z_2 =	**2.76 ft.**	**z_2 =**	**1.09 ft.**	(Hydraulic jump height)
Q_{high} =	330.0 cfs	Q_{low} =	75.0 cfs	(Capacity in channel)
A_2 =	85.5 ft^2	A_2 =	26.6 ft^2	(Flow area in channel)

VII. Calculate the energy lost through the jump (absorbed by the rock).

	High Flow		***Low Flow***	
E_1 =	3.58 ft.	E_1 =	1.39 ft.	(Total energy before the jump)
E_2 =	2.99 ft.	E_2 =	1.22 ft.	(Total energy after the jump)
R_E =	16.61 %	R_E =	12.38 %	(Relative loss of energy)

Calculate Quantities for Rock Chute

-------Rock Riprap Volume-------

Area Calculations	**Length @ Rock CL**
h = 2.76	Inlet = 17.87
x_1 = 11.13	Outlet = 20.39
L = 11.38	Slope = 30.59
A_s = 30.73	2.5:1 Lip = 2.41
x_2 = 10.80	**Total = 71.27 ft.**
A_b = 84.95	**Rock Volume**
A_b+2*A_s = 146.41 ft^2	**386.44 yd^3**

-------Bedding Volume-------

Area Calculations	
h = 5.46	**Bedding Thickness**
x_1 = 2.06	t_1, t_2 = ***6.00*** in.
L = 22.51	
A_s = 11.26	**Length @ Bed CL**
x_2 = 2.00	**Total = 71.24 ft.**
A_b = 11.39	**Bedding Volume**
A_b+2*A_s = 33.91 ft^2	**89.47 yd^3**

-------Geotextile Quantity-------

Width	**Length @ Bot. Rock**
2*Slope = 45.02	**Total = 71.25 ft.**
Bottom = 20.66	**Geotextile Area**
Total = 65.69 ft.	**520.01 yd^2**

Note: 1) The radius is not considered when calculating quantities of riprap, bedding, or geotextile.
2) The geotextile quantity does not include over-overlapping (18-in. min.) or anchoring material (18-in. min. along sides, 24-in. min. on ends).

Rock Chute Design - Plan Sheet

(Version 4.0 - 07/10/00, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Spillway protection
Designer: Jim Villa
Date: 9/27/00

County: Woodbury
Checked by:
Date:

Design Values

Angular D_{50} dia. = 16.2 in.
Rock$_{chute}$ thickness = 32.4 in.
Inlet apron length = 18 ft.
Outlet apron length = 20 ft.
Radius = 45 ft.
Will bedding be used? Yes ---------- Depth (in.) = 6.0

Rock Gradation Envelope

% Passing	*Diameter, in. (weight, lbs.)*
D_{100}	24 - 32 (1046 - 2479)
D_{85}	21 - 29 (681 - 1807)
D_{50}	16 - 24 (310 - 1046)
D_{10}	13 - 21 (159 - 681)

Quantities [a]

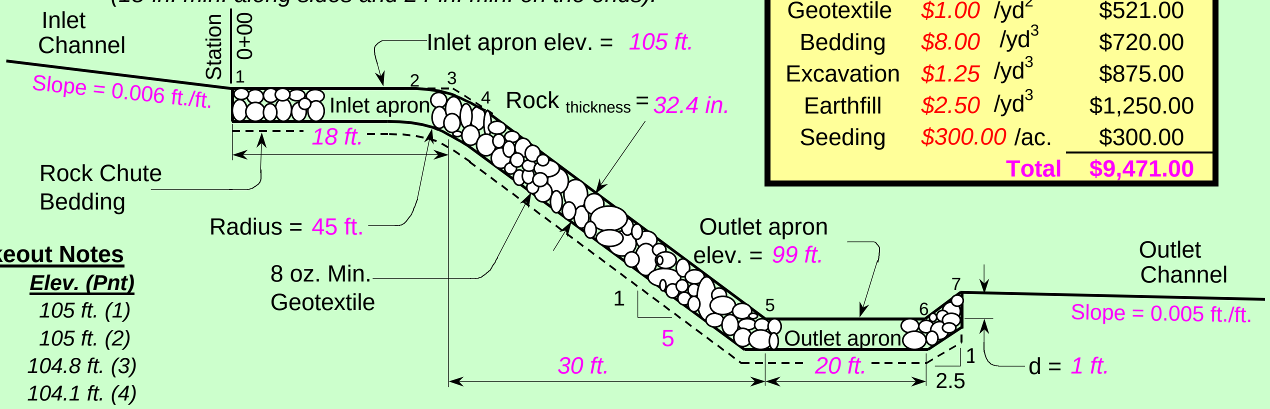
Angular Rock = 387 yd^3
Geotextile (8 oz.)[b] = 521 yd^2
Bedding (6 in.) = 90 yd^3
Excavation = 700 yd^3
Earthfill = 500 yd^3
Seeding = 1.0 acres

Notes: [a] *Rock, bedding, and geotextile quantities are determined from the x-section below (neglect radius).*

[b] *Geotextile shall be overlapped (18-in. min.) and anchored (18-in. min. along sides and 24-in. min. on the ends).*

Rock Chute Cost Estimate

Unit	*Unit Cost*	*Cost*
Rock	$15.00 /yd^3	$5,805.00
Geotextile	$1.00 /yd^2	$521.00
Bedding	$8.00 /yd^3	$720.00
Excavation	$1.25 /yd^3	$875.00
Earthfill	$2.50 /yd^3	$1,250.00
Seeding	$300.00 /ac.	$300.00
	Total	**$9,471.00**

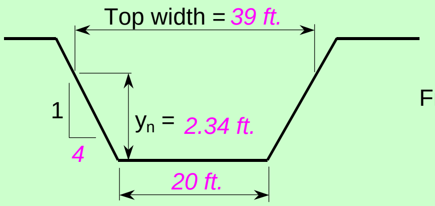


Profile Along Centerline of Rock Chute

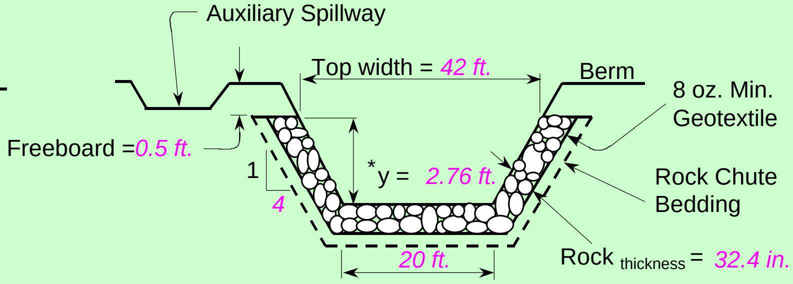
**** *Note*: *The outlet will function adequately***

Stakeout Notes

Sta.	*Elev. (Pnt)*
0+00	105 ft. (1)
0+13.5	105 ft. (2)
0+18	104.8 ft. (3)
0+22.4	104.1 ft. (4)
0+48	99 ft. (5)
0+68	99 ft. (6)
0+70.5	100 ft. (7)

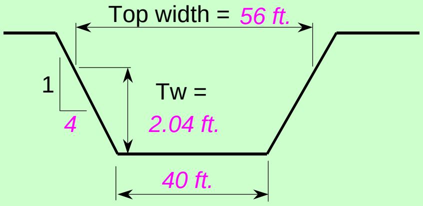


Inlet Channel Cross Section



Rock Chute Cross Section

* Use H_p throughout chute but not less than z_2.



Outlet Channel Cross Section

Profile, Cross Sections, and Quantities

Project: Spillway protection
Location: Woodbury County

U.S. Department of Agriculture
Natural Resources Conservation Service

Designed: Jim Villa
Drawn: NRCS Standard Dwg.
Traced:
Checked:

Approved by:
Title:
Title:
Sheet No.
of
Drawing No.

Design Values

Angular D_{50} dia. = 16.2 in.
$\text{Rock}_{\text{chute}}$ thickness = 32.4 in.
Inlet apron length = 18 ft.
Outlet apron length = 20 ft.
Radius = 45 ft.
Will bedding be used? Yes

Rock Gradation Envelope

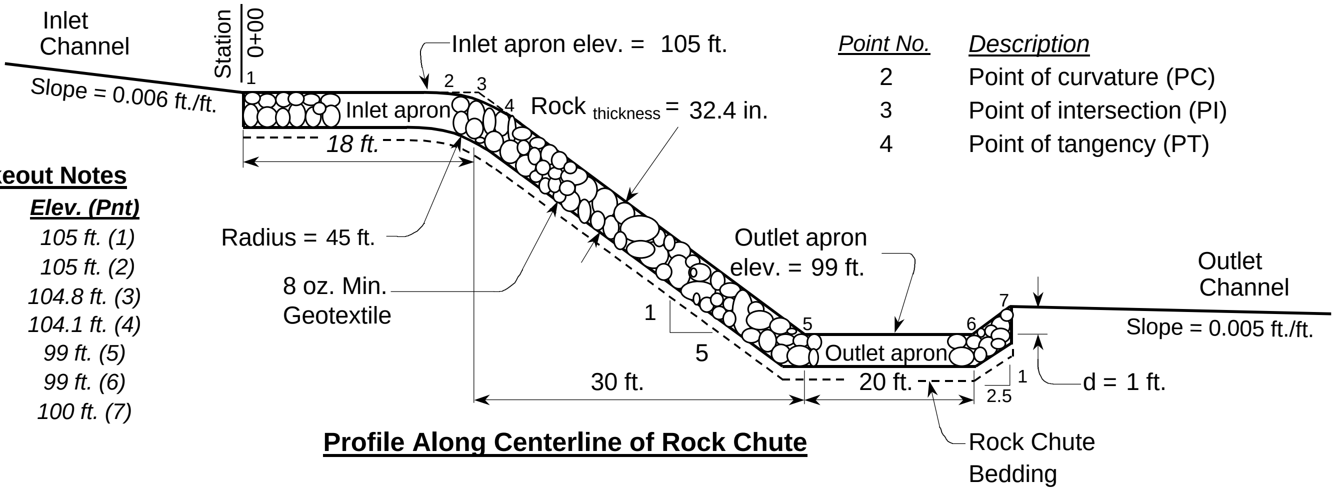
% Passing	Diameter, in. (weight, lbs.)
D_{100} ---------	24 - 32 (1046 - 2479)
D_{85} ---------	21 - 29 (681 - 1807)
D_{50} ---------	16 - 24 (310 - 1046)
D_{10} ---------	13 - 21 (159 - 681)

Coefficient of Uniformity, $(D_{60})/(D_{10}) \leq 2.0$

Quantities [a]

Angular Rock = 387 yd^3
Geotextile (8 oz.)[b] = 521 yd^2
Bedding (6 in.) = 90 yd^3
Excavation = 700 yd^3
Earthfill = 500 yd^3
Seeding = 1.0 acres

Notes: [a] *Rock, bedding, and geotextile quantities are determined from x-section below (neglect radius).*
[b] *Geotextile shall be overlapped (18-in. minimum) and anchored (18-in. minimum along sides and 24-in. minimum on the ends) --- quantity not included.*

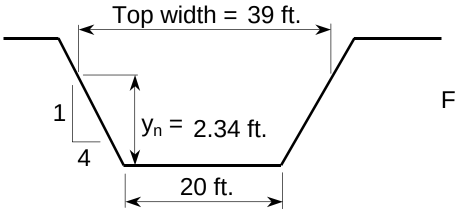


Point No.	Description
2	Point of curvature (PC)
3	Point of intersection (PI)
4	Point of tangency (PT)

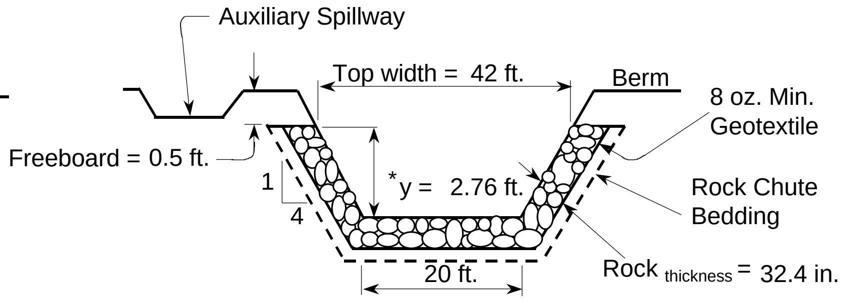
Stakeout Notes

Sta.	Elev. (Pnt)
0+00	105 ft. (1)
0+13.5	105 ft. (2)
0+18	104.8 ft. (3)
0+22.4	104.1 ft. (4)
0+48	99 ft. (5)
0+68	99 ft. (6)
0+70.5	100 ft. (7)

Profile Along Centerline of Rock Chute

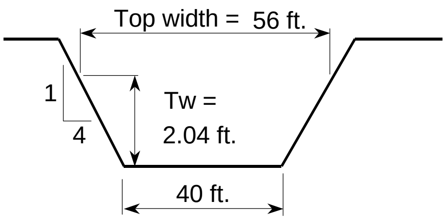


Inlet Channel Cross Section



Rock Chute Cross Section

* Use H_p throughout chute but not less than z_2.



Outlet Channel Cross Section

Profile, Cross Sections, and Quantities

Project: Spillway protection
Location: Woodbury County

U.S. Department of Agriculture
Natural Resources Conservation Service

Designed: Jim Villa
Drawn: NRCS Standard Dwg.
Traced: ________________
Checked: ______________
Approved by: ____________________
Title: ________________________
Title: ________________________
Sheet No. ____ of ____
Drawing No.

Instructions - Rock Chute Design Program

This Excel spreadsheet is included as a tool to design rock chutes for conservation practices. Median size for **angular** rock is determined along with the chute hydraulics and dimensions. This spreadsheet is based on "Design of Rock Chutes" by Robinson, Rice, and Kadavy, ASAE Vol. 41(3), pp. 621-626, 1998 (Ref. 1). One Spreadsheet version is included. Rock_Chute.xls is intended for Excel in Microsoft Office 97. The Excel file (.xls) is password protected. A ***Glossary*** is included below. All equations are available from the Iowa NRCS Design Staff by request.

Glossary

A_1 (ft^2) = *Area of flow corresponding to normal depth in the chute.*

A_2 (ft^2) = *Area of flow corresponding to the hydraulic jump height in the chute.*

Bw (ft.) = *Designates the bottom width for the inlet channel, the chute, and the outlet channel sections.*

d (ft.) = *Lower the outlet apron a depth d to submerge the hydraulic jump (1-ft. suggested minimum).*

D_{50} (ft.) = *Median* ***angular (cubical)*** *rock size (angular rock is stable at a unit discharge approximately 40% greater than that for rounded (spherical) stone of the same diameter).*

E_1 (ft.) = *Total energy before the jump.*

E_2 (ft.) = *Total energy after the jump.*

F_1 = *Froude number corresponding to normal chute depth.*

Freeboard = *The berm (or embankment) height above the top of rock in feet.*

F_s = *Factor of safety (multiplier) applied to the median angular rock size, D_{50}. The designer may use Minnesota Technical Release 3 , Loose Riprap Protection, July 1989, page 17, Table 2-1 for help.*

H_2 (ft.) = *Downstream head above weir crest, affects weir flow if H_2 is greater than $0.715y_c$ or the brink depth (When $H_2>0$ submerged weir flow exists and normal depth (z_1) will not occur in the chute slope, and the program may over-estimate the D_{50} size for this condition.)*

H_{ce} (ft.) = *Total minimum specific energy head (sum of critical depth and velocity head).*

h_{cv} (ft.) = *Velocity head ($V^2/2g$) corresponding to velocity at critical depth.*

H_{drop} (ft.) = *The difference in elevation between the inlet apron and outlet channel.*

H_p (ft.) = *Head upstream of the weir crest required to force flow through the weir.*

H_{pe} (ft.) = *Total energy head (sum of H_p and the velocity head).*

h_{pv} (ft.) = *Velocity head ($V^2/2g$) corresponding to velocity at depth H_p.*

m = *Horizontal component of the side slope ratio (m:1).*

n = *Manning's roughness coefficient measured in the middle 1/3 of the chute calculated by Equation 7 in Ref. 1, and also used to designate the inlet and outlet channel roughness.*

Q_{high} (cfs) = *High flow storm*

Q_{low} (cfs) = *Low flow storm*

(The user shall make sure that tailwater depths are at the hydraulic jump height or greater for high and low flow conditions.)

q_t (cfs/ft.) = *Equivalent unit discharge in the rock chute.*

R_E (%) = *Relative loss of energy = $(1-E_2/E_1)*100$.*

Tw (ft.) = *Tailwater depth above the outlet channel (determined by Manning's equation or input by user).*

Tw+d (ft.) = *Tailwater depth above the outlet apron (must be z_2 or greater).*

V_i (fps) = *Approach velocity upstream of weir crest (trial and error procedure solving simultaneously for approach velocity and head).*

y (ft.) = *Height of riprap (vertically) along the rock chute side slope, the greater of H_p or z_2.*

y_c (ft.) = *Critical depth occurs $2y_c$ to $4y_c$ upstream of the rock chute crest ($0.715y_c$ occurs at the crest).*

y_n (ft.) = *Normal depth in the inlet channel determined by using Manning's equation (accelerated flow continues upstream of the weir crest approximately $10y_c$).*

Instructions - Rock Chute Design Program

z_1 *(ft.) = Normal depth in the middle 1/3 of the chute, calculated by Equation 6 in Ref. 1.*

z_2 *(ft.) = Conjugate depth or hydraulic jump height due to the transition from supercritical to subcritical flow at the base of chute slope.*

z_{mean} *(ft.) = Mean depth in the rock chute.*

Factor of Safety - The factor of safety (or multiplier, F_s) is used to safeguard against possible undersizing of the rock chute's median rock size (D_{50}). ***F_s adjusts the D_{50} rock size, the rock chute thickness, and the outlet apron length***. The Iowa NRCS Design Staff also considered modifying (with F_s) the unit discharge (cfs/ft.), Q_{high}, and the bed slope (hydraulic grade line) instead of the D_{50}. Applying a F_s to the D_{50} will give a more conservative (larger) median rock size than applying the same F_s to the other above mentioned parameters. The user must decide what value of F_s to use. See Minnesota Technical Release 3 , Loose Riprap Protection, July 1989, page 17, Table 2-1.

Maximum values (or limits) were not considered in the spreadsheet. Only values that were outside the scope of the research were limited (chute bed slope and chute side slope). Each designer should consider what limits or maximum values they want for various parameters, such as the height of drop (H_{drop}), high flow storm (Q_{high}), bottom width (Bw), etc.

The program has 2 sheets, (Rock Chute Design Data and Rock Chute Design - Plan Sheet) that are available to the user by selecting the appropriate icon, besides the **Instructions** sheet. They are described below.

1) Rock Chute Design Data

The **Instructions** button (in the upper right) switches the user to this page (select the **Back to Design** button to return). The **Plan Sheet** button takes the user to the Profile, Cross Sections, and Quantities sheet (see below). The **Solve Spreadsheet** button (in the center of the sheet) must be selected after changing the design information. The **Tailwater from Program** button will enter the word "Program" in the tailwater cells (or the user may specify a tailwater by typing the value corresponding to high and low discharge). There are three main areas in the Design Data sheet: **1) Input Channel Geometry**, **2) Design Storm Data**, **3) Profile and Cross Section (Output)**. No print button is available on this sheet. The user should refer to the Rock Chute Design - Plan Sheet for print buttons. *The user should not print with the print icons (standard icons) or menus in Excel,* ***not all the design information will print***.

Input Channel Geometry

This is the major input area for setting channel geometry. All red, italicized values and text can be entered (or changed) by the user. The user should note the **Solve Spreadsheet** button in the center of the spreadsheet. Changing any value, with the exception of *Freeboard* under the inlet channel column, *Outlet apron depth, d,* and the *Factor of safety (multiplier)* under the chute column will blank the output values in the Profile and Cross Section area (see below). The user must select the **Solve Spreadsheet** button when finished inputting. The program sets a limit on the steepest side slope allowed in the chute (2:1) and the steepest bed slope (2.5:1). Values steeper than these will blank the output area and the program can not be solved or printed (just to the right of these cells will indicate *Too Steep)*. Also, the user should input a 1.0-foot "suggested" minimum for d (always make sure that T_w + d is greater than or equal to z_2).

Instructions - Rock Chute Design Program

Design Storm Data (Table 2, NHCP, NRCS Grade Stabilization Structure No. 410)

Here the user is prompted to input the *Drainage area* and the *Inlet and Outlet apron elevation*. The program will determine the NRCS minimum capacity (storm frequency year) for a full-flow open structure (chute and auxiliary spillway). The user must select the rainfall amount (0-3 in., 3-5 in., or 5+ in.) for a 5-year frequency, 24-hour duration storm. Input the high and low frequency storm (in cfs) flowing through the chute portion of the structure (this program does not design the auxiliary spillway). The tailwater must be adequate for both high and low flow events. The tailwater can be entered by the user or computed by the program for corresponding high and low flow storms. The **Tailwater from Program** button enters the word "Program" in the tailwater cells indicating that the spreadsheet will calculate the tailwater. The user should note that changing Q_{high} or Q_{low} will require the **Solve Spreadsheet** button to be selected.

Profile and Cross Section (Output)

No values need to be input. These results display chute hydraulics and dimensions for both high and low flow conditions. Low flow results are given in parenthesis and units are listed with the value. The user should make sure that T_w + d is greater than or equal to z_2 as indicated by T_w *o.k.* in the output. If output values give a dashed line or say "Not Solved" the user must select the **Solve Spreadsheet** button. If this doesn't work check the chute *Bed Slope* and *Side Slope* values and make sure they are not too steep. The High Flow Storm Information shows the D_{50} rock size by diameter (inches) and weight (pounds) for 50% angular and 50% round rock with a specific gravity (Gs) of 2.65. The weight comes from Minnesota Technical Release 3 (MN TR-3), Loose Riprap Protection, July 1989, page 18, Figure 2-2.

2) Rock Chute Design - Plan Sheet

This sheet gives the Profile, Cross Sections, and Quantities (along with a cost estimate) for the design. The user may input all red, italicized values and text. The design values can be changed by the user to make them more appropriate for construction *(we strongly discourage reducing the design values below what the program calculated)*. The user must enter the quantity of Excavation, Earthfill, and Seeding (if needed). Input the unit cost for each item in the cost estimate box. There are two print buttons in the upper left: **Print Documentation** will print this page as it appears on the screen (in addition to 3 pages of design information), and **Print Plan** will print a modified page that is a copy of the Plan Sheet (without the cost estimate). This page can then be pasted on the plan and includes stakeout notes for the finished rock chute grade. Use the **Back to Design** button to return to the design data sheet. The **Instructions** button (in the upper right) switches the user to this page. A uniform rock riprap size is required. Uniformly sized materials remained stable at higher flow rates than non-uniform (well graded) A coefficient of uniformity (D_{60}/D_{10}) of 2.0 or less was used to define the D_{10} size. The remainder of the values (D_{100}, D_{85}, and D_{50}) came from MN TR-3, Loose Riprap Protection, July 1989, page 21, Table 2-2.

Any questions or comments please contact:

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