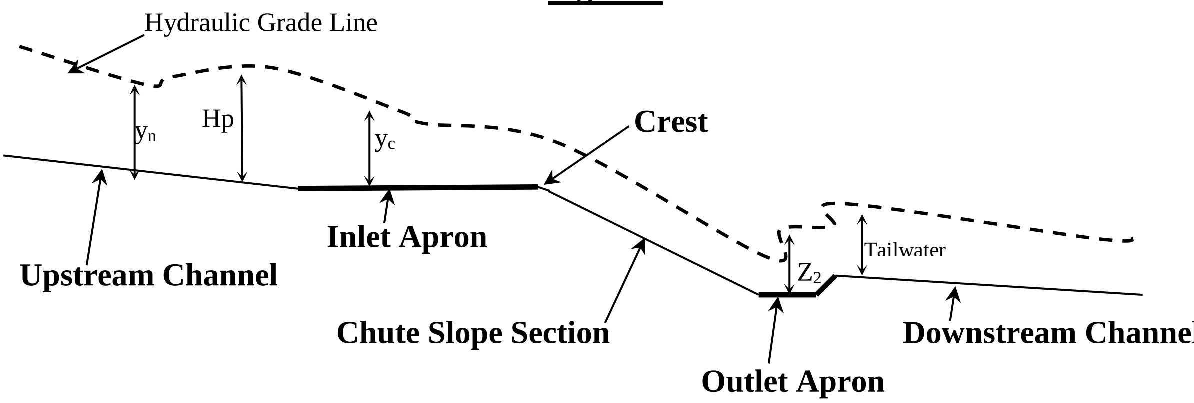
DESIGN PROCEDURES FOR ROCK-LINED CHUTE

Figure 1 displays different sections along the flow path of a rock chute, as they will be discussed in this supplement. The rock chute consists of an inlet apron, chute slope section, and an outlet apron. Criteria for hydraulic computations can be found in EFH Chapter 3.

Figure 1



Upstream Channel

The maximum channel slope upstream of the rock chute shall not be greater than the critical slope (S_c). The minimum length shall be 100 feet. This length can be used as a transitional area from the existing upstream channel to the rock chute. If this channel is a grassed waterway, the velocity n-value shall be used to compute S_c.

If no upstream channel exists, the structure should be flood routed to show the pool elevation upstream of the inlet apron is less than or equal to the weir head elevation (inlet apron elevation + Hp). High pool elevation will force a greater flow rate of water over the weir that may cause failure of the chute.

Rock Chute Inlet Apron

The slope of the inlet apron shall be flat (0% grade).

Length of the inlet apron shall be 10 x y_c, but no less than 10 feet. Critical depth, y_c in feet, occurs at a distance of $2y_c$ to $4y_c$ upstream of the rock chute crest.

Rock Chute Slope Section

The flow in the chute is considered to be uniform and the total rock-lined section must be straight (no curves in the centerline).

The maximum chute slope shall be 3 horizontal to 1 vertical (3:1).

Rock Chute Outlet Apron

The outlet section shall be flat (0% grade).

The length of the outlet section shall be 15 x D_{50} (ft) x F_s. The outlet apron may be recessed below the outlet channel bottom to provide additional tailwater.

Rock Chute Channel Depth

The minimum depth shall be the maximum depth of either the weir head (H_p) at the inlet apron or the depth of the hydraulic jump (Z_2) at the outlet apron. The depth shall be the same throughout the inlet apron, chute section and outlet apron.

Downstream Channel

The waterway downstream of the rock chute shall have the same side slopes and bottom width as the rock chute's outlet apron. The slope of the waterway shall not exceed 2%. There may be a transitional area at the end of the outlet apron. This transitional area can be used to gradually adjust the channel width at the end of the outlet apron to the width for a grassed waterway as long as the waterway is designed to carry the appropriate flow and there is enough tailwater for the chute to operate properly.

For outlets that are directly into streams or have outlets other than a grass waterway, the outlet must be stable, must be able to resist erosion, and provide sufficient tailwater for the chute.

Bedding

A geotextile (WCS-13 Class I) fabric must be placed beneath the rock. If sand-gravel bedding is used beneath the geotextile, the bedding thickness shall be a approximately two (2) inches.

If the bedding is planned to act as a filter for moist soils, it must be designed as a filter. Filter design criteria can be found in NRCS National Engineering Handbook Part 633, Chapter 26, Gradation Design of Sand and Gravel Filters.

Rock Size

Rock size for chutes shall be expressed by the D_{50} size (50 percent passing by weight). To provide an economical design, rock delivered from local quarries should be used. Therefore, a determination of the rock size and shape to be used shall be completed prior to the design of a rock chute. Rock that is larger than 2 times the D_{50} shall not be used. To determine the D_{50} size, use either Equation 1 or 2 depending on the chute's bed slope (S_{ch}) that is used.

for $S_{ch} < 0.10$ (10:1) i.e. 20:1 or 0.05 ft/ft

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

for $S_{ch} \geq 0.10$ (10:1) i.e. 5:1 or 0.20 ft/ft

$$D_{50} = \left[\frac{q_t (S_{ch})^{0.58}}{3.95(10)^{-2}} \right]^{\frac{1}{1.89}} \qquad \text{(Equation 2)}$$

Where D_{50} = median rock size in inches
q_t = equivalent unit discharge in ft^3/sec/ft
S_{ch} = chute bed slope in ft/ft

Rock Lining Roughness

The roughness value of the rock lining varies according to the rock size (D_{50}) and the slope of the chute's bed S_{ch}. Manning's "n" shall be found using Equation 3.

$$n = 0.047(D_{50} * S_{ch})^{0.147} \qquad \text{(Equation 3)}$$

Where n = Manning's "n" value for given rock size and chute slope
D_{50} = median rock size in inches
S_{ch} = chute bed slope in ft/ft

Factor of Safety (F_s)

The Factor of Safety is used to compensate for any unexpected variables in the flow, rock shape, or the "n" value. The F_s values are shown in Table 1. The minimum F_s allowed on any chute is 1.2. The F_s is used in Equation 4 to determine the D_{50}* that shall be used in the design.

$$D_{50} \text{ x } (F_s) = D_{50}^* \qquad \text{(Equation 4)}$$

Table 1 – Factor of Safety (F_s)

Condition	Factor of Safety Range	
	Rock Shape	
	50% angular[1] 50% round	100% round[2]
Uniform flow: straight reach; minimal to no impact from floating debris and ice; little or no uncertainty in design, chute drops ≤ 10 ft	1.2 - 1.3	1.7 - 1.8
Gradually varying flow; limited or minor impact from floating debris or ice, chute drops ≤ 10 ft	1.3 - 1.4	1.8 - 2.0
Chutes which have a drop greater than 10 feet where the chute capacity is based on the 25- year, 24-hour frequency storm and higher storms are routed through an auxiliary spillway.	1.3 - 1.4	1.8 - 2.0
Chutes which have a drop greater than 10 feet where chute capacity is based on greater than the 25-year, 24-hour frequency storm.	1.3 - 1.4	1.8 - 2.0

[1] 50% angular 50% round should be used for crushed stone. (Note: 100% angular is square cubed rock)
[2] For a given discharge, 100% round stone D_{50}* needs to be 40% larger than angular rock.

Rock Lining Thickness

The minimum rock thickness shall be 2 x D_{50}* which is also the size of the largest rock that shall be used.

The larger rock must be uniformly distributed throughout the entire rock mass and firmly in contact with each other. Smaller rock and spalls shall fill the voids between the larger rock.

Rock Gradation

Table 2 represents an acceptable gradation.

Table 2 – Rock Gradation

Percent Passing by weight	Size (inches)
100	1.5xD_{50}*--2.0xD_{50}*
85	1.3xD_{50}*--1.8xD_{50}*
50	1.0xD_{50}*--1.5xD_{50}*
10	0.8xD_{50}*--1.3xD_{50}*

D_{50}* equals the Designed D_{50} x factor of safety (F_s)

The State of Wisconsin Department of Transportation Standard Specifications for Highway and Structure Construction, Annotated 2005 Edition has four gradations that closely represent the Table 2 gradation. Table 3 shows the D_{50}* relationship with DOT riprap classifications.

Table 3 DOT Riprap Classifications

D_{50}* (in.)	DOT Riprap Category
9	Light Riprap
11	Medium Riprap
14	Heavy Riprap
18	Extra Heavy Riprap
> 18	Site Specific Gradation Required

Construction Layout:

To determine the bottom width (B’) for construction layout use the following formula:

$$B' = B + \frac{(T_L + T_B)}{z} \qquad \text{(Equation 5)}$$

Where T_L = thickness of rock
T_B = thickness of bedding
B = design bottom width
B’ = lowest excavation bottom width
z = side slope ratio

Design Example

Example:

Drainage area = 70 acres
Watershed slope = 4% (moderate)
RCN = 75
25-yr, 24-hr rainfall = 4.7 inches
5 yr. storm (Q_{low}) = 50 cfs
Peak discharge (Q_{high}) = 99 cfs
Overfall height = 8 ft
Upstream waterway: B = 25', z = 4:1, s = 2.0%
Downstream waterway: B = 20', z = 4:1, s = 1.0%

The topography at the site will allow a chute slope of 12:1 (8.33%). The available rock size is D_{50} = 8" (crushed stone). There will be sand bedding. The numbers being used for the calculations can be verified and are very close to actual data, so a factor of safety (F_s) of 1.2 can be used.

The following pages are printouts from the spreadsheet developed to design rock riprap chutes, showing the solution for this design example.

Pages 6-WI-30 through 6-WI-32 are the design documentation from the spreadsheet.

Page 6-WI-33 is the construction plan, quantities, and cost estimate from the spreadsheet.

Page 6-WI-34 is the construction plan, from the spreadsheet.

Rock Chute Design Data

(Version WI-Nov. 2017, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Sample project **County:** anywhere
Designer: sam **Checked by:**
Date: June 24, 2006 **Date:**

Input Geometry:

Upstream Channel	Chute	Downstream Channel
Bw = 25.0 ft.	Bw = 10.0 ft.	Bw = 20.0 ft.
Side slopes = 4.0 (m:1)	Factor of safety = 1.20 (F_s) 1.2 Min	Side slopes = 4.0 (m:1)
Velocity n-value = 0.080	Side slopes = 2.0 (m:1) → 2.0:1 max.	Velocity n-value = 0.040
Bed slope = 0.0200 ft./ft.	Bed slope (12:1) = 0.083 ft./ft → 3.0:1 max.	Bed slope = 0.0100 ft./ft.
Note: n value = a) velocity n from waterway program	Freeboard = 0.5 ft. →	
or b) computed mannings n for channel	Outlet apron depth, d = 1.0 ft.	Base flow = 0.0 cfs

Design Storm Data (Table 2, FOTG, WI-NRCS Grade Stabilization Structure No. 410):

Apron elev. --- Inlet = 100.0 ft. ------ Outlet 91.0 ft. --- (H_{drop} = 8 ft.)

Q_{high} = Runoff from design storm capacity from Table 2, FOTG Standard 410
Q_5 = Runofff from a 5-year,24-hour storm.

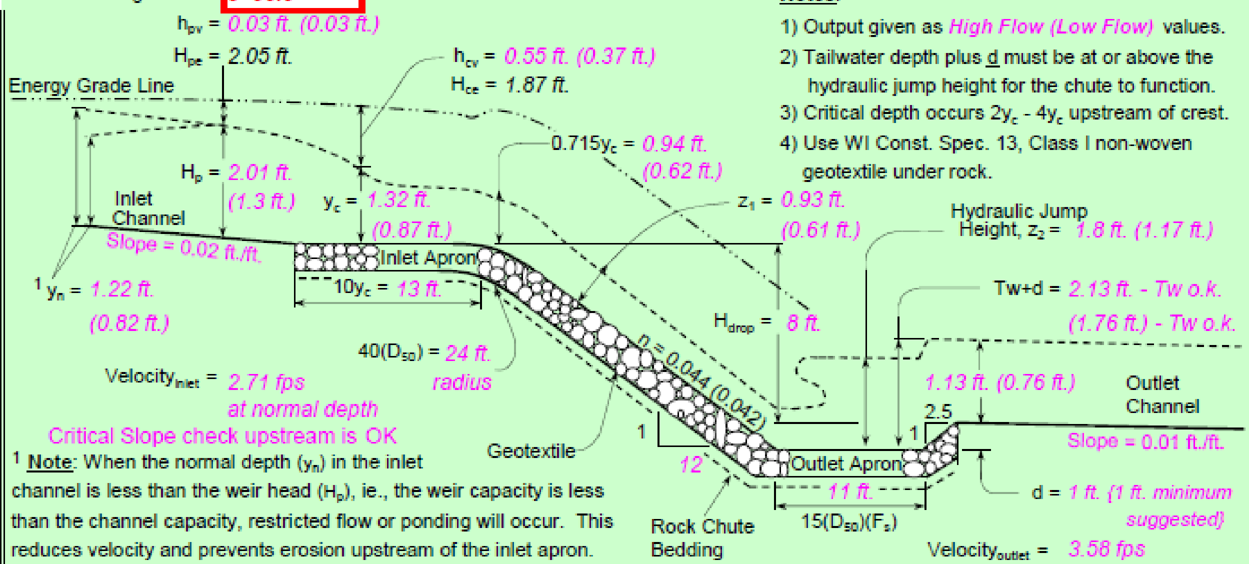
Q_{high} = 99.0 cfs High flow storm through chute → Tw (ft.) = Program
Q_5 = 50.0 cfs Low flow storm through chute → Tw (ft.) = Program

Note: The total required capacity is routed through the chute (principal spillway) or in combination with an auxiliary spillway.
Input tailwater (Tw): 0.08 1.20

Profile and Cross Section (Output):

Starting Station = 0+00.0

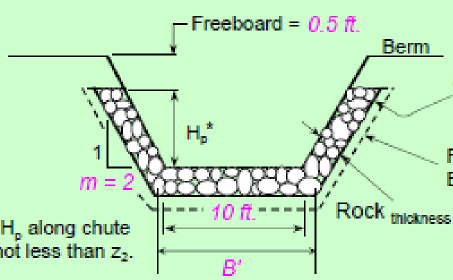
Notes:
1) Output given as *High Flow (Low Flow)* values.
2) Tailwater depth plus d must be at or above the hydraulic jump height for the chute to function.
3) Critical depth occurs $2y_c$ - $4y_c$ upstream of crest.
4) Use WI Const. Spec. 13, Class I non-woven geotextile under rock.



[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

Typical Cross Section



* Use H_p along chute but not less than z_2.

	8.61 cfs/ft.	Equivalent unit discharge
F_S =	1.20	Factor of safety (multiplier)
z_1 =	0.93 ft.	Normal depth in chute
n-value =	0.044	Manning's roughness coefficient
$D_{50}(F_s)$ =	8.8 in.	Minimum Design D50*
$2(D_{50})(F_s)$ =	17.6 in.	Rock chute thickness
Tw + d =	2.13 ft.	Tailwater above outlet apron
z_2 =	1.8 ft.	Hydraulic jump height
*** The outlet	will	function adequately

High Flow Storm Information

Rock Chute Design Calculations

(Version WI-Nov. 2017, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Sample project **County:** anywhere
Designer: sam **Checked by:**
Date: 6/24/2006 **Date:**

I. Calculate the normal depth in the inlet channel

High Flow			*Low Flow*			
y_n =	**1.22**	**ft.**	**y_n =**	**0.82**	**ft.**	(Normal depth)
Area =	36.6	ft^2	Area =	23.3	ft^2	(Flow area in channel)
Q_{high} =	99.0	cfs	Q_{low} =	50.0	cfs	(Capacity in channel)
Scupstreamchannel =	0.093	ft/ft				

II. Calculate the critical depth in the chute

High Flow			*Low Flow*			
y_c =	**1.32**	**ft.**	**y_c =**	**0.87**	**ft.**	(Critical depth in chute)
Area =	16.7	ft^2	Area =	10.1	ft^2	(Flow area in channel)
Q_{high} =	99.0	cfs	Q_{low} =	50.0	cfs	(Capacity in channel)
H_{ce} =	1.87	ft.	H_{ce} =	1.24	ft.	(Total minimum specific energy head)
h_{cv} =	0.55	ft.	h_{cv} =	0.37	ft.	(Velocity head corresponding to y_c)
$10y_c$ =	**13.21**	**ft.**	---	---		(Required inlet apron length)
$0.715y_c$ =	**0.94**	**ft.**	**$0.715y_c$ =**	**0.62**	**ft.**	(Depth of flow over the weir crest or brink)

III. Calculate the tailwater depth in the outlet channel

High Flow			*Low Flow*			
Tw =	**1.13**	**ft.**	**Tw =**	**0.76**	**ft.**	(Tailwater depth)
Area =	27.6	ft^2	Area =	17.6	ft^2	(Flow area in channel)
Q_{high} =	99.0	cfs	Q_{low} =	50.0	cfs	(Capacity in channel)
H_2 =	0.00	ft.	H_2 =	0.00	ft.	(Downstream head above weir crest, $H_2 = 0$, if $H_2 < 0.715*y_c$)

IV. Calculate the head for a trapezoidal shaped broadcrested weir

Cd = 1.00 (Coefficient of discharge for broadcrested weirs)

High Flow

H_p =	2.04	ft.	**2.01**	**ft.**	(Weir head)
Area =	67.6	ft^2	66.5	ft^2	(Flow area in channel)
V_o =	0.00	fps	**1.49**	**fps**	(Approach velocity)
h_{pv} =	0.00	ft.	0.03	ft.	(Velocity head corresponding to H_p)
Q_{high} =	99.0	cfs	99.0	cfs	(Capacity in channel)

Trial and error procedure solving simultaneously for velocity and head

Low Flow

H_p =	1.32	ft.	**1.30**	**ft.**	(Weir head)
Area =	40.0	ft^2	39.3	ft^2	(Flow area in channel)
V_o =	0.00	fps	**1.27**	**fps**	(Approach velocity)
h_{pv} =	0.00	ft.	0.03	ft.	(Velocity head corresponding to H_p)
Q_{low} =	50.0	cfs	50.0	cfs	(Capacity in channel)

Trial and error procedure solving simultaneously for velocity and head

Rock Chute Design Calculations

(Version WI-Nov. 2017, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Sample project **County:** anywhere
Designer: sam **Checked by:**
Date: 6/24/2006 **Date:**

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

High Flow			*Low Flow*			
q_t =	0.80	cms/m	q_t =	0.42	cms/m	(Equivalent unit discharge)
D_{50} (mm) =	186.65 → *(7.35 in.)*		D_{50} =	133.43	mm	(Median ***angular*** rock size)
n =	0.044		n =	0.042		(Manning's roughness coefficient)
z_1 =	0.93	ft.	z_1 =	0.61	ft.	(Normal depth in the chute)
A_1 =	11.0	ft^2	A_1 =	6.9	ft^2	(Area associated with normal depth)
Velocity =	9.03	fps	Velocity =	7.25	fps	(Velocity in chute slope)
z_{mean} =	0.80	ft.	z_{mean} =	0.55	ft.	(Mean depth)
F_1 =	1.78		F_1 =	1.72		(Froude number)
$L_{rock\ apron}$ =	9.19	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 =	**1.80**	**ft.**	**z_2 =**	**1.17**	**ft.**	(Hydraulic jump height)
Q_{high} =	99.0	cfs	Q_{high} =	50.0	cfs	(Capacity in channel)
A_2 =	24.5	ft^2	A_2 =	14.5	ft^2	(Flow area in channel)

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

High Flow			*Low Flow*			
E_1 =	2.19	ft.	E_1 =	1.43	ft.	(Total energy before the jump)
E_2 =	2.06	ft.	E_2 =	1.36	ft.	(Total energy after the jump)
R_E =	6.17	%	R_E =	5.16	%	(Relative loss of energy)

Calculate Quantities for Rock Chute

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

Area Calculations	Length @ Rock CL
h = 2.01	Inlet = 12.97
x_1 = 3.35	Outlet = 11.18
L = 4.49	Slope = 108.81
A_s = 6.74	2.5:1 Lip = 2.54
x_2 = 3.00	Total = 135.49 **ft.**
A_b = 20.56	Rock Volume
$A_b+2^*A_s$ = 34.05 **ft^2**	170.84 **yd^3**

-------*Bedding Volume*-------

Area Calculations	
h = 3.51	Bedding Thickness
x_1 = 0.00	t_1, t_2 = *0.00* in.
L = 7.85	
A_s = 0.00	Length @ Bed CL
x_2 = 0.00	Total = 135.48 **ft.**
A_b = 0.00	Bedding Volume
$A_b+2^*A_s$ = 0.00 **ft^2**	0.00 **yd^3**

-------*Geotextile Quantity*-------

Width	Length @ Bot. Rock
2*Slope = 15.70	Total = 135.48 **ft.**
Bottom = 10.71	Geotextile Area
Total = 26.41 **ft.**	397.48 **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 WI-Nov. 2017, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Sample project   **County:** anywhere
Designer: sam   **Checked by:**
Date: 6/24/2006   **Date:**

Minimum Design Values		*Enter Plan Values*
8.8 in.	D_{50} dia. =	9.00 in.
17.6 in.	$Rock_{chute}$ thickness =	18.00 in.
13 ft.	Inlet apron length =	13.00 ft.
11 ft.	Outlet apron length =	11.00 ft.
24 ft.	Radius =	25 ft.

Will bedding be used? No

Rock Gradation Envelope

% Passing		*Diameter, in. (weight, lbs.)*
D_{100}	-------	14 - 18 (174 - 413)
D_{85}	-------	12 - 16 (113 - 301)
D_{50}	-------	9 - 14 (52 - 174)
D_{10}	-------	7 - 12 (26 - 113)

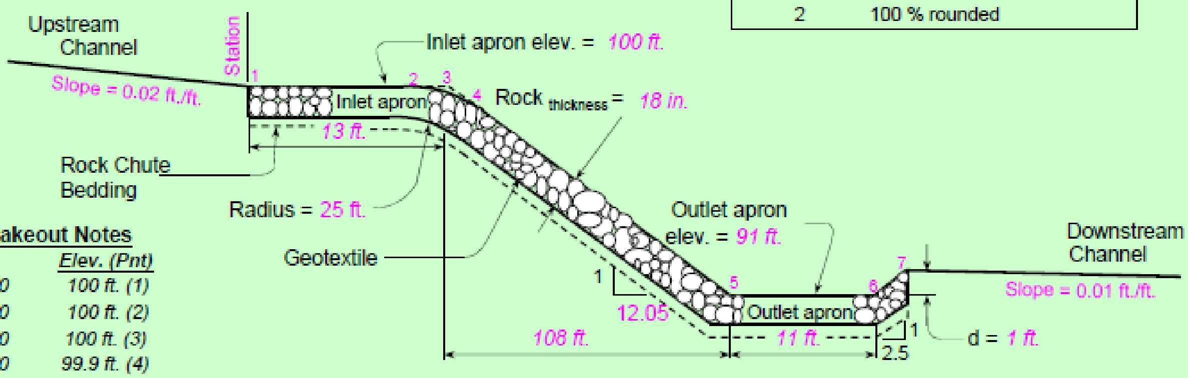
Quantities [a]

Rock = 171 yd³
Geotextile (WCS-13)[b] = 398 yd²
Bedding = 0 yd³
Excavation = 0 yd³
Earthfill = 0 yd³
Seeding = 0.0 acres

Notes: [a] *Rock, bedding, and geotextile quantities are determined from the x-section below (neglect radius).*
[b] *Geotextile Class I (non-woven) shall be overlapped and anchored (18-in. min. along sides and 24-in. min. on the ends).*

Degree of angularity = 1

1	50% angular, 50% rounded
2	100 % rounded



Profile Along Centerline of Rock Chute

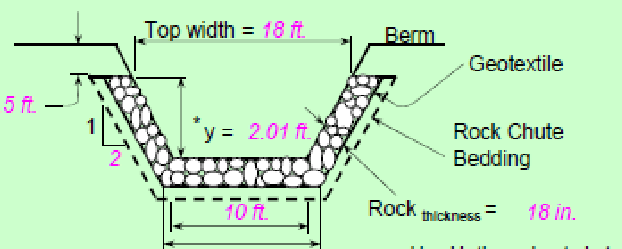
*** Note: The outlet will function adequately*

Stakeout Notes

Sta.	*Elev. (Pnt)*
0+00.0	100 ft. (1)
0+12.0	100 ft. (2)
0+13.0	100 ft. (3)
0+14.0	99.9 ft. (4)
1+21.4	91 ft. (5)
1+32.4	91 ft. (6)
1+34.9	92 ft. (7)

Class I non-woven

Rock gradation envelope can be met with DOT Light riprap Gradation



* Use H_p throughout chute but not less than z_2.

Rock Chute Cross Section

Rock Chute Cost Estimate

Unit	*Unit Cost*	*Cost*
Rock	$10.00 /yd³	$1,710.00
Geotextile	$12.00 /yd²	$4,776.00
Bedding	$12.00 /yd³	$0.00
Excavation	$12.00 /yd³	$0.00
Earthfill	$1.00 /yd³	$0.00
Seeding	$2.00 /ac.	$0.00
	Total	$6,486.00

Profile, Cross Sections, and Quantities

NRCS
Natural Resources Conservation Service
United States Department of Agriculture

Sample project
anywhere County

		Date
Designed	sam	
Drawn		
Checked		
Approved		

File Name
Drawing Name
Sheet __ of __

Rock Chute Design - Cut/Paste Plan

(Version WI-Nov. 2017, Based on Design of Rock Chutes by Robinson, Rice, Kadavy, ASAE, 1998)

Project: Sample project **County:** anywhere
Designer: sam **Checked by:**
Date: 6/24/2006 **Date:**

Design Values

D_{50} dia. = 9.0 in.
$Rock_{chute}$ thickness = 18.0 in.
Inlet apron length = 13 ft.
Outlet apron length = 11 ft.
Radius = 25 ft.
Will bedding be used? No

Rock Gradation Envelope

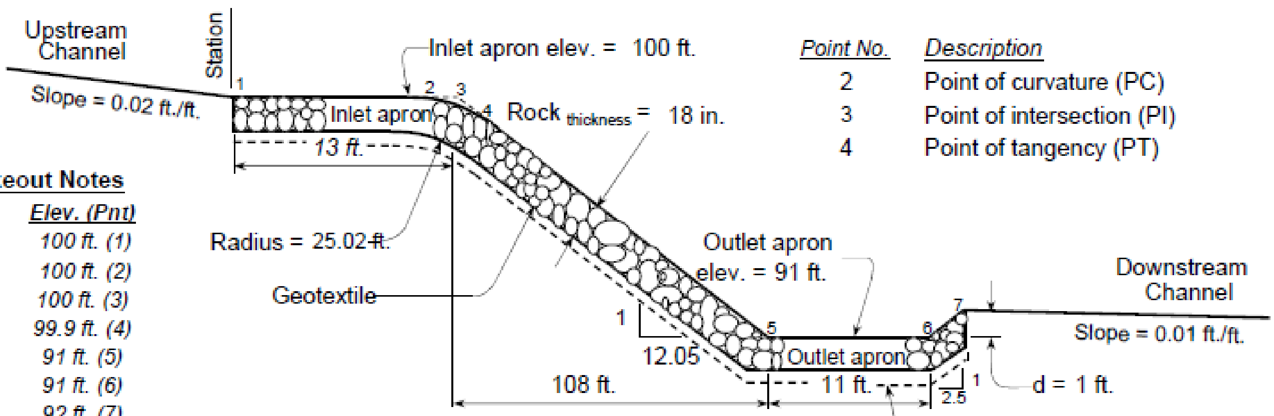
% Passing	*Diameter, in. (weight, lbs.)*
D_{100} --------	14 - 18 (174 - 413)
D_{85} --------	12 - 16 (113 - 301)
D_{50} --------	9 - 14 (52 - 174)
D_{10} --------	7 - 12 (26 - 113)

Coefficient of Uniformity, $(D_{60})/(D_{10}) < 1.7$

Quantities[a]

Rock = 171 yd^3
Geotextile (WCS-13)[b] = 398 yd^2
Bedding = 0 yd^3
Excavation = 0 yd^3
Earthfill = 0 yd^3
Seeding = 0.0 acres

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

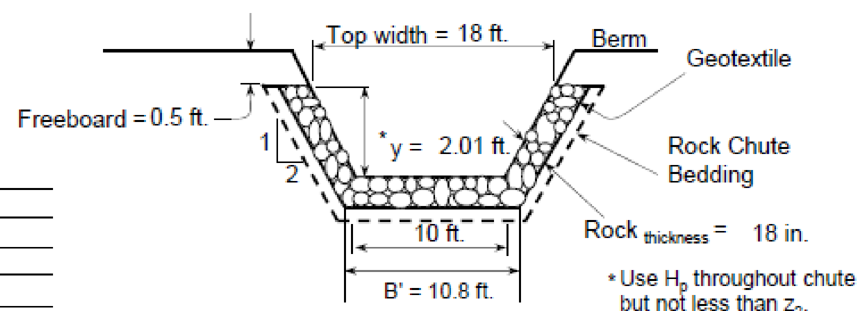


Point No.	*Description*
2	Point of curvature (PC)
3	Point of intersection (PI)
4	Point of tangency (PT)

Stakeout Notes

Sta.	*Elev. (Pnt)*
0+00.0	*100 ft. (1)*
0+12.0	*100 ft. (2)*
0+13.0	*100 ft. (3)*
0+14.0	*99.9 ft. (4)*
1+21.4	*91 ft. (5)*
1+32.4	*91 ft. (6)*
1+34.9	*92 ft. (7)*

Profile Along Centerline of Rock Chute



Rock Chute Cross Section

Notes:
Rock gradation envelope can be met with
DOT Light riprap Gradation

Profile, Cross Sections, and Quantities

NRCS
Natural Resources Conservation Service
United States Department of Agriculture

Sample project

anywhere County

		Date
Designed	sam	
Drawn		
Checked		
Approved		

File Name
Drawing Name
Sheet __ of __