Rock Sizing for Waterway & Gully Chutes

WATERWAY MANAGEMENT PRACTICES


Photo supplied by Catchments & Creeks Pty Ltd

Photo 1 – Rock-lined waterway chute


Photo supplied by Catchments & Creeks Pty Ltd

Photo 2 – Rock-lined gully chute

1. Introduction

A ‘waterway chute’ is a stabilised section of channel bed used to control bed erosion while maintaining desirable fish passage conditions in a manner similar to a natural riffle (Photo 1). These structures may also be referred to as ‘Grade Control Structures’ or ‘Rock Ramps’.

A ‘gully chute’ is a steep drainage channel, typically of uniform cross-section, used to stabilise the head of gully erosion (Photo 2).

These types of structures are highly susceptible to structural failure, usually as a result of the direct displacement of rocks by water flow, the undermining of the structure by downstream head-cut erosion, or as a result of flows bypassing either around or under the rocks.

2. Key design and operation issues

The critical design components of a chute are (1) flow entry into the chute, (2) the maximum flow velocity down the chute, and (3) energy dissipation at the base of the chute.

The critical operational issues are (1) ensuring suitable flow conditions upstream of the chute, (2) ensuring excessive flows do not bypass under or around the rocks, (3) ensuring flows do not displace rocks from the face of the chute, and (4) ensuring energy dissipation at the base of the chute does not undermine the chute.

Most chutes fail as a result of rock displacement; therefore, it is critical to size the rocks using rock properties (e.g. rock density, size distribution and shape) that are representative of the rocks that will **actually** be used within the structure. Don’t just simply adopt the parameters used within the quick reference design tables (i.e. Table 3 to 8).

3. Design of waterway and gully chutes

Chutes are hydraulic structures that need to be designed for a specified design storm/event using standard hydrologic and hydraulic equations. The design process can be broken down into three components:

- **Inlet design:** Flow conditions upstream of the chute may be determined using an appropriate weir equation. It is important to ensure that the water level upstream of the chute does not cause undesirable flooding or flow bypassing.
- **Chute face:** Determination of an appropriate rock size can be based on either the unit flow rate (preferred method), or the estimated flow velocity down the chute.
- **Outlet design:** Suitable energy dissipation conditions are required at the base of the chute. The design of energy dissipaters **must** be assessed on a case-by-case basis.

To the maximum degree practicable, the crest and face of the chute should be designed to achieve near-uniform flow conditions (e.g. depth) across the width of the chute, thus minimising 3-dimensional flow patterns. Uniform flow conditions are best achieved within rectangular channels; however, vertical sidewalls are usually not achievable within loose rock structures.

The placement of a low-flow channel through the crest of a grade control structure should be avoided. In most cases, trickle flows simply pass between the voids of the larger rocks, thus negating the need for a formal low-flow channel. If a low-flow channel must pass through the structure, then the depth of this channel should be minimised, especially at the crest of the chute. Typically the rocks around a low-flow channel need to be grouted in place to obtain the necessary stability and desirable flow conditions.

The following design steps have been provided as a general guide only.

1. Determine the effective unit discharge within the deepest section of the chute crest. If the chute contains a trickle-flow channel, then it will be necessary to determine the effective unit discharge at the deepest section of this channel during the designated design discharge.
2. Based on the unit flow rate and the gradient of the chute, estimate the rock size from tables 3 to 8. **Note:** rock sizes presented in tables 3 to 8 assume angular rock. A 36% increase in rock size must be adopted if rounded rocks (e.g. natural river boulders) as used.
3. Compute the water surface profile down the face of the chute and within the energy dissipation basin. Compute separately flow down the main drop and through the low-flow channel (if any) using a Manning's roughness (Eqn 5) based on the estimated rock size and hydraulic radius. Do not assume normal depth will be achieved down the face of the chute (the rock sizes presented within tables 3 to 8 assume uniform flow conditions).
4. Determine the location of the hydraulic jump. If the tailwater elevation is expected to be greater than the crest elevation, then adopt a conservative design by testing the chute for a 'lower than normal' tailwater condition.

   Normally, the critical design parameters used within the rock-sizing equations (i.e. velocity, depth and energy slope) reflect the flow conditions at the base of the chute, or just prior to the hydraulic jump if the jump is located on the face of the chute.

   Separate numerical computations of the main channel and low-flow flow channel conditions are performed because the hydraulic jump will normally be pushed further downstream in the region of a low-flow channel. The hydraulic jump in the main channel is usually located either at the toe of the chute, or on the face of the chute. However, flow energy from the low-flow channel can push the jump well into the energy dissipation basin. Scour protection will normally be required for distance of 5 to 6 times the tailwater depth downstream of the formation of the hydraulic jump.
5. Using equations 1 to 4 (as appropriate), iterate the acceptable solution for the mean rock size (d_{50}) based on verification of reasonable assumptions for the trial rock size and Manning's roughness.
6. Design appropriate rock stabilisation upstream of the chute's crest. Typically such protection measures extend upstream of the crest a distance of up to 5 times the depth of the approaching flow.

3.1 Design considerations

Chute gradients flatter than 6:1 (H:V) are inherently much more stable, safer and fish-friendly in comparison to steeper bed slopes.

The maximum recommended rock size is d_{50} = 600 mm due to the difficulties of both obtaining larger rock and placing such rock within natural waterways.

For reasons of stability, the drop height should not be greater than 1.2 m; however, fish passage requirements (if any) generally limit the fall of individual drops to no more than 0.5 m.

To help stabilise the hydraulic jump, either recess the energy dissipation basin, or place large boulders within the basin such that they protrude into the flow (ideally as much as 0.6 to 0.8 times the critical depth) to increase energy dissipation. It should be noted, however, that protruding 'impact' boulders are inherently **unsafe** if humans and aquatic wildlife could pass through the structure during high flows.

4. Sizing of rock for use down the face of chutes

Table 1 provides the recommended design equations for sizing rock placed on the face of waterway and gully chutes.

Tables 3 to 6 provide mean rock size (rounded up to the next 0.1 m unit) for angular rock, for a factor of safety of both 1.2 and 1.5. These tables are based on Equation 1 and are best used in the design of long gully chutes. Use of the unit flow rate as the primary design variable is preferred to the use of flow velocity because it avoids errors associated with the selection of Manning's roughness.

Alternatively, tables 7 and 8 provide mean rock size for angular rock and a safety factor of 1.2 and 1.5, based on Equation 1; however, flow velocity (V) is presented as the primary variable. These tables are best used in the design of waterway chutes where uniform flow conditions are unlikely to be achieved down the face of the chute.

Table 1 – Recommended rock sizing equations for small dam spillways [1]

Bed slope (%)	Design equations
Preferred equation: $S_o < 50\%$	Uniform flow conditions only, $S_e = S_o$ $d_{50} = \frac{127.SF.K_1.K_2.S_o^{0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)}$ (1)
A simplified equation independent of flow depth: $S_o < 50\%$	Uniform flow conditions only, $S_e = S_o$ $d_{50} = \frac{SF.K_1.K_2.S_o^{0.47}.q^{0.64}}{(s_r - 1)}$ (2)
A simplified, velocity-based equation: $S_o < 33\%$	Uniform flow conditions only, $S_e = S_o$ $d_{50} = \frac{SF.K_1.K_2.V^2}{(A - B.\ln(S_o)).(s_r - 1)}$ (3) For SF = 1.2: A = 3.95, B = 4.97 For SF = 1.5: A = 2.44, B = 4.60
Partially drowned chutes: $S_o < 50\%$	Steep gradient, non-uniform flow conditions, $S_e \neq S_o$ $d_{50} = \frac{127.SF.K_1.K_2.S_o^{0.5}.V^{2.5}.y^{0.75}}{V_o^{2.0}(s_r - 1)}$ (4)

[1] The above equations, with the exception of Equation 2, are based on the Manning's 'n' roughness for rock-lined surfaced determined from Equation 5.

The Manning's roughness of rock-lined surfaces used in the development of equations 1, 3 & 4 was based on Equation 5, which was specifically developed for application in both shallow-water and deep-water flow conditions. Rock roughness values are also presented in Table 7.

$$n = \frac{d_{90}^{1/6}}{26(1 - 0.3593^{(X)^{0.7}})} \qquad (5)$$

where: X = $(R/d_{90})(d_{50}/d_{90})$

R = hydraulic radius of flow over rocks [m]

d_{50} = mean rock size for which 50% of rocks are smaller [m]

d_{90} = rock size for which 90% of rocks are smaller [m]

For 'natural' rock extracted from streambeds the relative roughness value (d_{50}/d_{90}) is typically in the range 0.2 to 0.5. For quarried rock the ratio is more likely to be in the range 0.5 to 0.8.

where:

d_X = nominal rock size (diameter) of which X% of the rocks are smaller [m]

A & B = equation constants

K = 0.86 for highly turbulent flow

K_1 = correction factor for rock shape

= 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)

K_2 = correction factor for rock grading

= 0.95 for poorly graded rock ($C_u = d_{60}/d_{10} < 1.5$), 1.05 for well graded rock ($C_u > 2.5$), otherwise $K_2 = 1.0$ ($1.5 < C_u < 2.5$)

q = flow per unit width down the embankment [m^3/s/m]

s_r = specific gravity of rock (e.g. sandstone 2.1–2.4; granite 2.5–3.1, typically 2.6; limestone 2.6; basalt 2.7–3.2)

S_e = slope of energy line [m/m]

S_o = bed slope = $\tan(\theta)$ [m/m]

SF = factor of safety (refer to Table 2)

V = depth-average flow velocity over the rock [m/s]

V_o = depth-average flow velocity based on **uniform** flow down a slope, S_o [m/s]

y = depth of flow at a given location [m]

θ = slope of channel bed [degrees]

Table 2 – Recommended safety factor for use in determining rock size

Safety factor (SF)	Recommended usage	Example site conditions
1.2	• Low risk structures. • Failure of structure is most unlikely to cause loss of life or irreversible property damage. • Permanent rock chutes with all voids filled with soil and pocket planted.	• Waterway chutes where failure of the structure is likely to result in easily repairable soil erosion. • Waterway chutes that are likely to experience significant sedimentation and vegetation growth before experiencing the high flows. • Temporary (< 2 yrs) gully chutes with a design storm of 1 in 10 years of greater.
1.5	• High risk structures. • Failure of structure may cause loss of life or irreversible property damage. • Temporary structures that have a high risk of experiencing the design discharge while the voids remain open (i.e. prior to sediment settling within and stabilising the voids between individual rocks).	• Gully chutes where failure of the structure may cause severe gully erosion. • Waterway chutes where failure of the structure may cause severe gully erosion or damage to important infrastructure.

Table 3 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Unit flow rate (m^3/s/m)	**Bed slope = 1:2**		**Bed slope = 1:3**		**Bed slope = 1:4**		**Bed slope = 1:6**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.09	**0.20**	0.09	**0.20**	0.09	**0.10**	0.09	**0.10**
0.2	0.14	**0.30**	0.14	**0.20**	0.14	**0.20**	0.15	**0.20**
0.3	0.18	**0.30**	0.19	**0.30**	0.19	**0.20**	0.20	**0.20**
0.4	0.22	**0.40**	0.23	**0.30**	0.23	**0.30**	0.24	**0.20**
0.5	0.26	**0.40**	0.26	**0.40**	0.27	**0.30**	0.27	**0.30**
0.6	0.29	**0.50**	0.30	**0.40**	0.30	**0.40**	0.31	**0.30**
0.8	0.35	**0.60**	0.36	**0.50**	0.37	**0.40**	0.37	**0.40**
1.0	0.41	**0.70**	0.42	**0.60**	0.42	**0.50**	0.44	**0.40**
1.2	0.46	**0.70**	0.47	**0.60**	0.48	**0.50**	0.49	**0.50**
1.4	0.51	**0.80**	0.52	**0.70**	0.53	**0.60**	0.54	**0.50**
1.6	0.56	**0.90**	0.57	**0.70**	0.58	**0.70**	0.60	**0.50**
1.8	0.60	**1.00**	0.62	**0.80**	0.63	**0.70**	0.64	**0.60**
2.0	0.65	**1.00**	0.66	**0.90**	0.67	**0.70**	0.69	**0.60**
3.0	0.85	**1.30**	0.87	**1.10**	0.88	**1.00**	0.90	**0.80**
4.0	1.02	**1.60**	1.05	**1.30**	1.07	**1.20**	1.10	**1.00**
5.0	1.19	**1.80**	1.22	**1.50**	1.24	**1.30**	1.27	**1.10**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 4 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Unit flow rate (m^3/s/m)	**Bed slope = 1:10**		**Bed slope = 1:15**		**Bed slope = 1:20**		**Bed slope = 1:30**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.10	**0.10**	0.10	**0.10**	0.10	**0.05**	0.11	**0.05**
0.2	0.15	**0.10**	0.16	**0.10**	0.16	**0.10**	0.17	**0.10**
0.3	0.20	**0.20**	0.21	**0.20**	0.21	**0.10**	0.22	**0.10**
0.4	0.25	**0.20**	0.25	**0.20**	0.26	**0.20**	0.27	**0.10**
0.5	0.28	**0.20**	0.29	**0.20**	0.30	**0.20**	0.31	**0.20**
0.6	0.32	**0.30**	0.33	**0.20**	0.34	**0.20**	0.35	**0.20**
0.8	0.39	**0.30**	0.40	**0.30**	0.41	**0.20**	0.43	**0.20**
1.0	0.45	**0.30**	0.47	**0.30**	0.48	**0.30**	0.50	**0.20**
1.2	0.51	**0.40**	0.53	**0.30**	0.54	**0.30**	0.56	**0.20**
1.4	0.56	**0.40**	0.58	**0.30**	0.60	**0.30**	0.62	**0.30**
1.6	0.62	**0.40**	0.64	**0.40**	0.65	**0.30**	0.68	**0.30**
1.8	0.67	**0.50**	0.69	**0.40**	0.71	**0.30**	0.73	**0.30**
2.0	0.72	**0.50**	0.74	**0.40**	0.76	**0.40**	0.79	**0.30**
3.0	0.94	**0.60**	0.97	**0.50**	0.99	**0.50**	1.03	**0.40**
4.0	1.14	**0.80**	1.17	**0.60**	1.20	**0.60**	1.25	**0.50**
5.0	1.32	**0.90**	1.36	**0.70**	1.40	**0.60**	1.45	**0.50**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 5 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			**Specific gravity, s_r = 2.4**			**Size distribution, d_{50}/d_{90} = 0.5**		
Unit flow rate (m^3/s/m)	**Bed slope = 1:2**		**Bed slope = 1:3**		**Bed slope = 1:4**		**Bed slope = 1:6**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.10	**0.20**	0.10	**0.20**	0.10	**0.20**	0.10	**0.10**
0.2	0.15	**0.30**	0.15	**0.30**	0.16	**0.20**	0.16	**0.20**
0.3	0.20	**0.40**	0.20	**0.30**	0.21	**0.30**	0.21	**0.30**
0.4	0.24	**0.50**	0.25	**0.40**	0.25	**0.40**	0.26	**0.30**
0.5	0.28	**0.50**	0.28	**0.50**	0.29	**0.40**	0.30	**0.30**
0.6	0.31	**0.60**	0.32	**0.50**	0.33	**0.40**	0.34	**0.40**
0.8	0.38	**0.70**	0.39	**0.60**	0.40	**0.50**	0.41	**0.40**
1.0	0.44	**0.80**	0.45	**0.70**	0.46	**0.60**	0.47	**0.50**
1.2	0.50	**0.90**	0.51	**0.80**	0.52	**0.70**	0.53	**0.60**
1.4	0.55	**1.00**	0.57	**0.90**	0.58	**0.80**	0.59	**0.60**
1.6	0.60	**1.10**	0.62	**0.90**	0.63	**0.80**	0.64	**0.70**
1.8	0.65	**1.20**	0.67	**1.00**	0.68	**0.90**	0.70	**0.70**
2.0	0.70	**1.30**	0.72	**1.10**	0.73	**0.90**	0.75	**0.80**
3.0	0.92	**1.70**	0.94	**1.40**	0.96	**1.20**	0.98	**1.00**
4.0	1.11	**2.00**	1.14	**1.70**	1.16	**1.50**	1.19	**1.20**
5.0	1.29	**2.30**	1.32	**1.90**	1.34	**1.70**	1.38	**1.40**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 6 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			**Specific gravity, s_r = 2.4**			**Size distribution, d_{50}/d_{90} = 0.5**		
Unit flow rate (m^3/s/m)	**Bed slope = 1:10**		**Bed slope = 1:15**		**Bed slope = 1:20**		**Bed slope = 1:30**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.11	**0.10**	0.11	**0.10**	0.11	**0.10**	0.11	**0.05**
0.2	0.17	**0.20**	0.17	**0.20**	0.18	**0.10**	0.18	**0.10**
0.3	0.22	**0.20**	0.23	**0.20**	0.23	**0.20**	0.24	**0.10**
0.4	0.26	**0.20**	0.27	**0.20**	0.28	**0.20**	0.29	**0.20**
0.5	0.31	**0.30**	0.32	**0.20**	0.32	**0.20**	0.34	**0.20**
0.6	0.35	**0.30**	0.36	**0.30**	0.37	**0.20**	0.38	**0.20**
0.8	0.42	**0.40**	0.43	**0.30**	0.44	**0.30**	0.46	**0.20**
1.0	0.49	**0.40**	0.50	**0.30**	0.51	**0.30**	0.53	**0.30**
1.2	0.55	**0.50**	0.57	**0.40**	0.58	**0.30**	0.60	**0.30**
1.4	0.61	**0.50**	0.63	**0.40**	0.64	**0.40**	0.67	**0.30**
1.6	0.67	**0.50**	0.69	**0.50**	0.70	**0.40**	0.73	**0.30**
1.8	0.72	**0.60**	0.74	**0.50**	0.76	**0.40**	0.79	**0.40**
2.0	0.77	**0.60**	0.80	**0.50**	0.82	**0.50**	0.85	**0.40**
3.0	1.01	**0.80**	1.04	**0.70**	1.07	**0.60**	1.11	**0.50**
4.0	1.23	**1.00**	1.27	**0.80**	1.30	**0.70**	1.34	**0.60**
5.0	1.43	**1.10**	1.47	**0.90**	1.50	**0.80**	1.56	**0.70**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 7 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Local velocity (m/s)	**Bed slope (V:H)**							
	1:2	**1:3**	**1:4**	**1:6**	**1:10**	**1:15**	**1:20**	**1:30**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05
1.0	0.20	0.10	0.10	0.10	0.10	0.10	0.05	0.05
1.3	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10
1.5	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.10
1.8	0.40	0.30	0.30	0.30	0.20	0.20	0.20	0.20
2.0	0.50	0.40	0.40	0.30	0.30	0.30	0.20	0.20
2.3	0.60	0.50	0.50	0.40	0.30	0.30	0.30	0.30
2.5	0.70	0.60	0.60	0.50	0.40	0.40	0.30	0.30
2.8	0.80	0.70	0.70	0.60	0.50	0.40	0.40	0.40
3.0	1.00	0.90	0.80	0.70	0.60	0.50	0.50	0.40
3.5	1.30	1.10	1.00	0.90	0.80	0.70	0.60	0.60
4.0	1.70	1.50	1.30	1.20	1.00	0.90	0.80	0.70
4.5	2.10	1.90	1.70	1.50	1.20	1.10	1.00	0.90
5.0				1.80	1.50	1.30	1.20	1.10
6.0						1.90	1.70	1.60

[1] Based on <u>uniform</u> flow conditions, safety factor = 1.2, rock specific gravity of 2.4, and a rock size distribution such that the largest rock is approximately twice the size of the mean rock size.

Table 8 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Local velocity (m/s)	**Bed slope (V:H)**							
	1:2	**1:3**	**1:4**	**1:6**	**1:10**	**1:15**	**1:20**	**1:30**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05
1.0	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10
1.3	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.10
1.5	0.40	0.30	0.30	0.30	0.20	0.20	0.20	0.20
1.8	0.50	0.50	0.40	0.40	0.30	0.30	0.30	0.20
2.0	0.70	0.60	0.50	0.50	0.40	0.40	0.30	0.30
2.3	0.80	0.70	0.60	0.60	0.50	0.40	0.40	0.40
2.5	1.00	0.90	0.80	0.70	0.60	0.50	0.50	0.40
2.8	1.20	1.00	0.90	0.80	0.70	0.60	0.60	0.50
3.0	1.40	1.20	1.10	1.00	0.80	0.70	0.70	0.60
3.5	1.90	1.70	1.50	1.30	1.10	1.00	0.90	0.80
4.0			1.90	1.70	1.40	1.30	1.10	1.00
4.5					1.80	1.60	1.40	1.30
5.0						1.90	1.80	1.60
6.0								2.20

[1] Based on <u>uniform</u> flow conditions, **safety factor = 1.5**, rock specific gravity of 2.4, and a rock size distribution such that the largest rock is approximately twice the size of the mean rock size.

4.1 Manning roughness of rock-lined surfaces

The Manning's (n) roughness for rock-lined surfaces can be determined from Equation 5 or Table 9.

Table 9 – Manning's (n) roughness of rock-lined surfaces

	$d_{50}/d_{90} = 0.5$				$d_{50}/d_{90} = 0.8$			
d_{50} =	**200mm**	**300mm**	**400mm**	**500mm**	**200mm**	**300mm**	**400mm**	**500mm**
R (m)	Manning's roughness (n)				Manning's roughness (n)			
0.2	0.10	0.14	0.17	0.21	0.06	0.08	0.09	0.11
0.3	0.08	0.11	0.14	0.16	0.05	0.06	0.08	0.09
0.4	0.07	0.09	0.12	0.14	0.04	0.05	0.07	0.08
0.5	0.06	0.08	0.10	0.12	0.04	0.05	0.06	0.07
0.6	0.06	0.08	0.09	0.11	0.04	0.05	0.05	0.06
0.8	0.05	0.07	0.08	0.09	0.04	0.04	0.05	0.06
1.0	0.04	0.06	0.07	0.08	0.03	0.04	0.05	0.05

4.2 Rock type and grading

Crushed rock is generally more stable than natural rounded stone. A 36% increase in rock size is recommended for rounded rock.

The rock should be durable and resistant to weathering, and should be proportioned so that neither the breadth nor the thickness of a single rock is less than one-third of its length.

Broken concrete and building rubble should not be used.

Typical rock densities (s_r) are presented in Table 10.

Table 10 – Relative density (specific gravity) of rock

Rock type	Relative density (s_r)
Sandstone	2.1 to 2.4
Granite	2.5 to 3.1 (commonly 2.6)
Limestone	2.6
Basalt	2.7 to 3.2

In most situations the nominal rock size is usually between 300 mm to 600 mm.

Maximum rock size generally should not exceed twice the nominal (d_{50}) rock size. On very steep grades, the maximum rock size should not exceed 1.25 d_{50}.

Table 11 provides a suggested distribution of rock sizes for waterway chutes. The distribution of rock size can also be described by the coefficient of uniformity, $C_u = d_{60}/d_{10}$, which usually falls in the range 1.1 to 2.70, but typically around 2.1. Witter & Abt (1990) reported that poorly graded rock ($C_u = 1.1$) has a critical discharge 8% greater than well-graded rock ($C_u = 2.2$).

Table 11 – Typical distribution of rock size (provided as a guide only)

Rock size ratio	Assumed distribution value
d_{100}/d_{50}	2.0
d_{90}/d_{50}	1.8
d_{75}/d_{50}	1.5
d_{65}/d_{50}	1.3
d_{40}/d_{50}	0.65
d_{33}/d_{50}	0.50
d_{10}/d_{50}	0.20

4.3 Thickness and height of rock layer

The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size. The thickness of rock protection must also be sufficient to accommodate the largest rock size. It is noted that additional thickness will **not** compensate for undersized rock.

Generally, the minimum height of the rock protection placed on the banks should be equal to the critical flow depth (at the crest) plus 0.3 m.

In order to allow at least two layers of rock, the minimum thickness of rock protection (T) can be approximated by the values presented in Table 12.

Table 12 – Minimum thickness (T) of rock lining

Min. thickness (T)	Size distribution (d_{50}/d_{90})	Description
1.4 d_{50}	1.0	Highly uniform rock size
1.6 d_{50}	0.8	Typical upper limit of quarry rock
1.8 d_{50}	0.67	Recommended lower limit of distribution
2.1 d_{50}	0.5	Typical lower limit of quarry rock

4.4 Backing material or filter layer

Rock placed in gully chutes must be placed over a layer of suitably graded filter rock or geotextile filter cloth (minimum ‘bidim A24’ or the equivalent). The geotextile filter cloth must have sufficient strength and must be suitably overlapped to withstand the placement of the rock.

Use of a geotextile filter is unlikely to be required in the construction of waterway chutes.

If the rock is placed on a dispersive (e.g. sodic) soil (a condition **not** recommended), then prior to placement of filter cloth, the exposed bank **must** first be covered with a layer of non-dispersive soil, typically minimum 200 mm thickness, but preferably 300 mm.

4.5 Maximum bank gradient

The recommended maximum gradient of gully chutes is 1:2 (V:H). The recommended maximum gradient of waterway chutes is 1:20 (V:H) for reasons of fish passage.

4.6 Placement of vegetation over the rock cover

Vegetating rock-lined chutes can significantly increase the stability of these drainage structures, but can also reduce their hydraulic capacity. Obtaining experienced, expert advice is always recommended before establishing vegetation on drainage structures.

4.7 Common failure modes

Most failures of rock-lined hydraulic structures are believed to occur as a result of inappropriate placement of the rock, either due to inadequate design detailing, or poorly supervised construction practices. Rock-lined chutes are usually most vulnerable to damage in the first year or two after rock placement, i.e. while the voids remain open and free of sedimentation.

5. Reference

Witter, R.J. & Abt, S.R. 1990, *The influence of uniformity on riprap stability*. Proceedings of the 1990 National Conference – Hydraulic Engineering, San Diego, California, July-Aug 1990. Hydraulics Division of the American Society of Civil Engineers, New York, USA.

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